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DETERMINATION AND GEOPHYSICAL INTERPRETATION OF THE ORBIT OF CHINA 2 ROCKET (1971-18B)

by

H. Hiller

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Procurement Executive, Ministry of Defence Farnborough, Hants

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The orbit of China 2 rocket, 1971-18B, has been determined at 114 epochs throughout its 5-year life, using the RAE orbit refinement program PROP 6, with more than 7000 radar and optical observations from 83 stations.

The rocket passed slowly enough through the resonances 14:1, 29:2, 15:1 and 31:2 to allow lumped geopotential harmonic coefficients to be calculated for each resonance, by least-squares fittings of theoretical curves to the perturbationfree values of inclination and eccentricity. These lumped coefficients can be combined with values from satellites at other inclinations, to obtain individual harmonic coefficients.

The rotation rate of the upper atmosphere, at heights near 300 km, was estimated from the decrease in orbital inclination, and values of 1.15, 1.05, 1.10 and 1.05 rev/day were obtained between April 1971 and January 1976. From the variation in perigee height, 25 values of density scale height were calculated, from April 1971 to decay. Comparison with values from the COSPAR International Reference Atmosphere 1972 shows good agreement between April 1971 and October 1975, but the observational values are 10 per cent lower, on average, than CIRA thereafter.

A further 1400 observations, made during the final 15 days before decay, were used to determine 15 daily orbits. Analysis of these orbits reveals a very strong west-to-east wind, of 240 ± 40 m/s, at a mean height of 195 km under winter evening conditions, and gives daily values of density scale height in the last 7 days before decay.

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1 INTRODUCTION

China 2 rocket was launched on 3 March 1971 into an orbit having the following elements: inclination 69.9°, perigee height 265 km, apogee height 1825 km, eccentricity 0.105 and period 106.1 minutes. After nearly 5 years in orbit, the rocket decayed in the Earth's atmosphere on 16 February 1976. Over 7000 observations have been used with the RAE orbit refinement program¹, PROP 6, to determine 114 orbits, 40 of which contained at least one sequence of Hewitt-camera observations. Orbits between July 1971 and January 1972 have previously been determined² by Brookes and Ryland, mostly with slightly lower accuracies, for air-density studies.

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As the orbit contracted under the influence of air drag, it passed first through the tail-end of 27:2 resonance in April 1971, then through 14:1 resonance (when the ground track is repeated daily, every 14 revolutions of the orbit) during October 1972. In March 1974, the orbit passed through 29:2 resonance, followed by 15:1 resonance in March 1975, and then 31:2 resonance in November 1975.

An analysis was made of each of the four resonances specified above, using least-squares fittings to the perturbation-free values of inclination and eccentricity for each resonance, to give the lumped geopotential harmonic coefficients. Although the coefficients obtained are not of high accuracy, they may still be good enough, when used with values from satellites at other inclinations, to give improved individual harmonic coefficients. The variation of inclination during the whole life is shown in Fig I, with the variations during the resonant regions 'mapped in'. The resonances are discussed in section 7.

The rotational speed of the upper atmosphere, Λ , has been determined between the resonances, for various heights and local times, as discussed in section 6.

Density scale height, H, was calculated from variations in perturbationfree perigee height, as discussed in section 5.

Finally, when this study was near completion, a further 3000 or so radar observations, made during the final 15 days of orbital life, arrived from the North American Air Defense Command, NORAD. Daily orbits, determined from 1400 of these observations, were analysed to determine Λ and H.

2 MAIN ORBIT DETERMINATION

2.1 Observations

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About 7500 optical and radar observations were available initially, from which about 450 US Navy observations, with elevations below 20, were discarded as being less reliable. The remaining 7000 or so were distributed among 114 orbits which were determined throughout the 5-year orbital life of the rocket (Table 1). Almost 1500 observations (about 20 per cent) were rejected as illfitting, leaving about 5560 observation (49 per orbit on average) actually used in the orbital determinations. Forty of these 114 orbits contained highly accurate Hewitt-camera sequences of observations (with about four observations selected from each sequence), made at Malvern or Edinburgh: 31 of these orbits had Malvern only; 7, Edinburgh only. The remaining two orbits included sequences from both stations. Nine of the 31 Malvern-only orbits contained at least two sequences, one of which was rejected for orbits 31, 32 and 38. Only orbit 29 contained a single Malvern sequence which was rejected but, fortunately, the orbit was fairly accurate without it. This rejected sequence was at the end of the group of observations being used to determine the orbit and, in such a situation, rejection occasionally does occur, not because of any defects in the observations but because of irregular variations in air drag that spoil the fitting.

The largest group of observations used was about 2800 from the US Navy, of which only about 8 per cent were ultimately rejected. British radar observations were available almost daily from 22 April 1975 to 15 February 1976 (ie the final 300 days of the life). Since there were on average four sequences per day, only one observation per sequence was selected so that these observations would not have too great an influence. This resulted in 1225 observations distributed among 34 orbits, giving about 36 observations per orbit. About 15 per cent of these observations were ultimately rejected. Malvern radar supplied a further 51 sequences, with a mean of three observations per sequence, during 1971-73, but nearly half of these observations were rejected. Other observations available were 136 from the South African kinetheodolite (43 rejected); 115 sequences comprising 380 observations (23 rejected) from Jokioinen, Finland; and about 2180 visual observations (about 25 per cent rejected) supplied by the Appleton Laboratory at Slough. These visual observations were made by volunteer observers. predominantly in Britain, with stations 2414 (D.J. Hopkins), 2420 (R.D. Eberst) and 2421 (D.M. Brierley) all contributing more than 250 observations each. There were also observations from South Africa, Australia, Cyprus, the Netherlands and ten other countries.

2.2 Observational accuracy

				Rms res	iduals	
	Station	Number of observations	Range	Min	utes of	arc
L	and the second	Constraint of	km	RA	Dec	Total
1	US Navy	243		1.6	1.9	2.5
2	US Navy	63		1.4	1.8	2.3
3	US Navy	48		1.7	1.4	2.2
4	US Navy	62		1.8	1.4	2.3
5	US Navy	175		1.7	1.7	2.4
6	US Navy	195		1.6	1.7	2.3
29	US Navy	1775	0.6*	0.25*	0.4*	
414	Capetown	74		2.9	3.0	4.1
616	Adelaide 5	13		0.9	1.4	1.7
2152	Akrotiri 2	11		1.5	2.5	2.9
2265	Farnham	43		2.2	2.4	3.3
2303	Malvern Hewitt Camera	134		0.03	0.04	0.05
2304	Malvern radar	71	0.9	2.4	2.4	
2402	Stevenage 2	16		1.8	1.9	2.6
2414	Bournemouth	367		4.1	3.6	5.5
2419	Tremadoc	96		2.8	2.4	3.7
2420	Willowbrae	353		2.1	2.2	3.0
2421	Malvern 4	278		2.0	1.9	2.7
2430	Stevenage 4	16	1999	1.0	1.7	2.0
2432	Horsham	15		2.0	1.7	2.7
2437**	Warrington	10		7.6	2.1	7.9
2513	Colchester	17		4.0	2.4	4.6
2528	Aldershot	12		1.4	1.4	1.9
2534	Edinburgh Hewitt Camera	36		0.04	0.03	0.05
2539	Dymchurch	13		1.4	1.4	2.0
2577	Cape Kinetheodolite	93		0.7	0.8	1.1
2596	Akrotiri	20		2.7	3.8	4.7
4126	Gröningen	14		2.9	3.3	4.4
6702	Jokioinen	357	1. marines	3.4	3.4	4.8
8597	Adelaide 4	19		2.4	3.9	4.5

Table 2 - Residuals for selected stations

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* Geocentric ** includes station 47

Table 2 lists the observing stations which have contributed at least ten observations to the determination of the orbits in Table 1. The observational accuracy is given in the form of rms residuals, obtained using the computer program ORES³. As usual, the Hewitt cameras at Malvern and Edinburgh (the latter is no longer in use) have the highest accuracy, averaging around 3 seconds of arc. The South African kinetheodolite had a mean residual of about 1.1 minutes of arc. The US Navy stations showed remarkably uniform topocentric accuracies, between 2.2 and 2.5 minutes of arc. (Station 29 is a fictitious geocentric station whose residuals must be multiplied by a factor of about 5 to obtain an equivalent topocentric accuracy, which comes to 2.3 minutes of arc.) The Malvern radar yielded an accuracy of about 3.4 minutes of arc. The theodolite at Jokioinen, Finland was up to standard with a little less than 5 minutes of arc. The remaining 18 stations, all visual observers reporting to the Appleton Laboratory at Slough, have rms residuals mostly between 2 and 5 minutes of arc. Lists of the residuals have been sent to the observers.

2.3 Orbital accuracy

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Computed sets of orbital elements at 114 epochs between April 1971 and February 1976 are listed in Table 1, with standard deviations where appropriate. The sd in inclination varies from 0.0003 to 0.0026° , the rms being 0.0012° ; for the Hewitt-camera orbits only, the rms value was 0.0008° . For eccentricity, the sd varies from 3×10^{-6} (equivalent to 22 metres in perigee height) to 44×10^{-6} , with an rms of 15×10^{-6} .

