



NASA Orbital Debris Engineering Model ORDEM2008 (Beta Version)

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1. Introduction

This is an interim document intended to accompany the beta-release of the ORDEM2008 model. As such it provides the user with a guide for its use, a list of its capabilities, a brief summary of model development, and appendices included to educate the user as to typical runtimes for different orbit configurations. More detailed documentation will be delivered with the final product.

ORDEM2008 supersedes NASA's previous model - ORDEM2000. The availability of new sensor and *in situ* data, the re-analysis of older data, and the development of new analytical techniques, has enabled the construction of this more comprehensive and sophisticated model.

Integrated with the software is an upgraded graphical user interface (GUI), which uses project-oriented organization and provides the user with graphical representations of numerous output data products. These range from the conventional average debris size vs. flux magnitude for chosen analysis orbits, to the more complex color-contoured two-dimensional (2-D) directional flux diagrams in terms of local spacecraft pitch and yaw.

2. ORDEM2008 Model

2.1. Introduction

Two main constituencies compose the ORDEM user community: spacecraft designers/operators, and debris observers.

To facilitate implementation of cost effective shielding, the designer of an oriented spacecraft requires detailed estimates of the particle flux as a function of local pitch/yaw. (Such detail is not required in the case of a randomly tumbling spacecraft.). Accurately determining this flux requires careful assessment of the distribution of debris as a function of size and altitude. Because of the long lead times in new satellite designs, the temporal behavior of the debris environment over a satellite's lifetime is also of interest.

In the case of a debris observation campaign, predicted fluxes will depend upon the inclination and altitude distribution of resident space objects visible from the ground-based sensor location. Additionally, consideration must be made as to whether the sensor is fixed in its orientation or is steerable in azimuth and elevation. In the case of bistatic radars utilizing parallax, the altitude distribution becomes of crucial importance due to common field of view constraints.

The ORDEM series of engineering models have included assessments of the orbital debris environment as functions of altitude, latitude, and debris size. They have provided complete descriptions of the debris environment in terms of debris flux onto spacecraft surfaces or the debris detection rate observed by ground-based sensors. In the intervening years since ORDEM2000 was released, new data and analysis techniques have matured. These include: mappings of debris in GEO down to 10 cm via extension

of Michigan Orbital Debris Survey Telescope (MODEST) data, the recognition of the role of spacecraft materials in impact fragment lethality, the development of data analysis techniques (Bayesian statistics), and the advent of generation models for specific populations (e.g., fragmentation debris, RORSAT sodium potassium (NaK) coolant droplets).

The specific requirements of the new model, ORDEM2008, have been expanded to accommodate these advances. Table 2.1.1 compares the ORDEM2008 features to those in ORDEM2000.

Table 2.1.1. Feature Comparison of ORDEM2000 and ORDEM2008

Parameter	ORDEM2000	ORDEM2008
Spacecraft and Telescope/Radar analysis modes	YES	YES
Time range	1991 to 2030	1995 to 2035
Altitude range with minimum debris size	200 to 2000 km (>10 μm)	200 to 34,000 km (>10 μm) 34,000 to 38,000 km (>10 cm)
Model population breakdown (5 population types)	NO	Intacts Low-density fragments Medium-density fragments and degradation/ejecta High-density fragments and degradation/ejecta RORSAT NaK coolant droplets
Material density breakdown (5 density types)	NO	unknown low-density (<2 g/cc) medium-density (2-6 g/cc) high-density (>6 g/cc) RORSAT NaK coolant (0.9 g/cc)
Model cumulative size thresholds	10 μm , 100 μm , 1 mm, 1 cm , 10 cm, 1 m	10 μm , 31.6 μm , 100 μm , 316 μm , 1 mm, 3.16 mm, 1 cm, 3.16 cm, 10 cm, 31.6 cm, 1 m
Flux uncertainties	NO	YES
Total input file size	13.5 MB	930 MB
Meteoroids	NO	NO

Input populations in the ORDEM2008 are determined via data analysis coupled with modeling. Available data sets listed in Table 2.1.2 span the altitude and size regimes required in Table 2.1.1. Computer models, when verified through data (Table 2.1.3), yield reliable object populations throughout Earth orbit. These populations are generally restricted to regions in space and in object size where measurement data is available. Note that some data sets were only used for comparison and explicitly not used for population derivation.

Table 2.1.2. Contributing data sets

Observational Data	Role	Region/Size
SSN catalog (radars, telescopes)	Intacts & large fragments	LEO > 10cm, GEO > 70cm
Cobra Dane (radar)	Compare (only) with SSN	LEO > 4 cm
Haystack (radar)	Statistical populations	LEO > 1cm
Goldstone (radar)	Compare (only) with Haystack	LEO > 3 mm
STS windows (returned surfaces)	Statistical populations	LEO < 100 μ m
HST solar panels (returned surfaces)	Compare (only) with STS	LEO < 1mm
MODEST (telescope)	Only GEO data set	GEO > 30cm

Table 2.1.3. Contributing models (with corroborative data)

Model	Usage	Corroborative Data
LEGEND	LEO Fragments > 1mm GEO Fragments > 10cm	Haystack, SSN MODEST, Goldstone
NaK Module	NaK droplets > 1mm	Haystack
Degradation/Ejecta model	Degradation/Ejecta > 10um	STS windows, STS radiators

The ORDEM2008 process for applying modeling and data analysis to generate the files utilized by the algorithm is described in simple top-level terms in Figure 2-1. Data-verified model outputs are tagged with number weighting factors, to re-adjust the populations, and with error estimates ($1-\sigma$), to account for variation in observations. These results are compiled with predetermined orbital element bins of perigee altitude, eccentricity, and inclination. Each bin preserves total number and total measurement uncertainty. Template files tagged by year (discussed in Section 2.5) are the direct inputs to ORDEM2008.

