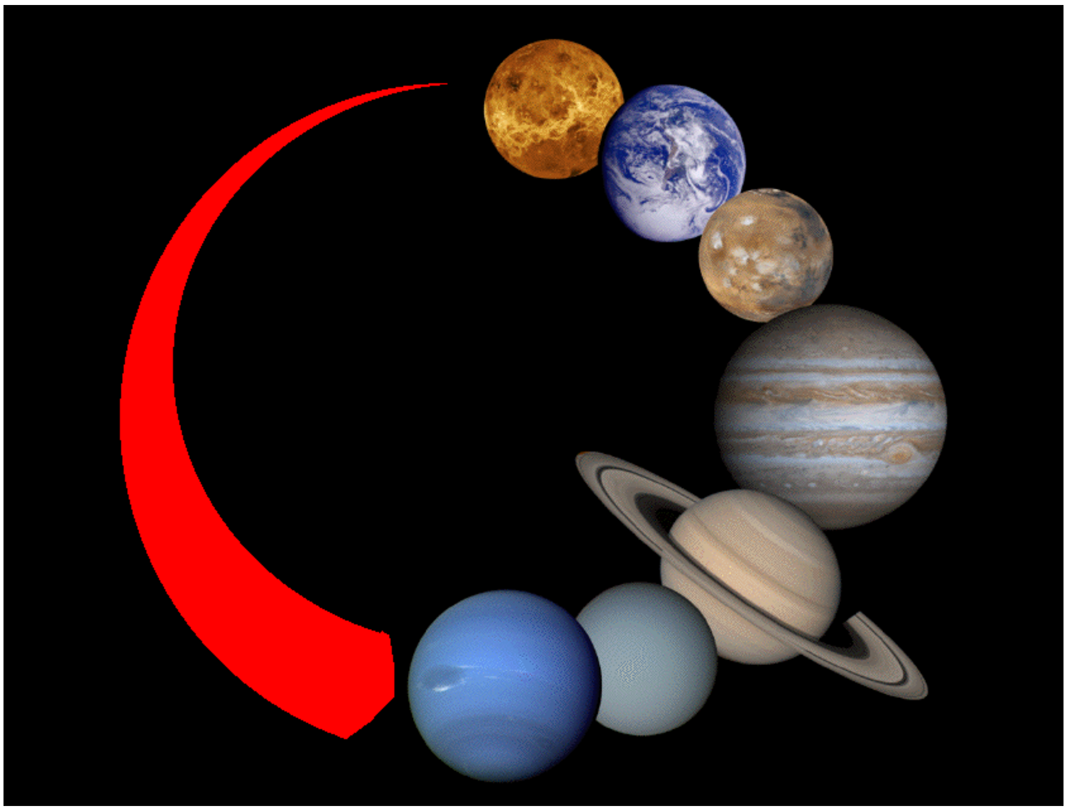
HyperPASS

Hypersonic Planetary Aeroassist Simulation System

Version 2.0

User and Installation Manual



June 21, 2013

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1 Introduction

The Hypersonic Planetary Aeroassist Simulation System (HyperPASS) is an aeroassist simulation software package coded using the MATLAB language. HyperPASS is intended for doing mission studies of aerocapture systems at planets with atmospheres and for carrying out trade studies to investigate performance with alternate aeroshell and ballute types, varying flight path angle and entry velocity, different g-load limits, angle of attack and angle of bank variations.

HyperPASS enables users to perform simulations at any of six planetary bodies (Venus, Earth, Mars, Jupiter, Saturn, Titan, Uranus or Neptune) using pre-programmed vehicles or user-entered vehicles. It allows users to perform trade study simulations without prior knowledge of MATLAB, by way of graphical user interfaces (GUIs). Functions currently implemented include Unguided Aeroassist Simulations, Guided Aerocapture Simulations, Guided Ballute Aerocapture Simulations, Aerobraking Simulations, and Orbit Decay Simulations.

During mission setup, the planet, atmosphere, gravity model, and vehicle parameters are chosen. Atmosphere models are exponentially interpolated tables. HyperPASS includes numerous atmosphere tables or the user can enter his own (up to 21 data points). Gravity models include inverse-square rotating, J2 rotating, and inverse-square non-rotating. HyperPASS currently assumes that the atmosphere rotates with the planet. Therefore, simulations specifying a non-rotating model assume zero atmosphere rotation and zero planet rotation. In such cases, inertial and planet relative values are equal. Vehicles include Apollo, Viking, Elliptical Raked-Cone, 45^0-Half-Cone, Sphere, Torus, or user-entered Custom models (e.g. aerodynamic coefficients as functions of Knudsen number or Mach number).

After completing a simulation, the simulation data can be saved, plotted, or exported to another format. If the user chooses to save the simulation, it can be reloaded at a later time using HyperPASS' "View Previous Simulation" option.

If any problems are encountered during the use of HyperPASS, please send an email to global@gaerospace.com describing the nature of the problem. Also, specify if you prefer to be contacted by telephone or through email.

2 Installing HyperPASS

2.1 System Requirements

2.1.1 PC

MATLAB Version 7.5 (R2007b) or higher. HyperPASS may work on earlier versions of MATLAB but has not been tested on any version earlier than indicated.

2.1.2 Macintosh

MATLAB Version 7.8 (R2009a) or higher. HyperPASS may work on earlier versions of MATLAB but has not been tested on any version earlier than indicated.

2.1.3 UNIX

TBD

2.2 PC Installation

NOTE: The following steps assume that MATLAB is already installed on the user's system. If MATLAB is not installed, be sure to install it prior to beginning HyperPASS installation.

EASY INSTALLATION:

- Insert HyperPASS CD-ROM into drive and open.
- Copy HyperPASS folder into the desired location on your computer.
- It is recommended that you copy it to a location with an easy "path" (i.e. C:\HyperPASS).
- Each time you wish to start HyperPASS, first start Matlab and select the HyperPASS folder (now saved on your computer) as the Matlab "Current Directory".
- To open HyperPASS, type *startup* in the Matlab Command Window.

ALTERNATE INSTALLATION:

- Insert HyperPASS CD-ROM into drive and open.
- Copy HyperPASS folder into the desired location on your PC.
- It is recommended that you copy it to a location with an easy "path" (i.e. C:\HyperPASS).

- Return to your Desktop and “Right-click” on the existing MATLAB shortcut icon and select “Create Shortcut”. (The MATLAB shortcut icon is automatically placed on your Desktop when MATLAB is installed).

Figure 2-1 MATLAB shortcut icon (courtesy of MathWorks)

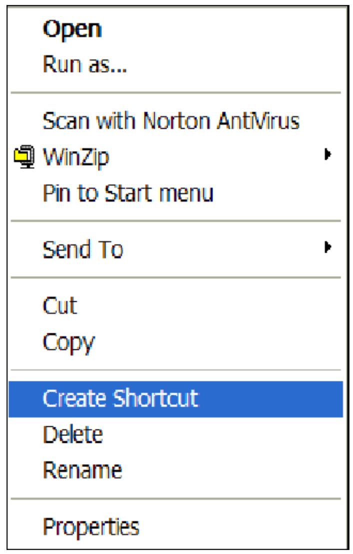

Figure 2-2 “Create Shortcut”

- “Right-click” on the newly created shortcut and select “Rename”. Rename the shortcut “HyperPASS”.

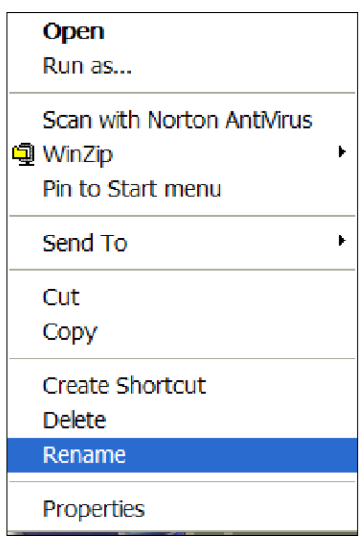

Figure 2-3 “Rename”

- “Right click” on the newly created HyperPASS shortcut and select “Properties.”

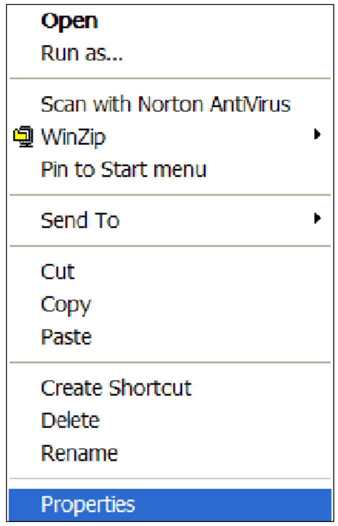

Figure 2-4 "Properties"

- Select the "Shortcut" Tab in the Properties Window.

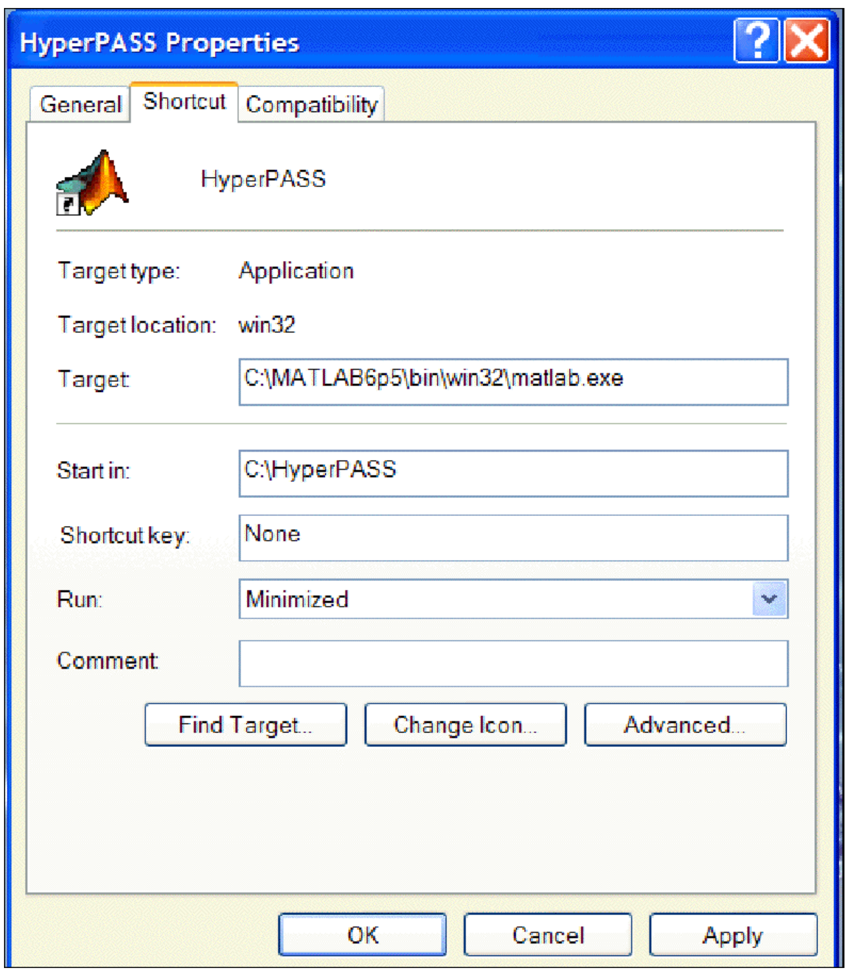

Figure 2-5 Properties Window – "Shortcut" Tab

- Where it says “Start in:” type the path where HyperPASS is located. If the path is incorrect, HyperPASS will not run.
- Click “Apply”. If the path is typed incorrectly, a warning will appear.
- Once the path is correct, click “OK” to close the Properties Window.
- This completes the installation process. “Double-click” on the new HyperPASS shortcut icon to begin HyperPASS. If the HyperPASS GUI is displayed, installation was successful.

2.3 MAC Installation

NOTE: The following steps assume that MATLAB is already installed on the user’s system. If MATLAB is not installed, be sure to install it prior to beginning HyperPASS installation.

- Insert HyperPASS CD-ROM into drive and open.
- Copy HyperPASS folder into the desired location on your computer.
- It is recommended that you copy it to a location with an easy “path”.
- Each time you wish to start HyperPASS, first start Matlab and select the HyperPASS folder (now saved on your computer) as the Matlab “Current Directory”.
- To open HyperPASS, type *startup* in the Matlab Command Window.

