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by

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SUMMARY

The definitive orbit for Ariel 2 (1964-15A) is computed, from Minitrack observations, for a period of twelve months from the launch of the satellite. The orbit is described by a model with eight orbital parameters and these parameters are listed at every twenty-fifth nodal passage. The angular observations are accurate to about 1' and, as a result, the average computed standard deviations of the eight fitted orbital parameters are as follows: 1 m in semi-major axis, $10^{-5}$ in eccentricity, 2" in inclination, 4" in right ascension of the node, 30" in argument of perigee, $0^{s}.03$ in time at the node, and 0.001 deg/d$^2$ and 0.001 deg/d$^3$ in the linear and quadratic coefficients occurring in the mean motion polynomial.

Ephemerides computed from the listed orbital parameters will be accurate to about $\frac{1}{2}$ km, the accuracy required by the Ariel 2 experimenters. Limitations which prevent the accuracy from being better than this are discussed.

Departmental Reference: Space 122

CONTENTS

## 1 INTRODUCTION

Ariel 2 is the second of the series of satellites being launched in the scientific programme based on Anglo-American co-operation. As with Ariel 1, the first of the series, the satellite was constructed and launched by the U.S. (NASA). Whereas British responsibility for Ariel 1 was confined to the scientific experiments (including telemetry data analysis), for Ariel 2 it has been extended to the determination of definitive orbital parameters. Responsibility of the U.K. will continue to grow for the third satellite of the series, at present styled U.K.3 and due to be launched early in 1967, since this will be the first spacecraft actually to be built in Britain.

Three experiments constituted the scientific payload of Ariel 2, each sponsored by a scientific establishment in the U.K.: measurement of galactic noise by the Mullard Radio Astronomy Laboratory, Cambridge; measurement of micrometeorite flux and particle sizes by the Nuffield Radio Astronomy Laboratory, Jodrell Bank; and measurement of atmospheric ozone by the Meteorological Office, Bracknell. The satellite, known before launch as S.52 or U.K.2 and after launch as Ariel 2 or 1964-15A, was successfully placed in orbit at 17.25 UT on 27th March 1964 from the NASA Wallops Station, Virginia, by a four-stage solid-propellant rocket. The experiments continued to work until the end of September 1964, by which time the spin rate of the satellite was too low for useful data to be obtainable.

Tracking data have been provided by the Minitrack network of NASA (STADAN)[1]. The first observations were from Lima, Peru, within 4 hours of the time of launch, and data are still (November, 1965) being obtained from the network, though it is expected that NASA will officially terminate the project in the near future. The data have been analysed in Space Department, R.A.E., and the main purpose of this Report is to tabulate the orbital parameters derived. These parameters have been calculated by use of the standard programmes[2,3] for the Pegasus computer and are given at intervals of 25 ascending nodes (about 1¾ days). Computation of orbital parameters was stopped after the orbit had been analysed for twelve months.

## 2 MINITRACK OBSERVATIONS

The STADAN network consists of a dozen Minitrack stations distributed as shown in Fig.1. The inclination of the Ariel 2 orbit being too low for data from Alaska, observations were obtained from the eleven stations listed in Table 1. The Table gives latitude, longitude and height relative to the Fischer ellipsoid[4], the currently best world-wide geodetic datum. Also given are the number of observations used from each station.

A total of about 3700 observations has been used over the twelve month period, corresponding to about ten per day. Of these, about 100 were rejected during analysis due to the size of residuals, but some of the rejections were due to incorrect punching of tapes before analysis so the data are in fact very reliable.

An accuracy of the order of a millisecond is claimed for the quoted times of observations, and time errors have been ignored in the analysis. Experience with Ariel 1 showed[5] that the angular accuracy is effectively about 1 minute of arc and this value was used in the analysis. It covers errors in the basic interferometer measurements, ionospheric refraction correction, station co-ordinates and orbital model, and can also be regarded as incorporating the explicitly ignored time errors.

For the first 36 hours after launch, observations with elevations as low as $20^\circ$ were made and have been used to obtain the first set of orbital parameters. To minimise unknown refraction errors, data made available after this initial short period have been confined to observations with high elevations; more than half the observations have had elevations greater than $80^\circ$ and there have been only four with elevations less than $60^\circ$.

The coverage of each interferometer essentially consists of a pair of narrow fans in the vertical plane, one north-south and the other east-west, only one being used on a given pass. For this reason the azimuths of most observations have been close to $0^\circ$, $90^\circ$, $180^\circ$ or $270^\circ$. A station supplies, for a given pass, one or two observations. If there are two, since they are both in the same narrow fan, they are only about 10 to 15 seconds apart in time.

## 3 ANALYSIS OF THE OBSERVATIONS

### 3.1 Dynamic model of the orbit

The analysis has been carried out using the standard R.A.E. orbit improvement technique[2,3] based on Merson's smoothed elements[6]. The orbital model chosen for Ariel 2 has twelve parameters associated with each of the epochs defined by every 25th ascending node. Eight of the twelve parameters are determined by differential correction of approximate values; these eight are: $a_o$ (semi-major axis), $e_o$ (eccentricity), $i_o$ (inclination), $\Omega_o$ (right ascension of the defining node), $\omega_o$ (argument of perigee), $t_o$ (time at the defining node) and the parameters $n_1$ and $n_2$ such that the mean motion at time t is given by:-

$$n = (\mu/a_o^3)^{\frac{1}{2}} + n_1(t - t_o) + n_2(t - t_o)^2 ,$$

where $\mu = 398\ 602\ km^3/sec^2$. The remaining four parameters - denoted by $e_1$, $i_1$, $\Omega_1$ and $\omega_1$ - give time-linear contributions to e, i, $\Omega$ and $\omega$; unlike $n_1$ and $n_2$, they are not fitted to the observations but are given pre-calculated values. They represent drag, luni-solar and earth-gravity ($J_3$, $J_4$ and $J_2^2$ terms) perturbations of the orbit, and are valid for only two or three days each side of the epoch $t_o$. It must be emphasised that $\Omega_1$ and $\omega_1$ do not include the large secular terms which arise from the $J_2$ perturbation; these are automatically allowed for by the model. Similarly, $e_1$ does not represent the main variation of e due to drag, this being allowed for through the parameter $n_1$. Some printed sets of parameters have been circulated in which coefficients $\Omega_2$ and $\omega_2$ were included in addition to $\Omega_1$ and $\omega_1$. However their values were so small as to be quite without significance (see also Section 5).

Ref.3 gives the complete set of formulae by means of which geocentric position is computed from the twelve orbital parameters. They differ from the formulae of the original Pegasus programme[2] in two respects. First, the position of the satellite at time t is computed as if the time was actually $t + \delta t$ where

$$\delta t = 0.088 \sin 2 (\theta - \Omega - 18^o) \text{ sec} ,$$

$\theta$ being the sidereal time. This formula gives a first-order approximation to the 12-hour along-track oscillation of the satellite caused by the tesseral harmonics - in particular by $J_{2,2}$ - of the earth's gravitational field. Further details are given in the Appendix. Naturally, the topocentric position of the satellite is found by taking the station co-ordinates (in space axes) at the true time t.

The other divergence from the formulae of the original Pegasus programme is that a term has been introduced into the expression for mean anomaly, M, associated with the parameters $\Omega_1$ and $\omega_1$. The full formula for M is

$$M = M_o + (n_o - \omega_1 - \Omega_1 \cos i_o)(t - t_o) + \tfrac{1}{2} n_1 (t - t_o)^2 + \tfrac{1}{3} n_2 (t - t_o)^3 ,$$

where $M_o$ is determined from $e_o$ and $\omega_o$; t is taken, of course, to include the 12-hour $\delta t$ term already mentioned. $n_o$ denotes $(\mu/a_o^3)^{\frac{1}{2}}$ and the formula for n given earlier is not affected.

## 3.2 Computer operation

From the receipt of observations from NASA to the generation of a given set of definitive orbital parameters, there are seven programmes which have to be run on the Pegasus computer. Allowing for the fact that the differential correction programme is used twice, the seven programmes correspond to eight operating stages as listed below. The first two stages apply to the observations in general and the remaining six to the analysis at a particular node.

(i) The direction cosines, of which the data consist, are punched on paper tape; they are converted to azimuth and elevation by the computer, which provides output in a form suitable for re-input with the next programme.

(ii) Observations, sometimes several hundred at a time, are stored on the Ariel 2 M.T.L. (magnetic tape library).

(iii) The initial parameters at a given node are predicted by extrapolation from the definitive parameters 25 nodes before (except for the first definitive node when NASA estimates are used).

(iv) About 30 observations, chosen by the operator for the analysis at the given node, are transferred from the M.T.L. to an Ariel 2 S.D.T. (selected data tape); some preliminary processing is incorporated in the selection programme.

(v) A single iteration of the main differential correction programme is run; the parameters - and in particular $n_1$ - are then sufficiently accurate for the next stage.

(vi) Contributions to $e_1$, $i_1$, $\Omega_1$ and $\omega_1$ due to gravity ($J_3$, $J_4$ and $J_2^2$ terms) and drag perturbations are found; these are functions of the orbital parameters and the drag terms depend on $n_1$.

(vii) The luni-solar contributions to $e_1$, $i_1$, $\Omega_1$ and $\omega_1$ are found and added in.

(viii) As many further iterations as necessary (normally two) of the differential correction programme are run, $e_1$ etc being held fixed; after the last iteration the standard deviations of $a_o$, $e_o$, $i_o$, $\Omega_o$, $\omega_o$, $t_o$, $n_1$ and $n_2$ are obtained.

Stage (ii) requires virtually the same computer time - about 40 min - irrespective of the number of observations involved (within the capacity of the M.T.L.). For the other stages the average times at the computer, based on a set of 30 observations, are as follows: for stage (i) 5 min; for (iii) 2 min; for (iv) 8 min; for (v) 15 min; for (vi) 1 min; for (vii) 1 min; for (viii) 30 min. Thus the total computing time for the analysis at each node worked out at about 70 min under ideal conditions. An actual average was nearer 90 min allowing for delays due to the rejection of observations etc. The time away from the machine, including a little more than 1 hr for punching 30 observations, was about another 90 min. Since analysis was conducted at 210 different nodes the routine work required grand totals of about 320 Pegasus hours and 650 man hours.

### 3.3 Miscellaneous points

Times of observations were provided relative to the WWV time transmissions from America. Since the experimenters were using telemetry data relative to WWV it was decided not to correct to any of the standard time systems (universal, ephemeris or atomic time). If it is so desired, the orbital parameters in this paper may be corrected to datum UT2 as follows, only $\Omega_0$ and $t_0$ being affected: to $t_0$ add the time (in seconds) by which WWV is slow on UT2; to $\Omega_0$ add $0^{\circ}.004 \times$ (UT2-WWV) where the time difference is in seconds.

The analysis at each defining node has used about 30 observations, spanning a period of 3 to 4 days centred on the node. Since the defining nodes are only $1\frac{3}{4}$ days apart there is considerable overlap, about half the observations being used twice. This was done deliberately since in any application of the 'fitting by moving arcs' method a narrow overlap is a source of inaccuracy. Accuracies actually obtained during the periods of overlap are considered in Section 5.

A difficulty arose in the analysis of the same observations at two different nodes since WWV time was set back $0^{s}.1$ at 1965 January 1.0. Each observation close to this time of discontinuity had to be duplicated in the library of Ariel 2 observations, once with the original observation time and again with an adjusted time, the observation selected depending on whether the defining node used was, respectively, the same side of the discontinuity as the observation or the opposite side.

## 4 RESULTS

Orbital parameters for Ariel 2 are listed in Table 2. Successive columns of the Table are as listed below, zero suffixes being omitted for convenience.

Node number, m

Date

Time

Semi-major axis, a (km)

Eccentricity, e

10000 $e_1$, with $e_1$ in units/100 days

a (1 - e)

Inclination, i (degrees)

100 $i_1$, with $i_1$ in degrees/100 days

Right ascension of the node, $\Omega$ (degrees)

100 $\Omega_1$, with $\Omega_1$ in degrees/100 days

Argument of perigee, $\omega$ (degrees)

$\omega_1$ (degrees/100 days)

Mean anomaly, M (degrees)

Mean motion, n (degrees/100 days)

$n_1$ (degrees/(100 days)$^2$)

$10^{-2}$ $n_2$, with $n_2$ in degrees/(100 days)$^3$

Number of observations used, N

Extent of the observations, D (days)

Standard deviation of an observation of unit weight, $\varepsilon$

Modified Julian Day representation of date/time, MJD.

The nodes are numbered such that m would have been zero at a fictitious node half an hour before launch. The quantities a(1 - e), M and n are useful derived parameters. Although a(1 - e) gives an indication of the perigee distance, $r_p$, it is not exactly equal to $r_p$. To $O(J_2)$ the perigee distance is given by:-

$$r_p = a(1 - e) + \frac{1}{4} J_2 \frac{R^2}{p} \{\sin^2 i \cos 2\omega - (1 - e)(2 - 3\sin^2 i)\} .$$

The values of the eight differentially-corrected parameters are followed, in Table 2, by their computed standard deviations, the unit in each case being that of the final figure quoted for the parameter. The quantity $\varepsilon$ is a measure of the goodness of fit. Its expected value is 1 (non-dimensional), corresponding to the adopted weighting of observations with standard deviation 1'; if $\varepsilon$ is, say, 2.5 the fit is such that the observations must, a posteriori, be regarded as only accurate to $2\frac{1}{2}'$. Every standard deviation includes $\varepsilon$ as a factor. If this factor were removed, the remaining quantity would be independent of fit and would depend on, and therefore provide an indication of, the geometrical coverage of the orbit by the relevant station observations.

It is seen that average values for the standard deviations of the eight basic parameters are as follows:-

| | | | |
|---|---|---|---|
| $\sigma_a$ | 1 metre | $\sigma_\omega$ | $0^\circ.007$ |
| $\sigma_e$ | 0.00001 | $\sigma_{t_o}$ | $0^s.03$ |
| $\sigma_i$ | $0^\circ.0005$ | $\sigma_{n_1}$ | $12^\circ/(100\ \text{days})^2$ |
| $\sigma_\Omega$ | $0^\circ.001$ | $\sigma_{n_2}$ | $1500^\circ/(100\ \text{days})^3$ . |

The remarkable accuracy assessed for semi-major axis arises from the relation $n^2 a^3 = \mu$ (Kepler's third law). It is really n that is being measured so accurately and the values of a may be systematically in error by as much as 20 m due to error in the adopted value for $\mu$, viz. 398 602 $km^3/sec^2$. The above $\sigma_a$ corresponds, in fact, to $\sigma_n = 0^\circ.1/100$ days or a maximum contribution to $\sigma_M$ (when $1\frac{3}{4}$ days away from $t_o$) of about $0^\circ.002$. A better assessment of orbital distance accuracy is given by $\sigma\ (a\ \overline{1 - e}) = 70$ metres. It can readily be checked that the values given for $\sigma_{n_1}$ and $\sigma_{n_2}$ also both correspond, for $t - t_o = 1\frac{3}{4}$ days, to contributions of about $0^\circ.002$ to $\sigma_M$. Thus an approximate estimate of the maximum along-track error in position computed from the definitive orbital parameters may be obtained from $\sqrt{3} \times 0^\circ.002$ at 7000 km; this estimate is less than $\frac{1}{2}$ km. Further discussion of errors in computed position is to be found in Section 5.

To indicate the behaviour of the basic parameters relative to their tabulated standard deviations, Figs.2-10 have been plotted. The idea behind these plots has been, as far as possible, to use a scale large enough for the representation of each fitted value of a parameter by a vertical line of length $2\sigma$ centred on the fitted value. To this end secular terms have been removed from some of the parameters by preliminary fitting of some suitable polynomial, and for two of the parameters - e and $\omega$ - the long-periodic variation has also largely been removed.

For i, $n_1$ and $n_2$ a suitable scale is available without modification of the data from Table 2; Figs.5, 9 and 10 represent these three parameters, the plotted lines being of length $2\sigma_i$, $2\sigma_{n_1}$ and $2\sigma_{n_2}$ respectively. Eccentricity, right ascension of the node and argument of perigee have been represented in Figs.4, 6 and 7 by graphs of $\Delta e$, $\Delta\Omega$ and $\Delta\omega$ respectively, where

$$\Delta e = e + 1.08 \times 10^{-6}\ m - 7 \times 10^{-4} \sin \omega \ ,$$

$$\Delta\Omega = \Omega + k \times 360^\circ + 0^\circ.287515\ m + 2^\circ.29 \times 10^{-7}\ m^2 + 1^\circ.18 \times 10^{-11}\ m^3$$

and

$$\Delta\omega = \omega + k \times 360^\circ - 0^\circ.21385\ m - 2^\circ.3 \times 10^{-7}\ m^2 - 0^\circ.4 \cos \omega \ ;$$

here k is an integer which has been introduced to avoid the discontinuities of $360^\circ$ in the tabulated values of $\Omega$ and $\omega$.

Figs.2 and 3 both relate to semi-major axis. The values of $\sigma_a$ are so small that the scale can not be made large enough over the whole range of a, even after removal of a very-high-order polynomial. Fig.2 corresponds to the removal of a quintic, and plots $\Delta_1 a$, where

$$\Delta_1 a = a + 1.61 \times 10^{-2}\ m - 1.288 \times 10^{-5}\ m^2 + 6.915 \times 10^{-9}\ m^3 - 1.501 \times 10^{-12}\ m^4 + 1.159 \times 10^{-16}\ m^5 .$$

In order that a graph showing standard deviations might be drawn, the data were divided into seven sections and a separate polynomial (quartic) removed from each section, the constant terms being adjusted so that the polynomials joined up. The resulting graph is given in Fig.3 by the plot of $\Delta_2 a$, where, in km,

$$\Delta_2 a = a + 2.517 \times 10^{-2}\ m - 3.854 \times 10^{-5}\ m^2 + 3.301 \times 10^{-8}\ m^3 - 1.082 \times 10^{-11}\ m^4 \qquad \text{for } 0 < m < 750 \ ,$$

$$\Delta_2 a = a + 8.4985 - 9.22 \times 10^{-3}\ m + 1.539 \times 10^{-5}\ m^2 - 6.976 \times 10^{-9}\ m^3 + 1.277 \times 10^{-12}\ m^4 \qquad \text{for } 750 < m < 1500 \ ,$$

$$\Delta_2 a = a - 180.9639 + 4.424 \times 10^{-1}\ m - 3.84 \times 10^{-4}\ m^2 + 1.48277 \times 10^{-7}\ m^3 - 2.1107 \times 10^{-11}\ m^4 \qquad \text{for } 1500 < m < 2250 \ ,$$

$$\Delta_2 a = a - 1142.1030 + 1.83778\ m - 1.092788 \times 10^{-3}\ m^2 + 2.88134 \times 10^{-7}\ m^3 - 2.82585 \times 10^{-11}\ m^4 \qquad \text{for } 2250 < m < 3000 \ ,$$

$$\Delta_2 a = a + 43.1415 - 4.1146 \times 10^{-2} m + 2.0548 \times 10^{-5} m^2$$
$$- 3.4637 \times 10^{-9} m^3 + 1.9394 \times 10^{-13} m^4 \qquad \text{for } 3000 < m < 3750 ,$$

$$\Delta_2 a = a + 375.2463 - 4.7361 \times 10^{-1} m + 2.24885 \times 10^{-4} m^2$$
$$- 4.53198 \times 10^{-8} m^3 + 3.34635 \times 10^{-12} m^4 \qquad \text{for } 3750 < m < 4500 ,$$

and

$$\Delta_2 a = a - 22497.1421 + 18.545985 m - 5.723216 \times 10^{-3} m^2$$
$$+ 7.845224 \times 10^{-7} m^3 - 4.027167 \times 10^{-11} m^4 \qquad \text{for } 4500 < m < 5250 .$$

Fig.8 relates to the remaining parameter, $t_o$. This is plotted in the Modified Julian Day number form, a quartic polynomial being removed from the values of Table 2. Again standard deviations cannot be represented and this time they are so small relative to the scale of the graph - the average $\sigma_{t_o}$ being $3.5 \times 10^{-7}$ day - that division of the data into sections would not help. The quantity plotted in Fig.8 is $\Delta t_o$, where, in days,

$$\Delta t_o = t_o - 7.0318 \times 10^{-2} m + 4.1 \times 10^{-8} m^2 + 4.06 \times 10^{-12} m^3 - 1.27 \times 10^{-16} m^4 .$$

Although the polynomial (and sinusoidal) expressions removed from the orbital parameters have been listed above, it is not claimed that the polynomials represent the real behaviour of the parameters or that the shapes of the residual plots are significant. As already stated, the polynomials have only been removed in order that the magnitudes of the standard deviations should be visible, on the graphs, against the background of the fluctuation of the parameters. The graphs indicate certain facts about interpolation that are discussed in the next paragraph.

Suppose that the orbital parameters corresponding to a certain node had not been available and that they were estimated by a suitable form of interpolation in the adjacent sets of parameters. Then Figs.4, 5, 6 and 7 show that the values interpolated for e, i, $\Omega$ and $\omega$, respectively, would be very good; it would be almost certain, in fact, that any interpolated value would be within two average standard deviations of the true parameter. For a and $n_1$, however, it is clear from Figs.3 and 9 that such accurate interpolation would be impossible and for $t_o$ the situation would be worse still. (The simplest thing to do with the final parameter, $n_2$, would be to set it zero - Fig.10 shows that the error would be no greater than in interpolating $n_1$.)

Inadequacy of interpolation for the parameters a, $t_0$ and $n_1$, due to irregular variation in air drag, explains why it was necessary to obtain orbital parameters as frequently as at 25 node intervals (see also Section 5) and suggests that an even finer analysis, say at 10 or 15 node intervals, might have given further information on drag fluctuations.

## 5 ACCURACY OF POSITION COMPUTATION

From a set of orbital parameters derived on the basis of a given orbital model, the position of a satellite at any time may be computed using the same orbital model; indeed, for satellites transmitting scientific measurements, the provision of an ephemeris - or world map - is one of the chief motives for determining orbital parameters. In the case of Ariel 2 the experimenters wanted positions to be normally accurate to $\frac{1}{2}$ km or better, and almost never worse than 1 km.

Successive orbit determinations were initially carried out at 50-node intervals, starting from node 25. Allowing for overlap this meant that a given set of parameters had to be valid for a period stretching from about 26 nodes before the relevant defining node to about 26 nodes after. A useful measure of the accuracy of position computation was available by comparing the positions at various times - in particular during the overlap period - as computed from two sets of parameters, those at the previous defining node and those at the following one.

Let d be the distance between two estimates of satellite position as above, d being a function of time. The behaviour of d might be expected to be compounded of a periodic term and a secular term. This is illustrated in Fig.11, based on orbital parameters for defining nodes 75 and 125. The lower plot shows the fine behaviour of d over a single revolution - from node 100 to node 101. The upper plot shows the coarse behaviour between nodes 92 and 110; a curve has not been drawn because of the oscillation which occurs between the plotted points. It is clear at once that the desired accuracy is not being achieved.

It was largely as a result of contemplating Fig.11 that the decision was made to produce orbital parameters for the intermediate nodes 50, 100 etc. Fig.12 gives the coarse and fine behaviour of d for compared positions based on the parameters for nodes 75 and 100. Fig.13 gives a similar picture based on nodes 100 and 125. Although the true position of the satellite is, of course, never known, it is now very probable that the desired accuracy is being attained.

A second way of estimating the accuracy of position computation is to employ the covariance matrix of the orbital parameters used for this computation. A Pegasus programme is available for doing this and has been described elsewhere[7]. Let S be the root mean square of the distance between the true position of a satellite and its computed position from the parameters at a defining node (only one defining node is involved now). Fig.14 gives the coarse behaviour of S between nodes 1950 and 1968 based on the covariance matrix of the orbital parameters at node 1950. Fig.15 gives the fine behaviour of S between nodes 1962 and 1963; values based on covariance matrices from nodes 1950 and 1975 have been averaged here, but they scarcely differed. On the same graph is the corresponding plot of d, similar to that plotted in earlier figures.

The agreement between the S and d plots of Fig.15 is excellent, bearing in mind that they arise from quite different methods of accuracy assessment. Similar plots are given in Fig.16, starting from a different pair of nodes, 2275 and 2300. This time the agreement is much worse, an average value for d/S being about $3\frac{1}{2}$. If the errors in the position of the satellite, computed from two sets of parameters, were uncorrelated, the expected value of d/S would be $\sqrt{2}$, but with the parameters based on overlapping sets of data the expectation would be less than this. Thus a value $3\frac{1}{2}$ probably represents a systematic error in the orbital model. However, it is felt that even in this case the accuracy is unlikely to be worse than 1 km. It should be remarked that the choice of nodes upon which Fig.11 to 16 were based was a purely random one.

The effect of two possible sources of systematic error was investigated in a similar way to the above, using the quantity d. It has been remarked in Section 3.1 that parameters $\Omega_2$ and $\omega_2$ were originally included in the model but later dropped. The effect of dropping $\Omega_2$ and $\omega_2$ from the parameters for node 75, all other parameters remaining unchanged, is shown in Fig.17. This effect is, of course, proportional to $(t - t_o)^2$ and its maximum value may be seen to be, in metres, about $33\ (t - t_o)^2$, measuring time in days. This is completely negligible.

The Fischer ellipsoid was adopted early in the analysis, but without recomputing all previous sets of parameters obtained when the stations were not all referred to the same datum. One set of parameters was recomputed, the set for node 525. Fig.18 indicates the negligible change in position as computed from the parameters before and after the change.

## 6 COMPARISON WITH OTHER ORBITS OF ARIEL 2

Elements of Ariel 2 have been issued by two American computing centres, Spacetrack and NASA. In each case new sets of elements are produced, on average, about every nine days, some five times less frequently than the elements tabulated in this paper. For this reason, among others, the American orbits must be regarded as significantly less accurate than the definitive R.A.E. orbit. The Spacetrack bulletins, in any case, describe their data as for prediction purposes only and unsuitable for scientific analysis.

