Analysis of the 2007 Chinese ASAT Test and the Impact of its Debris on the Space Environment

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ABSTRACT

On 2007 January 11, the People's Republic of China conducted a successful direct-ascent ASAT test against one of their own defunct polar-orbiting weather satellites. The test produced at least 2,087 pieces of debris large enough to be routinely tracked by the US Space Surveillance Network and the NASA Orbital Debris Program Office estimated it generated over 35,000 pieces of debris down to 1 centimeter in size.

While this event captured worldwide attention in the weeks and months after the test was revealed, much of the information provided in the press was inaccurate or misleading and did not appear to be based on scientific analysis of the data available to the public. In order to help the public and key policy makers more fully understand the nature of the event and its impact on the existing satellite population, the Center for Space Standards & Innovation developed a series of animations, images, and graphical analyses to more clearly portray this event and provide a factual foundation for the subsequent debate. Those materials were all made publicly available via the Internet without restriction and have appeared in numerous publications.

This paper will summarize the primary areas of analysis of this event, to include a confirmation of the basic facts initially reported in *Aviation Week & Space Technology*, a visualization of the initial spread of the debris cloud in the first couple of hours after the attack, analysis of the impact of the debris on the LEO space environment—including the number of satellites potentially affected and the increase in the number of conjunctions, a look at the current debris environment, and an assessment of the orbital lifetimes that shows that these impacts will last not for years but for centuries. The visualization techniques used to portray these analyses played a substantial role in helping the scientific community to quickly and easily convey important aspects of this event to policy makers and the public at large.

1. BACKGROUND

The People's Republic of China (PRC) surprised most of the world on 2007 January 17 when it was reported in *Aviation Week and Space Technology* that they had conducted a successful test of a direct-ascent anti-satellite (ASAT) weapon against one of their own satellites [1]. The test was reported to have been conducted almost a week earlier on 2007 January 11 at 17:28 EST (22:28 UTC) from the Xichang Space Center in Sichuan province against their FengYun 1C polar-orbiting weather satellite. FengYun 1C had been operating in an 850-km, 98.6° orbit since its launch from Taiyuan Space Center on 1999 May 10. While FengYun 1C stopped producing weather imagery in late 2004, it was still transmitting on 1700.4 MHz at the time of the test.

Once news of the Chinese ASAT test broke, an intense policy debate began regarding what had happened, why the test had been conducted, and what should be done about it. Much of the discussion seemed to be based not on actual analysis of the event, but rather preconceptions about what might have happened. The eventual confirmation by PRC government on January 23, stating that the test was not meant to threaten any country and that it did not pose a threat to any satellites, also lacked an independent analytical assessment.

The Center for Space Standards & Innovation (CSSI), which frequently works with researchers and educators to develop better ways to visualize astrodynamics analysis, realized the need to provide readily understandable analysis to facilitate an informed discussion of the Chinese ASAT test and highlight areas that needed further investigation. As orbital data, in the form of NORAD two-line element (TLE) sets, began to become available for the debris produced by this test, CSSI began working to develop graphics, interactive animations, and other analysis to help better understand this subject.

2. INITIAL DEBRIS EVOLUTION

While TLEs for the first 32 pieces of debris were released shortly after the public became aware of this event, it wasn't until about two weeks after the event that data for a large portion of the now 2,087 cataloged pieces of debris became available to the public. As can be seen in Fig. 1, new debris pieces have been gradually added to the public satellite catalog by NORAD, and their TLE data made available, from the time of the attack up until the beginning of August. As a result, analysis and visualizations provided by CSSI were periodically updated as data was made available and the latest information was provided on the CelesTrak web site [2].

