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# How to Improve Small Satellite Missions in Two Easy Steps: Adopting Space Debris Mitigation Guidelines and Improving Space Surveillance Network Tracking Support

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ABSTRACT: Of the many unique challenges faced by small satellite missions, there are two areas that may be enhanced: 1) launch and on-orbit tracking, and 2) debris mitigation.

Launch and on-orbit tracking can be improved through greater cooperation with the Space Surveillance Network (SSN). The accuracy and timeliness of “NORAD two-line elements” is dependent on a variety of factors that are complicated by the satellites’ small size. This becomes more of an issue with multiple payload launches because object correlation is problematic. Recent launches, including the Student Space Exploration and Technology Initiative (SSETI) multi-payload small satellite launch in October 2005, have demonstrated the cooperation and data exchange between SSN personnel and satellite operators can greatly enhance the accuracy, timeliness, and overall utility of two-line element sets. Not only is this beneficial for the SSN, but is often critically important to satellite operators and other users of mission data to assist their tracking and anomaly resolution.

Space debris issues can be reduced through the implementation of standard mitigation guidelines. As the space population continues to grow, concerns have developed, both in the United States and in the international space community, about the amount of added space debris, which may already be approaching a problematic quantity. The risks of collisions between space objects have increased, and will continue to increase, as the population grows. There have already been at least three documented collisions of satellites in orbit, one of which involved an operational small satellite (Cerise in 1996). As a reflection of the growing concern with the increasing space population the US and other space-faring countries have adopted voluntary debris mitigation guidelines, and small satellite operators should be aware of these guidelines.

Improving communication and data exchange with the SSN, while implementing debris mitigation guidelines, will benefit small satellite operators by increasing accuracy and timeliness of two-line elements while improving the orbital safety for all users of the space environment.

## INTRODUCTION

The growth of the earth orbiting, man-made satellite population (shown in Figure 1) has increased steadily since the dawn of the space age. There are many reasons for this increase, ranging from factors such as increased satellite launch rates to the addition of on-orbit space debris that has resulted from satellite breakups. As the space population has grown, so have the challenges in space operations. Specifically, the added quantity of satellites has increased the likelihood of on-orbit collisions. In addition, the challenges associated with tracking satellites and maintaining a catalog has increased. As part of our efforts to increase understanding and awareness of these issues, this paper will address two areas of interest. First, the issues of debris mitigation guidelines will be discussed and summarized. This is an area of growing concern in the international space community and small satellite operators should be aware of the issues and guidelines. Second, it has become apparent that many small satellite operators have become dependent on two line element sets (sometimes called TLEs, Keps, Goddard elsets NORAD elements, etc) to acquire, track and otherwise help with their satellite operations. As satellites have become smaller and their numbers have increased, the production of the element sets has become more challenging, it is hoped that further cooperation with the Space Surveillance Network can be achieved that will be mutually beneficial.


**Figure 1. Number of Trackable Man Made Satellites in Orbit: 1987-2006**

## DEBRIS MITIGATION GUIDELINES

The population of man made objects is composed largely of debris, inactive spacecraft or rocket stages. Figure 2 shows that less than 10% of the man-made objects in space are actual operational spacecraft.

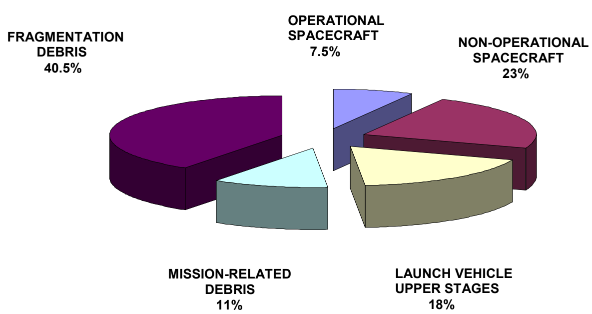


**Figure 2. Distribution of Object Types in Earth Orbit**

The predominant source of the satellite population is debris; either from fragmentation (break-up) events or from debris released during spacecraft operations. As earth orbit becomes more populated, it will be necessary to manage the number of objects that are placed into space. Some studies (ref 1) suggest that sometime in the future the number of collisions in the near earth regime will increase due to large amounts of debris. In fact, there have been at least three confirmed accidental on-orbit collisions between objects in earth orbit, (ref 2) and one of these involved an operational small satellite, Cerise. To help address this growing issue, the United States, along with others space-faring nations, have adopted and are implementing various (but similar) debris mitigation guidelines. Debris mitigation has even received some attention by the United Nations and the UN Committee on the Peaceful Uses of Outer Space (COPUOS) has developed a draft set of Debris Mitigation Guidelines.