The sd in right ascension of the node varies between 0.001° and 0.002° , except for the final orbit (0.004°) , showing very good consistency. The argument of perigee, ω , and mean anomaly at epoch, M_0 , have similar sd, varying from 0.003° to 0.016° for the first 64 orbits; then increasing, generally to between 0.02° and 0.04° up to orbit 102; then to 0.05° to 0.08° up to orbit 112; and finally to 0.13° and 0.34° for the last two orbits.

The mean anomaly M is modelled in the PROP program⁴ as

$$M = M_0 + M_1 t + M_2 t^2 + M_3 t^3 + M_4 t^4 + M_5 t^5,$$

where t is the time from epoch. It can be seen from Table 1 that during 1971 the M_5 -term is rarely required; by 1974 about half the orbits require the M_5 -term; for the final 12 orbits (in the three months before decay), ten required the M_5 -term.

Fifteen orbits contained at least one day during which there was a geomagnetic storm (defined here as having the planetary geomagnetic index $A_p \ge 50$), even though (some successful) steps were taken to exclude such stormy days by careful selection of the time-span of the observations. Although the accuracy of some of these 15 orbits may have been affected by the density variations associated with the storms, they compared well in accuracy with the 'stormless' orbits. (The effect of a storm on the upper atmosphere is not indicated by A_p alone.)

3 FURTHER ORBIT DETERMINATIONS NEAR DECAY

After the orbits described in section 2 had been computed, about 3000 observations, made during the last 15 days of the life, were received. These were made by the assigned and contributing sensors of the North American Air Defense Command (NORAD) Space Detection and Tracking System (SPADATS), and about 1400 of them were used to determine daily orbits during these 15 days. It was not possible to use all the observations because PROP only accepts 100 observations per epoch.

The 15 daily orbits are listed in Table 3. They are of excellent accuracy and consistency. The sd in inclination varies from 0.0007 to 0.0011° . The sd in eccentricity varies from 7×10^{-6} (equivalent to 50 metres in perigee height) to 17×10^{-6} . The sd in right ascension of the node Ω varies from 0.0006 to 0.0015° , while the argument of perigee ω and mean anomaly at epoch, M_0 , (generally of similar accuracy) have sd between 0.04 and 0.40° . The elements in Tables 1 and 3 can be compared for the same epoch, *ie* orbit 113 with orbit C and orbit 114 with K. On orbits 113 and 114, the sd in e is 0.00004, and this is reduced to 0.00001 on the one-day orbits, while the sd in i is reduced by a factor of about $2\frac{1}{2}$ and the sd in Ω by a factor of about 3. These illustrate the improved accuracy of the one-day orbits.

It is worth noting that the epoch of the final orbit is only about 2 hours before decay. This is why the values of $M_2 - M_4$ are so exceptionally large. However, the imminence of decay did not affect the accuracy of the orbital elements.

The orbital elements of Table 3 are plotted in Figs 14-18. These orbits are more accurate and frequent than any previously published, for a time so near decay, and their analysis gives values of scale height and upper-atmosphere winds with a finer time resolution than has previously been possible (see sections 5 and 6).

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4 VARIATION IN PERIGEE HEIGHT

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The values of semi major axis, a, and eccentricity, e, from Table 1 were used to calculate perigee height over a spherical Earth, h_{n} , from

$$h_{p} = a(1-e) - R$$
, (1)

where R is the Earth's equatorial radius, taken as 6378.16 km, as assumed in the PROP program. The values are plotted in Fig 2 as circles. The main oscillation is due to the odd-harmonic perturbation in e, which, combined with the lunisolar perturbation, was calculated using the PROD program⁴, to give a total perturbation Δe . A parameter Q, the perigee height over a spherical Earth, cleared of perturbations, can now be determined from

$$Q = h_p + a\Delta e_q$$

and the values obtained are shown in Fig 2 by triangles. The perturbation Δe is assumed to be zero initially, so that the Q values are relative rather than absolute. This is not significant here, since only the slope dQ/dt is used (in section 5) for calculating density scale height.

The values of h_p and Q, in the final 15 days before satellite decay, calculated using a and e from Table 3, are plotted in Fig 19, which is an extension of Fig 2.

5 DENSITY SCALE HEIGHT

The density scale height H is a measure of the rate of decrease of density ρ as height y increases, and is defined by $\frac{1}{H} = -\frac{1}{\rho} \frac{d\rho}{dy}$. Values of H were calculated from \dot{Q} , the rate of change of Q due to air drag, where⁵, for ae/H > 3,

$$\dot{q} = -\frac{2HM_2}{3M_1e} \left(1 - 2e + \frac{H}{4ae} - \frac{2\epsilon'}{e} \sin^2 i \cos 2\omega\right), \qquad (2)$$

 ϵ' is the ellipticity of the atmosphere (= 0.00335) and H is at a height 1.5 H p above the satellite's perigee height y . Ignoring small perturbations, we may take y as given by the right-hand side of equation (1) with R replaced by the local Earth radius at perigee latitude. For 1971-18B, at 70° inclination,

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$$y_{p} = h_{p} + 18.8 \sin^{2} \omega$$
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Values of \dot{Q} for use in equation (2) are obtained in the form $\Delta Q/\Delta t$, from the change ΔQ in Q over a suitable time interval Δt . Since Q has an accuracy of about 0.1 km, values of ΔQ of 3 km or more are required to give values of \dot{Q} accurate to 3 per cent, and the time intervals were chosen on this basis. Values of H were obtained from equation (2) using these values of \dot{Q} and mean values of the other parameters. The values of H are plotted against time in Fig 3 as circles, up to MJD 42770. At this point, $ae/H \stackrel{c}{=} 3$.

In the remainder of the calculations for H, from MJD 42770 to the end of the life, the value of ae/H was less than 3. The 'phase 2' regime discussed in Ref 6 (page 88) can then be used: equation (5.35) of Ref 6 gives

$$\frac{da}{dx} = y_0 + \frac{1}{2}e\left(4 - 3y_0^2 - y_0y_2\right) - \frac{1}{2}c \cos 2\omega(y_0 - 2y_2 + y_0y_3) = \beta, \text{ say,}$$
.....(3)

where $c = \frac{\epsilon' a(1 - e)}{2H} \sin^2 i$, $y_r = I_r/I_1$, and I_r is the Bessel function of the first kind and imaginary argument, of order r (*ibid*, page 36).

To calculate H from Q, put

$$\dot{Q} = \frac{dQ}{da} \cdot \frac{da}{dt} = -\frac{d(a - x)}{da} \cdot \frac{2na}{3n}$$

where $n(=M_1)$ is the mean motion and $n = 2M_2$. Hence

$$\frac{da}{dx} = 1/(1 + 3M_1 \dot{Q}/4M_2 a) = \alpha , \text{ say.}$$
(4)

H is now determined by guessing two values, H_1 and H_2 , which are used to calculate β_1 and β_2 from equation (3), and then by linear interpolation from

$$H = \frac{H_1(\beta_2 - \alpha) + H_2(\alpha - \beta_1)}{\beta_2 - \beta_1} .$$
 (5)

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These values of H have also been plotted in Fig 3 as circles, for 42770 < MJD < 42824 . The sd shown have been estimated from the errors in perigee height (usually 0.1 km).

For comparison, values of H obtained' from CIRA 1972, for the same heights and exospher. temperatures as the calculated values, are also plotted in Fig 3, as triangles. Consecutive points have been joined (where possible) to give an overall view of the difference. To avoid confusion between some of the points, only one half of the sd-bar is shown where overlap with a triangle would have occurred.

Fig 3 shows that from April 1971 to October 1975 the observational values of H, for heights between 250 and 350 km, are generally within 10 per cent of the CIRA 1972 values and have the same mean value. From November 1975, the observational values are mostly lower than CIRA 1972. Since atmospheric density varies so widely - by a factor up to 5 at 300 km - Fig 3 shows that CIRA 1972, which incorporates Jacchia's 1971 model⁸, provides a good reference atmosphere.

Ten values of H obtained from equations (3) to (5), using the 15 daily orbits near decay (given in Table 3), are also plotted in Fig 3 for MJD between 42810 and 42824; during this time the height falls from 260 to 205 km. The observational values are mostly lower than those from *CIRA 1972*, on everage by about 10 per cent, a difference that is probably significant.

The observational values of H have been plotted against height in Fig 4; they are shown as crosses or circles, and comparative curves from CIRA 1972 are given, for various exospheric temperatures. The observational values are numbered 1-25, with points 1-15 having bracketed numbers giving exospheric temperatures, corrected for semi-annual variation⁹, which have been calculated⁷ using CIRA 1972 with the appropriate values of solar 10.7 cm radiation energy and geomagnetic index. For points 1-7, the local time at perigee is used in calculating the temperature; but for points 8-15, local time is averaged, because the eccentricity is lower, and the position on the orbit where drag has most effect in altering Q (at a height 1.5 H above perigee) is at a considerable angular distance from perigee (60° when e = 0.02), so that the appropriate local time required is not that at perigee but averaged over a wide arc of the orbit. The bracketed temperatures given in Fig 4 are those used in calculating the CIRA values of H in Fig 3.

For points 16-25, the exospheric temperatures are between 770 and 810 K and are not shown on Fig 4.

