MODELING FLUXES RESULTING FROM NEW OR MOLNIYA-CLASS OBJECTS

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ABSTRACT

This paper deals with the special behavior of objects in Molniya-type orbits and debris objects produced in new breakups. Since the vast majority of breakups in highly eccentric orbits occurred in Molniya-type orbits, it is of interest whether and how debris objects might interfere with the GEO or LEO regions. The impact on the LEO region will be illustrated as the interference of debris objects with Space Station's orbit. On the other hand, possible intersections of Molniya type debris with the geostationary ring will also be demonstrated.

1. INTRODUCTION

Objects in high eccentricity orbits near the critical inclination of 63.4° (referred to in this paper as Molniya or Molniya-type orbits), breakup of objects in Molniya orbits, and new breakups have the common characteristic for risk assessment that assumptions of randomness in the right ascension of ascending node and argument of perigee cannot be made. The distinction for these three cases is the time scale for randomness to occur. For breakups away from Molniya orbits, randomization can occur over time periods of a few months, but for objects in near-Molniya orbits this time span can be much longer. For breakups in Molniya orbit, lunar solar perturbations cause oscillations of increasing amplitude in inclination and argument of perigee that eventually lead to a breakdown of the oscillatory behavior and perigee precession driven by J_2 in the Earth's gravitational potential.

Because new breakups and breakups of intact objects in near-Molniya orbits have similar non-randomization problems which must be addressed in risk assessment, the study of Molniya breakups has served as a paradigm for risk assessment for all types of new breakups. This risk is currently assessed at NASA/JSC using the NEWFRAG model.

Molniya-type orbits are highly elliptical with an inclination around 63° and typically have their perigee in the southern hemisphere. Satellites occupying these orbits are either Russian Molniya communications spacecraft with argument of perigee initially at 280° or 288° or Russian Cosmos spacecraft with argument of perigee initially at 316° or 318°. The inclinations of these orbits are chosen to maintain the argument of perigee fairly stable.

To calculate the fluxes on a spacecraft caused by orbital debris, it is a common practice to make the assumption that the argument of perigee (ω) and the right ascension of ascending node (Ω) are randomly distributed. For Molniya orbits, however, this assumption is no longer valid because their argument of perigee is stable rather than random. This is one of the major reasons why Molniya-type orbits have been excluded from modeling in ORDEM96 (the NASA 1996 engineering model). This paper addresses the problem of what type of argument of perigee distribution can be expected. Such results are important for the future update of ORDEM96 to include Molniya-type orbits.

In order to study the 15 fragmentations of Cosmos 862 Class satellites in highly eccentric orbits, the NASA Orbital Debris Evolution Model EVOLVE was used to model the debris clouds' evolution from these breakups. All debris pieces with a size of greater than one centimeter were considered, whereas no further size discrimination was performed. Since the breakup altitudes are not accurately known one has to use the results with some caution.

2. ORBIT EVOLUTION OF MOLNIYA TYPE OBJECTS

The objective of this chapter is to get an idea how the long term evolution of Molniya type objects might look. Special interest is put on the distribution of the argument of perigee and the associated perigee altitude. Those two values mainly determine the interference with LEO or GEO orbits. In order to accomplish this task all US Space Command cataloged Molniya type objects which were present in the April 1985 and April 1995 Two Line Element Sets were selected. A total number of 247 TLE objects matched this criterion. A thirty year orbit propagation was then performed in order to get a picture of the long time evolution of these objects. In general one could distinguish between objects with 1985 arguments of perigee above and below 300°. Those with initial arguments of perigee above 300° are mostly Cosmos surveillance mission related objects, whereas the other ones could mostly be attributed to Molniya telecommunication missions. Since the orbit evolution of all 247 objects is difficult to illustrate, two objects, namely Molniya 2-13 and Cosmos 1247, were selected which represent the behavior of these two classes of objects. Thus the following graphs show the behavior of these two objects. Each dotted line represents one object with a time difference between each dot of sixty days.

Figure 1 shows the Perigee altitude for the Molniya 2-13 as a function of the argument of perigee, which represents the objects with initial argument of perigees below 300°. One can see that the argument of perigee oscillates around the 270° value with an amplitude of about 20°. The period of this oscillation is about 23 years The other objects in this category had argument of perigee amplitudes of 15 to 30°. The amplitudes of the argument of perigee oscillation tend to increase with the initial inclination and time. The perigee altitude oscillates around 1500 km with a 1000 km amplitude, also increasing with time. The plots indicate a growing butterfly shape of the perigee altitude and argument of perigee relationship.

