Debris Assessment Software User's Guide

Orbital Debris Program Office

J.-C. Liou
NASA Johnson Space Center
Houston, Texas

John Opiela
Andrew Vavrin
Billy Draeger
Phillip Anz-Meador
Chris Ostrom
Jacobs
Houston, Texas

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Houston, Texas

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Available from:

NASA STI Program
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National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

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REVISION AND HISTORY PAGE

REV.	DESCRIPTION	PUB. DATE
Initial Release	New Document: Reference JSC 64047	November 2007
Rev. A	Throughout: Update to Section 1.1, 1.2, and 3.10.	January 2012
Revised for DAS 2.1	Changed ORDEM2000 to ORDEM 3.0. Added notes about increased run time due to ORDEM 3.0. Changed general references to the software from "DAS 2.0" to simply "DAS 2". Clarifications and additions related to installing and running DAS 2.1. Updated the acceptable mission date range to match the new DAS date range of 2010-2100.	March 2016
Revised for DAS 3.0	Revised to reflect functionality of DAS 3.0 and updated NS 8719.14B. Expanded technical appendix.	February 2019
Revised for DAS 3.1	Updated ORDEM 3.0 to ORDEM 3.1	April 2020
Revised for DAS 3.2	Updated to reflect functionality of DAS 3.2 and updated NS 8719.14C.	December 2021

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1. Introduction

The Debris Assessment Software (DAS) is provided by the NASA Orbital Debris Program Office as a means of assessing, during the planning and design phase, space missions' compliance with NASA's requirements for reduction of orbital debris.

1.1 Scope and Limitations

DAS is designed to assist NASA programs in performing orbital debris assessments (ODA), as described in NASA Technical Standard 8719.14C, *Process for Limiting Orbital Debris*. The software reflects the structure of the Standard and provides the user with tools to assess compliance with the requirements. If non-compliant, DAS may also be used to explore debris mitigation options to bring a program within requirements.

While DAS provides many functions useful in performing ODAs, its list of features is not exhaustive. Some analyses (*e.g.,* hardware reliability, space tethers) are better done outside DAS. The user should remember that DAS is a software tool, while the NASA Technical Standard 8719.14C contains the actual mission requirements.

DAS 3.2 will assess payloads operating from the year 2016 to 2130, and objects in orbit (non-operational) from 2016 to 2270. The time limits are based on the limits of the orbital debris environment model, ORDEM 3.1, as implemented in DAS. The small-object environment (objects with sizes <10 cm), which is required for assessment of Requirement 4.5-2, ends in the year 2050. The larger-object environment (sizes ≥10 cm), required for collision risk assessment during both operational and post-mission phases, is projected to 2270. As a result, **DAS 3.2 cannot fully assess Requirement 4.5-2 for payloads still operational after 2050.**

1.2 Software Changes

DAS 3 builds on the code base of DAS 2. Minor revisions to DAS 3 provide bug-fixes, important clarifications, and updated documentation. Some features of DAS 2 have been removed from DAS 3 due to their limited application or impractically long run-time.

1.2.1 Changes from DAS 3.1 to DAS 3.2

DAS 3.2 includes updates that address revisions in the NASA Standard 8719.14C. DAS 3.2 also includes the latest version of the Orbital Debris Engineering Model, ORDEM 3.1.2. The runtimes have not changed since the previous release of DAS.

1.2.2 Changes from DAS 3.0 to DAS 3.1

DAS 3.1 includes the latest version of the Orbital Debris Engineering Model, ORDEM 3.1. The runtimes are expected to be shorter than the previous ORDEM 3.0 model, and users should no

longer experience any "Not Responding" conditions. The ORDEM model has been extended to the year range 2016–2130 (with only the greater than 10 cm flux evaluated beyond 2050).

The simplified meteoroid flux model previously included in DAS is no longer sufficient to assess the probability of disabling damage due to the natural environment and has been removed from DAS. When evaluating penetration probability due to meteoroid flux, users must use the NASA Meteoroid Engineering Model (MEM). Users are encouraged to contact the NASA Orbital Debris Program Office (see https://orbitaldebris.jsc.nasa.gov/mitigation/debris-assessment-software.html).

1.2.3 Changes from DAS 2.1 to DAS 3.0

DAS 3.0 includes updates that address revisions in the NASA Standard 8719.14B, as well as several usability improvements. Assessment of intentional breakups and tether systems have been removed. In practice, those items are so unique that the general-purpose tool was of little use. The reentry survivability module now allows up to 1500 line items. Reflecting recent research, the carbon-fiber material types now have increased reentry survivability. Science and Engineering Tools that required days or weeks of computation due to ORDEM run-times have been removed.

As with DAS 2.1, version 3.0 incorporates the orbital debris environment model of ORDEM 3.0, the Orbital Debris Engineering Model also developed by the NASA Orbital Debris Program Office. The same run-time warnings apply to DAS 3.0.

IMPORTANT NOTE TO USERS: The higher-fidelity ORDEM 3.0 has greatly increased run-times compared to the previous ORDEM2.0 (a.k.a. ORDEM2000). Because DAS performs an ORDEM analysis for each year an object is in orbit, these increased run-times are multiplied.

1.3 Software Installation and Removal

Recommended system for DAS 3.2:

Windows 10
1GHz+ Intel (or compatible) CPU
256MB+ RAM
5.5GB+ available disk space
Latest Microsoft Visual C++ Redistributable runtime libraries

Software Installation:

DAS is distributed as an executable setup file. The setup will install the program's executable file and all necessary support files within the appropriate directories. The install program will analyze the computer's existing operating system to identify required support elements for installation. The installation program will prompt for the following information:

1. The **Welcome** window verifies that the installation of DAS is desired at this time. If not, select cancel.

2. The **Software License Agreement** verifies that the user agrees to accept the software's license. Disagreement will halt the installation. Agreement will proceed to the next step.

3. **Choose Install Location** defines the default location where the application will be installed. A "Browse" button enables the user to view the file structure to define an alternative location. **DAS must be installed in a location where the user has both read and write permissions.**

4. **Choose Start Menu Folder** defines a folder within the Windows **Start→Programs** list where the application shortcuts will be stored. The default setup will be provided but another name can be defined, or an existing program folder can be selected where this application will be loaded.

5. **Installing** shows the progress as the software and data files are uncompressed and installed.

6. **Installation Complete** notifies the user that the setup has completed. The computer will not require rebooting.

7. The **Completing** window gives the user options to create a Windows Desktop shortcut for DAS and to display the Release Notes for this version.

DAS 3 updates the internal Help function, so users no longer need to install separate software to use DAS Help. DAS relies on the Microsoft Visual C++ Redistributable runtime libraries. If not already installed, the user should install/update both the "x86" and "x64" versions provided by Microsoft:

> https://support.microsoft.com/en-us/topic/the-latest-supported-visual-c-downloads-2647da03-1eea-4433-9aff-95f26a218cc0

Do not remove or rename files and directories installed with DAS. Do not modify files within the DAS data directory ("[DAS]\data\"). Files and directories may be copied to another location if necessary, but DAS requires the files as originally installed. The **one exception** is the solar flux input table (file "[DAS]\data\solarflux_table.txt"), which the user must update when new versions are released. It should be replaced when a new version is posted on the NASA Orbital Debris Program Office website.

Because DAS stores some session information in the Windows Registry, the software may not behave as expected if the user installs multiple versions on the same computer. It is recommended that previous versions of DAS be removed as part of the installation process.

Software Removal:

DAS includes an automatic removal ("un-installer") feature (DAS3.2-Uninstall.exe), which is found in the installed directory. There is also a shortcut to the un-installer in the Windows Start Menu folder created during DAS installation. To remove DAS, activate the automatic un-installer either through the Start Menu shortcut or directly.

Alternatively, the user may use the Windows Control Panel "Add or Remove Programs" feature to remove DAS. From the Windows Start Menu, select **Settings → Control Panel**. In the Control Panel, double-click on "Add or Remove Programs." This brings up a window listing the installed programs, including DAS ("Debris Assessment Software"). Highlight the entry for DAS, click "Change/Remove," and click "Yes" when asked to confirm removal. You still may need to manually delete some files or folders from the directory where DAS was installed.

2. DAS Main Window Features

The DAS main window contains the top-level menus and toolbars, and a working area for the various DAS dialog windows.
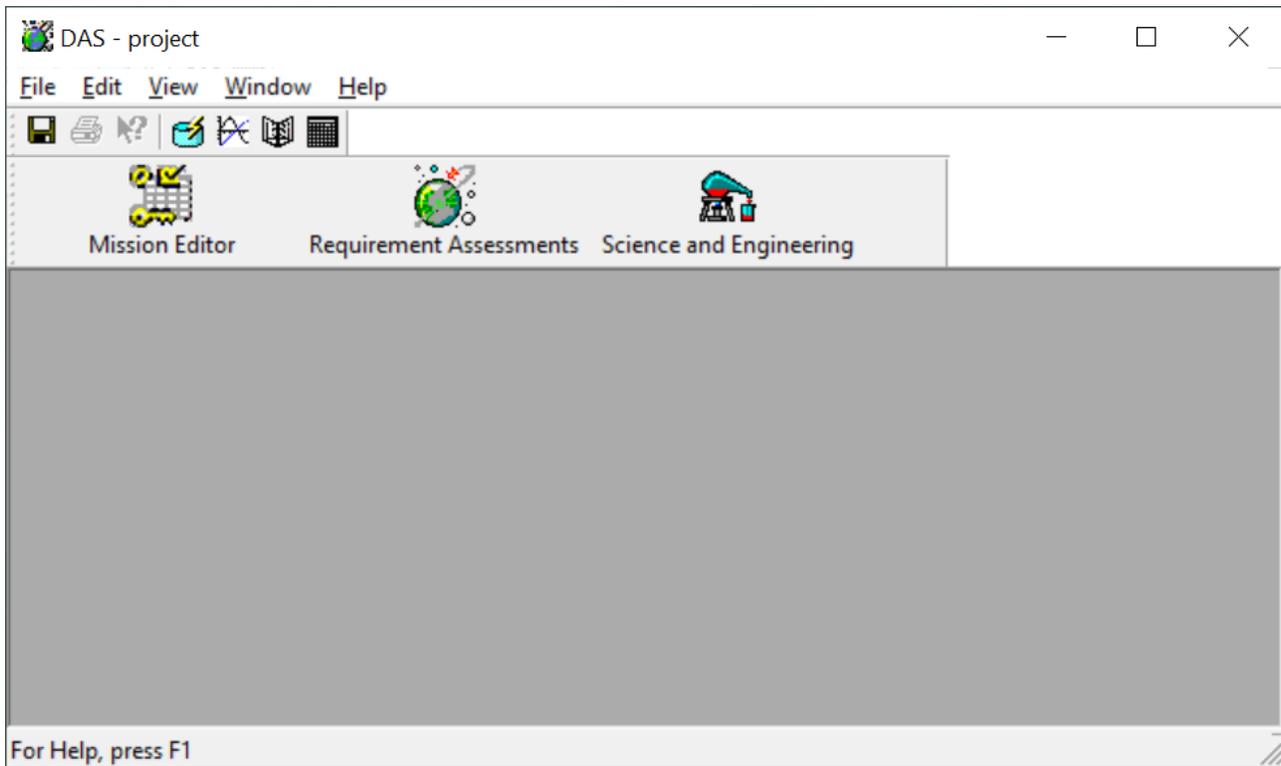
Figure 2 - 1: DAS Main Window

2.1 Viewing Toolbars

DAS provides two forms of toolbars to add convenience for application functions. The toolbars toggle on and off by selecting items from the **View** menu.

Run Toolbar contains buttons for easy navigation between the major dialogs:

 Mission Editor

 Requirement Assessments

 Science and Engineering
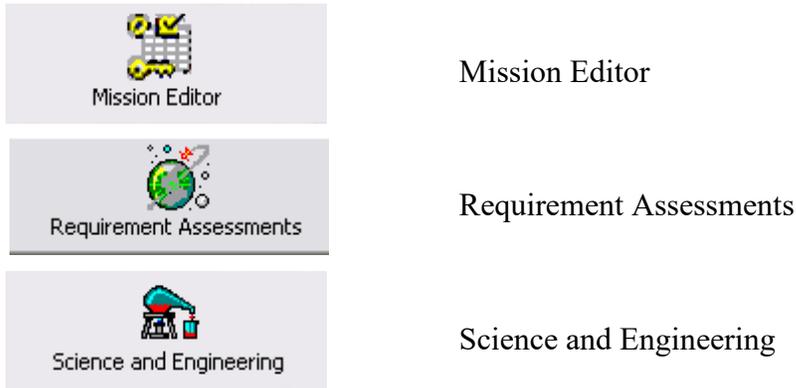
Toolbar contains buttons for the following commands:

 The disk button on the Toolbar saves the project to file (**File→Save Project**).

 The print button prints the Activity Log. The print button (**File→Print**) is only available when viewing the Activity Log.

 Context-Sensitive help is available by clicking this button, then clicking on the item in question. The cursor changes to this icon when context-sensitive help is engaged.

 The database button launches the Material Database Editor (**Edit→Material Database**).

 The plot button launches the Plot Utility (**View→View Plots**).

 The log button launches the Activity Log (**View→Activity Log→View**).

 The calendar button launches the Date Conversion Utility (**View→Date Converter**).

2.2 Using the Mission Editor

The Mission Editor is the starting point for assessing a mission's compliance with NASA Technical Standard 8719.14C, *Process for Limiting Orbital Debris*. The **Mission Editor** dialog (Fig. 2-2) allows users to define spacecraft, rocket bodies, and mission-related debris for requirement assessment. Launch year, mission duration, orbital characteristics, and many other items are specified within this window, thus eliminating the need for re-declaring them in each of the following requirement assessment windows.
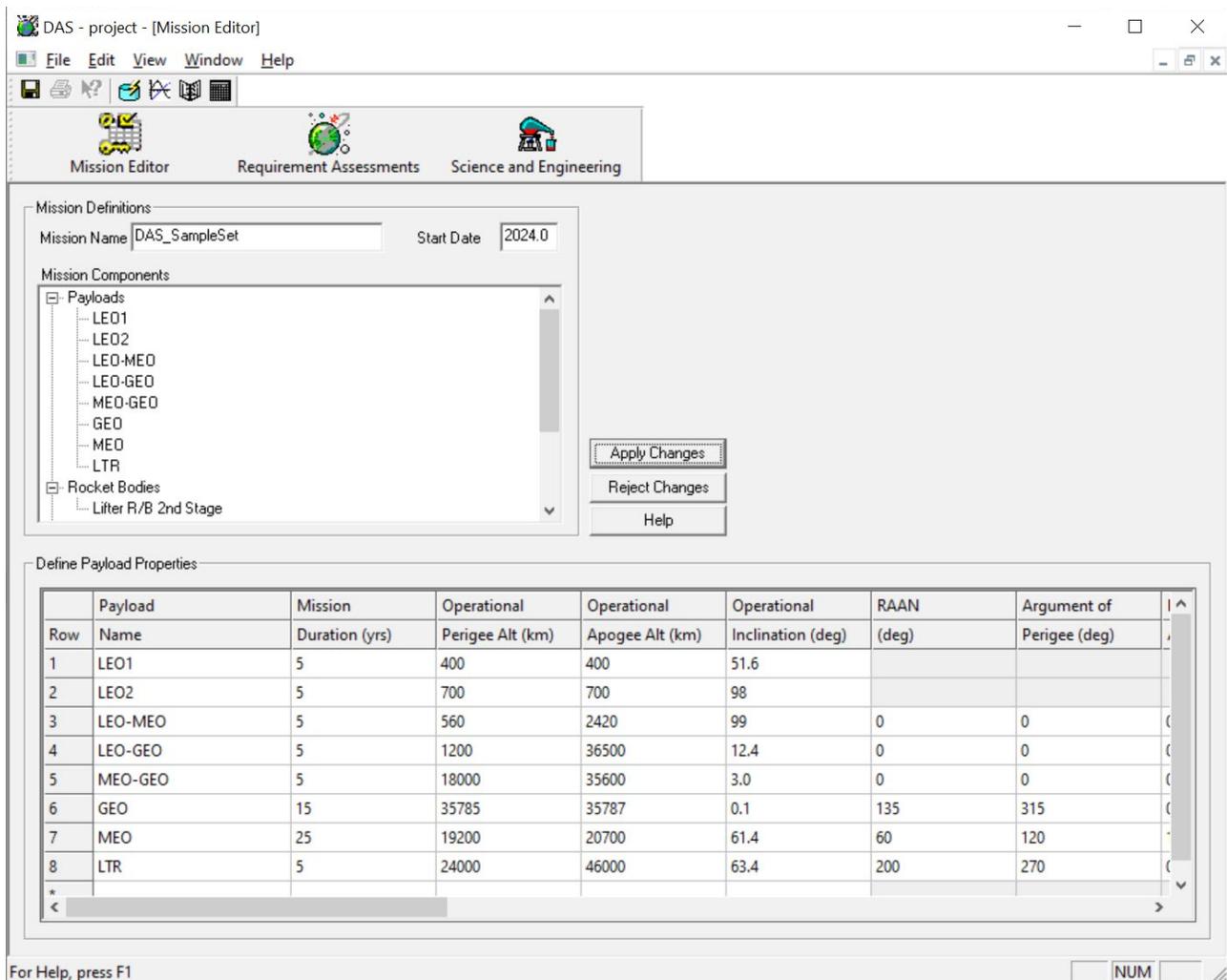
Figure 2 - 2: DAS Mission Editor Dialog

The **Mission Editor** window has three main editing areas: two edit fields at the top of the window (Mission Name and Launch Year), the **Mission Components** view, and the editable **Define Components Properties** table at the bottom of the window. These areas are defined below with specifics regarding each and information regarding the two buttons "Apply Changes" and "Reject Changes."

Mission Editor Fields:

- **Mission Name** – This is a text field that holds the name of the mission that is being assessed.

- **Start Date** – This field specifies the date the mission is planned to start. The date can be specified in decimal format. All years in orbit (*i.e.*, launch and operations) should fall between the years 2016 and 2130. This limit is enforced to ensure that the calculation models can provide accurate estimates.

- **Mission Components** – A tree structure provides a quick look at all defined components of the mission. It is broken into three categories: payloads, rocket bodies, and mission-related debris. Each of these categories has different specifications for its components. When selecting an item, the grid area below the tree structure will change to reflect the properties of that type of component. Also, the individual item in the tree will be highlighted within the grid for quick reference or editing.

- **Define Component Properties Grid** – This area is for defining and editing all the properties of each of the three categories of components. As mentioned above, there are three categories of components (payloads, rocket bodies, and mission-related debris). Each has its own set of properties, so selection of one type will only show components of that type. At the bottom of this grid is an empty row that can be used for adding new components. There is also a right mouse button menu available (click with the right mouse button on the table) for adding, deleting, or ordering of components.

  Upon completion of editing component data, the user should press the "Apply Changes" button. This will validate all the changes and save the data for later use in the requirement assessments. If the user wishes to abort changes since their last "Apply Changes" action, pressing the "Reject Changes" button will discard the changes. Each of these three category tables has different property fields and their descriptions and constraints are listed below.

Important Note: In DAS, highlighting a text field is DIFFERENT from selecting the field. When a text field is highlighted, it is ready for input from the keyboard. The "highlight" may be moved using the arrow keys or a single mouse-click. A highlighted field is not, however, ready for cut-and-paste operations. To select a field for cut, copy, or paste, the user must first highlight the field (using arrow keys or mouse), then click the mouse in the already-highlighted field. This will place a standard text cursor in the field. The user may then select the text within the field and use the standard cut/copy/paste operations.

Payloads:

Table 2 - 1: Mission Editor, Payload Grid

Payload Name	Payload Name is the unique identifier for each payload, and it must be distinct from all other component names.
Mission Duration (yr)	Mission Duration specifies the mission or operational lifetime of the payload beginning from the Launch Year. It is a decimal field (allowing partial years to be specified). This numeric value must be greater than zero.
Operational Perigee Alt (km)	Operational Perigee Altitude is measured from Earth's surface to the spacecraft's normal, operational orbit perigee point. This decimal value must be greater than 90 and less than or equal to 100,000 kilometers. Operational Perigee Altitude must be less than or equal to Operational Apogee Altitude.
Operational Apogee Alt (km)	Operational Apogee Altitude is the distance measured from Earth's surface to the spacecraft's normal, operational orbit apogee point. This decimal value must be greater than 90 and less than or equal to 100,000 kilometers. Operational Apogee Altitude must be greater than or equal to Operational Perigee Altitude.
Operational Inclination (deg)	Operational Inclination is the angle measured from Earth's equatorial plane to the payload's operational orbital plane. This decimal value must be between 0 and 180 degrees.
RAAN (deg)	Right Ascension of Ascending Node (RAAN) is a decimal value between 0 and 360 degrees. RAAN is only needed if the apogee altitude is greater than 2000 km. The field will remain inactive until an apogee altitude greater than 2000 km is entered.
Argument of Perigee (deg)	Argument of Perigee is a decimal value between 0 and 360 degrees. This value is only needed if the apogee altitude is greater than 2000 km. The field will remain inactive until an apogee altitude greater than 2000 km is entered.
Mean Anomaly (deg)	Mean Anomaly is a decimal value between 0 and 360 degrees. Mean Anomaly is only needed if the apogee altitude is greater than 2000 km. The field will remain inactive until an apogee altitude greater than 2000 km is entered.
PMD Maneuver (check if Yes)	Postmission Disposal Maneuver is a check box entry. Placing a check in the box indicates a planned disposal maneuver in space. A check in this field will enable the disposal orbital parameter fields of the grid.
Disposal Perigee Alt (km)	Perigee Altitude for postmission disposal orbit is a decimal value that must be greater than 90 and less than or equal to 100,000 kilometers. Perigee altitude must be less than or equal to apogee altitude.
Disposal Apogee Alt (km)	Apogee Altitude for postmission disposal orbit is a decimal value than must be greater than 90 and less than or equal to 100,000 kilometers. Apogee altitude must be greater than or equal to perigee altitude.