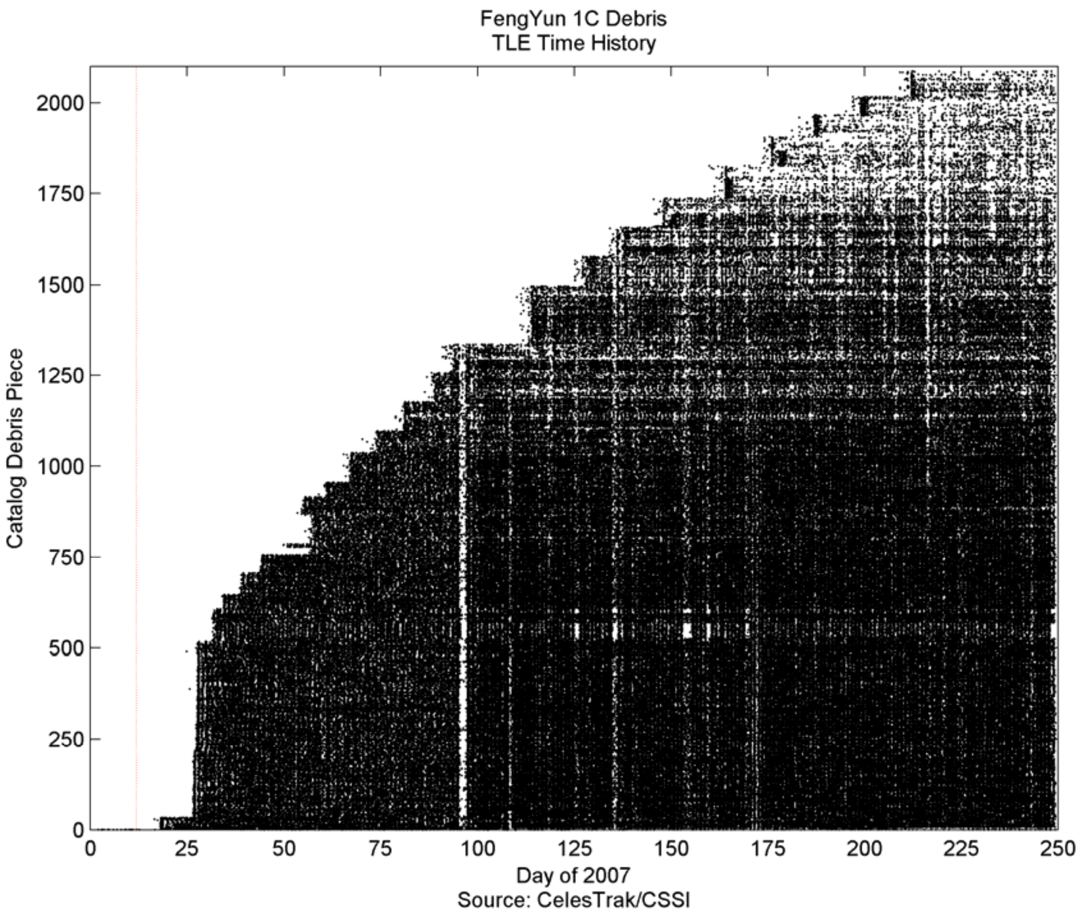

Fig. 1. FengYun 1C Debris TLE Time History. Each TLE released for the Chinese ASAT test debris pieces is shown as they were added to the catalog, with the vertical red line showing the reported time of the test.

The initial analysis focused on attempting to verify the basic facts reported by *Aviation Week & Space Technology*. A scenario was built using Satellite Tool Kit (STK) to propagate all the TLE data back to the time of the event. As can be seen in Figs. 2 through 4, the visualization was consistent with the initial reports. While the TLEs didn't propagate back well to a single point, as a result of deficiencies in modeling atmospheric drag effects, minimum out-of-plane separation occurred at a time of approximately 22:26:10 UTC, consistent with the reported event time of 22:28 UTC. At that time, FengYun 1C was rising over Xichang Space Center at 345° azimuth and 46° elevation at a distance of 1,135 km, putting it 737 km down range (maximum elevation occurred at 22:27:41 UTC).

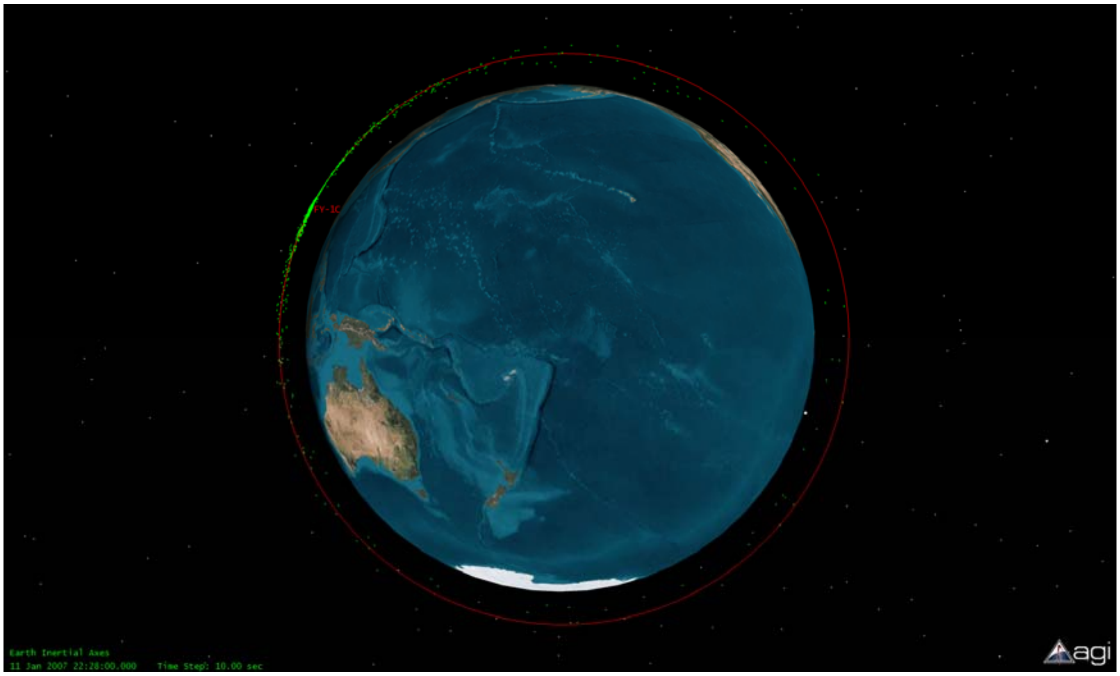

Fig. 2. Distribution of ASAT Debris on 2007 January 11 at 22:28 UTC. Pinch point in debris cloud over Xichang Space Center supports reports that the launch occurred from that location.

