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Author
Boileau, Almerian R

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University of California
Scripps Institution of Oceanography
San Diego 52, California

ATMOSPHERIC OPTICAL MEASUREMENTS IN WESTERN FLORIDA, FLIGHT 112, Part II, SKY LUMINANCES

Almerian R. Boileau

June 1960

SIO REFERENCE 60-32

Bureau of Ships
Contract NObs-72092

Project S F001 05 01

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Seibert Q. Duntley, Director
Visibility Laboratory

Approved for Distribution:

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Roger Revelle, Director
Scripps Institution of Oceanography

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ATMOSPHERIC OPTICAL MEASUREMENTS IN WESTERN FLORIDA, FLIGHT 112, Part II, SKY LUMINANCES*

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 concerning 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, during which data in this report were measured, was one of these flights.

Part I of this report, SIO Reference 60-22, of April 1960, presented data as a catalogue of recorded optical measurements less sky luminance and sky radiance distributions. This part of the report, Part II, presents the sky luminance distribution as it varied with altitude, zenith angle, and azimuth with respect to the sun. Sky radiance distribution will be presented at a later date as Part III of this report.

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

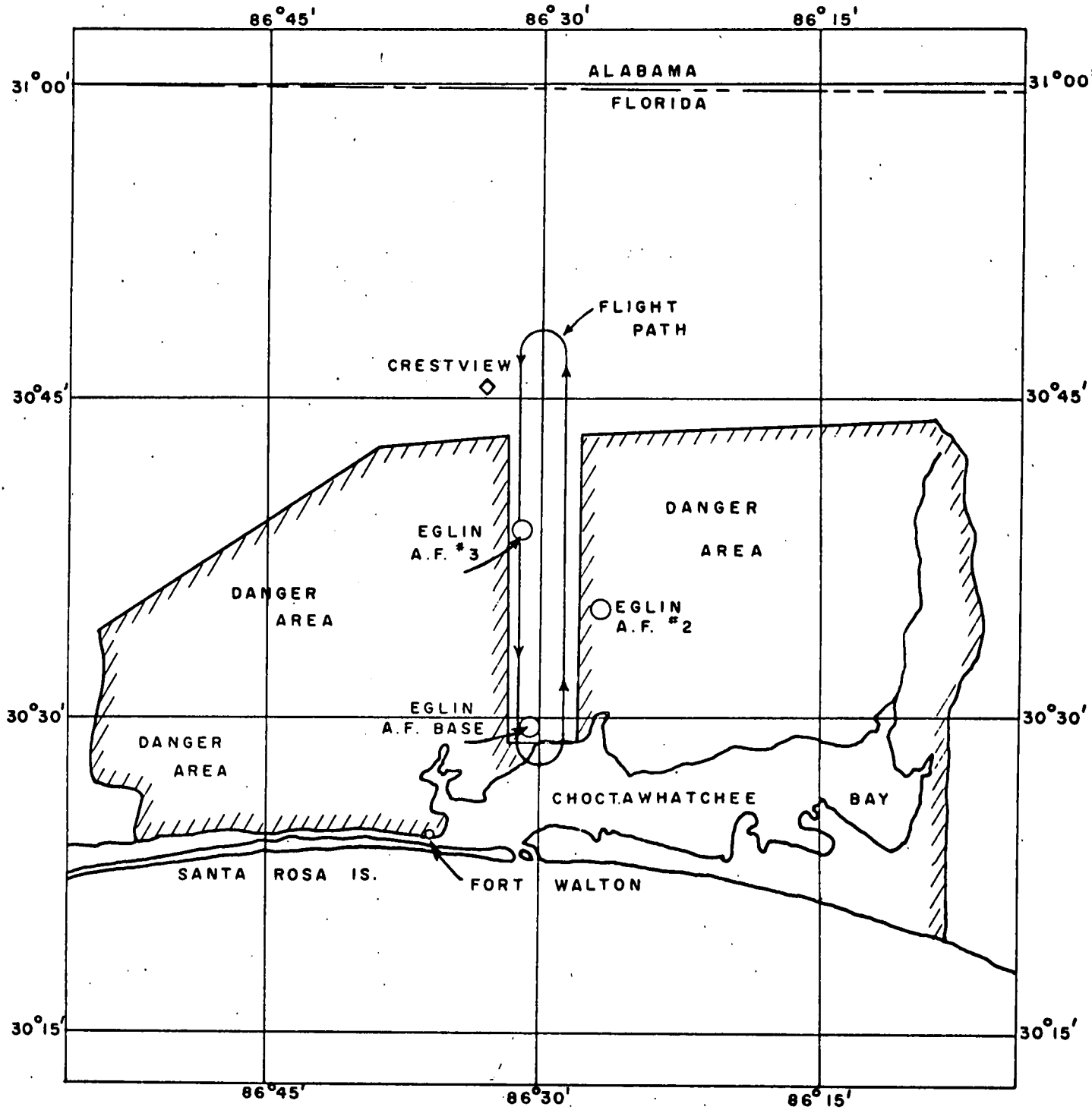
PROCEDURE

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. The airplane carried optical and meteorological instruments from the Visibility Laboratory of the University of California, La Jolla Campus. Two of these instruments were sky scanning telephotometers by which the sky luminance and radiance distributions were recorded. The airplane arrived at 20,000 feet altitude preparatory to data gathering at 1010.

Recording schedule. Sky luminance distribution data were recorded as follows:

Eastern Standard Time	Altitude	Heading
1010-1036	20 000 feet	000°
1057-1108	10 000 feet	175°
1119-1127	1 000 feet	180°
1200-1204	Eglin Air Force Base runway	185°

Flight pattern. The flight pattern was north and south between Eglin Air Force Base and Crestview, Florida, as shown in Fig. 1. However, the sky distribution data were recorded in the northern part of the flight path in the vicinity of Crestview in order that the terrain over which data were recorded would be consistently all of the same type.



FLIGHT TRACK

FIGURE 1
FLIGHT 112
16 MAY 1957
CRESTVIEW, FLORIDA

Weather. The day was clear and warm. During ascent haze layers were observed at 1500, 3000, 7000, 10 000, 12 000, and 14 000 feet altitudes. These layers were observable only when seen edge-on; they could not be determined by an observer looking in an upward direction or downward direction. At some distance from the flight pattern a few widely scattered altostratus and altocumulus clouds could be seen, apparently at the altitudes of some of the haze layers. Color prints showing the sky and terrain are included in Part I of this report.[1]

Position of sun. The azimuth and zenith angle of the sun, computed for 30°40' N. Lat. and 86°30' W. Long., the approximate location of Crestview, Florida, are shown in Fig. 2 immediately following this page. These angles are plotted for the period 1000 to 1230 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.

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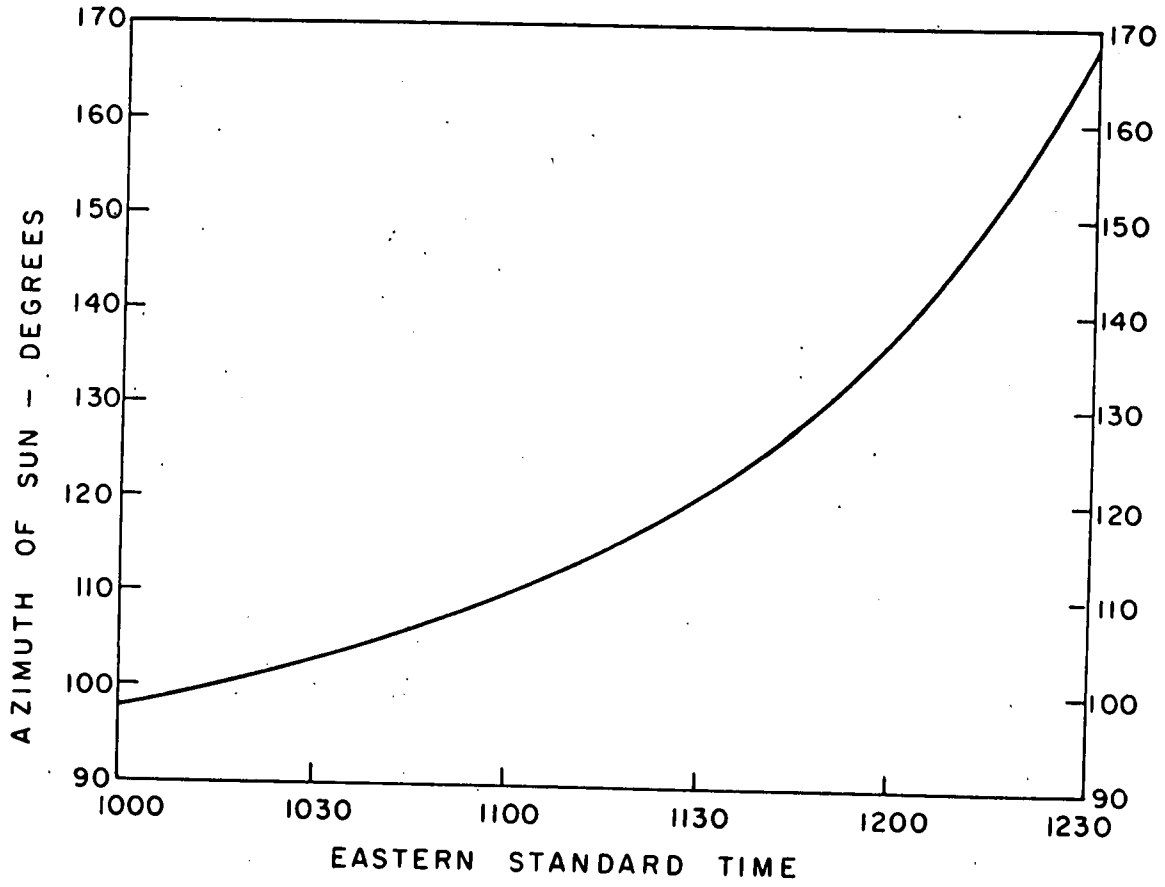
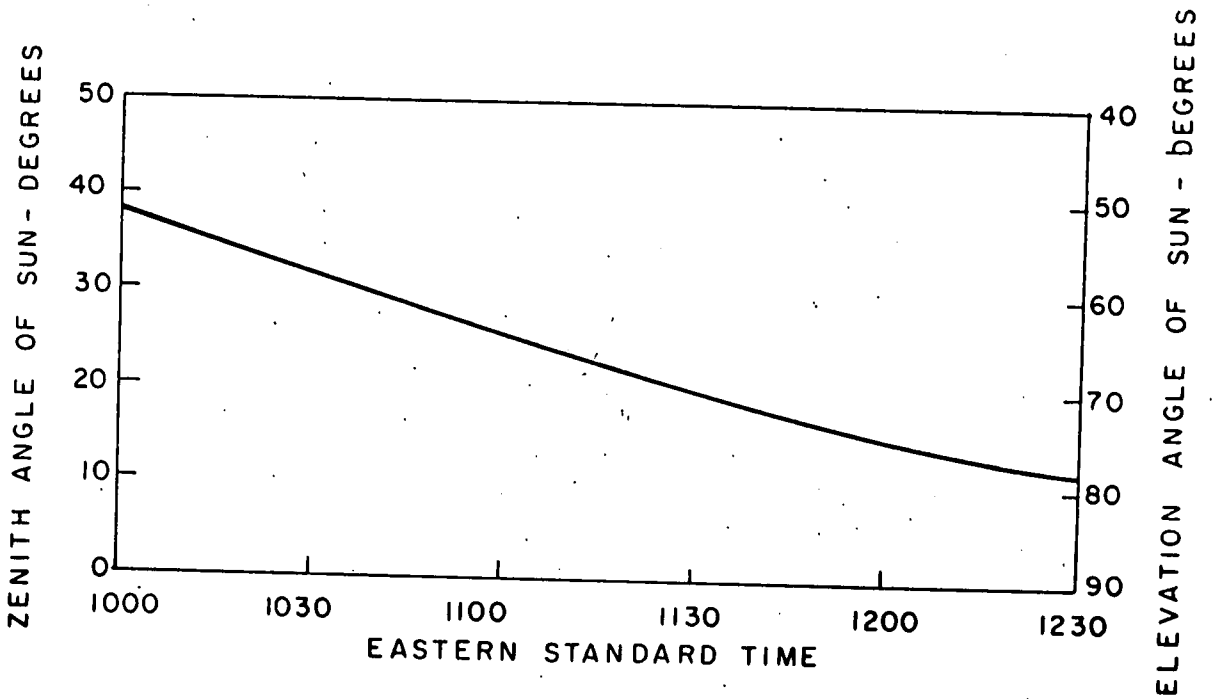
[1] "Atmospheric Optical Measurements in Western Florida, Flight 112, Part I," A. R. Boileau, SIO Ref. 60-22, April 1960





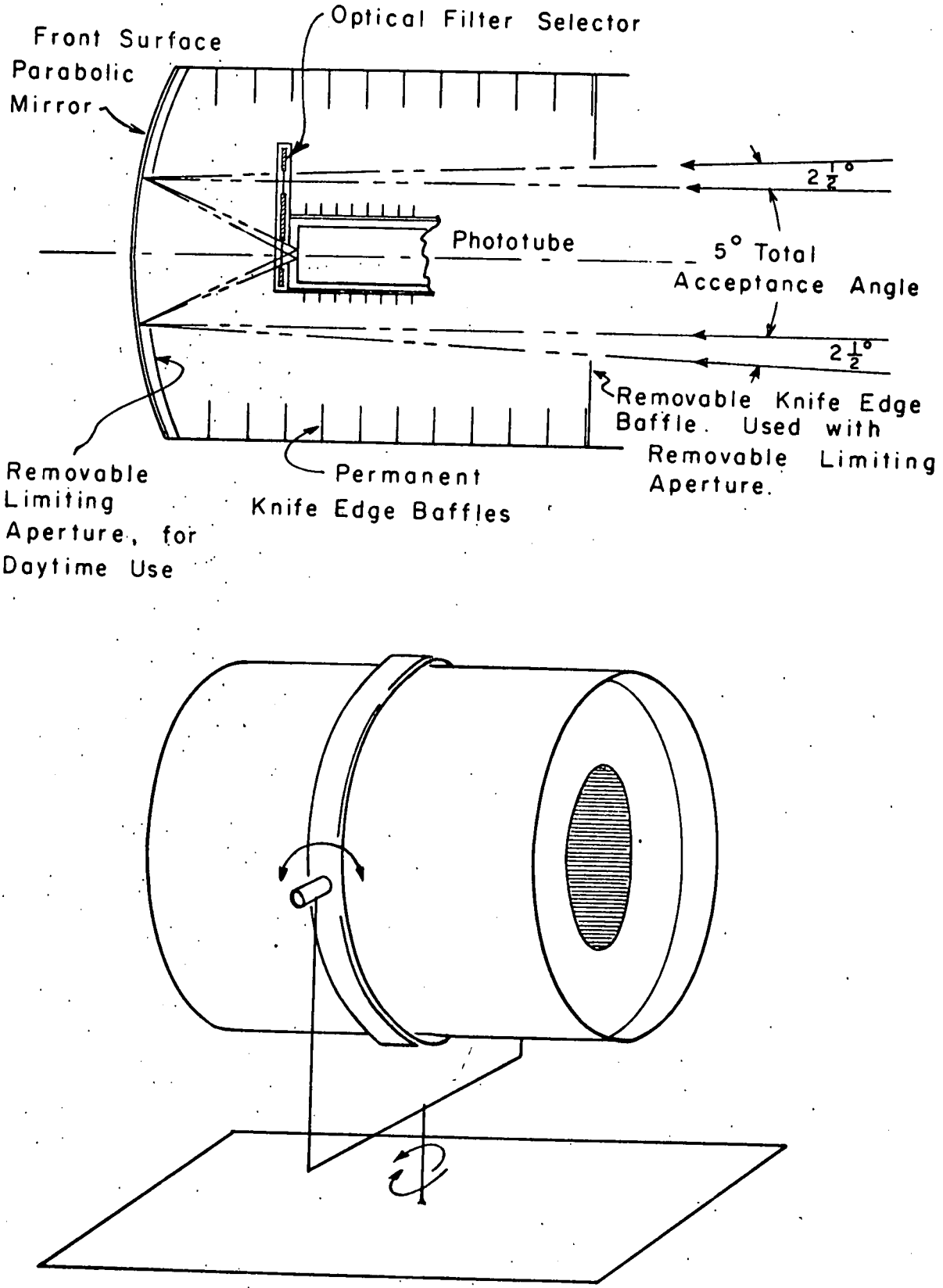
ANGLES OF SUN DURING FLIGHT 112
COMPUTED FOR LAT. 30-40 N.
LONG. 86-30 W.

FIGURE 2
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA

INSTRUMENTATION

Sky scanning telephotometers. Two sky scanning telephotometers were carried by the XB-29, one mounted in the forward upper gun turret position and one in a retracting mount in the rearmost lower gun turret position. The telephotometers were controlled from the control position in the pressurized after compartment of the XB-29. Once started, both telephotometers continued their scanning operations until completion, at which time they automatically stopped and remained stopped until restarted.

The sky scanning telephotometers are shown schematically in Fig. 3 immediately following this page. The optical unit, shown at the top of the figure, consists of a cylindrical shell with a 13" parabolic, front surface mirror mounted on one end of the shell, and an end-on multiplier phototube mounted with the light-sensitive surface at the focus of the mirror. A field stop in front of the light-sensitive surface limits the incoming rays to those contained in a 5° circular cone. In front of the field stop there is mounted an optical filter selector mechanism which by being operable from the control position in the XB-29 permits any one of three optical filters to be interposed in the flux path. The filters available for selection were photopic, narrow band blue, and narrow band red. The data presented in this report are photometric data, viz., luminance, measured through the photopic filter.



SKY SCANNING TELEPHOTOMETER

Figure 3

The optical units of the sky scanning telephotometers were designed for both daytime use with high light levels and night time use with low light levels. For daytime use the mirror limiting aperture and removable front baffle are used. The flux incident on the phototube is further reduced by use of neutral density filters. Internal scattering is reduced by the permanent knife-edge baffles throughout the inside length of the cylindrical shell and on the phototube housing.

Scanning patterns. The scanning patterns of the two sky scanning telephotometers are such that the optical units scan in elevation with a change of azimuth occurring between elevation scans in one case and simultaneously with elevation scans in the other case. The upper sky scanning telephotometer starts from $2\frac{1}{2}^{\circ}$ below the horizontal and scans through the zenith down to $2\frac{1}{2}^{\circ}$ below the horizontal 180° from starting azimuth. At the conclusion of an elevation scan it shifts 10° in azimuth before starting the return scan. It makes eighteen elevation scans, thereby completing the upper sky luminance measurement, in 90 seconds. At the end of the eighteenth elevation scan it reverses its azimuth drive and again scans the upper sky, in reverse, in 90 seconds. By changing the optical filter during the time of reversal two complete upper sky measurements are completed in three minutes.

The scanning pattern of the lower sky scanning telephotometer is similar to the scanning pattern of the upper sky scanning telephotometer in that it starts from $2\frac{1}{2}^{\circ}$ above the horizontal, and scans through the nadir up to $2\frac{1}{2}^{\circ}$ above the opposite horizontal. It differs from that of the upper sky scanning telephotometer in that it rotates in azimuth at a constant rate, changing 10° in azimuth with each elevation scan. At the conclusion of eighteen scans in a little less than 90 seconds it automatically reverses and retraces its pattern. By changing the optical filter during the time of reversal two complete lower sky measurements are completed in the same manner and in slightly less time than the upper sky measurements.

REDUCTION OF DATA

Method of recording. Data were recorded during Flight 112 on Sanborn Recorder strip charts. The data were continuous traces representing sky luminance values as the scanners swung through their elevation sweeps. The positions of the scanners in elevation, i.e., the zenith angles of the scanners' paths of sight, were indicated by a separate trace on the strip chart by a second marking stylus so that zenith angles indications and corresponding data were synchronized.

Handling of data. The strip chart data were read directly onto IBM cards by the use of computer peripheral equipment. Through the operation of U. S. Navy Electronics Laboratory's Burroughs No. 220 computer, which corrected for non-linearities of the electronic recording equipment, the data points were converted into tables of equivalent luminance values. The luminance values were then plotted vertically on semi-logarithmic graph paper against azimuth and a smooth curve was drawn for each zenith angle, the azimuth referred to above being the azimuth with reference to geographical North. The azimuth values along the horizontal coordinate were then shifted to cause the azimuth to be indicated with reference to the sun. The last step was to re-plot luminance values for selected zenith angles, horizontally on semi-logarithmic graph paper, against altitude. Continuous curves were then plotted through these points.

PRESENTATION OF DATA

Notation. The notation for luminance for any line of sight when the path length is not specified is $B(z,\Theta,\emptyset)$.[2] The symbol B indicates luminance and the parenthetic symbols indicate that the height of the photometer at the altitude z is the height above mean sea level and that the path of sight is specified by the zenith angle Θ and azimuth $\emptyset$. The zenith angle Θ is from 0° for looking vertically upward to 180° for looking vertically downward. The azimuth $\emptyset$, in this report, is with reference to the sun.

Organization of data. The data are presented as a series of graphs which have altitude as the ordinate values and sky luminance as abscissa values. Each curve represents the sky luminance value for a specific azimuth and a specific zenith angle. All of the curves for one specific azimuth are grouped together in one figure consisting of four sheets with the exception of the first Figure, this having one extra, or five sheets. The Figures are arranged in order of increasing azimuth of 20° increments starting with 0° and ending with 340°.

Each Figure, with the exception of the first Figure, consists of four sheets as follows:

Sheet a - zenith angles of 0°, 15°, 30°, 45°, and 60°

Sheet b - zenith angles of 75°, 80°, 85°, and 90°

Sheet c - zenith angles of 90°, 95°, 100°, and 105°

Sheet d - zenith angles of 120°, 135°, 150°, 165°, and 180°

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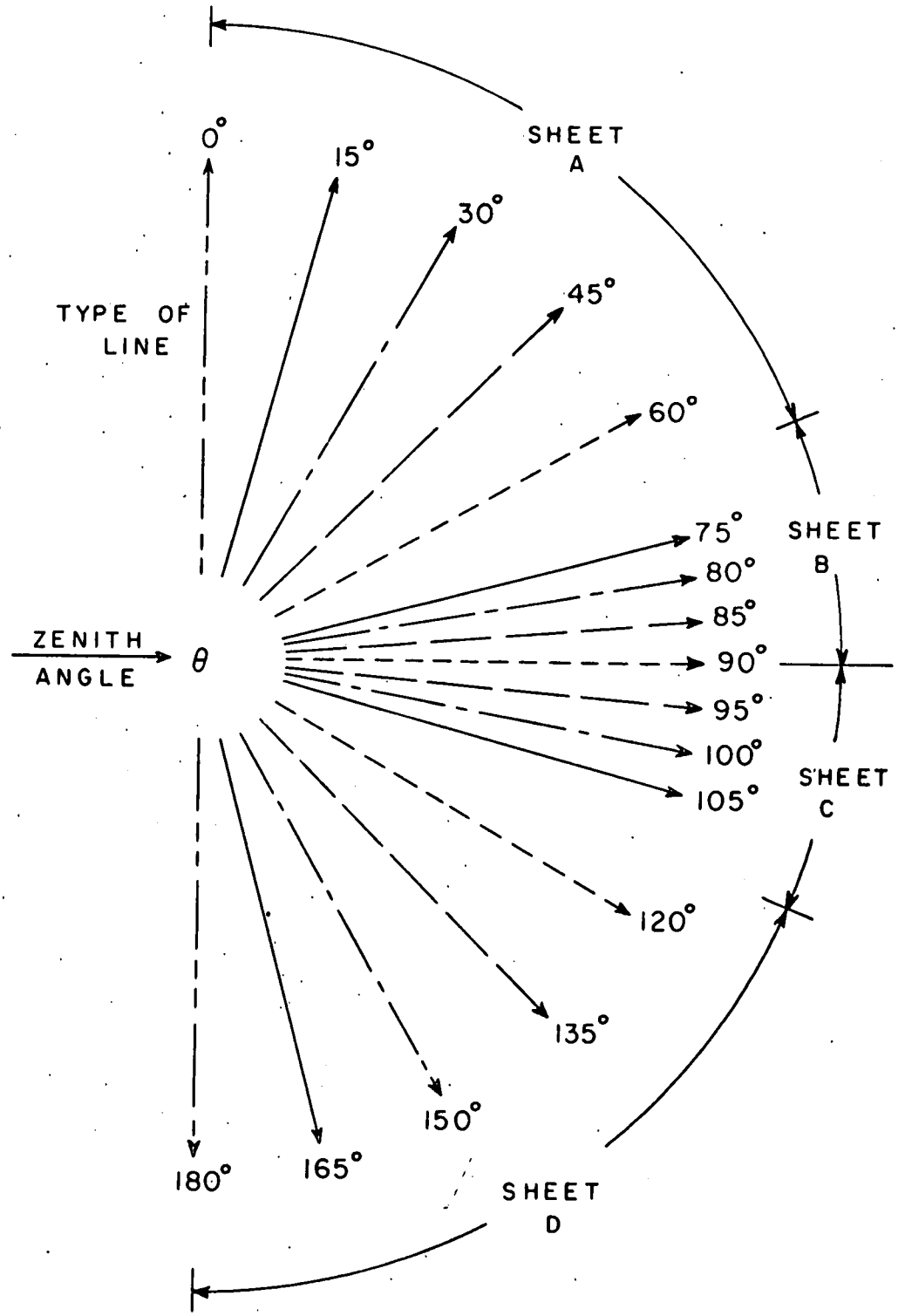
[2] See "Image Transmission by the Troposphere I," S. Q. Duntley, A. R. Boileau, and R. W. Preisendorfer, JOSA, 47, June 1957, pp. 499-506.

To differentiate between the different graphs on one sheet five distinctive types of lines are used. Fig. 4 immediately following this page identifies the sheets, the zenith angles, and the lines used for each zenith angle.

In the case of the first data Figure, Fig. 5, there are five sheets. The sky luminance value for 0° azimuth and 30° zenith angle is very high because of the proximity of the sun. Because its value exceeded the scale of luminance values printed on the standard data graph paper the graph for this sky luminance value could not be plotted with the other 0° azimuth values without causing confusion. Accordingly a separate sheet, identified as aa, is included in Fig. 5. Note that while the printed luminance scale values are the same as the other graphs the legend states that units are "foot-lamberts x 10^{-1}". In other words the sky luminance value in this one case ranges between 9500 and 13000 ft-L.

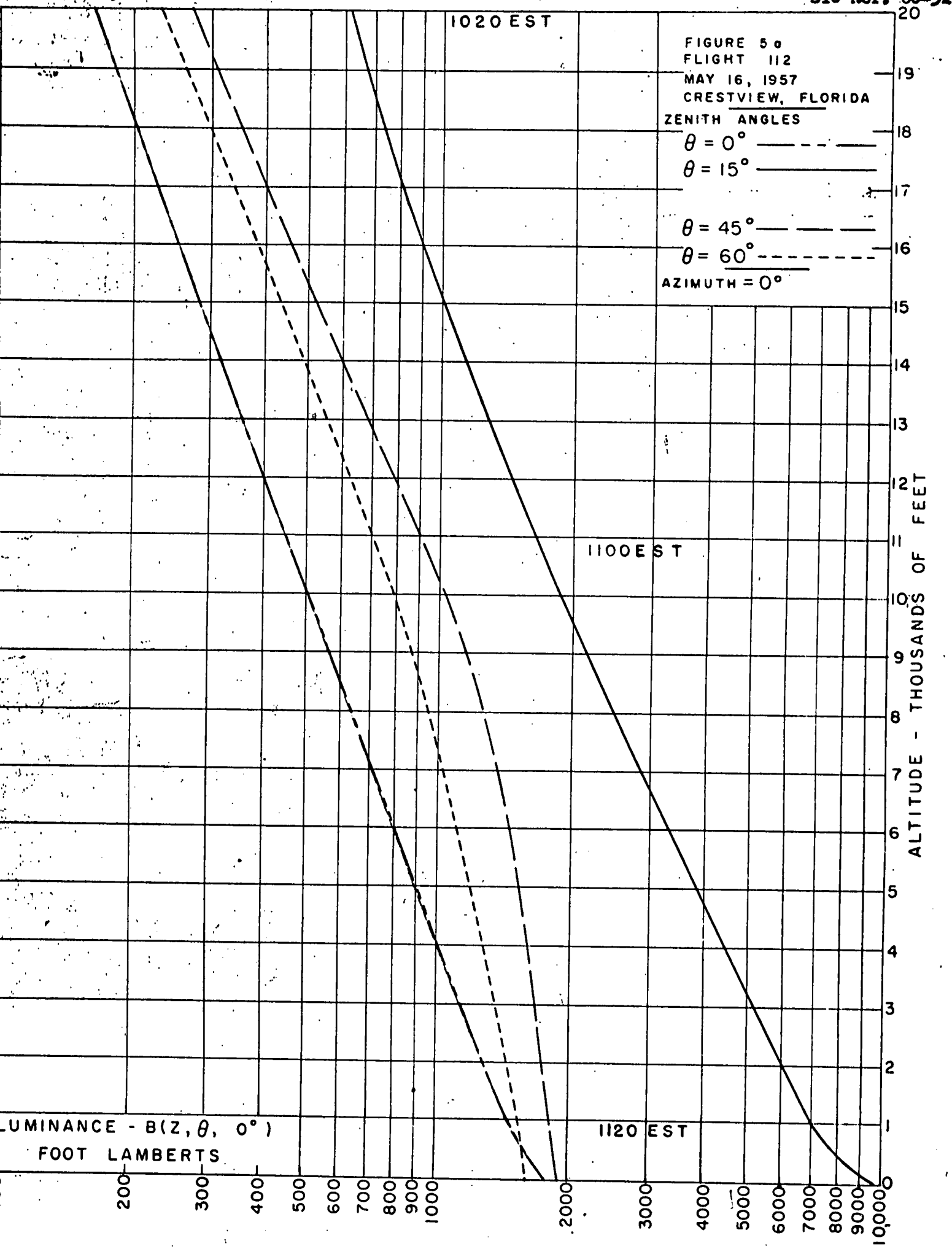


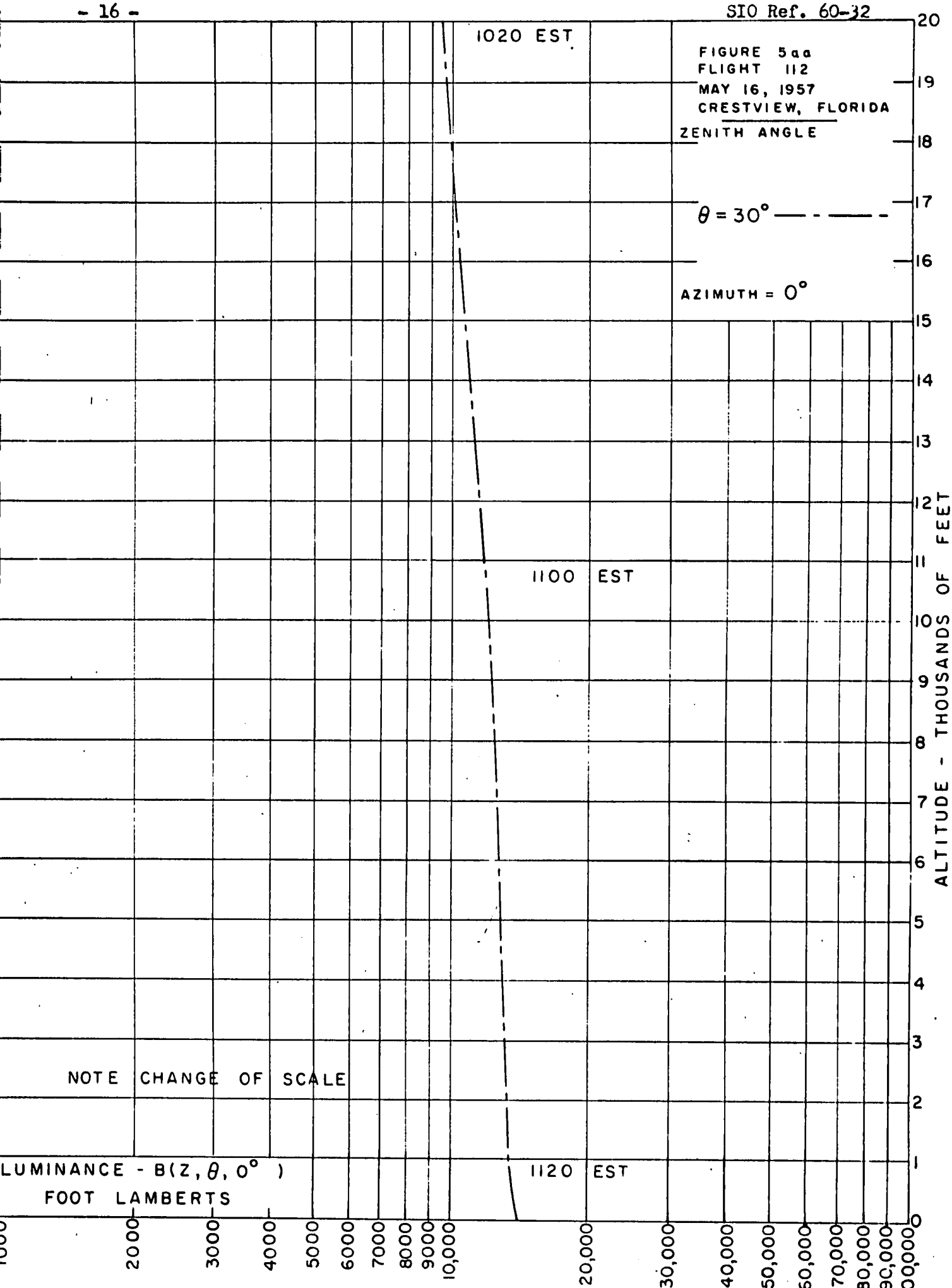
LINES USED FOR SKY LUMINANCE PLOTS, FIGS. 5 TO 22 INCLUSIVE

FIGURE 4
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA

INDEX OF GRAPHS

Figure	Azimuth	Page
5	0°	15
6	20°	20
7	40°	24
8	60°	28
9	80°	32
10	100°	36
11	120°	40
12	140°	44
13	160°	48
14	180°	52
15	200°	56
16	220°	60
17	240°	64
18	260°	68
19	280°	72
20	300°	76
21	320°	80
22	340°	84


1020 EST
1100 EST
1120 EST
FIGURE 5a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 45°
θ = 60°
AZIMUTH = 0°
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
LUMINANCE - B(Z, θ, 0°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
FIGURE 5aa
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLE
θ = 30°
AZIMUTH = 0°
1100 EST
NOTE CHANGE OF SCALE
1120 EST
LUMINANCE - B(Z, θ, 0°)
FOOT LAMBERTS
2000
3000
4000
5000
6000
7000
8000
9000
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
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

