Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's Meteoroid and Orbital Debris Programs

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Rising concerns about meteoroids and orbital debris, which put spacecraft and astronauts in potential danger, have prompted decision-makers to look into strategies for lessening the hazard they pose. Derelict satellites, equipment, paint fragments and other debris orbiting Earth—also called "space junk"—have been accumulating over many decades and could significantly damage, or even possibly destroy, satellites and human spacecraft if they collide. In 2010, NASA asked the National Research Council to evaluate the programs within the agency responsible for addressing meteoroids and orbital debris. This report examines NASA's efforts to understand the meteoroid and orbital debris environment, what NASA is and is not doing to mitigate the risks posed by this threat, and how they can improve their programs.

Background

On January 11, 2007, China conducted an anti-satellite test (ASAT) which involved an intentional collision with another Chinese-owned satellite. The event was followed by an accidental collision between the Cosmos 2251 and Iridium 33 satellites in February 2009. As the largest debris-generating event in the history of manmade orbital debris, the collisions, as shown below, more than doubled the amount of cataloged debris fragments. Two years after the destruction of the satellite, only 50 pieces of debris had decayed from orbit and added to decades of accumulated orbital debris.

The current population of orbital debris is numerous enough to potentially create a situation in which debris will continually collide with itself. In other words, existing objects are more likely to collide with other debris and produce additional smaller pieces, increasing the chance of further collisions and satellite failure.

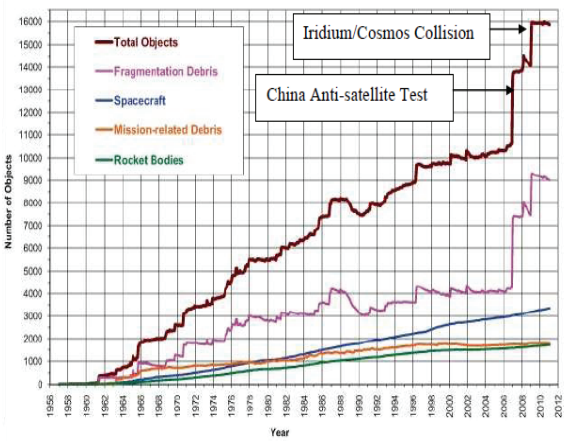


Figure 1.2 This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Network. Fragmentation debris includes satellite breakup debris and anomalous event debris, while mission-related debris includes all objects dispensed, separated or released as part of a planned mission. (Source: OD Quarterly News, Volume 15, Issue 1, January 2011)

Orbital Debris Hazards and Mitigation

As a result of the increase in the orbital debris population—and as a precautionary measure against meteoroids—NASA, among other U.S., international and commercial entities, has taken precautions to mitigate, deter or protect spacecraft from damage. For example, MMOD shielding was added to the International Space Station (ISS) to protect both spacecraft components and astronauts from potentially catastrophic damage resulting from smaller, untracked debris and meteoroid impacts. NASA has had an official orbital debris program in place since 1979, and its meteoroid program traces its roots back to the chartering of the agency.

In 2005, the Goddard Space Flight Center began using an approach called Conjunction Assessment Risk Analysis (CARA) to provide collision avoidance information for operational robotic spacecraft. A similar process conducted by the Johnson Space Center, called Collision Avoidance (CA), is used for crewed spacecraft like the ISS and was previously used for the Space Shuttle program.

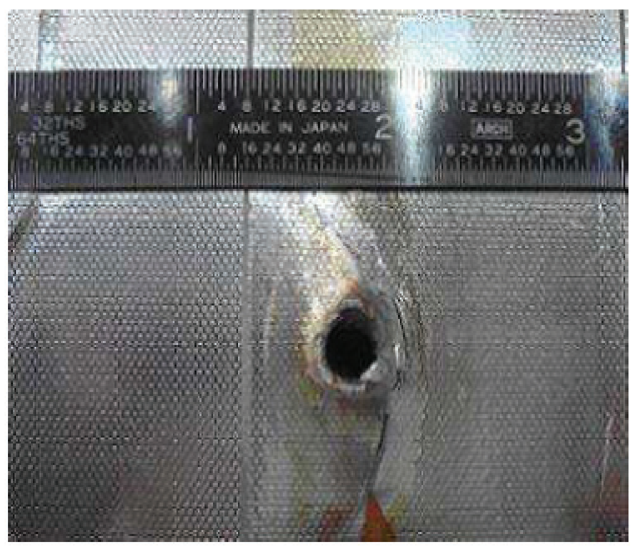
CARA/CA is the effort to determine the orbits of all known objects relative to operational satellites; tracking these objects helps to facilitate preemptive action to avoid potential collisions. Collision on Launch Avoidance (COLA), another screening process used by NASA, helps to prevent a collision with a cataloged object during the launch of spacecraft. NASA currently performs CARA/CA for 50 orbiting satellites to prevent collisions between satellites and with the ISS. While NASA and its partners, such as the European Space Agency, have the best data for those 50 satellites, they do not currently have the means to determine the orbit of thousands of untracked objects.