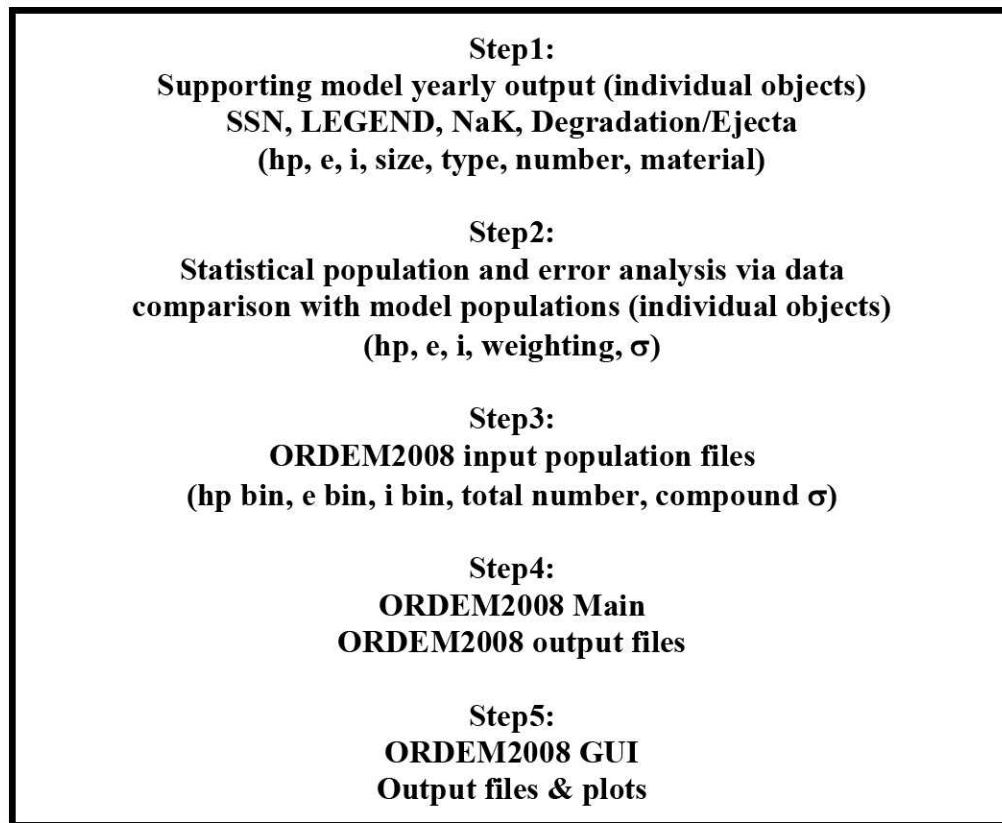


Figure 2-1. ORDEM2008 top-level flowchart

2.2. Program Requirements

The PC-based ORDEM2008 includes two programs: a GUI written in Microsoft C# (C Sharp) .Net and the main computational model written in Fortran 90. The template files that form the database of the model are stored in a subdirectory called “data”. The user selects program options and enters input parameters using the GUI. The results of the Fortran computation are stored in a user-defined project directory.

ORDEM2008 is designed to run on the 32-bit Microsoft Windows operating system (Windows 98 or greater). Installing ORDEM2008 requires about 1.0 gigabytes of free space on the hard drive and a recommended minimum of 512 MB of RAM. The Microsoft .Net framework 2.0 or greater is also required. The ORDEM2008 installer will prompt the user to download and install .NET if it is not present.

At present, a Microsoft installation package (MSI) must be downloaded from the common folder. Executing this package will install the application on the user’s chosen directory and create icons in the user's start menu.

The application can be run via two methods. The first, and most common, is through the GUI. Here, the user must choose the ORDEM2008-GUI.exe in the Application Directory (see Table 2.2.1). This will bring up the application displaying the initial ‘project

window'. The user will need to define a project directory before moving on to running any of the assessment models.

The second method of running ORDEM2008 is either via the DOS command prompt or by creating a batch file. This approach is possible because the GUI is a front end to the Fortran model executable.

Most of the files installed and created in the ORDEM2008 application are found in two separate locations. The Application Directory, noted in Table 2.2.1, holds ORDEM2008 input files, executables for the Fortran program and for the GUI, and the ORDEM2008 User's Guide. The Project Directory (Table 2.2.2) contains the input parameter file and all output files.

Table 2.2.1. Files in Application Directory*

File Name	Description
ORDEM2008.exe	Computational model executable
ORDEM2008-GUI.exe	Graphic User Interface executable
ORDEM2008-GUI.exe.config (XML file)	Default setting for the GUI (These can be altered by the user if desired.)
data/YYYY.POP data/*.SIG data/*.TIG data/*.DAT (three files) data/*.BIN	Input template data files for ORDEM2008 calculations Spacecraft-mode igloo description files Telescope-mode igloo description files Data defining the bin boundaries of the debris populations
ORDEM2008-UserGuide.pdf	User guide for ORDEM2008
TeeChart.dll	Graphics package DLL

* Default location of the Application Directory is c:\Program Files\NASA\ORDEM2008\.

Table 2.2.2. Files in Project Directory**

File Name	Description
ORDEM2008-Project.prj	The saved project values from the GUI.
ORDEM2008-GUI_Log.txt	The project log file.
ORDEM2008.IN	The command file, which holds the parameters for running the model executable.
* _SC.OUT	Spacecraft assessment output files (see Table 2.5.1)
* _TEL.OUT	Telescope assessment output files (see Table 2.5.1)

** Project Directory is located where the user creates it. It is a writable area for running the computational model and saving all the GUI values. The user may create as many project directories as desired.

2.3. Program Installation

The current ORDEM2008 beta program can be downloaded and run via the GUI by the following steps. GUI windows and graph examples are shown here, as well.

1. Access KA Common folder \Horstman Matt\ (user must have access to the common server at JSC),
2. Double click on NASABETA.zip (WinZip will open)
3. Click on “Extract” Icon
4. Select directory in which you wish to save the Beta Version (NASABETA\ folder will be created in the folder selected)
5. WinZip will spend a few moments extracting files
6. Close WinZip
7. In the Application Directory double click on ORDEM2008-GUI.exe,
8. From the GUI initial window (the project window), click the *New* button and select/or create a directory to become the Project Directory,
9. Go to the spacecraft, or telescope/radar, assessment window by clicking the spacecraft, or telescope/radar, icon on the left side in the quick select list,
10. Enter orbital parameters, or telescope/radar position and pointing, and year.
11. Click *Start*.
12. Graphs and data files may be viewed by clicking on *Graphs...*,
13. On the project window, the *View Log* button may be selected to review any past activity.

2.4. Program Execution

ORDEM2008 may be run using the graphical user interface (GUI) or the command-line (a.k.a. “DOS”) interface. The GUI accepts inputs from the user, sets up and performs a single run, and displays the results as on-screen plots. The command-line interface requires the user to supply a separate text input file, and does not produce plots, but allows the user to create their own driver/batch code for serial batch processing.

2.4.1. GUI-based computation

ORDEM2008 has two major assessment types. The first one is for spacecraft and mission designers. The second type gives orbital debris information as would be seen from a ground-based telescope or radar. Resultant plots and data files give estimates of population flux and velocity distributions.

The GUI graphing windows have a number of useful features. The graphs may be zoomed, panned, copied to the clipboard, and exported to various file types. The user may also take the raw output files and manipulate them as desired. The raw output files are column-separated for easy transfer into spreadsheets or visualization programs.

The project window is the initial window upon start up. It shows the location of the user's current project directory. The project directory is the directory location chosen by the user to which all output files and GUI setting will be saved. It is designed this way to allow a user the ability to work with more than one project at a time. Below in Figure 2-2 is a screen shot of the project window.

