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**ORBITAL PARAMETERS
OF SAMOS 2 (1961a1)
FOR MAY-AUGUST 1963**

by

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MINISTRY OF TECHNOLOGY
FARNBOROUGH HANTS

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R O Y A L A I R C R A F T E S T A B L I S H M E N T

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SUMMARY

534 visual observations of the satellite Samos 2 have been used to determine its orbit at intervals of 50 nodes from 28 April-12 August 1963. The orbit was previously determined for shorter periods in 1961 and 1962. The satellite was observed over only 6% of its orbit at most, making analysis difficult. About 30% of the observations were rejected, 12% coming from three French stations.

Departmental Reference: Space 199

CONTENTS

	<u>Page</u>
1 INTRODUCTION	3
2 OBSERVATIONS	3
3 ANALYSIS OF THE OBSERVATIONS	3
4 THE ORBIT	4
5 EVALUATION OF THE OBSERVATIONS	5
6 CONCLUSIONS	6
Table 1 Orbital parameters of Samos 2 (1961 $\alpha 1$) in 1963	9
Table 2 Observations of Samos 2	11
References	12
Illustrations	Figures 1-4
Detachable abstract cards	-

1 INTRODUCTION

The orbit of Samos 2 (1961 α 1) has been previously determined from visual observations in the summers of 1961 and 1962¹. Samos 2 has a nearly circular orbit at a height of just over 500 km and an inclination of 97.4° , with an expected life of 15 years. The period covered in this Report is May-August 1963, and visual observations made in Europe are used.

2 OBSERVATIONS

A total of 534 visual observations, all from Europe, were used. They were taken from lists issued by World Data Centre C at the Radio and Space Research Station at Slough, and by Meudon, Besancon and Jokioinen observatories². The observations were studied station by station and a breakdown of the analysis of these observations is made in Table 2. The calculated residuals in declination agree reasonably well with the estimated errors given by the observers themselves.

3 ANALYSIS OF THE OBSERVATIONS

The observations were used to determine orbital elements of the satellite at intervals of 50 revolutions, i.e. 3.2 days, from node 12400 to 14000 inclusive, with the aid of the R.A.E. orbit improvement programme³, in its modified form⁴, on a Pegasus computer. The observations were taken up to three days each side of the node to provide continuity. A complete description of the operation and uses of the various programmes required for orbit determination is given in Ref.7.

The orbit was determined in three stages. The first stage was to obtain an approximate set of orbital parameters using the prediction programme and the differential correction programme, the parameter n_1 being kept zero. Those elements were used to evaluate the luni-solar perturbations, perturbations due to the higher zonal harmonics of the Earth's gravitational field ($J_3, J_4, \dots, J_9; J_2^2$) and the perturbations due to air drag and rotation of the upper atmosphere. Estimates of n_1 , the rate of change of mean motion, were also obtained.

The differential correction programme was applied again, using estimated values of e (eccentricity) and ω (argument of perigee) from the model⁸

$$\xi = e \cos \omega = A \cos \{k(t - t_0)\}$$

$$\eta = e \sin \omega = A \sin \{k(t - t_0)\} + c/k$$

where t is time, and A , c and k are constants.

The final runs used the parameters obtained in the second run and all the non-rejected observations over a period of one and a half days on each side of the node, going up to three days each side if observations were scarce. The special facility for rejecting at low levels was used⁷ until a fairly satisfactory orbit was determined.

In all these runs e (eccentricity), i (inclination) and ω (argument of perigee) were kept fixed until a good fit was obtained, and then released. n_1 , the rate of change of mean motion, was kept fixed throughout with the value 76 degrees/100 days/100 days up to June 23 and the value 43 degrees/100 days/100 days from June 27 onwards. Fig.4 shows the variation of n , from which the above values were obtained.

4 THE ORBIT

The 33 sets of orbital parameters obtained are given in Table 1. The successive columns give

node number		
date		
time at the node	t_0	hours, min, sec
semi major axis	a	km
eccentricity	e	
inclination	i	degrees
R.A. of node	Ω	degrees
argument of perigee	ω	degrees
mean motion	n	degrees/100 days
	e_1	(100 days) ⁻¹
	i_1	deg/100 days
	Ω_1	deg/100 days
	ω_1	deg/100 days
mean anomaly	M	degrees
extent of observations	D	days
standard deviation	ϵ	of observation of unit weight
number of observations	N	
coverage	C	percentage of orbit

Date and time in modified Julian Days.

The exact definitions of these quantities are given in previous papers^{1,3,5,6}.

The figures in smaller type after the values of the parameters give the standard deviation in units of the final figure quoted.

