A Preliminary Analysis of the Chinese ASAT Test

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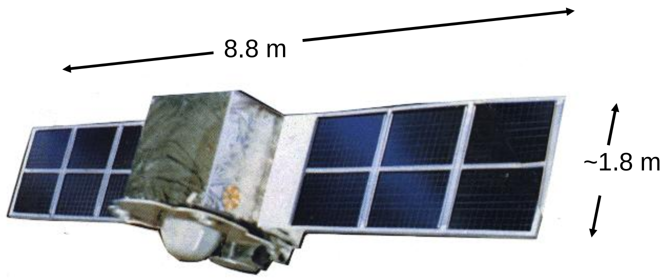
1. A Review of the Fengyun 1C physical and orbital properties
2. Estimates for the Interceptor booster
3. An analysis of the debris pattern from the collision
4. Possible use of China's phased array radar facility
5. Optical vs. Radar guidance:
6. Conclusions

The Target Satellite



Mass: 880 kg

Orbital parameters:
Apogee: 875 km
Inclination: 98.59°

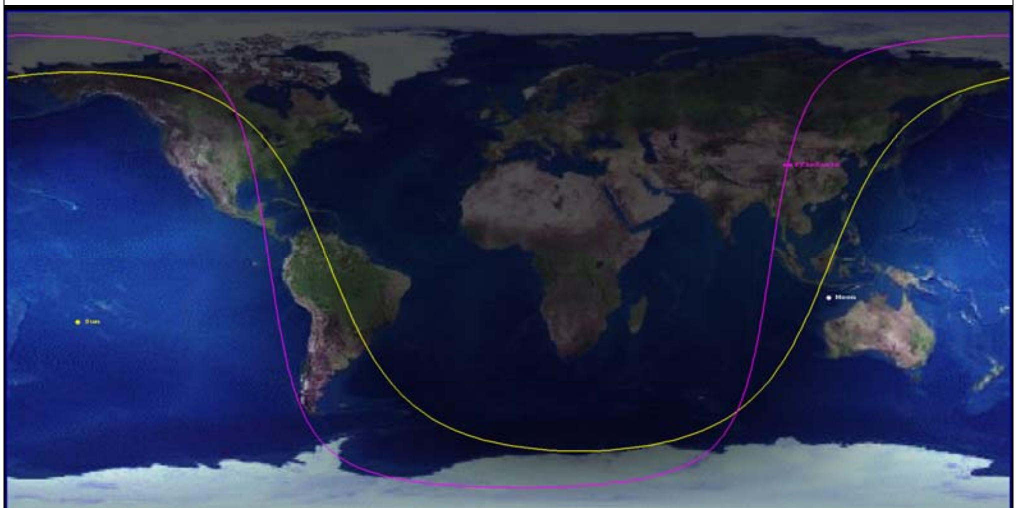
At time of interception:

Longitudinal speed: 7.42 km/s

Altitude: 856 km

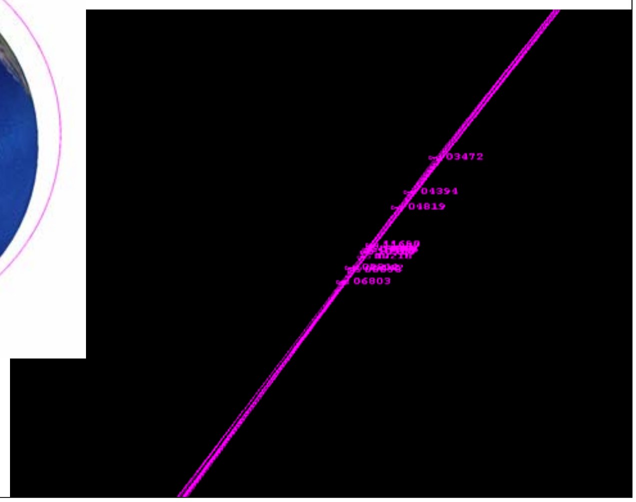
Launched May 10, 1999, the Fengyun 1C satellite broadcast on the 137 MHz band reserved for meteorological satellites. The satellite carried high density reaction wheels (for keeping the solar cells pointed toward the sun) and batteries which could be important for colliding with the interceptor.

Fengyun-1C was placed in a sun-synchronous orbit



The orbital plane of the Fengyun 1C satellite processes around the Earth in 24 hours so that it keeps the same position with respect to the sun and the Earth. While the interception occurred during the night at the launch site, the satellite remained fully illuminated by the sun because of its 860 km altitude.

There is no evidence that China changed the orbit of the target satellite anytime in the week before the interception.



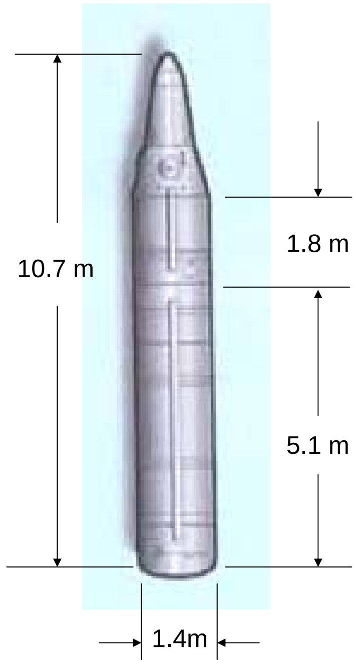
These correspond to the TLEs from 3 January to 11 January 2007.

Taking the satellite TLE’s for the week before the collision and extrapolating forward toward the time of the collsion gives a very small bunching. This indicates that the Chinese did not maneuver the satellite prior to the interception; contrary to some reports in the press.

Searching for the Interceptor Booster

It has been widely reported in the press that the Chinese used their DF-21 IRBM (known as in the West as the CSS-5). This is a solid propellant, two stage missile that is launched from a road mobile TEL.