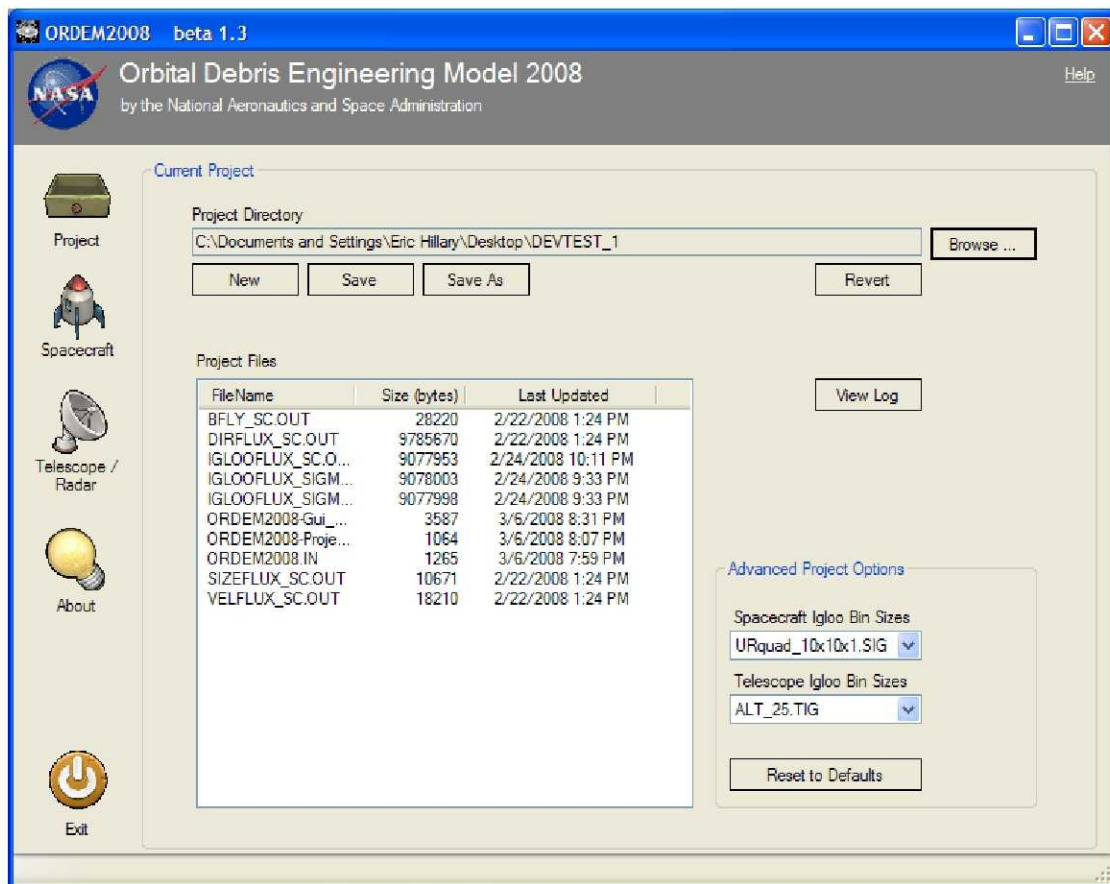


Figure 2-2. ORDEM2008 project window

The top area of the project window displays the currently selected project directory. This directory is the location for all the computational output and GUI settings. The *New* button, when pressed, creates a new project in another location that the user specifies. The application allows the user to save as many projects as desired. To open a previous

project, the user selects the **Browse** button and chooses the desired directory. The **Save** button will save all the current values in the GUI to a file. The **Save As** button allows the user to save the current GUI values into another project directory. The **Revert** button resets all the GUI values to the last saved values.

Near the bottom of the window is a list of files in the project directory. It provides a quick way to access and view any of the files. If double clicked, the file will be opened in another window for viewing. **View Log** will bring up a window allowing the user to view the log of past activity. Lastly, the **Reset to Defaults** button will reset all the GUI values to default values. This includes the currently known project directory in the project window and the system registry (used for loading the last used project on startup).

2.4.1.1. Telescope Assessment

The telescope and radar assessment window is provided for modeling the orbital debris environment as viewed from a ground-based telescope or radar. Figure 2-3 shows the Telescope/Radar Assessment Window.

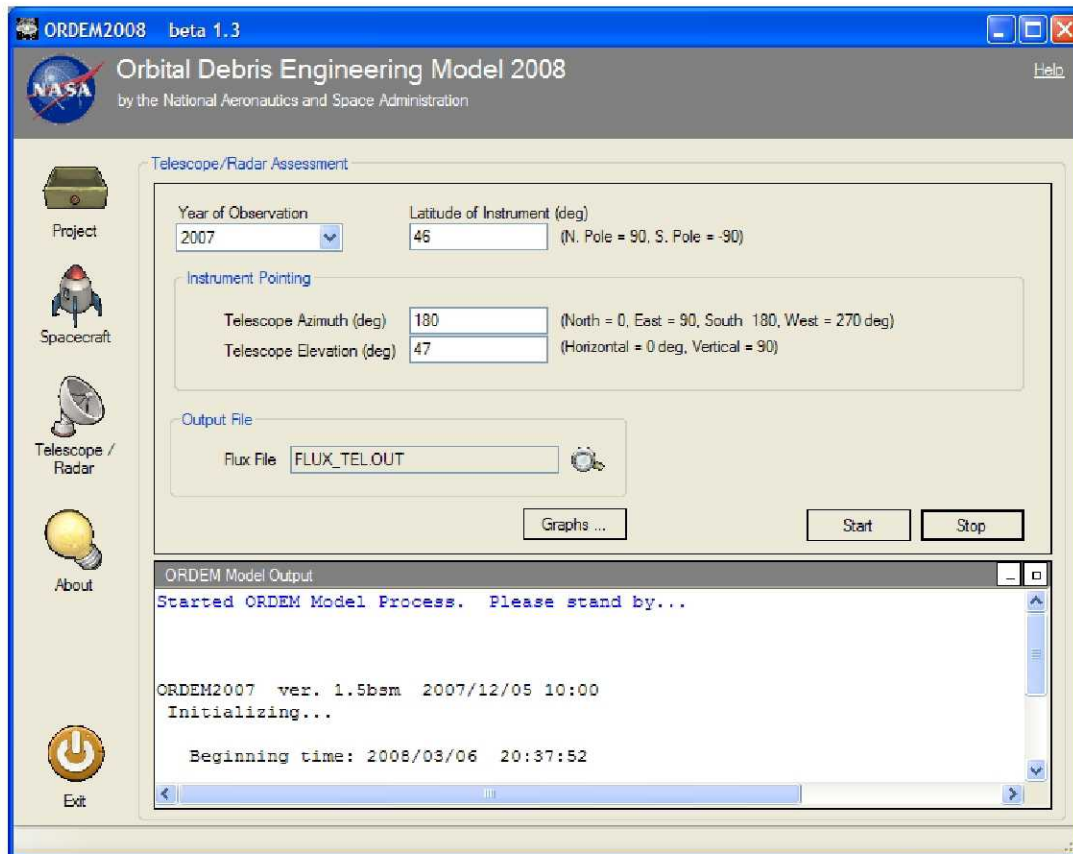


Figure 2-3. ORDEM2008 telescope/radar assessment window

This window is very similar in functionality to the spacecraft assessment window. There are fields for the inputs, start and stop buttons for running the model, and buttons for viewing the output. There is a single output files for Flux vs. Altitude: LEO only,

LEO+GEO, and GEO only. This file may be viewed by clicking the icon to the right of the file name, the **Graphs...** button. The full description of these graphs is in the next section.

2.4.1.2. Spacecraft Assessment

The spacecraft assessment window is used for evaluating the orbital debris environment for spacecraft and missions. This window contains the input fields at the top, and the runtime output window at the bottom. After running the computational model the user can view five output files and graphs: average flux vs. size, three views of a directional flux butterfly, and a velocity flux distribution. Figure 2-4 shows a screen shot of the spacecraft window. The files may be viewed by clicking the icon to the right of the file name, the graphs by clicking the graph button. The full description of these graphs can be found in the Section 2.5.