2.4 UNIX Installation

TBD

3 GUI Descriptions

This section describes all the GUIs used in HyperPASS.

3.1 HyperPASS GUI

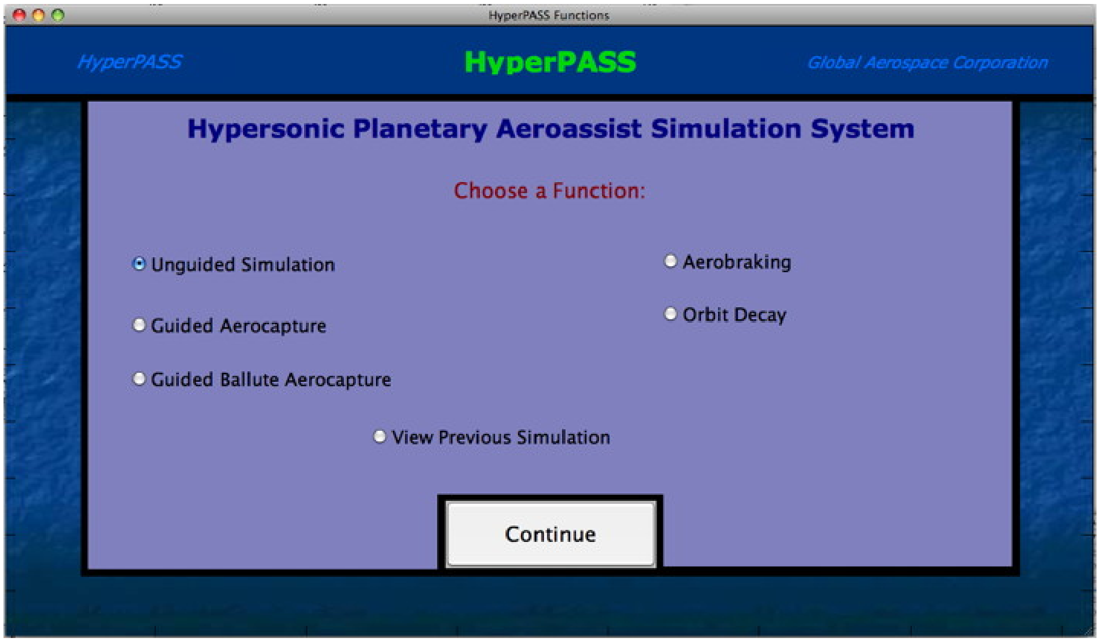

Figure 3-1 HyperPASS GUI

The HyperPASS GUI appears when HyperPASS is started or restarted. The user selects the desired function and then presses "CONTINUE". For function specific information, see Section 4.

3.2 Mission Setup GUI

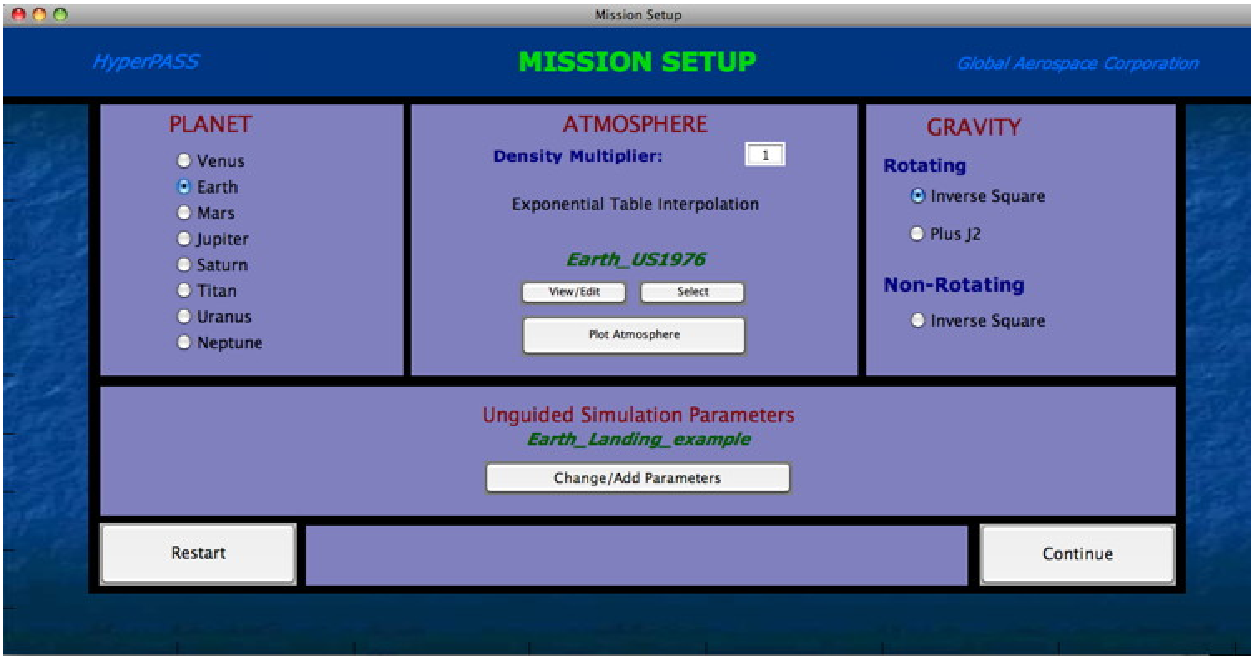

Figure 3-2 Mission Setup GUI

The Mission GUI appears after selecting a function from the HyperPASS GUI. This is where the user sets up the simulation.

*****WARNINGS*****

– Do NOT attempt to make changes to the MATLAB "Command" window while using HyperPASS. To do so may cause damage to HyperPASS requiring reinstallation.

– Before selecting "Continue" in the Mission Setup GUI, be sure to close any other GUIs (e.g. Simulation Parameters, Table Interpolated Atmosphere, and Add Ballute) by selecting "Continue" in those respective GUIs.

– When saving new files, only use letters, numbers and underscores. When saving these files avoid including periods, brackets, spaces, etc., otherwise the saved files will not be recognized by the program later.

3.2.1 Planetary Bodies

(See Section 8.2 for specific planet/moon information and constants)

- Venus
- Earth
- Mars
- Jupiter
- Saturn
- Titan
- Uranus

- Neptune

3.2.2 Atmosphere

(see Section 8.4 for default atmosphere information)

- Density Multiplier (Not Included in this version of HyperPASS)
  - Allows the user to scale the atmospheric density. (i.e. if density multiplier = 2, the density is increased by 200%)
- "Plot Atmosphere" Pushbutton
  - Plots the currently selected altitude vs. density & temperature profiles.

- Table Interpolation
  - "View/Edit" Pushbutton
    - Displays atmosphere table in the Table Interpolated Atmosphere GUI (see Section 3.3) allowing the user to view the currently selected atmosphere file and make changes if desired.
    - Only displays atmospheres containing up to 21 data points. For larger tables, use the "Plot Atmosphere" Pushbutton to view the atmosphere profile.

  - "Select" Pushbutton
    - Prompts the user to select an atmosphere profile from all available table profiles for the selected planet.

3.2.3 Gravity

- Rotating Planet – uses the Rotating Equations of Motion to propagate the trajectory.
  - Inverse Square – uses the inverse-square gravitational model.
  - J2 – uses the Zonal Harmonic J2 gravitational model.

- Non-Rotating Planet – uses the Non-Rotating Equations of Motion to propagate the trajectory.
  - Inverse Square – uses the inverse-square gravitational model.

3.2.4 Simulation Parameters

- The filename of the mission's simulation parameters is displayed.
- "Change/Add" Pushbutton
  - Opens the function specific Simulation Parameter GUI for viewing or to make changes.
  - See Sections 3.4 and 4.2.

3.3 Atmosphere GUIs

3.3.1 Table Interpolated Atmosphere GUI

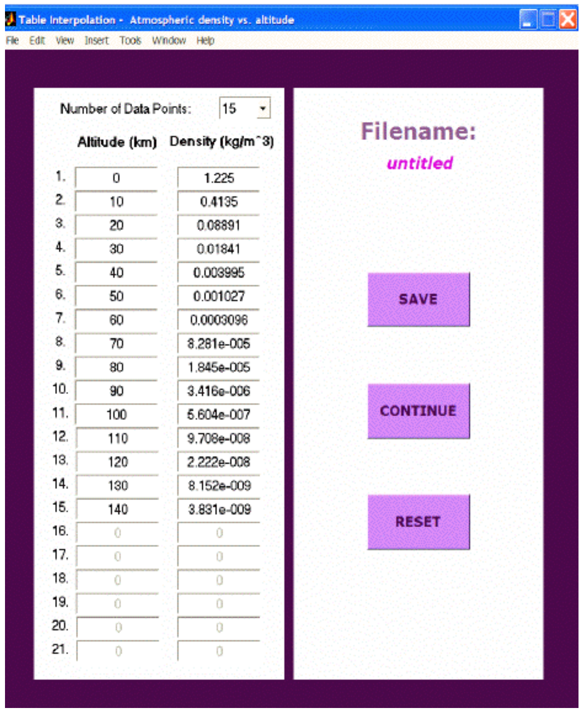

Figure 3-3 Table Interpolated Atmosphere GUI

The Table Interpolated Atmosphere GUI allows the user to view the currently selected atmosphere file and make changes if desired. **See warning in Section 3.2 about prematurely starting a run before closing this GUI.**

- "Number of Data Points" Pull-down Menu
  - Allows the user to change the number of atmospheric data points displayed (2 – 21 points).

- "Save" Pushbutton
  - Prompts the user to save any changes to the atmosphere table under a different file name.

- "Continue" Pushbutton
  - Returns the user to the Mission Setup GUI. If any changes were made without being saved, the filename will be displayed as "untitled".

- "Reset" Pushbutton
  - Resets the atmosphere table to its original set of values. If no changes were made, the values will remain the same.

3.4 Simulation Parameters GUIs

The format of this GUI will change depending upon the selected function. The various Simulation Parameter GUIs are displayed below. For additional information on each, refer to Section 4.2, "How to run each function." Also, custom vehicle models (CL/CD vs. Kn and CL/CD vs. Mach) can be entered and saved using the Unguided Simultion GUI's vehicle pulldown menus, See Section 3.5. **See warning in Section 3.2 about prematurely starting a run before closing these GUIs.**

