Lunar occultations of planets

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A report of the Computing Section (Director: G. E. Taylor)

A computer search has been made to detect all lunar occultations of planets for the years 1995–2045 inclusive. As a result a new package for IBM compatible microcomputers is now available from the Program and Data Library. This package provides predictions of the local circumstances for any point on the Earth of the 807 occultations which occur during this period.

Introduction

The rapid increase in the speed of microcomputers over the past decade has made it practical to generate special ephemerides of the Moon and eight planets, using the DE200/LE200 ephemeris (planetary and lunar ephemerides calculated at the Jet Propulsion Laboratory, the United States Naval Observatory and the Naval Surface Weapons Centre) and to write a search program to compare the lunar ephemeris with each of eight planetary ephemerides in turn, thereby detecting all possible occultations.

Search program

The program compares the lunar and planetary ephemerides and stores half-daily values of the RA, Dec and distance of the Moon and planets around the time of conjunction, together with other parameters which are required for calculating the track of the occultation across the Earth's surface. All conjunctions where the difference in ecliptic longitude of the Moon and planet is $<1^\circ.33$ have been retained. For Saturn a limit of $1^\circ.36$ has been used, so that if an algorithm for the position of Titan is available in years to come it can be incorporated into the program, knowing that no occultations will be missed. The number of occultations of each planet, together with the range of dates over which they occur is given in Table 1.

No exclusions have been made for proximity to the Sun but whenever predictions of local circumstances are printed, the position of the Sun is also given. Although it is impossible to observe occultations of a body as faint as Pluto at the present time, these have been included in case improvements in instrumentation make it possible by the time such occultations occur.

The end product of this program is a random access file with all the requisite data for the 807 occultations, and a separate index file which carries the number, the date and the planet number, in chronological order.

Other programs were written to add the apparent magnitudes and phases of all the planets, and further programs were required to generate data for the 106 occultations of Jupiter, to enable separate predictions of occultations of the four Galilean satellites to be made.

Table 1

Planet	*No. of occultations*	*Range of dates*
Mercury	103	1995–2045
Venus	101	1995–2045
Mars	105	1995–2045
Jupiter	106	1998–2045
Saturn	115	1997–2045
Uranus	109	1999–2045
Neptune	110	1999–2041
Pluto	58	2012–2026

Display program

This is the first program incorporated in the occultation package. It enables the user to interrogate the index and select any of the 807 occultations for which local predictions are required. A latitude-longitude grid is displayed, together with the envelope of the occultation. The display is so arranged that this envelope always appears in the centre of the screen. The observer's position (taken from a separate data file) is also shown. At this stage the observer's position may be altered at will and the map is displayed again. The method of calculation of the envelope is given in the Appendix.

If no graphics are available on the computer the user proceeds to the next program using the observer's position taken from the data file.

Interpolation program

This program interpolates the ephemerides of the Moon and planet to a one-minute interval, and then converts these geocentric ephemerides into topocentric ephemerides using the observer's position, also correcting for ΔT at the same time. The period of time covered is 3h 30m either side of conjunction in RA, except for Jupiter where the range is extended to 4h, to allow for occultations of the Galilean satellites.

If the planet is Jupiter the previous program automatically calls another program which calculates the positions of each of the four Galilean satellites, again at one-minute intervals.

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        Lunar occultation of Venus visible from GREENWICH
Longitude (W) 0    Latitude 51.5    height 0    Times in UT

1996 7 12 Friday        Moon's phase -10%    Delta T 62s

 Mag.        D          P.A.   C  Az  Alt        R          P.A.   C  Az  Alt
       m  d  h  m  s     o    o    o   o    m  d  h  m  s     o    o   o   o
-4.4   7 12  7 47 43    45 -59N 140   51    7 12  8 55 27   299  48N 166  56
                             Sun  96   33                         Sun 111  43

Venus   equatorial semi-diameter  20.10 arcseconds  phase 0.228


        Lunar occultation of Saturn visible from GREENWICH
Longitude (W) 0    Latitude 51.5    height 0    Times in UT

1997 11 12 Wednesday    Moon's phase  91%    Delta T 63s

 Mag.        D          P.A.   C  Az  Alt        R          P.A.   C  Az  Alt
       m  d  h  m  s     o    o    o   o    m  d  h  m  s     o    o   o   o
 0.5  11 12  1 27 29    43  70N 247   21   11 12  2 20 43   278 -56N 261  11
                             Sun  43  -50                      Sun  60 -44

Saturn  equatorial semi-diameter  9.67 arcseconds  phase 0.999
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Figure 1. Screen display of the output for the next two occultations visible from Great Britain.