Unlike meteoroids—of which it is impossible to track and predict the course—orbital debris can be tracked and cataloged; however, due to current capabilities, debris can only be tracked down to a certain size. Today there are over 22,000 pieces of debris being tracked—plus an estimated population of 500,000 particles between 1 and 10 cm—and more than tens of millions of particles smaller than 1 cm orbiting the Earth. Particles smaller than 10 cm are very difficult to track reliably with current capabilities.

Meteoroids versus Orbital Debris

While debris in low-Earth orbit (LEO) affects launch activities, a meteoroid collision hazard is of primary concern for spacecraft operating in near-Earth space (above an altitude of 2,000 km). Meteoroids are mainly generated from collisions between asteroids and the decay of comets, though a small percentage may originate from stellar activity outside the solar system.

Meteoroid impacts differ in important ways from space debris impacts: They often take the form of hypervelocity impacts to spacecraft surfaces, with average meteoroid velocities exceeding those of orbital debris. In addition, there is growing evidence that higher velocity meteoroid collisions may produce electrical damage from electrostatic discharges or electromagnetic pulses associated with the meteoroids. Therefore, the need to better characterize meteoroids with high velocities, even if the size would be considered too small for mechanical damage, should be stressed.



Box 6.1 MMOD impact of the Space Shuttle Endeavour from the August 2007 STS-118 mission. The puncture in Endeavour's left-side aft-most radiator panel measured 8.1 mm by 6.4 mm, but the exit hole through the radiator's backside facesheet measured 14 mm by 14 mm. (Source: NASA)

Preparing for the Future

The initial goals of NASA's MMOD efforts were to characterize the risk to humans in space, beginning with NASA's manned spacecraft programs over 50 years ago. Since then, NASA's efforts have expanded to include the risk to robotic spacecraft and to add an orbital debris population as another source of risk. This addition quickly led to the conclusion that the risk to spacecraft and astronauts could be reduced by minimizing the growth of the orbital debris population.

With an increase in orbital debris comes an increase in the cost of reducing the risk of debris impact. For example, shielding, debris avoidance maneuvers and other presently used methods raise the cost of spacecraft design and operation. These expensive passive techniques must be used to protect spacecraft from meteoroids in particular since it is currently impossible to track these objects and predict their course for evasive action. The same is true for small artificial debris which cannot be tracked with today's space surveillance networks. Until better space surveillance tracking capabilities are operational, the threat of collisions with these untracked objects cannot be mitigated.

In addition to these current technological and financial limitations, NASA MMOD programs are also faced with international policy challenges. For example, while active debris removal would minimize the risk of collision, actual removal of debris requires crossing a crucial national and international legal threshold. That is, it is a clear international legal principle that no nation may salvage, or otherwise collect, the space objects of other nations while in space. However, only approximately 30% of cataloged objects are attributed to the U.S. Therefore, in order to avoid perceptions that the U.S. is taking unilateral actions that may be a cover for nonpeacful purposes, it is in the national interest to develop a formal process to inform space actors about U.S. orbital debris actions.

Under the new 2010 National Space Policy, NASA is required to take efforts to preserve the space environment. However, such efforts are accompanied by complex economic, legal and technological challenges. NASA should collaborate with commercial, national and international agencies to develop more explicit information about the costs of debris avoidance, mitigation, surveillance and response.

With this information, NASA could develop a more detailed plan for long-term issues—active orbital debris removal, refined MMOD risk analysis and international policy development would be particularly critical to prepare for a changing space environment. In this formal strategic plan, NASA should also include a basis for prioritizing the allocation of funds and efforts over various MMOD program needs. The plan should consider short- and long-term objectives and a schedule of benchmark achievements and priorities.