The values of eccentricity and inclination are plotted in Fig.1. The changes in inclination for this satellite during 1963 should be small, and the fact that nearly all the determinations are consistent with an inclination of 97.40° suggests that the standard deviations are realistic.

The eccentricity should exhibit an oscillation under the influence of the odd harmonics in the Earth's gravitational field, with a maximum where $\omega = 90^\circ$ (about node 12950) and minimum where $\omega = 270^\circ$ (about node 13850). Fig.1 shows that the values of e do undergo such an oscillation, and most of the values are consistent with a mean sinusoidal curve drawn through them.

Since the eccentricity is small, the variation of e with ω is not exactly sinusoidal⁸ and can better be displayed by plotting $\xi = e \cos \omega$ against $\eta = e \sin \omega$: the resulting points should theoretically lie on a circle in the (ξ, η) plane, whose radius is the mean value of e . Fig.2 shows the values of ξ and η , together with a circle of radius 0.0056 centred at the point $\xi = 0$, $\eta = 0.0025$. The distance of the centre of the circle from the origin is determined by the values of the odd harmonics, and the most recent studies⁹ suggest a value near 0.0012. Although the scatter of the points in Fig.2 is regrettably large, they do conform well to a circular pattern and are in this respect superior to the values obtained in 1961 and 1962, which are more difficult to interpret⁹.

Fig.3 shows the values of the argument of perigee ω and the right ascension of the node Ω . The variations of these parameters with time should be almost linear, and Fig.3 shows that the values are nearly all consistent with a mean line drawn through them.

Fig.4 shows the values of the mean motion n . The slope of a curve drawn through the points should provide a measure of the air drag acting on the satellite. As the broken line in Fig.4 shows, the points tend to fall on two straight lines, thus implying that the drag between 28 April and 20 June was about twice as great as between 25 June and 5 August 1963. Since solar activity was low and fairly constant during 1963, the most likely explanation for this decrease in drag is the semi-annual effect. The drag on Samos 2 during 1961-2 has been analysed¹⁰ and it was found that the air density at 500 km height in April and October was almost twice that in July, for 1961-2. Fig.4 suggests that this effect is present even more strongly in 1963, although a more detailed analysis, as in Ref.10, would be required in order to establish this conclusion.

Most of the values of n in Fig.4 would appear to be in error by less than 1 deg/100 days, though at least one of the last three values is probably in error by a greater amount.

We may conclude from Figs.1-4 that the results show no obvious biases or anomalies, and are probably as good as can be expected when the average orbital coverage is only 4% and the average observational accuracy about 4' of arc.

5 EVALUATION OF THE OBSERVATIONS

534 observations from 30 different stations, all European, were used. During the analysis there were 70 major rejections (13%) and 79 minor rejections (15%). Major rejections are those whose residuals are greater than 16 times the expected rms value or greater than 5σ ; minor rejections⁵ are those with residuals greater than 4σ . It is possible that a large proportion of the minor rejections may be due to errors in the orbit rather than errors in the observations.

A breakdown of the observations is given in Table 2. The first column contains the station name, followed by its Cospar number, total number of observations used, total accepted, minor rejections and major rejections. This is followed by the observers' own estimates of their angular and timing errors. From these an effective compounded declination error is calculated using the formula^{2,7}

$$\sigma_{\text{dec}} = \left\{ \sigma_A^2 + (0.43 \sigma_T)^2 \right\}^{\frac{1}{2}}$$

the constant 0.43 being obtained from the satellite's average angular velocity relative to an observer on the ground. The values of σ_{dec} were used to weight the observations during the differential correction programme. The rms value of declination residuals from the final runs have been calculated and headed 'after'.

It was found during analysis that most of the observations from Uppsala (Sweden) were being rejected: on investigation it was discovered that 3 different station co-ordinates were quoted. One of these gave much smaller residuals, on average, than the others, and was used throughout the final runs.

There were also a large number of major rejections (20%) from the 3 French stations. The station co-ordinate programme (Appendix A, Ref.6) was used to determine a possible station position error, but no consistent error could be found. Therefore it was concluded that the wrong satellite had been observed on several occasions.

6 CONCLUSIONS

Orbital parameters of Samos 2 have been obtained at intervals of 50 revolutions between 28 April and 12 August 1963. The results appear to be free of

obvious biases and anomalies, and the accuracy is probably as good as can ever be expected with visual observations over a very small arc of the orbit (between 0.5% and 6%). The orbital parameters obtained should be useful in studies of upper-atmosphere density and also possibly in determining the odd zonal harmonics in the geopotential.