Prediction program

The prediction program is very similar to that used for occultations of stars in another microcomputer package.[1]

Comparison of the topocentric ephemerides of the Moon and the planet (and the Galilean satellites, if Jupiter is involved) enables a rapid prediction of the local circumstances of the occultation to be made, including the position of the Sun. In the rare cases where there is an eclipse of the Sun or Moon near the same time, this fact is brought to the attention of the observer. Predictions of the Galilean satellites are suppressed if the satellite is behind Jupiter and indications given if the satellite is in transit or eclipse. Predictions are still given in the latter case even though they are currently unobservable, in case improvements in instrumentation make such observations possible in the next century. The method of calculating the positions of these satellites has been adapted from that of Meeus.[2]

Figure 1 gives an example of output showing the next two occultations visible from Great Britain.

Acknowledgment

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Appendix: Calculation of an occultation envelope

In order to determine the area of Earth from which a lunar occultation of a planet or star is visible it is necessary to calculate the locus of all points on the northern and southern limits of the occultation, and also the western and eastern limits where the altitude is zero. If either the northern or southern limit misses the Earth it is also necessary to calculate the locus of all points around the northern or southern limb of the Earth, between the west and east ends of the northern or southern limit, where the altitude is zero.

A complication arises because of the duration of the occultation – the interval of time between the disappearance and reappearance phases – which can exceed an hour, in the case of a near central occultation. Fortunately the precise limit is of little importance since the computer package for which this method was devised will calculate the local circumstances of any particular station almost instantaneously. Therefore the envelope is calculated for the time of conjunction in right ascension except for the fact that an allowance for the Moon's semi-diameter is made when calculating the position of the ends of the central line.

The method which is described below has been developed from a method for calculating the track of an occultation of a star by a minor planet.[3]

In Figure 2 the plane of the paper is the fundamental plane which passes through the Earth's centre at right angles to the line joining the centre of the Earth and the centre of the occulted body. The viewpoint is from an infinite distance beyond the planet along the line passing though the centres of the Earth and the planet. This diagram illustrates the track of an occultation which crosses part of the northern hemisphere of the Earth, and where the northern limit, N misses the Earth completely. C and S indicate the paths of the central line and southern limit respectively. The suffixes W and E indicate the western and eastern limit on the limbs. The suffixes M and N indicate the points where the limits cross the central meridian and the nearest point on the N, C or S line to the Earth's centre, respectively. Θ is the angle at the centre of the Earth's disk O, always measured from true north, to any point on the track or to any point on the Earth's limb. Here $0 < \Theta < \pi$.

The following parameters are known since they were calculated in the search program:

T_0	=	time of conjunction in RA
GHA	=	Greenwich hour angle
ρ	=	position angle of the direction of motion of the Moon

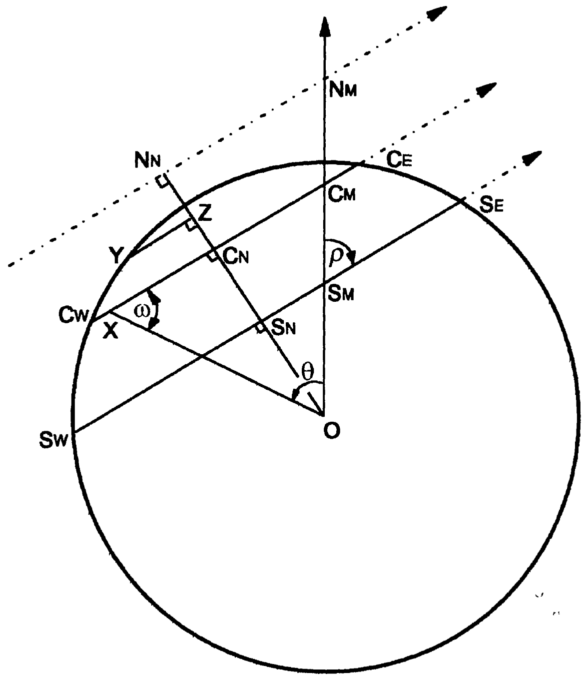

Figure 2. Geometry of the occultation track (see Appendix).

n = rate of motion of the Moon
δ = declination of planet
$\Delta\delta$ = difference in declination (Moon minus planet)
HP = Moon's horizontal parallax
sd = Moon's semi-diameter

All the last seven quantities are at T_0. To the accuracy required for the calculation of the occultation envelope, the small variation in these quantities during the occultation may be ignored. It is also unnecessary to take into account the non-sphericity of the Earth.