### *United States Debris Mitigation Guidelines*

The US has long recognized that debris mitigation is an area of concern. Orbital debris has been included in all national space policies since 1988. The current National Space Policy (PDD-NSC-49/NSTC-8, Sep 1996) expanded orbital debris guidance, as follows:

"The United States will seek to minimize the creation of space debris. NASA, the intelligence community, and the DoD, in cooperation with the private sector, will develop design guidelines for future government procurements of spacecraft, launch vehicles, and services. The design and operation of space tests, experiments and systems, will minimize or reduce the accumulation of space debris consistent with mission requirements and cost effectiveness."
"It is in the interest of the U.S. Government to ensure that space debris minimization practices are applied by other spacefaring nations and international fora to adopt policies and practices aimed at debris minimization and will cooperate internationally in the exchange of information on debris research and the identification of debris mitigation options."

In response to 1995 Interagency report, NASA and DoD developed orbital debris mitigation standard practices based upon NASA Safety Standard 1740.14. These Standard Practices cover four major areas:
- Control of debris released during normal operations
- Minimization of debris generated by accidental explosions
- Selection of safe flight profile and operational configurations
- Post-mission disposal of space structures (it should be noted that some studies and a number of existing national guidelines have found 25 years to be a reasonable and appropriate lifetime limit. )

In addition, since all US small satellite operators must receive a license from the Federal Communications Commission (FCC), they need to be specifically concerned about the new FCC regulations, which are not voluntary. The FCC considers factors such as passivation and LEO lifetimes. It should be noted that most small satellites placed in orbits above 650 km will be non-compliant with the 25-year rule. The operators need to consider true mission requirements which call for orbits above 650 km. In fact, a good example is the multi-payload Cubesat launch slated for 2006 which will employ altitudes which are well below 650km, and these objects should re-enter within the 25 year time period.

In summary, the US has been operating with debris mitigation guidelines since 2001, and the guidelines have been utilized by a number of US Government organizations.

***International Debris Mitigation Guidelines***

The international space-faring community has also recognized that there are concerns with the uncontrolled growth of space debris. In particular, the Inter-Agency Space Debris Coordination Committee (IADC), (an international governmental forum for the worldwide coordination of activities related to the issues of man-made and natural debris in space) has developed a set of guidelines for debris mitigation.

In the way of background, the primary purposes of the IADC are to exchange information on space debris research activities between member space agencies, to facilitate opportunities for cooperation in space debris research, to review the progress of ongoing cooperative activities, and to identify debris mitigation options. The IADC members include the following agencies:

- ASI (Agenzia Spaziale Italiana)
- BNSC (British National Space Centre)
- CNES (Centre National d'Etudes Spatiales)
- CNSA (China National Space Administration)
- DLR (German Aerospace Center)
- ESA (European Space Agency)
- ISRO (Indian Space Research Organisation)
- JAXA (Japan Aerospace Exploration Agency)
- NASA (National Aeronautics and Space Administration)
- NSAU (National Space Agency of Ukraine)
- ROSCOSMOS (Russian Federal Space Agency)

The IADC Space Debris Mitigation Guidelines, adopted by all members in 2002, may be found at http://www.iadc-online.org/index.cgi?item=docs_pub. The key points of the IADC debris mitigation guidelines are divided into two areas. The first guideline recommends development of a Space Debris Mitigation Plan for each program and project. The second involves the specific mitigation methods that should be employed (ref 3).

IADC recommends that the Space Debris Mitigation Plan should include the following items:
(1) A management plan addressing space debris mitigation activities
(2) A plan for the assessment and mitigation of risks related to space debris, including applicable standards
(3) The measures minimizing the hazard related to malfunctions that have a potential for generating space debris
(4) A plan for disposal of the space system at end of mission
(5) Justification of choice and selection when several possibilities exist
(6) Compliance matrix addressing the recommendations of these Guidelines.