The NASA elements, like the R.A.E. elements, have been derived from Minitrack observations. However, in addition to being issued less frequently they differ from R.A.E. elements in that they are related to a different dynamic model of the orbit; also, each set corresponds to some arbitrary epoch and not to the time of a particular nodal passage. The precise definitions of NASA elements are rather difficult to discover and it is not certain that the same orbital model is used for the analysis of all satellites. It was therefore of interest to compare NASA elements - interpolated to the time of the nearest set of R.A.E. elements - with the R.A.E. elements, using the differences to establish the most likely interpretation of the NASA elements.

The comparison has been made and it seems that NASA must have used a set of elements which will be defined in the next paragraph. They are denoted by $\bar{a}$, $\bar{e}$ etc. to distinguish them from R.A.E. elements. Formulae are given in Sections 6.1 and 6.2 which relate the two sets of elements. On the assumption that the NASA elements are the barred elements, a number of sets have been transformed into Merson's elements for comparison with R.A.E. elements. The average difference is then about three or four times the R.A.E. standard deviations and - since the R.A.E. elements are the more accurate - the agreement is very satisfactory. This is illustrated by Fig.19 which gives the R.A.E. eccentricity graph; values of e from NASA are plotted before and after transformation and it is seen that after transformation they lie on or near the R.A.E. curve. Comparison of R.A.E. and NASA ephemerides is considered in Section 6.3 and illustrated by Fig.20.

The elements $\bar{a}$, $\bar{e}$ etc. are defined, to O(e), by a double averaging of osculating elements. The first averaging is with respect to mean anomaly and the second with respect to argument of perigee; these averagings remove, respectively, short-periodic perturbations associated with the $J_2$ term of the geopotential function and long-periodic perturbations associated with the $J_3$ term. Despite the general uncertainty over their orbital methods, there is reason to believe that NASA remove $J_5$ perturbations also, but these are much smaller than the $J_3$ perturbations and are not considered here.

The formulae given below have been derived by using the results of Merson[8], who compared his smoothed elements[6] with the mean elements of Kozai[9]. The elements $\bar{e}$, $\bar{i}$ and $\bar{\Omega}$ are very close to those which Kozai reached after removing long-periodic terms but the $\bar{a}$ and $\bar{\omega}$ defined here differ from those of Kozai since each of the latter was given a bias relative to the true average short-periodic perturbation.

The element a is dealt with after e, i, Ω and ω in the comparisons below and is then considered in conjunction with the mean motion n and the anomalistic period. Mean anomaly, for which comparison would not be so straightforward, is omitted from consideration.

6.1 Eccentricity, inclination, right ascension of the node and argument of perigee

To O(e) the relations between e, i, Ω, ω and $\bar{e}$, $\bar{i}$, $\bar{\Omega}$, $\bar{\omega}$ respectively are given by:-

$$e - \bar{e} = \frac{3}{8} J_2 \left(\frac{R}{a}\right)^2 e\,(2 - 3\sin^2 i) - \frac{1}{2}\,\frac{J_3}{J_2}\,\frac{R}{a}\,\sin i \sin\omega \quad ,$$

$$i - \bar{i} = -\frac{1}{8} J_2 \left(\frac{R}{a}\right)^2 \sin 2i\,(3 + 4e\cos\omega) + \frac{1}{2}\,\frac{J_3}{J_2}\,\frac{R}{a}\,e \cos i \sin\omega \quad ,$$

$$\Omega - \bar{\Omega} = \frac{1}{2} J_2 \left(\frac{R}{a}\right)^2 \cos i\,(3\omega + 3M_0 + 4e\sin\omega) - \frac{1}{2}\,\frac{J_3}{J_2}\,\frac{R}{a}\,e \cot i \cos\omega$$

and

$$\omega - \bar{\omega} = -\frac{1}{4} J_2 \left(\frac{R}{a}\right)^2 \left\{(4 - 5\sin^2 i)(3\omega + 3M_0 + 2e\sin\omega) - \frac{9}{4}\sin^2 i \sin 2\omega\right\} - \frac{1}{2}\,\frac{J_3}{J_2}\,\frac{R}{a}\,e^{-1} \sin i \cos\omega \quad .$$

The first term in the expression for $e - \bar{e}$ is negligible here since $2 - 3\sin^2 i = O(e)$; the second term represents the transformation made to the plot of NASA eccentricity in Fig.19.

6.2 Semi-major axis, mean motion and anomalistic period

The semi-major axis and the mean motion are directly related by Kepler's third law. Since - with observations of direction and not range - it is n rather than a which is measured, it is preferable to give the formula relating n and $\bar{n}$. There being no long-periodic term, the relation - to O(e) - is:-

$$n - \bar{n} = \frac{3}{4} J_2 \left(\frac{R}{a}\right)^2 n \,(2 - 3 \sin^2 i) \; .$$

Although the true anomalistic period - the time from one passage through perigee to the next - is $2\pi/n$, it appears to be $2\pi/\bar{n}$ which is listed as 'anomalistic period' by NASA. Thus the latter is consistently half a second greater than the true anomalistic period.

Values listed in the Spacetrack bulletins do appear to be of the true anomalistic period and agree satisfactorily with values of $2\pi/n$ using Table 2.

## 6.3 Comparison of ephemerides

It does not matter that the definitions of R.A.E. and NASA elements are different, so long as the appropriate formulae are used for generating satellite positions in each case. A comparison has been made of satellite position computed from R.A.E. orbital elements with the ephemeris provided by the NASA 'Refined World Maps'. The period from node 600 to node 601 was chosen for the comparison since during this period the difference between e (NASA) and e (R.A.E.) was near its maximum (0.0008), as may be seen from Fig.19.

Fig.20 gives (lower curve) the difference between the R.A.E. and NASA computed satellite positions and (upper curve) the height component of this difference. It is seen that the height difference does not exceed 310 metres nor the total difference 800 metres. Since the R.A.E. elements are the more accurate, position agreement to this order is very satisfactory and confirms that both sets of orbital elements are being used correctly.

## 7 DISCUSSION

The accuracy required by the Ariel 2 experimenters has been achieved in the orbit provided. Had an order better accuracy been required, a careful analysis of the possible sources of error would have been necessary. At the expense of some complication, further improvements in the dynamic model of the orbit might have been made and the Pegasus computer programme improved. However, it is doubtful whether the Minitrack data themselves would have been accurate enough to warrant much refinement in the computing.

The average size of the residuals in angle is the 1 minute of arc that had been expected when the analysis was started. For a satellite at an average distance of about 1000 km this corresponds to an error in distance of about 300 m.

For observations with elevations as low as $60^{\circ}$ the greatest source of error is probably the inadequate correction of ionospheric refraction. It has been estimated[10] that for an elevation angle of $50^{\circ}$ the residual error after refraction correction is 2 minutes of arc so that for $60^{\circ}$ it is still important.

Other errors in the data are not likely to be significant. Systematic errors which arise during the periods between successive calibrations of a Minitrack station - periods of some months in general - should not average more than $\frac{1}{4}$ minute of arc[1]. Errors in station survey should not exceed 100 m, leading to errors of the same order as calibration errors.

Turning to the orbital model, appreciable errors - say about 200 m - still arise from inadequate allowance for the earth's tesseral harmonics (see the Appendix), despite the empirical modification made. Errors from neglect of the zonal harmonics beyond $J_4$ are thought to be negligible. The effect of $J_7$, for example, is not important for a satellite of inclination $51^{\circ}.6$. The values of $e_1$ in Table 2, which are from theory, are in general agreement with values from differencing e, bearing in mind that the orbital model automatically allows for the main drag term in e - i.e., if $e_1$ is zero it is $a(1 - e)$ and not e which is held constant.

Errors from inadequate representation of the effects of atmospheric drag are less easy to estimate. They may be divided into short-periodic and long-periodic errors. The short-periodic errors arise because drag is concentrated at perigee and not, as the mean anomaly polynomial would suggest, uniformly spread over the orbit. But the errors are negligible, being less than a second of arc - in the case of Ariel 2 - for mean anomaly and so equivalent to at most a few seconds of arc in an observation.

The long-periodic errors in the representation of drag effects are more serious and it is these which are difficult to estimate. They arise because of fluctuations in the density of the atmosphere which are, on the different time scale involved, of short period. These fluctuations have been investigated by King-Hele and Quinn[11] who have plotted values of $n_1$, as in Fig.9, as far as 10th September, 1964. Geomagnetic index, when plotted for comparison with the parameter $n_1$, shows the same general behaviour but has very pronounced 'spikes'. It is clear, in fact, that the calculation of $n_1$, even at intervals as fine as $1\frac{3}{4}$ days, has smoothed the true orbital acceleration and thereby introduced error. If the required corrections to $n_1$ could be estimated and doubly integrated, then the correction to mean anomaly could be found as a function of time. From a rough inspection of the $n_1$ and geomagnetic index curves it seems likely that the error could reach, or exceed, a minute of arc in equivalent topocentric observation.

It is interesting, in the light of the last paragraph, to speculate that to obtain more accurate orbits for satellites like Ariel 2 it may be necessary to feed in values of geomagnetic index over the three-or-four-day period of an orbit determination and to form terms contributing to the mean anomaly by a double numerical integration of these values of the index.

In addition to its application to the study of short-periodic fluctuations in atmospheric density the orbit of Ariel 2 has been used in the evaluation of the odd zonal harmonics of the earth's gravitational potential. King-Hele, Cook and Scott[12] have taken Ariel 2 as one of six satellites for this evaluation. They used the data for perigee radius, a (1 - e), rather than eccentricity, in order to remove drag effects as accurately as possible, and found that the corrected data were then as good as data for the other satellites in virtually drag-free orbits.

## 8 CONCLUSIONS

By use of an orbital model with eight parameters fitted from Minitrack observations, the orbit of Ariel 2 (1964-15A) has been successfully computed for a period of a year from its launch. The orbital parameters have been listed (in Table 2) for the time of every twenty-fifth passage through the ascending node.

Ephemerides calculated from the listed parameters should, in general, be accurate to about $\frac{1}{2}$ km, i.e. to the accuracy required by the experimenters. This estimate of accuracy is based on the view that the effective average error in a Minitrack observation is 1 minute of arc, a figure supported by the residuals in the observations after orbits have been fitted. The estimate has been confirmed by the comparison, over a short period, of ephemerides calculated from two sets of orbital parameters, corresponding to the epochs before and after the period in question.

Consideration has been given to the factors limiting the accuracy of the orbital determinations. It is concluded that the three main factors are: inadequacies in the correction of observations, other than at very high elevation, for ionospheric refraction; inadequacies in the representation of tesseral terms in the earth's gravitational field; and inadequacies in the representation of drag effects over periods of several days.

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## Appendix

## PERTURBATIONS OF ARIEL 2 DUE TO THE TESSERAL HARMONICS OF THE EARTH'S GRAVITATIONAL FIELD

During the first few orbital determinations, based on the standard dynamic model that was being used at the beginning of 1964, it was noticed that residuals from the Winkfield Minitrack station were consistently larger than residuals from the other stations. It was discovered moreover - using the original form of the orbit determination programme in which residuals in observation times as well as angular data were computed[2] - that the residuals were almost entirely along-track, equivalent to an error in the Winkfield clock. This error was oscillatory, with amplitude about $0^s.1$ and period just under (by about 10 minutes) half a day. It was realised that an error of this type could be caused by the neglect of the coefficient ($J_{2,2}$) of one of the tesseral harmonics of the earth's gravitational field, though it had earlier been thought that $J_{2,2}$ perturbations would not be detectable. The proof that the effect was in fact caused by gravitational perturbations - and that the Winkfield clock was blameless - was obtained by plotting time residuals for all the 185 observations which were obtained from the Minitrack network during the first 90 hours from launch. The residuals were plotted against the argument $\theta - \Omega$, where $\theta$ is sidereal time and $\Omega$ the right ascension of the satellite node.

Let the negative of the residual in an observation time (assuming the original form of the orbit determination programme) be denoted by $\delta t$. Then $\delta t$ is the amount by which an observation time has to be increased before computing satellite position from the standard dynamic model. It was found that a good fit to the plot of 185 $\delta t$'s was given by:-

$$\delta t = 0.088 \sin 2(\theta - \Omega - 18^{\circ}) \text{ sec} .$$

Now the formula for the along-track effect of $J_{2,2}$ is given[13], for a circular orbit, by:-

$$\delta L = \frac{9}{2} J_{2,2} \left(\frac{R}{p}\right)^2 \frac{n \sin^2 i}{\dot{\ell}} \sin 2(\theta - \Omega + \lambda_{2,2}) ,$$

where p, n and i are semi-latus rectum, mean motion and inclination respectively, R is the (mean) equatorial radius of the earth, $\lambda_{2,2}$ is the (east) longitude of one extremity of the major axis of the earth's equator, assumed elliptical, and $\dot{\ell}$ is $\dot{\theta} - \dot{\Omega}$. Taking $\delta L = n\,\delta t$ and substituting the values of p, n, i and $\dot{\Omega}$ for the Ariel 2 orbit, the observed $\delta t$ fit may be accounted for by a $J_{2,2}$

perturbation for which $J_{2,2} = 3.0 \times 10^{-6}$ and $\lambda_{2,2} = -18^{\circ}$. The orbit determination programme has consequently been modified by arranging that the time of an observation is increased by $\delta t$ where

$$\delta t = \frac{9}{2} J_{2,2} \left(\frac{R}{p}\right)^2 \frac{\sin^2 i}{\ell} \sin 2(\theta - \Omega + \lambda_{2,2}) ,$$

$J_{2,2}$ and $\lambda_{2,2}$ having the values above.

Now the values of $J_{2,2}$ and $\lambda_{2,2}$ obtained by Guier and Newton[14], with which other values are in fair agreement, are $1.72 \times 10^{-6}$ and $-13^{\circ}.4$ respectively, so that at first sight the correction is almost double what can be justified. The natural explanation is that the fitted $J_{2,2}$ accounts not only for the pure $J_{2,2}$ but also for (the along-track effects of) $J_{4,2}$, $J_{6,2}$, $J_{8,2}$ etc. However, this explanation has not been satisfactorily borne out on evaluating these effects as far as $J_{8,2}$, using values from Ref.14. The pure $J_{2,2}$ effect and the $J_{4,2}$, $J_{6,2}$ and $J_{8,2}$ effects are then given, respectively, by:-

$$\delta t = 0.051 \sin 2(\theta - \Omega - 13^{\circ}) ,$$

$$\delta t = 0.017 \sin 2(\theta - \Omega - 67^{\circ}) ,$$

$$\delta t = 0.004 \sin 2(\theta - \Omega + 22^{\circ})$$

and

$$\delta t = 0.002 \sin 2(\theta - \Omega - 11^{\circ}) ;$$

the formulae for the quantities $L_{2,2}$ and $L_{4,2}$ of Ref.13 have been used here, and similar formulae developed for $L_{6,2}$ and $L_{8,2}$. On combining, the total effect is given by:-

$$\delta t = 0.051 \sin 2(\theta - \Omega - 21^{\circ})$$

so that the amplitude is the same as for the pure $J_{2,2}$ effect though the phase has changed. Values for $J_{10,2}$ etc. are not available but there seems to be little hope of increasing the amplitude to the observed 0.088 sec through their agency.*

The efficacy of the empirical programme modification may be appreciated when it is stated that the mean value of the observation residuals is halved. Although the modification was based on the analysis at the early nodes it was tested also at later nodes; at node 3250, for example, the mean (rms) residual was 2'.80 without the modification, but 1'.46 with it.

It is recalled that the programme modification accounts for only that component of the pertubation due to tesseral harmonics which manifests itself as an apparent along-track error in satellite position with period about half a day. There are also components in the two directions perpendicular to the along-track direction. The perturbation which is cross-track but within the orbital plane contains eccentricity as a factor and may be neglected, but the perturbation perpendicular to the orbital plane is significant. Its effect is less noticeable than that of the along-track component, partly because it has a short-periodic factor superimposed on the half-day period. Its removal, however, might be expected to contribute to a further improvement in orbital fits.

For a complete representation of the effect of any particular tesseral harmonic the natural procedure would be to introduce the perturbations of the six orbital elements. With the normal notation[13] (but with $\sigma$ for the element sometimes denoted by $\chi^*$) there would be no perturbation in a, while perturbations in $\omega$ and $\sigma$ could, for a near-circular orbit, be combined; thus expressions for $\delta e$, $\delta i$, $\delta\Omega$ and $\delta\omega + \delta\sigma$ would be required instead of merely the expression for $\delta L$ ($= \delta\omega + \delta\sigma + \delta\Omega \cos i$).

Attempts have been made to represent the complete perturbations of Ariel 2 due to $J_{2,2}$ and $J_{4,2}$ by taking either the values of Ref.14 or else the empirical values for the along-track perturbation only, viz. $J_{2,2} = 3.0 \times 10^{-6}$, $\lambda_{2,2} = -18^{\circ}$ and $J_{4,2} = 0$. Both attempts were unsuccessful - residuals became larger not smaller - and perhaps this is not surprising. Since it was necessary to take an empirical $J_{2,2}$, based on residual fitting, to represent the along-track perturbation alone successfully, it would presumably be necessary to take a new empirical value to represent the complete perturbation. But the method of residual fitting would not then be so obvious; since the revised orbital model - with the empirical along-track correction - gave the Ariel 2 orbit to the required accuracy, the question of further improvement has not been closely studied.

The perturbations due to $J_{n,s}$ with $s \neq 2$ would, of course, have to be considered in a full analysis. The tables below give order-of-magnitude estimates of the amplitudes of the perturbations from $J_{n,s}$ as far as $J_{4,4}$ using values from Ref.14, the effects on the elements being represented in metres. Lines of the tables for which the perturbations include eccentricity ($e = 0.07$) as a factor are indicated by an asterisk.

$\delta e$

| n \ s | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 2* | | [illegible] | | |
| 3 | 130 | 45 | 25 | |
| 4* | 4 | 2 | 1 | 1 |

$\delta i$

| n \ s | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 2 | | 160 | | |
| 3* | 20 | 10 | 5 | |
| 4 | 12 | 30 | 50 | 7 |

$\delta \Omega$

| n \ s | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 2 | | 130 | | |
| 3* | 25 | 10 | 3 | |
| 4 | 170 | 40 | 20 | 5 |

$\delta \omega + \delta \sigma$

| n \ s | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 2 | | 300 | | |
| 3* | 120 | 25 | 10 | |
| 4 | 45 | 150 | 110 | 10 |

**Table 1**

**MINITRACK STATIONS OBSERVING ARIEL 2**

| Station location | Latitude | Longitude | Height (metres) | No. of observations |
|---|---|---|---|---|
| Blossom Point, Maryland, USA | 38.43053 N | 77.08629 W | -1 | 252 |
| East Grand Forks, Minnesota, USA | 48.02256 N | 97.01082 W | 254 | 760 |
| Fort Myers, Florida, USA | 26.54827 N | 81.86539 W | 7 | 225 |
| Goldstone Lake, California, USA | 35.33016 N | 116.89977 W | 937 | 202 |
| Hartebeeshoek, Johannesburg, SA | 25.88361 S | 27.70791 E | 1571 | 216 |
| Lima, Peru | 11.77635 S | 77.15024 W | 2 | 210 |
| Quito, Ecuador | 00.62237 S | 78.57900 W | 3548 | 140 |
| Santiago, Chile | 33.14896 S | 70.66865 W | 636 | 174 |
| St. Johns, Newfoundland | 47.74137 N | 52.72036 W | 106 | 698 |
| Winkfield, England | 51.44595 N | 0.69623 W | 91 | 649 |
| Woomera, Australia | 31.39167 S | 136.86972 E | 118 | 189 |

Latitude and longitude are referenced to the Fischer ellipsoid: a spheroid of semi-major axis 6378.166 km and flattening 1/298.3. Heights are measured upwards from this spheroid.