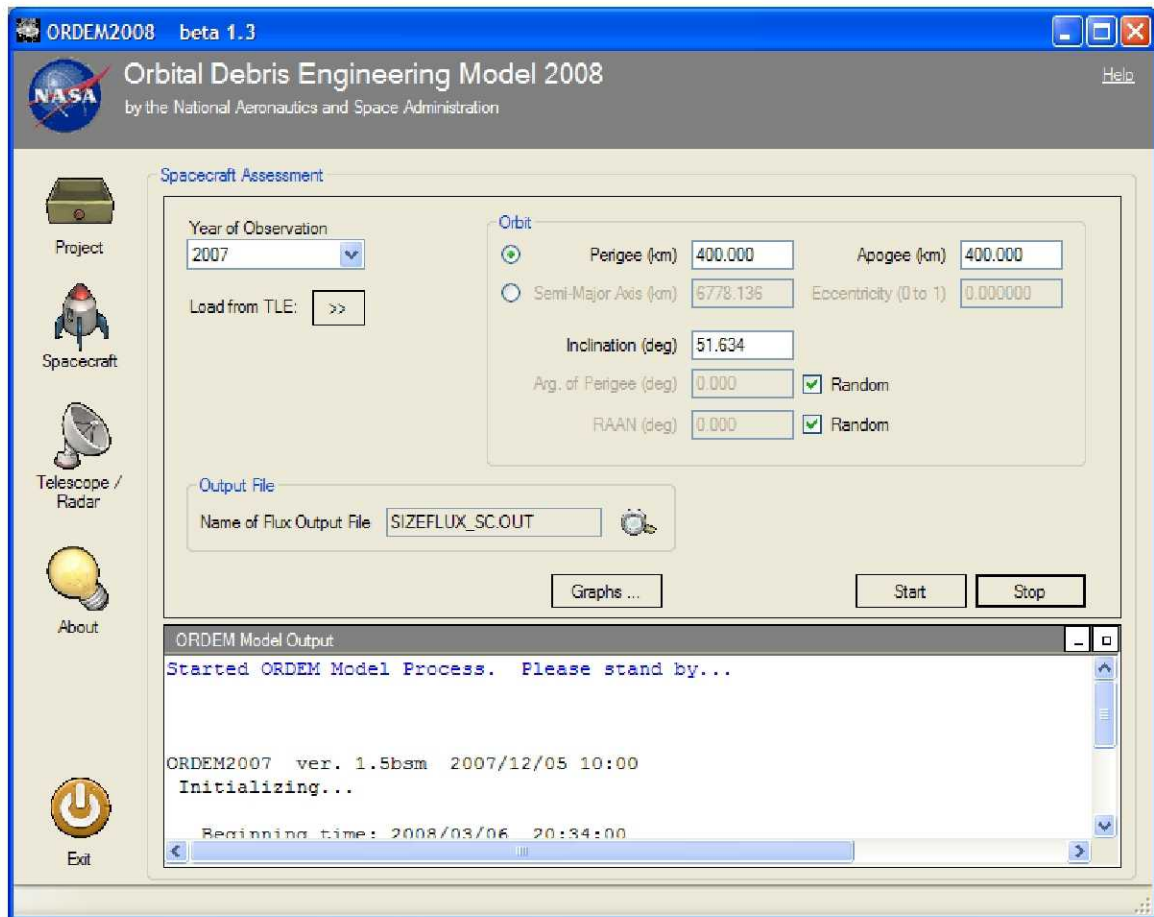


Figure 2-4. ORDEM2008 spacecraft assessment window

The input fields can be loaded from a Two Line Element (TLE) file or entered by hand. When entering by hand the user can define the orbit by perigee/apogee altitude or semi-major axis/eccentricity. Argument of perigee and RAAN may also be defined, but for most circular orbits, the random option is suggested.

To load from TLE click on the *Load from TLE* button on the left. Figure 2-5 shows the pop up window that will be displayed for decomposing a TLE.

Figure 2-5. ORDEM2008 spacecraft assessment TLE window

The TLE window allows the user to specify the TLE by loading from file, hand typing, or pasting into the TLE area. The *Calculate* button will break down the TLE into the various orbital parameters. If these are the desired values the user must click the *Accept* button. The TLE breakdown values will then appear in the spacecraft assessment window. The *Cancel* button will close this window, and the *Clear* button will clear the TLE area.

After all the input parameters are set in the spacecraft assessment window, the user may click the *Start* button to the right to begin the computations. The *Stop* button to the right is provided to abort a run. Immediately below the *Start* and *Stop* buttons is the *ORDEM 2008 Model Output* area. After clicking the *Start* button the model process will be started and the output messages will be redirected into this output area. Output messages from the model will be written in black text for normal messages and red text for error messages. The GUI will write other informative messages in blue text.

2.4.2. Command-line-based computation

ORDEM2008 can be run from the Windows command prompt or a batch file. The computational model is a separate executable file from the GUI. When the GUI is used, it produces a file called ORDEM2008.IN and then calls the computational model, which reads this file for input values. Running from the command line requires the user to

manually edit the ORDEM2008.IN input file. This file holds all the values needed to run the simulation. The file is well commented to assist in editing if needed (the user may wish to first create the file using the GUI).

To run, the user must set the current directory as the ORDEM2008.exe Application Directory. Then from the command line, the user must enter:

> ORDEM2008 [ProjectDirectoryPath]\

This will run the model and the user will see the output messages as it is running. Output files can be found in the project directory. No plots are produced when ORDEM2008 is run from the command line. The GUI can be used to plot output files generated in command-line mode.

2.5. Input Data

The input population files, derived in Step 3 of Figure 2-1, form the direct input database of the model. They are categorized by year (YYYY.POP). For non-geosynchronous populations these file contain debris population counts within preset bins of perigee, eccentricity, and inclination as shown in Table 2.5.1. Bin sizes are chosen to complement actual population distributions. Similarly for geosynchronous populations, mean motion and right-ascension of ascending node are binned in addition to eccentricity and inclination, as shown in in Table 2.5.2.

Table 2.5.1. Input file population bins for non-GEO

Parameter	Binning intervals	Total # bins
Perigee altitude, H_p	$100 \leq H_p < 2000 \text{ km} \rightarrow 33.33 \text{ km bins}$ $2000 \leq H_p < 10,000 \text{ km} \rightarrow 100 \text{ km bins}$ $10,000 \leq H_p < 40,000 \text{ km} \rightarrow 200 \text{ km bins}$	287
Eccentricity, \sqrt{e}	$0 \leq \sqrt{e} < 1 \rightarrow 0.01333 \text{ bins}$	74
Inclination, i	$0^\circ \leq i < 180^\circ \rightarrow 0.75^\circ \text{ bins}$	240

Table 2.5.2. Input file population bins for GEO

Parameter	Binning intervals	Total # bins
Mean Motion, MM	$0.497 \leq MM < 1.757 \rightarrow 0.01 \text{ rev/day bins}$	126
Eccentricity, \sqrt{e}	$0 \leq \sqrt{e} < 0.5 \rightarrow 0.02 \text{ bins}$	25
Inclination, i	$0^\circ \leq i < 0.2^\circ \rightarrow 0.2^\circ \text{ bins}$ $0.2^\circ \leq i < 1.0^\circ \rightarrow 0.8^\circ \text{ bins}$ $1^\circ \leq i < 25^\circ \rightarrow 1^\circ \text{ bins}$	26
Right ascension of ascending node, RAAN	$0^\circ \leq i < 360^\circ \rightarrow 5^\circ \text{ bins}$	72

2.6. Output Data and Graphs

Each of the graph windows works in the same way and each provides similar features. A series of buttons in the upper left menu bar area for each graph window that provide the following functions:

1. **Reset** – selecting this button resets the graph window. If zooming and reformatting of the graph takes place, the Reset button reverts the graph to the original setup.
2. **Copy** – selecting this button copies the graph to the clipboard, so the graph can be pasted directly into another document, such as a document editor.
3. **Export** – this button presents the user with a dialog from which they can select a number of image formats for exporting, such as jpg, etc.
4. **Configure** – this option presents a graph setup window from which almost any aspect of the graph can be customized. Axis limits, titles, line colors, etc. can all be customized using the controls presented in this window.
5. **Print** – this button causes a print preview window to be displayed. The user can then select the print button from that window, and the graph will be sent to the selected printer.