3.4.1 Unguided Simulation Parameters GUI

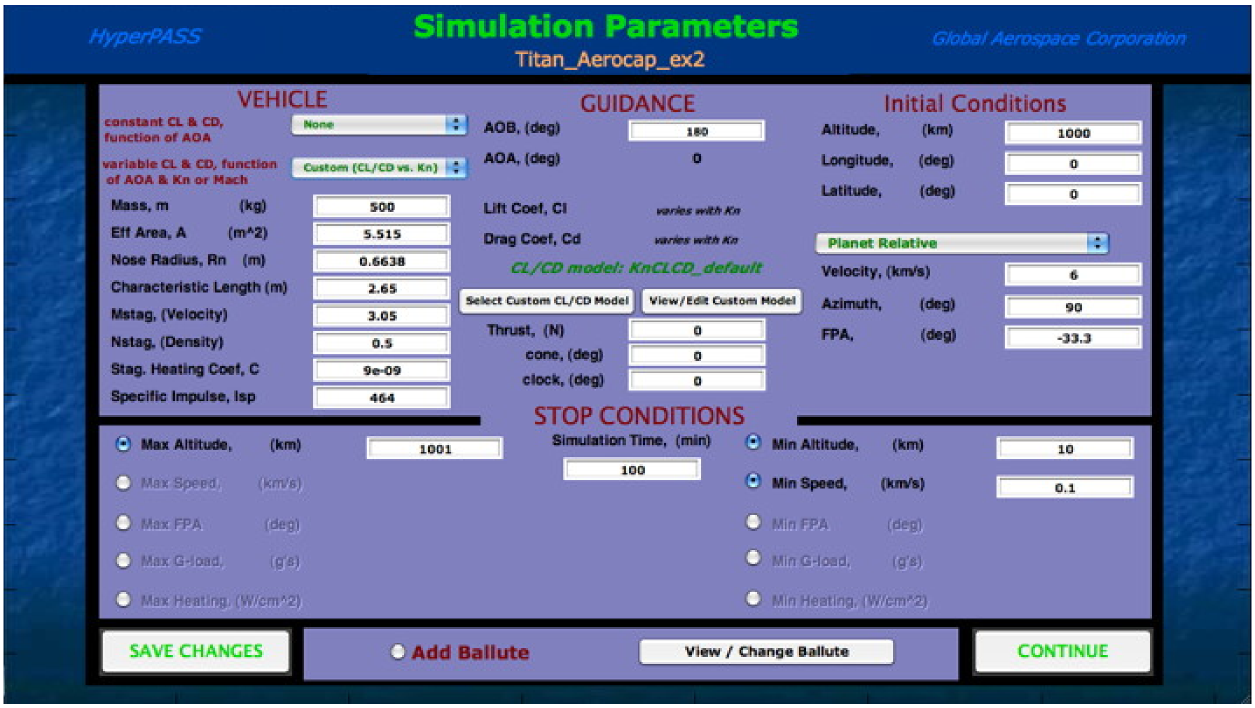

Figure 3-4 Simulation Parameters GUI - Unguided

3.4.2 Guided Aerocapture Simulation Parameters GUI

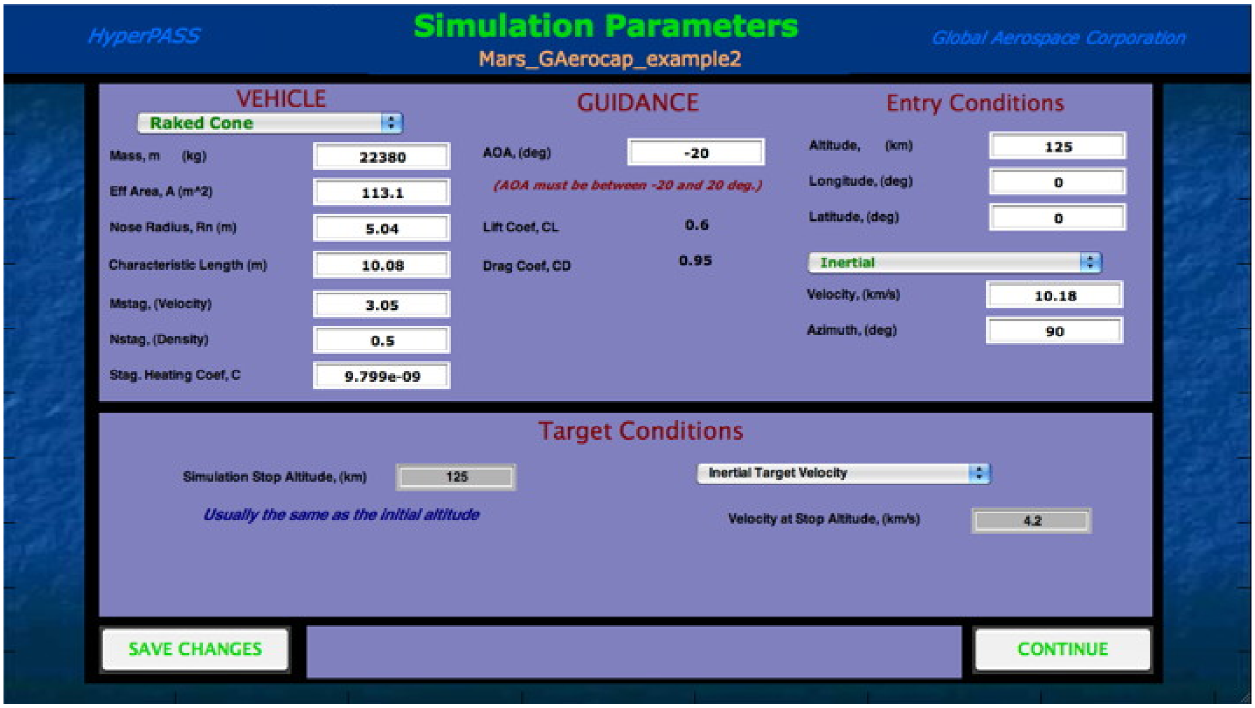

Figure 3-5 Simulation Parameters GUI – Guided Aerocapture

3.4.3 Guided Ballute Aerocapture Simulation Parameters GUI

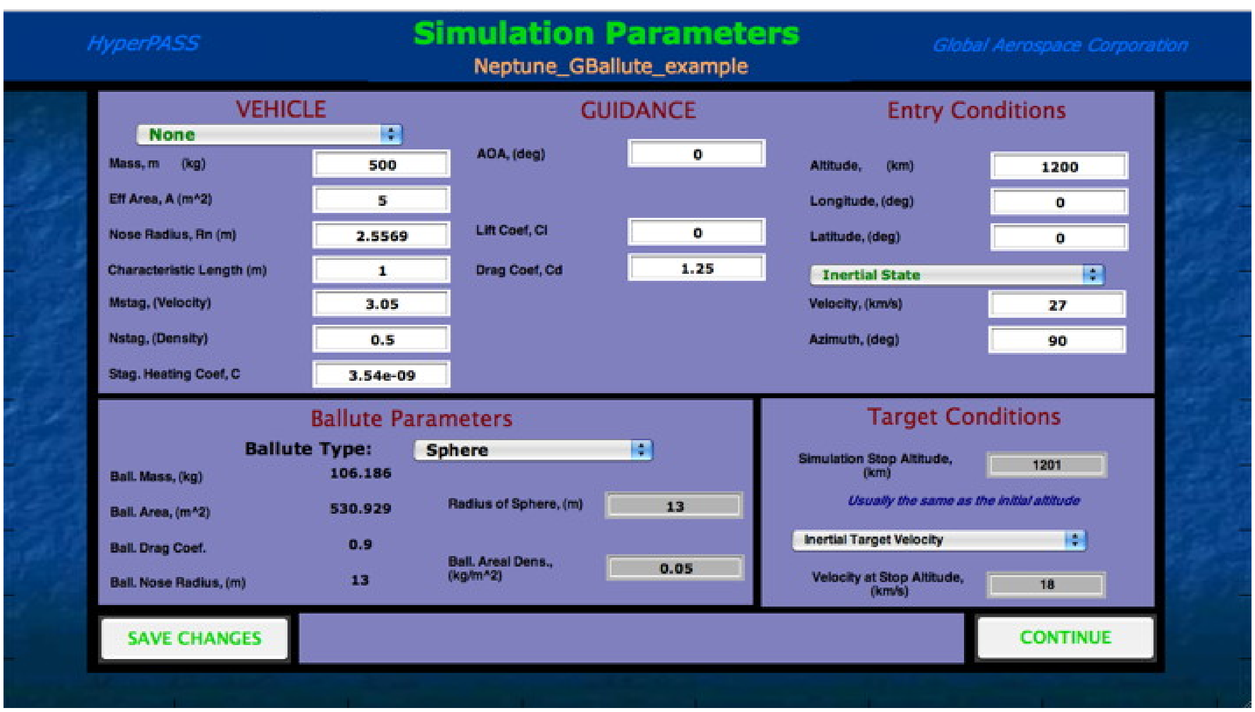

Figure 3-6 Simulation Parameters GUI – Guided Ballute Aerocapture

3.4.4 Aerobraking Simulation Parameters GUI

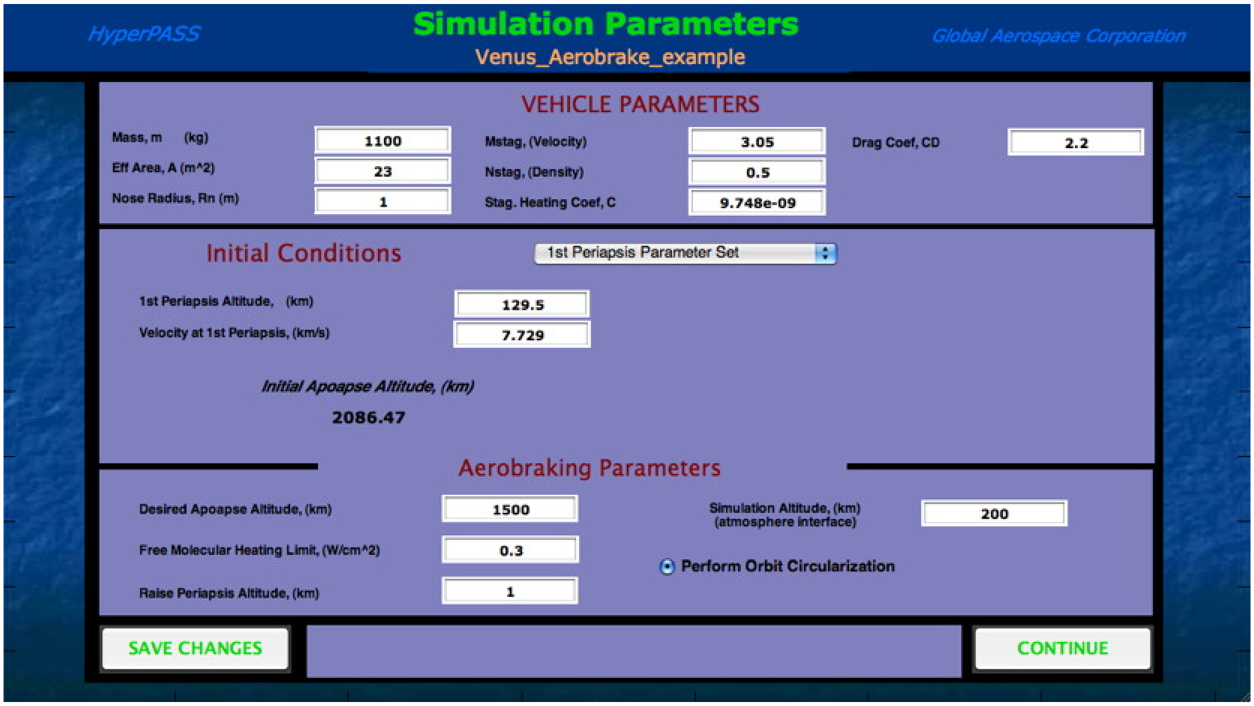

Figure 3-7 Simulation Parameters GUI – Aerobraking

3.4.5 Orbit Decay Simulation Parameters GUI

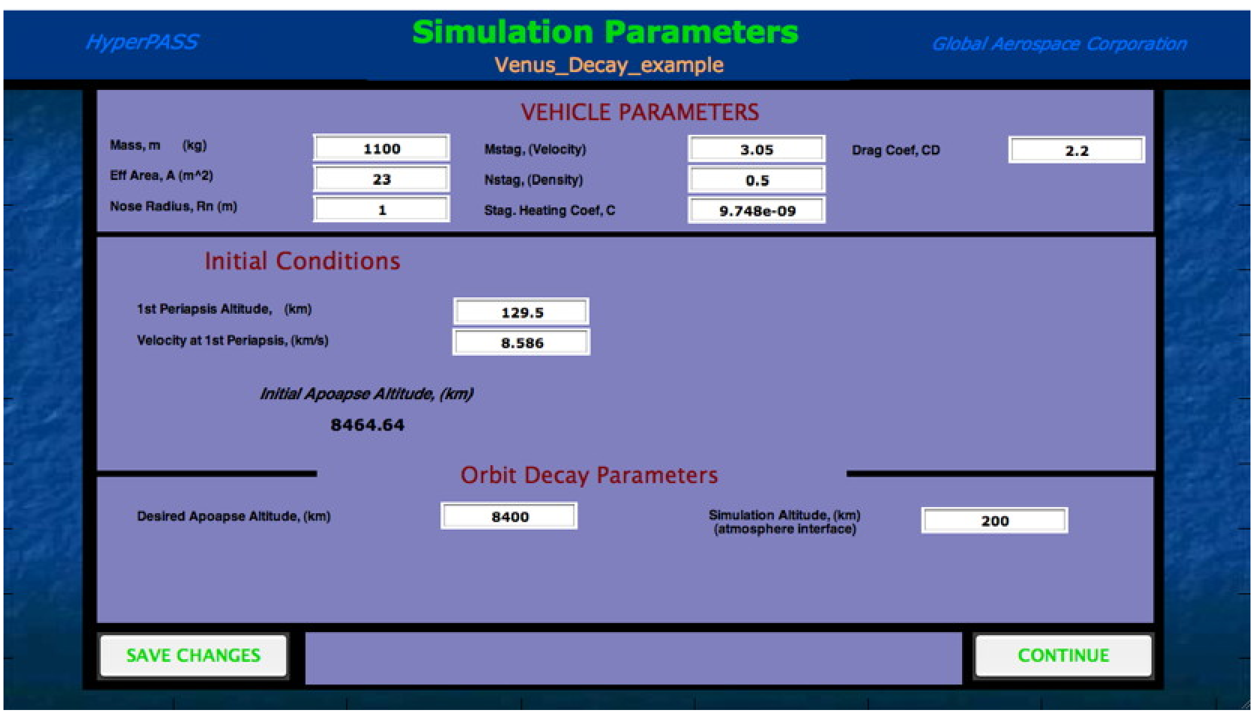

Figure 3-8 Simulation Parameters GUI – Orbit Decay

3.5 Vehicle Parameters GUIs

3.5.1 Custom CL/CD vs. Kn GUI

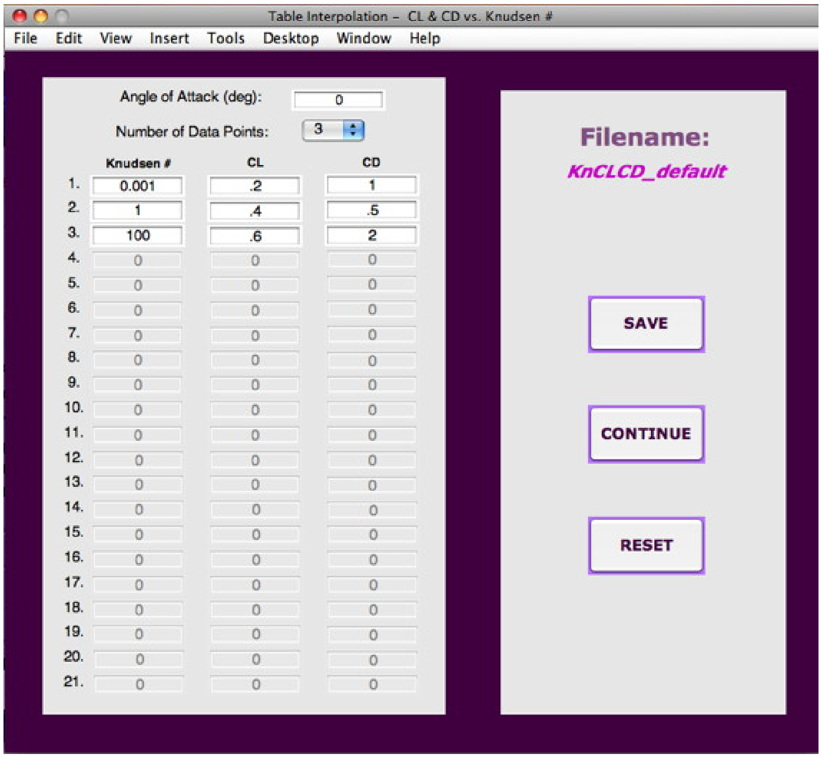

Figure 3-9 Custom CL/CD vs. Kn GUI

The Custom CL/CD vs. Kn GUI allows the user to view the currently selected vehicle file and make changes if desired. **See warning in Section 3.2 about prematurely starting a run before closing this GUI.**

- "Number of Data Points" Pull-down Menu
  - Allows the user to change the number of model data points displayed (2 – 21 points).

- "AOA" Text Box
  - AOA to be used with the CL/CD vs. Kn vehicle model displayed. When the "Continue" Pushbutton is selected, the AOA will appear in the Simulation Parameters GUI.

- "Save " Pushbutton
  - Prompts the user to save any changes to the CL/CD vs. Kn table under a different file name. The AOA is also saved to the new CL/CD vs. Kn file.

- "Continue" Pushbutton
  - Returns the user to the Simulation Parameters GUI. If any changes were made without being saved, the filename will be displayed as "untitled".

- “Reset” Pushbutton
    - Resets the CL/CD vs. Kn table to its original set of values. If no changes were made, the values will remain the same.

3.5.2 Custom CL/CD vs. Mach GUI

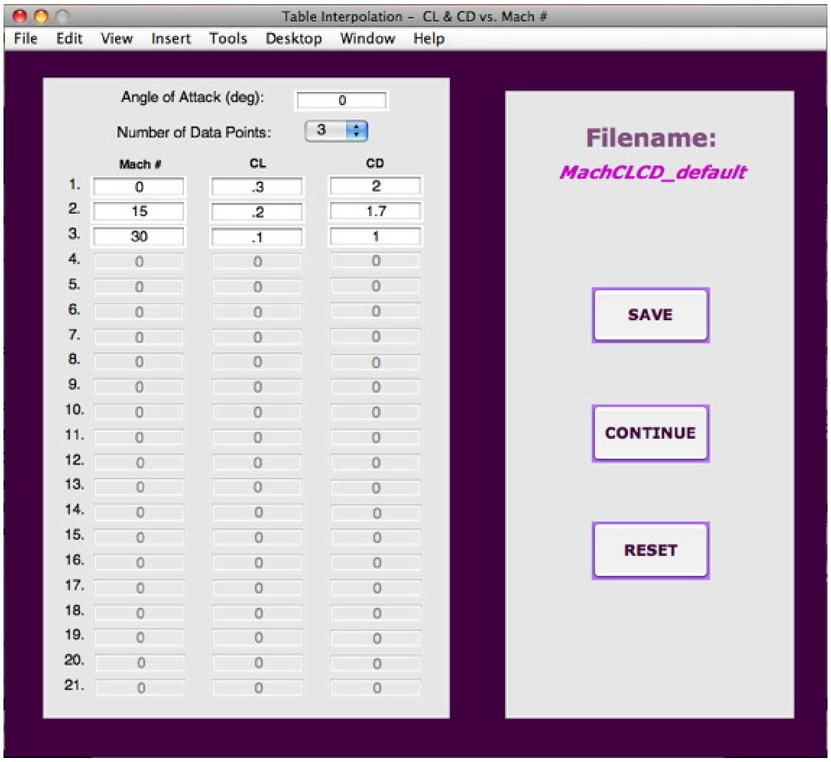

Figure 3-10 Custom CL/CD vs. Mach GUI

The Custom CL/CD vs. Mach GUI allows the user to view the currently selected vehicle file and make changes if desired. **See warning in Section 3.2 about prematurely starting a run before closing this GUI.**

- “Number of Data Points” Pull-down Menu
    - Allows the user to change the number of model data points displayed (2 – 21 points).

- “AOA” Text Box
    - AOA to be used with the CL/CD vs. Mach vehicle model displayed. When the “Continue” Pushbutton is selected, the AOA will appear in the Simulation Parameters GUI.