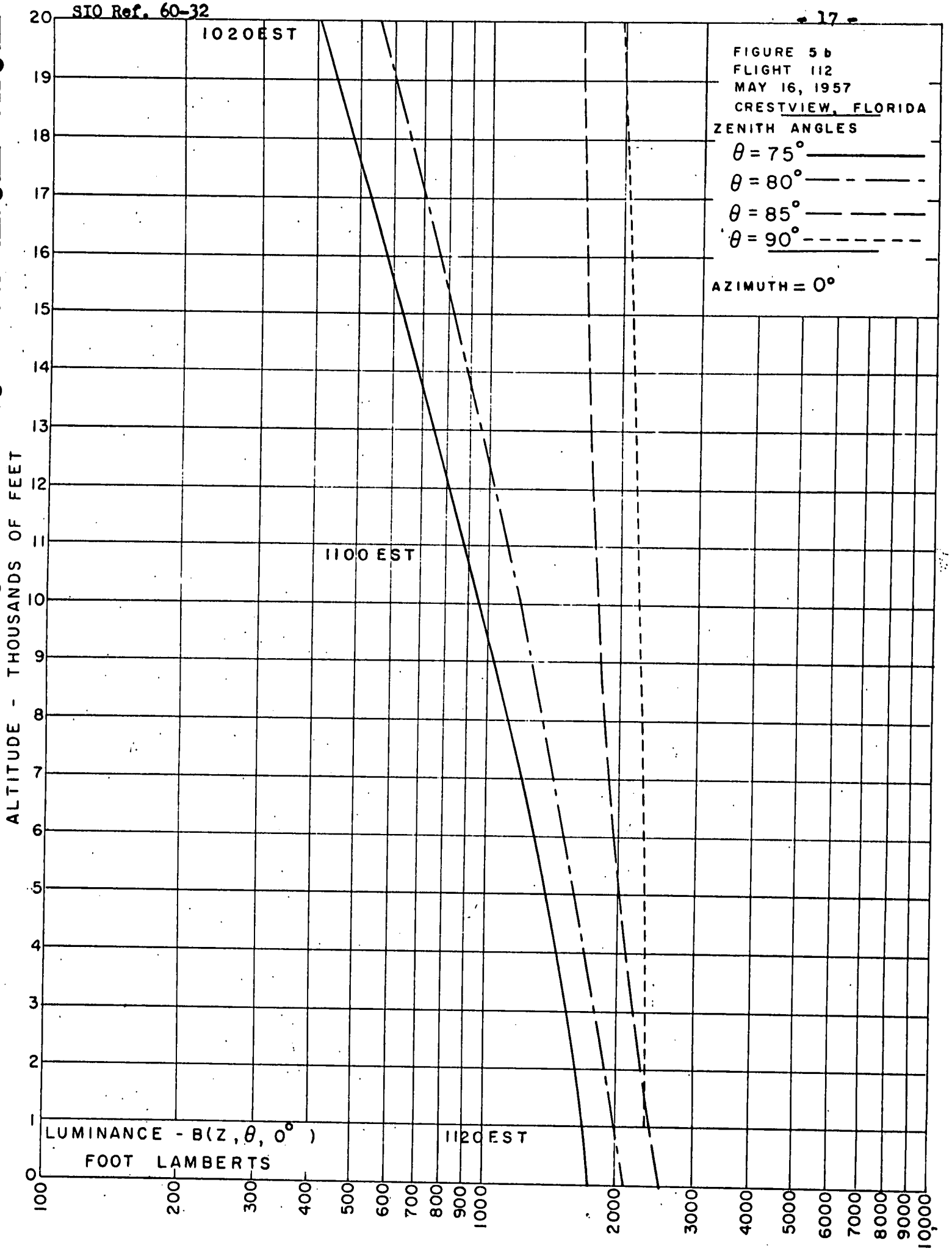

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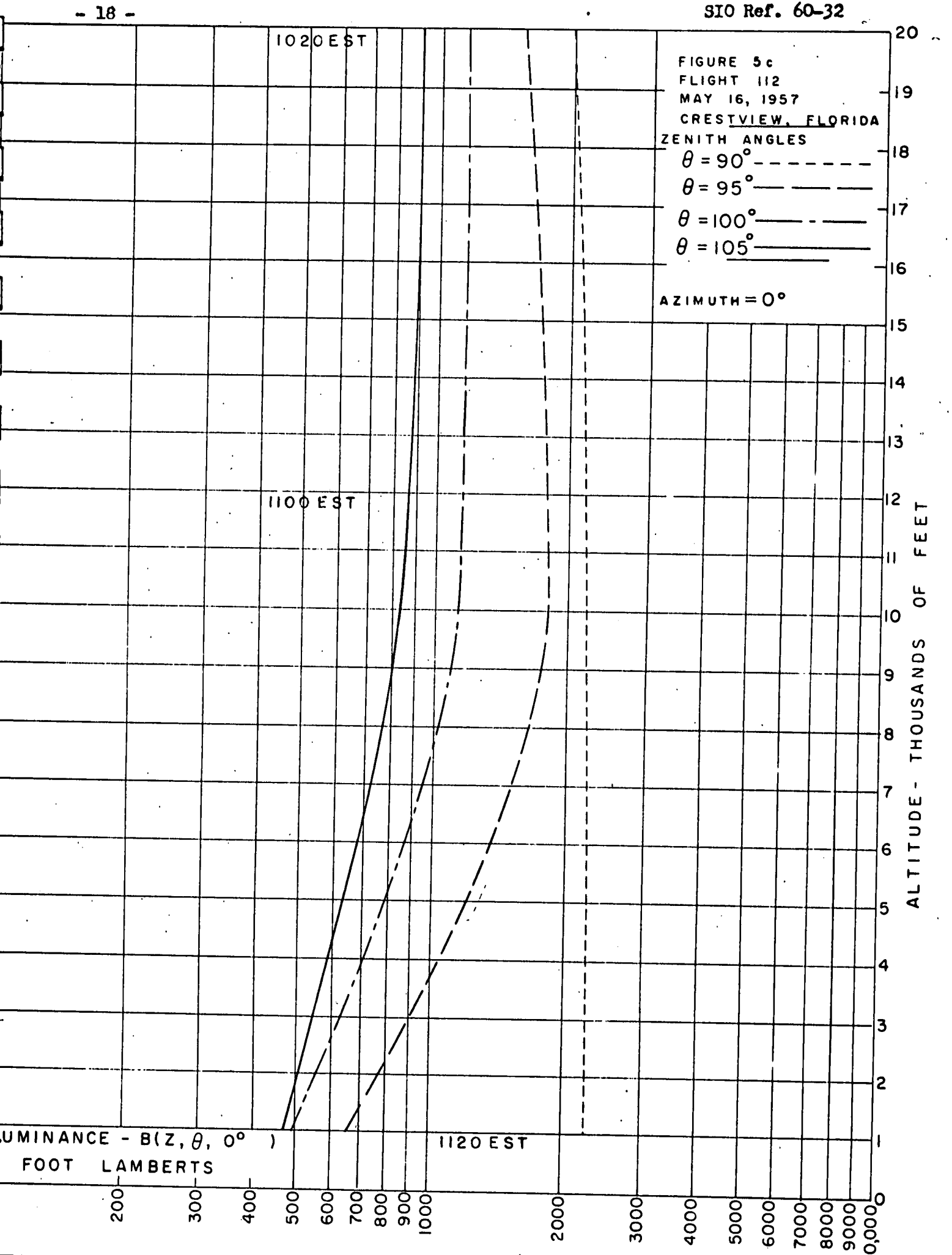
FIGURE 5b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 0°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 0°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
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1120 EST
FIGURE 5c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 0°
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
LUMINANCE - B(Z, θ, 0°)
FOOT LAMBERTS
200 300 400 500 600 700 800 900 1000 2000 3000 4000 5000 6000 7000 8000 9000 10,000

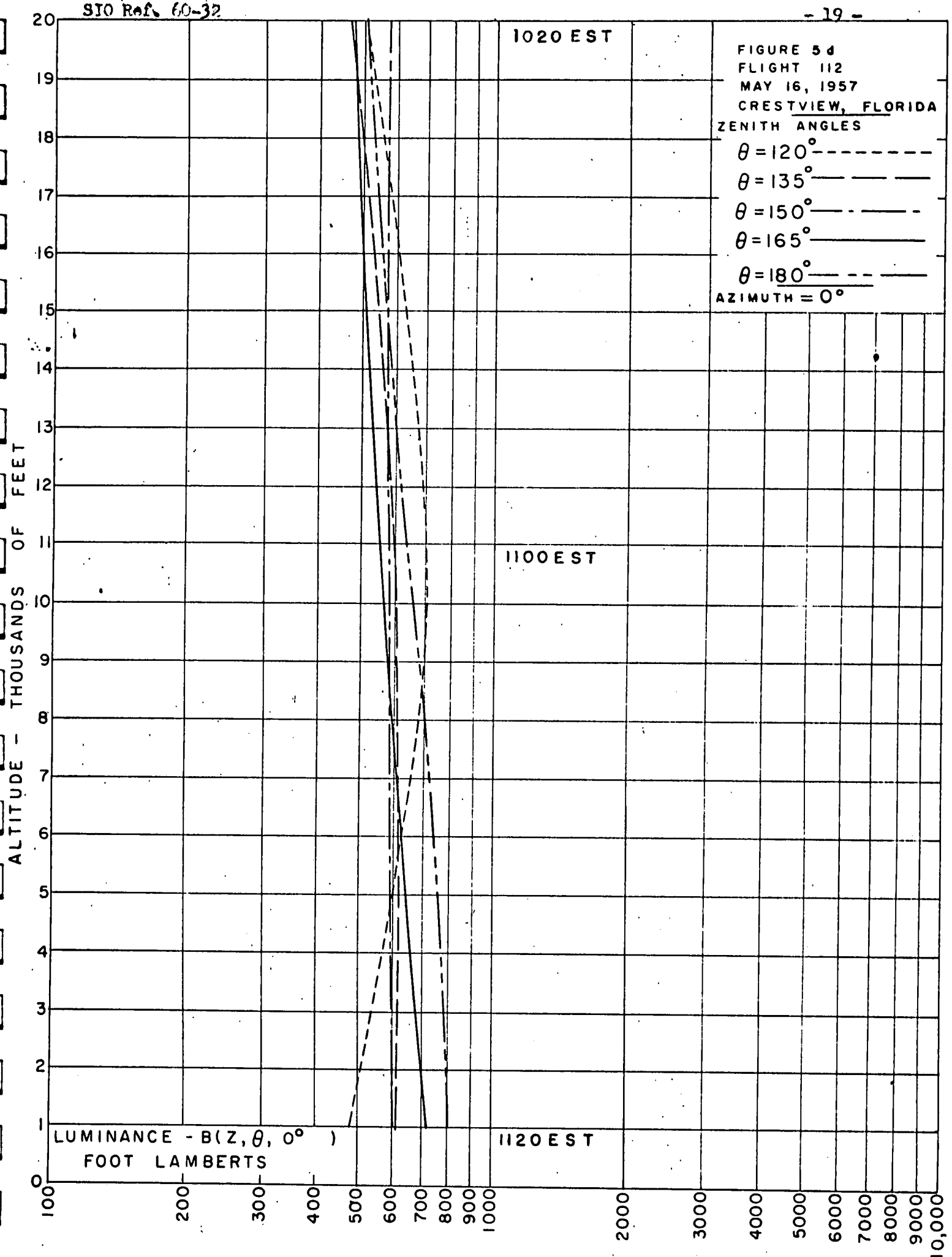
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FIGURE 5d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 0°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 0°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
300
400
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6000
7000
8000
9000
10,000

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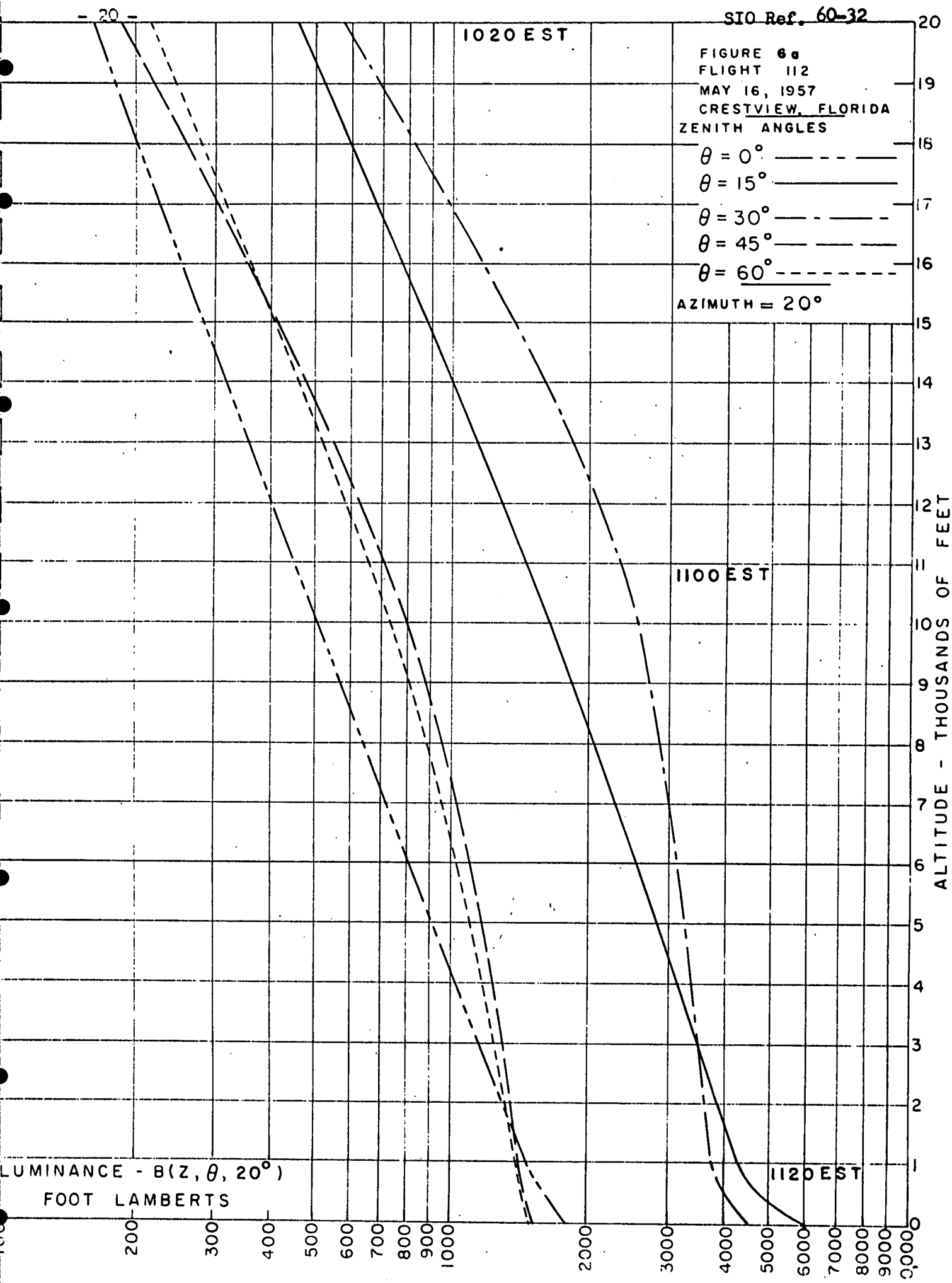
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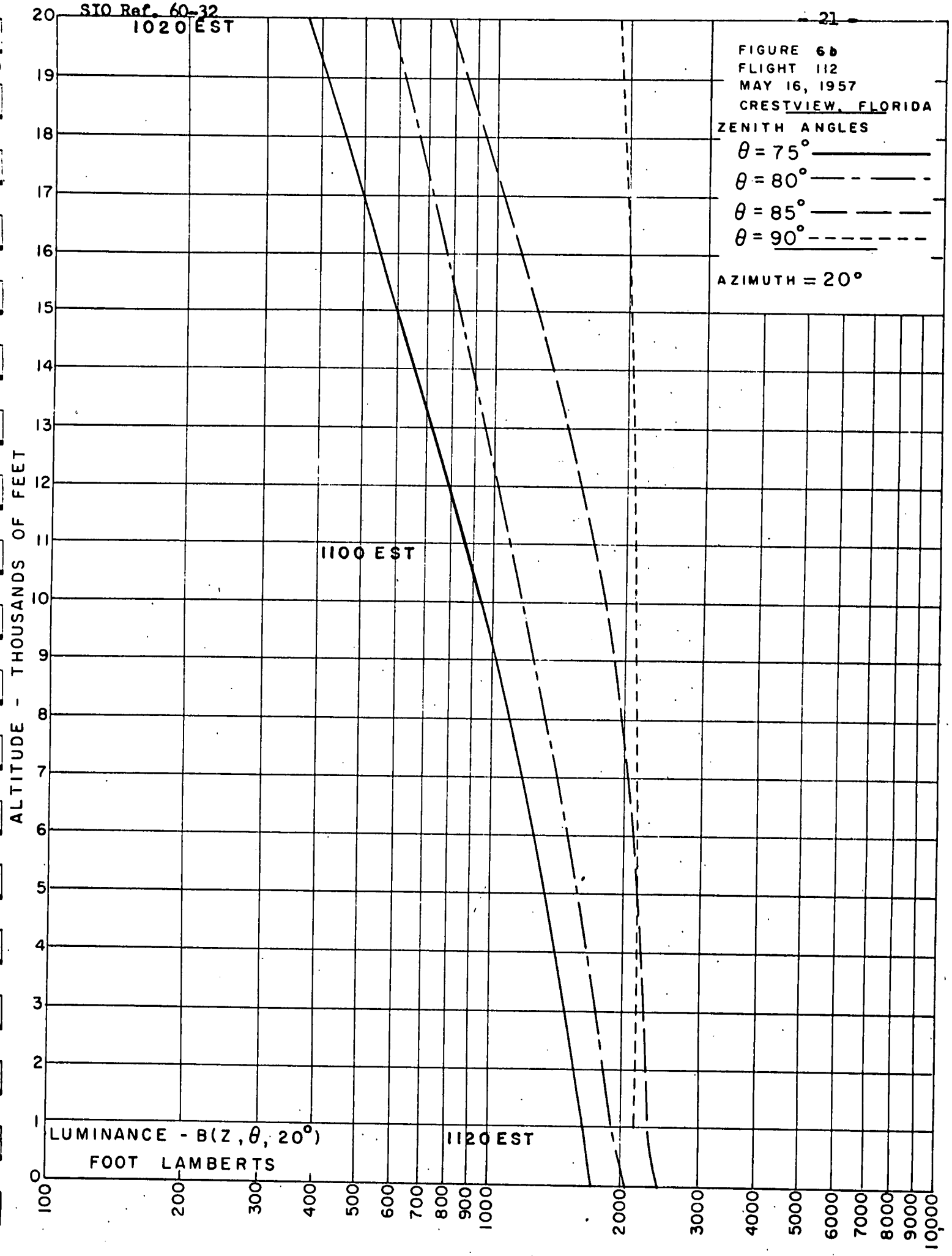
FIGURE 6a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 20°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 20°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000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1100 EST
1120 EST
FIGURE 6b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 20°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 20°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
300
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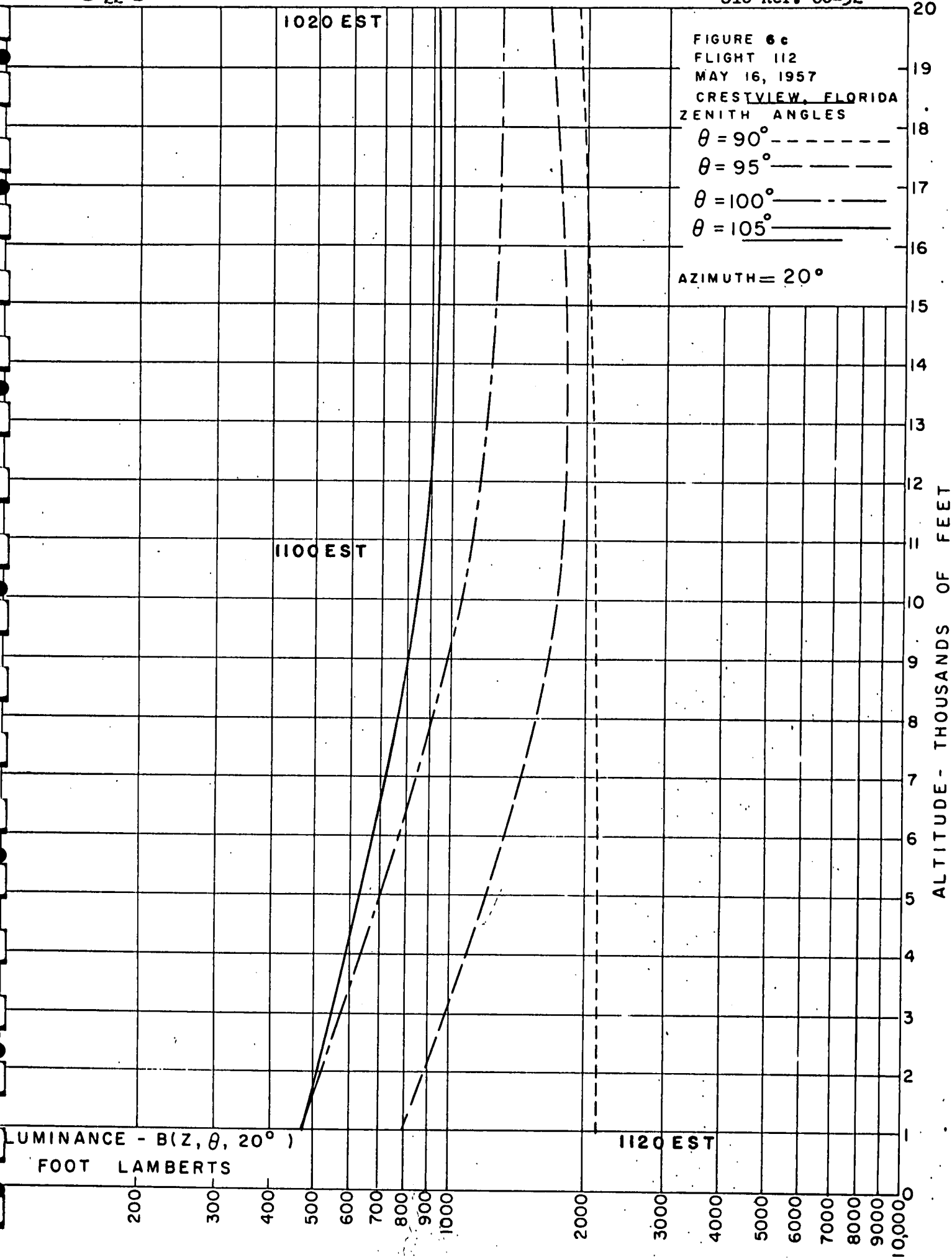
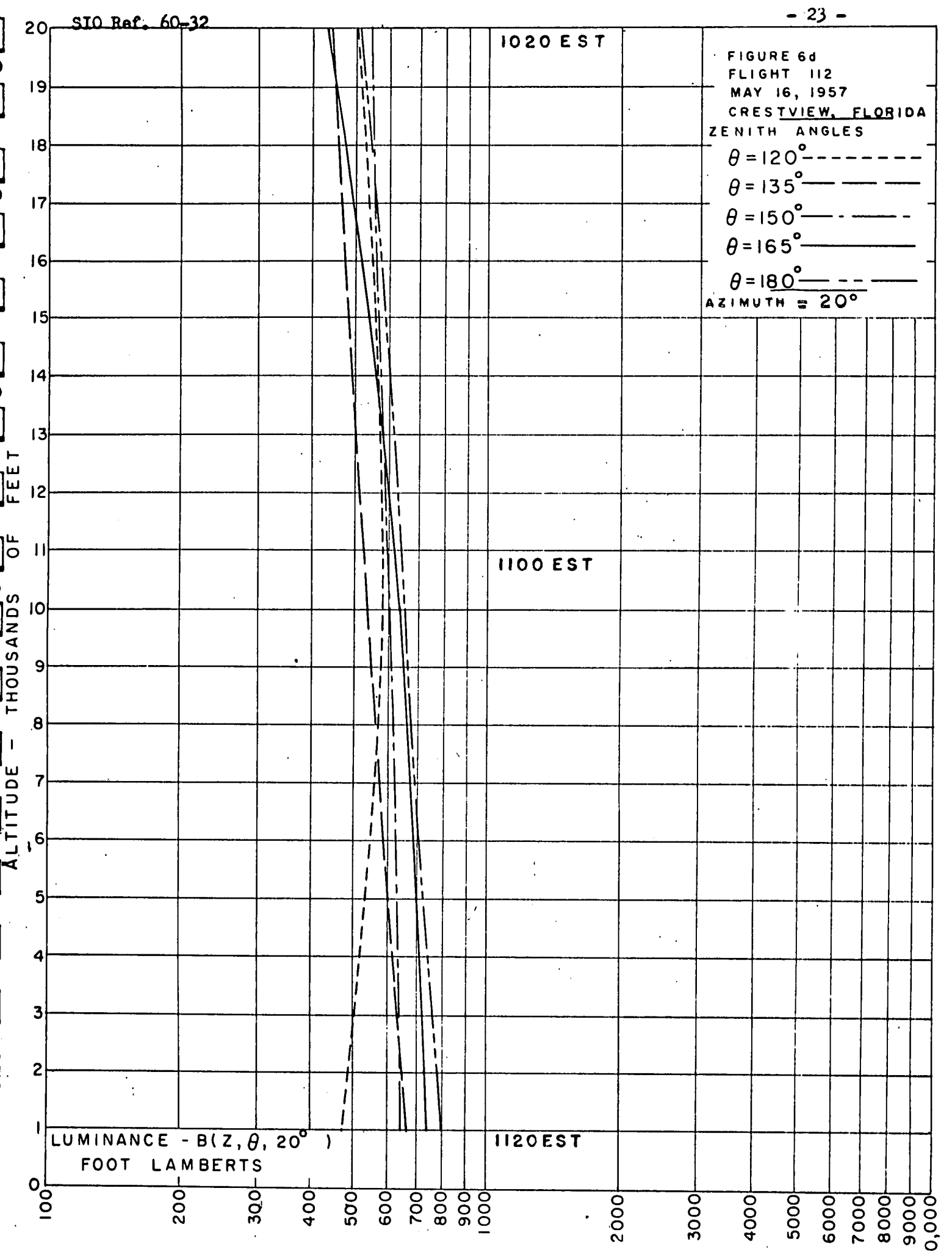
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 6c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 20°
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
LUMINANCE - B(Z, θ, 20°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 6d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 20°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 20°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
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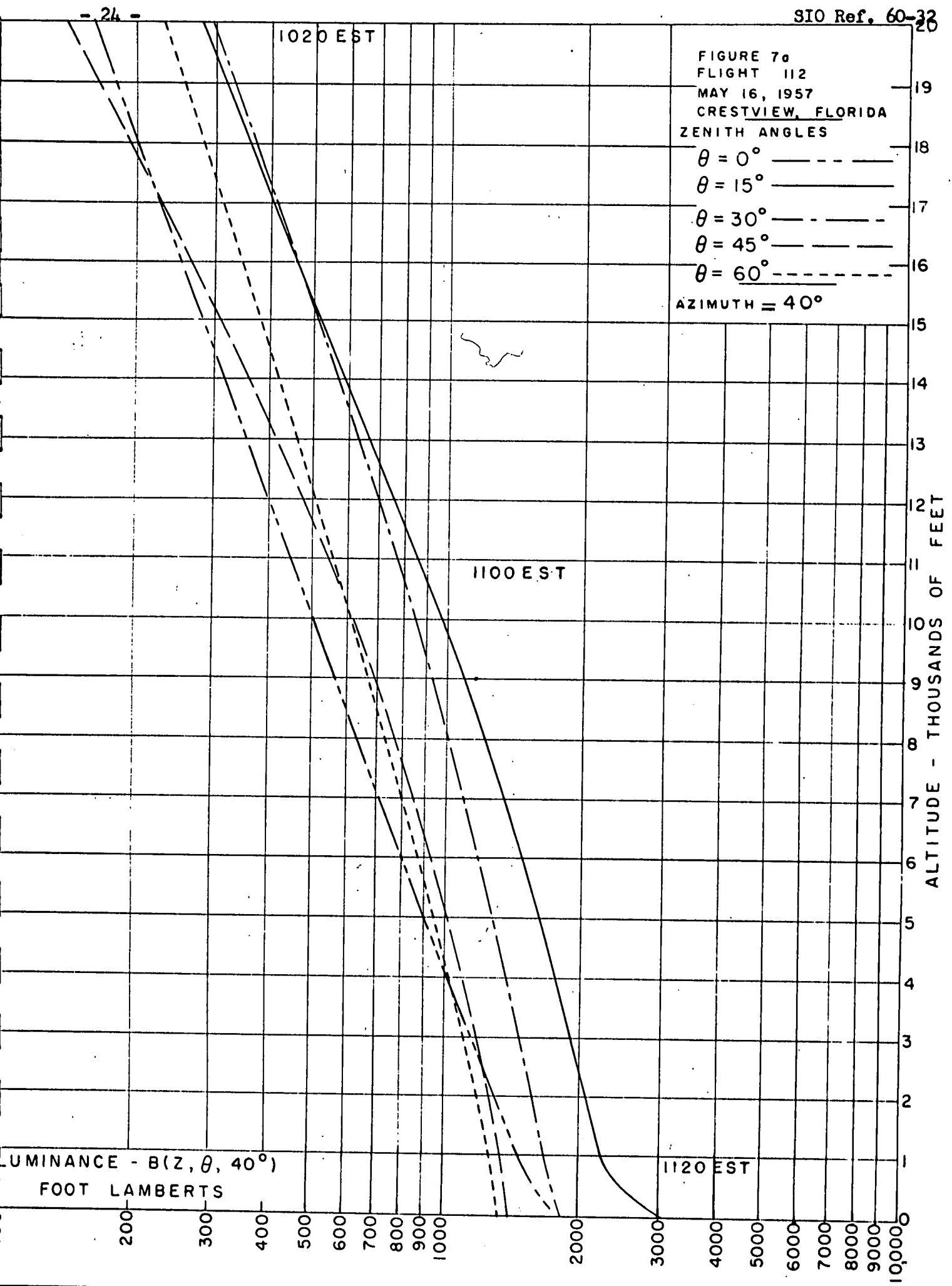
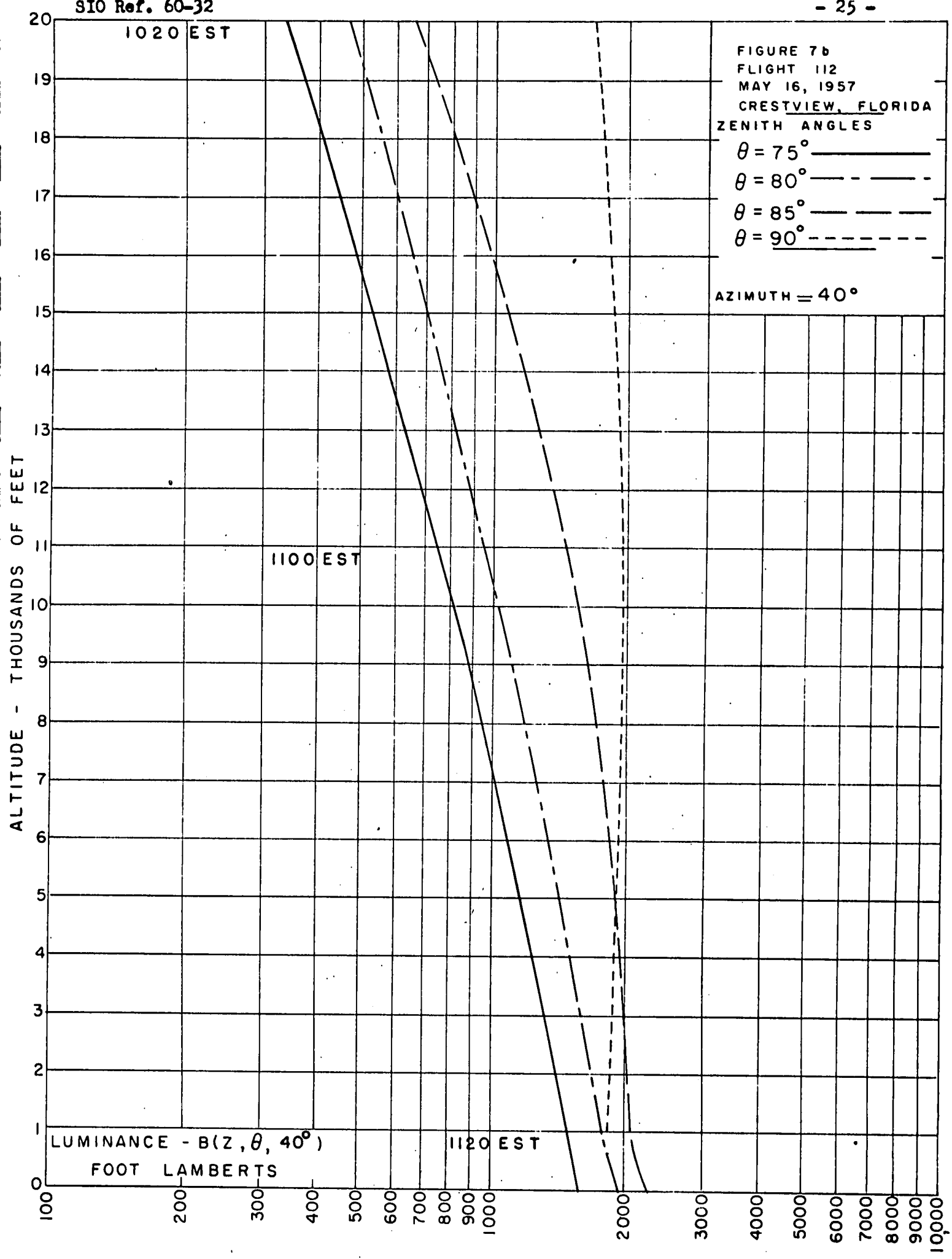
3000
4000
5000
6000
7000
8000
9000
0,000