There are also some standard capabilities available to the user within the graph window. Zooming is supported through the left mouse button. Simply select the zoom region by pressing and holding the left mouse button over the upper left corner of the area to be magnified, and drag the mouse cursor down and to the right until the entire zoom region is selected, then releasing the mouse button. At this point, panning is supported by pressing and holding the right mouse button, while dragging the graph as needed. Note that the results of a pan movement for a plot that has a logarithmic axis may give unexpected results.

To undo any zoom magnification and return to the original full graph, reverse the zoom movement of the mouse by pressing and holding the left mouse button and dragging the cursor to the left and up. When the mouse button is released, the graph will return to its original magnification state.

ORDEM output files are generated for the two analysis modes: spacecraft and telescope/radar. The files represent the debris fluxes encountered by the chosen spacecraft or telescope/radar beam. The fluxes are categorized mainly by size. **Table 2.6.1** lists files and descriptions.

Table 2.6.1. Files output by ORDEM2008 modes.

File Name	Description
Spacecraft assessment output files	
IGLOOFLUX_SC.OUT	Igloo element fluxes and velocities. Intermediate file.
IGLOO_FLUX_SIGMAPOP_SC.OUT	Correlated population error estimates
IGLOOFLUX_SIGMARAN_SC.OUT	Random error estimates
SIZEFLUX_SC.OUT	Average impact flux vs. size on the spacecraft along its orbit. Graph input.
VELFLUX_SC.OUT	Impact velocity distribution on the spacecraft along its orbit. Graph input.
BFLY_SC.OUT	Fluxes vs. yaw (collapsed in pitch) in the spacecraft frame. Graph input.
DIRFLUX_SC.OUT	Fluxes in 2-D map projection in the spacecraft frame. Graph input.
Telescope/Radar assessment output files	
ALTFLUX_TEL.OUT	Surface area flux vs. altitude of debris of a given size. Graph input.

The *Graphs...* button in either the spacecraft or telescope/radar assessment window initiates a window, from which different graphical output is generated. Figure 2-6 displays the current graphing window for the spacecraft assessment.

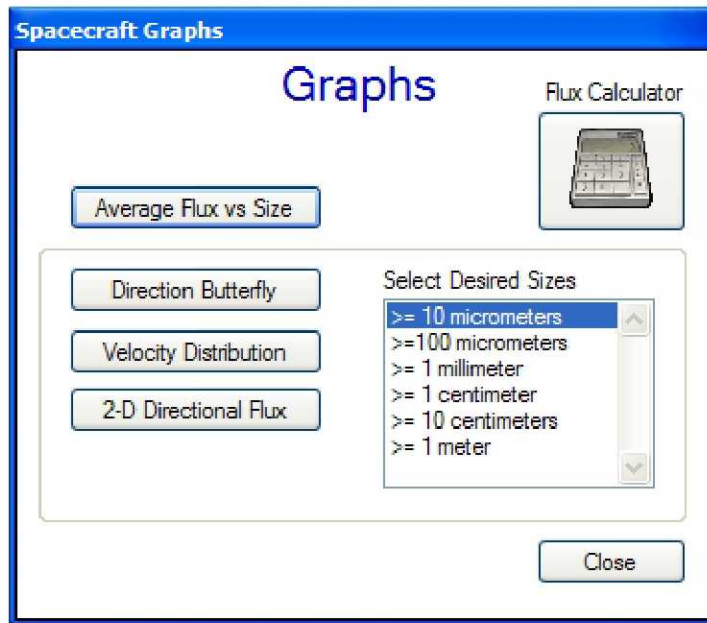


Figure 2-6. ORDEM2008 spacecraft assessment graphing window

An example of the *Average Flux vs Size* along the chosen spacecraft orbit is shown in Figure 2-7. Given the proven utility of this chart and underlying data a *flux calculator* is also included in the spacecraft assessment option. This function calculates flux given any value along the curve (Figure 2-8).

Examples of the three *Direction Butterfly* graphs are presented in Figure 2-9 through Figure 2-11. Figure 2-9 and Figure 2-10 represent average directional fluxes on the spacecraft from all directions in three-dimensions that are summed and then collapsed to the two-dimensional spacecraft plane containing velocity vector and the angular momentum vector. The 3-D average flux on the spacecraft is fully realized in the mapped 2-D directional flux projection in Figure 2-11. Debris velocity distribution on the spacecraft is displayed in Figure 2-12.

