ANALYSIS OF A BREAK-UP EVENT IN ORBIT

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ABSTRACT

This paper presents the results of an investigation into the trajectories of catalogued fragments from the break-up of the Rokot upper stage on 26 December 1994. The behaviour of one of the fragments, object 23575, showed similar behaviour to the other fragments but the magnitude of the perturbations was significantly larger. Our investigations show that it is possible to explain the behaviour of this object if it has a very high area to mass ratio by using a DERA orbit propagator. The surface mass density required to match observations with predictions is about 20 - 40 g/m^2. Candidate materials in this density range include thin sheets of foil.

1. INTRODUCTION

To date there have been over 140 break-ups of catalogued objects in orbit. Analysis of these break-ups is important for a number of reasons:

a) fragmentations of satellites and launch vehicle upper stages are the major source of objects recorded in the US Space Command catalogue and thus study of their evolution is important,
b) as the major contributor to the orbital debris population, the nature of these fragmentations should be investigated in order to determine their cause and if possible avoid future recurrences,
c) analysis of the distribution of the tracked fragments in both size and orbit provides a method of validation for the empirical break-up models used in debris environment evolution and collision hazard assessment programs.

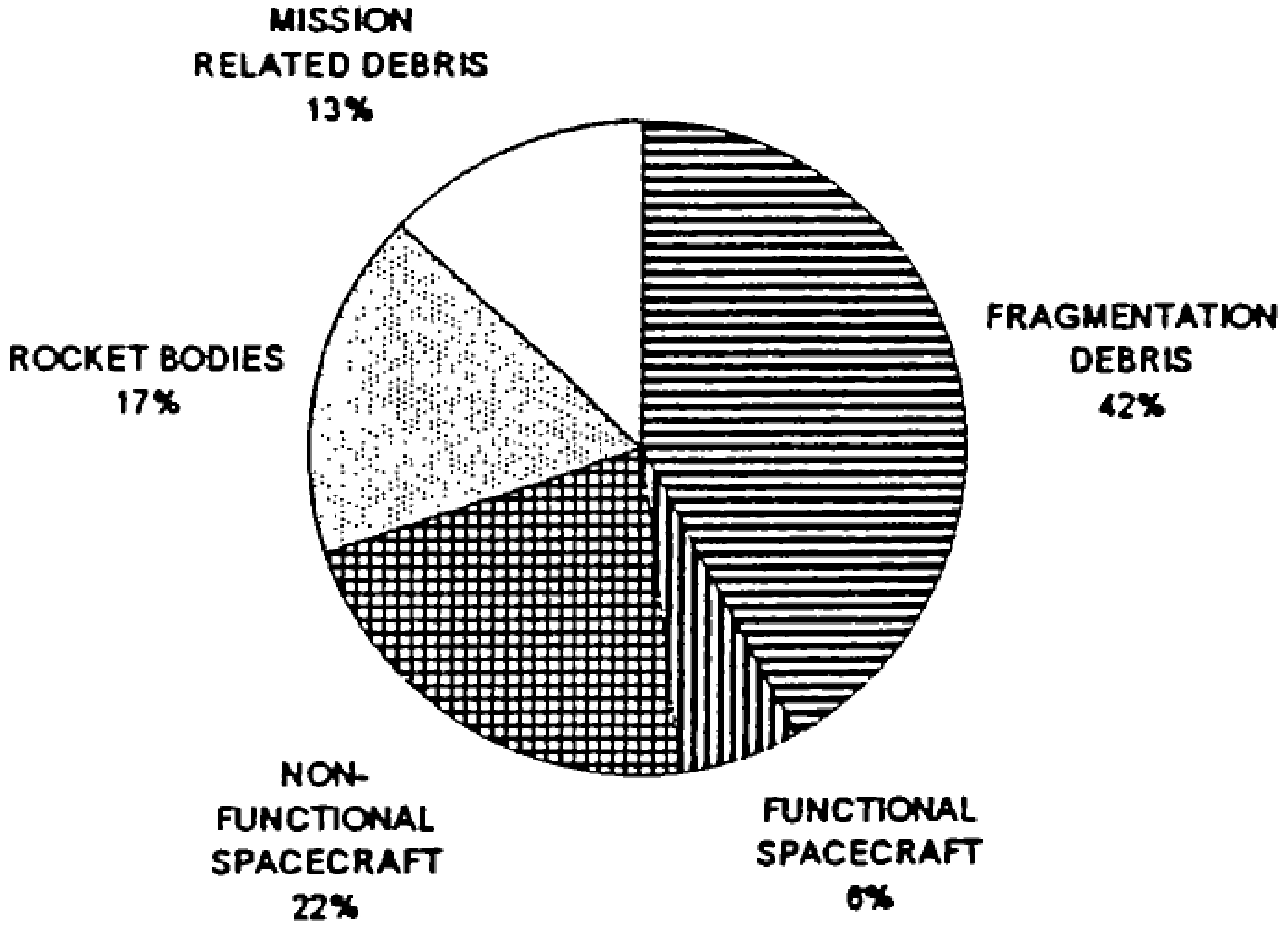

Fig 1 Categories of catalogued objects

In this paper we consider the trajectory evolution of fragments resulting from the break-up of a known parent object in an attempt to identify the nature of the fragments.

2. MISSION DESCRIPTION

On 26 December 1994 the Radio Rosto payload (1994-085A) was launched from Tyuratam by a Rokot 3rd stage. The third stage was a modified SS-19 vehicle termed Briz with a dry mass of 1120 kg and fuelled by UDMH/N_2O_4. Soon after launch and delivery of the payload, the third stage was observed to break-up at an altitude between 1800 km and 2000 km introducing more than 30 trackable objects into the orbital environment.

3. OBSERVED EVOLUTION OF TRAJECTORIES OF FRAGMENTS

The US Space Command derived state vectors of the fragments associated with the break-up of the Briz vehicle were analysed to observe the evolution in the respective orbital elements. These different elements would be expected to be vary due to the perturbing influence of:

a) the asphericity of the Earth