6 ATMOSPHERIC ROTATION RATE

The 114 derived values of inclination, given in Table 1, were cleared of lunisolar and geopotential perturbations using the PROD program⁴ with numerical

integration at one-day intervals. The modified values are plotted in Fig 1. The theoretical change in inclination was calculated for several values of atmospheric rotation rate (expressed as Λ times the Earth's rotation rate), using oblate-atmosphere theory¹⁰, with numerical integration at about 18-day intervals (corresponding to 22.5° steps in argument of perigee). The 114 points were considered in groups separated by the resonance regions. (These regions were filled, as explained in section 7, by the resonance oscillations.) Orbits 1-37 were taken as the first group (MJD 41068 to 41547) and the best fitting, shown in Fig 1, is given by $\Lambda = 1.15 \pm 0.05$ rev/day, at a mean height $\bar{y} = \bar{y}_p + 0.75H = 315$ km; the second group, orbits 42-61 (MJD 41665 to 42028), gives $\Lambda = 1.05 \pm 0.05$ at y = 310 km; the third group gives $\Lambda = 1.10 \pm 0.05$ for y = 295 km, for orbits 65-76 (MJD 42181-42413); and fourthly, for orbits 82-112 (MJD 42533-42798), $\Lambda = 1.05 \pm 0.05$ at y = 270 km.

It is known¹¹ that the zonal wind speed depends on local time, Λ being greater in the evening (18-24 h) than in the morning (04-12 h): so the local time at perigee is plotted at the top of Fig 1. The fitting of the first group of points reveals no bias in local time, *ie* evening and morning were sampled equally (mean conditions). The second fitting shows a slight morning bias; the third and fourth fittings are unbiased. So the results from the four fittings can be summarised as follows:

- (1) A = 1.15 ± 0.05, implying a west-to-east wind of 60 ± 20 m/s, under mean (evening and morning) conditions, at a mean height of 315 km.
- (2) $\Lambda = 1.05 \pm 0.05$ (west-to-east wind of 20 ± 20 m/s), with a slight morning bias, at 310 km height.
- (3) $\Lambda = 1.10 \pm 0.05$ (west-to-east wind of 40 ± 20 m/s), under mean conditions, at 295 km height.
- (4) $\Lambda = 1.05 \pm 0.05$, under mean conditions, at 270 km height.

The sd in the above values of Λ are obtained from the estimated accuracy of fitting the curve to the values of inclination in Fig 1. For example, the first group are fitted with an accuracy estimated as slightly better than 0.001° , say 0.0008° (of the 36 points, none is more than 0.0025° from the curve). This error is just under 5 per cent of the decrease in inclination over the first group of points, giving a similar proportional error in Λ , that is an error of 0.05.

In calculating the curves of Fig 1, meridional winds have been ignored: they are unlikely to have an appreciable effect because (a) the local time is

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averaged over day and night, and (b) the satellite has a high orbital inclination (70°) , for which meridional wind effects tend to be small.

The values of Λ , with sd, are plotted against height in Fig 5, together with the curves of mean atmospheric rotation rate, and morning and evening wind speeds, derived from analysis of 31 previous orbits¹¹. The values obtained here suggest that the average curve should be rather lower at heights between 260 and 300 km, for the years 1971-1975.

In the inset diagram on the left of Fig 1, the final two values of inclination from the main curve have been replaced by the values obtained from the 15 daily orbits just before decay. The curve shown has $\Lambda = 1.05$ up to 5 February 1976: but for the last 11 days the value is $\Lambda = 1.6 \pm 0.1$, at a mean height of 195 km. This implies a west-to-east wind of 240 ± 40 m/s at a local time of 19-23 h. It is well established (see Ref 11) that the west-to-east winds are strongest during the evening hours, 18-24 h, but 240 m/s is the highest reliable value of wind speed that has been obtained from analysis of satellite orbits. This is presumably because 1971-18B happened to sample the evening winds at their strongest during its last few days in orbit, and because the daily orbits allow an analysis over a much shorter time span than has generally been possible in the past. West-to-east winds of up to 300 m/s at the evening maximum in winter have been recorded by radar back-scatter measurements¹² at heights near 200 km at latitude 47° north in February 1970. These conditions are closely comparable with those experienced by the perigee of 1971-18B during its last 11 days in orbit (6 to 16 February 1976), when the perigee latitude increased from 15° north to 50° north.

The $\Lambda = 1.6$ curve has been plotted (unbroken line) in Fig 20, with a comparative curve for $\Lambda = 1.4$ (dashed). To assess the influence of meridional winds ¹³ (south-to-north), the effect of a 200 m/s south-to-north wind (a rotation rate $\mu = 0.4$ rev/day) has been calculated and is shown in Fig 20 by the dash-dot curve. It is seen that changing μ from 0 to 0.4 has slightly less effect than changing Λ from 1.4 to 1.6; so a change of 0.1 in Λ is equivalent to a change of about 0.3 in μ . Thus the $\Lambda = 1.6$; $\mu = 0$ curve might be replaced by the alternative $\Lambda = 1.5$; $\mu = 0.3$. However, a meridional wind of $\mu = 0.3$ (150 m/s) is most unlikely at local time 19-23 h, when such winds are usually slight¹⁴, averaging less than 50 m/s: so the estimate of $\Lambda = 1.6 \pm 0.1$ rev/day can stand unaltered, any effects of meridional winds being absorbed in the 0.1 error.

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7 RESONANCES

7.1 14th order

The rates of change of inclination i and eccentricity e near 14thorder resonance may be expressed¹⁵, in terms of the resonance angle $\phi = \omega + M + 14(\Omega - \nu)$, by the equations:

$$\frac{di}{dt} = \frac{n}{\sin i} \left(\frac{R}{a}\right)^{14} \left[\frac{R}{a} (14 - \cos i) \overline{F}_{15, 14, 7} \left\{\overline{S}_{14}^{0, 1} \sin \phi + \overline{C}_{14}^{0, 1} \cos \phi\right\} + \frac{15e}{2} (14)\overline{F}_{14, 14, 7} \left\{\overline{C}_{14}^{1, 0} \sin(\phi - \omega) - \overline{S}_{14}^{1, 0} \cos(\phi - \omega)\right\} + 11e(7 - \cos i)\overline{F}_{14, 14, 6} \left\{\overline{C}_{14}^{-1, 2} \sin(\phi + \omega) - \overline{S}_{14}^{-1, 2} \cos(\phi + \omega)\right\} + terms in e^{|q|} \cos_{sin} (\gamma \phi - q\omega) ;$$

$$\frac{de}{dt} = \frac{n}{2} \left(\frac{R}{a}\right)^{14} \left[e\left(\frac{R}{a}\right) \overline{F}_{15, 14, 7} \left(\overline{S}_{14}^{0, 1} \sin \phi + \overline{C}_{14}^{0, 1} \cos \phi\right) - 15 \overline{F}_{14, 14, 7} \left\{ \overline{C}_{14}^{1, 0} \sin (\phi - \omega) - \overline{S}_{14}^{1, 0} \cos (\phi - \omega) \right\} + 11 \overline{F}_{14, 14, 6} \left\{ \overline{C}_{14}^{-1, 2} \sin (\phi + \omega) - \overline{S}_{14}^{-1, 2} \cos (\phi + \omega) \right\} + terms in \left[e^{|q|-1} \left\{ q - \frac{1}{2} (k + q) e^2 \right\} \frac{\cos}{\sin} (\gamma \phi - q \omega) \right] \right].$$
(7)

 $\bar{c}_{14}^{q,k}$ and $\bar{s}_{14}^{q,k}$ are lumped 14th-order geopotential coefficients, defined in Ref 15, and the \bar{F} are Allan's normalized inclination functions¹⁶. The quantities γ , q are integers, with $\gamma = 1, 2, 3$... and $q = 0, \pm 1, \pm 2$ The value $\gamma = 2$ is associated with geopotential harmonics of order 28, and $\gamma = 3$ with harmonics of order 42, etc; only the $\gamma = 1$ terms have been used here, although $\gamma = 2$ terms were tried (without much success). The value q = 2 leads to terms in e^2 in equation (6), and since e = 0.08 here, only the q = 0 and ± 1 terms have been considered. The suffix k is given by $k = \gamma - q$.

The orbit of China 2 rocket was appreciably perturbed by 14th-order resonance between July and December 1972, and exact 14th-order resonance ($\dot{\Phi} = 0$)

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(6)

occurred on 14 October. The variations of Φ and $\dot{\Phi}$ between May 1972 and February 1973 are shown in Fig 6.

The variations in inclination and eccentricity during this time, after removal of other perturbations, were analysed using the computer program THROE¹⁷, which fits the values with numerically-integrated versions of the equations of the form (6) or (7). The orbits used include US Navy orbits as well as the PROP orbits of Table 1.

The final inclination fittings utilized 7 PROP values and 10 US Navy values between 11 August and 14 December 1972. The values of inclination were cleared of perturbations as follows. The lunisolar and odd harmonic perturbations were calculated using the computer program PROD⁴, the combined maximum value being 0.0052° . The perturbation due to atmospheric rotation was calculated within THROE, assuming a mean atmospheric rotation rate of 1.1 rev/day, the maximum value of the perturbations being 0.0068° . The PROP values were also cleared of tesseral harmonic perturbations due to the $J_{2,2}$ term in the geopotential (maximum value 0.0016°). The US Navy values were assigned a uniform standard deviation of 0.003° ; the PROP values had the sd given in Table 1.

In the analysis of the resonant variation in inclination, various (γ,q) pairs were tried, and the number of values of i included was also the subject of a trial-and-error process. After several trials with $(\gamma, q) = (1, 0)$, (1, 1)and (1, -1) in various combinations, it appeared that $(\gamma, q) = (1, 0)$ alone gave the best results. The number of values of i included was not a critical factor. Closely similar results were obtained with 35, 20 or 17 values.

