

FIRST "CONFIRMED" NATURAL COLLISION BETWEEN TWO CATALOGED SATELLITES

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ABSTRACT

Since the beginning of the space age in 1957 there have been several suspected natural satellite collisions but none have been definitively confirmed. This is primarily because the suspected collisions only involved one cataloged satellite. This paper examines the first natural collision between two cataloged man-made objects.

On the 24th of July 1996 the French microsat CERISE collided with a fragment of an Ariane rocket body. The resulting collision severed part of the gravity gradient boom on the CERISE payload. After the collision the period of the rocket body fragment increased and a new uncataloged piece appeared running with CERISE (suspected end of gravity gradient boom).

The paper presents a detailed examination of the orbits just prior to and after the collision. The paper also investigates the history of the two orbits leading up to the collision. This analysis is conducted to determine if there exist any advance warning signs of this extremely rare event that might be available in the orbital data. The conjunction history of CERISE/Ariane debris are then compared to a baseline of an entire orbital satellite catalog conjunction analysis in an attempt to find clues that would indicate that a collision is more likely to occur.

1. INTRODUCTION

The United States Space Command satellite catalog contains over 24,000 objects. The cataloging process is carried out by over a dozen ground-based sensors using both radar and optical measurement systems. These sensors are spread throughout the world. Only

slightly over a third of the cataloged objects are still in orbit today and two of them have inadvertently collided.

2. CONFIRMATION OF THE COLLISION

An examination of satellite period vs. time plot (Fig. 1) for both the CERISE payload and the Ariane debris shows a abrupt change in the period for the Ariane debris. The change is approximately 1.6 seconds corresponding to a delta-v of slightly less than a meter/sec and occurred after a reported telemetry anomaly on day 96/206. Taking General Perturbations (GP) element set data on this debris piece before and after the period change and running the Computation Of Miss Between Orbits (COMBO) program reveals that the delta-v added to the orbit occurred close to the time of a reported telemetry anomaly.

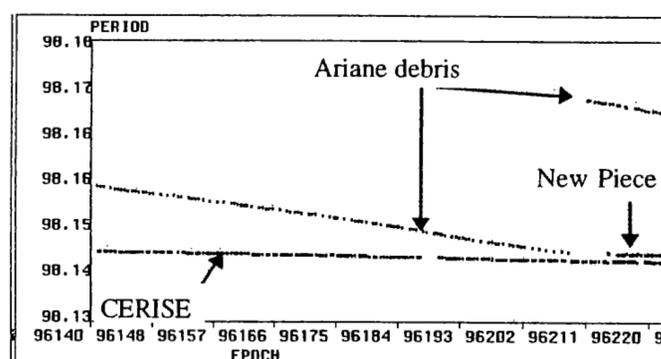


Figure 1. Period vs. time plot.

The plot also shows the appearance of a new piece running along with the CERISE payload. This new piece was discovered after the period change and is suspected to be part of the severed gravity gradient boom.

Running the COMBO program again this time with Special Perturbation (SP) vectors on the CERISE payload and the Ariane debris yields a close approach of 305 meters. This close

approach occurred on day 206 at 09:48:02 GMT which agrees with the telemetry anomaly within five seconds. The close approach distance and the time at which it occurred are well within model noise levels and telemetry time resolution respectively.

3. HIGH RISK GEOMETRY

Prior to the collision the CERISE/Ariane debris orbits were in a high risk geometry. The satellites had similar altitude (680 km circular), similar inclination (98.10° vs. 98.45°) and the planar alignment was such that they were almost in the same orbital plane but going in opposite directions. This type of geometry produced approximately 30 close approaches under 25 km per day.

The altitude of the debris piece kept getting closer to that of CERISE because it has a significantly larger area/mass ratio which causes it to decay faster than the CERISE payload. Having all of these similar features is not enough to cause a collision though, you also need to have the phasing of the satellites be such that they both arrive at the place(s) the orbits cross at the same time. The change in this phasing is the leading contributor to the variance in the daily closest approach distance over time (Fig. 2).

