PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
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Variations in air density at 280 km height

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The effect of air drag on the orbits of six Cosmos satellites having low perigee heights has been investigated. The diurnal variation of neutral atmospheric density at about 280 km is shown to have an amplitude of about 25% of its average value and to have a maximum value at about 14 h local time.

1. Introduction

In February and March 1965 two multiple launches of satellites in the Cosmos series occurred. Each launch put into orbit three satellites and these were given the internationa designations 1965–11A, 11B, 11C and 1965–20A, 20B and 20C. The orbits of the six satellites were very nearly identical in shape and inclination, with perigee and apogee heights around 260 and 1700 km respectively, and inclination about 56°. As shown in table 1, at the time of the second launch, the orbital planes of the two launches differed in right ascension by nearly 100° and the arguments of perigee by about 40°.

Table 1. Orbital elements of 1965–11A, B, C and 1965–20A, B, C

inclination	56·0°
nodal period	105 min
eccentricity	0·1
perigee height	260 km
apogee height	1700 km
rate of rotation of orbital planes	−3·45°/day
rate of rotation of perigee	+1·74°/day
difference in right ascension of nodes	97°
difference in arguments of perigee	38°

Because of the low perigee height the orbits are affected by air drag and therefore offer the opportunity of studying the neutral air density variations at a height of about 280 km; that is, at half the scale height above the perigee (King-Hele 1964).

From observed values of the mean nodal period T, at 10-day intervals, its rate of change $\dot{T}$ was derived for the period from mid-March to the end of December 1965. The interval of 10 days between the $\dot{T}$ values smoothed out variations in air drag of only a few days' duration, but left intact much longer term effects. In particular, since the argument of perigee and its local time changed only slowly with time, the variation of $\dot{T}$, due to the change in perigee position with respect to the maximum of the diurnal bulge of the atmosphere, was not lost.

2. Variations in air density at about 280 km

The perigee heights of orbits above the Earth's surface change slowly from day to day due to the odd harmonics in the Earth's gravitational field and due also to the variation of the Earth's radius with latitude. The observed values of $\dot{T}$ therefore refer to different heights and have, consequently, been corrected to a constant value of 260 km. Figure 1 shows the corrected rates of change of period, $\dot{T}$, of the six satellites for the period March to December 1965. It was impossible to transform the values of $\dot{T}$ into values of air density because no information was available about the cross-sectional areas and masses of the

