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NIGHT-SKY-BACKGROUND CONDITIONS AND LAUNCH WINDOWS FOR RESEARCH EXPERIMENTS

by Jean C. Keating

Langley Research Center

Langley Station, Hampton, Va.

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SUMMARY

Darkness of the night sky background is required by many research experiments during various portions of their flight. A method was originally developed for the Trailblazer series to define launch windows that coincide with periods during which the brightness of the night sky background results solely from the illumination produced by the myriad of stars. Since this same method has proved useful to many other experiments as well, a general description of the method and the computer program developed to determine such launch windows are discussed. For any location between latitudes 60° N and 60° S, such times of launch may be determined to an accuracy of 2 minutes.

INTRODUCTION

For an increasing number of research experiments, maximum darkness of the night sky background is required either during the launch of the vehicle, during the data-gathering phase, or throughout the entire interval from launch to completion of the flight. A method was originally developed for the Trailblazer series (ref. 1) to determine vehicle launch windows that would coincide with periods when the sky background would be no brighter than the average illumination produced by starlight. During such periods, the brightness of the sky background would be approximately 2.15×10^{-3} lux (ref. 2). This method was capable of defining such periods of darkness of the sky background to an accuracy of 2 minutes for any location between latitudes 60° N and 60° S. It was subsequently used to determine the launch windows of many other experiments where darkness of the sky background was essential. A description of the method is presented herein.

SYMBOLS

D_n	calendar day
GMT	Greenwich mean time

h	altitude, meters
N	integer
LMT	local mean time
ΔT	elapsed flight time between launch and some event with regard to flight, minutes
Δt	difference in times of moonrise (or moonset) on any two successive days, minutes
Δz	increase in zenith angle with altitude of astronomical phenomenon, degrees
λ	longitude, degrees
ϕ	latitude, degrees
λ_p	meridian of a standard time zone at which local standard time equals local mean time (for example, the 75^o meridian of the eastern standard time zone), degrees
δ	declination, degrees

Subscripts:

E	some geographic location
G	Greenwich
M	moon
T	astronomical twilight

SKY-BACKGROUND CONDITIONS

Maximum darkness of the sky background at any specific location is assumed to exist if the moon is below the horizon – after moonset and before moonrise – and the sun's zenith angle is greater than or equal to 108^o – after the end and before the beginning of astronomical twilight. During such time periods, the brightness of the sky background results from the illumination produced by the myriad of stars.

The local mean times of moonrise, moonset, and the end and beginning of astronomical twilight for latitudes between 60° N and 60° S at the Greenwich meridian, 0° longitude, may be obtained from the American Ephemeris and Nautical Almanac (ref. 3), which is published yearly approximately 16 months in advance. From data listed in reference 3, the times at which these four phenomena will occur at any location other than Greenwich are determined to an accuracy of 2 minutes for all locations between latitudes 60° N and 60° S. A plot of date and times of each of these four phenomena results in the four curves shown in figure 1. For all times defined by points which lie within the area enclosed by these four curves, maximum darkness conditions will exist at the given location.

Twilight

The end and beginning of astronomical twilight is defined as the instant when the true geocentric zenith distance of the center point of the sun's disk is 108°. For various latitudes between 0° N and 60° N the local mean times of the end and beginning of astronomical twilight at the meridan of Greenwich are given in reference 3 at 5-day intervals throughout the year, as shown in figure 2. Theoretically, interpolation is necessary to obtain the local mean time of the end and beginning of astronomical twilight for other days. Corrections for intermediate days are unnecessary, however, for the 2-minute accuracy requirement. On any given day D_n and for a given latitude ϕ, the local mean time of astronomical twilight at any meridian λ_E is assumed to be equal to the local mean time of astronomical twilight at Greenwich:

$$LMT_T\left(\lambda_E,\phi,D_n\right) = LMT_T\left(\lambda_G,\phi,D_n\right) \tag{1}$$

The local mean time of astronomical twilight at any latitude ϕ_E is obtained by assuming a linear interpolation between the two values of ϕ listed in reference 3 which are nearer to ϕ_E. The local mean time of astronomical twilight at a specific location of latitude ϕ_E and longitude λ_E thus determined is denoted as $LMT_T\left(\phi_E,\lambda_E\right)$.

Times for astronomical twilight are listed only for northern latitudes in reference 3. For southern latitudes, these times are determined by means of correction tables given at the bottom of the page of northern latitudes, as shown in figure 2.

Moonrise and Moonset

Moonrise and moonset are defined as the instant when the true geocentric zenith distance of the central point of the moon's disk is

$$90^{\circ}34' + S - \pi \quad (2)$$

away from the observer's zenith where

S	semidiameter of moon
π	horizontal parallax of moon
34'	atmospheric refraction

Correction for intermediate longitude.- For latitudes between 60° N and 60° S, the local mean times of moonrise and moonset at the meridian of Greenwich are tabulated in reference 3. The times are listed for both northern and southern latitudes. Moonrise and moonset occur later on each succeeding night by an amount which varies from about $\frac{1}{2}$ to $1\frac{1}{2}$ hours, as shown in figure 3. Therefore, a longitude correction is essential in determining the times of moonrise and moonset for meridians other than Greenwich. To the accuracies required by vehicle launch times, it is sufficient to assume a linear interpolation with longitude between the time of these events on two successive days. For any given day D_n, the local mean time of moonrise at the meridian of Greenwich is denoted as $LMT_M(\lambda_G,\phi,D_n)$. The corresponding time on the succeeding day D_{n+1} is denoted by $LMT_M(\lambda_G,\phi,D_{n+1})$, and the corresponding time on the preceding day D_{n-1} is denoted by $LMT_M(\lambda_G,\phi,D_{n-1})$. Any meridian λ_E other than the meridian of Greenwich is denoted by a positive sign if the meridian is west of Greenwich and by a negative sign if the meridian is east of Greenwich. For any meridian λ_E other than the meridian of Greenwich, the local mean time of moonrise for the day D_n, denoted by $LMT_M(\lambda_E,\phi,D_n)$, is determined from the following equation:

$$LMT_M(\lambda_E,\phi,D_n) = LMT_M(\lambda_G,\phi,D_n) + \left(\frac{\lambda_E}{360}\right)\Delta t \quad (3)$$

where if $\lambda_E > 0^{\circ}$

$$\Delta t = LMT_M(\lambda_G,\phi,D_{n+1}) - LMT_M(\lambda_G,\phi,D_n)$$

and if $\lambda_E < 0^{\circ}$

$$\Delta t = LMT_M(\lambda_G,\phi,D_n) - LMT_M(\lambda_G,\phi,D_{n-1})$$

Correction to intermediate latitudes.- For each of the two values of ϕ listed in reference 3 that are nearer to ϕ_E, the local mean times of moonrise or moonset at λ_E are determined from equation (3). A linear interpolation with latitude is used to determine $LMT_M(\lambda_E,\phi_E,D_n)$, the local mean time of moonrise or moonset at the given longitude and latitude. If the local mean times of moonrise, moonset, and the end and beginning of astronomical twilight thus calculated are plotted against date (as shown in fig. 1), the area enclosed by the four curves then defines the local mean times when darkness conditions will exist for that given location.

Altitude Corrections

The foregoing procedure determines the local mean times at which moonrise, moonset, and the end and beginning of astronomical twilight will occur at ground level. An increase in altitude produces an increase in the geocentric zenith angle necessary to attain similar conditions of illumination. This increase in zenith angle (in degrees) with altitude (in meters) is

$$\Delta z = 0.0321\sqrt{h} \tag{4}$$

for small values of Δz. (See, for example, ref. 2.) The elapsed time required to attain the increase in zenith angle Δz given by equation (4) is dependent on both the latitude of the location and the apparent declination of the celestial body. For extreme altitudes and latitudes such corrections are very complex. If altitude is a factor, use of the method described herein should be limited to cases where the latitude of the location is between 45° N and 45° S and values of Δz from equation (4) are 3° or less.

Altitude corrections for moonrise or moonset.- For small values of Δz, a change of Δz degrees causes a difference in times of rising and setting of the moon of $A\Delta z$ minutes (ref. 2) where

$$A = 4.14\left(\cos^2\phi - \sin^2\delta_M\right)^{-1/2}$$

The value of the factor A is dependent on the apparent declination of the moon δ_M which varies with time. For latitudes between 45° N and 45° S, the value of A never exceeds 8.0, however. In the program described herein, a constant value of A equal to 8.0 is used to eliminate the need for defining the value of δ_M. This altitude correction of $8\Delta z$ is added to the time of moonset and subtracted from the time of moonrise.

This approach gives a conservative accounting for the moonrise and moonset conditions for altitudes less than 9000 meters and latitudes between 45° N and 45° S. Geometry problems encountered for other latitudes and altitudes exceed the scope of this simplified approach. Thus, this method should not be used for altitudes greater than 9000 meters or for values of ϕ_E greater than 45° N or less than 45° S.

Altitude correction for astronomical twilight.- The illumination produced by the sun should be the problem of greatest concern. Based on data from reference 2, the illumination of the sky background which exists at various zenith angles of the sun is shown in figure 4. The times of three twilight conditions at the Greenwich meridian are readily available in the form of tabulations from references 3 and 4. They are as follows: (1) civil twilight, corresponding to a sun's zenith angle of 96°; (2) nautical twilight, corresponding to a sun's zenith angle of 102°; and (3) astronomical twilight, corresponding to a sun's zenith angle of 108°. The third condition, astronomical twilight, was used as a boundary condition for the launch windows. As shown in figure 4, the illumination of the night sky background produced by the sun at astronomical twilight is approximately 6.7×10^{-4} lux, a value which is less than the illumination produced by starlight. Thus, at a zenith angle of 105°, the illumination produced by the sun is still less than that resulting from starlight and the altitude correction for twilight may be omitted where Δz is less than 3°. This corresponds to an altitude of 9000 meters or less.