The most favoured fitting, to the 17 values of i, gave the following values of lumped 14th-order geopotential coefficients of odd degree:

$$10^9 \overline{c}_{14}^{0,1} = 32 \pm 11$$
; $10^9 \overline{s}_{14}^{0,1} = -2 \pm 20$ (8)

with $\varepsilon = 0.76$, where ε is the measure of fit ($\varepsilon^2 = \text{sum of the squares of the weighted residuals divided by the number of degrees of freedom). The values (8) were used in determining individual 14th-order coefficients of odd degree¹⁵. Fig 7a shows the fitting for 35 values of i (14 PROP plus 21 US Navy): this diagram is shown because it indicates (more fully than the 17-value fitting) how the resonant perturbations fall off on going away from the central resonance, and also shows conclusively that there is a mean decrease of 0.006° in i due to 14th-order resonance.$

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In the analysis of eccentricity, the effects of drag were removed within the THROE program, assuming a scale height H = 50 km. Other values of H were found to give inferior results. Lunisolar perturbations, calculated using the PROD program, were found to be negligible. The nine PROP values of e were given the standard deviations shown in Table 1, while the 11 US Navy values of e were initially assigned an sd of 0.0001. Two other values of sd were also tried (0.0002 and 0.0004) and the value 0.0002 was finally selected as giving the best fitting. This best fitting of the 20 values of e , made using the integrated form of equation (7), between 18 July and 24 December 1972, was shared by two alternative sets of (γ , q), namely (1, 1) and (1, ±1), and the fittings are shown in Fig 7b.

The lumped 14th-order coefficients given by the $(\gamma, q) = (1, 1)$ fitting are:-

$$10^{9}\bar{c}_{14}^{1,0} = 790 \pm 110$$
; $10^{9}\bar{s}_{14}^{1,0} = 400 \pm 20$ (9)

with $\varepsilon = 1.21$.

The lumped 14th-order coefficients given by the $(\gamma, q) = (1, \pm 1)$ fitting are:

$$10^{9}\overline{c}_{14}^{1,0} = 850 \pm 150 ; 10^{9}\overline{s}_{14}^{1,0} = 580 \pm 270$$

$$10^{9}\overline{c}_{14}^{-1,2} = 130 \pm 250 ; 10^{9}\overline{s}_{14}^{-1,2} = 40 \pm 170$$
(10)

and

with $\varepsilon = 1.27$.

These values are considerably larger than expected¹⁵, and the fittings (Fig 7b) are not satisfactory near resonance. In view of this deficiency, a simultaneous fitting of i and e was not attempted. No explanation has been found for the poor fit; at first sight the values in Fig 7b seem quite promising.

It was found necessary, for e, to make a correction in the use of the THROE program, which integrates assuming the value of M_2 for the first orbit of two consecutive orbits, whereas the M_2 should be averaged over the time interval between the orbits. This correction, which has been accomplished by taking M_2 at the nth epoch as $\left[(M_1)_{n+1} - (M_1)_n \right] / 2(t_{n+1} - t_n)$, represents the integrated effect of air drag between times t_n and t_{n+1} . This error does not affect i appreciably.

7.2 29:2 resonance

The resonance angle ϕ is now given by $\phi = 2(\omega + M) + 29(\Omega - \nu)$ and the variations of i and e may be expressed as:

$$\frac{di}{dt} = \frac{n}{\sin i} \left(\frac{R}{a}\right)^{29} \left[\frac{R}{a} (29 - 2 \cos i)\overline{F}_{30,29,14} \left\{\overline{\overline{S}}_{29}^{0,2} \sin \phi + \overline{\overline{C}}_{29}^{0,2} \cos \phi\right\} + 16e(29 - \cos i)\overline{F}_{29,29,14} \left\{\overline{\overline{C}}_{29}^{1,1} \sin(\phi - \omega) - \overline{\overline{S}}_{29}^{1,1} \cos(\phi - \omega)\right\} + 12e(29 - 3 \cos i)\overline{F}_{29,29,13} \left\{\overline{\overline{C}}_{29}^{-1,3} \sin(\phi + \omega) - \overline{\overline{S}}_{29}^{-1,3} \cos(\phi + \omega)\right\} + terms in e^{|q|} \cos_{sin}(\gamma\phi - q\omega) ; \qquad (11)$$

$$\frac{de}{dt} = n \left(\frac{R}{a}\right)^{29} \left[-\frac{R}{a} \bar{F}_{30,29,14} e^{\begin{pmatrix} 0,2\\ \bar{S}_{29} & \sin \phi + \bar{C}_{29} & \cos \phi \end{pmatrix} - 16 \bar{F}_{29,29,14} \left\{ \bar{C}_{29}^{1,1} & \sin(\phi - \omega) - \bar{S}_{29}^{1,1} & \cos(\phi - \omega) \right\} + 12 \bar{F}_{29,29,13} \left\{ \bar{C}_{29}^{-1,3} & \sin(\phi + \omega) - \bar{S}_{29}^{-1,3} & \cos(\phi + \omega) \right\} + terms in e^{|q|-1} \left\{ q - \frac{1}{2} (k + q) e^2 \right\} \frac{\cos}{\sin} (\gamma \phi - q \omega) \right] .$$
(12)

This time, 16 sets of values of i or e were fitted by integrated forms of (11) or (12), as described in section 7.1 (for 14th-order), between December 1973 and April 1974. Fig 8 shows the variations of Φ and $\dot{\Phi}$: exact 29:2 resonance ($\dot{\Phi}$ = 0) occurred on 2 March 1974 (MJD 42108). Only three PROP values were available, combined with 13 US Navy values (with standard deviations as for 14th-order resonance).

As for 14th-order resonance, $(\gamma, q) = (1, 0)$ gave the best least-squares fit for i alone, shown in Fig 9a. However, for e alone, the best fit, given in Fig 9b, was obtained with $(\gamma, q) = (1, \pm 1)$, where [q, k] = [1, 1] and [-1, 3]. A simultaneous least-squares fit to i and e was made using the SIMRES program¹⁸ for $(\gamma, q) = (1, 0)$, $(1, \pm 1)$. The resulting sets of lumped values for the 29th-order harmonic coefficients are:

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(1) Inclination i alone:

$$10^9 \overline{c}_{29}^{0,2} = 50 \pm 20$$
, $10^9 \overline{s}_{29}^{0,2} = -160 \pm 70$, (13)

where $\varepsilon = 0.63$.

(2) Eccentricity e alone:

$$10^{9}\overline{c}_{29}^{-1,1} = 40 \pm 610, \quad 10^{9}\overline{s}_{29}^{-1,1} = -2750 \pm 860,$$

$$10^{9}\overline{c}_{29}^{-1,3} = -980 \pm 590, \quad 10^{9}\overline{s}_{29}^{-1,3} = -1950 \pm 700,$$
(14)

where $\varepsilon = 0.72$.

(3) For i and e simultaneously:

$$10^{9}\bar{c}_{29}^{0,2} = 340 \pm 230 , 10^{9}\bar{s}_{29}^{0,2} = -360 \pm 200$$

$$10^{9}\bar{c}_{29}^{1,1} = -240 \pm 280 , 10^{9}\bar{s}_{29}^{1,1} = -510 \pm 340$$

$$10^{9}\bar{c}_{29}^{-1,3} = -620 \pm 300 , 10^{9}\bar{s}_{29}^{-1,3} = -260 \pm 250 ,$$
(15)

with a weighting factor of 1.41 and ε = 0.61. The values in (14) and (15) cannot be regarded as reliable because the standard deviations are so large, but the values (13) are better and may be useful in future in deriving individual coefficients of 29th order.

It is to be expected that the numerical values of the lumped coefficients would be poor because the total variations in i and e are no greater than the errors in the observational values. However, Fig 9 is valuable in showing that the overall changes in both i and e are virtually zero in passing through 29:2 resonance, due to the effects of resonance itself, and the fitting at resonance provided the end points for the Λ curves in Fig 1. After restoring the atmospheric-rotation perturbation, the inclination variation was mapped into the appropriate gap in Fig 1.

7.3 15th order

The 15th-order resonance equations 18,20 , ignoring e^2 terms, may be expressed as:

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$$\frac{di}{dt} = \frac{n}{\sin i} \left(\frac{R}{a}\right)^{15} \left[(15 - \cos i)\overline{F}_{15,15,7} \{\overline{C}_{15}^{0,1} \sin \phi - \overline{S}_{15}^{0,1} \cos \phi \} + \left(\frac{R}{a}\right) \frac{17e}{2} \overline{F}_{16,15,8}^{(15)} \{\overline{S}_{15}^{1,0} \sin(\phi - \omega) + \overline{C}_{15}^{1,0} \cos(\phi - \omega) \} + \left(\frac{R}{a}\right) \frac{13e}{2} (15 - 2\cos i)\overline{F}_{16,15,7} \{\overline{S}_{15}^{-1,2} \sin(\phi + \omega) + \overline{C}_{15}^{-1,2} \cos(\phi + \omega) \} \right] (16)$$

and the corresponding terms in the equation for e are:

$$\frac{de}{dt} = n \left(\frac{R}{a}\right)^{15} \left[\frac{e}{2} \bar{F}_{15,15,7} \left(\bar{C}_{15}^{0,1} \sin \phi - \bar{S}_{15}^{0,1} \cos \phi\right) - \left(\frac{R}{a}\right) \frac{17}{2} \bar{F}_{16,15,8} \left\{\bar{S}_{15}^{1,0} \sin(\phi - \omega) + \bar{C}_{15}^{1,0} \cos(\phi - \omega)\right\} + \left(\frac{R}{a}\right) \frac{13}{2} \bar{F}_{16,15,7} \left\{\bar{S}_{15}^{-1,2} \sin(\phi + \omega) + \bar{C}_{15}^{-1,2} \cos(\phi + \omega)\right\}$$
(17)

15th-order resonance has been investigated between 4 December 1974 and 13 June 1975, where 13 PROP orbits were available (Table 1) as well as 10 US Navy orbits. Exact 15th-order resonance ($\dot{\Phi}$ = 0) occurred on 9 March 1975: Fig 10 shows the variations of Φ and $\dot{\Phi}$.