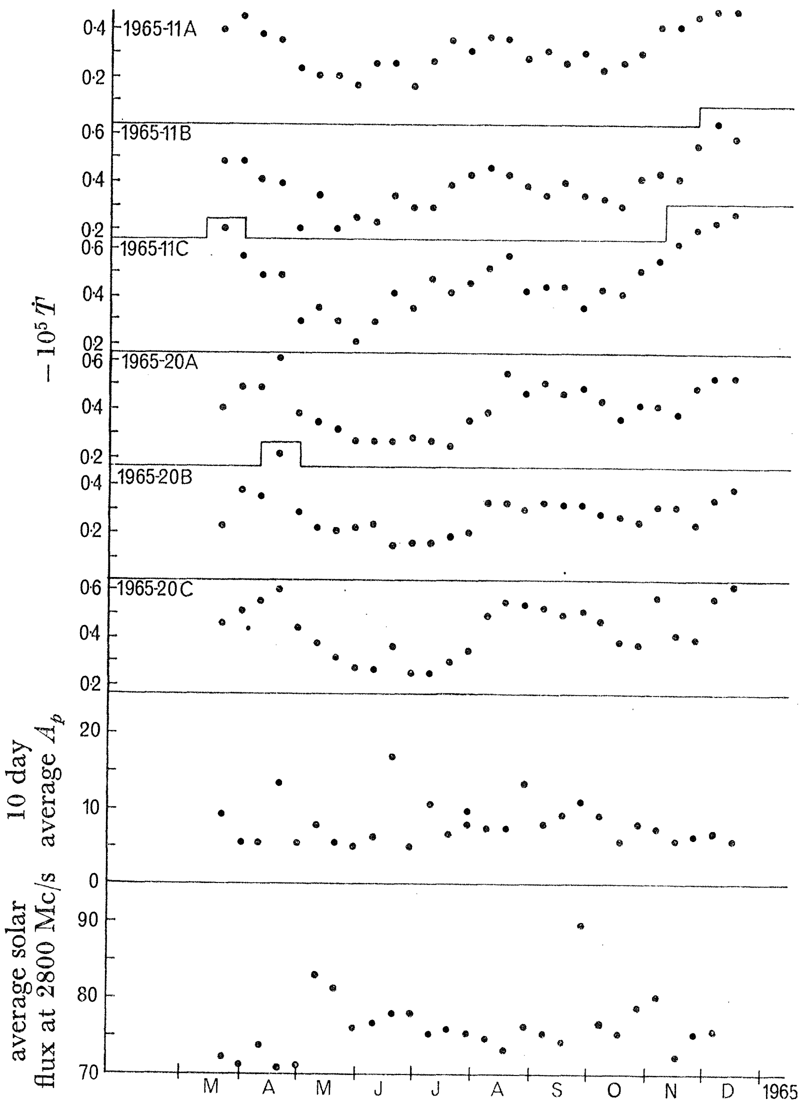

FIGURE 1. The rates of change of period of the 1965–11A, B, C and 1965–20A, B, C satellites.

satellites but since $|\dot{T}|$ is proportional to density (King-Hele 1964) it is possible to study the variations in density. Also shown are the geomagnetic index A_p and the solar flux at 2800 Mc/s for the same period.

It is interesting to note the similarity in detail between the three curves for the same launch and in one or two instances between all six curves. The increase in A_p and solar flux around the middle of April is accompanied by corresponding changes in $\dot{T}$ for the 1965–20 satellites and to a lesser extent for the 1965–11 satellites. Conversely in mid-May, aberrations in $\dot{T}$ are noticeable for the 1965–11 satellites but not for the 1965–20 satellites.

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Although there are these occasions when the $\dot{T}$ curves appear to reflect changes in the A_p and solar flux values, this is not the general rule.

With respect to the Sun, the perigees of the 1965–20 satellites follow almost exactly the same path in latitude and local time as the perigees of the 1965–11 orbits, but about 3 to

