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AN UNPREDICTED PERIOD IN THE ORBITAL MOTION OF THE ALOUETTE I ARTIFICIAL EARTH SATELLITE

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Abstract—Analysis of the orbital elements of the Alouette I artificial Earth satellite has yielded a variation with an approximately 91-day period in the inclination, the regression of the nodes, and in the time derivative of the argument of perigee. These periodic variations are additional to periodic variations of the elements due to harmonics of the Earth's gravitational field. In analogy to the case of other satellites whose orbits are more suited to mathematical analysis, it is likely that the 91-day periodic variations are to be attributed to solar gravitational attraction.

Approximately 3 years of successful operation of the Alouette I satellite have produced a series of orbital observations long enough to permit identification of periodic variations whose amplitude is only slightly above the "noise level". This note deals with periodic variations of the orbital inclination and certain other parameters which had not been predicted and which were discovered accidentally in the course of other work.

The position of Alouette I is determined by the Minitrack stations of NASA from interferometric measurements of its radio beacon emission. The data so obtained are believed to be free of periodic errors. Orbital elements for successive epochs are computed at Goddard Space Flight Center, Washington, D.C., and sets of bi-weekly projected ("interim definitive") elements are published routinely with the so-called World Maps, that is the tables of the hourly positions of the satellite.

Alouette I is in a nearly circular orbit at an altitude of approximately 1000 km (perigee 996 km, apogee 1031 km, eccentricity 0·00250). Owing to this high altitude and the massiveness of the satellite body (cross-section to mass ratio $A/M \approx 0{\cdot}011$ m²/kg) environmental influences, especially air drag and photon pressure drag, can be expected to be negligible. This is born out by the fact that the observed orbital period of 105·41 min has been very constant and has shown an overall decrease of only 0·25 sec in 2 years, corresponding to a 0·0026 per cent loss of the energy.

The orbital properties of such a drag-free satellite can be expected to correspond, to a good approximation, to those predicted by the formulas of King-Hele,[1] obtained from an analysis of the motion of near-Earth satellites which takes into account the various harmonics of the Earth's gravitational field under the assumption of negligible perturbation by drag or gravitational attraction by other celestial bodies. For the near-polar orbit of Alouette I with inclination $i = 80°{\cdot}5$ and the given altitude and (small) eccentricity, one obtains a regression $d\Omega/dt$ of the nodes of 0·984 degrees per day and a variation of the argument of perigee ω (rotation of the orbital plane) with a period of 140 days. Both these theoretical results are in agreement with observation.

The theoretical orbits obtained on the basis of King-Hele's work have constant inclination and eccentricity: in fact constant inclination and eccentricity are basic assumptions to the analysis. When it was noticed that the values for the inclination of Alouette I varied periodically (see below) it was at first suspected that this discrepancy with theory was due to periodic observational, or residual computing errors. It was however definitely established that errors of this type and magnitude were not present.[2] Obviously, therefore, a different approximation to the motion in the Earth's gravitational field had to be applied, or perturbing forces had to be taken into account, or both.

Figures 1–3 give, plotted against time, the orbital elements of Alouette I that show periodic variations. Figures 1 and 2 are based on the bi-weekly projected values given in the World Maps. Figure 3 presents the original values, determined about once a week from the observations, which were made available privately. The periodic variations are seen most distinctly in the projected values, but they are also discernable in the original data.