In terms of mitigation measures, the IADC has developed several specific measures that should be employed:
(1) Limit debris released during normal operations. Specifically, space systems should be designed to not release debris during normal operations, and this applies to all operational orbit regimes. Where this is not feasible, any release of debris should be minimized in quantity, size and orbital lifetime.

(2) Minimize the potential for on-orbit break-ups. This includes addressing the following areas:

(a) Minimize the potential for post mission break-ups resulting from stored energy. All on-board sources of stored energy of a space system, such as residual propellants, batteries, high-pressure vessels, self-destructive devices, flywheels and momentum wheels, should be depleted or safed when they are no longer required for mission operations or post-mission disposal. Propellant, battery or other depletion should occur as soon as this operation does not pose an unacceptable risk to the payload.

(b) Minimize the potential for break-ups during operational phases. During the design of a space system, the program or project should demonstrate, using failure mode and effects analyses or an equivalent analysis, that there is no probable failure mode leading to accidental break-ups. If such failures cannot be excluded, the design or operational procedures should minimize the probability of their occurrence. During the operational phases, a space system should be monitored periodically to detect malfunctions that could lead to a break-up or loss of control. In the case that a malfunction is detected, adequate recovery measures should be planned and conducted; otherwise disposal and passivation measures for the system should be planned and conducted.

(c) Avoidance of intentional destruction and other harmful activities. Intentional destruction of a space system, (self-destruction, intentional collision, etc.), and other harmful activities that may significantly increase collision risks to other systems should be avoided. For instance, intentional break-ups should be conducted at sufficiently low altitudes so that orbital fragments are short lived.

(3) Post mission disposal. The disposal recommendations are based on the operational altitude of the spacecraft, as follows:

(a) Geosynchronous Region.
Spacecraft that have terminated their mission in the geosynchronous (GEO) region should be maneuvered far enough away from GEO so as not to cause interference with space systems still in geostationary orbit. The recommended minimum increase in perigee altitude at the end of re-orbiting, which takes into account all orbital perturbations, is:

Minimum Geosynchronous Spacecraft Perigee Increase

$$= 235 \text{ km} + (1000 \cdot C_R \cdot A/m) \quad (1)$$

Where:
$C_R$: Solar radiation pressure coefficient (typical values are between 1 & 2),
A/m: Aspect area to dry mass ratio [m2/kg]
235 km: Sum of the upper altitude of the GEO protected region (200 km) and the maximum descent of a re-orbited space system due to luni-solar and geopotential perturbations (35 km).

(b) Objects Passing Through the Low Earth Orbit (LEO) Region.
Whenever possible, space systems that complete their operational phases in orbits that pass through the LEO region, or have the potential to intersect with the LEO region, should be de-orbited (direct re-entry is preferred) or where appropriate maneuvered into an orbit with a reduced lifetime. Another disposal option is retrieval. A space system should be left in an orbit in which, using an accepted nominal projection for solar activity, atmospheric drag will limit the orbital lifetime after completion of operations. A study on the effect of post-mission orbital lifetime limitation on collision rate and debris population growth has been performed by the IADC. As mentioned above, the IADC and other studies and a some existing national guidelines have found 25 years to be a reasonable and appropriate lifetime limit.

(c) Other Orbits.
Space systems that are terminating their operational phases in other orbital regions should be maneuvered to reduce their orbital lifetime, commensurate with LEO lifetime limitations, or relocated if they cause interference with highly utilized orbit regions.

(4) Prevention of On-Orbit Collisions.
When developing the design and mission profile of a space system, a program or project should estimate and limit the probability of accidental collision with known objects during the system's orbital lifetime. If reliable orbital data is available, avoidance maneuvers for spacecraft and coordination of launch windows may be considered if there is a collision risk. Spacecraft design should limit the probability of collision with small debris which could cause a loss of control, thus preventing post-mission disposal.

Finally, the United Nations COPUOS is currently considering a draft set of debris mitigation guidelines that closely parallel those prepared by the IADC (ref 4). These are summarized below:
(1) Limit debris released during normal operations
(2) Minimize the potential for break-ups during operational phases
(3) Limit the probability of accidental collision in orbit
(4) Avoidance of intentional destruction and other harmful activities
(5) Minimize potential for post-mission break-ups resulting from stored energy
(6) Limit the long term presence of spacecraft and launch vehicle orbital stages in the lower earth orbit (LEO) region at the end of their mission
(7) Limit the long term interference of spacecraft and launch vehicle orbital stages with the geosynchronous earth orbit (GEO) region after the end of their mission.