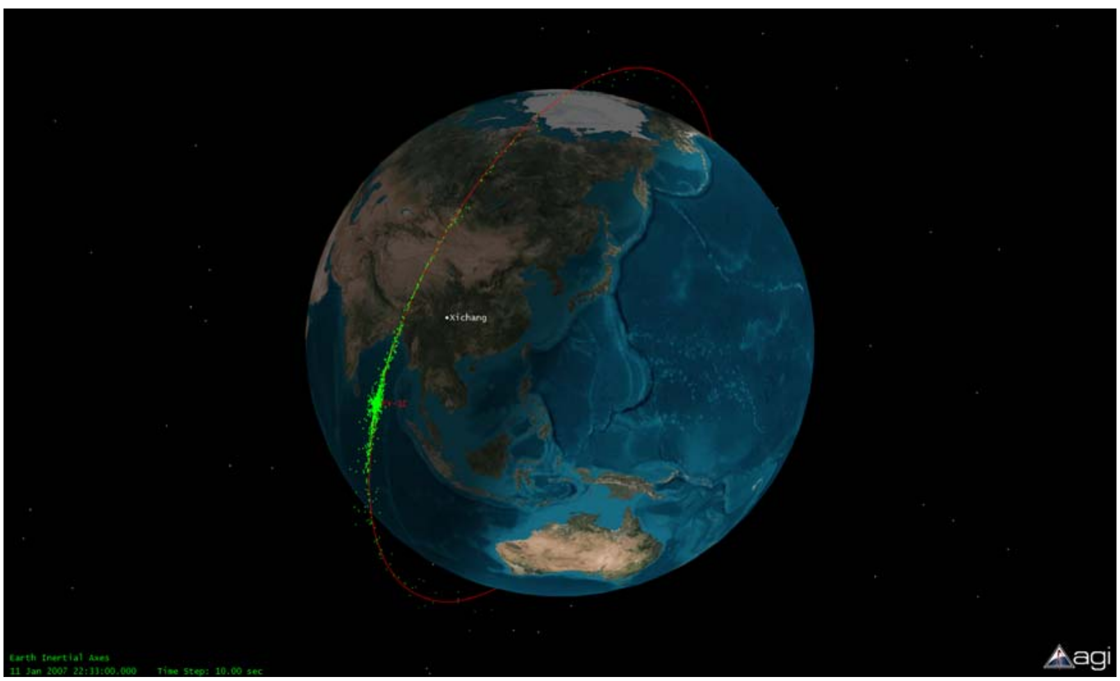

Fig. 3. Distribution of ASAT Debris Pieces on 2007 January 11 at 22:33 UTC. Debris cloud is already beginning to spread out just five minutes after the reported time of the event.

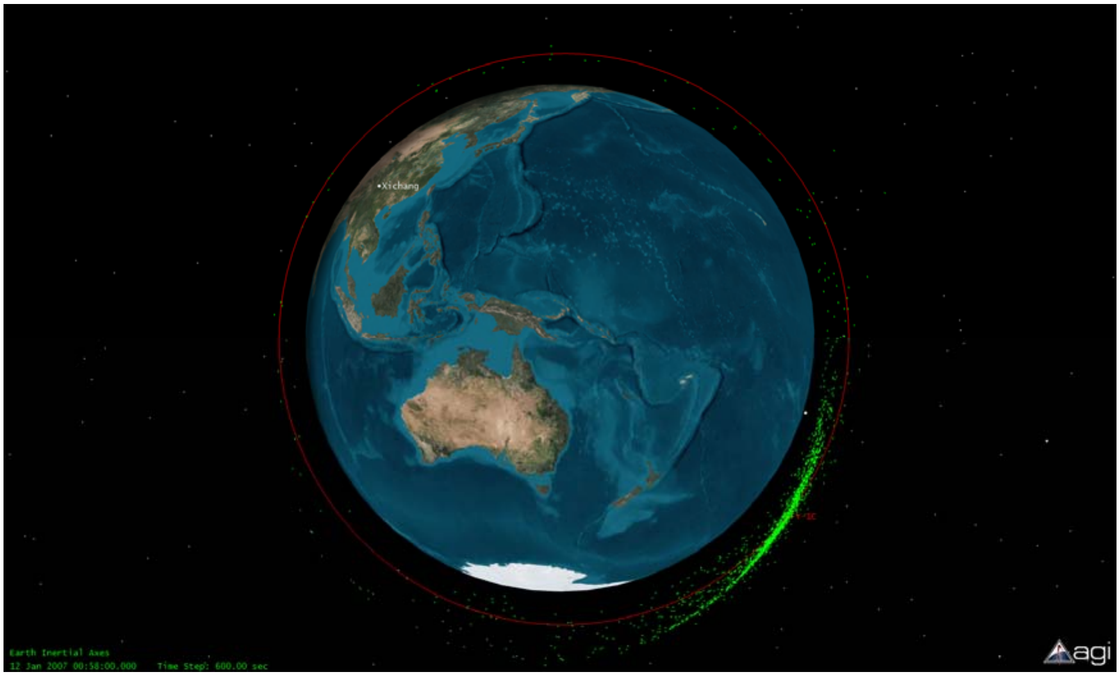

Fig. 4. Distribution of ASAT Debris Pieces on 2007 January 12 at 00:58 UTC. Within one and one half orbits, the debris cloud is already beginning to spread out along a significant portion of the original orbit.