1020 EST
1100 EST
1120 EST
FIGURE 7a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 40°
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
LUMINANCE - B(Z, θ, 40°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 7b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 40°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 40°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
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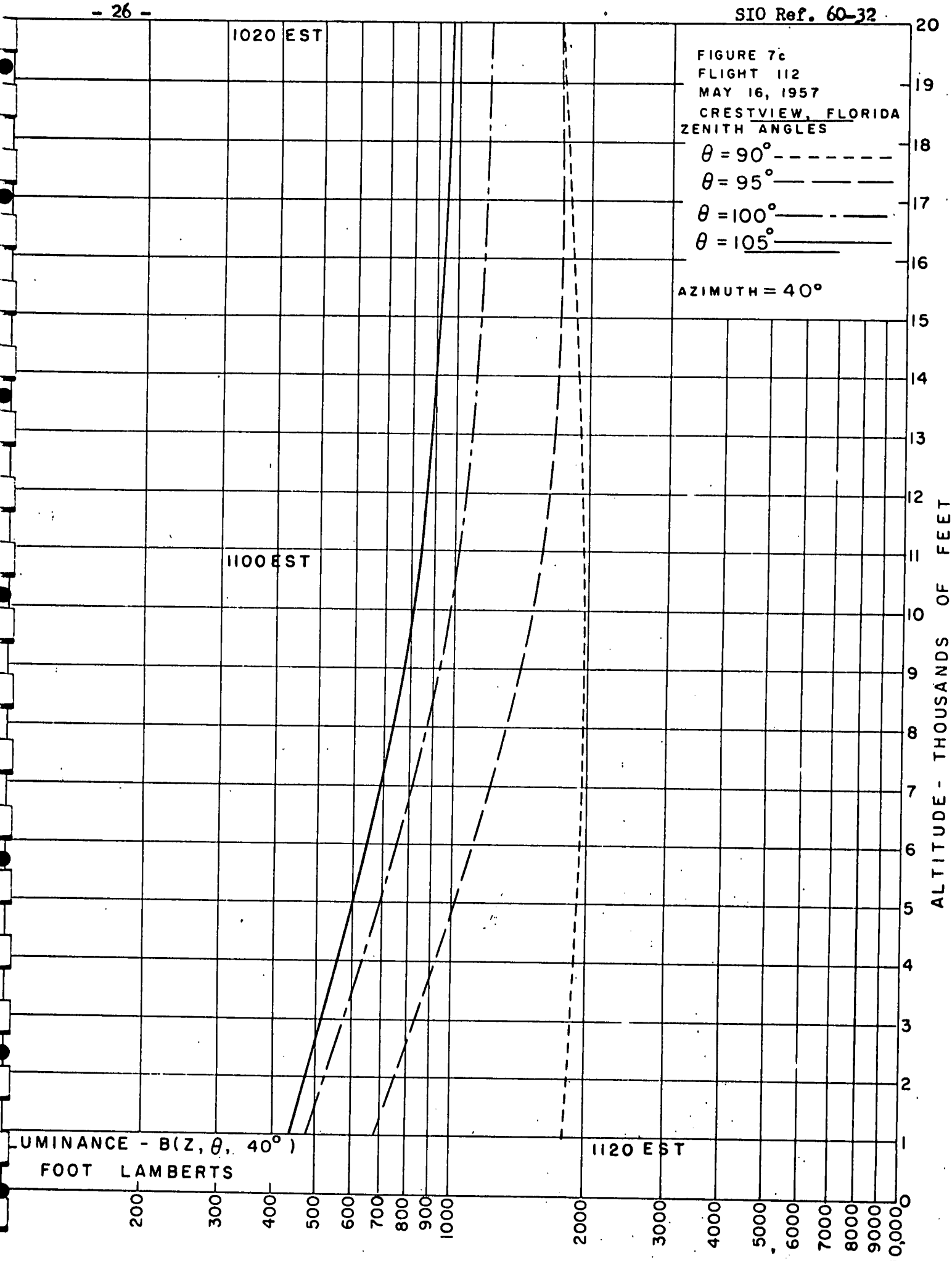
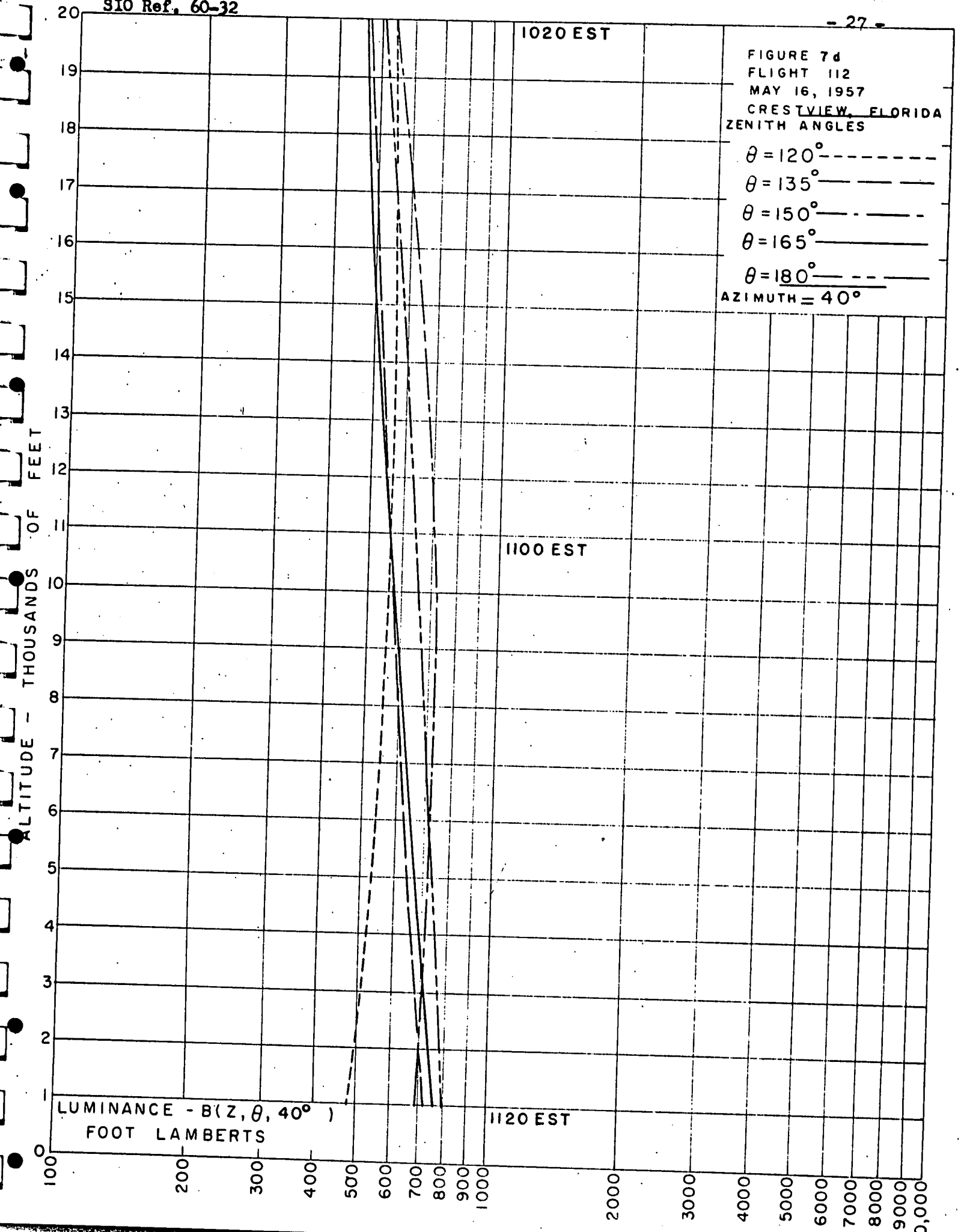
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 7c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 40°
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
LUMINANCE - B(Z, θ, 40°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 7d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 40°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 40°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
300
400
500
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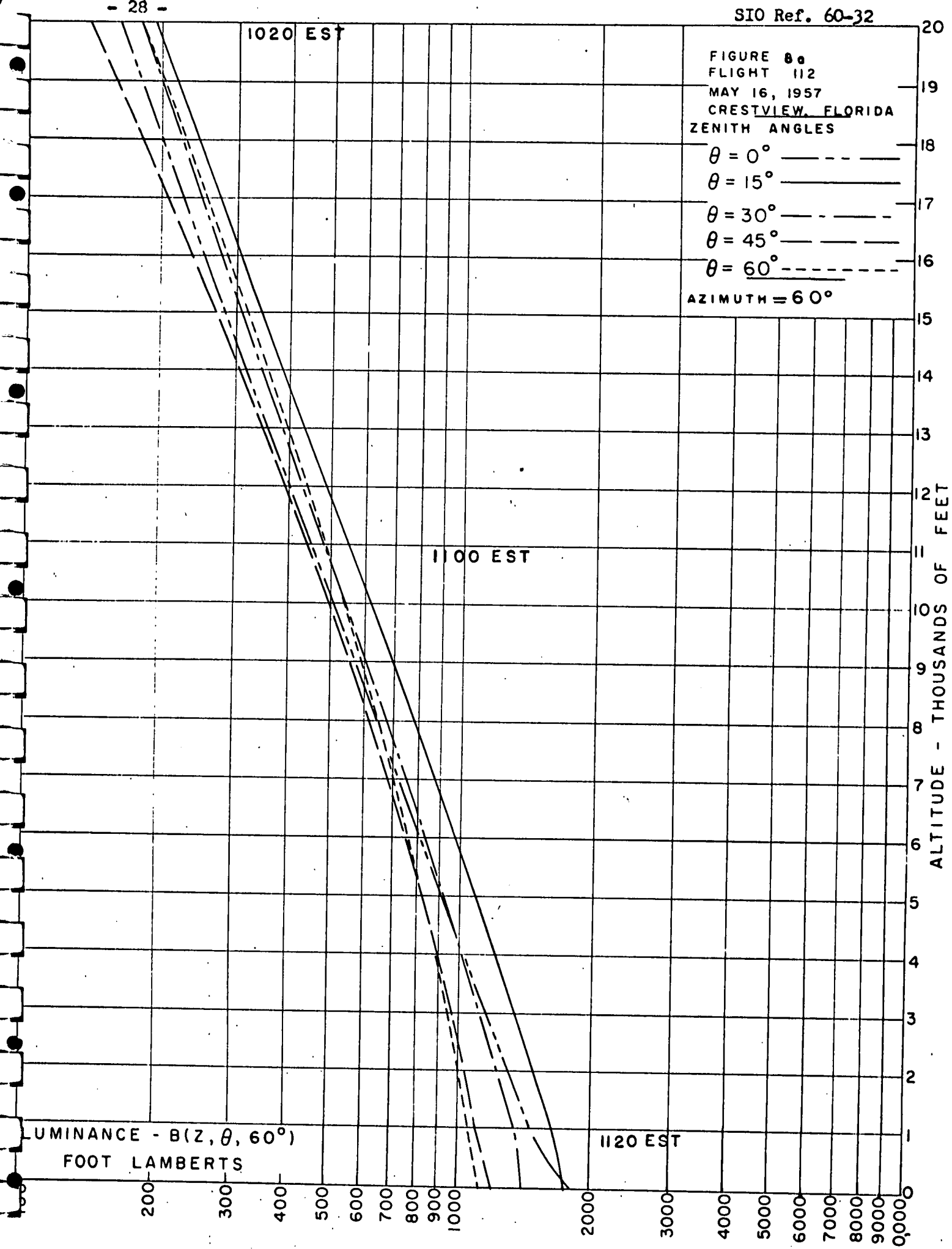
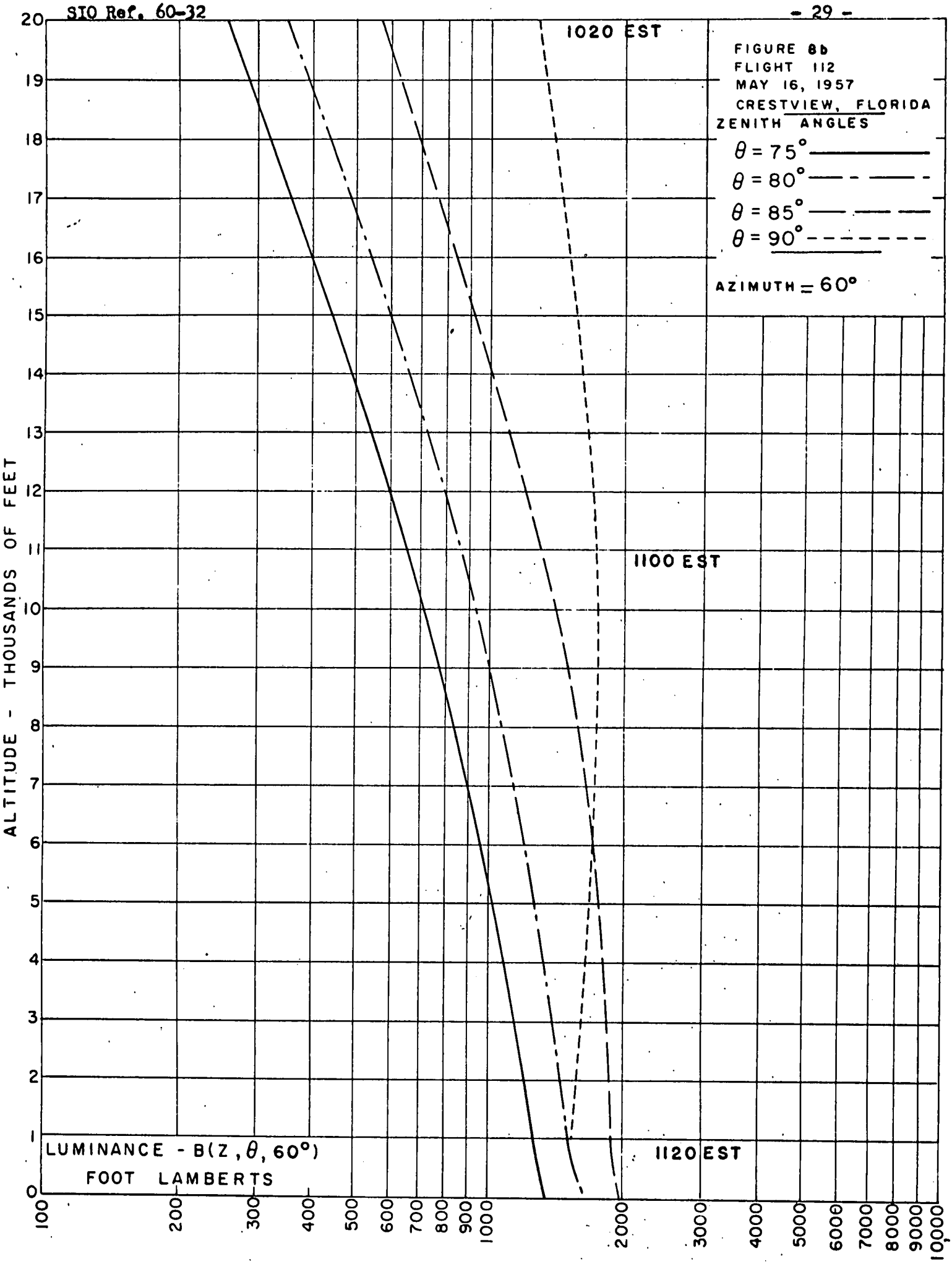
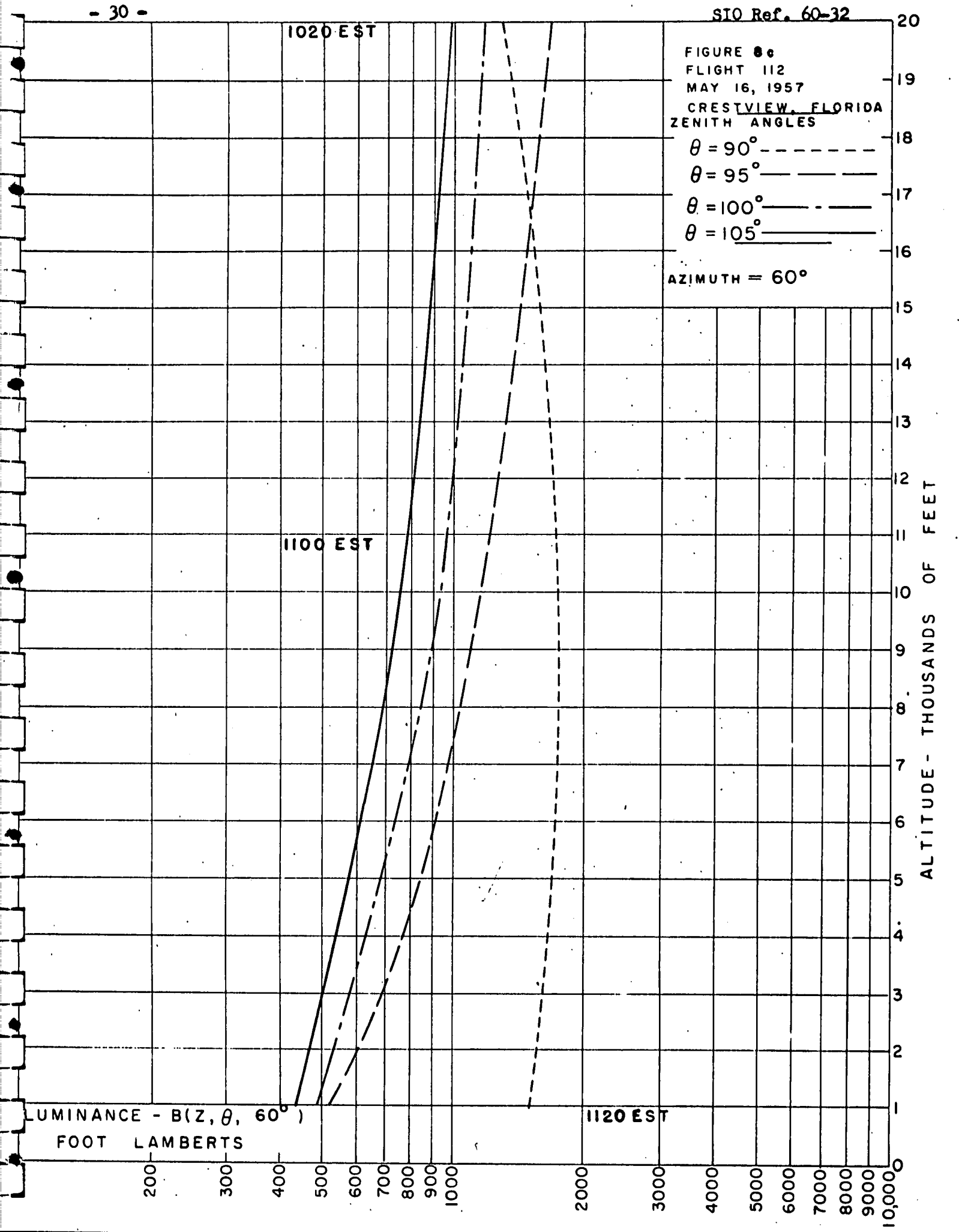
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 8a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 60°
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
LUMINANCE - B(Z, θ, 60°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 8b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 60°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 60°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 8c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 60°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 60°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
0
1
2
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6
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11
12
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14
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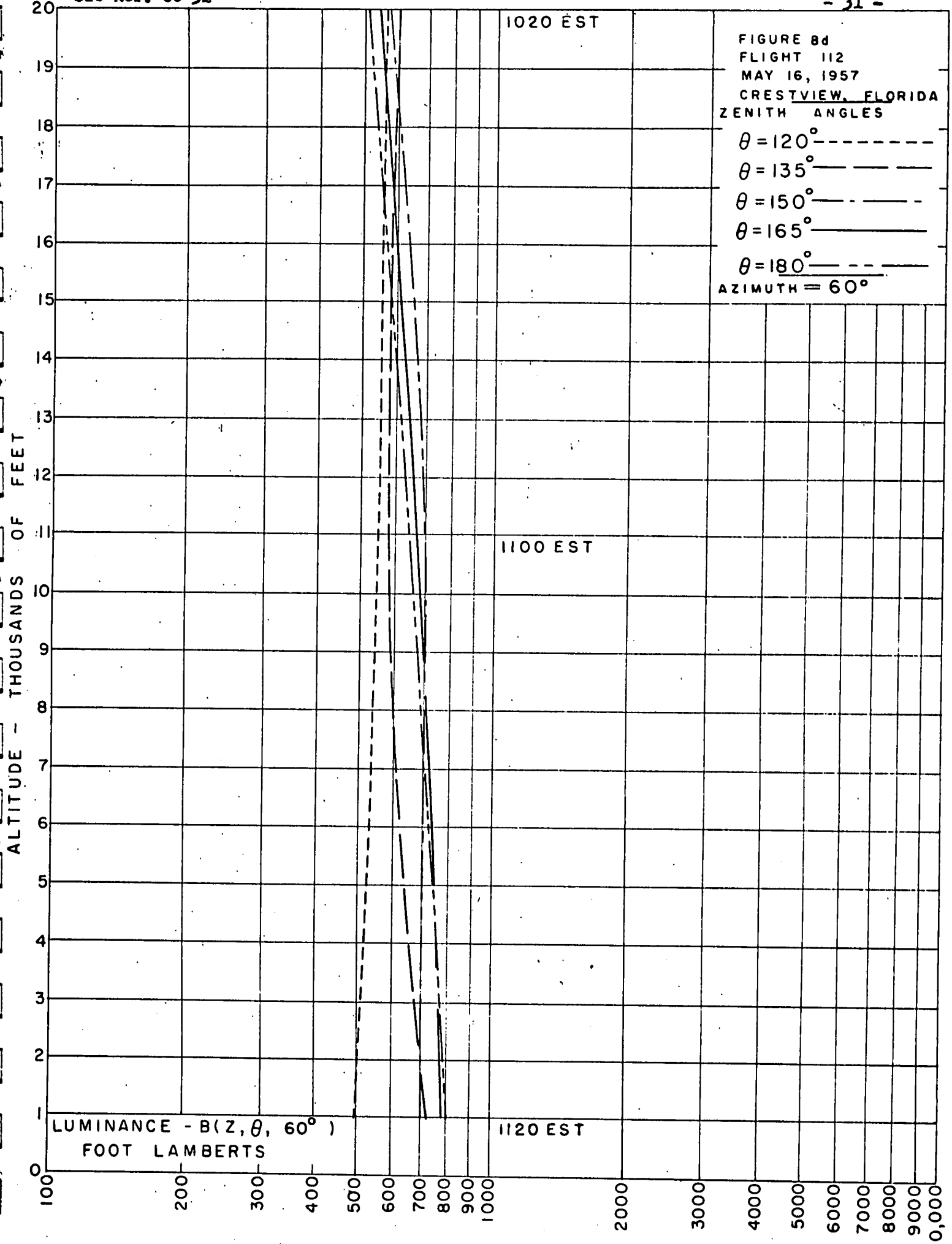
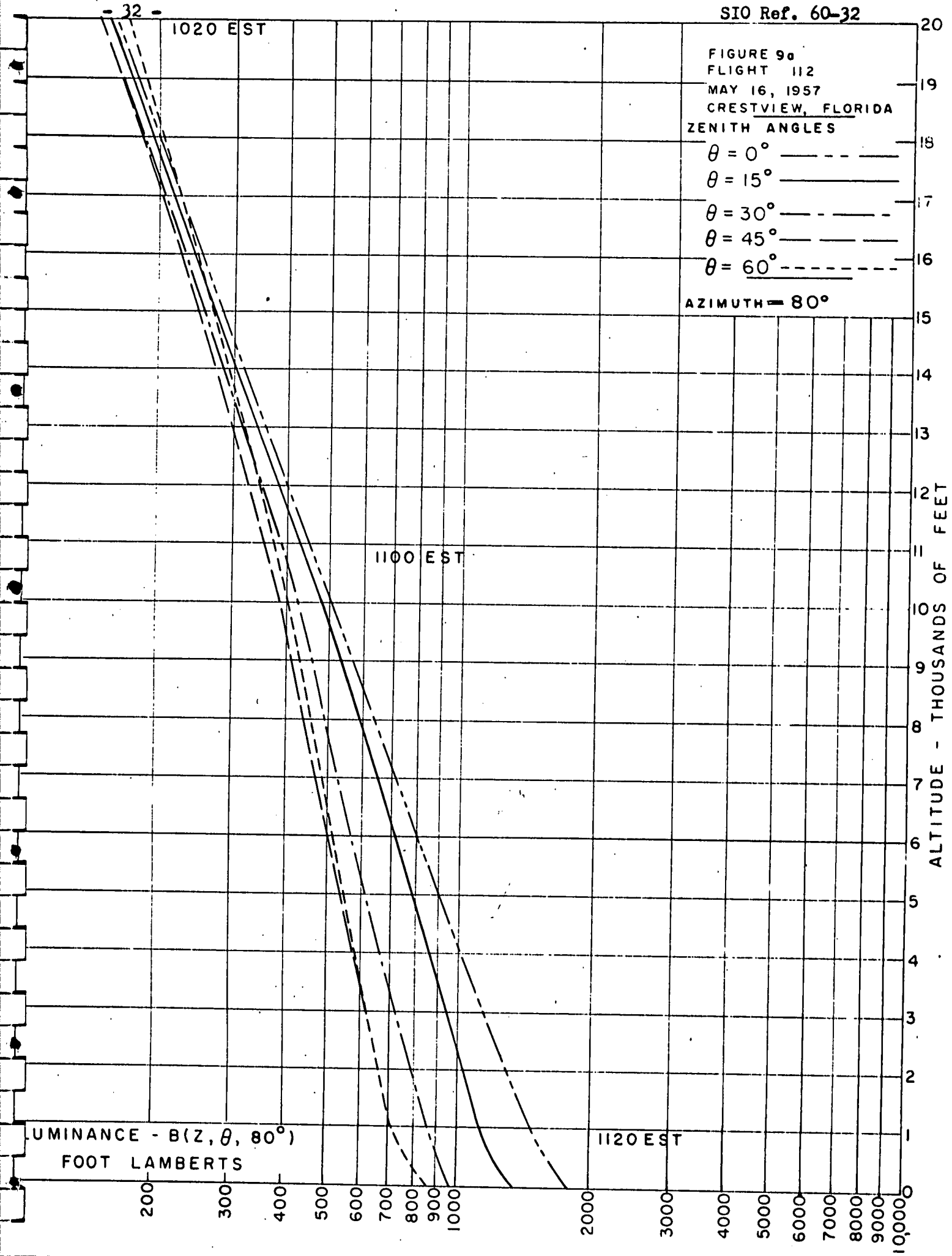
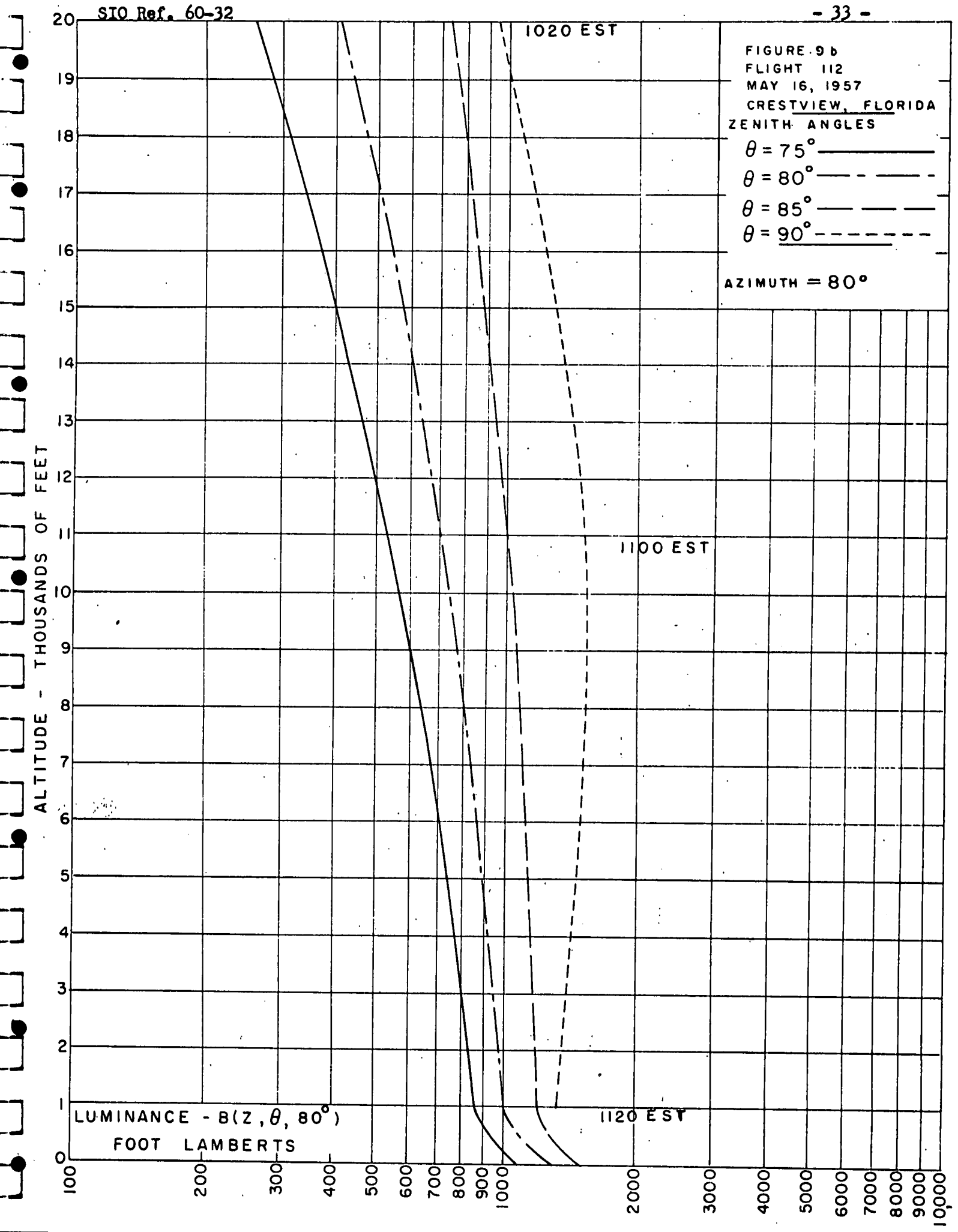

1020 EST
1100 EST
1120 EST
FIGURE 8d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 60°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 60°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 9a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 80°
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
LUMINANCE - B(Z, θ, 80°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 9b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 80°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 80°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
300
400
500
600
700
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5000
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7000
8000
9000
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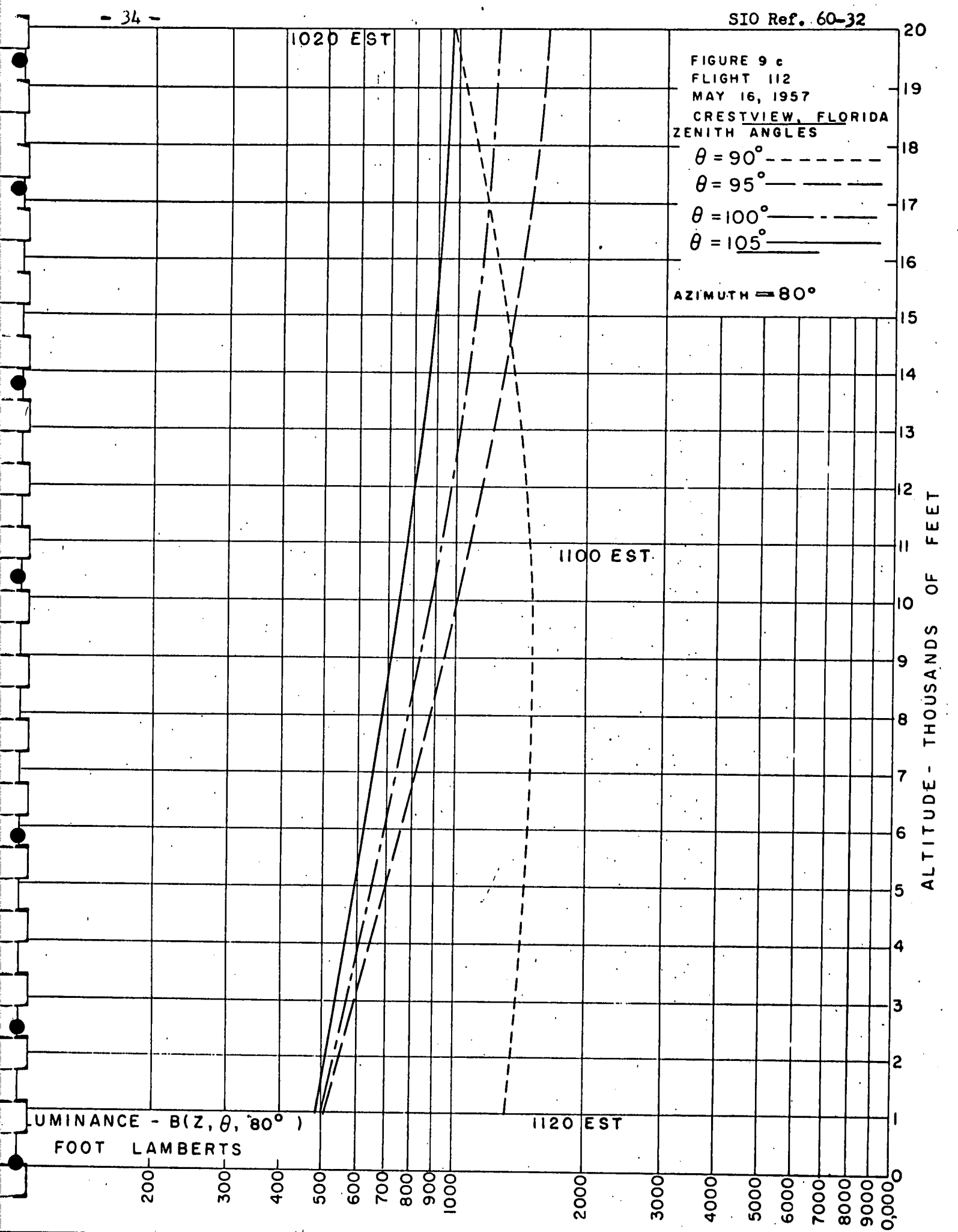
1020 EST
1100 EST
1120 EST
FIGURE 9 c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 80°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 80°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
0,000
0
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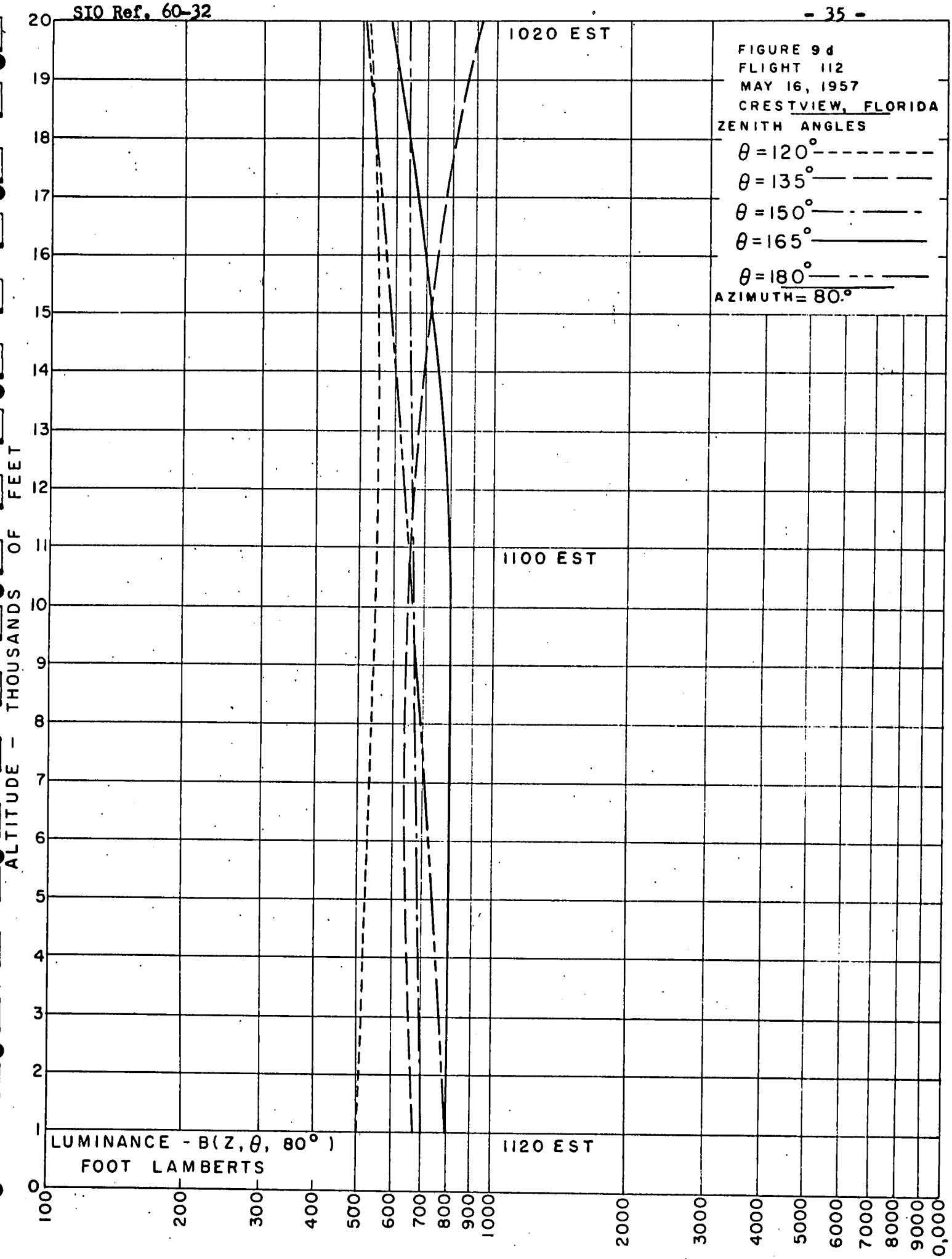
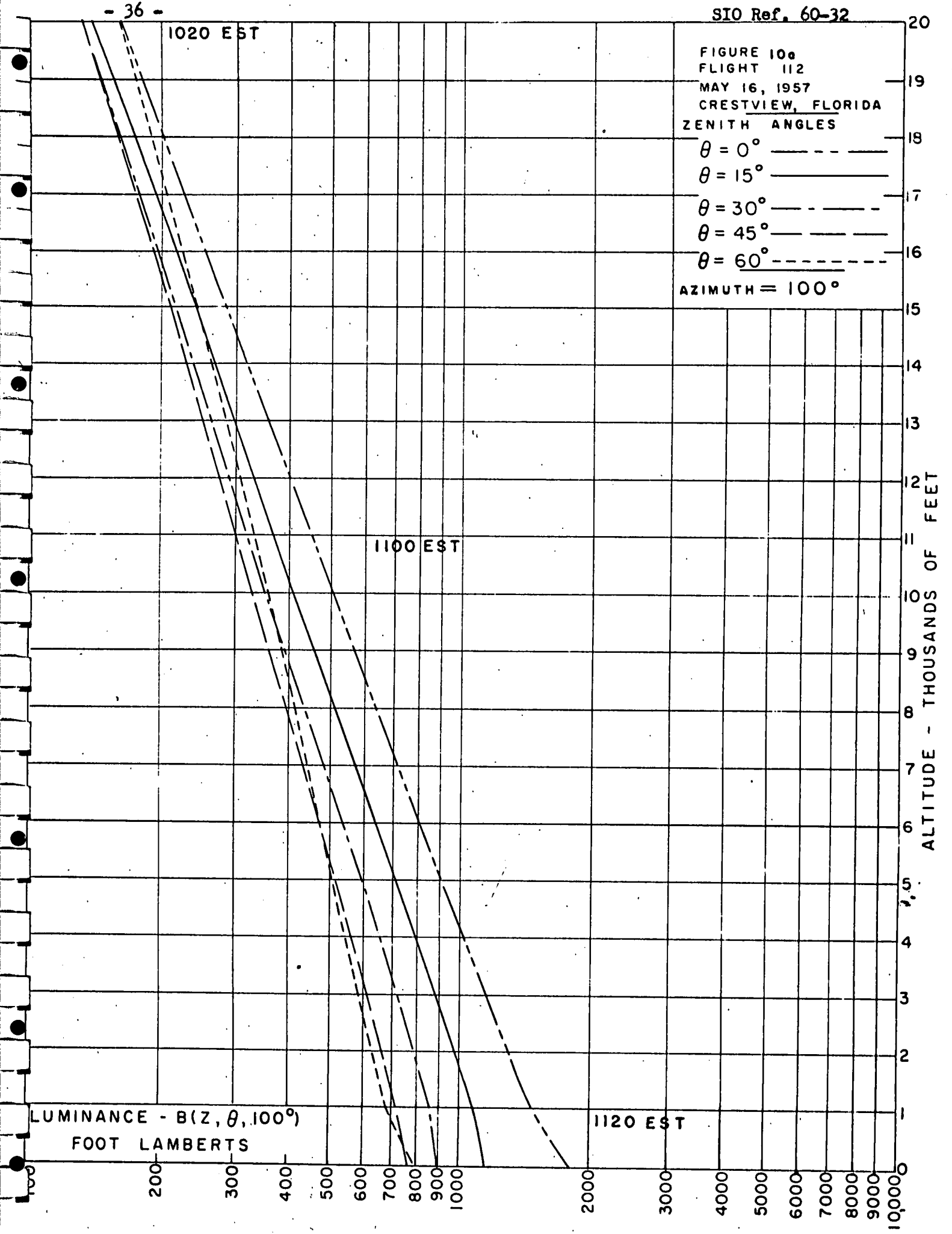

1020 EST
1100 EST
1120 EST
FIGURE 9 d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 80.°
ALTITUDE - THOUSANDS OF FEET
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
LUMINANCE - B(Z, θ, 80°)
FOOT LAMBERTS
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 10a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 100°
LUMINANCE - B(Z, θ, 100°)
FOOT LAMBERTS
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
ALTITUDE - THOUSANDS OF FEET
0
1
2
3
4
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6
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10
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14
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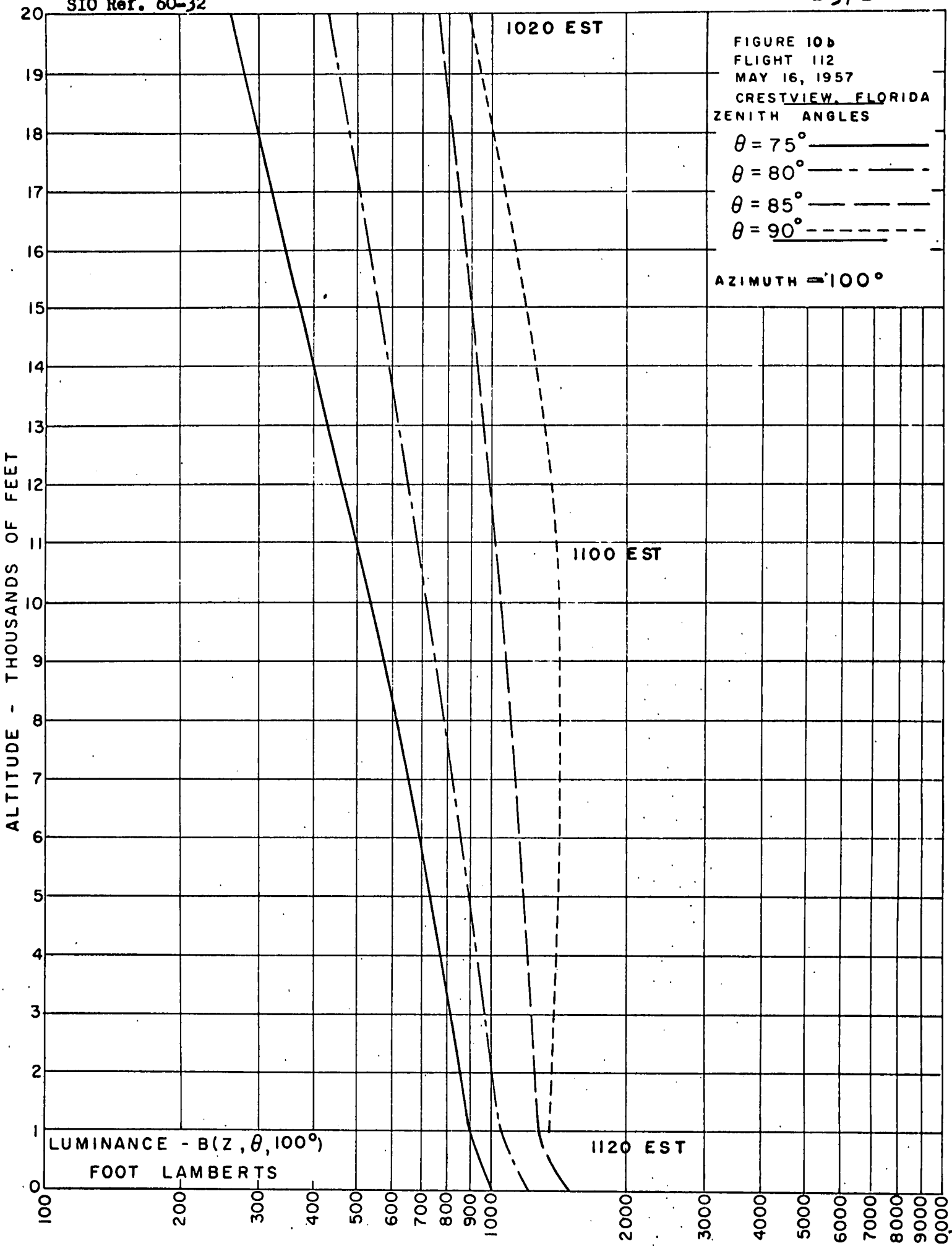
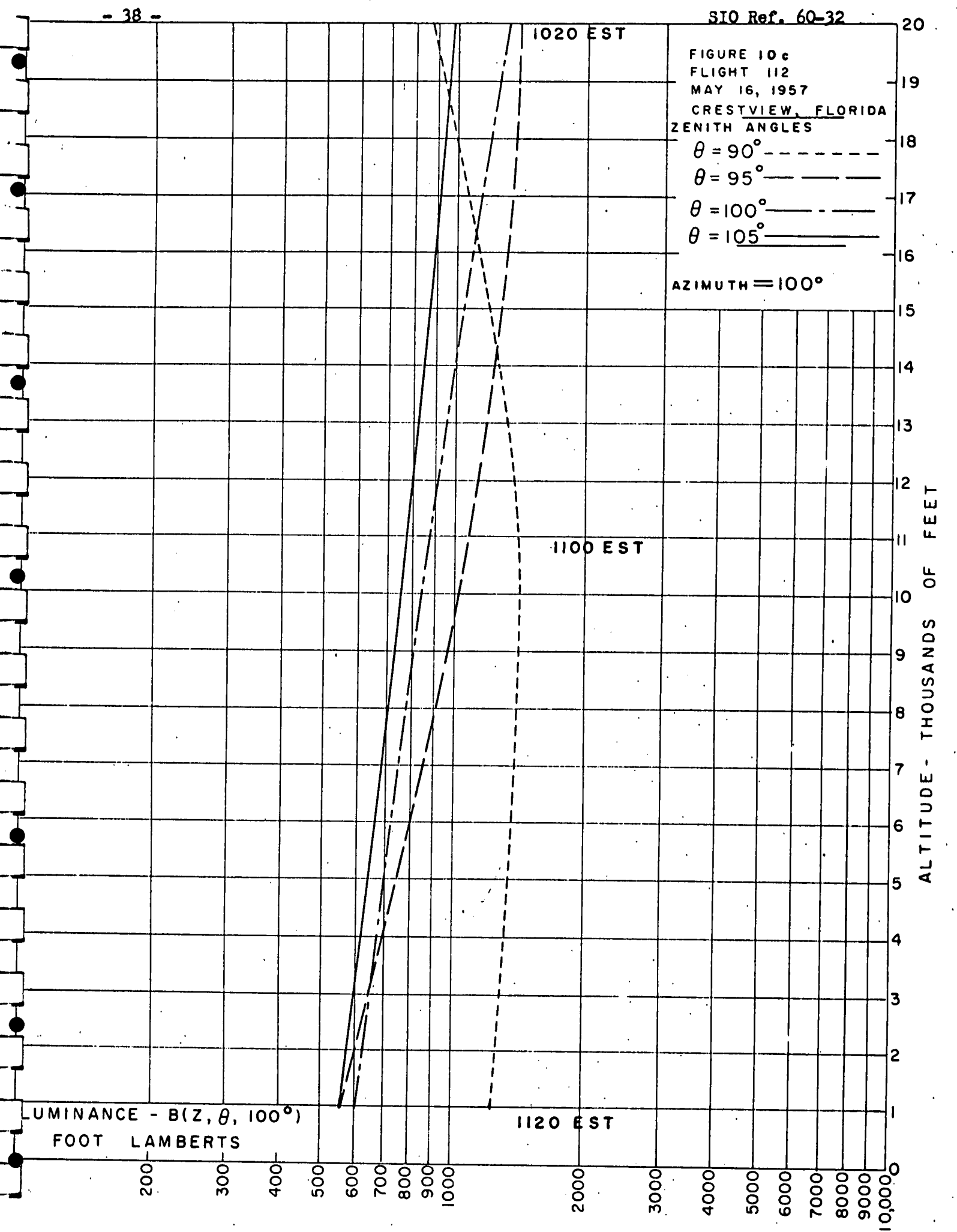
16
17
18
19
20