Table 2 - 1 - Continued

Disposal Inclination (deg)	Inclination for postmission disposal orbit is a decimal value that must be between 0 and 180 degrees.
Disposal RAAN (deg)	RAAN for postmission disposal orbit is a decimal value that must be between 0 and 360 degrees. RAAN is only needed if the disposal apogee altitude is greater than 2000 km. The field will remain inactive until a disposal apogee altitude greater than 2000 km is entered.
Disposal Arg of Perigee (deg)	Argument of Perigee for postmission disposal orbit is a decimal value that must be between 0 and 360 degrees. Argument of Perigee is only needed if the disposal apogee altitude is greater than 2000 km. The field will remain inactive until a disposal apogee altitude greater than 2000 km is entered.
Disposal Mean Anomaly (deg)	Mean Anomaly value for postmission disposal orbit is a decimal value that must be between 0 and 360 degrees. Mean Anomaly is only needed if the disposal apogee altitude is greater than 2000 km. The field will remain inactive until a disposal apogee altitude greater than 2000 km is entered.
Initial Mass (kg)	Initial Mass is a decimal field for the mass of the payload (in kilograms) at the start of the mission in the operational orbit, including all fluids and all internal fragments (aero mass).
Initial Area-to-Mass (m2/kg)	Initial Area-To-Mass is a decimal value representing the frontal cross-sectional area of the rocket body (in square meters) divided by the final mass of the rocket body (in kilograms). Calculation of the frontal area depends on orientation of the payload; uncontrolled orientation uses the average cross-sectional area.
Final Mass (kg)	Final Mass is a decimal field representing the mass of the payload (in kilograms) after the payload's mission and all postmission passivation actions are completed. This should be the dry aero mass of the payload if all fluids have been expended.
Final Area-To-Mass (m^2/kg)	Final Area-To-Mass is a decimal field representing the frontal cross-sectional area of a payload (in square meters) divided by the final mass of the payload (in kilograms). Calculation of the frontal area depends on orientation of the payload; uncontrolled orientation uses the average cross-sectional area.
Station Keeping (check if Yes)	Station Keeping is a check box field. If checked, the payload's orbital elements are fixed throughout its mission duration. During its mission duration, the payload is precluded from natural orbital decay by active station keeping devices, *e.g.*, thrusters. DAS 3 assumes that if an object is "Station Kept," the user input orbital elements will not be subject to decay. Objects that are not Station Kept will be assumed to decay naturally throughout their lifetime.
Long-Term Reentry (check if Yes)	Long-Term Reentry is a check box field. If checked, the payload's postmission disposal will be automatically assessed against Requirement 4.6-3, the long-term reentry option, only.

Rocket Bodies:

<div align="center">

Table 2 - 2: Mission Editor, Rocket Body Grid

</div>

Rocket Body Name	Rocket Body Name is the unique identifier for each rocket body and it must be distinct from all other component names.
Perigee Alt (km)	Perigee Altitude is measured from Earth's surface to the rocket body's disposal orbit apogee point. This decimal value must be greater than 90 and less than or equal to 100,000 kilometers. Perigee altitude must be less than or equal to apogee altitude.
Apogee Alt (km)	Apogee Altitude is measured from Earth's surface to the rocket body's disposal orbit perigee point. This decimal value must be greater than 90 and less than or equal to 100,000 kilometers. Apogee altitude must be greater than or equal to perigee altitude.
Inclination (deg)	Inclination of the disposal orbit with respect to Earth's equatorial plane. This decimal value must be between 0 and 180 degrees.
RAAN (deg)	Right Ascension of Ascending Node (RAAN) is a decimal between 0 and 360 degrees. RAAN is only needed if the apogee altitude is greater than 2000 km. The field will remain inactive until an apogee altitude greater than 2000 km is entered.
Argument of Perigee (deg)	Argument of Perigee value is a decimal value between 0 and 360 degrees. This value is only needed if the apogee altitude is greater than 2000 km. The field will remain inactive until an apogee altitude greater than 2000 km is entered.
Mean Anomaly (deg)	Mean Anomaly is a decimal value between 0 and 360 degrees. This value is only needed if the apogee altitude is greater than 2000 km. The field will remain inactive until an apogee altitude greater than 2000 km is entered.
Final Mass (kg)	Final Mass is a decimal value representing the mass of the rocket body (in kilograms) after the rocket body's mission is complete and after passivation.
Final Area-To-Mass (m^2/kg)	Final Area-To-Mass is a decimal value representing the average cross-sectional area of the rocket body (in square meters) divided by the final mass of the rocket body (in kilograms).
Long-Term Reentry (check if Yes)	Long-Term Reentry is a check box field. If checked, the rocket body's postmission disposal will be automatically assessed against Requirement 4.6-3, the long-term reentry option, only.

Mission-Related Debris:

Mission-Related Debris items only need to be defined if they pass through low Earth orbit (LEO) and are 1 mm or larger in size, or if they pass through geosynchronous orbit (GEO) and are 5 mm or larger in size.

Table 2 - 3: Mission Editor, Mission-Related Debris Grid

Debris Name	Debris Name is the unique identifier for this component and its value must be distinct from all other component names.
Released Year	Released Year is a decimal value that defines the date that this debris is released from the spacecraft or rocket body. This value must be equal to or greater than the mission's launch year.
Quantity of Each Element	Quantity of Each Element is the number of debris items of this type that will be released. It must have a value of one or greater.
Area-To-Mass (m^2/kg)	Area-To-Mass is a decimal value for the average cross-sectional area of the debris (in square meters) divided by the mass of the debris (in kilograms).
Perigee Alt (km)	Perigee Altitude is measured from Earth's surface to the debris object's perigee point. This decimal value must be greater than 90 and less than or equal to 100,000 kilometers. Perigee altitude must be less than or equal to the apogee altitude.
Apogee Alt (km)	Apogee Altitude is measured from Earth's surface to the debris object's apogee point. This decimal value must be greater than 90 km and not exceeding 100,000 km. Apogee altitude must be greater than or equal to the perigee altitude.
Inclination (deg)	Inclination of the debris object's orbit; a decimal value between 0 and 180 degrees.
RAAN	Right Ascension of Ascending Node (RAAN) is a decimal value between 0 and 360 degrees. This value is only needed if the apogee altitude is greater than 2000 km. The field will remain inactive until an apogee altitude greater than 2000 km is entered.
Argument of Perigee (deg)	Argument of Perigee is a decimal value between 0 and 360 degrees. This value is only needed if the apogee altitude is greater than 2000 km. The field will remain inactive until an apogee altitude greater than 2000 km is entered.
Mean Anomaly (deg)	Mean Anomaly is a decimal value between 0 and 360 degrees. This value is only needed if the apogee altitude is greater than 2000 km. The field will remain inactive until an apogee altitude greater than 2000 km is entered.

2.3 Requirement Assessments

The **Requirement Assessments** window provides an adjustable split window to view the dialogs for each requirement supported by DAS. The dialog contains a list of supported requirements in the left window pane. As a requirement is selected, the supporting dialog will appear in the right pane. Data entered into the Mission Editor serve as input data for the requirements, though additional input may be required. As data are analyzed in each requirement, the compliance state is displayed as an icon next to that label in the left window. Additional information appears in the output area at the bottom of each requirement assessment window. If the mission is compliant with a requirement, a green check icon will appear next to the requirement name. If the mission is not compliant, a red "X" will appear. The user may use the mouse to adjust the position of the divider between the left and right windows. If one object in a list of multiple parent objects fails assessment (*i.e.*, status is "Non-Compliant") DAS will halt assessment and mark subsequent, unassessed objects as "Incomplete." The user will need to address the non-compliance before proceeding with assessments.

As data are input, requirements are assessed, and output is generated, the data will be retained within the project's data. It is saved to the project files when the user agrees to saving the data on application termination or selects the **File→Save Project** command from the main menu.

Selecting various requirements only affects the current view in the right side of the window. The information and state are retained if the requirement assessment window is open. Assessment status is lost when the window is closed.

Changes within the Mission Editor can affect data used within the previously opened requirements. When changes to mission data are applied within the Mission Editor, the **Requirement Assessments** window is closed, and all compliance states are reset.

All assessments can be reset to initial state (not run) by depressing the "Reset" button in the right windowpane displayed with the upper requirement level (NS 8719.14 - Process for Limiting Orbital Debris).

Chapter 3 provides details of each assessment's operations.
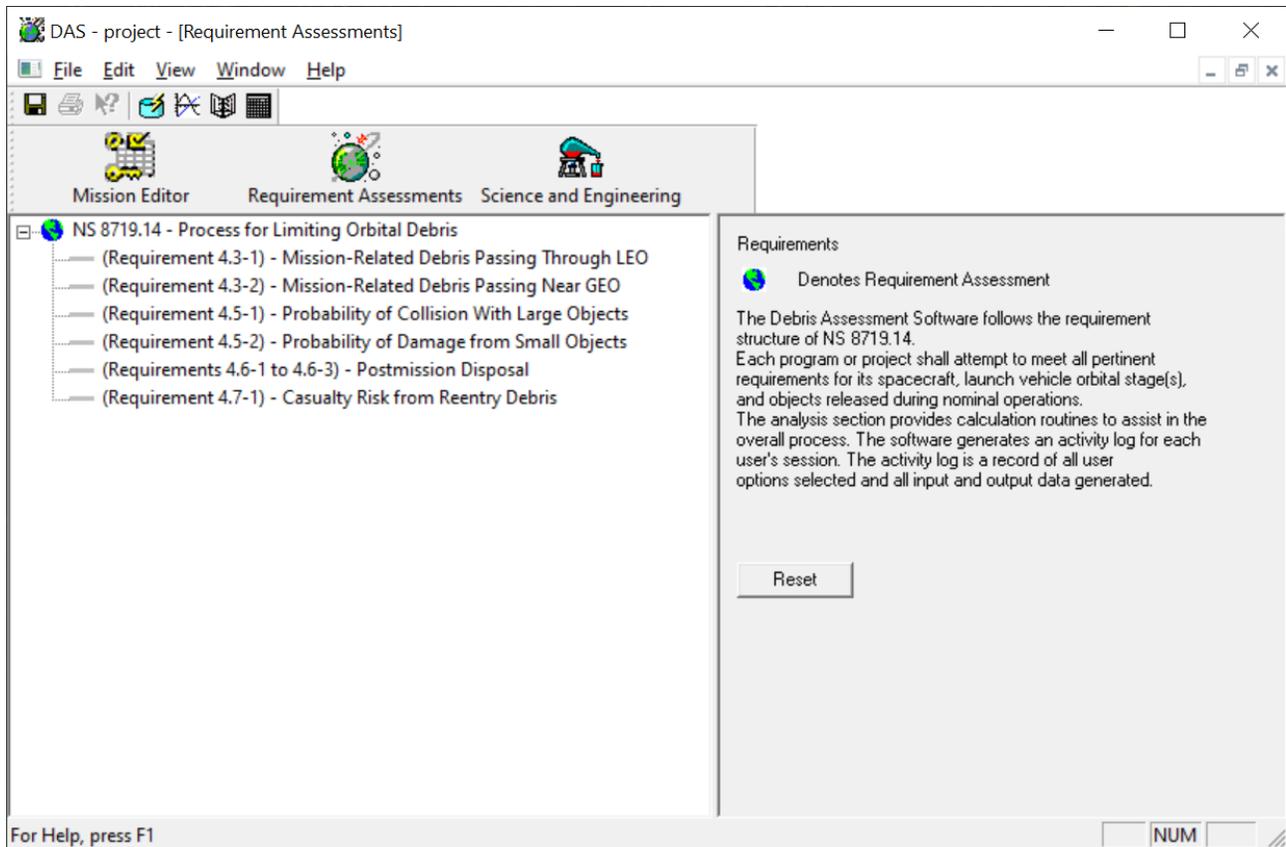
Figure 2 - 3: Requirement Assessments – Top-level Dialog

2.4 Science and Engineering Utilities

The Science and Engineering Utilities allow the user to analyze some aspects of orbit/mission design outside the context of Requirement Assessments.

To access each tool, expand a category from the tree and then double-click the mouse over the selected routine. The corresponding dialog will appear.

Chapter 4 provides details of the Science and Engineering Utilities.

2.5 Using the Material Database Editor

Reentry assessment requires information on the type of material used in an object's construction. The Material Database provides a view of standard materials used by the underlying application and a means to define additional materials specific to a mission. See Appendix C for a table of properties of the standard materials.

The **Material Database** dialog can be opened to view the defined data or add user-defined materials by pressing the database button ![icon] on the Toolbar or selecting **Edit→Material Database** from the application menu.

If an object uses a material that is not on the standard list, user-defined materials may be created specifically for the current project, defining:

- Unique material name
- Density
- Specific heat
- Heat of fusion
- Melt temperature

Note that material density is only used as a "sanity check" (*i.e.,* limiting case) on user inputs of mass and size. It is used to verify that the data input for an object's mass and dimensions are consistent.

Newly defined materials are saved to the *project\matprop.csv* file by pressing the "Save" button.

Closing the dialog without saving updates will prompt the user to save.

2.6 Using the Plot Viewer

DAS includes a two-dimensional plot viewing utility for displaying previously-saved DAS .dpl files.

To activate the plot utility, press the plot viewer button ![icon] on the Toolbar, or select **View→View Plots** from the application menu. The DAS **Plot** window will open containing a blank two-dimensional plot layout. The plot window will also be generated by functions in the Science and Engineering utilities.

The utility provides the following buttons to manage plot files:

- **Load Plot** – Displays an Open Plot File dialog to navigate to a previously saved *.dpl file to be loaded into the display area of the Plot Utility.
- **Save Plot** – Provides a Save Plot dialog to specify the name and directory location for the saved *.dpl file. The dialog defaults to the "My Documents" directory.

- **Copy to Clipboard** – Copies the plot image to the Windows clipboard. An acknowledgement dialog will appear, requiring an "OK" to proceed. The image may then be pasted into other (non-DAS) applications.

- **Close** – Closes the Plot Utility. Be certain that all desired changes have been saved before closing the window since no save prompt will remind the user before closing the window.

A single right-click or double left-click of the mouse on the plot area (left windowpane) will display a pop-up menu with additional plotting functionality:

- **Select** – Allows users to select objects with the mouse. Select returns the cursor state to a pointed arrow and turns off other cursor functions (Zoom, Pan, Cursor).

- **Zoom** – Allows users to isolate and enlarge a rectangular area of the plot. The cursor changes to a cross-hair (**+**). By holding the left-mouse button while dragging the cross-hair over the plot, a rectangular highlight area appears. Size the rectangle by maneuvering the mouse over the plot. Releasing the mouse button enlarges the highlighted rectangular area. The axes adjust to the zoomed size.

- **Reset** – Allows users to reset all axes to optimal values.

- **Pan** – Allows users to move the plotted curve(s) within the plot area. The cursor changes to the pan cursor (✛). The cursor can be moved by holding the left-mouse button while dragging the cursor over the plot. The axes scale to fit the pan. To stop the action, release the mouse. To leave Pan mode, right-click on the plot and choose "Select" from the pop-up menu.

- **Cursor** – Provides the means to capture the mouse's position on the plot, interpolating the mouse coordinates to the corresponding plot scale. The cursor changes to a cross-hair (**+**), and one vertical and one horizontal line intersect marking the cursor's position. Clicking the left-mouse button inserts a label onto the graph with the interpolated values. Clicking the right-mouse button launches the pop-up menu. Choose "Select" from the pop-up menu to change the cursor back to a pointing arrow. To remove the labels from the graph, return to Select mode, click the left-mouse button over the desired label object, noting that the item has been activated, and then depress the "Delete" key on the keyboard.

- **Insert Label** – Inserts a blank label (text box) onto the plot. Click the left-mouse button on the label until the object is activated, and then double-click the left mouse button within the label. This action should change the cursor to a vertical text cursor within the label. Once the cursor changes, begin typing or paste any previously copied text. The label can be moved and sized by manipulating the mouse after activating the label. When the object is activated, additional functionality becomes available. Clicking the right-mouse button within the activated label launches a label properties dialog box:

  - Background color – Launches a color palette for selecting and changing background color.

  - Font – Launches a common font dialog.

  - Alignment – Provides a means to align the text Left, Centered or Right.

  - Connect to curve – Combo box allows users to choose to which curve the label will be attached,

o Transparent and Border check boxes – Provide optional label bordering.

Labels in the plot area may be selected with a single left-mouse click. Once selected, a label may be moved, resized, activated (for editing), or deleted. This applies to both user-inserted labels and to automatic labels (such as the plot title).

- **Print** – Provides a means to print an active plot to a designated printer by selecting printer characteristics and functions from a print dialog window. Currently, only grayscale printing is available; however, plots copied to another application (*e.g.*, word processor) can be printed based on that application's print support.

- **Properties** – Opens a dialog to set various properties for the displayed plot. Once properties are changed, click "Apply" (immediately apply changes and leave dialog open) or "OK" (apply changes and close dialog) to activate the changed properties. "Cancel" will close the dialog without applying any selected changes. The three tabbed sets of property categories are:

  o Chart – Has nine controls that offer additional features for changing the way the plot is displayed

    - *Background color* – Dialog that allows users to set the color outside the plot area and labels.

    - *Exterior color* – Dialog that allows users to set the color behind the axes and the color of the grid lines on their plot.

    - *Interior color* – Dialog that allows users to set the color of the plot inside the axes.

    - *Show Legend* – Position the legend to either the left or right of the plot or remove it.

    - *Snap Cursor to nearest curve* – Position the cursor to the curve within a specified tolerance (up to 100 pixels).

    - *Select x-axis* – Applies the x-axis properties on the Axis property dialog. Leaving the field blank selects the y-axis.

    - *Select y-axis* – Applies the y-axis properties on the Axis property dialog. Leaving the field blank selects the x-axis.

    - *Select curve* – Selects a specific curve's properties on the Curve property dialog.

    - *Double Buffering* – Turns double buffering either on or off. Double buffering can improve the appearance of moving images (pan and zoom).

  o Axis – properties allow users to modify various axis features such as scale, tick-size, font, and grid color. Select an axis in the Chart tab before modifying properties in the Axis tab. Once choices have been completed for each axis, depress "Apply" or "OK" to process the changes.

  o Curve – properties allow users to modify various curve features such as line width, line color, curve trends, and marker size. Select a curve in the Chart tab before modifying properties in the Curve tab. For each curve, depress "Apply" or "OK" to process the selected changes.

2.7   Using the Date Conversion Utility

The Date Conversion Utility is provided for easy conversion between the following date formats:

- **Calendar Format** – The year, month and day can be selected in the calendar control. The user may select another month by pressing the previous (left) or next (right) arrow buttons within the calendar title, or by clicking on the name of the month. To select another year, click on the year within the title and then roll forward (up) or back (down) using the control that will appear next to the year. The day selected within the lower calendar will remain selected for the changed year or month.

- **Decimal Date** – The format for decimal date is: **yyyy.ddd**, where ddd is the decimal portion of the year, *i.e.,* June 30, 2006 is formatted as "2006. 496", and November 15, 2005 is formatted as "2005.874".

- **Day of Year** – The format for day of year is **yyyy doy**, where doy is the numeric day within the year's days (365, 366). For example: June 30, 2006 is formatted as "2006 181", and November 15, 2005 is formatted as "2005 319".

Activate the Date Conversion Utility by pressing the calendar button [image] on the Toolbar, or by selecting **View➔Date Converter** from the application menu. As a date is entered within any control, that date will be displayed in the other controls in the control's supported format.

2.8   Viewing the Activity Log

The Activity Log provides a means to view all data processed within the DAS application. As requirements are assessed, the data input and the resulting output are written to the Activity Log. The data are written to the text file *ActivityLog* in the current project's directory. The file can be used to track a problem with data, or to capture text based on the project being defined. To view the activity log, press the logbook button [image] on the Toolbar, or select **View➔Activity Log➔View** from the application menu.

As the program starts, the previous *ActivityLog* file is over-written. To save a copy of the current *ActivityLog* file to an alternate location, select **File➔Save Log As…** from the application menu. The file can be viewed outside DAS in a text editor/viewer (*e.g.*, WordPad or Word) and printed using the DAS menu items **File➔Print Setup**, **File➔Print Preview** and **File➔Print**.

The Activity Log can be cleared during processing by selecting **View➔Activity Log➔Clear** from the application menu. This function can be used to reduce the amount of data viewed during processing without changing the underlying text saved in the log file.

Previously cleared views of the Activity Log can be restored (to view all data processed since the program started) by selecting the **View➔Activity Log➔Restore** menu item.

The clear and restore functions do not affect the underlying *ActivityLog* file.

2.9 Saving and Loading Projects

In DAS, all data are stored as a "project." A project consists of a directory with many files that retain all the data that the user may define within the application. The default project is an example directory folder named "project/" within the installed DAS directory.

Use the **File→New Project** menu function to create a new project. The **Define New Project Path** dialog will appear for entering the path. A browse button (**…**) next to the path entry opens the **Browse for New Project Folder** dialog to view the computer's paths and select existing directories with defined mapped paths. The dialog contains an edit control to enter the name of the new directory if it does not already exist. When the OK button in either dialog is pressed, the directory will be created. If the project directory already exists, DAS will prompt the user with a reminder that any previously saved data in that directory will be replaced by the new project. The new project is opened in its initial (blank) state. This action will then launch the Mission Editor so that a new mission may be defined.

To create a new project based on a currently open project, select the **File→Save Project As…** menu item. Its function is like the New Project function except that any existing data is saved in the new directory, including any updates applied since the project was opened or previously saved. If the project directory already exists, DAS will prompt the user with a reminder that any previously saved data in that directory will be replaced by the new project.

To open a project, select the menu item **File→Open Project**. The **Open Project** dialog is like the **Define New Project Path** dialog except that the browse dialog does not support the creation of new directories and the Open Project dialog will verify that the selected directory contains the required **das.prj** file. An invalid (incomplete) project directory will not open and the dialog will remain open.

As projects are opened, the path is saved and will appear on the **File** menu above the **Exit** item. Up to four projects are collected as recently-used projects and will appear in the order referenced, with the latest at the top. When the application opens, if the most recent project path is still valid, that project will open instead of the initial default path.

The application does not retain updates to the project unless the user selects the **File→Save Project** menu item, presses the project save button on the toolbar, or closes the application and chooses "Yes" on the prompt to save their data. This allows the user the option to close without saving and return to the last saved state.

3. Assessing Compliance with the NASA Debris Requirements

The **Requirement** dialog contains a list of supported requirements in the left window (some requirements must be assessed outside of DAS). As a requirement is selected, the supporting dialog will appear in the right window. All data input into the requirement window will be retained until the application closes. The result of the requirement assessment will appear as an icon next to that label in the **Requirements** window. If one object in a list of multiple parent objects fails assessment (*i.e.*, status is "Non-Compliant") DAS will halt assessment and mark subsequent, unassessed objects as "Incomplete." The user will need to address the non-compliance before proceeding with assessments.

As requirements are processed and output is generated, the information will be retained within the project data. It will be saved to the project files when the user agrees to saving the data on application termination.

Selecting various requirements only affects the current view in the right side of the window. The data and state are retained as long as the requirement assessments window is open. Compliance state is lost when the window is closed.

Changes within the Mission Editor can affect data used within the previously open requirements. When changes to data are applied within the Mission Editor, the **Requirement Assessments** window is closed, and all states are reset.

Note: The information in this section pertains to the DAS assessment of elements from NASA's Process for Limiting Orbital Debris. Because these instructions contain excerpts and paraphrasing from the NASA Technical Standard, the reader should consult the Standard itself for the official text of the requirements. The text of the requirements is provided in Appendix B of this User's Guide.

3.1 Requirement 4.3-1: Debris Passing Through LEO

For missions leaving debris in orbits passing through LEO, released debris with diameters of 1 mm or larger must satisfy both of the following conditions:

  a. All debris released during the deployment, operation, and disposal phases shall be limited to a maximum orbital lifetime of 25 years from date of release.

  b. The total object-time product shall be less than 100 object-years per launch vehicle upper stage or per spacecraft.

The intent of Requirement 4.3-1 is to remove debris in LEO from the environment in a reasonable period of time. The 25-year removal time from LEO limits the growth of the debris environment over the next 100 years while limiting the cost burden to programs and projects.

Debris in near-circular orbits with perigee altitudes below 600 km will usually have orbital lifetimes of less than 25 years. This requirement will have the greatest effect on programs and projects with perigee altitudes above 700 km, where objects may remain in orbit naturally for hundreds of years.