Table 2

ORBITAL PARAMETERS OF ARIEL 2

| Node | Date 1964 | Time h m s | a | e | $10^4 e_1$ | a(1−e) | i | $100\ i_1$ | Ω | $100\ \Omega_1$ | ω | $\omega_1$ | M | n | $n_1$ | $10^{-2} n_2$ | N | D | s | MJD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 25 | MAR 29 | 11 06 46.53 2 | 7201.0102 7 | 0.074629 6 | −36 | 6663.61 | 51.6450 4 | 4 | −137.2597 9 | 30 | 143.137 5 | −2.83 | −137.769 | 511465.06 | 2316 12 | 210 13 | 44 | 3.5 | 1.5 | 38483.4630385 |
| 50 | MAR 31 | 05 18 51.65 2 | 7200.5681 7 | 0.074518 7 | −38 | 6664.00 | 51.6458 4 | 1 | −144.4483 10 | 30 | 148.442 5 | −2.58 | −143.751 | 511512.17 | 2825 7 | 20 12 | 35 | 3.2 | 1.1 | 38485.2214311 |
| 75 | APR 1 | 23 30 41.33 3 | 7200.0919 9 | 0.074388 13 | −39 | 6664.49 | 51.6461 5 | 0 | −151.6363 13 | 28 | 153.757 7 | −2.36 | −149.791 | 511562.91 | 3207 9 | 248 14 | 45 | 3.8 | 1.4 | 38486.9196450 |
| 100 | APR 3 | 17 42 13.81 3 | 7199.5452 8 | 0.074254 9 | −40 | 6664.95 | 51.6456 4 | 0 | −158.8259 10 | 27 | 159.067 6 | −2.11 | −155.862 | 511621.18 | 2954 9 | −160 14 | 37 | 3.2 | 1.0 | 38488.7376598 |
| 125 | APR 5 | 11 53 30.16 3 | 7199.0946 7 | 0.074128 9 | −40 | 6665.44 | 51.6460 5 | 2 | −166.0100 5 | 26 | 164.394 7 | −1.81 | −161.981 | 511669.22 | 2624 6 | −63 8 | 46 | 4.1 | 1.5 | 38490.4954880 |
| 150 | APR 7 | 06 04 32.40 3 | 7198.6802 8 | 0.074010 6 | −41 | 6665.91 | 51.6460 5 | 4 | −173.2018 6 | 25 | 169.728 7 | −1.42 | −168.129 | 511713.40 | 2439 7 | −30 12 | 36 | 3.1 | 1.3 | 38492.2531528 |
| 175 | APR 9 | 00 15 21.59 3 | 7198.2829 8 | 0.073899 7 | −42 | 6666.34 | 51.6468 6 | 3 | 179.6053 7 | 25 | 175.073 7 | −1.01 | −174.303 | 511755.76 | 2311 6 | −95 10 | 40 | 3.9 | 1.7 | 38494.0106666 |
| 200 | APR 10 | 18 25 58.68 4 | 7197.9319 12 | 0.073781 8 | −42 | 6666.86 | 51.6473 8 | 0 | 172.4118 10 | 24 | 180.428 7 | −0.65 | −180.495 | 511793.19 | 1998 13 | −34 21 | 30 | 3.5 | 1.8 | 38495.7680403 |
| 225 | APR 12 | 12 36 25.30 3 | 7197.6090 10 | 0.073637 7 | −42 | 6667.60 | 51.6477 6 | −3 | 165.2181 9 | 21 | 185.788 6 | −0.41 | −186.688 | 511827.64 | 1850 6 | −78 10 | 41 | 4.1 | 1.5 | 38497.5252928 |
| 250 | APR 14 | 06 46 42.54 2 | 7197.3301 9 | 0.073516 6 | −40 | 6668.21 | 51.6465 5 | −2 | 158.0274 10 | 19 | 191.140 6 | −0.24 | −192.860 | 511857.39 | 1570 9 | −43 15 | 36 | 3.5 | 1.0 | 38499.2824367 |
| 275 | APR 16 | 00 56 51.88 2 | 7197.0828 7 | 0.073410 6 | −39 | 6668.74 | 51.6468 4 | 1 | 150.8343 11 | 18 | 196.503 7 | 0.00 | −199.025 | 511883.78 | 1557 7 | 49 9 | 40 | 4.1 | 1.0 | 38501.0394893 |
| 300 | APR 17 | 19 06 53.59 3 | 7196.8140 11 | 0.073293 7 | −37 | 6669.34 | 51.6476 5 | 3 | 143.6415 14 | 19 | 201.870 10 | 0.36 | −205.165 | 511912.45 | 1614 8 | −31 16 | 32 | 3.4 | 1.0 | 38502.7964536 |
| 325 | APR 19 | 13 16 47.46 3 | 7196.5531 8 | 0.073191 7 | −35 | 6669.83 | 51.6469 5 | 2 | 136.4496 16 | 20 | 207.230 11 | 0.75 | −211.263 | 511940.29 | 1517 6 | −43 7 | 35 | 4.1 | 1.0 | 38504.5533271 |
| 350 | APR 21 | 07 26 34.16 4 | 7196.3243 12 | 0.073064 10 | −34 | 6670.53 | 51.6461 4 | −1 | 129.2553 14 | 18 | 212.619 6 | 1.05 | −217.348 | 511964.71 | 1216 14 | −67 28 | 31 | 2.9 | 0.9 | 38506.3101175 |
| 375 | APR 23 | 01 36 15.26 3 | 7196.1476 6 | 0.072966 9 | −32 | 6671.07 | 51.6453 4 | −2 | 122.0602 12 | 15 | 218.001 5 | 1.22 | −223.378 | 511983.56 | 970 5 | −49 6 | 43 | 4.2 | 0.8 | 38508.0668433 |
| 400 | APR 24 | 19 45 52.20 3 | 7196.0019 13 | 0.072889 8 | −30 | 6671.49 | 51.6445 5 | 0 | 114.8657 10 | 14 | 223.416 5 | 1.34 | −229.391 | 511999.11 | 885 13 | 25 24 | 33 | 3.0 | 0.9 | 38509.8235208 |
| 425 | APR 26 | 13 55 25.37 2 | 7195.8376 7 | 0.072825 7 | −26 | 6671.80 | 51.6459 5 | 2 | 107.6682 8 | 14 | 228.817 4 | 1.47 | −235.327 | 512016.64 | 1127 6 | 68 7 | 46 | 4.7 | 1.1 | 38511.5801547 |
| 450 | APR 28 | 08 04 53.95 2 | 7195.6274 13 | 0.072732 6 | −22 | 6672.28 | 51.6460 5 | 4 | 100.4777 8 | 16 | 234.209 5 | 1.63 | −241.187 | 512039.08 | 1395 14 | −50 26 | 31 | 3.1 | 0.9 | 38513.3367355 |
| 475 | APR 30 | 02 14 16.65 2 | 7195.4266 9 | 0.072672 7 | −18 | 6672.52 | 51.6480 6 | 3 | 93.2805 9 | 18 | 239.605 5 | 1.83 | −246.987 | 512060.51 | 1082 8 | −50 9 | 38 | 4.2 | 1.2 | 38515.0932482 |
| 500 | MAY 1 | 20 23 34.92 3 | 7195.2569 12 | 0.072616 8 | −15 | 6672.84 | 51.6493 5 | 1 | 86.0833 8 | 18 | 245.022 7 | 2.03 | −252.737 | 512078.63 | 1037 14 | −20 22 | 26 | 3.1 | 0.9 | 38516.8497097 |
| 525 | MAY 3 | 14 32 49.37 3 | 7195.1047 9 | 0.072541 7 | −12 | 6673.16 | 51.6491 4 | 0 | 78.8966 9 | 16 | 250.459 6 | 2.20 | −258.431 | 512094.88 | 787 7 | −54 12 | 41 | 3.6 | 0.8 | 38518.6061270 |
| 550 | MAY 5 | 08 42 00.69 2 | 7194.9865 12 | 0.072505 7 | −09 | 6673.31 | 51.6486 5 | 0 | 71.6988 9 | 15 | 255.871 6 | 2.29 | −264.030 | 512107.49 | 749 16 | 41 28 | 35 | 2.9 | 0.8 | 38520.3625079 |
| 575 | MAY 7 | 02 51 09.53 3 | 7194.8685 11 | 0.072471 8 | −07 | 6673.45 | 51.6486 8 | 1 | 64.5054 10 | 14 | 261.279 8 | 2.28 | −269.549 | 512120.10 | 663 8 | −22 11 | 44 | 4.1 | 1.3 | 38522.1188603 |
| 600 | MAY 8 | 21 00 16.14 2 | 7194.7657 15 | 0.072429 6 | −03 | 6673.66 | 51.6503 8 | 3 | 57.3088 9 | 16 | 266.697 6 | 2.20 | −275.002 | 512131.08 | 595 15 | 7 29 | 32 | 3.0 | 1.2 | 38523.8751869 |
| 625 | MAY 10 | 15 09 20.85 2 | 7194.6556 11 | 0.072405 8 | 02 | 6673.73 | 51.6520 9 | 2 | 50.1135 11 | 19 | 272.122 7 | 2.10 | −280.389 | 512142.83 | 892 11 | 134 13 | 41 | 4.0 | 1.9 | 38525.6314913 |
| 650 | MAY 12 | 09 18 22.06 2 | 7194.4792 12 | 0.072402 8 | 07 | 6673.58 | 51.6503 8 | −1 | 42.9211 9 | 19 | 277.542 6 | 2.08 | −285.702 | 512161.66 | 781 17 | −201 26 | 33 | 3.0 | 1.4 | 38527.3877554 |
| 675 | MAY 14 | 03 27 20.00 2 | 7194.3744 10 | 0.072405 8 | 11 | 6673.47 | 51.6496 7 | −3 | 35.7253 9 | 18 | 282.959 5 | 2.14 | −290.941 | 512172.86 | 751 9 | 98 17 | 40 | 3.3 | 1.4 | 38529.1439815 |
| 700 | MAY 15 | 21 36 15.16 1 | 7194.2291 10 | 0.072405 11 | 14 | 6673.33 | 51.6492 5 | −2 | 28.5299 8 | 16 | 288.378 4 | 2.19 | −296.113 | 512188.37 | 880 15 | −34 30 | 35 | 2.9 | 1.0 | 38530.9001755 |
| 725 | MAY 17 | 15 45 06.83 3 | 7194.0940 14 | 0.072413 14 | 16 | 6673.15 | 51.6475 7 | 0 | 21.3311 16 | 18 | 293.792 7 | 2.12 | −301.216 | 512202.80 | 778 14 | −26 18 | 35 | 3.7 | 1.4 | 38532.6563290 |
| 750 | MAY 19 | 09 53 55.59 3 | 7193.9794 13 | 0.072431 9 | 18 | 6672.91 | 51.6488 5 | −1 | 14.1364 17 | 20 | 299.223 10 | 1.93 | −306.274 | 512215.04 | 608 13 | −18 22 | 21 | 3.1 | 0.7 | 38534.4124489 |
| 775 | MAY 21 | 04 02 42.08 5 | 7193.8771 19 | 0.072459 8 | 22 | 6672.62 | 51.6479 6 | −1 | 6.9410 16 | 22 | 304.649 14 | 1.66 | −311.270 | 512225.96 | 615 16 | −40 28 | 21 | 3.1 | 0.9 | 38536.1685426 |
| 800 | MAY 22 | 22 11 26.13 3 | 7193.7749 13 | 0.072484 5 | 25 | 6672.34 | 51.6485 6 | −3 | −0.2569 14 | 22 | 310.038 13 | 1.41 | −316.178 | 512236.88 | 685 19 | 2 24 | 24 | 3.1 | 0.9 | 38537.9246079 |
| 825 | MAY 24 | 16 20 07.53 3 | 7193.6525 10 | 0.072513 6 | 29 | 6672.02 | 51.6477 5 | −4 | −7.4546 13 | 21 | 315.432 11 | 1.20 | −321.043 | 512249.95 | 901 19 | 53 21 | 23 | 3.1 | 0.8 | 38539.6806427 |
| 850 | MAY 26 | 10 28 45.15 2 | 7193.4928 9 | 0.072583 8 | 33 | 6671.37 | 51.6485 4 | −2 | −14.6466 8 | 21 | 320.822 6 | 1.03 | −325.861 | 512267.01 | 940 7 | −28 9 | 21 | 4.0 | 0.8 | 38541.4366336 |
| 875 | MAY 28 | 4 37 18.43 1 | 7193.3460 9 | 0.072635 7 | 36 | 6670.86 | 51.6477 4 | −1 | −21.8470 6 | 22 | 326.198 4 | 0.88 | −330.626 | 512282.70 | 879 9 | −23 15 | 19 | 3.3 | 0.8 | 38543.1925744 |

Previous page was blank, therefore not filmed.

Table 2 (Contd)

ORBITAL PARAMETERS OF ARIEL 2

| Node | Date 1964 | Time h m s | a | e | $10^4 e_1$ | a(1−e) | i | $100\ i_1$ | Ω | $100\ Ω_1$ | ω | $ω_1$ | M | n | $n_1$ | $10^{-2} n_2$ | N | D | ε | MJD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 900 | MAY 29 | 22 45 47.77 1 | 7193.2086 6 | 0.072687 10 | 38 | 6670.36 | 51.6473 4 | -1 | -29.0490 5 | 25 | 331.581 4 | 0.70 | -335.362 | 512297.37 | 817 8 | -7 9 | 19 | 3.4 | 0.7 | 38544.9484696 |
| 925 | MAY 31 | 16 54 13.58 5 | 7193.0804 14 | 0.072802 18 | 39 | 6669.41 | 51.6479 6 | -2 | -36.2444 12 | 27 | 336.976 10 | 0.12 | -340.081 | 512311.07 | 746 25 | -37 27 | 18 | 3.0 | 1.0 | 38546.7043238 |
| 950 | JUN 2 | 11 02 55.73 4 | 7192.9657 20 | 0.072821 20 | 39 | 6669.17 | 51.6466 8 | -3 | -43.4444 14 | 28 | 342.349 11 | 0.12 | -344.753 | 512323.32 | 641 27 | -46 47 | 26 | 3.5 | 1.4 | 38548.4601358 |
| 975 | JUN 4 | 5 10 54.79 3 | 7192.8584 8 | 0.072890 9 | 40 | 6668.57 | 51.6459 3 | -4 | -50.6454 7 | 27 | 347.716 6 | -0.28 | -349.403 | 512334.79 | 685 6 | +34 12 | 30 | 3.4 | 0.7 | 38550.2159119 |
| 1000 | JUN 5 | 23 19 10.53 3 | 7192.7439 10 | 0.072948 12 | 42 | 6668.05 | 51.6444 4 | -2 | -57.8434 11 | 26 | 353.086 6 | -0.68 | -354.040 | 512347.02 | 660 7 | -24 14 | 26 | 3.3 | 0.8 | 38551.9716497 |
| 1025 | JUN 7 | 17 27 23.10 2 | 7192.6443 10 | 0.073076 7 | 44 | 6667.03 | 51.6437 4 | 0 | -65.0395 9 | 28 | 358.441 7 | -0.98 | -358.657 | 512357.66 | 630 11 | +64 17 | 26 | 3.0 | 0.9 | 38553.7273507 |
| 1050 | JUN 9 | 11 35 52.18 2 | 7192.5216 12 | 0.073127 9 | 45 | 6666.55 | 51.6433 6 | 0 | -72.2431 12 | 31 | 3.797 8 | -1.21 | -3.271 | 512370.77 | 1095 12 | +266 17 | 23 | 3.6 | 1.3 | 38555.4830113 |
| 1075 | JUN 11 | 5 43 35.46 4 | 7192.2695 11 | 0.073156 17 | 45 | 6666.11 | 51.6425 4 | -3 | -79.4453 14 | 35 | 9.157 7 | -1.46 | -7.892 | 512397.71 | 1573 10 | -116 19 | 25 | 3.1 | 1.0 | 38557.2386049 |
| 1100 | JUN 12 | 23 51 30.70 2 | 7192.0487 6 | 0.073234 9 | 43 | 6665.35 | 51.6418 3 | -5 | -86.6458 9 | 35 | 14.530 5 | -1.80 | -12.532 | 512421.31 | 1133 5 | -110 10 | 37 | 3.5 | 1.0 | 38558.9941053 |
| 1125 | JUN 14 | 17 59 19.65 2 | 7191.8860 9 | 0.073286 12 | 41 | 6664.82 | 51.6415 5 | -4 | -93.8491 13 | 34 | 19.876 7 | -2.20 | -17.162 | 512438.70 | 964 8 | -3 14 | 34 | 3.2 | 1.5 | 38560.7495330 |
| 1150 | JUN 16 | 12 07 03.31 2 | 7191.7379 6 | 0.073340 9 | 40 | 6664.30 | 51.6420 3 | -1 | -101.0504 9 | 33 | 25.212 5 | -2.57 | -21.803 | 512454.53 | 039 8 | 20 12 | 29 | 2.9 | 0.9 | 38562.5048994 |
| 1175 | JUN 18 | 6 14 42.08 2 | 7191.6025 4 | 0.073376 7 | 39 | 6663.91 | 51.6426 3 | 0 | -108.2541 8 | 35 | 30.544 4 | -2.89 | -26.467 | 512469.00 | 786 6 | 3 8 | 33 | 3.7 | 0.9 | 38564.2602093 |
| 1200 | JUN 20 | 0 22 16.21 2 | 7191.4648 7 | 0.073433 5 | 37 | 6663.37 | 51.6437 3 | 0 | -115.4568 9 | 37 | 35.845 6 | -3.15 | -31.131 | 512483.71 | 990 6 | 92 12 | 28 | 3.1 | 1.1 | 38566.0154654 |
| 1225 | JUN 21 | 18 29 44.66 1 | 7191.2875 6 | 0.073477 4 | 35 | 6662.89 | 51.6432 3 | -2 | -122.6598 8 | 38 | 41.134 7 | -3.40 | -35.819 | 512502.67 | 1013 5 | -71 8 | 24 | 3.3 | 0.9 | 38567.7706558 |
| 1250 | JUN 23 | 12 37 07.16 1 | 7191.1317 5 | 0.073498 5 | 32 | 6662.60 | 51.6423 3 | -4 | -129.8613 6 | 39 | 46.460 6 | -3.63 | -40.582 | 512519.32 | 963 6 | -17 9 | 27 | 3.0 | 0.9 | 38569.5257773 |
| 1275 | JUN 25 | 6 44 23.96 2 | 7190.9768 7 | 0.073527 6 | 28 | 6662.25 | 51.6417 4 | -4 | -137.0669 7 | 38 | 51.779 5 | -3.86 | -45.383 | 512535.88 | 1016 9 | 73 16 | 26 | 3.0 | 1.0 | 38571.2808329 |
| 1300 | JUN 27 | 0 51 34.69 2 | 7190.8043 7 | 0.073558 7 | 24 | 6661.86 | 51.6403 4 | -2 | -144.2716 8 | 37 | 57.081 5 | -4.07 | -50.216 | 512554.33 | 986 8 | -33 13 | 26 | 3.2 | 1.1 | 38573.0358182 |
| 1325 | JUN 28 | 18 58 39.32 1 | 7190.6436 7 | 0.073593 5 | 21 | 6661.46 | 51.6402 3 | 1 | -151.4784 7 | 37 | 62.374 4 | -4.28 | -55.095 | 512571.51 | 1007 5 | 20 10 | 29 | 3.4 | 1.0 | 38574.7907329 |
| 1350 | JUN 30 | 13 05 37.71 2 | 7190.4791 11 | 0.073603 7 | 18 | 6661.24 | 51.6411 4 | 3 | -158.6855 11 | 38 | 67.668 8 | -4.46 | -60.033 | 512589.11 | 910 8 | -66 17 | 24 | 3.1 | 1.6 | 38576.5455753 |
| 1375 | JUL 2 | 7 12 30.39 2 | 7190.3463 10 | 0.073618 8 | 14 | 6661.01 | 51.6396 5 | 1 | -165.8891 14 | 39 | 72.988 9 | -4.59 | -65.057 | 512603.30 | 840 10 | 70 16 | 17 | 3.5 | 1.5 | 38578.3003517 |
| 1400 | JUL 4 | 1 19 17.53 4 | 7190.1833 12 | 0.073627 9 | 11 | 6660.79 | 51.6394 5 | -1 | -173.0946 15 | 38 | 78.287 13 | -4.66 | -70.124 | 512620.74 | 1158 14 | 55 28 | 17 | 3.2 | 1.7 | 38580.0550640 |
| 1425 | JUL 5 | 19 25 57.69 2 | 7190.0006 6 | 0.073628 6 | 06 | 6660.62 | 51.6395 3 | -2 | 179.6976 10 | 38 | 83.614 7 | -4.72 | -75.288 | 512640.27 | 1012 6 | -35 10 | 30 | 3.2 | 1.4 | 38581.8096955 |
| 1450 | JUL 7 | 13 32 31.33 2 | 7189.8325 7 | 0.073605 6 | 01 | 6660.62 | 51.6397 3 | 2 | 172.4915 10 | 36 | 88.925 7 | -4.62 | -80.508 | 512658.25 | 1207 5 | 129 10 | 36 | 3.3 | 1.6 | 38583.5642515 |
| 1475 | JUL 9 | 7 38 57.54 2 | 7189.6109 6 | 0.073580 5 | -04 | 6660.60 | 51.6404 3 | 5 | 165.2832 9 | 37 | 94.222 5 | -4.70 | -85.786 | 512681.95 | 1304 6 | -44 10 | 30 | 3.3 | 1.3 | 38585.3187215 |
| 1500 | JUL 11 | 1 45 15.74 2 | 7189.4126 4 | 0.073534 5 | -08 | 6660.75 | 51.6422 4 | 5 | 158.0770 7 | 38 | 99.513 5 | -4.71 | -91.134 | 512703.16 | 1096 9 | -49 5 | 26 | 4.4 | 1.2 | 38587.0730988 |
| 1525 | JUL 12 | 19 51 26.99 2 | 7189.2479 4 | 0.073502 4 | -11 | 6660.82 | 51.6431 3 | 3 | 150.8666 7 | 38 | 104.812 6 | -4.64 | -96.560 | 512720.78 | 959 4 | -9 5 | 24 | 3.1 | 1.1 | 38588.8273957 |
| 1550 | JUL 14 | 13 57 32.04 3 | 7189.0938 11 | 0.073466 6 | -15 | 6660.94 | 51.6439 4 | 0 | 143.6602 8 | 36 | 110.119 11 | -4.50 | -102.068 | 512737.26 | 881 8 | -47 16 | 20 | 3.1 | 1.4 | 38590.5816208 |
| 1575 | JUL 16 | 8 03 31.25 3 | 7188.9585 9 | 0.073412 5 | -19 | 6661.20 | 51.6443 5 | 1 | 136.4517 9 | 33 | 115.427 10 | -4.31 | -107.652 | 512751.74 | 850 9 | 54 13 | 32 | 3.2 | 1.6 | 38592.3357784 |
| 1600 | JUL 18 | 2 09 24.80 2 | 7188.7909 8 | 0.073356 6 | -23 | 6661.45 | 51.6441 4 | 3 | 129.2423 10 | 33 | 120.724 6 | -4.11 | -113.294 | 512769.67 | 1230 10 | 11 15 | 36 | 3.1 | 1.4 | 38594.0898704 |
| 1625 | JUL 19 | 20 15 11.00 2 | 7188.5878 6 | 0.073292 6 | -27 | 6661.72 | 51.6447 3 | 4 | 122.0320 8 | 33 | 126.032 4 | -3.90 | -119.018 | 512791.41 | 1190 10 | -37 14 | 36 | 2.9 | 1.2 | 38595.8438773 |
| 1650 | JUL 21 | 14 20 50.01 3 | 7188.4092 5 | 0.073226 11 | -30 | 6662.03 | 51.6446 4 | 5 | 114.8229 12 | 34 | 131.342 7 | -3.70 | -124.809 | 512810.52 | 1009 9 | -44 7 | 36 | 3.1 | 1.4 | 38597.5978010 |
| 1675 | JUL 23 | 8 26 22.71 3 | 7188.2445 8 | 0.073148 9 | -34 | 6662.44 | 51.6450 4 | 3 | 107.6157 13 | 33 | 136.647 9 | -3.50 | -130.657 | 512828.14 | 1000 6 | -16 11 | 32 | 3.3 | 1.4 | 38599.3516517 |
| 1700 | JUL 25 | 2 31 49.16 3 | 7188.0841 7 | 0.073060 4 | -36 | 6662.92 | 51.6452 4 | 1 | 100.4063 10 | 31 | 141.977 7 | -3.26 | -136.590 | 512845.31 | 994 9 | 32 14 | 34 | 3.1 | 1.3 | 38601.1054301 |
| 1725 | JUL 26 | 20 37 09.54 3 | 7187.9143 7 | 0.072984 4 | -37 | 6663.31 | 51.6458 4 | 0 | 93.1967 7 | 30 | 147.310 7 | -2.99 | -142.578 | 512863.48 | 1017 9 | -15 15 | 41 | 3.4 | 1.4 | 38602.8591382 |
| 1750 | JUL 28 | 14 42 23.86 3 | 7187.7482 9 | 0.072904 4 | -38 | 6663.73 | 51.6459 4 | 1 | 85.9846 8 | 25 | 152.640 7 | -2.64 | -148.606 | 512881.25 | 1058 11 | 31 15 | 43 | 3.1 | 1.6 | 38604.6127762 |

Table 2 (Contd)