1020 EST
1100 EST
1120 EST
FIGURE 10b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 100°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 100°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000


1020 EST
1100 EST
1120 EST
FIGURE 10c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 100°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 100°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
0
1
2
3
4
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10
11
12
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14
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16
17
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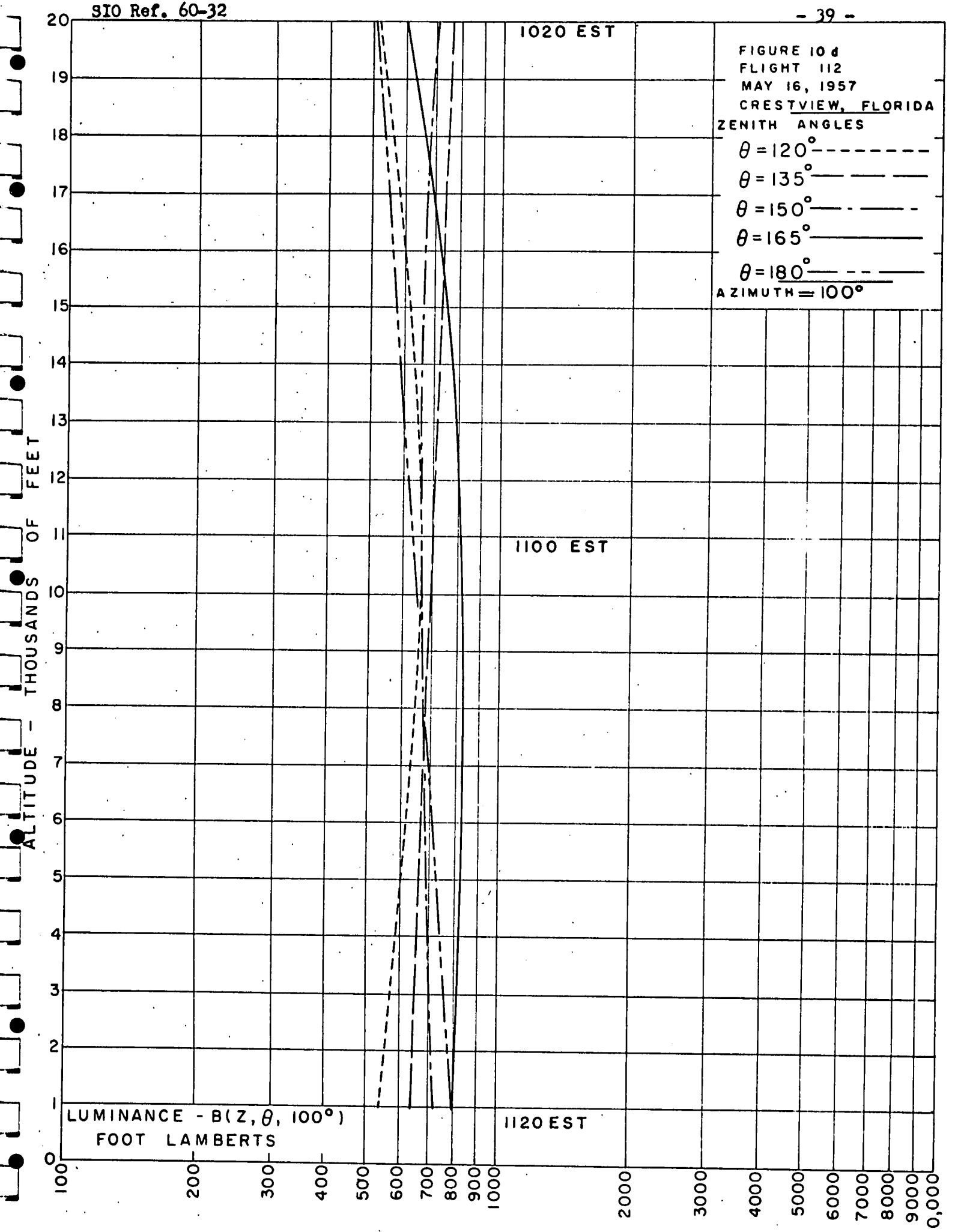
19
20


1020 EST
1100 EST
1120 EST
FIGURE 10 d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 100°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 100°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
300
400
500
600
700
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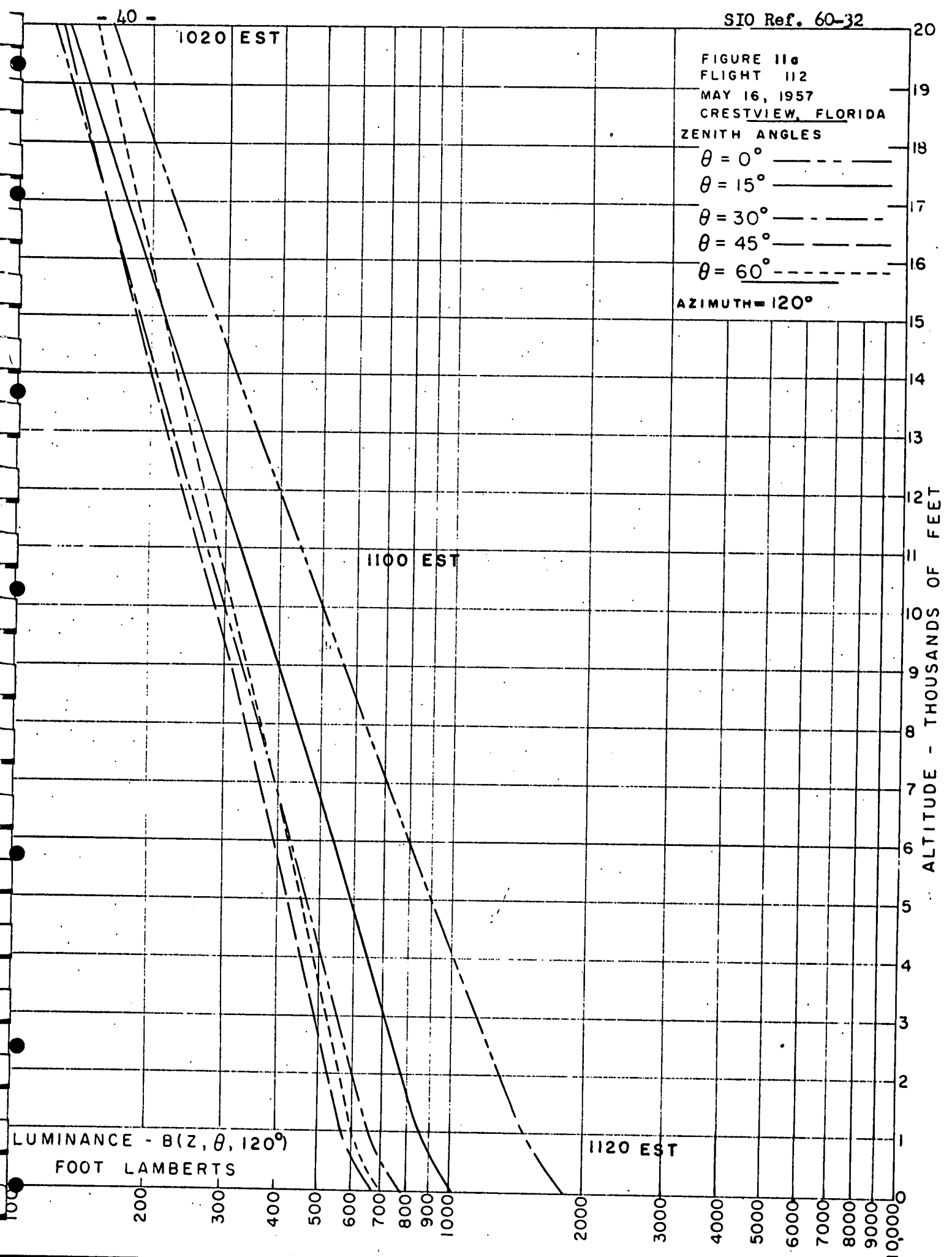
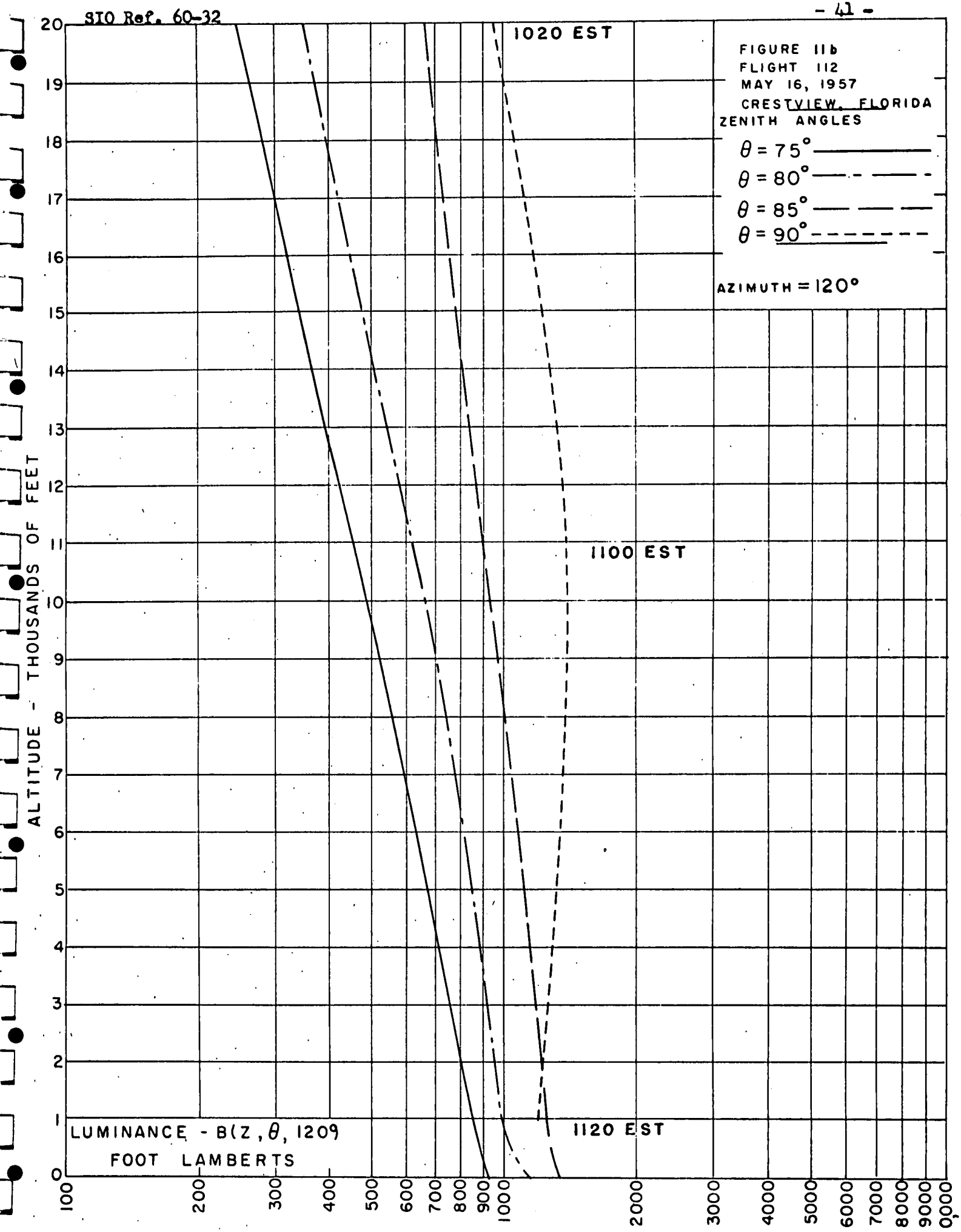
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 11c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 120°
LUMINANCE - B(Z, θ, 120°)
FOOT LAMBERTS
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
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


1020 EST
1100 EST
1120 EST
FIGURE 11b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 120°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 1209
FOOT LAMBERTS
0
1
2
3
4
5
6
7
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15
16
17
18
19
20
100
200
300
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700
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1000
2000
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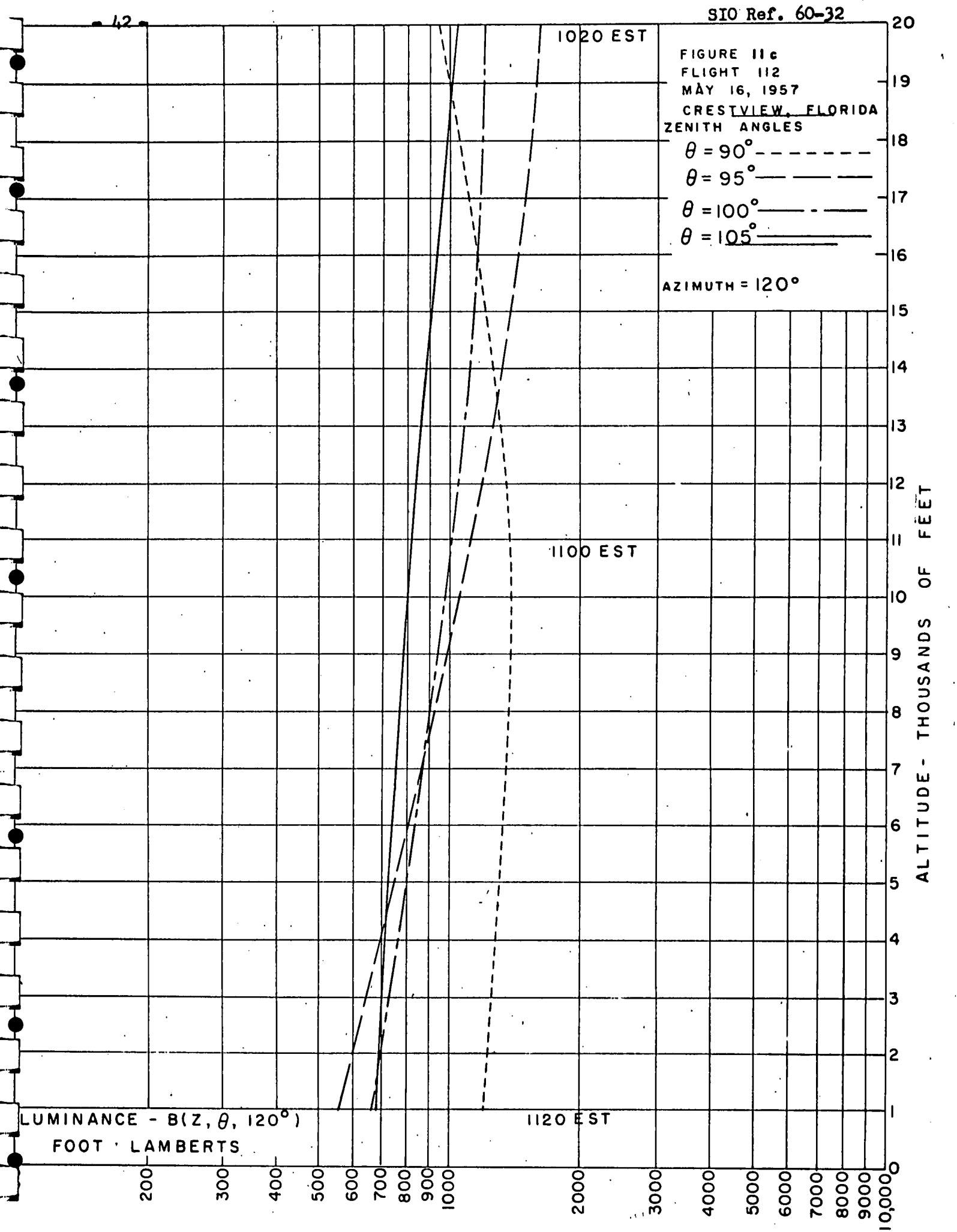
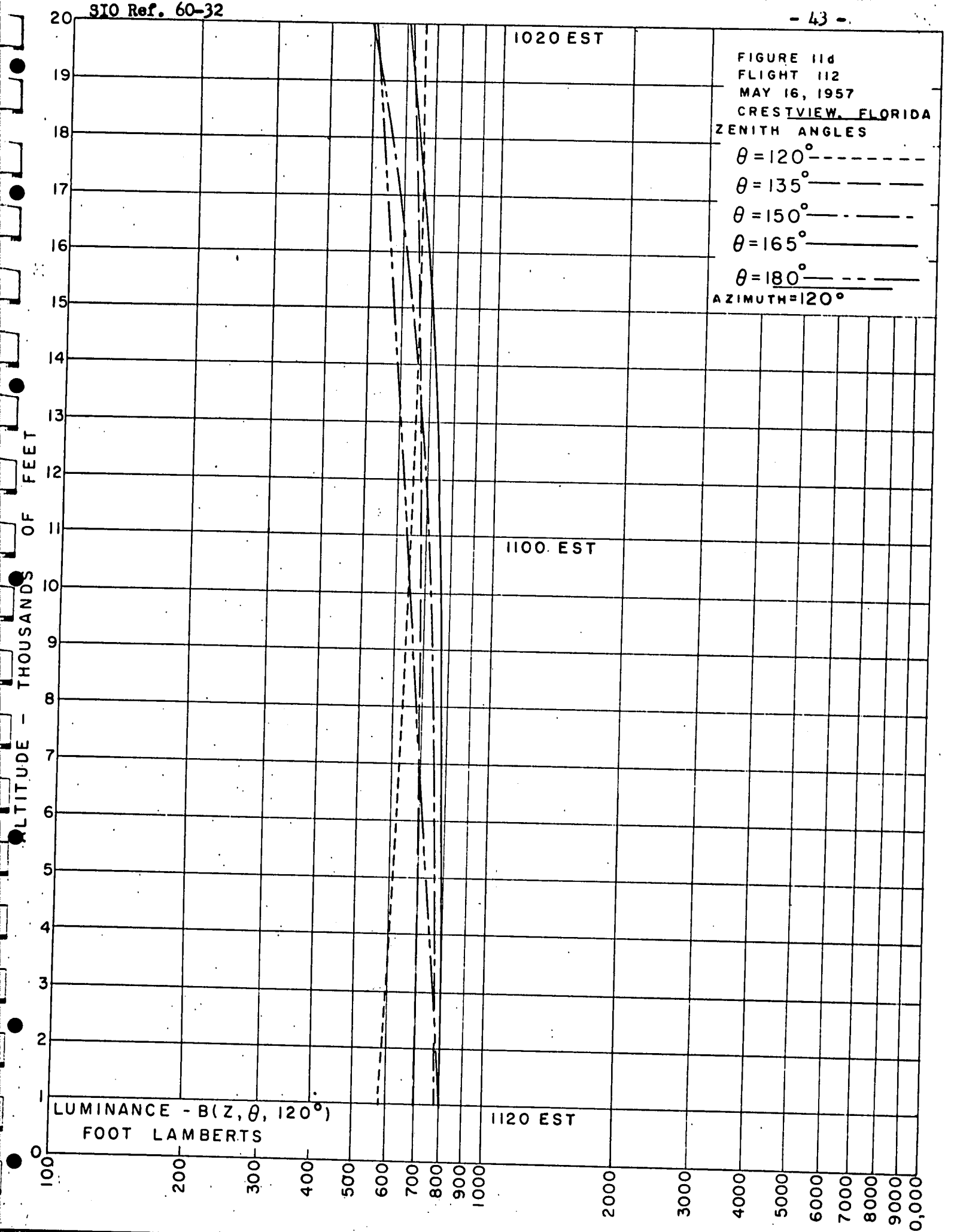
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 11c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 120°
LUMINANCE - B(Z, θ, 120°)
FOOT · LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
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


1020 EST
1100 EST
1120 EST
FIGURE 11d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 120°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 120°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
300
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10,000

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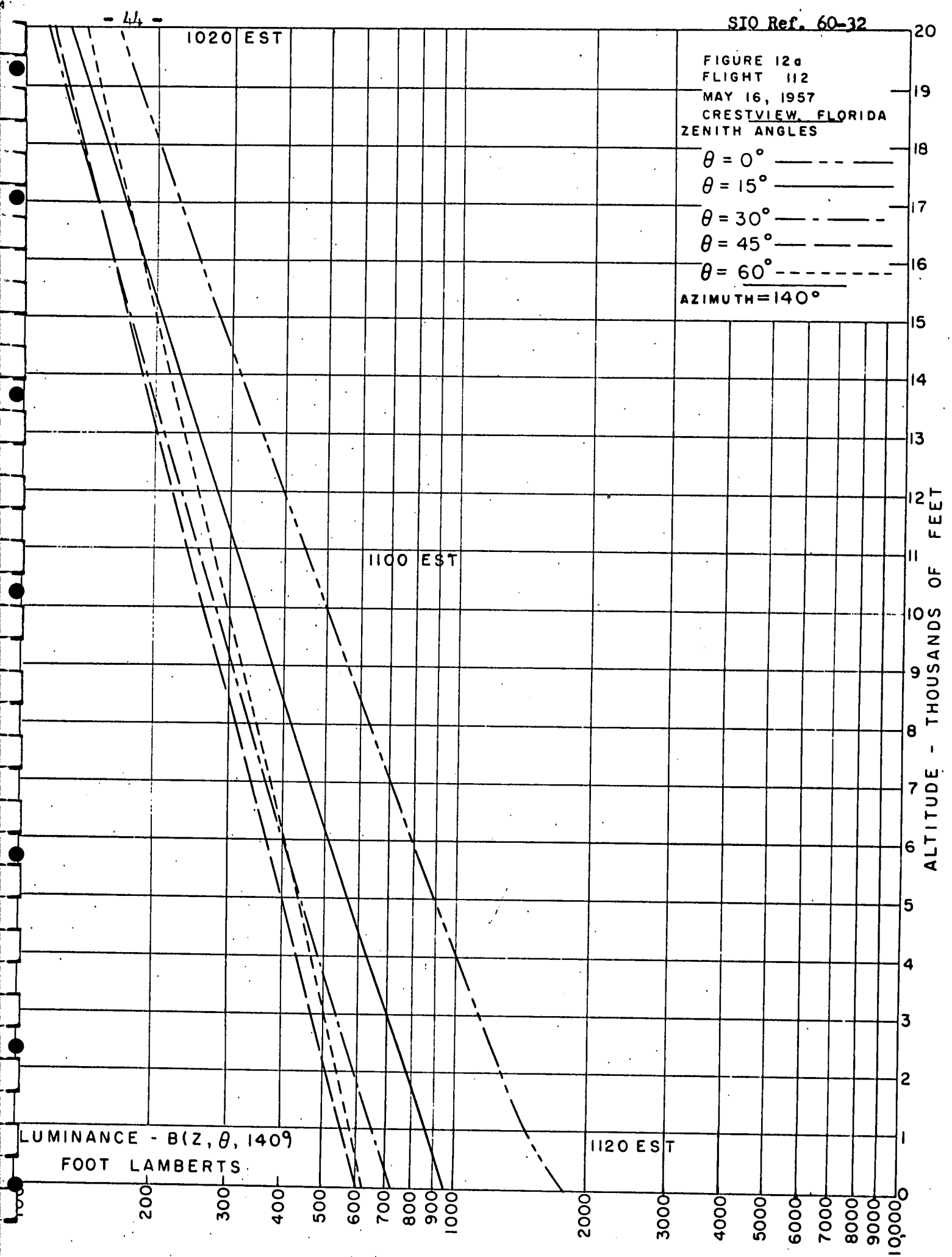
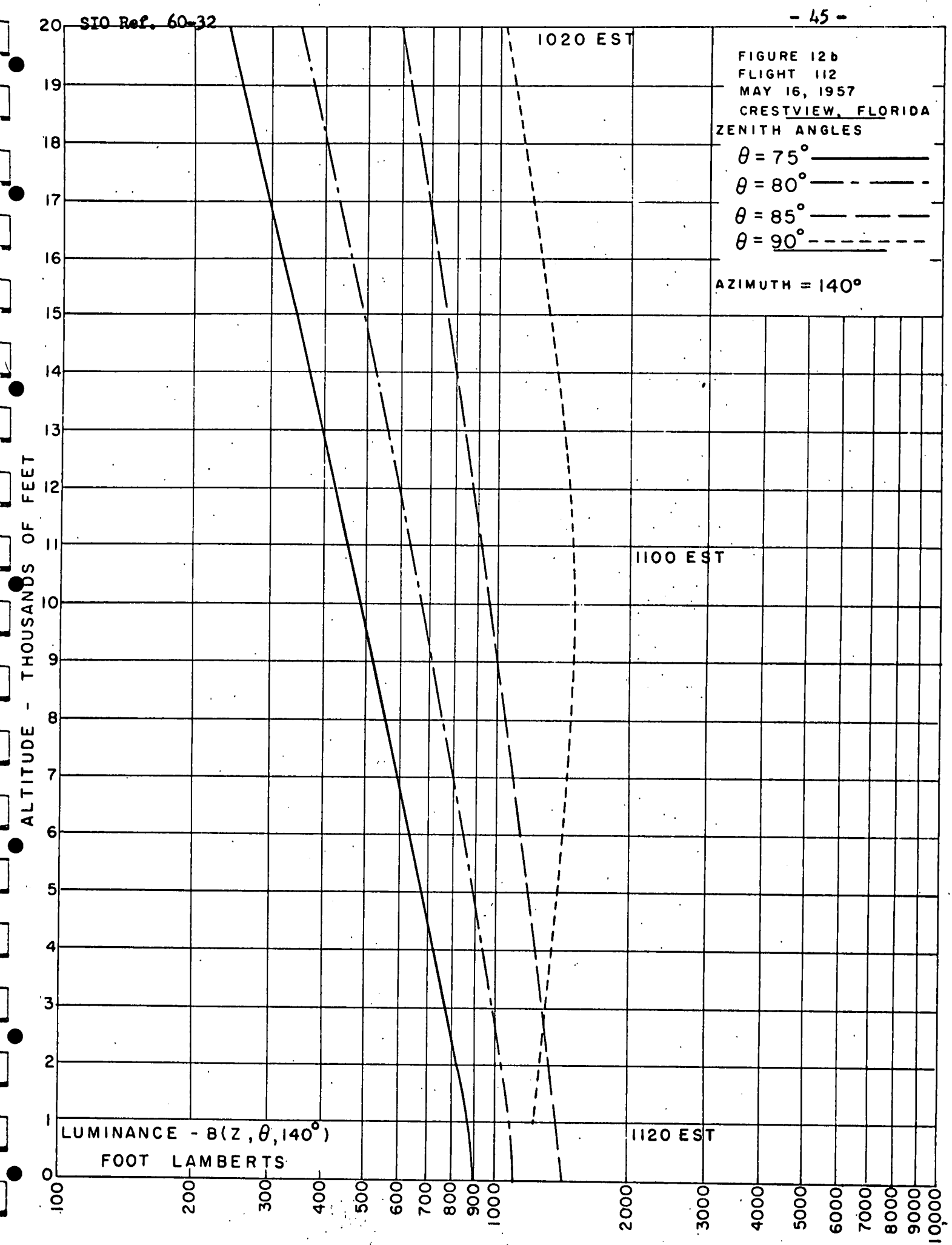

1020 EST
1100 EST
1120 EST
FIGURE 12a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH=140°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 140°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000