Table 1

ORBITAL PARAMETERS OF SAMOS

Node	Date 1963	Time			a	e	i	Ω	ω
		h	m	s					
12400	APRIL 28	20	56	57.0 10	6885.048 9	0.00522 36	97.38 2	-147.45 3	218.3 115
12450	MAY 2	3	57	55.8 6	6885.014 3	0.00387 33	97.49 1	-144.07 2	210.0 53
12500	5	10	58	51.2 8	6884.970 2	0.00464 70	97.40 1	-140.98 2	189.5 75
12550	8	17	59	44.8 8	6884.962 3	0.00581 83	97.40 3	-137.76 4	171.9 31
12600	12	1	00	38.6 3	6884.921 2	0.00516 33	97.39 1	-134.54 2	166.1 14
12650	15	8	01	29.5 7	6884.898 4	0.00602 75	97.40 3	-131.30 3	153.2 7
12700	18	15	02	19.3 6	6884.880 2	0.00637 83	97.41 2	-128.06 2	143.1 6
12750	21	22	03	08.3 4	6884.855 1	0.00575 44	97.37 1	-124.89 2	132.8 9
12800	25	5	03	55.2 6	6884.851 3	0.00609 65	97.40 3	-121.63 4	122.1 26
12850	28	12	04	41.1 9	6884.815 3	0.00578 107	97.42 3	-118.37 4	109.6 67
12900	31	19	05	23.8 3	6884.798 3	0.00767 32	97.43 3	-115.12 4	110.6 25
12950	JUNE 4	2	06	07.3 26	6884.774 3	0.00698 205	97.31 3	-112.03 4	98.3 194
13000	7	9	06	49.6 13	6884.762 2	0.00641 28	97.36 2	-108.75 3	86.2 131
13050	10	16	07	27.0 6	6884.757 6	0.00735 90	97.47 6	-105.41 8	84.5 110
13100	13	23	08	05.7 3	6884.724 1	0.00645 21	97.40 1	-102.25 2	65.0 51
13150	17	6	08	41.0 4	6884.704 3	0.00659 10	97.40 5	-99.02 6	66.6 44
13200	20	13	09	13.9 23	6884.694 9	0.00624 57	97.38 6	-95.87 9	70.7 223
13250	23	20	09	48.9 14	6884.685 5	0.00589 12	97.41 5	-92.57 6	52.0 195
13300	27	3	10	22.9 11	6884.664 2	0.00588 48	97.41 2	-89.33 3	31.1 133
13350	30	10	10	56.5 11	6884.660 5	0.00741 134	97.44 9	-86.05 11	0.9 109
13400	JULY 3	17	11	25.6 9	6884.660 7	0.00552 78	97.72 11	-82.46 15	5.8 74
13450	7	0	11	56.8 6	6884.642 3	0.00464 69	97.43 2	-79.61 3	-0.8 58
13500	10	7	12	27.9 3	6884.627 2	0.00496 34	97.39 2	-76.42 2	-17.5 13
13550	13	14	12	57.6 2	6884.617 1	0.00434 29	97.37 1	-73.22 1	-29.6 8
13600	16	21	13	28.5 2	6884.614 2	0.00630 25	97.45 2	-69.89 3	-42.5 4
13650	20	4	13	57.0 8	6884.605 3	0.00395 93	97.34 2	-66.79 3	-59.8 64
13700	23	11	14	26.5 5	6884.598 2	0.00374 49	97.41 3	-63.49 4	-76.8 60
13750	26	18	14	57.3 5	6884.578 2	0.00530 43	97.42 2	-60.23 2	-73.1 42
13800	30	1	15	25.0 4	6884.574 2	0.00442 21	97.35 2	-57.09 2	-98.8 58
13850	AUGUST 2	8	15	55.3 4	6884.559 1	0.00489 20	97.36 2	-53.85 2	-92.5 46
13900	5	15	16	23.6 6	6884.546 7	0.00563 44	97.39 3	-50.59 5	-93.7 67
13950	8	22	16	50.5 6	6884.552 4	0.00454 5	97.41 2	-47.33 4	-117.4 75
14000	12	5	17	16.1 3	6884.513 1	0.00514 14	97.36 2	-44.19 2	-148.0 26