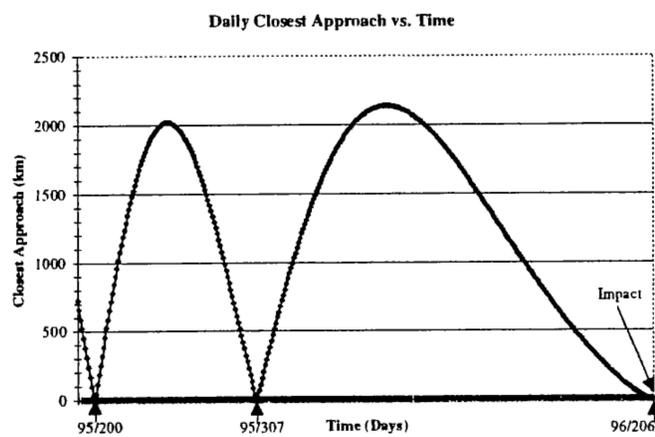


Figure 2. Daily closest approach vs. time plot for CERISE and Ariane debris.

Just before the collision the daily closest approach did not drop below 100 km until 18 days prior to the collision and did not drop below 10 km until just 5 days before. The other 2 cusps never did get below 10 km and only stayed below 100 km for 4 or 5 days. Two days before the collision there were 15 close

approaches between 18 - 23 km and another 14 between 1- 3 km. The last 24 hours before the collision produced 15 close approaches between 18 - 23 km, 11 between 1 - 3 km and 3 additional approaches less than 1 km.

4. TOTAL CATALOG STATISTICS

When we use the COMBO program again this time comparing each satellite in the catalog against all other satellites for the date of interest and two randomly selected one day intervals we find some interesting results. First we find that there are over a half million close approaches per day under a 100 km (Table 1). Approximately 7% of these approaches were below 25 km and slightly over 1% were below 10 km.

All Satellites vs. All Satellites Catalog Statistics

DAY	< 10 KM	< 25 KM	< 100 KM
96/206	6,171	38,078	571,967
96/276	7,373	44,940	667,959
96/352	7,049	43,826	655,372

Table 1. Number of close approaches/day for various separation distances.

Tabulating and sorting the close approaches under 10 km produces a list of satellite pairs that deserve to be examined further. When we examine the last 24 hours before the CERISE/Ariane debris collision (Day 96/206) this list contains seven pairs of satellites with 10 or more conjunctions (Table 2).

Number of Satellite Pairs with 10 or More Close Approaches

DAY	Number of pairs < 10 km
96/206	7
96/276	8
96/352	8

Table 2. Number of pairs of satellites with 10 or more close approaches/day under 10 km.

It is interesting to note that two of these satellite pairs had more conjunctions than the CERISE/Ariane debris pair. Upon closer examination of these other pairs we see that most of them do not have, including the two with more conjunctions, as small as radial and out-of-plane residuals as the CERISE/Ariane

debris pair. This is important because GP element set data is much more reliable in these two components when compared to the in-track component. Screening out these pairs of satellites that do not have radial and out-of-plane residuals that are a kilometer or less leaves us with only 3 pairs of satellites.

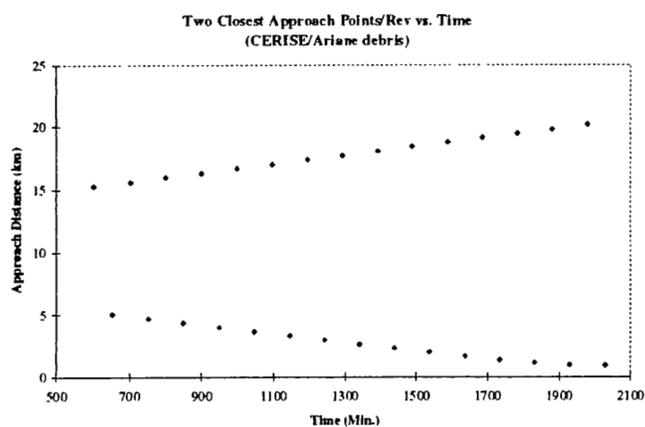


Figure 3. Approach distance vs. time for CERISE/Ariane debris pair.

