SAVE

From PU, Petrone
Memo 22 Dec 86
PG-C-0716-86

APPENDIX A

SOLAR/LUNAR EFFECTS SUBROUTINE

```
*****************************************************
*                                                   *
*  All portions of this appendix are Unclassified.  *
*                                                   *
*****************************************************
```

Based on
Julian 2000:000.5

A.1 CHECKOUT OF TIME

Time is entered in the subroutine in terms of a Julian date. In order to convince ourselves that we could do this correctly, we obtained the solar/lunar positions for an arbitrary date and time from "The Nautical Almanac" (see Figure A-1), and compared them to the subroutine's output.

The time was:

ALMANAC: 22 November 1986 : 12:00:00 UT

SUBROUTINE: Julian Date = -5114.5
Day = 326
UTH = 12

The position was entered as:

LAT = 0 ; LON = 0

and the computed vectors in UP, EAST, NORTH were:

$$\text{SUN} = \begin{bmatrix} 1.38465722202 \; 10^{11} \\ -8.41132285467 \; 10^{9} \\ -5.08431288119 \; 10^{10} \end{bmatrix} \text{ft}$$

$$\text{MOON} = \begin{bmatrix} 1.39266021515 \; 10^{8} \\ -3.41443987035 \; 10^{8} \\ 1.62445237254 \; 10^{8} \end{bmatrix} \text{ft}$$

THE NAUTICAL ALMANAC

FOR THE YEAR

1986

1986 NOVEMBER 22 (SAT.)

G.M.T. (UT) d	h	SUN G.H.A. ° ′	SUN Dec. ° ′	MOON G.H.A. ° ′	MOON v ′	MOON Dec. ° ′	MOON d ′	MOON H.P. ′
22	00	183 30.8	S20 01.3	298 04.2	11.5	N25 16.9	06.8	54.3
	01	198 30.6	01.8	312 34.7	11.6	25 10.1	07.0	54.3
	02	213 30.4	02.4	327 05.3	11.6	25 03.1	07.1	54.3
	03	228 30.3	. . 02.9	341 35.9	11.6	24 56.0	07.3	54.3
	04	243 30.1	03.4	356 06.5	11.7	24 48.7	07.3	54.3
	05	258 30.0	04.0	10 37.2	11.8	24 41.4	07.5	54.4
	06	273 29.8	S20 04.5	25 08.0	11.8	N24 33.9	07.5	54.4
	07	288 29.6	05.1	39 38.8	11.9	24 26.4	07.7	54.4
S	08	303 29.5	05.6	54 09.7	11.9	24 18.7	07.8	54.4
A	09	318 29.3	. . 06.2	68 40.6	11.9	24 10.9	07.9	54.4
T	10	333 29.1	06.7	83 11.5	12.0	24 03.0	08.0	54.4
U	11	348 29.0	07.2	97 42.5	12.1	23 55.0	08.1	54.4
R	12	3 28.8	S20 07.8	112 13.6	12.1	N23 46.9	08.3	54.5
D	13	18 28.6	08.3	126 44.7	12.1	23 38.6	08.3	54.5
A	14	33 28.5	08.8	141 15.8	12.2	23 30.3	08.5	54.5
Y	15	48 28.3	. . 09.4	155 47.0	12.3	23 21.8	08.5	54.5
	16	63 28.2	09.9	170 18.3	12.3	23 13.3	08.7	54.5
	17	78 28.0	10.4	184 49.6	12.4	23 04.6	08.7	54.5
	18	93 27.8	S20 11.0	199 21.0	12.4	N22 55.9	08.9	54.6
	19	108 27.7	11.5	213 52.4	12.4	22 47.0	09.0	54.6
	20	123 27.5	12.0	228 23.8	12.5	22 38.0	09.1	54.6
	21	138 27.3	. . 12.6	242 55.3	12.6	22 28.9	09.2	54.6
	22	153 27.2	13.1	257 26.9	12.6	22 19.7	09.3	54.6
	23	168 27.0	13.6	271 58.5	12.7	22 10.4	09.4	54.6

Figure A-1. Solar/lunar positions for 22 November 1986 from "The Nautical Almanac".

The hour angle and declination are computed as:

$$\text{GHA} = \arctan \frac{(-\text{EAST})}{\text{UP}}$$

$$\text{DEC NORTH} = \arctan \frac{\text{NORTH}}{\text{SQRT}(\text{UP}^2+\text{EAST}^2)}$$

The comparison shown in Table A-1 convinces us that we are handling time properly.

Table A-1. Solar/lunar positions.

	GHA	DEC
SUN		
Almanac	3° 28.6'	S 20° 07.7'
Subroutine	3° 28.8'	S 20° 07.8'
MOON		
Almanac	112° 11.4'	N 23° 46.5'
Subroutine	112° 13.6'	N 23° 46.9'

A.2 LISTING AND CHECKOUT

There are three solar/lunar gravity effects:

(1) gravitational attraction,
(2) distortion, and
(3) tides.

