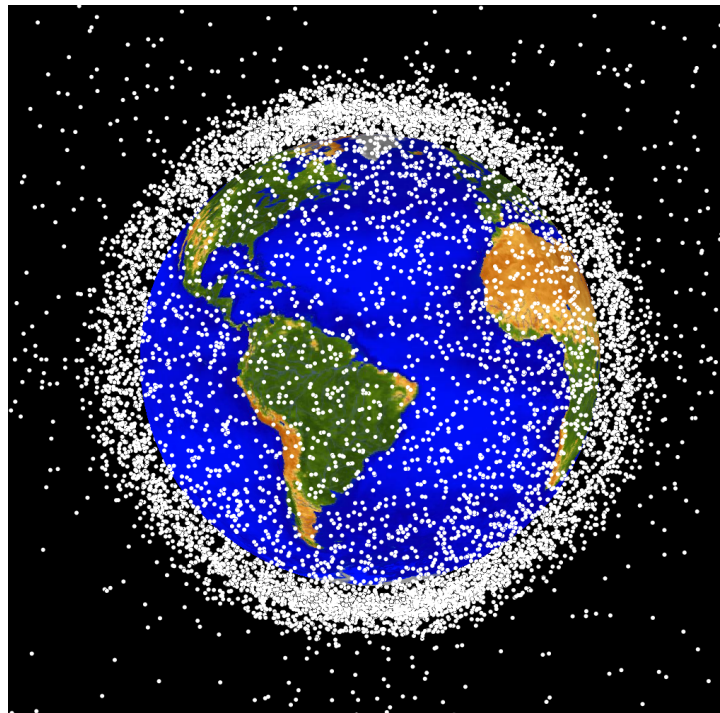


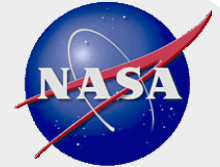
Assessing Compliance with United States Government Orbital Debris Mitigation Guidelines



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USG OD Mitigation Standard Practices, Objective 1

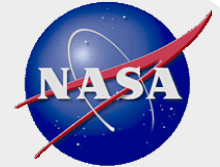
OBJECTIVE

1. CONTROL OF DEBRIS RELEASED DURING NORMAL OPERATIONS

Programs and projects will assess and limit the amount of debris released in a planned manner during normal operations.

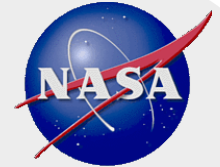
MITIGATION STANDARD PRACTICES

-
- 1-1. *In all operational orbit regimes:* Spacecraft and upper stages should be designed to eliminate or minimize debris released during normal operations. Each instance of planned release of debris larger than 5 mm in any dimension that remains on orbit for more than 25 years should be evaluated and justified on the basis of cost effectiveness and mission requirements.



USG OD Mitigation Standard Practices, Objective 1

- Compliance Issues
 - The release of operational debris is not a typically planned occurrence for CubeSats
- Assessment
 - The mission editor in DAS 2.0.2 provides the capability to evaluate the orbital lifetime for any mission related debris



USG OD Mitigation Standard Practices, Objective 2

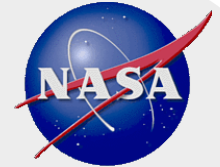
OBJECTIVE

2. MINIMIZING DEBRIS GENERATED BY ACCIDENTAL EXPLOSIONS

Programs and projects will assess and limit the probability of accidental explosion during and after completion of mission operations.

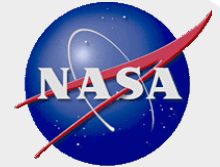
MITIGATION STANDARD PRACTICES

- 2-1. *Limiting the risk to other space systems from accidental explosions during mission operations:* In developing the design of a spacecraft or upper stage, each program, via failure mode and effects analyses or equivalent analyses, should demonstrate either that there is no credible failure mode for accidental explosion, or, if such credible failure modes exist, design or operational procedures will limit the probability of the occurrence of such failure modes.
- 2-2. *Limiting the risk to other space systems from accidental explosions after completion of mission operations:* All on-board sources of stored energy of a spacecraft or upper stage should be depleted or safed when they are no longer required for mission operations or postmission disposal. Depletion should occur as soon as such an operation does not pose an unacceptable risk to the payload. Propellant depletion burns and compressed gas releases should be designed to minimize the probability of subsequent accidental collision and to minimize the impact of a subsequent accidental explosion.