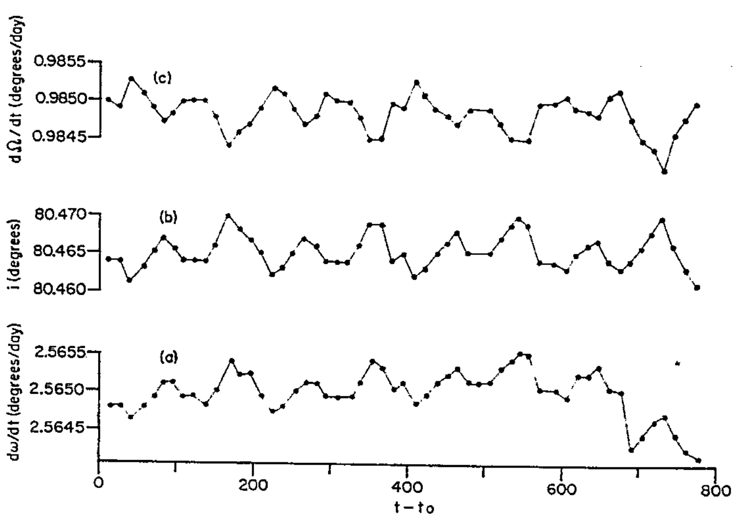

FIG. 1. (a) DAILY INCREMENT OF ARGUMENT OF PERIGEE $d\omega/dt$ (DEGREES PER DAY), (b) INCLINATION i (DEGREES), (c) DAILY INCREMENT OF RIGHT ASCENSION OF NODE $d\Omega/dt$ (DEGREES PER DAY), AS FUNCTIONS OF TIME SINCE LAUNCH IN DAYS. (PROJECTED VALUES.)

The curves fall into two groups, one varying with a period of 140 days, the other with a period of 91–92 days, perhaps a quarter of a year. The former period, 140 days, is the period predicted by the King-Hele theory for the variation of the argument of perigee ω. It also occurs, as observation shows, in the eccentricity, both as fundamental and second harmonic. The period of approximately a quarter of a year is shown by the inclination i, the regression of the equatorial nodes $d\Omega/dt$ and by the time derivative $d\omega/dt$ of the argument of perigee.

The three curves of Fig. 1 correspond to each other in detail, within the accuracy of the computated values. The curve for the daily increment of the right ascension of the ascending node is phase shifted by half a period against the other two.

Kozai[3] approaches the problem of satellite motion in the Earth's gravitational field by a method different from that of King-Hele. If one applies this method to the orbit of Alouette I one obtains for both eccentricity and inclination a time variation with a period of 140 days. As far as the eccentricity goes, this theoretical result agrees with observation (Fig. 2). This is not the case for the inclination for which a variational period of $\sim$91 days is observed. However the theoretical 140-day variation of the inclination has an amplitude of only $\sim 0^\circ{\cdot}0005$, while the amplitude of the observed $\sim$91-day variation is $\sim 0^\circ{\cdot}004$. A periodic variation with an amplitude of only $0^\circ{\cdot}0005$ could not be discerned in the data—in

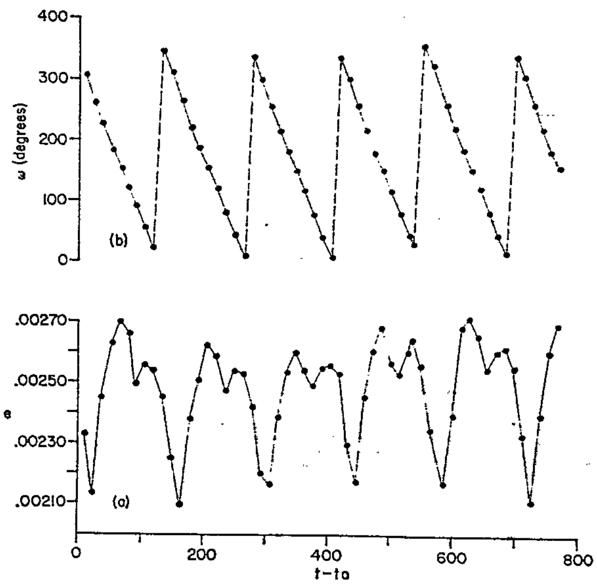

FIG. 2. (a) ECCENTRICITY e, (b) ARGUMENT OF PERIGEE ω (DEGREES), AS FUNCTIONS OF TIME SINCE LAUNCH IN DAYS. (PROJECTED VALUES.)