LAUNCH WINDOWS

In general, the need for darkness conditions by any particular experiment should fall into one of three basic categories. Darkness of the night sky background might be required (1) during the launch operations of the flight, (2) during some data-gathering phase or reentry phase occurring downrange, or (3) during the entire interval from launch to termination of the flight. The geographic location of the particular event is used to determine the local mean time at which maximum darkness conditions will prevail for that location. To be of any practical use, however, these local mean times must be expressed in terms of some standard or clock time, either Greenwich or the local standard time of the launch site. The local standard time must be corrected by a factor of ΔT to account for the elapsed flight time between launch and the arrival of the vehicle at a particular point downrange.

Vehicle launch times are defined as the intervals during which the launching of the vehicle will insure that the occurrence of some particular portion of the flight will coincide with maximum darkness of the sky background. Such times are expressed as plots similar to figure 1. The area enclosed by the four curves is called the launch window.

Conversion to Local Standard Time

The Greenwich mean time GMT at which moonrise, moonset, and the end and beginning of astronomical twilight will occur at a specific location (ϕ_E,λ_E) is determined by adding the equivalent of λ_E expressed in time to the local mean time of these events. Thus,

$$GMT = LMT + \left(\frac{\lambda_E}{15}\right) \tag{5}$$

The times of maximum darkness conditions at some point (ϕ_E,λ_E) in terms of any standard time are as follows:

$$LST = GMT - \left(\frac{\lambda_P}{15}\right) \tag{6}$$

where λ_P is the prime meridian for the standard time zone.

Determination of Launch Windows for Three Example Conditions

As outlined previously, the needs of various experiments will dictate the locations for which darkness conditions are necessary. However, most of the factors likely to be involved in the determination of launch windows for any individual experiment can be illustrated by the following examples. The information necessary for the determination of these example launch windows was given previously in figures 2 and 3. The ground track of a vehicle which will be used as an example is shown in figure 5. It was considered to be launched from NASA Wallops Station along a flight azimuth of 130°. At ΔT = 660 seconds after launch, reentry occurred at Q, a point downrange at latitude 30° N and longitude 65.3° W. Darkness of the night sky background might be required (1) during the launch phase only, (2) 660 seconds after launch when the reentry occurred at Q, or (3) during both launch and reentry. The launch windows which satisfy each of these three conditions are shown in figures 6.

Maximum darkness conditions during launch.- Of the three example conditions, the simplest to determine is the launch window for maximum darkness during the launch phase of the flight. The local mean times of moonrise, moonset, and the end and beginning of astronomical twilight are determined for the coordinates of the launch site and converted to the desired standard times. The correct launch window is obtained by plotting the standard times of these four phenomena against date. The launch window for this condition, in eastern standard time, is represented by the area enclosed by the dashed curves in figure 6.

Maximum darkness conditions downrange.- Other experiments may require darkness conditions at some geographic location and time other than launch – for example, during the reentry or data-gathering portions of the flight. The determination of launch times which insure that this downrange event occurs during periods of maximum darkness is similar to that for the maximum darkness conditions during launch. Times of maximum darkness conditions are determined for the latitude and longitude of this downrange event rather than the launch site, and they are corrected to the desired standard time. But for this case, an additional correction must be made for ΔT, the elapsed time in flight between launch and the downrange event. The local standard times of moonrise, moonset, and the end and beginning of astronomical twilight must be corrected by $-\Delta T$. The launch window is obtained by plotting these corrected times against date. The eastern standard times of these four limiting conditions at Q are corrected by $-\Delta T$ of 11 minutes to obtain the correct launch window, which is represented by the area enclosed by the solid curves in figure 6.

Maximum darkness conditions during entire flight.- For still other experiments, maximum darkness conditions are necessary during the entire interval from launch to termination. The launch window which satisfies these conditions is obtained by treating the problem as a combination of the two previous cases. The launch window insuring maximum darkness conditions at launch is computed as previously described and represented in figure 6 by the dashed curves. A second launch window, insuring maximum darkness conditions at the end point of the flight is then computed and superimposed upon the previous plot. Maximum darkness conditions will prevail during the entire interval of the vehicle flight so long as the vehicle is launched during any time within the enclosed area of both windows, which is represented by the shaded area of figure 6. Maximum darkness conditions would exist at ground level during the entire interval of the ground track shown in figure 5 so long as the vehicle was launched from NASA Wallops Station during the launch window represented by this shaded area of figure 6.

APPLICATION OF METHOD

Frequently, difficulties with wind and weather conditions, with the vehicle, or with the payload may cause delays in the countdown. It is often desirable to know what sacrifices, if any, would be made by exceeding the limits of a given launch window by a few minutes. In the procedure discussed herein, the points which lie within some of the individual windows but are not common to all are effective in determining critical features associated with exceeding the limits of the launch window.

In the launch windows discussed in the preceding section, the points which lie within the areas of one or the other of the windows, which insure maximum darkness conditions at launch or reentry but are not common to both, may be roughly divided into four areas. These four groups are designated by the letters A, B, C, and D in figure 6.

The significances of the launch times represented by points which lie within these four groups are as follows:

A maximum darkness conditions would exist at reentry but launch would take place prior to the end of astronomical twilight at the launch site.

B maximum darkness conditions would exist during launch but reentry would occur after the beginning of astronomical twilight

C maximum darkness conditions would exist during launch but reentry would occur after moonrise

D maximum darkness conditions would exist at reentry but launch would take place prior to moonset

In the example case, the vehicle was assumed to be launched from NASA Wallops Station toward the southeast. Thus, launching the vehicle at some time earlier than the nominal launch window, as represented by points in groups A or D, would be more desirable than an extension of the launch time into area B. No extension of launch time into area C could be tolerated.

For any particular experiment, darkness conditions might be required at one, two, or more locations. Regardless of the number of locations at which darkness conditions are needed, the launch window may be obtained by extending the method described previously. Darkness requirements at N different geographic locations and times during a flight would result in N individual windows. The launch time which would insure maximum darkness conditions at all N locations would be represented by points in common to all N windows.

COMPUTER PROGRAM TO DETERMINE LAUNCH WINDOWS

The use of a computer is a big time-saver where launch windows at several different sites are needed, since the basic information from reference 2 necessary for the computations can be programed once and reused. A program for this purpose was written in FORTRAN IV for use with the Control Data 6600 computer system at Langley Research Center. Inputs required by the program are listed in the appendix and include the times of the various astronomical events at the Greenwich meridian, the longitude of the location at which darkness conditions are required, the prime meridian of the standard time in which launch windows will be expressed, the elapsed flight time from launch to occurrence of the event, and the altitude for which corrections to moonrise and moonset are to be made. No corrections are made for intermediate latitudes.

A listing of the program and the inputs for and printout of data necessary to determine the launch window defined by the solid line in figure 6 are given in the appendix. Input values for latitude and altitude are tested by the program. Those in excess of values for which this program has been defined to be applicable will cause the program to abort.

CONCLUDING REMARKS

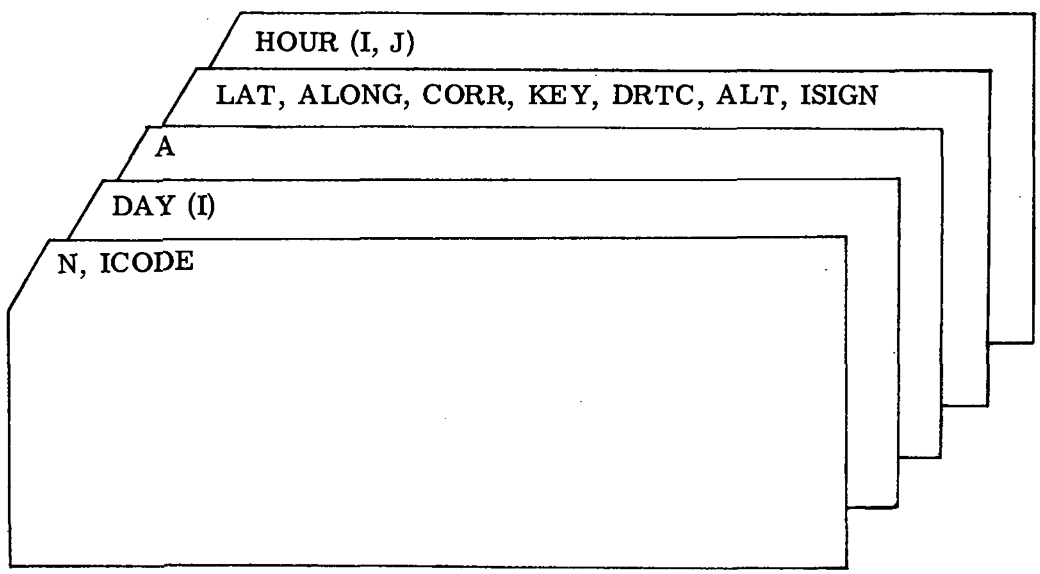
The method described herein has proved useful to many research experiments in determining launch windows which coincide with periods of maximum darkness of the night sky background. During such time intervals, the brightness of the night sky background results from the illumination produced by starlight. For any location between latitudes 60° N and 60° S, these time intervals may be determined to an accuracy of 2 minutes by this method.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., Dec. 31, 1968,
715-02-00-01-23.