ORBITAL PARAMETERS OF ARIEL 2

| Node | Date 1964 | Time h m s | a | e | $10^4e_1$ | a(1−e) | i | $100\ i_1$ | Ω | $100\ Ω_1$ | ω | $ω_1$ | M | n | $n_1$ | $10^{-2}n_2$ | N | D | s | MJD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1775 | JUL 30 | 8 47 31.92 3 | 7187.5502 7 | 0.072804 5 | -39 | 6664.27 | 51.6456 4 | 3 | 78.7742 8 | 25 | 157.977 6 | -2.24 | -154.693 | 512902.45 | 1380 10 | 79 14 | 35 | 3.1 | 1.2 | 38606.3663417 |
| 1800 | AUG 1 | 2 52 32.40 3 | 7187.3182 9 | 0.072704 7 | -41 | 6664.77 | 51.6473 4 | 4 | 71.5616 8 | 26 | 163.311 6 | -1.84 | -160.787 | 512927.28 | 1322 7 | -40 14 | 31 | 3.3 | 1.1 | 38608.1198195 |
| 1825 | AUG 2 | 20 57 25.65 3 | 7187.1085 6 | 0.072599 8 | -43 | 6665.33 | 51.6477 5 | 3 | 64.3562 9 | 26 | 168.657 7 | -1.52 | -166.929 | 512949.73 | 1294 12 | -6 3 | 31 | 2.9 | 1.5 | 38609.8732135 |
| 1850 | AUG 4 | 15 2 11.69 3 | 7186.8681 10 | 0.072486 6 | -44 | 6665.92 | 51.6478 6 | 0 | 57.1421 9 | 23 | 174.004 6 | -1.29 | -173.087 | 512975.47 | 1712 13 | 90 17 | 33 | 3.4 | 1.5 | 38611.6265242 |
| 1875 | AUG 6 | 9 6 48.84 2 | 7186.5800 11 | 0.072355 9 | -43 | 6666.60 | 51.6482 5 | 0 | 49.9282 12 | 20 | 179.372 7 | -1.08 | -179.277 | 513006.32 | 1594 12 | -84 20 | 28 | 3.1 | 1.1 | 38613.3797319 |
| 1900 | AUG 8 | 3 11 17.64 3 | 7186.3247 10 | 0.072252 6 | -41 | 6667.10 | 51.6484 4 | 2 | 42.7189 9 | 18 | 184.726 5 | -0.76 | -185.447 | 513033.65 | 1545 8 | -52 14 | 34 | 3.4 | 1.0 | 38615.1328431 |
| 1925 | AUG 9 | 21 15 38.52 4 | 7186.0804 13 | 0.072158 11 | -39 | 6667.55 | 51.6483 5 | 4 | 35.5043 11 | 19 | 190.107 8 | -0.36 | -191.640 | 513059.82 | 1472 11 | -28 24 | 30 | 3.1 | 1.2 | 38616.8858625 |
| 1950 | AUG 11 | 15 19 52.04 3 | 7185.8260 8 | 0.072046 6 | -38 | 6668.12 | 51.6484 5 | 3 | 28.2932 8 | 20 | 195.506 6 | 0.06 | -197.834 | 513087.06 | 1729 16 | 37 18 | 30 | 3.4 | 1.2 | 38618.6387967 |
| 1975 | AUG 13 | 9 23 57.18 3 | 7185.5351 10 | 0.071937 6 | -37 | 6668.63 | 51.6487 5 | 1 | 21.0770 8 | 20 | 200.887 6 | 0.42 | -203.981 | 513118.22 | 1698 11 | -66 19 | 36 | 3.1 | 1.4 | 38620.3916340 |
| 2000 | AUG 15 | 3 27 54.24 3 | 7185.2791 14 | 0.071828 8 | -36 | 6669.17 | 51.6493 6 | 0 | 13.8654 12 | 19 | 206.254 8 | 0.69 | -210.078 | 513145.64 | 1502 12 | -23 23 | 37 | 3.2 | 1.5 | 38622.1443778 |
| 2025 | AUG 16 | 21 31 44.10 2 | 7185.0353 8 | 0.071722 8 | -35 | 6669.71 | 51.6501 5 | 0 | 6.6521 9 | 17 | 211.662 6 | 0.89 | -216.181 | 513171.76 | 1496 10 | 8 11 | 36 | 3.8 | 1.1 | 38623.8970382 |
| 2050 | AUG 18 | 15 35 27.05 2 | 7184.7868 7 | 0.071604 5 | -33 | 6670.33 | 51.6509 5 | 0 | -0.5631 7 | 15 | 217.053 5 | 1.06 | -222.216 | 513198.38 | 1483 10 | -39 11 | 24 | 3.5 | 0.8 | 38625.6496186 |
| 2075 | AUG 20 | 9 39 3.13 2 | 7184.5490 19 | 0.071515 6 | -30 | 6670.75 | 51.6494 8 | 0 | -7.7745 9 | 15 | 222.450 7 | 1.43 | -228.206 | 513223.86 | 1387 25 | -63 63 | 19 | 2.4 | 1.1 | 38627.4021195 |
| 2100 | AUG 22 | 3 42 32.91 6 | 7184.3300 29 | 0.071441 14 | -25 | 6671.07 | 51.6498 17 | 1 | -14.9886 13 | 18 | 227.852 11 | 1.43 | -234.144 | 513247.33 | 1273 22 | -60 41 | 13 | 3.2 | 1.7 | 38629.1545476 |
| 2125 | AUG 23 | 21 45 57.15 7 | 7184.1231 14 | 0.071327 23 | -21 | 6671.70 | 51.6503 9 | -1 | -22.2014 8 | 19 | 233.306 11 | 1.67 | -240.071 | 513269.51 | 1249 21 | -94 27 | 9 | 2.9 | 0.8 | 38630.9069115 |
| 2150 | AUG 25 | 15 49 16.17 4 | 7183.9376 16 | 0.071268 10 | -18 | 6671.95 | 51.6488 8 | -3 | -29.4150 11 | 17 | 238.724 6 | 1.93 | -245.899 | 513289.38 | 1169 41 | -18 45 | 21 | 2.7 | 1.1 | 38632.6592149 |
| 2175 | AUG 27 | 9 52 30.31 2 | 7183.7370 15 | 0.071225 7 | -16 | 6672.08 | 51.6496 5 | -3 | -36.6305 7 | 15 | 244.141 4 | 2.14 | -251.655 | 513310.89 | 1228 16 | -117 40 | 39 | 2.6 | 1.2 | 38634.4114619 |
| 2200 | AUG 29 | 3 55 39.52 2 | 7183.5601 11 | 0.071167 6 | -14 | 6672.33 | 51.6498 5 | -1 | -43.8492 8 | 14 | 249.569 4 | 2.25 | -257.350 | 513329.84 | 973 14 | -71 21 | 41 | 3.1 | 1.2 | 38636.1636518 |
| 2225 | AUG 30 | 21 58 44.93 2 | 7183.4090 9 | 0.071122 6 | -11 | 6672.51 | 51.6502 6 | 0 | -51.0654 8 | 15 | 255.008 7 | 2.25 | -262.984 | 513346.04 | 1001 12 | 32 13 | 39 | 3.8 | 1.1 | 38637.9157978 |
| 2250 | SEP 1 | 16 1 46.57 3 | 7183.2311 11 | 0.071053 7 | -7 | 6672.84 | 51.6491 6 | -2 | -58.2771 7 | 18 | 260.456 5 | 2.21 | -268.550 | 513365.11 | 1152 12 | -6 16 | 35 | 3.3 | 1.1 | 38639.6679002 |
| 2275 | SEP 3 | 10 4 43.43 2 | 7183.0474 9 | 0.071021 6 | -2 | 6672.90 | 51.6488 7 | -5 | -65.4944 7 | 18 | 265.889 5 | 2.21 | -274.031 | 513384.81 | 1126 13 | 6 15 | 34 | 3.5 | 1.3 | 38641.4199471 |
| 2300 | SEP 5 | 4 7 35.74 2 | 7182.8645 11 | 0.071003 6 | 2 | 6672.86 | 51.6477 8 | -5 | -72.7085 10 | 17 | 271.335 6 | 2.28 | -279.452 | 513404.42 | 1151 18 | 47 24 | 22 | 3.1 | 1.1 | 38643.1719414 |
| 2325 | SEP 6 | 22 10 23.33 2 | 7182.6702 14 | 0.070985 7 | 6 | 6672.81 | 51.6468 7 | -3 | -79.9243 9 | 15 | 276.774 6 | 2.33 | -284.795 | 513425.25 | 1340 12 | 152 22 | 17 | 3.2 | 0.8 | 38644.9238811 |
| 2350 | SEP 8 | 16 13 5.07 5 | 7182.4167 15 | 0.070976 12 | 9 | 6672.64 | 51.6459 7 | -1 | -87.1415 9 | 15 | 282.215 13 | 2.35 | -290.069 | 513452.43 | 1663 11 | 67 21 | 17 | 3.4 | 0.8 | 38646.6757532 |
| 2375 | SEP 10 | 10 15 39.35 2 | 7182.1427 9 | 0.070967 5 | 12 | 6672.45 | 51.6454 6 | 0 | -94.3605 8 | 17 | 287.634 5 | 2.28 | -295.255 | 513481.82 | 1523 16 | -82 18 | 17 | 3.1 | 0.7 | 38648.4275388 |
| 2400 | SEP 12 | 4 18 6.85 2 | 7181.9114 19 | 0.070956 8 | 15 | 6672.31 | 51.6463 8 | -1 | -101.5785 8 | 19 | 293.072 7 | 2.15 | -300.395 | 513506.62 | 1322 23 | -100 47 | 19 | 2.7 | 1.1 | 38650.1792459 |
| 2425 | SEP 13 | 22 20 28.49 2 | 7181.7089 13 | 0.070971 7 | 18 | 6672.02 | 51.6452 6 | -3 | -108.7976 6 | 21 | 298.501 5 | 1.97 | -305.466 | 513528.34 | 1268 12 | 25 22 | 25 | 3.1 | 0.9 | 38651.9308853 |
| 2450 | SEP 15 | 16 22 44.66 3 | 7181.5014 12 | 0.070982 6 | 22 | 6671.74 | 51.6460 6 | -3 | -116.0160 8 | 21 | 303.951 9 | 1.78 | -310.499 | 513550.60 | 1262 47 | 2 49 | 19 | 2.4 | 0.7 | 38653.6824614 |
| 2475 | SEP 17 | 10 24 54.82 1 | 7181.2539 8 | 0.071000 7 | 26 | 6671.38 | 51.6460 6 | -2 | -123.2337 7 | 21 | 309.387 5 | 1.60 | -315.466 | 513577.15 | 1619 13 | -50 15 | 29 | 3.2 | 1.3 | 38655.4339679 |
| 2500 | SEP 19 | 4 26 57.52 2 | 7181.0087 11 | 0.071037 9 | 29 | 6670.89 | 51.6449 6 | 0 | -130.4538 8 | 21 | 314.799 5 | 1.43 | -320.363 | 513603.45 | 1394 12 | -15 19 | 25 | 3.1 | 1.3 | 38657.1853879 |
| 2525 | SEP 20 | 22 28 53.71 2 | 7180.7897 12 | 0.071064 9 | 31 | 6670.49 | 51.6443 6 | 2 | -137.6739 12 | 23 | 320.218 7 | 1.28 | -325.221 | 513626.95 | 1394 22 | 111 26 | 20 | 2.9 | 1.0 | 38658.9367327 |
| 2550 | SEP 22 | 16 30 43.26 2 | 7180.5255 9 | 0.071084 6 | 33 | 6670.11 | 51.6452 5 | 1 | -144.8924 9 | 25 | 325.641 6 | 1.10 | -330.042 | 513655.29 | 1772 9 | 44 13 | 30 | 3.5 | 1.1 | 38660.6880006 |
| 2575 | SEP 24 | 10 32 24.18 1 | 7180.2323 7 | 0.071134 4 | 35 | 6669.47 | 51.6452 4 | -2 | -152.1134 5 | 27 | 331.032 3 | 0.84 | -334.802 | 513686.76 | 1722 6 | -15 12 | 42 | 3.4 | 1.0 | 38662.4391687 |
| 2600 | SEP 26 | 4 33 56.69 1 | 7179.9624 6 | 0.071187 5 | 37 | 6668.84 | 51.6442 4 | -5 | -159.3363 4 | 28 | 336.438 3 | 0.46 | -339.545 | 513715.72 | 1589 8 | -14 11 | 39 | 3.2 | 1.0 | 38664.1902394 |
| 2625 | SEP 27 | 22 35 21.36 1 | 7179.7075 17 | 0.071221 8 | 39 | 6668.36 | 51.6437 5 | -4 | -166.5605 7 | 27 | 341.842 5 | 0.07 | -344.262 | 513743.07 | 1811 13 | 322 46 | 30 | 2.5 | 1.0 | 38665.9412194 |

Table 2 (Contd)

ORBITAL PARAMETERS OF ARIEL 2

| Node | Date 1964 | Time h m s | a | e | $10^4 e_1$ | a(1−e) | i | 100 $i_1$ | Ω | 100 $Ω_1$ | ω | $ω_1$ | M | n | $n_1$ | $10^{-2} n_2$ | N | D | s | MJD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2650 | SEP 29 | 16 36 36.93 2 | 7179.3550 8 | 0.071265 7 | 41 | 6667.72 | 51.6434 5 | 0 | −173.7817 9 | 28 | 347.251 7 | −0.23 | −348.963 | 513780.92 | 2157 15 | −28 12 | 32 | 3.9 | 1.3 | 38667.6920941 |
| 2675 | OCT 1 | 10 37 41.48 1 | 7179.0104 5 | 0.071302 5 | 42 | 6667.13 | 51.6427 4 | 2 | 178.9925 6 | 31 | 352.631 5 | −0.43 | −353.625 | 513817.91 | 2101 7 | −32 14 | 29 | 3.4 | 0.9 | 38669.4428412 |
| 2700 | OCT 3 | 4 38 35.45 2 | 7178.6798 10 | 0.071339 9 | 23 | 6666.56 | 51.6414 4 | 1 | 171.7671 11 | 39 | 358.020 6 | −0.68 | −358.288 | 513853.40 | 2079 10 | 142 17 | 24 | 3.1 | 0.9 | 38671.1934658 |
| 2725 | OCT 4 | 22 39 18.59 3 | 7178.2934 9 | 0.071350 7 | 42 | 6666.12 | 51.6416 4 | −4 | 164.5469 12 | 32 | 3.410 9 | −1.04 | −2.948 | 513894.89 | 2608 17 | −35 20 | 25 | 2.9 | 1.1 | 38672.9439651 |
| 2750 | OCT 6 | 16 39 48.52 1 | 7177.8920 6 | 0.071389 3 | 42 | 6665.47 | 51.6419 3 | −5 | 157.3204 5 | 32 | 8.760 5 | −1.48 | −7.577 | 513938.00 | 2196 13 | 9 20 | 37 | 3.1 | 0.9 | 38674.6943116 |
| 2775 | OCT 8 | 10 40 6.59 1 | 7177.5405 5 | 0.071426 4 | 42 | 6664.88 | 51.6411 3 | −4 | 150.0922 4 | 32 | 14.122 4 | −1.91 | −12.225 | 513975.75 | 2152 5 | 27 8 | 49 | 3.4 | 1.0 | 38676.4445208 |
| 2800 | OCT 10 | 4 40 13.27 1 | 7177.1817 7 | 0.071473 5 | 41 | 6664.21 | 51.6408 4 | −1 | 142.8626 6 | 33 | 19.464 6 | −2.26 | −16.868 | 514014.30 | 2099 5 | −117 10 | 38 | 3.3 | 1.2 | 38678.1945980 |
| 2825 | OCT 11 | 22 40 8.90 2 | 7176.8724 17 | 0.071510 6 | 40 | 6663.65 | 51.6411 5 | 0 | 135.6353 9 | 35 | 24.799 9 | −2.54 | −21.523 | 514047.53 | 1887 9 | 84 26 | 26 | 3.1 | 1.5 | 38679.9445474 |
| 2850 | OCT 13 | 16 39 54.24 3 | 7176.5419 18 | 0.071541 6 | 39 | 6663.12 | 51.6394 6 | 0 | 128.4073 11 | 36 | 30.172 10 | −2.77 | −26.236 | 514083.04 | 1863 23 | 168 41 | 25 | 2.9 | 1.6 | 38681.6943778 |
| 2875 | OCT 15 | 10 39 28.82 1 | 7176.2404 6 | 0.071564 4 | 37 | 6662.68 | 51.6388 3 | −1 | 121.1768 8 | 36 | 35.533 5 | −3.02 | −30.968 | 514115.43 | 1734 5 | −45 10 | 41 | 3.4 | 1.1 | 38683.4440835 |
| 2900 | OCT 17 | 4 38 53.85 2 | 7175.9666 6 | 0.071592 5 | 34 | 6662.22 | 51.6389 3 | −2 | 113.9451 8 | 35 | 40.879 5 | −3.30 | −35.722 | 514144.86 | 1698 4 | 14 10 | 42 | 3.3 | 1.1 | 38685.1936789 |
| 2925 | OCT 18 | 22 38 9.45 [illegible] | 7175.6832 13 | 0.071605 5 | 30 | 6661.87 | 51.639[illegible] 4 | −2 | 106.7141 8 | 34 | 46.205 7 | −3.64 | −40.498 | 514175.32 | 1869 8 | 111 20 | 30 | 3.2 | 1.4 | 38686.9431649 |
| 2950 | OCT 20 | 16 37 14.64 2 | 7175.3562 12 | 0.071620 8 | 27 | 6661.46 | 51.6392 5 | 1 | 99.4801 9 | 34 | 51.530 12 | −3.99 | −45.317 | 514210.47 | 1834 20 | −229 22 | 26 | 3.3 | 1.7 | 38688.6925306 |
| 2975 | OCT 22 | 10 36 9.62 [illegible] | 7175.0983 9 | 0.071630 7 | 25 | 6661.15 | 51.6399 5 | 4 | 92.2467 12 | 36 | 56.841 8 | −4.26 | −50.170 | 514238.19 | 1487 12 | −51 20 | 36 | 3.1 | 1.9 | 38690.4417780 |
| 3000 | OCT 24 | 4 34 56.26 [illegible] | 7174.8886 8 | 0.071646 6 | 23 | 6660.84 | 51.6402 4 | 4 | 85.0146 12 | 39 | 62.171 7 | −4.39 | −55.094 | 514260.74 | 1210 13 | 13 15 | 33 | 3.5 | 1.6 | 38692.1909289 |
| 3025 | OCT 25 | 22 33 35.63 3 | 7174.6747 11 | 0.071665 7 | 20 | 6660.50 | 51.6403 4 | 2 | 77.7815 14 | 39 | 67.516 9 | −4.43 | −60.087 | 514283.73 | 1540 9 | 124 17 | 26 | 3.3 | 1.7 | 38693.9399957 |
| 3050 | OCT 27 | 16 32 6.11 [illegible] | 7174.3993 6 | 0.071658 6 | 15 | 6660.30 | 51.6408 3 | 0 | 70.5503 11 | 37 | 72.840 7 | −4.47 | −65.122 | 514313.35 | 1650 8 | −72 11 | 30 | 3.5 | 1.5 | 38695.6889596 |
| 3075 | OCT 29 | 10 30 27.04 [illegible] | 7174.1455 9 | 0.071637 6 | 10 | 6660.21 | 51.6417 4 | 2 | 63.3151 8 | 35 | 78.151 6 | −4.61 | −70.211 | 514340.64 | 1576 9 | 20 23 | 34 | 2.9 | 1.5 | 38697.4378130 |
| 3100 | OCT 31 | 4 28 38.80 [illegible] | 7173.8930 6 | 0.071613 4 | 4 | 6660.15 | 51.6425 4 | 4 | 56.0794 7 | 36 | 83.475 6 | −4.75 | −75.379 | 514367.79 | 1422 5 | −89 10 | 36 | 3.2 | 1.4 | 38699.1865602 |
| 3125 | NOV 1 | 22 26 42.06 [illegible] | 7173.6686 15 | 0.071593 5 | 16 | 6660.08 | 51.6436 4 | 3 | 48.8428 8 | 38 | 88.789 8 | −4.78 | −80.603 | 514391.93 | 1598 28 | 168 [illegible] | 22 | 2.8 | 1.2 | 38700.9352090 |
| 3150 | NOV 3 | 16 24 36.13 3 | 7173.4042 27 | 0.071564 10 | −3 | 6660.05 | 51.6417 6 | 3 | 41.6099 13 | 39 | 94.076 11 | −4.91 | −85.872 | 514420.37 | 1445 11 | −80 29 | 16 | 3.7 | 1.6 | 38702.6837515 |
| 3175 | NOV 5 | 10 22 21.47 3 | 7173.1836 8 | 0.071528 8 | 6 | 6660.10 | 51.6427 5 | 1 | 34.3747 14 | 38 | 99.414 9 | −4.84 | −91.264 | 514444.10 | 1349 13 | 6 17 | 25 | 4.0 | 1.8 | 38704.4321929 |
| 3200 | NOV 7 | 4 19 58.60 3 | 7172.9622 8 | 0.071484 7 | −9 | 6660.21 | 51.6430 4 | 0 | 27.1394 11 | 36 | 104.750 9 | −4.67 | −96.725 | 514467.92 | 1252 10 | −82 15 | 29 | 3.1 | 1.8 | 38706.1805393 |
| 3225 | NOV 8 | 22 17 28.01 2 | 7172.7615 6 | 0.071426 6 | −14 | 6660.44 | 51.6436 4 | 1 | 19.9025 7 | 34 | 110.065 7 | −4.48 | −102.239 | 514489.51 | 1419 5 | 133 9 | 36 | 3.4 | 1.6 | 38707.9287964 |
| 3250 | NOV 10 | 16 14 48.93 7 | 7172.5095 6 | 0.071370 4 | −18 | 6660.61 | 51.6445 3 | 2 | 12.6636 7 | 33 | 115.390 7 | −4.28 | −107.833 | 514516.63 | 1430 5 | −97 9 | 41 | 3.3 | 1.5 | 38709.6769552 |
| 3275 | NOV 12 | 10 12 1.31 2 | 7172.2967 5 | 0.071312 4 | −23 | 6660.83 | 51.6452 3 | 2 | 5.4254 7 | 34 | 120.729 6 | −4.10 | −113.512 | 514539.52 | 1308 6 | −2 9 | 32 | 3.6 | 1.2 | 38711.4250152 |
| 3300 | NOV 14 | 4 9 5.89 2 | 7172.0840 7 | 0.071252 7 | −27 | 6661.06 | 51.6448 4 | 1 | −1.8122 11 | 34 | 126.063 6 | −3.95 | −119.253 | 514562.41 | 1257 12 | −39 14 | 17 | 2.9 | 1.0 | 38713.1729848 |
| 3325 | NOV 15 | 22 6 2.80 5 | 7171.8763 14 | 0.071206 25 | −30 | 6661.20 | 51.6437 6 | −1 | −9.0515 20 | 33 | 131.417 15 | −3.80 | −125.078 | 514584.55 | 1499 10 | 172 22 | 14 | 3.3 | 1.2 | 38714.9208657 |
| 3350 | NOV 17 | 16 2 51.29 3 | 7171.6074 8 | 0.071055 7 | −32 | 6662.03 | 51.6443 3 | −1 | −16.2859 9 | 30 | 136.719 7 | −3.63 | −130.915 | 514613.70 | 1592 5 | −79 10 | 30 | 3.4 | 1.3 | 38716.6686492 |
| 3375 | NOV 19 | 9 59 30.51 3 | 7171.3701 7 | 0.070976 7 | −33 | 6662.37 | 51.6443 [illegible] | 0 | −23.5290 8 | 27 | 142.061 6 | −3.32 | −136.844 | 514639.25 | 1326 7 | −82 13 | 36 | 3.1 | 1.4 | 38718.4163254 |
| 3400 | NOV 21 | 3 56 2.15 3 | 7171.1776 11 | 0.070929 10 | −34 | 6662.53 | 51.6448 6 | 2 | −30.7692 11 | 26 | 147.410 9 | −2.89 | −142.829 | 514659.97 | 1143 13 | 8 18 | 25 | 3.4 | 1.7 | 38720.1639137 |
| 3425 | NOV 22 | 21 52 27.08 3 | 7170.9762 19 | 0.070834 11 | −37 | 6663.03 | 51.6450 7 | 3 | −38.0091 12 | 27 | 152.762 8 | −2.45 | −148.865 | 514681.66 | 1445 13 | 117 29 | 28 | 3.3 | 1.8 | 38721.9114245 |
| 3450 | NOV 24 | 15 48 43.91 3 | 7170.7084 9 | 0.070715 6 | −39 | 6663.63 | 51.6448 4 | 0 | −45.2472 11 | 28 | 158.123 8 | −2.12 | −154.949 | 514710.49 | 1453 8 | −229 13 | 27 | 3.4 | 1.2 | 38723.6588416 |
| 3475 | NOV 26 | 9 44 52.74 4 | 7170.5107 10 | 0.070617 5 | −41 | 6664.15 | 51.6445 [illegible] | −1 | −52.4871 10 | 24 | 163.489 11 | −2.00 | −161.067 | 514731.77 | 1346 16 | 112 21 | 35 | 3.0 | 1.7 | 38725.4061660 |
| 3500 | NOV 28 | 3 40 54.27 4 | 7170.2728 8 | 0.070515 5 | −42 | 6664.66 | 51.6451 [illegible] | 0 | −59.7306 8 | 23 | 168.864 9 | −1.65 | −167.218 | 514757.39 | 1440 10 | −17 14 | 41 | 3.6 | 1.7 | 38727.1534059 |

Table 2 (Contd)