Requirement 4.3-1 applies to staging components, separation and deployment hardware, and other objects that are known to be released during normal operations and EOM passivation/disposal. Spacecraft and spent orbital stages are addressed in other Requirements, with the exception that satellites smaller than a 1U standard CubeSat must follow this 100 object-years per mission deployment limit in addition to other applicable requirements. This DAS module can help the user assess such small satellites with respect to Requirement 4.8-1b.

(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)	Inclination (deg)	RAAN (deg)	Argument of Perigee (deg)	Mean Anomaly (deg)
1	Lens Caps	2024.01	1	0.01864407	157	171	97.4			
2	Straps	2024.0	1	0.004615385	215	15777	38.7	0.1	0.1	0
3	Staging Bolts	2024.0	3	0.1185	806	815	98.8			

[Run] [Requirement] [Help]

Output

Row	Debris Name	Compliance Status	Lifetime (yrs)	Object Time (obj-yrs)
1	Lens Caps	Compliant	0.0	0.0
2	Straps	Compliant	11.8	2.6
3	Staging Bolts	Compliant	21.8	65.3

TOTAL OBJECT TIME:
67.9 obj yrs

Messages

Requirement 4.3-1
Compliant

Figure 3 - 1: Requirement 4.3-1 – Debris Passing Through LEO Dialog

Input Data:

The data displayed in the input grid are "read-only." To modify the input data, the user must return to the **Define Mission-Related Debris Properties** grid of the Mission Editor.

Output Data:

Each debris object is assigned a compliance status. If any object is not in compliance, then the mission does not comply with Requirement 4.3-1.

The total object time product (applies to Requirement 4.3-1b) is the sum, over all objects, of the orbital dwell time in LEO. If the debris is in an orbit with apogee altitude below 2000 km, the orbit dwell time equals the orbital lifetime. The total object-time product should be no larger than 100 object-years per rocket body or per spacecraft.

For example, if the LEO dwell time for a debris object is calculated to be 25 years, then no more than four such objects can be released for the mission to be compliant with the 100 object-years limit of Requirement 4.3-1b. Requirement 4.3-1a limits the total orbital lifetime of each single piece of debris passing through LEO to 25 years, regardless of how much time per orbit is spent below 2000 km. If the LEO dwell time of the debris is only 20 years, then a total of up to five debris objects can be released and still satisfy Requirement 4.3-1b, as long as the maximum orbital lifetime of each object does not exceed 25 years.

Messages and comments developed during analysis are displayed on the dialog, below the output data.

3.2 Requirement 4.3-2: Debris Passing Near GEO

For missions leaving debris in orbits with the potential of traversing GEO (GEO altitude ± 200 km and ± 15° inclination), released debris with diameters of 5 mm or greater shall be left in orbits which will ensure that within 25 years after release, the apogee will no longer exceed GEO - 200 km or the perigee will not be lower than GEO + 200 km, and also ensures that the debris is incapable of being perturbed to lie within that GEO ± 200 km and ± 15° zone for at least 100 years thereafter.

Debris that are not removed from GEO altitude may remain in the GEO environment for many thousands of years or longer. Therefore, Requirement 4.3-2 limits the accumulation of debris at GEO altitudes and will help mitigate the development of a significant debris environment, as currently exists in LEO. To ensure that the mission is compliant with Requirement 4.3-2, the spacecraft must be sufficiently above or below GEO at the time of debris release. The 200 km offset distance takes into account the operational requirements of GEO spacecraft.

Requirement 4.3-2 includes debris released by a spacecraft, such as solid rocket motor casings and other objects that are known to be released during normal operations.

Mission-related debris passing near GEO, in general, can be categorized as in "nearly circular" or in "highly eccentric" orbits. An example of a nearly circular orbit would be debris, *e.g.*, a solid rocket motor casing, released by a spacecraft after the spacecraft has already been inserted into an orbit near GEO.

Debris might also originate from a launch vehicle orbital stage that has inserted its payload directly into an orbit near GEO. In such a case, all debris should be eliminated entirely, or the orbital stage should be sufficiently removed from the GEO regime at the time of debris release.

In limited cases, debris may also be released into highly-eccentric geosynchronous transfer orbits (GTO) with perigee altitudes near LEO or at higher altitudes with apogee altitudes near GEO, but releases must be consistent with Requirement 4.6-2. Debris released at the time of payload separation on a mission of this type would fall under Requirement 4.3-2. For debris passing through LEO, Requirements 4.3-1a and 4.3-1b take precedence.

Debris can be left in an eccentric orbit traversing GEO if orbital perturbations will cause the object to leave the GEO regime within 25 years. The orbit propagator within DAS can be used to determine the long-term orbital perturbation effects for specific initial orbital conditions and hence, to determine compliance with Requirement 4.3-2 by ensuring the debris will not reenter the GEO protection zone within 100 years.

Special orbit propagation models are necessary to evaluate the evolution of disposal orbits to ensure that debris do not later interfere with GEO as a result of major perturbations such as solar and lunar gravitational perturbations and solar radiation pressure.

Figure 3 - 2: Requirement 4.3-2 – Debris Passing Near GEO Dialog

Input Data:

The data displayed in the input grid is "read-only." Input to the requirement is entered through the Mission Editor under the **Define Mission-Related Debris Properties** grid.

Output Data:

Once processed, output is displayed in the output area of the dialog. Each debris object is assigned a compliance status. If any object is not in compliance, then the mission does not comply with Requirement 4.3-2.

Messages and comments developed during analysis are displayed on the dialog, below the output data.

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3.3   Requirements 4.4-1, 4.4-2, 4.4-3, and 4.4-4: Not Covered by DAS

DAS 3 will not determine compliance with Requirements 4.4-1, 4.4-2, 4.4-3, or 4.4-4. The project must demonstrate compliance with Requirements 4.4-1 and 4.4-2 though its own calculations. For Requirements 4.4-3 and 4.4-4, contact the NASA Orbital Debris Program Office for assistance.

3.4   Requirement 4.5-1: Debris Generated by Collisions with Large Objects

Catastrophic collisions during orbital lifetime represent a direct source of debris, and the probability of this occurring is addressed by Requirement 4.5-1. This Requirement limits the amount of debris that will be created by collisions between spacecraft or launch vehicle stages passing through heavily populated orbit bands (LEO and GEO) and other large objects in orbit. .

Figure 3 - 3: Requirement 4.5-1 – Limiting Debris Generated by Collisions with Large Objects Dialog

Input Data:

Payloads and rocket bodies defined for the mission are included as input for this assessment. The data displayed in the input grid are "read-only." To modify the input data, the user must return to the **Define Mission-Related Debris Properties** grid of the Mission Editor.

Output Data:

The output area of the dialog displays results listed by component. The output table displays compliance status of each component and the computed probability of collision with a large object. The probability of accidental collision with space objects larger than 10 cm in diameter must be less than 0.001.

Messages and comments developed during analysis are displayed on the dialog, below the output data. **Note that increased fidelity of the debris environment model results in greatly increased DAS run times.**

If the user selects the long-term reentry option (see Section 3.6), then the probability of collision with large objects reported here is only for the operational phase (*i.e.*, mission duration).

3.5 Requirement 4.5-2: Probability of Damage from Small Debris

Requirement 4.5-2 limits the probability that a spacecraft will become disabled and unable to perform end-of-mission tasks, such as disposal maneuvers and passivation. This could contribute to the long-term growth of the orbital debris environment by subsequent collision or explosion fragmentation. DAS assesses whether a spacecraft's probability of being disabled by small orbital debris impacts is less than the limit of 0.01 (1 in 100).

Due to the very short mission duration of launch vehicle orbital stages (normally less than 24 hours), the probability of a disabling small debris impact on orbital stages is not significant.

Requirement 4.5-2 applies only to subsystems that are vital to completing postmission disposal. This includes components needed for either controlled reentry or transfer to a disposal orbit. Examples of such subsystems are propellant lines and tanks, attitude control system, batteries and power lines, and communications equipment. The same methodology can be used to evaluate the vulnerability of the spacecraft instruments and mission-related hardware. This information can be used to verify the reliability of the mission with respect to orbital debris and meteoroid hazards.

Payloads are defined in the Mission Editor and displayed in Requirement 4.5-2.

Note, **DAS 3.2 cannot assess Requirement 4.5-2 for missions operating after 2050**. See Appendix C.3 for more information.

(Requirement 4.5-2) Probability of Damage from Small Debris

Payload Critical Surfaces

- LEO1
  - Gas Tank
  - Star Tracker
- LEO2
  - Gas Tank
  - Star Tracker
- LEO-MEO
  - Gas Tank
  - Star Tracker

[Add] [Delete]

Payload Orientation: Gravity Gradient

Critical Surface

Surface Name: Gas Tank
Areal Density: 2   g/cm^2
Surface Area: 3   m^2
Unit Normal Vector: 1.01 2.02 3.03   UVW
Pressurized ☑

Outer Walls (LEO1 - Gas Tank)

R...	Outer Wall Name	Areal Density (g/cm^2)	Separation (cm)	
1	Foam Wall	3	2	
2	Plastic Wall	3	4	
3	Metal Wall	1	5	
*				

[Run] [Requirements] [Help]

Output

Spacecraft	Compliance Status	Probability of PMD Failure	Critical Surface	Probability of Penetration	
LEO1	Compliant	4.1114E-04	Gas Tank	1.9156E-04	
			Star Tracker	2.1962E-04	
LEO2	Non-Compliant	1.1638E-01	Gas Tank	3.2947E-02	

Messages

Requirement 4.5-2: Non-Compliant
LEO2: Failed
LEO-MEO: Failed

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

Figure 3 - 4: Requirement 4.5-2 – Probability of Damage from Small Debris Dialog

Input Data:

Payloads cannot be added to a mission through Requirement 4.5-2, only through the Mission Editor. Critical surfaces are created and defined for the payload by depressing the "Add" button. Once the surface has been created, fields to define the critical surface become available.

The user selects a Payload Orientation from the drop-down combo box. Orientation is defined as one of:

- **Random tumbling** – No axes will be fixed during the mission lifetime in question.

- **Gravity gradient** – The gravity (nadir) direction will be maintained with respect to the spacecraft during the orbital lifetime in question.

- **Fixed orientation** – The velocity (ram) direction and gravity (nadir) direction will be maintained with respect to the spacecraft during the orbital lifetime in question.

"Random tumbling" should be used to describe payloads that do not have attitude maintenance capability. For payloads that are "gravity gradient" or have "fixed orientation," users must define unit vectors in spacecraft coordinates.

A critical surface is the surface that, if damaged, may cause postmission disposal to fail. Each payload may have one or many critical surfaces. Examples of components with critical surfaces include fuel tanks, conduits, wires, and circuit boards. Each critical surface is defined by surface name, areal density (the product of material mass density and thickness), surface area, unit normal vectors U, V, W (if Payload Orientation is not random tumbling), and whether the back wall is the wall of a pressurized vessel (check the box if "Yes"). The coordinate system is defined as:

- **U** – "Up" (the direction opposite to the direction of gravity)

- **V** – In the direction of velocity

- **W** – "Port" or orthogonal to both U and V (*i.e.,* **U**×**V**)

Note that a single hardware component may have more than one critical surface. The user cannot always tell whether a heavily or weakly armored surface is most vulnerable since this depends on the surface's location on the vehicle. Therefore, assessment needs to account for all "critical surfaces" of each critical hardware component, including any surface that points in a different direction or has a different outer wall configuration. Random tumbling surfaces do not need to consider pointing but do need to consider wall configurations.

If checked, the check box labeled "Pressurized" indicates that the back wall is the wall of a pressurized vessel.

Each critical surface requires definition (physical characteristics) of the layers between that surface and the space environment. These bordering layers include any layers between the back wall and an external wall, inclusively. The physical characteristics of these layers are defined in the **Outer Walls** input grid. Defining characteristics are listed in Table 3-1. Figures 3-5 through 3-7 show a simple example of defining critical surfaces. Figure 3-5 shows the critical hardware (circle) within

the payload, with critical surfaces identified on two sides. Figure 3-6 shows the decomposition of the payload into the critical surfaces and shielding layers. Figure 3-7 shows the arrangement and separation distances of the layers. Table 3-2 lists the example properties and resulting DAS inputs for the example Critical Surface 2.

Table 3 - 1: Requirement 4.5-2 Outer Walls Input Grid

Name	A descriptive name (text field) for the layer.
Areal Density	Areal Density (g/cm^2) of the layer. The density must be a positive numeric value greater than zero. Decimal values are valid. This value, the product of material mass density and thickness, accounts for material density and thickness.
Separation Distance	Distance (cm) between the critical surface (*i.e.,* back wall) and this layer. The distance must be a positive numeric value greater than zero. Decimal values are valid. The layers do not need to be sorted by separation distance.
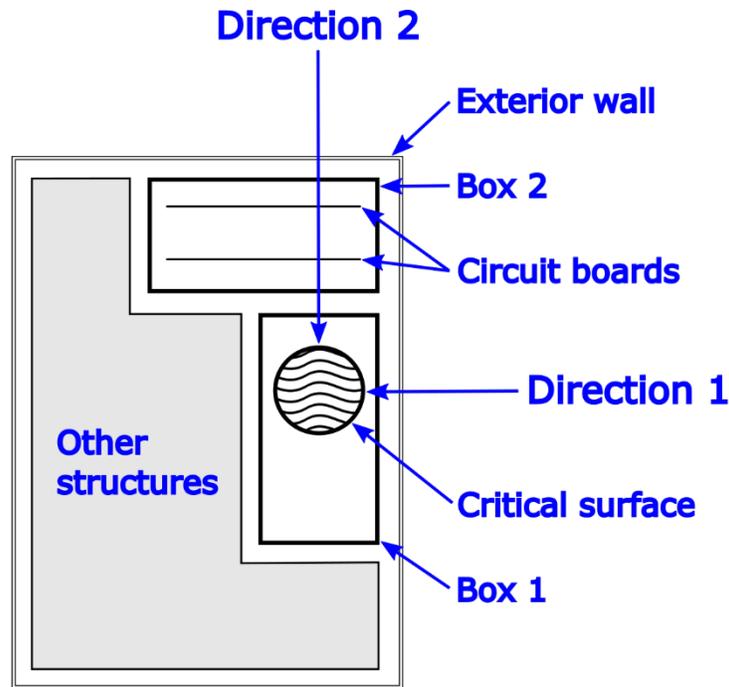
Figure 3 – 5: Block diagram of a "critical surface" within a spacecraft.
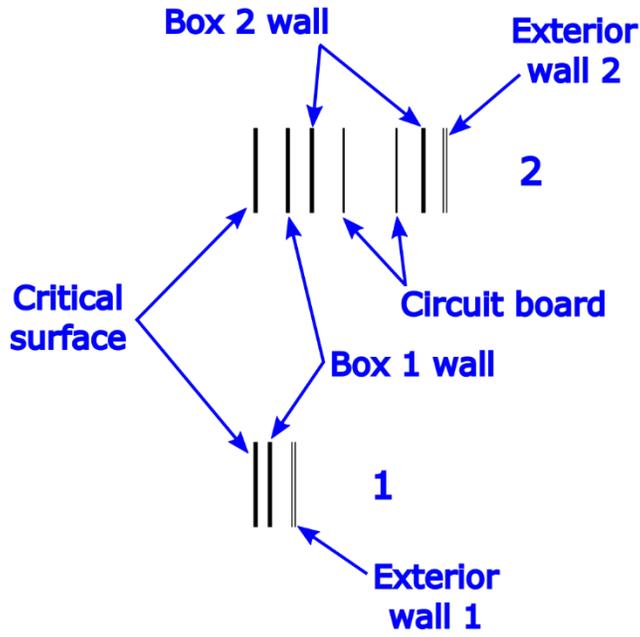
Figure 3 – 6: Conversion of critical surface block diagram to layers.
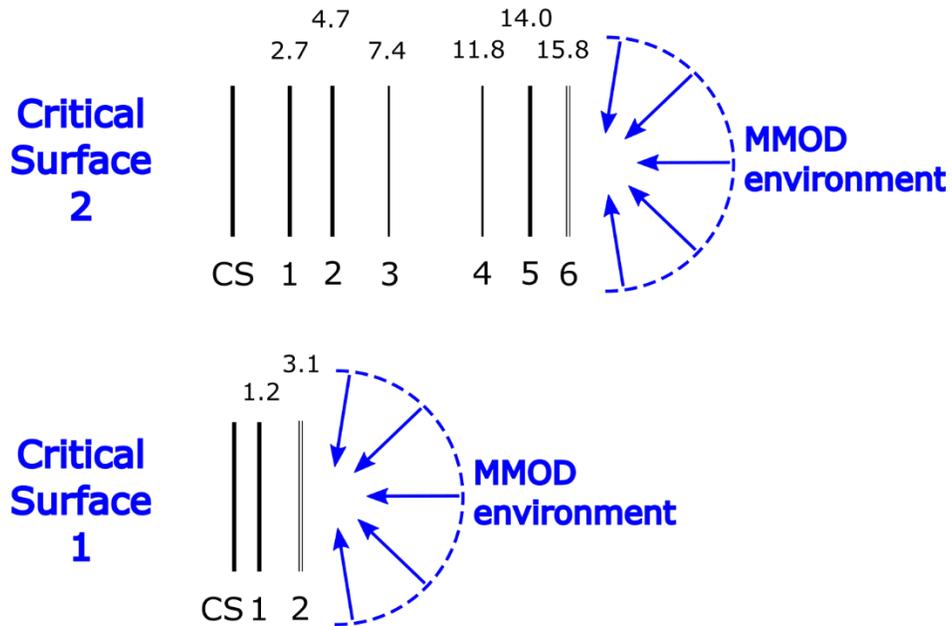
Figure 3 – 7: Critical Surface and shielding layers arrangement and separation.

Table 3 – 2: Properties used to evaluate the example Critical Surface 2

Layer Name	Material	Material Density (kg/m^3)	Layer Thickness (cm)	Areal Density [Density x Thickness] (g/cm^2)	Separation Distance from Critical Surface (cm)
Critical Surface 2	Al	2700	0.2	0.540	N/A
Box 1 wall	Al	2700	0.2	0.540	2.7
Box 2 wall 1	Al	2700	0.2	0.540	4.7
Circuit board 1	GFRP	1840	0.1	0.184	7.4
Circuit board 2	GFRP	1840	0.1	0.184	11.8
Box 2 wall 2	Al	2700	0.2	0.540	14.0
Exterior wall, top, inner sheet	Graphite Epoxy	1550.5	0.1	0.155	15.5
Exterior wall, top, outer sheet	Graphite Epoxy	1550.5	0.1	0.155	16.1

Output Data:

Compliance status for each spacecraft is displayed in the Output and Message area of the dialog, as is the probability that small debris impacts will cause components critical to postmission disposal to fail. For each spacecraft, each user-defined critical surface is also listed, along with the probability that the critical surface will be penetrated by a small object.

Messages and comments developed during analysis are displayed on the dialog, below the output data. **Note that increased fidelity of the debris environment model results in greatly increased run times compared to earlier versions of DAS.**

The assessment of Requirement 4.5-2 should be used to determine whether damaging impacts by small particles can reasonably prevent successful postmission disposal operations. The procedure estimates the probability that orbital debris impacts will cause components critical to postmission disposal to fail. If this estimate shows that there is a significant probability of failure, a full penetration analysis should be conducted to guide any redesign and to validate any shielding design.

Note: This module is computationally intensive and may require many minutes or hours to complete. For each year of the mission (duration), DAS computes penetration probability over a full range of particle speeds and impact angles.

Note: Users seeking to evaluate penetration probability due to meteoroid flux must use the MEM software tool; they are encouraged to contact the NASA Orbital Debris Program Office.

3.6 Requirement 4.6-1, 4.6-2, 4.6-3: Postmission Disposal of Space Structures

NASA space programs and projects are to plan for the disposal of structures (*i.e.*, launch vehicle components, upper stages, spacecraft, and other payloads) at the end of their respective missions. Postmission disposal is used to remove a space structure from Earth orbit in a timely manner or to leave a space structure in a disposal orbit where the structure will pose as small a threat as practical to other space systems.

A space structure shall be disposed of by one of the following options: (1) natural reentry, direct reentry, or direct retrieval, (2) storage or Earth escape, or (3) long-term reentry.

Requirement 4.6 is divided into the following four postmission disposal categories:

- **4.6-1** – *Natural reentry, direct reentry, or direct retrieval:* A spacecraft or orbital stage planned for atmospheric reentry or direct retrieval.

- **4.6-2** – *Storage and Earth escape:* A spacecraft or orbital stage planned for MEO or GEO storage options, or for a direct Earth-escape trajectory.

- **4.6-3** – *Long-term reentry for structures in MEO, Tundra orbits, highly inclined GEO, and other orbits:* A spacecraft or orbital stage planned to exploit natural resonances to increase eccentricity over time and reenter the atmosphere within 200 years postmission.

- **4.6-4** – *Reliability of postmission disposal maneuver operations in Earth orbit* is not addressed by DAS 3.

Upon selection of Requirement 4.6, all payloads and rocket bodies defined in the Mission Editor are categorized (by altitude region), assessed, and displayed in a corresponding grid. Because of the variety of possible inputs for Requirement 4.6-3, the user desiring the long-term reentry option must specify this option by selecting the "Long-Term Reentry" check-box for the object in the Mission Editor.

Figure 3 – 8: Requirements 4.6-1, 4.6-2, 4.6-3 – Postmission Disposal of Space Structures Dialog

Input Data:

Launching Requirement 4.6 will categorize all payloads and rocket bodies defined in the Mission Editor by requirement region, then run the assessment. The structures are then displayed in a corresponding grid.

- **Requirement 4.6-1** – Natural reentry, direct reentry, or direct retrieval.

- **Requirement 4.6-2** – Storage and Earth escape,

- **Requirement 4.6-3** – Long-term reentry for structures in medium Earth orbit (MEO), Tundra orbits, highly inclined GEO, and other orbits,

The input data displayed in the grid are "read-only." To modify the input data, the user must return to the Mission Editor's **Define Payload Properties** or **Define Rocket Body Properties** grid.

Output Data:

This dialog analyzes each payload or rocket body defined for the mission and assesses its disposal compliance based on its orbital definition. If the user inputs an invalid storage orbit, DAS will assess it based on the natural reentry option.

Compliance status is returned for each payload and rocket body. If a space structure is non-compliant, DAS provides a Suggested Perigee and Apogee Altitude (km), which may help the mission designer determine the magnitude and direction of the non-compliance. All other entries are input fields from the Mission Editor.

The fields labeled **PMD Perigee Altitude** and **PMD Apogee Altitude** are computed for objects without a specified PMD maneuver. This is the case for rocket bodies and payloads that are abandoned at their end-of-mission. If an object is abandoned at the end of its mission, then its PMD altitudes are set to its end-of-mission altitudes. For station-kept objects these are the same as the operational altitudes. For non-station-kept and abandoned objects the end-of-mission orbit is found by propagation. This is the reason the two fields **PMD Perigee Altitude** and **PMD Apogee Altitude** may have different values than those input by the user.

Messages and comments developed during analysis are displayed on the dialog, below the output data. Non-compliant items are listed by requirement in the message area of the dialog along with a reason for non-compliance. If any items are non-compliant, Requirement 4.6 fails assessment.