The positions of the sun and moon and their gravitational attraction at a point on the Earth are computed by this subroutine according to the NSWC algorithms.

The corrections for the solar/lunar distortion effects are not done according to the NSWC algorithms; instead, at the suggestion of W. Robertson, we merely multiplied the computed gravitational attraction by 1.16 to get δG.

The tide effect is ignored in this subroutine.

One check case was run comparing the value computed by this subroutine with that computed by WMR.GRAVTIDE, which is a validated gravity-effects program used at CSDL. Both programs compute three components of the gravity effect; only the vertical component is used. The comparison is shown in Table A-2.

Table A-2. Check case.		
	CLP	WMR
UP	0.96 nano-g	0.9 nano-g
NORTH	-33.66	-34.1
EAST	12.48	12.7

MAC LISTING

This program was specified and written by C.L. Pu.

```
//CLP1431   JOB 5400,CLP1431,TIME=(,30),REGION=512K,NOTIFY=CLP1431
/*JOBPARM   ROOM=UP
//          EXEC MACOMPIL
//C.SYSIN   DD  *
*       MAC* CLP.SUNMOON1
R
R               THIS PROGRAM COMPUTES CONTRIBUTION OF SUN AND MOON
R               TO REFERENCE GRAVITY BASED ON FORMULATION BY NAVAL
R               SURFACE WEAPONS CENTER.
R
R               THIS PROGRAM IS USED AS A SUBROUTINE CALLED BY PIGA
R               CALIBRATION PROGRAM TO MODIFY G AT CSDL TO INCLUDE
R               SUN AND MOON ATTRACTION.
R
M       INIT    SUBROUTINE UTH,UTM,UTS,D,J
R
M               LATD=42.3643
M               LOND=288.93
M               H=0
R
M               PRINT MSG,SP2
E               LATD: INPUT GEODETIC LATITUDE (CSDL)
M               LOND: INPUT GEODETIC LONGITUDE (CSDL)
S               H   : INPUT GEODETIC ALTITUDE (CSDL)
R
M               PRINT HDG,LATD,LOND,H,SP2
M               LATD      LOND      H
M               NIL=0
M               PRINT MSG,SP2
M               UTH,UTM,UTS,DAY=INPUT UNIVERSAL TIME HOURS,MINUTES,
S                               SECONDS,DAY OF THE YEAR
M               PRINT MSG,SP2
M               UTH=EASTERN STANDARD TIME + 5 HR OR
```

```
S                    EASTERN DAY LIGHT SAVING TIME + 4 HR
R
M           PRINT HDG,UTH,UTM,UTS,D,SP2
M           UTH       UTM       UTS       D
M           PRINT MSG,SP2
M           J=JULIAN DAYS FROM J2000
M           PRINT HDG,J,SP2
M           J
R
M           A=6378137
M           E=.081819191
M           PI=3.1415926535897
M           D2R=PI/180
E                          25
M           GMS=1.327124 10
E                         17
M           GMM=4.90279 10
R
M           PRINT MSG
E           A=SEMIMAJOR AXIS EARTH ELLIPSOID
M           E=ECCENTRICITY EARTH ELLIPSOID
M           PRINT MSG,SP2
M           GMM=MOON'S GRAVITY CONSTANT IN MILLIGAL-METER SQ
S           GMS=SUN'S  GRAVITY CONSTANT IN MILLIGAL-METER SQ
M           PRINT HDG,A,E,GMS,GMM,SP2
M           A         E         GMS       GMM
R
M           LAT=D2R LATD
M           CLAT=COS(LAT)
M           SLAT=SIN(LAT)
M           LON=D2R LOND
M           CLON=COS(LON)
M           SLON=SIN(LON)
R
M           SFN=1020
E                 -6
M           PPM=10
M           SCALE=SFN PPM  980
R
M           PRINT MSG,SP2
