Satellite Accelerations and Air Densities at Extreme Altitudes

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Since 1962 observational studies on very high satellites have been made by means of the 24 in. reflecting telescope of the University of London Observatory. Analysis of the observations involves use of orbit elements specially provided by the Smithsonian Astrophysical Observatory (S.A.O.).

Initially our attention was concentrated on the Midas type objects; these are Agena vehicles in nearly polar and nearly circular orbits, at heights of 3000 to 4000 km. It was hoped that precise observations might show small accelerations due to air drag, though it would be necessary to resolve $\dot{P}$ to better than 1×10^{-10} for this purpose. Observations are confined to the times when the orbit does not contain shadow; for the Midas orbits these periods last roughly 3 months. The acceleration due to solar radiation pressure when the orbit includes shadow is in principle calculable—and is indeed included in routine analyses for the higher satellites, by for example the S.A.O. It is important to realize, though, that for the very high satellites this acceleration due to solar radiation pressure (s.r.p.) may greatly exceed the acceleration due to air drag. For example, even in the case of Echo 2 at a height of about 1200 km, presently (1966) $\dot{P}_{\text{s.r.p.}}$ may at times equal $\dot{P}_{\text{drag.}}$ (see Cook & Scott 1966). In the case of the small balloon satellite 1963–30D, with a mean altitude of about 3500 km and an orbital eccentricity of nearly 0·1 presently, $\dot{P}_{\text{s.r.p.}}$ may exceed $\dot{P}_{\text{drag.}}$ by a factor of 100 on occasion. Consequently one cannot extract the air drag effect from the total observed acceleration; the value of $\dot{P}_{\text{s.r.p.}}$ is not known to an accuracy of 1 % for various reasons—neither the area/mass ratio for the satellite is known to this accuracy, nor is the reflexion coefficient. Therefore, one must confine the investigations of air drag effects to the all-in-sunlight phases (or, possibly, use very nearly circular orbits, for which $\dot{P}_{\text{s.r.p.}}$ is much reduced; but unfortunately the balloon satellites' orbits rapidly depart from initially small eccentricities through s.r.p. perturbations).

Even if the investigations are limited to the all-in-sunlight phases other problems remain, not yet wholly resolved. Some perturbations other than those due to s.r.p. may compete with air drag to produce real accelerations, i.e. real changes in orbital energy. Coulomb charge drag may be detectable, though probably not for the large balloon satellites. Electro-magnetic drag forces might also be detected for very large balloon satellites, at large heights, as suggested by Drell, Foley & Ruderman (1965), but it seems likely that none of the satellites currently studied reveal this effect, with the possible exception of the Echo-type satellite Pageos 1, at a mean altitude of 4200 km. The accelerations (both positive and negative) due to terrestrial radiation pressure have been discussed by Shapiro (1963) and Wyatt (1963); for the high balloon satellites studied in our programme it seems possible that terrestrial radiation pressure may contribute to a significant extent, though the average effect is much reduced during the all-in-sunlight phases due to the geometry then of the orbit plane relative to the Sun. Other possible sources of real accelerations are discussed also by Shapiro (1963); it seems unlikely that the remaining effects are significant at present.

One important problem does not yet appear satisfactorily resolved; the orbital period which correctly represents the actual total orbited energy needs defining. The anomalistic period is clearly not useful, as it contains 'spurious' accelerations arising from the non-uniform precession of perigee (the latter motion is produced largely by s.r.p. for the balloon satellites). Until now we have used (Fea 1965) a method closely similar to that employed by the S.A.O. (see, for example, Jacchia & Slowey 1963); that is, one uses the quantity $(M+\omega)$ instead of M, in deriving the mean motion and the corrected anomalistic period and its variations, M being the mean anomaly and ω the argument of perigee. This is, however, an approximation and a more correct approach is probably that followed by Smith (1965), from considerations of total angular momentum; a modified relation giving the mean nodal period in terms of the observed anomalistic period and other elements has also been given by D. E. Smith (1966, private communication). However, recent observations made on the satellite 1963–30D show accelerations which suggest that the orbital period may still not be correctly defined; for example, the values of $\dot{P}$ during this series (November 1965 to January 1966) show a clear correlation with values of $\ddot{\omega}$. Use of either the corrected anomalistic period or of the mean nodal period gives roughly the same values of $\dot{P}$. Other perturbations than air drag may be present but it seems quite possible that the effect arises from an incorrect definition of the period. The values of $\dot{P}$ also are strongly positive for part of this series.

To make a comparison with an earlier derivation of air density at 3500 km from observations of the 1963–30D satellite (Fea 1965, and a further discussion of densities and scale heights to 3500 km by Fea 1966) data were obtained from the S.A.O. on the Pageos 1 satellite during its first month of life (July, 1966). The corrected anomalistic period and its rate of change indicates an average air density about three times that given by G. Kockarts (1966, private communication) from recent model calculations. This may indicate: (i) the models do not represent the hydrogen exosphere accurately; (ii) some other source of drag (electro-magnetic drag?) is significant; (iii) the incorrect definition of orbital period vitiates the results.

These studies of the 1963–30D and Pageos 1 satellites continue, both observationally and with regard to the interpretation of the observed accelerations. A possible correlation of short-term variations in $\dot{P}$, for 1963–30D, with 10·7 cm solar flux data for November and December 1965 provides a further stimulus. It is also of interest to investigate the existence of the semi-annual variations in density at these extreme heights.

Note added. Recent work by D. E. Smith (1966, private communication) suggests that the usual assumption that $\dot{P}_{\text{s.r.p.}}$ is zero during all-in-sunlight periods may not be strictly correct when $\dot{P}$ is of order 10^{-8}. However, this effect does not seem to account for more than a small part of the observed anomalies.

References (Fea)

Cook, G. E. & Scott, D. W. 1966 *Planet. Space Sci.* **14**, 1149.
Drell, S. D., Foley, H. M. & Ruderman, M. A. 1965 *J. Geophys. Res.* **70**, 3131.
Fea, K. 1965 *Planet. Space Sci.* **13**, 1289.
Fea, K. 1966 *Planet. Space Sci.* **14**, 291.
Jacchia, L.G. & Slowey, J. 1963 *Smithson. Contrib. Astrophys.* **8**, 1.
Shapiro, I . I. 1963 *Dynamics of satellites* (edited by M. Roy), p. 257. Berlin: Springer-Verlag.
Smith, D. E. 1965 *Planet. Space Sci.* **13**, 1283.
Wyatt, S. P. 1963 *Dynamics of satellites* (edited by M. Roy), p. 180. Berlin: Springer-Verlag.