Modeling the DF-21:



Total weight = 14,700 kg

Payload = 600 kg

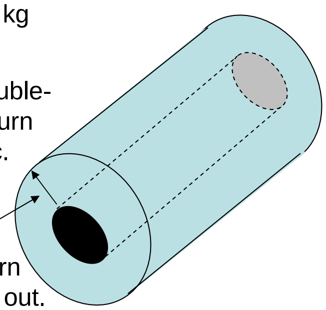
Booster weight = 14,100 kg

Scaling by stage length:

1st stage: 10,389 kg

2nd stage: 3,710 kg

A sophisticated double-base grain has a burn rate of 1.2 inch/sec.

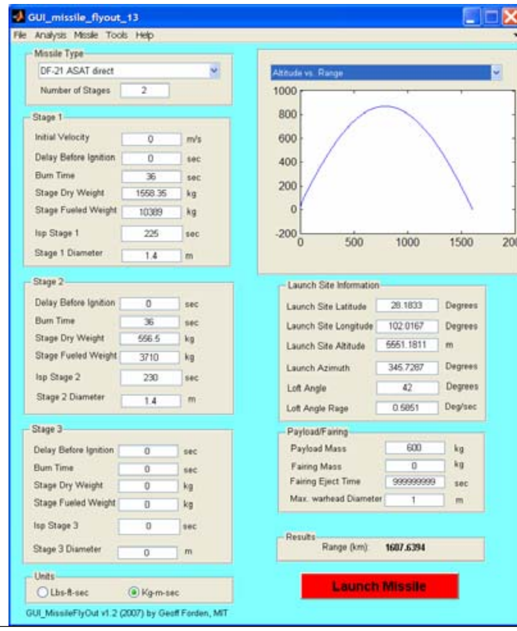


Solid grains burn from the inside out.

=> Burn time is independent of stage length: 36 s.

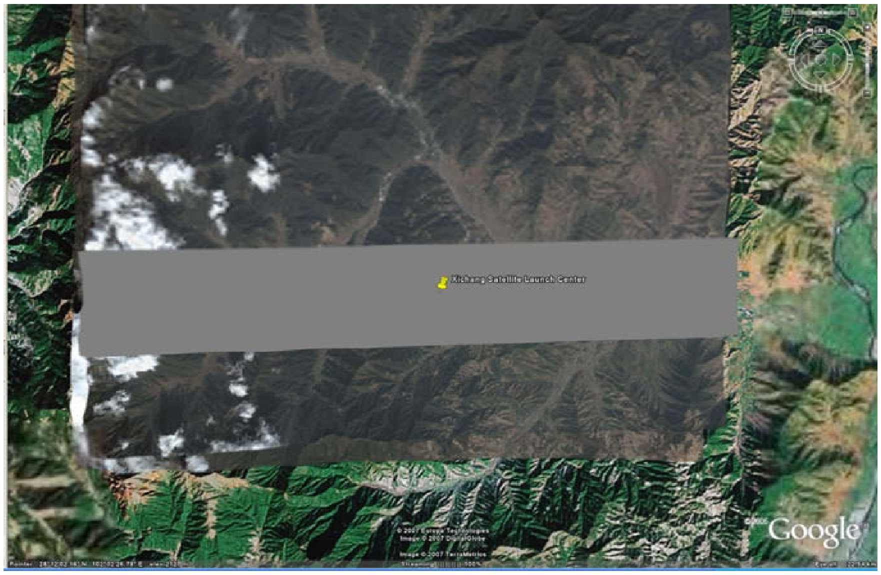
There is little technical information about the DF-21 available in the open literature. In fact, the only information after an extensive web search is that the total weight is 14.7 tons (with fuel), the payload is 600 kg, the length and the diameter are 10.7m and 1.4m respectively. Using a Western diagram for the missile, the lengths of the two stages can be estimated and, extracting even further by scaling the weight of each stage by its length gives total stage weights. Then, assuming a conservative mass ratio of 0.85 for each stage (the payload is not included in this calculation), an estimate for the amount of fuel can be determined. Finally, the burn rate of each stage must be estimated. For grains (ie the propellant) of greater than 0.5m in diameter, the most common configuration is for a central bore that burns from the inside out, all along the motor. Picking a double base, as a fairly conservative propellant, gives an Isp of 220, and a burn rate of 1.2 inches per second. This means that, since both the first and the second stages have the same diameter, they have the same burn time, which is estimated as 36 seconds.

This leads to the following model for the DF-21 ASAT:



This can be simulated using GUI_missileFlyout, which is available at http://mit.edu/stgs/downloads.html for windows based PCs.

Google Earth Censored the launch site:

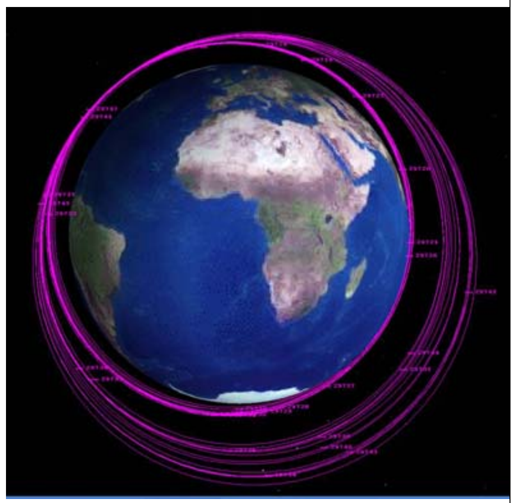


China has published the geographical location of its Xichang Satellite Launch Site in its Long March users manuals (manuals used to potential clients of China's satellite launch services. Nevertheless, it is clear that something has "censored" Google Earth's image of this spot. Google has a history of being willing to censor its online services at the request of the Chinese government.