M           SFN=1020 MICRORAD/S PER CM/S SQ
S           SCALE=CONVERSION FROM MICROGAL TO MICRORAD/S
M           PRINT HDG,SFN,SCALE,SP2
M           SFN       SCALE
R
R           UNIVERSAL TIME IN HOURS
R
M           TUT=UTH+UTM/60+UTS/3600
M           TUTO=TUT
M           DO=D
R
M           RETURN
R
M     SUB   SUBROUTINE T
```

```
M                TUT=TUTO+T/3600
M                IF TUT GOREQ 24,TUT=TUT-24,D=DO+1
R
R                NUMBER OF DAYS FROM J2000
R
M                EN=J+D+TUT/24
R
R                JULIAN CENTURIES
R
M                T=EN/36525
R
R                GREENWICH MEAN SIDEREAL TIME (SECONDS)
R
M                GMST=24110.54841+8640184.812866 T
E                                  2        -6  3
M                     +.093104 T -6.2 10    T
M                ALPH=GMST/3600+TUT
R
M                IF ALPH PNZ,GO TO 1
M                IF ALPH NEG,GO TO 3
R
M        1       IF ALPH LSTHN 24,GO TO 2
M                ALPH=ALPH-24
M                GO TO 1
M        2       GO TO 5
R
M        3       IF ALPH PNZ,GO TO 4
M                ALPH=ALPH+24
M                GO TO 3
M        4       NIL=0
R
M        5       NIL=0
R
R                ALPH IN DEGREES
R
M                ALP=ALPH 15
R
R                MEAN ANOMALY OF SUN
R
.M               G=357.528+.9856003 EN
R
R                MEAN LONGITUDE OF SUN
R
M                EL=280.460+.9856474 EN
M                GR=G D2R
R
M                SG=SIN(GR)
M                CG=COS(GR)
M                GR2=2 GR
M                S2G=SIN(GR2)
M                C2G=COS(GR2)
R
R                ECLIPTIC LONGITUDE OF SUN
R
```

```
M              LAM=EL+1.915 SG+.020 S2G
R
R              OBLIQUITY OF ECLIPTIC
R
M              EPS=23.439-.0000004 EN
R
R              DISTANCE OF SUN FROM EARTH IN ASTRONOMIC UNITS
R
M              RAU=1.00014-.01671 CG-.00014 C2G
R
R              DISTANCE OF SUN FROM EARTH (METERS)
R
E                                     11
M              RS=RAU 1.495978707 10
R
M              EPS=D2R EPS
M              SEPS=SIN(EPS)
M              CEPS=COS(EPS)
M              ALP=D2R ALP
M              CALP=COS(ALP)
M              SALP=SIN(ALP)
M              LAM=D2R LAM
M              CLAM=COS(LAM)
M              SLAM=SIN(LAM)
R
R              POSITION VECTOR EARTH TO SUN(METERS) IN EQUATORIAL
R              FRAME
R
M              XS=RS CLAM
M              YS=RS CEPS SLAM
M              ZS=RS SEPS SLAM
M              XS1=CALP XS+SALP YS
M              YS1=-SALP XS+CALP YS
M              XS2=CLON XS1+SLON YS1
M              YS2=-SLON XS1+CLON YS1
M              ZS2=ZS
R
R              SUN'S POSITION VECTOR IN VERTICAL,EAST,NORTH (V,E,N)
R              FRAME AT POINT ON EARTH
R
M              XS=CLAT XS2+SLAT ZS2
M              ZS=-SLAT XS2+CLAT ZS2
M              YS=YS2
R
M              DENOM=SQRT(1-E E SLAT SLAT)
M              NE=A/DENOM
M              XP1=(NE+H)CLAT CLON
M              YP1=(NE+H)CLAT SLON
M              ZP1=((1-E E)NE+H)SLAT
R
M              XP2=CLON XP1+SLON YP1
M              YP2=-SLON XP1+CLON YP1
M              ZP2=ZP1
R
```

```
R             POSITION VECTOR OF POINT ON EARTH IN (V,E,N) FRAME
R
M             XP=CLAT XP2+SLAT ZP2
M             YP=YP2