1020 EST
1100 EST
1120 EST
FIGURE 12b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 140°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 140°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
300
400
500
600
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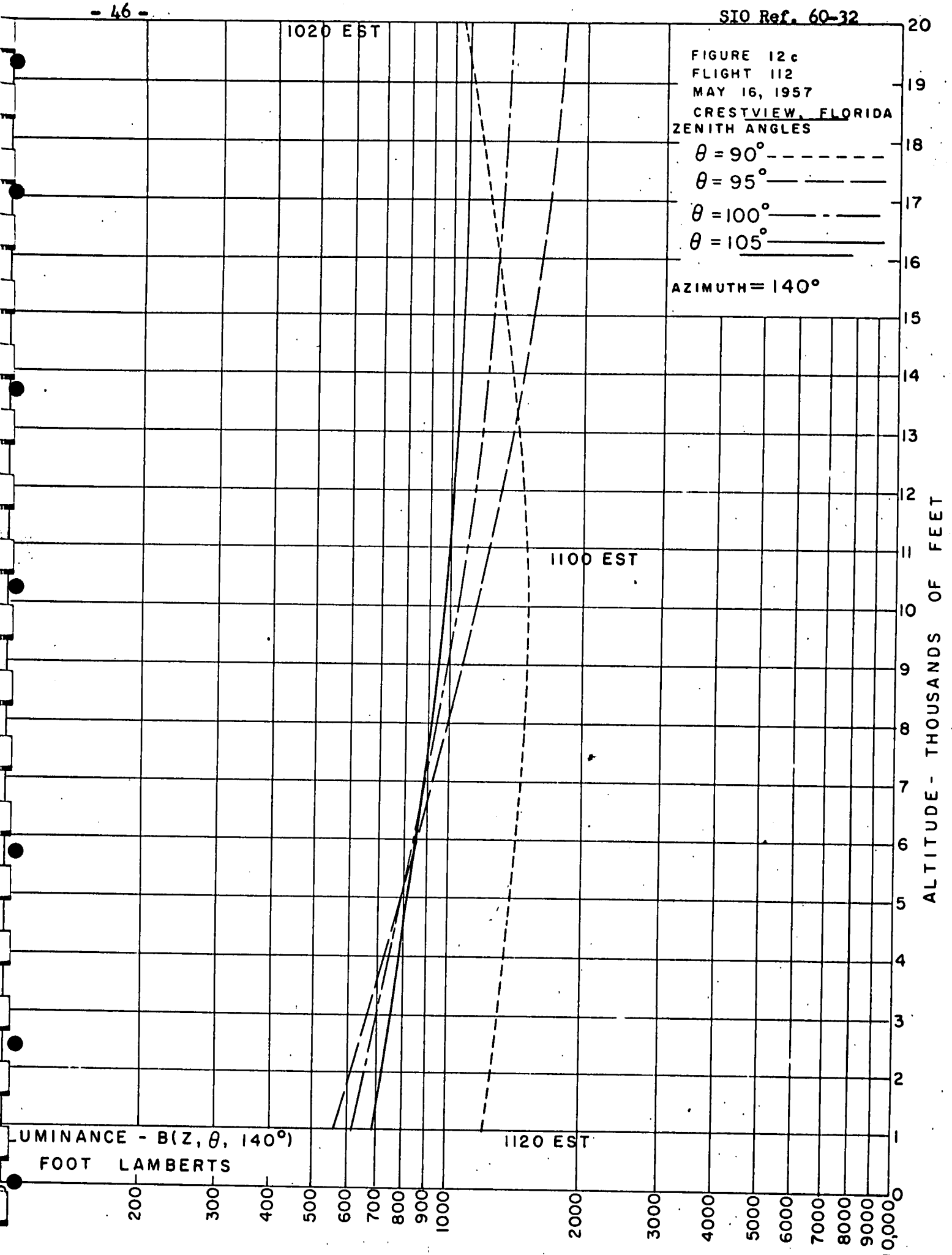
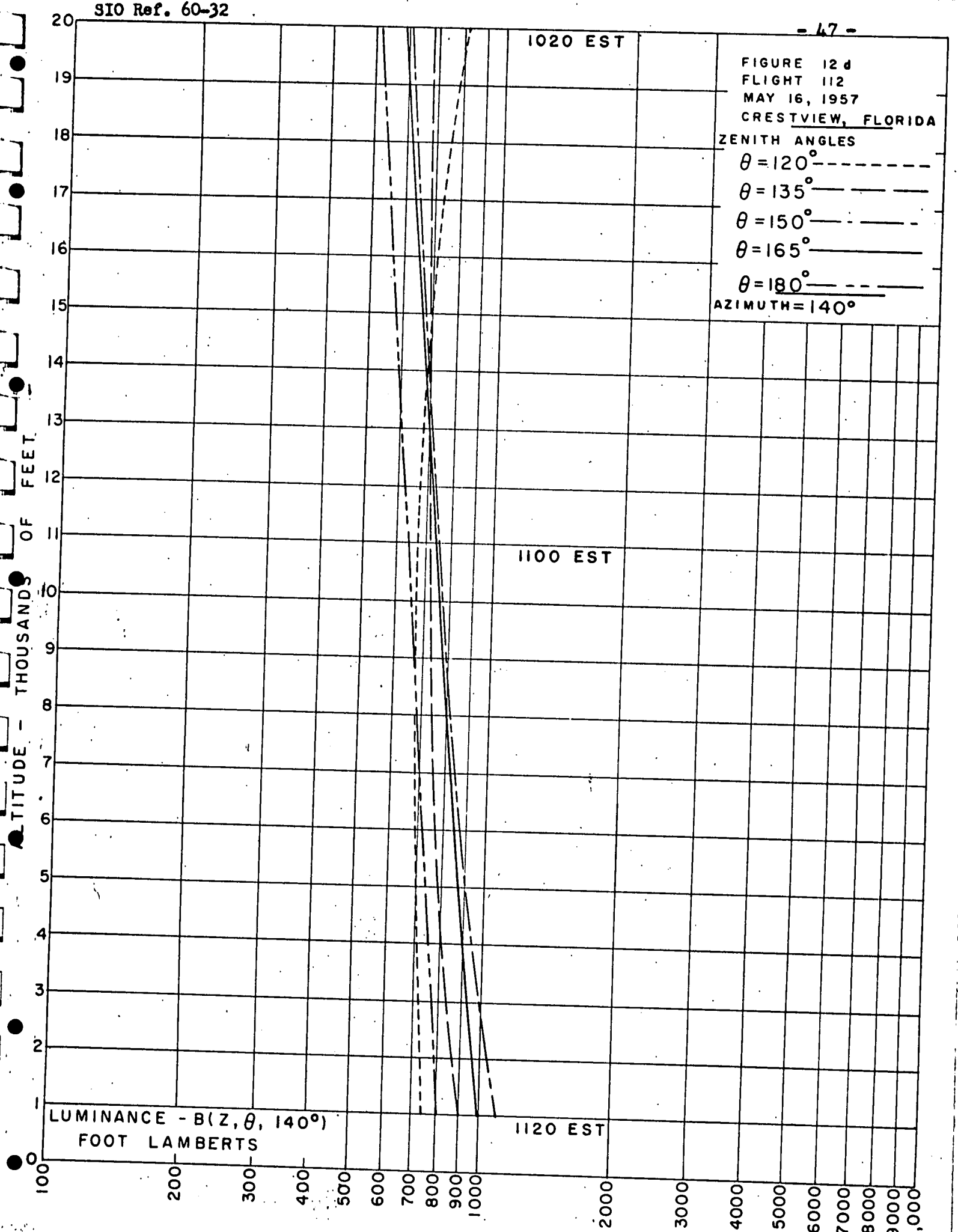
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 12c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 140°
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
LUMINANCE - B(Z, θ, 140°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 12 d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 140°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 140°)
FOOT LAMBERTS
0
1
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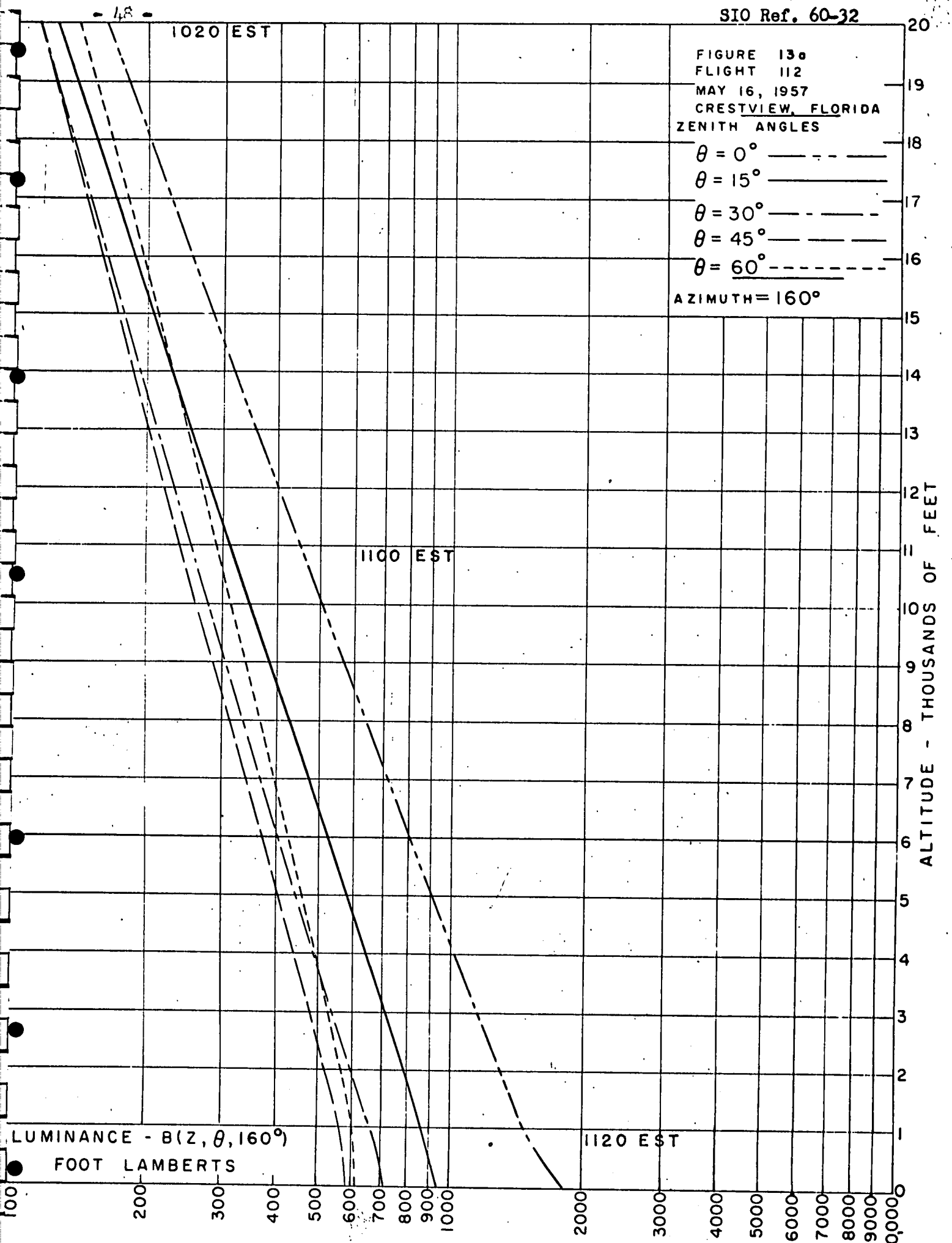
1020 EST
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1120 EST
FIGURE 13a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 160°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 160°)
FOOT LAMBERTS
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
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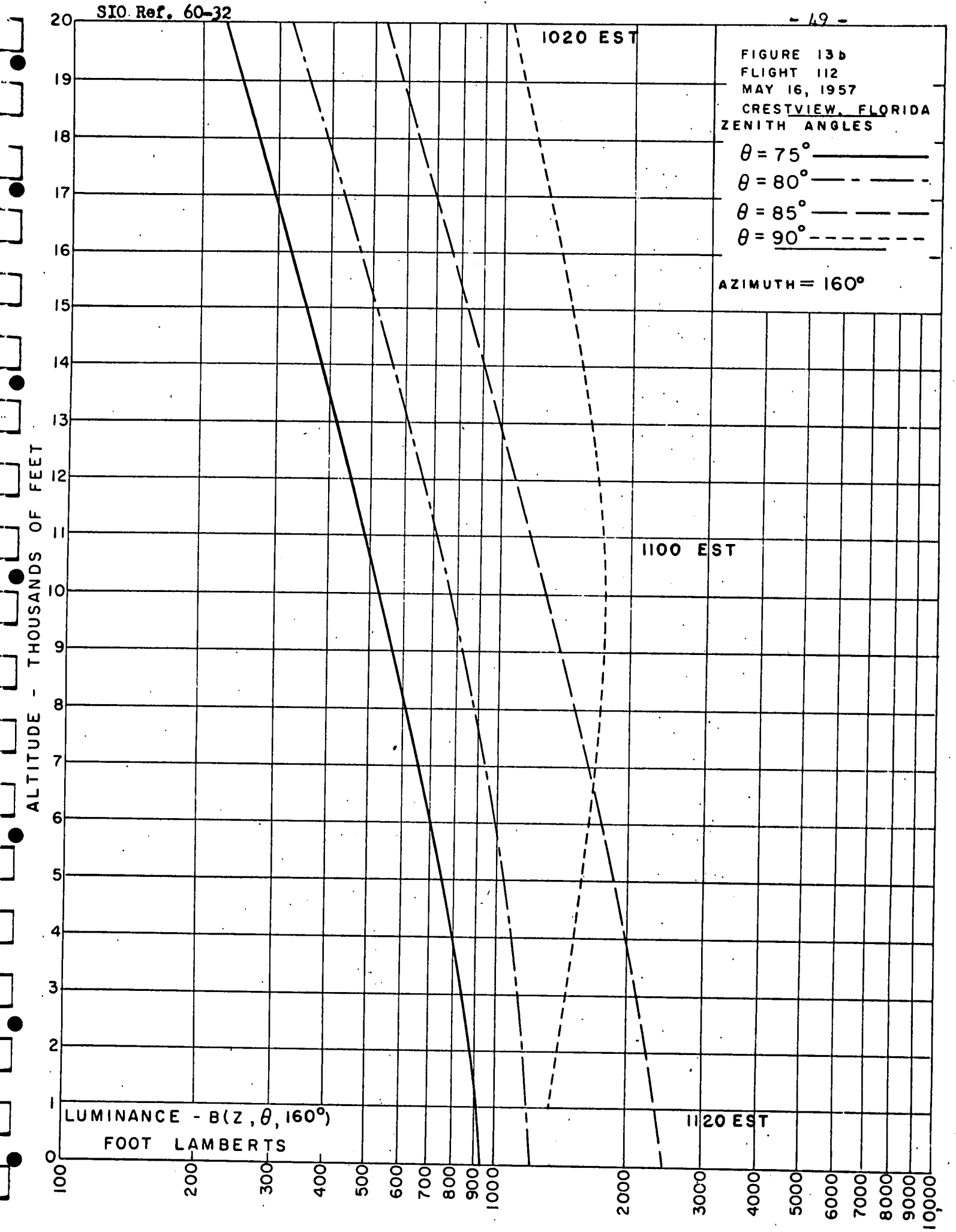
1020 EST
1100 EST
1120 EST
FIGURE 13b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 160°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 160°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
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15
16
17
18
19
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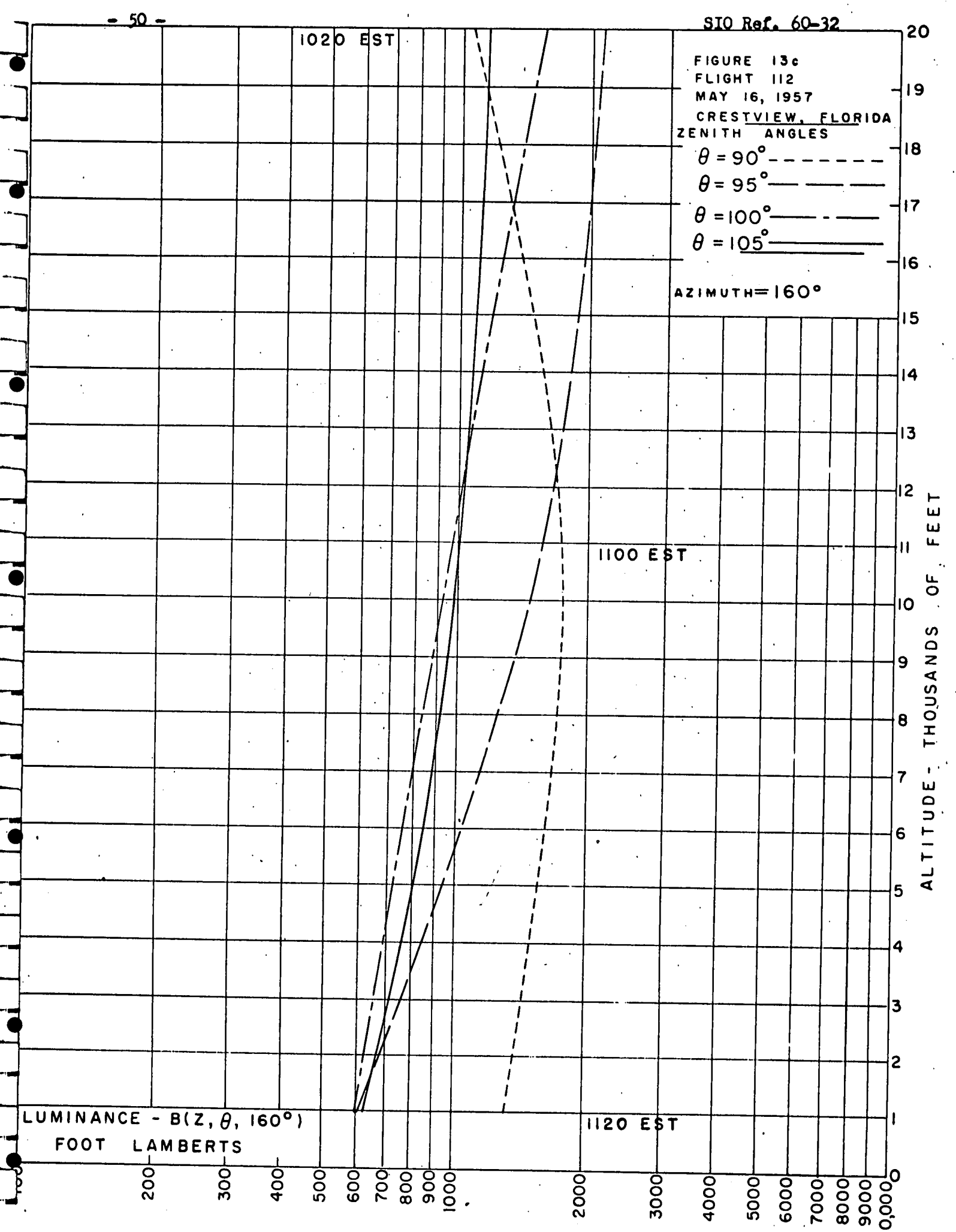
SIO Ref. 60-32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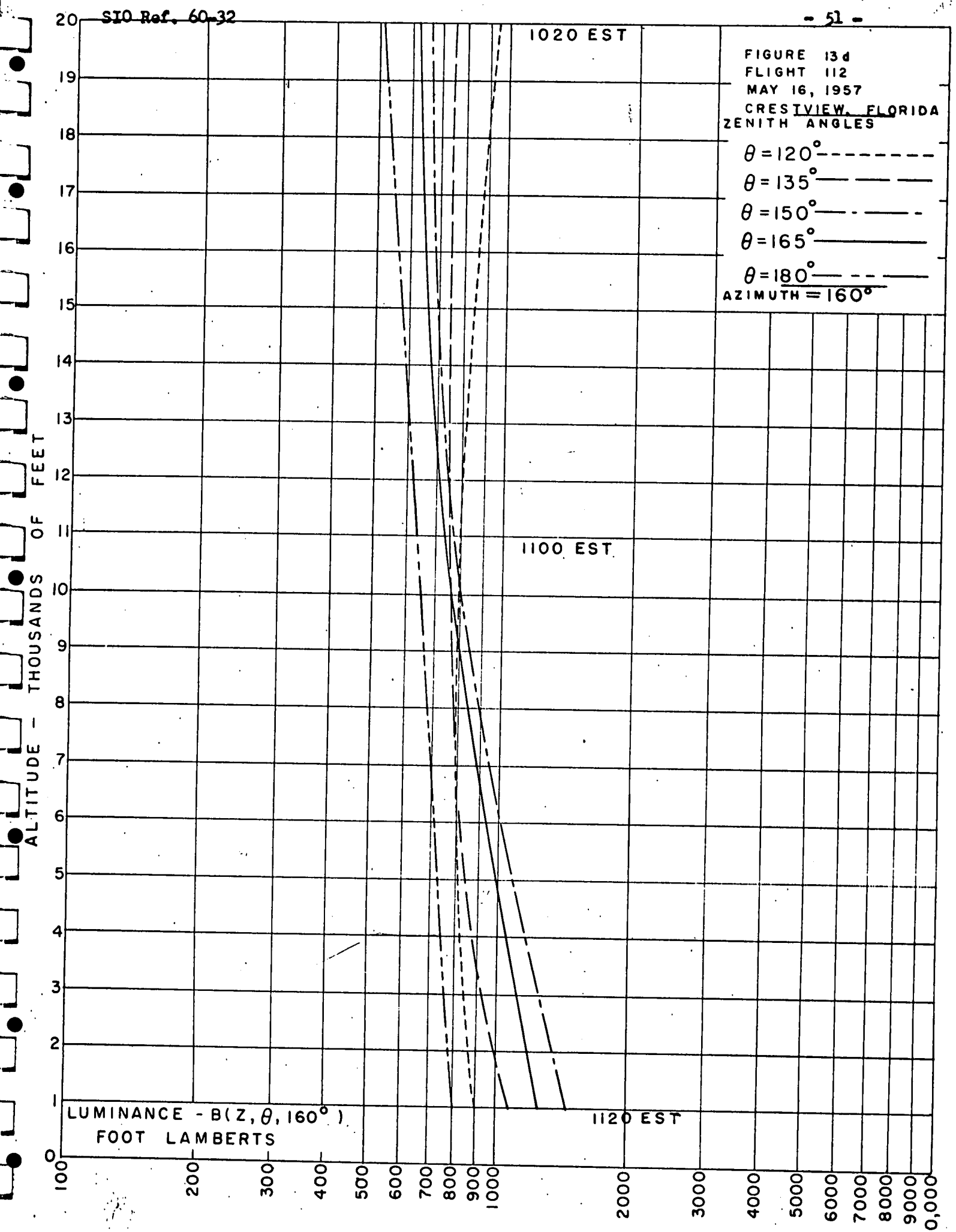
1120 EST
FIGURE 13c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 160°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 160°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 13d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 160°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 160°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
100
200
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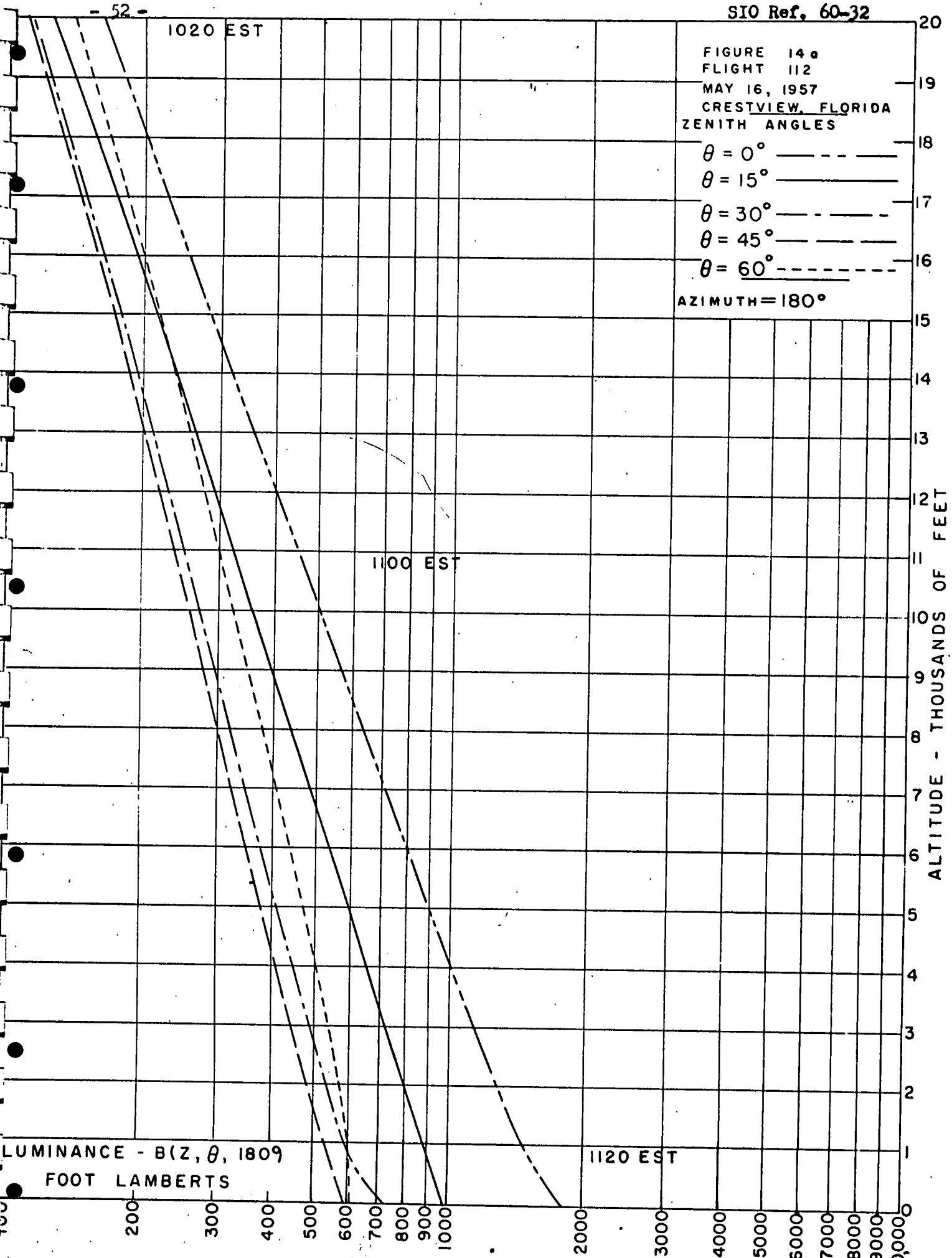
1020 EST
1100 EST
1120 EST
FIGURE 14 c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 180°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 180)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
0
1
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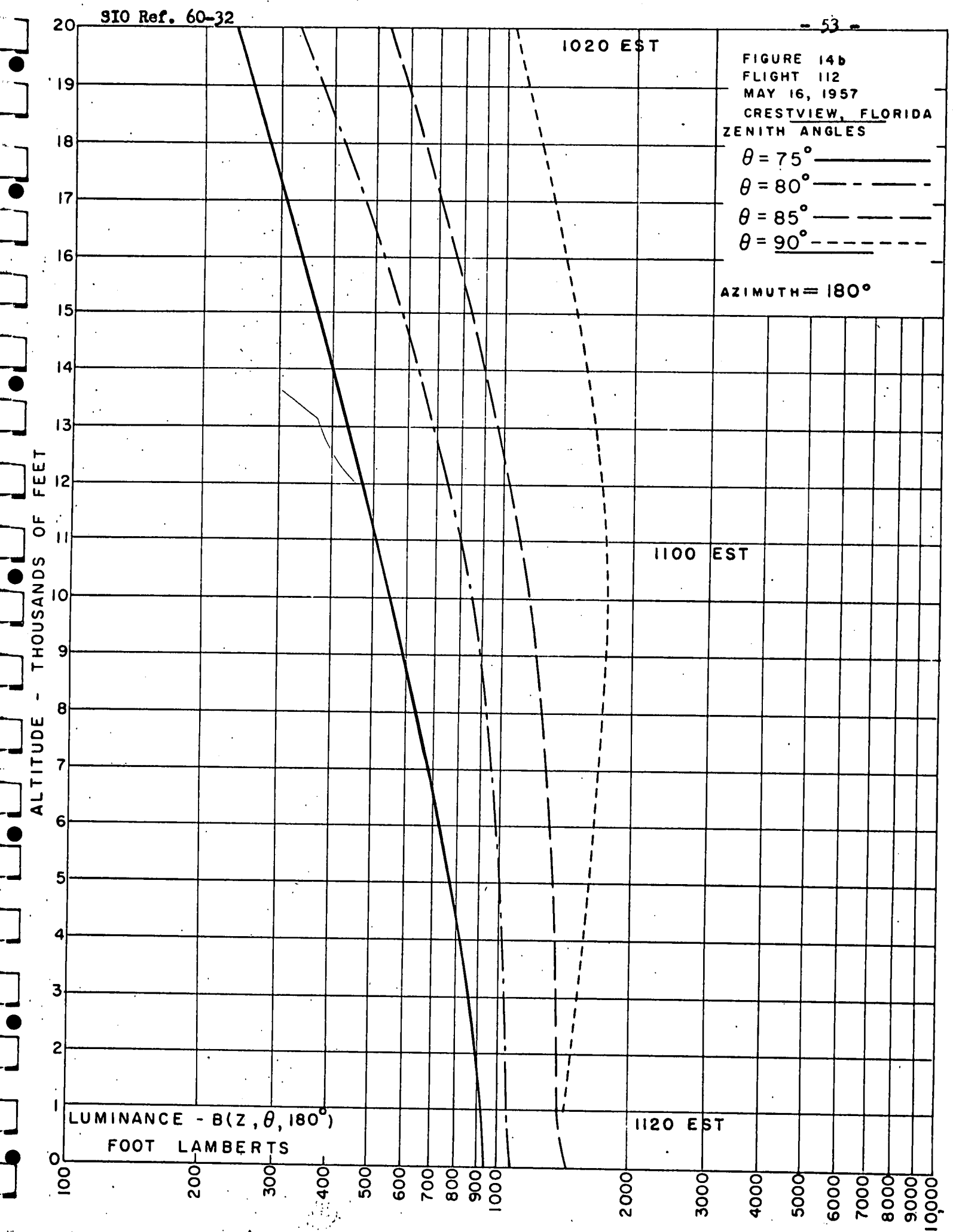
1020 EST
1100 EST
1120 EST
FIGURE 14b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 180°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 180°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
11
12
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14
15
16
17
18
19
20
100
200
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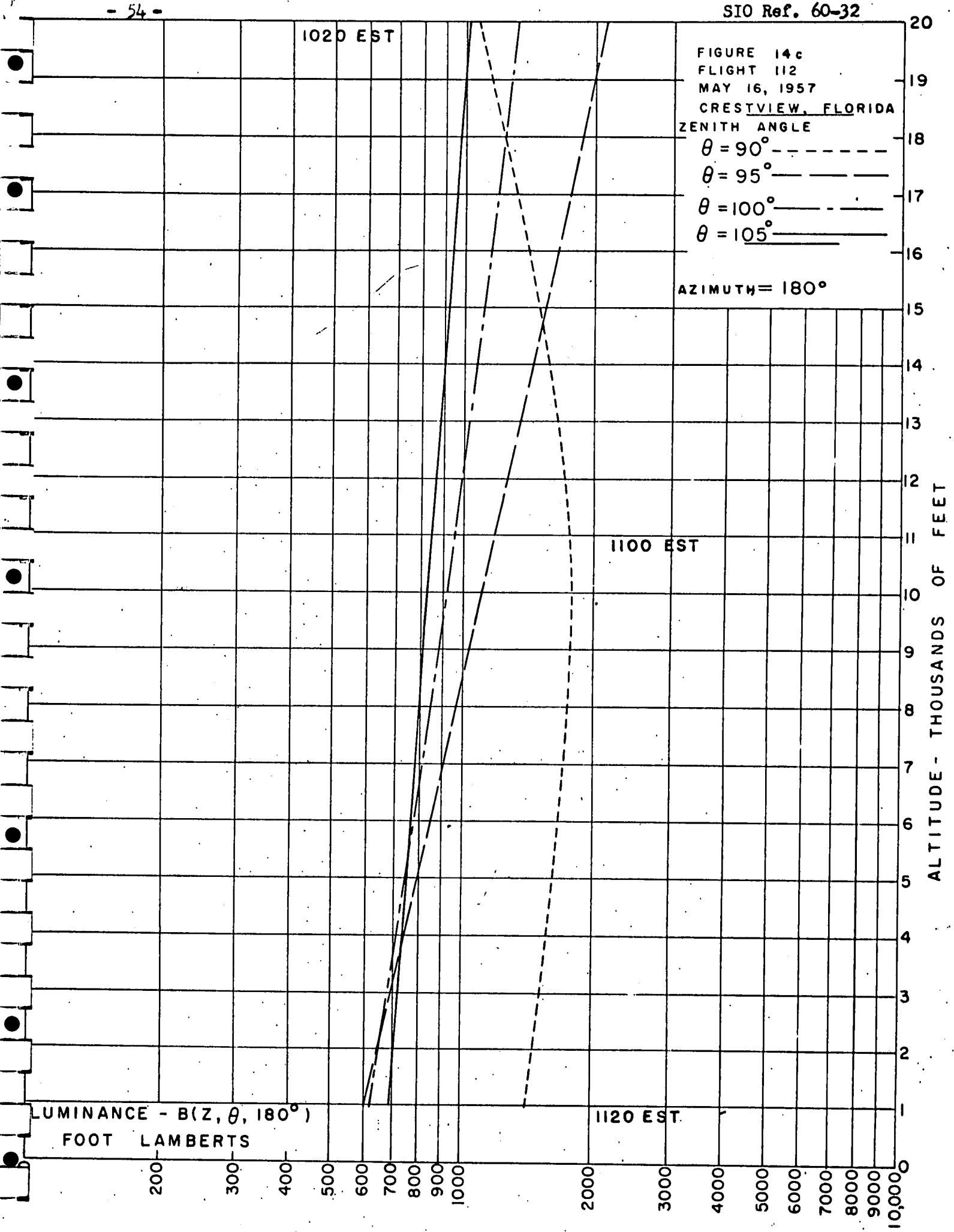
1020 EST
FIGURE 14c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLE
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 180°
1100 EST
1120 EST
LUMINANCE - B(Z, θ, 180°)
FOOT LAMBERTS
200
300
400
500
600
700
800
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1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
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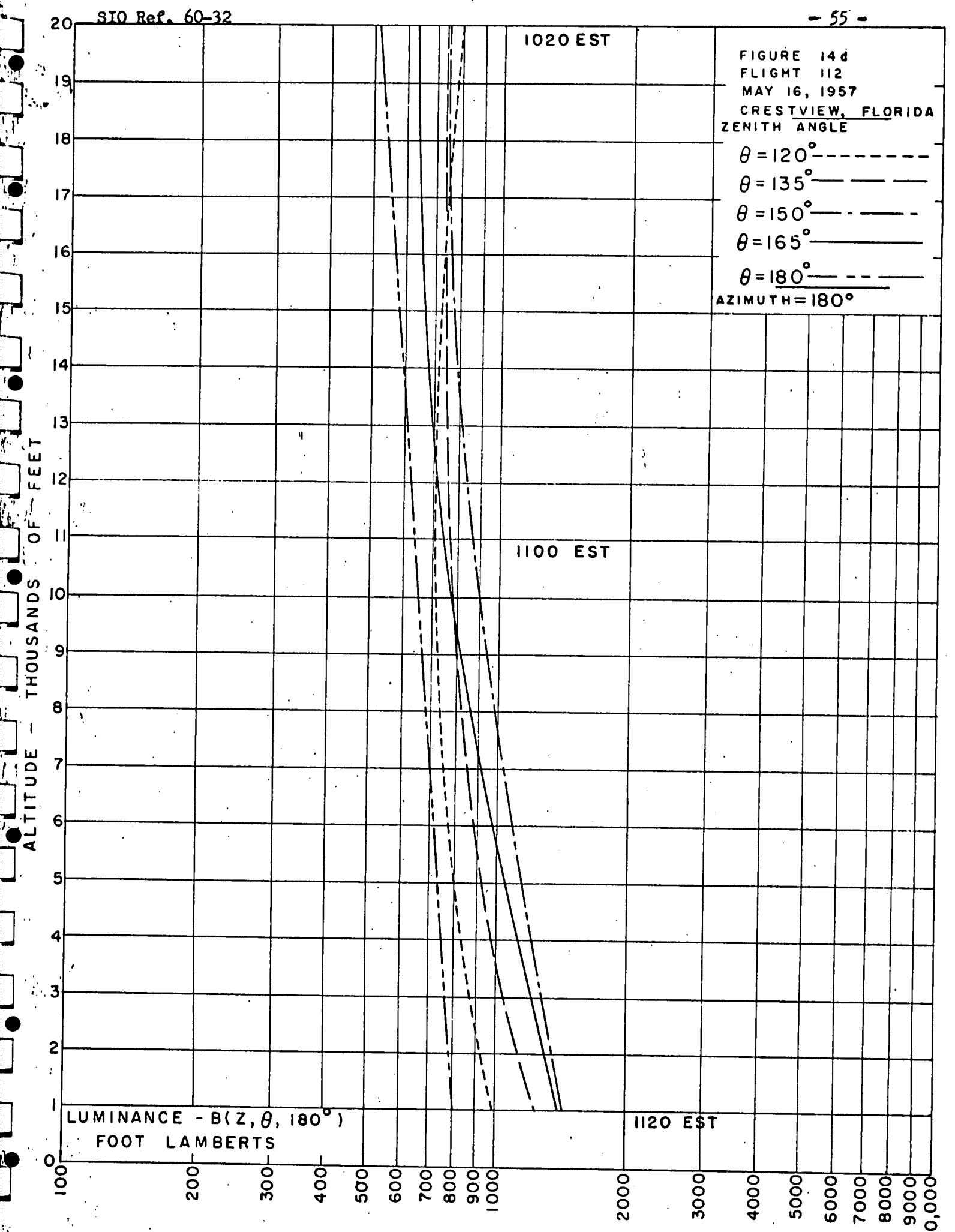
ALTITUDE - THOUSANDS OF FEET


1020 EST
1100 EST
1120 EST
FIGURE 14d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLE
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 180°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 180°)
FOOT LAMBERTS
0
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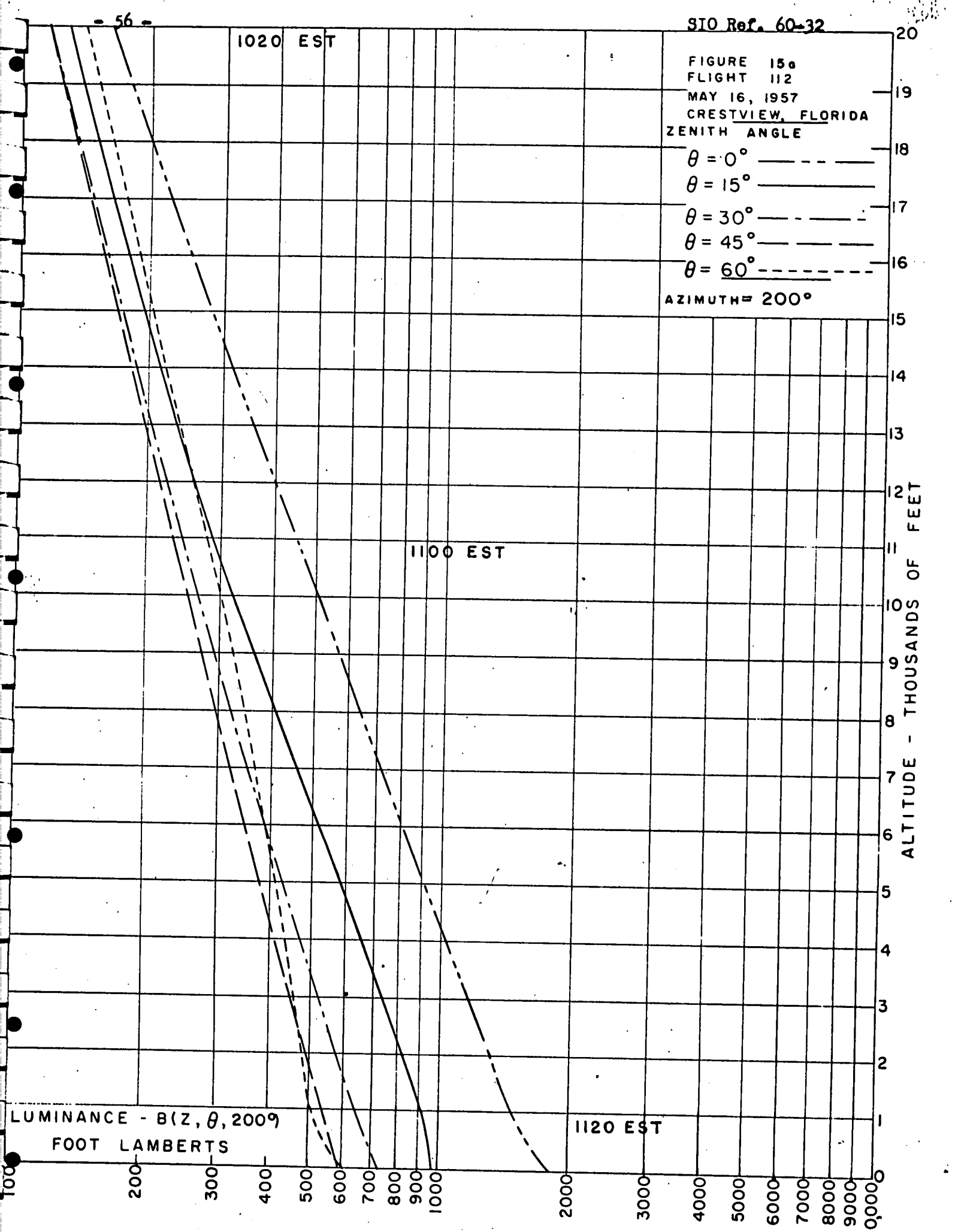
SIO Ref. 60-32


