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Debris Assessment Software User's Guide
Version 2.1

Orbital Debris Program Office

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October 2016

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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 2010-2070.	March 2016

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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 8719.14A, *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) are better done outside DAS. The user should remember that DAS is a software tool, while the NASA Technical Standard 8719.14A contains the actual mission requirements.

DAS 2.1 will assess payloads operating from the year 2010 to 2035, and objects in orbit (non-operational) from 2010 to 2070. The time limits are based on the limits of the orbital debris environment model, ORDEM 3.0. The small-object environment (objects with sizes <10 cm), which is required for assessment of Requirement 4.5-2, ends in the year 2035. The larger-object environment (sizes ≥10 cm), required for collision risk assessment during both operational and post-mission phases, is projected to 2070. As a result, **DAS 2.1 cannot assess Requirement 4.5-2 for payloads still operational after 2035.**

1.2 Software Changes

DAS 2 uses all-new computer code while building on the features of previous DAS versions. Minor revisions to DAS 2 provide bug-fixes, important clarifications, and updated documentation, but do not change the features of the software.

1.2.1 Changes from DAS 1.5.3 to DAS 2.0

The release of NASA's Debris Assessment Software (DAS) version 2.0 provides an all-new tool for mission designers to assess their mission's compliance with NASA's requirements for limiting orbital debris. Updated models and methods make the new DAS more useful, and a Microsoft Windows user interface makes it much easier to use.

DAS 2.0 includes updated propagators, environment models, and a reentry-survivability model. The "fast" propagator used by DAS 1.5.3 has been replaced by NASA's newer propagators, "PROP3D" and "GEOPROP." These are the propagators used by NASA's debris environment evolutionary models. Although they take longer to run, the new propagators produce more realistic results. Improved force models include Earth's atmosphere and gravitational field, solar and lunar gravitation, and solar radiation pressure. The solar flux value (used for atmospheric drag calculations) is no longer a user input; the user now enters the date, and the appropriate values are retrieved from a model based on NOAA short-term predictions and NASA long-term predictions. (Periodically updated solar flux tables should be obtained from the Orbital Debris Program Office Web site.) The debris environment has also been updated from the previous "ORDEM96" model to the newer "ORDEM2000."

Numerous upgrades have been applied to the assessment of human casualty due to reentering debris. Routines based on NASA's Object Reentry Survival Analysis Tool version 6 determine which objects may survive reentry, and the resulting risk of casualty is calculated based on an updated world population database. Improvements to the model include the specification of orbital inclination, an improved aero-heating model, temperature-dependent material properties (for the included materials), and improved impact kinetic energy calculation. Up to 200 unique hardware components may now be entered into up to four nested levels. This last feature allows the software to more accurately model components which are exposed below the initial breakup altitude.

DAS 2.0 also includes a new native Microsoft Windows graphical user interface (GUI), which is a vast improvement over the old DOS-based interface. The user enters detailed information about each of their launched objects into the Mission Editor. This information is then available to the various assessment modules, without having to be reentered. Some modules, most notably the assessment of reentry survivability, require additional information to be entered by the user. For ease of use, the entered information may be saved and reloaded from **.csv** (comma-separated values) text files. In addition to the assessment modules, DAS still has a number of **Science and Engineering** modules to assist in the assessment process. DAS 2.0 also includes on-line help features familiar to Windows users.

1.2.2 Changes to DAS 2.0

DAS version 2.0.1 fixes an error in two material properties and a bug that resulted in incorrect rocket body mass and A/M data being transferred from the Mission Editor to the assessment routines for Requirements 4.7-1 and 4.8-1.

DAS version 2.0.2 fixes a number of errors that resulted in an incomplete assessment of some orbits and inconsistencies between modules. A new software packager/installer works on all current versions of Microsoft Windows. For a full description of the changes, please refer to the text file "DAS202_release_notes.txt" in the installed DAS directory.

1.2.3 Changes from DAS 2.0 to DAS 2.1

DAS version DAS 2.1 incorporates the orbital debris environment model of ORDEM 3.0, the Orbital Debris Engineering Model also developed by the NASA Orbital Debris Program Office. This is the only major change in this version.

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

DAS runs that formerly took a few minutes will now take substantially longer.

During lengthy calculations, DAS may not respond and Windows may display the "Not Responding" label and faded DAS window. DAS continues to run and will display results when the computations are complete.

1.3 Software Installation and Removal

Recommended system for DAS 2.1:

Windows 7
1GHz+ Intel (or compatible)
256MB+ RAM
2 GB available disk space
CD-ROM drive (optional)
Windows Help software (https://support.microsoft.com/en-us/kb/917607)

Software Installation:

DAS 2.1 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 2.1 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 to which 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. A **pop-up dialog** reminds the user to download and install the Microsoft Windows Help program from the Web site https://support.microsoft.com/en-us/kb/917607.
7. **Installation Complete** notifies the user that the setup has completed. The computer will not require rebooting.
8. The **Completing** window gives the user the option to create a Windows Desktop shortcut for DAS, and to display the Release Notes for this version.

DAS 2.1 does not update the internal Help function, which uses an old Windows Help format. If the user's system cannot open the DAS Help, the user must install the appropriate version of the Windows Help program for their system. This is a free download from **https://support.microsoft.com/en-us/kb/917607**.

Do not remove or rename files and directories installed with DAS 2.1. 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.dat"), which is updated periodically. It should be replaced when a new version is posted on the Orbital Debris Program Office Web site.

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 2.1 includes an automatic removal ("un-installer") feature (DAS21-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 2.1, 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 may still 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.

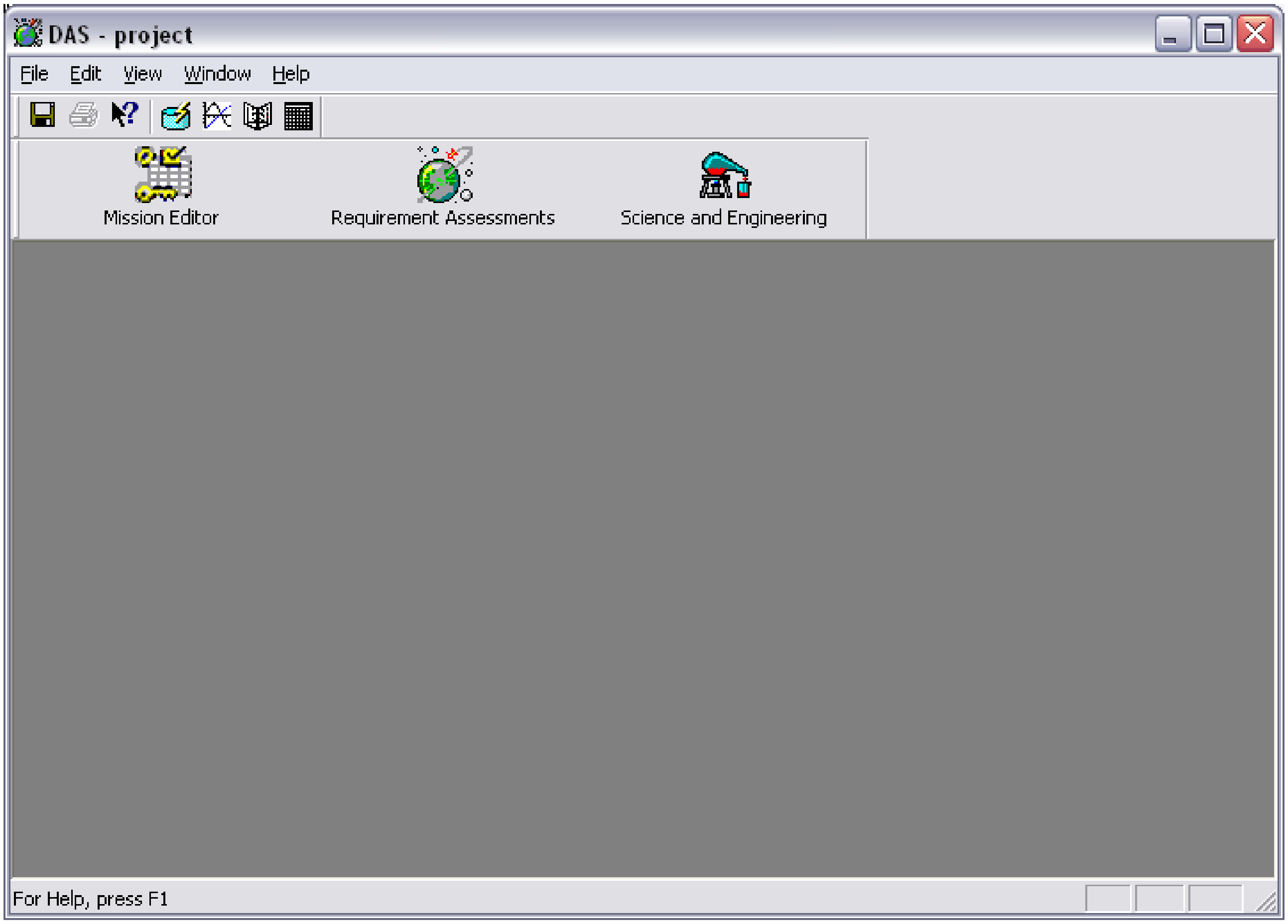


Figure 2 - 1: DAS 2 Main Window

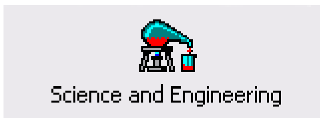
2.1 Viewing Toolbars

DAS 2 provides two forms of toolbars to add convenience for application functions. The toolbars toggle on and off by selecting the items from the **View** menu.

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

Mission Editor

Requirement Assessment



Science and Engineering

Toolbar contains buttons for the following commands:

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

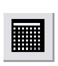
 The print button prints the Activity Log. The print button (**File→Print**) is only available when viewing the Activity Log.

 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 8719.14A, *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.

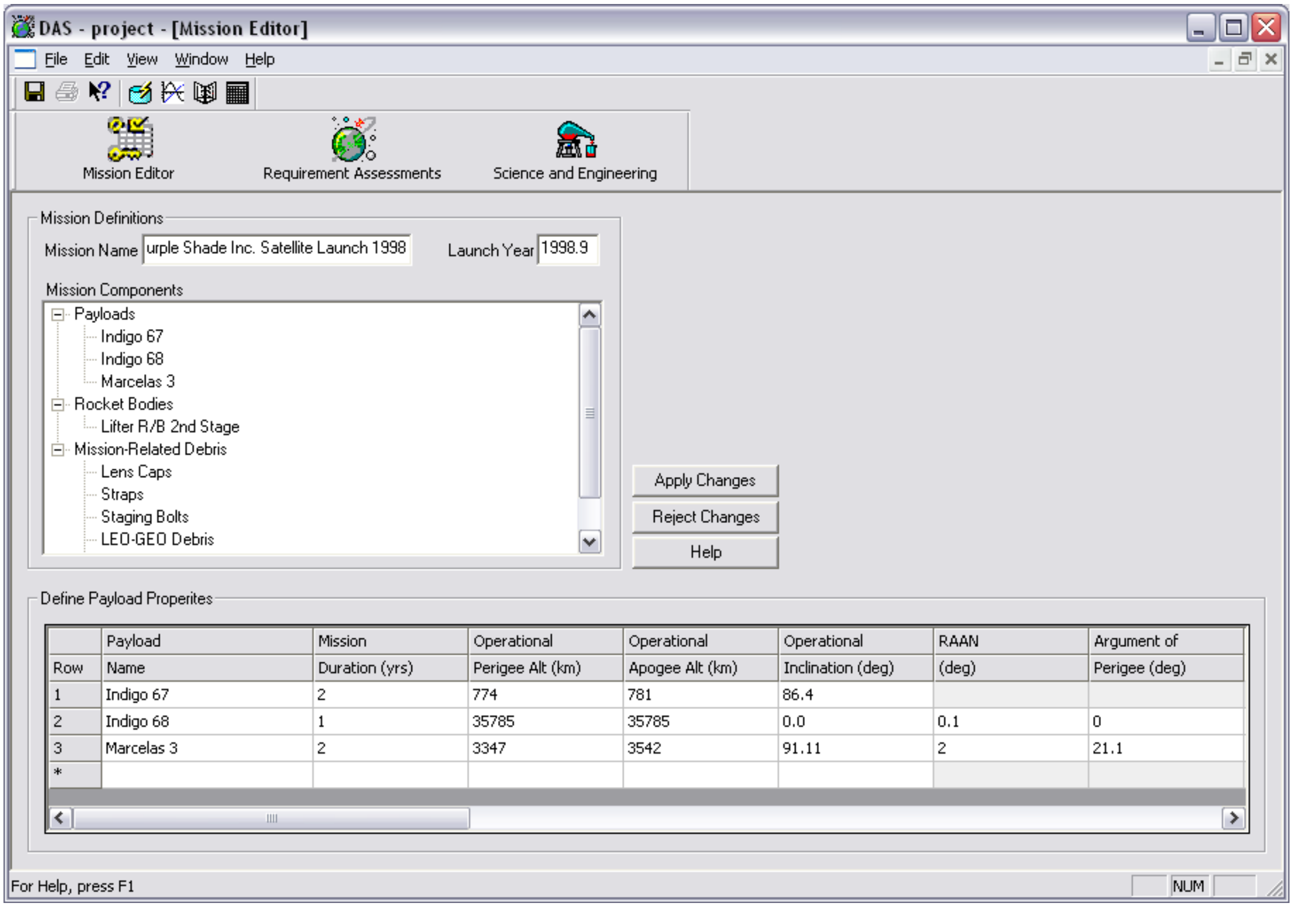


Figure 2 - 2: DAS 2 Mission Editor Dialog

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 also 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.
- **Launch Year –** This field specifies the year the mission is planned to start. The year can be specified in decimal format. All years in orbit should fall between the years 2010 and 2070. 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 2, highlighting a text field is NOT the same as 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 is a field that specifies the desired 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 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).
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 average cross-sectional area of a payload (in square meters) divided by the final mass of the payload (in kilograms).
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 2 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.
Planned Breakup (check if Yes)	Planned Breakup is a check box field. If checked, the payload will be broken apart (exploded) as part of its postmission disposal. The breakup is assumed to occur on the descending leg of the orbit revolution, *i.e.* at or approaching perigee.

Rocket Bodies:

Table 2 - 2: Mission Editor, Rocket Body Grid

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 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).
Planned Breakup (check if "Yes")	Planned Breakup is a check box field. If checked, the rocket body will be broken apart (exploded) as part of its postmission disposal. The breakup is assumed to occur on the descending leg of the orbit revolution, *i.e.* at or approaching perigee.

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 cm 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 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 2. 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.

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 as long as 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 window pane displayed with the upper requirement level (NASA-STD-8719.14A, *Process for Limiting Orbital Debris*).

Chapter 3 provides details of each assessment's operations.

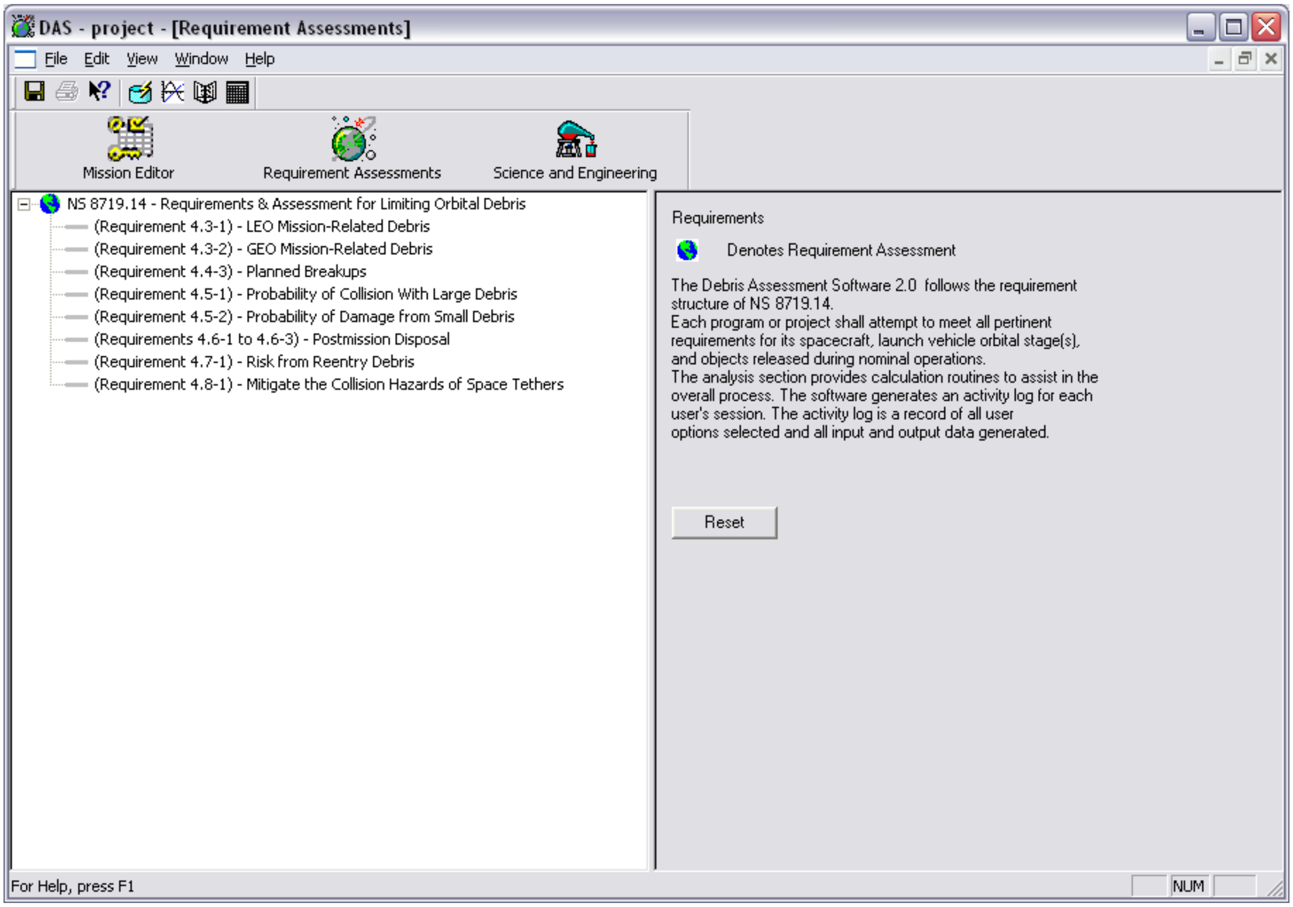


Figure 2 - 3: Requirement Assessments Top-level Dialog

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.

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:

- 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.

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

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. To activate the plot utility, press the plot viewer button on the Toolbar, or select **View→View Plots** from the application menu. The DAS **Plo**t 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-mouse or double left-mouse click on the plot area (left window pane) 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:
    - <u>Background color</u> – Launches a color palette for selecting and changing background color.
    - <u>Font</u> – Launches a common Font dialog.
    - <u>Alignment</u> – Provides a means to align the text Left, Centered or Right.
    - <u>Connect to curve</u> – Combo box allows users to choose to which curve the label will be attached,
    - <u>Transparent and Border</u> 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:
    - Chart – Has nine controls that offer additional features for changing the way the plot is displayed
        - *Background colo*r – 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).
    - Axis – properties allow users to modify various axis features such as scale, tick-size, font, and grid color. Once choices have been completed for each axis, depress "Apply" or "OK" to process the changes.
    - Curve – properties allow users to modify various curve features such as line width, line color, curve trends, and marker size. 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", or 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 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 2 application. As requirements are assessed, the data input and the resulting output are written to the Activity Log. The data are written to the file *ActivityLog* in the application's directory. The file can be used to track a problem with data, or to capture text based on the project being defined.

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 2 in text editor/viewer (*e.g.*, WordPad or Word) and printed using **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 2 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 a 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 similar to 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 similar to 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.

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 reset.

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 shall 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 no larger than 100 object-years per mission. The object-time product is the sum over all debris of the total time spent below 2000 km altitude (*i.e.* LEO dwell time) during the orbital lifetime of each object.

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

Requirement 4.3-1 applies to staging components, deployment hardware, and other objects that are known to be released during normal operations. Spacecraft and launch vehicle stages are addressed in other Requirements.