- “Save” Pushbutton
    - Prompts the user to save any changes to the CL/CD vs. Mach table under a different file name. The AOA is also saved to the new CL/CD vs. Mach file.

- "Continue" Pushbutton
  - Returns the user to the Simulation Parameters GUI. If any changes were made without being saved, the filename will be displayed as "untitled".

- "Reset" Pushbutton
  - Resets the CL/CD vs. Mach table to its original set of values. If no changes were made, the values will remain the same.

3.6 Post Simulation GUI

The Post Simulation GUI is displayed after a simulation is completed. The information displayed and the post simulation options vary depending on the chosen function. The various Post Simulation GUIs are displayed and described in this section.

3.6.1 Unguided Simulation Post Simulation GUI

This Post Simulation GUI displays the final state (including altitude, velocity, and flight path angle). The *inertial* final state is displayed if inertial initial conditions were entered or if using the non-rotating model. The *planet relative* final state is displayed if planet relative initial conditions are entered and a rotating model is being used.

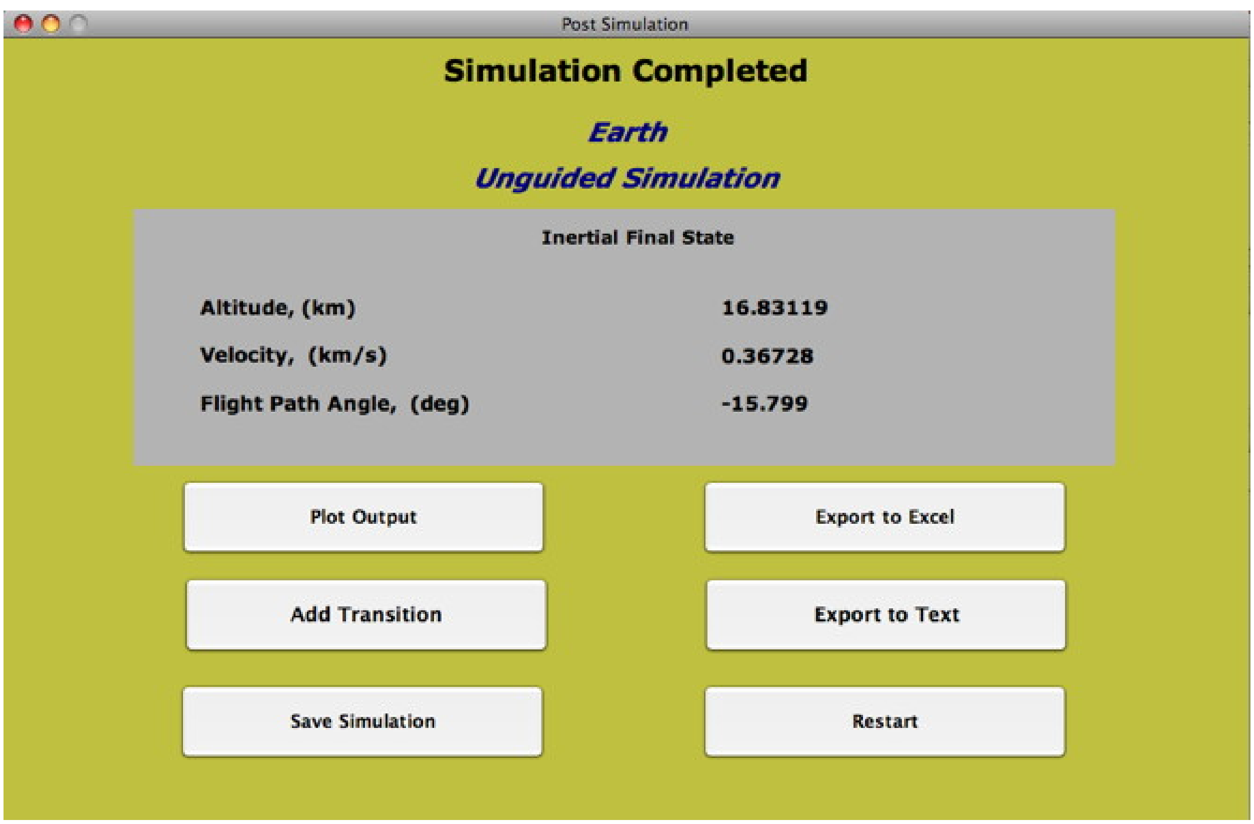

Figure 3-11 Post Simulation GUI – Unguided

- Plot Output (see Section 3.7)

- Opens the Plot Output GUI

- Add Transition (see Section 4.1.1)
  - Opens the Add Transition GUI
  - This is not an option if a ballute is added (i.e. "Add Ballute" is selected in the Simulation Parameters GUI). If a ballute is added, the user will have the option to "Cut Ballute" instead of "Add Transition".

- Cut Ballute (see Section 4.1.1)
  - Opens the Cut Ballute GUI
  - This is only an option if a ballute is added (i.e. "Add Ballute" is selected in the Simulation Parameters GUI). If no ballute is added, the user will have the option to "Add Transition" instead of "Cut Ballute".

- Save Simulation (See Section 4.1.3)
  - Prompts the user to save the current simulation.
  - Simulation MUST be saved in order to use the View Previous Simulation function. (The View Previous Simulation function allows the user to reload previously run simulations.)

- Export to Excel (See Section 5.4.1)
  - Allows the user to export user-selected simulation data into M/S Excel.
  - This option is only available on Windows (PC) systems with M/S Excel installed.