Backtracking debris orbits

At time of interception

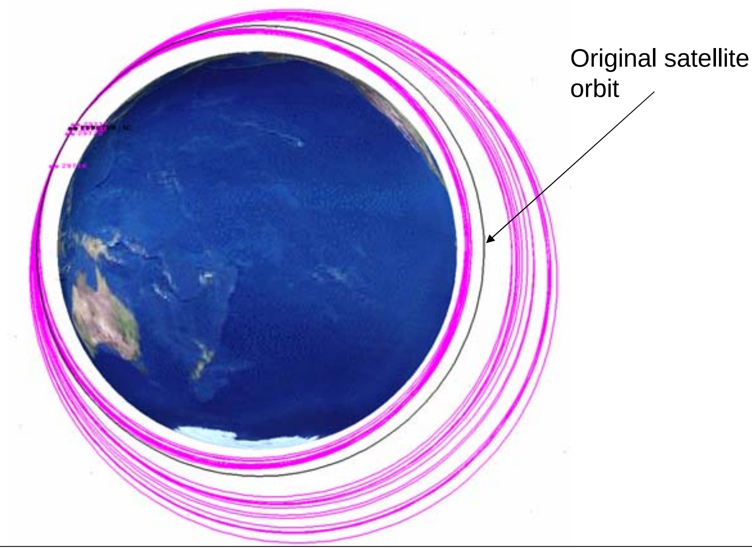
(22:26 GMT, 11 Jan 2007)



On the day I first became interested (18 Jan 2007)

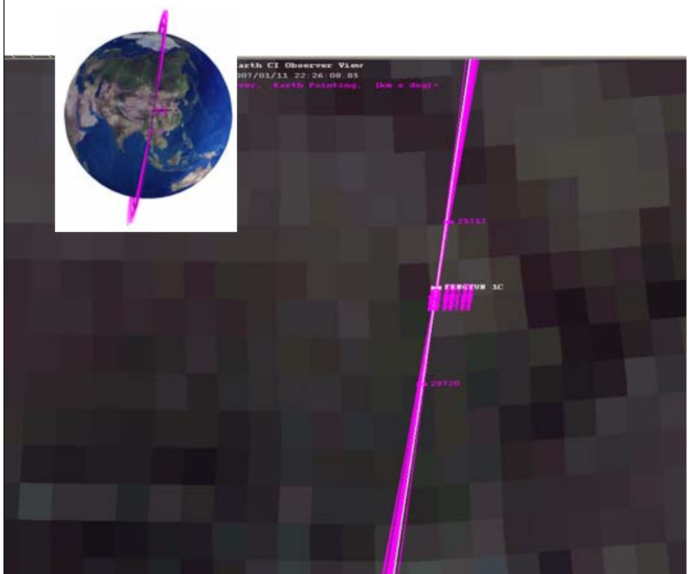
Some 40 pieces of debris have been tracked and cataloged by NORAD. Some of these pieces have apogees as high as 3,500 km. As we shall see, these correspond to orbital velocities at the time of the interception of over 8 km/s, much greater than the velocity of either the initial satellite or the interceptor (or their velocities added together—more about this later.) The orbital parameters of these debris pieces can be backtracked to the point in time when they are essentially co-located; this is the point of the interception.

The gap between these regions of debris must be due to observational limitations of tracking closely packed pieces.



Note the gap between the upper and lower debris bands. The orbit of the original satellite lies between these two bands, indicating that the gap is an artifact of the tracking algorithm where a unique object must be observed at least three times to have its orbital parameters estimated. If there are hundreds (or thousands!) of objects very closely spaced, it is impossible to be sure you know which observations below to which particles each time. The debris in this “gap” will start being cataloged as time goes on and they get more spaced out.

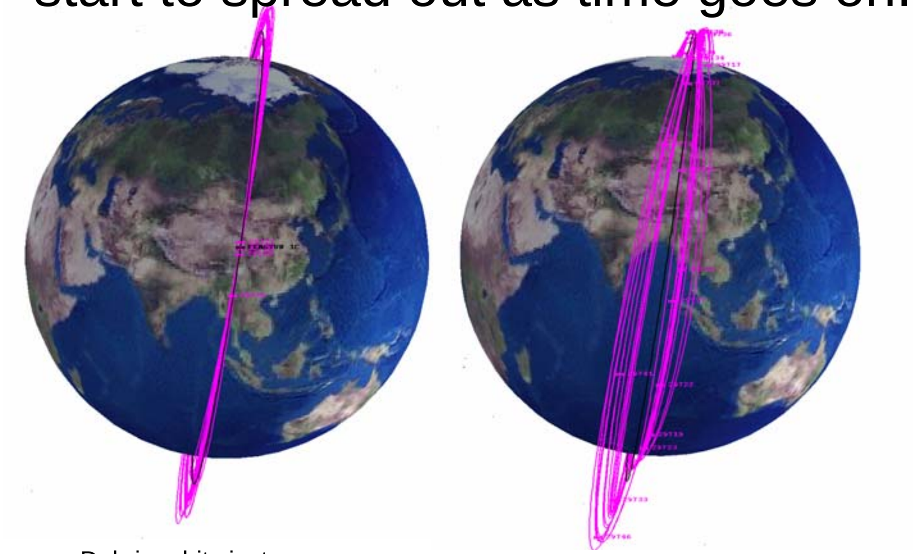
Debris is tracked back to the point of interception but:



1. Except for one outliner (29717, the second debris particle to be found) all the pieces are ahead of the satellite.
2. All the pieces of the debris ended up on "one side." More will be said about this whe I discuss the velocity distributions.

The debris can be "tracked" backwards to the point where they are closest together, which is 22:26 GMT on 11 January 2007. There is, however, a systematic displacement of the debris from the position of the target satellite at the same time (except of the one of the two "outliers". One possible explanation of this is that the drag coefficients for the tracks have systematically been underestimated. The most likely cause of this underestimation is that the pieces are much lighter than the average satellite—which is almost certainly true for those objects that land in the high band of debris.

Even the debris already tracked will start to spread out as time goes on.