APPENDIX

COMPUTER PROGRAM TO DETERMINE VEHICLE LAUNCH WINDOWS

In order to speed the calculations of launch windows, the method described in the text was incorporated into a computer program (A2259), written in FORTRAN IV for use with the Control Data 6600 computer system at the Langley Research Center. A complete listing of the program is given in table I. The inputs required by the program are as follows:



1. N, ICODE
   Format (I4, I2)

   N specifies the time interval in days for the particular case.

   ICODE is used to distinguish whether computations deal with sun or moon. ICODE = 2 signifies twilight conditions; ICODE = 0 signifies moonrise or moonset conditions.

2. DAY (I)
   Format (18I4)

   DAY array provides a 4-digit designation of the date; that is, March 7 is shown as 0307.

3. A
   Format (12A6)

   A array provides a 72 field label available for case identification on printout.

4. LAT, ALONG, CORR, KEY, DRTC, ALT, ISIGN
   Format (I3, 2F6.1, I3, F6.1, F10.1, I2)

   LAT gives the latitude for which moon and twilight conditions are required.

   ALONG gives the longitude for which the times of moon and twilight conditions are required. West longitude is denoted by a plus; east longitude, by a minus.

   CORR is the prime meridian λ_p of the standard time in which launch windows will be expressed. For example, CORR value used to obtain launch windows in eastern standard time would be 75°.

   KEY is used to indicate computations that should be repeated for different latitudes using the same dates in the DAY array. KEY $\neq 0$ causes program to repeat for a second latitude.

   DRTC gives the correction for elapsed flight time from launch to the occurrence of the downrange event, ΔT. The value of DRTC used as input to the program must always be positive.

   ALT denotes the altitude in meters for which moonrise and moonset are to be corrected.

   ISIGN is used to designate whether computations deal with moonrise or moonset. ISIGN = -1 indicates moonrise; ISIGN = 1 indicates moonset.

5. HOUR (I,J)
   Format (36I2)

   HOUR array denotes the local mean time of twilight or moon condition at Greenwich. Information is punched in form given in American Ephemeris and Nautical Almanac (ref. 3), in hours and minutes.

The launch window defined by the solid curves in figure 6 may be determined from information found in figures 2 and 3. This same information in the form of inputs to the computer program is shown in table II. The output which would be obtained from these inputs is shown in table III. A plot of this output results in the launch window defined by the solid curves in figure 6.

Use of input values for altitude in excess of 9000 meters will cause the program to abort and result in a printout similar to the one shown in table IV. Use of input values for latitudes greater than 45° N or less than 45° S when $0 < h \leqq 9000$, will cause the program to abort and result in a printout similar to the one shown in table V.

REFERENCES

1. Gardner, William N.; Brown, Clarence A., Jr.; Henning, Allen B.; Hook, W. Ray; Lundstrom, Reginald R.; and Ramsey, Ira W., Jr.; Description of Vehicle System and Flight Tests of Nine Trailblazer I Reentry Physics Research Vehicles. NASA TN D-2189, 1964.
2. Anon.: Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac. H.M. Nautical Almanac Office, 1961, pp. 398-406.
3. Anon.: The American Ephemeris and Nautical Almanac for the Year 1968. U.S. Nav. Observ., 1966.
4. Anon.: The Air Almanac. U.S. Nav. Observ., May-Aug. 1967.

TABLE I.- LISTING OF COMPUTER PROGRAM

```
      PROGRAM A2259 (INPUT, OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      INTEGER DAY,DATE,HOUR,TIME,DELTAT,RAWT
      DIMENSION MINUTE(365),RAWT(365),A(12)
      DIMENSION DAY(365),DATE(365),HOUR(365,2),TIME(365),DELTAT(365)
C     ICODE SPECIFIES WHETHER MOON OR SUN BEING COMPUTED
C                               ICODE = 2     SUN
C                               ICODE = ZERO MOON
C
C     KEY NOT EQUAL TO ZERO INDICATES CASE TO BE REPEATED USING SAME
C                DATES FOR DIFFERENT LATITUDE
C
C                            ALT = ALTITUDE IN METERS
C                            DRTC = DOWNRANGE TIME CORRECTION IN MINUTES
C          ISIGN =   -1 FOR MOONRISE AND +1 FOR MOONSET
    4 READ(5,100)N,ICODE
  100 FORMAT(I4,I2)
      IF(EOF,5) 55,5
    5 READ(5,101)(DAY(I),I=1,N)
  101 FORMAT(18I4)
      READ(5,103)A
  103 FORMAT(12A6)
  300 READ(5,102)(LAT,ALONG,CORR,KEY,DRTC,ALT,ISIGN)
  102 FORMAT(I3,2F6.1,I3,F6.1,F10.1,I2)
      READ(5,104)((HOUR(I,J),J=1,2),I=1,N)
  104 FORMAT(36I2)
      WRITE(6,200)A
  200 FORMAT(1H1,12A6//)
      ALT=ABS(ALT)
      WRITE(6,203)DRTC,ALT,ISIGN
  203 FORMAT(1H0,23H DOWNRANGE TIME CORR. =,F6.2/13X10HALTITUDE =,F9.1,6
     1X24HSIGN OF ALTITUDE CORR. =,I2)
      WRITE(6,201)LAT,ALONG,CORR
  201 FORMAT(1H03X8HLATITUDE7X9HLONGITUDE5X13HSTANDARD TIME//I9,7XF11.1,
     17XF9.1////2X13HSTANDARD TIME7X4HDATE/2X4HHOUR3X6HMINUTE5X4HMON.1X3
     2HDAY//)
      DO 10 M=1,N
   10 MINUTE(M)=(HOUR(M,1)*60)+HOUR(M,2)
      IF(ICODE.EQ.2) GO TO 6
      CALT=8.*.0321*SQRT(ALT)*FLOAT(ISIGN)
      IF(LAT.GT.60) GO TO 40
      IF (ALT.LT..01) GO TO 7
      IF(ALT.GT.9000.) GO TO 45
      IF(LAT.GT.45) GO TO 46
    7 J=1
      IN=N-2
      DO 90 K=1,IN
      IF(MINUTE(K+1).GT.MINUTE(K)) GO TO 30
      MINUTE(K+1)=MINUTE(K+1)+1440
      DELTAT(K)=FLOAT(MINUTE(K+1)-MINUTE(K))*ALONG/360.
      RAWT(K)=MINUTE(K)+DELTAT(K)+IFIX((ALONG-CORR)*4.-DRTC+CALT)
      MINUTE(K+1)=MINUTE(K+1)-1440
      IF (RAWT(K).GT.0) GO TO 1
      TIME(K)=RAWT(K)+1440
      DATE(K)=DAY(J-1)
      GO TO 3
```

```
    1 IF(RAWT(K).LT.1440) GO TO 2
      TIME(K)=RAWT(K)-1440
      DATE(K)=DAY(J+1)
      GO TO 3
    2 TIME(K)=RAWT(K)
      DATE(K)=DAY(J)
    3 J=J+2
      GO TO 75
   30 DELTAT(K)=FLOAT(MINUTE(K+1)-MINUTE(K))*ALONG/360.
      RAWT(K)=MINUTE(K)+DELTAT(K)+IFIX((ALONG-CORR)*4.-DRTC+CALT)
      IF(RAWT(K).GT.0) GO TO 50
      TIME(K)=RAWT(K)+1440
      DATE(K)=DAY(J-1)
      GO TO 70
   50 IF(RAWT(K).LT.1440) GO TO 60
      TIME(K)=RAWT(K)-1440
      DATE(K)=DAY(J+1)
      GO TO 70
   60 TIME(K)=RAWT(K)
      DATE(K)=DAY(J)
   70 J=J+1
   75 M=0
   80 IF(TIME(K).LT.60) GO TO 90
      M=M+1
      TIME(K)=TIME(K)-60
      GO TO 80
   90 WRITE(6,202)M,TIME(K),DATE(K)
  202 FORMAT(I5,4X,I4,8X,I5)
      IF(KEY.EQ.0) GO TO 4
      GO TO 300
    6 IF(LAT.GT.60) GO TO 40
      IF(ALT.GT.9000.) GO TO 45
      DO 20 K=1,N
      DATE(K)=DAY(K)
      RAWT(K)=MINUTE(K)+DELTAT(K)+IFIX((ALONG-CORR)*4.-DRTC)
      M=0
   25 IF(RAWT(K).LT.60) GO TO 20
      M=M+1
      RAWT(K)=RAWT(K)-60
      GO TO 25
   20 WRITE(6,202) M,RAWT(K),DATE(K)
      GO TO 8
   40 WRITE(6,204)
  204 FORMAT(1H05X27HLATITUDE EXCEEDS 60 DEGREES)
      GO TO 8
   45 WRITE(6,205)
  205 FORMAT(1H05X28HALTITUDE EXCEEDS 9000 METERS)
      GO TO 8
   46 WRITE(6,206)
  206 FORMAT(1H05X37HLATITUDE EXCEEDS 45 FOR ALTITUDE CASE)
    8 IF(KEY.EQ.0) GO TO 4
      GO TO 300
   55 CONTINUE
      END
```

