Improvements to NASA's Debris Assessment Software

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Abstract

NASA's Debris Assessment Software (DAS) has been substantially revised and expanded. DAS is designed to assist NASA programs in performing orbital debris assessments, as described in NASA's "Guidelines and Assessment Procedures for Limiting Orbital Debris." The extensive upgrade of DAS was undertaken to reflect changes in the debris mitigation guidelines, to incorporate recommendations from DAS users, and to take advantage of recent software capabilities for greater user utility.

DAS 2.0 includes an updated environment model and enhanced orbital propagators and reentry-survivability models. The ORDEM96 debris environment model has been replaced by ORDEM2000 in DAS 2.0. The new DAS is also designed to accept anticipated revisions to the debris environment definition. Numerous upgrades have also been applied to the assessment of human casualty potential due to reentering debris. Routines derived from the Object Reentry Survival Analysis Tool, Version 6.0 (ORSAT 6.0), determine which objects are assessed to survive reentry, and the resulting risk of human casualty is calculated directly based upon the orbital inclination and a future world population database. When evaluating reentry risks, the user may enter up to 200 unique hardware components for each launched object, in up to four nested levels. This latter feature allows the software to model more accurately components that are exposed below the initial breakup altitude.

The new DAS 2.0 provides an updated set of tools for users to assess their mission's compliance with the NASA Safety Standard and does so with a clear and easy-to-understand interface. The new native Microsoft Windows graphical user interface (GUI) is a vast improvement over the previous DOS-based interface. In the new version, the layout of functions is clear, and the GUI includes the standard Windows-style "Help" functions. The underlying routines within the DAS code are also improved.

Introduction

The first version of NASA's Debris Assessment Software (DAS) was produced in 1996. It was an MS-DOS program, which was actually a front-end to a collection of software routines. The routines were designed to help mission planners seeking to comply with NASA Safety Standard 1740.14, "Guidelines and Assessment Procedures for Limiting Orbital Debris" [1]. This Standard supported the NASA Management Directive 1700.8, "Policy to Limit Orbital Debris Generation" (1993) and later NASA Policy Directive 8710.3, "Policy for Limiting Orbital Debris Generation" (1997). The most recent DAS, version 1.5.3, included incremental updates and fixes, and ported the DOS-based user interface to work under MS-Windows.

Several factors led the Orbital Debris Program Office to set aside DAS 1.5.3 and start from scratch when composing the new DAS 2.0. The most important reasons for developing the new version were that the models and user interface of DAS 1.5.3 are outdated, and a new DAS could be written to specifically address the requirements of the draft NASA Standard 8719.14, "Guidelines and Assessment Procedures for Limiting Orbital Debris" [2] (which will replace NSS 1740.14). Additionally, a new version would address the years of feedback received from DAS users. Considering the difficulties of updating and maintaining the old software, it was decided to proceed with a full re-write of the DAS code.

Improved Models and Methods

In the years since the release of DAS 1.0 and 1.5, the Orbital Debris Program Office has improved several of its models and methods. DAS 2.0 will include improved orbit propagators, debris and meteoroid environment models, and reentry casualty estimation.

Propagators

The new DAS will use the orbit propagators "PROP3D" and "GEOPROP", developed for NASA's debris evolutionary models. These propagators produce more realistic results than the previous "fast" propagator. The new model will include improved force models for Earth's atmosphere and gravitational field, solar and lunar gravitation, and solar radiation pressure, including the effects of Earth's shadow. The atmosphere is modeled as oblate and rotating with the Earth's surface. Earth's gravitational field includes the three zonal terms J_2, J_3, and J_4.

The solar flux value, used for atmospheric drag calculations, is no longer an input for the user. The user will specify a date, and the appropriate values will be retrieved from a model based on standard data published by the National Oceanic and Atmospheric Administration (NOAA). The future projection of solar activity begins as the NOAA near-term prediction. After the near-term, the projection transitions to a repeating cycle, computed by the Orbital Debris Program Office as the curve fit to daily historical values since 1947 [3]. The Orbital Debris Program Office updates its solar flux table every six months. The updated flux table will be made available to DAS users.