3.7 Requirement 4.6-4: Postmission Disposal Reliability

DAS cannot assess compliance with Requirement 4.6-4. The project must demonstrate compliance with Requirement 4.6-4 though its own calculations. For assistance with Requirement 4.6-4, contact the NASA Orbital Debris Program Office.

3.8 Requirement 4.7-1: Casualty Risk from Uncontrolled Reentry

NASA space programs and projects that use atmospheric reentry as a means of disposal for space structures need to limit the amount of debris that can survive reentry and pose a threat to people on the surface of Earth. This area applies to full spacecraft as well as jettisoned components and NASA-associated hardware carried on non-NASA vehicles. This section of DAS assesses compliance with Requirement 4.7-1a, which addresses risk from uncontrolled reentry. DAS does not address concerns related to controlled reentry (Requirements 4.7-1b and 4.7-1c).

The potential for human casualty is determined for objects returning to Earth's surface with a kinetic energy exceeding 15 joules. The expected debris casualty area is based on the quantity of each surviving object multiplied by its casualty area. The casualty risk is the product of the total expected debris casualty area and the statistical population density based on the orbital inclination and the year of return. World population densities have been computed up to the year 2100. The risk from any potential reentry beyond that year will need to be computed outside DAS. For reference, see:

Opiela, J.N., and M.J. Matney, "Improvements to NASA's Estimation of Ground Casualties from Reentering Space Objects," *Space Debris and Space Traffic Management Symposium*, AAS Science and Technology Series, vol. 109, p. 385-392, 2004.

Ostrom, C.L., "Improving Estimation of Ground Casualty Risk from Reentering Space Objects," *9th International Association for the Advancement of Space Safety Conference*, Toulouse, 2017.

To calculate the risk of human casualty, the arrangement of each space structure element needs to be defined to assess its reentry survival potential. An example of the nested "parent-child" relationship is shown in Figure 3-9. The parent object (*i.e.*, the spacecraft) is depicted at step "A" in the figure; it contains three main subcomponents, or "children". Based on empirical and theoretical data, the outermost structure (*i.e.,* the "parent" object) is assumed to break apart at an altitude of 78 km. The first level of "child" objects is exposed at this point, labeled "B." The child objects are then subjected to the various forces of the reentry model. If a child object is destroyed ("demises," shown as a dotted line) due to the reentry forces, it does not contribute to the final casualty area calculation. If a child object contains further levels of children, those children are exposed at the same point at which their immediate parent object demises (point "C"). Objects that survive the most intense reentry forces have reached their terminal velocity and begin to cool as they approach the ground (point "D"). This process allows a realistic progression of the exposure of nested structures.
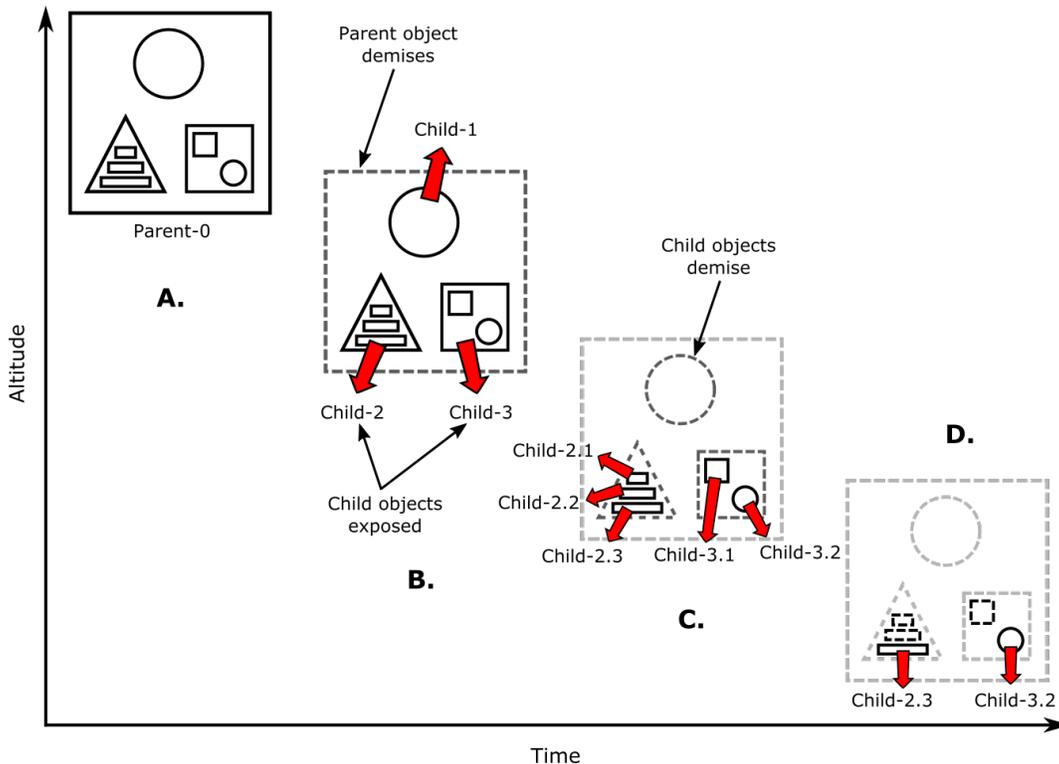
Figure 3 – 9: Parent-child relationship of nested components in the DAS reentry assessment.

Note that the DAS reentry model includes neither pre-heating of internal structures nor partial ablation. The lack of pre-heating means that each level of children is exposed with the same starting temperature of 300 kelvin. The lack of partial ablation means that an exposed structure's cross-sectional area is either zero (demised) or is the usual product of the initial dimensions.

Any spacecraft or upper stage with a total risk of human casualty above 1:10,000 or 7 m^2 total debris casualty area for the long-term reentry option will be identified as non-compliant.

This part of DAS is intended to be a "first cut" assessment tool, providing somewhat conservative results. That is, DAS will classify as non-compliant all missions that clearly do not satisfy this requirement of NASA-STD-8719.14C but may also classify as non-compliant some missions that are borderline compliant. For this reason, missions that fail the DAS reentry assessment may require a more thorough, higher-fidelity analysis than DAS can provide. Such issues must be resolved during the mission design and ODA review processes.

(Requirement 4.7-1) Limit the Risk of Human Casualty

Input

- 1 Side Panels
- 1 Bottom Panel
- 1 Top Panel
- 1 Separation Ring
- 1 Prop Tanks
- 1 Pressurant Tank
- 1 Thrusters
- 1 Service Valves
- 1 EFI Radials
- 1 Batteries
- 1 Harness
- 1 Electronics Box
  - 1 computer assy

Inclination Angle: 51.6

Payload or Rocket Body - displayed mass is aerodynamic mass - includes mass of all subcomponents

Only 70.4% of mass has been defined by subcomponents

[Add Sub-Item] [Import Sub-Items] [Delete]

Component Data

	Name	Quantity	Material Type	Object Shape	Thermal Mass (kg)	Diameter/Width (m)	Length (m)	Height (m)
1	LEO1	1	Aluminum 7075-T6	Box	150	1.66	1.66	0.88
2	1 Side Panels	4	Graphite Epoxy 1	Flat Plate	2.5	0.88	1.66	
3	1 Bottom Panel	1	Graphite Epoxy 1	Flat Plate	12.1	1.66	1.66	
4	1 Top Panel	1	Graphite Epoxy 1	Flat Plate	4.5	1.66	1.66	
5	1 Separation Ring	1	Aluminum 7075-T6	Box	3.1	0.45	0.88	0.45
6	1 Prop Tanks	2	Inconel 718	Sphere	5.45	0.3683		

[Run] [Requirement] [Help]

Output

Object Name	Compliance Status	Risk of Human Casualty	SubComponent Object	Demise Altitude (km)	Total Debris Casualty Area (m**2)	Kinetic Energy (J)	
LEO1	Non-Compliant	1:1700			33.65		
			1 Side Panels	0.0	13.08	69.85	
			1 Bottom Panel	0.0	5.11	867.65	
			1 Top Panel	0.0	5.11	119.97	
			1 Separation R...	75.3	0.00	0.00	

Messages

LEO1 Requirement 4.7-1 Non-Compliant
LEO2 Requirement 4.7-1 Non-Compliant
LEO-MEO Requirement 4.7-1 Non-Compliant
Lifter R/B 2nd Stage Requirement 4.7-1 Non-Compliant
Lens Caps Requirement 4.7-1 Compliant
Straps Requirement 4.7-1 Compliant
Staging Bolts Requirement 4.7-1 Compliant

Figure 3 – 10: Requirement 4.7-1 – Limit the Risk of Human Casualty Dialog

Input Data:

The subcomponents and their relationships within each element are defined in a "reentry objects tree." Objects subject to reentry are provided as root objects, based on a project's rocket body, payload, and mission debris data entered in the Mission Editor. All subcomponents of these objects should be defined (up to four levels deep) for assessment of potential risk of human casualty.

When a mission object is selected, comments are displayed for that object within the **Input Comments** field (next to the objects tree). The inclination angle defined within the Mission Editor is displayed in the Input Comments. A warning is displayed if the mass of defined subcomponents does not define at least 95% of the object's mass. These comments do not display when subcomponent objects are selected.

The quantity of an item is the total quantity of that uniquely-named item within the parent object. Items with a quantity multiplier (other than 1) must be physically identical and must be at the same level in the parent-child tree, *e.g.*, the quantity multiplier cannot be used for identical items enclosed within non-identical assemblies. When any component is selected, a warning will be displayed if the defined quantity is not a multiple of the quantity of its immediate "parent" object. Also listed will be any immediate subcomponents of the selected object that do not have quantities that are multiples of the object's quantity. Specifying the correct quantity is important because the debris casualty area is based on the quantity of each surviving object multiplied by its casualty area.

Each component is defined using the quantities shown in Table 3-3.

<div align="center">Table 3 - 3: Requirement 4.7-1 – Subcomponent Input Grid</div>

Name	Unique textual name for the component.
Quantity	Integer quantity.
Material Type	Textual material type. A drop-down alphabetic list of defined materials in the Material Database (DB) (including "user" materials) for this project. The materials can be selected from the list or typed in. If the typed material is not found in the Material DB, the edit will not be accepted. (See Sect. 2.5 for Material DB.)
Object Shape	Shape of the element. A drop-down list of acceptable shapes: Sphere, Cylinder, Flat Plate, Box. Any other typed word will not be accepted. **Body Type must be defined before the subsequent inputs (which may vary based on Body Type).**
Thermal Mass	Mass of each element in kilograms. Thermal mass does not include the mass of defined subcomponents.
Diameter/Width	The diameter of sphere and cylinder objects, or width of flat plate and box objects, in meters. Must be greater than or equal to Height.
Length	The length of cylinder, flat plate, and box objects, in meters. Must be greater than or equal to Diameter or Width.
Height	The height of box objects, in meters.

The dimension data are editable based on the body type selected for each element.

Up to four levels of subcomponents can be defined using the "Add Sub-Item" button. A new element will be added as a subcomponent to the currently selected item with a unique label based on **New Component**. A row is added below the current item in the **Component Data** grid for the new item. The name can be edited within the component data grid. Entering a new name that is used on another object within the grid will fail and the name will remain unchanged until a unique name is entered.

As items within the reentry objects tree are selected, the corresponding row in the grid is selected for data entry. When subcomponents at the lowest level are selected, the "Add Sub-Item" button is disabled to limit further levels.

Note: The mission elements' data, defined within the Mission Editor, are not available for update within this dialog.

The structure of a mission element can be defined by adding each subcomponent and its sub-items individually. The data can also be imported from a comma-separated-values text file created in the same format as the project's reentry file by selecting the Import Sub-Items button. The data must contain the quantities listed in Table 3-4. The first row of the file is assumed to contain column headers.

Table 3 - 4: Requirement 4.7-1 – Comma-Separated Subcomponent File Format

ID	Integer row number, beginning with 1.
Name	Unique textual name for the component.
Parent	Row number for this item's parent component. The root element must be defined on row 1 with a parent of 0.
Qty	Integer quantity.
Material	Textual material type – this is validated against the Material DB defined for this project. If the given material is not defined in this project, the material will be left blank and require selection within the dialog.
Body Type	Shape of the element. Valid body types are: Sphere, Cylinder, Flat Plate, and Box.
Thermal Mass	Mass of the element in kilograms, not including defined subcomponents.
Diameter/Width	The diameter of sphere and cylinder objects, or width of flat plate and box objects, in meters. Must be greater than or equal to Height.
Length	The length of cylinder, flat plate, and box objects, in meters. Must be greater than or equal to Diameter or Width.
Height	The height of box objects, in meters.

Microsoft's Excel spreadsheet can load and save comma-separated values in a text file, which it gives the extension ".csv". In Excel, to save a single "worksheet" as a **.csv** file, select "Save As" from the File Menu. In the **Save As** file selection dialog, click on the pull-down selection menu labeled "Save as type," and scroll down to the option "CSV (Comma delimited) (*.csv)." Give the file a name and click on the "Save" button. Note that Excel does not add trailing commas to delimit blank data cells beyond the last filled column but will add extra commas to pad short lines up to the last filled column. This may cause errors in DAS by shortening some input lines and extending others. Short rows may need to be manually edited (using a text editor) to add the commas delimiting trailing blank cells, and to delete extra commas from extended rows. The user will find it instructive to first view and edit the file ("reentry.csv") created by DAS using a plain-text editor. Note that a Windows or DAS error may result if the user opens DAS data files while DAS is running.

Selecting the "Import Sub-Items" button will display the **Open File** dialog. Select the input file from its current directory location and select "OK." The data will be read from the selected file and added to the reentry objects tree and the **Component Data** grid. Imported data will be saved in the *project\reentry.csv* file. Names that are not unique will be empty within the grid and must be renamed before the data can be assessed. Editing the name within the grid will change the name within the tree.

A selected subcomponent and its defined elements can be deleted with the "Delete Item" button. The user will be prompted to confirm that the item and its contents are to be deleted. The delete button is disabled when a mission element is selected.

All required data defined in the component grid are validated when the "Run" button is selected. Data validity is based on the following:

- All required fields have been entered for each object.

- For components with multiple dimensions, the values must be entered such that Length ≥ Width ≥ Height.

- Defined mass does not exceed a limit determined by the material density and the object's dimensions (*i.e.*, mass ≤ density×volume).

  Note: The computed density for a flat plate is based on a height of one-tenth the width. A thicker plate, or one which does not pass input validation, should be modeled as a box.

- A cylinder must have a length of at least 30% of its diameter. If its length is less than 10% of its diameter, then define the component as a flat, square plate of equivalent area. If its length is between the 10% and 30% limits, then the component may be approximated as a box with equivalent area.

If any of the data are not valid, the assessment ceases and the dialog selects the invalid object. The data must be corrected before the process can continue.

Output Data:

Output data will provide information (see Table 3-5) on compliance of each mission element.

Table 3 - 5: Requirement 4.7-1 – Mission Element Output Data

Object Name	The name defined within the Mission Editor for objects determined to qualify for reentry analysis.
Compliance Status	The result of analysis: Compliant or Non-Compliant. Non-Compliant data will be highlighted in red text.
Risk of Human Casualty	The computed results are displayed in 1:nnn format. Except for the long-term reentry option, any risk larger than 1:10,000 will result in non-compliance.
Total Debris Casualty Area	The sum of debris casualty area for all subcomponents possessing kinetic energy greater than 15 joules. For the long-term reentry option, a total debris casualty area above 7 m^2 will result in non-compliance.

The displayed data for subcomponents and mission elements without subcomponents is shown in Table 3-6.

Table 3 - 6: Requirement 4.7-1 – Subcomponent Output Data

Subcomponent Object	The name provided for the subcomponent object.
Demise Altitude	Predicted demise altitude in kilometers. Altitude of zero (0) indicates surviving debris expected to impact Earth.
Total Debris Casualty Area	Predicted casualty area of debris in square meters. Objects demising above Earth's surface will have a debris casualty area of zero (0).
Kinetic Energy	The impact kinetic energy in joules.

Messages and comments developed during analysis are displayed on the dialog, below the output data. The user should press the "Reset" button in the top-level **Requirement Assessments** dialog window before editing the inputs for this Requirement for making additional assessment runs.

When the project is saved, all input and output data for this dialog are saved in the *project\reentry.csv* file.

3.9 Requirement 4.8-1: Special Classes of Space Missions

Special classes of space missions, including large constellations; rendezvous, proximity operations, and satellite servicing; safety of active debris removal operations; tethers; and small satellites, shall comply with requirements in Sections 4.3 through 4.7 of NS 8719.14C. DAS 3.2 will not assess compliance with additional conditions of Requirement 4.8-1. The project must demonstrate compliance with this Requirement though its own calculations. As noted in section 3.1 of this

Guide, the DAS module for assessment of Requirement 4.3-1 can help the user assess Requirement 4.8-1b (additional requirements for spacecraft smaller than 10 cm × 10 cm × 10 cm when fully deployed). In this case, the user would create a second entry for the spacecraft in the Mission-Related Debris category. Contact the NASA Orbital Debris Program Office for assistance.

4. Science and Engineering Utilities

The Science and Engineering Utilities are intended to answer questions of general interest for debris assessments that might or might not also be covered in the specific requirement areas. In the left windowpane of the GUI, preceding each section of the Science and Engineering Utilities tree, is an image. Utilities with a flask image ⚗ allow calculations. Descriptive levels of the tree are denoted by a page ▯ image. Expand the folder levels by depressing the adjacent plus ⊞, revealing the calculating utilities.

Utilities that make heavy use of the ORDEM model have been removed from DAS 3 due to the impractically-long run times.

4.1 Analysis of Postmission Disposal Maneuvers

These Science and Engineering Utilities may assist users in the assessment of compliance with Requirement 4.6, the "postmission disposal of space structures." These utilities address orbital maneuvers necessary for disposal by atmospheric reentry or potential storage orbits above LEO.

Three utilities are available within this group. **Disposal by Atmospheric Reentry** is a plotting utility that plots disposal Delta-V contours as a function of Initial Perigee and Initial Apogee. **Maneuver to Storage Orbit** calculates First Burn, Second Burn, and the Total Delta-V required to reach the minimum acceptable storage orbit. **Reentry Survivability Analysis** provides this function, self-contained and separate from an actual mission assessment.

4.1.1 Disposal by Atmospheric Reentry

This utility plots contours of Delta-V corresponding to the Delta-V required to move from LEO to a decay orbit with a user-specified lifetime. This may aid the user in determining the cost of deorbit maneuvers. Users should specify at least one Delta-V contour value. Figure 4-1 shows the input dialog, and Table 4-1 describes the values.

Figure 4 - 1: Disposal by Atmospheric Reentry Input Dialog

Table 4 - 1: Disposal by Atmospheric Reentry Input Data

Start Year	Marks the beginning date (in decimal form) for the period currently under study. The input value must be a positive numeric value equal to or greater than 2016 and less than or equal to 2130. In addition, the sum of the Start Year and Decay Orbit Lifetime must not exceed the year 2200.
Decay Orbit Lifetime	The length of the orbital lifetime, beginning at the Start Year. It is required to be in years (decimal years are acceptable). This input value must be a positive, numeric value greater than zero. In addition, the sum of the Start Year and Decay Orbit Lifetime must not exceed the year 2200.
Area-to-Mass	The object's average cross-sectional area (m^2) divided by its final mass (kg). A positive, numeric value is required, and a decimal value is acceptable.
Delta-V	Each contour value is entered into the edit box below the list. Once entered, the user clicks the "Add" button to load the value into the list. The user may remove a previously-defined contour value by highlighting the value and clicking the "Remove" button. The maximum number of entries is 20. Each entry must be a positive, numeric value, and decimal values are acceptable. Units are m/s.

The "Plot" button will send input values from the dialog to the calculating routines. As the utility processes the data, a **Processing** dialog will appear. Plot processing may take several minutes. To cease processing, depress the "Stop" button on the dialog.

The calculating routines will produce a plot of returned points. If no points are returned, a warning message will be generated, requiring the user to click the OK button to continue.

The "Reset" button will clear all input values from the dialog.

Output Data:

The generated plot is viewable in a separate plot window. The user can find the disposal Delta-V requirement for any low-Earth orbit by pairing perigee and apogee values from the plot axes. On the plot, Delta-V increases from the bottom and left toward the top and right. Note that, by definition, no values exist above the 1:1 boundary line. See Figure 4-2 for an example plot. **Section 2.6, Using the Plot Viewer**, provides information on plot utility functions.
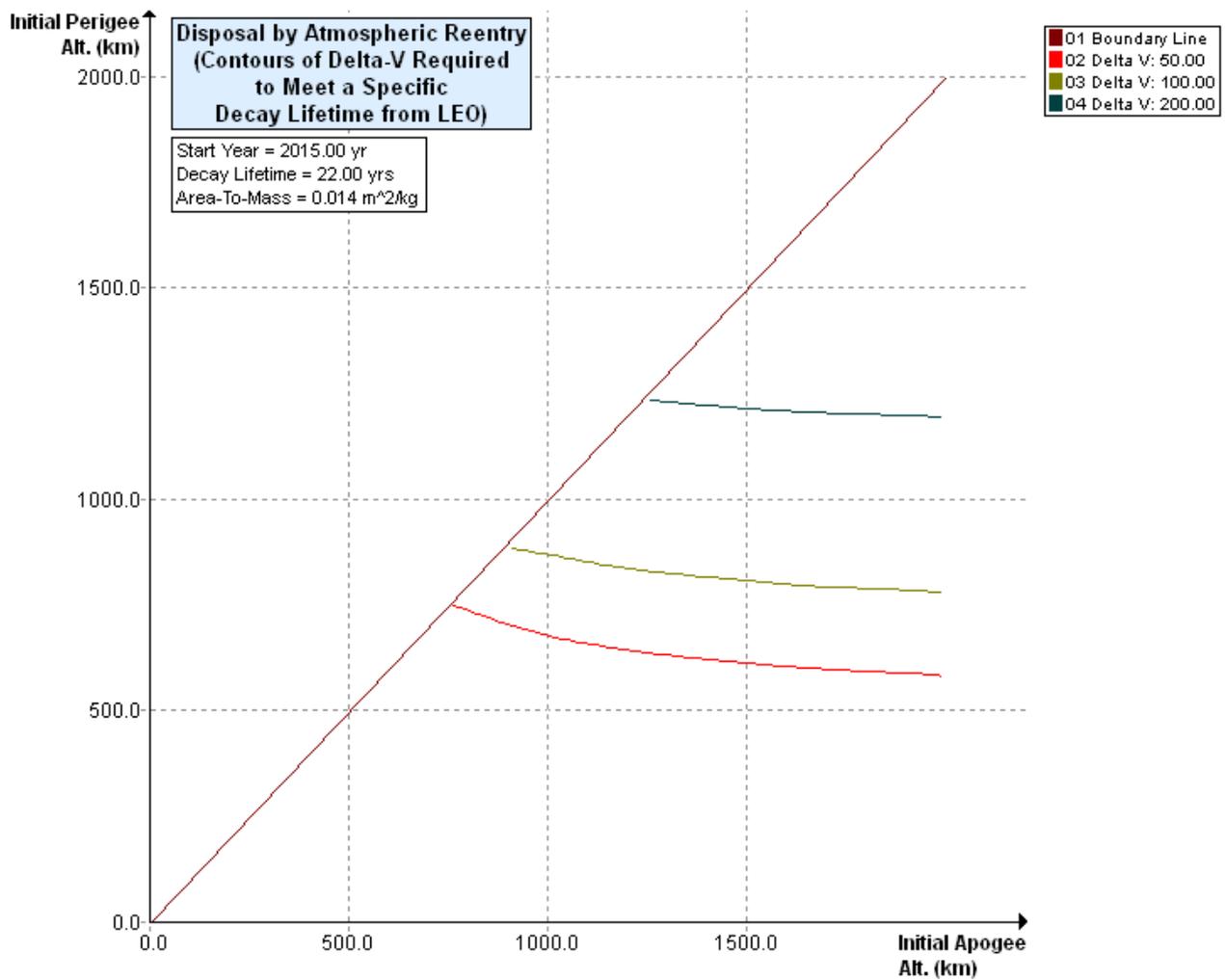
Figure 4 - 2: Disposal by Atmospheric Reentry

4.1.2 Maneuver to Storage Orbit

This utility calculates the minimal storage orbit and the Delta-V required to maneuver from the object's initial orbit to that storage orbit using a two-burn, minimum-energy transfer orbit. This may aid the user in determining the cost of a storage orbit maneuver. Figure 4-3 shows the input/output dialog, and Tables 4-2 and 4-3 describe the input and output values.