The best least-squares fitting of the integrated form of equation (16) to the 23 values of perturbation-free inclination was given by $(\gamma, q) = (1, 0)$. The lumped values for 15th-order odd harmonic coefficients are:-

$$10^{9} \frac{0,1}{C_{15}} = -37 \pm 6$$
, $10^{9} \frac{0,1}{S_{15}} = 10 \pm 6$, (18)

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with $\varepsilon = 0.58$. Fig 11 shows the inclination values and the fitted curve. The fitting is entirely satisfactory and the change in inclination should be large enough to give reliable values of the lumped coefficients. Fig 11 also clearly shows an increase of 0.004° in inclination due to 15th-order resonance.

Various fittings were attempted with eccentricity values, using equation (17), but no satisfactory results were obtained and so no graph is shown.

7.4 31:2 resonance

No reliable values of lumped 31st-order geopotential harmonic coefficients can be expected here, as resonance passed rather rapidly. However, a leastsquares fitting was made for $(\gamma, q) = (1, 0)$ in order to determine the overall

change in inclination. The resonance region considered was between 14 October and 25 December 1975 and Fig 12 shows the variations of ϕ and $\dot{\phi}$. Exact resonance, where $\dot{\phi} = 0$, occurred on 19 November. Ten PROP and nine US Navy inclination values were fitted by a least-squares curve after removing the usual perturbations, to give 31st-order lumped coefficients as:

$$0^{9}\overline{c}^{0,2}_{31} = 24 \pm 18$$
, $10^{9}\overline{s}^{0,2}_{31} = 30 \pm 23$, (20)

with $\varepsilon = 0.99$. The fitting is quite satisfactory, and the coefficients are as good as can be expected when drag is so high.

Atmospheric rotation has a strong influence at this late stage in the satellite's life and Fig 13a shows the values of inclination originally and after removal of the perturbation due to an atmosphere rotating at $\Lambda = 1.05 \text{ rev/day}$. It can be seen that this perturbation can change the inclination by up to 0.01° . Fig 13b gives the inclination values with the perturbation removed, showing the best least-squares fitting. The overall change in i due to resonance, in passing through the resonance, is virtually zero and so can be ignored in Fig 1.

8 CONCLUSIONS

The orbit of China 2 rocket, 1971-18B, has been determined at 114 epochs between 1971 and 1976, using more than 7000 radar and optical observations, including 170 observations made by Hewitt cameras. The standard deviations in inclination varied from 0.0003 to 0.0026°, and the sd in eccentricity was between 3×10^{-6} (equivalent to 22 m in perigee height) and 44×10^{-6} .

Values of density scale height have been determined from the change in perigee height and compared with values calculated from the CIRA 1972 reference atmosphere: the agreement is good between April 1971 and October 1975, but the ensuing observational values (near decay) are about 10 per cent lower, on average.

Four values of atmospheric rotation rate \therefore have been determined for heights y between 270 and 315 km. All four give west-to-east winds (superrotation). The results (Fig 1) are:

(1) $\Lambda = 1.15 \pm 0.05$ at y = 315 km between April 1971 and August 1972; (2) $\Lambda = 1.05 \pm 0.05$ at y = 310 km between December 1972 and December 1973; (3) $\Lambda = 1.10 \pm 0.05$ at y = 295 km between April 1974 and January 1975; (4) $\Lambda = 1.05 \pm 0.05$ at y = 270 km between May 1975 and February 1976.

The values (1), (3) and (4) are for mean (evening and morning) conditions; the value (2) has a slight morning bias.

The effects of four orbital resonances, of order 14:1, 29:2, 15:1 and 31:2, have been investigated, and the lumped harmonic coefficients in the geopotential have been determined. Although not of great accuracy, these values should be of use, in combination with values from satellites at other inclinations, in determining individual harmonic coefficients. The analyses of the resonances were necessary to determine the overall change in inclination and eccentricity on passing resonance, and they served this purpose well. However, the difficulties encountered suggest that accurate values of harmonic coefficients for the 29:2 and 31:2 resonances cannot be obtained from a high-drag satellite unless a number of very accurate orbits from Hewitt camera observations are available close to the time of resonance.

Further orbits were determined for each day during the final 15 days before decay in February 1976 from 1400 NORAD observations: the accuracy of these daily orbits was very consistent, and slightly better than the average of the original 114 orbits. Analysis of the change in inclination in the last 12 days before decay revealed a very strong west-to-east wind, of 240 ± 40 m/s, at a mean height of 195 km, at a local time of 19-23 h and at a latitude of 15-50° N in winter (5-16 February 1976). This is the highest reliable wind speed obtained from analysis of satellite orbits: it arises because the satellite's perigee was at the evening maximum of the zonal wind, and because of the fine time resolution and excellent accuracy of the daily orbits. Analysis of the perigee height gave a further 10 values of density scale height H with a sharper time resolution than has previously been possible, and an accuracy of about ±3 per cent. These values of H , like those in the preceding three months, are about 10 per cent lower than indicated by CIRA 1972.

Table 1

ORBITAL PARAMETERS FOR CHINA 2 ROCKET, WITH STANDARD DEVIATIONS

N	62	41	45	38	64	35	57	2	83	69	29	62	11	56	60	60	55	52	48	47	45	37	43	37	28
9	1.7	8.4	9.0	8.8	8.0	6.9	9.4	7.9	6.8	6.1	6.1	0.6	6.5	2.0	6.5	5.7	4.1	8.4	9.3	8.9	9.4	9.4	0.9	10.1	5.9
3	0.64	0.68	0.71	0.54	0.66	0.62	0.50	0.48	0.51	0.52	0.64	0.53	19.0	0.48	0.49	0.54	0.56	0.45	0.42	0.46	0.47	0.77	0.69	0.54	0.74
MS	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	-0.00025	•	•	-0.000048	-0.00003	•	0.000055	•
M4	0.00015	0.00032	,	-0.00041	•	•	0.00008	•	0.00012	0.00029	6000.0	-0.00077	,	,	0.00077	0.0007	0.0012	0.00035	0.00021	-0.00038	-0.00003	0.00036	, ,	-0.00034	•
M3	-0.00156	0.00062	-0.00065	0.00006	-0.0032	0.00021	0.00083	0.00060	-0.0020	-0.0018	0.0069	60000.0	-0.0011	0.0119	-0.0017	-0.0048	0.0020	0.0083	0.00020	-0.0020	0.0027	-0.0021	-0.00044	-0.0009	-0.0022
M2	0.1516	0.1379	0.1185	0.1592	0.1534	0.1094	6160.0	0.1320	0.1263	0.1263	0.1585	0.1746	0.1151	0.1119	0.1022	0.0921	0.0836	0.1032	0.1604	0.2229	0.2128	0.1983	0.1407	0, 1818	0.1555
M	4906.8071	4909.1075	4915.1386	4917.4384	4927.9705	4929.9549	4937.4607	4939.5265	4941.7293	4943.5964	4945.7864	10 494 8.40 78	4950.8424	4951.5116	25 4952.2013	4953.2791	4954.2756	4955.4180	4960.4392	4964.7244	4970.3387	4975.6241	4982.8130	4986.2455	4989.9201
Mo	279.280	303.023	265.754	231.596	72.745	264.917	149.246	315.058	240.070	278.618	235.839	212.894	120.407	213.996	309.638	233.389	76.125	285.343	245.480	112.297	250.467	166.352	214.076	323.039	112.535
э	124.898	114.993	90.308	79.132	39.443	29.469	345.605	334.267	324.174	315.313	305.231	3 295.037	283.568	279.732	275.905	269.537	261.894	254.239	231.311	217.283	200.723	185.381	156.032	142.021	127.939
a	169.196	152.597	111.023	92.282	25.472	8.717	295.272	276.345	259.505	244.754	227.881	210.992	191.973	185.631	2179.286	168.704	156.003	143.293	105.114	81.739	54.058	28.444	339.222	315.633	292.010
i	6606.69	69.9006	5006.69	69.9023	8106.69	2668.69	61 69.9043	8006.69	69.8986	8 69.8984	1868.69	0106.69	6606.69	8 69.9023	01 6106.90	69.9031	\$006.69	01 69.8985	0668.69	1006.69	69.9029	69.8986	69.8946	69.8956	61.8940
v	0.102908	0.102578	0.101997	0.101730	0.100327	0.0999986	0.098516	0.098145	661760.0	0.097508	0.097117	0.096781	0.096500	0.096345	0.096282	0.096111	0.096017	0.095923	0.095459	001560.0	0.094651	0.094166	199860.0	0.093440	0.093062
•	7403.9249	7401.6121	2252.2957	1393.2521	7382.7167	7380.7358	7373.2557	1371.2001	1369.0098	7367.1547	7364.9801	1362.3797	7359.9665	1359.3034	7358.6202	7357.5530	7356.5665	7355.4360	7350.4727	7346.2436	7340.7119	7335.5136	7328.4579	7325.0952	7321.4994
Date	1971 Apr 27	May 5	May 25	S nul	2 Iul	EI INC	Aug 17	Aug 26	Sep 3	Sep 10	Sep 18	Sep 26	Oct 5	Oct 8	Oct 11	Oct 16	Oct 22	Oct 28	Nov 15	Nov 26	Dec 9	Dec 21	1972 Jan 13	Jan 24	Feb 4
MUN	41068	076	960	105	137	145	180	189	197	204	212	220	229	232	235	240	246	252	270	281	294	306	329	340	351
Orbit	-	2	*	*	\$	9	1	*8	*6	01	•	12*	13*	14*	15*	16*	•21	18	61	20	21	22	23	24	25