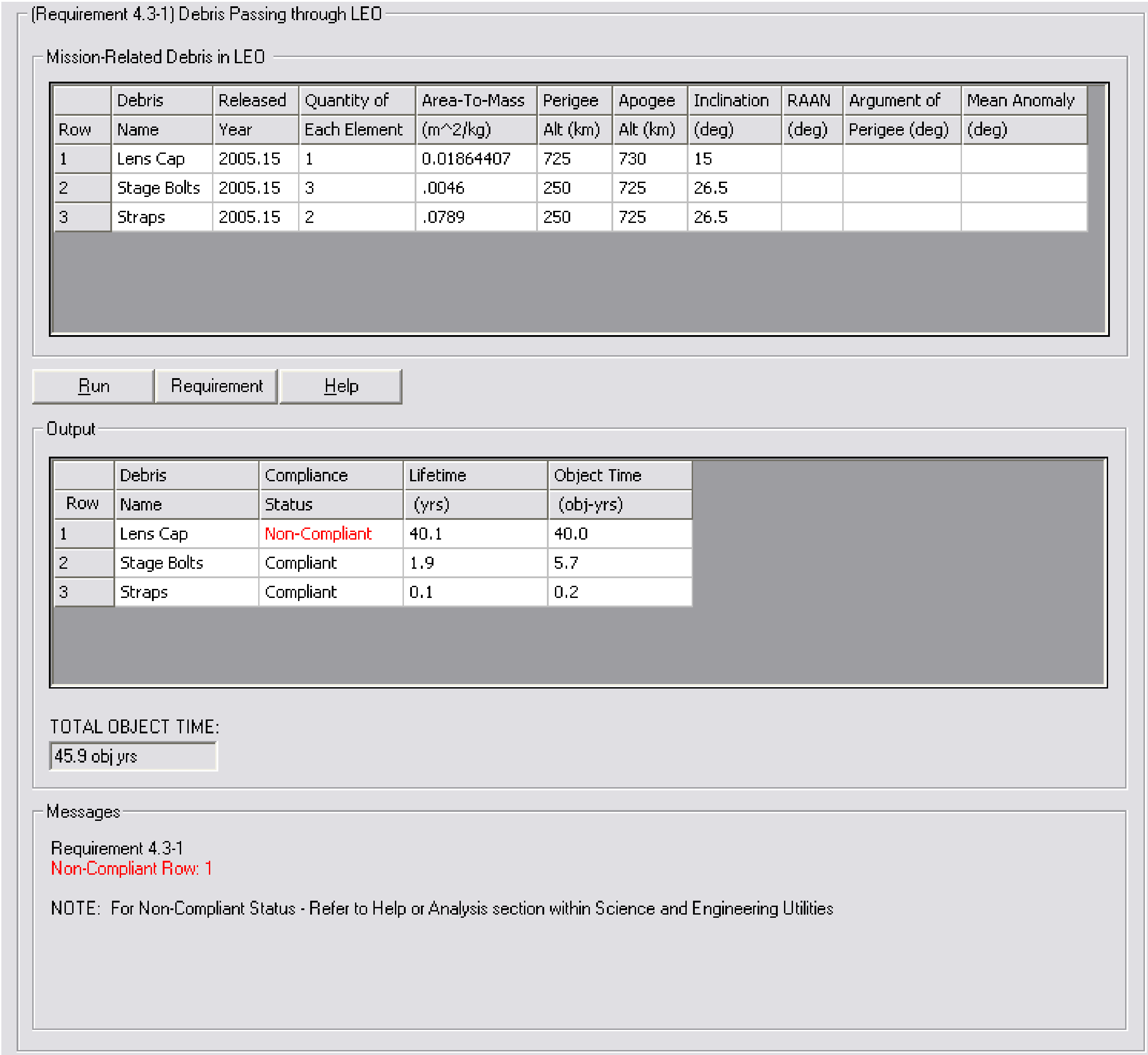


Figure 3 - 1: Requirement 4.3-1 Debris Passing Through LEO Dialog

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 mission.

If the calculated 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 a 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 degrees latitude), released debris with diameters of 5 cm 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.

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.

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.

Debris might also originate from a launch vehicle orbital stage which has directly inserted its payload 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.

Debris might also be released into highly-eccentric geosynchronous transfer orbits (GTO) with perigee altitudes within LEO or at higher altitudes and with apogee altitudes near or passing through GEO. Debris released at the time of payload separation on a mission of this type would fall under Requirement 4.3-2.

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. 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 region within 100 years.

Debris that are not removed from GEO altitude can remain in the GEO environment for many thousands of years. Requirement 4.3-2 limits the accumulation of debris at GEO altitudes and will help prevent the development of a significant debris environment, as currently exists in LEO. The 200 km offset distance (see requirement text) takes into account the operational requirements of GEO spacecraft.

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

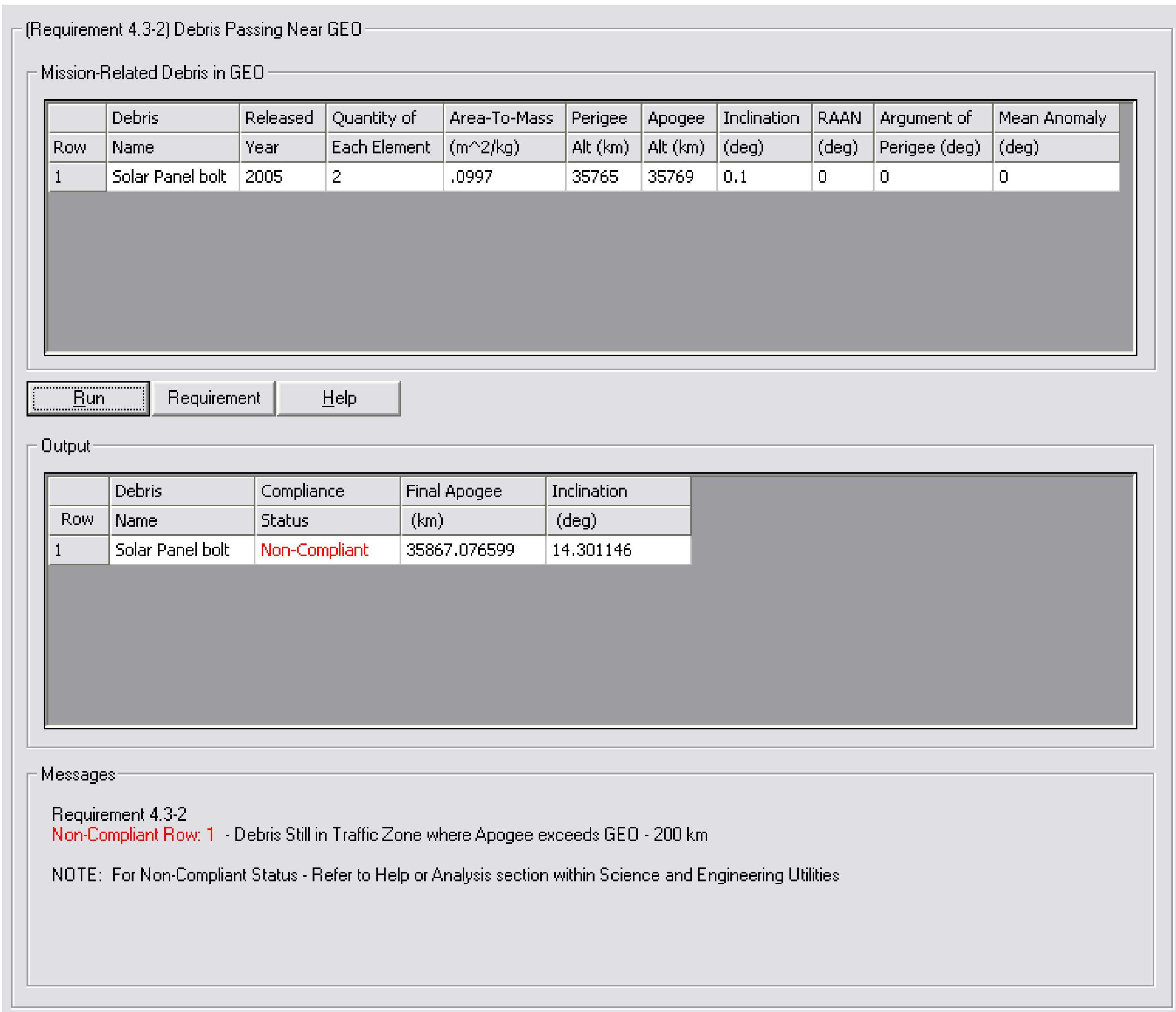


Figure 3 - 2: Requirement 4.3-2 Debris Passing Near GEO Dialog

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.

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

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

3.4 Requirement 4.4-3: Planned Breakups

The objective of Requirement 4.4-3 is to understand and limit the impact of the debris contributions from on-orbit tests on the space environment, specifically, long-term contributions to the orbital debris environment. Orbital characteristics at breakup are given for the space structure and estimates of the number, size, and lifetime of the generated orbital debris are returned.

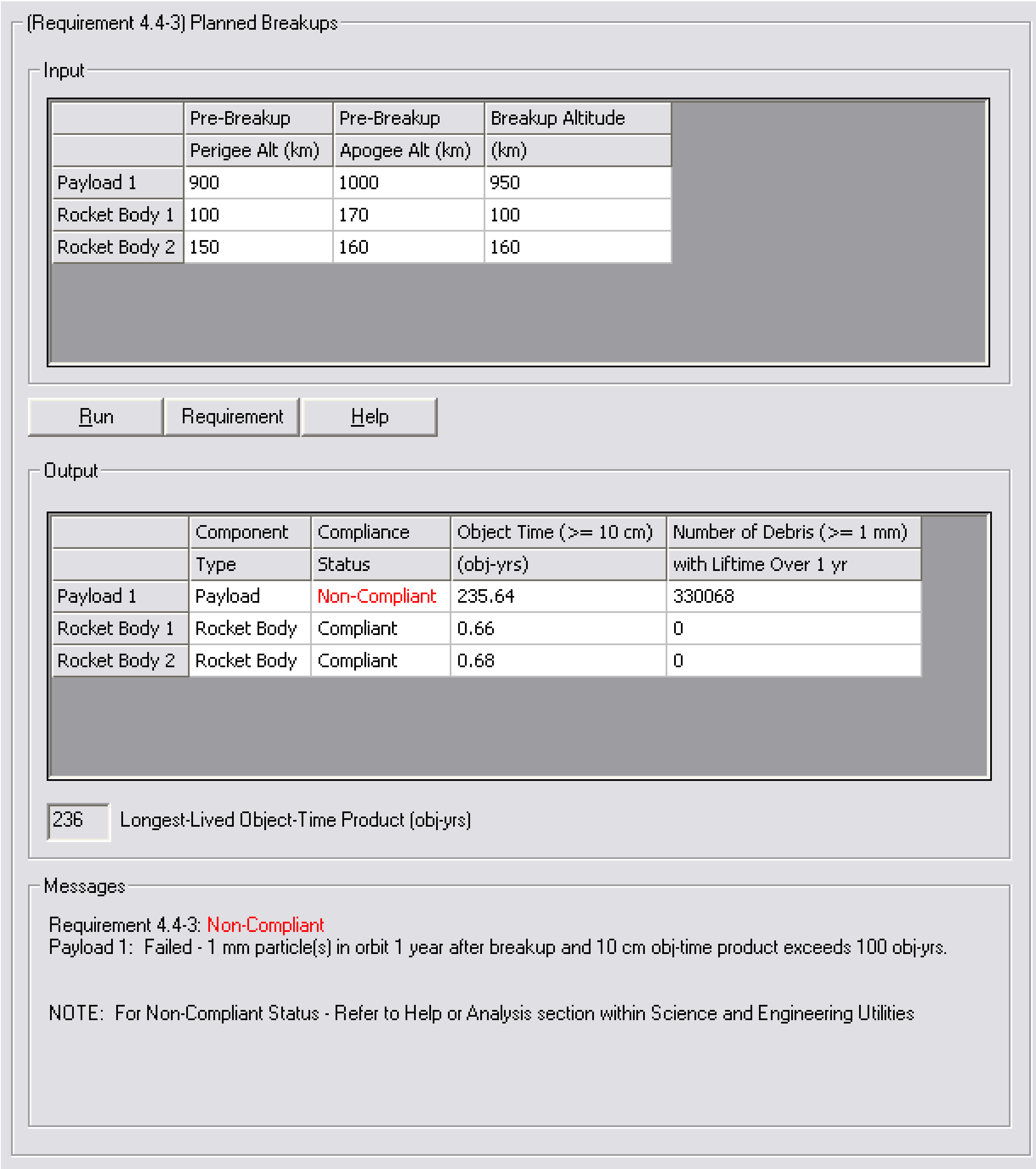


Figure 3 - 3: Requirement 4.4-3 Planned Breakups Dialog

Input Data:

Users specify pre-breakup perigee altitude, pre-breakup apogee altitude, and planned breakup altitude for the space structure before running the assessment. Other required orbit elements are entered into the Mission Editor. Only items checked as “Planned Breakup” in the Mission Editor will appear in Requirement 4.4-3. Before assessment, the planned breakup altitude is checked to be between the defined orbital perigee and apogee.

Note that the breakup is assumed to occur on the descending leg of the orbit revolution, *i.e.* at or approaching perigee.

Output Data:

The output area of the dialog displays a table listed by component. Each component displays compliance status: object-time product sum for debris larger than 10 cm and the number of debris larger than 1 mm with a lifetime longer than a year.

Longest Lived Object-Time Product applies to Requirement 4.4-3. The total object-time product for 10 cm debris should be no larger than 100 object-years per mission. The longest lived object-time field gives the longest object-time product of all components. If this returned value exceeds 100 object years, then the mission is non-compliant.

Component(s) that fail this requirement should be brought into compliance. Each component must have no debris larger than 1 mm in orbit longer than one year.

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

3.5 Requirement 4.5-1: Limiting 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 created by collisions between spacecraft or launch vehicle orbital stages in or passing through LEO and other large objects in orbit. By limiting the probability of collision between a spacecraft or orbital stage and other large objects to less than 0.001, the average probability of an operating spacecraft colliding with collision fragments larger than 1 mm from the subject spacecraft or orbital stage will be less than 10^{-6} per “average spacecraft.”

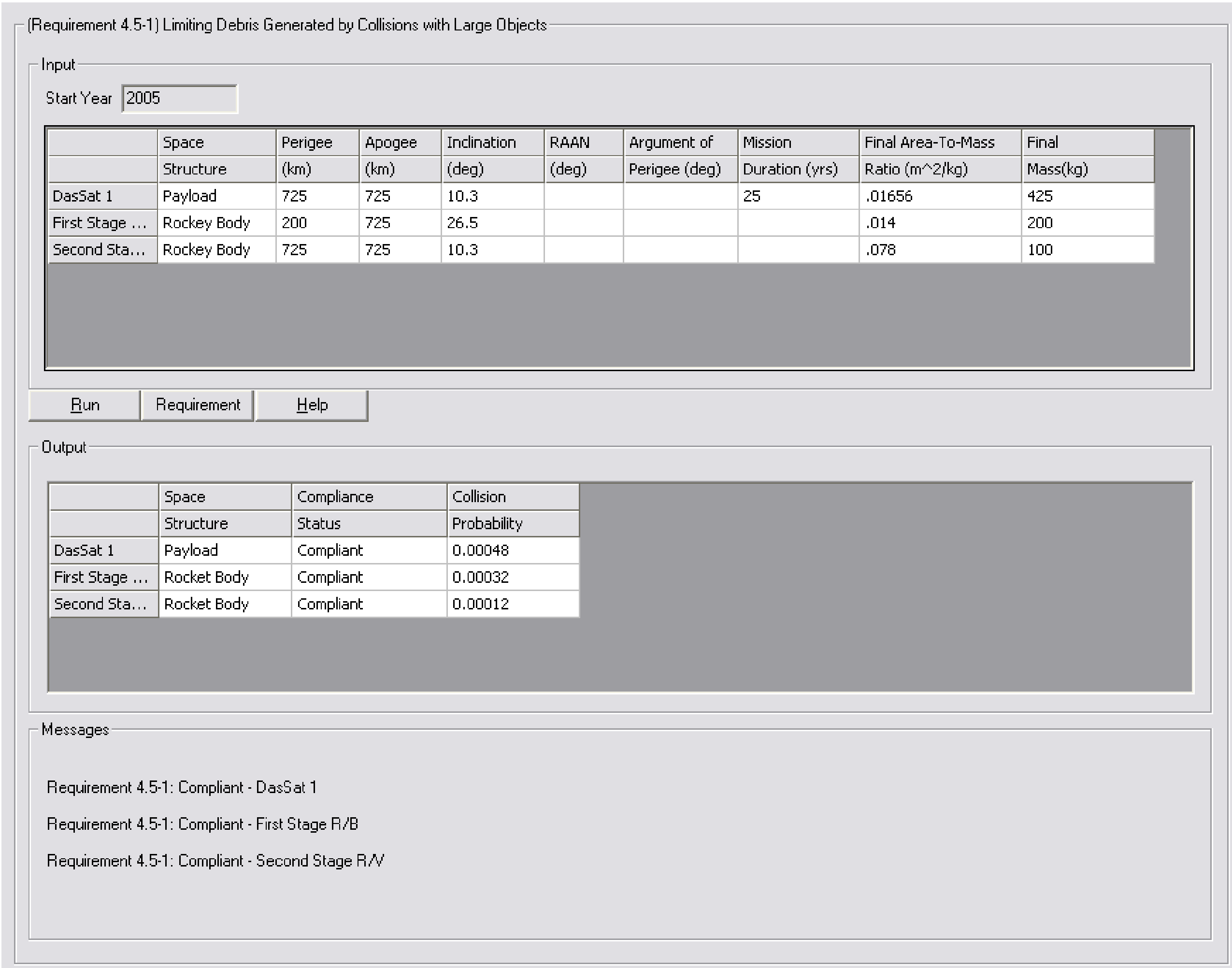


Figure 3 - 4: Requirement 4.5-1 Limiting Debris Generated by Collisions with Large Objects Dialog

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.**

3.6 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. The probability of a disabling collision with small debris and meteoroids must be less than 0.01.

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 would include the propulsion system and all necessary subsystems if a postmission disposal maneuver is required. If no disposal maneuver is required, only subsystems accomplishing passivation of the vehicle should be addressed. Examples of such subsystems are batteries and communications equipment. However, 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.

The debris environment model in DAS 2.1 has been simplified by excluding small debris in years 2036-2070. Therefore, **DAS 2.1 cannot assess Requirement 4.5-2 for missions operating after 2035**. See Appendix C.3 for more information.

Figure 3 - 5: 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, 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.

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

Name	A descriptive name (text field) for the layer.
Areal Density	Areal Density (gm/cm^2) of the layer. The density must be a positive numeric value greater than zero. Decimal values are valid. This value 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.

Output Data:

Compliance status for each spacecraft is displayed in the Output and Message area of the dialog as well as 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 DAS run times.**

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 meteoroid or 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 several minutes to complete. For each year of the mission (duration), DAS computes penetration probability over a full range of particle speeds and impact angles.