Figure 4 - 3: Maneuver to Storage Orbit Dialog

Table 4 - 2: Maneuver to Storage Orbit Input Data

Perigee Altitude	The perigee altitude (in kilometers) for the object currently under study, immediately before the maneuver to storage orbit. The input value must be a positive numeric value greater than 90 and less than or equal to 100,000. In addition, the perigee altitude must be less than or equal to the apogee altitude.
Apogee Altitude	The apogee altitude (in kilometers) for the object currently under study, immediately before the maneuver to storage orbit. The input value must be a positive numeric value greater than 90 and less than or equal to 100,000. In addition, the apogee altitude must be equal to or greater than the perigee altitude.
Area-To-Mass	The object's average cross-sectional area (m^2) divided by its final mass (kg). The input value must be a positive numeric value greater than or equal to 0.00001 (m^2/kg) and less than or equal to 1000 (m^2/kg). This value is only required when all or part of the orbit resides in the range of GEO ± 200 km.

The "Run" button sends the user input to the calculating routines. If input values are valid, the output fields will display the calculated results. Messages and comments developed during calculation are displayed on the dialog, below the output data.

The "Reset" button clears all input values from the dialog.

Table 4 - 3: Maneuver to Storage Orbit Output Data

Storage Orbit – Perigee Altitude	The suggested storage orbit perigee required to minimally satisfy the postmission disposal requirement.
Storage Orbit – Apogee Altitude	The suggested storage orbit apogee required to minimally satisfy the postmission disposal requirement.
Transfer Orbit – Perigee Altitude	The calculated perigee altitude attained after Delta-V (first burn).
Transfer Orbit – Apogee Altitude	The calculated apogee altitude attained after Delta-V (first burn).
First Burn Delta-V	The Delta-V required to place the object on the minimum-energy transfer orbit connecting the initial and storage orbits.
Second Burn Delta-V	The Delta-V required to move the object from the transfer orbit to the storage orbit.
Total Delta-V	The Delta-V required to maneuver the object from initial to disposal orbit, using a two-burn, minimal energy transfer. This quantity represents the sum of the first and second burn Delta-V's.
Message	The possible returned messages include the following: • No associated message for object. • Input orbit parameters do not satisfy any storage categories. • Initial perigee is low enough that user should consider disposal by atmospheric reentry. • Initial orbit is in (non-semi-synchronous) medium Earth orbit; no disposal maneuver is necessary.

4.1.3   Reentry Survivability Analysis

This utility provides a tool to study reentry survivability without changing the input characteristics of the actual mission (as specified in the Mission Editor). A single object and its subcomponents can be assessed, rendering the demise altitude, total debris casualty area, and kinetic energy for each item.

Based on empirical and theoretical data, the outermost structure (*i.e.,* the "parent" object) is assumed to break apart at an altitude of 78 km. The first level of "child" objects is exposed at this point. The objects are then subjected to the various forces of the reentry model. If a child object is destroyed ("demises") due to the reentry forces, it does not affect the final casualty area calculation. If a child object contains further levels of children, those children are exposed at the same point at which their immediate parent object demises. This process allows a more realistic progression of the exposure of nested structures.

This utility supports the definition of a single object and its subcomponents. See Table 3-3 (Sect. 3.9) for a description of the input data. Figure 4-5 shows the input dialog, and Table 4-4 describes the output values.

Re-Entry Calculation

Input

- Root Object
  - Exp Mod 1
    - grapple 1
    - acs bot 1
      - rem adapt
        - elec box 1
      - battery 3
    - grapple 2
    - elec box 2
  - Exp Mod 2
    - grapple 3
    - elec box 3
    - battery 1

Inclination Angle (deg):

0

Root object's mass is aerodynamic mass - includes mass of all subcomponents

[Add Sub-Item] [Delete] [Import] [Save]

Component Data

	Name	Quantity	Material Type	Object Shape	Thermal Mass	Diameter/Width	Length	Height
					(kg)	(m)	(m)	(m)
1	Root Object	1	Stainless Steel 21-6-9	Cylinder	1111	.7620	3.3	
2	Exp Mod 1	1	Aluminum 2024-T8xx	Cylinder	119.8	.279	2.64	
3	grapple 1	2	Titanium (6 Al-4 V)	Sphere	37.6	.295		
4	acs bot 1	1	Aluminum 6061-T6	Cylinder	8.0	.152	.254	
5	rem adapt	1	Aluminum 2024-T8xx	Cylinder	2.7	.635	1.09	
6	elec box 1	1	Aluminum 2024-T8xx	Cylinder	2.6	.508	.533	
7	battery 3	1	Aluminum 2024-T8xx	Cylinder	4.9	.29	.316	
8	grapple 2	1	Titanium (6 Al-4 V)	Sphere	19.1	.413		

[Run] [Help]

Output

Object	SubComponent	Demise	Total Debris	Kinetic	
Name	Object	Altitude (km)	Casualty Area ...	Energy (J)	
Root Object			13.47		
	Exp Mod 1	59.6	0.00	0	
	grapple 1	0.0	1.48	365047	
	acs bot 1	44.3	0.00	0	
	rem adapt	0.0	2.05	401	
	elec box 1	0.0	0.00	0	
	battery 3	0.0	0.81	2434	

Figure 4 - 4: Reentry Survivability Analysis Dialog

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Output Data:

The displayed data for the root element and its subcomponents' survivability is shown in Table 4-4. Note that since the root object is assumed to break up at 78 km, its output will only contain the sum of its subcomponent's debris casualty area.

Table 4 - 4: Reentry Survivability Output Data

Sub-Component Object	The name provided for the subcomponent object.
Demise Altitude	Predicted demise altitude in kilometers. An altitude of zero (0) indicates surviving debris is expected to impact Earth.
Total Debris Casualty Area	Predicted casualty area of debris in square meters. Objects demising above Earth's surface will have a debris casualty area of zero (0).
Kinetic Energy	The impact kinetic energy in joules.

4.2 Orbit Evolution Analysis

These Science and Engineering Utilities may assist users in the assessment of compliance with Requirement 4.6, the "postmission disposal of space structures."

Two utilities are available within this group. **Apogee/Perigee Altitude History for a Given Orbit** is a plotting utility that plots Apogee/Perigee History over time. **Orbit Lifetime/Dwell Time** calculates Orbit Lifetime and LEO Dwell Time, and the final year of propagation.

4.2.1 Apogee/Perigee Altitude History for a Given Orbit

This utility creates a predicted "history" of Perigee and Apogee Altitudes for the user-entered orbit elements. The output of this utility is a plot of Altitude (in kilometers) along the vertical axis and Time (in years) along the horizontal axis. For LEO objects, the plot may indicate the orbital decay rate and reentry date. Figure 4-5 shows the input dialog, and Table 4-5 describes the values.

Figure 4 - 5: Apogee/Perigee Altitude History for a Given Orbit Input Dialog

Table 4 - 5: Apogee/Perigee Altitude History for a Given Orbit Input Data

Perigee Altitude	The perigee altitude (in kilometers) for the object currently under study. The input value must be a positive numeric value greater than 90 and less than or equal to 100,000. In addition, the perigee altitude must be less than or equal to the apogee altitude.
Apogee Altitude	The apogee altitude (in kilometers) for the object currently under study. The input value must be a positive numeric value greater than 90 and less than or equal to 100,000. In addition, the apogee altitude must be greater than or equal to the perigee altitude.
Inclination	The orbital inclination angle. Positive, numeric degrees between zero and 180 (inclusive). Decimal numbers are accepted.
R.A. of Ascending Node	Right Ascension of Ascending Node must be a positive numeric value (in degrees) greater than or equal to 0 and less than or equal to 360. Decimal entries are valid. Although all input fields are required, entry into this field will not affect the calculations when the apogee altitude is less than 2000 km.
Argument of Perigee	A positive numeric value (in degrees) greater than or equal to 0 and less than or equal to 360. Decimal entries are valid. Although all input fields are required, entry into this field will not affect the calculations when the apogee altitude is less than 2000 km.
Mean Anomaly	Positive numeric value (in degrees) greater than or equal to 0 and less than or equal to 360. Decimal entries are valid. Although all input fields are required, entry into this field will not affect the calculations when the apogee altitude is less than 2000 km.
Area-To-Mass Ratio	The object's average cross-sectional area (m^2) divided by its final mass (kg). The input value must be a positive numeric value greater than or equal to 0.00001 (m^2/kg) and less than or equal to 1000 (m^2/kg). Decimal entries are valid.
Start Year	The beginning date (in decimal years) for the period currently under study. The input value must be a positive numeric value equal to or greater than 2016 and less than or equal to 2130. In addition, the sum of the Start Year and the Integration Time must not exceed the year 2200.
Integration Time	The length of time (decimal years) desired for propagation. This input value must be a positive numeric value greater than zero. In addition, the sum of Integration Time and Start Year must not exceed 2200.

The "Reset" button will clear all input values from the dialog.

Depressing the "Plot" button sends input values from the dialog to the calculating routines. As the utility processes the data, a **Processing** dialog will appear. To cease processing, depress the "Stop" button on the dialog.

If no points are calculated, a message box will appear notifying the user. The user must then select "OK" to exit the message box.

Output Data:
The generated plot is viewable in a separate plot window. See Figure 4-6 for an example plot. **Section 2.6, Using the Plot Viewer** provides information on plot utility functions.
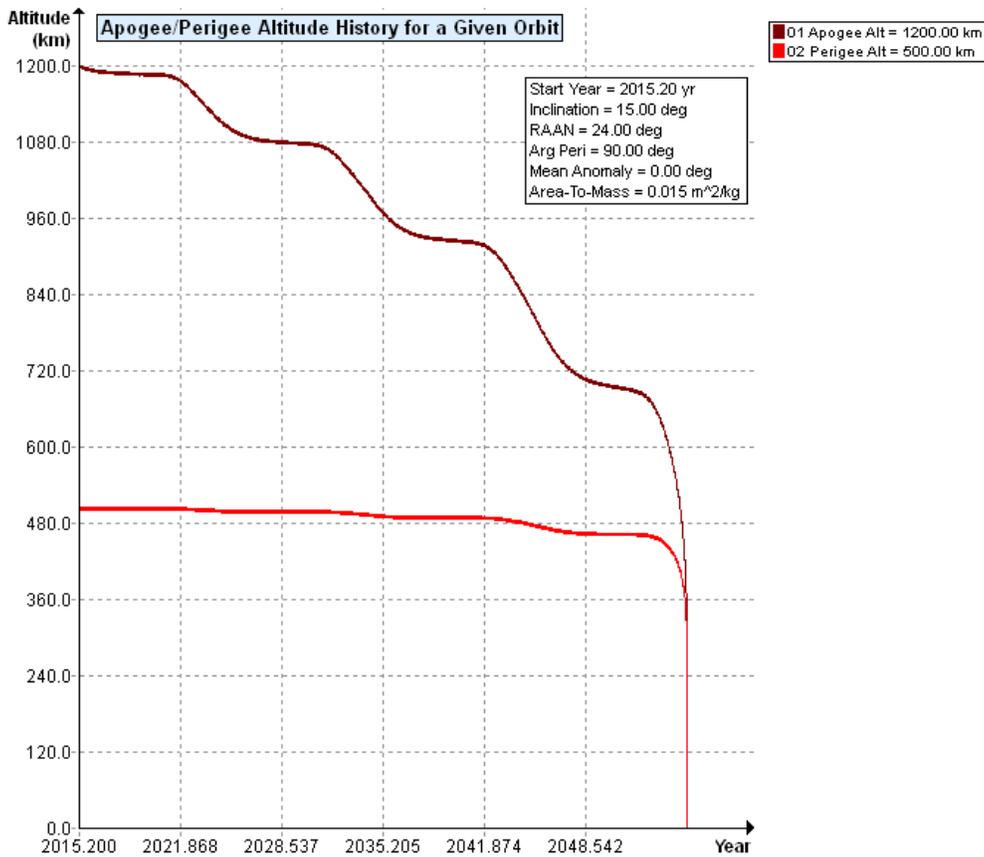
Figure 4 - 6: Apogee/Perigee Altitude History for a Given Orbit

4.2.2 Orbit Lifetime/Dwell Time

This utility calculates the Orbital Lifetime and LEO Dwell Time of an object in a specified orbit. These values relate directly to the assessment of the Requirements imposed on LEO debris. The Message area (below the Output area) of the dialog will display a message to users upon process completion. Figure 4-7 shows the input/output dialog. The input and output values are described in Tables 4-6 and 4-7, respectively.

Figure 4 - 7: Orbit Lifetime/Dwell Time Dialog

Table 4 - 6: Orbit Lifetime/Dwell Time Input Data

Start Year	The beginning date (in decimal years) for the period currently under study. The input value must be positive, numeric, and fall in the range of 2016-2100.
Perigee Altitude	The perigee altitude (in kilometers) for the object currently under study. The input value must be a positive numeric value greater than 90 and less than or equal to 100,000. In addition, the perigee altitude must be less than or equal to the apogee altitude.
Apogee Altitude	The apogee altitude (in kilometers) for the object currently under study. The input value must be a positive numeric value greater 90 and less than or equal to 100,000. In addition, the apogee altitude must be greater than or equal to the perigee altitude.
Inclination	The orbital inclination angle. Positive, numeric degrees between 0 and 180 (inclusive). Decimal numbers are accepted.
R. A. of Ascending Node	Right Ascension of Ascending Node must be a positive numeric value (in degrees) greater than or equal to 0 and less than or equal to 360. Decimal entries are valid. Although all input fields are required, entry into this field will not affect the calculations when the apogee altitude is less than 2000 km.
Argument of Perigee	A positive numeric value (in degrees) greater than or equal to 0 and less than or equal to 360. Decimal entries are valid. Although all input fields are required, entry into this field will not affect the calculations when the apogee altitude is less than 2000 km.
Area-to-Mass	The object's average cross-sectional area (m^2) divided by its final mass (kg). The input must be a positive numeric value greater than or equal to 0.00001 (m^2/kg) and less than or equal to 1000 (m^2/kg). Decimal entries are valid.

The "Reset" button will clear all input from the dialog.

The "Run" button sends the user input to the calculating routines. If input values are valid, the output fields will display the calculated results. Messages and comments developed during calculation are displayed on the dialog, below the output data.

Output Data:

<p style="text-align: center;">Table 4 -7: Orbit Lifetime/Dwell Time Output Data</p>

Calculated Orbit Lifetime	Orbital Lifetime is calculated from the Start Year.
Calculated Orbit Dwell Time	The time spent in LEO during Orbital Lifetime.
Last Year of Propagation	The year that the object either reentered or exceeded the propagation time limit.
Messages	The message area displays a textual message after completion of "Run." The possible returned messages include the following: - No associated message for object. - Object will remain in orbit and above LEO for the foreseeable future (>100 years). - NOTE: The orbit is NOT processed. - Object reentered. - Object did not reenter within the maximum years of propagation.

4.3 Delta-V for Postmission Maneuver

These Science and Engineering Utilities may assist users in the assessment of compliance with Requirement 4.6, the "postmission disposal of space structures." These utilities calculate the change in velocity required for maneuvers needed to achieve atmospheric reentry within 25 years.

Two utilities are available within this group. **Delta-V for Decay Orbit Given Orbital Lifetime** plots area-to-mass contour points corresponding to the Delta-V required to move an object, with a specified orbital lifetime, from an initial circular LEO orbit to a decay orbit. The user specifies a list of area-to-mass contour values. **Delta-V for Decay Orbit Given Area-To-Mass** plots lifetime contour points corresponding to the Delta-V required to move an object, with a specified area-to-mass ratio, from an initial circular LEO orbit to a decay orbit.

4.3.1 Delta-V for Decay Orbit, Given Orbital Lifetime

This utility plots Area-To-Mass ratio contour points corresponding to the Delta-V required to move an object from an initial circular LEO to a decay orbit with specified Orbital Lifetime. The user specifies a list of Area-To-Mass contour values. The plot allows the user to explore the cost of deorbiting a vehicle. Figure 4-8 shows the input dialog, and Table 4-8 describes the values.
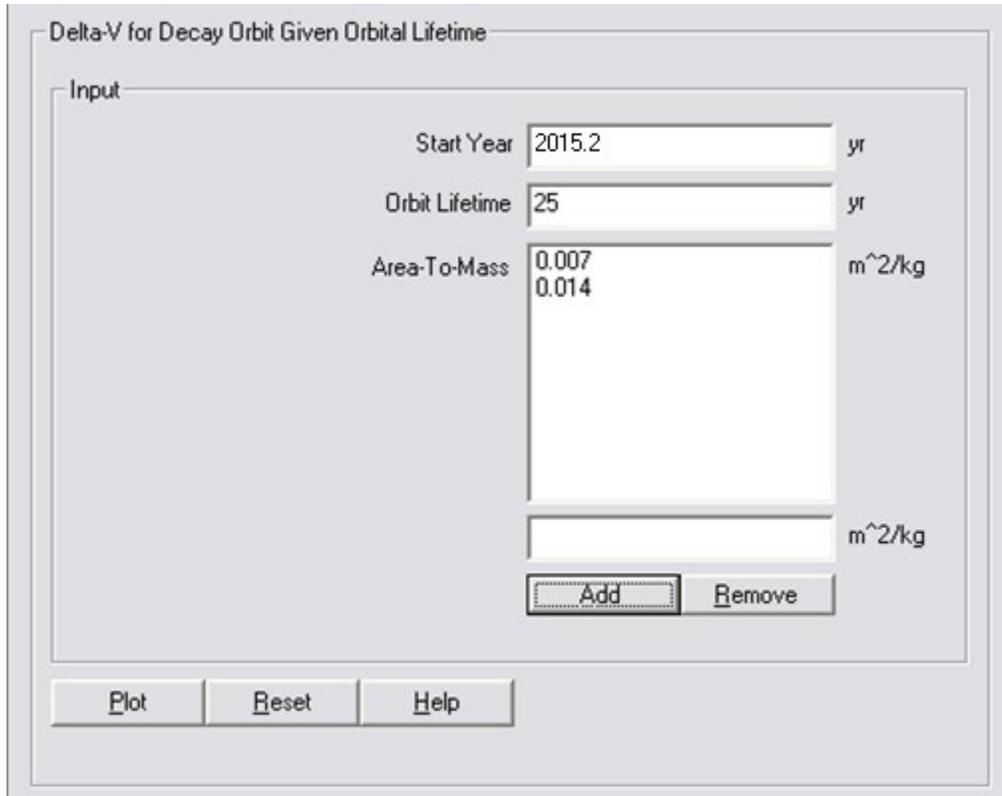
Figure 4 - 8: Delta-V for Decay Orbit Given Orbital Lifetime Dialog

Table 4 -8: Delta-V for Decay Orbit Given Orbital Lifetime Input Data

Start Year	The beginning date (in decimal years) for the period currently under study. The input must be a positive numeric value equal to or greater than 2016 and less than or equal to 2130. In addition, the sum of the Start Year and the Orbital Lifetime must not exceed the year 2200.
Orbit Lifetime	The length of time (decimal years) the object is expected to stay in orbit. This input value must be a positive numeric value greater than or equal to 0.01 and less than or equal to 10,000.0; however, the sum of Orbital Lifetime and Start Year must not exceed 2200.
Area-To-Mass	Each Area-To-Mass ratio contour value is entered into the edit box below the list. Once entered, the user depresses the "Add" button to load the value into the list. The user may remove a contour value by highlighting the value in the list and depressing the "Remove" button. The maximum number of entries is 20. This input must be a positive numeric value greater than or equal to 0.0001 (m^2/kg) and less than or equal to 1000.0 (m^2/kg). Decimal values are valid.

The "Reset" button will clear all input values from the dialog.

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Depressing the "Plot" button sends input values from the dialog to the calculating routines. As the utility processes the data, a **Processing** dialog will appear. To cease processing, depress the "Stop" button on the dialog.

If no points are calculated, a message box will appear notifying the user. The user must then select "OK" to exit the message box.