A

Table 1

PARAMETERS OF SAMOS 2 (1961 α 1) IN 1963

Ω	ω	n	e_1	i_1	Ω_1	ω_1	M	D	e	N	C	MJD
45 3	218.3 115	547073.5	0.0068	-0.014	0.046	-39.8	-218.6	1.0	1.0	15	4.2	38147.872882
07 2	210.0 53	547077.5	0.0074	0.002	0.037	-21.5	-210.3	1.1	0.4	8	3.8	38151.165229
98 2	189.5 75	547082.8	0.0076	0.021	0.021	-5.1	-189.6	4.0	1.1	12	4.6	38154.457587
76 4	171.9 31	547083.7	0.0076	-0.002	0.016	9.6	-177.8	4.1	1.0	16	4.6	38157.749824
54 2	166.1 14	547088.7	0.0073	-0.021	0.030	22.0	-165.9	6.0	1.0	40	5.4	38161.042113
30 3	153.2 7	547091.4	0.0067	-0.004	0.040	32.9	-153.9	4.0	0.9	22	5.5	38164.334370
06 2	143.1 6	547093.5	0.0059	0.031	0.025	40.9	-142.7	2.9	0.9	20	4.2	38167.626613
89 2	132.8 9	547096.5	0.0049	0.016	-0.011	47.8	-132.3	6.0	1.1	26	5.4	38170.918861
63 4	122.1 26	547096.9	0.0040	-0.022	0.025	52.9	-121.5	2.0	0.6	36	3.5	38174.211056
37 4	109.6 67	547101.2	0.0027	-0.010	0.034	56.5	-108.9	2.0	0.7	17	2.3	38177.503253
12 4	110.6 25	547103.3	0.0015	0.018	0.012	58.6	-109.8	2.0	0.5	29	2.6	38180.691248
03 4	98.3 194	547106.2	0.0003	0.023	0.010	59.5	-97.5	5.0	0.6	6	1.3	38184.087584
75 3	86.2 131	547107.6	0.0010	-0.001	0.012	59.0	-85.5	5.9	1.1	11	1.8	38187.379741
41 8	84.5 110	547108.6	-0.0022	-0.023	0.027	57.3	-83.6	4.0	1.0	11	1.5	38190.671841
25 2	65.0 51	547112.1	-0.0034	-0.004	0.032	54.2	-64.3	6.0	0.6	13	3.0	38193.963955
02 6	66.6 44	547114.5	-0.0045	0.033	0.013	49.7	-65.9	3.0	0.6	18	3.3	38197.256019
87 9	70.7 223	547115.7	-0.0055	0.010	0.011	43.4	-70.0	4.0	0.8	11	2.3	38200.548078
57 6	52.0 195	547116.8	-0.0063	-0.024	0.020	37.0	-51.5	4.0	1.2	14	2.4	38203.840150
33 3	31.1 133	547119.3	-0.0070	-0.011	0.031	25.8	-30.7	4.0	0.9	22	3.4	38207.215543
05 11	0.9 109	547119.8	-0.0074	0.016	0.019	14.0	-0.9	4.0	0.8	8	0.7	38210.424265
46 15	5.8 74	547119.8	-0.0076	0.002	-0.012	0.4	-5.8	1.0	0.6	15	1.7	38213.716268
61 3	-0.8 58	547121.8	-0.0074	-0.005	0.021	-15.2	0.8	2.0	0.7	10	3.5	38217.082966
42 2	-17.5 13	547123.7	-0.0069	-0.028	0.036	-32.5	17.4	4.0	0.9	28	3.8	38220.322523
22 1	-29.6 8	547124.8	-0.0061	-0.003	0.030	-50.0	29.3	4.0	0.8	41	4.0	38223.592333
89 3	-42.5 4	547125.2	-0.0049	0.031	0.013	-67.0	42.6	3.0	0.4	11	4.9	38226.884358
79 3	-59.8 64	547126.3	-0.0034	0.003	0.022	-80.9	59.4	4.0	1.3	31	6.0	38230.176354
49 4	-76.8 60	547127.1	-0.0015	-0.025	0.034	-89.8	76.4	5.9	1.0	25	5.5	38233.468362
23 2	-73.1 42	547129.5	0.0004	-0.025	0.027	-92.1	72.6	3.0	0.5	39	4.3	38236.760386
09 2	-98.8 58	547130.0	0.0023	0.013	0.018	-87.4	98.3	4.0	0.7	34	3.5	38240.052373
85 2	-92.5 46	547131.8	0.0040	0.021	0.014	-76.4	92.0	4.0	0.8	17	4.2	38243.344390
59 5	-93.7 67	547133.4	0.0055	-0.007	0.024	-61.5	23.1	1.9	0.9	15	4.0	38246.636384
33 4	-117.4 75	547132.6	0.0065	-0.033	0.031	-44.0	116.9	4.0	0.6	21	4.1	38249.927204
19 2	-148.0 26	547137.3	0.0065	-0.001	0.015	-52.9	147.7	6.0	0.6	28	3.6	38253.220325