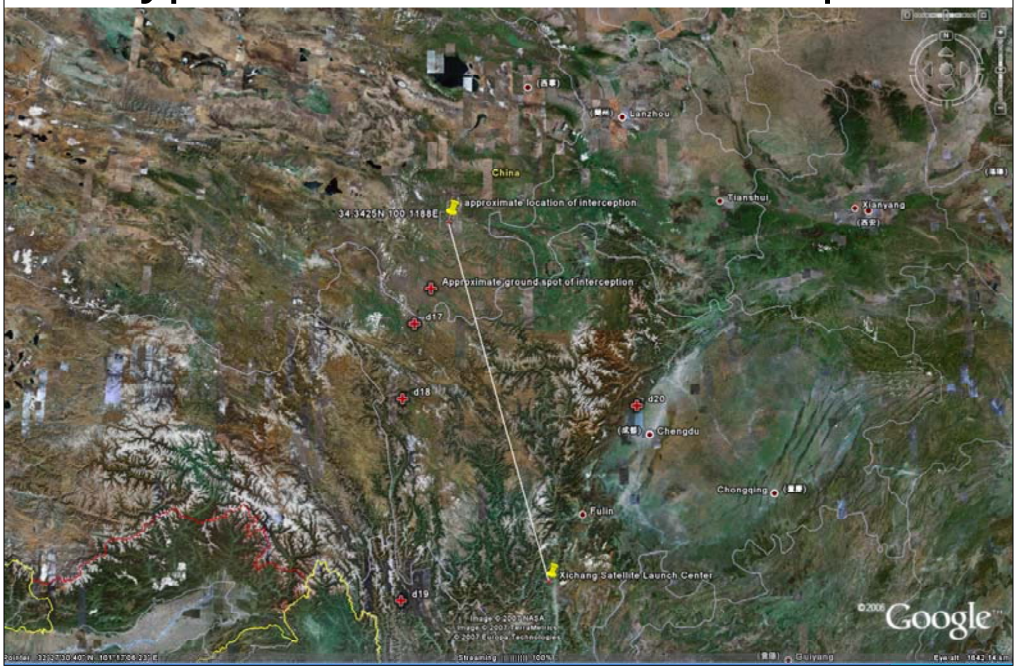


Debris orbits just after collision.

Debris orbits as they will be on Feb. 2 2007

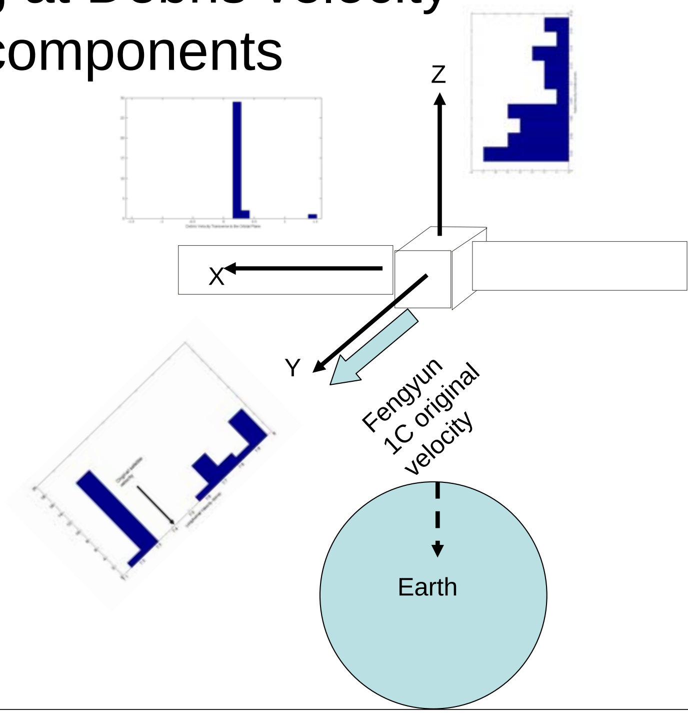
As more and more debris is "discovered" it will be clear that more and more of space is threatened. However, even the debris already tracked will start to spread out with time and threaten more and more satellites.

Hypothesized track of interceptor

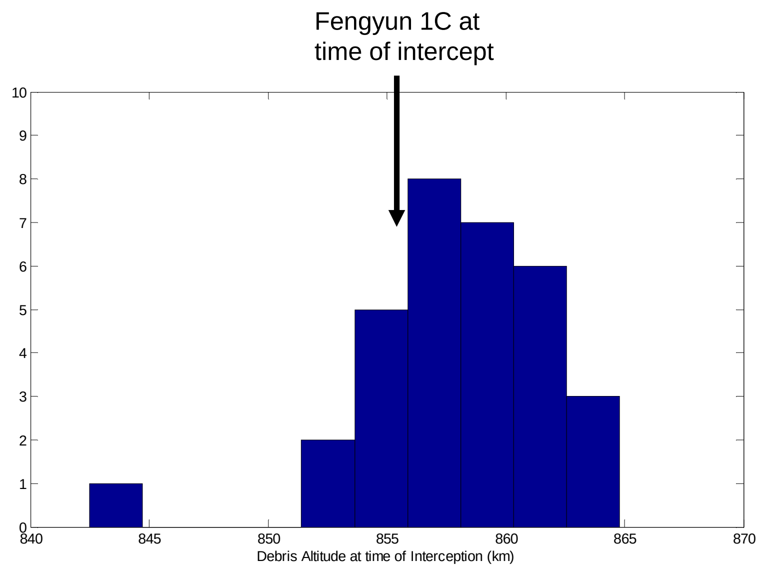


China has a space launch facility that is within striking distance of the interception point. The ground distance separation of these two places is about 700 km. This distance, and the angle between the interceptor trajectory and satellite trajectory will have significant implications for limiting the possible interception speeds.