b) gravitational attraction of the Sun and Moon
c) aerodynamic forces produced as the satellite passes through the atmosphere
d) solar radiation pressure.

The different disturbing forces would be expected to cause a variety of perturbations to the elements, both periodic and secular, and would be independent of, or dependent upon, the material characteristics of the fragments.

The asphericity of the Earth gives rise to a secular regression in the line of nodes, a secular precession of the argument of perigee, and an oscillation in perigee height. This oscillation in perigee height could be expected to be significant as the critical inclination value of 63.4 degrees is approached.

The drag forces produced by the transit of a satellite through the atmosphere would be expected to cause a secular decrease in semi-major axis, a secular decrease in eccentricity and a secular decrease in orbital

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inclination. The magnitude of these effects would be dependent upon the attitude of the object and its area to mass ratio.

The gravitational attraction of the Sun and Moon would be expected to induce small periodic perturbations in all the orbital elements except semi-major axis, and minor secular variations in the argument of perigee and right ascension of ascending node.

The forces due to solar radiation pressure will act within and normal to the orbital plane depending upon its orientation to the solar vector and thus can affect all orbital elements. Like aerodynamic forces, solar radiation pressure is dependent upon the area to mass ratio of the object. Solar radiation pressure forces are found to dominate aerodynamic forces above ~600 km altitude.

Perturbations due to the Earth's magnetic field and charged particle drag are negligible.

The effects are summarised in Table 1 below (P-periodic, S-secular, size relates to magnitude of perturbation).

Table 1 Perturbations to a satellite orbit

Disturbance	***a***	***e***	***i***	**Ω**	**ω**
Earth gravitation	-	p	p	S	S
Sun and Moon gravitation	p	p	p	p,s	p,s
Magnetic field	-	-	-	-	-
Aerodynamic	S	S	s	p	p
Charged particles	-	-	-	-	-
Solar radiation	p,s	p,s	p,s	p,s	p,s

Techniques exist which permit us to derive material characteristics of orbiting objects by observing the manner in which their state vectors vary due to the influence of the perturbing forces. Derived quantities are mass, area and aerodynamic characteristics. Intact objects that have been analysed in the past are the Salyut 7 complex[1] and the ANS-1 satellite[2].