12

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Table 2

OBSERVATIONS OF SAMOS 2

Station	Cospas No.	Observations				σ_A (deg)	σ_T (sec)	σ_{dec}	
		Total	Acc.	Rej. min.	Rej. maj.			Before	After
<u>U.K.</u>									
Bexhill 1	2212	7	6	-	1	0.08	0.6	24	11
Cowbeech	2392	9	7	2	-	0.2	0.2	14	-
Crowborough	2373	8	5	3	-	0.09	0.15	8	5
Farnham	2265	16	10	6	-	0.08	0.15	8	5
Hanwell	2277	5	2	3	-	0.1	0.3	13	17
Newton Ste. art	2312	5	4	1	-	0.7	0.9	55	20
Thames Ditto.	2344	18	12	5	1	0.4	0.1	5	4
Willesden	2356	10	4	6	-	0.07	0.1	6	6
Windsor B	2358	59	42	10	7	0.1	0.6	24	12
Winkfield	2360	44	29	4	11	0.1	0.4	17	35
11 others		26	24	-	2				
<u>FRANCE</u>									
Meudon	3101	133	103	11	19	0.033	0.1	3	3
Besancon	3102	50	33	5	12	0.033	0.1	3	3
Strasbourg	3104	20	5	2	13	0.033	0.1	3	4
1 other		1	-	-	1				
<u>HOLLAND</u>									
Zwijndrecht	4108	3	1	-	2	0.1	0.1	7	12
Oost-Soubourg	4119	2	2	-	-	0.25	0.1	15	16
<u>FINLAND</u>									
Jokioinen	8121	53	32	1	-	0.1	0.1	7	4
<u>SWEDEN</u>									
Uppsala	?	82	63	17	2	Not known		7	5
<u>MALTA</u>									
	2541	4	1	3	-	0.01	0.05	3	6
Totals		534	387	79	70				

NOTES σ_A , σ_T are the assumed angular and time accuracies
 σ_{dec} (before) = $\{\sigma_A^2 + (0.43 \sigma_T)^2\}^{1/2}$ expressed in minutes of arc
 σ_{dec} (after) = rms of declination residuals

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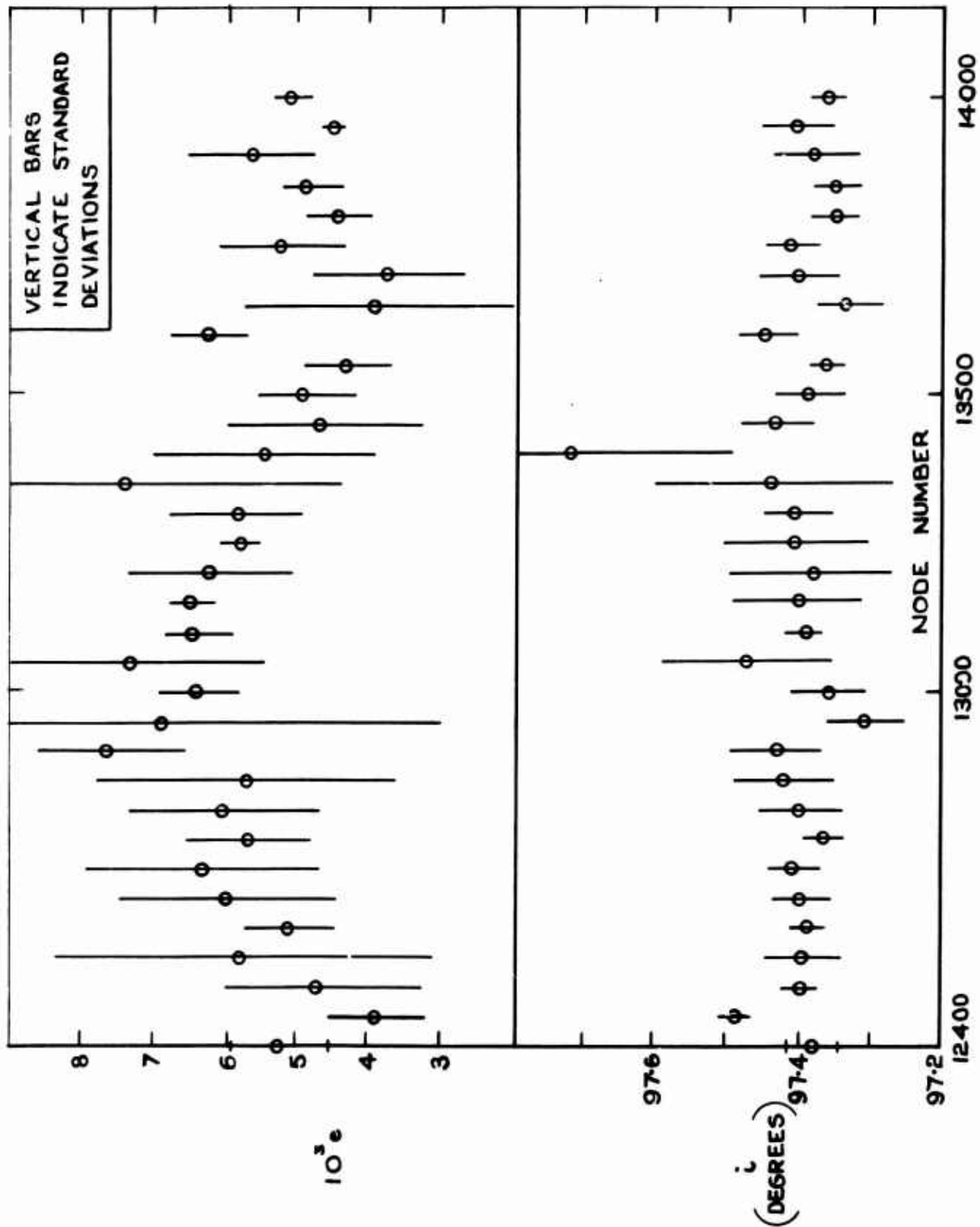
FIG.1 VALUES OF ECCENTRICITY e AND ORBITAL INCLINATION i