- Export to Text (See Section 5.5.1)
  - Allows the user to export the simulation data into a tab delimited text (*.txt) file.

- Restart
  - Restarts HyperPASS.
  - Any unsaved simulations are deleted when HyperPASS is restarted.

3.6.2 Guided Aerocapture Post Simulation GUI

This Post Simulation GUI displays the initial flight path angle and final state (including altitude, velocity, and flight path angle). *Inertial* results are displayed if inertial initial conditions are entered or if using the non-rotating model. *Planet relative* results are displayed if planet relative initial conditions are entered and a rotating model is being used.

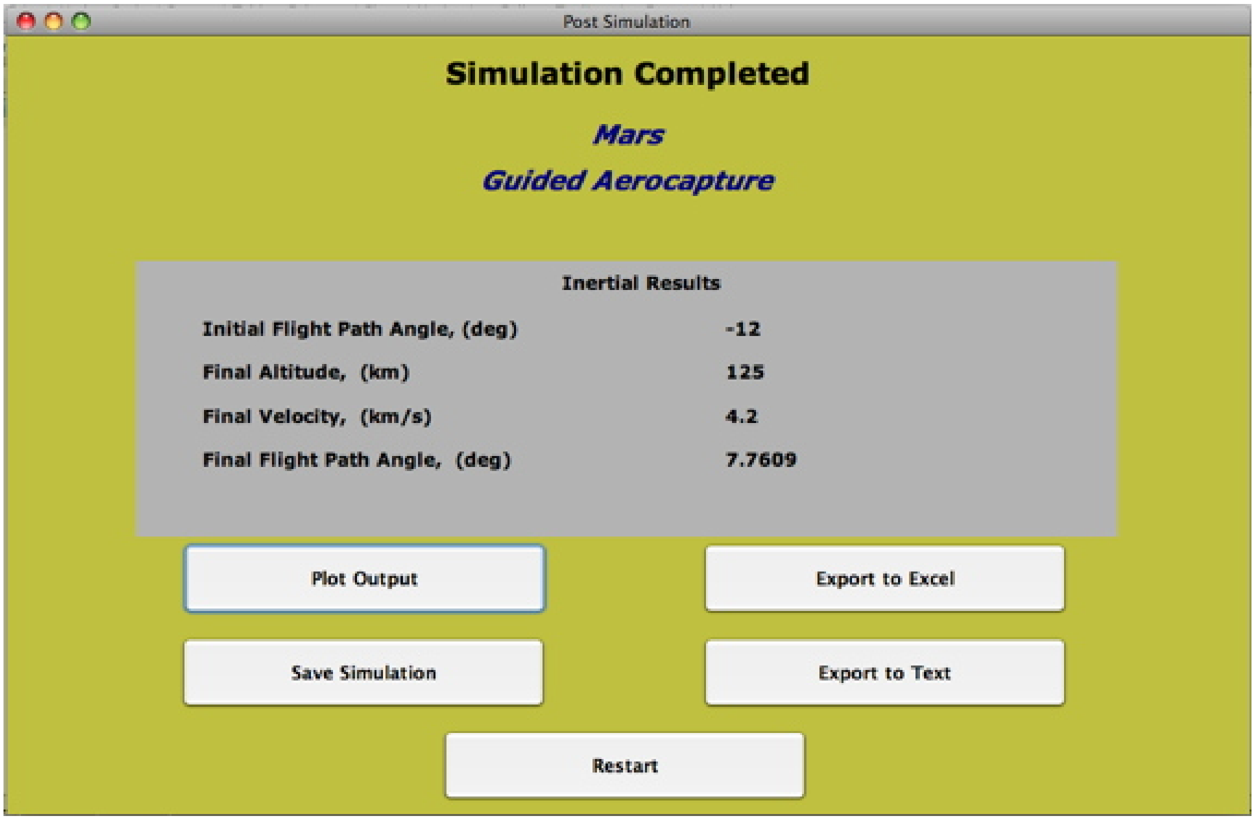

Figure 3-12 Post Simulation GUI – Guided Aerocapture

- Plot Output (See Section 3.7.1)
    - Opens the Plot Output GUI

- Save Simulation (See Section 4.1.3 View Previous Simulation)
    - Prompts the user to save the current simulation.
    - Simulation MUST be saved in order to use the View Previous Simulation function. (The View Previous Simulation function allows the user to reload previously run simulations.)

- Export to Excel (See Section 5.4.1)
    - Allows the user to export user-selected simulation data into M/S Excel.
    - This option is only available on Windows (PC) systems with M/S Excel installed.

- Export to Text (See Section 5.5.1)
    - Allows the user to export the simulation data into a delimited text (*.txt) file.

- Restart
    - Restarts HyperPASS.
    - Any unsaved simulations are deleted when HyperPASS is restarted.

3.6.3 Guided Ballute Post Simulation GUI

This Post Simulation GUI displays the initial flight path angle, final state (including altitude, velocity, and flight path angle) and the ballute cut time. *Inertial* results are displayed if inertial initial conditions were entered or if using the non-rotating model. *Planet relative* results are displayed if planet relative initial conditions were entered and a rotating model is being used.

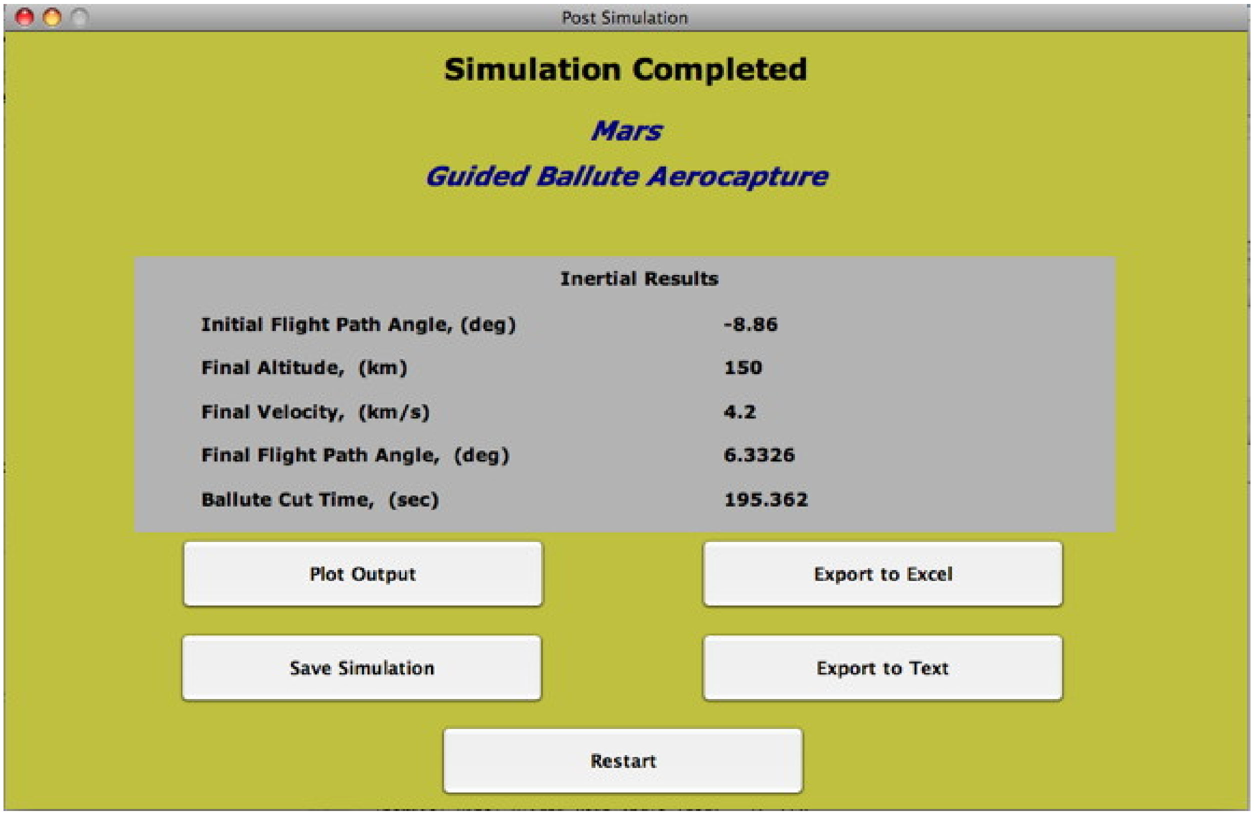

Figure 3-13 Post Simulation GUI – Guided Ballute Aerocapture

- Plot Output (See Section 3.7.1)
  - Opens the Plot Output GUI

- Save Simulation (See Section 4.1.3 View Previous Simulation)
  - Prompts the user to save the current simulation.
  - Simulation MUST be saved in order to use the View Previous Simulation function. (The View Previous Simulation function allows the user to reload previously run simulations.)

- Export to Excel (See Section 5.4.1)
  - Allows the user to export user-selected simulation data into M/S Excel.
  - This option is only available on Windows (PC) systems with M/S Excel installed.

- Export to Text (See Section 5.5.1)
  - Allows the user to export the simulation data into a delimited text (*.txt) file.

- Restart
    - Restarts HyperPASS.
    - Any unsaved simulations are deleted when HyperPASS is restarted.

3.6.4 Aerobraking Post Simulation GUI

This Post Simulation GUI displays several output parameters. The number of raise periapsis delta-V's and total aerobraking time are displayed for all simulations. The orbit insertion delta-V and the lower periapsis delta-V are displayed if initial conditions are entered using the v-infinity parameter set in the Simulation Parameters GUI. The circularization delta-V is displayed if "Orbit Circularization" is chosen in the Simulation Parameters GUI.

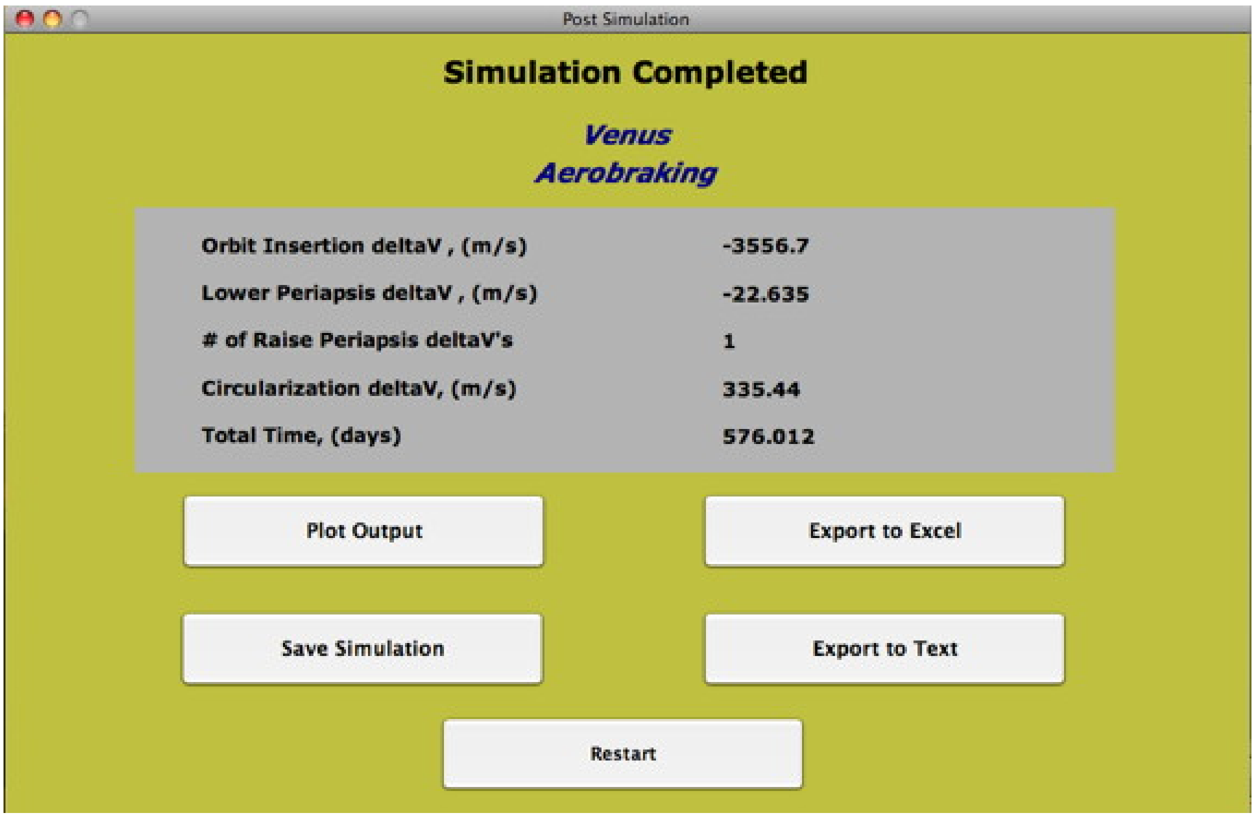

Figure 3-14 Post Simulation GUI – Aerobraking

- Plot Output (See Section 3.7.2)
    - Opens the Plot Output GUI

- Save Simulation (See Section 4.1.3 View Previous Simulation)
    - Prompts the user to save the current simulation.
    - Simulation MUST be saved in order to use the View Previous Simulation function. (The View Previous Simulation function allows the user to reload previously run simulations.)