China was reported to have used a DongFeng-21 (NATO Designation CSS-5) road-mobile intermediate range ballistic missile (IRBM) with a payload capacity of 600 kg and a range of 1,770 km to conduct this test (Fig. 5). Given the reported capabilities of this system and the relative geometry of FengYun 1C as it passed over the Xichang Space Center at the time of the event, it seems that this system would have the ability to have conducted this test from this location. Examination of the Xichang Space Center (Fig. 6) at 28 N, 102 E using Google Earth shows a raceway with a large pad suitable for launching mobile IRBMs at the northwest end of the complex which launches ChangZheng-2 (CZ-2) and CZ-3 space launch vehicles (ChangZheng is Chinese for Long March). According to the US Department of Defense, the PRC has 34–38 launchers for the DF-21 and somewhere between 19 and 50 of the missiles, providing a ready supply for additional tests [4]. The mobile nature of this launch vehicle has been a cause for additional concern regarding the potential for other tests or operational deployment.

Fig. 5. DongFeng-21 Road-Mobile IRBM being prepared for launch [3].

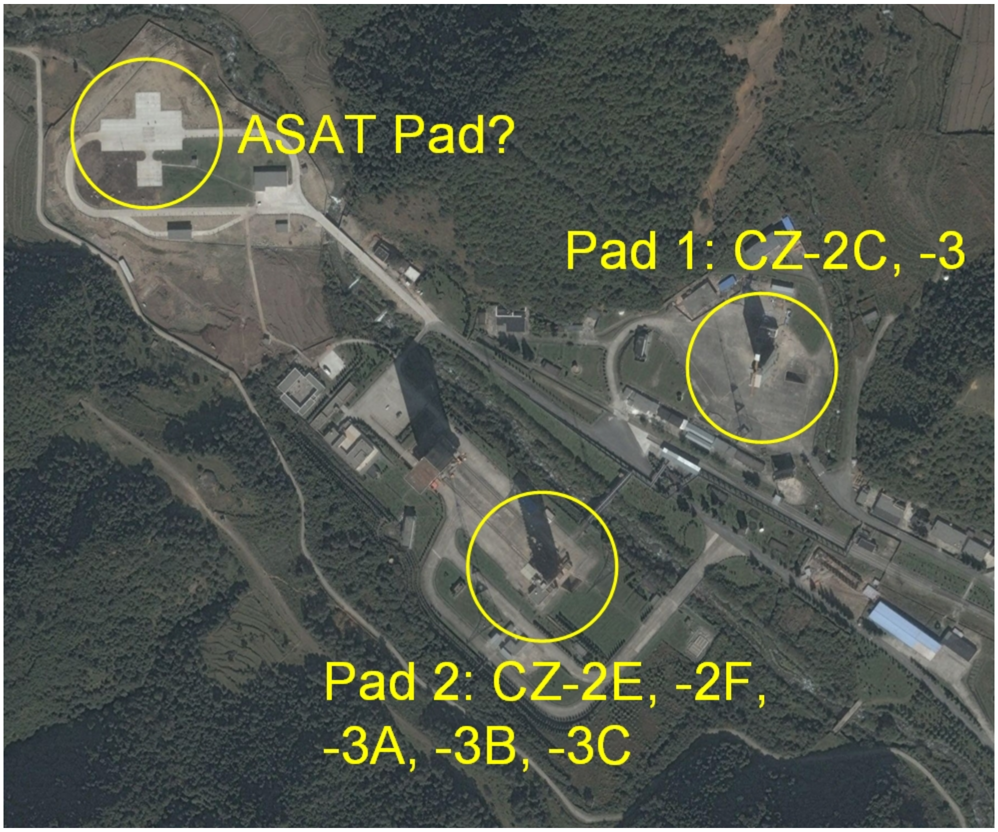

Fig. 6. Imagery of Xichang Space Center from Google Earth. Location of the possible ASAT launch pad is shown relative to the space launch pads.

One of the key values of performing the analysis of the initial event in STK was its ability to save an interactive animation, as an AGI Viewer file, to allow users without access to STK to be able to view the rapid spread of the resulting debris relative to the pre-event orbit of FengYun 1C using their free AGI Viewer software [5]. That animation is available, along with all the other animations, graphics, and analyses, on the CelesTrak web site [2].