4. ANALYSIS OF RESULTS

The orbital elements for the catalogued fragments derived from the break-up were analysed over a period of many months to ascertain their suitability for analysis. The observed evolution of the semi-major axis and the eccentricity for these objects is shown in Figures 2 and 3. Under normal circumstances, because of the high altitude of the perigee we would expect both semi-major axis and eccentricity to remain nominally fixed and therefore would not be good candidates for analysis. However it is clear that there are significant secular and periodic perturbations to the orbits of some of the fragments. The phasing of the periodic variations seems to be common for those objects which exhibit a perturbation. Further, object 23575 appears to exhibit an exaggerated, but similar, behaviour compared to the other fragments. What is the reason for these perturbations and the variability between fragment orbits? Intuitively we can make a number of assumptions.

1) If the effects were due to gravitational influences, then all objects in similar orbits would experience nominally the same type and magnitude of perturbation.

2) If the effects are similar in character but vary in their magnitude from object to object, then these are probably due to the individual material characteristics of the objects such as area to mass ratio.

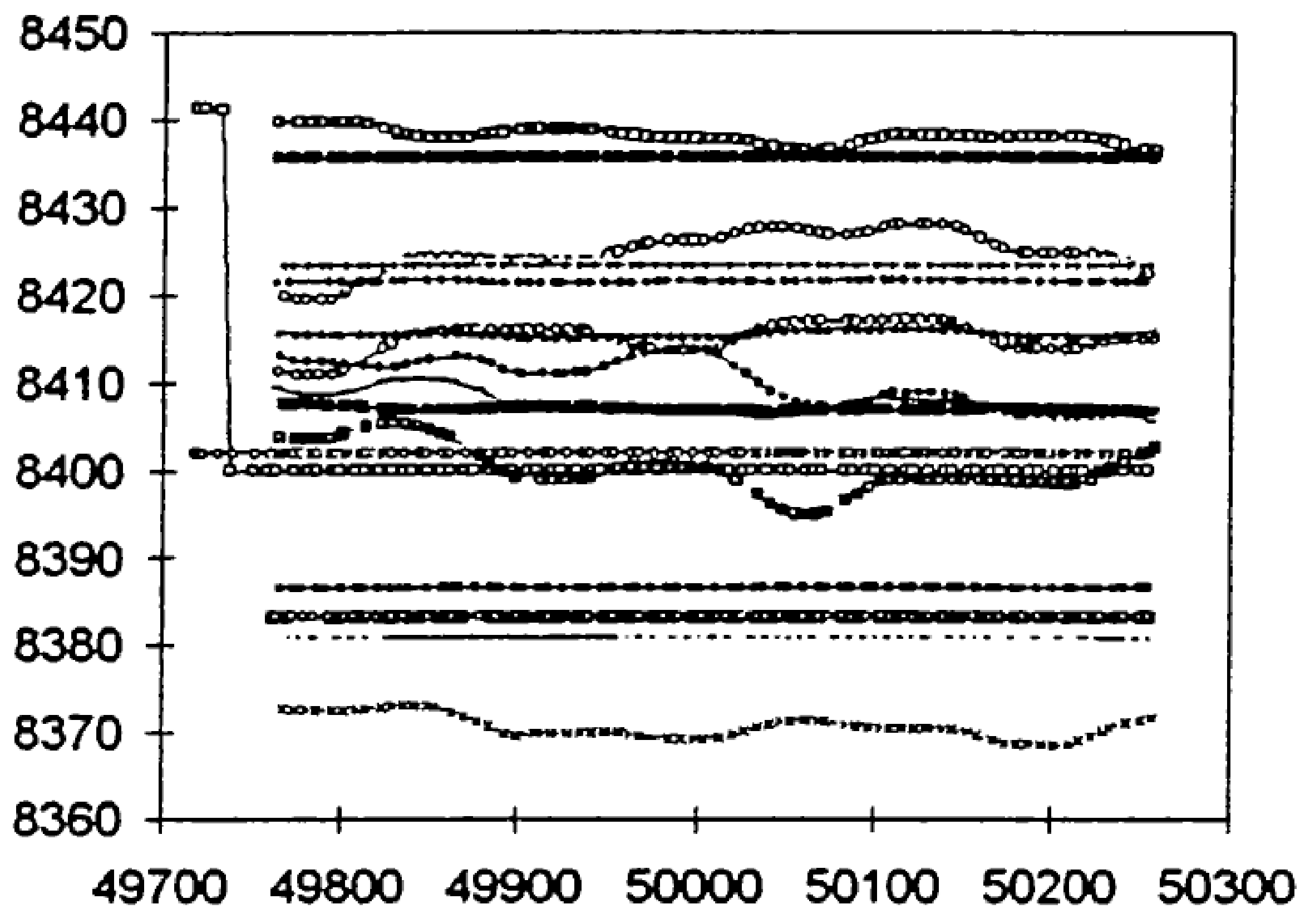

Fig 2 **Plot of semi-major axis versus Modified Julian Date for all objects except 23575**