Output Data:
The generated plot is viewable in a separate plot window. Delta-V (m/s) is along the vertical axis and Altitude (km) is along the horizontal axis. On the plot, A/M increases from the top and left toward the bottom and right. See Figure 4-9 for an example plot. **Section 2.6, Using the Plot Viewer** provides information on plot utility functions.
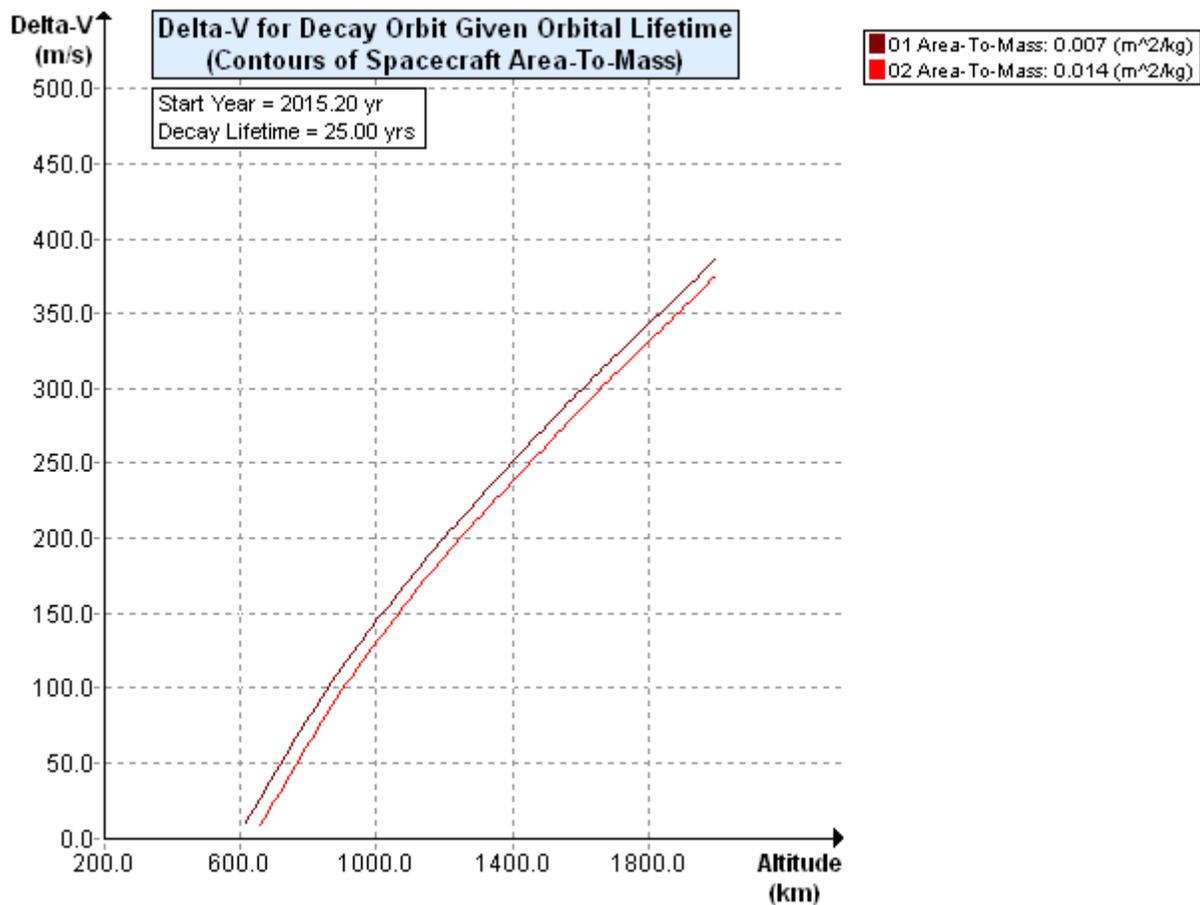
Figure 4 - 9: Delta-V for Decay Orbit Given Orbital Lifetime

4.3.2   Delta-V for Decay Orbit, Given Area-to-Mass

This utility plots **Orbital Lifetime** contour points corresponding to the Delta-V required to move an object, with specified area-to-mass ratio, from an initial circular low Earth orbit to a decay orbit. The user specifies a list of Orbital Lifetime contour values. The plot allows the user to explore the cost of deorbiting a vehicle over a range of decay lifetimes. Figure 4-10 shows the input dialog and Table 4-9 describes the values.

Figure 4 - 10: Delta-V for Decay Orbit Given Area-To-Mass Dialog

Table 4 -9: Delta-V for Decay Orbit Given Area-To-Mass Input Data

Start Year	The beginning date (in decimal years) for the period currently under study. The input must be a positive numeric value equal to or greater than 2016 and less than or equal to 2130. In addition, the sum of the Start Year and the Orbital Lifetime must not exceed the year 2130.
Area-To-Mass	The area-to-mass ratio is the object's average cross-sectional area (m^2) divided by its final mass (kg). The input must be a positive numeric value greater than or equal to 0.00001 (m^2/kg) and less than or equal to 1000 (m^2/kg). Decimal entries are valid.
Orbit Lifetime	Each Orbital Lifetime contour value is entered into the edit box below the list. Once entered, the user depresses the "Add" button to load the value into the list. The user may remove a contour value by highlighting the value in the list and depressing the "Remove" button. The maximum number of entries is 20. The input value must be a positive numeric value greater than or equal to 0.01 (yr) and less than or equal to 10000.0 (yr); however, the sum of Orbital Lifetime and Start Year must not exceed 2130.

The "Reset" button will clear all input values from the dialog.

Depressing the "Plot" button sends input values from the dialog to the calculating routines. As the utility processes the data, a **Processing** dialog will appear. To cease processing, depress the "Stop" button on the dialog.

If no points are calculated, a message box will appear notifying the user. The user must then select "OK" to exit the message box.

Output Data:

The generated plot is viewable in a separate plot window. Delta-V (m/s) is along the vertical axis and Altitude (km) is along the horizontal axis. On the plot, orbital lifetime increases from the top and left toward the bottom and right. See Figure 4-11 for an example plot. **Section 2.6, Using the Plot Viewer** provides information on plot utility functions.
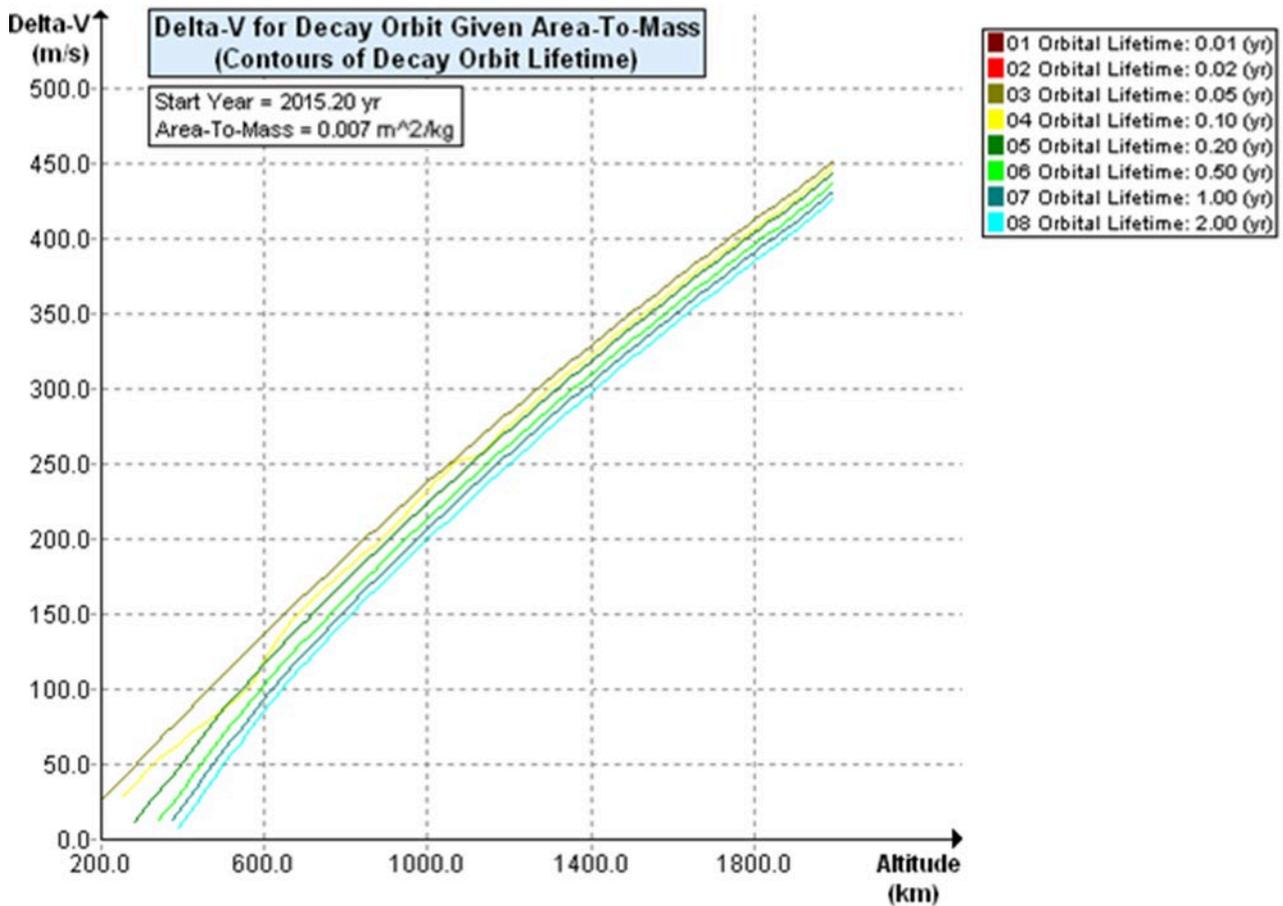
Figure 4 - 11: Delta-V for Decay Orbit Given Area-To-Mass

4.4 Delta-V for Orbit-to-Orbit Transfer

This Science and Engineering Utility may assist users in the assessment of compliance with Requirement 4.6, the "postmission disposal of space structures." This utility calculates the minimum change in velocity required to maneuver from one orbit to a second, co-planar orbit.

4.4.1   Orbit-to-Orbit Transfer

This utility calculates the Delta-V required for a coplanar orbit transfer. Figure 4-12 shows input/output dialog, and Tables 4-10 and 4-11 describe the values, respectively.

Figure 4 - 12: Delta-V for Orbit-to-Orbit Transfer Dialog

Input Data:

Table 4 - 10: Delta-V for Orbit-to-Orbit Transfer Input Data

First Orbit Perigee Altitude	The perigee altitude (in kilometers) for the object currently under study, immediately before the orbit transfer maneuver. The input must be a positive numeric value greater than 90 and less than or equal to 100,000. In addition, the perigee altitude must be less than or equal to the apogee altitude.
First Orbit Apogee Altitude	The apogee altitude (in kilometers) for the object currently under study, immediately before the orbit transfer maneuver. The input must be a positive numeric value greater than 90 and less than or equal to 100,000. In addition, the apogee altitude must be equal to or greater than the perigee altitude.
Second Orbit Perigee Altitude	The final (destination) perigee altitude (in kilometers) for the object currently under study. The input must be a positive numeric value greater than 90 and less than or equal to 100,000. In addition, the perigee altitude must be less than or equal to the final apogee altitude.
Second Orbit Apogee Altitude	The final (destination) apogee altitude (in kilometers) for the object currently under study. The input must be a positive numeric value greater than 90 and less than or equal to 100,000. In addition, the apogee altitude must be equal to or greater than the final perigee altitude.

The "Reset" button will clear all input values from the dialog. The "Run" button sends the user input to the calculating routines. If input values are valid the output fields will display the calculated results.

Table 4 - 11: Delta-V for Orbit-to-Orbit Transfer Output Data

Transfer Orbit Perigee	The perigee altitude attained after Delta-V (first burn).
Transfer Orbit Apogee	The apogee altitude attained after Delta-V (first burn).
Delta-V (First Burn)	First Burn Delta-V is the Delta-V required to place the object on the minimum-energy transfer orbit connecting the first and second orbits.
Delta-V (Second Burn)	Second Burn Delta-V is the Delta-V required to move the object from the transfer orbit to the second (destination) orbit.
Delta-V (Total)	Total Delta-V is the total Delta-V required to maneuver the object from first to second orbit, using a two-burn, minimum-energy transfer. This quantity represents the sum of the first and second burn Delta-Vs.

4.5 Other Utilities

Utilities not directly related to specific requirements are provided to support the definition of data related to orbital mechanics.

4.5.1 Two Line Element Converter

This utility provides the user with a means to convert a two-line element (TLE) set into orbital parameters that can be used in DAS.
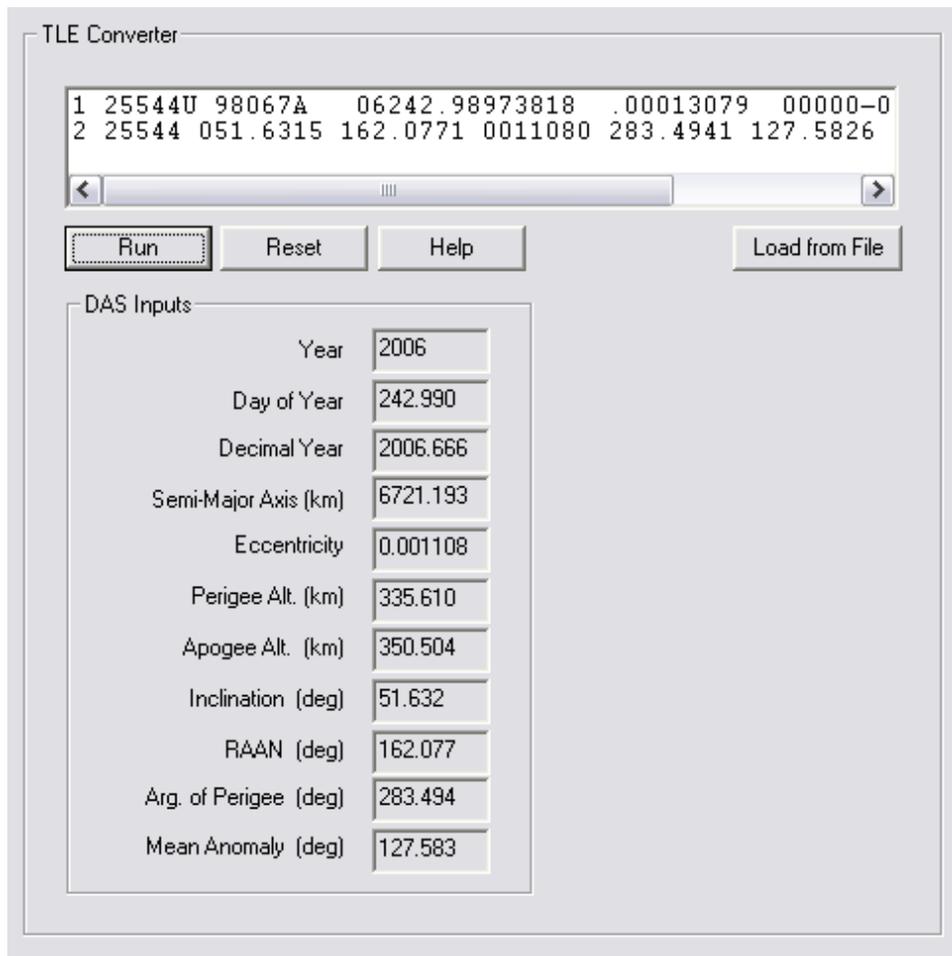
Figure 4 - 13: Two Line Element Conversion Dialog

Input Data:

The TLE converter has only one input area: the edit box at the top of the window. The TLE text can be hand typed, pasted from the clipboard, or loaded from a file. When loading from a file, this utility converts only the first two lines of input text.

DAS will detect and process the current 69-character TLE. A two-line element set consists of two lines of text data which can be used to determine the position and velocity of an object orbiting Earth. Tables 4-12 and 4-13 contain descriptions of the current format of TLE lines 1 and 2.

Table 4 --12: Two-Line Element Set Format Definition, Line 1

Field	Column	Description
1.1	01	Line Number of Element Data
1.2	03-07	Satellite Number
1.3	08	Classification
1.4	10-11	International Designator (Last two digits of launch year) (Four-digit launch year)
1.5	12-14	International Designator (Launch number of the year)
1.6	15-17	International Designator (Piece of the launch)
1.7	19-20	Epoch Year (Last two digits of year) (Four-digit year)
1.8	21-32	Epoch Day (Day of the year and fractional portion of the day)
1.9	34-43	One-half the First Time Derivative of the Mean Motion
1.10	45-52	One-sixth the Second Time Derivative of Mean Motion (decimal point assumed) or "AGOM"
1.11	54-61	BSTAR drag term (decimal point assumed)
1.12	63	Ephemeris type
1.13	65-68	Element number (Removed from line 1 of proposed format)
1.14	69	Checksum (Modulo 10) (Letters, blanks, periods, plus signs=0; minus signs=1)

Table 4 -13: Two-Line Element Set Format Definition, Line 2

Field	Column	Description
2.1	01	Line Number of Element Data
2.2	03-07	Satellite Number
2.3	09-16	Inclination [Degrees]
2.4	18-25	Right Ascension of the Ascending Node [Degrees]
2.5	27-33	Eccentricity (decimal point assumed) (decimal point included, no leading digit)
2.6	35-42	Argument of Perigee [Degrees]

Field	Column	Description
2.7	44-51	Mean Anomaly [Degrees]
2.8	53-63	Mean Motion [Revs per day]
2.9	64-68	Revolution number at epoch [Revs]
2.10	69	Checksum (Modulo 10)

Output Data:

DAS Inputs

Year	2006
Day of Year	242.990
Decimal Year	2006.666
Semi-Major Axis (km)	6721.193
Eccentricity	0.001108
Perigee Alt. (km)	335.610
Apogee Alt. (km)	350.504
Inclination (deg)	51.632
RAAN (deg)	162.077
Arg. of Perigee (deg)	283.494
Mean Anomaly (deg)	127.583

Figure 4 - 14: Elements Converted to DAS Input Values

The DAS Input Area displays the values that are obtained from running the TLE Converter. These values will be useful for specifying the orbital parameters needed throughout the DAS. Note that the DAS orbit propagator, designed for long-term propagation, assumes the mission inputs are *mean* orbital elements.

4.5.2   Calculate Cross-Sectional Area

This Science and Engineering Utility may assist users in estimating the effective cross-sectional area of a structure. This quantity is divided by the structure's mass to produce the area-to-mass ratio, used in propagating the orbit for Requirement assessment.

This utility provides a means to create a "wire-frame" model of a spacecraft and to estimate the average cross-sectional area of a spacecraft. This cross-sectional area can be used to calculate the area-to-mass ratio entry in the DAS Mission Editor. For many projects, this tool will not need to be

used; it is included here to augment the standard area estimation techniques outlined in the NASA-STD-8719.14C. Subsection 4.3.4.1 of the Standard gives simple methods for estimating an object's average cross-sectional area.

The model is constructed using a collection of triangles, cylinders, and spheres. The wire-frame plot feature may be used to check for errors in data entry. The cross-sectional area estimation tool is intended to provide a basic, but reasonably accurate, estimate of average cross-sectional area. The fidelity of the result will depend upon the level of detail provided by the user. Figure 4-15 shows the input/output dialog.

Calculate Cross-Sectional Area

Input

Random Tumbling ▼   Orientation

R...	Compo... Shape	Point 1 U (LU)	Point 1 V (LU)	Point 1 W (LU)	Point 2 U (LU)	Point 2 V (LU)	Point 2 W (LU)	Point 3 U (LU)	Point 3 V (LU)	Point 3 W (LU)	Radiu... (LU)	Radiu... (LU)
1	Cylin... ▼	0	0	0	0	0	1				.5	.5
2	Sphe... ▼	0	0	0							.5	
3	Sphe... ▼	0	0	1							.5	
4	Trian... ▼	0	2	.375	0	-2	.625	0	2	.625		
5	Trian... ▼	0	2	.375	0	-2	.625	0	-2	.375		
*	▼											

Run   Reset   Help   Plot

Output

Cross-Sectional   1.893E+00   (LU)^2   LU = Length Unit
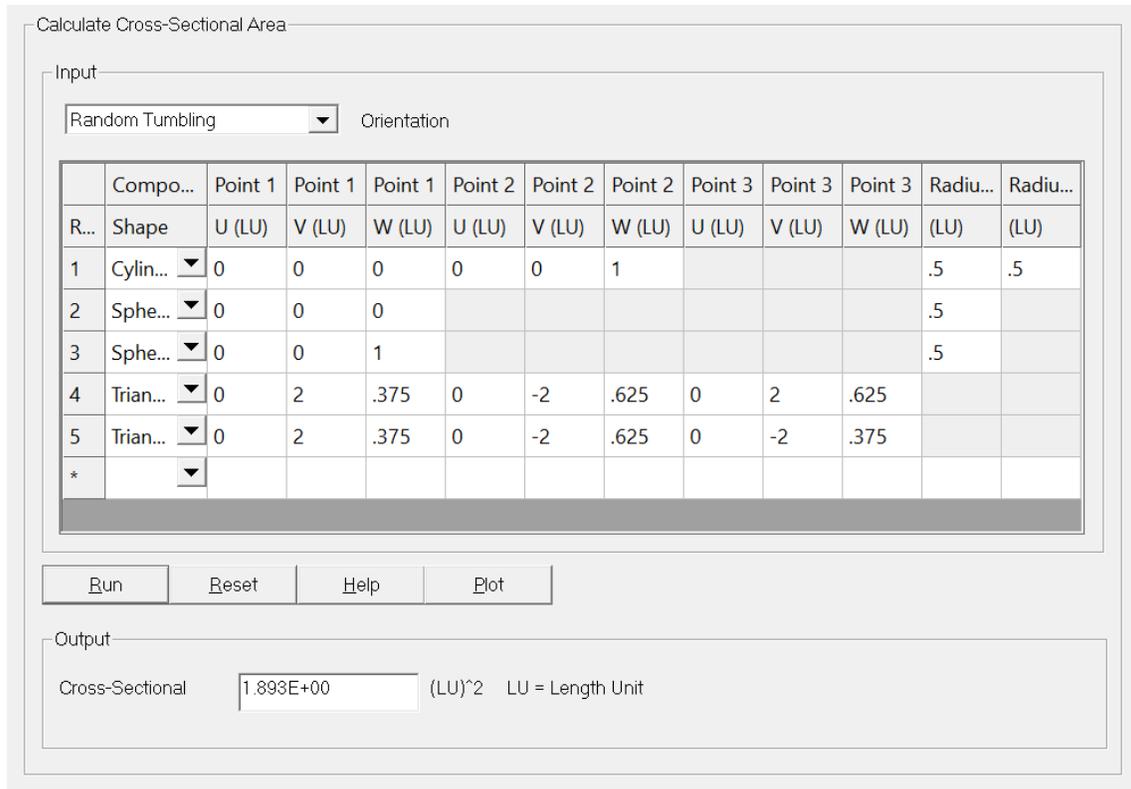
Figure 4 - 15: Calculate Cross-Sectional Area Dialog

Input Data:

The user must first define the spacecraft's orientation as being "random tumbling," "gravity gradient," or "fixed orientation."

- **Random tumbling** – No axes will be fixed during the orbital lifetime in question.

- **Gravity gradient** – The gravity (nadir) direction will be maintained with respect to the spacecraft during the orbital lifetime in question.

- **Fixed orientation** – The velocity (ram) direction and gravity (nadir) direction will be maintained with respect to the spacecraft during the orbital lifetime in question.

For objects that are "gravity gradient" or have "fixed orientation," the coordinate system shall be defined as U, V, and W, where +U is "up" (the opposite direction from gravity), +V is in the direction of velocity, and W is "port" (orthogonal: U×V). For "random tumbling" objects, the user may choose any convenient coordinate origin and orientation for the UVW system.

Component data are entered into the input grid by typing in any field in the last line of the grid (labeled as row "*"). Users input values for shape, point coordinates, and radius as required. The units need only be consistent, as the resulting units of area are simply the square of the input length (position) units. **Note that this module can process a maximum of 1000 rows.**

Component shapes are defined as follows:

- **Triangles** – U, V, and W for three corner points are needed. For square or rectangular surfaces, two adjoining triangles must be entered. While this is a tedious way to enter the data, it is necessary to ensure that each surface remains in a plane, a requirement of the cross-sectional area estimation software. For thin plates, such as solar panels, the thickness may be ignored.

- **Cylinders** – U, V, and W for the center points and radii of each end disk are needed. The cylinder may have end disks of different radii. A cone would have one end disk with a radius of 0. A flat disk can be entered as cylinder with a minimal distance between the two end disks.

- **Spheres** – U, V, and W for the center and its radius are needed.

Triangles are two-dimensional, while cylinders and spheres are three-dimensional. Surfaces that are interior to another surface will not affect the cross-sectional area estimation. For example, if the center point for a sphere is identical to one of the end points for a cylinder, only the portion of the sphere that is exterior to the cylinder will be considered. Surfaces that are entirely interior do not need to be defined.