Debris Environment Model

The orbital debris environment model (ORDEM) has been updated from the previous ORDEM96 to the newer ORDEM2000 [4]. This model provides an estimate of the debris environment in low Earth orbit (from 200 to 2000 km altitude). This, in turn, is used to assess the probability of collision with debris (sizes of 10 μm and greater) in orbit. The ORDEM2000 model spans the years of 1991 to 2030, and altitudes of 200 to 2,000 km. The ORDEM2000 environmental data must be extended, since DAS is designed to span the years 1991 to 2110, and altitudes of 200 to 100,000 km. The data are extended beyond the year 2030 using scale factors derived from the output of NASA's LEGEND debris environment evolutionary model. A scale factor is applied to the ORDEM2000 spatial density, based on annual LEGEND results normalized by the last year (2030) of ORDEM2000 results. The ORDEM2000 altitude range is

also extended, and the velocities scaled, from 2,000 km up to 100,000 km. While these extensions to the ORDEM2000 environment are simplistic, the DAS 2.0 software is written such that improved models may be easily added in the future. The release of the new ORDEM2007 model is anticipated in 2008.

Damage Caused by Small Objects

Systems critical to post-mission disposal must be shielded sufficiently against penetration by small debris (less than 10 cm in size) and meteoroids. Given information about the shielding layers, DAS will apply the orbital debris, meteoroid, and penetration models in order to assess compliance with the NASA Standard. In addition to the ORDEM2000 debris model, DAS uses a meteoroid model to complete the small-object environment. The method [5] uses an isotropic meteoroid flux, a modified velocity distribution, and gravitational focusing and shielding due to Earth.

Rather than requiring a series of hand calculations, DAS 2.0 requires the user to specify the separation distance and areal density (g/cm^2) of shielding layers, as well as the pointing vector on a stabilized platform. The software then assesses compliance based on these inputs and the mission profile.

Reentry-Survivability Model

DAS 2.0 uses a simplified version of NASA's Object Reentry Survival Analysis Tool (ORSAT), including some of the updated features of ORSAT 6.0 [6], in order to determine which objects may survive reentry. Improvements in the reentry routines include the specification of orbital inclination, an improved aero-heating model, temperature-dependant material properties (for the included materials), and an improved calculation of impact kinetic energy. Up to 200 unique hardware components may now be entered in up to four nested levels. This last feature allows the software to model more accurately those components which are exposed below the initial breakup altitude.

Reentry Casualty Estimation

DAS uses the output of the reentry-survivability model to assess the risk of human injury due to reentering debris from the mission. The probability of human casualty is a function of the object's year of reentry, its orbital inclination at reentry, and its debris casualty area [7]. The year of reentry—used primarily to determine the world population—is calculated by DAS based on the mission profile.

The human population distribution used by DAS is based on data from two sources. The International Data Base (IDB) [8], produced by the International Programs Center of the United States Bureau of the Census, provides historical and predicted population estimates of countries/areas around the world. The Gridded Population of the World (GPW) [9] provides the spatial (longitude and latitude) distribution of the population within each country or area. The model used by DAS 2.0 was created using IDB data as of May 2000, and the GPW version 2,

updated to the year 1995. These data were combined to create a table of population for every year in the DAS date range. Because DAS does not assess targeted reentry, the population data are summed over all longitudes in regularly-spaced latitude bands.

The debris casualty area is a function of the dimensions of an average person and of the specific debris fragment. The model does not consider more complicated aspects, such as sheltering within structures and the possibility of debris bouncing. The total casualty area is the sum of the casualty areas of all surviving debris fragments which reach the ground with kinetic energy greater than 15 Joules [10].