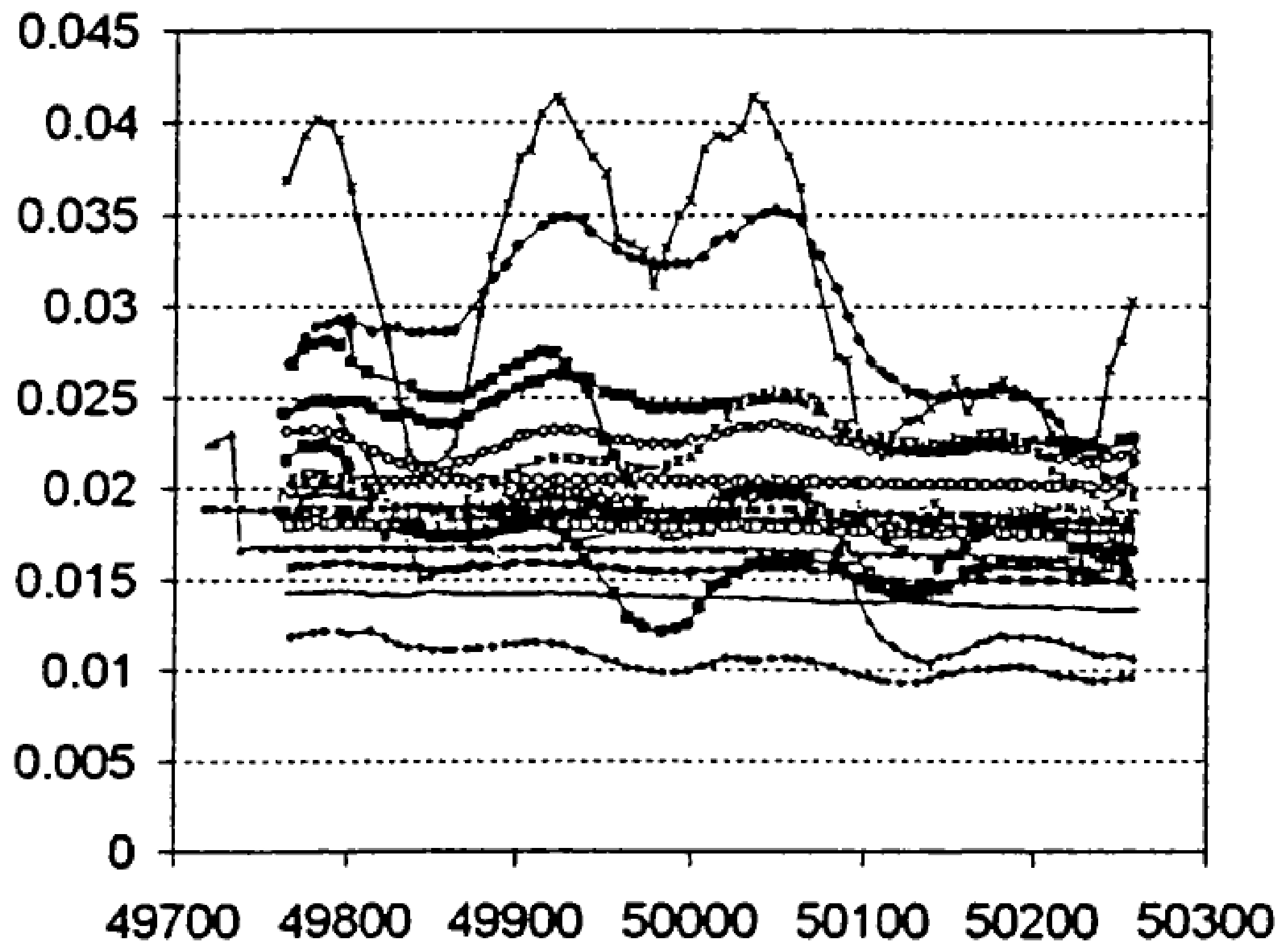

Fig 3 **Plot of eccentricity versus Modified Julian Date for all objects except 23575**

This leads us to believe that the effects are due to either solar radiation pressure, aerodynamic drag, or a combination of both. We have chosen to attempt to model the evolution of the orbit of object 23575 in order to estimate the material characteristics of that object. Figures 4 and 5 show the observed evolution of semi-major axis and eccentricity with time.

We seek to demonstrate under what conditions the behaviour of the object can be explained by natural perturbations. Since nothing is known about these objects, it is not possible to match observations precisely with predictions. This would require knowledge of the object's area, mass, reflectivity, attitude and rotation.

To model the effects of environmental forces on the object, a number of area to mass ratios were assumed and studied in conjunction with models of the solar radiation pressure and atmospheric drag. DERA's StrefP orbit propagator[3] was used to model the effects of environmental perturbations due to Earth gravity, lunisolar gravitation, solar radiation pressure and atmospheric drag.

Atmospheric drag is expected to have negligible effects at such high altitudes (the orbit altitude varies from 1100 km to 3300 km, minimum perigee to maximum apogee). Solar radiation pressure is greater than drag at these altitudes by approximately two orders of magnitude at perigee.

5. FITTING THE SEMI-MAJOR AXIS

The semi-major axis of object 23575 decreases by 80 km in a 1.1 yr period of observations. Calculations reveal that is possible to achieve this reduction in semi-major axis if the area to mass ratio is approximately 40 m^2/kg .

The results are presented in Fig 6. However, in detail there are differences (compare Figs 4 and 6). The observed variation has more pronounced oscillations. Also, there are peaks and troughs in semi-major axis which means that atmospheric drag cannot be wholly responsible for the observed behaviour.