Fig.2

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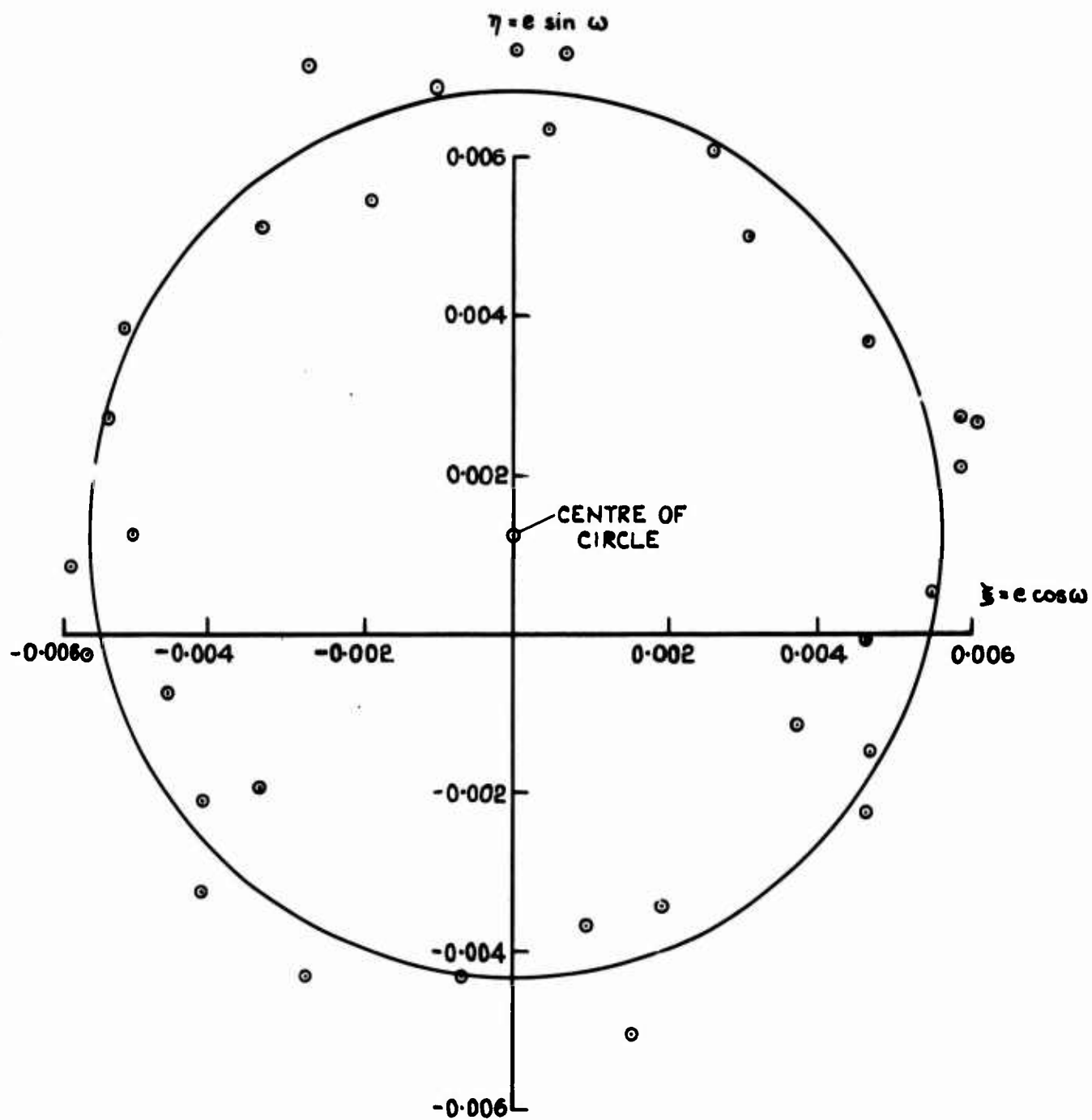