M             ZP=-SLAT XP2+CLAT ZP2
R
M             RSP2=(XS-XP)(XS-XP)+(YS-YP)(YS-YP)+(ZS-ZP)(ZS-ZP)
M             RSP3=RSP2 SQRT(RSP2)
M             RS2=XS XS+YS YS+ZS ZS
M             RS3=RS2 SQRT(RS2)
R
R             NET ATTRACTION OF SUN AT POINT ON EARTH
R             ****************************************
R
M             DGSX=GMS((XS-XP)/RSP3-XS/RS3)
M             DGSY=GMS((YS-YP)/RSP3-YS/RS3)
M             DGSZ=GMS((ZS-ZP)/RSP3-ZS/RS3)
R
R             NUMBER OF JULIAN CENTURIES FROM J2000.0
R
M             T=EN/36525
M             LM=218.32+481267.883 T+6.29 SIN(D2R(134.9+477198.85 T))
M             LM=LM-1.27 SIN(D2R(259.2-413335.38 T))
M                  +.66 SIN(D2R(235.7+ 890534.23 T))
M             LM=LM+.21 SIN(D2R(269.9+954397.7 T))
M                  -.19 SIN(D2R(357.5+ 35999.05 T))
R
R             ECLIPTIC LONGITUDE OF MOON
R
M             LM=LM-.11 SIN(D2R(186.6+966404.05 T))
R
R
M             BET=5.13 SIN(D2R(93.3+483202.03 T))
M                     +.28 SIN(D2R(228.2+ 960400.87 T))
R
R             ECLIPTIC LATITUDE OF MOON
R
M             BET=BET-.28 SIN(D2R(318.3+6003.18 T))
M                    -.17 SIN(D2R(217.6- 407332.2 T))
R
M             VPI=.9508+.0518 COS(D2R(134.9+477198.85 T))
M                     +.0095 COS(D2R(259.2-413335.38 T))
M                     +.0078 COS(D2R(235.7+890534.23 T))
R
R             HORIZONTAL PARALLAX
R
M             VPI=VPI+.0028 COS(D2R(269.9+954397.7 T))
R
R             DISTANCE FROM EARTH TO MOON IN EARTH RADII
R
M             RM=1/SIN(D2R VPI)
R
R             DISTANCE EARTH TO MOON IN METERS
R
```

```
M      RM=RM A
R
M      CBET=COS(D2R BET)
M      SBET=SIN(D2R BET)
M      CLM=COS(D2R LM)
M      SLM=SIN(D2R LM)
R
R      POSITION VECTOR EARTH TO MOON IN EQUATORIAL FRAME
R
M      XM1=RM CBET CLM
M      YM1=RM(.9175 CBET SLM-.3978 SBET)
M      ZM1=RM(.3978 CBET SLM+.9175 SBET)
M      XM2=CALP XM1+SALP YM1
M      YM2=-SALP XM1+CALP YM1
M      ZM2=ZM1
M      XM3=CLON XM2+SLON YM2
M      YM3=-SLON XM2+CLON YM2
M      ZM3=ZM2
R
R      MOON'S POSITION VECTOR FROM GEOCENTER IN (V,E,N) FRAME
R
M      XM=CLAT XM3+SLAT ZM3
M      YM=YM3
M      ZM=-SLAT XM3+CLAT ZM3
R
M      RMP2=(XM-XP)(XM-XP)+(YM-YP)(YM-YP)+(ZM-ZP)(ZM-ZP)
M      RMP3=RMP2 SQRT(RMP2)
M      RM2=XM XM+YM YM+ZM ZM
M      RM3=RM2 SQRT(RM2)
R
R      NET ATTRACTION OF MOON AT POINT ON EARTH
R      ****************************************
R
M      DGMX=GMM((XM-XP)/RMP3-XM/RM3)
M      DGMY=GMM((YM-YP)/RMP3-YM/RM3)
M      DGMZ=GMM((ZM-ZP)/RMP3-ZM/RM3)
R
R      NET ATTRACTION OF SUN & MOON AT POINT ON EARTH
R      **********************************************
R
M      DGSMX=DGSX+DGMX
M      DGSMY=DGSY+DGMY
M      DGSMZ=DGSZ+DGMZ
R
R      GRAVITY DISTURBANCE DUE TO DISTORTION OF EARTH
R      **********************************************
R
R      FACTORS TO CONVERT EFFECT OF ATTRACTION TO
R      INCLUDE DISTORTION ACCORDING TO WMR.GRAVTIDE:
R      VERTICAL=1.16
R      HORIZONTAL=.68
R
M      DGS=1.16 DGSX SCALE
M      DGM=1.16 DGMX SCALE
```

```
R
R              GRAVITY CORRECTION IN MICRORAD/S
R
M              DG=DGS+DGM
R
M              RETURN DGS,DGM,DG
R
M              START AT INIT,SUB
/*
```