3. IMPACT ON THE SPACE ENVIRONMENT

One of the most common questions asked following the event had to do with the impact on the space environment. The immediate quantifiable impact, supported by observations from the US Space Surveillance Network (SSN), has been the addition of at least 2,087 pieces of debris large enough to be tracked by the SSN sensors. Analysis by the NASA Orbital Debris Program Office also estimates there are 35,000 pieces of debris larger than 1 cm [6]. This size is significant since it is the level to which the International Space Station (ISS) is hardened against orbital impacts.

Using a Gabbard plot of the first TLEs for each piece of FengYun 1C debris (Fig. 7), it can be seen that the debris cloud ranges from a minimum perigee of 167 km up to a maximum apogee of 3,921 km, which in the 98.6 inclination of the original FengYun 1C orbit, crosses the orbits of many satellites in low-Earth orbit. In fact, of the 2,833 payloads for which TLE data is available (as of 2007 August 28), 1,893 of these pass through this debris cloud, causing at least some increase in the overall risk to each satellite.

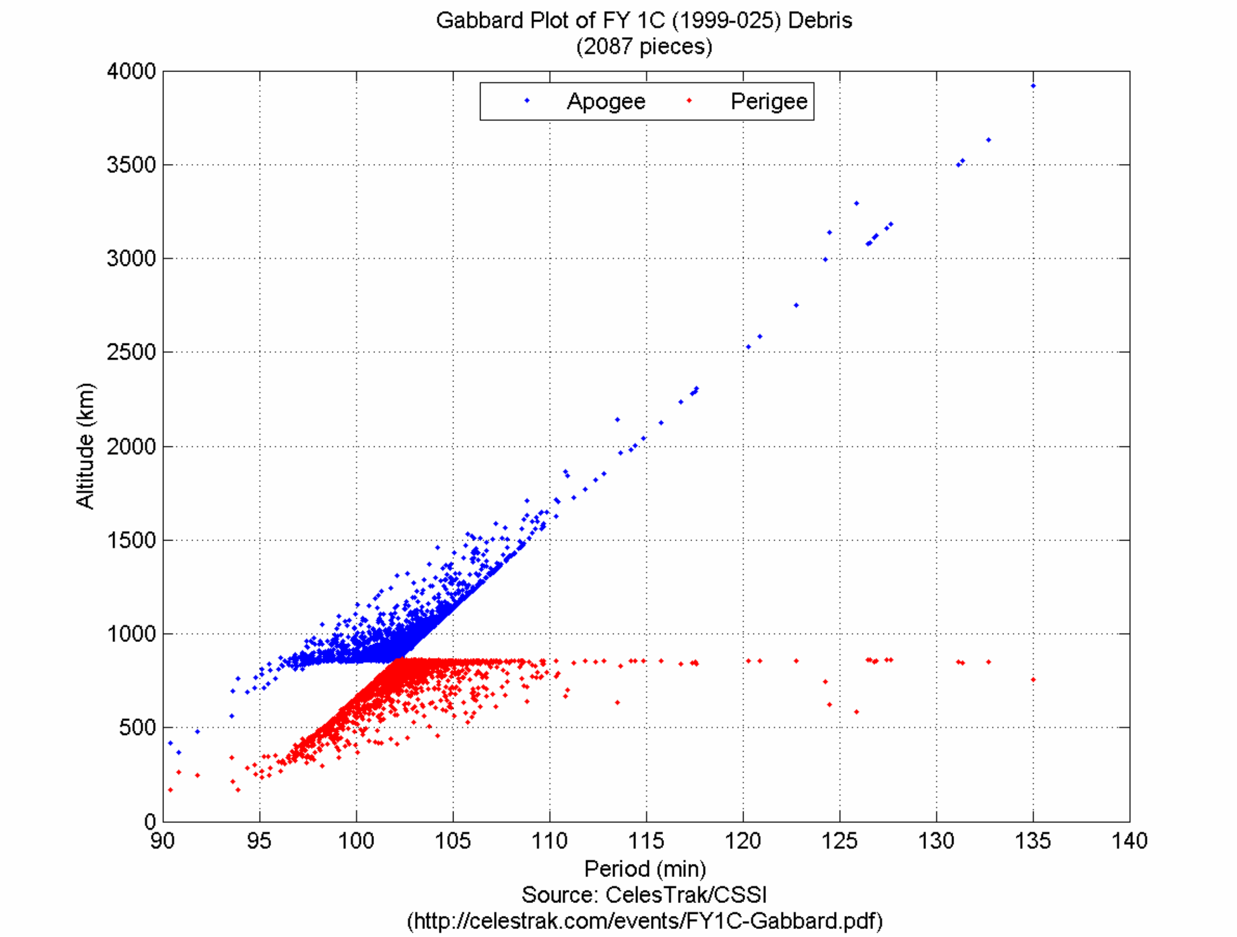

Fig. 7. Gabbard Plot of FengYun 1C Debris. Plot shows the apogee and perigee of each piece plotted against its orbital period.