TABLE II.- COMPUTER-PROGRAM INPUTS FOR SAMPLE CASE

```
  16
0114011501160117011801190120012101220123012401250126012701280129
   MOONRISE BEGINNING JAN. 14,1968
 30  65.3  75.0     11.0
16101711181419192022212522282332003701450255040405100608065 8


  18
01270128012901300131020102020203020402050206020702080209021002110212 0213
   MOONSET BEGINNING JAN. 27,1968
 30  65.3  75.0     11.0
151016171724183019322030212622212315001001060203030103580451054006 23


   6 2
010501100115012001250130
 BEGINNING OF ASTRONOMICAL TWILIGHT - BEGINNING JAN. 5, 1968
 30  65.3  75.0     11.0
053105320533053205320531


   6 2
010501100115012001250130
       END OF ASTRONOMICAL TWILIGHT - BEGINNING JAN. 5, 1968
 30  65.3  75.0     11.0
183918431846184918531857
```

TABLE III.- OUTPUT OF COMPUTER PROGRAM FOR SAMPLE CASE

```
   MOONRISE BEGINNING JAN. 14,1968


DOWNRANGE TIME CORR. = 11.00
               ALTITUDE =        0.0     SIGN OF ALTITUDE CORR. =-0

   LATITUDE         LONGITUDE        STANDARD TIME

        30              65.3              75.0



STANDARD TIME          DATE
HOUR    MINUTE       MON. DAY


   15       32            114
   16       33            115
   17       36            116
   18       41            117
   19       44            118
   20       47            119
   21       50            120
   22       54            121
   24        0            122
    1        8            124
    2       18            125
    3       26            126
    4       31            127
    5       28            128
```

TABLE III.- OUTPUT OF COMPUTER PROGRAM FOR SAMPLE CASE – Continued

MOONSET BEGINNING JAN. 27,1968

DOWNRANGE TIME CORR. = 11.00

ALTITUDE = 0.0 SIGN OF ALTITUDE CORR. =-0

LATITUDE	LONGITUDE	STANDARD TIME
30	65.3	75.0

STANDARD TIME HOUR	MINUTE	DATE MON. DAY
14	33	127
15	40	128
16	46	129
17	52	130
18	53	131
19	51	201
20	46	202
21	41	203
22	35	204
23	31	205
0	27	207
1	24	208
2	22	209
3	18	210
4	10	211
4	58	212

TABLE III.- OUTPUT OF COMPUTER PROGRAM FOR SAMPLE CASE – Continued

```
BEGINNING OF ASTRONOMICAL TWILIGHT - BEGINNING JAN. 5, 1968

DOWNRANGE TIME CORR. = 11.00
               ALTITUDE =        0.0      SIGN OF ALTITUDE CORR. =-0

   LATITUDE         LONGITUDE         STANDARD TIME

     30                  65.3                75.0


STANDARD TIME        DATE
HOUR   MINUTE       MON. DAY

   4       54         105
   4       55         110
   4       55         115
   4       54         120
   4       53         125
   4       52         130
```

TABLE III.- OUTPUT OF COMPUTER PROGRAM FOR SAMPLE CASE – Concluded

```
        END OF ASTRONOMICAL TWILIGHT - BEGINNING JAN. 5, 1968

DOWNRANGE TIME CORR. = 11.00
            ALTITUDE =         0.0       SIGN OF ALTITUDE CORR. =-0

  LATITUDE          LONGITUDE        STANDARD TIME

     30                65.3               75.0


STANDARD TIME         DATE
HOUR   MINUTE       MON. DAY

  18      2             105
  18      6             110
  18      8             115
  18     11             120
  18     14             125
  18     18             130
```

TABLE IV.- SAMPLE OF OUTPUT OBTAINED IF INPUT VALUE FOR ALTITUDE EXCEEDS 9000 METERS

```
   MOONRISE BEGINNING JAN. 14,1968



DOWNRANGE TIME CORR. = 11.00
                ALTITUDE =  10000.0       SIGN OF ALTITUDE CORR. =-1

  LATITUDE          LONGITUDE          STANDARD TIME

     30                 65.3                 75.0



STANDARD TIME         DATE
HOUR   MINUTE       MON. DAY



      ALTITUDE EXCEEDS 9000 METERS
```

TABLE V.- SAMPLE OF OUTPUT OBTAINED IF INPUT VALUE FOR LATITUDE EXCEEDS 45° FOR CASE WHERE ALTITUDE CORRECTION IS TO BE APPLIED

```
    MOONRISE BEGINNING JAN. 14,1968



  DOWNRANGE TIME CORR. = 11.00
                   ALTITUDE =    7000.0        SIGN OF ALTITUDE CORR. =-1

      LATITUDE             LONGITUDE        STANDARD TIME

         50                   65.3                 75.0



  STANDARD TIME             DATE
  HOUR    MINUTE         MON. DAY



          LATITUDE EXCEEDS 45 FOR ALTITUDE CASE
```

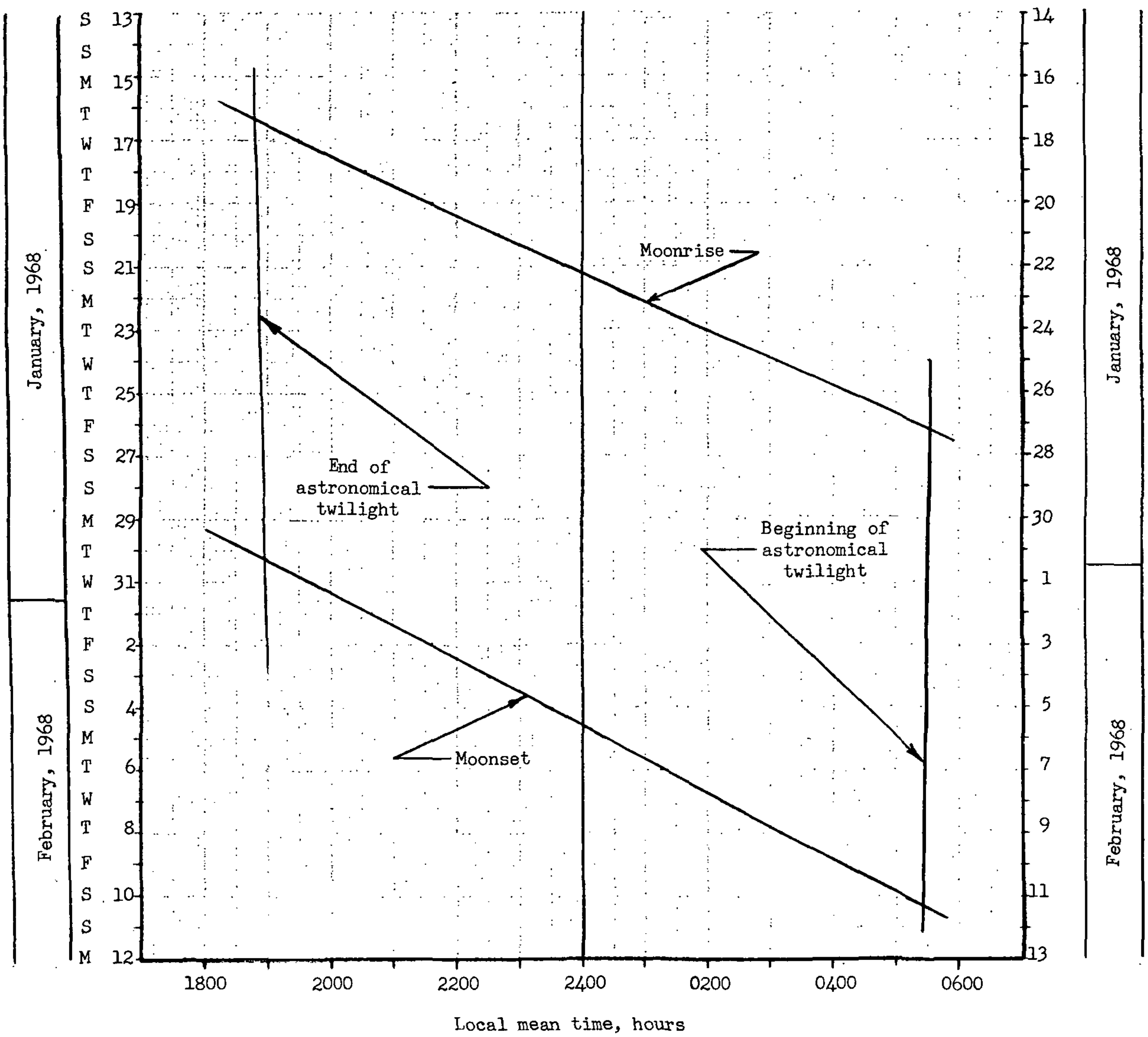


Figure 1.- Time interval during January-February 1968, when the illumination of the sky background at latitude 30° N and longitude 65° W will result only from starlight.