USG OD Mitigation Standard Practices, Objective 2

- Compliance Issues
 - CubeSat missions rarely provide a FMEA prior to launch
 - The most likely source of failure on most missions are the batteries
 - Batteries are rarely disconnected from the charging circuit at end of mission
 - For CubeSats up to 3U NASA OSMA has accepted that a battery failure is not likely to impact the orbital debris environment
- Assessment
 - The FMEA should discuss all possible failure modes that could lead to a fragmentation event
 - For batteries in particular information should be provided regarding the hardware heritage and any certification testing performed
 - Passivation is a binary activity
 - Either stored energy sources are depleted or they are not



USG OD Mitigation Standard Practices, Objective 3

OBJECTIVE

3. SELECTION OF SAFE FLIGHT PROFILE AND OPERATIONAL CONFIGURATION

Programs and projects will assess and limit the probability of operating space systems becoming a source of debris by collisions with man-made objects or meteoroids.

MITIGATION STANDARD PRACTICES

- 3-1. *Collision with large objects during orbital lifetime:* In developing the design and mission profile for a spacecraft or upper stage, a program will estimate and limit the probability of collision with known objects during orbital lifetime.
- 3-2. *Collision with small debris during mission operations:* Spacecraft design will consider and, consistent with cost effectiveness, limit the probability that collisions with debris smaller than 1 cm diameter will cause loss of control to prevent post-mission disposal.
- 3-3. *Tether systems* will be uniquely analyzed for both intact and severed conditions.



USG OD Mitigation Standard Practices, Objective 3

- Compliance Issues
 - The likelihood of collision with large objects is driven by where the CubeSat is deployed
 - CubeSats do not typically use propulsion and therefore cannot perform collision avoidance maneuvers
 - The ability for other object to avoid the CubeSat is limited by the ability to track the CubeSat
 - For small object collisions there is no risk as the post mission operations are typically passive
 - Tethers are not typically utilized by CubeSats
- Assessment
 - The mission editor in DAS 2.0.2 provides the capability to determine the risk of collision with large and small objects, as well as the ability to evaluate risks associated with tethers



USG OD Mitigation Standard Practices, Objective 4

OBJECTIVE

4. POSTMISSION DISPOSAL OF SPACE STRUCTURES

Programs and projects will plan for, consistent with mission requirements, cost effective disposal procedures for launch vehicle components, upper stages, spacecraft, and other payloads at the end of mission life to minimize impact on future space operations.

MITIGATION STANDARD PRACTICES

4-1. *Disposal for final mission orbits:* A spacecraft or upper stage may be disposed of by one of three methods:

- a. Atmospheric reentry option: Leave the structure in an orbit in which, using conservative projections for solar activity, atmospheric drag will limit the lifetime to no longer than 25 years after completion of mission. If drag enhancement devices are to be used to reduce the orbit lifetime, it should be demonstrated that such devices will significantly reduce the area-time product of the system or will not cause spacecraft or large debris to fragment if a collision occurs while the system is decaying from orbit. If a space structure is to be disposed of by reentry into the Earth's atmosphere, the risk of human casualty will be less than 1 in 10,000.
- b. Maneuvering to a storage orbit: At end of life the structure may be relocated to one of the following storage regimes:
 - I. Between LEO and MEO: Maneuver to an orbit with perigee altitude above 2000 km and apogee altitude below 19,700 km (500 km below semi-synchronous altitude)
 - II. Between MEO and GEO: Maneuver to an orbit with perigee altitude above 20,700 km and apogee altitude below 35,300 km (approximately 500 km above semi-synchronous altitude and 500 km below synchronous altitude.)
 - III. Above GEO: Maneuver to an orbit with perigee altitude above 36,100 km (approximately 300 km above synchronous altitude)
 - IV. Heliocentric, Earth-escape: Maneuver to remove the structure from Earth orbit, into a heliocentric orbit.

Because of fuel gauging uncertainties near the end of mission, a program should use a maneuver strategy that reduces the risk of leaving the structure near an operational orbit regime.