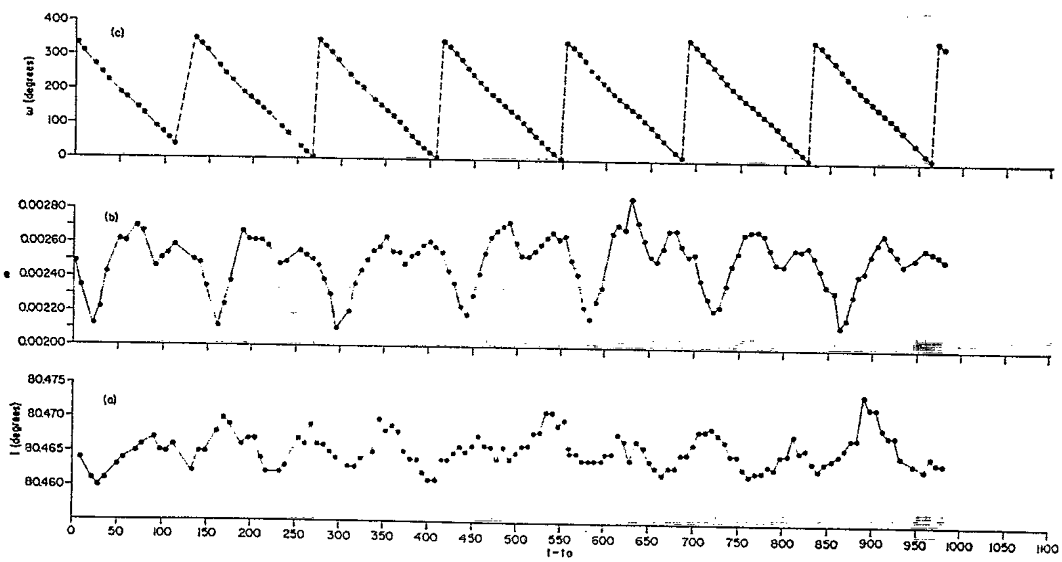

FIG. 3. (a) INCLINATION i (DEGREES), (b) ECCENTRICITY e, (c) ARGUMENT OF PERIGEE ω (DEGREES), AS FUNCTIONS OF TIME SINCE LAUNCH IN DAYS. (VALUES DETERMINED FROM OBSERVATIONS.)

the projected values (Fig. 1b) because of lack of accuracy, in the directly derived values (Fig. 3a) because of the amplitude of the irregular fluctuations.

Apparently, therefore, the 91-day period in the orbital inclination cannot be accounted for by the effect of the non-spherical gravitational field, but must be due to some extraneous perturbation. Murphy and Felsentreger,[4] in order to identify the physical cause for the variation in the inclination of Alouette I and other satellites not affected by air drag, have analyzed the effect of solar and lunar gravitational attraction and solar radiation pressure on the orbits of such objects. In the cases of the satellites Relay I and Telstar 2, they have successfully accounted in this way for the observed variation in the inclination. For the Alouette I orbit however, according to this analysis, these effects, more particularly the solar gravitational attraction can, at best, account only for half the observed amplitude of the variation in inclination.

The discrepancy between the observed and the theoretical amplitude in the variation of the inclination does not necessarily mean that the effect is not mainly, or wholly, due to the solar gravitational attraction. Brouwer's[5] solution of the problem of an artificial satellite without drag which was used by Murphy and Felsentreger, becomes less accurate when applied to satellite orbits with very small eccentricity, like Alouette I. Further, the analysis of the Alouette I orbit is complicated by the presence of resonances, for instance the coincidence between the period of nodal regression and the solar year.

It is not impossible that more reliable results for the solar gravitational effect on the Alouette I orbit could be obtained by making use of Lyddane's extension[6] to the case of small eccentricity of Brouwer's analytical methods. The attempt has not been made so far. It is not certain that it would be successful on account of the resonances mentioned above.

It is interesting to note that the period of 91 days or a quarter of a year which is observed in the inclination and in the regression of the nodes and the time derivative of the argument of perigee is commensurate with the period of one year of the nodal regression and of the motion of the Earth about the Sun.

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Резюме—Анализ орбитальных злементов искусственного спутника Земли «Алуэтт I» обнаружил изменение с прибл. 91-дневным периодом в наклонении, в регрессии узлов и в производной времени независимой переменной перигея. Такие периодические изменения дополнительны к периодическим изменениям, обусловленные гармониками гравитационного поля Земли. По аналогии с примером других спутников, орбиты которых более подходящи для математического анализа, возможно, что 91-дневные периодические изменениям огут быть отнесены за счет гравитационного солнечного притяжения.

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