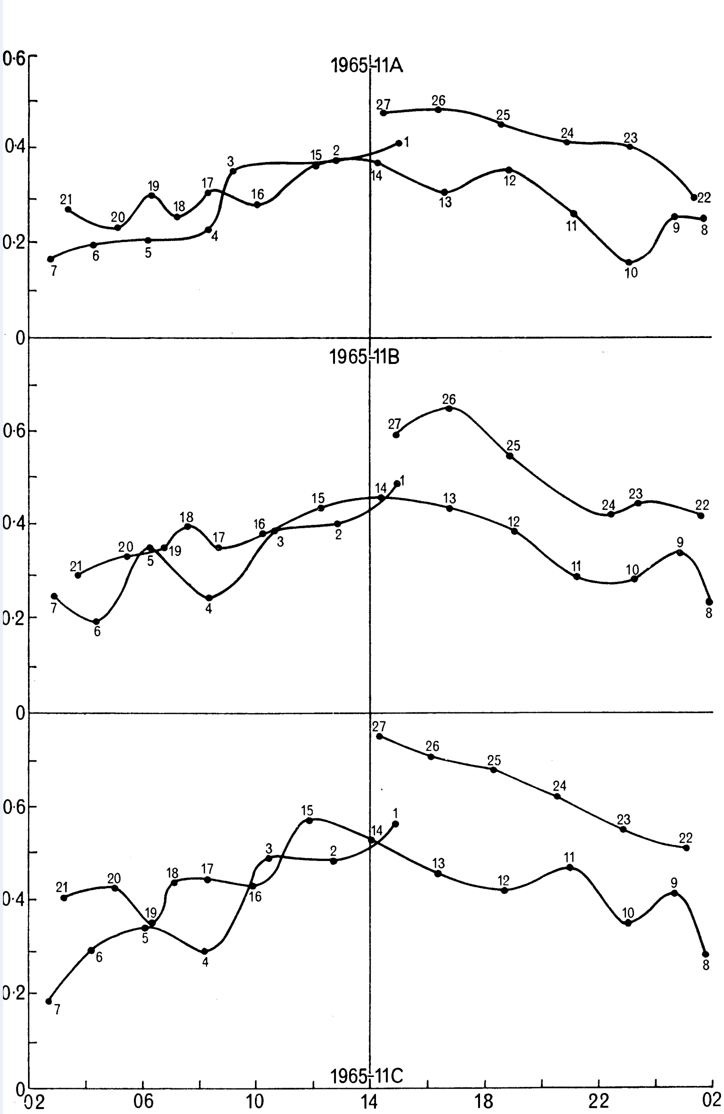

FIGURE 2. The variation of $\dot{T}$ with local time at perigee for 1965–11A, B, C satellites.

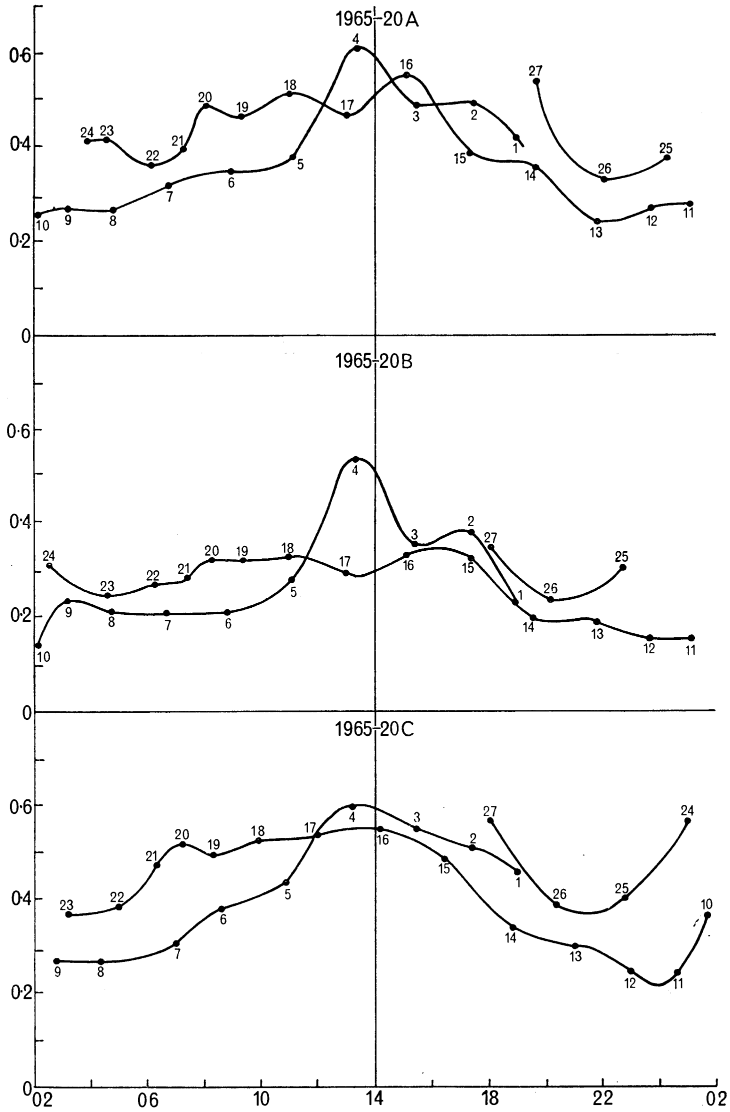

FIGURE 3. The variation of $\dot{T}$ with local time at perigee for 1965–20A, B, C satellites.

4 weeks later. If the $\dot{T}$ results in figure 1 are further smoothed so that short-period variations are removed, we see that the curves for the 1965–20 satellites are similar but displaced later by 3 to 4 weeks relative to those for the other satellites.