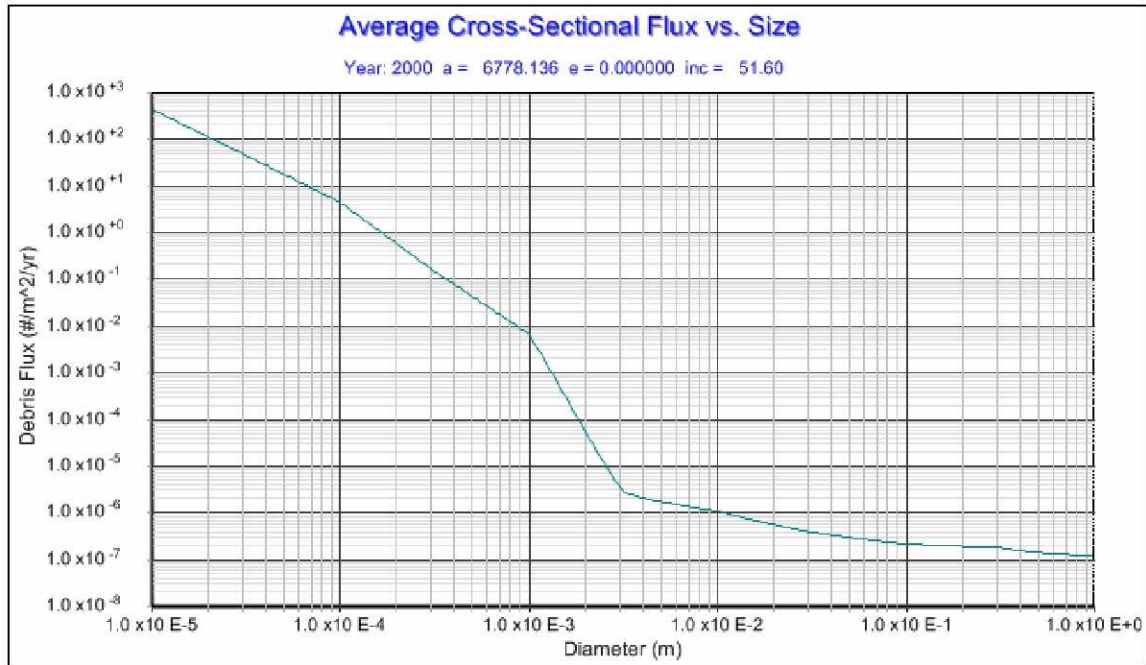


Figure 2-7. Spacecraft assessment average flux vs. size graph

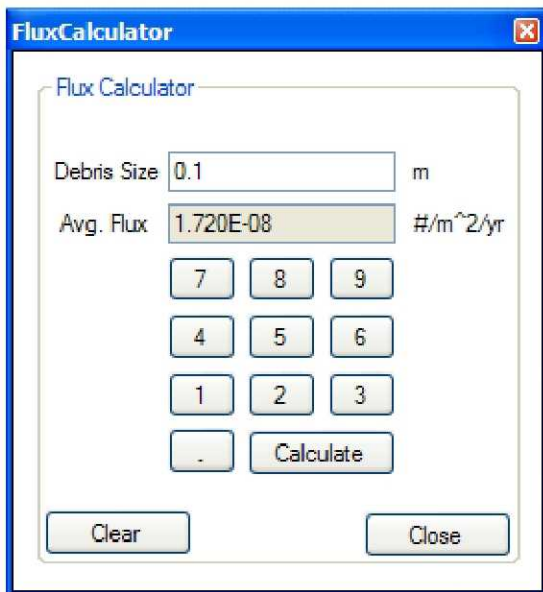


Figure 2-8. Spacecraft assessment flux calculator

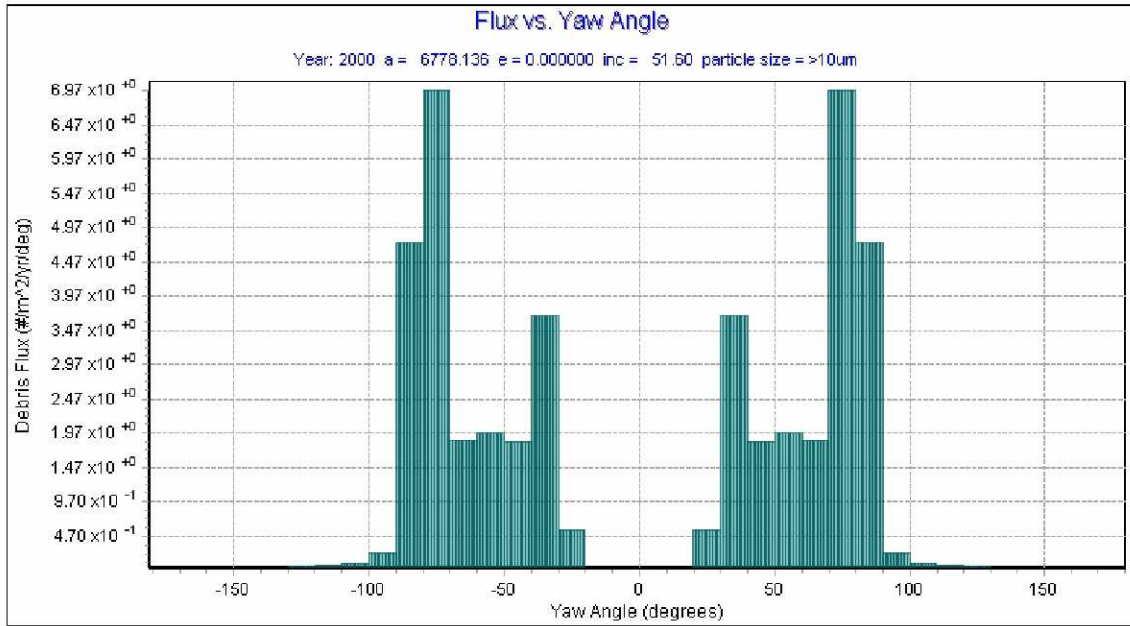


Figure 2-9. Spacecraft assessment skyline butterfly graph

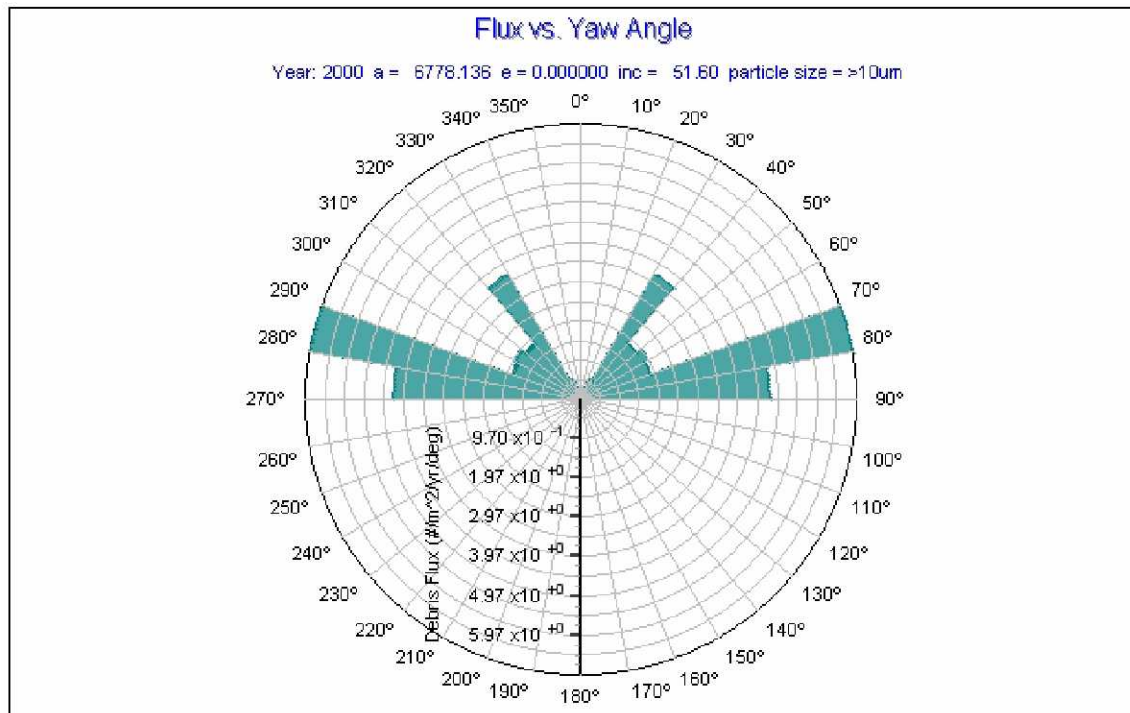


Figure 2-10. Spacecraft assessment radial butterfly graph

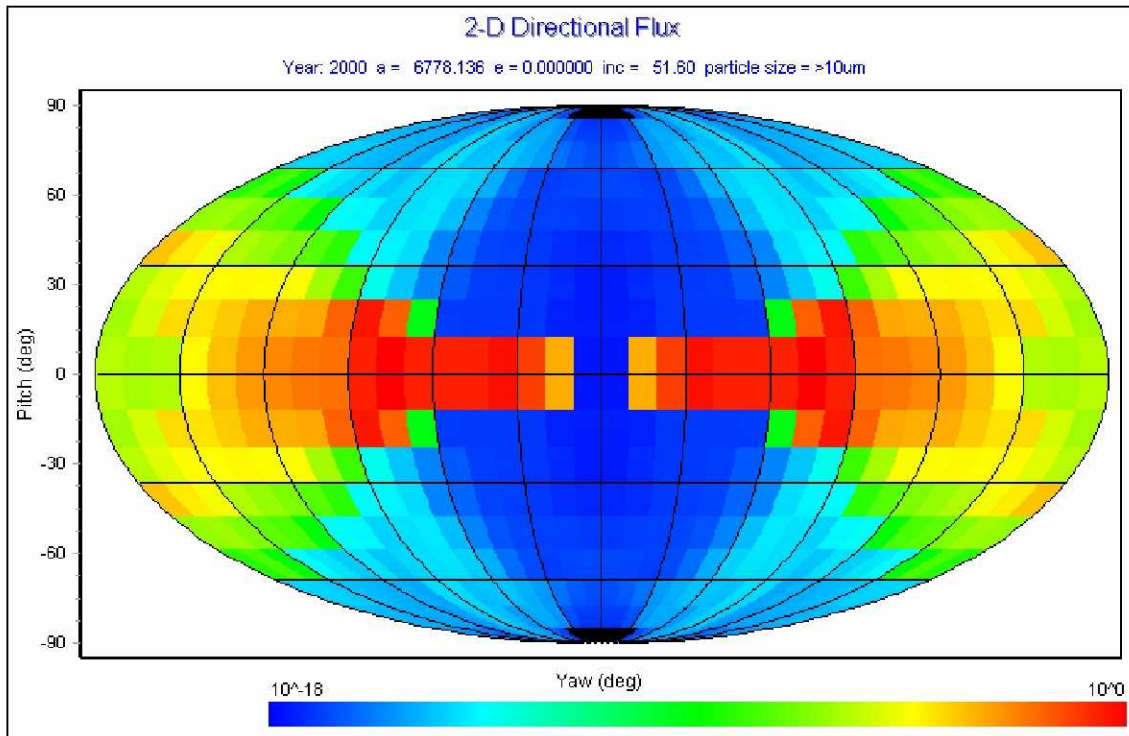


Figure 2-11. Spacecraft assessment 2-D directional flux projection

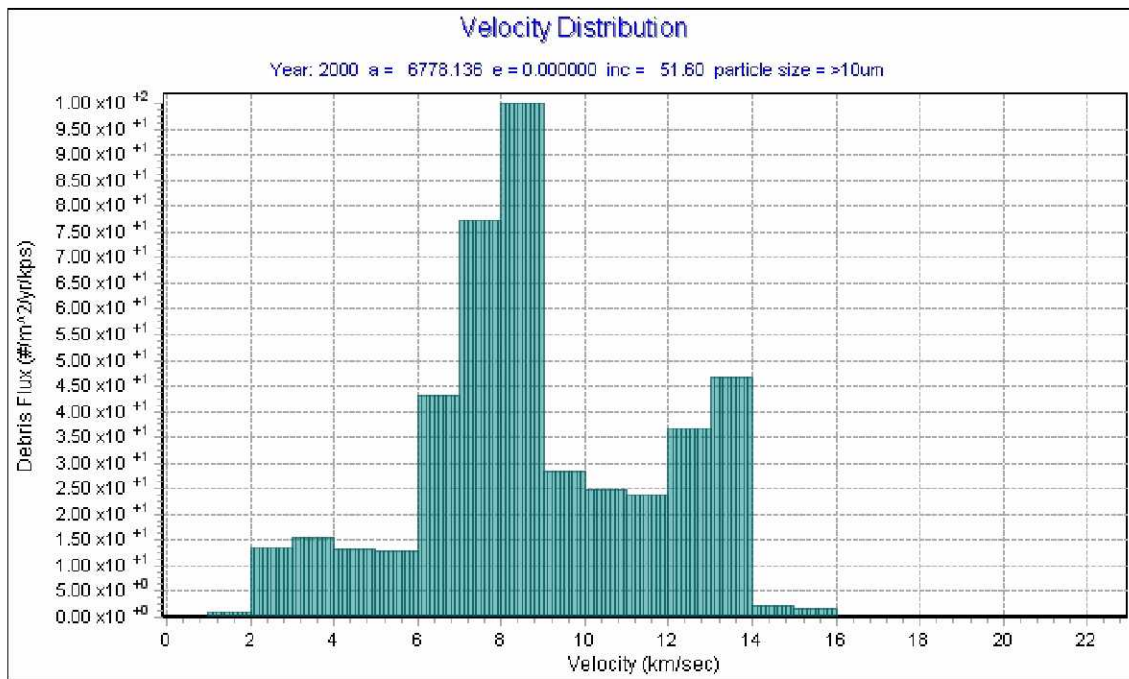


Figure 2-12. Spacecraft assessment velocity flux distribution

Figure 2-13, below, displays the current graphing window for the telescope/radar assessment.

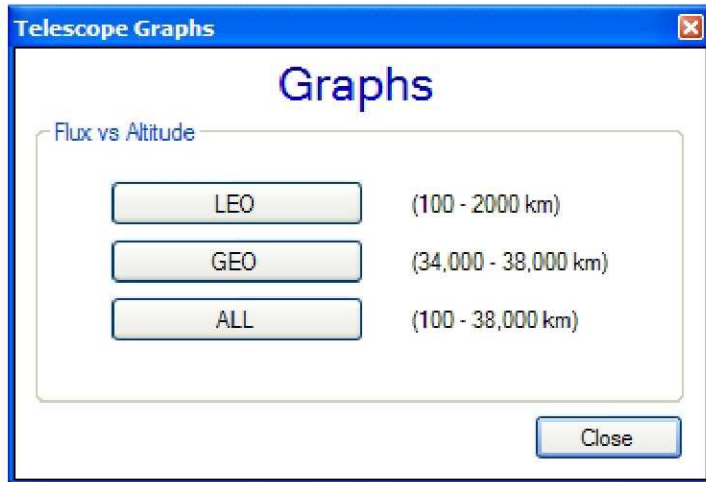


Figure 2-13. ORDEM2008 telescope/radar assessment graphing window

An example of a *Flux vs Altitude* graph is displayed in Figure 2-14 for the LEO-only case. The other two cases, LEO+GEO and GEO-only, can be construed from this one. The cutoffs of data of different