FIG.2 VALUES OF $\xi = e \cos \omega$ AND $\eta = e \sin \omega$, WITH CIRCLE OF RADIUS 0.0056 CENTRED AT (0, 0.00125)

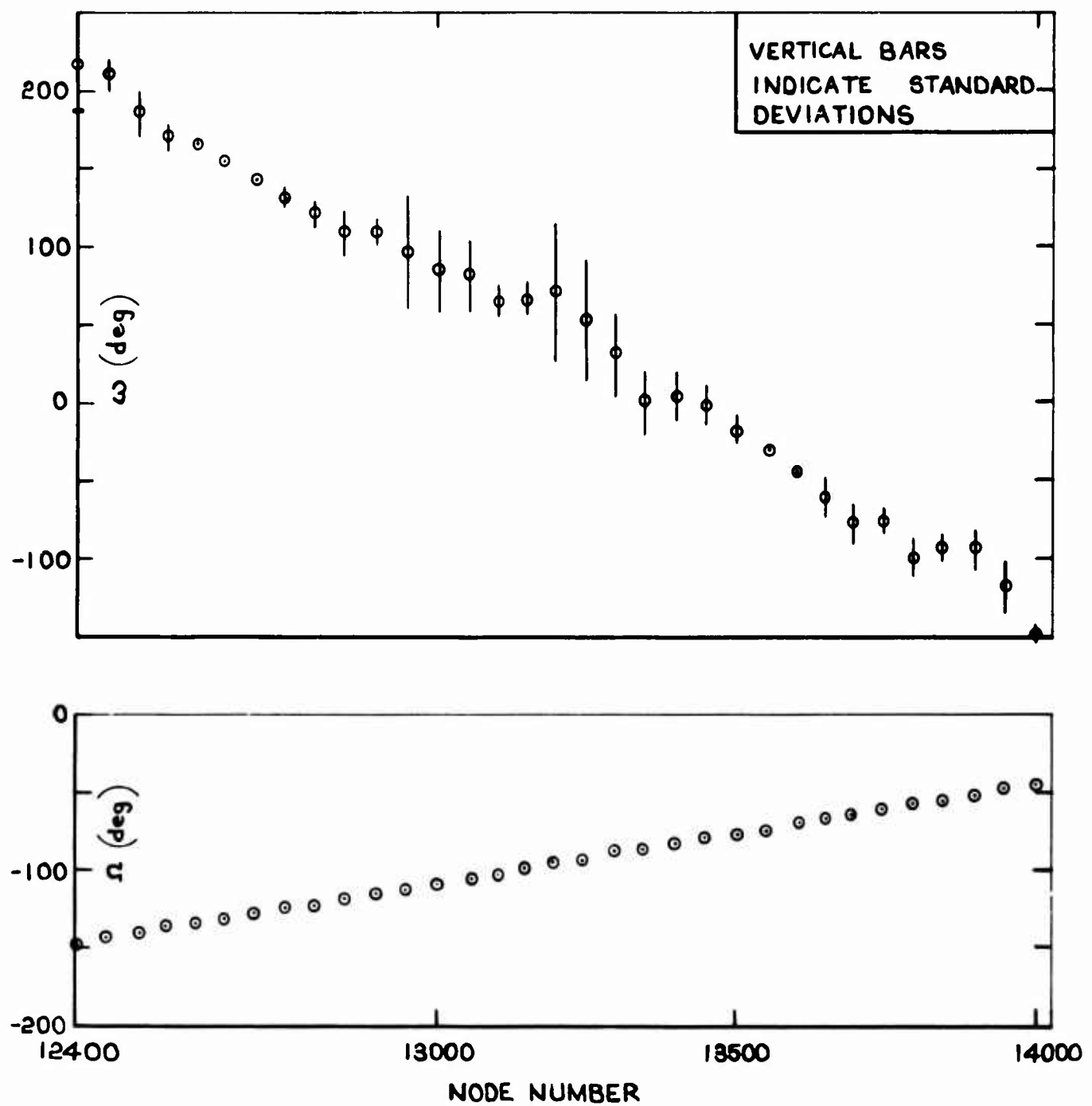