A possible explanation is that solar radiation pressure is causing an increase in semi-major axis at certain epochs. Solar radiation pressure could affect orbit semi-major axis if the magnitude of solar radiation pressure varied around the orbit (solar radiation pressure would only normally affect eccentricity if the surface area presented to the sun is unchanging). This may be due to the changing orientation of the object or eclipse effects.

6. FITTING THE ECCENTRICITY

Calculations reveal that is possible to achieve a plausible fit to the eccentricity evolution if the area to mass ratio for the solar radiation pressure calculations is approximately 20 m^2/kg.

However, the fit is not exact. Comparing Figs 5 and 7, the first two peaks in eccentricity are in reasonable agreement with theoretical predictions. However, the predicted troughs are considerably deeper than those observed (~0.6 versus ~0.8). One possible explanation is a change in the area to mass ratio presented to the Sun.

The peaks in semi-major axis (Fig 4) coincide with the troughs of the eccentricity evolution (Fig 5) which are not as deep as expected from the theoretical prediction. If solar radiation pressure is the cause of the small localised increase in semi-major axis then the eccentricity evolution will deviate from expected behaviour, as is observed.

7. CONCLUSIONS

It is possible that the in-orbit behaviour of object 23575 can therefore be explained by natural perturbations if the area to mass ratio of the object is high enough

Therefore, on the basis of our calculations it is plausible that object 23575 is a lightweight object with surface mass density of about 20 - 40 g/m^2. Candidates in this density range include thin sheets of foil etc. The next stage in the analysis should be to ascertain the nature of the material used in the construction of the Briz vehicle and identify potential candidate materials.

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[1] R. Crowther, Re-entry Aerodynamics Derived From Space Debris Trajectory Analysis. Planetary and Space Science, Vol. 40, No. 5, pp. 641-646, 1992.