FORTRAN LISTING

This program was written and checked out by D. Millard. It is a translation of the MAC program.

```
C
      SUBROUTINE SUNMUN (
     G                 T
     Y                 DGS, DGM, DG)
C
C    PURPOSE
C
C     SUNMOON COMPUTES CONTRIBUTION OF SUN AND MOON NET ATTRACTION
C     TO REFERENCE GRAVITY BASED ON FORMULATON BY NAVAL SURFACE
C     WEAPONS CENTER.
C
C
C    PARAMETER LIST
C
C     GIVEN ARGUMENTS
C
C       T      SEC          TIME MEASURED FROM TUTO
C
C     YIELDED ARGUMENTS
C
C       DGS    MICRO RAD/S  GRAVITY CORRECTION DUE TO SUN
C       DGM    MICRO RAD/S  GRAVITY CORRECTION DUE TO MOON
C       DG     MICRO RAD/S  GRAVITY CORRECTION DUE TO SUN+ MOON
C
C     JULIAN DAYS FROM J2000 FOR OHUT,JANO(MIDNIGHT)
C     (REF.: NSWC LTR OF 18 MAR 86, SUBJ; DOCKSIDE MK6 CALIB.)
C        TR      (R) SEC    TIME OF LOOPS OPEN
C
C     INITIALIZATION INPUT FILE
C
C       PRNTSW          PRINT CONTROL SWITCH
C       LATD     DEGS   GEODETIC LATITUDE
C       LOND     DEGS   GEODETIC LONGITUDE
C       H               GEODETIC ALTITUDE
C       UTH             UNIVERSAL TIME HOURS, MINUTES, SECONDS
C       UTM
C       UTS
C       DO              DAY OF THE YEAR
```

```
C       JO              JULIAN DAYS FROM J2000
C
C
      INTEGER  IFILE /55/
      INTEGER  INITSW /0/
C
      REAL*8  A
      REAL*8  ALP
      REAL*8  ALPH
      REAL*8  BET
      REAL*8  CALP
      REAL*8  CBET
      REAL*8  CEPS
      REAL*8  C2G
      REAL*8  CG
      REAL*8  CLAM
      REAL*8  CLAT
      REAL*8  CLM
      REAL*8  CLON
      REAL*8  D
      REAL*8  DG
      REAL*8  DO
      REAL*8  DATA(9)
      REAL*8  DENOM
      REAL*8  D2R
      REAL*8  DGM
      REAL*8  DGMX
      REAL*8  DGMY
      REAL*8  DGMZ
      REAL*8  DGS
      REAL*8  DGSX
      REAL*8  DGSY
      REAL*8  DGSZ
      REAL*8  DGSMX
      REAL*8  DGSMY
      REAL*8  DGSMZ
      REAL*8  E
      REAL*8  EN
      REAL*8  EL
      REAL*8  EPS
      REAL*8  G
      REAL*8  GMM
      REAL*8  GMS
      REAL*8  GMST
      REAL*8  GR2
      REAL*8  GR
      REAL*8  H
      REAL*8  J
      REAL*8  JO
      REAL*8  LAM
      REAL*8  LAT
      REAL*8  LATD
      REAL*8  LM
      REAL*8  LON
```

```
REAL*8  LOND
REAL*8  NE
REAL*8  PI
REAL*8  PPM
REAL*8  PRNTSW
REAL*8  RAU
REAL*8  RM
REAL*8  RM2
REAL*8  RM3
REAL*8  RMP2
REAL*8  RMP3
REAL*8  RS
REAL*8  RS2
REAL*8  RS3
REAL*8  RSP2
REAL*8  RSP3
REAL*8  SALP
REAL*8  SBET
REAL*8  SCALE
REAL*8  SEPS
REAL*8  S2G
REAL*8  SG
REAL*8  SFN
REAL*8  SLAM
REAL*8  SLAT
REAL*8  SLM
REAL*8  SLON
REAL*8  T
REAL*8  TUT
REAL*8  TUTO
REAL*8  XM
REAL*8  XM1
REAL*8  XM2
REAL*8  XM3
REAL*8  XP
REAL*8  XP1
REAL*8  XP2
REAL*8  XS
REAL*8  XS1
REAL*8  XS2
REAL*8  UTH
REAL*8  UTM
REAL*8  UTS
REAL*8  VPI
REAL*8  YM
REAL*8  YM1
REAL*8  YM2
REAL*8  YM3
REAL*8  YP
REAL*8  YP1
REAL*8  YP2
REAL*8  YS
REAL*8  YS1
REAL*8  YS2
```

```
      REAL*8  ZM
      REAL*8  ZM1
      REAL*8  ZM2
      REAL*8  ZM3
      REAL*8  ZP
      REAL*8  ZP1
      REAL*8  ZP2
      REAL*8  ZS
      REAL*8  ZS1
      REAL*8  ZS2
C
      EQUIVALENCE (DATA(1), PRNTSW)
      EQUIVALENCE (DATA(2), LATD)
      EQUIVALENCE (DATA(3), LOND)
      EQUIVALENCE (DATA(4), H)