If the configuration of the object can change (*i.e.*, moving solar panels), the average of cross-sectional area over each anticipated configuration may be used, based upon an intelligent assumption about the expected time spent in each configuration.

For more detailed projects, the user might find it useful to edit the comma separated value (CSV) file *xsectional.csv* within the **Project** directory, rather than use the graphical user interface.

The "Reset" button will clear all input values from the dialog.

Depressing the "Plot" button sends input values from the dialog to the plotting tool.

The purpose of the plotting tool is to provide a basic "sanity check" of the input values. This visual depiction should assist the user in constructing the objects for cross-sectional evaluation, but it is not necessary for actual calculation of cross-sectional area.

The plotting tool generates three, two-dimensional plots showing the V-W (top), V-U (side), and W-U (front) orthogonal views of the triangles, cylinders, and spheres used to define the spacecraft. However, because of the difficult nature of showing complex, three-dimensional objects in two-dimensional plots, there are two basic limitations:

1. To be plotted, the axis of a cylinder (*i.e.*, the line between the centers of the two end disks) must be defined in only one or two of the three user-defined UVW directions. If the axis of a cylinder varies in the U, V, AND W directions, it will be omitted on the graph. It is important to note, the omission does NOT affect the cross-sectional area calculation. All cylinders, regardless of their orientation, will be considered when the cross-sectional area is estimated.

2. For visual clarity, all points interior to a perfect cylinder (end disk radii identical) will be removed if the axis of the cylinder is in a primary (U, V, or W) direction only. Any cylinder axis in two directions or any cylinder with end disks of different radii will not "hide" any interior points. All points interior to a sphere will be removed for visual clarity, as well.

Output Data:

Output is the average projected cross-sectional area of the defined object. Output units are the square of the input units.

By clicking the "Plot" button, the user may generate a three-view representation of the wire-frame model. The generated plot is viewable in a separate plot window. An example of this can be seen in Figure 4-16. This is useful for finding data-entry errors that may have occurred during definition of the model points. **Section 2.6, Using the Plot Viewer** provides information on plot utility functions.
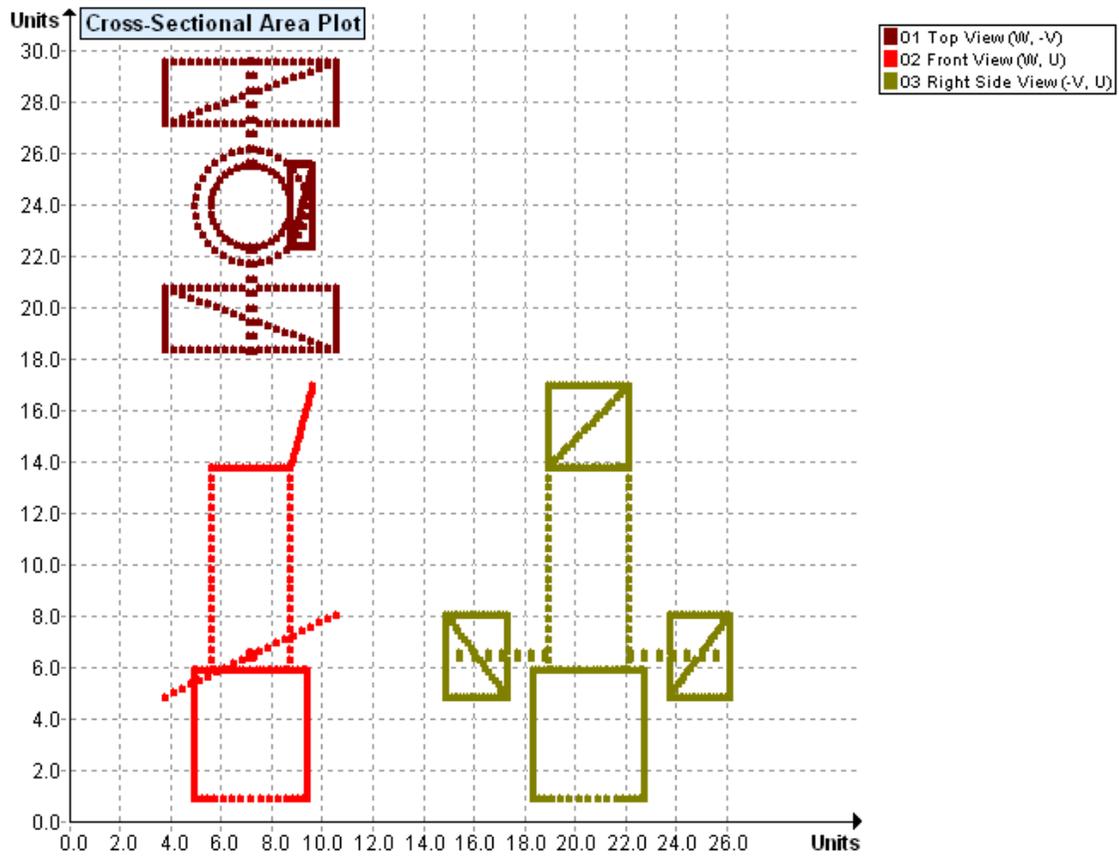
Figure 4 - 16: Three-View Cross-Sectional Area Plot

Note: Depending on the size and complexity of the object, the process may take several minutes to converge upon a result.

Appendix A: Glossary of Terms and Acronyms

Aero mass – The aerodynamic mass of an object is the mass of that specific object plus the mass of all internal fragments. Consequently, the aero mass must be at least equal to the object's mass.

Altitude – The height above Earth's surface (distinguished from radius, measured from Earth's center).

Apogee – The point on the orbit that is the farthest from the center of Earth. The apogee altitude is the distance of the apogee point above the surface of Earth.

Apsis (pl. apsides) – The point in the orbit where a satellite is at the lowest altitude (perigee) or at the highest altitude (apogee). The line connecting apogee and perigee is the *line of apsides*.

Area-to-Mass ratio (AOM, A/M) – The area-to-mass ratio, which is a measurement of the effective cross-sectional area of an orbiting object divided by its mass. Normal units are square meters per kilogram. Higher AOM will yield faster decay for LEO objects, while lower AOM (a denser object) yields slower decay. AOM should include deployed surfaces (*e.g.* solar panels).

Argument of perigee – The angle between the line extending from the center of Earth to the ascending node of an orbit and the line extending from the center of Earth to the perigee point in the orbit, measured from the ascending node in the direction of motion of the satellite.

Ascending node – The point in the orbit where a satellite crosses Earth's equatorial plane in passing from the southern hemisphere to the northern hemisphere.

Casualty – Serious injury to a person on the surface of Earth, caused by being struck by an object with kinetic energy of 15 joules or greater.

Combo box – A GUI component with a drop-down arrow that users click to display an associated list of choices. The current selection appears in an editable or noneditable text field next to the drop-down arrow. The user displays the list by clicking or dragging the drop-down arrow.

Cratering flux – The number of impacts per square meter per year of objects which will leave a crater at least as large as a specified diameter.

Critical surface – A surface in a component of a payload that, when the surface is damaged by impact, will cause the component to fail.

Debris flux – The number of impacts per square meter per year expected on a randomly-oriented planar surface of an orbiting space structure.

Debris flux to limiting size – The number of impacts per square meter per year of debris objects of a specified diameter or larger.

Delta-V, ΔV – The change in the velocity vector caused by thrust, measured in units of meters per second.

Demise – The total destruction of a reentering object, caused mainly by frictional heating with the atmosphere.

Dialog – A top-level GUI window, with a title and a border, which is typically used to take some form of input from the user.

Disposal orbit – The final orbit of an object after a completed mission. The project may elect to alter the end-of-mission orbit via a maneuver to a disposal orbit so that it may satisfy Requirement 4.6.

Eccentricity – A measure of an orbit's ellipticity, calculated as the orbit's apogee altitude minus its perigee altitude, divided by twice its semi-major axis. Eccentricity is zero for circular orbits and less than one for all elliptical (*i.e.,* bound) orbits.

F10.7 – An index of solar activity; typically a 13-month running average of the energy flux from the Sun measured at a wavelength of 10.7 cm, expressed in units of 10^4 janskys or Solar Flux Units (sfu).

Final mass – The expected mass after all propellants and fluids have been burned or vented and all mission related debris have been released.

Geosynchronous orbit (GEO) – An orbit with a period equal to the sidereal day. A circular GEO orbit with 0° inclination is a geostationary orbit, *i.e.*, the sub-satellite point is at a fixed longitude on Earth's equator. The altitude of a circular GEO orbit is 35,786 km.

Geosynchronous transfer orbit (GTO) – A highly eccentric orbit with perigee within or near LEO altitude and apogee near or above GEO altitude.

Grid – A GUI control to display the fields of a data source as columns in a table. Each row in the control represents a record in the data source.

GUI – Graphical user interface for computer software. The dialog window provided for user interface with an application's functional process.

High Earth Orbit, High Altitude Orbit (HEO) – An orbit with a mean altitude greater than 2000 km or, equivalently, an orbit with a period greater than 127 minutes.

Inclination – The angle an orbital plane makes with Earth's equatorial plane.

Initial mass – The mass of the object at the beginning of the mission, including propellants.

Jansky – A unit of electromagnetic power density equal to 10^{-26} watts/m^2/Hz.

Launch (GUI) – An action within a GUI dialog causing an additional dialog to open for user application interface.

Launch vehicle – Any space transportation mode, including expendable launch vehicles (ELVs), reusable launch vehicles (RLVs).

Line of apsides – The line connecting the apogee and perigee points in an orbit. This line passes through the center of Earth.

Line of nodes – The line formed by the intersection of the orbit plane with Earth's equatorial plane. This line passes through the center of Earth. The ascending node is the point where a satellite crosses the equator from the southern hemisphere to the northern hemisphere.

Low Earth Orbit (LEO) – An orbit with a mean altitude less than or equal to 2,000 km, or equivalently, an orbit with a period less than or equal to 127 minutes.

Mean anomaly – An angle measure, the product of the orbiting object's mean motion (mean angular rate) and the time since periapse passage.

Medium Earth orbit (MEO) – An orbit (or the region itself) between LEO and GEO.

Meteoroids – Naturally occurring particles associated with solar system formation or evolution processes. Meteoroid material is often associated with asteroid breakup or material released from comets.

Mission duration – The length of time that a mission is actively supported by ground operations.

Near-GEO – An orbit that has low eccentricity and both the perigee and apogee points are within the altitude range of (GEO-500 km) and (GEO+300 km).

NOAA – The National Oceanic and Atmospheric Administration, part of the U.S. Department of Commerce. NOAA's Space Environment Center provides historical and predicted solar flux data.

Operational orbit – The orbit of an object during its primary (and extended) missions.

Orbital debris – Artificial objects, including derelict spacecraft and spent launch vehicle orbital stages, left in orbit, which no longer serve a useful purpose. In this document, only debris of diameter 1 mm and larger are considered.

Orbital lifetime – The length of time an object remains in orbit. Objects in LEO or passing through LEO lose energy as they pass through Earth's upper atmosphere, eventually getting low enough in altitude that the atmosphere removes them from orbit.

Orbital stage – A part of the launch vehicle left in a parking, transfer, or final orbit during or after payload insertion; includes liquid propellant systems, solid rocket motors and any propulsive unit ejected from a spacecraft.

ORDEM – NASA's Orbital Debris Engineering Model. This is a statistical model, based on observations, that describes the orbital debris environment between 200 and 2000 km altitude. DAS 3.2 uses ORDEM 3.1.2, which describes the orbital debris environment between the altitudes of 100 and 40,000 km. NOTE: Increased fidelity of the ORDEM 3 comes at the cost of greatly-increased DAS run times.

ORSAT – The Object Reentry Survival Analysis Tool, NASA's computer code for predicting the reentry survivability of satellite and launch vehicle upper-stage components entering from orbital decay or from controlled entry.

Penetration debris flux – The number of impacts per square meter per year that will penetrate a surface of specified orientation with specified materials and structural characteristics.

Perigee – The point in the orbit that is nearest to the center of Earth. The perigee altitude is the distance of the perigee point above the surface of Earth.

Right ascension of ascending node – The angle between the line extending from the center of Earth to the ascending node of an orbit and the line extending from the center of Earth to the vernal equinox, measured from the vernal equinox eastward in Earth's equatorial plane.

Semi-major axis – Half the sum of the distances of apogee and perigee from the center of Earth (or other body); equal to half the length of the major axis of the elliptical orbit.

Semi-synchronous Orbit– An orbit with approximately a 12-hour period. A circular semi-synchronous is at an altitude of 20,200 km.

Solar flux unit (sfu) – Equal to 10^4 janskys measured at a wavelength of 10.7 cm.

Space debris – General class of debris, including both meteoroids and orbital debris.

Stabilized – When the spacecraft maintains its orientation along one or more axes.

Station-Keeping – During its mission duration, the payload is precluded from natural orbital decay by active station-keeping devices, *e.g.* thrusters.

Thermal mass – The thermal mass is strictly the mass of one specific object. This is the mass used for determining how much material needs to burn up.

Vernal equinox – The direction of the Sun in space when it passes from the southern hemisphere to the northern hemisphere (on March 20 or 21) and appears to cross Earth's equator. The vernal equinox is the reference point for measuring angular distance along Earth's equatorial plane (right ascension). It is one of two angles usually used to locate objects in orbit (the other being declination).

Wet/Dry mass – Wet mass is the mass of an object (payload or orbital stage) including propellant or any other expendable fluid, while dry mass is the mass of an object less any expendables.

Appendix B: NASA Technical Standard 8719.14C Requirements

4.3. ASSESSMENT OF DEBRIS RELEASED DURING NORMAL OPERATIONS

Orbital debris analyses assess the amount of launch vehicle and spacecraft debris released during normal operations. This requirement area applies to all space structures while in Earth. Operators are encouraged to limit the release of debris while in Moon or Mars orbit, or in the vicinity of Sun-Earth or Earth-Moon Lagrange Points.

NASA programs and projects assess and limit the amount of debris released as part of the mission.

REQUIREMENTS

4.3-1. *Planned debris release passing through LEO – released debris with diameters of 1 mm or larger*:

    4.3-1a.   All debris released during the deployment, operation, and disposal phases shall be limited to a maximum orbital lifetime of 25 years from date of release.

    4.3-1b.   The total object-time product shall be less than 100 object-years per launch vehicle upper stage or per spacecraft.

4.3-2. *Planned debris release passing near GEO:*
For missions leaving debris in orbits with the potential of traversing GEO (GEO altitude ± 200 km and ± 15 degrees inclination), released debris with diameters of 5 mm or greater shall be left in orbits which will ensure that within 25 years after release the apogee will no longer exceed GEO - 200 km or the perigee will not be lower than GEO + 200 km, and also ensures that the debris is incapable of being perturbed to lie within that GEO ± 200 km and ± 15° zone for at least 100 years thereafter.

4.4. ASSESSMENT OF DEBRIS GENERATED BY EXPLOSIONS AND INTENTIONAL BREAKUPS

Orbital debris analyses assess accidental explosion probability and intentional breakups during and after completion of mission operations. Section 4.4 is not intended to mandate the use of techniques that could cause unreasonable passivation errors or malfunctions that involve nonreversible passivation methods.

NASA programs and projects assess and limit the probability of accidental spacecraft and launch vehicle orbital stage explosion during and after completion of deployment and mission operations.

REQUIREMENTS

4.4-1. *Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon*:
　　For each spacecraft and launch vehicle orbital stage employed for a mission (*i.e.*, every individual free-flying structural object), the program or project shall demonstrate, via failure mode and effects analyses, probabilistic risk assessments, or other appropriate analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts).

4.4-2. *Design for passivation after completion of mission operations while in orbit about Earth or the Moon*:
　　Design of all spacecraft and launch vehicle orbital stages shall include the ability and a plan to either 1) deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or postmission disposal or 2) control to a level which cannot cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft. The design of depletion burns and ventings should minimize the probability of accidental collision with tracked objects in space.

NASA programs and projects assess and limit the effect of intentional breakups of spacecraft and launch vehicle orbital stages on other users of space.

REQUIREMENTS

4.4-3. *Limiting the long-term risk to other space systems from planned breakups for Earth and lunar missions*:
　　Planned explosions or intentional collisions shall:
　a) be conducted at an altitude such that for orbital debris fragments larger than 10 cm the object-time product is less than 100 object-years. For example, if the debris fragments greater than 10 cm decay in the maximum allowed 1 year, a maximum of 100 such fragments can be generated by the breakup.
　b) not generate debris larger than 1 mm that remains in Earth orbit longer than one year.

4.4-4. *Limiting the short-term risk to other space systems from planned breakups for Earth orbital missions:*

Immediately before a planned explosion or intentional collision, the probability of debris, orbital or ballistic, larger than 1 mm colliding with any operating spacecraft within 24 hours of the breakup shall be less than 10^{-6}.

4.5. ASSESSMENT OF DEBRIS GENERATED BY ON-ORBIT COLLISIONS

Orbital debris analyses assess the ability of the design and mission profile of a space system to limit the probability of accidental collision with known resident space objects during the system's orbital lifetime. Requirement area 4.5 applies to all space structures in Earth orbit.

NASA programs and projects assess and limit the probability that the operating space system becomes a source of debris if it collides with orbital debris or meteoroids.

REQUIREMENTS

4.5-1. *Limiting debris generated by collisions with large objects when in Earth orbit:*
For each spacecraft and launch vehicle orbital stage, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001. For the purpose of this assessment, 100 years is used as the maximum orbital lifetime for the storage disposal option.

4.5-2. *Limiting debris generated by collisions with small objects when operating in Earth orbit:*
For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable postmission disposal maneuver requirements is less than 0.01.

4.6. POSTMISSION DISPOSAL OF SPACE STRUCTURES

NASA space programs and projects are to plan for the disposal of a space structure (*i.e.,* launch vehicle components, upper stages, spacecraft, and other payloads) at the end of their respective missions. Disposal can be accomplished by one of the following methods: (1) Earth atmospheric reentry, (2) direct reentry, (3) maneuvering to a storage orbit, (4) direct retrieval, (5) long-term reentry, or (6) Earth escape. Requirement area 4.6 applies to all space structures when in Earth orbit.

REQUIREMENTS

4.6-1. *Natural reentry, direct reentry, or direct retrieval shall comply with the following*:

 a. Natural reentry: Leave the space structure in an orbit in which, using conservative projections for solar activity, atmospheric drag will limit the orbital lifetime to as short as practicable but no more than 25 years after the completion of mission.

 b. Direct reentry: Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.

 c. Direct retrieval: Retrieve the space structure and remove it from orbit preferably at completion of mission, but no more than 5 years after completion of mission.

4.6-2. *Storage and Earth escape shall comply with the following:*

 a. Storage between LEO and GEO:

 (1) Maneuver to a highly eccentric disposal orbit (*e.g.*, GEO transfer orbit) where (i) perigee altitude remains above 2000 km for at least 100 years, (ii) apogee altitude remains below 35,586 km for at least 100 years, and (iii) the time spent by the space structure between 20,182 +/- 300 km is limited to 25 years or less over 200 years; or,

 (2) Maneuver to a near-circular disposal orbit to (i) avoid crossing 20,182 +/- 300 km, the GEO zone, and the LEO zone for at least 100 years, and (ii) limit the risk to other operational constellations, for example, by avoiding crossing the altitudes occupied by known missions of 10 or more spacecraft using near-circular orbits, for 100 years.

 b. Storage above GEO: Maneuver to a disposal orbit above GEO with a predicted minimum perigee of 35,986 km for a period of at least 100 years after disposal.

 c. Earth escape: Maneuver to a heliocentric, Earth-escape trajectory.

4.6-3. *Long-term reentry for space structures in medium Earth orbit (MEO), Tundra orbits, highly inclined GEO, and other orbits shall*:

 a. Maneuver to a disposal orbit where orbital resonances will increase the eccentricity for long-term reentry of the space structure,

 b. Limit the postmission orbital lifetime to as short as practicable but no more than 200 years,

c. Limit the time spent by the space structure in the LEO zone, the GEO zone, and between 20,182 +/- 300 km to 25 years or less per zone, and

d. Limit the probability of collisions with debris 10 cm and larger to less than 0.001 (1 in 1,000) during orbital lifetime.

4.6-4. *Reliability of postmission disposal maneuver operations in Earth orbit*:
NASA space programs and projects shall ensure that all postmission disposal operations to meet Requirements 4.6-1, 4.6-2, and 4.6-3 are designed for a probability of success as follows:

a. Be no less than 0.90 at EOM, and

b. For controlled reentry, the probability of success at the time of reentry burn must be sufficiently high so as not to cause a violation of Requirement 4.7-1 pertaining to limiting the risk of human casualty.

4.7. ASSESSMENT OF DEBRIS SURVIVING ATMOSPHERIC REENTRY

Orbital debris analyses assess the risks associated with the disposal of a space vehicle in Earth's atmosphere. Requirement area 4.7 applies to all spacecraft and launch vehicles returning to the surface of Earth from an altitude of greater than 130 km.

NASA space programs and projects that use atmospheric reentry as a means of disposal for space structures need to limit the amount of debris that can survive reentry and pose a threat to people on the surface of the Earth. This area applies to full spacecraft as well as jettisoned components.

REQUIREMENTS

4.7-1. *Limit the risk of human casualty*:
　　The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules.

a. For uncontrolled reentry, the risk of human casualty from surviving debris shall be less than 0.0001 (1:10,000).

b. For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica.

c. For controlled reentry, the product of the probability of failure to execute the reentry burn and the risk of human casualty assuming uncontrolled reentry shall be less than 0.0001 (1:10,000).

d. For long-term reentry of space structures in MEO, Tundra orbits, highly inclined GEO, and other orbits: Surviving debris shall have less than 7 m^2 total debris casualty area or 0.0001 (1 in 10,000) risk of human casualty.

4.8. ADDITIONAL ASSESSMENT REQUIREMENTS FOR SPECIAL CLASSES OF SPACE MISSIONS

The 2019 ODMSP includes a new section on certain special classes of space missions and establishes additional measures to mitigate the risk of debris generation from such missions. Those missions include (1) large constellations, (2) small satellites, including CubeSats, (3) rendezvous, proximity operations, and satellite servicing, (4) safety of active debris removal operations, and (5) tether systems. NASA programs or projects planning such missions shall meet the standard practices established in Objective 5 of the 2019 ODMSP. Due to the unique nature of large constellations and tether systems, please contact the NASA Orbital Debris Program Office for technical assistance to prepare ODAR and EOMP deliverables. The example below is an illustration of the complexities of the tether systems.

Orbital debris analyses assess the potential hazard of tethered systems considering both an intact and a severed system. A tether is a long flexible structure greater than 300 meters in length. Tethers can have a variety of purposes but are typically used electro-dynamically for power generation or to impart changes in linear or angular momentum. The potential to damage operating spacecraft can be larger than would be expected solely from the tether mass and cross-sectional area. Requirement area 4.8 applies to all space structures using tethers in Earth orbits.

NASA programs and projects assess and limit the collision hazard posed by tether systems on other users of space and on the near-Earth environment.