[2] R. Crowther, J. Stark, The Determination of the Gas-Surface Interaction from Satellite Orbit Analysis as Applied to ANS-1. Planetary and Space Science, Vol. 39, pp. 729-736, 1991.

[3] A.W. Odell, R.H. Merson, The Skynet 2 Ephemeris Program SKEPH2. RAE Technical Report TR 75084, 1975.

Fig 4 Object 23575 evolution of semi-major axis with time

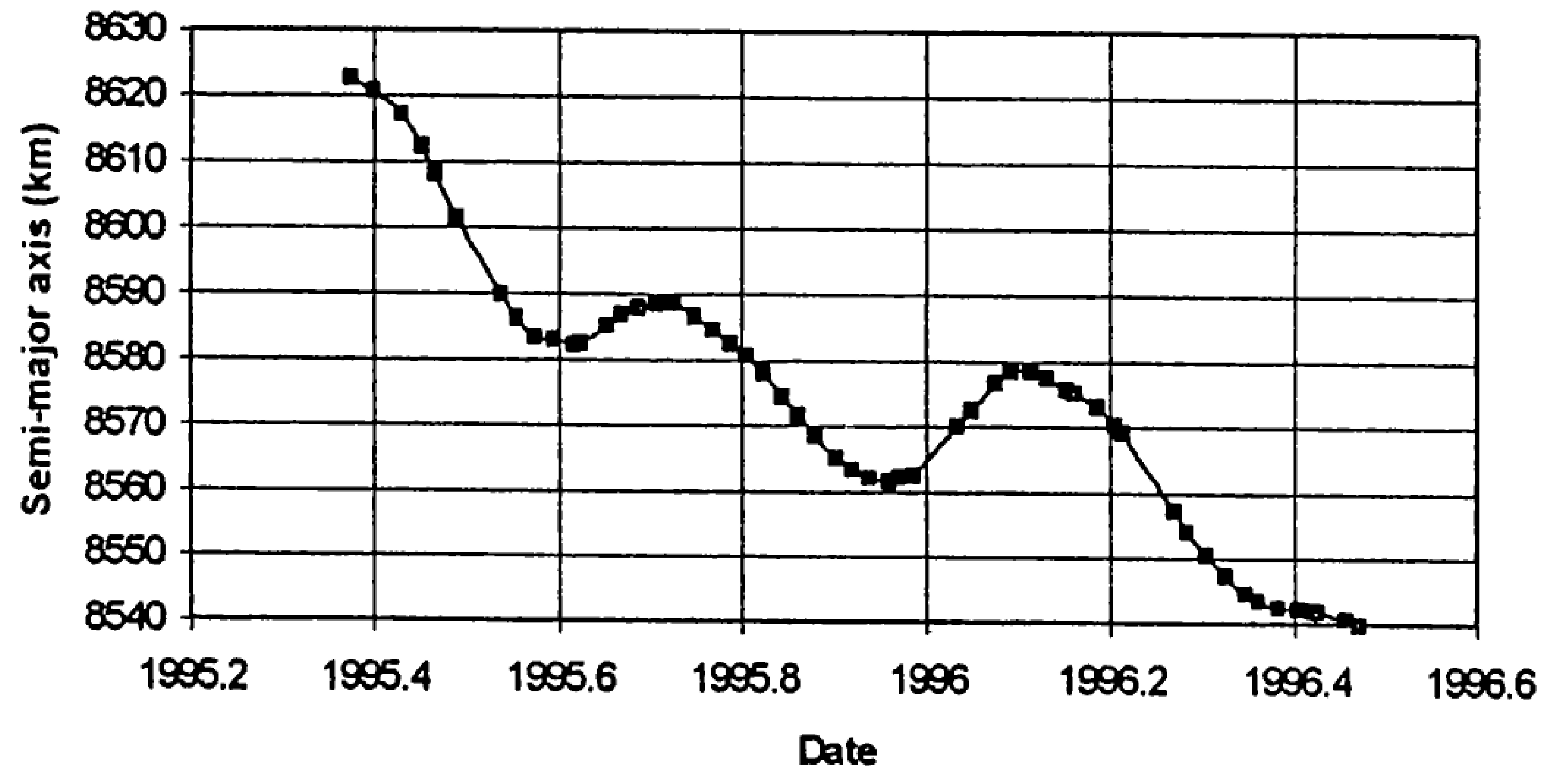

Fig 5 Object 23575 evolution of eccentricity with time