The distance from the centre of the Earth's disk, O, to C_M is the difference in declination, Moon minus planet, at T_0. A line drawn from O at right-angles to the track cuts the northern limit at N_N, the central line at C_N and the southern limit at S_N. The lines C_NN_N and C_NS_N represent the Moon's semi-diameter. Therefore

$$ON_N = ON_M \sin \rho$$
$$OC_N = OC_M \sin \rho$$
$$OS_N = OS_M \sin \rho$$

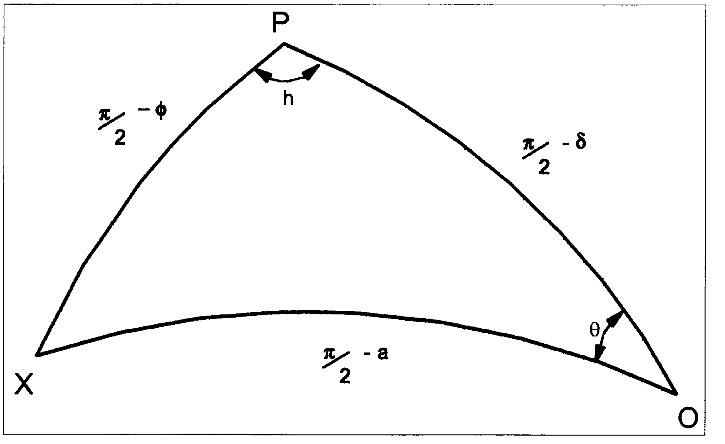

Figure 3. Spherical triangle on the Earth's surface (see Appendix).

Clearly if any of these three values divided by the horizontal parallax is greater than unity then that particular limit or central line misses the Earth. In fact, dividing any radial line by the horizontal parallax has the effect of making the radius of the Earth's disk equal to unity, thereby simplifying the calculations since the distance of any point from O is equal to the cosine of the altitude at that point. In particular it is noted that the altitude of the planet above the observer's horizon is 90° at O and 0° at any point on the Earth's limb. The maximum altitudes on the northern limit, A_N, central line, A_C and southern limit A_S, are, respectively

$$A_N = \arccos(ON_N / HP)$$
$$A_C = \arccos(OC_N / HP)$$
$$A_S = \arccos(OS_N / HP)$$

It is convenient to calculate the positions of several points along the central line and southern limit starting at the west end with an altitude of 0° and adding increments until the maximum altitude is reached, and then decreasing the altitude until an altitude of 0° is reached at the east end. For example let X be a point on the central line where the altitude is a, then the angle ω at X, between XO and XC_N is found from

$$\omega = \arcsin (O\,C_N / HP) / \cos a$$

When the point X is west of C the angle Θ is found from

$$\Theta = \pi - \rho - \omega$$

and when X is east of C

$$\Theta = \rho - \omega$$

Similar calculations can be performed for the northern and southern limits replacing OC_N by (OC_N + sd) and (OC_N − sd) respectively, though in the example the northern limit would not be calculated.

If a track passed south of O,

$\Theta = \pi - \rho + \omega$ when X is west of C
$\Theta = \rho + \omega$ when X is east of C.

Figure 3 shows a spherical triangle on the Earth's surface, P being the north pole. Since the declination of the planet, δ, the altitude, a, and the angle Θ are known, the hour angle, h, and latitude, φ, can be calculated from

$$\varphi = \arcsin [\sin \delta \sin a + \cos \delta \cos a \cos \Theta]$$
$$h = \arctan [\sin \Theta / (\tan a \cos \delta - \sin \Theta \sin \delta)]$$

For points around the northern and southern limbs the procedure has to be modified, firstly because the altitude is zero, and secondly because the radial distance to the chord passing though the point and at right-angles to the line CN_N is unknown.

For a chosen value of Θ the location of a point Y on the limb is determined. The equations are modified as will be seen from an inspection of Figure 2. A perpendicular from Y onto the line ON_N cuts that line at Z. The distance OZ has to be calculated first but the following equations are simplified because the altitude is zero.

On the northern limb, for points west of ON_N,

$$YZ = \sin [\Theta + \rho - (\pi/2)]$$
$$OZ = \sqrt{(1 - YZ^2)} / HP$$

while for points east of the line ON_N, YZ is found from

$$YZ = \sin [\Theta - \rho + \pi]$$

For the southern limb, for points west of OS_N,

$$YZ = \sin [(\pi/2) + (\pi - \rho - \Theta)]$$

and for points east of OS_N,

$$YZ = \sin [(\pi/2) + (\rho - \Theta)]$$

The values of OZ are determined as before.

Then

$$\varphi = \arcsin [\cos \delta \cos \Theta]$$
$$h = \arctan [\sin \Theta / (- \sin \varphi \sin \delta)]$$

So far there has been no allowance for the rotation of the Earth, relative to the time of conjunction. The correction to the hour angle, Δh, is calculated from

$$\Delta h = | \, p (\sin \Theta / n \sin \omega) \, |$$

in minutes of time, where p = ON_N, OC_N, or OS_N for points on the northern limit, central line or southern limit respectively, or p = OZ for points on the limb.

If the position is west of the meridian, h is positive and Δh is negative; if east, h is negative and Δh is positive. The final value of the longitude, λ is found from

$$\lambda = GHA + h + \Delta h$$

The envelope thus defined is displayed on the screen and is a good guide to the area of visibility of the occultation.

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References

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