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

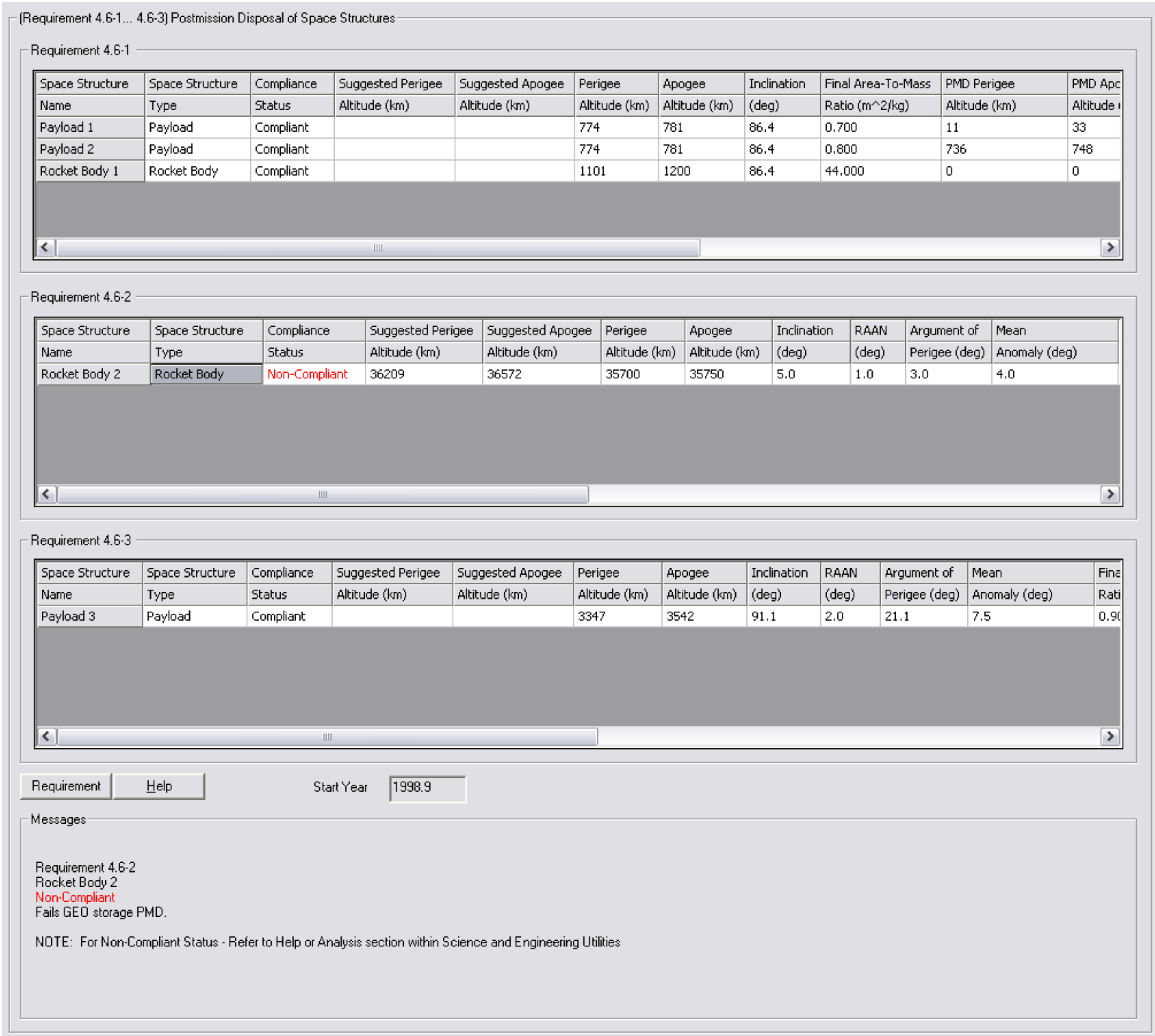
NASA space programs and projects shall plan for the disposal of spacecraft and launch vehicle orbital stages and space structures at the end of their respective missions. Postmission disposal shall be used to remove a space structure from Earth orbit in a timely manner or to leave a space structure in a disposal orbit where the structure will pose as small a threat as practical to other space systems.

The postmission disposal options are (1) natural or directed reentry into the atmosphere within a specified time frame, (2) maneuver to one of a set of disposal regions in which the space structures will pose little threat to future space operations, and (3) retrieval and return to Earth. The last option requires use of the Space Shuttle or similar vehicle and will generally not be an option, due to logistical constraints, cost, and crew safety.

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

- **4.6-1** – *Disposal for space structures passing through LEO:* A spacecraft or orbital stage with a perigee altitude below 2000 km.
- **4.6-2** – *Disposal for space structures near GEO:* A spacecraft or orbital stage in an orbit near GEO.
- **4.6-3** – *Disposal for space structures between LEO and GEO:* A spacecraft or orbital stage with a perigee altitude between 2000 km and GEO, and which does not qualify as “near GEO.”
- **4.6-4** – *Reliability of Postmission Disposal Operations in Earth orbit* is not addressed by DAS 2.
- **4.6-5** – *Operational design for EOM passivation* is not addressed by DAS 2.

Upon selection of Requirement 4.6, all payloads and rocket bodies defined in the Mission Editor are categorized (by region), assessed, and displayed in a corresponding grid. Note that for disposal considerations, “structures near GEO” includes all objects that could potentially penetrate the region within 500 km (both above and below) of GEO after end-of-mission plus 25 years.



(Requirement 4.6-1... 4.6-3) Postmission Disposal of Space Structures

Requirement 4.6-1

Space Structure Name	Space Structure Type	Compliance Status	Suggested Perigee Altitude (km)	Suggested Apogee Altitude (km)	Perigee Altitude (km)	Apogee Altitude (km)	Inclination (deg)	Final Area-To-Mass Ratio (m^2/kg)	PMD Perigee Altitude (km)	PMD Ap Altitude
Payload 1	Payload	Compliant			774	781	86.4	0.700	11	33
Payload 2	Payload	Compliant			774	781	86.4	0.800	736	748
Rocket Body 1	Rocket Body	Compliant			1101	1200	86.4	44.000	0	0

Requirement 4.6-2

Space Structure Name	Space Structure Type	Compliance Status	Suggested Perigee Altitude (km)	Suggested Apogee Altitude (km)	Perigee Altitude (km)	Apogee Altitude (km)	Inclination (deg)	RAAN (deg)	Argument of Perigee (deg)	Mean Anomaly (deg)
Rocket Body 2	Rocket Body	Non-Compliant	36209	36572	35700	35750	5.0	1.0	3.0	4.0

Requirement 4.6-3

Space Structure Name	Space Structure Type	Compliance Status	Suggested Perigee Altitude (km)	Suggested Apogee Altitude (km)	Perigee Altitude (km)	Apogee Altitude (km)	Inclination (deg)	RAAN (deg)	Argument of Perigee (deg)	Mean Anomaly (deg)	Fina Rati
Payload 3	Payload	Compliant			3347	3542	91.1	2.0	21.1	7.5	0.9

Requirement | Help | Start Year 1998.9

Messages

Requirement 4.6-2
Rocket Body 2
Non-Compliant
Fails GEO storage PMD.

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

Figure 3 - 6: Requirements 4.6-1, -2, -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 –** Disposal for space structures passing through LEO.
- **Requirement 4.6-2 –** Disposal for space structures near GEO.
  [(GEO-500 km) < Alt. < (GEO+200 km)].
- **Requirement 4.6-3 –** Disposal for space structures between LEO and GEO.
  (2000 km < Alt. < GEO-500 km).

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.

Compliance status is returned for each payload and rocket body. If a space structure is non-compliant a Suggested Perigee and Apogee Altitude (km) are given. 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.

3.8 Requirement 4.6-4: Postmission Disposal Reliability

DAS 2 cannot assess compliance with Requirement 4.6-4. The project must demonstrate compliance with Requirement 4.6-4 though its own calculations. For Requirement 4.6-4, contact the JSC Orbital Debris Program Office for assistance.

3.9 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 the Earth. This area applies to full spacecraft as well as jettisoned components. This section of DAS 2 assesses compliance with Requirement 4.7-1.a, which addresses risk from uncontrolled reentry. DAS 2 does not address concerns related to controlled reentry (Requirement 4.7-1.b).

The risk of 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 2070. The risk from any potential return beyond that year will need to be computed outside DAS 2. For reference, see "Improvements to NASA's Estimation of Ground Casualties from Reentering Space Objects" by J.N. Opiela and M.J. Matney, *Space Debris and Space Traffic Management Symposium*, AAS Science and Technology Series, vol. 109, 2004.

In order to calculate the risk of human casualty, the arrangement of each space structure element needs to be defined to assess its reentry survival potential. Based on empirical and theoretical values, 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 realistic progression of the exposure of nested structures.

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 object with a risk of human casualty above 1:10,000 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 which clearly do not satisfy this requirement of NASA-STD-8719.14A, but may also classify as non-compliant some missions which are borderline compliant. For this reason, missions which fail the DAS ODA 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.

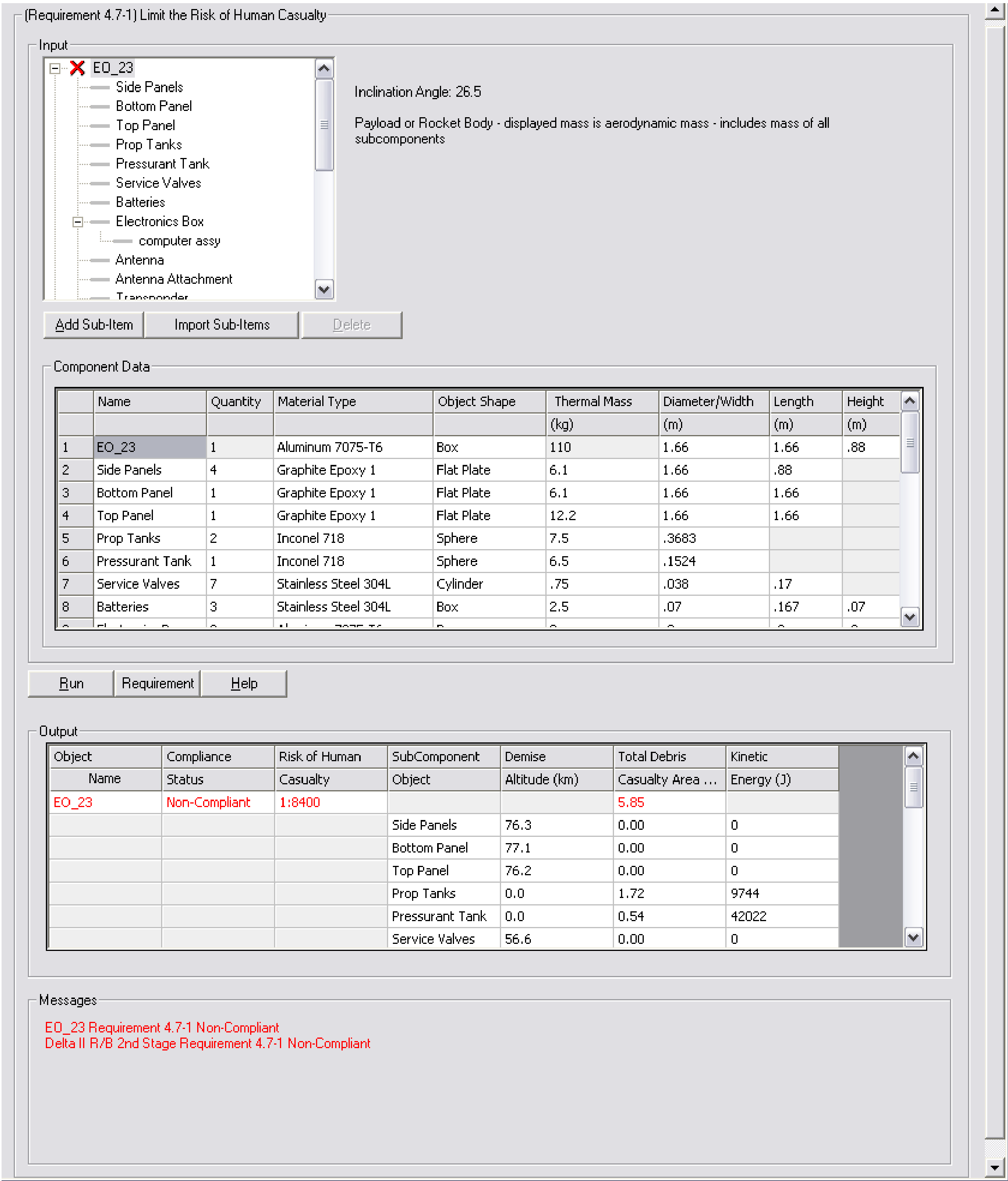


Figure 3 - 7: Requirement 4.7-1 Limit the Risk of Human Casualty Dialog

Input Data:

The sub-components 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 sub-components does not define at least 95% of the object's mass. These comments do not display when sub-component objects are selected.

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 sub-components of the selected object that do not have quantities defined which are multiples of the object's quantity.

Each component is defined using the quantities shown in Table 3-2.

Table 3 - 2: Requirement 4.7-1 Sub-component Input Grid

Name	Unique textual name for the component.
Qty	Integer quantity.
Material	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.)
Body Type	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 sub-components.
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 sub-components can be defined using the "Add Sub-Item" button. A new element will be added as a sub-component 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 sub-components 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 sub-component and its sub-items individually. The data can also be imported from a comma-separated 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 3-3. The first row of the file is assumed to contain column headers.

Table 3 - 3: Requirement 4.7-1 Comma-Separated Sub-Component 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, Box.
Thermal Mass	Mass of the element in kilograms, not including defined sub-components.
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 cells, so short rows may need to be manually edited (using a text editor) to add the commas delimiting trailing blank cells. The user will find it instructive to first view and edit the file ("reentry.csv") created by DAS.

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 sub-component 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.

  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 3-4) on compliance of each mission element.

Table 3 - 4: 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. Any risk larger than 1:10,000 will result in non-compliance.
Total Debris Casualty Area	The sum of debris casualty area for all sub-components possessing kinetic energy greater than 15 Joules.

The displayed data for sub-components and mission elements without subcomponents is shown in Table 3-5.

Table 3 - 5: Requirement 4.7-1 Sub-Component Output Data

Sub-Component 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 impacting kinetic energy in Joules. Any item with kinetic energy above 15 Joules will be displayed in red.

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 the purpose of 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.

3.10 Requirement 4.8-1: Mitigate the Collision Hazard of Space Tethers

NASA space programs and projects shall assess and limit the collision hazard posed by tether systems on other users of space and on the near-Earth environment. This requirement applies to all space structures using tethers in Earth or lunar orbits.

DAS provides a means to define a basic tether system for assessment. Because of the wide range of design parameters which have a great effect on assessing a tether, several simplifying assumptions must be made by DAS:

1. The tether system is gravity-gradient stabilized and under tension.
2. The tether is a simple, single strand.
3. The tether is used only for the purpose of deorbit.
4. The tether is not retracted once deployed.
5. Only LEO orbits are allowed (*i.e.*, apogee height is not greater than 2000 km).
6. Only near-circular orbits are allowed (*i.e.*, the difference between apogee and perigee heights is not greater than 50 km).
7. The mean anomaly or the orbit is not necessary because the apogee is in LEO.

If a tether system cannot be defined within these limits, contact the JSC Orbital Debris Program Office for further assessment qualifications.

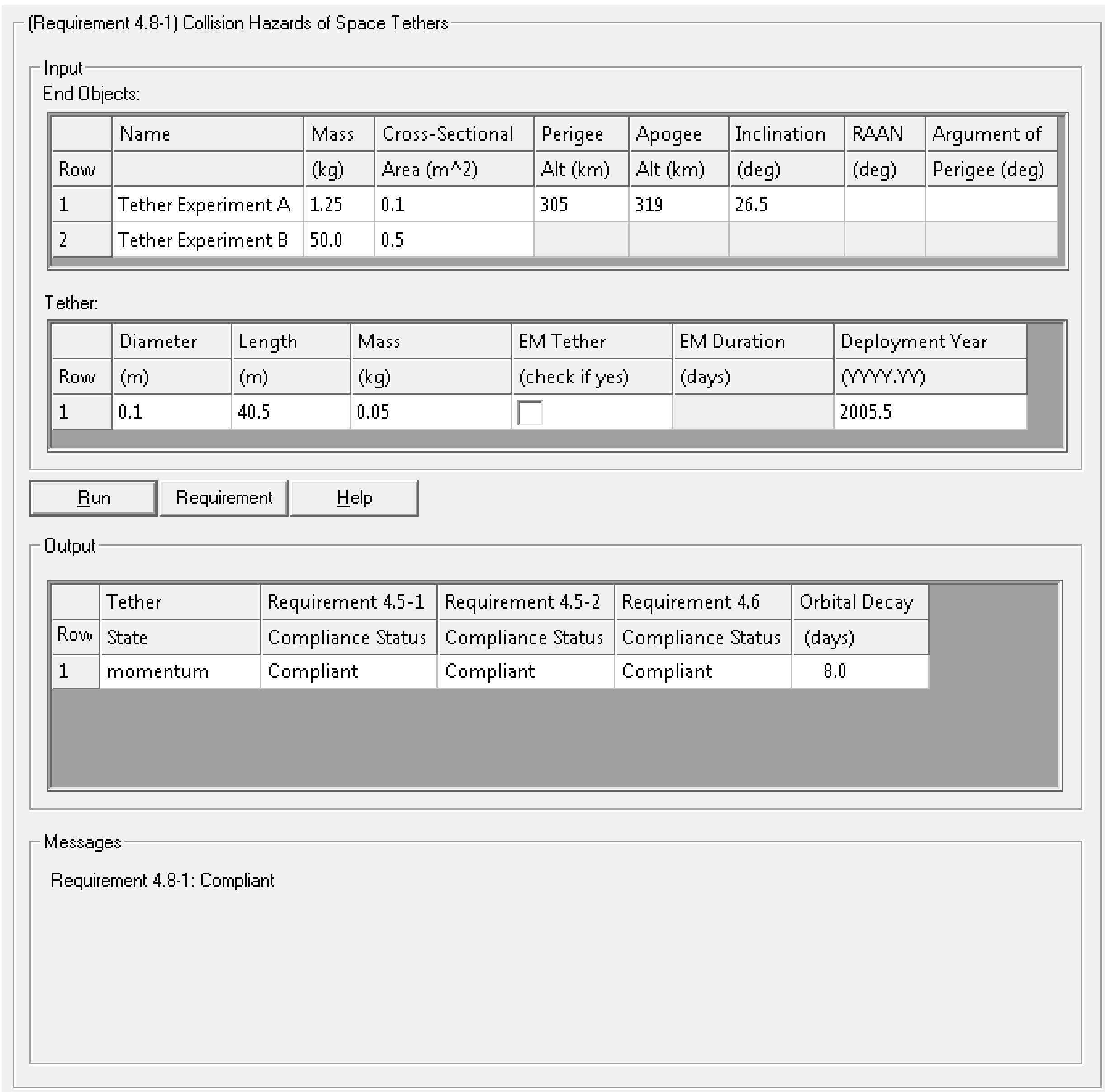


Figure 3 - 8: Requirement 4.8-1 Collision Hazards of Space Tethers Dialog

Input Data:

A basic tether system is made up of two end objects connected by a momentum tether or an electromagnetic (EM) tether. EM tethers are assumed to be used for deorbit only. If an EM tether is to be used for purposes other than deorbit (*e.g.* orbit maintenance), then it must be assessed outside of DAS.

The **End Objects** ("End Masses") grid is provided to define the orbit and mass of each object. End objects used for tether system definition can be selected from previously defined mission objects (rocket body, payload or mission debris). However, this requirement also supports end objects defined for this purpose alone. The required data are the orbit, mass, and area of the higher-altitude object and the mass and area of the lower-altitude object.

Table 3-6 summarizes the required input data for the tether end objects.

Table 3 - 6: Requirement 4.8-1 End-Object Input Data

Name	Textual name for the component. To edit this data, a drop down list includes previously defined objects either from the mission editor or objects defined within this dialog. Selecting an object from the mission will load previously defined data. Entering a name that has not been defined will blank all columns of data for that object.
Mass	Mass of the end object (kg).
Cross-Sectional Area	Cross-sectional area of the end object (m^2).
Perigee	Perigee altitude for the object during deployed phase (km).
Apogee	Apogee altitude for the object during deployed phase (km).
Inclination	Inclination of the object's orbit in degrees.
RAAN	(Optional) Right Ascension of ascending node (RAAN): 0-360 degrees.
ArgP	(Optional) Argument of perigee: 0-360 degrees.

Assessment uses the object mass and area data for both objects and the orbital data for the higher altitude object. These data cells are editable in case the tether deployment data differ from the underlying mission object.

The **Tether** grid is used to define the tether. The required data are the tether's diameter, length, mass, type (EM or momentum), and mission duration if the tether is EM. Optional data include deployment date and retraction date.

Table 3-7 summarizes the required input data for the tether.

Table 3 - 7: Requirement 4.8-1 Tether Input Data

Diameter	The tether's diameter in meters.
Length	The tether's length in meters.
Mass	The tether's mass in kg.
EM Tether	Check box to select the type of tether: Check "yes" for an EM tether or leave blank ("no") for a momentum tether.
EM Duration	Number of days that the EM tether is actively deployed. This cell is disabled for momentum tethers.
Deployment Year	(Optional) The date that the tether is deployed. The format is YYYY for year and .YY for fraction of year.