- c. Direct retrieval: Retrieve the structure and remove it from orbit as soon as practical after completion of mission.

4-2. *Tether systems* will be uniquely analyzed for both intact and severed conditions when performing trade-offs between alternative disposal strategies.

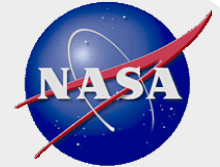


USG OD Mitigation Standard Practices, Objective 4

- Compliance Issues
 - The lack of propulsion systems on CubeSats mean that natural decay is the only viable disposal option
 - Orbital lifetime is driven by the deployment orbit, which is driven by the primary payload
 - ISS deployed CubeSats all reenter within 25 years
 - At least one CubeSat is reported to have a 500 year lifetime
 - Not launched through NASA
 - Reentry risk of CubeSats is typically minimal
 - If the use of certain materials (i.e. Tungsten) is avoided, it is highly unlikely that components of CubeSats will impact the ground with an energy greater than 15 J.
- Assessment
 - The mission editor in DAS 2.0.2 provides the capability to predict the orbital lifetime and to perform reentry risk assessments

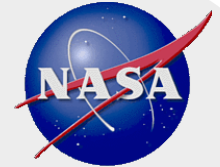


NASA Debris Assessment Software (DAS)



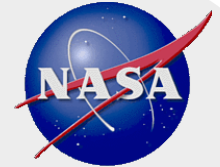
Introduction

- **The NASA Debris Assessment Software (DAS) is actually a set of custom tools designed to assist space programs and projects in preparing orbital debris assessment reports.**
 - Assessment requirements are described in NASA Standard 8719.14, “Process for Limiting Orbital Debris”
 - DAS 2.0 addresses most requirements point-by-point
 - Referenced in FCC regulations as method to assess compliance
 - Widely used by satellite designers around the world as a method to assess compliance with general orbital debris mitigation guidelines
- **Download software and reference materials at:**
<http://www.orbitaldebris.jsc.nasa.gov/mitigate/das.html>