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-	6	4	3	9	-	6	6	6	5	2	e e	0	6	-	0	1	9	5	6	7 4	9	7 8	-	6	6
-	6	.6	6	10.	7.	4.	4.	.6 0	.6 0	8.	8	5	5.	4.			.6	7.	8.	6	.6	6	2.	5.	8
ω	0.66	0.7	0.74	0.4	0.24	0.5	0.5	0.6(0.50	0.4	0.4	0.3	0.4	0.3	0.8	0.6	0.4	0.8	0.5	0.49	0.4	0.5	0.69	0.3	0.50
MS	0.000039	-0.00007	•	•	•	•	•	•	,	•	•	1	•	•	•	,	•	1	•	,	-0.000034		•	•	0.00027
M4	-0.00018	0.00012	-0.00014	0.00037	0.00030	ר י	•	0.00030	-0.00014	0.00037	3 0.0008	- 7	0.0011		•	0.00083	-0.00005	0.00022	0.00053	0.00025	0.00016	- 2	•	0.0008	-0.00121
M3	0.0012	0.0054	0.00206	0.00140	0.00356	0.00166	-0.00425	-0.00141	0.00023	0.00077	-0.0073	0.0053	3 0.0055	2 0.0012	6 0.0025	0.0047	0.00423	-0.0049	-0.0014	0.00054	-0.0008	0.00090	-0.0049	-0.00041	-0.0101 3
M2	0.1755	0.1879	0.2731	0.2698	0.2687	0.3027	0.2693	0.1375	1260.0	0.1092	0.1161	0.0968	0.1355	0.2055	0.1861	0.1622	0.1513	0.1639	0.1730	0.1683	0.1796	0.1830	0.2169	0.1628	0.2270 5
М	4992.9816	5005.3522	5017.8743	5024.1491	5030.8087	5033.7353	5037.4461	5047.0555	8 5054.8242	5 5057.6867	5060.8815	12 5062.1840	5063.9539	15 5066.6210	13 5071.5781	15 5074.3041	5112.1670	5125.1240	5127.8360	5135.2727	5140.6757	5146.1782	5149.2132	5150.6898	5153.4429
Mo	346.581	206.949	41.082	192.506	43.179	4.413	338.155	43.979	8 80.634	291.238	143.204	294.125	95.524	8 272.087	8 291.631	11 195.584	191.224	259.314	230.467	353.805	284.470	138.977	172.487	252.512	316.275
э	115.235	76.769	36.881	22.654	7.056	0.535	352.685	319.790	8 273.350	256.024	241.371	232.047	8 222.706	213.424	196.133	11 185.542	74.915	30.615	166.01	351.345	332.203	310.227	300.561	295.013	285.312
a	270.504	205.754	138.516	114.550	88.336	17.394	64.240	9.262	292.003	263.249	238.881	223.363	207.833	192.290	163.382	2 145.561	318.796	243.843	225.606	177.632	145.562	108.820	92.717	83.506	67.369
i	69.8949	1168.69	69.8897	69.8886	69.8902	1068.69	69.8927	69.8898	11 69.8932	5 69.8916	10 69.8854	9 69.8838	11 69.8844	13 69.8878	12 69.8882	181 69.8891	69.8753	69.8750	8 69.8706	69.8720	69.8743	69.8709	69,8692	69.8680	5 6698.69 8
e	0.092809	0.091380	0.089656	0.088834	0.087846	0.087425	0.086929	0.085419	0.084178	8 0.083859	0.083570	0.083485	0.083410	0.083207	0.082760	24 0.092621	166820.0	161270.0	0.076838	0.075588	0.074729	0.073887	0.073504	0.073245	0.072925
	7318.5070	7306.4464	7294.2885	7288.2153	7281.7835	7278.9615	7275.3874	7266.1517	7258.7068	5 7255.9683	7252.9148	7251.6709	7249.9816	1247.4379	7242.7158	7240.1223	7204.3373	7192.1928	7189.6570	7182.7159	7177.6835	7172.5672	7169.7492	7168.3791	7165.8266
Date	1972 Feb 14	Mar 15	Apr 15	Apr 26	May 8	May 13	May 19	Jun 13	Jul 18	16 Jul	Aug 11	Aug 18	Aug 25	Sep 1	Sep 14	Sep 22	Dec 14	1973 Jan 16	Jan 24	Feb 14	Feb 28	Mar 16	Mar 23	Mar 27	Apr 3
MUD	41361	391	422	433	445	450	456	181	- 516	529	540	547	554	561	574	582	665	698	106	727	141	157	164	768	115
Orbit	26	27	28*	*62	30*	31*	32*	33	34*	35	36	37	38	39	40	41	42*	43*	44	45*	46	414	*8*	*65	20*

Table 1 (continued)

z	47	44	48	45	65	42	42	38	38	72	67	41	69	60	35	44	32	38	52	52	68	48	35	33	34
•	7.9	8.6	9.7	7.3	9.5	9.6	9.5	6.9	4.9	8.7	7.9	9.4	1.6	9.4	6.6	2.8	9.6	4.9	9.6	9.8	8.3	9.5	9.6	0.6	0.6
w	0.50	0.52	0.53	0.61	0.47	0.51	0.71	0.46	0.89	0.60	67.0	0.45	0.63	0.53	0.68	0.69	0.62	0.62	0.68	67.0	0.53	0.62	0.80	0.72	0.71
M5		•	•	-0.00018	^.	-0.000033	-0.00015		•	11000.0-	•	•	-0.000062		0.00012	*	60000.0		-0.00012	•	•	-0,00009		-0.00012	0.00014
M4	0.00017	-0.00017	-0.00012	-0.0011	0.00052	-0.00035	-0.00005	-0.00009	•	-0.00008	0.00038	-0.00026	0.00069	-0.00067	0.0014		-0.00093	× •	-0.00014	-0.00012	N -	0.00028	-0.00011	-0.00093	-0.00083
M ₃	-0.0024	0.00135	-0.00117	0.0093	-0.00478	0.00123	0.0098	-0.00271	0.0039	0.0016	-0.0028	0.0014	-0.0032	-0.0006	0.0029	-0.0081	-0.0017	-0.0073	0.0082	0.00129	-0.00047	0.0032	0.0066	-0.0028	-0.0081
M2	0.1428	0.1296	0.2237	0.2369	0.1363	0.1364	0.2069	0.2682	0.2377	0.1706	0.1017	0.2186	0.1617	0.1778	0.2027	0.2306	0.3487	0.2440	0.1638	0.1574	0.1475	0.1825	0.3050	0.4897	0.2656
W	5158.1218	5160.2982	5177.0906	5181.5914	5185.6423	5194.2731	5219.0389	5230.9588	5236.0073	8 5242.8989	5245.0944	5255.3723	5260.1972	8 5264.7206	5307.2583	5309.1823	5321.7769	5327.6490	5348.8201	5352.3914	5355.8904	5361.6587	21 5367.9936	5396.2298	21 5411,1529 23
M ₀	138.065	131.340	74.486	229.815	227.418	71.256	177.632	97.267	66.501	21.520	214.506	207.048	301.469	38.171	120.591	113.275	143.866	112.571	226.761	44.779	260.928	1.669	226.330	23 290.541	18 22.512 18
Э	265.877	253.399	185.452	171.618	157.824	109.442	12.201	342.573	326.904	303.987	292.485	8 240.633	223.313	201.693	72.340	66.573	30.454	15.778	289.469	272.919	256.287	233.614	212.609	159.955	128.177
a	35.050	14.247	260.556	237.246	213.891	131.949	326.930	277.027	250.789	212.526	193.358	106.893	17.975	41.754	182.422	172.582	110.880	86.105	301.447	273.889	246.283	208.571	173.291	84.472	30.676
i	69.8735	69.8763	69.8723	69.8708	8 69.8644	101	69.8654	1198.69	69.8625	6198.69	69.8621	01 69.8673	9 69.8631	4 69.8594	69.8549	69.8567	5 69.8552	69.8599	69.8560	61-85-19	1678.69	10 69.8523	69.8529	69.8439	15 69.8455
a	0.072348	0.072123	016010.0	0.070486	0.070319	0.069620	0.066293	0.064643	0.063872	0.062896	0.062571	0.061444	0.061076	6 0.060784	0.056870	0.056606	0.054987	0.054124	0.050736	0.050338	0.050027	0.049504	0.049000	0.046596	0.045218
8	7161.4938	7159.4807	7143.9945	7139.8580	7136.1398	7128.2351	7105.6723	7094.8762	7090.3162	7084.1030	7082.1265	7072.8926	7068.5678	7064.5193	7026.7305	7025.0333	7013.9480	7008.7949	6990.2930	6987.1839	6984.1411	6979.1325	6973.6422	6949.3004	6936.5215
Date	1973 Apr 17	Apr 26	Jun 14	Jun 24	4 Iul	Aug 8	Oct 17	Nov 7	Nov 18	Dec 4	Dec 12	1974 Jan 17	Jan 29	Feb 13	May 14	May 18	Jun 12	Jun 22	Aug 19	Aug 30	Sep 10	Sep 25	0ct 9	EL VON	Derc 4
NUD.	41789	862	847	857	867	902	972	666	42004	020	028	064	076	160	181	185	210	220	278	2899	300	315	329	364	3865
Orbit	51	52	\$3*	\$4*	\$5\$	\$95	57*	\$8*	*65	60	19	62	63*	64	65 *	*99	+19	*89	69	20	11	72	73	74	75