REQUIREMENTS

4.8-1. *Special classes of space missions: Special classes of space missions, including large constellations; rendezvous, proximity operations, and satellite servicing; safety of active debris removal operations; tethers; and small satellites, shall comply with (1) the requirements in Sections 4.3 through 4.7, (2) the applicable mitigation standard practices established in Objective 5 of the 2019 ODMSP, and (3) the following*:

a. Tether systems: Intact and remnants of severed tether systems in Earth orbit shall limit the generation of orbital debris from on-orbit collisions with other operational spacecraft. Tether systems should generally not remain deployed after the completion of their mission objectives. After mission objectives are met, such tethers should have provisions for disposal (full retraction/stowing and/or removal from Earth orbit) with a >0.90 probability of success, including an assessment of the reliability of the disposal system and accounting for the possibility of damage to or cutting of the tether prior to disposal.

b. Small satellites, including CubeSats: For spacecraft smaller than 10 cm × 10 cm × 10 cm when fully deployed:

(1) Any spacecraft in LEO shall be limited to an orbital lifetime as short as practicable but no more than 25 years after completion of mission.

(2) The total spacecraft object-time product in LEO shall be less than 100 object-years per mission.

Appendix C: DAS Technical Notes

C.1   Orbit Propagators

DAS 3 uses the NASA propagators "PROP3D" and "GEOPROP". GEOPROP calculates the motion of objects in geosynchronous orbits, while PROP3D calculates the orbits of all other objects. A geosynchronous orbit is defined as having orbital eccentricity less than 0.1, inclination less than 15°, and period between 0.95 and 1.05 days. The propagators are designed to maintain integration accuracy over long propagation periods (decades) with reasonable computation speed.

Both propagators account for all significant perturbing forces. Table C-1 lists the perturbations and some of the reference models used. PROP3D propagates five orbital elements, describing the shape and orientation of the orbit, but not the position of the object along that orbit. GEOPROP propagates all six orbital elements, based on the disturbing-function formulation of Van der Ha [1].

Table C - 1: Perturbations included in the DAS orbit propagators

Perturbation	PROP3D	GEOPROP
Atmospheric drag	Oblate, rotating atmosphere [2, 3]	None
Solar & Lunar gravity	Yes [4]	Yes
Solar radiation pressure (SRP)	Yes	Yes
Earth's shadow for SRP	Yes	Neglected
Earth's gravity field	Zonal harmonics: J_2, J_3, J_4, $(J_2)^2$ [5]	Zonal harmonics: J_2, J_3, J_4 Tesseral harmonics: $J_{2,2}$, $J_{3,1}$, $J_{3,3}$, $J_{4,2}$, $J_{4,4}$

For DAS 3, the coefficient of drag is assumed to be 2.2. The coefficient of reflectivity (for the solar radiation pressure perturbation) is assumed to be 1.25. For reference, a perfectly transparent object would have a coefficient of reflectivity of zero, while a planar mirror normal to the (solar) flux would have a coefficient of 2.0.

1. Van der Ha, J.C., "Long-term evolution of near-geo orbits," *J. Guidance*, **9**, p. 363-370, 1986.
2. Jacchia, L.G., *Thermospheric Temperature, Density and Composition: New Models*, Smithsonian Astrophysical Observatory, Special Report 375, 1977.
3. King-Hele, D., *Satellite Orbits in an Atmosphere*, Blackie & Son, LTD., London, 1987.
4. Cook, G.E., "Luni-solar perturbations of the orbit of an Earth satellite," *The Geophysical Journal of the Royal Astronomical Society*, **6**, p. 271-291, 1962.
5. Vallado, D.A., *Fundamentals of Astrodynamics and Applications*, McGraw-Hill, NY, 1997.

C.2   Orbital Elements

Orbital elements are mathematical quantities used to describe the path (trajectory) of an object traveling through space. DAS uses a set of Keplerian mean orbital elements. Figures C-1 and C-2 depict the physical nature of the elements, which are listed in Table C-2. One common format of the orbital elements is the "two-line element" (TLE) format, described in Sect. 4.6.1 of this Guide. For more information, the reader should consult any basic celestial mechanics textbook.
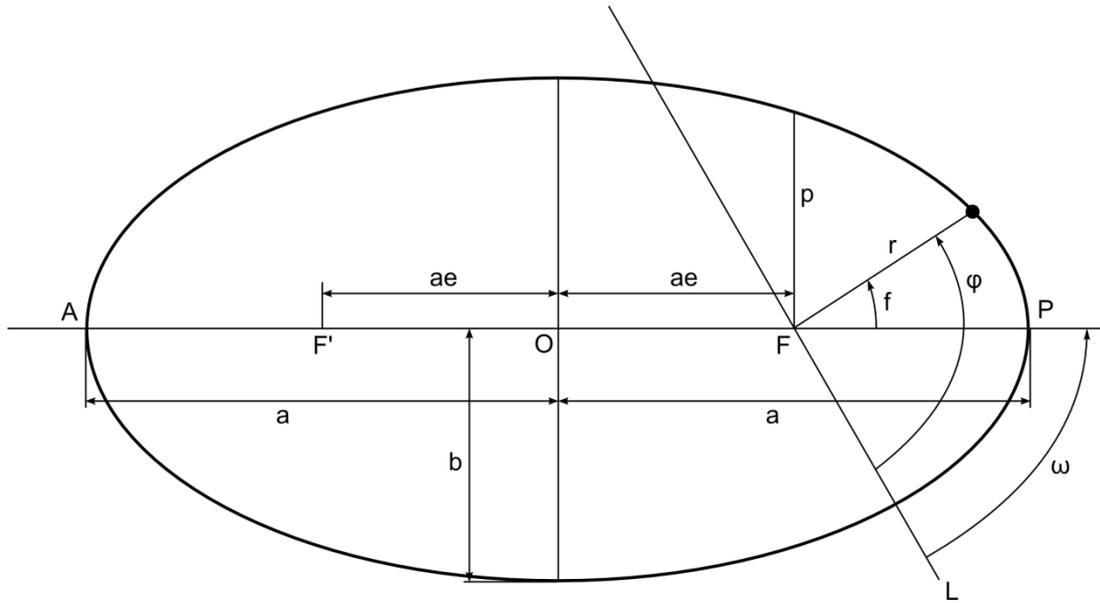
Figure C - 1: Orbital Elements in the Orbital Plane
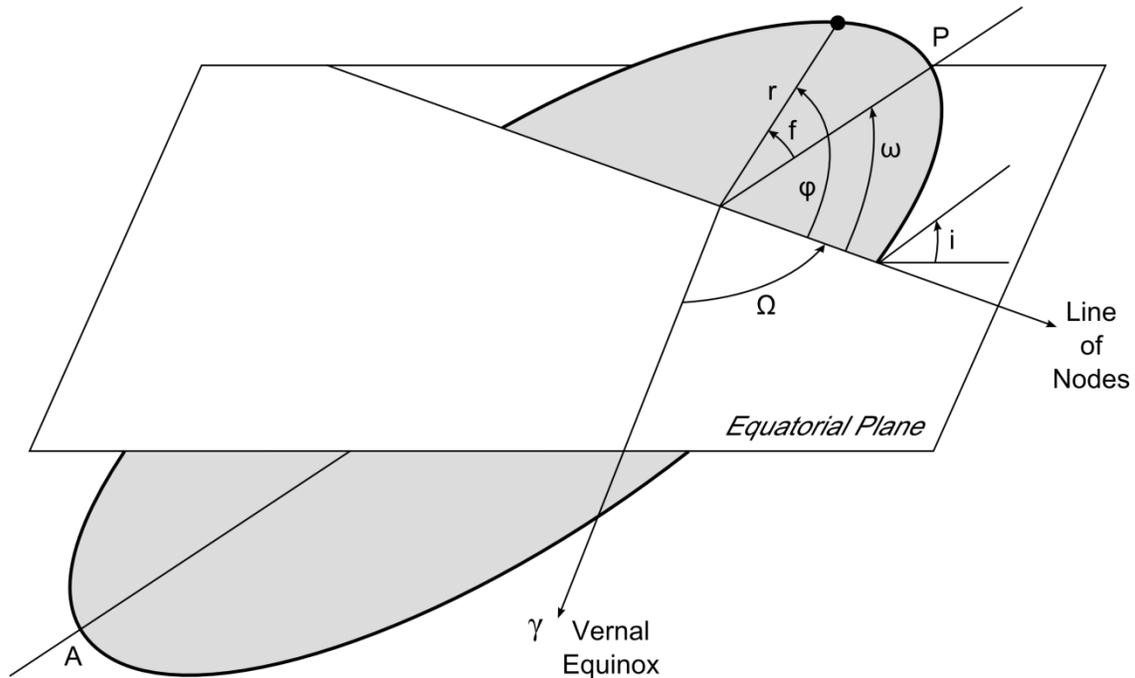
Figure C - 2: Orbital Elements

Table C - 2: Description of the Orbital Elements

Orbital Element	Symbol	Description
Semi-major axis	a	Half the sum of the distances of apogee and perigee from the center of Earth. Half the length of the major axis of the elliptical orbit.
Eccentricity	e	A measure of an orbit's ellipticity, calculated as the orbit's apogee altitude minus its perigee altitude, divided by twice its semi-major axis.
Inclination	i	The angle an orbital plane makes with Earth's equatorial plane.
Right ascension of the ascending node	Ω	The angle between the line extending from the center of Earth to the ascending node of an orbit and the line extending from the center of Earth to the vernal equinox, measured from the vernal equinox eastward in Earth's equatorial plane.
Argument of perigee	ω	The angle between the line extending from the center of Earth to the ascending node of an orbit and the line extending from the center of Earth to the perigee point in the orbit, measured from the ascending node in the direction of motion of the satellite.
Mean anomaly (not pictured)	M	An angle measure: the product of the orbiting object's mean motion (mean angular rate) and the time since periapse passage.

C.3   Orbital Debris Environment Model

DAS 3.2 incorporates the orbital debris environment model of ORDEM 3.1, the Orbital Debris Engineering Model also developed by the NASA Orbital Debris Program Office. The higher-fidelity ORDEM 3.1 has greatly increased run-times compared to ORDEM2.0 (a.k.a. ORDEM2000) used in DAS versions 2.X. Because DAS performs an ORDEM analysis for each year an object is in orbit, these increased run-times are multiplied. Highly elliptical orbits, crossing a wider parameter space, will see the greatest increase in run-time.

ORDEM 3.1 contains updated debris populations covering low Earth orbit (LEO, up to 2000 km altitude) to geosynchronous orbit (GEO, up to 40,000 km altitude) and can assess debris calculations (debris sizes greater than 10µm) up to year 2050, extending coverage past the previous limit of 2035 in ORDEM 3.0. In DAS 3.2, the time period is extended to year 2130. However, years 2051 through 2130 do not include small debris populations (*i.e.*, sizes below 10 cm). An important result of this is that **DAS cannot assess Requirement 4.5-2 for missions operating after 2050**. This shall be addressed in a future version of DAS.

In DAS 3, two Assessments use functions derived from ORDEM 3.1. The increase in run-time depends on the number of times DAS must call the ORDEM functions.

Table C - 3: DAS Functions that use ORDEM

DAS function	Number of times ORDEM routines are called
Assessment of Requirement 4.5-1: Limiting Debris Generated by Collisions with Large Objects	Once for every calendar year in orbit (not just mission lifetime) **[orbital lifetime × 1]**
Assessment of Requirement 4.5-2: Probability of Damage from Small Debris	Once for every calendar year of mission lifetime **[mission lifetime × 1]**

For further details and references, please see:

Matney, M. J., "The NASA Orbital Debris Engineering Model 3.1: Development, Verification, and Validation," First International Orbital Debris Conference, Houston, TX, USA, 9-12 Dec. 2019.

Orbital Debris Engineering Models (ORDEM 3.1), https://orbitaldebris.jsc.nasa.gov/modeling/ordem-3.1.html (retrieved 30 April 2020).

NASA Orbital Debris Engineering Model ORDEM 3.1 – User's Guide, NASA/TP-2019-220448, NASA Orbital Debris Program Office, NASA-JSC, Houston, TX, USA, Dec. 2019.

C.4   Solar Flux Model

The value of the solar flux at a wavelength of 10.7 cm (2800 MHz), often called the F10.7 value, is used as a measure of solar activity. In DAS, the F10.7 value is used to compute the temperature, and therefore density, of Earth's upper atmosphere. The user enters a starting date and a mission length, and the software looks up the appropriate F10.7 values in an included data table. The table includes historical values archived by the U.S. National Oceanic and Atmospheric Administration's (NOAA) Space Weather Prediction Center (SWPC) (https://www.swpc.noaa.gov), as well as the SWPC's "near-term" predictions. For epochs beyond the near term, a curve-fit technique using sixth-order sine and cosine terms was performed to fit historical daily solar flux values from 1947 through the end of the daily solar flux data available from NOAA. This curve-fit equation was then used to generate future flux predictions.

The DAS solar flux input table is updated periodically. The updated file should be downloaded from the NASA Orbital Debris Program Office website and placed in the DAS "data" directory.

For further information, see:

Whitlock, D.O., "Modeling the Effect of High Solar Activity on the Orbital Debris Environment," *NASA Orbital Debris Quarterly News*, vol. 10, no. 2, p. 4, April 2006. (https://orbitaldebris.jsc.nasa.gov/quarterly-news/newsletter.html)
Manis, A., and Matney, M., "Updated Solar Cycle Predictions for Orbital Debris Modeling," *NASA Orbital Debris Quarterly News*, vol. 24, no. 4, p. 4, November 2020. (https://orbitaldebris.jsc.nasa.gov/quarterly-news/newsletter.html)

C.5   Human Casualty Expectation

Human casualty expectation is the product of the population density and the computed debris casualty area. The probability of a surviving debris object striking a person on the ground is defined as the reciprocal of the casualty expectation. Since DAS is typically concerned with objects reentering years or even decades in the future, the population density must be treated statistically. Therefore, the population density is averaged over longitude, and the population density along an object's ground-track is a function of its orbit inclination. The computed casualty area is a function of the debris size and the size of an "average" person.

For further details and references, please see:

Opiela, J.N., and M.J. Matney, "Improvements to NASA's Estimation of Ground Casualties from Reentering Space Objects," *Space Debris and Space Traffic Management Symposium*, AAS Science and Technology Series, vol. 109, p. 385-392, 2004.
Ostrom, C.L., "Improving Estimation of Ground Casualty Risk from Reentering Space Objects," *9th International Association for the Advancement of Space Safety Conference*, Toulouse, 2017.

C.6   Properties of the Default Materials

DAS includes a built-in list of the most common materials used in space vehicles. Three material properties are used in assessment of an object's reentry survivability: specific heat, heat of fusion, and melt temperature. DAS also uses mass density to make sure a component's mass and size are consistent. The properties of the DAS built-in materials are listed in the table below. Note that the specific heat of many of the materials is a function of the materials' temperature.

Table C - 4: Properties of DAS 3 Built-In Materials

Material Description	Specific Heat (J/kg-K)	Heat of Fusion (J/kg)	Melt Temper-ature (K)	Density (kg/m³)
Acrylic	1465	0.0	505.0	1170.00
Alumina	694.0 < Cp < 1219.0	106757.0	2305.4	3990.00
Aluminum (generic)	1100	390000.0	850.0	2700.00
Aluminum 1145-H19	904	386116.0	919.0	2697.00
Aluminum 2024 - T3	972.7	386116.0	856.0	2803.20
Aluminum 2024-T8xx	600.0 < Cp < 1100.0	386116.0	856.0	2803.00
Aluminum 2219-T8xx	864.5 < Cp < 981.6	386116.0	867.0	2812.80
Aluminum 5052	900.2	386116.0	880.0	2684.90
Aluminum 6061-T6	896	386116.0	867.0	2707.00
Aluminum 7075-T6	650.7 < Cp < 1177.9	376788.0	830.0	2787.00
Barium element	285	55824.0	983.0	3492.00
Beryllium element	1203.0 < Cp < 3595.0	1093220.0	1557.0	1842.00
Beta cloth	837.5	232.6	650.0	1581.00
Brass, Red (85% Cu, 15% Zn)	397.7 < Cp < 410.3	195372.0	1280.0	8746.00
Brass, Cartridge (70% Cu, 30%Zn)	397.7 < Cp < 414.5	179091.0	1208.0	8521.80
Brass, Muntz (60% Cu, 40% Zn)	397.7 < Cp < 427.0	167461.0	1174.0	8393.67
Carbon-Carbon Reinforced	707.0 < Cp < 1719.0	37650.0	2144.0	1688.47
Cobalt	313.6 < Cp < 690.0	259600.0	1768.0	8862.00
Cork	1629.2	2860980.0	922.0	261.29
Cu alloy	385.0 < Cp < 472.0	204921.0	1356.0	8938.00
Cu/ Be (0.5% Beryllium)	397	204921.0	1320.0	8800.00
Cu/ Be (1.9% Beryllium)	460.5 < Cp < 652.0	204921.0	1199.0	8248.60
Fiberfrax	1130.5	0.0	2089.0	96.10
Fiberglass	1046.8	232.6	1200.0	1840.35
FRCI-12 (also LI-2200 w/ diff rho) shuttle tiles	293.0 < Cp < 1268.0	0.0	1922.0	192.22
Gallium Arsenide (GaAs)	325	0.0	1510.0	5316.00
Germanium	314.1 < Cp < 397.7	430282.6	1210.7	5320.00
Gold element	126.0 < Cp < 153.0	64895.0	1336.0	19300.00
Graphite epoxy 1	879	232.6	700.0	1550.50

Table C - 4: Continued

Material Description	Specific Heat (J/kg-K)	Heat of Fusion (J/kg)	Melt Temper-ature (K)	Density (kg/m^3)
Graphite epoxy 2	879	232.6	700.0	1550.50
Hastelloy c (57% Ni, 15% Cr, 15% Mo, 5% Fe, 4% W)	498.4 < Cp < 693.7	309803.0	1620.0	8920.67
Hastelloy 25 (aka Haynes alloy 25, 51% Co, 20% Cr, 10% Ni, 15% W)	403.0 < Cp < 590.0	309803.0	1643.0	9130.00
Hastelloy 188 (aka Haynes alloy 188, 42% Co, 22% Cr, 22% Ni, 14% W)	403.0 < Cp < 590.0	309803.0	1635.0	8980.00
Hastelloy n (71% Ni, 7% Cr, 16% Mo, 55% Fe)	419.0 < Cp < 578.0	309803.0	1623.0	8576.40
Inconel x (aka x-750, Ni > 70%, 15% Cr, 7% Fe)	341.4 < Cp < 541.8	311664.0	1683.2	8297.50
Inconel 600 (Ni >72%, 15% Cr, 18% Fe)	412.6 < Cp < 650.2	297206.0	1683.9	8415.00
Inconel 601 (Ni 60%, 23% Cr, 13% Fe)	412.6 < Cp < 650.2	311664.0	1659.0	8057.29
Inconel 625 (Ni >58%, 21% Cr, 9% Mo, 3% Nb)	410	311664.0	1593.0	8440.00
Inconel 718 (Ni 53%, 19% Cr, 17% Fe)	435	311664.0	1571.0	8190.00
Invar	500.0 < Cp < 653.2	274000.0	1700.0	8050.00
Iron (Armco)	307.0 < Cp < 709.0	272125.0	1812.0	7865.00
Lead element	130.5 < Cp < 138.8	23958.0	600.0	11677.00
Macor ceramic	790	236850.0	1300.0	2520.00
Magnesium AZ31 (3% Al, 1% Zn)	1008.0 < Cp < 1398.0	339574.0	868.0	1682.00
Magnesium HK31A (3% Th, 1% Zr)	1019.2 < Cp < 1340.6	325619.0	877.0	1794.00
Molybdenum	246.0 < Cp < 412.0	293057.0	2899.0	10219.00
MLI	1046.6	232.6	617.0	772.48
MP35N (35% Ni, 33% Co, 20% Cr, 10% Mo)	333.34 < Cp < 622.15	309803.0	1650.0	8430.00
Nickel	333.34 < Cp < 622.15	309803.0	1728.2	8906.26
Niobium (a.k.a. columbium)	270 < Cp < 345.0	290000.0	2741.0	8570.00
NOMEX	1256	232.6	572.0	1380.00
Platinum	129.0 < Cp < 146.0	113967.0	2046.4	21448.70
Polyimide	1130	232.6	723.0	1420.00
Polycarbonate (Lexan)	1260	0.0	573.0	1250.00
RCG Coating	627.0 < Cp < 1633.0	0.0	1922.0	1665.91
Rene41 (52% Ni, 19% Cr, 11% Co, 10% Mo)	346.9 < Cp < 914.9	311664.0	1728.0	8249.00
Silver element	222.5 < Cp < 243.0	105833.0	1234.0	10492.00
Sodium-Iodide	84	290759.6	924.0	3470.00
Stainless Steel (generic)	600	270000.0	1700.0	7800.00
Steel 17-4 ph (Precipitation Hardening SS, Fe + 17%Cr + 4%Ni+ 3-4%Cu alloy)	666.8	286098.0	1728.0	7833.03
Steel 21-6-9 (Stainless Steel, 64%Fe+ 21% Cr+ 6% Ni+ 9% Mn alloy)	439	286098.0	1728.0	7832.80
Steel A-286 (Stainless Steel, 60% Fe + 15% Cr + 25% Ni alloy)	460.6	286098.0	1644.0	7944.90

Table C - 4: Concluded

Material Description	Specific Heat (J/kg-K)	Heat of Fusion (J/kg)	Melt Temper-ature (K)	Density (kg/m³)
Steel AISI 304 (Stainless Steel, 69% Fe + 19% Cr + 10% Ni alloy)	482.0 < Cp < 608.0	286098.0	1700.0	7900.00
Steel AISI 316 (Stainless Steel, 62% Fe + 18% Cr + 14% Ni alloy)	460.6	286098.0	1644.0	8026.85
Steel AISI 321 (Stainless Steel, 69% Fe + 17% Cr + 11% Ni alloy)	565.2 < Cp < 651.2	286098.0	1672.0	8026.60
Steel AISI 347 (Stainless Steel, 68% Fe + 17% Cr + 11% Ni alloy)	462.0 < Cp < 638.0	286098.0	1686.0	7960.00
Steel AISI 410 (Stainless Steel, 86% Fe + 13% Cr alloy)	485.7	286098.0	1756.0	7749.50
Strontium element	737	95599.0	1043.0	2595.00
Teflon	1674	0.0	533.0	2162.50
Titanium (generic)	600	470000.0	1950.0	4400.00
Titanium (6 Al-4 V)	450.0 < Cp < 1110.0	393559.0	1943.0	4437.00
Tungsten	127.0 < Cp < 187.6	220040.0	3650.0	19300.00
Uranium	115.0 < Cp < 178.5	52523.0	1405.0	19099.00
Uranium Zirconium Hydride (UZrH)	418.7	131419.0	2144.0	6086.80
Water	4300.0 < Cp < 6900.0	0.1	370.0	999.00
Zerodur	800.0 < Cp < 1600.0	250000.0	1424.0	2530.00
Zinc	372.0 < Cp < 444.0	100942.0	692.6	7144.20
Aluminum 2195 (Al-Li)	167.0 < Cp < 1088.0	386116.0	878.0	2700.0
Aluminum 2090	209.0 < Cp < 1109.0	386116.0	878.0	2574.2
A356	1109.0	389000.0	858.0	2691
Nextel	741.1	233.0	2073.0	2700
Kevlar	340.0	0.0	763.0	1206.0