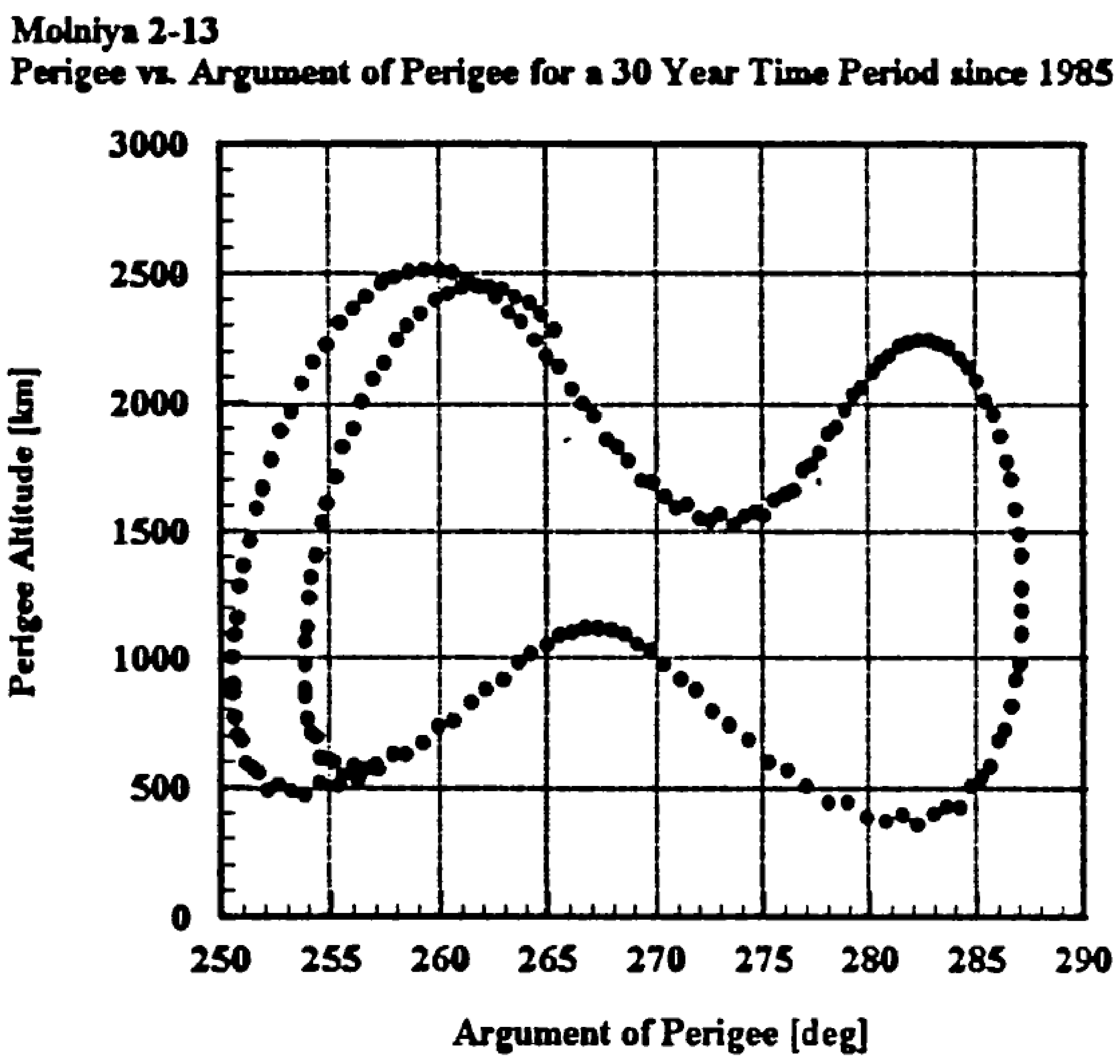

Figure 1.

This is caused by the fact that Lunar/Solar perturbations force the inclination to oscillate (Figure 2). If this oscillation has a median close to the critical value of 63.4°, the argument of perigee also oscillates. This is due to fact that the J_2 gravitational perturbations cause the argument of perigee to increase if the inclination is below and decrease if it is above that value. Once the inclination grows too big and is then too far off the critical value, the argument of perigee is not locked anymore and drifts to lower values since the inclination then tends to average above 63.5°.