1020 EST
1100 EST
1120 EST
FIGURE 15a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLE
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 200°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 200)
FOOT LAMBERTS
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
0
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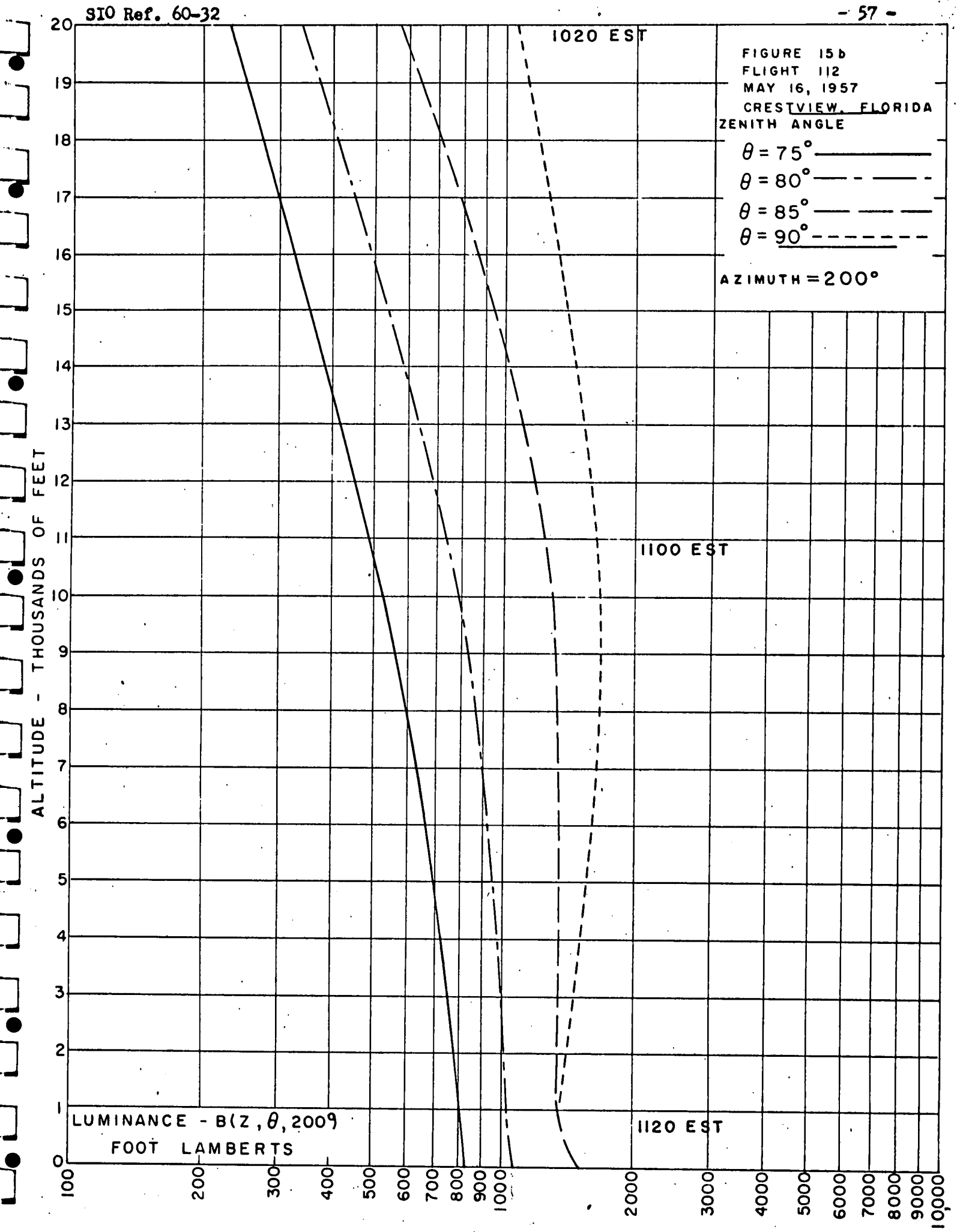
1020 EST
1100 EST
1120 EST
FIGURE 15b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLE
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 200°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 2009)
FOOT LAMBERTS
0
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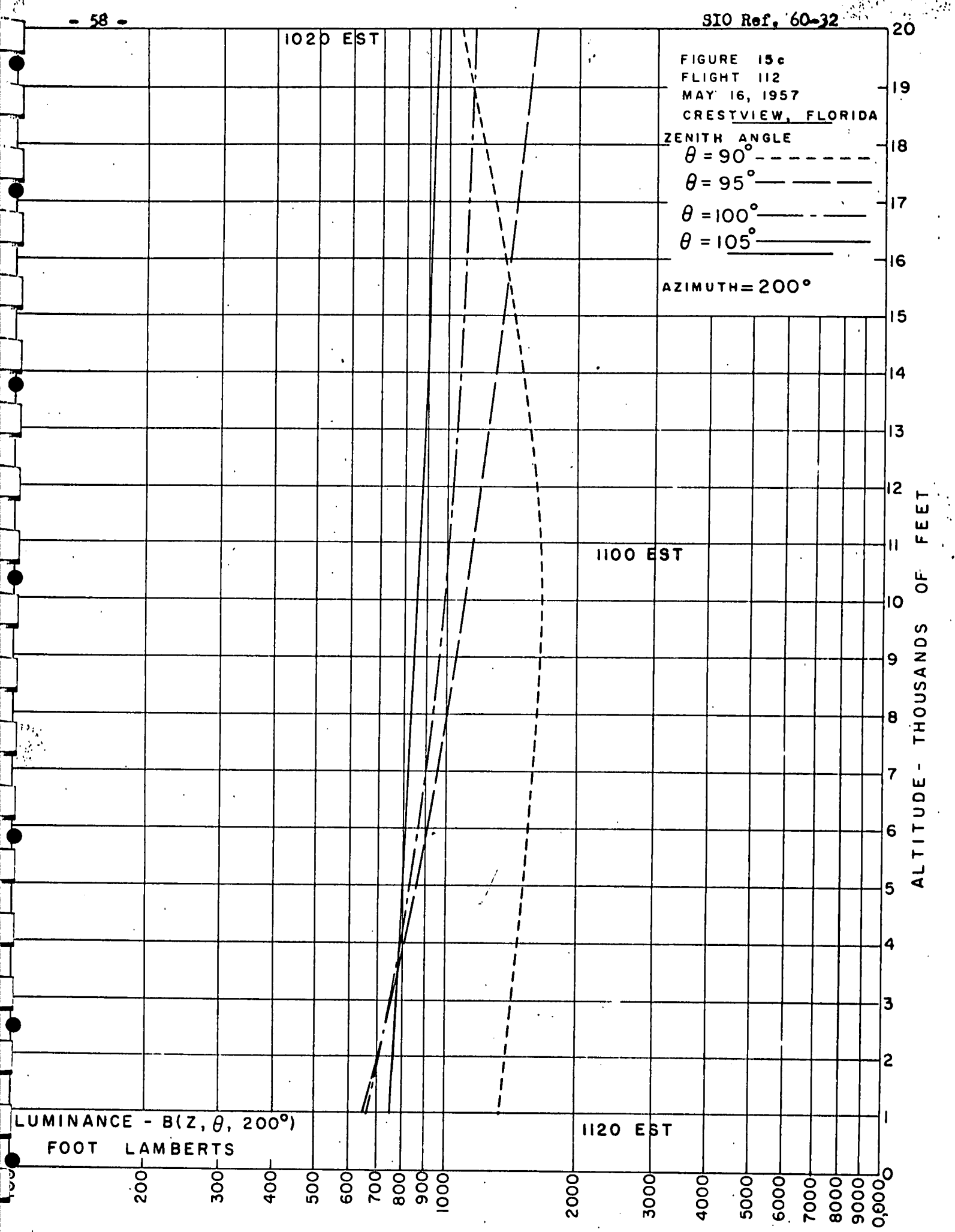
1020 EST
1100 EST
1120 EST
FIGURE 15c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLE
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 200°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 200°)
FOOT LAMBERTS
200
300
400
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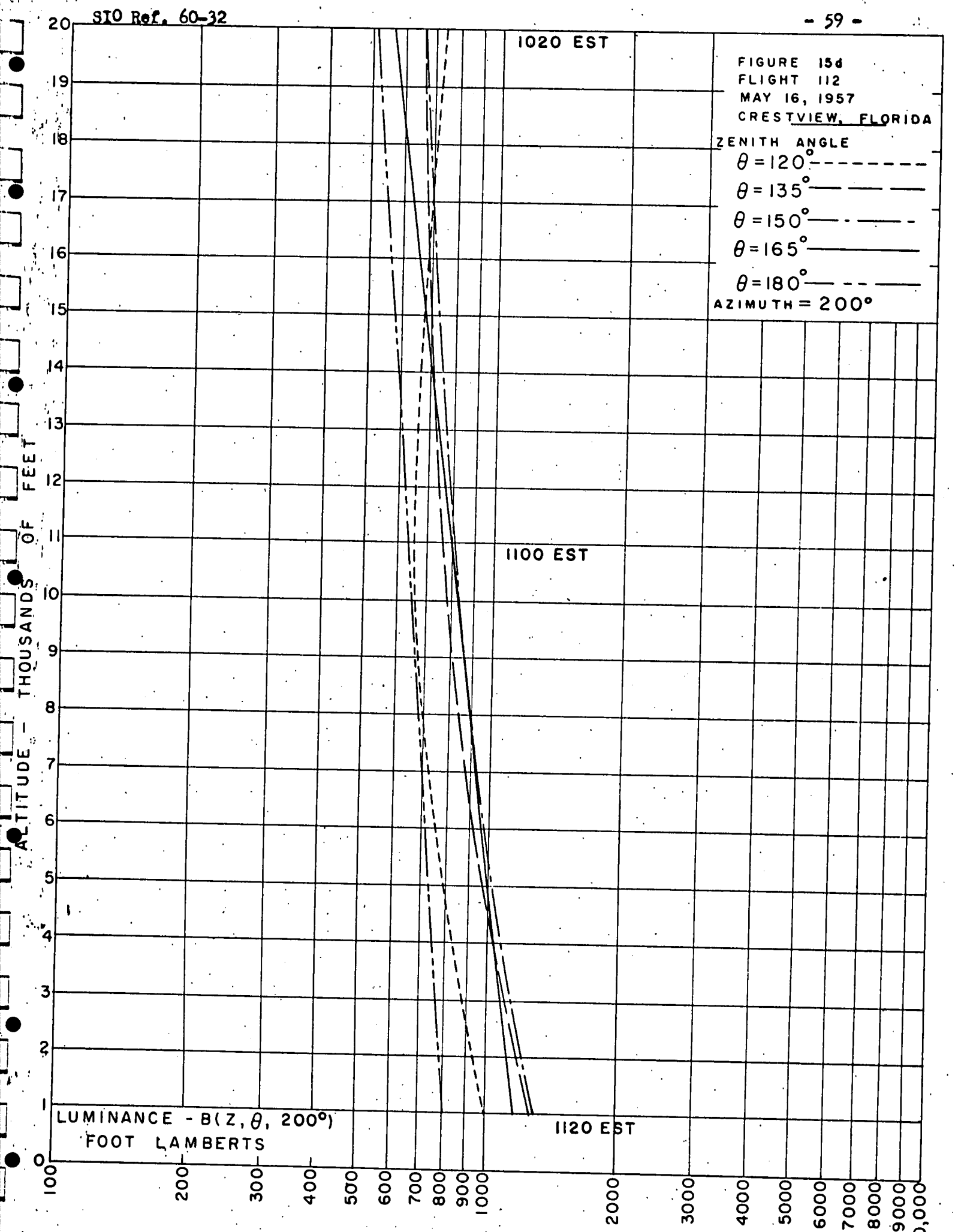
1020 EST
1100 EST
1120 EST
FIGURE 15d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLE
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 200°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 200°)
FOOT LAMBERTS
0
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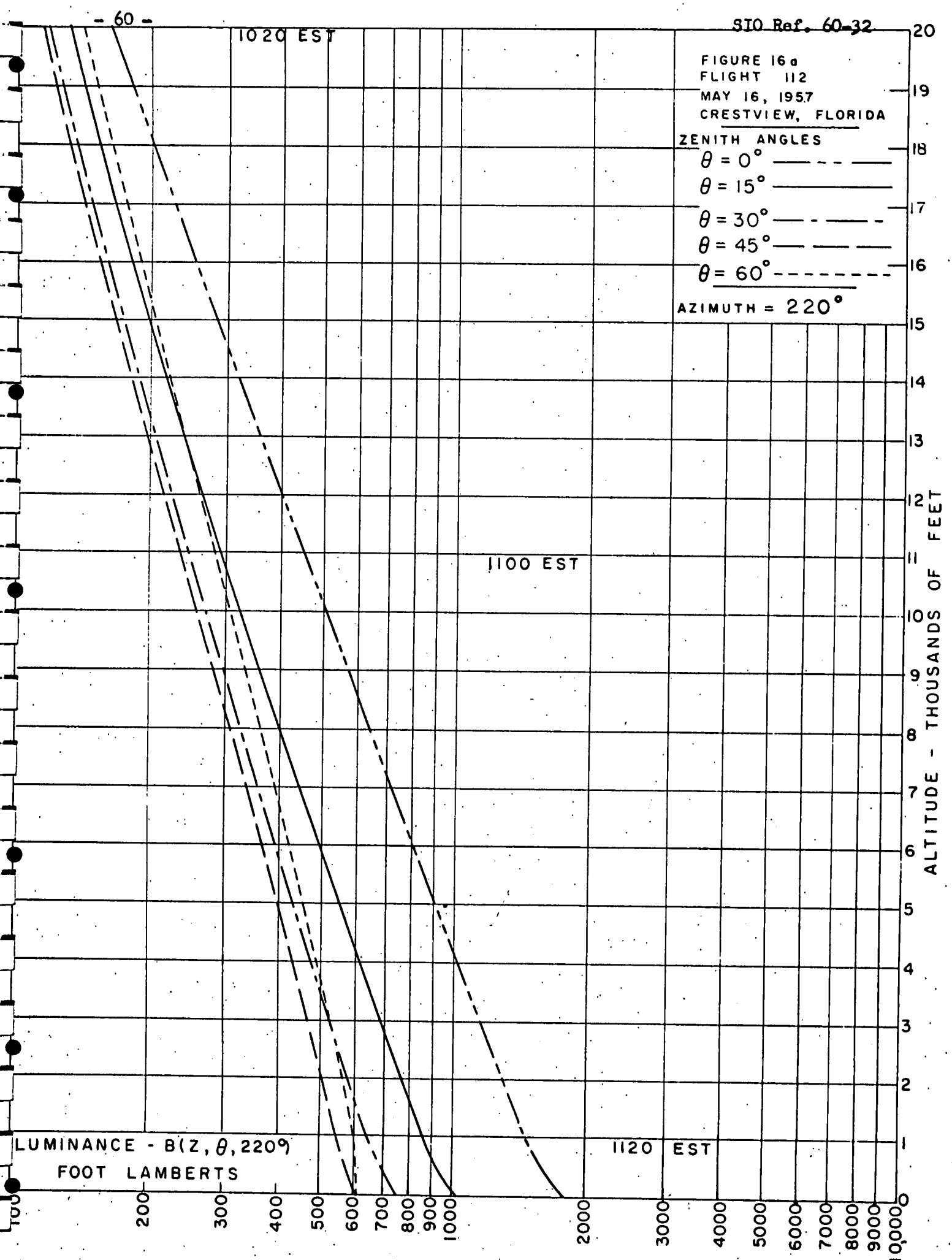
1020 EST
1100 EST
1120 EST
FIGURE 16a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 220°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 220°)
FOOT LAMBERTS
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
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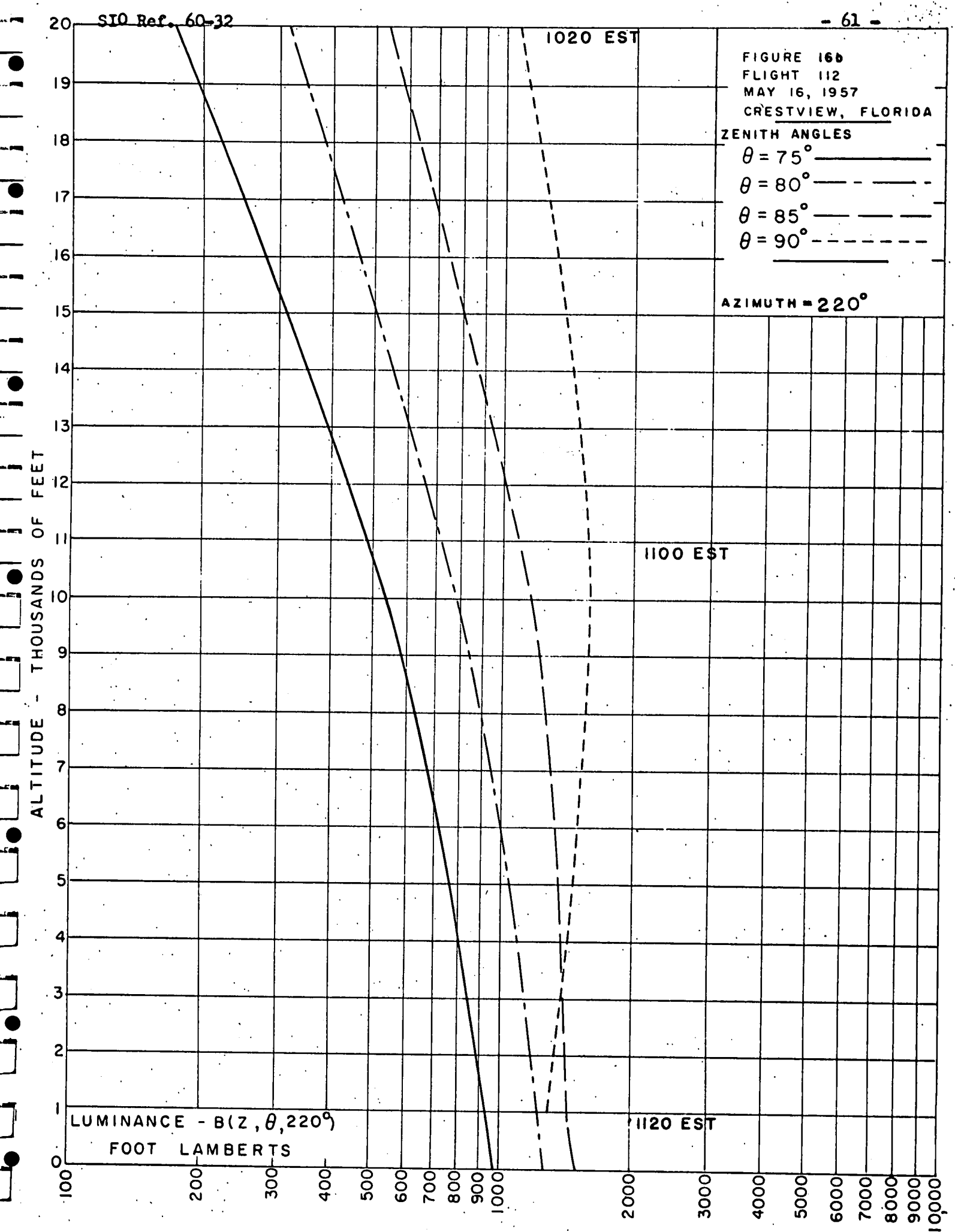
1020 EST
1100 EST
1120 EST
FIGURE 16b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 220°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 220°)
FOOT LAMBERTS
0
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2
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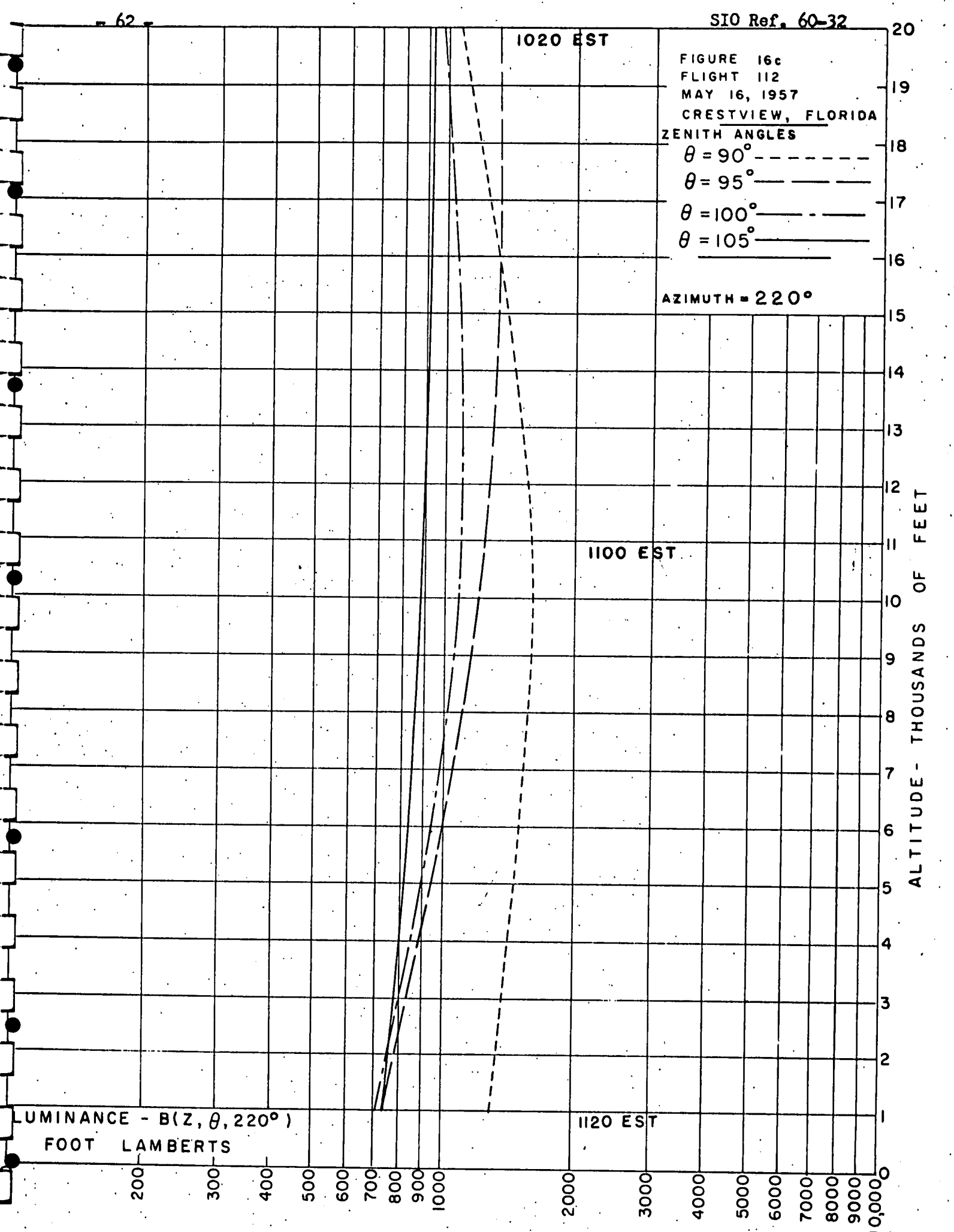
1020 EST
FIGURE 16c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 220°
1100 EST
1120 EST
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 220°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
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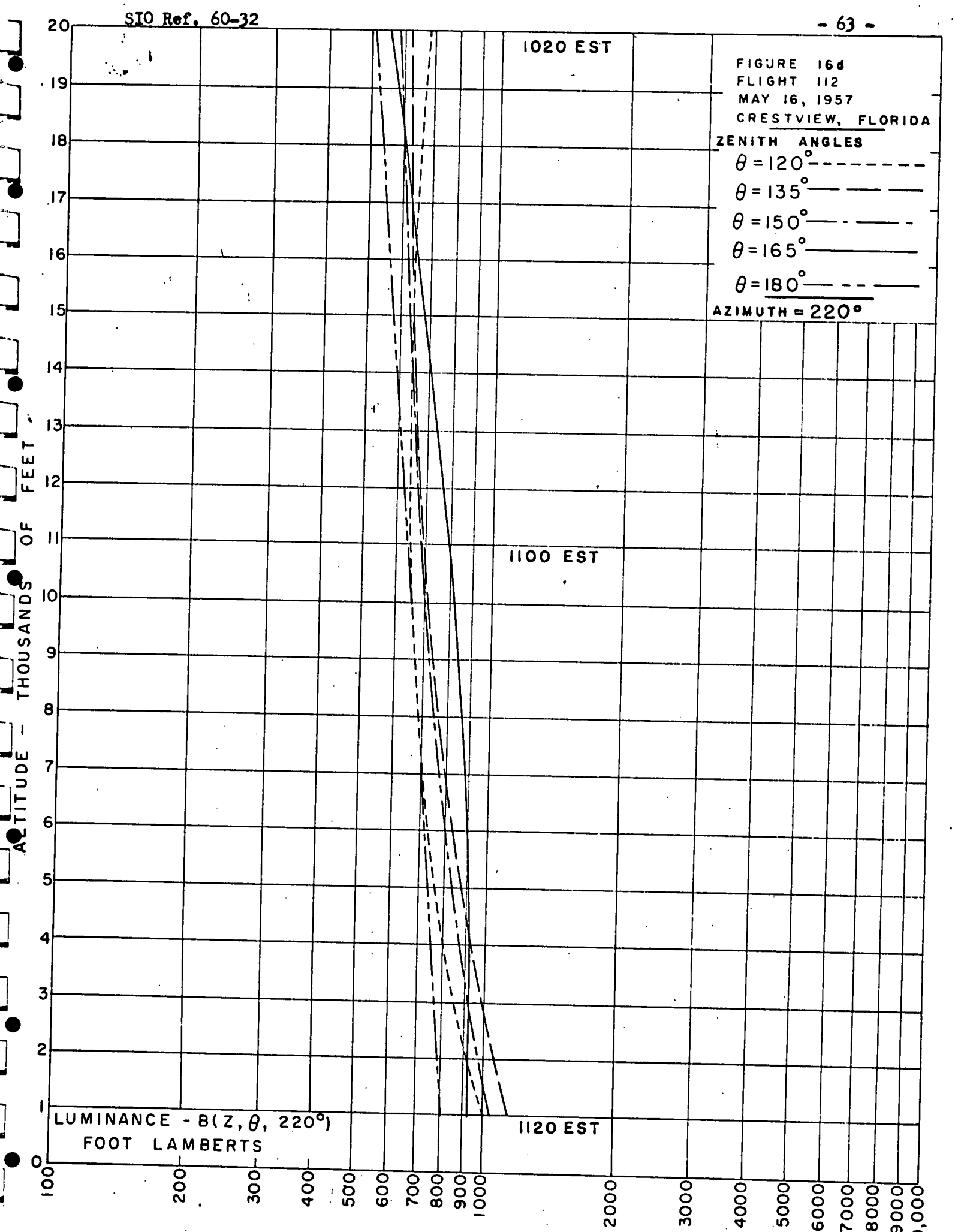
1020 EST
1100 EST
1120 EST
FIGURE 16d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 220°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 220°)
FOOT LAMBERTS
0
1
2
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4
5
6
7
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15
16
17
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19
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100
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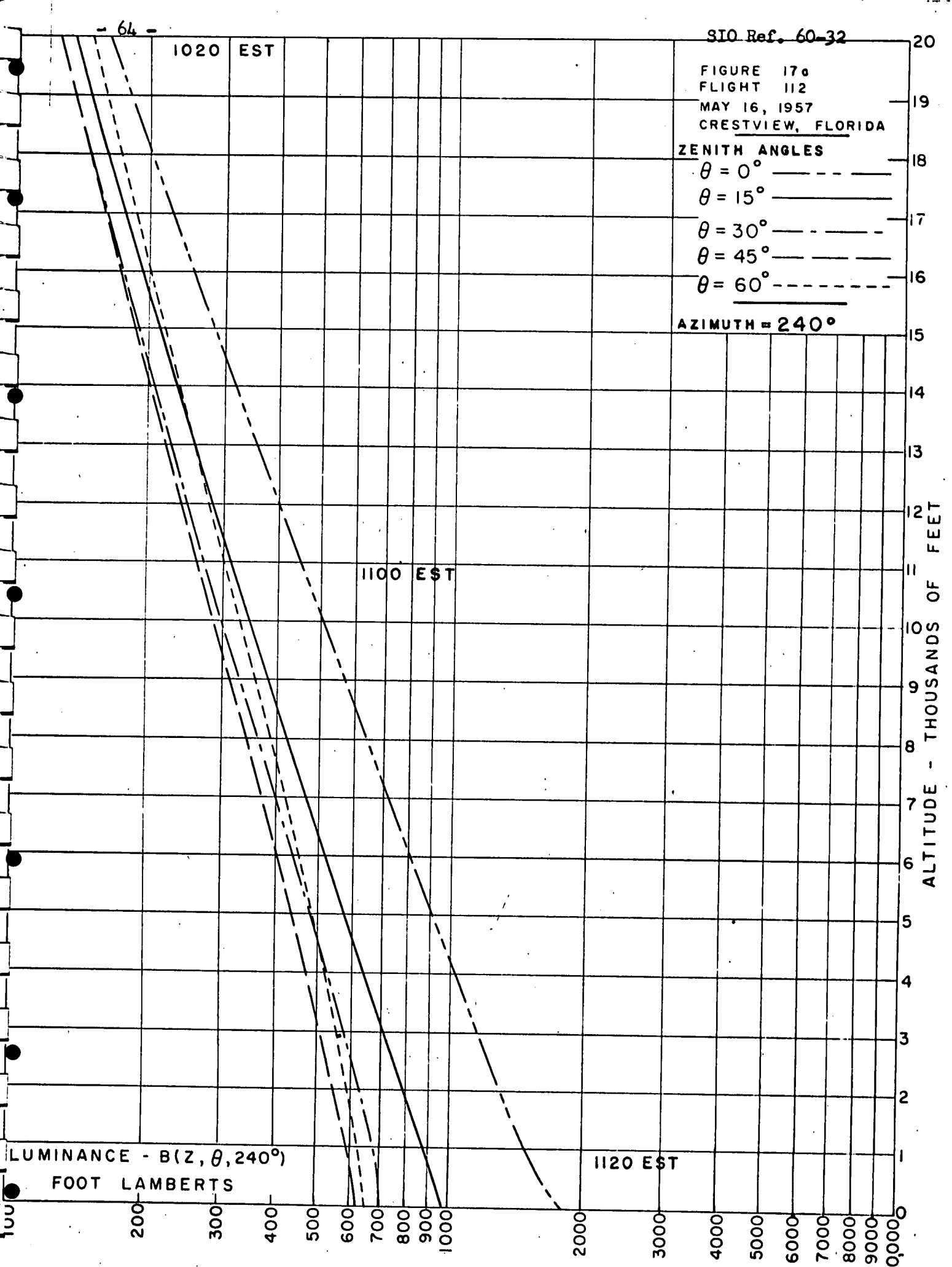
1020 EST
1100 EST
1120 EST
FIGURE 17a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 240°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 240°)
FOOT LAMBERTS
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
0000
0
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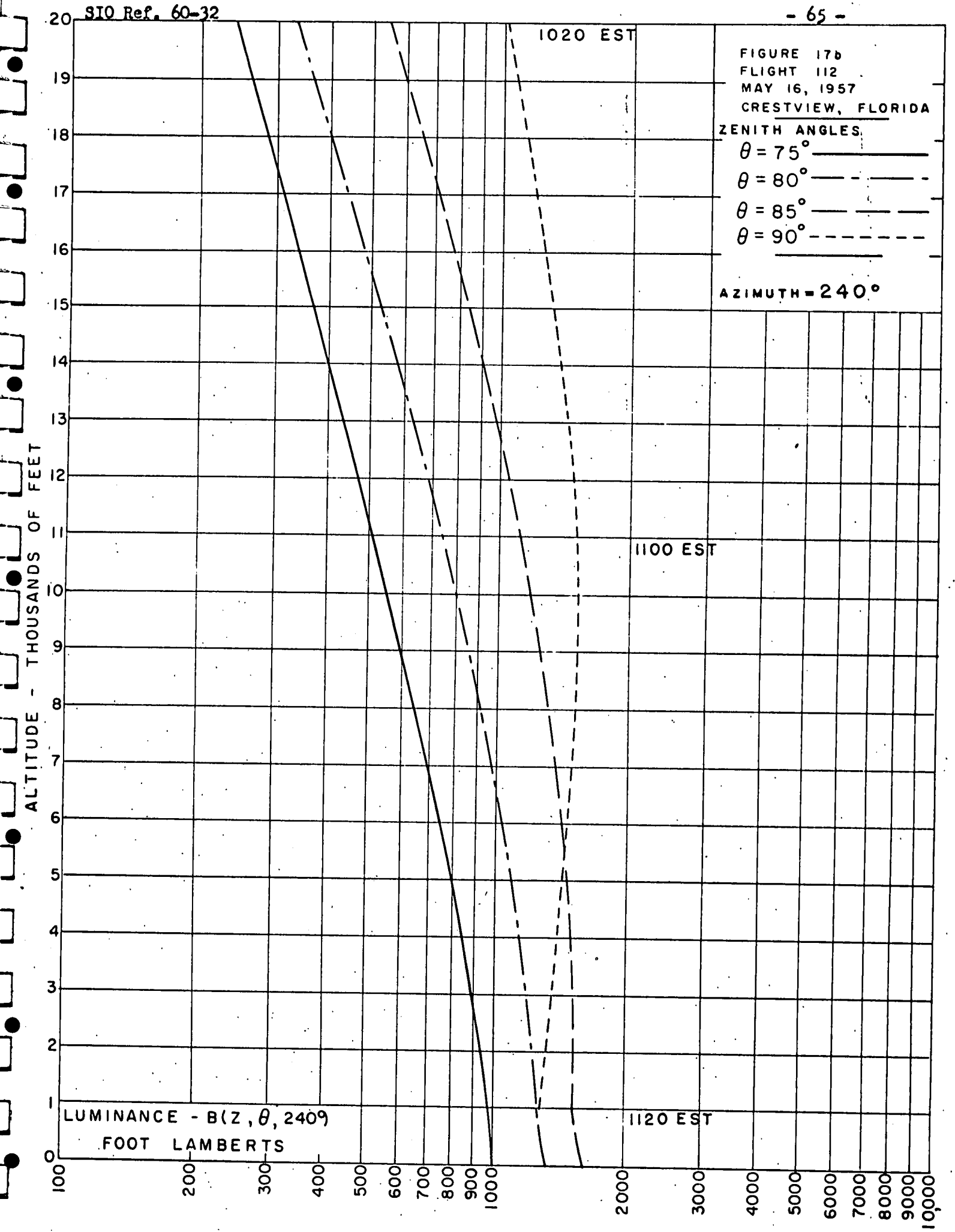
1020 EST
1100 EST
1120 EST
FIGURE 17b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 240°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 2409)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
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14
15
16
17
18
19
20
100
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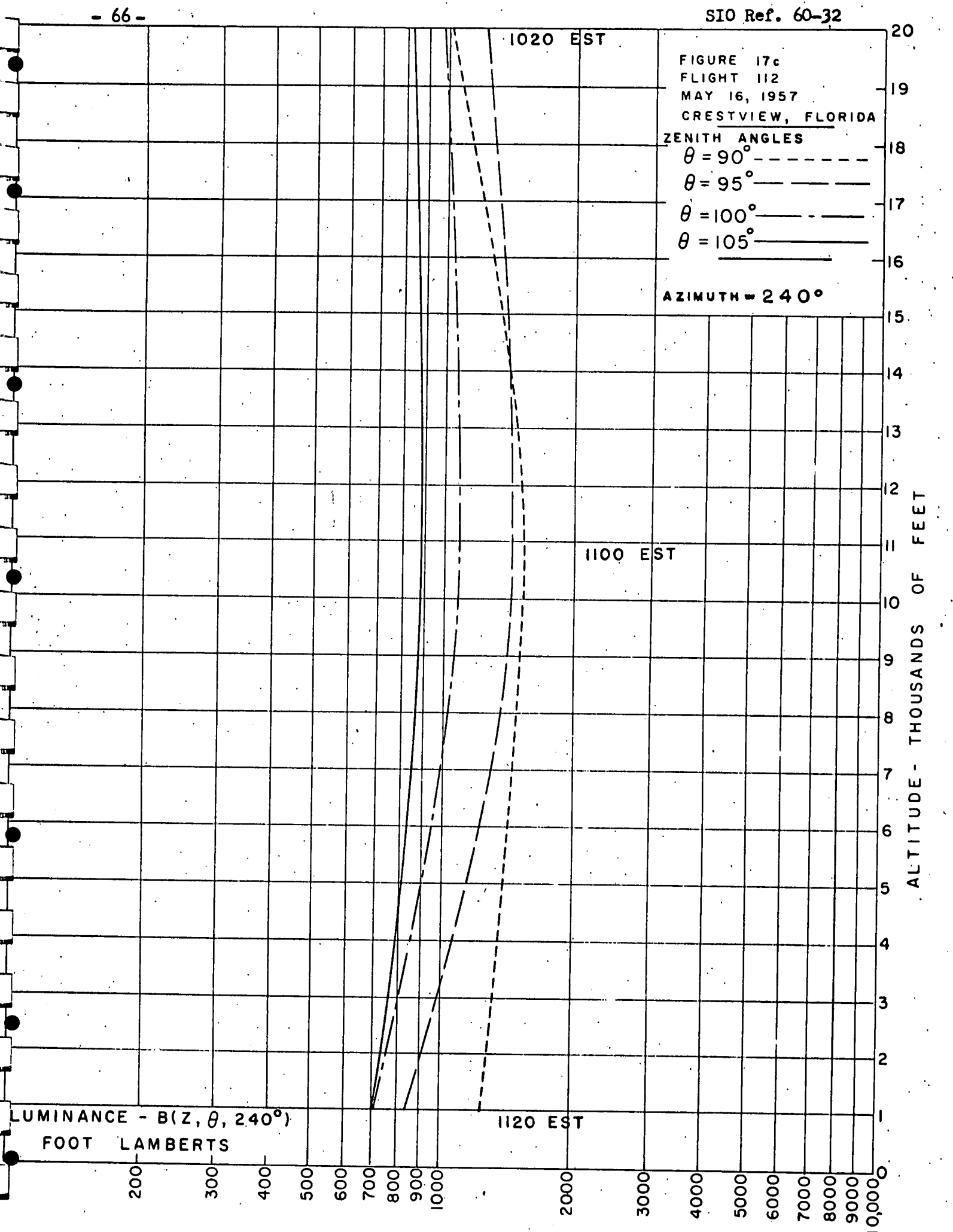
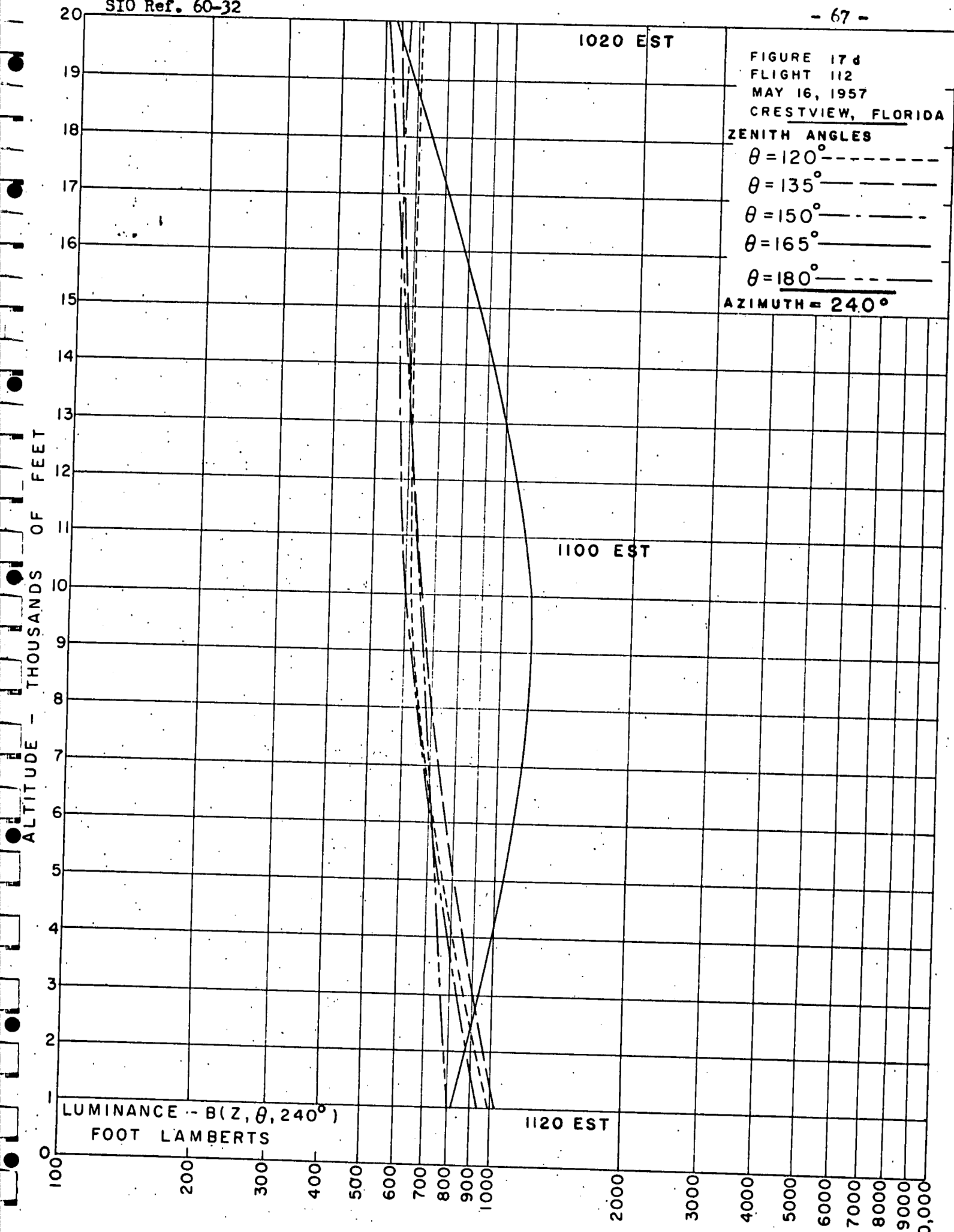

1020 EST
1100 EST
1120 EST
FIGURE 17c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 240°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 240°)
FOOT LAMBERTS
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000