- Export to Excel (See Section 5.4.2)
    - Allows the user to export user-selected simulation data into M/S Excel.

- This option is only available on Windows (PC) systems with M/S Excel installed.

- Export to Text (See Section 5.5.2)
  - Allows the user to export the simulation data into a delimited text (*.txt) file.

- Restart
  - Restarts HyperPASS.
  - Any unsaved simulations are deleted when HyperPASS is restarted.

3.6.5 Orbit Decay Post Simulation GUI

This Post Simulation GUI displays total orbit decay time. (Orbit insertion delta-V, lower periapsis delta-V, # of raise periapsis delta-V's, and circularization delta-V are only displayed after running an Aerobraking simulation).

Figure 3-15 Post Simulation GUI – Orbit Decay

- Plot Output (See Section 3.7.3)
  - Opens the Plot Output GUI

- Save Simulation (See Section 4.1.3 View Previous Simulation)
  - Prompts the user to save the current simulation.

- Simulation MUST be saved in order to use the View Previous Simulation function. (The View Previous Simulation function allows the user to reload previously run simulations.)

- Export to Excel (See Section 5.4.3)
  - Allows the user to export user-selected simulation data into M/S Excel.
  - This option is only available on Windows (PC) systems with M/S Excel installed.

- Export to Text (See Section 5.5.3)
  - Allows the user to export the simulation data into a delimited text (*.txt) file.

- Restart
  - Restarts HyperPASS.
  - Any unsaved simulations are deleted when HyperPASS is restarted.

3.7 Plot Output GUI

This GUI allows the user to view plots of the selected data from the simulation. The plotting options vary, depending on which function is chosen.

3.7.1 Plot Unguided, Guided Aerocapture, & Guided Ballute Aerocapture GUI

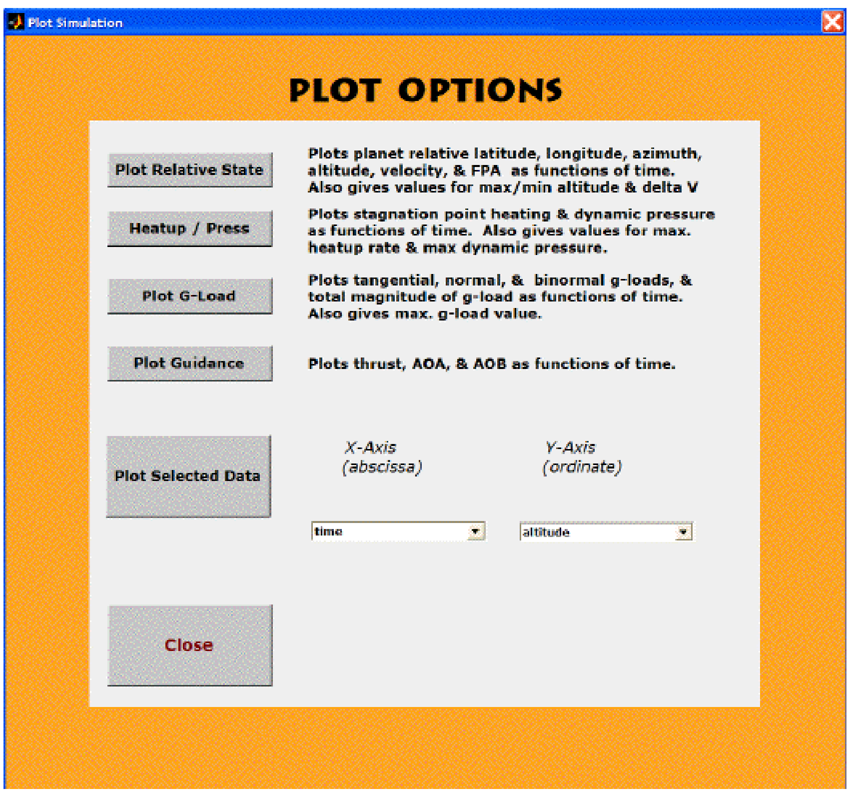

Figure 3-16 Plot Output GUI – Unguided, Guided Aerocapture & Guided Ballute Aerocapture

- Plot State
  - Plots the planet relative latitude, longitude, azimuth, altitude, velocity, and flight path angle as functions of time.

- Plot Guidance
  - Plots thrust, Angle of Attack and Angle of Bank as functions of time.

- Plot G-load
  - Plots tangential, normal, and binormal acceleration forces, and total magnitude of acceleration forces as functions of time.

- Heat-up/Pressure
  - Plots stagnation point (continuum) heating and dynamic pressure as functions of time.

- Plot Selected Data
  - Allows the user to decide what variables will be plotted on the x-axis and y-axis
  - The following plot options are available from the x-axis and y-axis pull-down menus
    - Time
    - Altitude
    - Latitude
    - Longitude
    - Planet Relative Velocity
    - Inertial Velocity
    - Planet Relative Flight Path Angle
    - Inertial Flight Path Angle
    - Planet Relative Azimuth Angle
    - Inertial Azimuth Angle
    - Thrust
    - Angle of Attack
    - Angle of Bank
    - Stagnation Point (continuum) Heating Rate
    - Free Molecular Heating Rate
    - Acceleration force (tangential)
    - Acceleration force (normal)
    - Acceleration force (binormal)
    - Acceleration force (magnitude)
    - Lift force
    - Drag force
    - Angular Momentum - X
    - Angular Momentum - Y
    - Angular Momentum - Z
    - Angular Momentum (magnitude) atmospheric density
    - Atmospheric Density
    - Knudsen Number

- Mach Number
- Drag Coefficient
- Lift Coefficient
- Mass
- Aerodynamic cross-section area
- Nose Radius
- Characteristic Length

3.7.2 Plot Aerobraking GUI

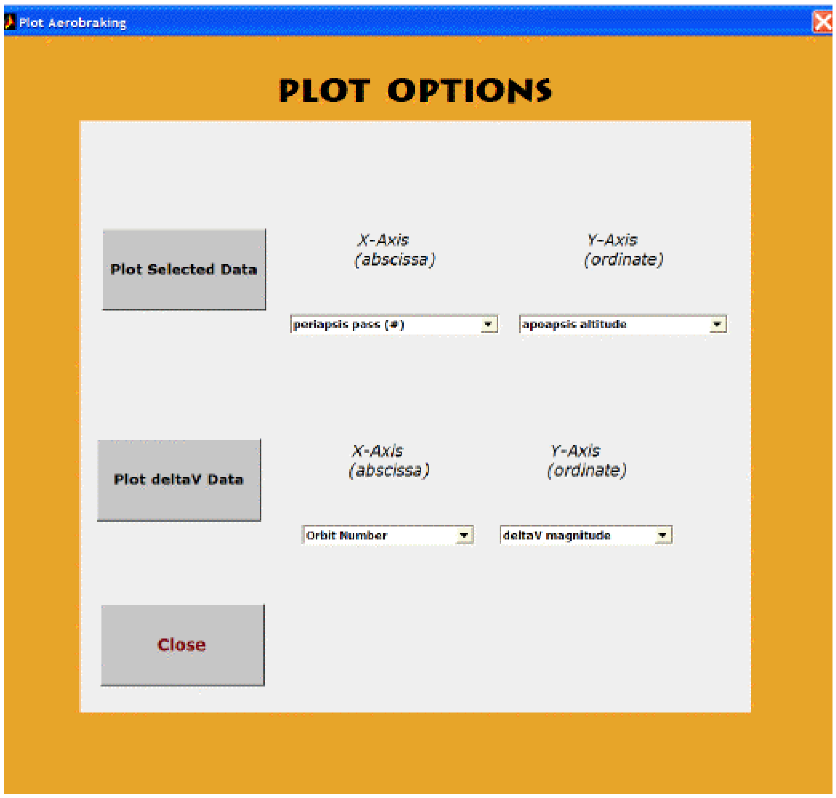

Figure 3-17 Plot Output GUI – Aerobraking

- Plot Selected Data
  - Allows the user to decide what variables will be plotted on the x-axis and y-axis
  - The following plot options are available from the x-axis and y-axis pull-down menu-s
    - Periapsis Pass (#)
    - Elapsed Time (days)
    - Periapsis Altitude
    - Apoapsis Altitude
    - Free Molecular Heating at Periapsis
    - Continuum (stagnation point) Heating Periapsis
    - Inertial Velocity at Periapsis
    - Orbit Period (hrs)

- Plot delta-V Data
    - Allows the user to decide what raise periapsis deltaV variables will be plotted on the x-axis and y-axis
    - If no periapsis raise maneuvers occurred during aerobraking, no data will be plotted.
    - The following plot options are available from the x-axis and y-axis pull-down menus:
        - Orbit Number (of raise periapsis maneuver)
        - Time of delta-V implementation (days)
        - Delta-V magnitude
        - old periapsis altitude
        - new periapsis altitude

3.7.3 Plot Orbit Decay GUI

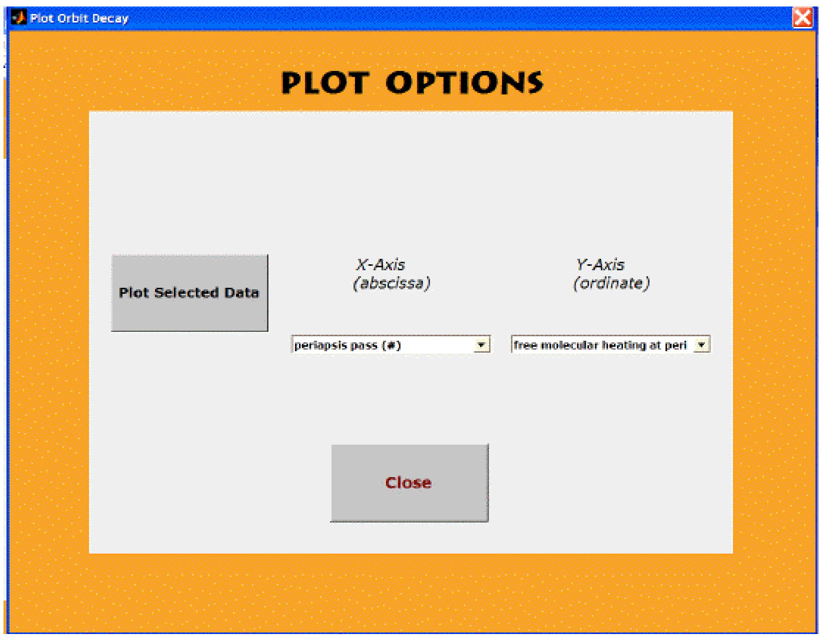

Figure 3-18 Plot Output GUI – Orbit Decay

- Plot Selected Data
    - Allows the user to decide what variables will be plotted on the x-axis and y-axis
    - The following plot options are available from the x-axis and y-axis pull-down menus
        - Periapsis Pass (#)
        - Elapse Time (days)
        - Periapsis Altitude
        - Apoapsis Altitude
        - Free Molecular Heating at Periapsis
        - Continuum (stagnation point) Heating Periapsis
        - Inertial Velocity at Periapsis

- Orbit Period (days)

3.8 Other GUIs

See warning in Section 3.2 about prematurely starting a run before closing these GUIs.