ORBITAL PARAMETERS OF ARIEL 2

| Node | Date 1964 | Time h m s | a | e | $10^4 e_1$ | a(1−e) | i | 100 $i_1$ | Ω | 100 $Ω_1$ | ω | $ω_1$ | M | n | $n_1$ | $10^{-2} n_2$ | N | D | ε | MJD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3525 | NOV 29 | 21 36 48.28 4 | 7170.0515 5 | 0.070404 10 | -41 | 6665.25 | 51.6457 6 | 2 | -66.9722 10 | 22 | 174.230 3 | -1.35 | -173.374 | 514781.22 | 1318 9 | 0 14 | 33 | 3.2 | 1.5 | 38728.9005588 |
| 3550 | DEC 1 | 15 32 35.39 2 | 7169.8315 8 | 0.070265 8 | -40 | 6666.04 | 51.6457 5 | 3 | -74.2130 8 | 22 | 179.598 5 | -0.97 | -179.538 | 514804.92 | 1357 10 | -16 15 | 35 | 3.3 | 1.3 | 38730.6476319 |
| 3575 | DEC 3 | 9 28 15.48 3 | 7169.6122 13 | 0.070184 8 | -39 | 6666.42 | 51.6456 5 | 2 | -81.4530 12 | 23 | 184.967 8 | -0.56 | -185.702 | 514828.54 | 1339 10 | -10 20 | 34 | 3.4 | 1.2 | 38732.3946236 |
| 3600 | DEC 5 | 3 23 48.74 4 | 7169.3990 12 | 0.070082 8 | -39 | 6666.95 | 51.6455 6 | 0 | -88.6947 12 | 24 | 190.384 8 | -0.19 | -191.910 | 514851.50 | 1289 15 | 14 23 | 34 | 3.3 | 1.5 | 38734.1415364 |
| 3625 | DEC 6 | 21 19 15.66 3 | 7169.1914 12 | 0.069976 6 | -38 | 6667.52 | 51.6459 6 | -2 | -95.9381 10 | 23 | 195.802 7 | 0.12 | -198.100 | 514873.87 | 1278 16 | 37 24 | 25 | 3.0 | 1.2 | 38735.8883757 |
| 3650 | DEC 8 | 15 14 36.46 2 | 7168.9672 10 | 0.069867 7 | -38 | 6668.09 | 51.6456 5 | -2 | -103.1771 6 | 21 | 201.187 4 | 0.30 | -204.228 | 514898.02 | 1335 8 | -73 15 | 31 | 3.2 | 1.2 | 38737.6351442 |
| 3675 | DEC 10 | 9 9 50.81 3 | 7168.7615 12 | 0.069760 7 | -36 | 6668.67 | 51.6461 7 | -1 | -110.4230 6 | 19 | 206.597 5 | 0.63 | -210.350 | 514920.17 | 1239 11 | -31 20 | 40 | 3.3 | 1.6 | 38739.3818381 |
| 3700 | DEC 12 | 3 4 59.54 2 | 7168.5779 10 | 0.069662 6 | -34 | 6669.20 | 51.6454 5 | 1 | -117.6669 9 | 18 | 2[illegible] 026 6 | 0.88 | -216.453 | 514939.96 | 1019 9 | -39 15 | 36 | 3.2 | 1.0 | 38741.1284669 |
| 3725 | DEC 13 | 21 0 3.89 4 | 7168.4129 18 | 0.069570 11 | -31 | 6669.71 | 51.6447 4 | 1 | -124.9045 12 | 18 | 217.452 8 | 1.14 | -222.507 | 514957.74 | 1170 17 | 41 53 | 33 | 2.6 | 1.0 | 38742.8750450 |
| 3750 | DEC 15 | 14 55 3.16 2 | 7168.2152 10 | 0.069487 6 | -27 | 6670.12 | 51.6452 4 | -1 | -132.1493 9 | 19 | 222.877 6 | 1.40 | -228.507 | 514979.04 | 1173 11 | -34 16 | 37 | 3.2 | 1.0 | 38744.6215644 |
| 3775 | DEC 17 | 8 49 57.34 3 | 7168.0236 14 | 0.069404 7 | -25 | 6670.53 | 51.6449 7 | -4 | -139.3909 11 | 19 | 228.320 9 | 1.64 | -234.469 | 514999.69 | 1231 11 | 19 21 | 37 | 3.4 | 1.4 | 38746.3680248 |
| 3800 | DEC 19 | 2 44 46.27 2 | 7167.8288 13 | 0.069311 5 | -23 | 6671.02 | 51.6450 7 | -5 | -146.6343 9 | 17 | 233.768 6 | 1.83 | -240.374 | 515020.69 | 1145 12 | 41 23 | 40 | 3.2 | 1.3 | 38748.1144245 |
| 3825 | DEC 20 | 20 39 30.26 2 | 7167.6401 10 | 0.069240 5 | -20 | 6671.35 | 51.6434 6 | -1 | -153.8805 7 | 16 | 239.221 5 | 1.98 | -246.219 | 515041.03 | 1102 9 | -62 15 | 31 | 3.5 | 1.1 | 38749.8607669 |
| 3850 | DEC 22 | 14 34 9.74 3 | 7167.4768 11 | 0.069209 10 | -17 | 6671.42 | 51.6437 7 | 2 | -161.1235 10 | 16 | 244.663 5 | 2.08 | -251.988 | 515058.63 | 981 12 | 5 19 | 23 | 3.3 | 1.3 | 38751.6070572 |
| 3875 | DEC 24 | 8 28 45.39 2 | 7167.3119 17 | 0.069147 8 | -13 | 6671.71 | 51.6450 7 | 2 | -168.3697 10 | 17 | 250.103 7 | 2.18 | -257.682 | 515076.40 | 999 16 | -42 26 | 27 | 3.4 | 1.3 | 38753.3533031 |
| 3900 | DEC 26 | 2 23 17.28 3 | 7167.1611 16 | 0.069074 11 | -9 | 6672.10 | 51.6444 8 | -1 | -175.6141 11 | 18 | 255.573 13 | 2.28 | -263.332 | 515092.66 | 907 16 | -49 22 | 22 | 3.5 | 1.1 | 38755.0995055 |
| 3925 | DEC 27 | 20 17 45.73 2 | 7167.0175 10 | 0.069034 5 | -6 | 6672.25 | 51.6453 6 | 2 | 177.1436 7 | 18 | 261.045 6 | 2.34 | -268.916 | 515108.14 | 860 18 | 0 22 | 19 | 3.0 | 0.8 | 38756.8456681 |
| 3950 | DEC 29 | 14 12 10.78 3 | 7166.8741 14 | 0.069015 8 | -2 | 6672.25 | 51.6421 9 | -2 | 169.8969 10 | 17 | 266.499 8 | 2.42 | -274.412 | 515123.60 | 959 12 | 31 17 | 17 | 3.5 | 1.1 | 38758.5917914 |
| 3975 | DEC 31 | 8 6 32.20 3 | 7166.7126 21 | 0.068998 8 | 2 | 6672.22 | 51.6435 8 | 0 | 162.6548 11 | 17 | 271.971 7 | 2.43 | -279.853 | 515141.01 | 955 18 | -13 38 | 22 | 3.1 | 1.4 | 38760.3378727 |
| 4000 | JAN 2 | 2 0 49.67 2 | 7166.5549 13 | 0.068990 7 | 5 | 6672.13 | 51.6444 8 | 2 | 155.4076 10 | 19 | 277.427 6 | 2.38 | -285.208 | 515158.02 | 1059 14 | 44 21 | 27 | 3.3 | 1.3 | 38762.0839082 |
| 4025 | JAN 3 | 19 55 3.17 2 | 7166.3827 19 | 0.068963 7 | 9 | 6672.17 | 51.6463 8 | 3 | 148.1640 8 | 20 | 282.912 7 | 2.28 | -290.521 | 515176.58 | 1059 13 | 20 30 | 28 | 3.2 | 1.4 | 38763.8298978 |
| 4050 | JAN 5 | 13 49 12.27 2 | 7166.2133 10 | 0.068981 7 | 13 | 6671.88 | 51.6455 8 | 1 | 140.9181 8 | 22 | 288.375 6 | 2.15 | -295.750 | 515194.85 | 1002 16 | 9 21 | 29 | 3.1 | 1.5 | 38765.5758364 |
| 4075 | JAN 7 | 7 43 17.26 2 | 7166.0490 10 | 0.068981 7 | 16 | 6671.73 | 51.6427 6 | -1 | 133.6728 8 | 21 | 293.816 6 | 2.04 | -300.894 | 515212.57 | 1090 11 | 39 12 | 25 | 3.6 | 1.1 | 38767.3217276 |
| 4100 | JAN 9 | 1 37 17.60 2 | 7165.8498 13 | 0.069013 5 | 22 | 6671.31 | 51.6447 5 | -3 | 126.4290 7 | 21 | 299.255 5 | 1.92 | -305.980 | 515234.05 | 1299 13 | 18 21 | 28 | 3.2 | 1.0 | 38769.0675648 |
| 4125 | JAN 10 | 19 31 12.24 2 | 7165.6426 13 | 0.069041 6 | 24 | 6670.92 | 51.6442 7 | -1 | 119.1795 8 | 20 | 304.714 6 | 1.81 | -311.027 | 515256.40 | 1246 26 | -88 32 | 27 | 2.8 | 1.2 | 38770.8133361 |
| 4150 | JAN 12 | 13 25 1.73 2 | 7165.4519 15 | 0.069065 8 | 26 | 6670.57 | 51.6459 7 | 1 | 111.9343 9 | 22 | 310.195 7 | 1.64 | -316.041 | 515276.97 | 1307 12 | 27 21 | 32 | 3.4 | 1.6 | 38772.5590478 |
| 4175 | JAN 14 | 7 18 45.38 1 | 7165.2327 12 | 0.069086 8 | 28 | 6670.22 | 51.6450 6 | 2 | 104.6863 8 | 25 | 315.629 6 | 1.41 | -320.964 | 515300.62 | 1348 17 | -35 23 | 32 | 3.2 | 1.3 | 38774.3046919 |
| 4200 | JAN 16 | 1 12 22.85 2 | 7165.0190 11 | 0.069112 6 | 30 | 6669.83 | 51.6444 5 | 0 | 97.4400 8 | 27 | 321.048 6 | 1.10 | -325.832 | 515323.67 | 1317 9 | 2 14 | 33 | 3.5 | 1.2 | 38776.0502645 |
| 4225 | JAN 17 | 19 5 54.19 1 | 7164.8020 10 | 0.069170 5 | 33 | 6669.21 | 51.6440 5 | -3 | 90.1916 7 | 26 | 326.471 4 | 0.78 | -330.666 | 515347.08 | 1438 9 | 71 16 | 38 | 3.2 | 1.2 | 38777.7957660 |
| 4250 | JAN 19 | 12 59 18.81 2 | 7164.5667 9 | 0.069233 6 | 37 | 6668.54 | 51.6430 5 | -4 | 82.9404 8 | 24 | 331.912 5 | 0.50 | -335.482 | 515372.47 | 1399 10 | 8 15 | 39 | 2.9 | 1.3 | 38779.5411899 |
| 4275 | JAN 21 | 6 52 36.64 1 | 7164.3278 11 | 0.069268 6 | 40 | 6668.07 | 51.6422 4 | -2 | 75.6889 8 | 24 | 337.346 5 | 0.28 | -340.262 | 515398.25 | 1698 15 | 117 32 | 29 | 2.9 | 1.0 | 38781.2865352 |
| 4300 | JAN 23 | 0 45 46.13 4 | 7164.0212 22 | 0.069257 18 | 41 | 6667.86 | 51.6430 9 | 0 | 68.4379 18 | 26 | 342.729 16 | -0.06 | -344.973 | 515431.33 | 2117 31 | 134 41 | 13 | 2.9 | 1.1 | 38783.0317839 |
| 4325 | JAN 24 | 18 38 45.74 2 | 7163.6956 15 | 0.069336 7 | 41 | 6666.99 | 51.6433 7 | 0 | 61.1924 11 | 29 | 348.167 6 | -0.22 | -349.717 | 515466.48 | 1815 12 | -81 23 | 16 | 3.2 | 1.0 | 38784.7769183 |
| 4350 | JAN 26 | 12 31 36.12 1 | 7163.4219 9 | 0.069378 5 | 41 | 6666.44 | 51.6425 4 | -1 | 53.9387 7 | 31 | 353.563 5 | -0.57 | -354.410 | 515496.02 | 1734 22 | 42 23 | 30 | 3.0 | 1.0 | 38786.5219458 |
| 4375 | JAN 28 | 6 24 17.89 2 | 7163.1259 9 | 0.069449 7 | 42 | 6665.65 | 51.6416 5 | -3 | 46.6840 9 | 30 | 358.976 7 | -0.98 | -359.111 | 515527.97 | 1972 8 | 20 15 | 31 | 3.4 | 1.3 | 38788.2668738 |

Table 2 (Contd)

ORBITAL PARAMETERS OF ARIEL 2

| Node | Date 1964 | Time h m s | a | e | $10^4e_1$ | a(1−e) | i | 100 $i_1$ | Ω | 100 $Ω_1$ | ω | $ω_1$ | M | n | $n_1$ | $10^{-2}n_2$ | N | D | ε | MJD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4400 | JAN 30 | 0 16 49.80 2 | 7162.8066 9 | 0.069491 7 | 42 | 6665.06 | 51.6410 4 | 2 | 39.4337 10 | 30 | 4.373 7 | −1.40 | −3.796 | 515562.44 | 1965 12 | −18 20 | 35 | 3.1 | 1.2 | 38790.0116875 |
| 4425 | JAN 31 | 18 9 11.51 2 | 7162.4832 7 | 0.069507 6 | 43 | 6664.64 | 51.6409 3 | −1 | 32.1815 8 | 30 | 9.771 5 | −1.80 | −8.486 | 515597.36 | 2087 6 | 52 11 | 41 | 3.5 | 1.0 | 38791.7563831 |
| 4450 | FEB 2 | 12 1 22.40 1 | 7162.1369 6 | 0.069539 4 | 44 | 6664.09 | 51.6412 3 | 0 | 24.9270 5 | 31 | 15.150 5 | −2.13 | −13.168 | 515634.76 | 2153 5 | 10 9 | 37 | 3.3 | 1.0 | 38793.5009537 |
| 4475 | FEB 4 | 5 53 22.01 1 | 7161.7771 7 | 0.069573 6 | 44 | 6663.51 | 51.6415 4 | 1 | 17.6694 7 | 34 | 20.523 7 | −2.40 | −17.859 | 515673.61 | 2421 7 | 110 11 | 37 | 3.4 | 1.1 | 38795.2453936 |
| 4500 | FEB 5 | 23 45 9.07 1 | 7161.3712 7 | 0.069613 5 | 42 | 6662.85 | 51.6420 4 | 0 | 10.4147 9 | 36 | 25.890 7 | −2.63 | −22.565 | 515717.46 | 2475 10 | 3 14 | 40 | 3.5 | 1.5 | 38796.9896883 |
| 4525 | FEB 7 | 17 36 42.67 2 | 7160.9286 9 | 0.069633 6 | 40 | 6662.29 | 51.6410 5 | −2 | 3.1574 12 | 36 | 31.261 6 | −2.88 | −27.299 | 515765.27 | 3086 9 | 144 16 | 45 | 3.4 | 1.9 | 38798.7338272 |
| 4550 | FEB 9 | 11 28 0.43 1 | 7160.4427 6 | 0.069652 5 | 36 | 6661.70 | 51.6411 3 | −2 | −4.0990 7 | 35 | 36.638 6 | −3.20 | −32.068 | 515817.77 | 2710 5 | −122 10 | 37 | 3.4 | 1.3 | 38800.4777827 |
| 4575 | FEB 11 | 5 19 3.60 1 | 7160.0549 7 | 0.069660 4 | 33 | 6661.27 | 51.6408 4 | 0 | −11.3596 8 | 34 | 41.983 7 | −3.61 | −36.846 | 515861.84 | 2379 9 | −86 12 | 40 | 3.2 | 1.5 | 38802.2215694 |
| 4600 | FEB 12 | 23 9 54.02 2 | 7159.6797 7 | 0.069674 5 | 31 | 6660.84 | 51.6409 4 | 1 | −18.6198 9 | 36 | 47.342 7 | −3.99 | −41.675 | 515900.23 | 2074 9 | −31 13 | 40 | 3.5 | 1.7 | 38803.9652085 |
| 4625 | FEB 14 | 17 0 33.07 2 | 7159.3462 8 | 0.069680 5 | 29 | 6660.48 | 51.6405 4 | 0 | −25.8783 10 | 39 | 52.697 6 | −4.27 | −46.544 | 515936.28 | 2171 9 | 57 13 | 37 | 3.3 | 1.6 | 38805.7087161 |
| 4650 | FEB 16 | 10 51 0.35 2 | 7158.9915 7 | 0.069691 6 | 27 | 6660.07 | 51.6405 3 | −3 | −33.1372 9 | 40 | 58.043 7 | −4.40 | −51.454 | 515974.64 | 2144 26 | −96 26 | 32 | 3.0 | 1.3 | 38807.4520874 |
| 4675 | FEB 18 | 4 41 15.93 1 | 7158.6732 7 | 0.069679 4 | 23 | 6659.86 | 51.6399 3 | −4 | −40.3999 7 | 38 | 63.389 6 | −4.48 | −56.418 | 516009.03 | 1882 6 | −20 11 | 42 | 3.2 | 1.4 | 38809.1953232 |
| 4700 | FEB 19 | 22 31 20.98 1 | 7158.3730 5 | 0.069682 4 | 18 | 6659.56 | 51.6397 3 | −2 | −47.6635 7 | 36 | 68.731 6 | −4.67 | −61.434 | 516041.49 | 1895 6 | 17 9 | 43 | 3.3 | 1.4 | 38810.9384373 |
| 4725 | FEB 21 | 16 21 15.39 2 | 7158.0620 6 | 0.069662 5 | 13 | 6659.42 | 51.6395 4 | 0 | −54.9267 9 | 36 | 74.072 6 | −4.70 | −66.510 | 516075.13 | 1991 8 | 35 11 | 43 | 3.4 | 1.6 | 38812.6814281 |
| 4750 | FEB 23 | 10 10 58.78 2 | 7157.7450 6 | 0.069645 5 | 8 | 6659.24 | 51.6393 4 | 0 | −62.1882 9 | 37 | 79.419 6 | −4.84 | −71.654 | 516109.41 | 2115 6 | 161 10 | 39 | 3.5 | 1.6 | 38814.4242914 |
| 4775 | FEB 25 | 4 0 30.22 2 | 7157.3760 7 | 0.069605 5 | 4 | 6659.19 | 51.6393 3 | 0 | −69.4534 7 | 38 | 84.755 6 | −4.95 | −76.857 | 516149.32 | 2260 5 | −26 11 | 36 | 3.3 | 1.5 | 38816.1670165 |
| 4800 | FEB 26 | 21 49 49.04 2 | 7157.0195 7 | 0.069570 6 | 0 | 6659.11 | 51.6390 4 | −2 | −76.7186 9 | 39 | 90.098 7 | −4.99 | −82.131 | 516187.89 | 2183 8 | −14 12 | 32 | 3.6 | 1.7 | 38817.9095953 |
| 4825 | FEB 28 | 15 38 55.57 3 | 7156.6666 11 | 0.069529 8 | −3 | 6659.07 | 51.6377 5 | −3 | −83.9837 13 | 37 | 95.443 9 | −4.97 | −87.478 | 516226.07 | 2243 16 | 12 28 | 25 | 3.0 | 1.9 | 38819.6520320 |
| 4850 | MAR 2 | 9 27 49.61 3 | 7156.3083 10 | 0.069472 7 | −7 | 6659.15 | 51.6382 5 | −1 | −91.2484 11 | 35 | 100.799 7 | −4.87 | −92.908 | 516264.84 | 2378 27 | 140 32 | 27 | 3.0 | 1.6 | 38821.3943242 |
| 4875 | MAR 4 | 3 16 30.27 3 | 7155.8721 14 | 0.069397 8 | −12 | 6659.28 | 51.6387 7 | 2 | −98.5178 14 | 33 | 106.137 9 | −4.64 | −98.392 | 516312.04 | 2963 12 | 55 20 | 35 | 3.4 | 2.5 | 38823.1364614 |
| 4900 | MAR 5 | 21 4 54.87 2 | 7155.4010 7 | 0.069319 5 | −16 | 6659.40 | 51.6392 4 | 3 | −105.7869 8 | 33 | 111.484 6 | −4.53 | −103.954 | 516363.03 | 2711 7 | −45 13 | 32 | 3.1 | 1.4 | 38824.8784128 |
| 4925 | MAR 7 | 14 53 4.28 3 | 7154.9692 10 | 0.069229 7 | −21 | 6659.64 | 51.6395 7 | 3 | −113.0563 11 | 34 | 116.831 8 | −4.35 | −109.588 | 516409.78 | 2711 12 | 13 17 | 30 | 3.5 | 1.8 | 38826.6201884 |
| 4950 | MAR 9 | 8 40 58.92 3 | 7154.5435 11 | 0.069136 7 | −25 | 6659.91 | 51.6400 6 | 1 | −120.3241 9 | 35 | 122.180 8 | −4.19 | −115.289 | 516455.87 | 2561 7 | −19 15 | 34 | 3.4 | 1.9 | 38828.3617931 |
| 4975 | MAR 11 | 2 28 39.48 3 | 7154.1486 11 | 0.069046 6 | −28 | 6660.18 | 51.6402 6 | −1 | −127.5961 9 | 34 | 127.534 8 | −4.05 | −121.059 | 516498.63 | 2327 27 | −53 37 | 31 | 3.0 | 1.9 | 38830.1032348 |
| 5000 | MAR 12 | 20 16 6.96 4 | 7153.7605 12 | 0.068944 9 | −30 | 6660.55 | 51.6392 5 | 0 | −134.8669 11 | 31 | 132.886 10 | −3.84 | −126.890 | 516540.66 | 2554 17 | 03 20 | 22 | 3.2 | 1.6 | 38831.8445250 |
| 5025 | MAR 14 | 14 3 20.48 3 | 7153.3305 8 | 0.068838 6 | −33 | 6660.91 | 51.6399 5 | 4 | −142.1363 12 | 30 | 138.254 8 | −3.51 | −132.794 | 516587.24 | 2734 20 | 77 21 | 28 | 2.8 | 1.5 | 38833.5856536 |
| 5050 | MAR 16 | 7 50 19.07 3 | 7152.8791 7 | 0.068721 6 | −36 | 6661.33 | 51.6409 4 | 6 | −149.4105 10 | 30 | 143.629 7 | −3.12 | −138.759 | 516636.14 | 2658 11 | −120 17 | 35 | 3.6 | 1.4 | 38835.3266096 |
| 5075 | MAR 18 | 1 37 3.45 2 | 7152.4784 7 | 0.068604 5 | −39 | 6661.79 | 51.6413 4 | 4 | −156.6813 8 | 31 | 148.997 5 | −2.75 | −144.762 | 516679.56 | 2395 6 | −48 10 | 42 | 3.4 | 1.3 | 38837.0674010 |
| 5100 | MAR 19 | 19 23 34.95 2 | 7152.1067 8 | 0.068473 6 | −41 | 6662.38 | 51.6419 4 | 0 | −163.9557 10 | 30 | 154.375 5 | −2.44 | −150.818 | 516719.84 | 2279 7 | 6 13 | 38 | 3.3 | 1.2 | 38838.8080434 |
| 5125 | MAR 21 | 13 9 54.25 3 | 7151.7313 8 | 0.068348 5 | −42 | 6662.92 | 51.6424 4 | −1 | −171.2297 10 | 28 | 159.770 7 | −2.18 | −156.925 | 516760.52 | 2471 12 | 24 18 | 34 | 3.1 | 1.4 | 38840.5485446 |
| 5150 | MAR 23 | 6 56 0.64 3 | 7151.3164 8 | 0.068222 5 | −42 | 6663.44 | 51.6433 5 | −1 | −178.5058 8 | 27 | 165.162 6 | −1.89 | −163.056 | 516805.49 | 2757 9 | 124 14 | 36 | 3.1 | 1.5 | 38842.2888963 |
| 5175 | MAR 25 | 0 41 52.80 3 | 7150.8553 8 | 0.068095 8 | −42 | 6663.92 | 51.6426 5 | 1 | 174.2194 8 | 26 | 170.551 7 | −1.54 | −169.203 | 516855.48 | 2781 8 | −83 14 | 36 | 3.3 | 1.4 | 38844.0290833 |
| 5200 | MAR 26 | 18 27 30.66 3 | 7150.4230 9 | 0.067954 6 | −42 | 6664.52 | 51.6424 5 | 3 | 166.9447 9 | 25 | 175.947 8 | −1.13 | −175.367 | 516902.35 | 2587 9 | −103 15 | 41 | 3.4 | 1.5 | 38845.7691048 |
| 5225 | MAR 28 | 12 12 55.38 3 | 7150.0354 5 | 0.067826 5 | −43 | 6665.08 | 51.6437 5 | 2 | 159.6690 9 | 25 | 181.358 6 | −0.70 | −181.552 | 516944.39 | 2275 10 | −88 6 | 43 | 3.1 | 1.5 | 38847.5089743 |
| 5250 | MAR 30 | 5 58 8.69 3 | 7149.6950 12 | 0.067697 8 | −43 | 6665.68 | 51.6433 6 | −2 | 152.3919 12 | 22 | 186.780 7 | −0.45 | −187.744 | 516981.30 | 1968 26 | −91 39 | 31 | 2.8 | 1.3 | 38849.2487117 |

## REFERENCES


| No. | Author | Title, etc. |
|---|---|---|
| 1 | G. M. Truszynski | Radio tracking of earth satellites. Proc. Second Intl. Space Science Symposium, Florence, SPACE RESEARCH II p.178, North Holland Publishing Co., Amsterdam |
| 2 | R. H. Merson | A Pegasus computer programme for the improvement of the orbital parameters of an earth satellite. R.A.E. Technical Note Space 16 (A.R.C.24290), August 1962 |
| 3 | R. H. Gooding | Modifications to the model for satellite orbits used in R.A.E. orbit determination. R.A.E. Technical Memo. Space 41 (A.R.C.26135), July 1964 |
| 4 | Irene Fischer | An astrogeodetic world datum from geoidal heights based on the flattening f = 1/298.3. J. of Geophys. Res., 64(7) 2067-76, July 1960 |
| 5 | R. H. Merson<br>R. J. Tayler | The orbital elements of Ariel 1 for April-August 1962 and a comparison of R.A.E. and NASA ephemerides. R.A.E. Technical Note Space 39 (A.R.C.25016), July 1963 |
| 6 | R. H. Merson | The perturbations of a satellite orbit in an axi-symmetric gravitational field. R.A.E. Technical Note Space 26 (A.R.C.24869), February 1963 |
| 7 | R. H. Gooding | A Pegasus computer programme for estimating errors in the ephemeris of a satellite and an application to Ariel 1. R.A.E. Technical Note Space 37 (A.R.C.25058), July 1963 |
| 8 | R. H. Merson | A comparison of the satellite orbit theories of Kozai and Merson and their application to Vanguard 2. R.A.E. Technical Note Space 42 (A.R.C.25244), July 1963 |

REFERENCES (Contd)


| No. | Author | Title, etc. |
|---|---|---|
| 9 | Y. Kozai | The motion of a close earth satellite. Astron. J. 64, 367-377, November 1959 |
| 10 | J. G. Noyes | An outline of the observation input programme. OIP1, E.S.Te.C. Internal Note No.3, May 1965 |
| 11 | D. G. King-Hele<br>Eileen Quinn | Examples of short-period fluctuations in upper-atmosphere density. R.A.E. Technical Memo. Space 55 (A.R.C.26841), February 1965 |
| 12 | D. G. King-Hele<br>G. E. Cook<br>Diana W. Scott | The odd zonal harmonics in the earth's gravitational potential. R.A.E. Technical Report 65123 (A.R.C.27114), June 1965 |
| 13 | G. E. Cook | Perturbations of satellite orbits by tesseral harmonics in the earth's gravitational potential. R.A.E. Technical Note Space 19 (A.R.C.24438), October 1962 |
| 14 | W. H. Guier<br>R. R. Newton | The earth's gravity field deduced from the Doppler tracking of five satellites. Johns Hopkins University, Applied Physics Laboratory, TG-634, December 1964 |