All data must be defined before the "Run" button is pressed. All required data are verified before assessment. If data are not provided, the assessment will prompt the user to complete data entry.

Output Data:

The output grid will provide information on compliance of the system for the following cases:

- **Requirement 4.5-1 –** The probability of collision with space objects larger than 10 cm is less than 0.001.
- **Requirement 4.5-2 –** The probability of disabling collision with small objects is less than 0.01.
- **Requirement 4.6 –** Natural decay will occur within the minimum of 25 years after mission or 30 years after launch.

The assessment output data (see Table 3-8) are provided in the **Output** grid. **Note that increased fidelity of the debris environment model results in greatly-increased DAS run times.**

Table 3 - 8: Requirement 4.8-1 Output Data

Tether State	The assessed state. EM tethers are analyzed as a successful EM and as a failed EM, equivalent to a momentum tether.
Requirement 4.5-1 Compliance	The result of assessment. Compliant or Non-Compliant. Non-Compliant data will be highlighted in red text.
Requirement 4.5-2 Compliance	The result of assessment. Compliant or Non-Compliant. Non-Compliant data will be highlighted in red text.
Requirement 4.6-1 Compliance	The result of assessment. Compliant or Non-Compliant. Non-Compliant data will be highlighted in red text.
Orbital Decay	The computed result is displayed as the predicted number of days for orbital decay. Any orbital lifetime longer than the minimum of 30 years and 25 years beyond mission will result in non-compliance.

In the case of Requirement 4.5-1 or 4.5-2 non-compliance, analysis of severed tether is provided for each end object. Half the mass of the tether is added to each end object when assessing compliance with Requirement 4.6.

In the case of EM tethers, the system is assessed for successful electro-magnetic function as well as compliance in the case of failure and the tether functioning as momentum only.

In all cases, the tether system is assessed for possible severance. If severance is determined as likely, each end mass is assessed for compliance with Requirement 4.6 based on its own mass and the mass of half the tether.

Note: If the mass of an end object exceeds 500 kg that object should be defined within the Mission Editor for Requirement 4.7-1 assessment.

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

All input data for this dialog are saved in the *tetherObjects.csv* and *tether.csv* files within the *project* directory.

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 window pane 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.

4.1 On-Orbit Collisions

These Science and Engineering Utilities may assist users in the assessment of compliance with Requirement 4.5, to limit the probability of operating space systems becoming a source of debris through collisions with orbital debris or meteoroids.

Three contour plotting tools are available within this category. They include **Debris Impacts vs. Orbit Altitude**, **Debris Impacts vs. Debris Diameter**, and **Debris Impacts vs. Date**. Each contour plot can be displayed in terms of Impact Rate or Number of Impacts.

IMPORTANT NOTE: The utilities in this section repeatedly perform calculations using ORDEM-based routines over a range of times and orbits. **Because each calculation using the higher-fidelity ORDEM 3.0 takes much longer than in previous versions of DAS, the On-Orbit Collisions utilities may require overnight run times.** See Appendix C.3 for more information.

4.1.1 Debris Impacts vs. Orbit Altitude

This utility plots the expected impacts along contours of impactor diameter, in centimeters, as a function of orbit altitude, in kilometers (assuming a circular orbit). The plot indicates the number (or number per year) of impacts, of each impactor size and larger, that the user may expect upon a spacecraft. The user may select either "Impact Rate" or "Number of Impacts" for the vertical axis. "Orbital Altitude" is on the horizontal axis. Both Impact Rate and Number of Impacts are given on a logarithmic (base 10) scale. The results are cumulative down to each user-specified diameter threshold value. Figure 4-1 shows the input dialog, and Table 4-1 defines the values.

This utility is useful for visualizing both quantitative and qualitative characteristics of the debris environment at different altitudes.

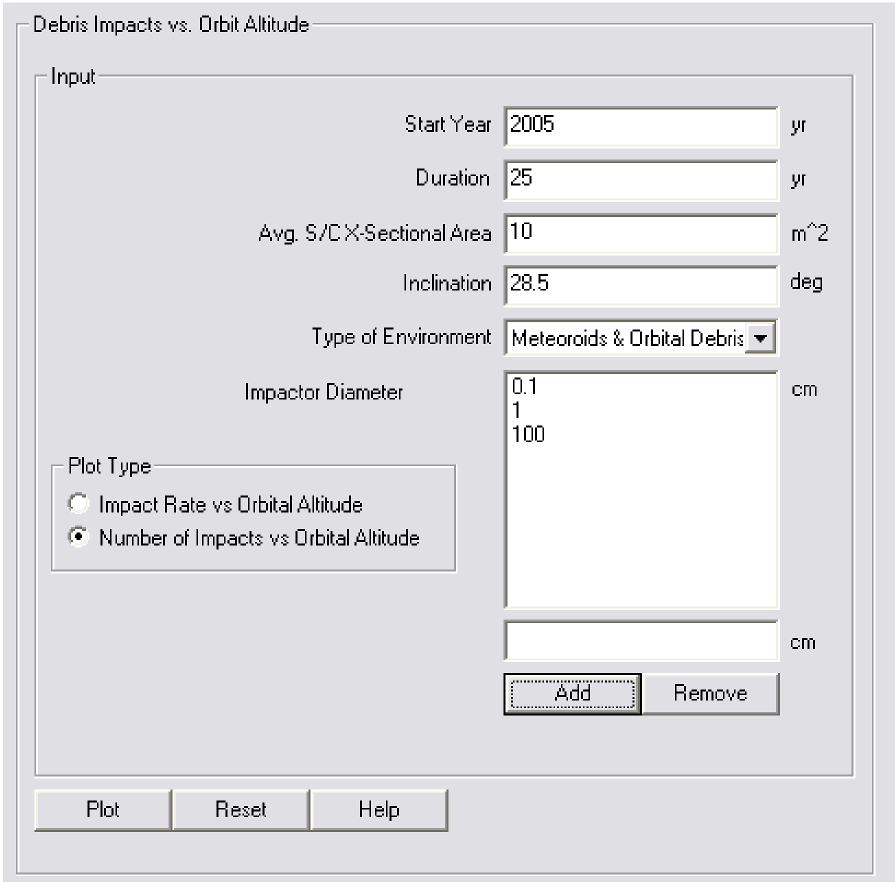


Figure 4 - 1: Debris Impacts vs. Orbit Altitude Input Dialog

Table 4 - 1: Debris Impacts vs. Orbit Altitude Input Data

Start Year	The beginning date (in decimal years) for the time period currently under study. The input value must be a positive numeric value equal to or greater than 2010 and less than or equal to 2070. In addition, the sum of the Start Year and the Duration must not exceed the year 2070.
Duration	The length of time (decimal years) currently under study. This input value must be a positive numeric value greater than zero. In addition, the sum of Duration and Start Year must not exceed 2070.
Avg S/C X-Sectional Area	The average projected cross-sectional area (in square meters) of the spacecraft. A positive, numeric value is required.
Inclination	The orbital inclination angle. Positive, numeric degrees between zero and 180 (inclusive). Decimal numbers are accepted.
Type of Environment	Select one: Meteoroids & Orbital Debris; Orbital Debris Only; or Meteoroids Only.
Impactor Diameter Threshold	Define the lower threshold for each plot contour. All diameters above the given threshold will be included. Enter the diameter (in centimeters) in the edit box below the list, then press “Add” to include the value in the list. Select a previously defined threshold and press “Remove” to delete it from the list. The maximum number of entries is 20. Each entry must be a positive numeric value and decimal values are acceptable.
Plot Type	The vertical plot axis, either Impact Rate or Number of Impacts. Either choice displays the logarithmic (base 10) values along the vertical axis against the Orbital Altitude (in kilometers) along the horizontal axis, assuming a circular orbit.

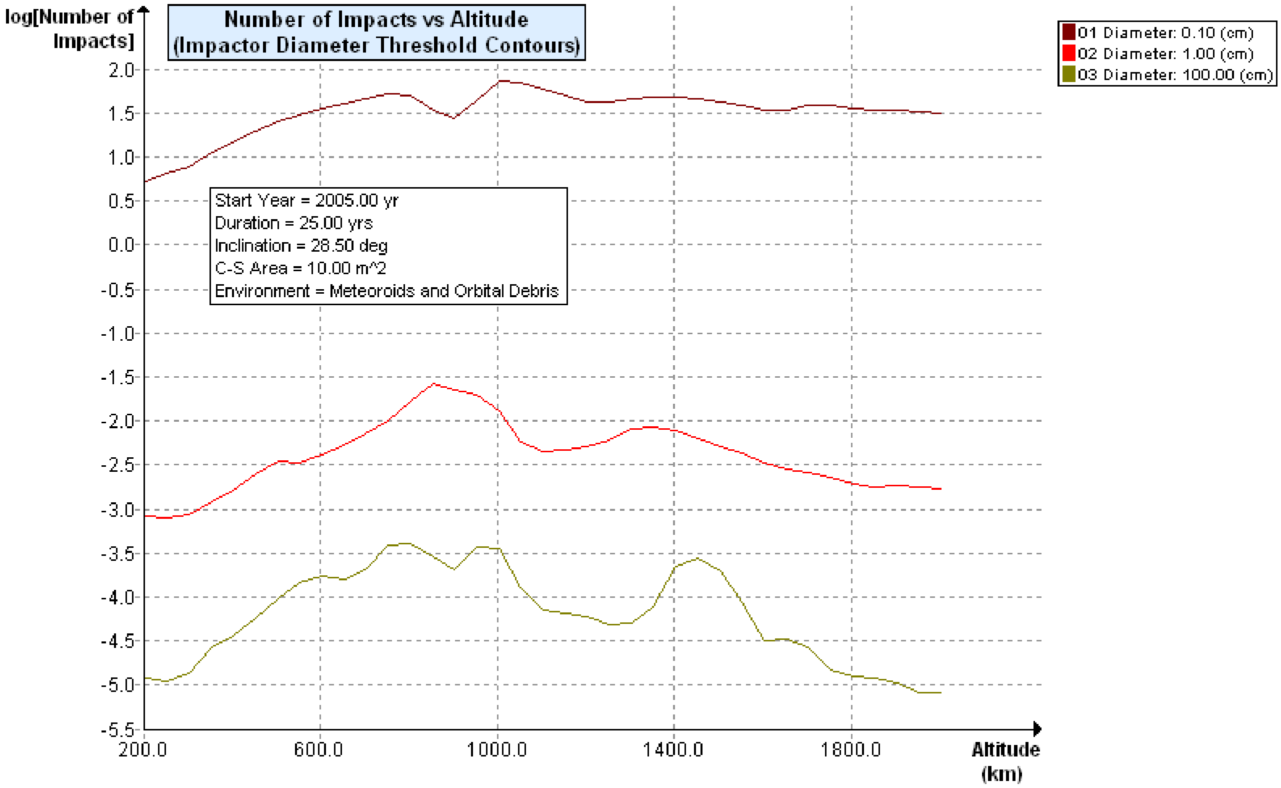
The “Reset” button will clear all input values from the dialog.

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. The processing may take several minutes to complete. 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. Using the log10 scale, the actual values are 10 raised to the power of the plotted value ($val=10^{plotval}$). **Section 2.6, Using the Plot Viewer,** provides information on plot utility functions. The underlying data are automatically saved as file *plots/ImpactGivenAlt.dpl*.



Plot 1 - Debris Impacts vs. Orbit Altitude

4.1.2 Debris Impacts vs. Debris Diameter

This utility plots the expected impacts along contours of orbital altitude as a function of debris diameter (assuming a circular orbit). The plot indicates the number (or number per year) of impacts, for each selected altitude, that the user may expect upon a spacecraft. The user may select either "Impact Rate" or "Number of Impacts" for the vertical axis. "Debris Diameter" is on the horizontal axis. Impact Rate, Number of Impacts, and Debris Diameter are given on a logarithmic (base 10) scale. The results are cumulative down to the diameter threshold value. Figure 4-2 shows the input dialog, and Table 4-2 defines the values.

This utility is useful for visualizing both quantitative and qualitative characteristics of the debris environment at different minimum debris sizes.

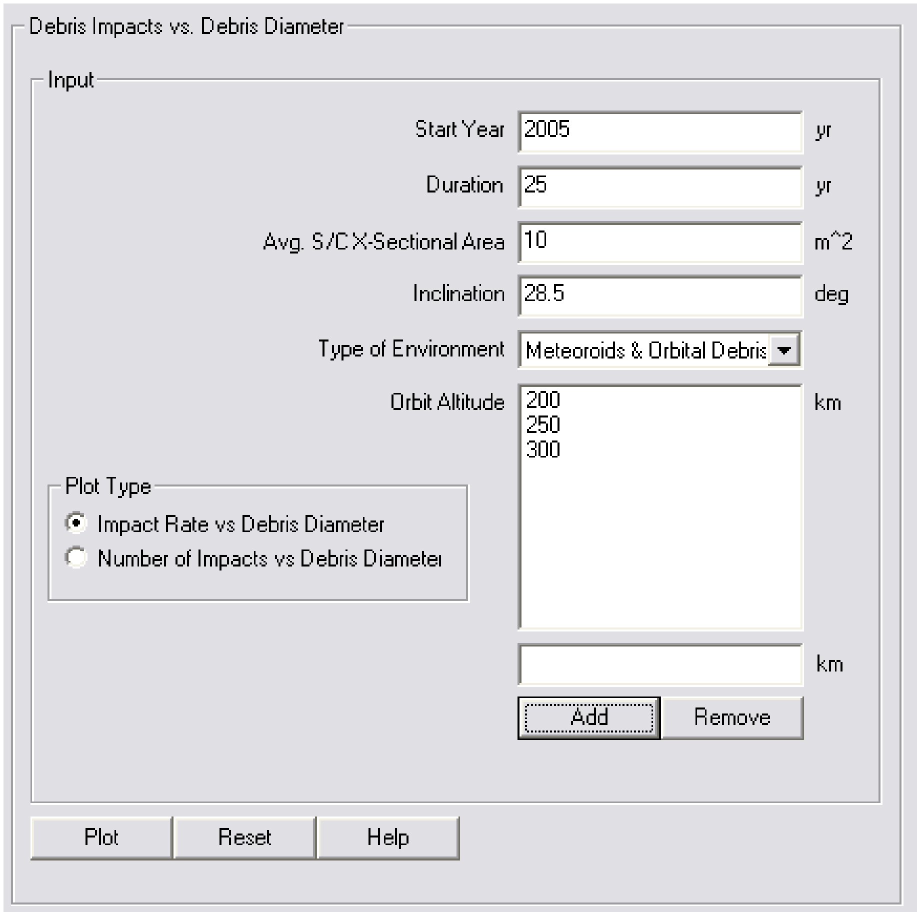


Figure 4 - 2: Debris Impacts vs. Debris Diameter Input Dialog

Table 4 - 2: Debris Impacts vs. Debris Diameter Input Data

Start Year	The beginning date (in decimal years) for the time period currently under study. The input value must be a positive numeric value equal to or greater than 2010 and less than or equal to 2070. In addition, the sum of the Start Year and the Duration must not exceed the year 2070.
Duration	The length of time (decimal years) currently under study. This must be a positive numeric value greater than zero. The sum of Duration and Start Year must not exceed 2070.
Avg S/C X-Sectional Area	The average, projected cross-sectional area (in square meters) of the spacecraft. A positive, numeric value is required.
Inclination	The orbital inclination angle. Positive, numeric degrees between zero and 180 (inclusive). Decimal numbers are accepted.
Type of Environment	Select one: Meteoroids & Orbital Debris; Orbital Debris Only; or Meteoroids Only.
Orbital Altitude	Define the orbital altitude for each plot contour. Enter the altitude (km) in the edit box below the list, then press "Add" to include the value in the list. Select a previously defined altitude and press "Remove" to delete it from the list. The maximum number of entries is 20. Each entry must be a positive numeric value, and decimal values are acceptable.
Plot Type	The vertical plot axis, either Impact Rate or Number of Impacts. Either choice displays the logarithmic (base 10) values along the vertical axis against the Debris Diameter [in $\log_{10}$(cm)] along the horizontal axis, assuming a circular orbit.

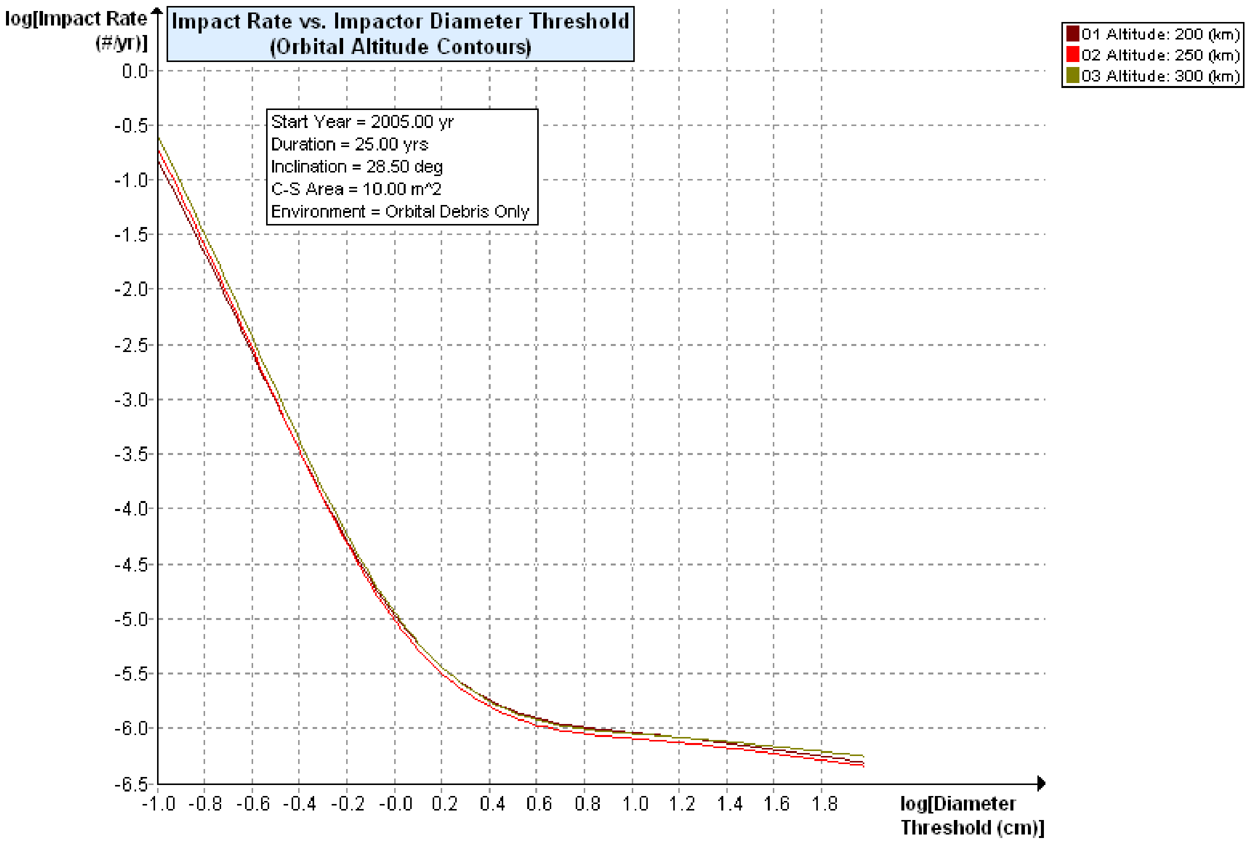
The "Reset" button will clear all input values from the dialog.

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. Using the log10 scale, the actual values are 10 raised to the power of the plotted value (val=$10^{plotval}$). **Section 2.6, Using the Plot Viewer,** provides information on plot utility functions. The underlying data are automatically saved as file *plots/ ImpactGivenDia.dpl*.



Plot 2 - Debris Impacts vs. Debris Diameter

4.1.3 Debris Impacts vs. Start Date

This utility plots the expected impacts along contours of impactor diameters, in centimeters, as a function of starting date, in years (assuming a circular orbit). The plot indicates the number (or number per year) of impacts, for each impactor size and larger, that the user may expect upon a spacecraft. Results are a function of start (*i.e.* launch) date. The user may select either "Impact Rate" or "Number of Impacts" for the vertical axis. "Start Date" is on the horizontal axis. Both Impact Rate and Number of Impacts are given on a logarithmic (base 10) scale. The results are cumulative down to each user-specified diameter threshold value. Figure 4-3 shows the input dialog, and Table 4-3 describes the values.