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9	6.	10	10	6	6	6	00	00	-	00	80	-	80	. 0	0	80	6	9	~	6	6	-	-	-	-	0		_
æ	0.46	0.85	0.62	0.63	0.58	0.48	0.54	0.54	0.40	0.52	0.45	0.51	0.47	0	05.0	0.68	0.57	0.50	0.62	0.55	0.55	0.54	0.49	0.50	0.47		0.48	
M5	0.000073	•	•	-0.00007	-0.00020	•	-0.00004	-,	0.00034	-0.00011	- 7	-0.00017	- 2	000000	-0.00039	0.00033	0.00012		0.00029	0.00035	- 2	0.00051	° .	0.00030	3 0.00015	2	2 -	
M4	0.00047	-0.00004	0.00031	-0.00028	-0.00043	-0.00064	-0.00061	4	0.00048	-0.00039	-0.00076	-0.00196	-0.00024	4	0.0012	-0.00192	0.00073	0.00154	0.00039	-0.00037	0.00073	-0.00096	0.00117	0.00095	0.00143	4	-0.00031	4
M3	-0.0014	-0.0019	66000.0	0.0055	0.0095	0.0014	0.0064	3 -0.0028	-0.0029	0.0062	-0.0026	0.0025	-0.0033	1 010 0	0.0104	-0.0114	-0.0033	-0.0018	-0.0029	-0.0156	0.00508	0.0020	-0.0067	-0.0027	0.0035	* · · · · · ·	-0.0022	-
M2	0.1880	0.2100	0.2379	0.2985	0.3222	0.1869	0.1366	0.1766	0.2033	0.2627	0.3184	6 0.3286	0.2649	9 2070 0	0.2485	0.3339	0.2276	0.2311	0.3544	0.4061	0.3446	0.4703	0.3584	0.3652	8 0.4820	50000	0.6908	9
M	5422.8115	5434.5943	5440.0720	5466.1558	5473.0808	5479.3662	5482.3030	12 5485.7189	5488.5616	5492.2698	30 5497.8944	12 5502.3973	20 5507.7647	01	22	5517.0511	5523.3110	5527.5178	5532.3082	5540.4692	25 5547.6084	7 5557.0644	44 44 5563.6175	5570.2319	21 5577.6296	91 16	5603.8775	6
w _o	138.688	105.392	192.120	265.214	21.922	300.031	30.096	32 66.077	37 42.691	45.875	275.766	356.977	20 20 20	16	269./00	84.319	86.755	6.490	326.777	248.898	43 249.622	36 276.628	319.945	21.496	25 331.415	17	71 677.271	24
Э	86.148	50.137	31.836	315.722	296.605	275.784	259.772	30 245.410	35 232.744	219,968	204.169	191.532	177.365	51 15	196.001	148.903	130.260	117.756	105.338	89.632	73.878	37 55.029	37 43.935	29.726	26	11	17 344.387	22
a	318.559	256.453	225.283	97.179	65.587	31.268	4.825	340.994	319.781	1 298.535	271.936	250.609	226.571	1 170 100	198./02	178.347	146.094	124.551	102.963	75.910	48.764	16.085	356.955	332.300	310.312	201 110	254.973	-
i	69.8444	69.8426	69.8416	69.8427	1078.69	69.8458	13 69.8456	8 69.8446	16 69.8410	11 69.8384	13 69.8421	11 69.8426	13 69.8391	12	69.8340 9	69.8328	69.8358	69.8388	69.8364	69.8349	69.8312	13 69.8359	17 69.8354	14 69.8337	12 69.8315	6 60 60	69.8278	6
e	0.044081	0.042591	0.041929	0.038112	0.037250	0.036481	90.036184	0.035899	0.035677	0.035376	0.035011	0.034726	22 0.034275	61	01 10	0.033637	0.033146	0.032730	0.032278	0.031479	0.030692	0.029617	0.028881	0.027960	0.027093	8 0102010	0.023950	18
a	6926.5787	6916.5660	6911.9235	6889.9236	6884.1121	6878.8483	10 6876.3922	10 6873.5381	11 6871.1651	12 6868.0726	25 6863.3892	10 6859.6454	16 6855.1892	8 8 6 6 8 6 9 6 9 6 9 6 9 6 9 6 9 6 9 6	1106.2000	6847.4964	6842.3234	6838.8524	6834.9051	6828.1936	6822.3357	6814.5967	36 6809.2461	6803.8560	17 6797.8403	13 6785 5706	6776.6029	1
Date	1975 Jan 1	Jan 25	Feb 6	Mar 27	Apr 8	Apr 21	May 1	May 10	May 18	May 26	Jun 5	Jun 13	Jun 22	06	67 UNC	01 Inf	Jul 22	Jul 30	Aug 7	Aug 17	Aug 27	Sep 8	Sep 15	Sep 24	0ct 2	044 14	0ct 22	_
MUD	42413	437	677	498	510	523	533	542	550	558	568	576	585	202	760	603	615	623	631	641	651	663	670	619	687	600	101	
Orbit	76	11	78	62	80	81	82*	83	84	85	86	87	88	00	69	06	16	\$24	93	54	95	96	16	86	66	*001	101	_

Table 1 (concluded)

										_					-					
z	62	45	48	56	58	64	19	56	48	07	34	76	5	80						
0	7.6	7.1	7.2	7.3	7.6	7.7	7.1	7.5	6.8	5.2	8.8	6 4	*	4.0						
ε	0.53	0.54	0.57	0.67	0.50	0.59	0.46	0.50	0.60	0.53	0.76	0 47		0.64	1					
MS	1	0.00070	0.00030	17000.0-	1	-0.00041	0.00027	-0.00086	3 0.00044	9.0011	-0.00035	3		0.0057						
M.4	-0.00139	0.0033	76100.0	-0.0052	-0.00307	-0.00169	-0.00259	0.00285	5 0.00208	0.0072	0.00240	6 000266	8	0.08067			W			
M3	0.00045	-0.0220	-0.0071	0.0042	1110.0	0.0160	-0.0049	0.0404	-0.0174	-0.0051	21 0.0222	8 0 0 1910 0	2	0.2546 50			nomial for		days)	
M2	0.6920	0.5868	0.5041	0.6885	0.6310	0.6628	0.7441	90.7724	8 0.8126	0.8505	29	6 0100 0	01	4.7950	deg)	()	in poly		ations (used	
Ч	5614.3727	5625.8078 31	5635.5604	5644.8553	5653.3935	5662.8909	5673.5717	27 5684.6363	24 5697.6387	25 5711.6431	35 37.9168	09 2517 2772	12	5830.6397	at epoch (n (deg/da	efficients		of observ	
MO	49.068	10.222	56.994	006.771	12.524	278.457	68 263.898	336.686	215.247	51	69 68.742	64 70	125	352.358 332	n anomaly	n motion,	itional co	sure of fi	e coverage	
з	331.077	317.157	303.390	289.380	275.454	261.679	65 248.096	62 234.561	42 42	49 417	68 187.598	76	126	146.240	mea	шеа	-M. add	C .	tin	
a	232.668	210.268	187.761	165.166	142.485	119.720	2 96.862	73.912	53.721	10.533	355.435	2 213 045	2	289.869	W	ж.	W	7 3	DA	
i	69.8264	69.8286	69.8252	69.8225	8 69.8197	12 69.8194	13 69.8206	12 69.8228	12 69.8201	13 69.8167	91 69.8160	81 0110 09	20	69.8014 26					tions	
e	0.022706	0.021399	0.020312	0.019365	0.018533	0.017636	0.016740	01015743	0.014723	0.013519	22 0.011435	33	44	0.005271				(deg)	g) ra observa	
a	6768.1576 8	6758.9860	6751.1880	6743.7770	6736.9873	6729.4549	23 6721.0092	21 6712.2880	19 6702.0751	91 1136	27 6670.6838	9707 0079	6	6599.7955	tan Day	cis (km)	(deg)	ion of node	perigee (de dewitt came	
	30	-	15	23	-	6	17	25	-	0	21		,	12	Juli	or an	ion (ensi	of h	
Date	1975 Oct	Nov	Nov	Nov	Dec	Dec	Dec	Dec	1976 Jan	Jan	Jan	4v4	22	Feb	Modified	semi majo	inclinat	right as	argument orbits w	
DILM	42715	723	731	139	747	755	763	171	778	786	798		710	820	DUM	-		a	3 *	
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dified Julia	axı	
dib.	major	
D Mo	semi	