SUNSET AND TWILIGHT, 1968

LOCAL MEAN TIME OF SUNSET AND END OF ASTRONOMICAL TWILIGHT—MERIDIAN OF GREENWICH

SUNSET (UPPER LIMB)

Date \ Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Jan. 0	18 07	17 49	17 31	17 10	16 58	16 44	16 27	16 07	15 57	15 46	15 34	15 20	15 03
5	18 09	17 52	17 34	17 14	17 02	16 48	16 32	16 12	16 03	15 52	15 40	15 26	15 10
10	18 11	17 55	17 37	17 18	17 06	16 53	16 37	16 18	16 09	15 59	15 48	15 35	15 19
15	18 13	17 57	17 41	17 22	17 11	16 58	16 43	16 25	16 17	16 07	15 56	15 44	15 30
20	18 15	18 00	17 44	17 26	17 16	17 04	16 50	16 33	16 25	16 16	16 06	15 55	15 41
25	18 16	18 02	17 47	17 30	17 21	17 10	16 57	16 41	16 34	16 25	16 16	16 06	15 54
30	18 17	18 04	17 50	17 35	17 26	17 16	17 04	16 49	16 42	16 35	16 27	16 17	16 07
Feb. 4	18 17	18 06	17 53	17 39	17 31	17 22	17 11	16 58	16 52	16 45	16 38	16 29	16 20
9	18 18	18 07	17 56	17 43	17 36	17 28	17 18	17 06	17 01	16 55	16 49	16 41	16 33
14	18 18	18 08	17 58	17 47	17 41	17 34	17 25	17 15	17 10	17 05	17 00	16 53	16 46
19	18 17	18 09	18 01	17 51	17 46	17 39	17 32	17 24	17 20	17 15	17 11	17 05	16 59
24	18 17	18 10	18 03	17 55	17 50	17 45	17 39	17 32	17 29	17 25	17 21	17 17	17 12
29	18 16	18 11	18 05	17 58	17 55	17 51	17 46	17 41	17 38	17 35	17 32	17 29	17 25
Mar. 5	18 15	18 11	18 07	18 02	17 59	17 56	17 53	17 49	17 47	17 45	17 43	17 40	17 38
10	18 14	18 11	18 08	18 05	18 04	18 02	17 59	17 57	17 56	17 54	17 53	17 52	17 50
15	18 12	18 11	18 10	18 08	18 08	18 07	18 06	18 05	18 05	18 04	18 04	18 03	18 02
20	18 11	18 11	18 11	18 11	18 12	18 12	18 12	18 13	18 13	18 13	18 14	18 14	18 15
25	18 09	18 11	18 12	18 15	18 16	18 17	18 19	18 21	18 22	18 23	18 24	18 25	18 27
30	18 08	18 11	18 14	18 18	18 20	18 22	18 25	18 29	18 30	18 32	18 34	18 37	18 39
Apr. 4	18 06	18 11	18 15	18 21	18 24	18 27	18 32	18 37	18 39	18 42	18 44	18 48	18 51

END OF ASTRONOMICAL TWILIGHT

Date \ Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Jan. 0	19 22	19 04	18 50	18 35	18 29	18 21	18 13	18 06	18 02	17 59	17 56	17 52	17 48
5	19 24	19 07	18 52	18 39	18 32	18 25	18 18	18 10	18 08	18 04	18 00	17 56	17 53
10	19 25	19 10	18 55	18 43	18 36	18 29	18 22	18 15	18 12	18 10	18 07	18 03	17 59
15	19 27	19 11	18 58	18 46	18 40	18 34	18 27	18 21	18 19	18 16	18 13	18 10	18 07
20	19 28	19 14	19 01	18 49	18 44	18 39	18 33	18 28	18 26	18 23	18 21	18 19	18 15
25	19 29	19 15	19 03	18 53	18 49	18 44	18 39	18 35	18 33	18 30	18 29	18 27	18 25
30	19 29	19 17	19 06	18 57	18 53	18 49	18 45	18 41	18 40	18 39	18 38	18 36	18 35
Feb. 4	19 29	19 18	19 08	19 01	18 57	18 55	18 52	18 49	18 48	18 47	18 47	18 46	18 46
9	19 29	19 19	19 11	19 04	19 02	19 00	18 58	18 56	18 56	18 56	18 56	18 56	18 56
14	19 29	19 19	19 12	19 08	19 06	19 05	19 04	19 04	19 04	19 05	19 06	19 06	19 08
19	19 27	19 20	19 15	19 11	19 11	19 10	19 10	19 12	19 13	19 14	19 16	19 17	19 19
24	19 27	19 20	19 17	19 15	19 14	19 15	19 17	19 20	19 22	19 23	19 25	19 28	19 31
29	19 25	19 21	19 18	19 18	19 19	19 21	19 24	19 29	19 30	19 33	19 36	19 40	19 44
Mar. 5	19 24	19 21	19 20	19 21	19 23	19 26	19 31	19 37	19 40	19 43	19 47	19 52	19 58
10	19 23	19 21	19 21	19 24	19 28	19 32	19 37	19 45	19 49	19 53	19 58	20 05	20 11
15	19 21	19 21	19 23	19 28	19 32	19 37	19 44	19 54	19 59	20 04	20 10	20 17	20 25
20	19 20	19 21	19 24	19 31	19 37	19 43	19 51	20 03	20 08	20 15	20 23	20 31	20 41
25	19 18	19 21	19 26	19 35	19 41	19 49	19 59	20 12	20 19	20 27	20 35	20 45	20 58
30	19 17	19 21	19 28	19 39	19 46	19 55	20 06	20 23	20 30	20 39	20 49	21 02	21 16
Apr. 4	19 15	19 21	19 29	19 42	19 51	20 01	20 15	20 33	20 42	20 52	21 04	21 19	21 36

SOUTHERN LATITUDES (July to October)

For dates on first line *below*, enter tables above with dates on second line, and apply the correction (in minutes) given on the third line.

Date	July 1	6	11	16	22	27	Aug. 1	Aug. 7	12	17	22	28	Sept. 2	Sept. 7	12	17	22	27	Oct. 3	Oct. 8
Use	Jan. 0	5	10	15	20	25	Jan. 30	Feb. 4	9	14	19	24	Feb. 29	Mar. 5	10	15	20	25	Mar. 30	Apr. 4
Apply	+1	0	−2	−3	−4	−6	−7	−8	−9	−10	−11	−12	−13	−14	−14	−14	−15	−15	−15	−15

(a) The GMT of sunset and end of astronomical twilight.

Figure 2.- Sample pages from the American Ephemeris and Nautical Almanac (ref. 3).

SUNRISE AND TWILIGHT, 1968

LOCAL MEAN TIME OF SUNRISE AND BEGINNING OF ASTRONOMICAL TWILIGHT—MERIDIAN OF GREENWICH

SUNRISE (UPPER LIMB)

Date \ Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Jan. 0	5 59	6 16	6 35	6 55	7 08	7 22	7 38	7 59	8 08	8 19	8 32	8 46	9 03
5	6 01	6 18	6 36	6 57	7 09	7 22	7 38	7 58	8 08	8 18	8 30	8 44	9 01
10	6 04	6 20	6 37	6 57	7 09	7 22	7 37	7 56	8 05	8 16	8 27	8 40	8 56
15	6 06	6 21	6 38	6 57	7 08	7 20	7 35	7 53	8 02	8 12	8 22	8 35	8 49
20	6 07	6 22	6 38	6 56	7 06	7 18	7 32	7 49	7 57	8 06	8 16	8 28	8 41
25	6 09	6 23	6 37	6 54	7 04	7 15	7 28	7 44	7 51	8 00	8 09	8 19	8 31
30	6 10	6 23	6 37	6 52	7 01	7 11	7 23	7 38	7 45	7 52	8 00	8 10	8 21
Feb. 4	6 10	6 22	6 35	6 49	6 57	7 07	7 18	7 31	7 37	7 44	7 51	7 59	8 09
9	6 11	6 21	6 33	6 46	6 53	7 01	7 11	7 23	7 28	7 34	7 41	7 48	7 57
14	6 11	6 20	6 30	6 42	6 48	6 56	7 04	7 14	7 19	7 24	7 30	7 36	7 44
19	6 11	6 19	6 27	6 37	6 43	6 49	6 56	7 05	7 09	7 13	7 18	7 24	7 30
24	6 10	6 17	6 24	6 32	6 37	6 42	6 48	6 56	6 59	7 02	7 06	7 11	7 16
29	6 09	6 15	6 21	6 27	6 31	6 35	6 40	6 46	6 48	6 51	6 54	6 58	7 01
Mar. 5	6 08	6 12	6 17	6 22	6 24	6 27	6 31	6 35	6 37	6 39	6 41	6 44	6 47
10	6 07	6 10	6 13	6 16	6 18	6 20	6 22	6 25	6 26	6 27	6 28	6 30	6 32
15	6 06	6 07	6 09	6 10	6 11	6 12	6 13	6 14	6 14	6 15	6 16	6 16	6 17
20	6 04	6 04	6 04	6 04	6 04	6 04	6 03	6 03	6 03	6 03	6 02	6 02	6 02
25	6 03	6 01	6 00	5 58	5 57	5 56	5 54	5 52	5 51	5 50	5 49	5 48	5 47
30	6 01	5 58	5 55	5 52	5 50	5 47	5 45	5 41	5 40	5 38	5 36	5 34	5 31
Apr. 4	6 00	5 56	5 51	5 46	5 43	5 39	5 35	5 30	5 28	5 26	5 23	5 20	5 16