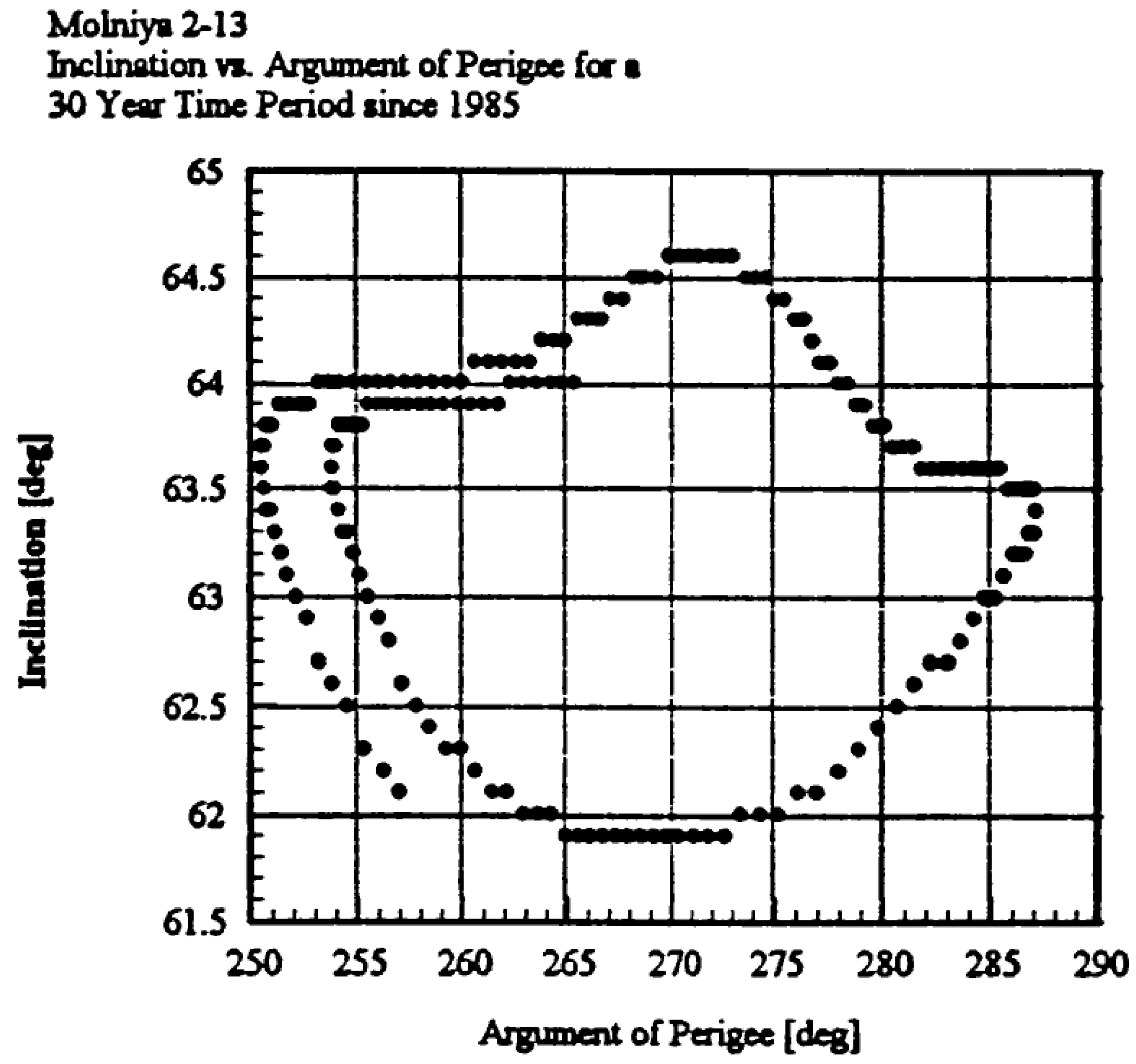

Figure 2.

Figure 3 shows the Perigee altitude for the Cosmos 1247 object as a function of the argument of perigee. Contrary to the Molniya case the argument of perigee seems not to oscillate around 270°. This case is quite representative for all objects which had an initial argument of perigee of more than 300°.

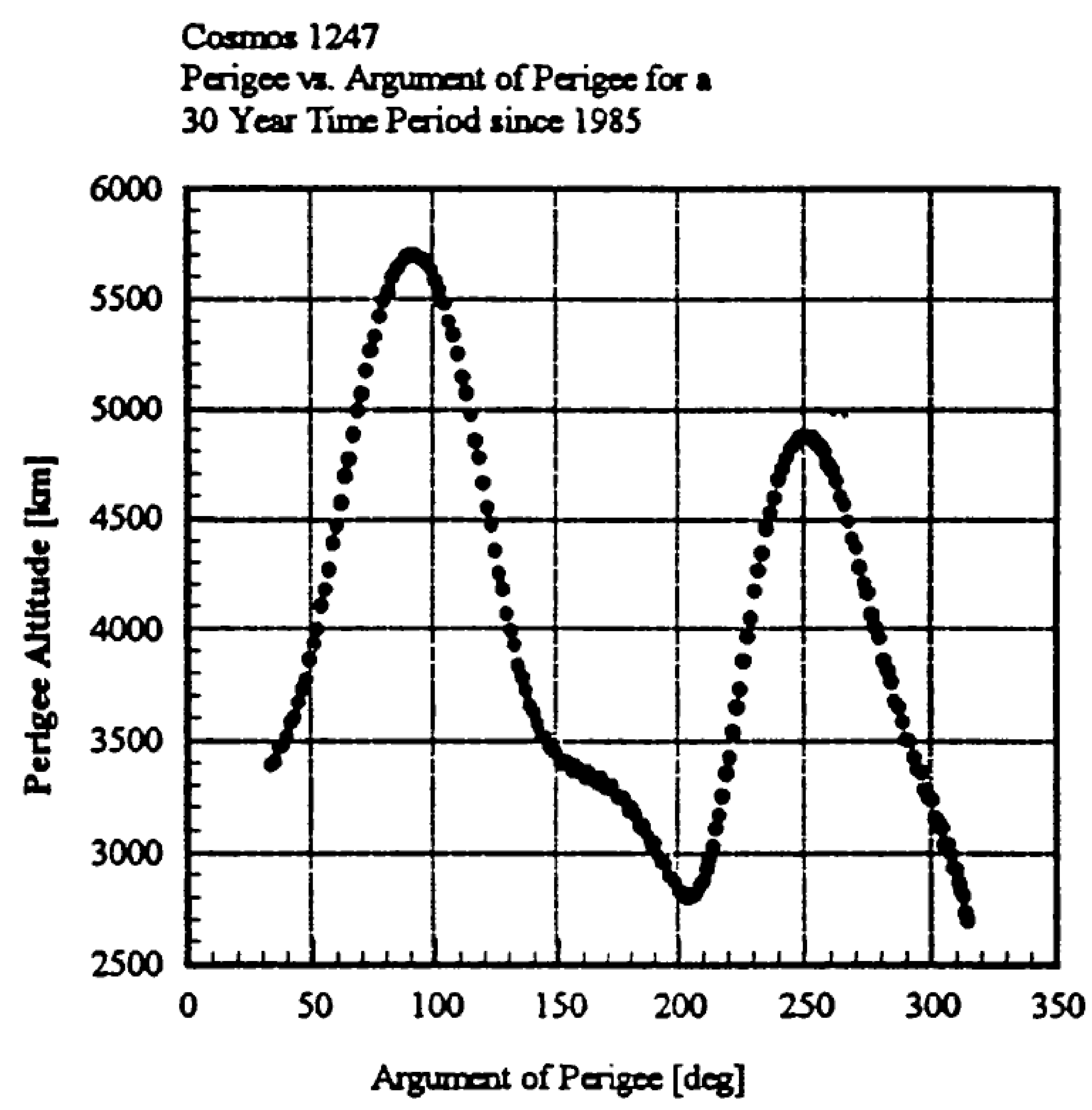

Figure 3.

The reason for this behavior is that initially the inclination raises steeply (Figure 4) and then does not decrease enough to reach back to the critical inclination. The fact that the initial argument of perigee is above 300° might be the underlying cause for the inclination to build up that fast. For almost all cases we can observe a decreasing argument of perigee until possibly catastrophic decay. This diving into the atmosphere takes place for argument of perigees of either around 0 or 180° (not shown here). The amplitudes of the perigee altitudes are very large and can reach four to six thousand kilometers for these type of objects.