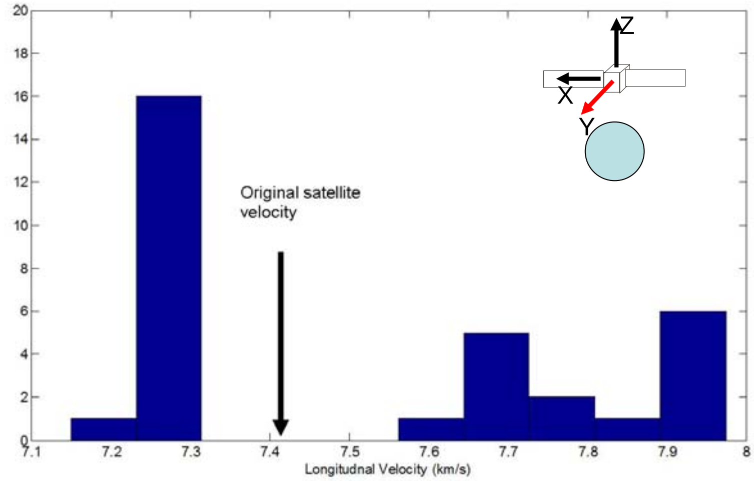
Looking at Debris velocity components



The debris is roughly at the same altitude as the original satellite.

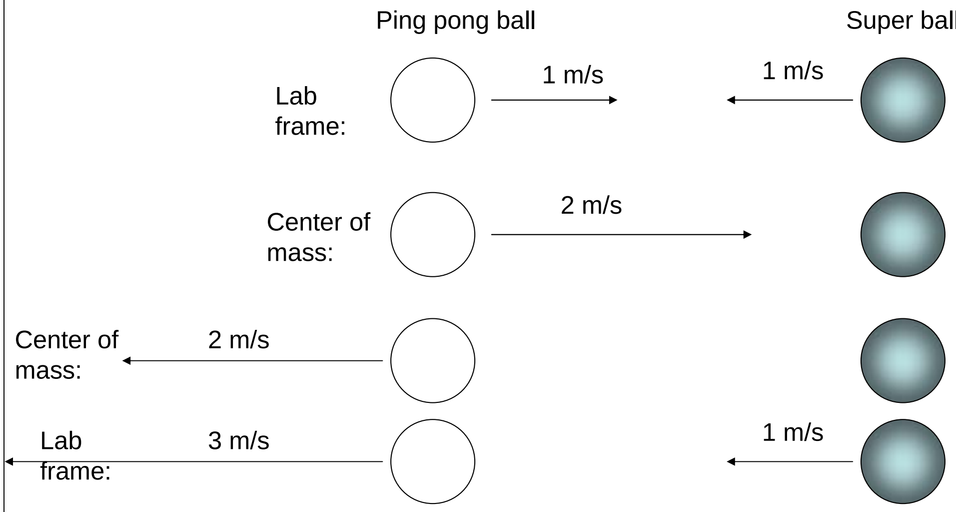


Longitudinal velocity of debris



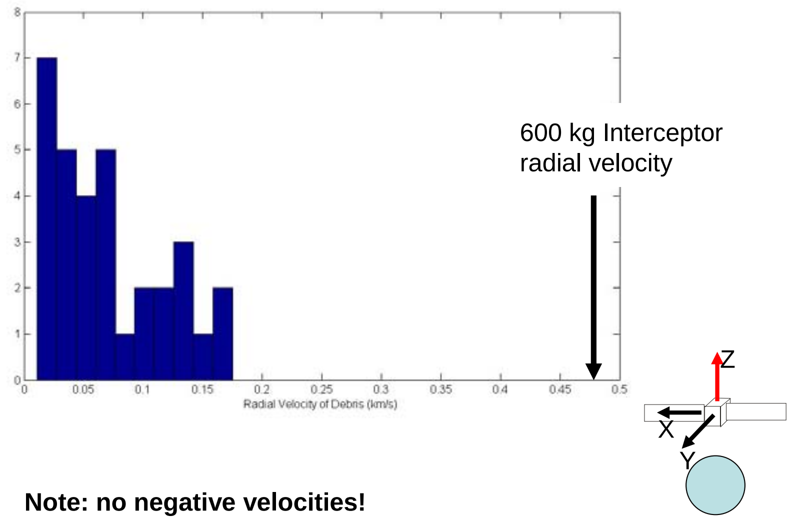
Note: the gap is most likely due to observational difficulties in tracking individual pieces in the "swarm."

How is it possible to get such high velocity debris?



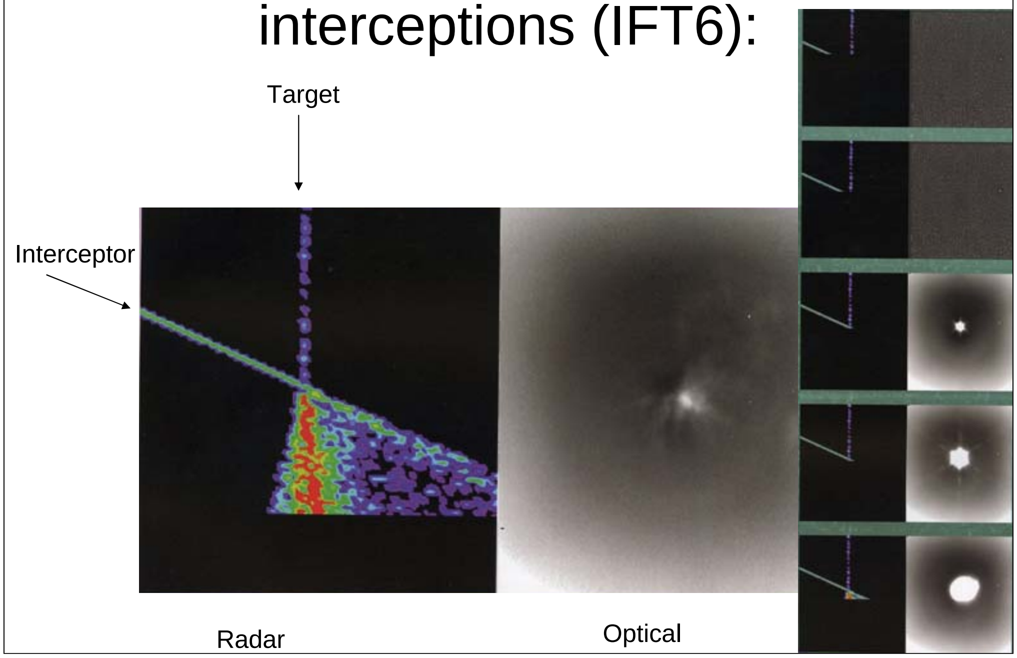
Collisions between very light objects (such as a ping pong ball) with a very massive object (the superball) can result in the light particle moving very much faster after the collision than before. At the orbital velocities the ASAT collision took place at, you can think of the two objects, the satellite and the interceptor, as “liquids”—ie they are not held together by significant forces. If a low density portion of the interceptor collides with a high density of the satellite, the low density piece can bounce back with velocities as much as 15 km/s, well past the 11.2 km/s escape velocity of the Earth.