1020 EST
1100 EST
1120 EST
FIGURE 17 d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 240°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 240°)
FOOT LAMBERTS
0
1
2
3
4
5
6
7
8
9
10
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14
15
16
17
18
19
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100
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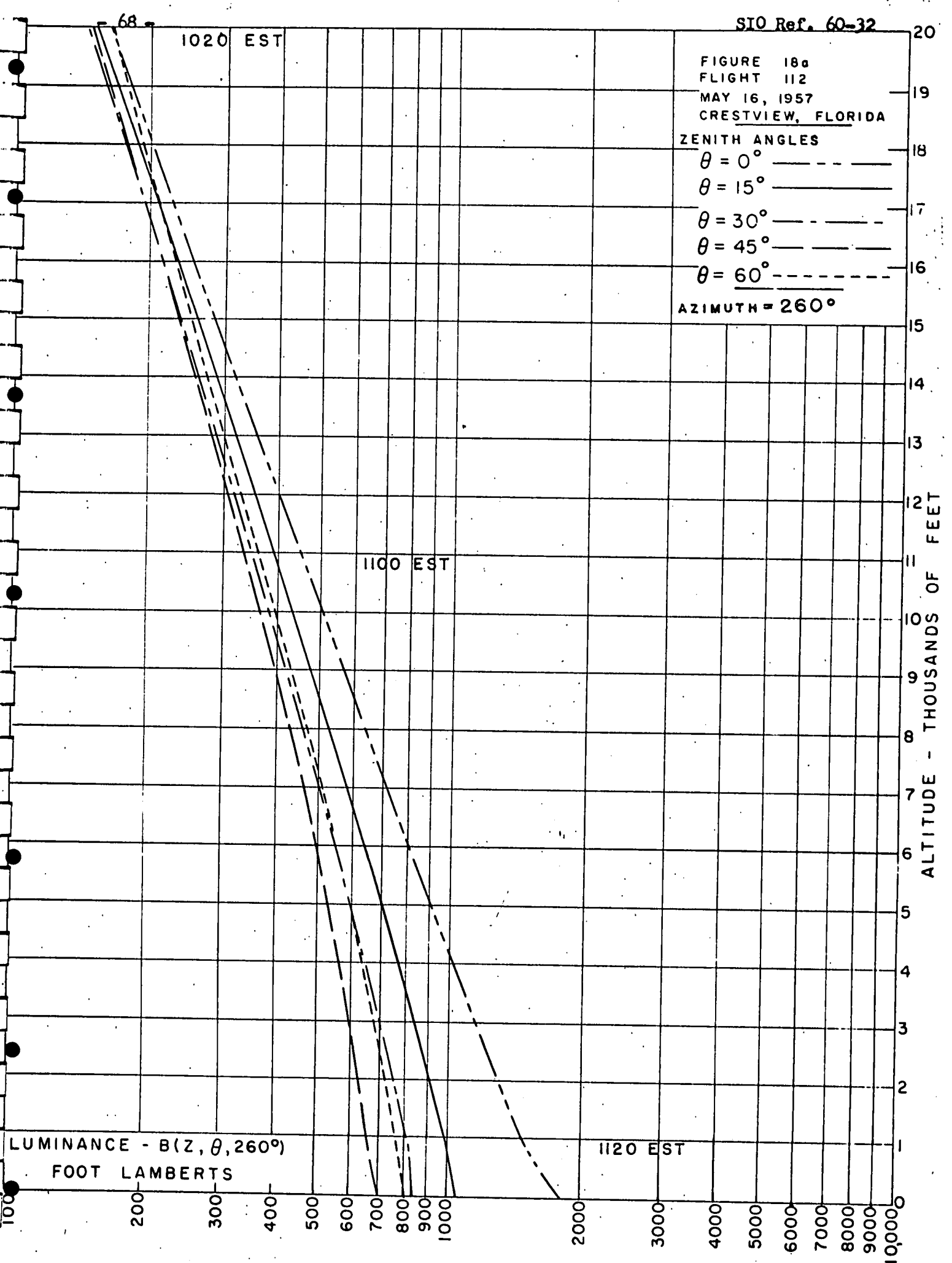
1020 EST
1100 EST
1120 EST
FIGURE 18a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 260°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 260°)
FOOT LAMBERTS
100
200
300
400
500
600
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10,000
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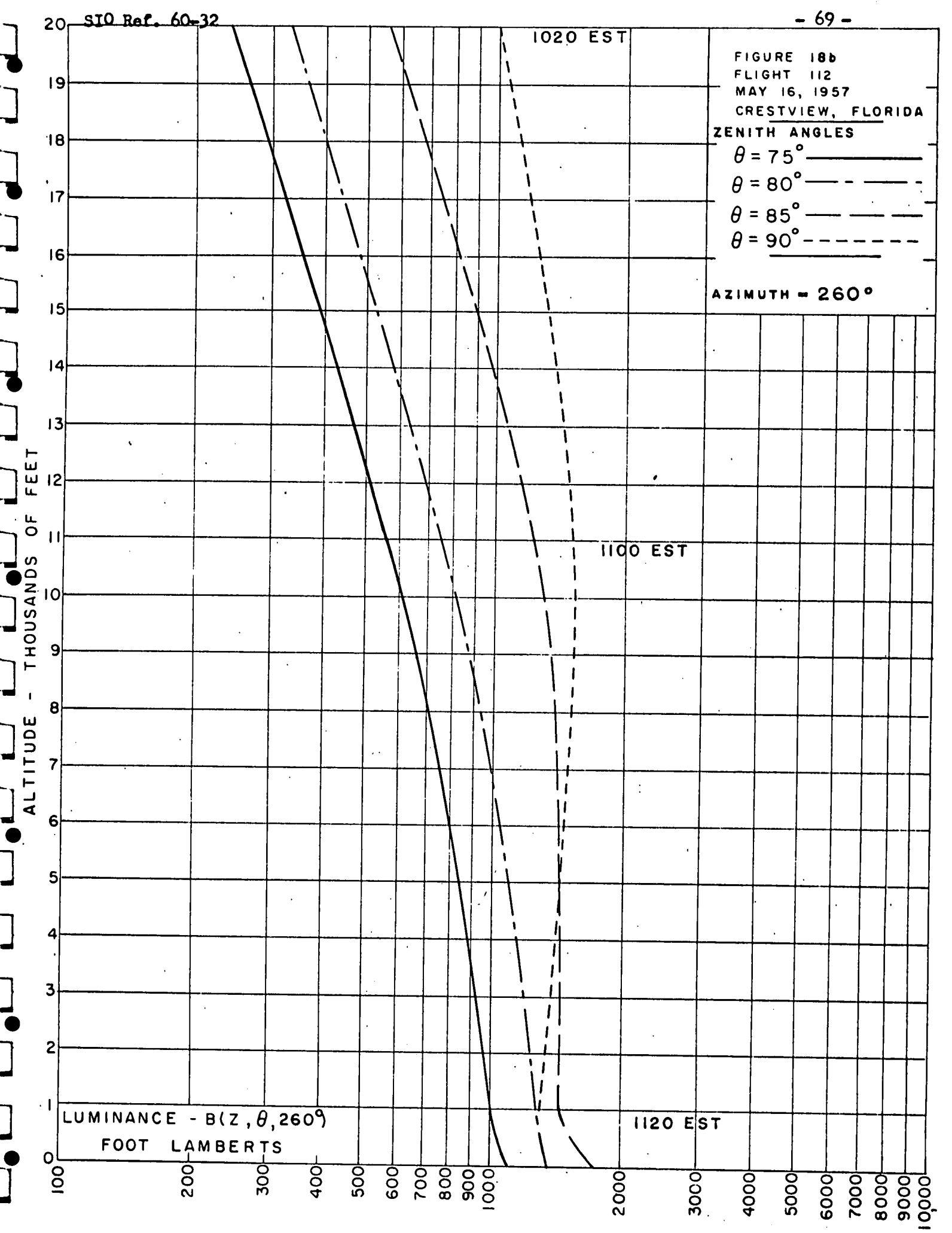
1020 EST
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FIGURE 18b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 260°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 260°)
FOOT LAMBERTS
0
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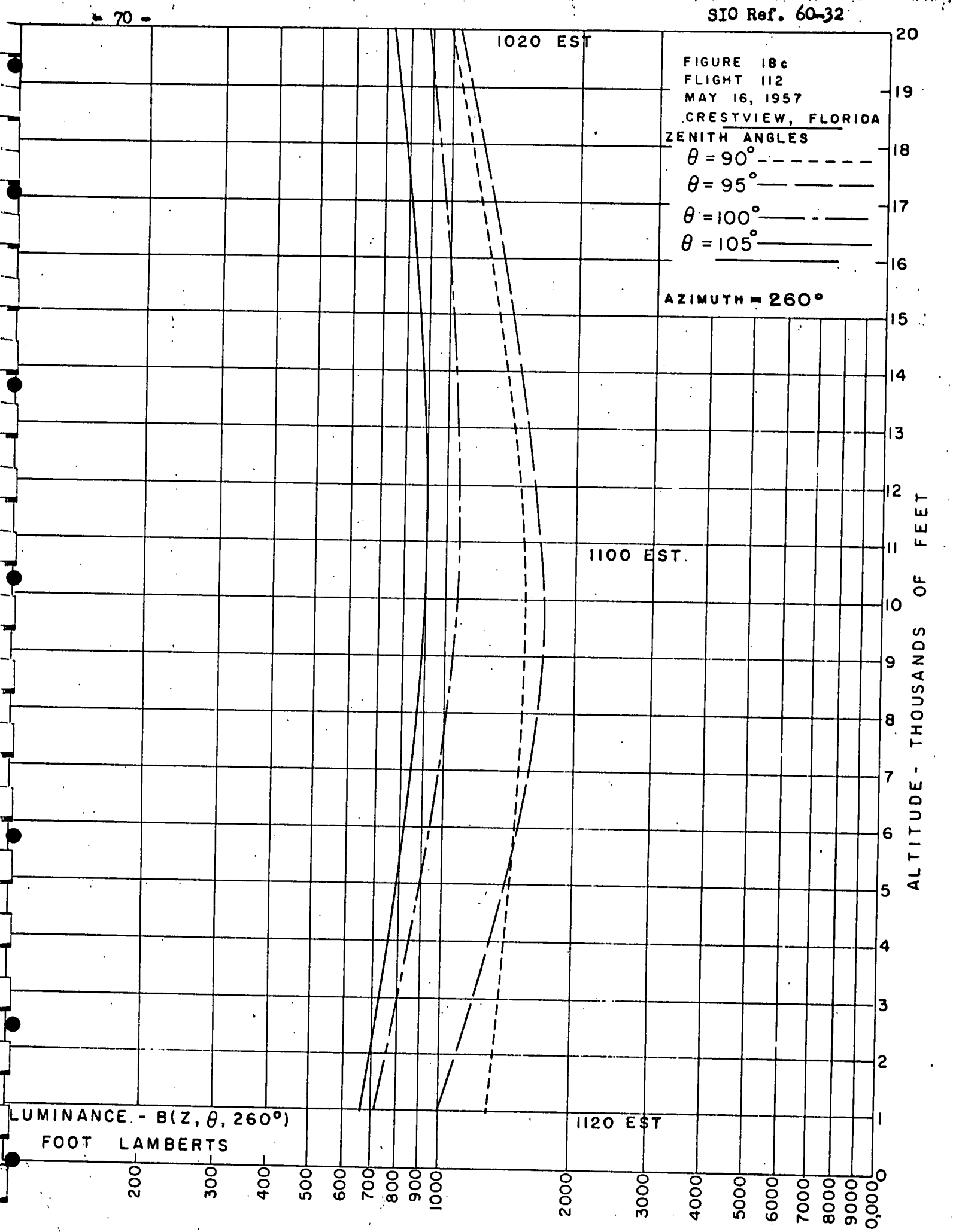
1020 EST
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FIGURE 18c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 260°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 260°)
FOOT LAMBERTS
200
300
400
500
600
700
800
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1000
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6000
7000
8000
9000
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SIO Ref. 60-32

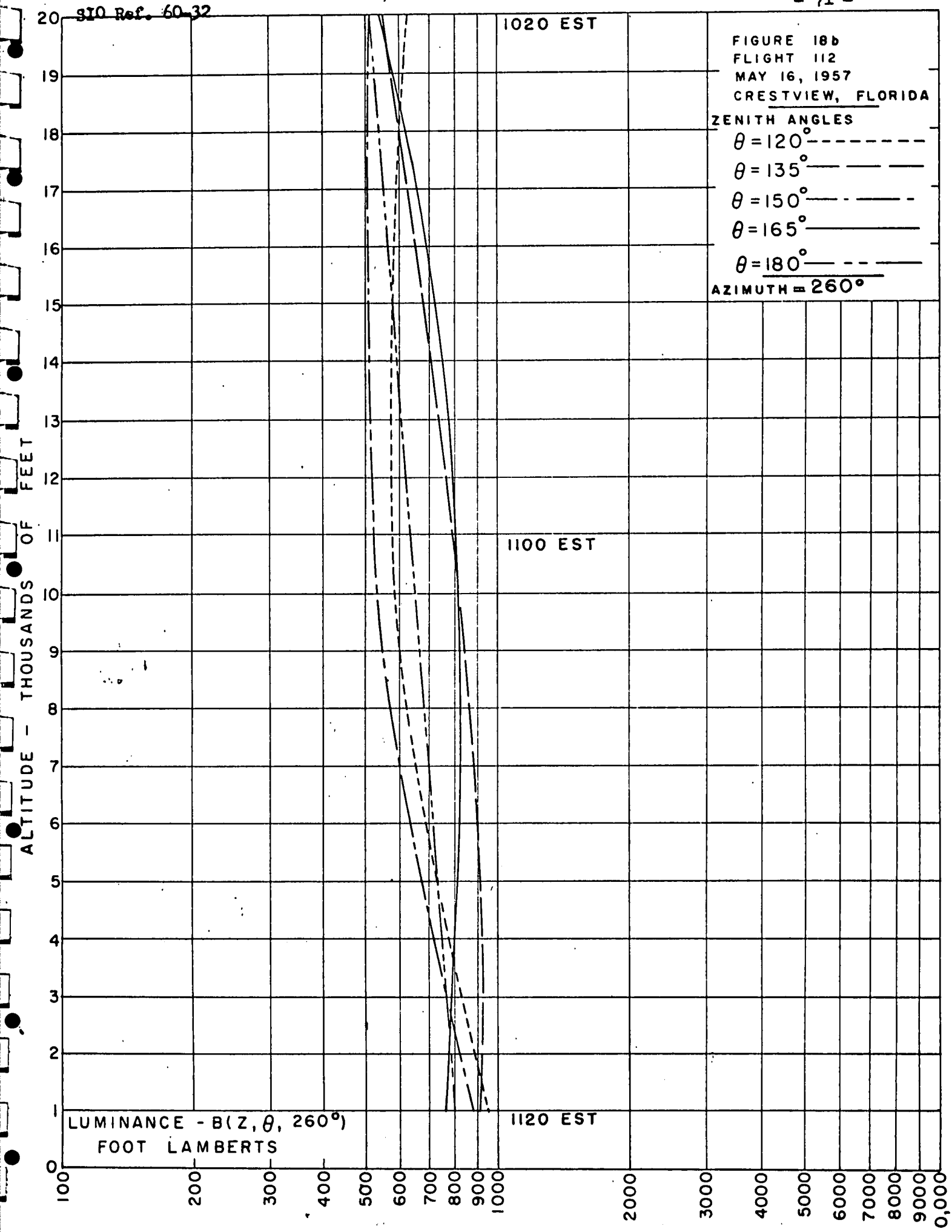
1020 EST
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FIGURE 18b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 260°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 260°)
FOOT LAMBERTS
0
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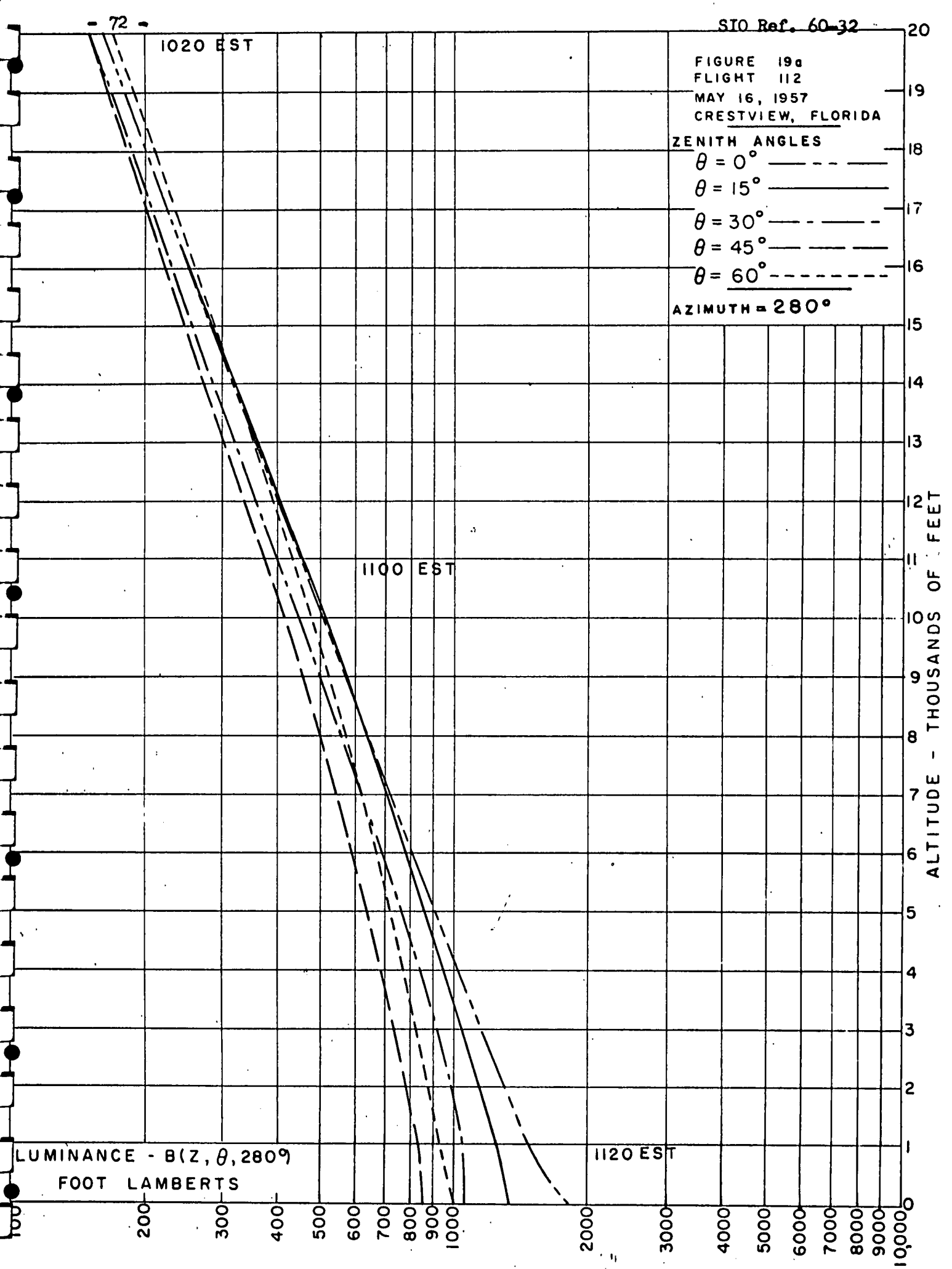
1020 EST
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FIGURE 19a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 280°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 280°)
FOOT LAMBERTS
100
200
300
400
500
600
700
800
900
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2000
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4000
5000
6000
7000
8000
9000
10,000
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SIO Ref. 60-32

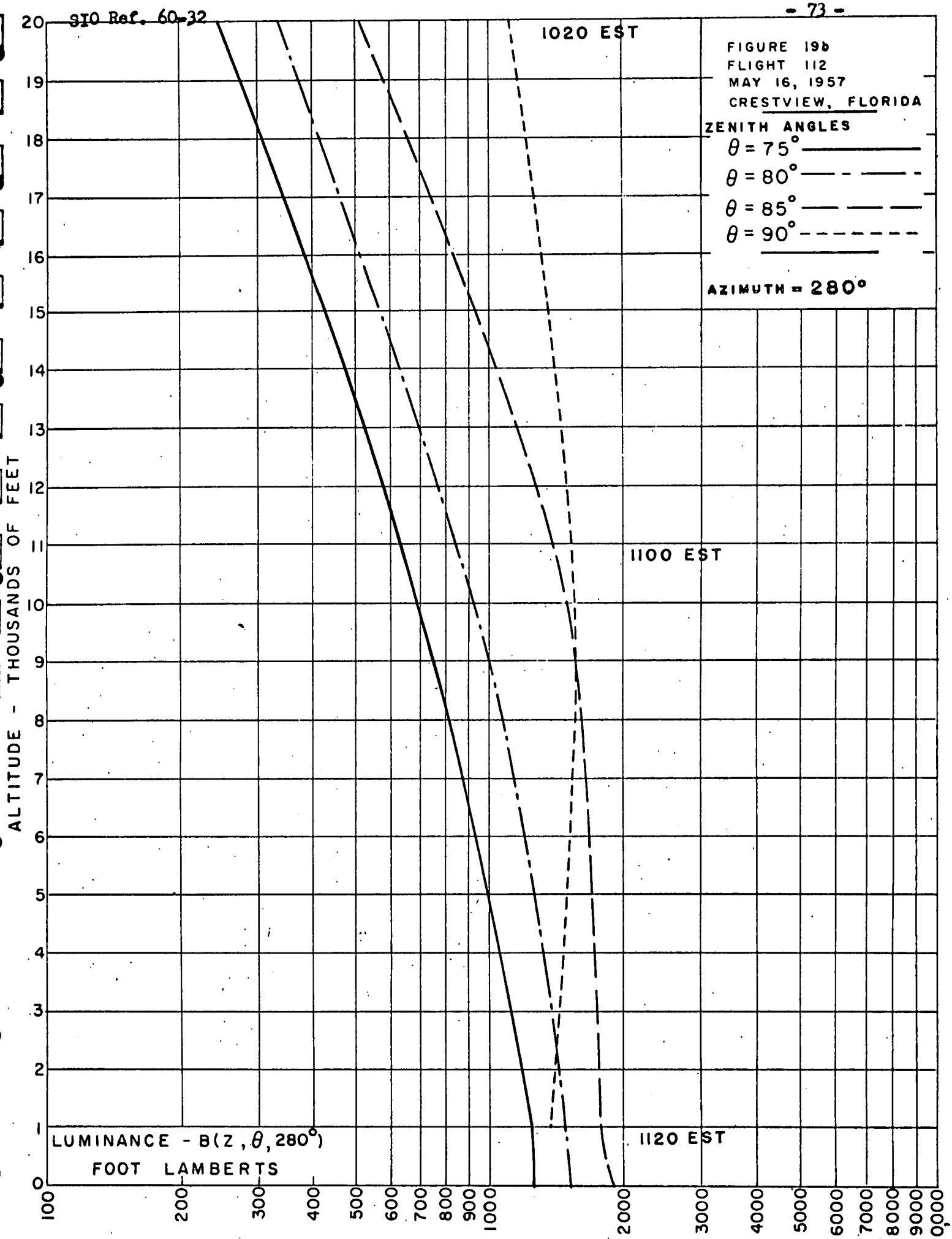
1020 EST
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FIGURE 19b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 280°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 280°)
FOOT LAMBERTS
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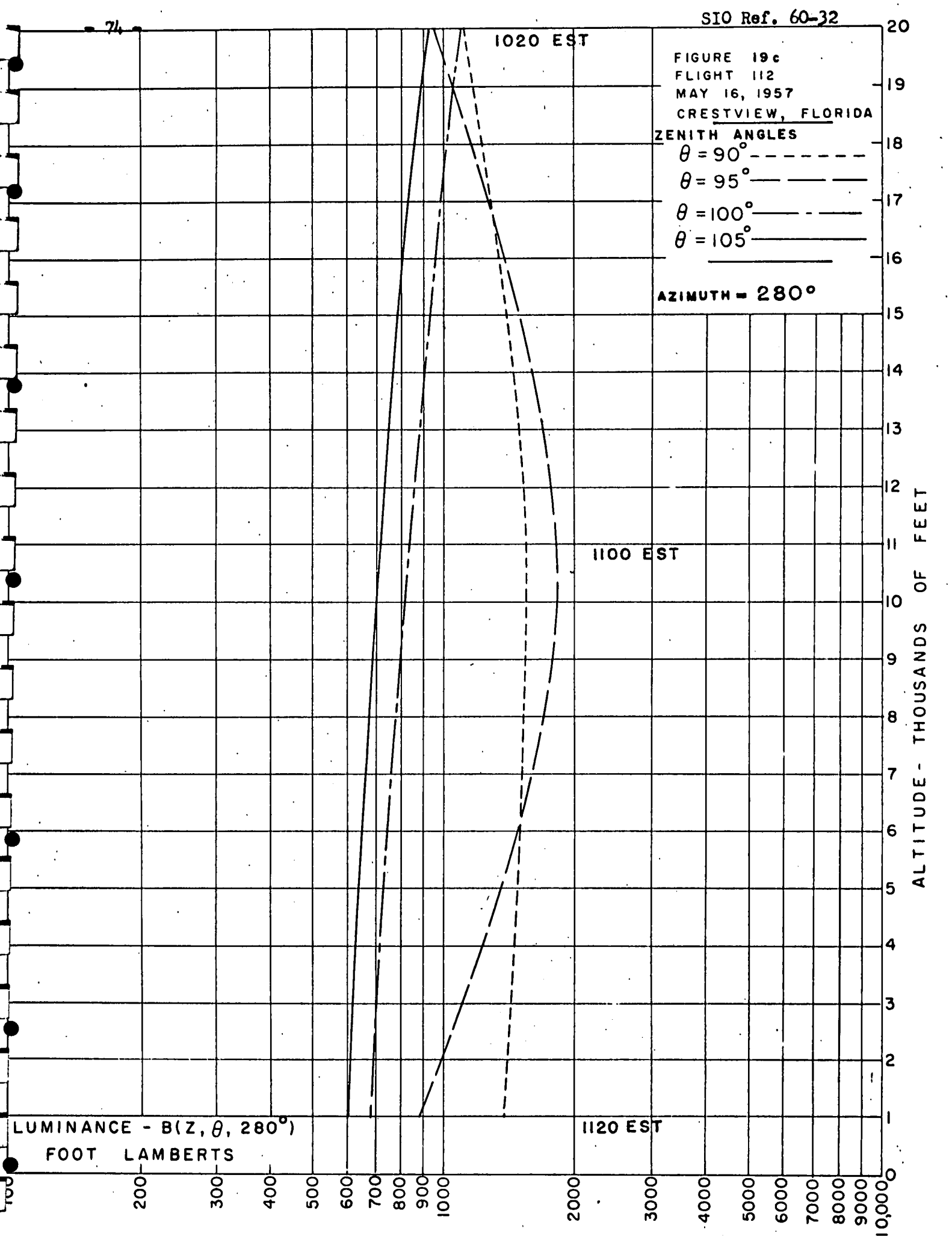
1020 EST
1100 EST
1120 EST
FIGURE 19c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 280°
LUMINANCE - B(Z, θ, 280°)
FOOT LAMBERTS
100
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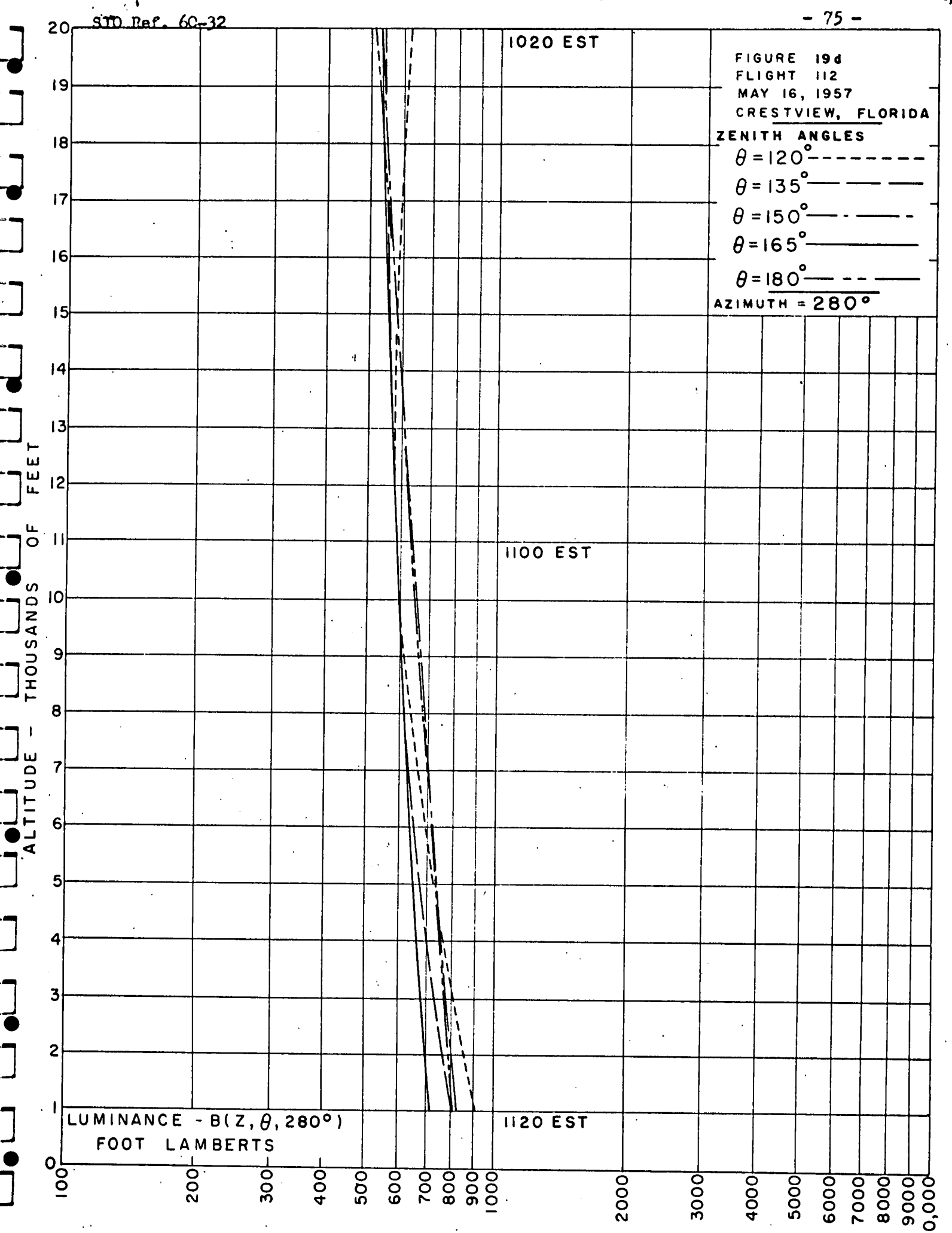
ALTITUDE- THOUSANDS OF FEET