3.8.1 Add Transition GUI

This GUI is displayed when “Add Transition” is selected, after running an unguided simulation. The Transition Parameters GUI pertains only to unguided simulations that do not have an added ballute. (See Section 3.4.1)

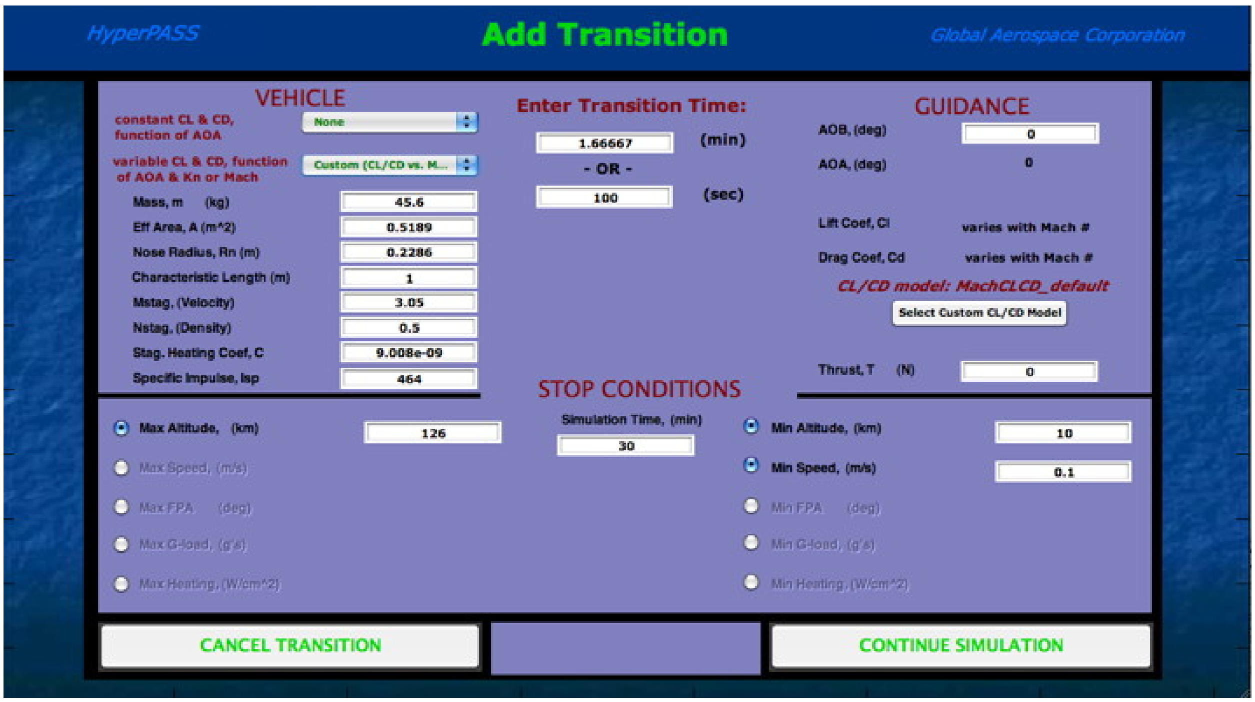

Figure 3-19 Add Transition GUI

3.8.2 Cut Ballute GUI

This GUI is displayed when “Cut Ballute” is selected, after running an unguided simulation. The Cut Ballute GUI pertains only to unguided simulations that have an added ballute. (See Section 4.2.1)

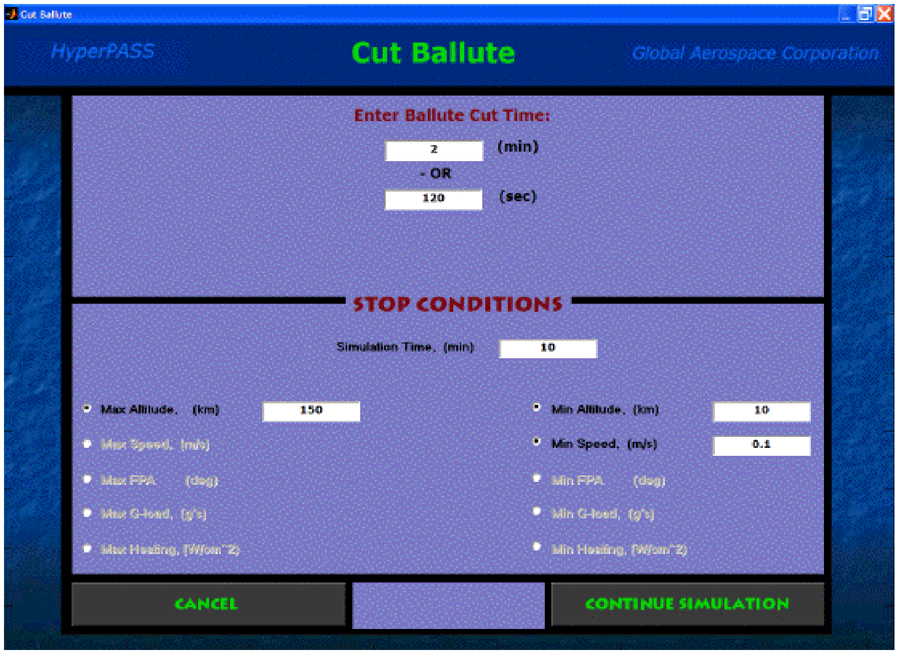

Figure 3-20 Cut Ballute GUI

3.8.3 Warning GUIs

HyperPASS has numerous built in warnings to assist the user in running a successful simulation. Warnings display the appropriate warning message with a red colored background. Two examples of possible Warning GUIs are displayed below:

Figure 3-21 Warning GUI – example 1

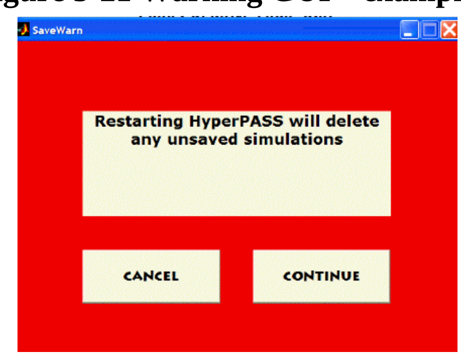

Figure 3-22 Warning GUI – example 2

3.8.4 Export Excel GUI

NOTE: This option is only available on Windows (PC) systems with M/S Excel installed.

The Export Excel GUI is displayed when exporting to M/S Excel after an Unguided, Guided Aerocapture, or Guided Ballute Aerocapture simulation has been completed. (See Section 5.4.1)

Figure 3-23 Export Excel GUI

4 Functions

4.1 Descriptions

4.1.1 Unguided Simulations

The user controls an unguided simulation by supplying a set of initial stopping conditions for the simulation. Once the simulation is complete, the user can add an infinite number of simulation transitions in order to achieve the desired results. For information on how to run an unguided simulation see Section 4.2.1. There are also three examples given in section 6.

- Aerocapture (See Section 6.1)
- Ballute Aerocapture (See Section 6.2)
- Entry-Descent-Landing (See Section 6.3)

4.1.2 Guided Simulations

The guided simulation options require the user to enter function specific inputs in order to perform the various tasks:

4.1.2.1 Guided Aerocapture

HyperPASS selects the appropriate entry flight path angle and modulates the vehicle's bank angle in order to achieve the desired target (exit) conditions. For information on how to run a Guided Aerocapture simulation see 4.2.2. There is also an example given in 6.4.

4.1.2.2 Guided Ballute Aerocapture

HyperPASS selects the appropriate entry flight path angle and determines the proper ballute cut time in order to achieve the desired target (exit) conditions. . For information on how to run a Guided Ballute Aerocapture simulation see 4.2.3. There is also an example given in 6.6.

4.1.2.3 Aerobraking

HyperPASS performs simulations through the planet's atmosphere until the desired apoapsis altitude is achieved. HyperPASS will perform raise periapsis delta-V maneuvers as necessary, to prevent the free molecular heating limit from being exceeded. HyperPASS will perform other delta-V maneuvers, including orbit insertion delta-V and lower periapsis delta-V, if the initial simulation conditions are entered using the V-infinity Parameter Set. The user also has the option to perform a circularization delta-V maneuver to circularize the orbit when the desired apoapsis altitude is achieved. **All aerobraking simulations are performed using the inverse-square gravity model and the non-rotating planet/atmosphere.** For information on how to run an Aerobraking simulation see 4.2.4. There is also an example given in 6.6.

4.1.2.4 Orbit Decay

HyperPASS performs simulations through the planet's atmosphere until the desired apoapsis altitude is achieved. All orbit decay simulations are performed using the inverse-square gravity model and the non-rotating equations of motion. . For information on how to run an Orbit Decay simulation see 4.2.5.

4.1.3 View Previous Simulation

The user is prompted to choose between previously saved simulations. HyperPASS then loads the selected simulation and displays the appropriate Post Simulation GUI. The user can then view or export the data. Only simulations saved by selecting "Save Simulation" in the Post Simulation GUI will be available using "View Previous Simulation" (See Section 5.3).

4.2 How To Run Each Function

The following sections describe how to run each function.

*****WARNING*****

– Before selecting "Continue" in the Mission Setup GUI, be sure to close any other GUIs (e.g. Simulation Parameters, Table Interpolated Atmosphere, and Add Ballute) by selecting "Continue" in those respective GUIs.