debris sizes, noted in **Table 2.1.1**, are clearly represented in the curves of $> 10 \mu\text{m}$ and $> 100 \mu\text{m}$ objects. It must be clear that these cutoffs are based on the availability of data in the prescribed regions of space and not on any actual deficit of particles in those regions.

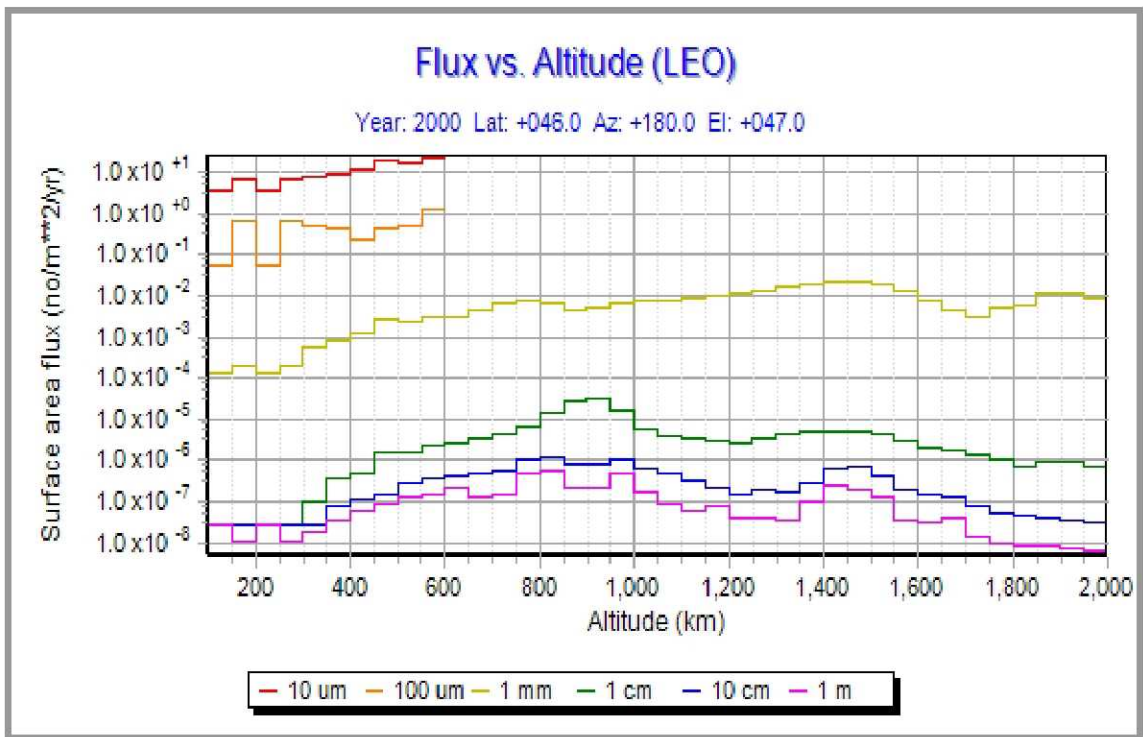


Figure 2-14. Telescope/radar assessment flux vs. altitude, LEO-only graph

A. Appendix A: ORDEM2008 Runtime Estimates for Spacecraft Assessment Model

The nature of ORDEM2008 dictates that for a random target orbit, there exists the potential for an infinite number of intersecting debris orbits. Some areas of space are more active than others in the way other orbit regimes intersect them. Initial tests of ORDEM2008 runtime performance show that sample cases of both Satellite and Telescope mode can take anywhere from 7 minutes to 4 hours. These results are displayed below in Tables A.1 and A.2 with companion Figures A-1 and A-2. They are provide as a guide for beta testers.