One way to estimate the overall increase in risk is to look at the twice-daily SOCRATES (Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space) reports provided on CelesTrak [7]. Each report looks for any time any object (for which orbital data is available) is predicted to come within 5 km of any payload (operating or not) over the upcoming week. Using the data from the 2007 September 6 report at 1200 UTC, the debris from the Chinese ASAT test accounted for 2,873 of the predicted conjunctions for that week, out of a total of 10,619. That's an increase of just over 37 percent. While this is a significant increase in a very short time, it does not really help to assess the overall increase in risk for an individual satellite. Just as with a similar increase in automobile traffic, an individual's risk of being in an accident is determined by a number of factors, such as the traffic density on the roads that individual travels on. There is little a satellite operator can do to mitigate this increased risk other than constantly looking far enough ahead for specific threats to allow them to take preventative action (just as you do when driving your car).

Finally, it is informative to examine the overall impact of this event from a historical perspective in terms of the number of objects added to the public satellite catalog maintained by NORAD. Since the launch of Sputnik in 1957, NORAD has cataloged all objects reaching Earth orbit. Fig. 8 shows the growth in the number of items in that catalog over time. The blue line shows the overall growth in the number of items in the catalog, the red line shows the cumulative number of objects which have decayed or landed from orbit, and the green line is the difference—the cumulative number of objects in Earth orbit and beyond. It is clear that the number of objects added to the satellite catalog as a result of the Chinese ASAT test represents the single largest debris-generating event on record, far surpassing the 713 pieces cataloged in the breakup on 1996 June 3 of the Pegasus rocket body used to launch STEP 2.

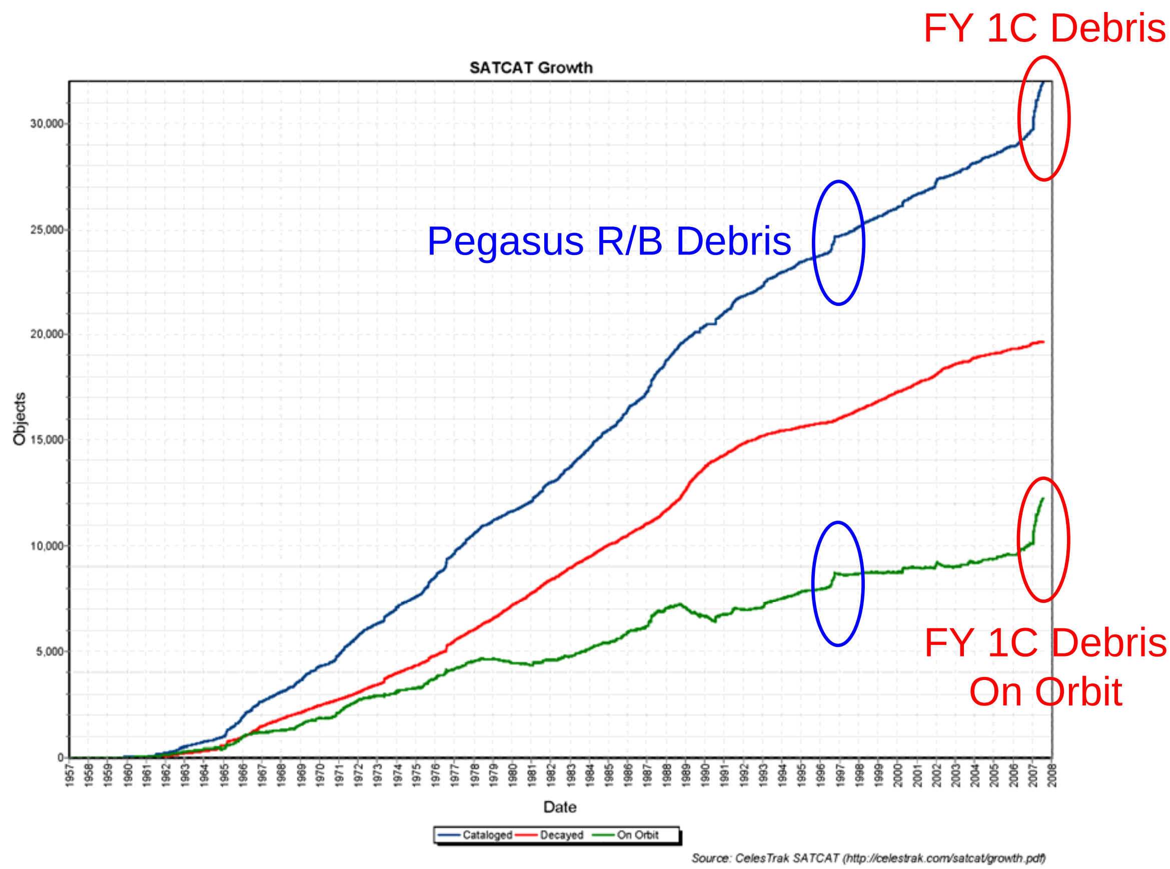

Fig. 8. Plot of the Overall Growth in the Number of Objects in the NORAD Satellite Catalog. The blue line shows the cumulative number of objects in the catalog, the red line shows the number decayed from orbit, and the green line shows the number of object still in orbit.