This utility is useful for visualizing both quantitative and qualitative characteristics of the debris environment for different launch years.

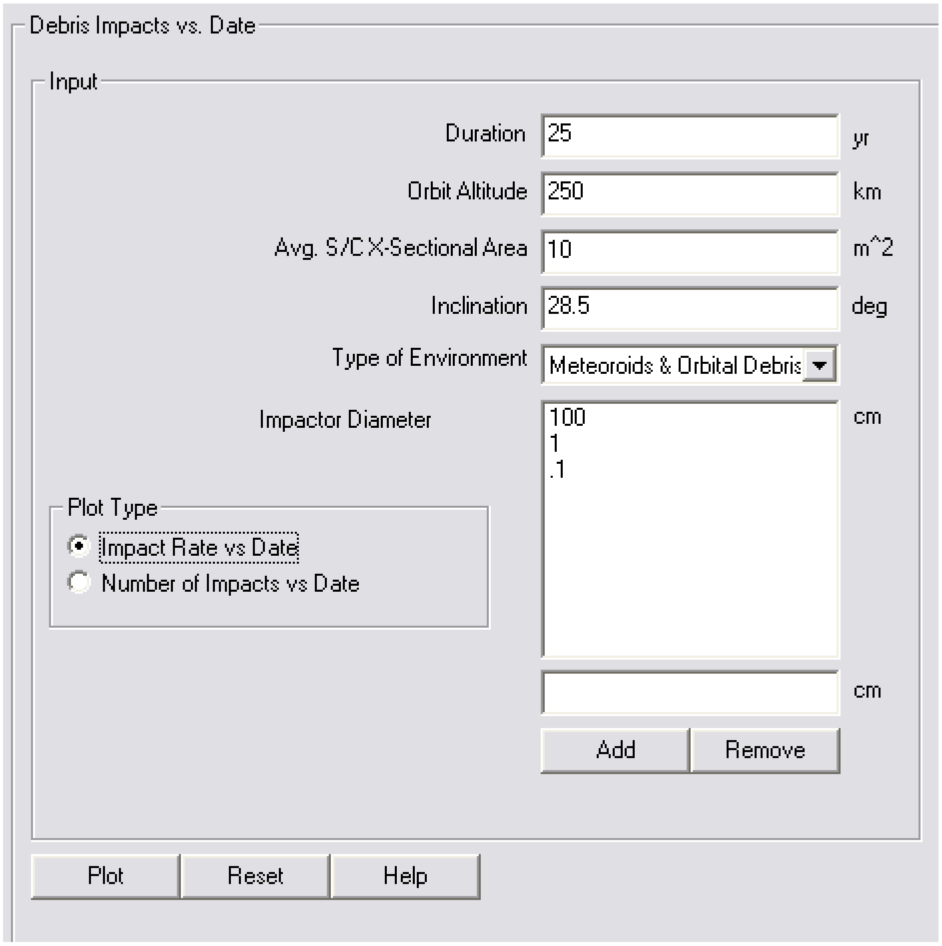


Figure 4 - 3: Debris Impacts vs. Date Dialog

Table 4 - 3: Debris Impacts vs. Start Date Input Data

Duration	The length of time (decimal years) currently under study. This must be a positive numeric value greater than zero. In addition, the sum of Start Year and Duration must not exceed the year 2070.
Orbit Altitude	The distance, in kilometers, of the object above Earth's surface, assuming a circular orbit.
Avg S/C X-Sectional Area	The average projected cross-sectional area (in square meters) of a spacecraft. A positive, numeric value is required.
Inclination	The orbital inclination angle. Positive, numeric degrees between zero and 180 (inclusive). Decimal numbers are accepted.
Type of Environment	Select one: Meteoroids & Orbital Debris; Orbital Debris Only; or Meteoroids Only.
Impactor Diameter Threshold	Define the lower threshold for each plot contour. All diameters above the given threshold will be included. Enter the diameter in centimeters in the edit box below the list, then press "Add" to include the value in the list. Select a previously defined threshold and press "Remove" to delete it from the list. The maximum number of entries is 20. Each entry must be a positive numeric value and decimal values are acceptable.
Plot Type	The vertical plot axis, either Impact Rate or Number of Impacts. Either choice displays the logarithmic (base 10) values along the vertical axis against the Date (in years) along the horizontal axis, assuming a circular orbit.

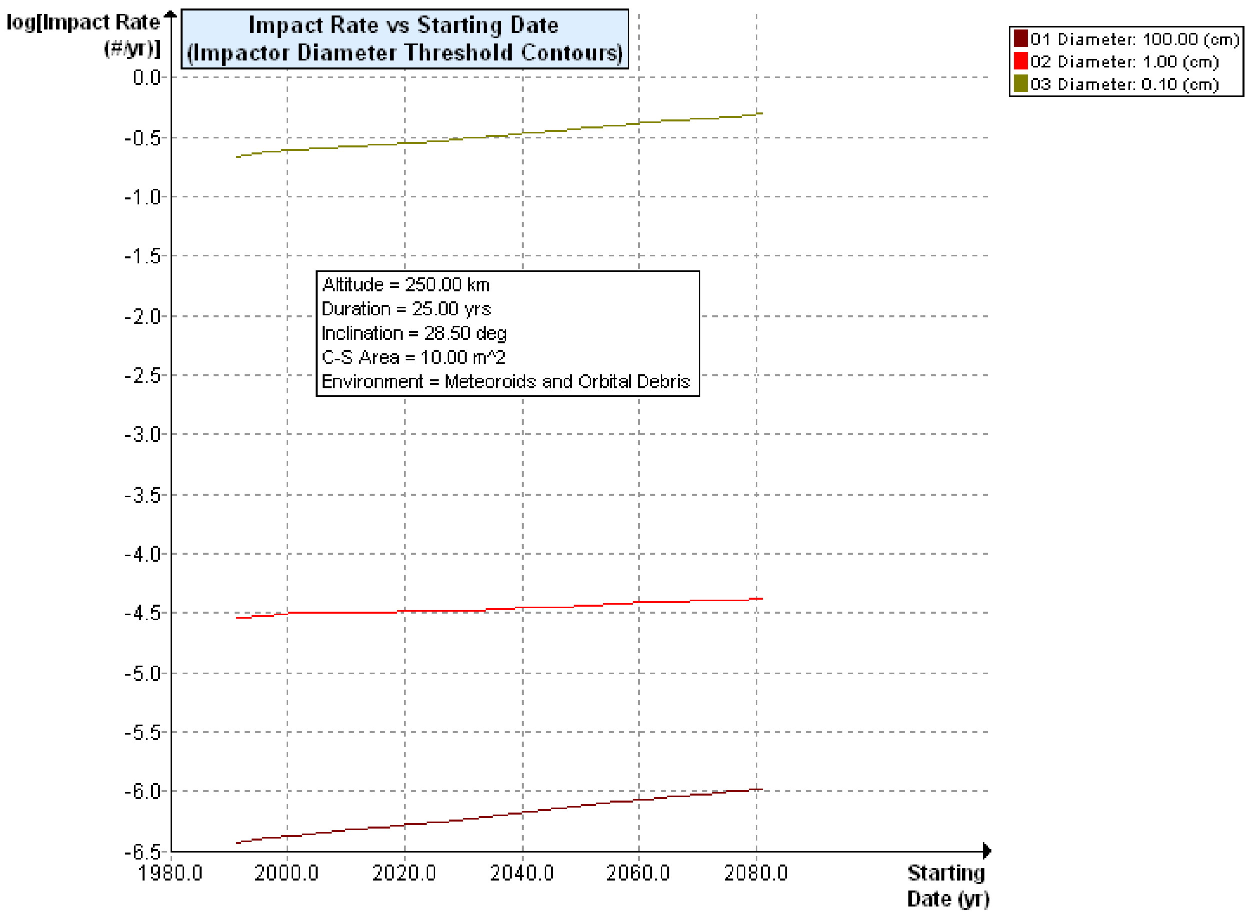
The "Reset" button will clear all input values from the dialog.

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. Using the log10 scale, the actual values are 10 raised to the power of the plotted value ($val=10^{plotval}$). **Section 2.6, Using the Plot Viewer,** provides information on plot utility functions. The underlying data are automatically saved as file *plots/ImpactGivenDate.dpl*.



Plot 3 - Debris Impacts vs. Date

4.2 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.

Two 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.

4.2.1 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 4-4 shows the input dialog, and Table 4-4 describes the values.

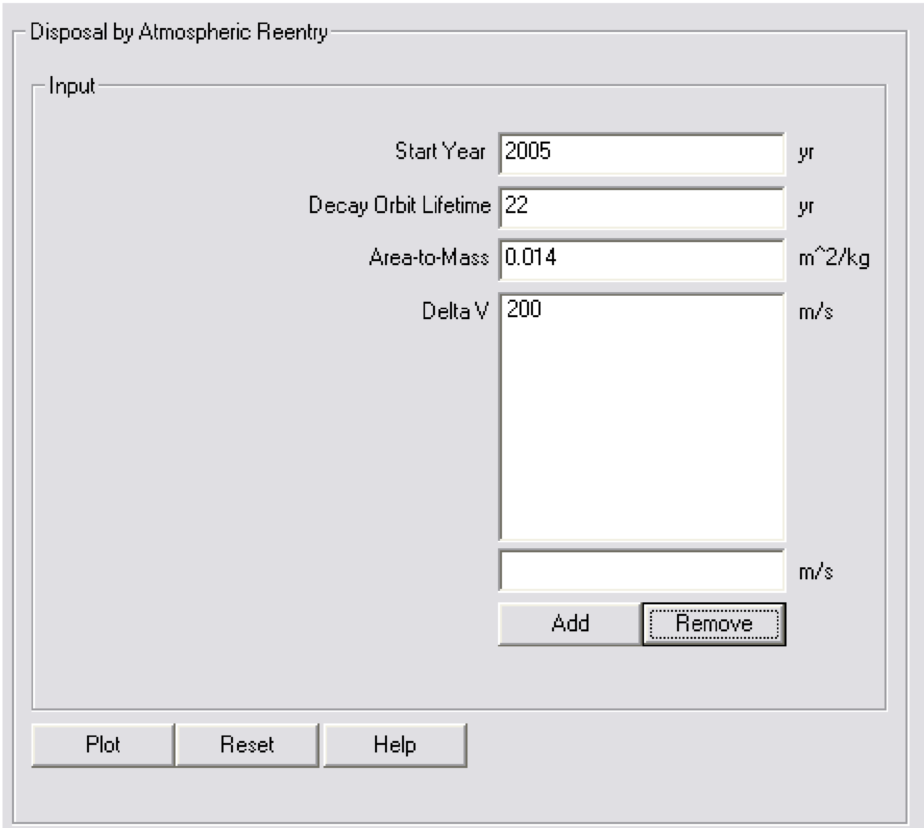


Figure 4 - 4: Disposal by Atmospheric Reentry Input Dialog

Table 4 - 4: Disposal by Atmospheric Reentry Input Data

Start Year	Marks the beginning date (in decimal form) for the time period currently under study. The input value must be a positive numeric value equal to or greater than 2010 and less than or equal to 2070. In addition, the sum of the Start Year and Decay Orbit Lifetime must not exceed the year 2070.
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 2070.
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 depresses the "Add" button to load the value into the list. The user may remove a previously defined contour value by highlighting the value and depressing 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.

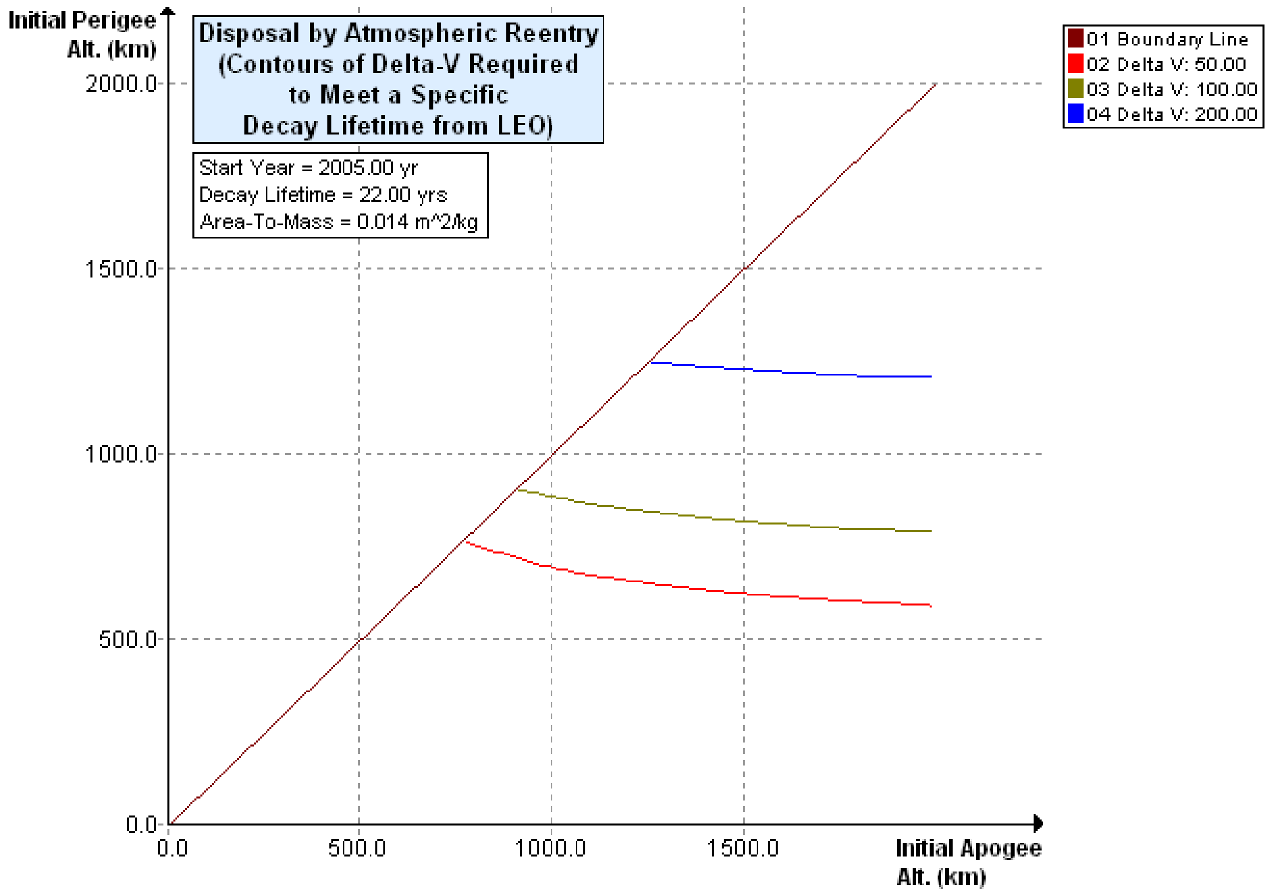
The "Plot" button will send input values from the dialog to the calculating routines. As the utility processes the data, a **Processing** dialog will appear. Plot processing may take several minutes. To cease processing, depress the "Stop" button on the dialog.

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. **Section 2.6, Using the Plot Viewer**, provides information on plot utility functions. The underlying data are automatically saved as file *plots/AtmReentry.dpl*.



Plot 4 - Disposal by Atmospheric Reentry

4.2.2 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 4-5 shows the input/output dialog, and Tables 4-5 and 4-6 describe the input and output values.

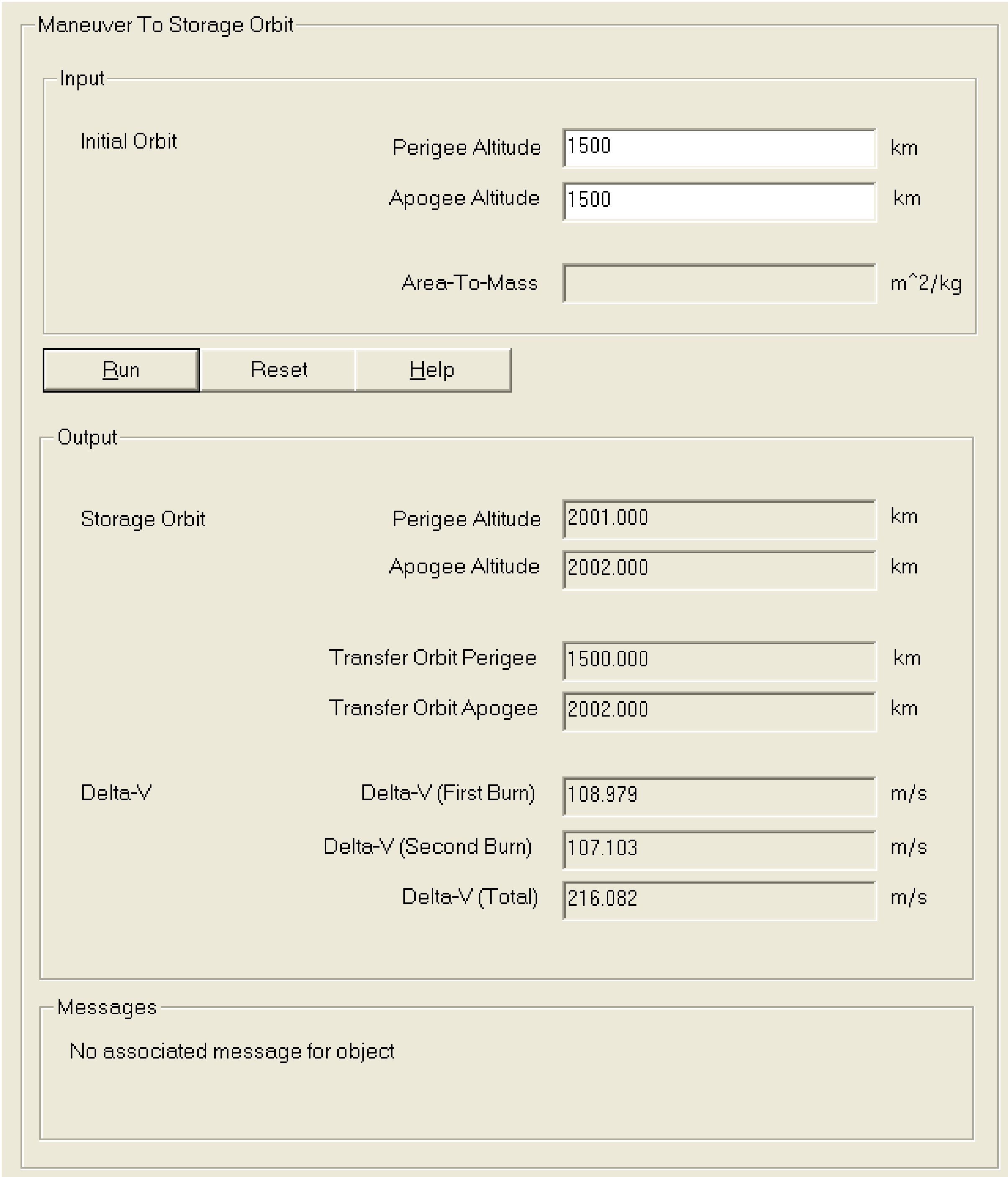


Figure 4 - 5: Maneuver to Storage Orbit Dialog

Table 4 - 5: 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 - 6: 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-semisynchronous) medium Earth orbit; no disposal maneuver is necessary

4.2.3 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 values, 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 are 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 sub-components. See Table 3-2 (Sect. 3.9) for a description of the input data. Figure 4-6 shows the input dialog, and Table 4-7 describes the output values.