The position of maximum density at 280 km is thought to be about 14 h local time (Jacchia 1965) and figures 2 and 3 show the rate of change of period plotted against the local time at perigee. All six curves indicate that the maximum rate of change of period is, in fact, displaced by about 2 h from local noon, as might be expected.

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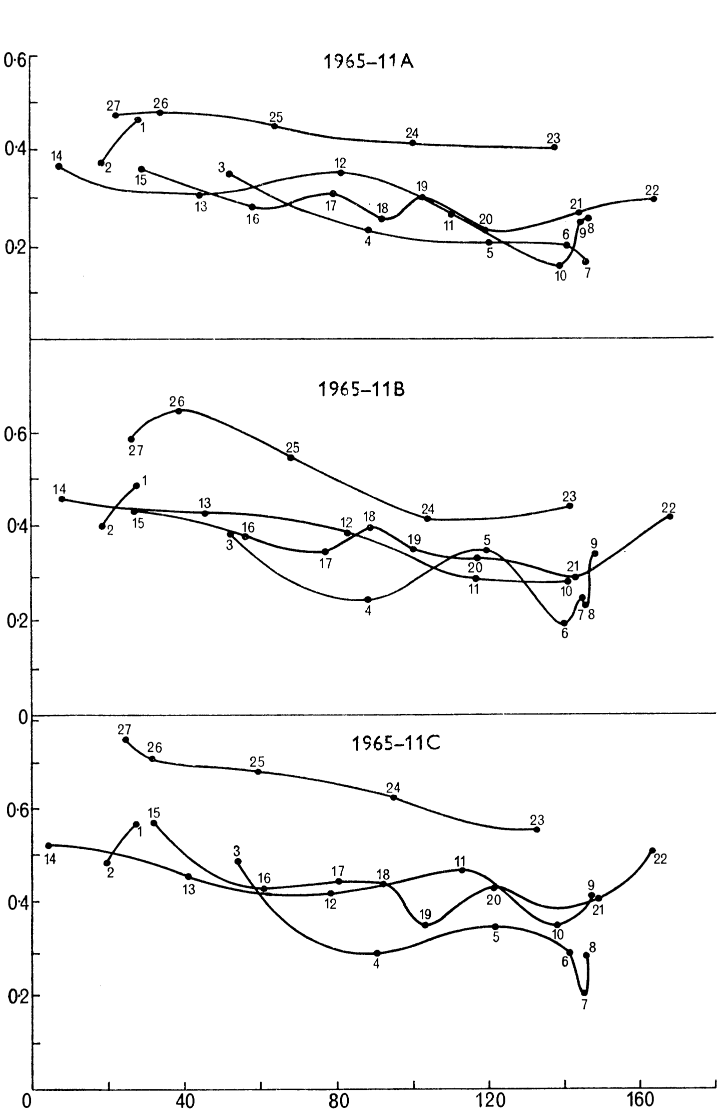
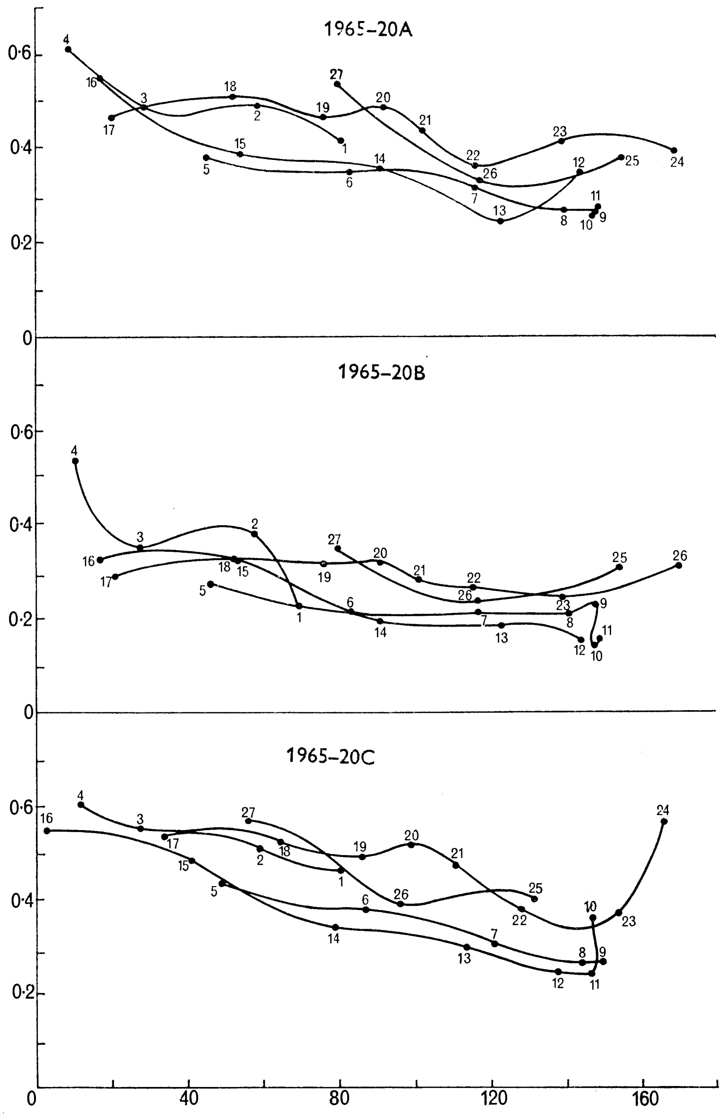
One of the difficulties of interpreting figures 2 and 3 is that they show only the effect of the longitude difference between the centre of the bulge and the perigee, and the effect of any latitude difference is obscured. For the orbits considered here, with inclinations of 56°, the perigees could be as much as 80° from the bulge position when the longitude difference