The radial debris velocities:



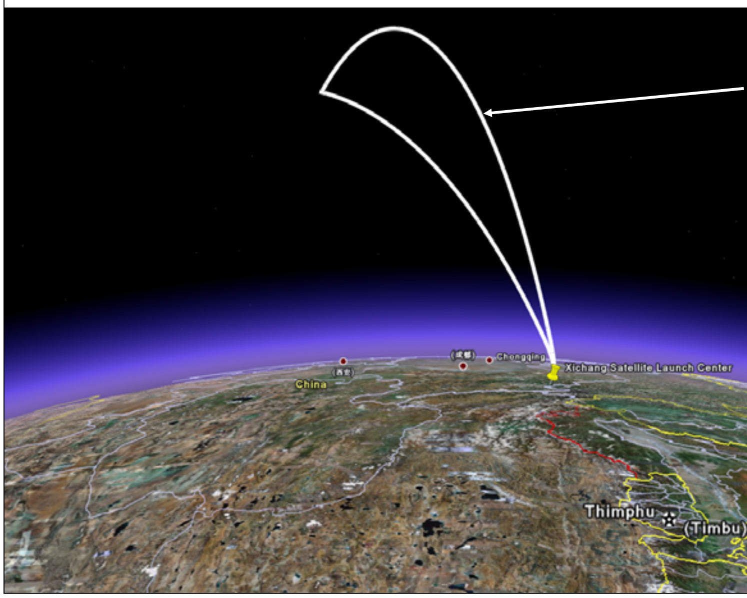
Note: no negative velocities!

Experience from previous interceptions (IFT6):



Note that the main debris follows the tracks of the interceptor and target (with other pieces filling in the angular region between them). There are a few tracks that scatter back in the direction of the incoming interceptor but none in the direction from whence the target came from. In the Integrated Flight Test, both interceptor and target have velocities greater than 6 km/s.

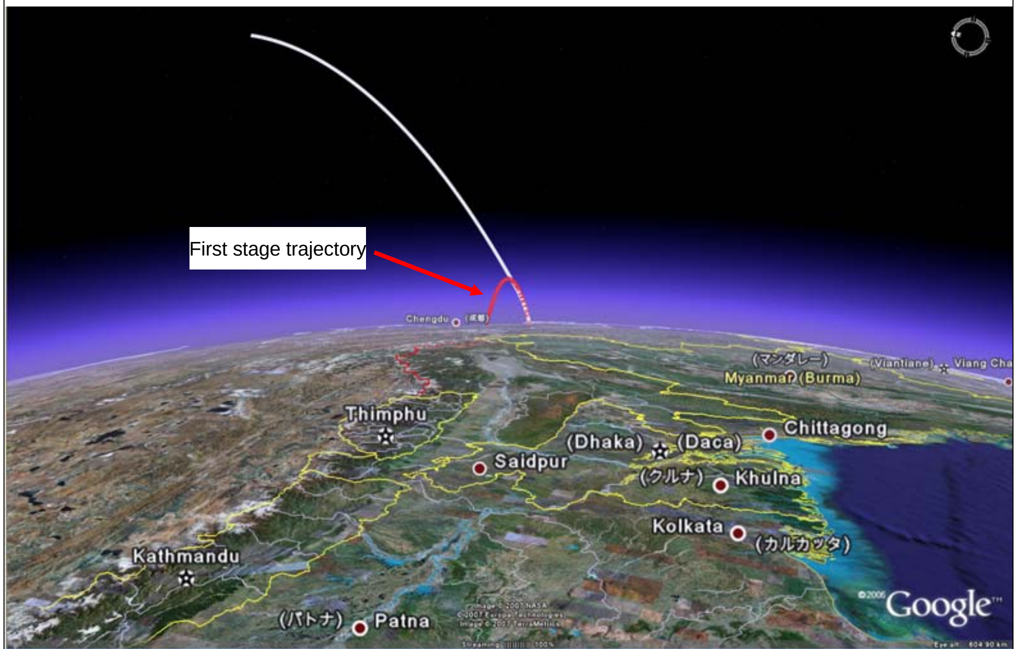
The two possible interception trajectories:



Lofted trajectories should impart some downward velocity—so this can be ruled out!

Assuming the interceptor payload has the same 600 kg mass that the DF-21's warhead is supposed to weigh, then there are two different trajectories that the interceptor could take to collide with the satellite (not shown here). The lower one is the "direct" trajectory and represents the fastest path for getting to the collision point. The higher, or lofted, trajectory takes considerably longer (785 s) from launch to interception but would also allow an optical sensor even more time to observe the target and more time for the interceptor to maneuver. Longer times to maneuver can reduce the requirements for the interceptor rocket engines.

Since no debris is observed moving down, we can conclude that it was the fast, or lower, trajectory that was used.