      EQUIVALENCE (DATA(5), UTH)
      EQUIVALENCE (DATA(6), UTM)
      EQUIVALENCE (DATA(7), UTS)
      EQUIVALENCE (DATA(8), DO)
      EQUIVALENCE (DATA(9), JO)
C
C
      IF (INITSW .EQ. 1) GO TO 100
C
C
C*************************************************************************
C  SUNMOON SUBROUTINE INITIALIZATION
C*************************************************************************
C
C
      REWIND IFILE
C
C
   10 READ (IFILE, 1000, END=20) I, DATA(I)
      GO TO 10
   20 CONTINUE
C
      REWIND IFILE
C
C
      A  = 6378137.DO
      E  = .081819191DO
      PI = 3.1415926535898DO
      J  = JO
C
      D2R = PI/180.DO
C
      GMS = 1.327124D25
      GMM = 4.902790D17
C
      SFN = 1020.DO
      PPM = 10D-6
C
      SCALE = SFN*PPM*980.DO
```

```
C
      LAT = D2R*LATD
      LON = D2R*LOND
C
      SLAT = DSIN(LAT)
      CLAT = DCOS(LAT)
C
      SLON = DSIN(LON)
      CLON = DCOS(LON)
C
C
      TUT = UTH + UTM/60.DO + UTS/3600.DO
C
      TUTO = TUT
C
      D = DO
C
C
      PRINT 1010
C
      PRINT 1020, LATD, LOND, H, UTH, UTM, UTS, TUTO, DO, JO
C
C
      INITSW = 1
C
C
C*************************************************************************
C  END SUNMOON INITIALIZAGION
C*************************************************************************
C
C

  100 CONTINUE
C
C
C  COMPUTE TIME IN HOURS (TUT) WRT TO START TIME AND COUNT THE DAYS (D)
C
C
      TUT = TUTO + T/3600.DO
C
      IF (TUT .GE. 24.DO) THEN
C
        TUT = TUT - 24.DO
C
        D = DO + 1.DO
C
      END IF
C
C
C  RESOLVE TIME IN DAYS FROM J2000 (EN) AND JULIAN CENTURIES (T)
C
C
      EN = J + D + TUT/24.DO
C
```

```
      T = EN/36525.DO
C
C
C  GREENWICH MEAN SIDEREAL TIME IN SECONDS (GMST) AND HOURS (ALPH)
C
C
      GMST = 24110.54841DO + 8640184.812866DO*T
     X                     +        .093104DO*T*T - (6.2D-6)*T*3
C
      ALPH = TUT + GMST/3600.DO
C
C
      IF (PRNTSW .GT. O.DO) PRINT 1060, EN,T,GMST,ALPH
C
C
C  RESOLVE +/- ALPH BETWEEN O TO +24 HOURS
C
C
      IF (ALPH .GE. 24.DO) THEN
C
  110   ALPH = ALPH - 24.DO
C
        IF (ALPH .GE. 24.DO) GO TO 110
C
      ELSE IF (ALPH .LT. O.DO) THEN
C
  120   ALPH = ALPH + 24.DO
C
        IF (ALPH .LT. O.DO) GO TO 120
C
      END IF
C
C
C  COMPUTE ALPH IN DEGREES (ALP) (15 DEG./HOUR)
C
C
      ALP = ALPH*15.DO
C
C
C  MEAN ANOMALLY OF SUN (G) DEGREES
C
C
      G = 357.528DO + .9856003DO*EN
C
C
C  MEAN LONGITUDE OF SUN
C
C
      EL = 280.460DO + .9856474DO*EN
C
C
      IF (PRNTSW .GT. O.DO) PRINT 1070, ALPH, ALP, G, EL
C
C
```

```
      GR = G*D2R
C
      SG = DSIN(GR)
C
      CG = DCOS(GR)
C
      GR2 = 2.DO*GR
C
      S2G = DSIN(GR2)
C
      C2G = DCOS(GR2)
C
C
C  ECLIPTIC LONGITUDE OF SUN
C
C
      LAM = EL + 1.915DO*SG + .020DO*S2G
C
C
C  OBLIQUITY OF ECLIPTIC
C
C
      EPS = 23.439DO - EN*O.4D-6
C
C
C  DISTANCE FROM SUN TO EARTH IN ASTRONOMIC UNITS (RAU) AND METERS (RS)
C
C
      RAU = 1.00014DO - .01671DO*CG - .00014DO*C2G
C
      RS = RAU*1.495978707D11
C
C
      IF (PRNTSW .GT. O.DO) PRINT 1040, LAM,EPS,RAU,RS
C
C
      EPS = D2R*EPS
C
      SEPS = DSIN(EPS)
C
      CEPS = DCOS(EPS)
C
      ALP = D2R*ALP
C
      SALP = DSIN(ALP)
C
      CALP = DCOS(ALP)
C
      LAM = D2R*LAM