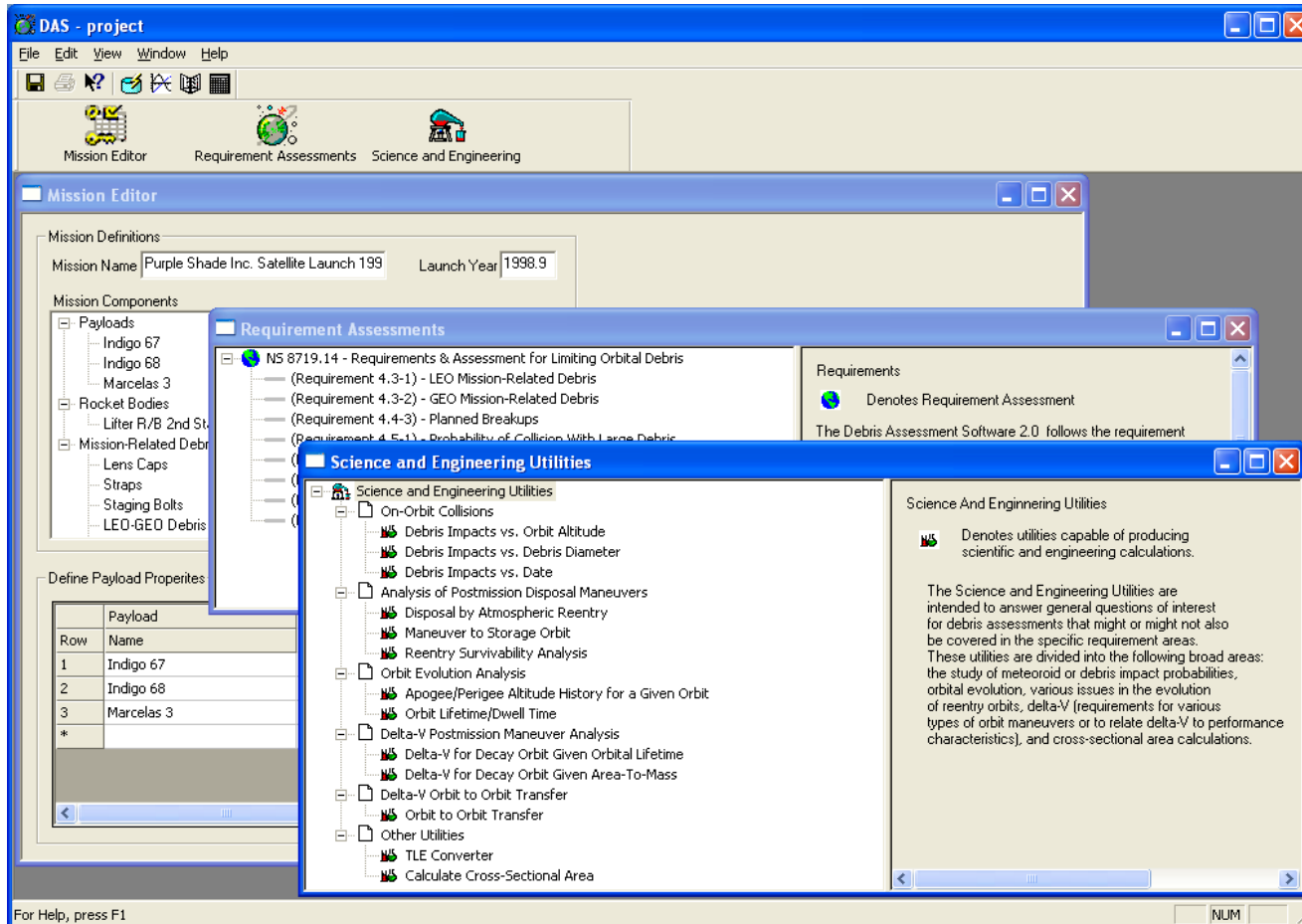
User Interface

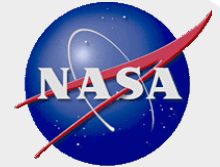
- **Microsoft Windows User Interface**
 - DAS 2.0 uses a “native” Windows graphical user interface (GUI)
 - Runs on Windows 2000, XP, Vista, and Windows 7
 - The GUI consolidates user input and avoids long chains of menu
- **“Project” Orientation**
 - DAS 2.0 saves the user’s input and output files as a “project” in a single directory
 - Other files and directories are not affected by the projects
 - Moving or sharing a project is as simple as moving or sharing the project directory
- **Division of Modules**
 - Mission Editor
 - Requirement Assessments
 - Science and Engineering Utilities
 - Supporting features



DAS 2.0 User Interface

The DAS 2.0 top-level window, and three main dialog windows





GUI: Mission Editor

- The user enters most of the mission information into the Mission Editor
- Most assessments are complete using only the information in the Mission Editor

Mission Definitions

Mission Name: Launch Year:

Mission Components

- [-] Payloads
 - EO_23
- [-] Rocket Bodies
 - Delta II R/B 2nd Stage
- [-] Mission-Related Debris
 - Despin Yo-yos
 - Tether Experiment
 - geodeb
 - geocross
 - crossboth
 - neither
 - supergeo

Buttons:

Define Payload Properties

Row	Payload Name	Mission Duration (yrs)	Operational Perigee Alt (km)	Operational Apogee Alt (km)	Operational Inclination (deg)	RAAN (deg)	Argument of Perigee (deg)
1	EO_23	5	400	2500	26.5	322.5	26.5
*							

For Help, press F1



GUI: Requirement Assessments

The user may assess the mission's compliance with each requirement

The screenshot shows the DAS - project_leo - [Requirement Assessments] window. The title bar is blue with the text "DAS - project_leo - [Requirement Assessments]". The menu bar includes File, Edit, View, Window, and Help. The toolbar contains icons for file operations and navigation. The main area is divided into three tabs: Mission Editor, Requirement Assessments (selected), and Science and Engineering. The Requirement Assessments tab displays a tree view of requirements under the heading "NS 8719.14 - Requirements & Assessment for Limiting Orbital Debris". The requirements listed are:

- (Requirement 4.3-1) - LEO Mission-Related Debris
- (Requirement 4.3-2) - GEO Mission-Related Debris
- (Requirement 4.4-3) - Planned Breakups
- (Requirement 4.5-1) - Probability of Collision With Large Debris
- (Requirement 4.5-2) - Probability of Damage from Small Debris
- (Requirements 4.6-1 to 4.6-3) - Postmission Disposal
- (Requirement 4.7-1) - Risk from Reentry Debris
- (Requirement 4.8-1) - Mitigate the Collision Hazards of Space Tethers

The right pane shows the "Requirements" section, which includes a globe icon and the text "Denotes Requirement Assessment". Below this, there is a detailed description of the Debris Assessment Software 2.0, stating that it follows the requirement structure of NS 8719.14 and provides calculation routines to assist in the overall process. A "Reset" button is located at the bottom of the right pane. The status bar at the bottom left says "For Help, press F1" and the bottom right shows a "NUM" indicator.