Improved User Interface

The most obvious change to DAS is the new Microsoft Windows graphical user interface (GUI). Designed to run on Windows 2000, XP, or Vista, DAS 2.0 is a complete departure from the awkward DOS/Windows interface of DAS 1.5.3. The new GUI is designed to consolidate user input and to avoid long chains of menus. The figure below shows the top-level window of DAS 2.0.
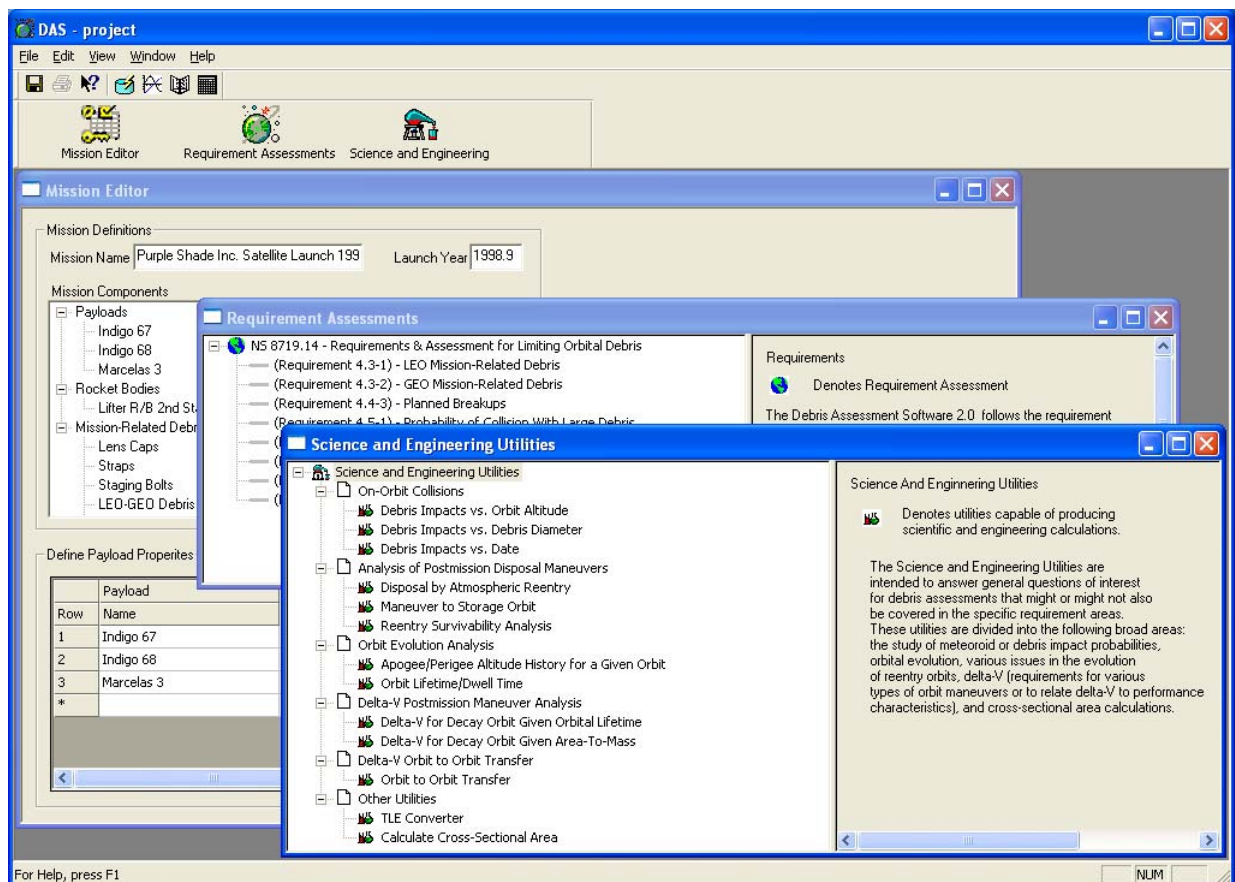

Figure: The DAS 2.0 top-level window, and three main dialog windows.

