Orbits Determined at the Royal Aircraft Establishment from Visual Observations: A Brief Review

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Orbits determined at the Royal Aircraft Establishment from visual observations: a brief review

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In orbital determinations at the Royal Aircraft Establishment special attention has been given to low-perigee satellites, with perigee height of 150 to 300 km, because few accurate orbits are available for such satellites. The observations used have been mainly visual. The significance of the main results is discussed.

1. Introduction

Most people who are not immediately concerned with the subject probably believe that the best possible orbits are determined for all satellites, on the basis of all available observations. Unfortunately this is very far from the truth. Only a selected few satellites have well-determined orbits, and from the view-point of the orbital analyst interested in the upper atmosphere, the selection is not very satisfactory. Minitrack observations are used by N.A.S.A. to determine accurate orbits for their scientific satellites (about 35 in number). The Baker-Nunn camera observations are used by the Smithsonian Astrophysical Observatory to determine accurate orbits for their satellites, about 25 in number. Accurate orbits are also determined from Doppler tracking by the Applied Physics Laboratory at Johns Hopkins University for a few satellites (less than 10).

The snag is that nearly all these satellites are in high orbits, relatively unaffected by air drag; only four of them have perigees lower than 300 km. These orbits are therefore valuable for studies of the Earth's gravitational field and some are useful for studies of air density at high altitudes. But anyone wishing to study the atmosphere below 300 km has to look elsewhere for suitable orbits.

What is to be found elsewhere? Orbits for nearly all satellites are available in the form of the five-card elements issued by the United States Air Force. These orbits are intended to be accurate enough for prediction, and they are in fact remarkably good, but they are not orbits determined in retrospect from all available observations. These Spacetrack orbits, as they are often called, can be very useful for studies of air density over time intervals of several days; but they are not accurate enough for gravitational field studies, and are of marginal accuracy in determining the rotational speed of the upper atmosphere from changes in the orbital inclination.

If the atmosphere in the important height range of 150 to 300 km is to be properly studied, accurate orbits for the many low-perigee satellites are needed, and if their orbits are not determined the geophysical information they could yield will be lost. So, in our orbital determinations at the Royal Aircraft Establishment, which began on a regular basis about 3 years ago and have been under the direction of R. H. Merson, we decided to concentrate attention on low-perigee satellites (though we also undertook to provide orbits for Ariel 1 and Ariel 2 from Minitrack observations). Very few of the low-perigee satellites have transmitted radio signals, so in general there are no Minitrack or Doppler observations;

and they are not S.A.O. objects, chiefly because they are difficult to predict well enough for the Baker-Nunn cameras to be sure of seeing them. Consequently, we have, up to now, had to rely mainly on visual observations, backed up by kinetheodolite observations, many of them photovisual.

2. The difficulties

We therefore began with the following disadvantages:

(1) Most of the satellites were not being regularly observed as part of a pre-arranged programme, and there was no guarantee that enough observations would be available.

(2) Observations were confined to rather limited and random geographical areas, chiefly Europe, and orbital coverage was usually poor.

(3) Most of the observations in 1961–63 were not as accurate as the Baker-Nunn or Minitrack observations.

(4) Low-perigee orbits are much more difficult to determine than drag-free orbits, which virtually dig a groove in the sky for themselves. Far more observations are needed for low-perigee satellites, whereas there are usually fewer available.

3. The satellites studied

We have selected satellites in many different kinds of orbit, to discover which orbits could be determined most accurately, and therefore which satellites were best worth observing. We also wished to assess the accuracy of visual observations and to test the orbital determination program in a variety of circumstances. So the orbits studied have been varied, from near-circular to highly eccentric, having inclinations from polar down to 48°. Several orbits have also been determined from Minitrack observations to provide a standard for comparison. The eleven Reports so far published are marked by asterisks in the list of References, p. 110. Here I shall merely pick out the most significant findings from them.

4. Results

4·1. *Coverage of the orbit*

In the orbits so far determined, most of the observations have been from Europe, including Russia; there are fewer observations from Moonwatch teams because they were observing mainly S.A.O. objects. Usually the coverage has been between 10 and 20% of the orbit. The orbits would be much more accurate if a wider coverage could be secured, as will be shown in more detail in the next paper (D. W. Scott & D. H. D. Warren, this volume, p. 111).

4·2. *Accuracy of the observations*

One aim of these studies was to check the accuracy of the visual observers. With very low orbits the residuals from good observers were found to be about 5′, but it was clear that this was due partly to timing errors and partly to the orbit itself not being accurate enough.

In the last 6 months we have been obtaining residuals for satellites with low perigees and high apogees observed near apogee, where they are slow-moving. These residuals show that many observers are achieving directional accuracies from 1 to 2′, as shown in table 1.