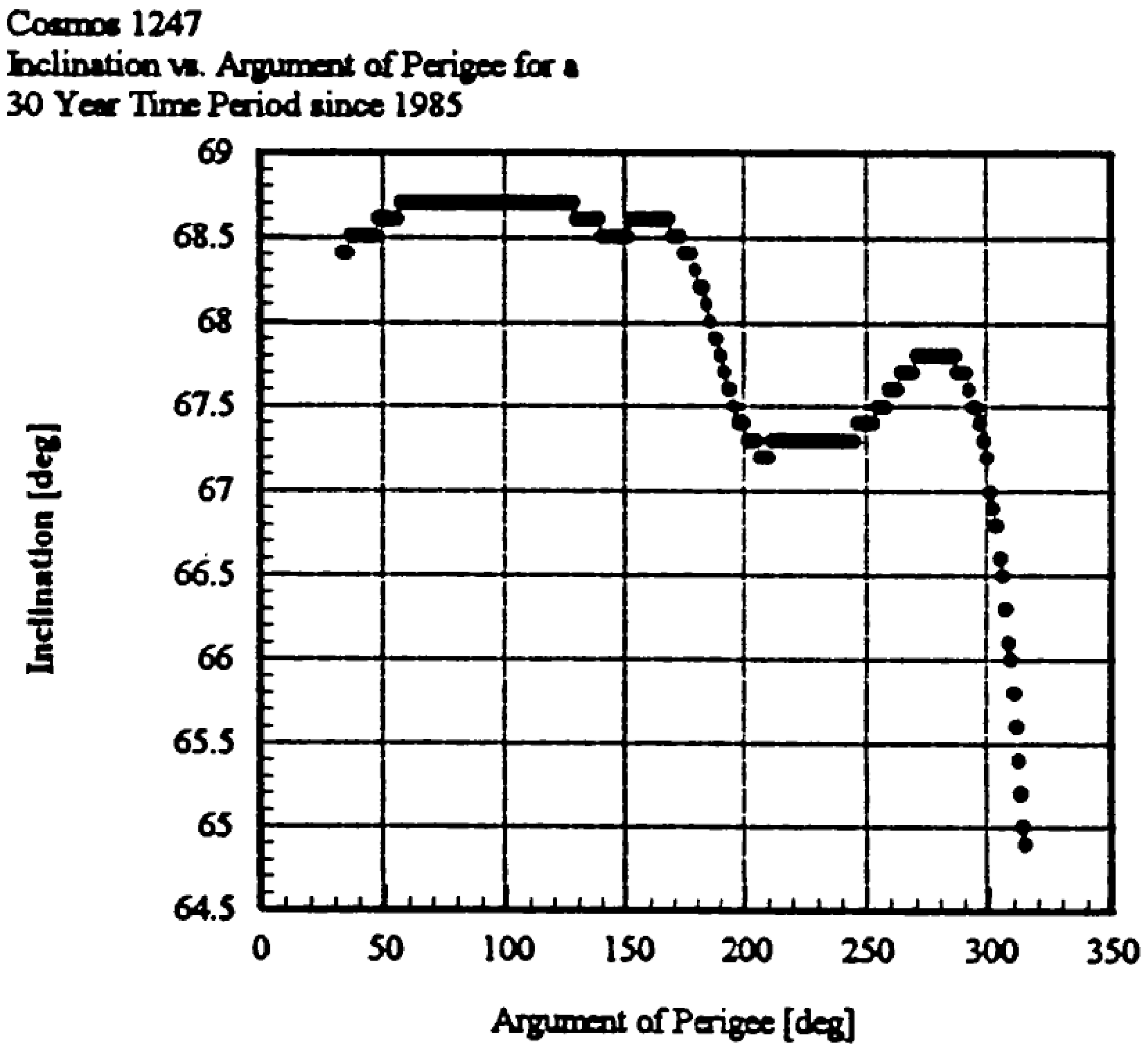

Figure 4.

3. BREAKUPS IN MOLNIYA TYPE ORBITS

The vast majority of breakups (Ref. 10) which occurred in highly eccentric orbits can be attributed to Cosmos surveillance missions, which have inclinations around 63° and apogees above 40,000 km. The following table (Table 1) lists all known breakup events sorted by launch date. Only Cosmos-class breakups were studied in this work because these spacecraft have shown a propensity for breakup which is not displayed by Molniya-class space craft.

It is quite visible that in most cases the breakups occurred during the first couple of months to one year of the mission. The last measured argument of perigee of all mentioned satellites is close to 320° and did not change much until the breakup, due to the closeness to the critical inclination. Since the argument of perigee determines whether the orbit intersects certain LEO or GEO regions, its initial value and time evolution are of utmost importance. It needs to be determined, if the breakup objects interfere during their remaining on orbit lifetime with certain LEO or GEO regions. According to the results of section 2 one could expect such an interference.

The following results have been obtained with the NASA Orbital Debris Evolution Model EVOLVE. The EVOLVE breakup model was used to determine the initial orbits of all objects bigger than one centimeter in diameter. This was done for sixteen known Cosmos 862 Class breakups. Figure 5 illustrates the initial distribution of all breakup clouds at their respective event date.