4. CURRENT DEBRIS ENVIRONMENT

CSSI also wanted to take advantage of the coverage on this event to educate the public on not only the impact of the Chinese ASAT test debris on the near-Earth space environment, but to show how it fits in the larger space debris environment. In addition to the views shown in Fig. 9, which show where the Chinese ASAT test debris cloud was on July 9 and its density relative to the other objects in Earth orbit, CSSI provided a series of interactive animations which allows users to view not only this debris but all the objects in Earth orbit out to geostationary orbit and beyond [2].

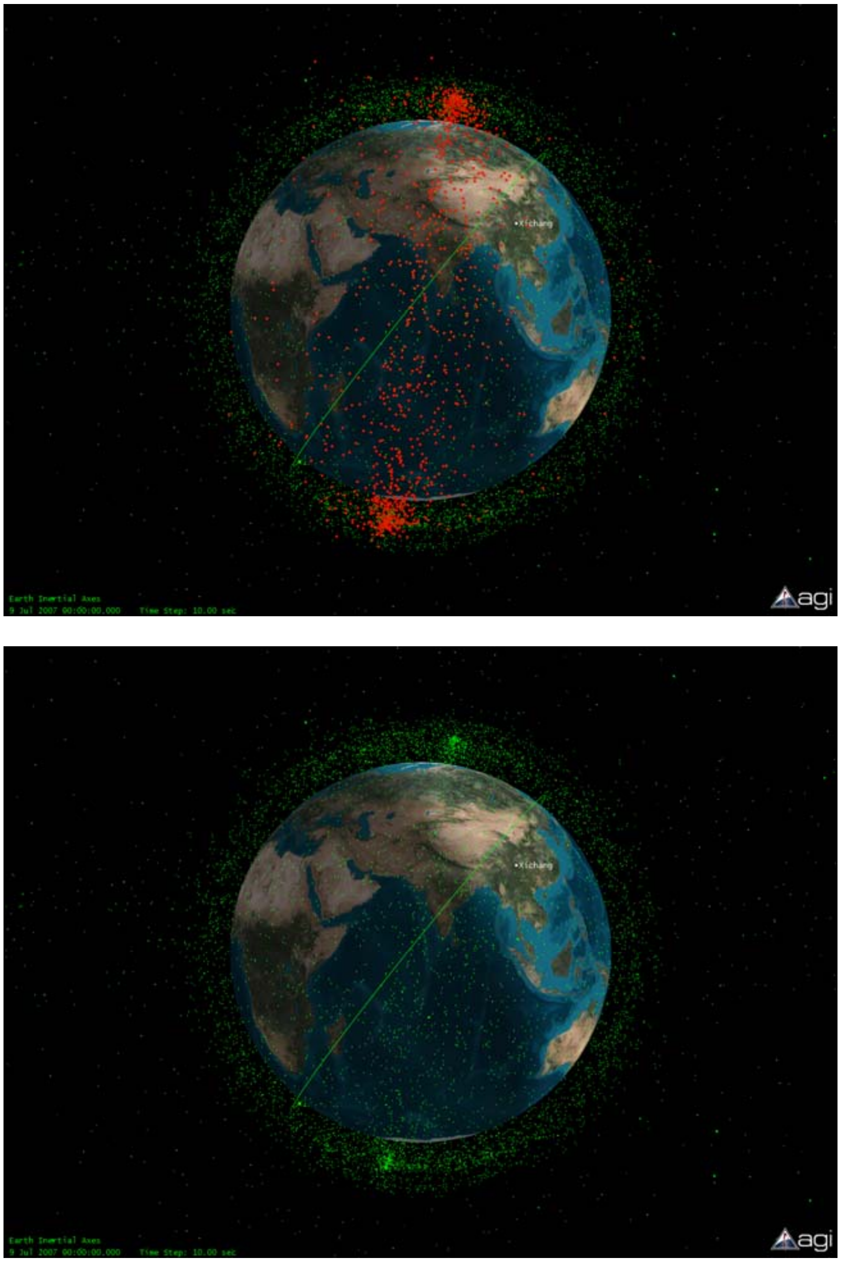

Fig. 9. Distibution of Chinese ASAT Test Debris as of 2007 July 9. Top figure shows the Chinese ASAT Test debris in red, relative to the other debris in Earth orbit. Even without highlighting, the debris cloud is still visible.

5. ORBITAL LIFETIMES

The final piece of analysis was developed in response to suggestions by some that most debris from this event would decay within 10 years. These assertions seemed to be based again on preconceptions rather than actual analysis. Predictions of orbital lifetimes can be difficult for single objects of known mass, size, and attitude, due to the lack of good models to predict atmospheric density. The difficulty is compounded in attempting to determine the orbital lifetimes for this debris because the size and mass are not known and the pieces are likely small enough that they could experience lifting effects in addition to drag effects.

In an initial attempt to explore this question, CSSI used the Lifetime tool in STK to look out one hundred years to see if these assertions were reasonable. Without specific information on size, mass, and shape of individual pieces, it was assumed that all pieces were large enough to be tracked by US SSN (approximately 10 cm) which, given the size of the original satellite, meant that each piece would be roughly the same size. Assuming they had roughly the same densities, the total dry mass of satellite prior to the test (850 kg) was divided by the number of pieces currently in the public SATCAT (2,087), yielding an average mass of 0.41 kg.