TABLE 1. RESIDUALS (AVERAGE UNDER BEST CONDITIONS) FOR STATIONS WITH MOST OBSERVATIONS

V = visual; K–T kinetheodolite.

station		no. of observations used	residual (*a.b.c*)
1962 $\beta\kappa$ (Sept.–Oct. 1965)			
Cowbeech	V	8	2·0′
Farnham	V	19	0·9′
Hanwell	V	11	2·5′
Herstmonceux	K–T	15	1·3′
Malta	K–T	29	0·9′
Oceanport	V	9	2·5′
Sacramento	V	19	1·7′
Thames Ditton	V	19	1·3′
1962 $\beta\tau 6$ (Aug. 1963–Oct. 1965)			
Cowbeech	V	19	1·3′
Earlyburn	K–T	40	0·4′
Farnham	V	26	1·3′
Herstmonceux	K–T	22	0·5′
Kessel-Lo	V	15	1·7′
Mountcastle	V	20	1·1′
Phoenix	V	15	5·0′
Thames Ditton	V	15	0·7′

The a.b.c. residual is the ‘average under best conditions’, and is the arithmetic mean of the best 70% of the observations from any particular station. This criterion has been introduced (Scott 1966) because observers are encouraged to work on cloudy and misty nights when faint stars cannot be seen, and the observer’s accuracy is therefore not so good. The r.m.s. residual gives undue weight to these inferior observations.

Table 1 shows that some visual observers already achieve a directional accuracy as good as Minitrack and field-reduced Baker-Nunn observations, and are almost as good as kinetheodolites. So if the coverage of the orbits can be improved, the orbital elements obtained from visual observations could be almost as good as those from Minitrack and field-reduced Baker-Nunn observations.

4·3. *The best satellites to observe*

The orbits so far determined have shown, as was expected, that if an accurate value of orbital inclination is to be obtained, it is necessary to have observations near apex, and preferably right under apex. This was very strikingly shown (Merson & Sinclair 1964) by Transit 1B, for which the inclination was obtained with an accuracy of 0·002° from a rather small number of observations in 1962, which were not as accurate as many recent observations. On the other hand, the inclination of a nearly-polar satellite not observed near the pole, such as Samos 2, is rather poorly determined (Merson & Neville 1966), with an accuracy of 0·01 to 0·02°.

Another unsatisfactory situation arises when a low-perigee satellite is observed at perigee. The main disadvantage is the very short visibility time, which makes the satellite difficult to observe visually, except on a very few days, and often there are not enough observations. When observations are made, they are frequently less accurate than usual, because the sky is not quite dark or because the satellite is fast-moving.

From the viewpoint of British observers, at latitudes 50° to 56°, the ideal satellite would be at an inclination of about 56° with a reasonably high apogee. This has the advantages that the inclination should be well determined and that the north-bound and south-bound spells of visibility tend to merge. The ideal satellite would also be a fairly bright one, because, now we know that the directional accuracy of visual observers can be so good, it is worth trying to observe out to quite great distances, certainly 3000 km at least; if the satellite is to be observed at this distance, it must be fairly large. At the moment the rocket of Cosmos 54, 1965–11D, is the satellite most nearly conforming to this specification.

For studies of changes in orbital inclination, which reveal the rotational speed of the upper atmosphere, we require satellites which show a substantial change in orbital period. This fits in well with the other requirements, for it means that we need satellites with low perigee and high apogee. It is for this purpose that satellites 1962 $\beta\kappa$, 1962 $\beta\tau 6$, 1966–51A and 1965–11D are being given high priority at present.

4·4. *Geophysical uses*

When the orbital determinations of low-perigee satellites began, we envisaged that the main geophysical use would be in determining air density and its variations, and in finding the scale height of the upper atmosphere. The orbits are useful for this purpose, but other geophysical applications have also emerged. In particular the change in the orbital inclinations of some of these satellites can show the rotational speed of the upper atmosphere (King-Hele & Scott 1966), and now we also feel confident that the orbits will soon be contributing to the determination of the zonal harmonics in the Earth's gravitational field. The reason for this is that in the determination of zonal harmonics the emphasis has now shifted towards high-degree harmonics, and these have much more influence on a low satellite than on a high one. So low satellites will have to be used if further progress is to be made. For example, the effect of the zonal harmonic of degree 21 falls off as the 19th power of the distance from the Earth's centre and therefore has 7 times more influence on a satellite at 300 km height than on a drag-free satellite at 1000 km.

5. CONCLUSION

Several of the disadvantages of visual observations mentioned in previous paragraphs are now being overcome. Observations from the southern hemisphere have been much more satisfactory in the last few months, chiefly because adequate predictions are now being provided. In the last few months also we have been obtaining radar observations in the daytime from Malvern on south-bound transits of low-perigee satellites observed visually on north-bound transits at night; this should greatly improve the coverage and accuracy. Observations on low-perigee satellites are now being made by the Hewitt cameras: this too should improve the orbital accuracy a great deal. More visual observers are now being supplied with accurate stopwatches and optical aids: this should improve their accuracy and their ability to keep track of faint satellites. Finally, we have the new orbit determination program PROP (Merson 1966), for use on a much faster computer: this can utilize radar range measurements and therefore give better orbits, as well as determining them more rapidly.

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(For explanation of the asterisks, see page 107)

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