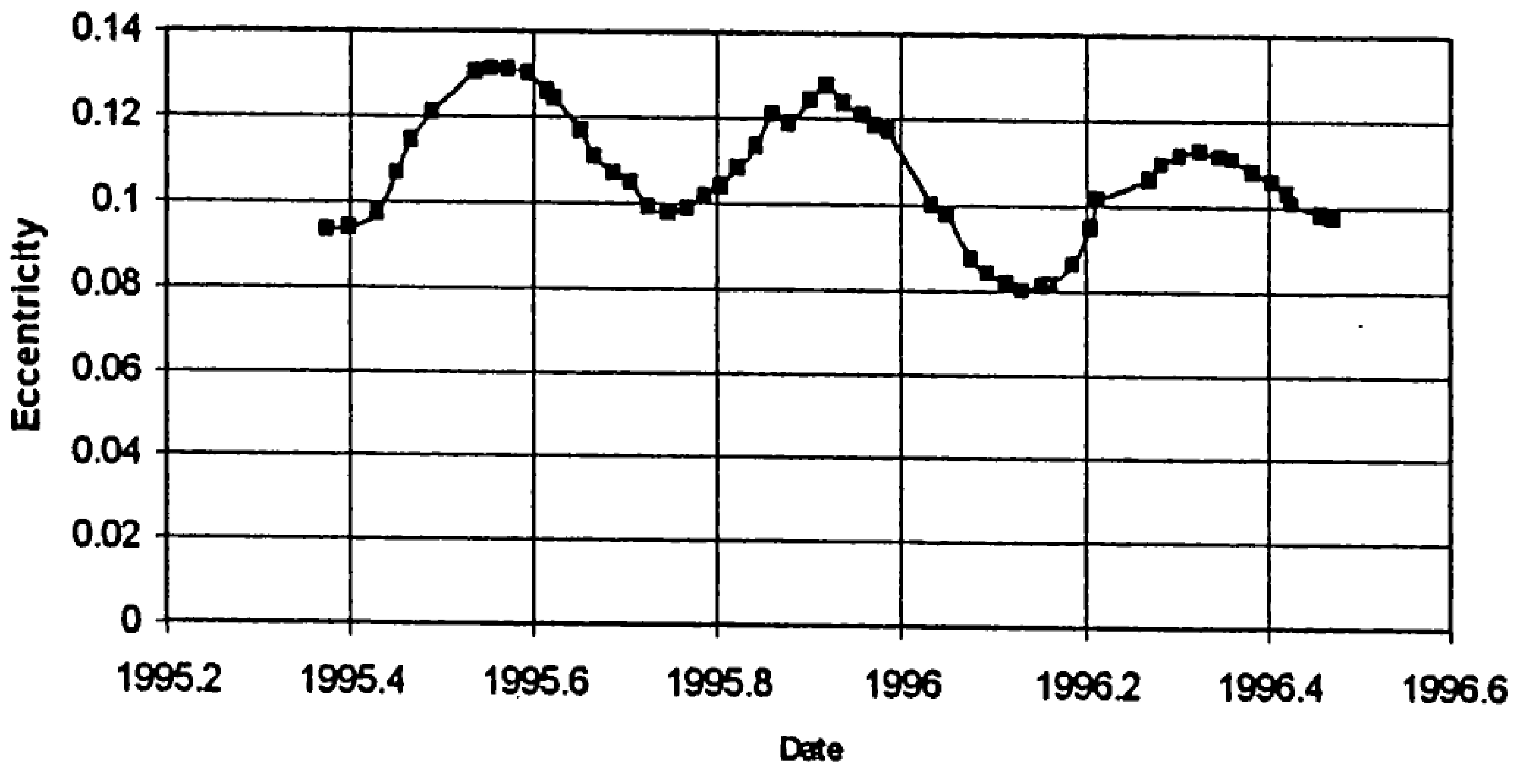

Fig 6 Predicted evolution of semi-major axis with time

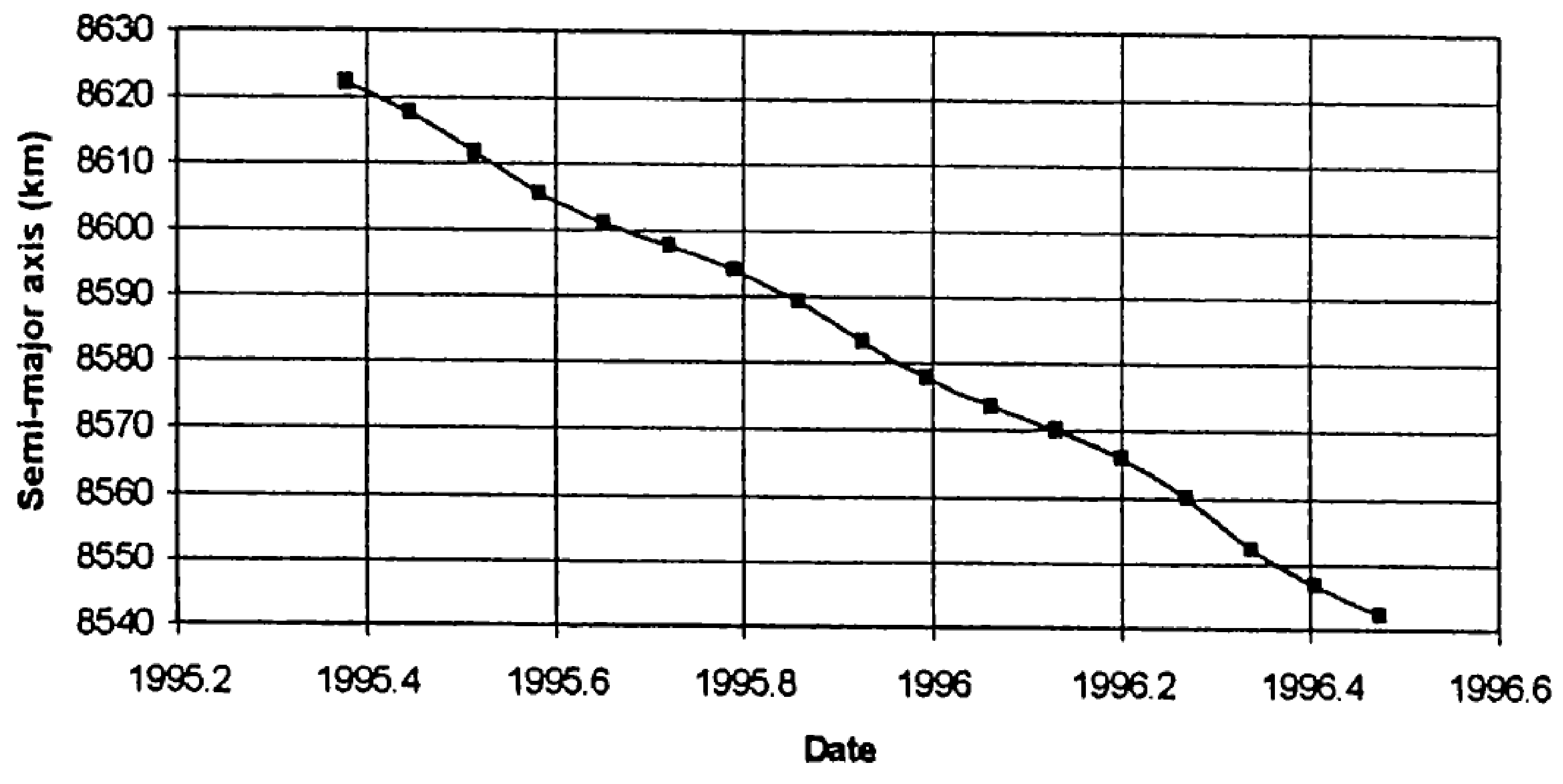

Fig 7 Predicted evolution of eccentricity with time