- eccentricity inclination (deg) right ascension of node (deg) argument of perigee (deg) orbits with Hewitt camera observations

measure of fit time coverage of observations (days) number of observations used

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 Table 3

 ORBITAL PARAMETERS FOR THE FINAL 15 DAYS BEFORE DECAY

78 66 93 83 80 79 17 83 89 82 78 72 99 60 29 N 0.93 0.89 0.69 1.36 0.74 0.80 0.56 0.88 0.96 0.89 0.77 1.00 0.93 0.81 0.53 P 0.65 0.60 0.98 0.63 0.64 0.60 0.59 0.82 0.70 0.83 0.66 0.64 0.66 1.00 0.89 ω 79.94** 1.99 8.88 13.25 2.23 2.25 2.29 3.93 4.40 6.16 3.41 4.11 4.81 2 2.01 'n 5935.024 23 5779.715 5788.142 5813.049 5830.707 5841.469 5856.055 5771.744 5775.664 5792.594 5798.034 5805.304 5821.537 5877.881 5783.861 x 179.37 5 102.33 6 228.80 6 286.43 352.94 69.48 11 159.69 21 267.03 53.43 39 352.76 6.56 24.30 46.04 5 72.18 137.55 S W 6 150.15 6 147.96 143.10 143.10 1139.29 23 136.08 15 125.94 16 165.17 163.30 161.50 5 157.83 5 156.27 152.26 5 159.74 154.32 з 316.9723 280.6310 6 277.4893 289.8660 2 310.9916 10 307.9947 304.9943 12 301.9843 295.9435 292.9097 10 2 286.8060 283.7306 12 313.9894 298.9691 319.9555 C; 11 69,8136 69.8118 69.8133 10 69.8126 69.8108 69.8110 69.8068 69.7996 69.8028 69.7925 6 69.8089 8 80 8 69.7966 69.7831 69.8127 6 69,8041 Ξ Ξ • •• 0.007731 16 0.007283 0.001380 0.009014 0.008536 0.008208 0.007925 0.006825 0.006331 8 6 0.005268 0.004680 80 0.003940 10 0.003048 0.008791 12 6 0.005841 = e 6522.207 6564.396 6618.978 6599.745 6591.639 6580.692 6644.603 6641.597 6638.494 6635.322 6628.653 6624.508 6613.099 6606.671 6632.051 3 Feb 14 Feb 13 16 Feb 10 Feb 11 Feb 12 Feb 15 Feb 8 Feb 9 Feb 3 Feb 5 Feb 6 Feb 7 1976 Feb 2 Feb 4 Feb Date 11.0 12.0 14.0 15.0 16.0 17.0 18.0 19.0 20.02 21.0 22.0 23.0 24.0 13.0 42810.0 MUD Orbit -C A 0 H 1 X P. ¥ E1 54 -M Z

See Table 1 for key. **(M₃ = 90.1 ± 1.0 M₄ = 56.7 ± 1.3

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REFERENCES

No.	Author	<u>Title, etc</u>
1	R.H. Gooding R.J. Tayler	A PROP 3 users' manual. RAE Technical Report 68299 (1968)
2	C.J. Brookes F.C. Ryland	Air density at heights near 300 km, from analysis of the orbit of China 2 rocket (1971-18B). Planet.Space Sci., <u>25</u> , 1011-1020 (1977)
3	D.W. Scott	ORES: a computer program for analysis of residuals from PROP. RAE Technical Report 69163 (1969)
4	G.E. Cook	Basic theory for PROD, a program for computing the development of satellite orbits. <i>Celestial Mechanics</i> , <u>7</u> , 301-314 (1973) RAE Technical Report 71007 (1971)
5	D.G. King-Hele D.M.C. Walker	Air density at heights near 150 km in 1970, from the orbit of Cosmos 316 (1969-108A). <i>Planet. Space Sci.</i> , <u>19</u> , 1637-51 (1971) RAE Technical Report 71129 (1971)
6	D.G. King-Hele	Theory of satellite orbits in an atmosphere. Butterworths, London (1964)
7	-	CIRA 1972 (Cospar International Reference Atmosphere 1972). Akademie-Verlag, Berlin (1972)
8	L.G. Jacchia	Revised static models of the thermosphere and exosphere with empirical temperature profiles. Smithsonian Astrophys. Obs. Spec. Rpt. 332 (1971)
9	D.M.C. Walker	Variations in air density from January 1972 to April 1975 at heights near 200 km. <i>Planet. Space Sci.</i> , <u>26</u> , 291-309 (1978) RAE Technical Report 77078 (1977)
10	D.G. King-Hele D.W. Scott	A revaluation of the rotational speed of the upper atmosphere. <i>Planet. Space Sci.</i> , <u>14</u> , 1339-1365 (1966) RAE Technical Report 66189 (1966)

REFERENCES (continued)

No.	Author	<u>Title, etc</u>
11	D.G. King-Hele	Upper-atmosphere zonal winds: variation with height
	D.M.C. Walker	and local time.
		Planet. Space Sci., 25, 313-336 (1977)
		RAE Technical Report 76055 (1976)
12	R.G. Roble	The seasonal variation of the diurnal thermospheric winds
	J.E. Salah	over Millstone Hill during solar cycle maximum.
	B.A. Emery	Journ. Atmos. Terr. Phys., 39, 503-511 (1977)
13	D.G. King-Hele	The effect of a meridional wind on a satellite orbit.
		Proc. Roy. Soc. A, 294, 261-272 (1966)
		RAE Technical Report 66010 (1966)
14	B.K. Ching	Ionospheric model effects on thermospheric calculations.
	J.M. Straus	Journ. Atmos. Terr. Phys., 39, 1389-1394 (1977)
15	D.G. King-Hele	Evaluation of 14th-order harmonics in the geopotential.
	D.M.C. Walker	RAE Technical Report 78015 (1978)
	R.H. Gooding	
16	R.R. Allan	Resonant effect on inclination for close satellites.
		Planet. Space Sci., <u>21</u> , 205-225 (1973)
		RAE Technical Report 71245 (1971)
17	R.H. Gooding	Lumped geopotential coefficients $\overline{C}_{15,15}$ and $\overline{S}_{15,15}$
		obtained from resonant variation in the orbit of Ariel 3.
		RAE Technical Report 71068 (1971)
18	R.H. Gooding	Studies of resonance in the orbits of Ariel satellites.
		RAE Technical Report (to be issued)
19	D.M.C. Walker	29th-order harmonics in the geopotential from the orbit
		of Ariel 1 at 29:2 resonance.
		Planet. Space Sci., <u>25</u> , 337–342 (1977)
		RAE Technical Report 76110 (1976)
20	J. Klokočník	Changes in the inclination of a close earth satellite due
		to orbital resonances.
		Bull. Astronom. Inst. Czechoslovakia. 27, 287-295 (1976)





Fig 1



Fig 2 Perigee heights, h_p , and Q (cleared of perturbations), over a spherical earth



TR 78107



Fig 3











Fig 5





Fig 7a&b Values for 14th-order resonance, with fitted curves





Fig 9a&b Values for 29:2 resonance, with fitted curves



Fig 10 Φ and $\dot{\Phi}$, for 15th-order resonance







Fig 12 Φ and $\dot{\Phi}$, for 31:2 resonance

- O PROP observational values
- × US Navy observational values
- Values cleared of atmospheric rotation perturbations (A = 1.05 rev/day)



a The removal of atmospheric-rotation perturbations



b Fitting of curve to perturbation - free values

Fig 13a&b Values of inclination for 31:2 resonance



Date: modified Julian day

Fig 14 Observational values of eccentricity, near decay



Fig 15 Observational values of semi major axis, near decay

Fig 16



Fig 16 Observational values of argument of perigee, near decay









Fig 19 Perigee heights, hp, and Q (cleared of perturbations), near decay

Fig 19



Fig 20 Perturbation-free inclination, with sd, and fitted rotation curves, near decay

REPORT DOCUMENTATION PAGE

Overall security classification of this page

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The orbit of China 2 rocket, 1971-18B, has been determined at 114 epochs throughout its 5-year life, using the RAE orbit refinement program PROP 6, with more than 7000 radar and optical observations from 83 stations.

The rocket passed slowly enough through the resonances 14:1, 29:2, 15:1 and 31:2 to allow lumped geopotential harmonic coefficients to be calculated for each resonance, by least-squares fittings of theoretical curves to the perturbation-free values of inclination and eccentricity.

The rotation rate of the upper atmosphere, at heights near 300 km, was estimated from the decrease in orbital inclination, and values of 1.15, 1.05, 1.10 and 1.05 rev/day were obtained between April 1971 and January 1976. From the variation in perigee height, 25 values of density scale height were calculated, from April 1971 to decay.

A further 1400 observations, made during the final 15 days before decay, were used to determine 15 daily orbits. Analysis of these orbits reveals a very strong west-to-east wind, of 240 \pm 40 m/s, at a mean height of 195 km under winter evening conditions.

RAE Form A143