STK has nine atmospheric models which can be used in its Lifetime tool. Sensitivity analysis using the various models showed differences on the order of months, which was expected to be a small difference when compared to the overall lifetime of most of the pieces. Therefore, the Jacchia-Roberts model was chosen, since it is an analytical model and runs much faster than the other models, most of which are numerical or not as sophisticated.

The initial analysis assumed a coefficient of drag of 2.2. This choice bears additional investigation, since recent research shows that coefficient of drag increases with orbital altitude and more irregular shape [8]. Future analysis will examine curves for higher coefficients of drag (which would be equivalent to increasing the size or reducing the mass) and will be made available on CelesTrak when ready.

The analysis used the latest Schatten space weather predictions for the period 2006 October until 2030 May. STK/Lifetime replicates this cycle throughout the analysis period (2007–2107). Considerable variability is likely in the overall results, though, since our ability to predict solar and geomagnetic cycles is still quite crude. The impact, however, should not be as significant for the majority of debris pieces, which are above the original FY 1C orbit.

The initial results, shown in Fig. 10, seem to clearly contradict the assertions about the longevity of the debris cloud. Just under 7 percent (135 pieces) are predicted to decay within 10 years and over 79 percent are still predicted to be in orbit 100 years from the event.

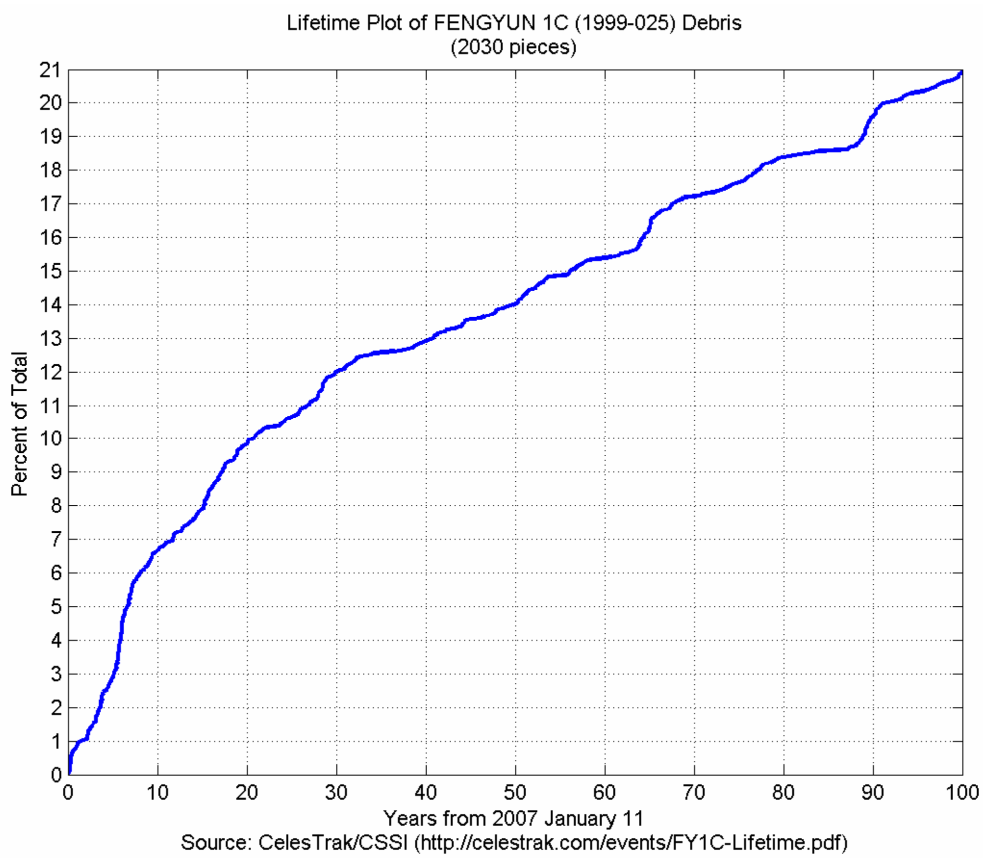

Fig. 10. Predicted Orbital Lifetimes of Chinese ASAT Test Debris.

6. SUMMARY AND CONCLUSIONS

The direct-ascent ASAT test conducted by the PRC on 2007 January 11 was the worst debris-generating event on record, generating at least 2,087 pieces of debris large enough to be tracked by the US SSN. It far surpassed the previous record of 713 pieces from the explosion on 1996 June 3 of the Pegasus rocket body used to launch STEP 2. This event has significantly increased the amount of debris in Earth orbit and much of the debris will likely remain in orbit for centuries. This 20 percent increase in the number of objects in Earth orbit has produced a 37 percent increase in predicted conjunctions. The implications of these findings is that this debris will further complicate satellite operators attempts to avoid on-orbit collisions and will present a continual and increasing challenge for maintaining space situational awareness.

For more details on this event, including expanded analysis, see the CelesTrak web site [2].

7. REFERENCES

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