BEGINNING OF ASTRONOMICAL TWILIGHT

Date \ Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Jan. 0	4 44	5 01	5 15	5 30	5 36	5 43	5 51	6 00	6 02	6 06	6 10	6 14	6 18
5	4 46	5 03	5 18	5 31	5 38	5 45	5 52	6 00	6 03	6 07	6 10	6 14	6 18
10	4 49	5 05	5 19	5 32	5 39	5 45	5 53	5 59	6 02	6 05	6 09	6 12	6 16
15	4 51	5 07	5 20	5 33	5 39	5 45	5 51	5 58	6 01	6 04	6 06	6 09	6 13
20	4 54	5 08	5 21	5 32	5 38	5 44	5 49	5 55	5 57	5 59	6 03	6 05	6 08
25	4 55	5 10	5 21	5 32	5 37	5 42	5 46	5 51	5 54	5 55	5 58	5 59	6 01
30	4 58	5 10	5 21	5 31	5 35	5 39	5 42	5 46	5 48	5 50	5 51	5 53	5 54
Feb. 4	4 58	5 10	5 20	5 28	5 31	5 35	5 38	5 41	5 41	5 43	5 44	5 45	5 46
9	5 00	5 10	5 18	5 25	5 28	5 31	5 32	5 34	5 35	5 35	5 35	5 36	5 35
14	5 00	5 10	5 17	5 22	5 24	5 26	5 27	5 27	5 27	5 26	5 26	5 26	5 24
19	5 01	5 08	5 14	5 18	5 19	5 19	5 20	5 19	5 18	5 17	5 16	5 14	5 13
24	5 00	5 07	5 11	5 13	5 14	5 14	5 12	5 09	5 08	5 07	5 05	5 02	5 00
29	5 00	5 05	5 08	5 08	5 08	5 06	5 04	5 00	4 58	4 55	4 53	4 49	4 45
Mar. 5	4 59	5 03	5 05	5 04	5 02	4 59	4 55	4 49	4 46	4 44	4 40	4 36	4 30
10	4 58	5 00	5 01	4 58	4 55	4 51	4 46	4 39	4 35	4 31	4 26	4 21	4 14
15	4 57	4 58	4 56	4 51	4 48	4 43	4 37	4 27	4 23	4 17	4 12	4 05	3 57
20	4 56	4 55	4 52	4 45	4 40	4 34	4 26	4 15	4 10	4 04	3 57	3 49	3 39
25	4 54	4 52	4 48	4 39	4 33	4 26	4 16	4 03	3 57	3 50	3 41	3 31	3 20
30	4 53	4 49	4 42	4 32	4 25	4 17	4 05	3 50	3 43	3 34	3 25	3 13	2 58
Apr. 4	4 51	4 46	4 38	4 26	4 17	4 08	3 54	3 36	3 28	3 18	3 06	2 53	2 36

SOUTHERN LATITUDES (July to October)

For dates on first line *below*, enter tables above with dates on second line, and apply the correction (in minutes) given on the third line.

Date	July 1	6	11	16	22	27	Aug. 1	Aug. 7	12	17	22	28	Sept. 2	Sept. 7	12	17	22	27	Oct. 3	Oct. 8
Use	Jan. 0	5	10	15	20	25	Jan. 30	Feb. 4	9	14	19	24	Feb. 29	Mar. 5	10	15	20	25	Mar. 30	Apr. 4
Apply	+1	0	−2	−3	−4	−6	−7	−8	−9	−10	−11	−12	−13	−14	−14	−14	−15	−15	−15	−15

(b) The GMT of sunrise and beginning of astronomical twilight.

Figure 2.- Concluded.

MOONRISE, NORTHERN LATITUDES, 1968

LOCAL MEAN TIME OF MOONRISE (UPPER LIMB)
MERIDIAN OF GREENWICH

Date	Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Jan.	0	6 11	6 34	6 58	7 26	7 42	8 01	8 24	8 54	9 09	9 26	9 47	10 12	10 47
	1	7 13	7 34	7 56	8 22	8 36	8 53	9 14	9 40	9 53	10 07	10 23	10 43	11 08
	2	8 11	8 28	8 47	9 08	9 20	9 34	9 51	10 11	10 21	10 32	10 44	10 59	11 15
	3	9 02	9 16	9 30	9 46	9 55	10 06	10 19	10 34	10 41	10 48	10 57	11 07	11 18
	4	9 49	9 58	10 08	10 19	10 25	10 32	10 41	10 50	10 55	11 00	11 06	11 12	11 19
	5	10 32	10 37	10 42	10 48	10 51	10 55	10 59	11 04	11 06	11 09	11 12	11 15	11 18
	6	11 13	11 13	11 14	11 14	11 15	11 15	11 16	11 16	11 16	11 17	11 17	11 17	11 18
	7	11 53	11 49	11 45	11 41	11 38	11 35	11 32	11 28	11 26	11 24	11 22	11 19	11 17
	8	12 33	12 25	12 17	12 07	12 02	11 56	11 48	11 40	11 36	11 32	11 27	11 22	11 16
	9	13 14	13 02	12 50	12 36	12 27	12 18	12 07	11 54	11 48	11 41	11 34	11 26	11 16
	10	13 58	13 42	13 26	13 07	12 56	12 44	12 29	12 11	12 03	11 54	11 43	11 31	11 18
	11	14 45	14 26	14 06	13 43	13 30	13 15	12 56	12 34	12 23	12 11	11 57	11 41	11 21
	12	15 35	15 14	14 51	14 25	14 10	13 52	13 31	13 04	12 51	12 36	12 19	11 58	11 31
	13	16 28	16 06	15 42	15 14	14 58	14 39	14 16	13 46	13 31	13 15	12 54	12 29	11 55
	14	17 23	17 01	16 37	16 10	15 53	15 34	15 11	14 42	14 27	14 10	13 50	13 24	12 49
	15	18 18	17 58	17 36	17 11	16 55	16 38	16 17	15 50	15 37	15 22	15 04	14 43	14 15
	16	19 12	18 55	18 36	18 14	18 01	17 47	17 29	17 07	16 57	16 45	16 31	16 15	15 56
	17	20 03	19 50	19 35	19 19	19 09	18 58	18 44	18 28	18 21	18 12	18 02	17 52	17 39
	18	20 52	20 43	20 33	20 22	20 16	20 09	20 00	19 50	19 45	19 39	19 33	19 27	19 19
	19	21 39	21 35	21 31	21 25	21 22	21 19	21 15	21 10	21 08	21 05	21 03	21 00	20 56
	20	22 26	22 26	22 27	22 28	22 29	22 29	22 30	22 31	22 31	22 31	22 32	22 32	22 33
	21	23 13	23 19	23 25	23 32	23 36	23 40	23 46	23 52	23 55	23 58	.. ..	.. ..	.. ..
	22	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	0 02	0 06	0 11
	23	0 02	0 13	0 24	0 37	0 45	0 53	1 03	1 16	1 22	1 28	1 35	1 43	1 53
	24	0 55	1 10	1 26	1 45	1 56	2 09	2 24	2 42	2 51	3 01	3 12	3 25	3 41
	25	1 51	2 10	2 31	2 55	3 09	3 25	3 45	4 09	4 21	4 35	4 51	5 10	5 34
	26	2 52	3 14	3 37	4 04	4 20	4 39	5 02	5 31	5 46	6 03	6 23	6 48	7 23
	27	3 55	4 17	4 42	5 10	5 27	5 46	6 10	6 41	6 56	7 14	7 35	8 02	8 41
	28	4 57	5 18	5 42	6 08	6 24	6 43	7 05	7 33	7 47	8 02	8 21	8 44	9 13
	29	5 56	6 15	6 35	6 58	7 12	7 28	7 46	8 09	8 20	8 33	8 47	9 04	9 24
	30	6 50	7 05	7 21	7 40	7 51	8 03	8 17	8 35	8 43	8 52	9 03	9 14	9 28
	31	7 39	7 50	8 02	8 15	8 23	8 32	8 42	8 54	9 00	9 06	9 13	9 20	9 29
Feb.	1	8 24	8 31	8 38	8 46	8 50	8 56	9 02	9 09	9 12	9 16	9 20	9 24	9 29
	2	9 07	9 09	9 11	9 14	9 15	9 17	9 19	9 21	9 23	9 24	9 25	9 26	9 28
	3	9 47	9 45	9 43	9 40	9 39	9 37	9 35	9 33	9 32	9 31	9 30	9 29	9 27
	4	10 28	10 21	10 14	10 07	10 03	9 58	9 52	9 45	9 42	9 39	9 35	9 31	9 26
	5	11 09	10 58	10 47	10 35	10 27	10 19	10 10	9 58	9 53	9 47	9 41	9 34	9 26
	6	11 51	11 37	11 22	11 05	10 55	10 43	10 30	10 14	10 07	9 58	9 49	9 38	9 26
	7	12 37	12 19	12 00	11 39	11 26	11 12	10 55	10 34	10 24	10 13	10 00	9 46	9 28
	8	13 25	13 05	12 43	12 18	12 03	11 46	11 26	11 00	10 48	10 34	10 18	9 59	9 34
	9	14 17	13 55	13 31	13 04	12 47	12 29	12 06	11 37	11 23	11 06	10 47	10 22	9 50
	10	15 11	14 49	14 24	13 56	13 40	13 20	12 57	12 26	12 11	11 54	11 33	11 06	10 29
	11	16 06	15 45	15 22	14 55	14 39	14 21	13 59	13 30	13 16	13 00	12 40	12 16	11 44
	12	17 01	16 42	16 22	15 58	15 45	15 28	15 09	14 45	14 33	14 20	14 04	13 46	13 23
	13	17 54	17 39	17 23	17 04	16 53	16 40	16 25	16 06	15 57	15 48	15 36	15 23	15 08
	14	18 45	18 34	18 23	18 09	18 02	17 53	17 42	17 30	17 24	17 17	17 10	17 01	16 52
	15	19 34	19 28	19 22	19 14	19 10	19 05	19 00	18 53	18 50	18 46	18 42	18 38	18 33
	16	20 22	20 21	20 20	20 19	20 18	20 17	20 17	20 16	20 15	20 15	20 14	20 14	20 13

(a) The GMT of moonrise.