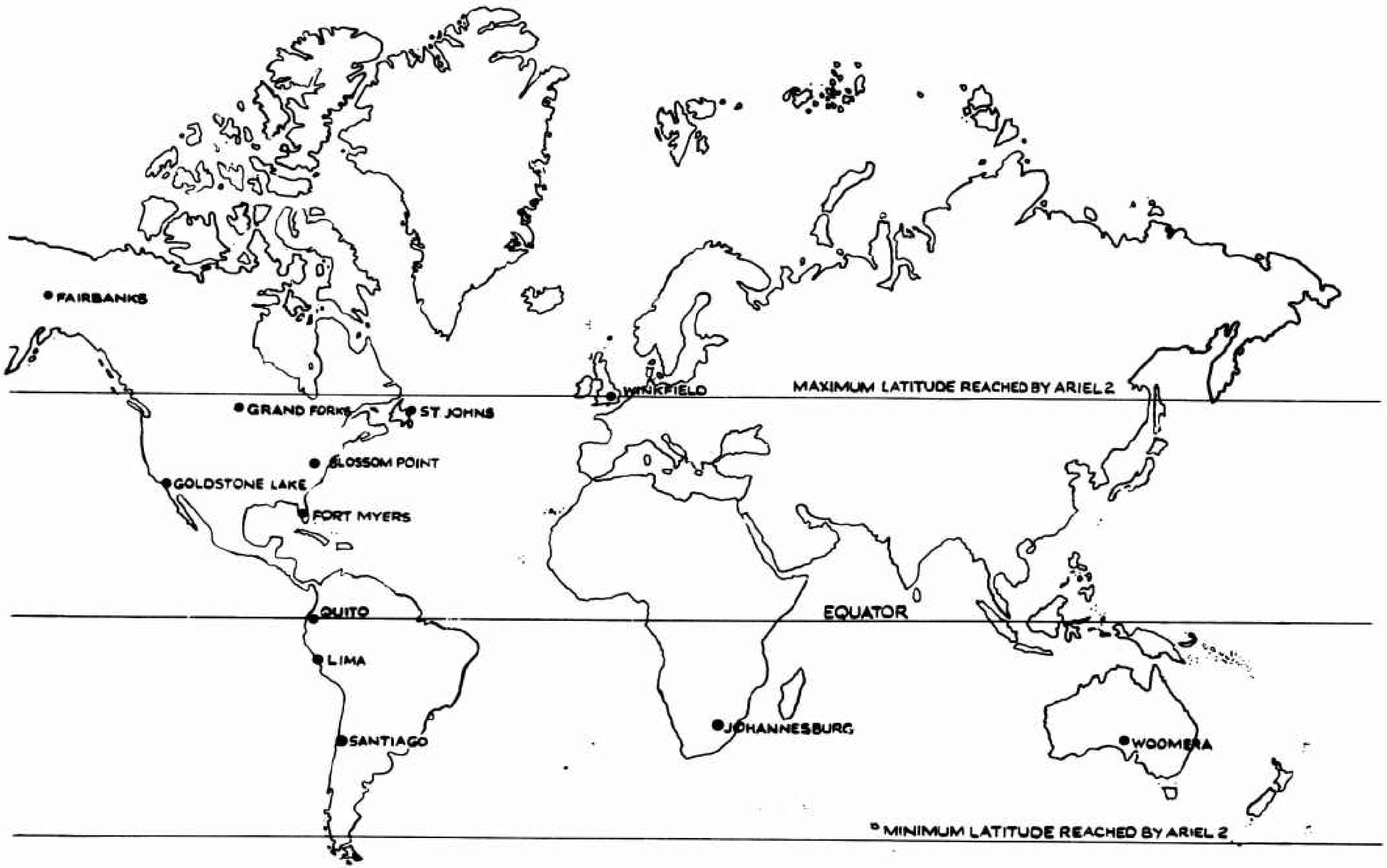



FIG.I THE STADAN NETWORK OF MINITRACK STATIONS

Fig.2



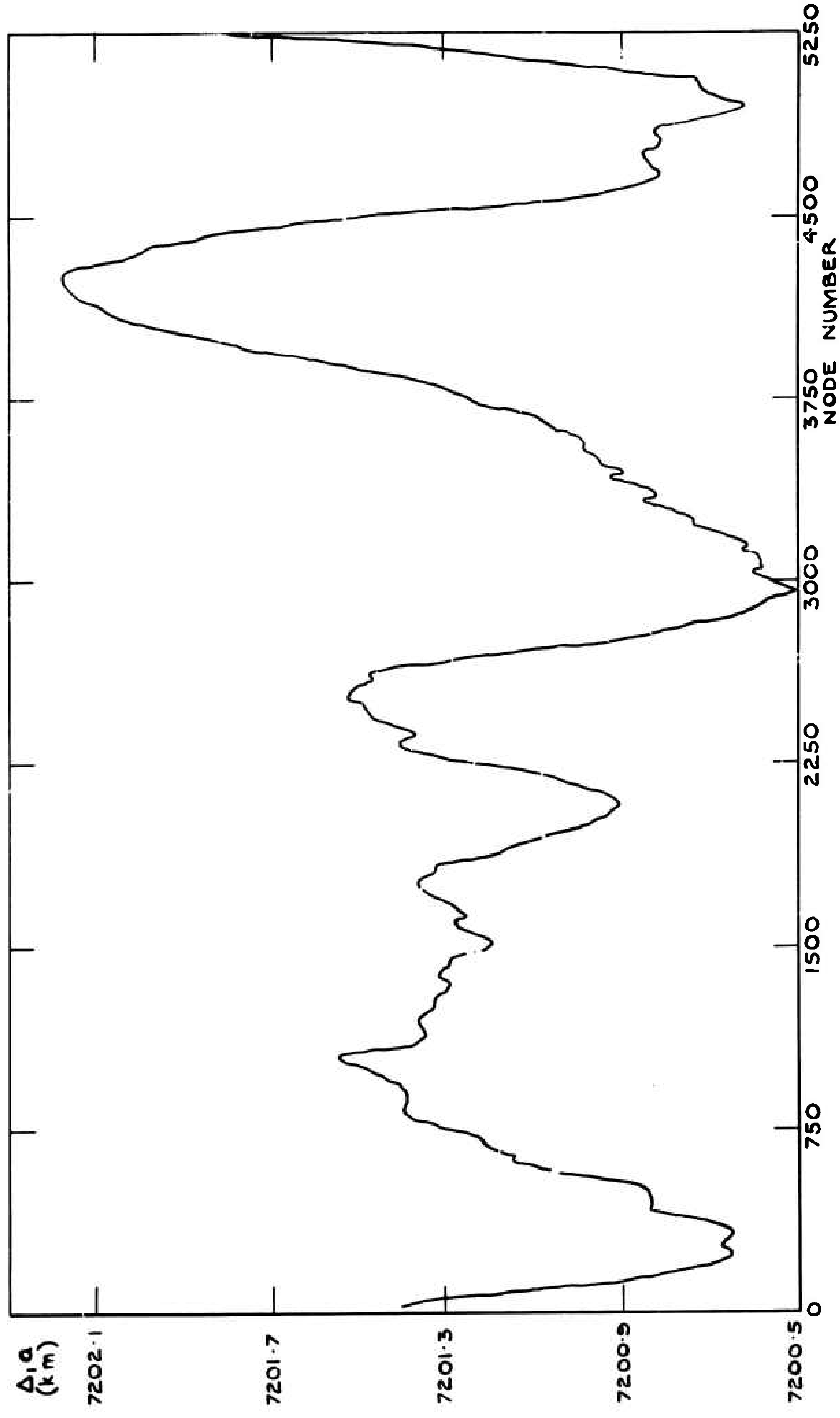



FIG. 2 SEMI-MAJOR AXIS, a, WITH QUINTIC POLYNOMIAL REMOVED

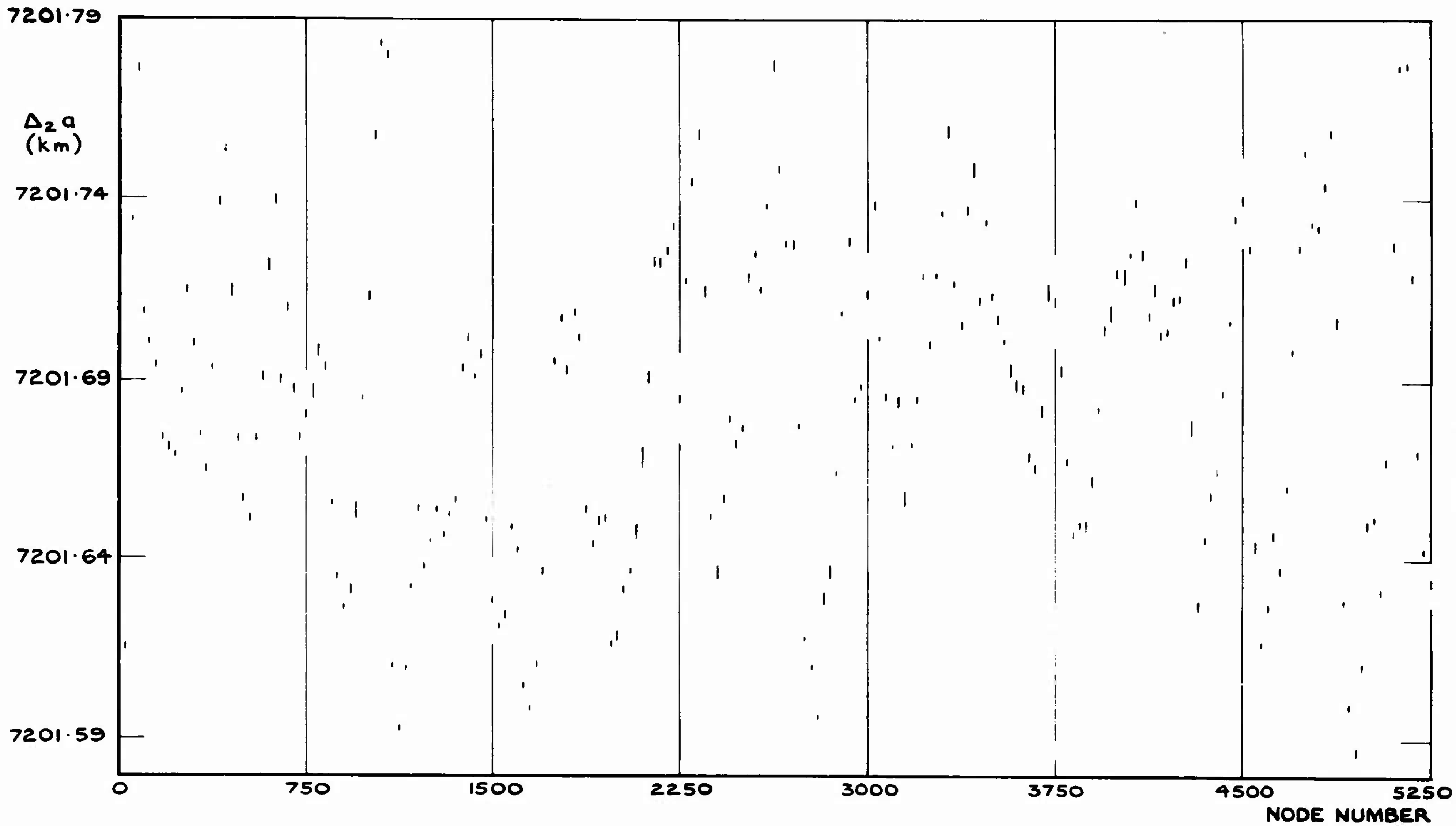



FIG. 3 SEMI-MAJOR AXIS, a, WITH QUARTIC POLYNOMIALS REMOVED IN SECTIONS

Fig.4



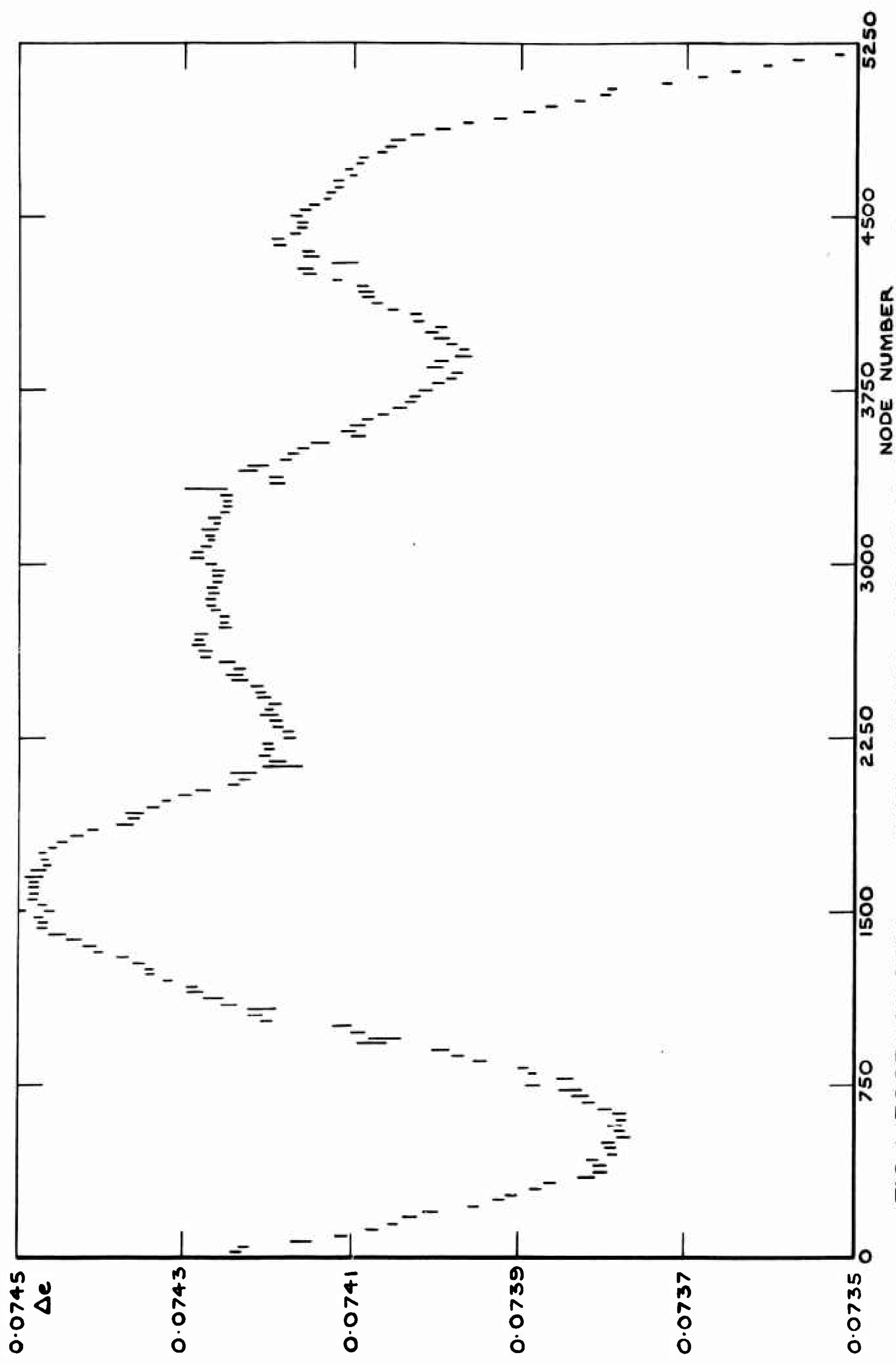



FIG.4 ECCENTRICITY, e , WITH LINEAR AND SINE TERMS REMOVED

Fig.5

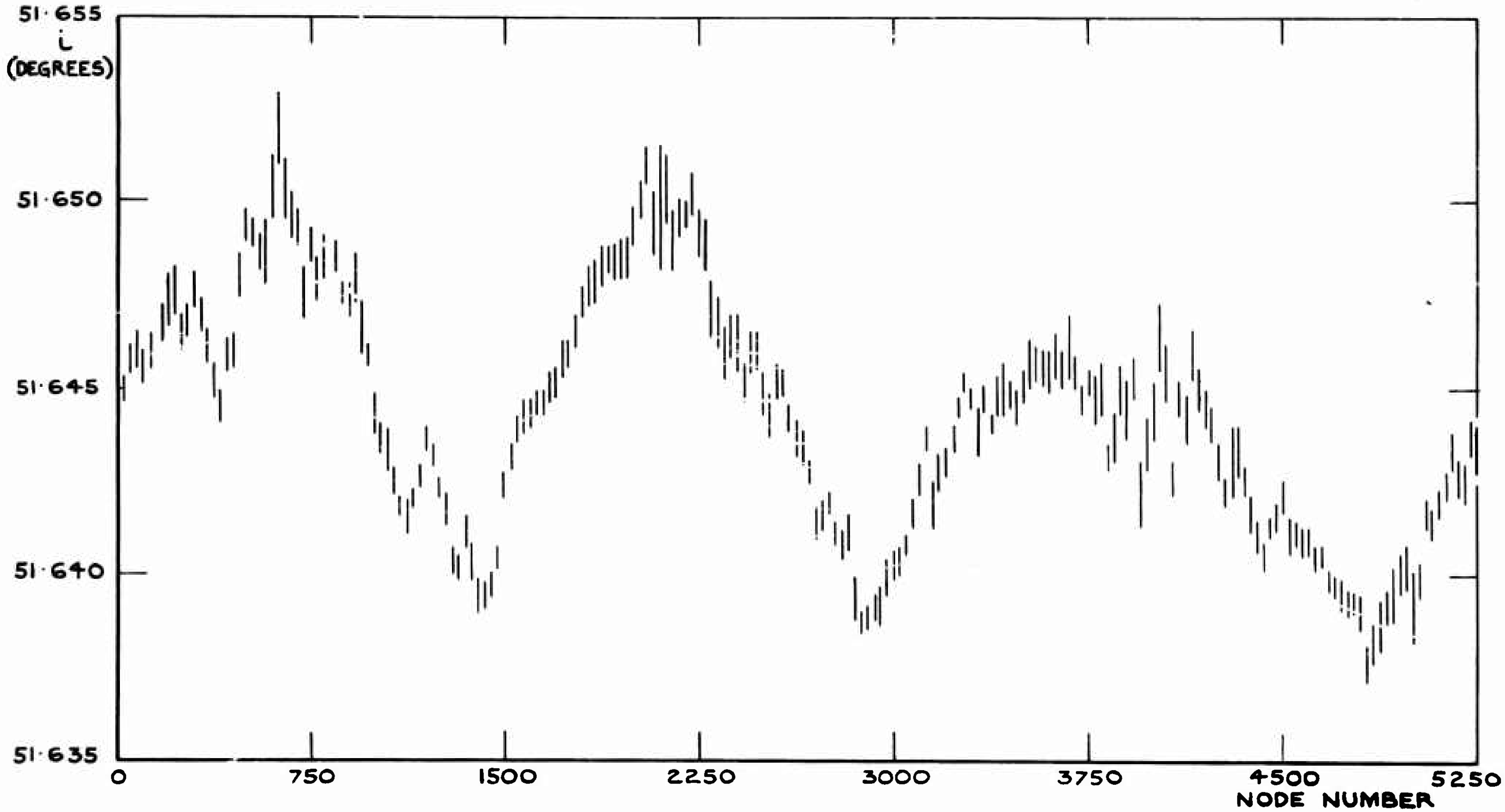



FIG. 5 ORBITAL INCLINATION i

Fig.6

SPA/P 1883

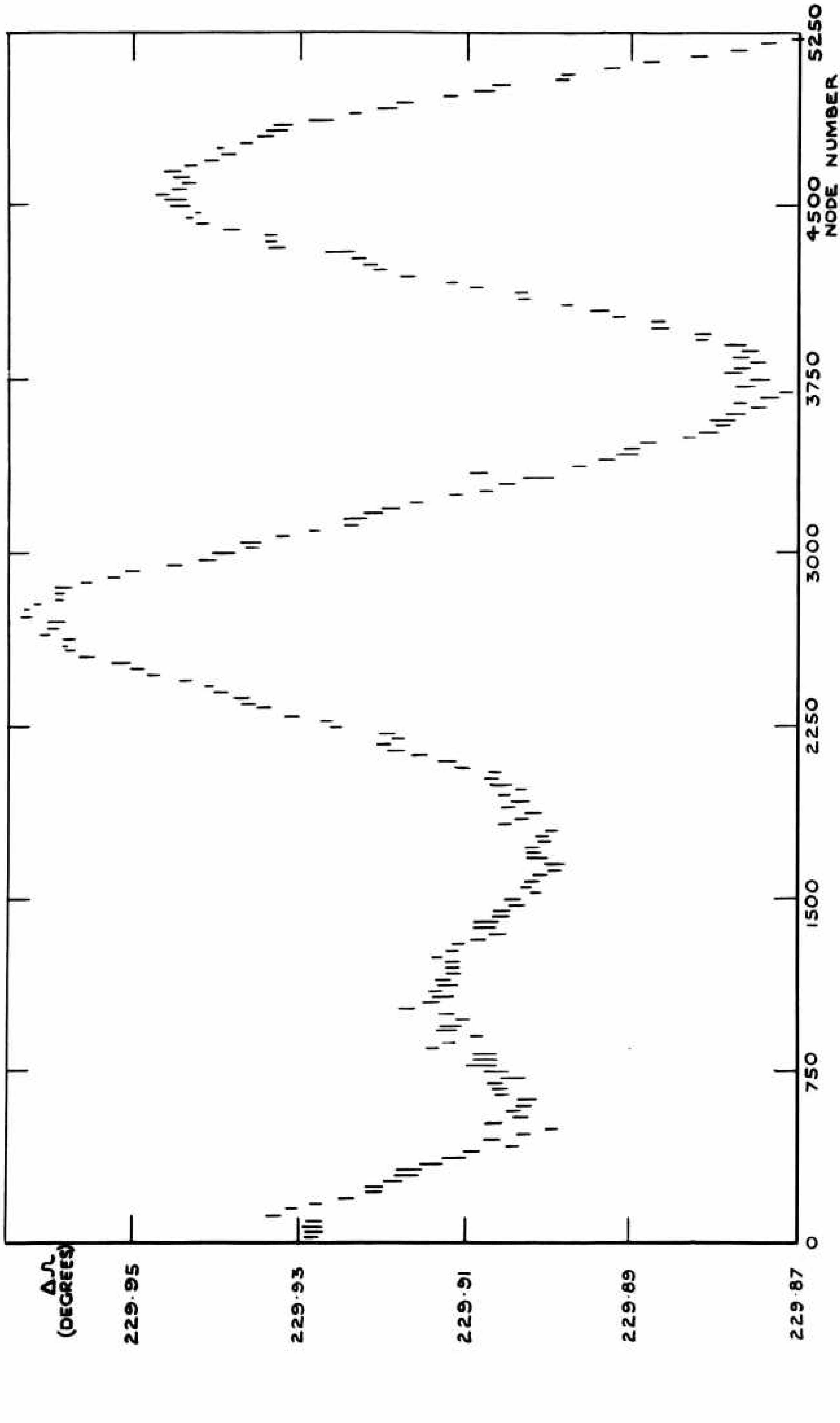



FIG. 6 RIGHT ASCENSION OF THE NODE, Ω, WITH CUBIC POLYNOMIAL REMOVED