FIG.3 VALUES OF ARGUMENT OF PERIGEE, ω ,
AND R.A. OF NODE, Ω

Fig.4

004 900763

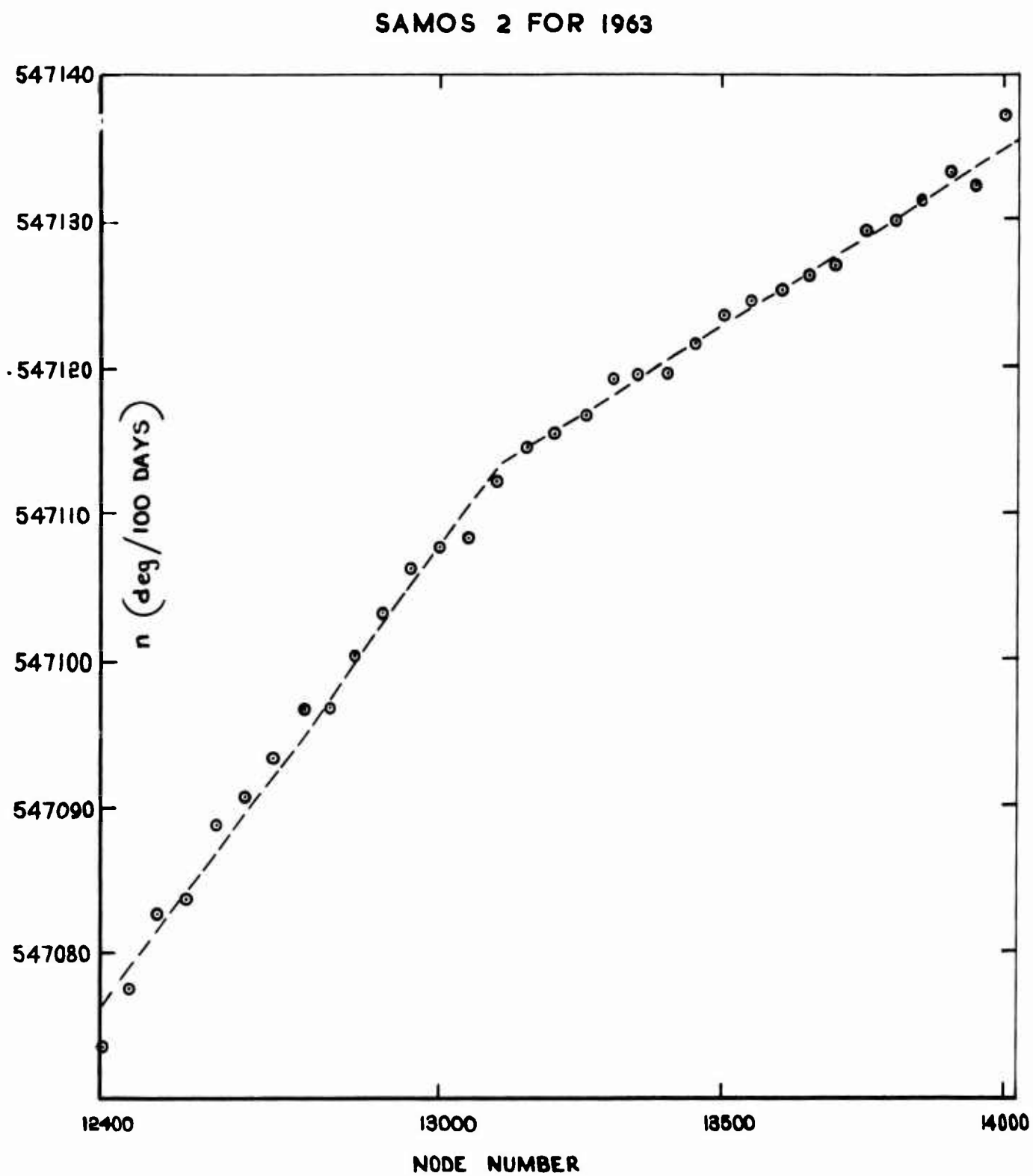


FIG. 4 VALUES OF THE MEAN MOTION n