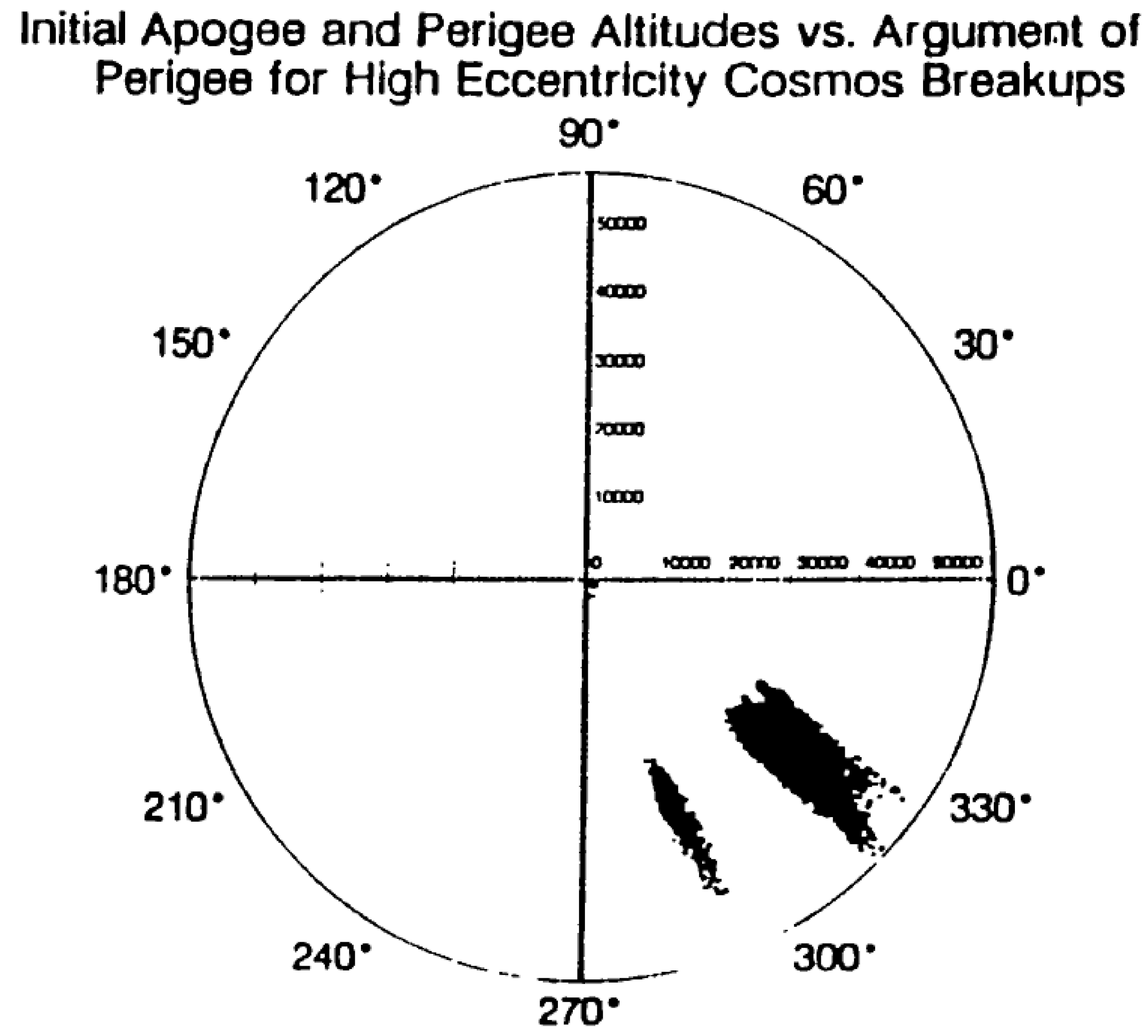

Figure 5.

The range of the apogee altitudes of the debris clouds starts at 30,000 km and goes up to almost 60,000 km. The argument of perigee distribution shows that the vast majority of objects lies in the 315° to 330° bin. One breakup (Cosmos 1247) had a before breakup argument of perigee of 291° and is the reason for that debris cloud at 290°. The associated perigee altitudes are not detectable in this figure.

3.1 Interference With The Geo Region

Figure 6 depicts the apogee altitude and argument of perigee distribution of all simulated Cosmos 862 breakup debris pieces as it was in the year of 1995. Considering the initial state shown in figure 5 one can see that the arguments of perigee tend to move backwards (or clockwise in the polar plot) and seem not to be locked at 320°. This fact is in compliance with the previous results in section 2 where the argument of perigee of the Cosmos 1247 object traveled to increasingly lower values. Since each dot on the polar plot represents one debris particle sized one centimeter or bigger the impression of a debris cloud becomes apparent.

BREAKUPS IN MOLNIYA TYPE ORBITS

Int Designator	Catalog No.	Mission	Name	Country	Launch Date	Event Date
1976-105A	9495	Cosmos 862	Cosmos 862 Class	CIS	22-Oct-76	15-Mar-77
1977-027A	9911	Cosmos 903	Cosmos 862 Class	CIS	11-Apr-77	8-Jun-78
1977-047A	10059	Cosmos 917	Cosmos 862 Class	CIS	16-Jun-77	30-Mar-79
1977-068A	10150	Cosmos 931	Cosmos 862 Class	CIS	20-Jul-77	24-Oct-77
1978-083A	11015	Cosmos 1030	Cosmos 862 Class	CIS	6-Sep-78	10-Oct-78
1979-058A	11417	Cosmos 1109	Cosmos 862 Class	CIS	27-Jun-79	Feb-80 (Mid)
1979-077A	11509	Cosmos 1124	Cosmos 862 Class	CIS	28-Aug-79	9-Sep-79
1980-085A	12032	Cosmos 1217	Cosmos 862 Class	CIS	24-Oct-80	12-Feb-83
1980-057A	11871	Cosmos 1191	Cosmos 862 Class	CIS	2-Jul-80	14-May-81
1981-016A	12303	Cosmos 1247	Cosmos 862 Class	CIS	19-Feb-81	20-Oct-81
1981-031A	12376	Cosmos 1261	Cosmos 862 Class	CIS	31-Mar-81	Apr-81
1981-058A	12547	Cosmos 1278	Cosmos 862 Class	CIS	19-Jun-81	Dec-86 (Early)
1981-071A	12672	Cosmos 1285	Cosmos 862 Class	CIS	4-Aug-81	21-Nov-81
1981-108A	12933	Cosmos 1317	Cosmos 862 Class	CIS	31-Oct-81	Jan-84 (Late)
1983-038A	14034	Cosmos 1456	Cosmos 862 Class	CIS	25-Apr-83	13-Aug-83
1983-070A	14182	Cosmos 1481	Cosmos 862 Class	CIS	8-Jul-83	9-Jul-83

Table 1.