GUI: Sample Requirement Assessment

The right-hand pane shows inputs, outputs, and compliance status

DAS - project_leo - [Requirement Assessments]

File Edit View Window Help

Mission Editor Requirement Assessments Science and Engineering

NS 8719.14 - Requirements & Assessment for Limiting Orbital Debris

- ✗ (Requirement 4.3-1) - LEO Mission-Related Debris
- (Requirement 4.3-2) - GEO Mission-Related Debris
- (Requirement 4.4-3) - Planned Breakups
- ✓ (Requirement 4.5-1) - Probability of Collision With Large Debris
- ✓ (Requirement 4.5-2) - Probability of Damage from Small Debris
- (Requirements 4.6-1 to 4.6-3) - Postmission Disposal
- ✗ (Requirement 4.7-1) - Risk from Reentry Debris
- (Requirement 4.8-1) - Mitigate the Collision Hazards of Space Tethers

(Requirement 4.3-1) Debris Passing through LEO

Mission-Related Debris in LEO

Row	Debris Name	Released Year	Quantity of Each Element	Area-To-Mass (m ² /kg)	Perigee Alt (km)	Apogee Alt (km)
1	Despin Yo-yos	2005	2	.079115	305	2500
2	Tether Experiment	2005	1	.000515	305	310
3	crossboth	2005	1	.001	1000	37000

Run Requirement Help

Output

Row	Debris Name	Compliance Status	Lifetime (yrs)	Object Time (obj-yrs)
1	Despin Yo-yos	Compliant	2.4	4.5
2	Tether Experim...	Compliant	2.7	2.7
3	crossboth	Non-Compliant	100.0	3.3

TOTAL OBJECT TIME:
10.4 obj yrs

Messages

Requirement 4.3-1
Non-Compliant Row: 3

NOTE: For Non-Compliant Status - Refer to Help or Analysis section within Science and Engineering Utilities

For Help, press F1



GUI: Science and Engineering Utilities

These utilities allow the user to explore options in mission design and to perform other supporting calculations

DAS - project_leo - [Science and Engineering Utilities]

File Edit View Window Help

Mission Editor Requirement Assessments Science and Engineering

Science and Engineering Utilities

- On-Orbit Collisions
 - Debris Impacts vs. Orbit Altitude
 - Debris Impacts vs. Debris Diameter
 - Debris Impacts vs. Date
- Analysis of Postmission Disposal Maneuvers
 - Disposal by Atmospheric Reentry
 - Maneuver to Storage Orbit
 - Reentry Survivability Analysis
- Orbit Evolution Analysis
 - Apogee/Perigee Altitude History for a Given Orbit
 - Orbit Lifetime/Dwell Time
- Delta-V Postmission Maneuver Analysis
 - Delta-V for Decay Orbit Given Orbital Lifetime
 - Delta-V for Decay Orbit Given Area-To-Mass
- Delta-V Orbit to Orbit Transfer
 - Orbit to Orbit Transfer
- Other Utilities
 - TLE Converter
 - Calculate Cross-Sectional Area

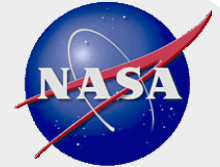
Science And Engineering Utilities

Denotes utilities capable of producing scientific and engineering calculations.

The Science and Engineering Utilities are intended to answer general questions of interest for debris assessments that might or might not also be covered in the specific requirement areas. These utilities are divided into the following broad areas: the study of meteoroid or debris impact probabilities, orbital evolution, various issues in the evolution of reentry orbits, delta-V (requirements for various types of orbit maneuvers or to relate delta-V to performance characteristics), and cross-sectional area calculations.