Figure 3.- Sample pages from the American Ephemeris and Nautical Almanac (ref. 3).

MOONSET, NORTHERN LATITUDES, 1968

LOCAL MEAN TIME OF MOONSET (UPPER LIMB)
MERIDIAN OF GREENWICH

Date	Lat.	0°	+10°	+20°	+30°	+35°	+40°	+45°	+50°	+52°	+54°	+56°	+58°	+60°
		h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m	h m
Jan.	0	18 41	18 19	17 56	17 28	17 13	16 54	16 31	16 01	15 47	15 30	15 10	14 45	14 10
	1	19 41	19 22	19 01	18 37	18 23	18 07	17 47	17 22	17 10	16 56	16 40	16 20	15 56
	2	20 36	20 20	20 04	19 44	19 33	19 20	19 04	18 45	18 36	18 26	18 14	18 00	17 44
	3	21 25	21 14	21 02	20 48	20 40	20 30	20 19	20 06	19 59	19 52	19 45	19 36	19 25
	4	22 10	22 03	21 56	21 47	21 42	21 36	21 30	21 22	21 18	21 14	21 09	21 04	20 59
	5	22 52	22 49	22 47	22 43	22 42	22 39	22 37	22 34	22 33	22 31	22 29	22 28	22 25
	6	23 32	23 34	23 36	23 38	23 39	23 40	23 42	23 44	23 45	23 45	23 46	23 48	23 49
	7	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..
	8	0 12	0 18	0 24	0 31	0 35	0 40	0 46	0 52	0 55	0 59	1 03	1 07	1 11
	9	0 52	1 02	1 13	1 25	1 32	1 40	1 50	2 01	2 07	2 13	2 19	2 27	2 35
	10	1 35	1 49	2 03	2 20	2 30	2 42	2 55	3 12	3 19	3 28	3 38	3 49	4 02
	11	2 20	2 37	2 56	3 17	3 30	3 44	4 02	4 23	4 33	4 45	4 58	5 14	5 33
	12	3 09	3 29	3 50	4 15	4 30	4 47	5 08	5 34	5 47	6 01	6 18	6 39	7 05
	13	4 00	4 22	4 46	5 13	5 29	5 48	6 11	6 40	6 55	7 12	7 32	7 57	8 31
	14	4 55	5 17	5 41	6 09	6 25	6 45	7 08	7 38	7 52	8 10	8 30	8 56	9 31
	15	5 50	6 11	6 34	7 01	7 16	7 34	7 56	8 23	8 37	8 52	9 10	9 32	10 00
	16	6 44	7 03	7 24	7 47	8 00	8 16	8 35	8 58	9 08	9 21	9 35	9 52	10 11
	17	7 37	7 52	8 09	8 28	8 38	8 51	9 05	9 23	9 31	9 41	9 51	10 03	10 16
	18	8 27	8 38	8 50	9 04	9 11	9 20	9 30	9 43	9 48	9 55	10 02	10 09	10 18
	19	9 15	9 21	9 28	9 36	9 41	9 46	9 52	9 59	10 02	10 06	10 09	10 14	10 18
	20	10 01	10 03	10 05	10 07	10 08	10 10	10 11	10 13	10 14	10 15	10 16	10 17	10 18
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	22	11 36	11 28	11 20	11 10	11 04	10 58	10 51	10 42	10 38	10 34	10 29	10 24	10 18
	23	12 27	12 14	12 00	11 45	11 36	11 26	11 14	11 00	10 53	10 46	10 38	10 29	10 18
	24	13 21	13 04	12 46	12 25	12 13	11 59	11 43	11 23	11 13	11 03	10 51	10 37	10 21
	25	14 20	13 59	13 38	13 12	12 57	12 40	12 20	11 54	11 42	11 28	11 11	10 52	10 27
	26	15 22	14 59	14 35	14 07	13 51	13 32	13 08	12 39	12 24	12 07	11 47	11 21	10 46
	27	16 25	16 02	15 38	15 10	14 53	14 34	14 10	13 40	13 25	13 07	12 46	12 19	11 40
	28	17 25	17 05	16 43	16 17	16 02	15 44	15 22	14 55	14 42	14 26	14 08	13 46	13 16
	29	18 22	18 05	17 46	17 24	17 12	16 57	16 39	16 17	16 07	15 55	15 41	15 25	15 06
	30	19 14	19 01	18 46	18 30	18 20	18 09	17 56	17 40	17 32	17 24	17 14	17 03	16 51
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Feb.	1	20 45	20 40	20 36	20 30	20 27	20 23	20 19	20 14	20 12	20 09	20 06	20 03	19 59
	2	21 26	21 26	21 26	21 26	21 26	21 26	21 26	21 26	21 26	21 26	21 26	21 26	21 26
	3	22 07	22 11	22 15	22 21	22 24	22 27	22 31	22 36	22 38	22 41	22 43	22 46	22 50
	4	22 47	22 56	23 05	23 15	23 21	23 28	23 36	23 46	23 50	23 55	.. ..	.. ..	.. ..
	5	23 29	23 41	23 55	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	0 00	0 07	0 14
	6	.. ..	.. ..	.. ..	0 10	0 19	0 29	0 41	0 56	1 03	1 10	1 19	1 29	1 40
	7	0 13	0 29	0 46	1 06	1 18	1 31	1 47	2 07	2 16	2 27	2 39	2 53	3 10
	8	1 00	1 19	1 39	2 03	2 17	2 34	2 53	3 18	3 30	3 44	3 59	4 18	4 42
	9	1 50	2 11	2 34	3 01	3 17	3 35	3 58	4 26	4 40	4 57	5 16	5 40	6 12
	10	2 43	3 05	3 30	3 58	4 14	4 34	4 57	5 27	5 42	6 00	6 21	6 48	7 25
	11	3 38	4 00	4 24	4 51	5 07	5 26	5 49	6 18	6 32	6 48	7 08	7 32	8 05
	12	4 33	4 53	5 15	5 40	5 54	6 11	6 31	6 56	7 08	7 22	7 38	7 57	8 20
	13	5 27	5 44	6 02	6 23	6 35	6 49	7 05	7 25	7 35	7 45	7 57	8 11	8 27
	14	6 19	6 32	6 46	7 01	7 10	7 21	7 33	7 47	7 54	8 01	8 09	8 19	8 29
	15	7 09	7 17	7 26	7 36	7 42	7 48	7 56	8 04	8 09	8 13	8 18	8 24	8 30
	16	7 57	8 00	8 04	8 08	8 10	8 13	8 16	8 20	8 21	8 23	8 25	8 27	8 29

(b) The GMT of moonset.

Figure 3.- Concluded.