Table A.1. Spacecraft mode runtime test parameter list

	GEO1	GEO2	LEO1	LEO2	GTO1	GTO2
Perigee Altitude (km)	35863	35863	342	200	200	400
Apogee Altitude (km)	35863	35863	353	1000	40000	26000
Inclination (deg)	0	0	51.64	10	1.5	25
RAAN (deg)	<i>RANDOM</i>	37	<i>RANDOM</i>	<i>RANDOM</i>	<i>RANDOM</i>	42
Argument of Perigee (deg)	<i>RANDOM</i>	129	<i>RANDOM</i>	<i>RANDOM</i>	<i>RANDOM</i>	27

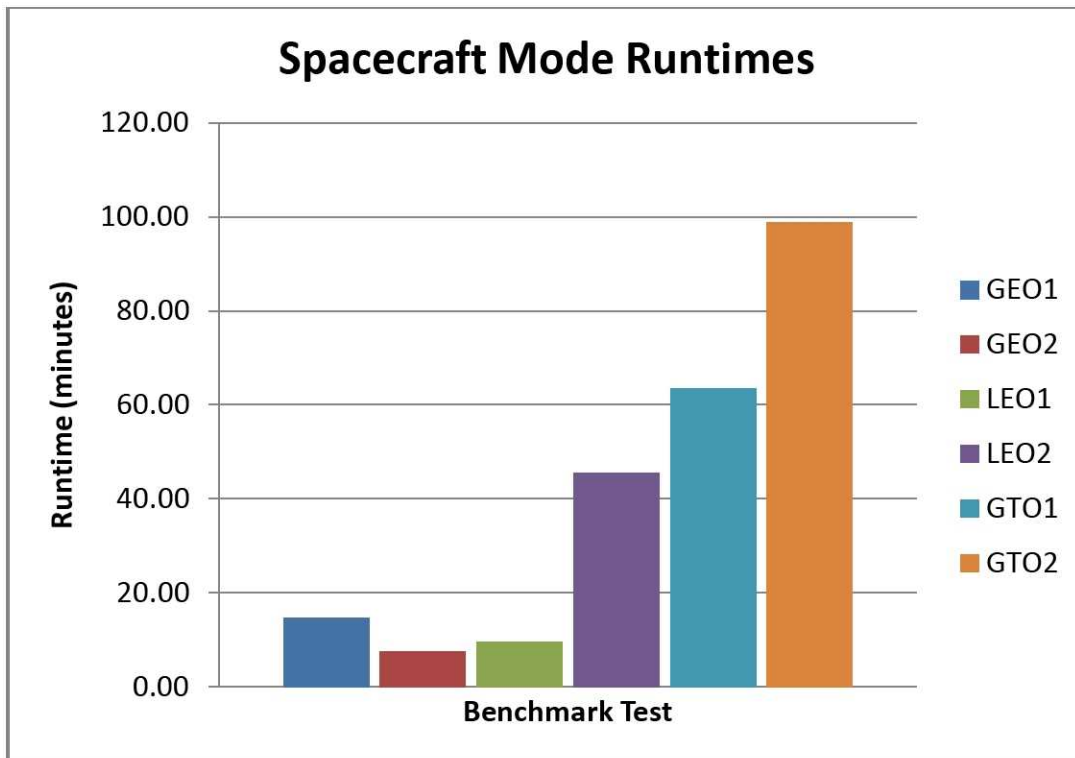


Figure A-1. Graphical display of Spacecraft mode test runtimes

Table A.2. Telescope mode runtime test parameter list

	Latitude	Azimuth (deg)	Elevation(deg)	Range
Case 1	46	90	75	All
Case 2	46	90	75	LEO
Case 3	46	90	75	GEO
Case 4	0	90	90	All
Case 5	0	90	90	LEO
Case 6	0	90	90	GEO
Case 7	-46	180	20	All
Case 8	-46	180	20	LEO
Case 9	-46	180	20	GEO

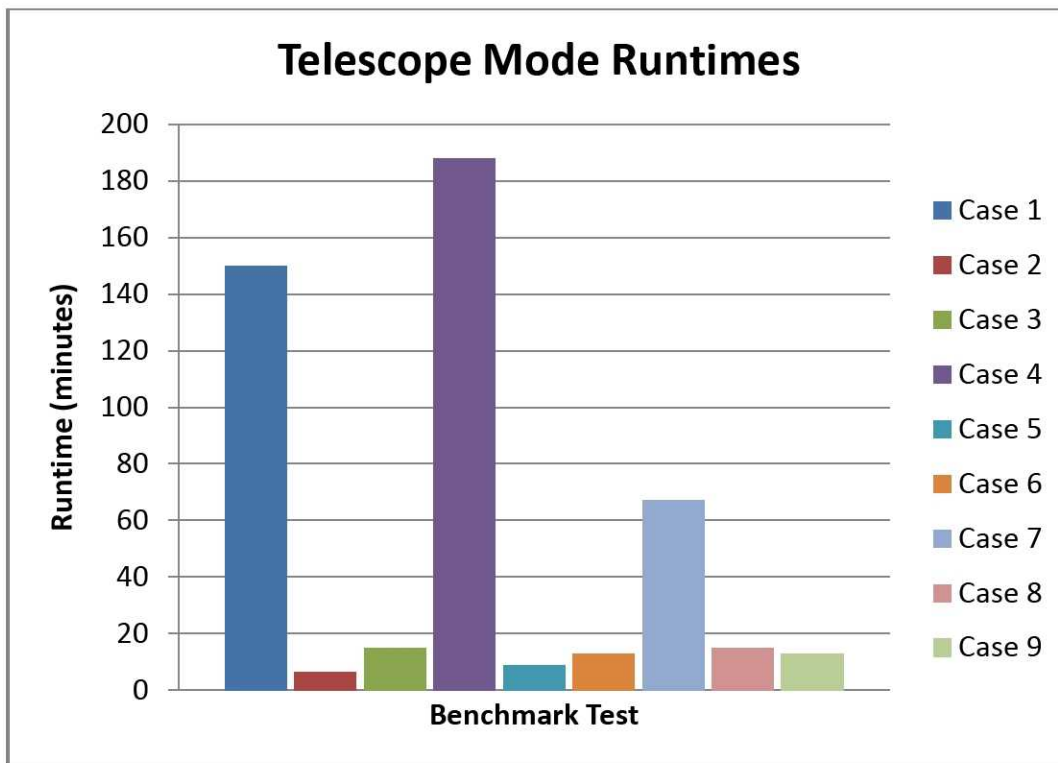


Figure A-2. Graphical display of Telescope mode test runtimes