angle from perigee to a point 30° E of the Sun

FIGURE 4. Variation of $\dot{T}$ with distance from the diurnal bulge for 1965–11A, B, C satellites.

FIGURE 5. Variation of $\dot{T}$ with distance from the diurnal bulge for 1965–20A, B, C satellites.

was zero. Since it is possible that, at a fixed height, the contours of equal atmospheric density about the centre of the diurnal bulge approximate to circles or ellipses with their major axes parallel to longitude lines it would seem appropriate to plot $\dot{T}$ against the angle subtended at the centre of the Earth between the bulge centre and perigee. Figures 4 and 5 show the variation of $\dot{T}$ with this angle for the six satellites concerned; the centre of the bulge has been taken to be 30° east of the Sun (see §2) and at the same declination as the

Sun. In general, all six curves show a decrease in the atmospheric density as the angle from the centre of the bulge increases.

From figures 4 and 5 we can obtain estimates of $\dot{T}_{max.}$ and $\dot{T}_{min.}$, the maximum and minimum values of $\dot{T}$, and the ratio of these quantities. The numbers on the curves in figures 4 and 5 indicate the date-order of the observed quantities and the separation between the points is 10 days. Because the atmospheric density may have changed during the period, due to very long-term effects such as the solar cycle or semi-annual variations, it is desirable, when comparing $\dot{T}_{max.}$ with $\dot{T}_{min.}$, to compare the two ends of the same part of the curve rather than all the points at each end together. In this way we obtain the average value of $\dot{T}_{max.}/\dot{T}_{min.}$ for the six curves to be about 1·7, showing there is a variation in density from the average value of about $\pm 25\%$. This figure is only approximate, since other long-term variations, already mentioned, have been neglected. The factor of 1·7 is slightly lower than indicated by other studies (King-Hele & Quinn 1966) at a height of 280 km.

3. Conclusions

The rates of change of period of six Cosmos satellites resulting from two triple launches in February and March 1965 have been studied. The variations in air density at 280 km appear to show some correlation with geomagnetic index A_p and with 2800 Mc/s solar flux values on a few isolated occasions but not in general. Effects associated with the diurnal variation in air density are evident and indicate that the density reaches its maximum value at about 14 h local time. The amplitude of the diurnal variation at 280 km appears to be about 25% of the average value.

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