Figure 3 shows a plot of the two closest approach points per revolution vs. time for the CERISE/Ariane debris pair. Looking at the slope of the closest approach line we see that the CERISE/Ariane debris pair has a very shallow slope. This is confirmed by calculating the rate of change of the close approach distance per satellite revolution. When this is accomplished we see that the CERISE/Ariane debris pair has a much smaller rate of change per revolution than the other pairs (Fig. 4). It should be pointed out that in Figure 4 positive values indicate that the two objects are getting closer while negative values indicate the objects are separating.

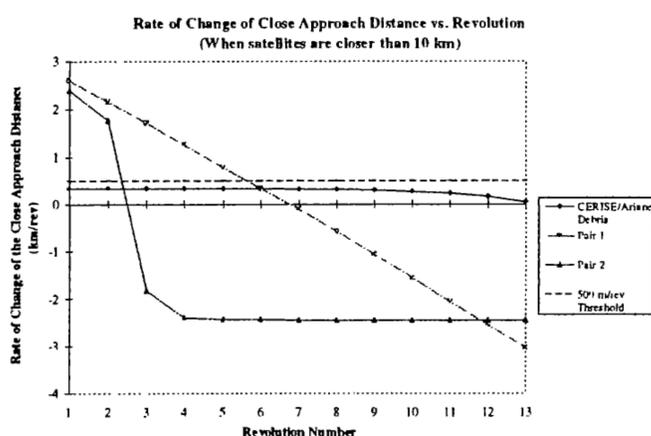


Figure 4. Rate of change of close approach distance vs. satellite revolution.

The CERISE/Ariane pair rate of change decreases gradually from 350 meters/rev down to 60 meters/rev. The rate of change for pair 1 decreases from 2.6 km/rev down to 335 meters/rev before it starts to increase with only one of the decreases below the 500 meters/rev level. The other pair (pair 2) starts at 2.4 km/rev and goes down to 1.7 km/rev before it starts to increase. Using a decreasing rate of 500 meters/rev rate of change of the close approach distance as a further screening criteria and requiring that the rate be held for several revolutions we would then be left with only the CERISE/Ariane debris pair as a high risk candidate.

Testing out these screening filters on two different one day intervals we find that on both day 96/276 and day 96/352 there were eight pairs of satellites that had 10 or more conjunctions under 10 km (Table 2). Screening these pairs of satellites for radial and out-of-plane residuals that are a kilometer or less leaves 3 pairs remaining on day 96/276 and on day 96/352 only two remained. Then applying the several revolutions of 500 meters/rev rates of change of the close approach distance left no high risk pairs remaining on both days.

5. CONCLUSION

This paper has examined the first natural collision between two cataloged man-made objects. The abrupt change in the period of the Ariane debris occurring simultaneously with the close approach of CERISE and a reported telemetry anomaly seems to confirm that these two objects did indeed collide. The high risk geometry of the two objects produced extremely high levels of very close approaches in the last couple of days before the collision.

The paper then investigated the entire orbiting satellite catalog data to aid in the development of some screening criteria for finding other satellite pairs that might be at risk of a collision. Three separate one day intervals were analyzed and three separate criteria were established. The first was to require that a minimum of 10 close approaches under 10 km exist. The second was that pairs (that passed the first criteria) have radial and out-of-plane residuals of a kilometer or less. The third was to look at the rate of change of the close approach

distance per revolution for pairs that passed the first two criteria. A criteria of several revolutions below a decreasing closing rate of 500 meters/rev was established. The only satellite pair to survive all three criteria was the CERISE/Ariane debris. This is not to imply that any satellite pair that survives all of these criteria will collide, only that the risk of a collision has significantly increased. It should also be stated that just because a satellite pair does not display this type of a geometry that they will never collide, only that the risk is not as great. Further work needs to be accomplished in understanding how these or other criteria might be used to develop some longer term predictions of a satellite collision.