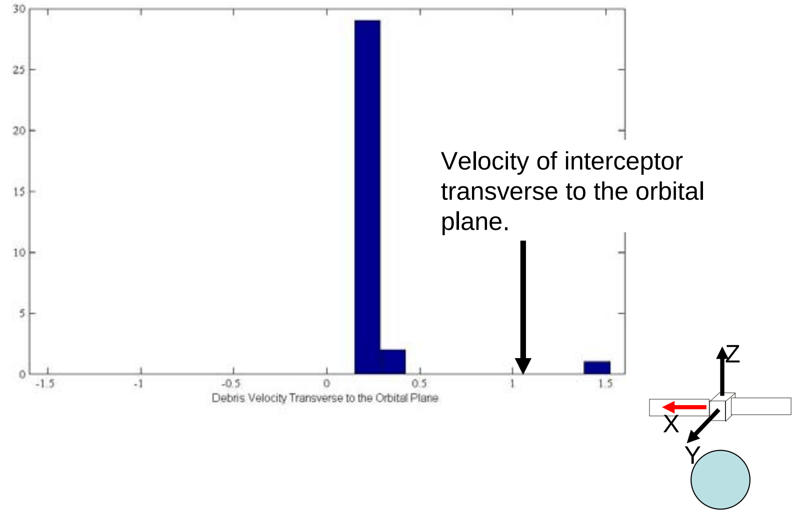


First stage trajectory
Chengdu
Myanmar (Burma)
(Vientiane)
Thimphu
(Dhaka)
(Daca)
Chittagong
Saidpur
(クルナ)
Khulna
Kolkata
(カルカッタ)
Kathmandu
(パトナ)
Patna
Google

The 1st stage lands in an unpopulated, mountainous region.

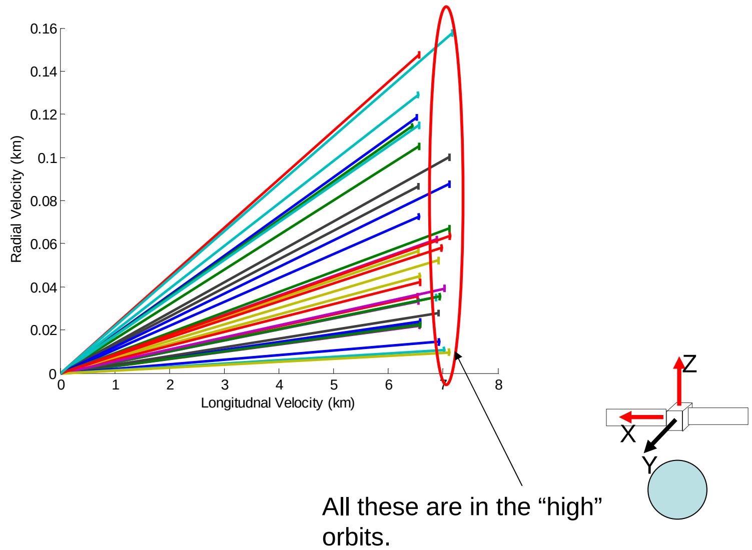
China had little to worry about in terms of range safety since there are few, if any, population centers along the entire interceptor trajectory.

Debris velocities transverse to the orbital plane:

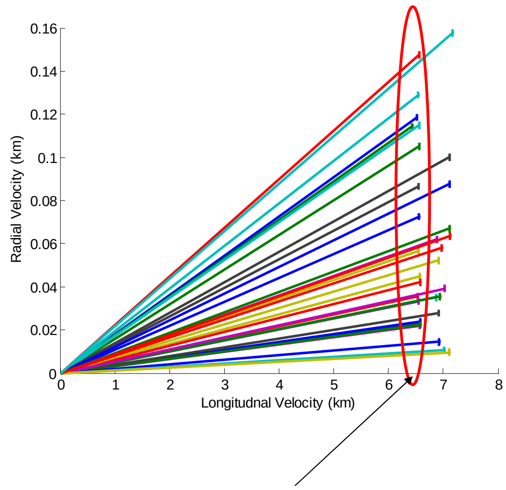


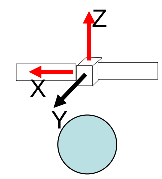
There are no tracked debris going opposite the direction of the interceptor. The few debris that have been tracked mostly have very little transverse velocity compared to the interceptor. Most of the debris from the interceptor itself would have velocities comparable to the interceptor➔ they would not make it into orbit. The one piece was tracked, and hence has a significant velocity along the longitudinal direction, and has a large transverse velocity probably comes from a light piece of the original satellite that hit a heavy piece of the interceptor, much like the pieces with large apogees where most likely light pieces of the interceptor that hit heavy pieces of the satellite.

There is no correlation between the radial velocity and the longitudinal velocity.



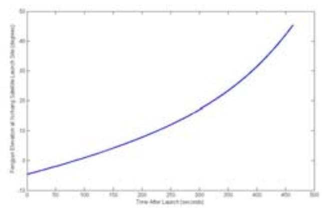
There is no correlation between the radial velocity and the longitudinal velocity.



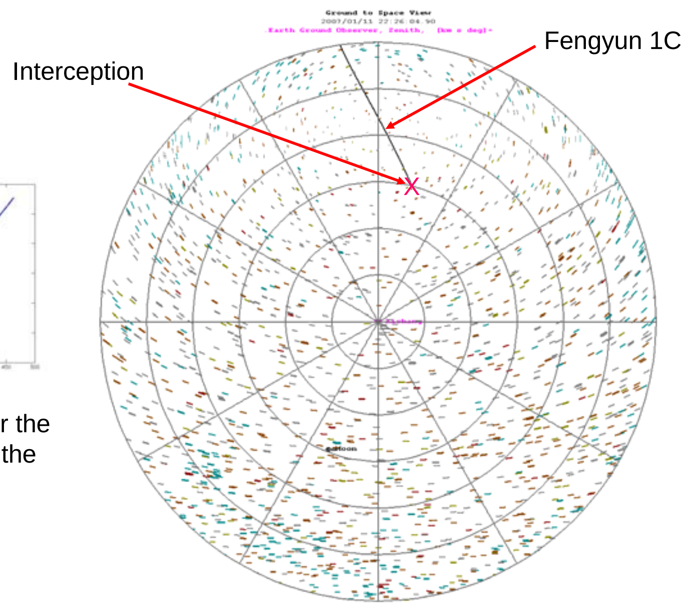


All these are in the “low” orbits.