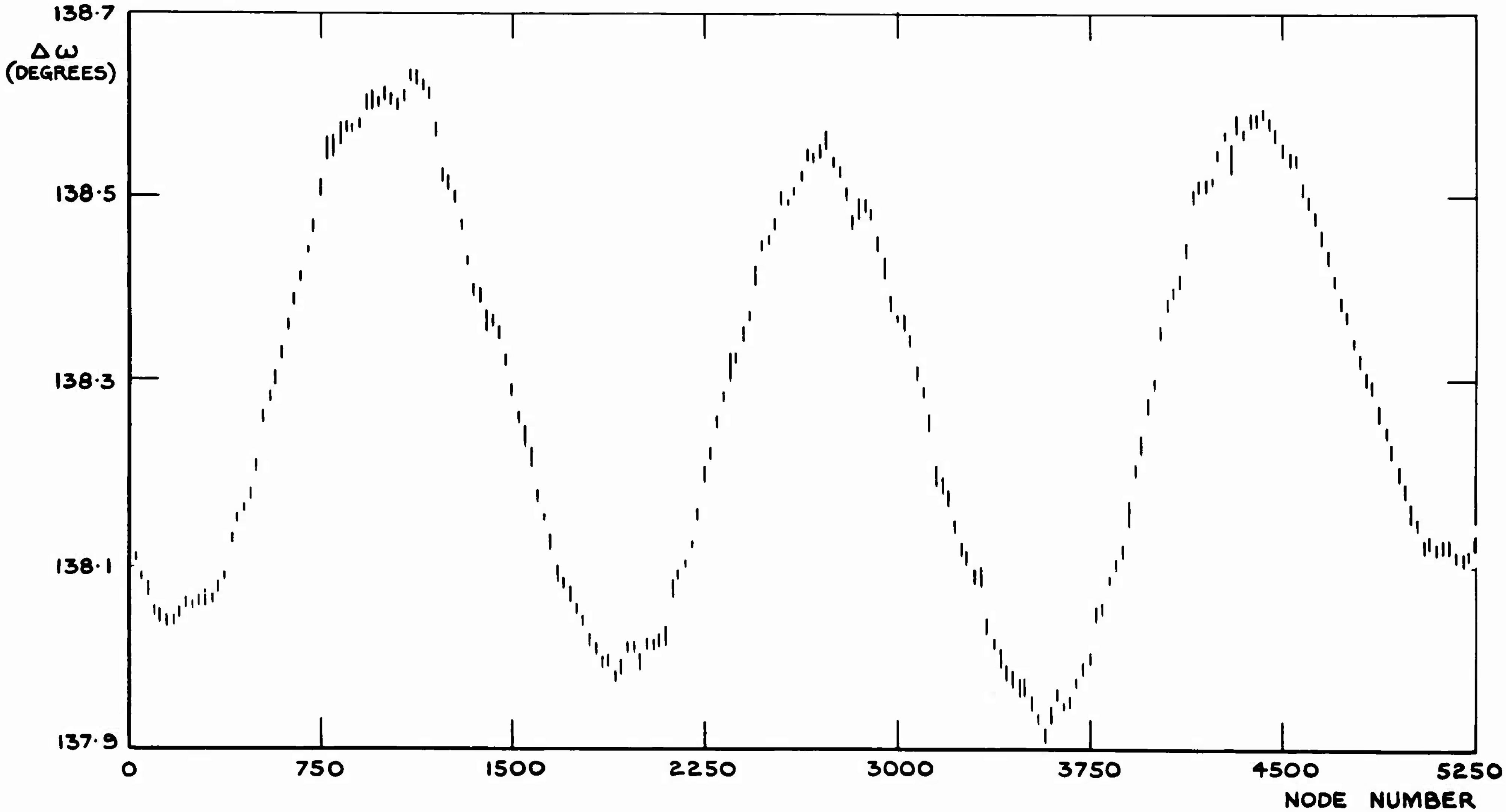



FIG.7 ARGUMENT OF PERIGEE, ω, WITH QUADRATIC AND COSINE TERMS REMOVED

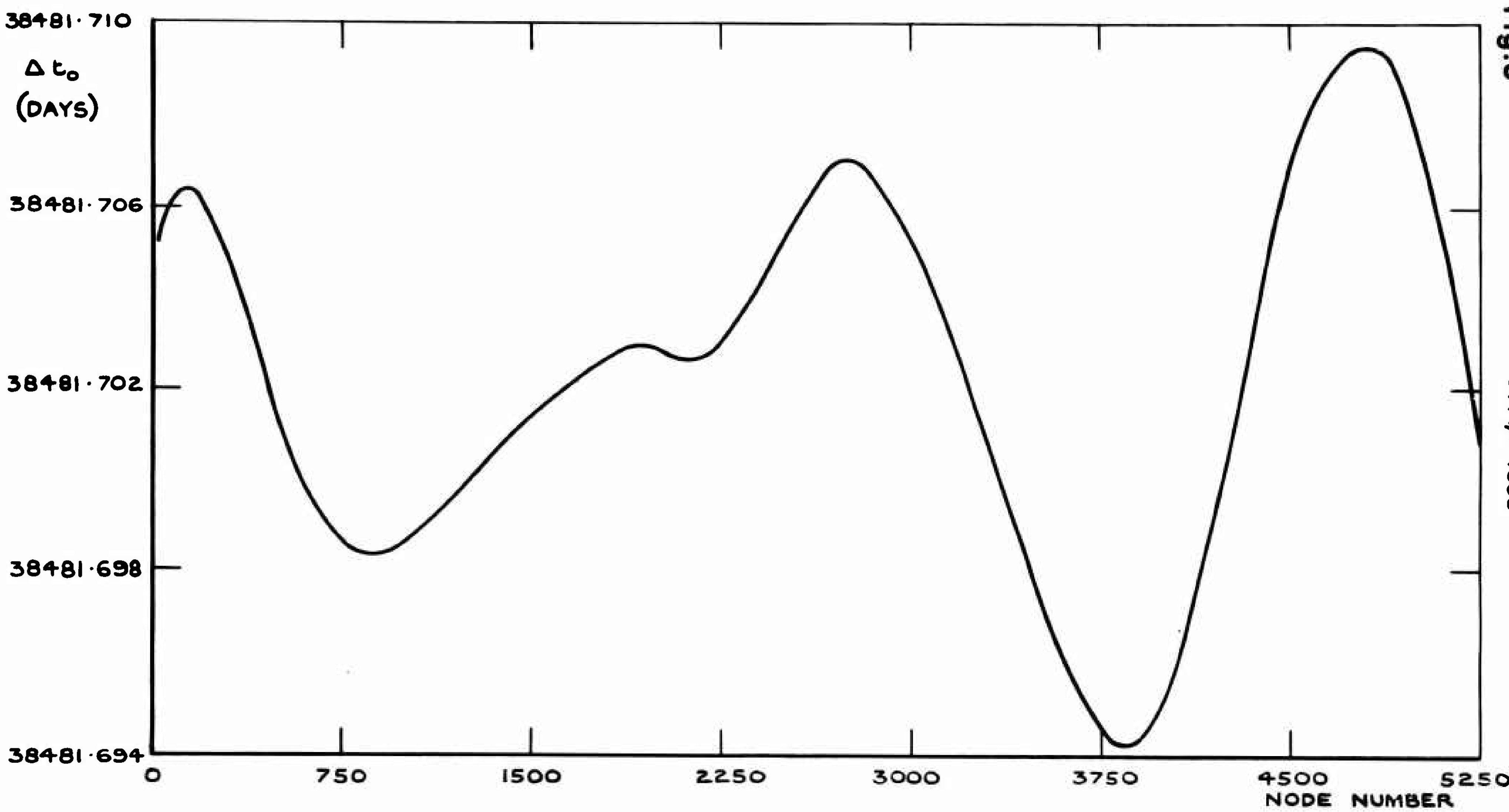



FIG. 8 EPOCH, $t_o$, WITH QUARTIC POLYNOMIAL REMOVED

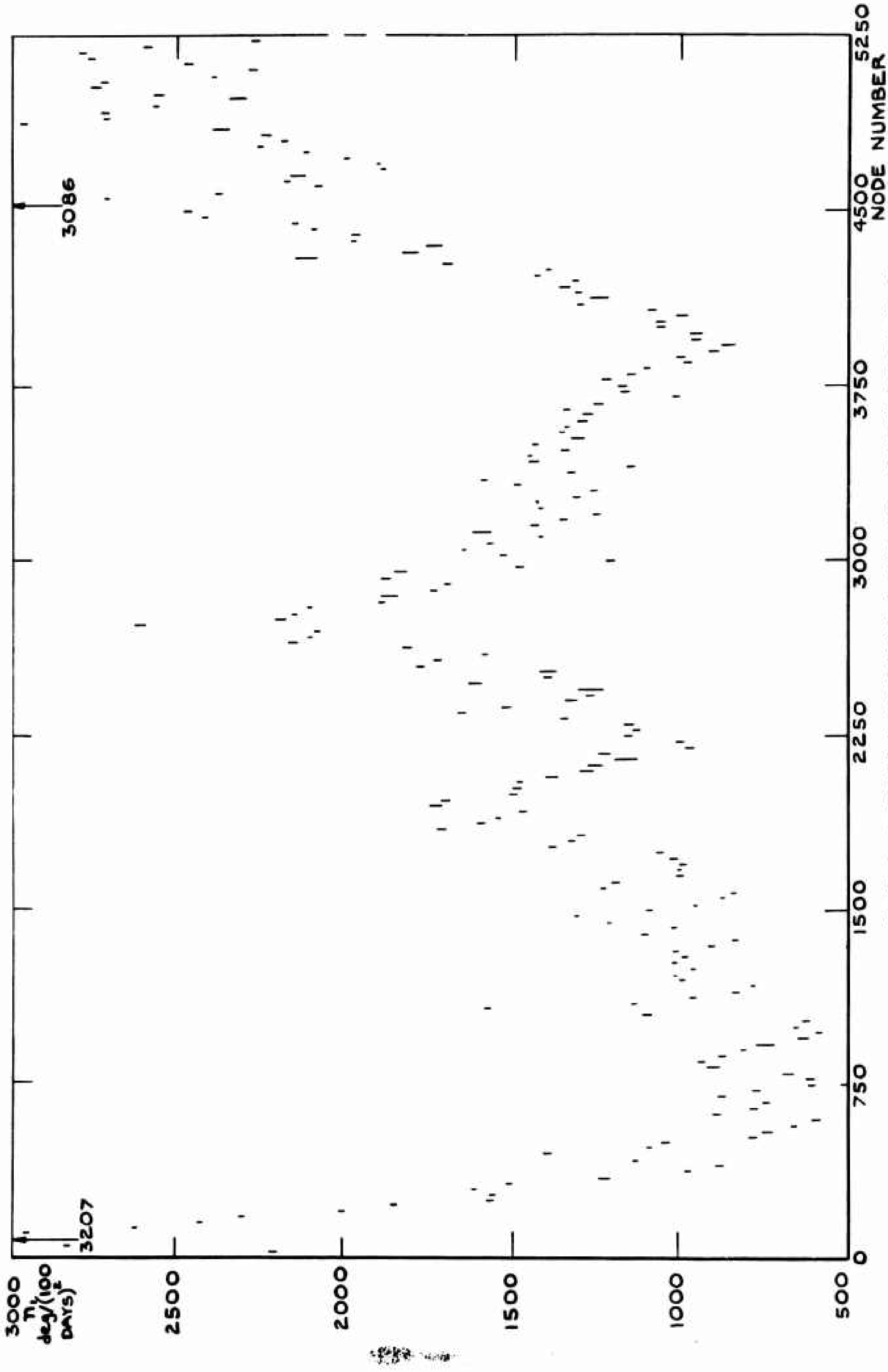



FIG.9 MEAN MOTION LINEAR COEFFICIENT $n_1$

Fig.10

SPA/P 1887

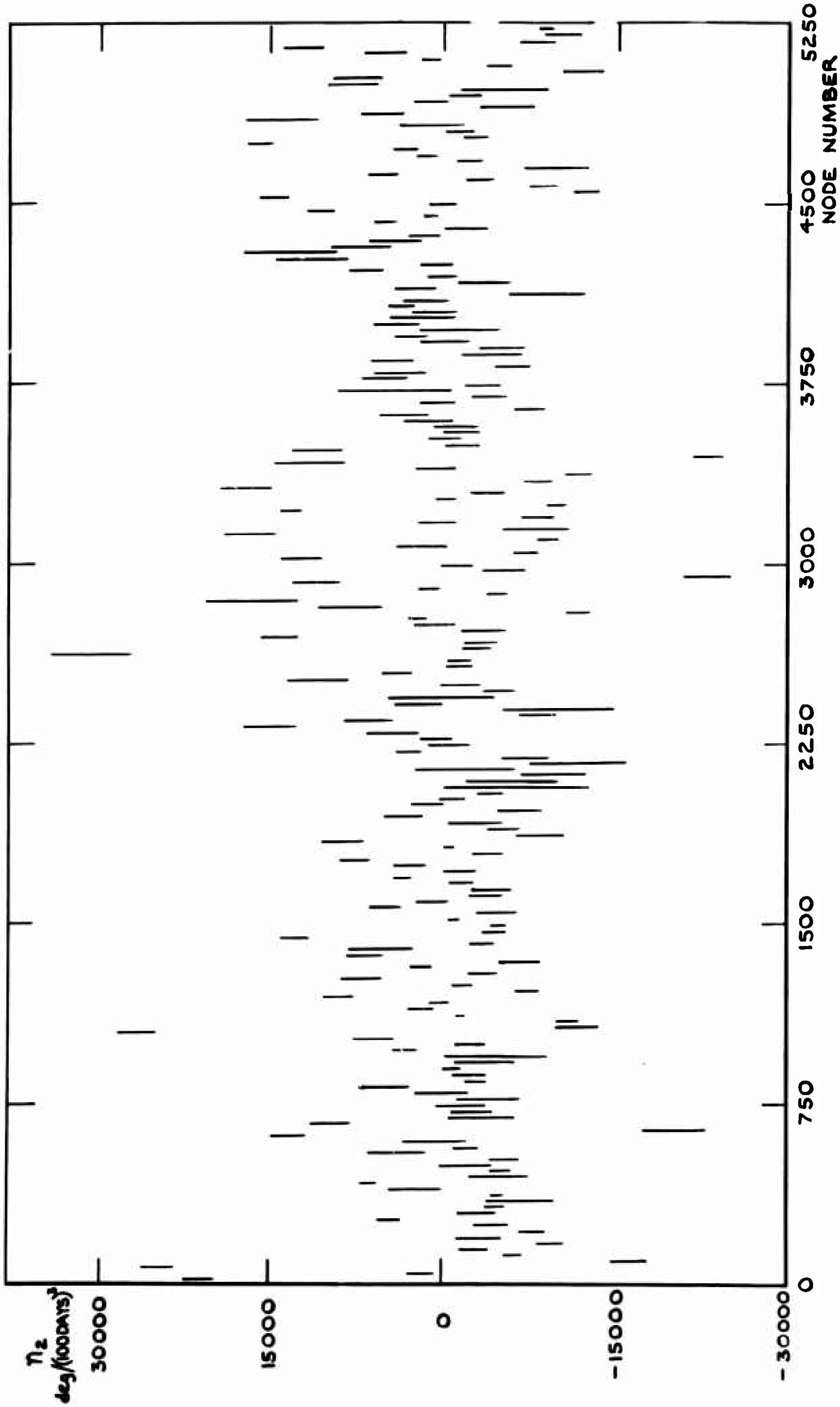



FIG.10 MEAN MOTION QUADRATIC COEFFICIENT $n_2$

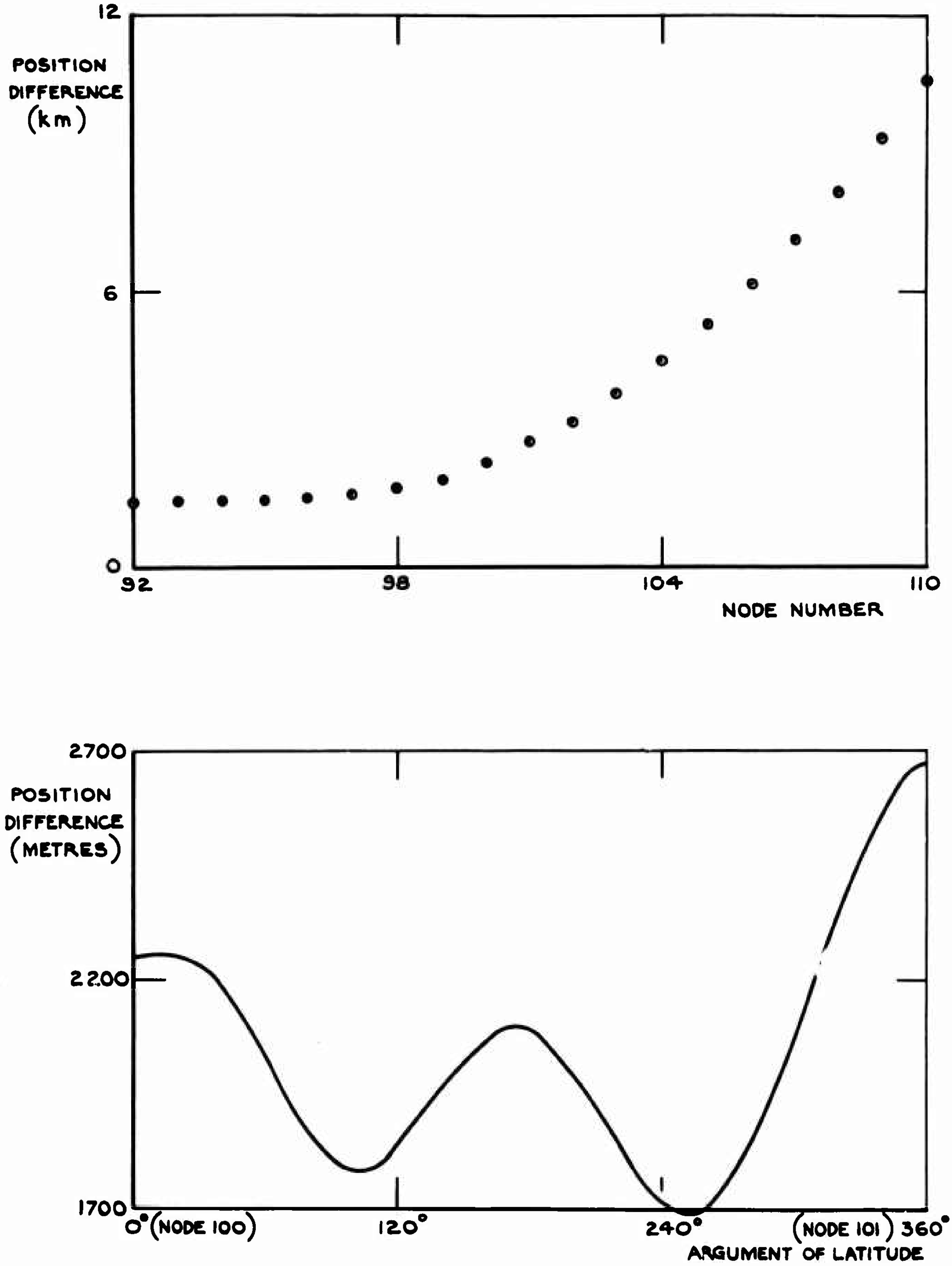



FIG. 11 DIFFERENCE BETWEEN COMPUTED SATELLITE POSITIONS BASED ON ORBITAL PARAMETERS FOR NODES 75 AND 125

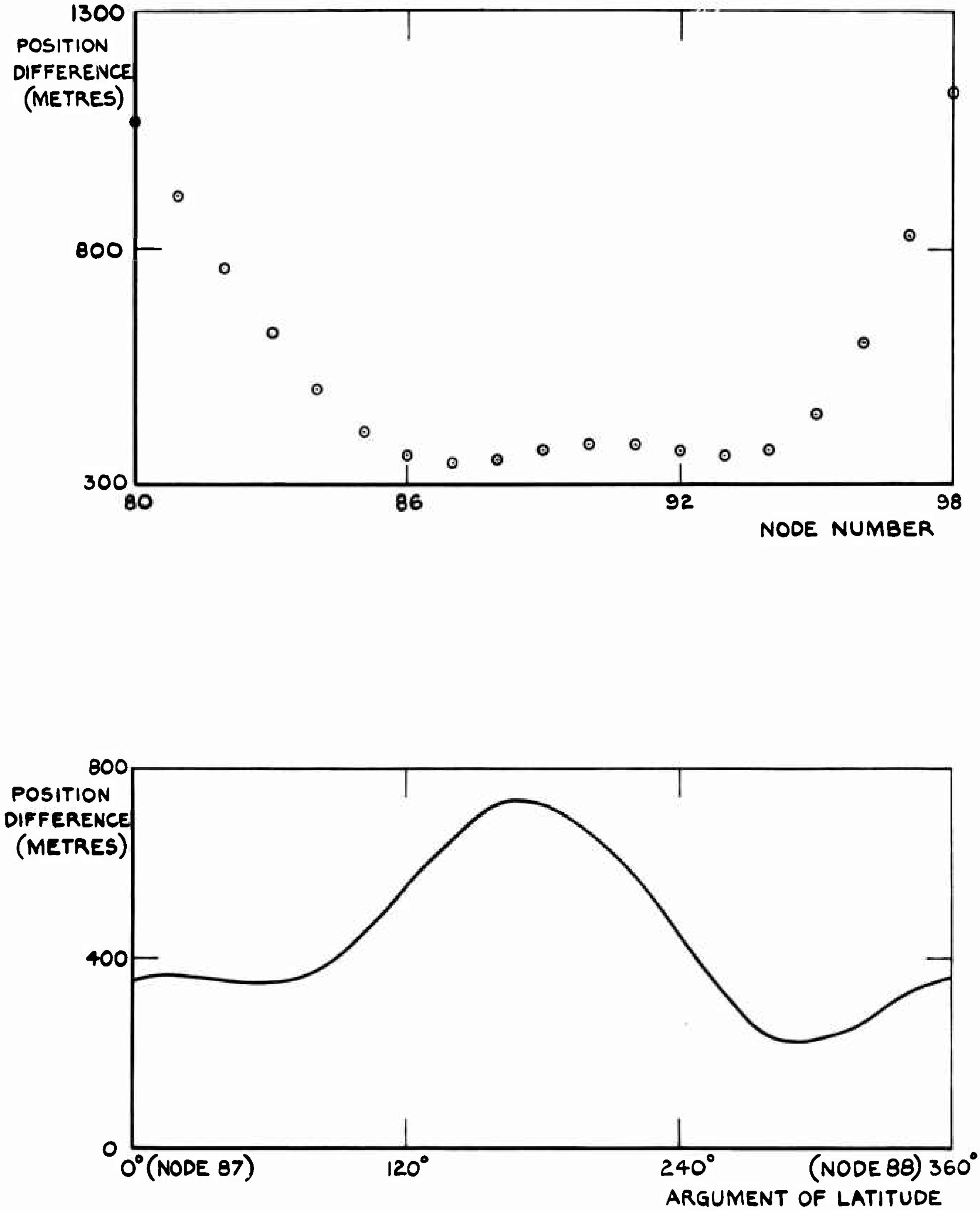
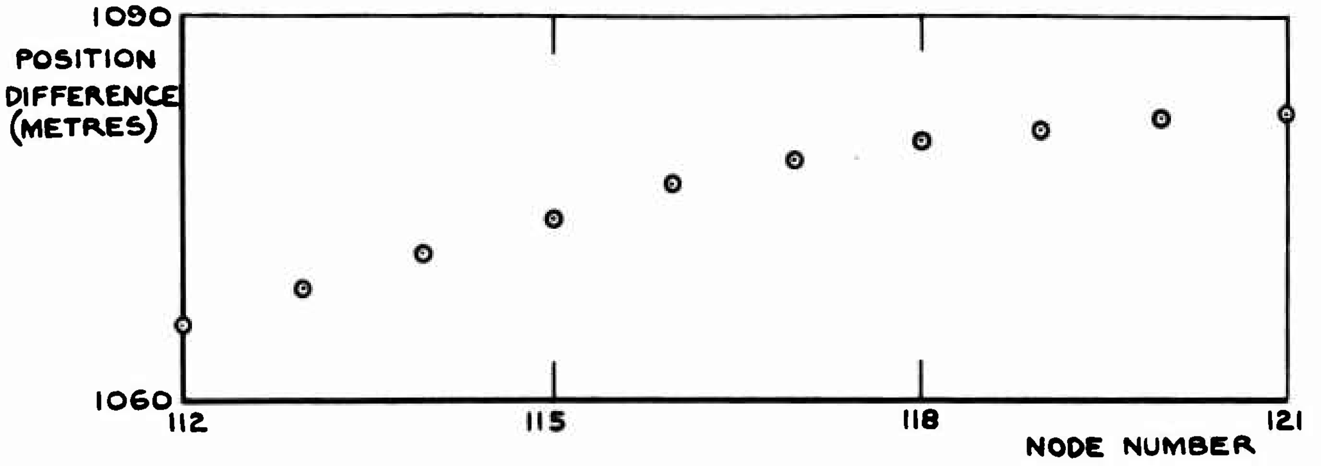