Apogee Altitudes vs. Argument of Perigee for High Eccentricity Cosmos Breakups and Involvement with the GEO Region as of 1995

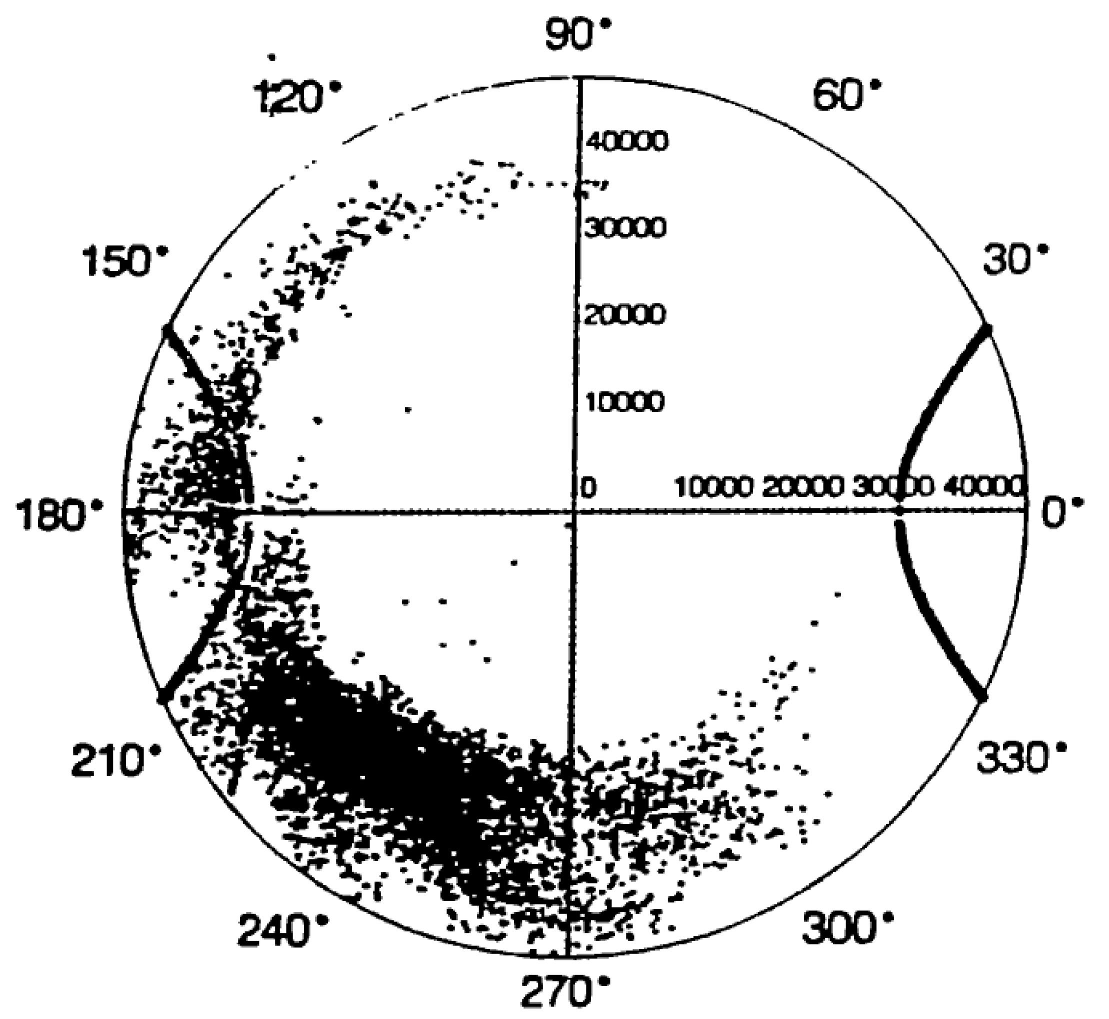

Figure 6.

The intersection with the geosynchronous ring is illustrated by the two bold lines at the right or left of this plot. These lines are computed under the assumption of a 35,767 km geosynchronous altitude and a zero degree inclined orbit, which makes this orbit geostationary. If one considers not only the GEO orbit but a GEO region (say GEO altitude plus or minus 500 km), these lines would span some area. The same holds true if the orbits to be intersected are not geostationary but geosynchronous. This would allow for some inclination and the area of possible intersections becomes bigger. Figure 7 shows the same as Figure 6 at a different time and is a snapshot of the environment in the year 2004. The debris clouds still tend to move clockwise in this plot and the arguments of perigee of the debris population seems to be more stretched. It seems that the debris cloud reintersects the GEO environment for another time.