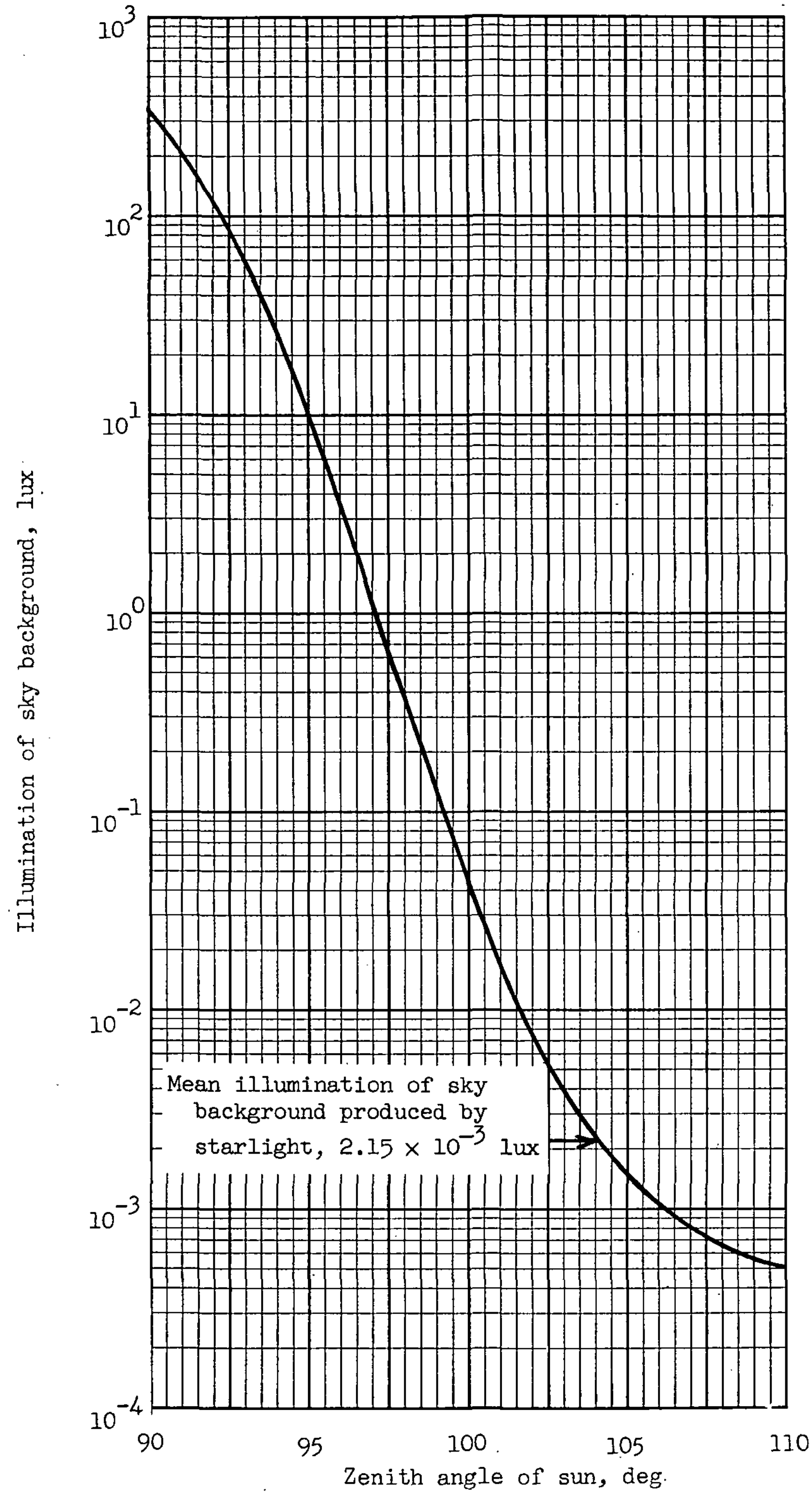

Figure 4.- Illumination of sky background as a function of the zenith angle of the sun.

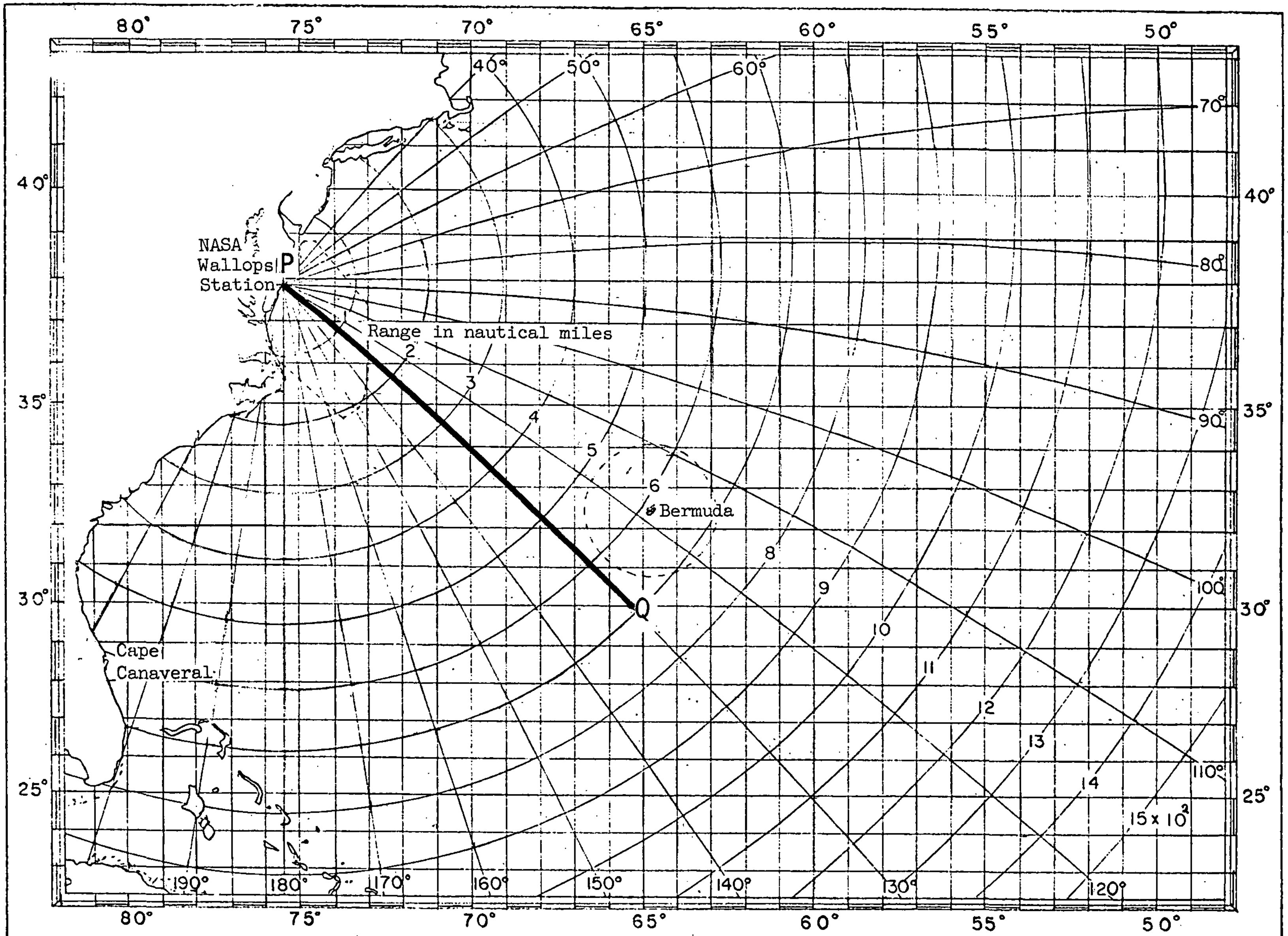

Figure 5.- Ground track of vehicle launched from NASA Wallops Station along a 130° azimuth.

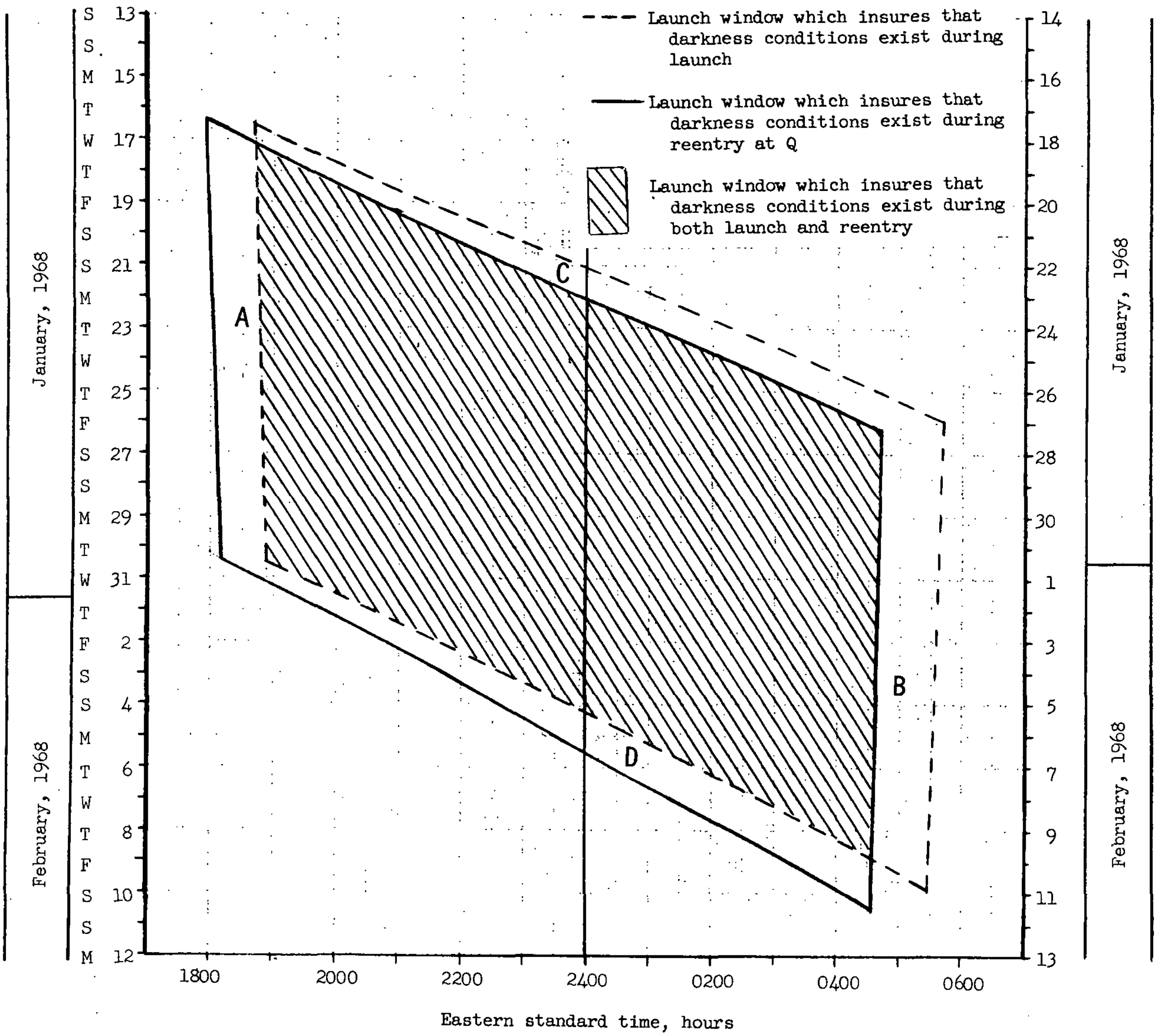

Figure 6.- Launch window which insures that maximum darkness conditions will exist during both launch and 660 seconds after launch when reentry occurs at Q.

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