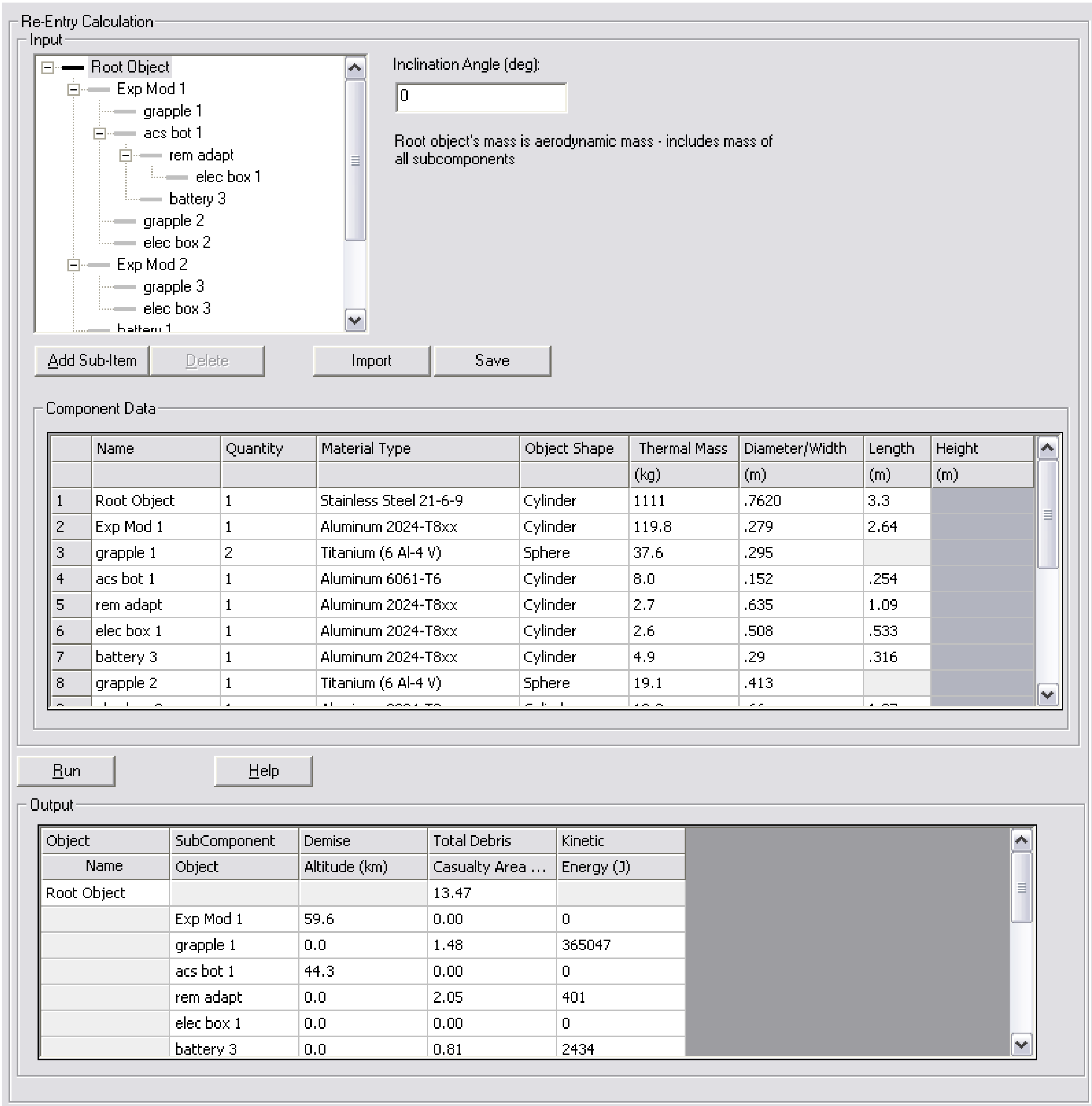


Figure 4 - 6: Reentry Survivability Analysis Dialog

Output Data:

The displayed data for the root element and its sub-components' survivability are shown in Table 4-7. Note that since the root object is assumed to break up at 78 km, its output will only contain the sum of its sub-components' debris casualty area.

Table 4 - 7: 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 impacting kinetic energy in Joules. Any item with kinetic energy above 15 Joules will be displayed in red.

4.3 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.

4.3.1 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 4-7 shows the input dialog, and Table 4-8 describes the values.

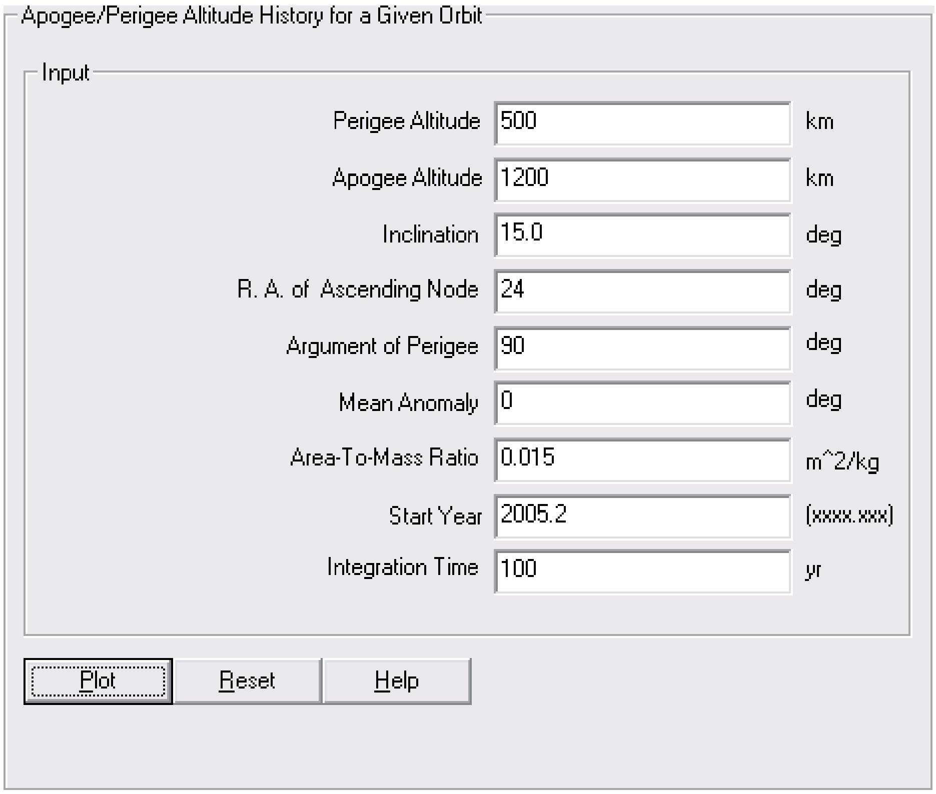


Figure 4 - 7: Apogee/Perigee Altitude History for a Given Orbit Input Dialog

Table 4 - 8: Apogee/Perigee Altitude History for a Given Orbit Input Data

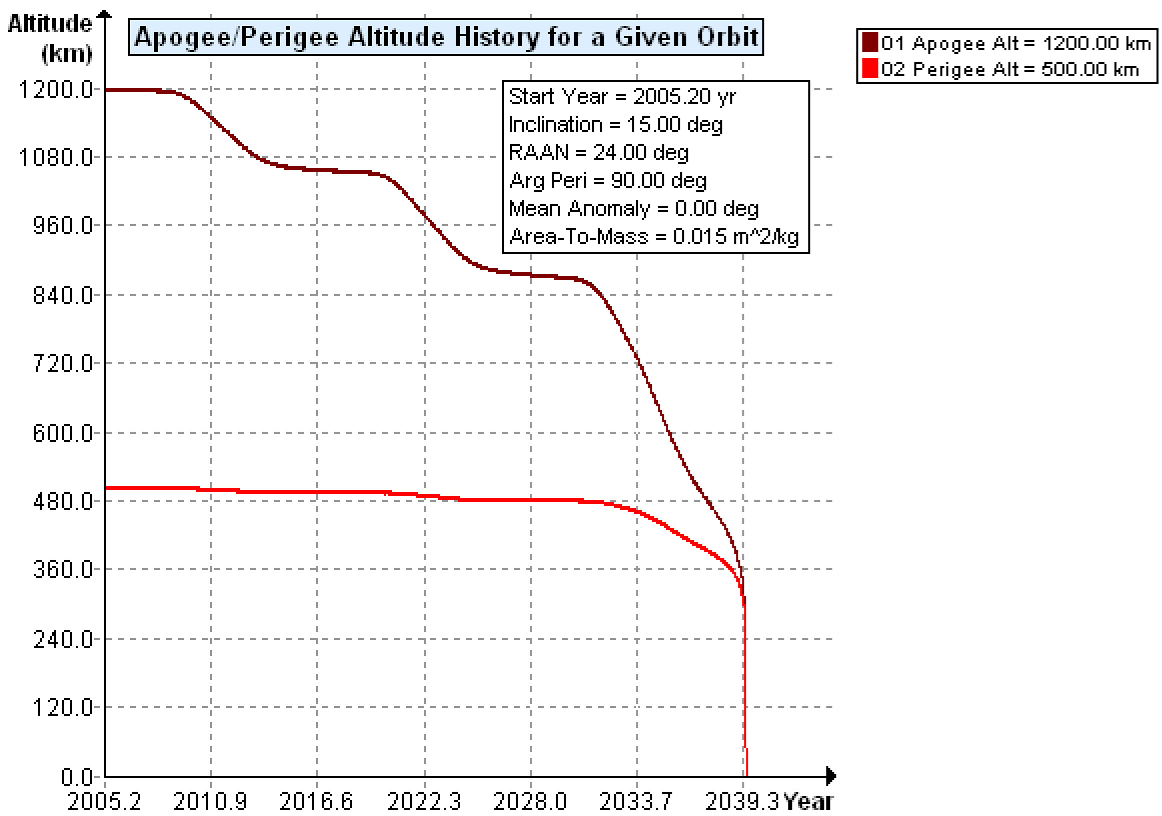
Perigee Altitude	The perigee altitude (in kilometers) for the object currently under study. The input value must be a positive numeric value greater than 90 and less than or equal to 100,000. In addition, the perigee altitude must be less than or equal to the apogee altitude.
Apogee Altitude	The apogee 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 time period currently under study. The input value must be a positive numeric value equal to or greater than 2010 and less than or equal to 2070. In addition, the sum of the Start Year and the Integration Time must not exceed the year 2070.
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 2070.

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. **Section 2.6, Using the Plot Viewer** provides information on plot utility functions. The underlying data are automatically saved as file *plots/AltHistory.dpl*.



Plot 5 - Apogee/Perigee Altitude History for a Given Orbit

4.3.2 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 4-8 shows the input/output dialog. The input and output values are described in Tables 4-9 and 4-10, respectively.

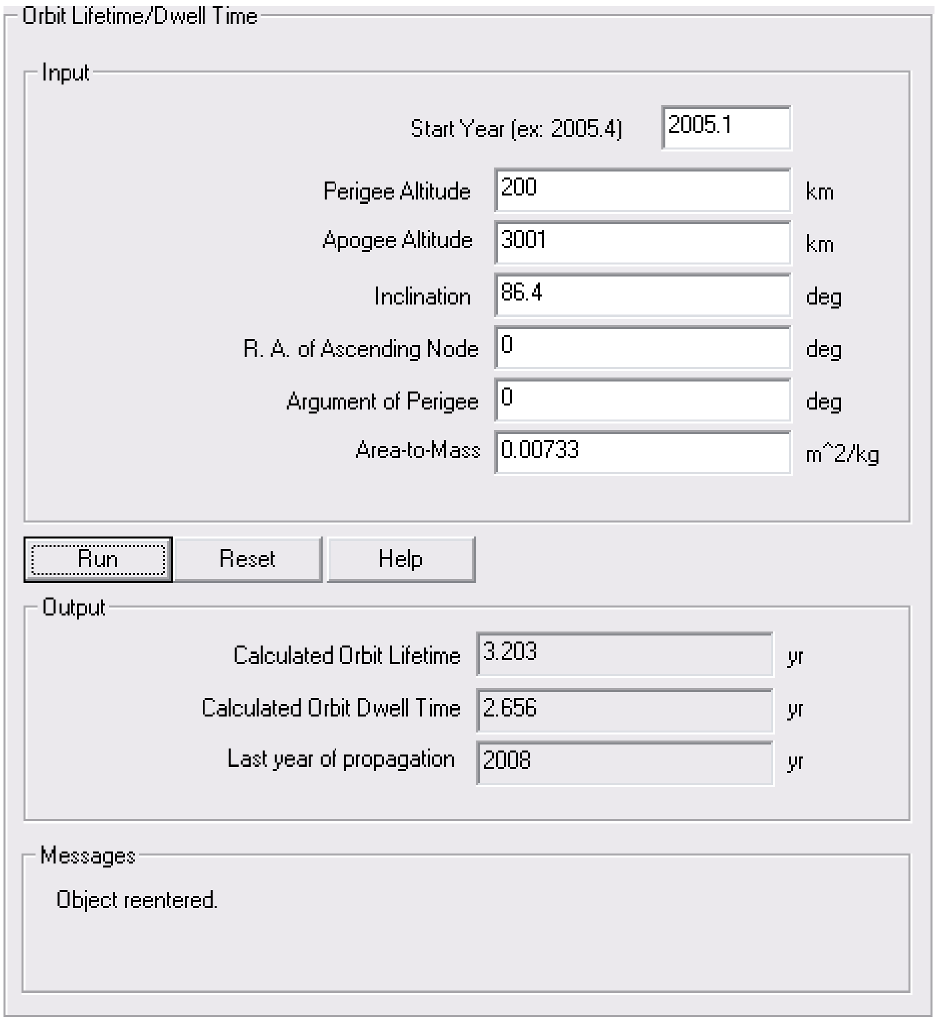


Figure 4 - 8: Orbit Lifetime/Dwell Time Dialog

Table 4 - 9: Orbit Lifetime/Dwell Time Input Data

Start Year	The beginning date (in decimal years) for the time period currently under study. The input value must be positive, numeric, and fall in the range of 2010-2070.
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:

Table 4 - 10: Orbit Lifetime/Dwell Time Output Data

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) o NOTE: The orbit is NOT processed. • Object reentered • Object did not reenter within the maximum years of propagation.

4.4 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-Mas**s 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.

4.4.1 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, with specified Orbital Lifetime, from an initial circular LEO to a decay orbit. 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 4-9 shows the input dialog, and Table 4-11 describes the values.

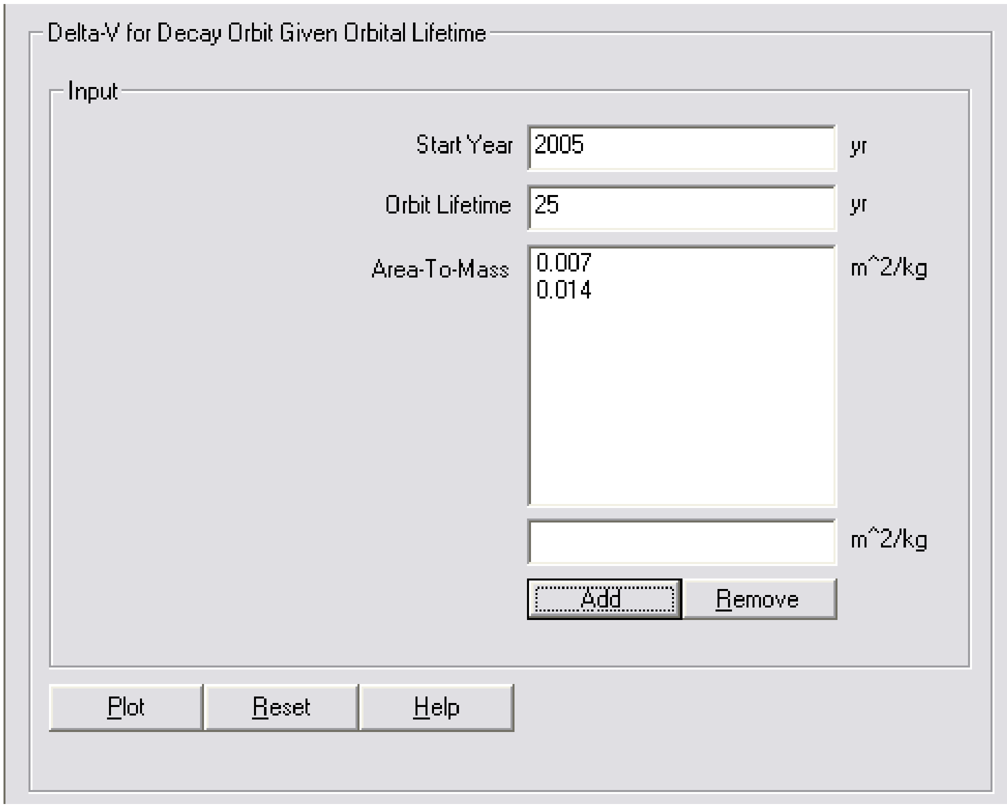


Figure 4 - 9: Delta-V for Decay Orbit Given Orbital Lifetime Dialog

Table 4 - 11: Delta-V for Decay Orbit Given Orbital Lifetime Input Data

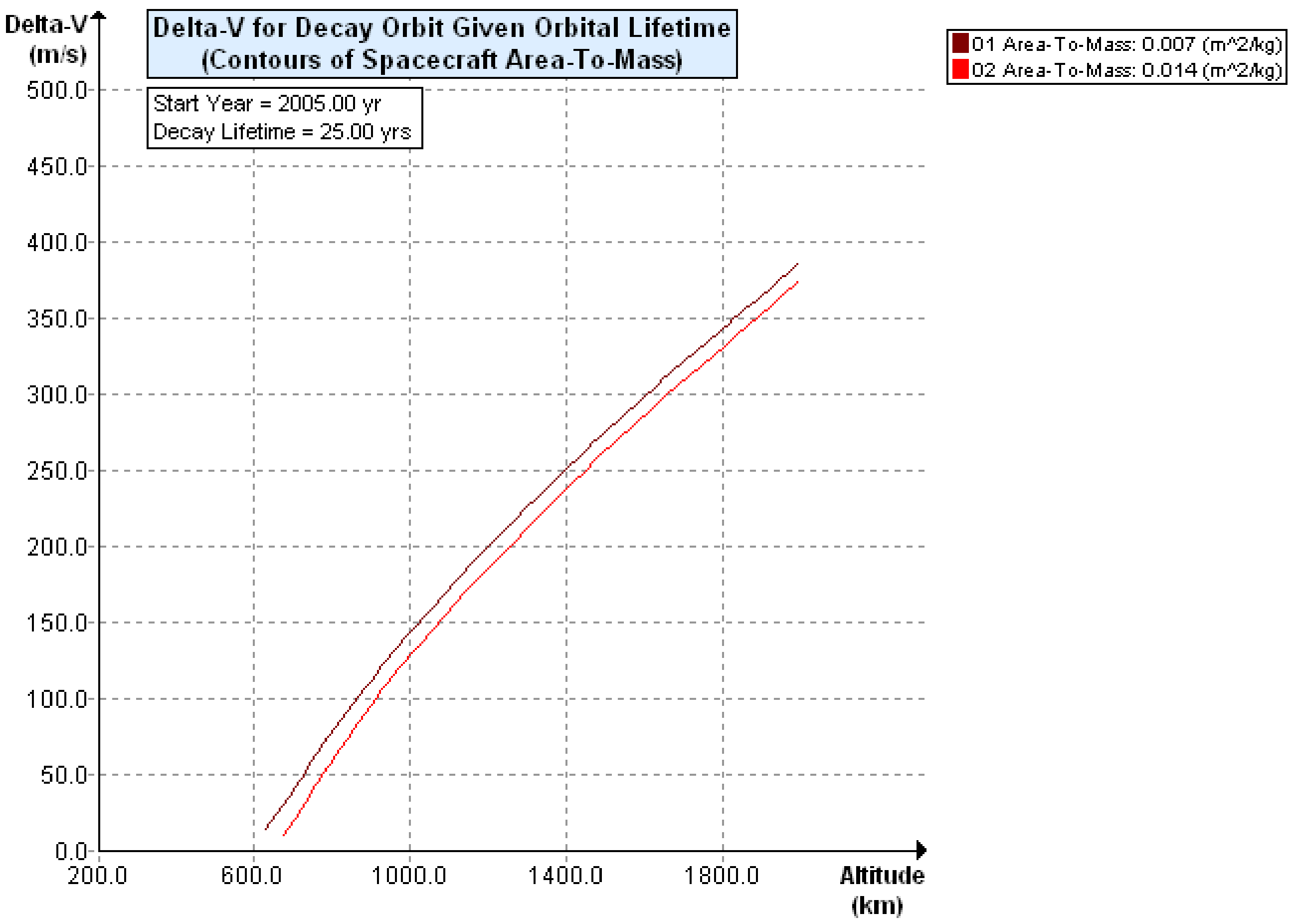
Start Year	The beginning date (in decimal years) for the time period currently under study. The input must be a positive numeric value equal to or greater than 2010 and less than or equal to 2070. In addition, the sum of the Start Year and the Orbital Lifetime must not exceed the year 2070.
Orbit Lifetime	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 2070.
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.