### *Debris Mitigation Summary*

As the number of objects in earth orbit continues to grow, the concern with possible collisions is also increasing. Small satellite designers, developers and operators should be aware of orbital debris mitigation guidelines and incorporate them into their processes. The reduction of space debris is a concern that affects all users of space, and the space debris mitigation guidelines will benefit current and future generations of space operations.

## IMPROVING SSN TRACKING SUPPORT

Small satellites present unique challenges for the US Space Surveillance Network (SSN). Not only is their inherently small size a significant issue, but the fact that they are usually launched with a multitude of other small satellites causes additional tracking difficulties.

Since many small satellite missions are at least partially reliant upon SSN produced two-line element sets, sometimes referred to as "NORAD two-line elements", the quality and timeliness of this data can be critical for mission success. In order to provide top quality data to mission users, information exchange with SSN operators is essential.

***SSN Overview***

The SSN is the most advanced space surveillance system in the world. It is comprised of over two dozen individual sensors that regularly track over 10,000 resident space objects. The network of optical and radar systems collects and processes over 300,000 observations per day that are used to update orbit information and produce two-line element sets. These are made available to authorized users through a web based interface. The nerve center for this complex system is the 1st Space Control Squadron (1 SPCS) at Cheyenne Mountain Air Force Station.

*1 SPCS Mission*

*1 SPCS accomplishes the space control mission for USSTRATCOM by providing space situation awareness, space protection, and expert space analysis support for all man-made earth orbiting space objects* (ref 5)

It is the goal of 1 SPCS to track all man-made objects from launch to decay. They also assist US domestic missions, as well as other cooperative users, with orbital safety planning, launch object correlation, early orbit determination, and object cataloging. 1 SPCS has catalogued over 29,000 objects since the launch of Sputnik in 1957.

***Launch Tracking***

Routine satellite tracking is a relatively simple task because an existing element set is available to queue the sensor. Launch tracking can be much more difficult due to trajectory uncertainty and because early-orbit profiles are not always available. Sensors are often required to detect launches based on 'best guess' pointing information. This is often generated using previous launch data; but if none exists then analysts are required to generate profiles based on assumptions. If any wrong guesses are made it can then result in significant delays with regard to detection and element set publication. In order for the first element set to be published, sufficient SSN data must be collected to ensure accurate data is provided.

Difficulties finding launch objects can significantly delay Elset 1 publication. This is often a source of angst for satellite operators that rely on early-orbit element sets to verify proper orbit insertion or otherwise have urgent need for quality data in the early phases of the mission.

Small satellite operators can significantly enhance the ability of the SSN to expeditiously generate Elset 1, as well increase the timeliness of subsequent element sets, simply by coordinating their expected launch profile with 1 SPCS.

***Multi-Satellite Launches***

In addition to the usual difficulties associated with launch tracking, multiple satellites deployed by the same launch vehicle present a number of additional challenges. Not only are the objects small, but they are often very similar in size, shape, and weight. To further complicate the issue there is often very little separation time between satellite releases from the delivery vehicle. This is especially true of satellites that are designed to the Cubesat standard, which are nearly identical from an SSN sensor perspective. As a result of these issues, object correlation becomes very difficult. Element sets can easily become cross-tagged as the wrong object. This compounds the correlation problem and can mislead users. Eventually the objects will disperse due to natural orbit perturbations but until this happens problems with correlation can persist.

There are several ways to improve the odds of properly correlating element sets: 1) provide the deployment sequence to 1 SPCS in advance of launch, 2) increase the separation time between sequential satellite releases to more than 20 seconds, 3) provide separation velocity of the satellite from the delivery vehicle of at least 5 meters/second, and 4) provide 1 SPCS with basic details regarding object shape and size. In addition to improving object correlation, following these guidelines should also improve element accuracy and timeliness.