Fengyun 1C as seen from Xichang Satellite Launch Center

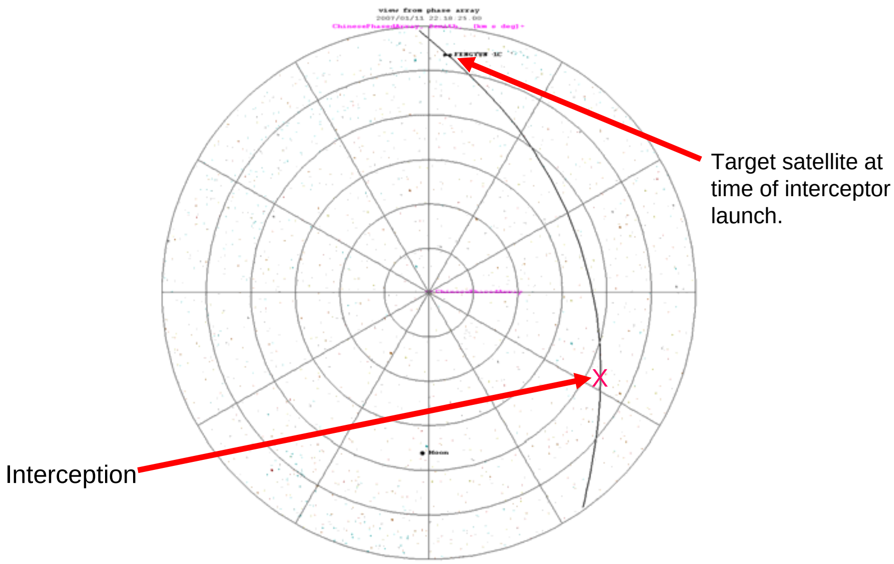


The satellite appears over the horizon 86 seconds after the interceptor launches.



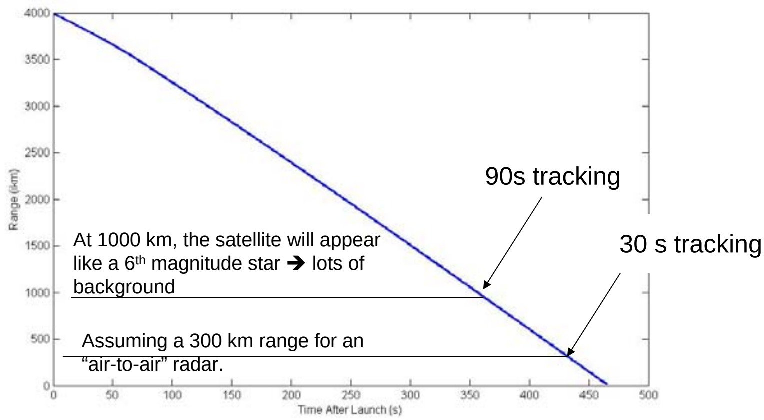
The FY-1C satellite was below the horizon when the interceptor was launched.

View from China's Large Phased Array Radar:



China supposedly (according to globalsecurity.org) has a large phased array radar at 40o36'20"N 115o02'47"E that was built to provide early warning of any Russian attack and also serves as a space surveillance station. Presumably because of its early warning mission, it faces north and east, which would mean it could have tracked the satellite well before the interceptor had to launch. (It rose above the radar's horizon at 22:16, 2 and half minutes before the interceptor launched and 10 minutes before the interception, which was also visible to the radar. Thus, the Chinese could have an excellent view of the entire interception for analysis and diagnosis.) I have not been able to identify the phased array station on Google earth.

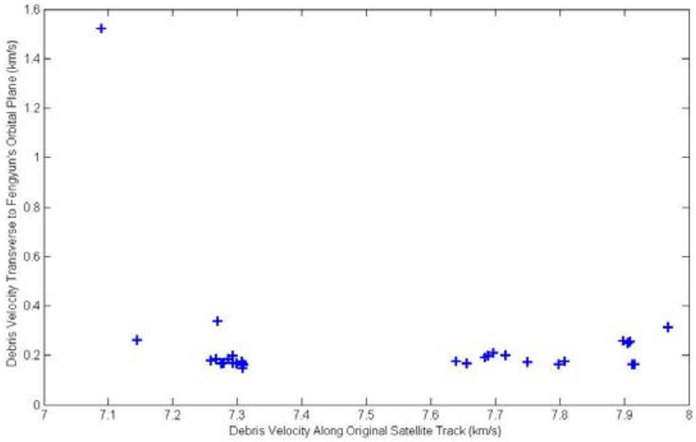
Radar vs. Optical Tracking:



It is unknown what type of tracking capabilities are on the interceptor. In principle it could be either an optical tracker—using a camera much like is available in the digital vedio cameras that are widely available today—or a radar tracker like a fighter aircraft might have. Both have advantages and disadvantages. One of the most important, is that the range—and hence the amount of time available for tracking—of the optical tracker would be considerably greater than the radar tracker. The amount of time the on-board sensor has to track the target will reduce the amount of fuel needed and hence the weight of the interceptor. Since the target satellite is always in sunlight, there is no problem with that. However, the interceptor tracking algorithm for an optical system must be able distinguish the target from background stars, something that would take considerable development time and effort.

Conclusions

1. An interceptor mass of 600 kg is consistent the debris velocity patterns. It cannot be much more than that if it is going to be able to reach the target satellite in this incident. (1000 kg is ruled out.)
2. A 600 kg interceptor could be used to destroy geostationary satellites in a direct accent mode.
3. China most likely “coordinated” the interception with a radar (possibly a phased array but it could also be a large dish antenna) at a distant location.
4. The most likely on-board tracker is an optical system. If China used such a system, it most likely flew previous test missions during its development.



Debris Velocity Transverse to Fengyun's Orbital Plane (km/s)
Debris Velocity Along Original Satellite Track (km/s)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
7
7.1
7.2
7.3
7.4
7.5
7.6
7.7
7.8
7.9
8