Apogee Altitudes vs. Argument of Perigee for High Eccentricity Cosmos Breakups and Involvement with the GEO Region as of 2004

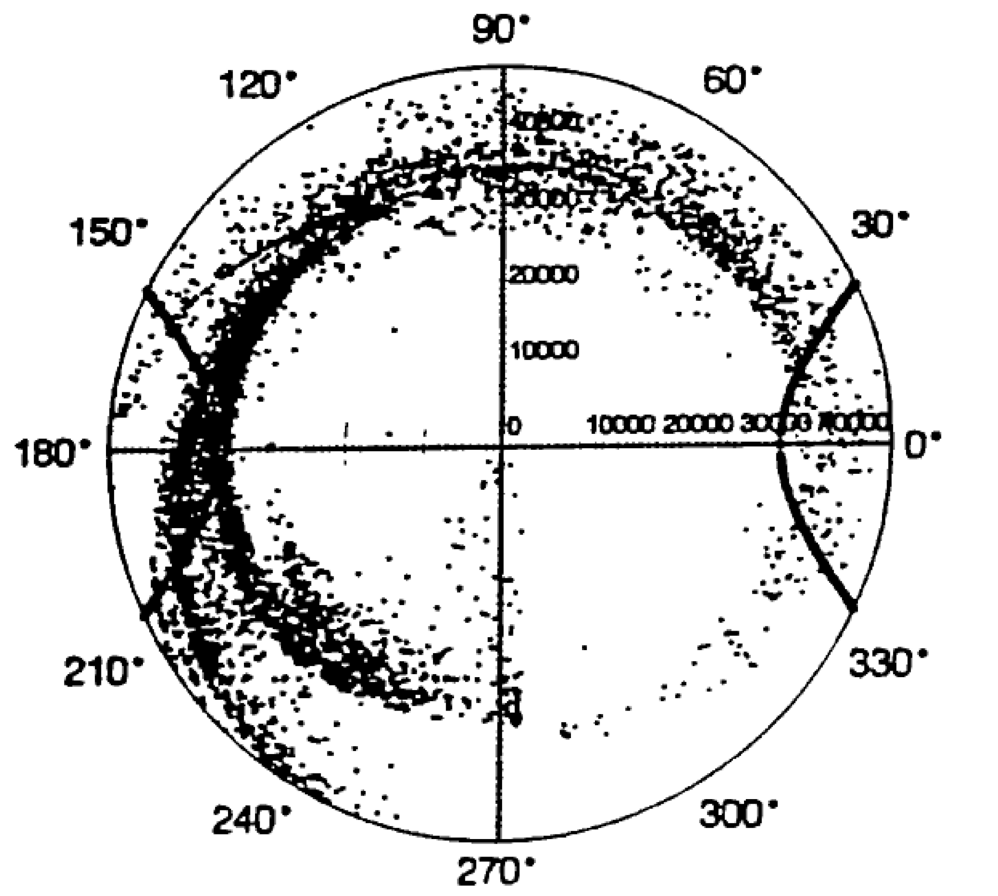

Figure 7.

3.2 Interference With The Leo Region

Figure 8 depicts the possible interference of Cosmos breakup pieces with an object on a circular orbit at 450 km altitude with 51° inclination in the year 1995. This is near the orbit of the International Space Station (ISS).

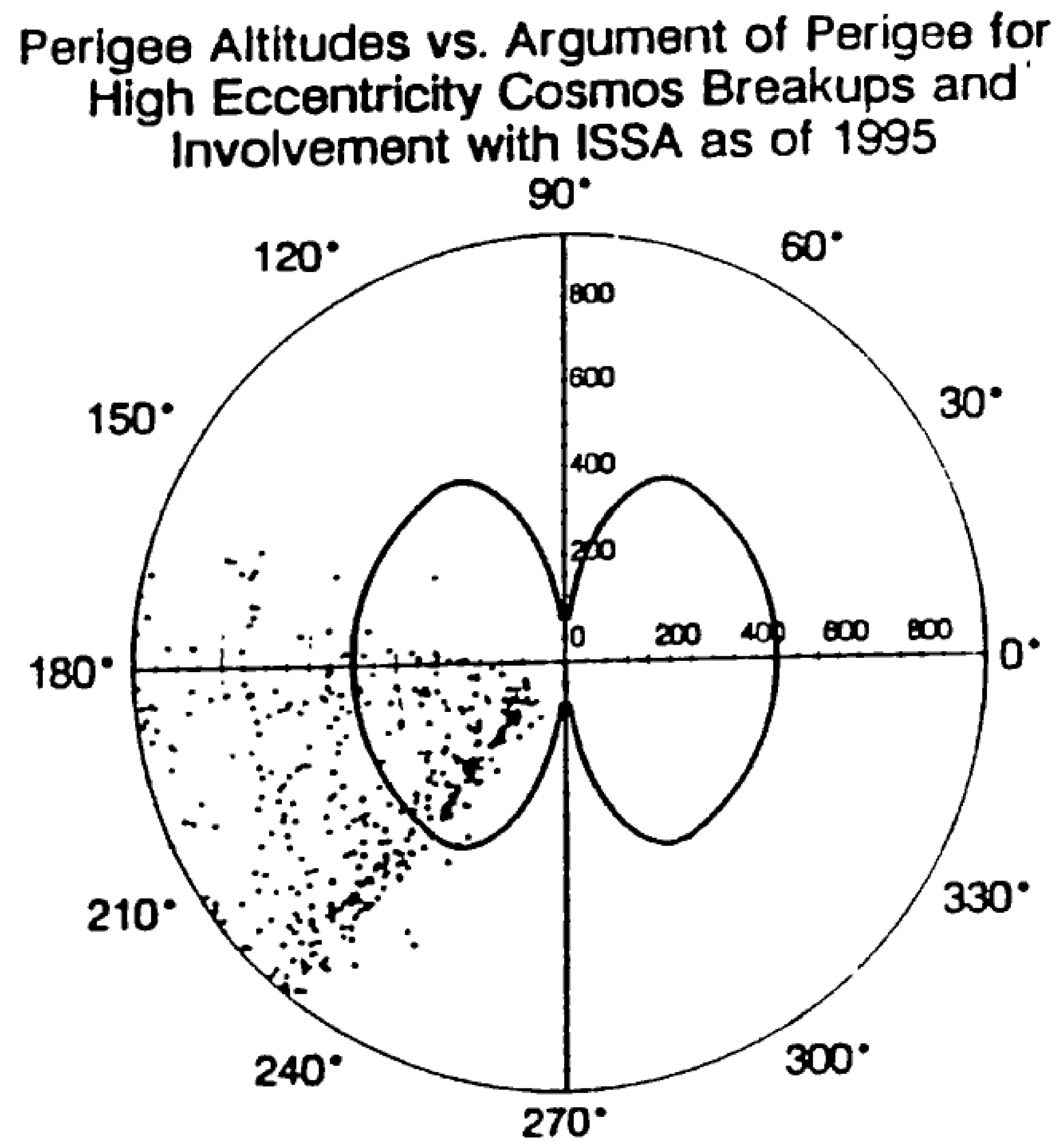

Figure 8.