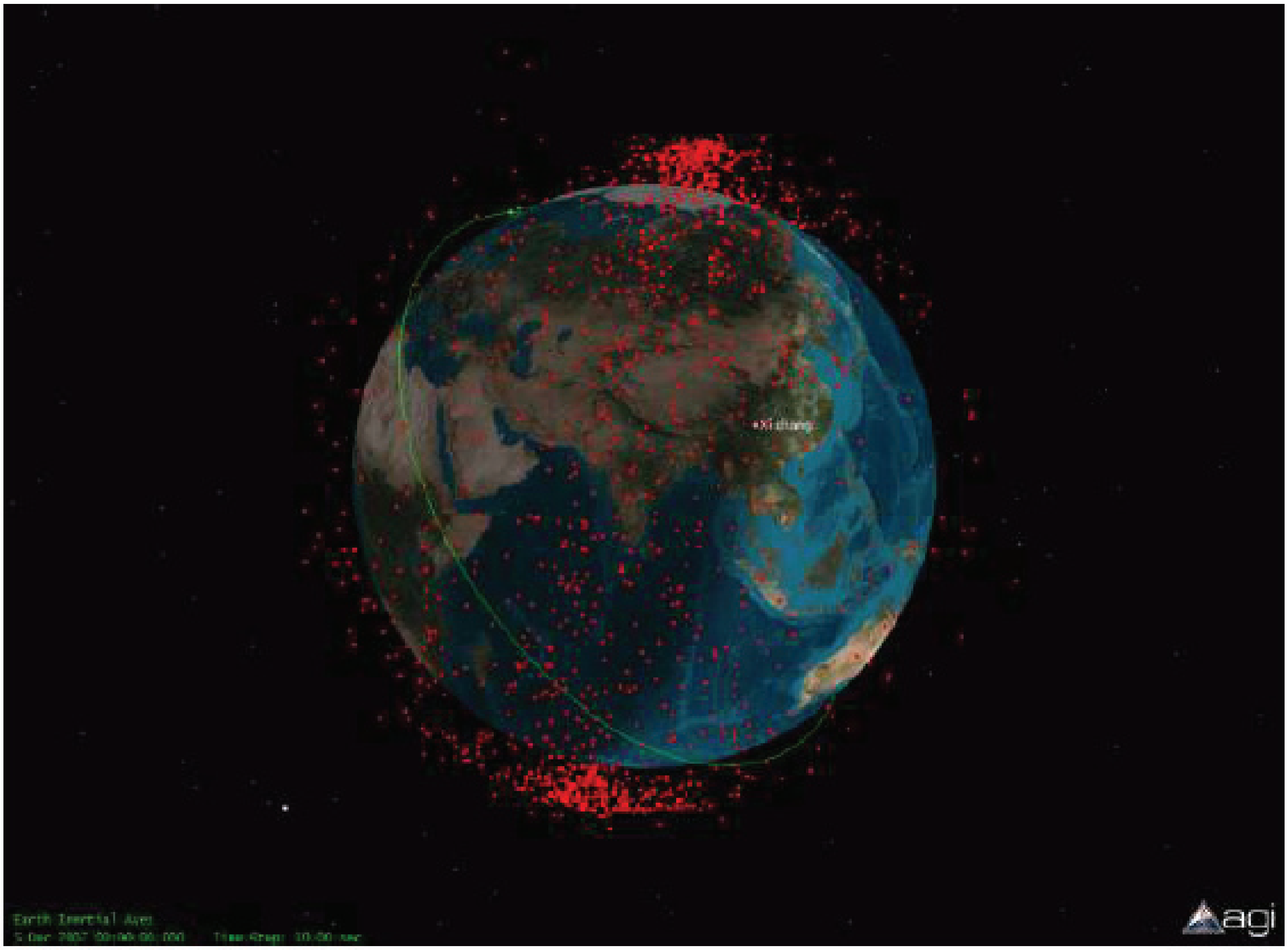


Figure International Space Station's orbit (in green) and the Debris Ring (red) from the Chinese ASAT test (image from December 5, 2007). (Source: CelesTrak.com)

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