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. **Section 2.6, Using the Plot Viewer** provides information on plot utility functions. The underlying data are automatically saved as file *plots/DecayLifetime.dpl*.



Plot 6 - Delta-V for Decay Orbit Given Orbital Lifetime

4.4.2 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 4-12 describes the values.

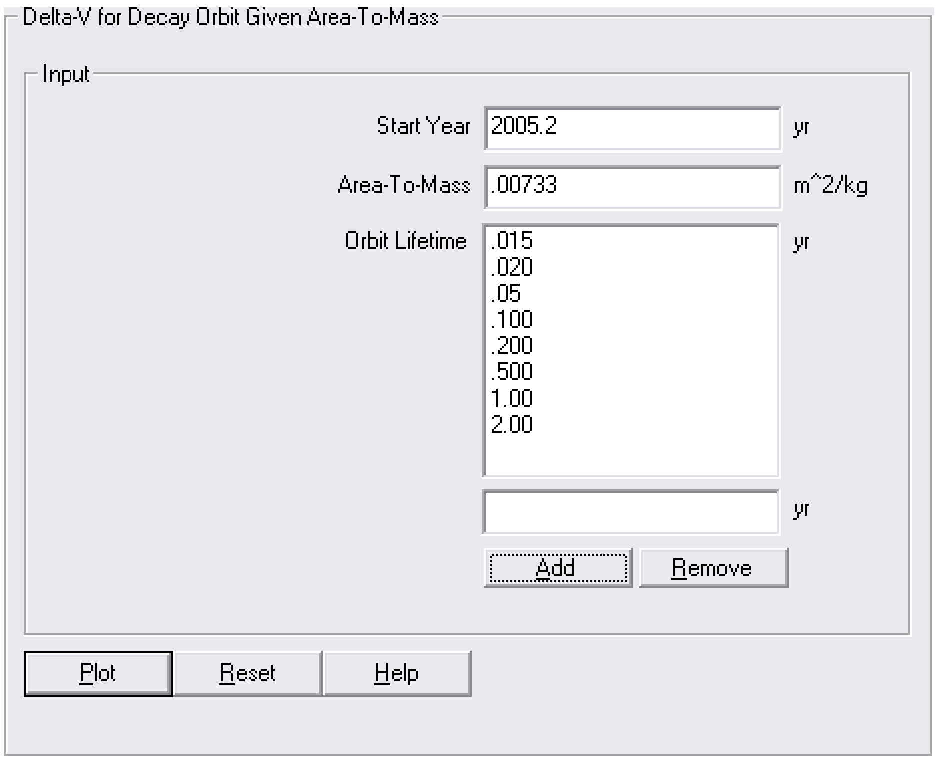


Figure 4 - 10: Delta-V for Decay Orbit Given Area-To-Mass Dialog

Table 4 - 12: Delta-V for Decay Orbit Given Area-To-Mass Input Data

Start Year	The beginning date (in decimal years) for the time period currently under study. The input must be a positive numeric value equal to or greater than 2010 and less than or equal to 2070. In addition, the sum of the Start Year and the Orbital Lifetime must not exceed the year 2070.
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 2070.

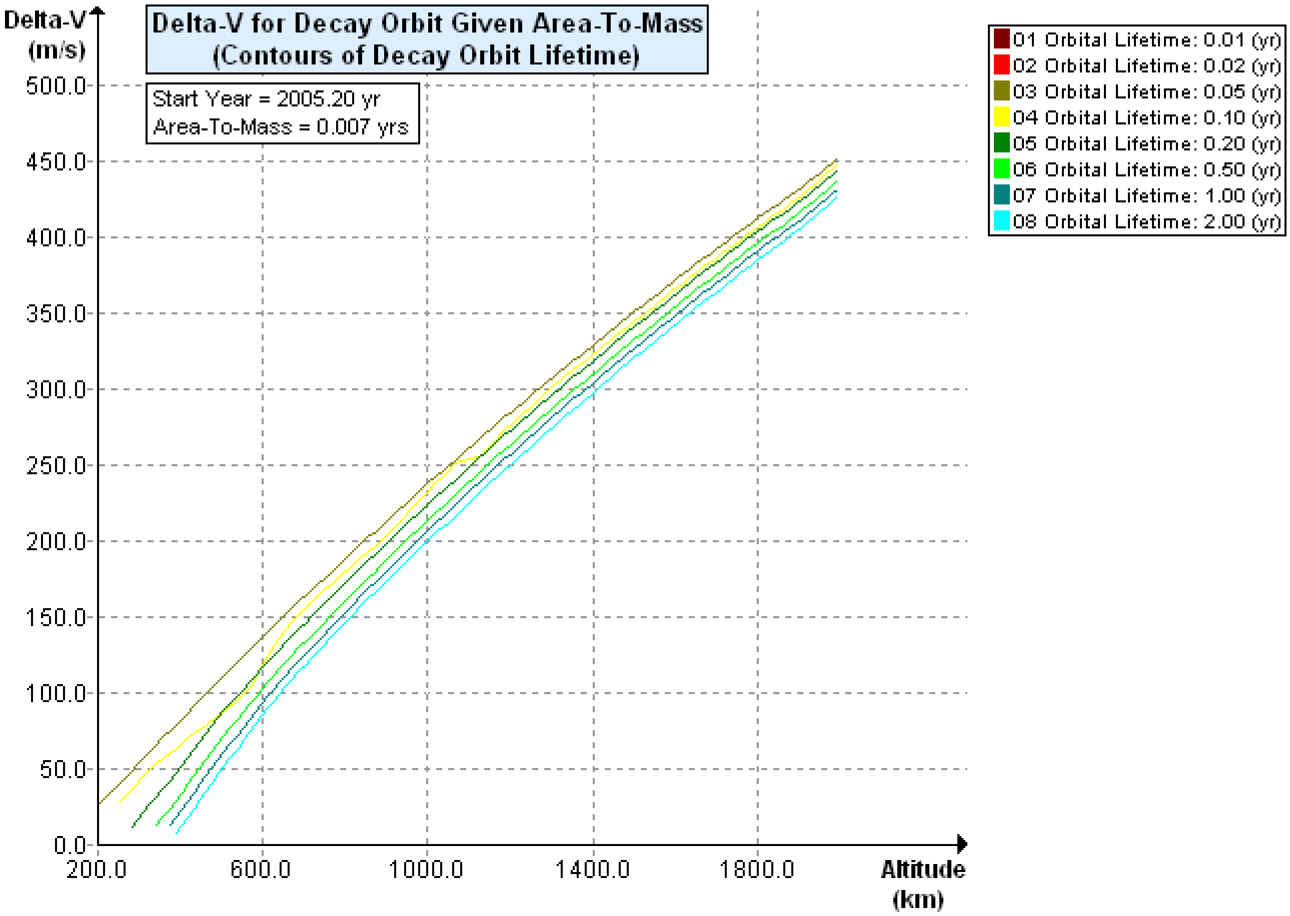
The "Reset" button will clear all input values from the dialog.

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. **Section 2.6, Using the Plot Viewer** provides information on plot utility functions. The underlying data are automatically saved as file *plots/DecayAOM.dpl*.



Plot 7 - Delta-V for Decay Orbit Given Area-To-Mass

4.5 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.

4.5.1 Orbit-to-Orbit Transfer

This utility calculates the Delta-V required for a coplanar orbit transfer. Figure 4-11 shows input/output dialog, and Tables 4-13 and 4-14 describes the values, respectively.

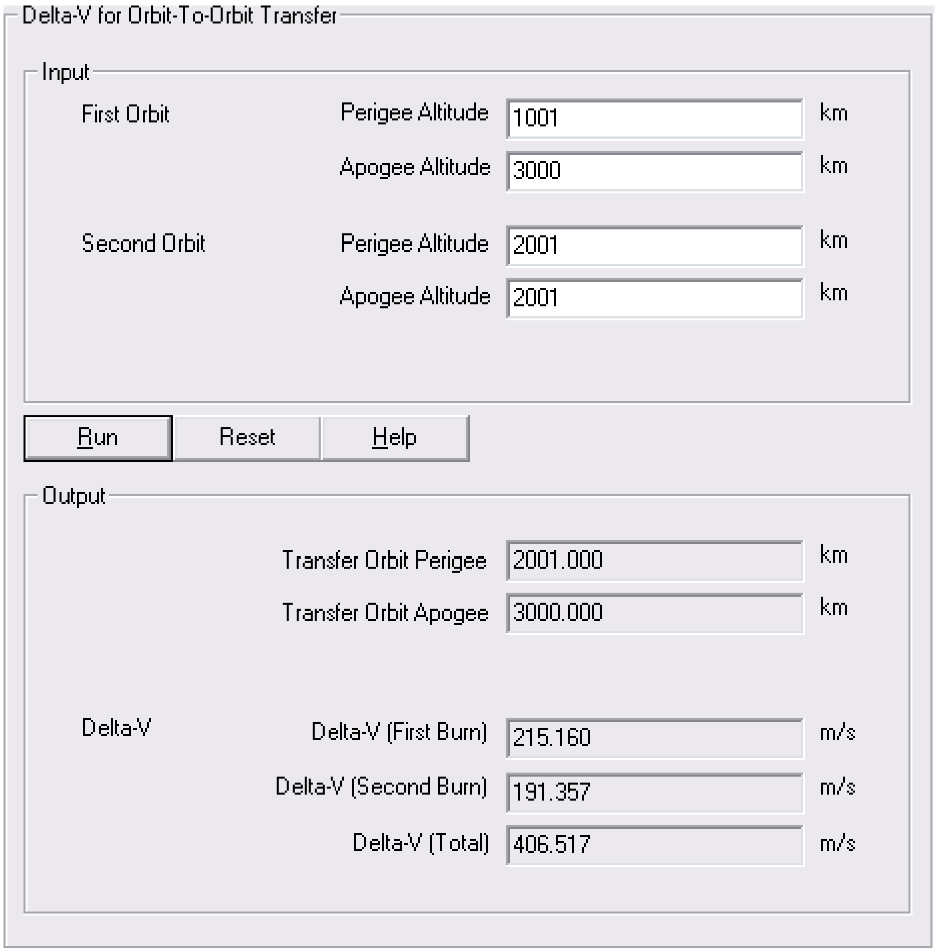


Figure 4 - 11: Delta-V for Orbit-to-Orbit Transfer Dialog

Input Data:

Table 4 - 13: 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 - 14: 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.

4.6 Other Utilities

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

4.6.1 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.

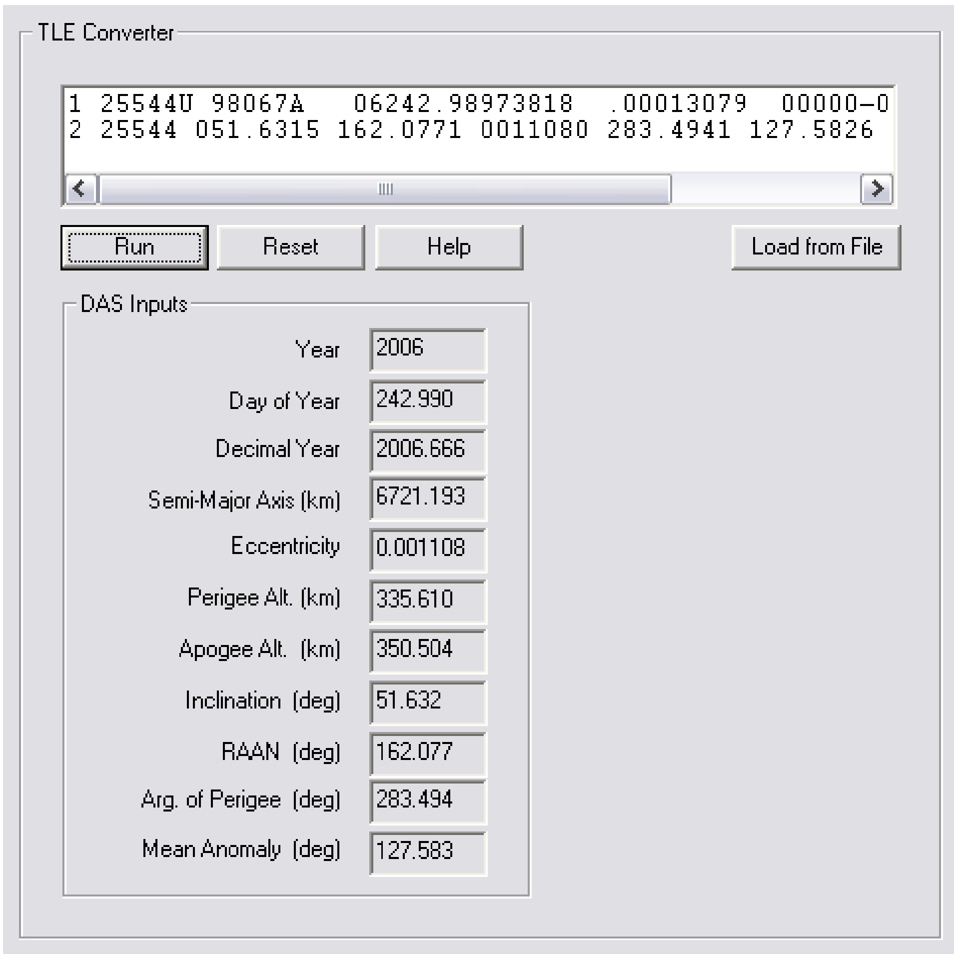


Figure 4 - 12: Two Line Element Conversion Dialog

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 valid TLE set it finds.

A two-line element set consists of two, 69-character lines of data which can be used to determine the position and velocity of an object orbiting Earth. Below is a reference chart for the fields in a two-line element set.

Table 4 - 15: 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)
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)
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)
1.11	54-61	BSTAR drag term (decimal point assumed)
1.12	63	Ephemeris type
1.13	65-68	Element number
1.14	69	Checksum (Modulo 10) (Letters, blanks, periods, plus signs=0; minus signs=1)

Table 4 - 16: 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)
2.6	35-42	Argument of Perigee [Degrees]
2.7	44-51	Mean Anomaly [Degrees]

Table 4 - 17 - Continued

Field	Column	Description
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:

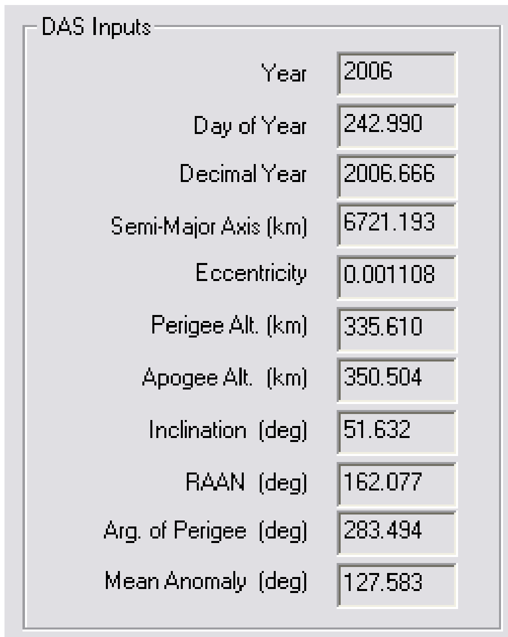


Figure 4 - 13: Elements Converted to DAS Input Values

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.

4.6.2 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 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 Section 4.5

of the NASA-STD-8719.14A. Subsection 4.5.4.1 of the Standard gives simple methods for estimating an object's average cross-sectional area.

The model is constructed using a series 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 4-12 shows the input/output dialog.

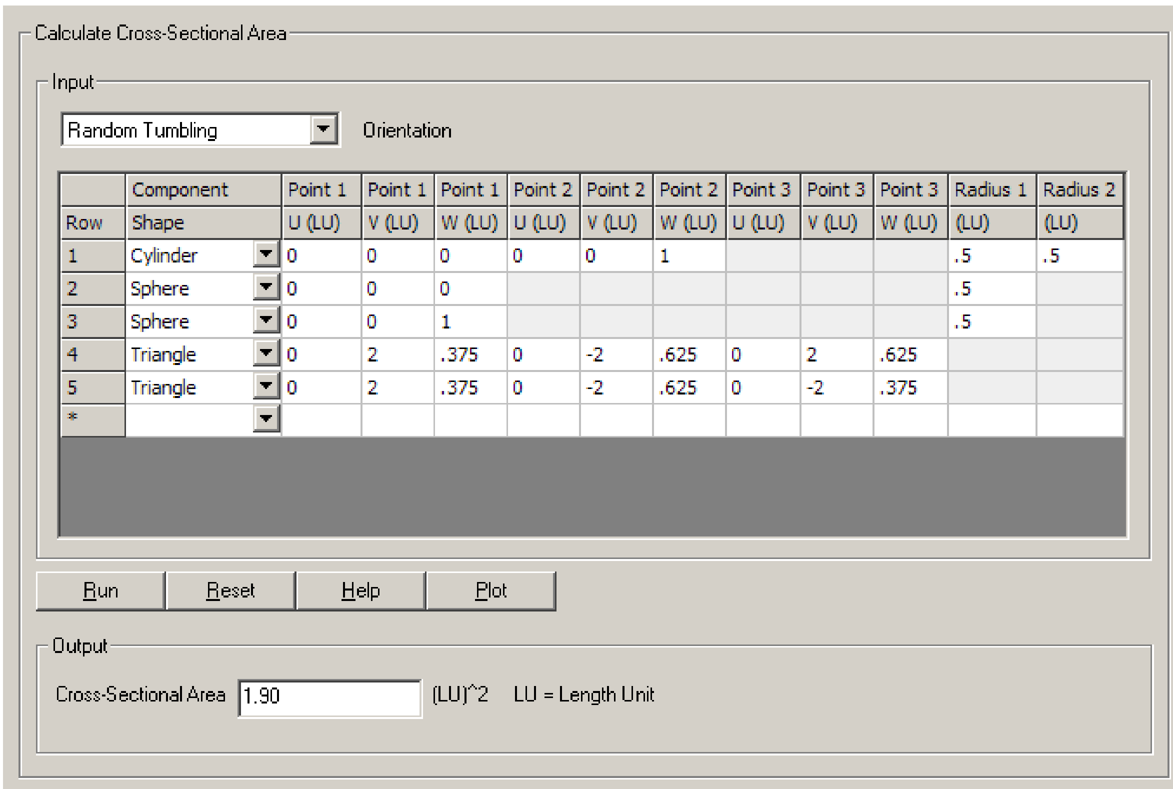


Figure 4 - 14: Calculate Cross-Sectional Area Dialog

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).

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 objects.**

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.