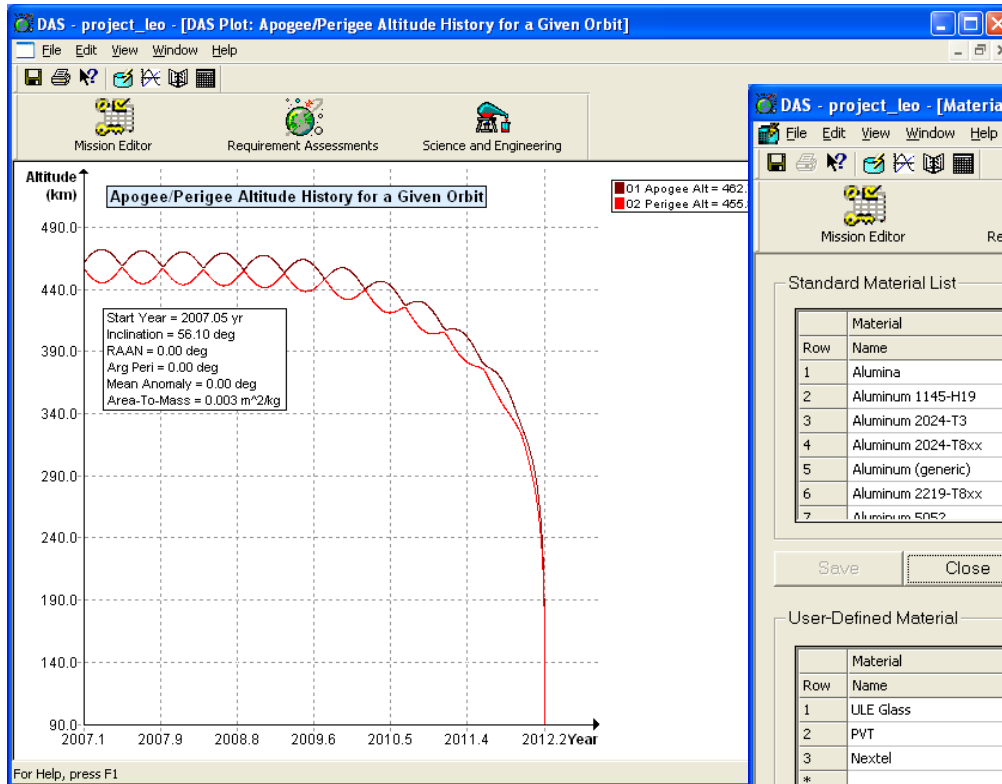
For Help, press F1

NUM



GUI: Other Supporting Features

- Customizable plots
- Material properties database
- Text activity log
- Date conversion tool



DAS - project_leo - [Material Database]

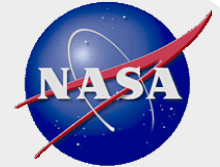
Standard Material List

Row	Material Name	Density (kg/m ³)
1	Alumina	3990
2	Aluminum 1145-H19	2697
3	Aluminum 2024-T3	2803.2
4	Aluminum 2024-T8xx	2803
5	Aluminum (generic)	2700
6	Aluminum 2219-T8xx	2812.8
7	Aluminum 5052	2684.0

User-Defined Material

Row	Material Name	Density (kg/m ³)	Specific Heat (J/kg-K)	Heat of Fusion (J/kg)	Melt Temperature (K)
1	ULE Glass	123	776	250000	1760
2	PVT	234	1338.9	233	343.16
3	Nextel	345	741.1	233	2073.16
*					

For Help, press F1



Summary

- **DAS is the standard method of assessing compliance with NASA's space debris mitigation requirements (NS 8719.14A).**
 - DAS provides point-by-point assessment of a mission's compliance with NASA's requirements.
 - Results from DAS may be included in reports to NASA as well as other regulating agencies
 - DAS provides additional tools for mission-planning and input conversion.
- **The modular internal structure of the software allows for easy updates (such as to the debris environment model or the human population density) in the future. Solar activity forecasts are updated quarterly.**
- **Software and documentation are available on the NASA Orbital Debris Program Office's internet site:**

<http://www.orbitaldebris.jsc.nasa.gov/mitigate/das.html>