FIG.12 DIFFERENCE BETWEEN COMPUTED SATELLITE POSITIONS BASED ON ORBITAL PARAMETERS FOR NODES 75 AND 100



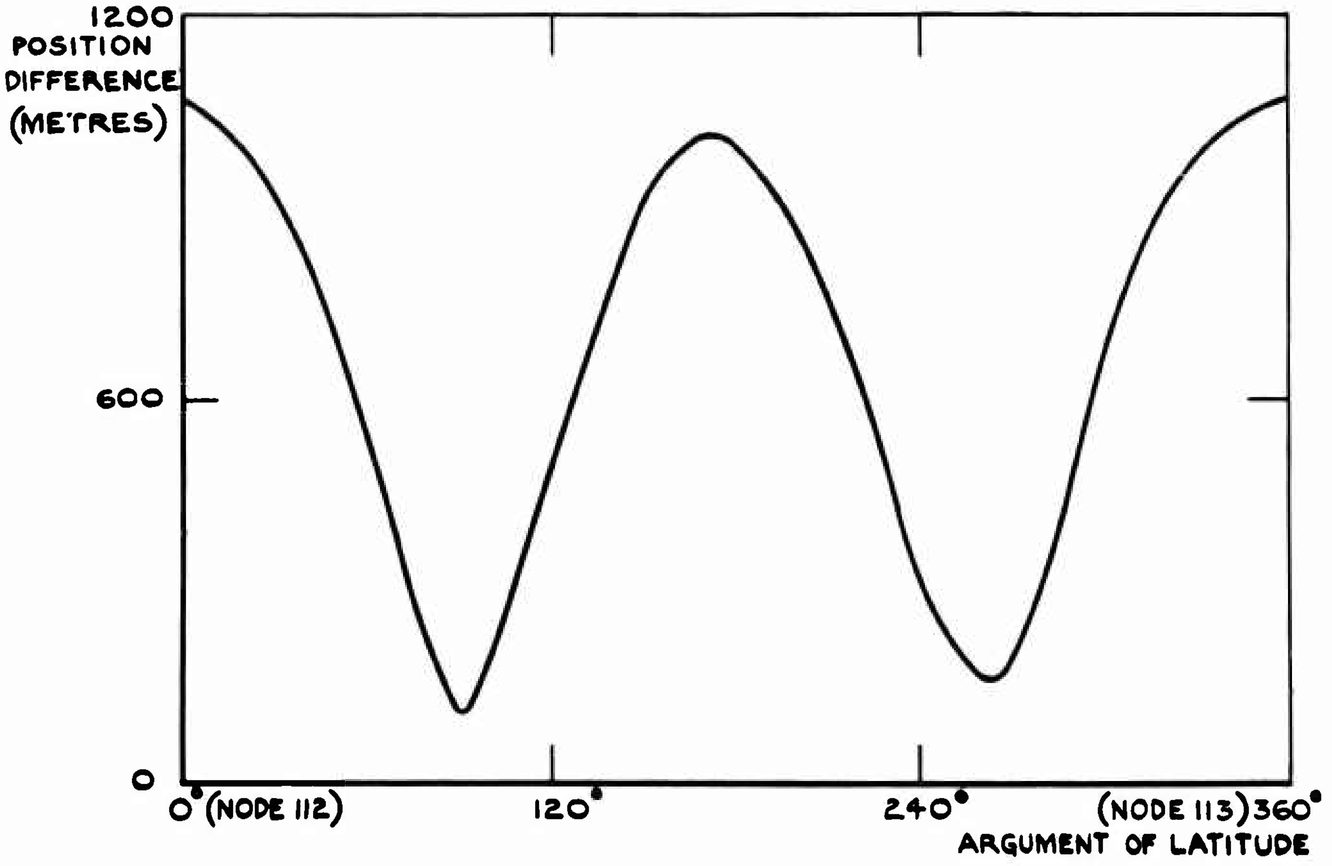




FIG.13 DIFFERENCE BETWEEN COMPUTED SATELLITE POSITIONS BASED ON ORBITAL PARAMETERS FOR NODES 100 AND 125

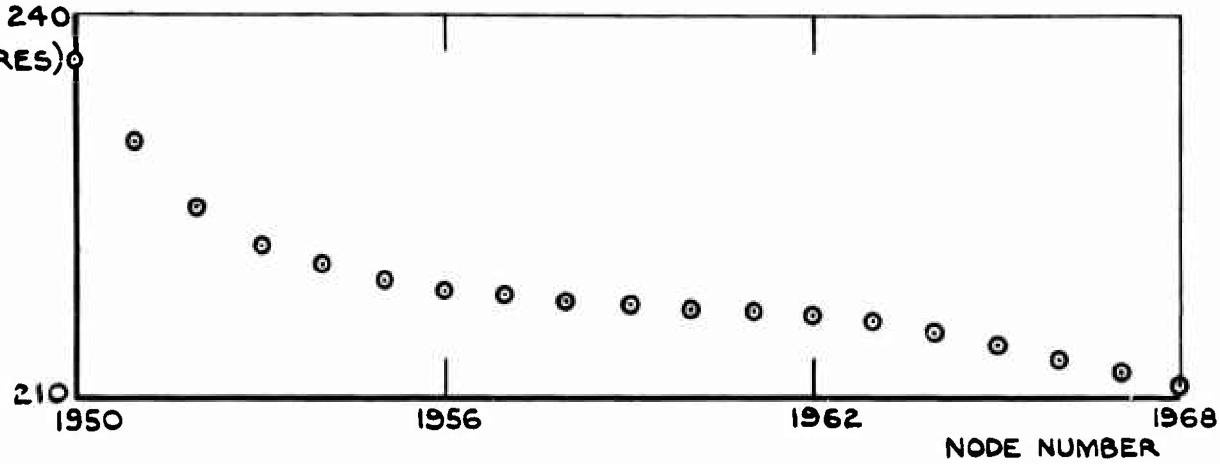



FIG.14 PLOT OF S BASED ON COVARIANCE MATRIX FOR NODE 1950

d AND S ARE DEFINED ON FIG16

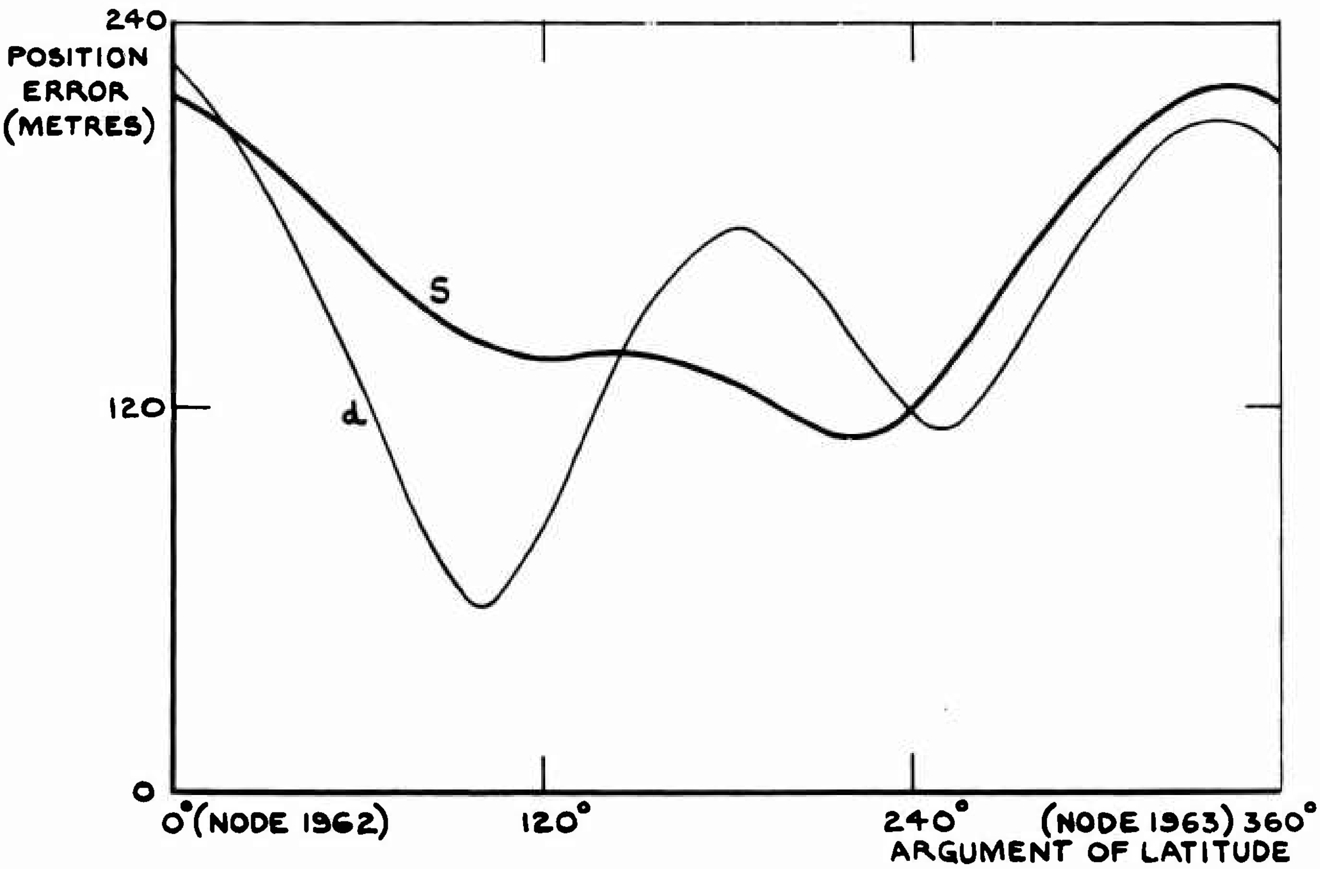



FIG.15 ACCURACY OF COMPUTED SATELLITE POSITION ASSOCIATED WITH PARAMETERS FOR NODES 1950 & 1975

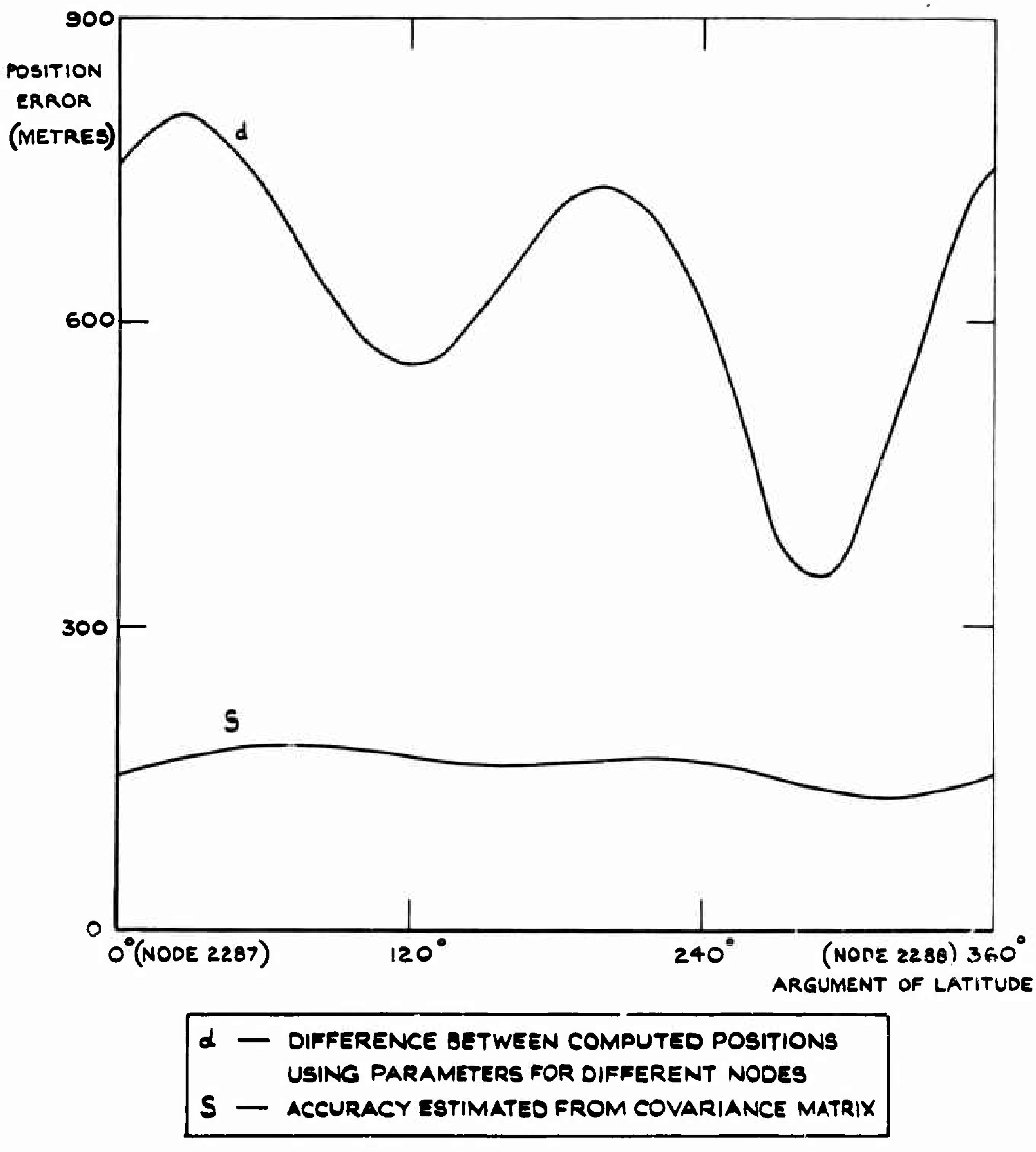
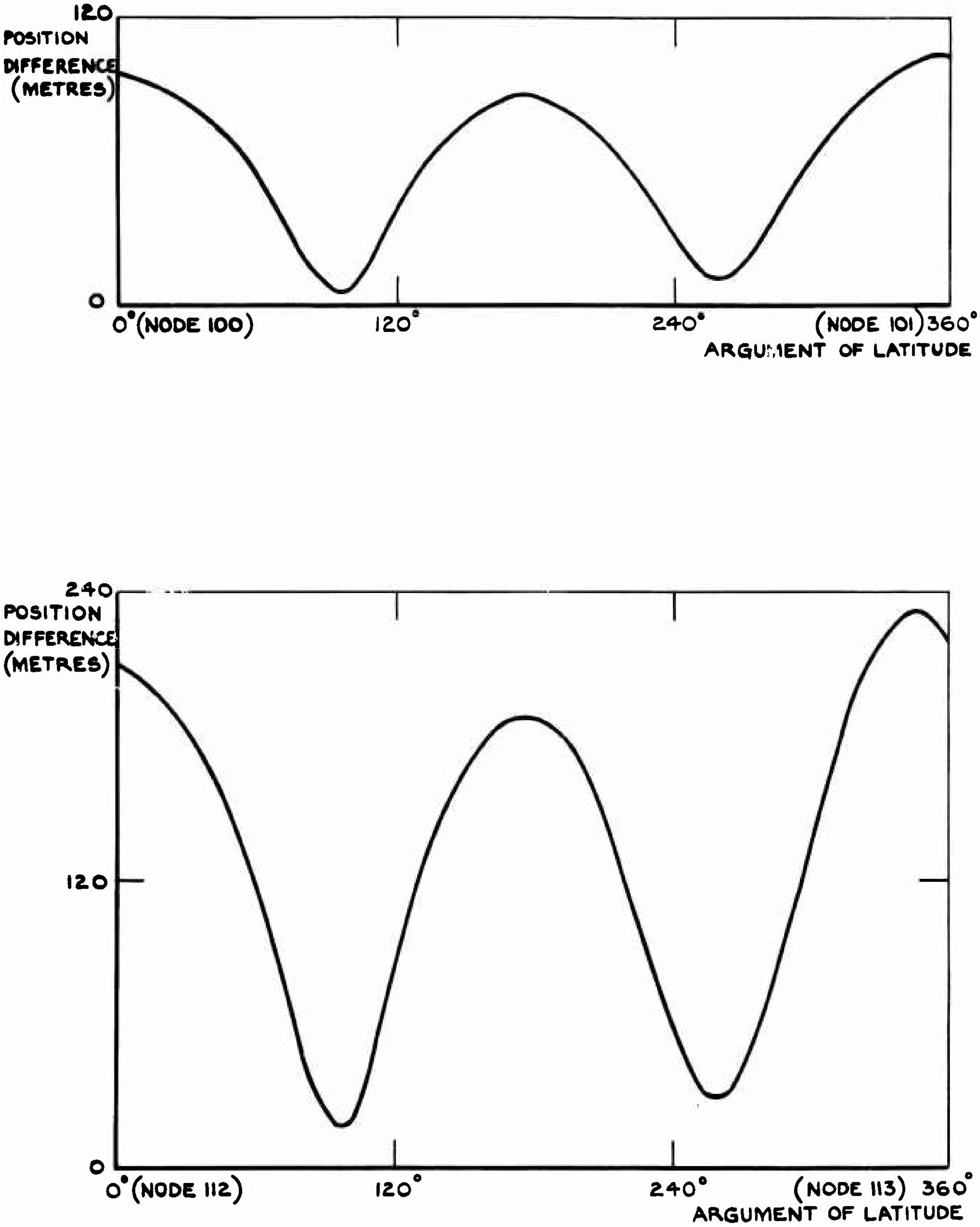



FIG 16 ACCURACY OF COMPUTED SATELLITE POSITION ASSOCIATED WITH PARAMETERS FOR NODES 2275 AND 2300




BOTH PLOTS BASED ON ORBITAL PARAMETERS FOR NODE 75

FIG. 17 VARIATION OF COMPUTED SATELLITE POSITION DUE TO DROPPING $\Omega_2$ AND $\omega_2$

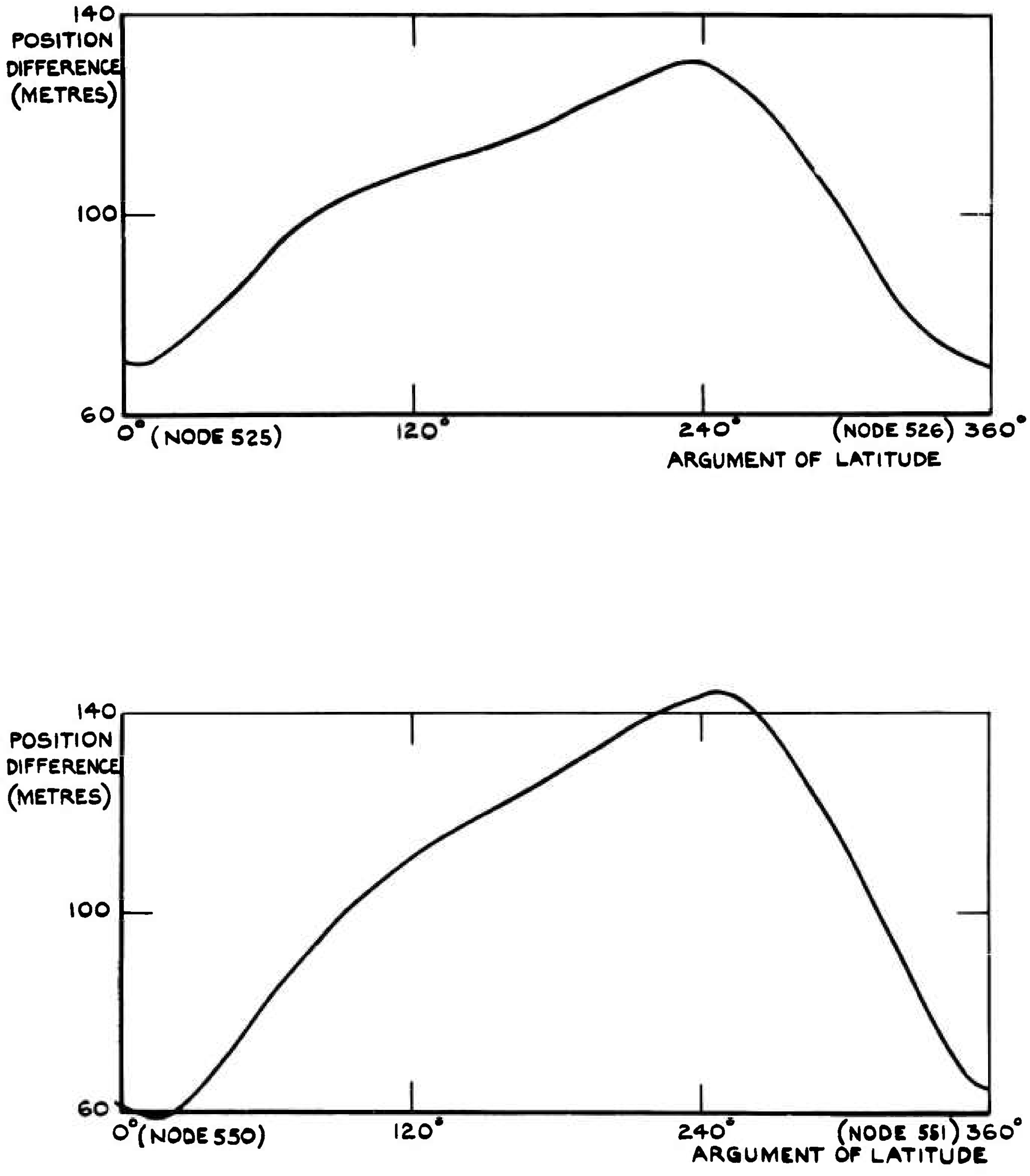



FIG.18 VARIATION OF COMPUTED SATELLITE POSITION DUE TO ADOPTION OF FISCHER ELLIPSOID

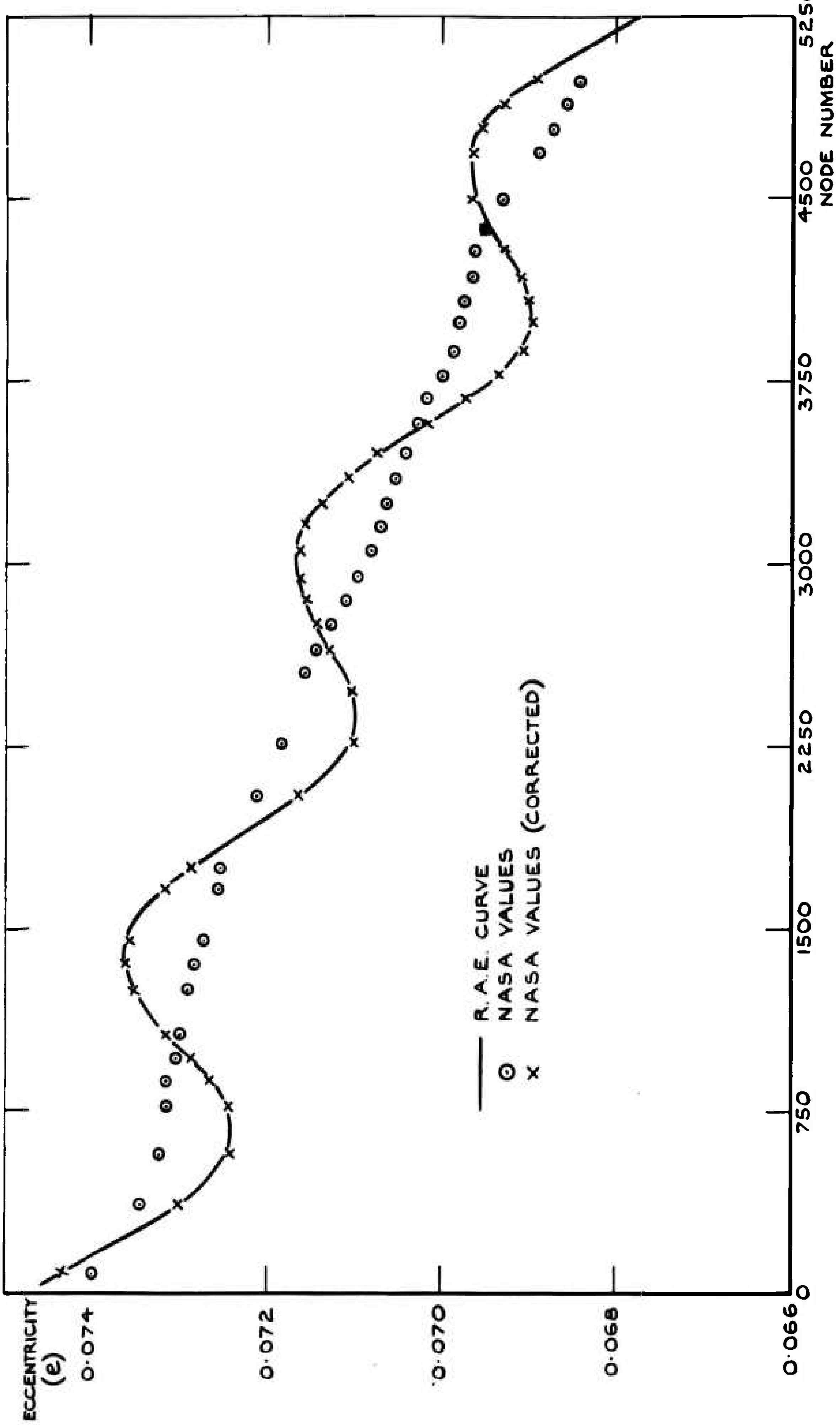
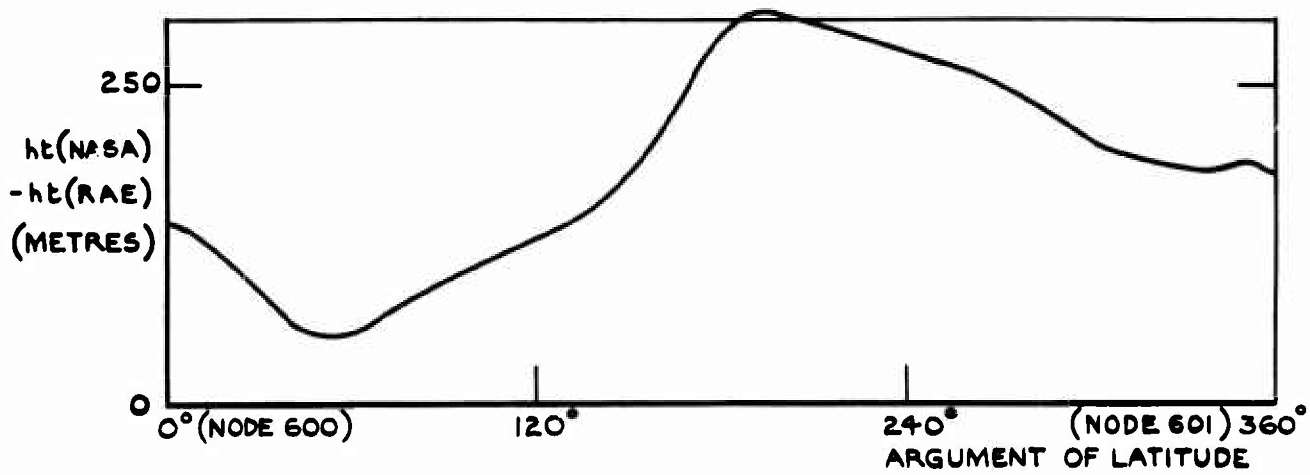



FIG.19 ECCENTRICITY OF NASA COMPARED WITH e (R.A.E.)



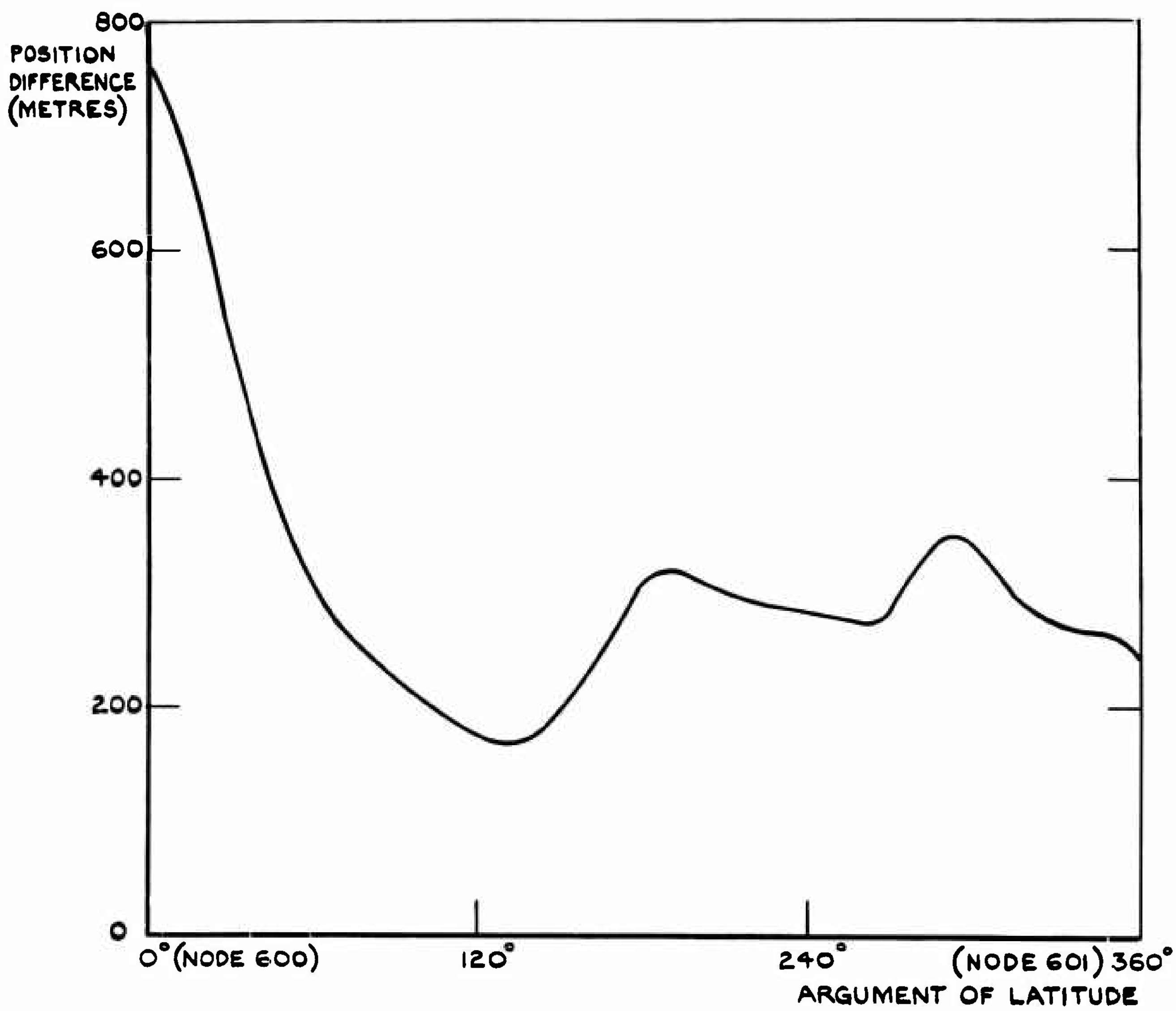




FIG. 20 COMPARISON OF NASA AND R.A.E. EPHEMERIDES

DETACHABLE ABSTRACT CARDS

Gooding, R. H. 521.6

THE ORBIT OF ARIEL 2 (1964-15A) - THE FIRST TWELVE MONTHS

Royal Aircraft Establishment Technical Report 65274 December 1965

The definitive orbit for Ariel 2 (1964-15A) is computed, from Minitrack observations, for a period of twelve months from the launch of the satellite. The orbit is described by a model with eight orbital parameters and these parameters are listed at every twenty-fifth nodal passage. The angular observations are accurate to about 1' and, as a result, the average computed standard deviations of the eight fitted orbital parameters are as follows: 1 m in semi-major axis, $10^{-5}$ in eccentricity, 2" in inclination, 4" in right ascension of the node, 30" in argument of perigee, $0^s.03$ in time at the node, and 0.001 deg/$d^2$ and 0.001 deg/$d^3$ in the linear and quadratic coefficients occurring in the mean motion polynomial.

(over)

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(over)

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(over)

Ephemerides computed from the listed orbital parameters will be accurate to about ½ km, the accuracy required by the Ariel 2 experimenters. Limitations which prevent the accuracy from being better than this are discussed.

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