1020 EST
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1120 EST
FIGURE 19d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 280°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 280°)
FOOT LAMBERTS
0
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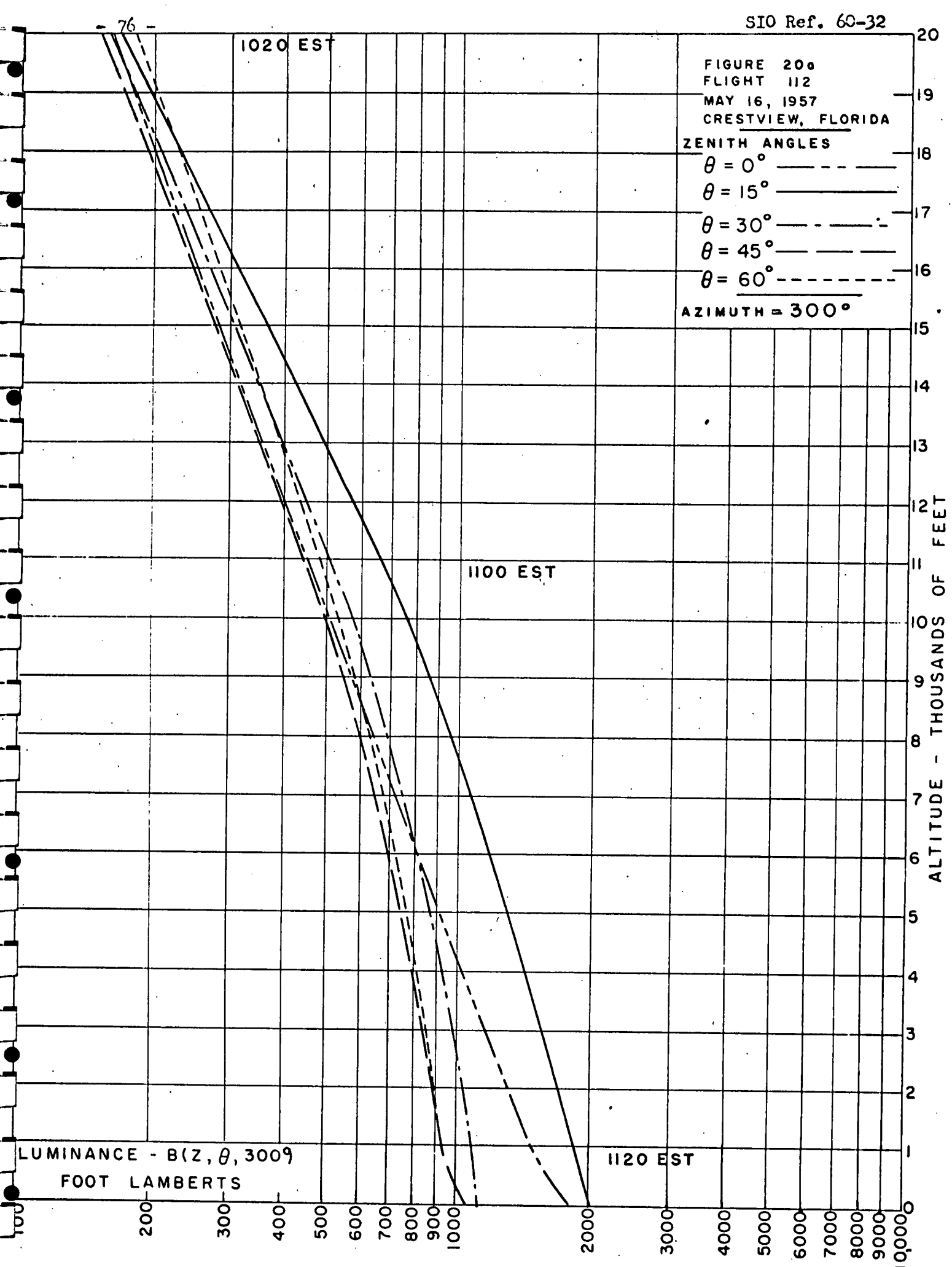
1020 EST
1100 EST
1120 EST
FIGURE 20a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 300°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 3009)
FOOT LAMBERTS
100
200
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1000
2000
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4000
5000
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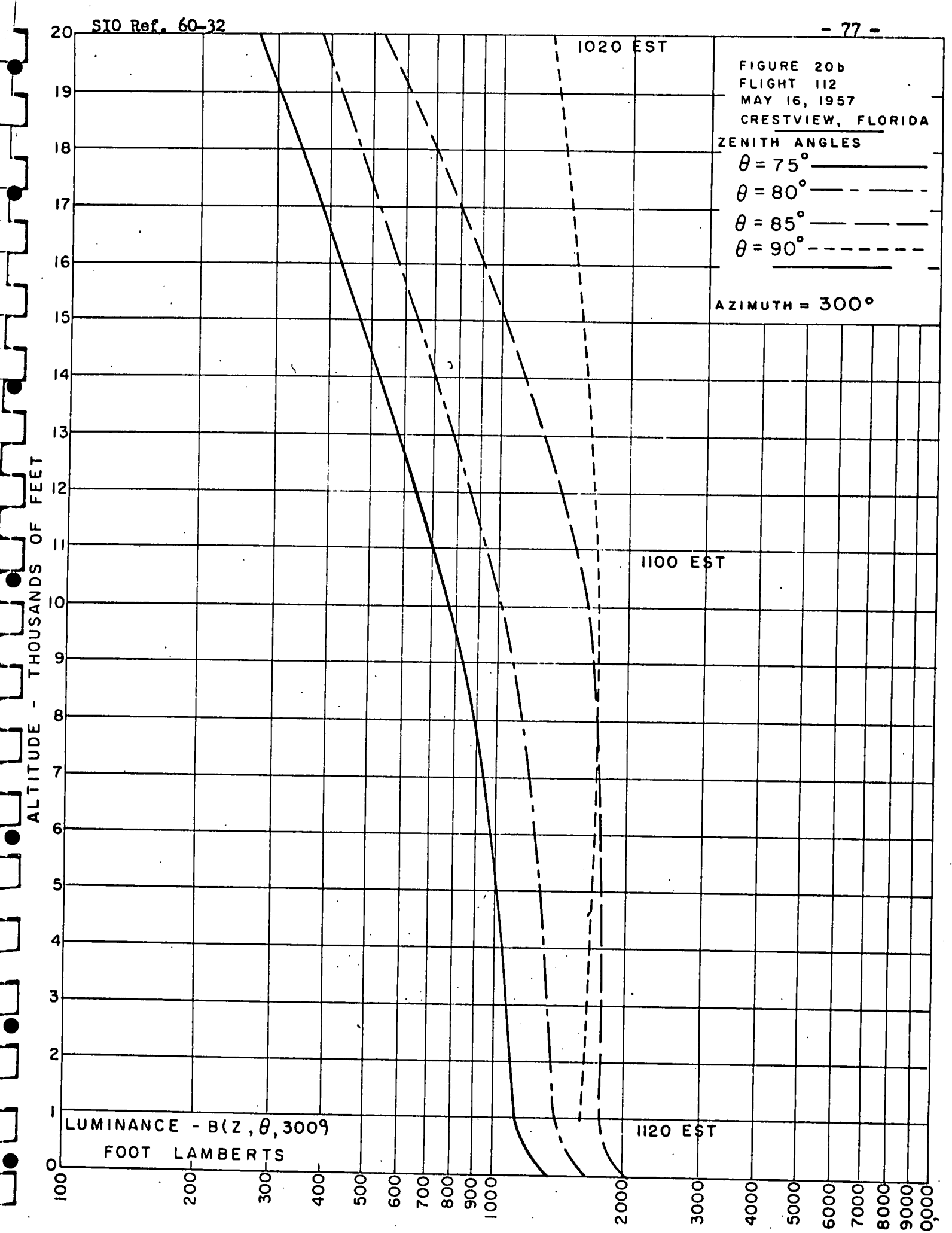
1020 EST
1100 EST
1120 EST
FIGURE 20b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 300°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 3009)
FOOT LAMBERTS
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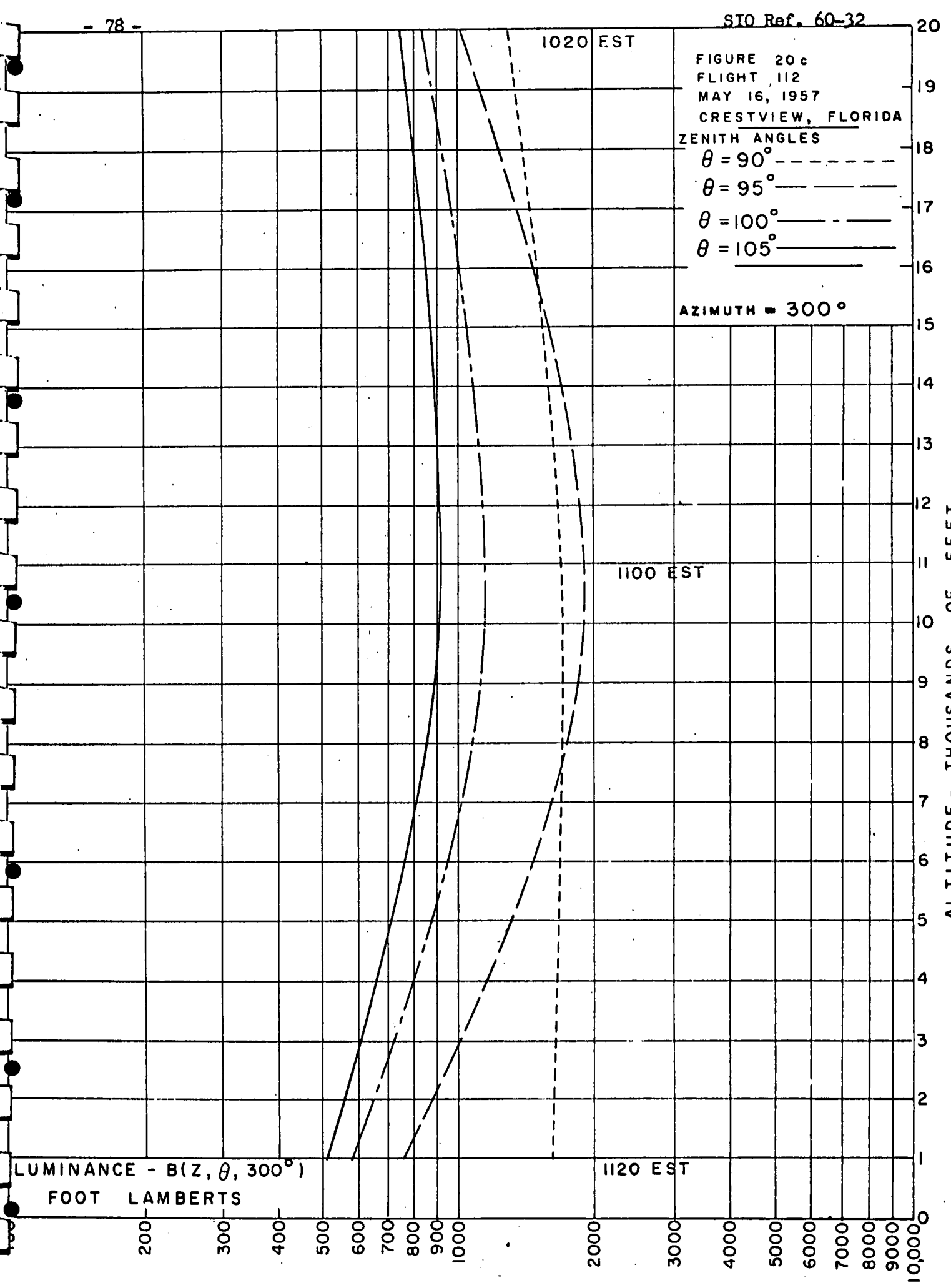
1020 EST
1100 EST
1120 EST
FIGURE 20c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 300°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 300°)
FOOT LAMBERTS
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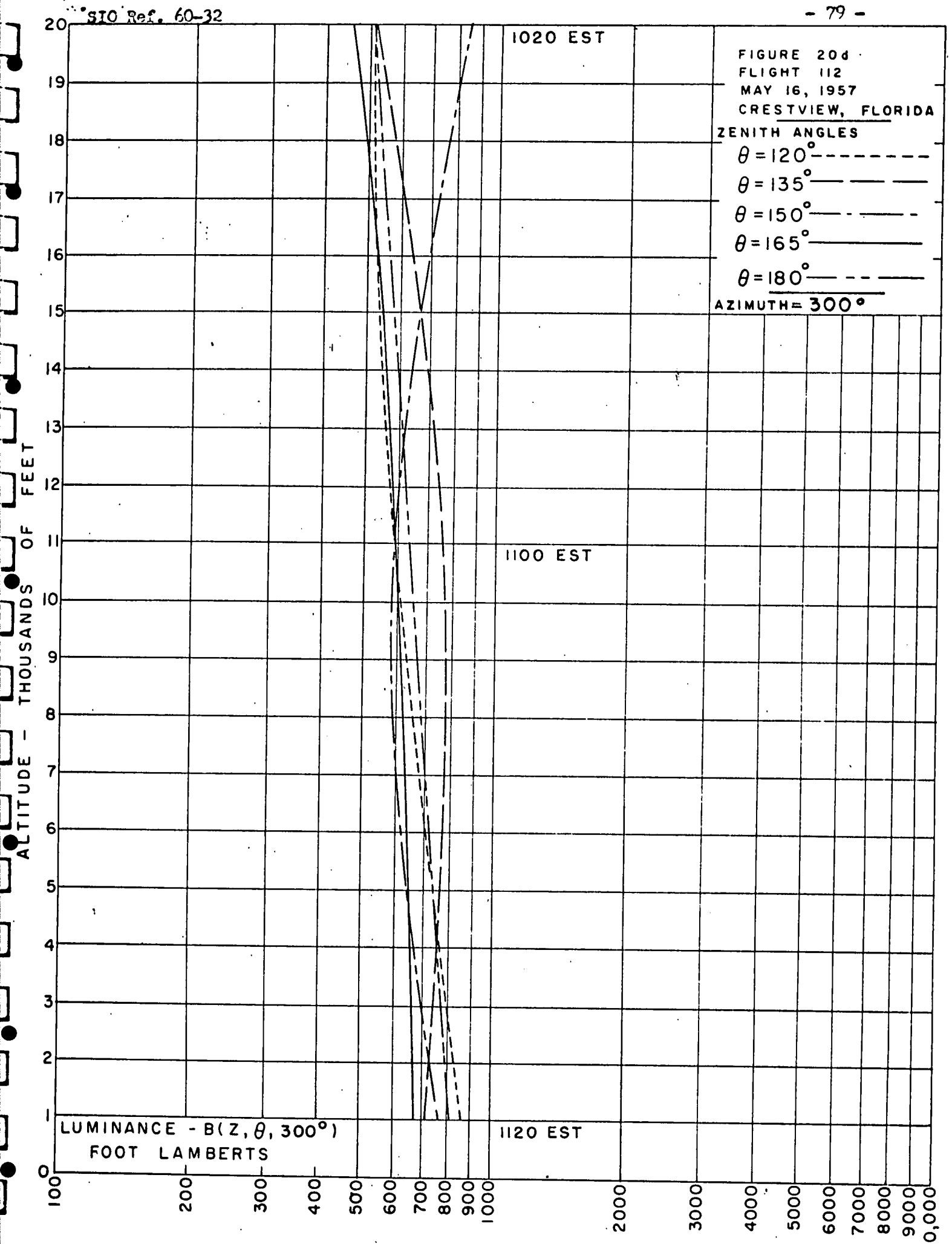
1020 EST
1100 EST
1120 EST
FIGURE 20d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 300°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 300°)
FOOT LAMBERTS
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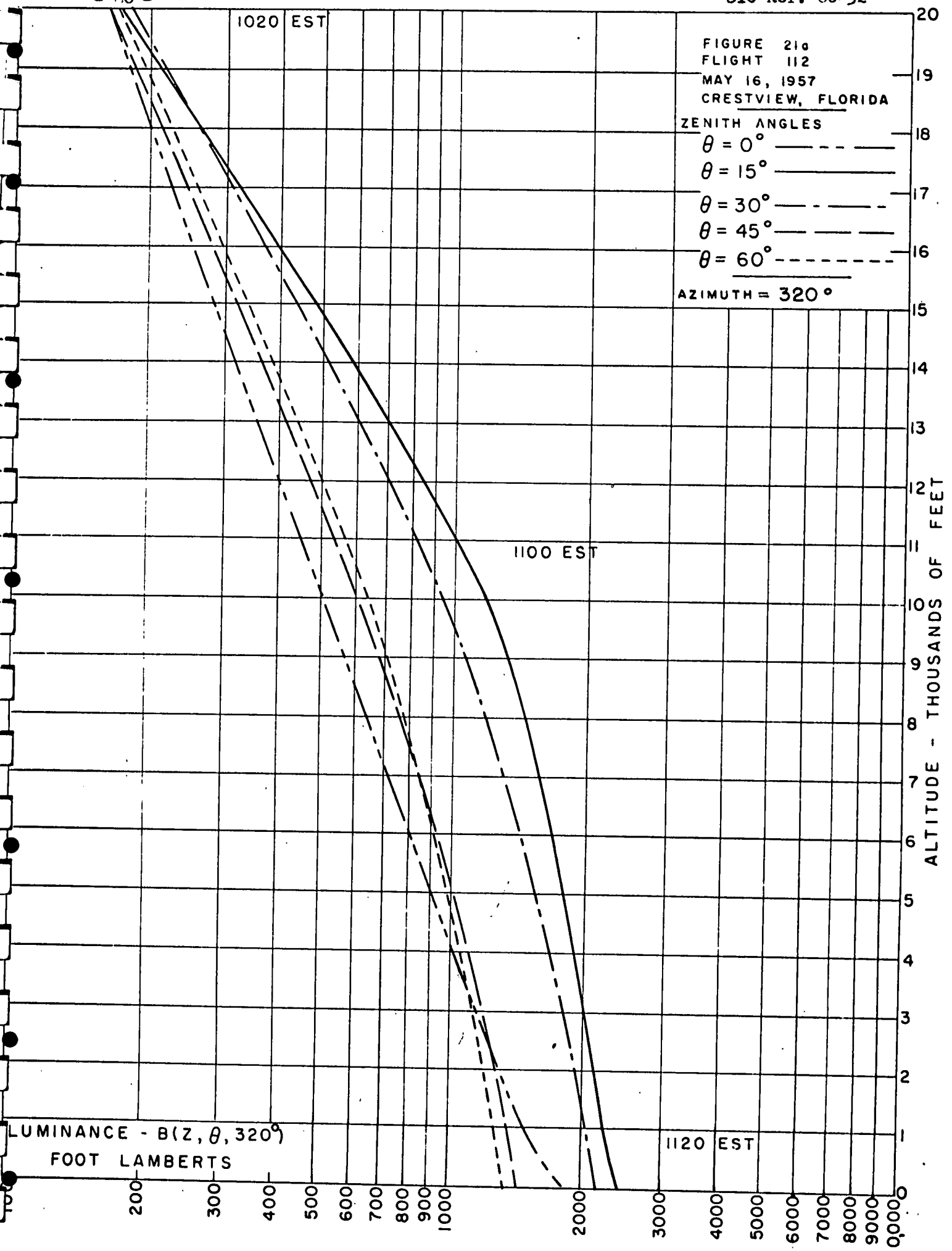
1020 EST
1100 EST
1120 EST
FIGURE 21a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 320°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 320°)
FOOT LAMBERTS
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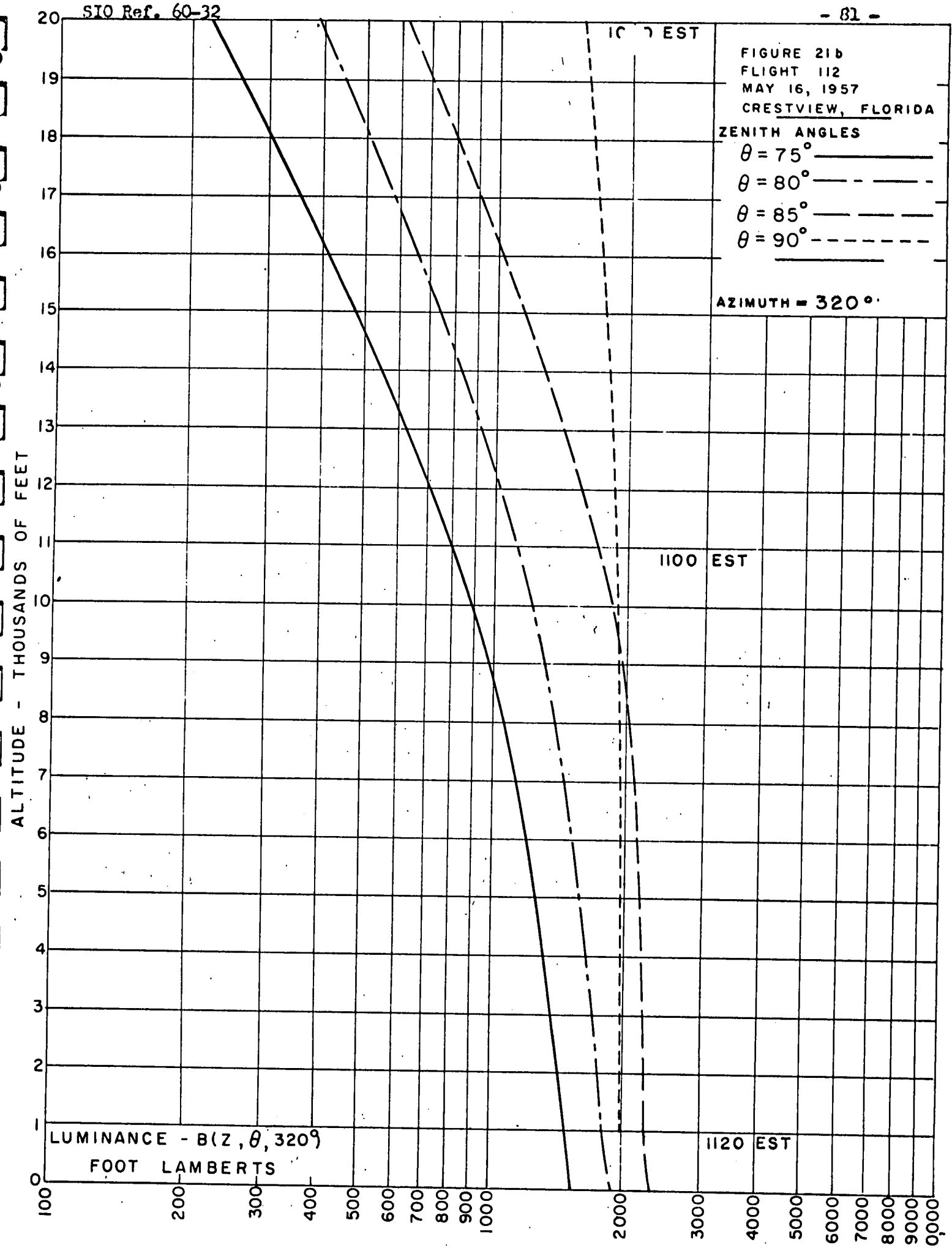
FIGURE 21b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 320°
1100 EST
1120 EST
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 320°)
FOOT LAMBERTS
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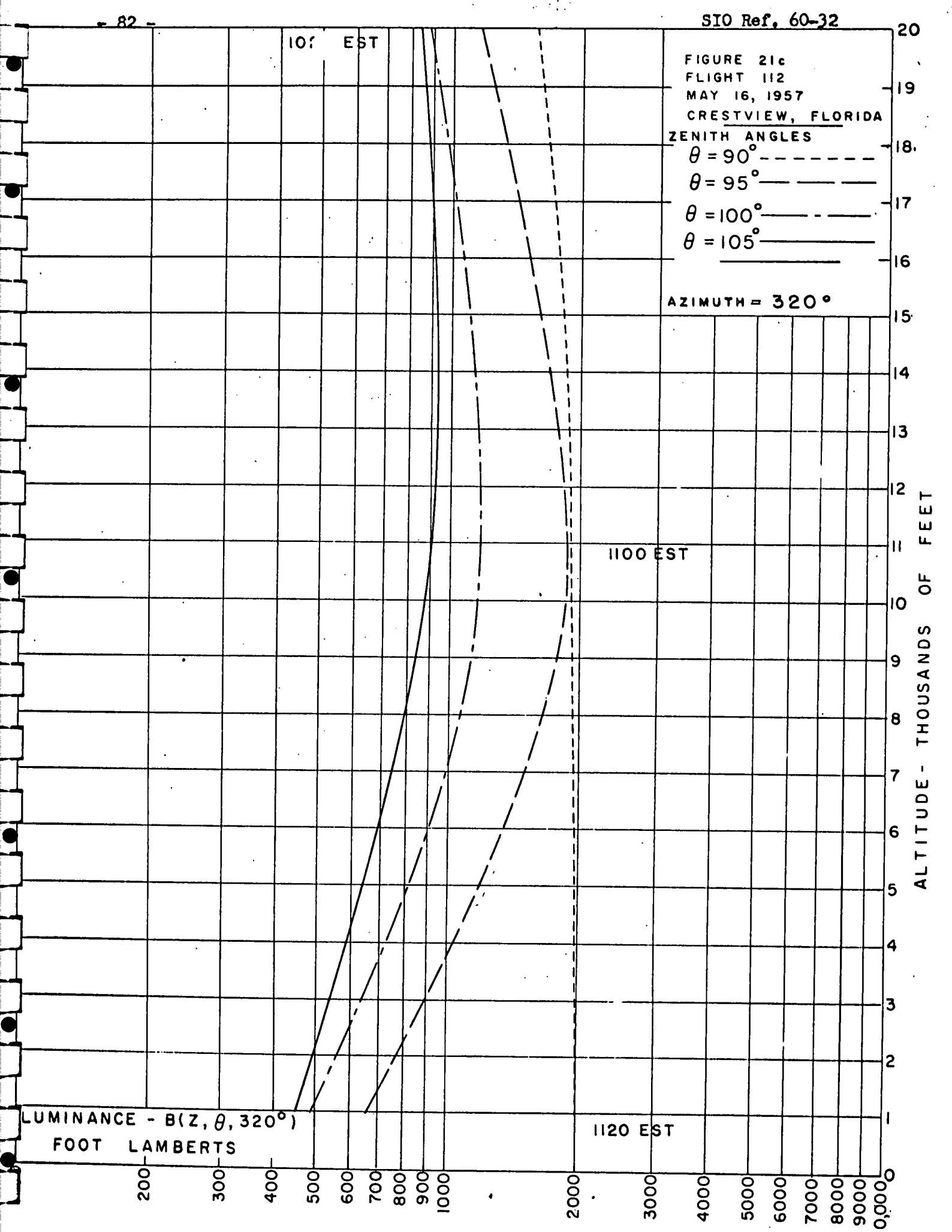
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FIGURE 21c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 320°
1100 EST
1120 EST
LUMINANCE - B(Z, θ, 320°)
FOOT LAMBERTS
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ALTITUDE - THOUSANDS OF FEET
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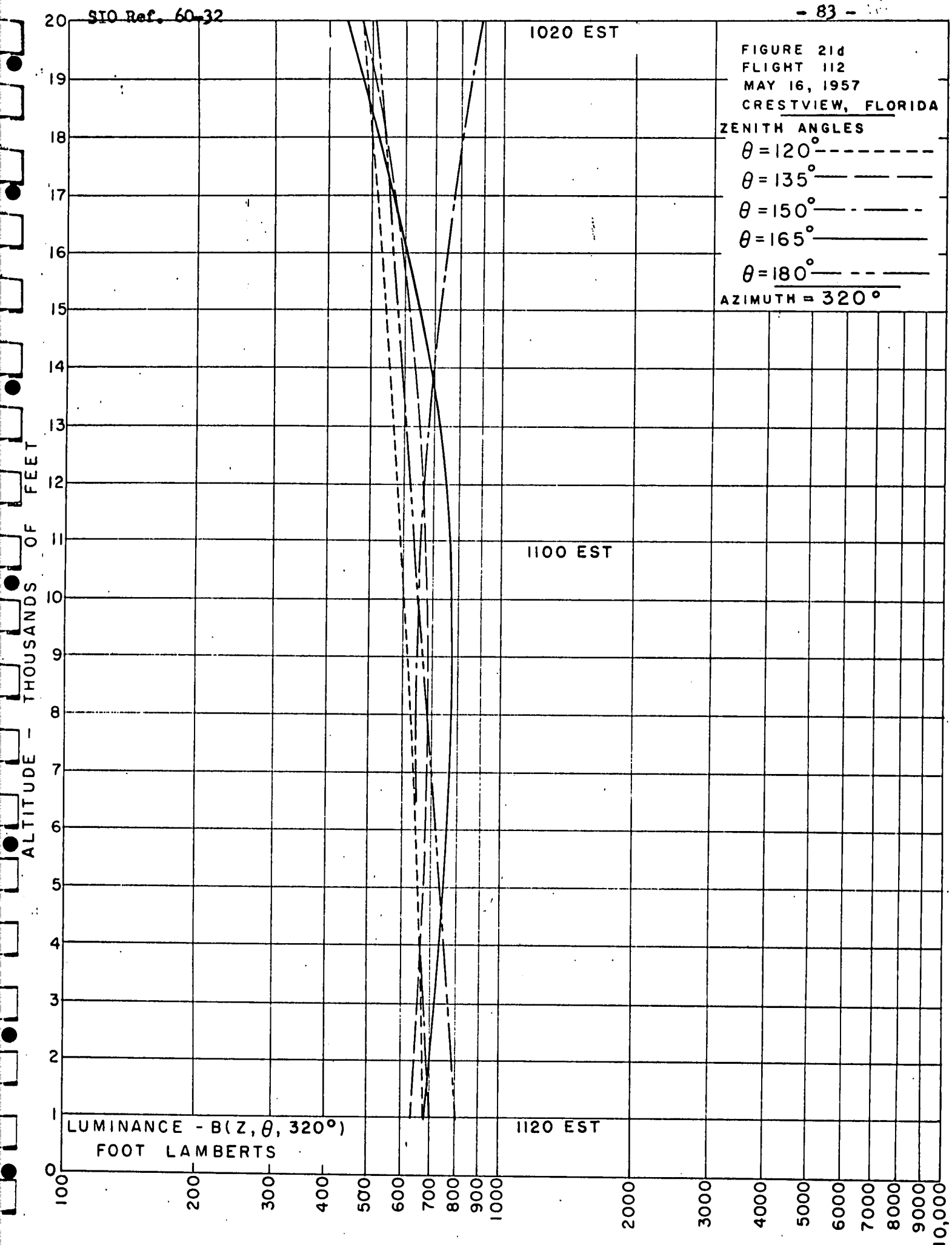
1020 EST
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FIGURE 21d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 320°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 320°)
FOOT LAMBERTS
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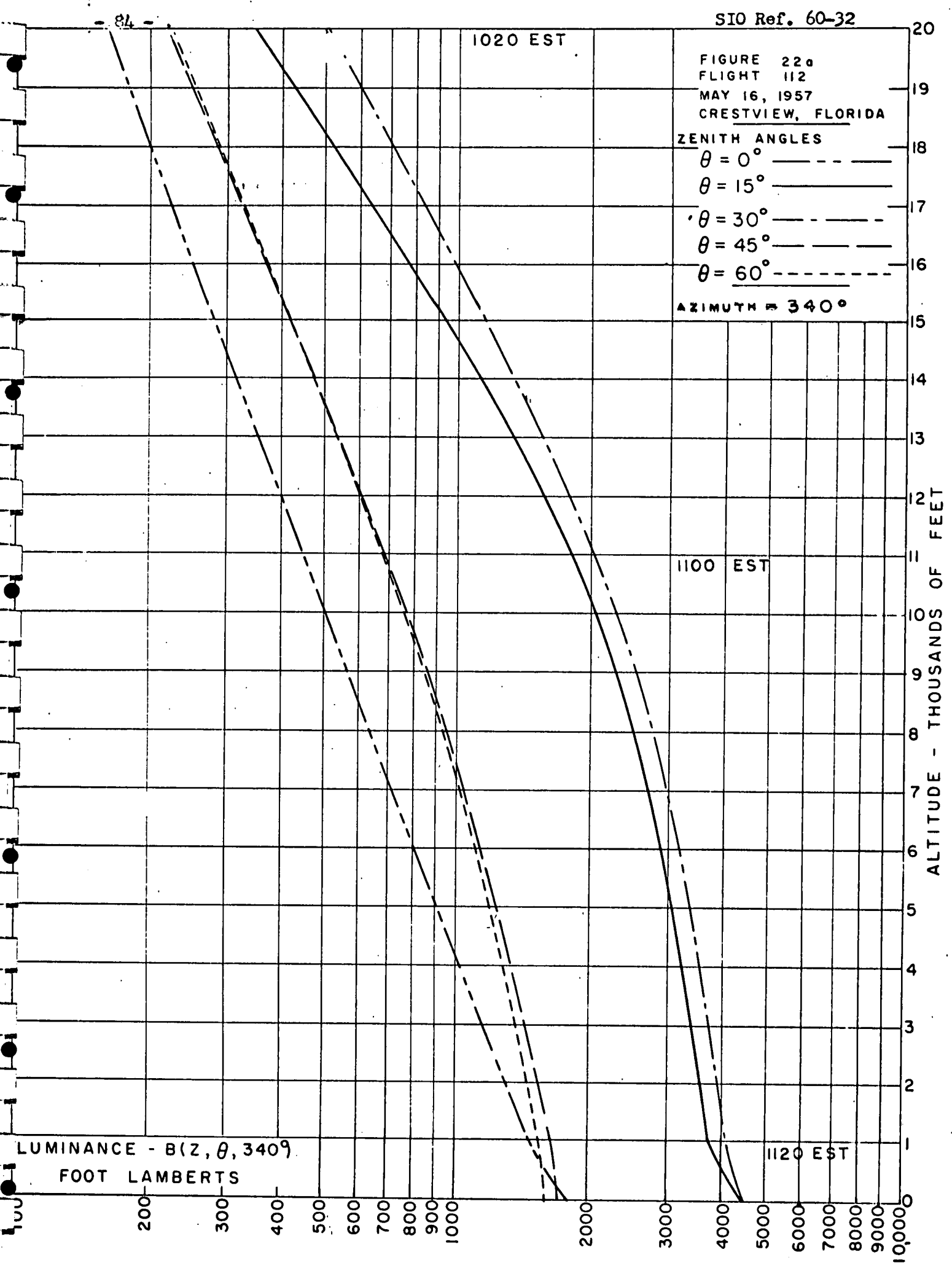
1020 EST
1100 EST
1120 EST
FIGURE 22a
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 0°
θ = 15°
θ = 30°
θ = 45°
θ = 60°
AZIMUTH = 340°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 340°)
FOOT LAMBERTS
100
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7000
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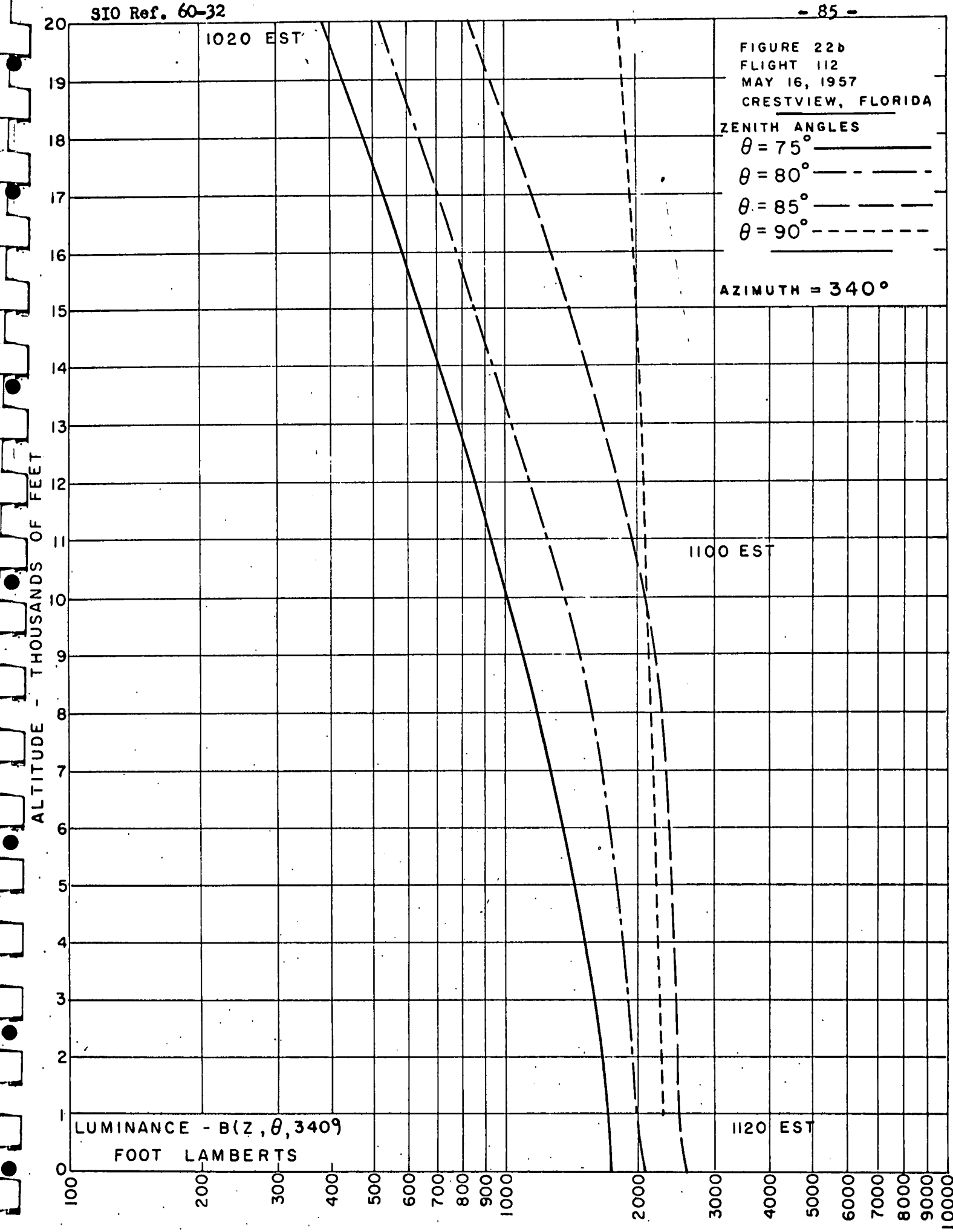
1020 EST
1100 EST
1120 EST
FIGURE 22b
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 75°
θ = 80°
θ = 85°
θ = 90°
AZIMUTH = 340°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 340°)
FOOT LAMBERTS
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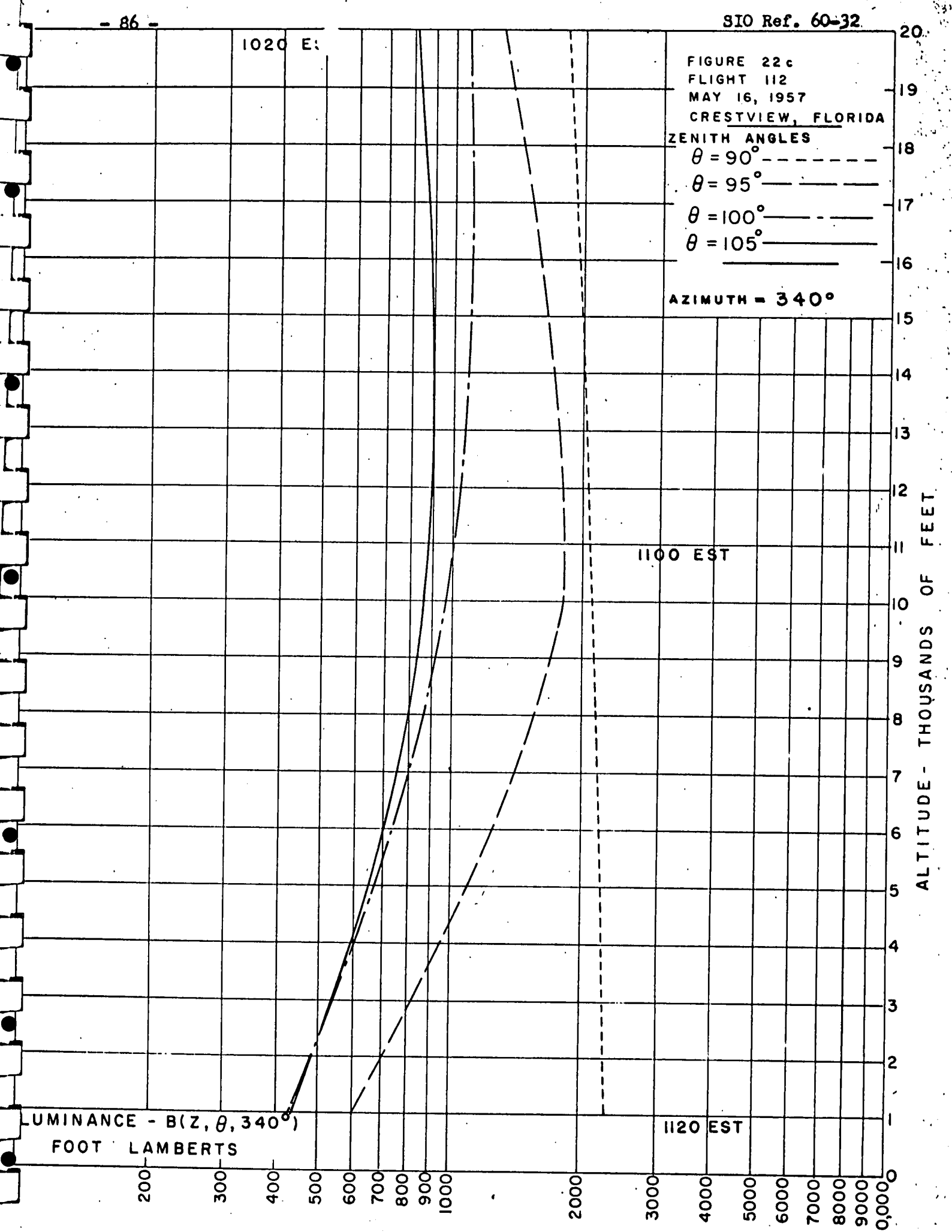
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FIGURE 22c
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 90°
θ = 95°
θ = 100°
θ = 105°
AZIMUTH = 340°
1100 EST
1120 EST
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 340°)
FOOT LAMBERTS
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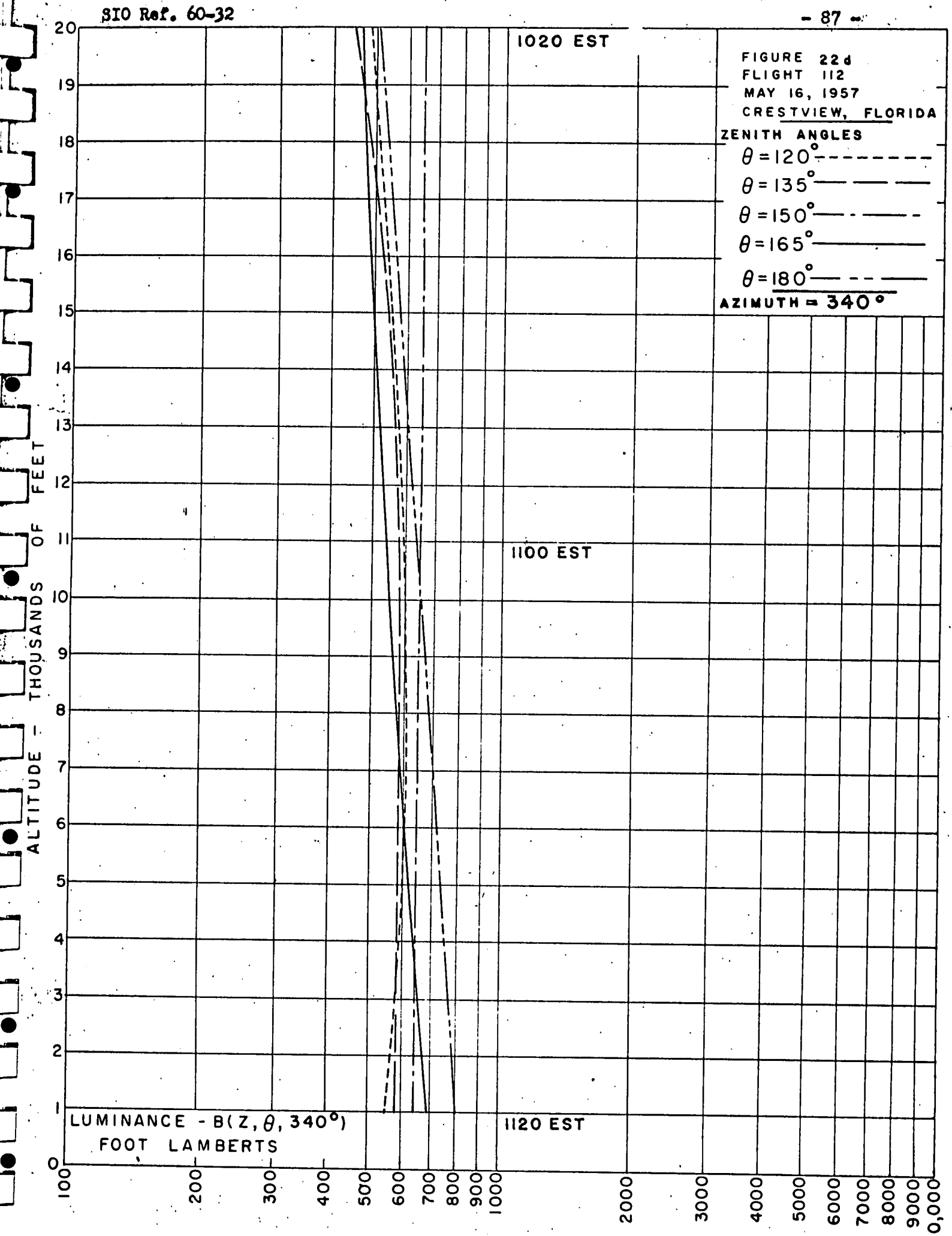
1020 EST
1100 EST
1120 EST
FIGURE 22d
FLIGHT 112
MAY 16, 1957
CRESTVIEW, FLORIDA
ZENITH ANGLES
θ = 120°
θ = 135°
θ = 150°
θ = 165°
θ = 180°
AZIMUTH = 340°
ALTITUDE - THOUSANDS OF FEET
LUMINANCE - B(Z, θ, 340°)
FOOT LAMBERTS
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1. Boileau, A. R., "Atmospheric Optical Measurements in Western Florida, Flight 112, Part I," SIO Ref. 60-22, Scripps Institution of Oceanography, University of California, La Jolla Campus, April 1960.

2. 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).

ACKNOWLEDGEMENTS

While the assistance of all who have helped in this work is very much appreciated special mention is made of the crew of the B-29, No. 4224725, Captain Robert Baron, USAF, Aircraft Commander, 1st Lieutenant Donald Crandall, USAF, and Air Force Cambridge Research Center Test Support Group. Thanks are also extended to Mr. H. C. Schepler and Mr. Fritz Mantey of Air Force Armament Center, Eglin Air Force Base, for their assistance during the period of operations at that base.