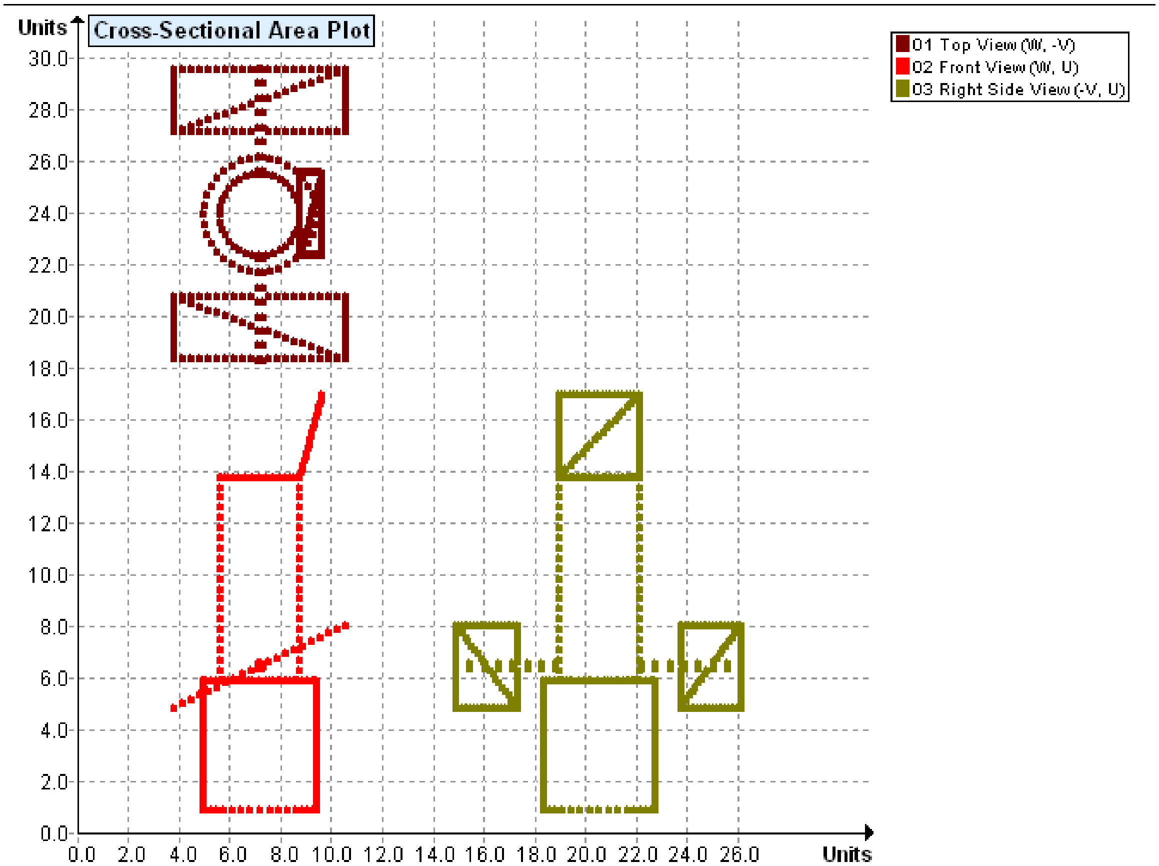
The plotting tool generates three, two-dimensional plots showing the V-W (top), V-U (side), and W-U (front) orthogonal views of the triangles, cylinders, and spheres used to define the spacecraft. However, because of the difficult nature of showing complex, three-dimensional objects in two-dimensional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



Plot 8 - 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 more dense 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 – 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, that 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 semimajor 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), reusuable launch vehicles (RLVs), and the Space Shuttle.

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) – The region of space below the altitude of 2000 km.

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 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 debris – Man-made objects, including inactive spacecraft and spent launch vehicle orbital stages, left in orbit. In this document, only debris of diameter 1 mm and larger are considered.

Orbital stage – A part of the launch vehicle left in a parking, transfer, or final orbit during payload insertion; includes both liquid propellant systems and 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 2.1 uses ORDEM 3.0, which describes the orbital debris environment between the altitudes of 100 and 40,000 km. NOTE: Increased fidelity of the ORDEM 3.0 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.

Semimajor axis – 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.

Semisynchronous Orbit (SSO) – An orbit with approximately a 12-hour period. A circular SSO 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 – Either meteoroid or orbital debris.

Stabilized – When the spacecraft maintains its orientation relative to some external frame of reference.

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 8719.14A Requirements

4.3. REQUIREMENTS FOR THE CONTROL OF DEBRIS RELEASED DURING NORMAL OPERATIONS

Orbital debris analyses assess the amount of launch vehicle and spacecraft debris released in normal operations. This requirement area applies to all space structures while in Earth orbit and is recommended for lunar and Mars orbital operations.

NASA space programs and projects shall assess and limit the amount of debris released.

REQUIREMENTS

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 shall satisfy both Requirement 4.3-1a and Requirement 4.3-1b:

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 no larger than 100 object-years per mission. The object-time product is the sum of all debris of the total time spent below 2000 km altitude during the orbital lifetime of each object.

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 degrees latitude), released debris with diameters of 5 cm 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.

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. Requirements 4.4-1, 4.4-1, and 4.4-3 are required for all space structures in Earth and lunar orbits. Requirement 4.4-3 is recommended for Earth-Sun Lagrange points, Earth-Moon Lagrange points, and Mars operations.

NASA space programs and projects shall 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 orbital about Earth or the Moon:* For each spacecraft and launch vehicle orbital stage employed for a mission, the program or project shall demonstrate, via failure mode and effects analyses or equivalent 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 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 control to a level which can not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft.

NASA space programs and projects shall 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:* 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 does not exceed 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 shall remain in Earth orbit longer than one year.

4.4-4. *Limiting the short-term risk to other space systems from planned breakups:* 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 verified to not exceed 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 4.5 shall apply for all space structures in Earth and lunar orbits.

NASA space programs and projects shall 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 operating in Earth orbit:* For each spacecraft and launch vehicle orbital stage in or passing through LEO, 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.

4.5-2. *Limiting debris generated by collisions with small objects when operating in Earth or lunar 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 requirements is less than 0.01.

4.6. POST MISSION DISPOSAL OF SPACE STRUCTURES

NASA space programs and projects shall plan for the disposal of spacecraft and launch vehicle orbital stages and space structures at the end of their respective missions. Postmission disposal shall be 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.

REQUIREMENTS

4.6-1. *Disposal for space structures in or passing through LEO:* A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of the following three methods:

a. Atmospheric reentry option:
   - Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or
   - Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.

b. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.

c. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission.

4.6-2. *Disposal for space structures near GEO:* A spacecraft or orbital stage in an orbit near GEO shall be maneuvered at EOM to a disposal orbit above GEO with a predicted minimum perigee of GEO + 200 km (35,986 km) or below GEO with an apogee of GEO – 200 km (35,586 km) for a period of at least 100 years after disposal.

4.6-3. *Disposal for space structures between LEO and GEO*:

a. A spacecraft or orbital stage shall be left in an orbit with a perigee greater than 2000 km above the Earth's surface and apogee less than 500 km below GEO.

b. A spacecraft or orbital stage shall not use nearly circular disposal orbits near regions of high value operational space structures, such as between 19,200 km and 20,700 km.

4.6-4. *Reliability of postmission disposal 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/or 4.6-3 are designed for a probability of success as follows:

a. Be no less than 0.90 at EOM.

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. SURVIVAL OF DEBRIS FROM THE POST-MISSION DISPOSAL ATMOSPHERIC REENTRY OPTION

Orbital debris analyses assess the risks associated with the disposal of a space vehicle in Earth's atmosphere. This area applies to full spacecraft as well as jettisoned components. Requirement area 4.7 applies to all space structures in Earth orbital area returning to the surface of the Earth from an altitude of greater than 100 km (~62 mi).

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.

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 not exceed 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 reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000).

4.8. ADDITIONAL ASSESSMENT REQUIREMENT FOR TETHER MISSIONS

Orbital debris analyses assess the potential hazard of tethered systems considering both an intact and a severed system. Tethers are flexible, long, and narrow space structures with two of the dimensions much smaller than the third. The potential to damage operating spacecraft can be larger than would be expected solely from the tether mass and cross-sectional area. Due to the potential of tether systems being severed by orbital debris or meteoroids, all possible remnants of a severed tether system shall be compliant with the requirements for the collision, debris, and disposal of space structures. Requirement area 4.8 applies to all space structures using tethers in Earth or lunar orbits.

NASA programs and projects shall 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. *Mitigate the collision hazards of space tethers in Earth or Lunar orbits:* Intact and remnants of severed tether systems in Earth and lunar orbit shall meet the requirements limiting the generation of orbital debris from on-orbit collisions (Requirements 4.5-1 and 4.5-2) and the requirements governing postmission disposal (Requirements 4.6-1 through 4.6-4) to the limits specified in those paragraphs.

Appendix C: DAS 2 Technical Notes

C.1 Propagators

DAS 2 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 Tesserral harmonics: $J_{2,2}$, $J_{3,1}$, $J_{3,3}$, $J_{4,2}$, $J_{4,4}$

For DAS 2, 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 example, 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 2 uses a set of Keplerian 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.

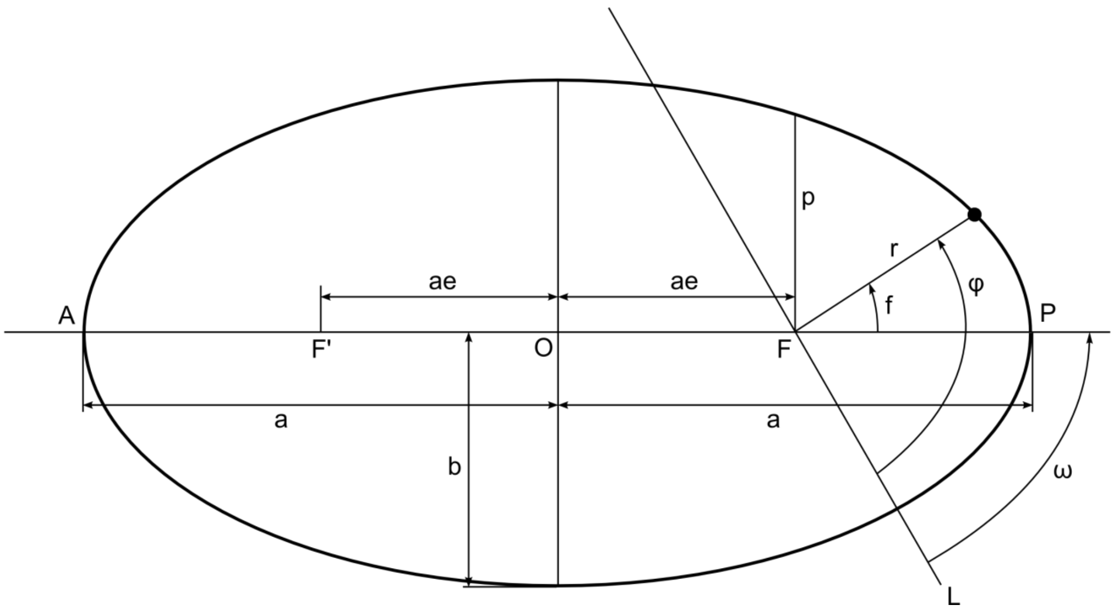


Figure C - 1: Orbital Elements in the Orbital Plane

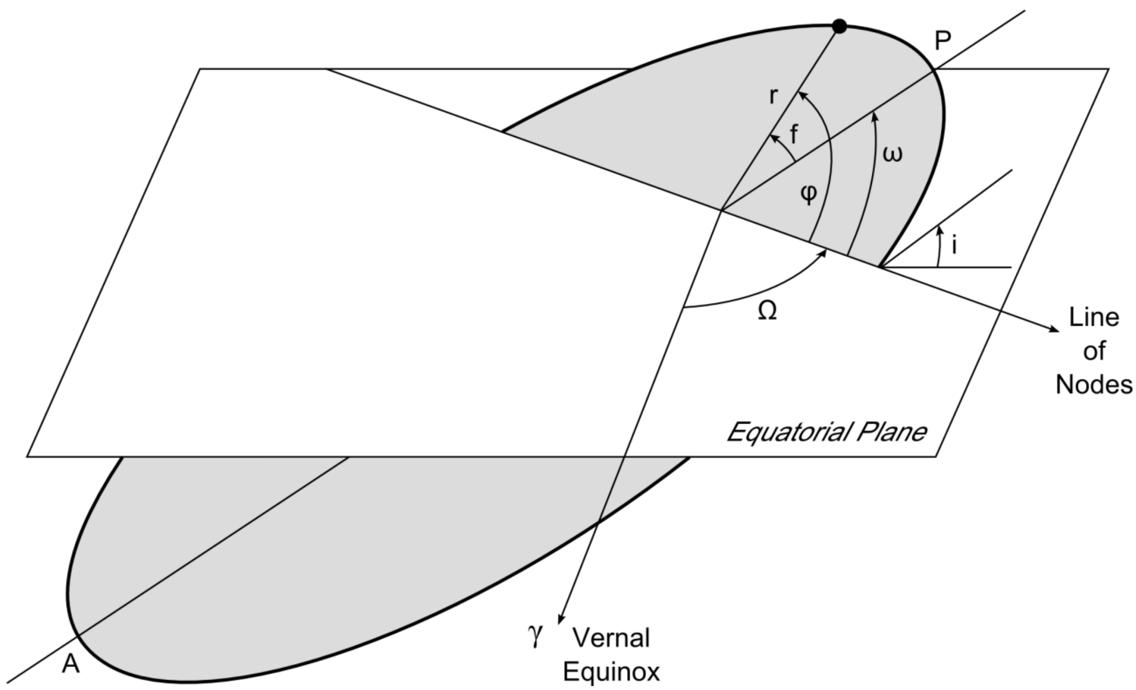


Figure C - 2: Orbital Elements

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 semimajor 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 2.1 incorporates the orbital debris environment model of ORDEM 3.0, the Orbital Debris Engineering Model also developed by the NASA Orbital Debris Program Office. This is the only major change in this version. The higher-fidelity ORDEM 3.0 has greatly increased run-times compared to the previous ORDEM2 (a.k.a. ORDEM2000). Because DAS performs an ORDEM analysis for each year an object is in orbit, these increased run-times are multiplied. DAS runs that formerly lasted minutes will now take substantially longer. Highly elliptical orbits, crossing a wider parameter space, will see the greatest increase in run-time.

The ORDEM 3.0 debris populations have been simplified to reduce storage requirements and computation times. Debris sizes below 316 μm are excluded, and the time period from 2036 to 2070 (the ORDEM 3.0 time period is 2010-2035) does not include small debris (*i.e.*, sizes below 10 cm). An important result of this is that **DAS cannot assess Requirement 4.5-2 for missions operating after 2035**. This shortcoming shall be addressed in a future version of DAS.

In DAS, three Assessments and three Science and Engineering routines use functions derived from ORDEM 3.0. The increase in run-time depends on the number of times DAS must call the ORDEM functions. Due to the large number of ORDEM runs, users may find the On-Orbit Collisions plotting tools impractical.

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]**
Assessment of Requirement 4.8-1: Mitigate the Collision Hazard of Space Tethers	Twice for every calendar year in orbit (not just mission lifetime): once each for Req. 4.5-1 and Req. 4.5-2 **[orbital lifetime × 2]**
Sci & Eng — On-Orbit Collisions: Debris Impacts vs. Orbit Altitude	For each “duration” year and a fixed range of altitude steps **[duration × 37]**
Sci & Eng — On-Orbit Collisions: Debris Impacts vs. Debris Diameter	For each “duration” year and a user-entered list of altitudes **[duration × number of altitudes]**
Sci & Eng — On-Orbit Collisions: Debris Impacts vs. Start Date	For each “duration” year and a single user-entered altitude **[60]**

For further details and references, please see:

Krisko, P.H, "The New NASA Orbital Debris Engineering Model ORDEM 3.0," AIAA/AAS Astrodynamics Specialist Conference, San Diego, CA, USA, 4-7 Aug. 2014. http://dx.doi.org/10.2514/6.2014-4227

Orbital Debris Engineering Models (ORDEM 3.0), https://orbitaldebris.jsc.nasa.gov/modeling/engrmodeling.html (retrieved 29 Feb. 2016).

NASA Orbital Debris Engineering Model ORDEM 3.0 – User's Guide, NASA/TP-2014-217370, NASA Orbital Debris Program Office, NASA-JSC, Houston, TX, USA, April 2014.

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 2, the F10.7 value is used to compute the temperature, and therefore density, of Earth's upper atmosphere. In previous versions of DAS, the user entered a single value of F10.7 for the given mission. In DAS 2, 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 Environment Center (SEC) (http://www.swpc.noaa.gov/), as well as the SEC'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 September 2005. 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 Orbital Debris Program Office Web site 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. (http://orbitaldebris.jsc.nasa.gov/newsletter/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.

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 2 Built-In Materials

Material Description	Specific Heat (J/kg-K)	Heat of Fusion (J/kg)	Melt Temper-ature (K)	Density (kg/m^3)
Acrylic	1465	0.0	505.0	1170.00
Alumina	790.6 < Cp < 1231.4	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	845.3 < Cp < 1100.0	386116.0	856.0	2803.00
Aluminum 2219-T8xx	866.0 < Cp < 1147.2	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	846.8 < Cp < 1177.9	376788.0	830.0	2787.00
Barium element	285	55824.0	983.0	3492.00
Beryllium element	1675.4 < Cp < 3594.8	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	785.1 < Cp < 1730.0	37650.0	2144.0	1688.47
Cobalt	412.4 < Cp < 904.5	259600.0	1768.0	8862.00
Cork	1629.2	2860980.0	922.0	261.29
Cu alloy	389.4 < Cp < 471.8	204921.0	1356.0	8938.00
Cu/ Be (0.5% beryllium)	397	204921.0	1320.0	8800.00
Cu/ Be (1.9% berylium)	253.0 < 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	705.3 < Cp < 1273.6	0.0	1922.0	192.22
Gallium Arsenide (GaAs)	325	0.0	1510.0	5316.00
Germanium	329.7 < Cp < 397.7	430282.6	1210.7	5320.00
Gold element	126.4 < Cp < 153.3	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 < 694.6	309803.0	1620.0	8920.67
Hastelloy 25 (aka Haynes alloy 25, 51% Co, 20% Cr, 10% Ni, 15% W)	406.2 < Cp < 590.0	309803.0	1643.0	9130.00
Hastelloy 188 (aka Haynes alloy 188, 42% Co, 22% Cr, 22% Ni, 14% W)	406.2 < Cp < 590.0	309803.0	1635.0	8980.00
Hastelloy n (71% Ni, 7% Cr, 16% Mo, 55% Fe)	419.0 < Cp < 584.4	309803.0	1623.0	8576.40
Inconel x (aka x-750,Ni > 70%, 15% Cr, 7% Fe)	426.3 < Cp < 541.8	311664.0	1683.2	8297.50
Inconel 600 (Ni >72%, 15% Cr, 18% Fe)	426.7 < Cp < 650.2	297206.0	1683.9	8415.00
Inconel 601 (Ni 60%, 23% Cr, 13% Fe)	449.9 < Cp < 815.9	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	479.9 < Cp < 653.2	2740000.0	1700.0	8050.00
Iron (Armco)	433.7 < Cp < 711.5	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)	1027.3 < Cp < 1398.3	339574.0	868.0	1682.00
Magnesium HK31A (3% Th, 1% Zr)	1028.9 < Cp < 1340.6	325619.0	877.0	1794.00
Molybdenum	231.7 < 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)	440.0 < Cp < 726.0	309803.0	1650.0	8430.00
Nickel	440.0 < Cp < 726.7	309803.0	1728.2	8906.26
Niobium (a.k.a. columbium)	268.8 < Cp < 346.5	290000.0	2741.0	8570.00
NOMEX	1256	232.6	572.0	1380.00
Platinum	130.7 < Cp < 146.2	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	814.7 < Cp < 1633.7	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	222.6 < Cp < 243.7	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/m^3)
Steel AISI 304 (Stainless Steel, 69% Fe + 19% Cr + 10% Ni alloy)	482.0 < Cp < 608.2	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)	471.9 < 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)	500.4 < Cp < 1114.6	393559.0	1943.0	4437.00
Tungsten	127.1 < Cp < 188.0	220040.0	3650.0	19300.00
Uranium	116.8 < Cp < 201.1	52523.0	1405.0	19099.00
Uranium Zirconium Hydride (UZrH)	418.7	131419.0	2144.0	6086.80
Water	4081.1 < Cp < 6900.0	0.1	273.0	999.00
Zerodur	842.4 < Cp < 1644.7	250000.0	1424.0	2530.00
Zinc	366.6 < Cp < 444.0	100942.0	692.6	7144.20

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13. ABSTRACT *(Maximum 200 words)*

The Debris Assessment Software (DAS) is provided by the NASA Orbital Debris Program Office as a means of assessing, during the planning and design phases, a space mission's compliance with NASA's requirements for reduction of orbital debris as stated in NASA Technical Standard (NASA-STD)-8719.14A. After the software user inputs basic payload and mission data, DAS determines whether or not the mission complies with several (though not all) of the requirements described in the Standard. In addition to the *assessment* functions, a set of *science and engineering* utilities provide a number of functions useful for mission planning. The utilities may aid the user in determining why some aspect of their mission failed a Requirement Assessment and help them explore options that will pass assessment.

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