C
      SLAM = DSIN(LAM)
C
      CLAM = DCOS(LAM)
C
```

```
C
C  POSITION VECTOR EARTH TO SUN (METERS) IN EQUITORIAL FRAME
C
C
      XS = RS*CLAM
C
      YS = RS*CEPS*SLAM
C
      ZS = RS*SEPS*SLAM
C
C
      XS1 = CALP*XS + SALP*YS
C
      YS1 =-SALP*XS + CALP*YS
C
C
      XS2 = CLON*XS1 + SLON*YS1
C
      YS2 =-SLON*XS1 + CLON*YS1
C
      ZS2 = ZS
C
C
C  SUN'S POSITION VECTOR IN VERTICAL, EAST, NORTH (V,E,N) FRAME
C  AT POINT ON EARTH
C
C
      XS = CLAT*XS2 + SLAT*ZS2
C
      YS = YS2
C
      ZS =-SLAT*XS2 + CLAT*ZS2
C
C
      DENOM = DSQRT(1.DO - E*E*SLAT*SLAT)
C
      NE = A/DENOM
C
      XP1 = (NE + H)*CLAT*CLON
C
      YP1 = (NE + H)*CLAT*SLON
C
      ZP1 = ((1.DO - E*E)*NE + H)*SLAT
C
C
      XP2 = CLON*XP1 + SLON*YP1
C
      YP2 =-SLON*XP1 + CLON*YP1
C
      ZP2 = ZP1
C
C
C  POSITION VECTOR OF POINT ON EARTH IN (V,E,N) FRAME
C
```

```
C
      XP = CLAT*XP2 + SLAT*ZP2
C
      YP = YP2
C
      ZP =-SLAT*XP2 + CLAT*ZP2
C
C
      IF (PRNTSW .GT. 0.D0)
     X  PRINT 1050, XS,YS,ZS,XP1,YP1,ZP1,XP2,YP2,ZP2,XP,YP,ZP
C
C
      RSP2 = (XS-XP)*(XS-XP) + (YS-YP)*(YS-YP) + (ZS-ZP)*(ZS-ZP)
C
      RSP3 = RSP2*DSQRT(RSP2)
C
      RS2  = XS*XS + YS*YS + ZS*ZS
C
      RS3  = RS2*DSQRT(RS2)
C
C
C  NET ATTRACTION OF SUN AT POINT ON EARTH
C
C
      DGSX = GMS*((XS - XP)/(RSP3) - XS/RS3)
C
      DGSY = GMS*((YS - YP)/(RSP3) - YS/RS3)
C
      DGSZ = GMS*((ZS - ZP)/(RSP3) - ZS/RS3)
C
C
C  NUMBER OF JULIAN CENTURIES FROM J2000.0
C
C
      T = EN/36525.D0
C
C
C  ECLIPTIC LONGITUDE OF MOON
C
C
      LM = 218.32D0 + 481267.883D0*T
     X                   + 6.290D0*DSIN(D2R*(134.9D0 + 477198.85D0*T))
C
      LM = LM - 1.27D0*DSIN(D2R*(259.2D0 - 413335.38D0*T))
     X                   + 0.660D0*DSIN(D2R*(235.7D0 + 890534.23D0*T))
C
      LM = LM + 0.21D0*DSIN(D2R*(269.9D0 + 954397.70D0*T))
     X                   - 0.190D0*DSIN(D2R*(357.5D0 + 35999.050D0*T))
C
      LM = LM - 0.11D0*DSIN(D2R*(186.6D0 + 966404.05D0*T))
C
C
C  ECLIPTIC LATITUDE OF MOON
C
```

```
C
      BET = 5.13DO*DSIN(D2R*(93.3DO + 483202.03DO*T))
     X                   + .28DO*DSIN(D2R*(228.2DO + 960400.87DO*T))
C
      BET = BET - .28DO*DSIN(D2R*(318.3DO + 6003.18DO*T))
     X                   - .17DO*DSIN(D2R*(217.6DO - 407332.2DO*T))
C
C
C  HORIZONTAL PARALLAX
C
C
      VPI = .9508DO + .0518DO*DCOS(D2R*(134.9DO + 477198.85DO*T))
     X              + .0095DO*DCOS(D2R*(259.2DO - 413335.38DO*T))
     X              + .0078DO*DCOS(D2R*(235.7DO + 890534.23DO*T))
C
      VPI = VPI + .0028DO*DCOS(D2R*(269.9DO + 954397.7DO*T))
C
C
C  DISTANCE FROM EARTH TO MOON IN METERS
C
C
      RM = A/DSIN(D2R*VPI)
C
C
C  POSITION VECTOR EARTH TO MOON IN EQUATORIAL FRAME
C
C
      SBET = DSIN(D2R*BET)
C
      CBET = DCOS(D2R*BET)
C
      SLM  = DSIN(D2R*LM)
C
      CLM  = DCOS(D2R*LM)
C
C
      XM1 = RM*CBET*CLM
C
      YM1 = RM*(.9175DO*CBET*SLM - .3978DO*SBET)
C
      ZM1 = RM*(.3978DO*CBET*SLM + .9175DO*SBET)
C
C
      XM2 = CALP*XM1 + SALP*YM1
C
      YM2 =-SALP*XM1 + CALP*YM1
C
      ZM2 = ZM1
C
C
      XM3 = CLON*XM2 + SLON*YM2
C
      YM3 =-SLON*XM2 + CLON*YM2
C
```

```
      ZM3 = ZM2
C
C
C  MOON'S POSITION VECTOR FROM GEOCENTER IN (V,E,N) FRAME