As with other computer programs that use multiple input and output files, DAS 2.0 saves the user's files as a "project". All the files unique to a project are stored within that project's directory. This means that moving or sharing a project is accomplished by simply moving,

renaming, or sharing the entire project directory. Other files and directories within the DAS directory are not affected by the projects.

Division of Modules

The major functions of DAS are divided into three sections: the mission editor, requirement assessments, and associated science and engineering utilities. Other supporting features include a two-line element (TLE) converter, a materials database editor, a plotter, and on-line help.

The user enters most of the mission information into the Mission Editor. This part of the GUI is dominated by a data table, which the user must fill with values for each launched object. These are "high level" values, such as mission duration, operational orbit parameters, disposal orbit parameters (if applicable), mass, and area-to-mass ratio. Most of the assessments are completed using only the information in the Mission Editor.

The Requirement Assessments section of DAS includes routines to assess the mission's compliance with each NASA debris-limiting requirement. The assessments do not need to be completed in sequence. Most of the assessments may be run without further input, but three of them do require the user to define the space structure in more detail. In the latter cases, the GUI provides the user with spaces and tables in which to enter the information. To assess the mission, the user selects one of the requirements from the list, enters additional information if required, and clicks the "Run" button. The results (output data and notes) then appear below the input data in the Assessments window. Any non-compliant features are flagged for the user's attention. The user may study non-compliant features using DAS's Science and Engineering Utilities.

The 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. The utilities are separated into six categories: on-orbit collision, postmission disposal (PMD), orbit evolution (propagation), delta-V analysis of PMD maneuver and orbit transfer, and other utilities. The on-orbit collision routines apply the debris and meteoroid models, producing data and plots which allow the user to explore a mission's susceptibility to on-orbit impacts. Analysis of PMD maneuvers includes a version of the reentry survivability analysis which may be used separately from the routine in the Requirement Assessments section. The routines for orbit evolution and delta-V analysis apply the orbit propagators and standard orbital mechanics to estimate how long an object will stay in orbit and to estimate the velocity change required for disposal. The other utilities include a simple tool for converting a two-line orbital element set (TLE) to DAS-style input values and a utility for estimating an object's cross-sectional area. The cross-sectional area utility requires the user to "construct" a 3-dimensional representation of the object using basic shapes. The representation may be as simple or as complex as the user requires.

The new materials database editor simplifies the addition of user-specified materials which may be used in the assessment of reentry survivability. The required properties must still, of course, be obtained from other reference materials. The user enters a name for the new material, and values for its density, specific heat capacity, heat of fusion, and melt temperature. (The density

value is used only as a "sanity check" within the software.) This "user materials database" is stored as a comma-separated-values (CSV) file in the individual project's directory.

DAS 2.0 includes a new plot viewer. Though not used for requirement assessment, many of the Science and Engineering Utilities display their results as plots. The plot viewer also allows the user to modify the plot properties (titles, labels, axis limits, line colors, etc.). Plots may be copied directly to the Windows "clipboard" and then pasted into documents or image editors. Plots may also be saved to disk (in an internal format) and later re-loaded into the plot viewer.

The new software also includes on-line help features familiar to Windows users. The Help menu item includes links to the Requirements Document (NASA Standard) and to the DAS on-line help. The "hyperlinked" help system mostly condenses the information found in the DAS 2.0 User's Guide.

Summary

NASA's Debris Assessment Software is the standard method of assessing compliance with the agency's space debris reduction requirements. As such, the DAS 2.0 will be an important tool for use in space mission design. The many improvements in both the interface and the underlying models have yielded a product that is of higher fidelity and easier to use than previous versions of DAS. The improvements to the force models, the solar flux model, and the environment model have increased the size of the DAS software package and the calculation time of several routines. When the software is released, instructions for obtaining DAS 2.0 will appear on the NASA Orbital Debris Program Office's Web site, http://orbitaldebris.jsc.nasa.gov.

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