***Routine On-Orbit Tracking***

Provided that launch and early orbit elements sets are of good quality and are properly correlated, routine on-orbit tracking becomes a fairly simple process. The frequency of SSN tracking is determined based on parameters such as orbit regime and atmospheric drag. Optimized sensor tasking is issued to the SSN sensors by 1 SPCS in a manner which ensures that an adequate number of tracks are collected on each object while balancing network utilization efficiency. Once the SSN sensors receive their daily tasking, observations are collected and transmitted to 1 SPCS where they are used to update the corresponding element sets. Updated element sets are then provided to users through the Space Track website. Routine on-orbit tracking is generally a simple process; however, there are situations which can cause issues.

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Another source of problems for routine tracking is caused by satellites that are intentionally clustered with other satellites. These 'formation flyers' present correlation problems similar to those caused by multi-satellite deployments; however, unlike multi-satellite deployments which naturally tend to separate, clustered satellite issues can persists indefinitely. Future improvements to SSN sensors and processing techniques may improve discrimination issues with clustered satellites.

Tethered satellites present another unique issue that can negatively impact element set accuracy. There is much speculation about the magnitude of the problem and what the ultimate impact will be for orbit determination. Future launches of small tethered satellites will present interesting challenges for SSN analysts. It is likely that radar reflective material placed in the tether itself will improve SSN tracking and element accuracy.

***Satellite Anomalies and Anomaly Resolution***

There have been a number of cases where satellites anomalies have caused mission operators to lose contact with their satellite. In some instances satellites have been recovered with the assistance of orbit data provided by 1 SPCS.

Depending on the nature of the event, mission of the satellite, orbital safety factors, and other considerations, 1 SPCS may be able to provide varying levels of support for satellites that have been lost as a result of an onboard anomaly. These types of issues are handled on a case-by-case basis. In some situations sensor tasking may be increased in order to maximize the amount of data collected on the object in question.

***Collision Avoidance***

1 SPCS routinely performs predictive screening for manned spaceflight objects against all possible conjunction targets. In the event of a possible conjunction with the International Space Station (ISS), NASA is notified of the event and makes a decision on whether or not to perform collision avoidance maneuvers. Small satellites are included in this screening process.

In the event of a sudden loss of contact with a small satellite or if a significant change in the satellites orbit is detected, 1 SPCS may choose to perform analyses to determine if a collision was responsible. Unfortunately this would occur after the event and may only provide positive confirmation.

The amount of resources required to provide predictive collision analyses on all known orbital objects is overly prohibitive and is unlikely to provide much benefit. In the history of the SSN, only three accidental collisions have been confirmed.

***Decay Prediction***

1 SPCS routinely provides decay predictions for uncontrolled satellite reentries. This may be of benefit to some satellite operators. This data is available on the Space Track website.

***How to Acquire 1 SPCS Data Products***

Element set data can be retrieved from the Space Track website (www.space-track.org) after submitting an account request.

Data requests that cannot be satisfied through Space Track must go through the Form 1 approval process. Additional details can be found at https://www.cheyennemountain.af.mil/1SPCS

***Recommendations***

There are several areas where communication with SSN personnel at 1 SPCS could improve the overall quality and timeliness of data provided to the user community. Small satellite operators may benefit significantly depending on their level of reliance on element set data. In order to specifically improve SSN tracking and data products for small satellites the following guidelines are recommended:

1. Coordinate launch trajectory and initial orbit information.
2. For multi-satellite launches information regarding deployment sequence, separation timing, and object shape and size is extremely beneficial.
3. Sequential satellite deployments should be separated by at least 20 seconds.
4. Separation velocity between the satellite and the launch vehicle should be at least 5 meters/second or more.

5. Report problems identified in two-line element sets (wrong object, bad orbit parameters, etc).
6. Notify 1 SPCS if assistance is desired with issues regarding satellite anomalies and/or loss of contact.

***Tracking Summary***

Small satellites present unique tracking problems for the Space Surveillance Network. In order to improve the quality and timeliness of two-line element sets provided to mission operators, improved communication with SSN personnel at 1 SPCS is recommended. Pre-launch trajectory and initial orbit information, along with details regarding multi-satellite deployments will go a long way towards improving data products provided to the user community. Improved communication is also likely to improve the resolution of problems identified in routine tracking data and may even help with some issues involving satellite anomalies and collision avoidance.

***Contact Information***

1 SPCS Launch Officer:
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