Each dot which lies inside that butterfly shaped line represents a one centimeter or larger particle which has the potential to intersect Space Station's orbit. One can see that the reentering objects have mainly arguments of perigee in the 160° to 230° range. This effect is still visible for the environment in the year 2004 as shown in Figure 9.

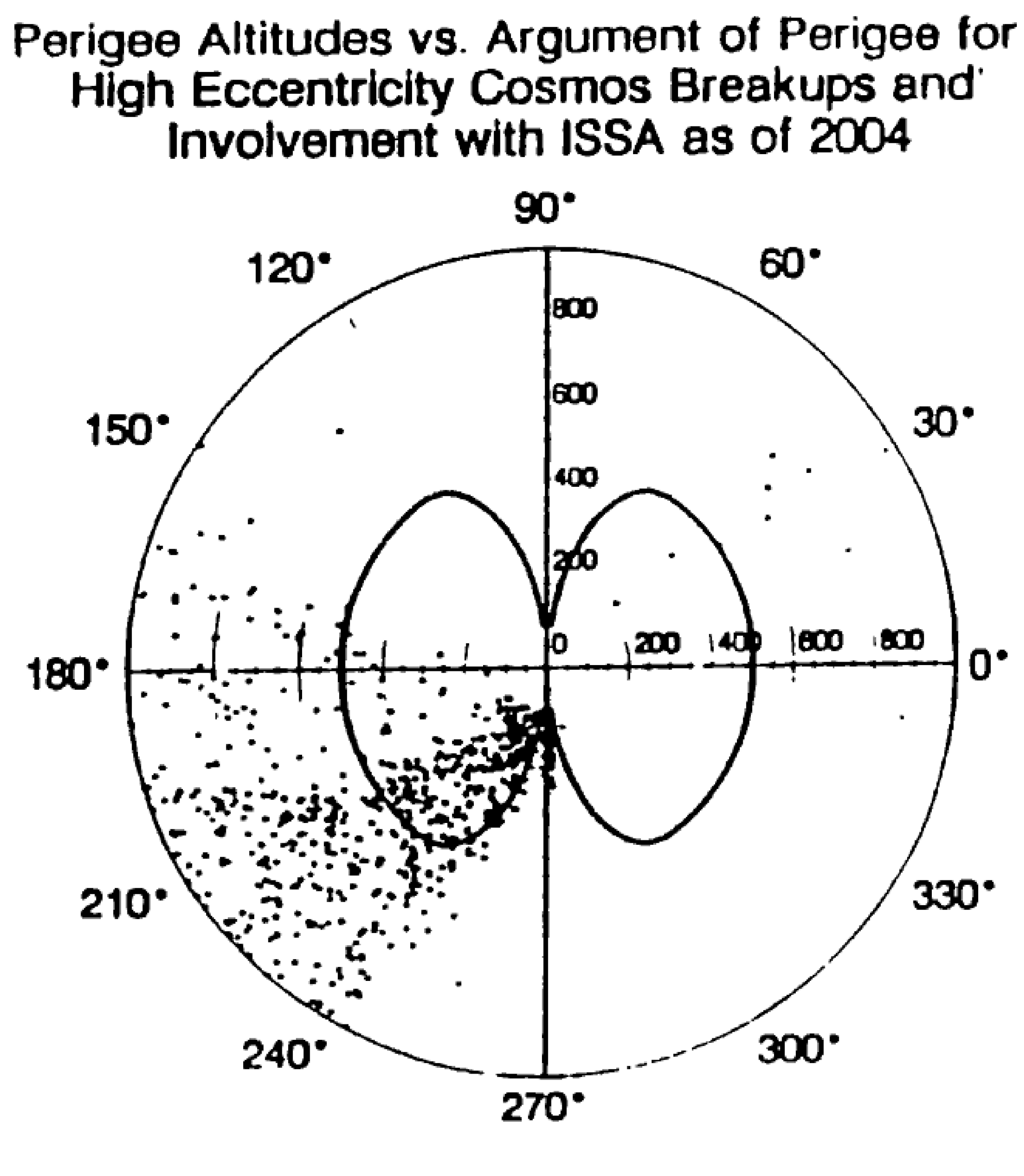

Figure 9.

4. CONCLUSIONS

The orbit evolution of Molniya type objects was explained. Two cases (Molniya 2-13 and Cosmos 1247) were used to represent quite well the behavior of the whole range of orbits one would define as to be Molniya type. The different behavior of those objects is mainly determined by the initial argument of perigee and the initial inclination. The closer the initial orbit's argument of perigee is to the 270° value and the inclination to the critical inclination of 63.4°, the longer the perigee seems to be locked in the southern hemisphere. For Cosmos objects which had an initial argument of perigee above 300° one could say that the argument of perigee is not locked and its value oscillates by some thousand kilometers. Furthermore the possibility of Cosmos 862 type breakup debris interference with the GEO environment and the Space Station was shown. But actual surface fluxes which are the governing factor for risk assessment form these breakups have not yet been determined and is left for further studies. That will lead to the implementation of Molniya type debris fluxes in NASA's ORDEM96 Engineering model.

5. REFERENCES

1. History of On-Orbit Satellite Fragmentations, *Teledyne Brown Engineering Technical Report CS95-KS-024, 1995.*