C
C
      XM = CLAT*XM3 + SLAT*ZM3
C
      YM = YM3
C
      ZM =-SLAT*XM3 + CLAT*ZM3
C
C
      RMP2 = (XM-XP)*(XM-XP) + (YM-YP)*(YM-YP) + (ZM-ZP)*(ZM-ZP)
C
      RMP3 = RMP2*DSQRT(RMP2)
C
      RM2  = XM*XM + YM*YM + ZM*ZM
C
      RM3  = RM2*DSQRT(RM2)
C
C
C  NET ATTRACTION OF MOON AT POINT ON EARTH
C
C
      DGMX = GMM*((XM-XP)/(RMP3) - XM/RM3)
C
      DGMY = GMM*((YM-YP)/(RMP3) - YM/RM3)
C
      DGMZ = GMM*((ZM-ZP)/(RMP3) - ZM/RM3)
C
C
C  NET ATTRACTION OF SUN AND MOON AT POINT ON EARTH
C
C
      DGSMX = DGSX + DGMX
C
      DGSMY = DGSY + DGMY
C
      DGSMZ = DGSZ + DGMZ
C
C
C  GRAVITY DISTURBANCE DUE TO DISTORTION OF EARTH
C
C  **************************************************
C  * FACTORS TO CONVERT EFFECT OF ATTRACTION TO INCLUDE*
C  * DISTORATION ACCORING TO WMR.GRAVTIDE:            *
C  *                                 VERTICAL   = 1.16*
C  *                                 HORZONTAL = .68*
C  **************************************************
C
C
      DGS = 1.16DO*DGSX*SCALE
C
```

```
      DGM = 1.16DO*DGMX*SCALE
C


C
C
C  GRAVITY CORRECTION IN MICRORADS/SECOND
C
C
      DG = DGS + DGM
C
C
C
      IF (PRNTSW .GT. O.DO)
     X  PRINT 1030, T,DGSX,DGSY,DGSZ,DGMX,DGMY,DGMZ,DGSMX,DGSMY,DGSMZ
C
C
C
C
      RETURN
C
C
C***************************************************************************
C
C
C   ALL FORMATS ARE HERE.
C
C
 1000 FORMAT (I5,F20.10)
C

 1010 FORMAT ('1 SUNMOON SUBROUTINE INITIALIZATION  REV 1  12/30/86',//)
C
 1020 FORMAT ( ' LATD     ' ,F16.8,/
     X         ' LOND     ' ,F16.8,/
     X         ' H        ' ,F16.8,/
     X         ' UTH      ' ,F16.8,/
     X         ' UTM      ' ,F16.8,/
     X         ' UTS      ' ,F16.8,/
     X         ' TUTO     ' ,F16.8,/
     X         ' DO       ' ,F16.8,/
     X         ' JO       ' ,F16.8,//)
C
 1030 FORMAT ( ' T        ' ,E16.10,/
     X         ' DGSX     ' ,E16.10,/
     X         ' DGSY     ' ,E16.10,/
     X         ' DGSZ     ' ,E16.10,/
     X         ' DGMX     ' ,E16.10,/
     X         ' DGMY     ' ,E16.10,/
     X         ' DGMZ     ' ,E16.10,/
     X         ' DGSMX    ' ,E16.10,/
     X         ' DGSMY    ' ,E16.10,/
     X         ' DGSMZ    ' ,E16.10,//)
C
 1040 FORMAT ( ' LAM      ' ,E16.10,/
```

```
     X          ' EPS      ' ,E16.10,/
     X          ' RAU      ' ,E16.10,/
     X          ' RS       ' ,E16.10,//)
C
 1050 FORMAT ( ' XS       ' ,E16.10,/
     X          ' YS       ' ,E16.10,/
     X          ' ZS       ' ,E16.10,/
     X          ' XP1      ' ,E16.10,/
     X          ' YP1      ' ,E16.10,/
     X          ' ZP1      ' ,E16.10,/
     X          ' XP2      ' ,E16.10,/
     X          ' YP2      ' ,E16.10,/
     X          ' ZP2      ' ,E16.10,/
     X          ' XP       ' ,E16.10,/
     X          ' YP       ' ,E16.10,/
     X          ' ZP       ' ,E16.10,//)
C
 1060 FORMAT ( ' EN       ' ,E16.10,/
     X          ' T        ' ,E16.10,/
     X          ' GMST     ' ,E16.10,/
     X          ' ALPH     ' ,E16.10,//)
C
 1070 FORMAT ( ' ALPH     ' ,E16.10,/
     X          ' ALP      ' ,E16.10,/
     X          ' G        ' ,E16.10,/
     X          ' EL       ' ,E16.10,//)
C
      END
```