4.2.1 Unguided Simulation

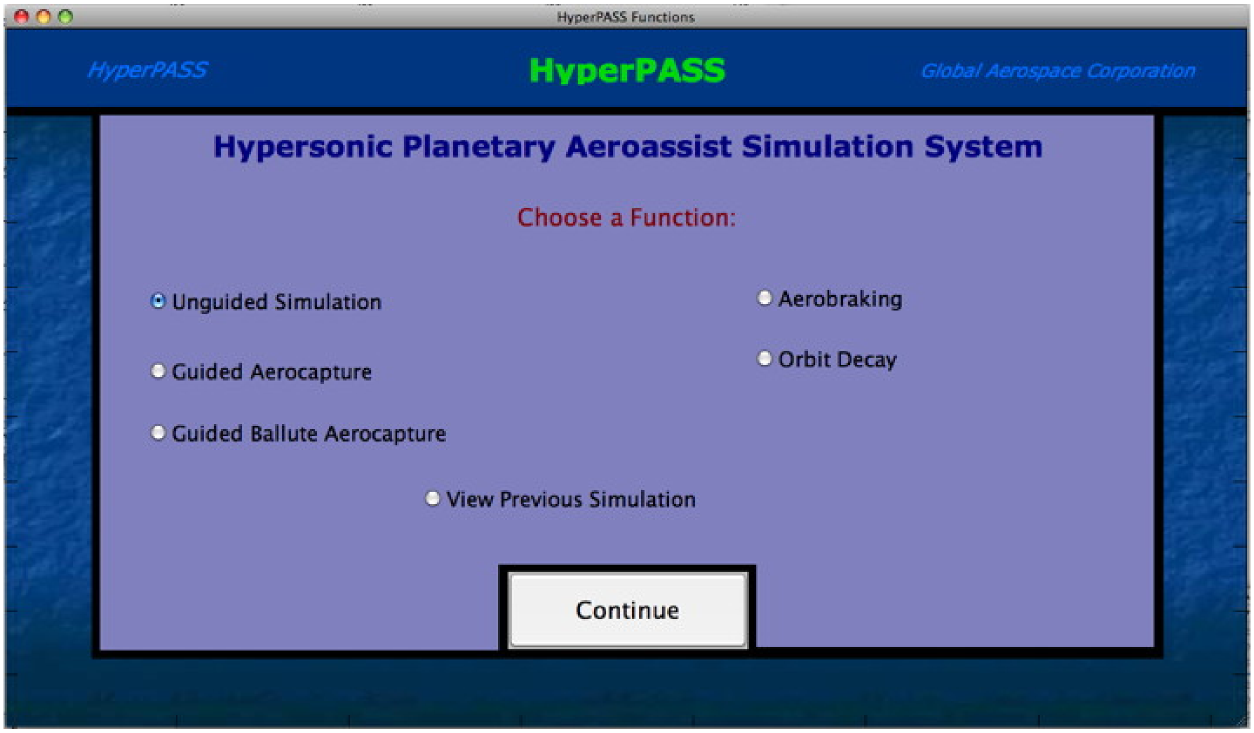

Figure 4-1 HyperPASS GUI - Unguided

1. Select "Unguided Simulation" in the HyperPASS GUI and press "Continue". The Mission Setup GUI will then appear.

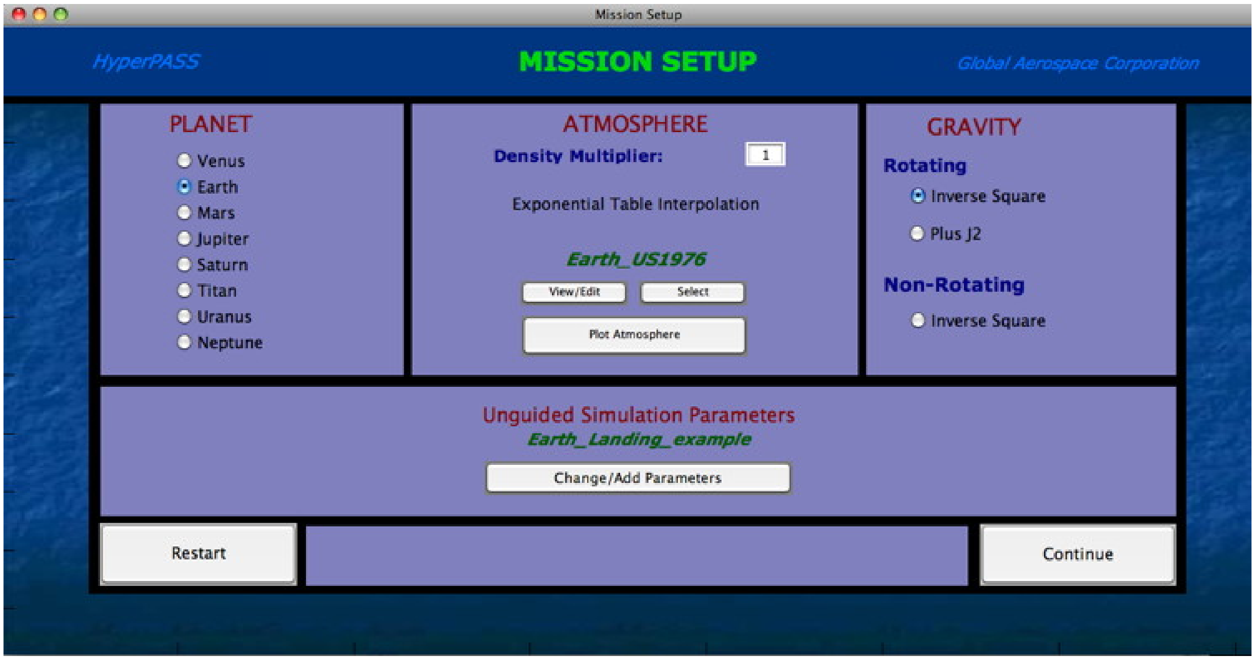

Figure 4-2 Mission Setup GUI – Unguided

2. Select the desired "Planet" in the Mission Setup GUI. (See Section 8.2)

3. Select the desired "Atmosphere" model in the Mission Setup GUI. (See Section 8.4)

4. Select the desired "Gravity" (rotating or non-rotating) model in the Mission Setup GUI.

5. Press the "Change/Add" Parameters" Pushbutton in the Mission Setup GUI to open the Simulation Parameters GUI and view or change the simulation parameters. Save any changes (if it is desired to save the parameter set for future simulations) and press "Continue" to return to the Mission Setup GUI. Simulation parameters are given below:

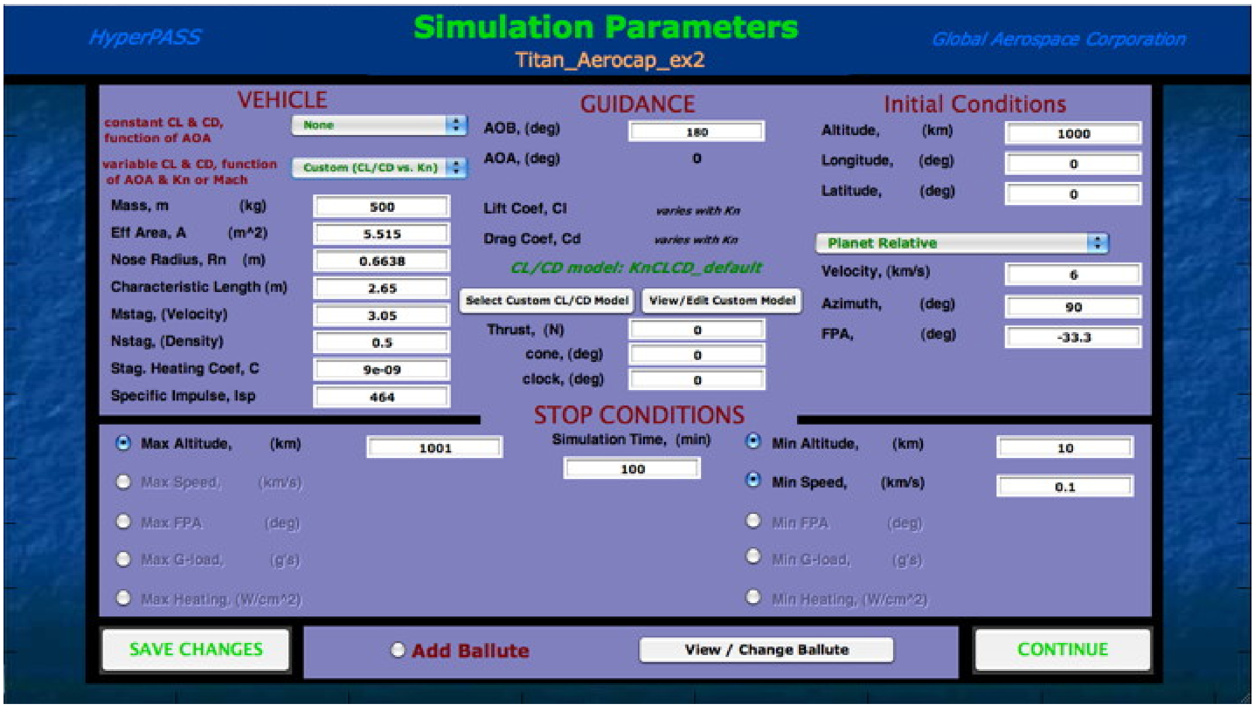

Figure 4-3 Simulation Parameters GUI – Unguided

- VEHICLE
  - o Type
    - None
    - Elliptical Raked Cone
    - Viking
    - Apollo
    - 45-deg cone
    - Sphere
    - Torus
    - Custom CL/CD vs. Knudsen Number
    - Custom CL/CD vs. Mach Number
  - o m
  - o A
  - o Rn
  - o L
  - o Mstag
  - o Nstag
  - o C
  - o Isp

NOTE: If Raked Cone, Viking, or Apollo vehicle type is selected, the CL and CD are displayed as a function of vehicle angle of attack. The 45-deg Cone and Torus have aerodynamic coefficients that vary with Knudsen number. The Sphere model calculates CD as a function of both Knudsen and Mach numbers. For more information on vehicle models see Section 8.3.

- GUIDANCE
  - AOB
  - AOA
  - CL
  - CD
  - Thrust
  - Cone angle
  - Clock angle

- INITIAL CONDITIONS
  - Altitude
  - Longitude
  - Latitude
  - Velocity
  - Azimuth
  - FPA

NOTE: Velocity options are planet relative, inertial or v-infinity. If planet relative is chosen, azimuth and FPA are also planet relative. If inertial is chosen, azimuth and FPA are also inertial. If a v-infinity is entered, azimuth and FPA are inertial and the initial velocity is calculated at the initial altitude.

- STOP CONDITIONS
  - Simulation Time
  - Max. Altitude
  - Max. Speed
  - Max. FPA
  - Max. G-load
  - Max. Heating
  - Max. Altitude
  - Max. Speed
  - Max. FPA
  - Max. G-load
  - Max. Heating

NOTE: Maximum and minimum stopping conditions can be turned "on" and "off" by using the corresponding radio buttons.

- ADD BALLUTE

If ADD BALLUTE is selected, a ballute will be added to the vehicle. The ballute parameters can be changed by pressing the "View/Change Ballute" Pushbutton. The simulation is run with the ballute attached (*m = vehicle mass + ballute mass; CD = ballute CD, A = ballute Area*). After the simulation is complete, the user has the option of releasing the ballute at any time during the simulation by choosing "Cut Ballute" in the Post Simulation GUI.

If ADD BALLUTE is not selected, the user will have the option of adding a transition by choosing "Add Transition" in the Post Simulation GUI.

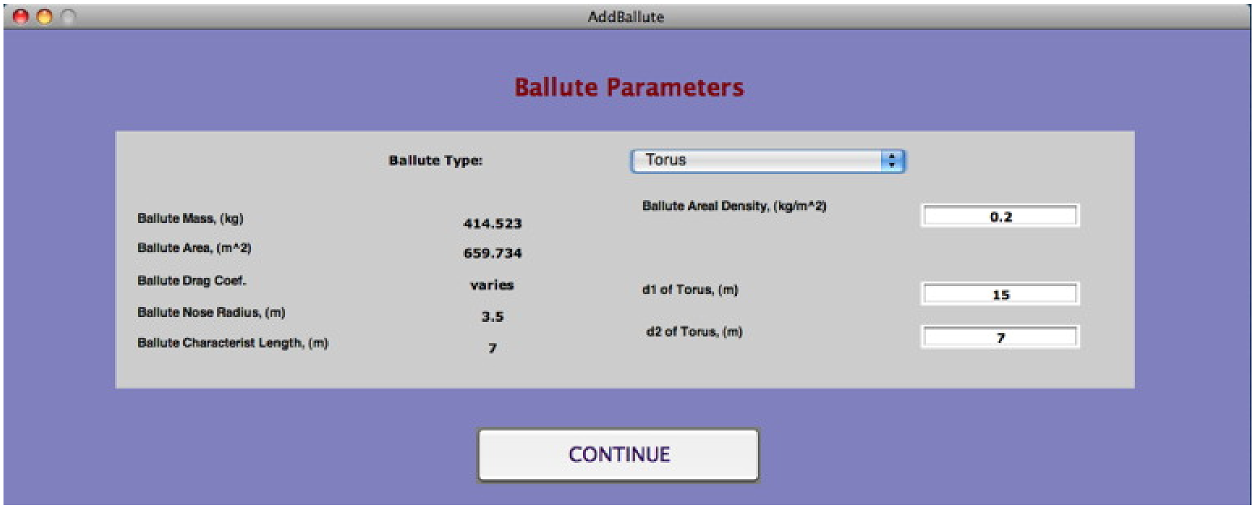

Figure 4-4 Ballute Parameters GUI – Unguided

- Ballute Type:
  - None
  - Sphere
    - radius of sphere
    - ballute areal density
  - Torus
    - d1 of torus
    - d2 of torus
    - ballute areal density
- Ballute Mass
- Ballute Area
- Ballute Drag Coefficient (varies with Kn & Mach for sphere and varies with Kn for torus)
- Ballute Nose Radius
- Ballute Characteristic Length

NOTE: If "Sphere" or "Torus" is selected, the user must input the ballute dimensions and the areal density of the ballute material and HyperPASS automatically displays the corresponding ballute mass, ballute area, ballute nose radius, and ballute characteristic length. The ballute drag coefficient varies with Kn & Mach for sphere and varies with Kn for torus. If no ballute type is selected, the ballute's m, A, CD, Rn and L are entered independently.

NOTE: If ADD BALLUTE is selected, the ballute lift coefficient is equal to zero. If one desires to run a lifting ballute scenario, run an unguided simulation with ADD BALLUTE NOT SELECTED and use Transitions instead.

6. Press "Continue" in the Mission Setup GUI to start the simulation. A simulation progress window will be displayed while the simulation is running. When the simulation is completed, the Post Simulation GUI will appear. **See warning in Section 4.2 about prematurely starting a run before closing this GUI.**

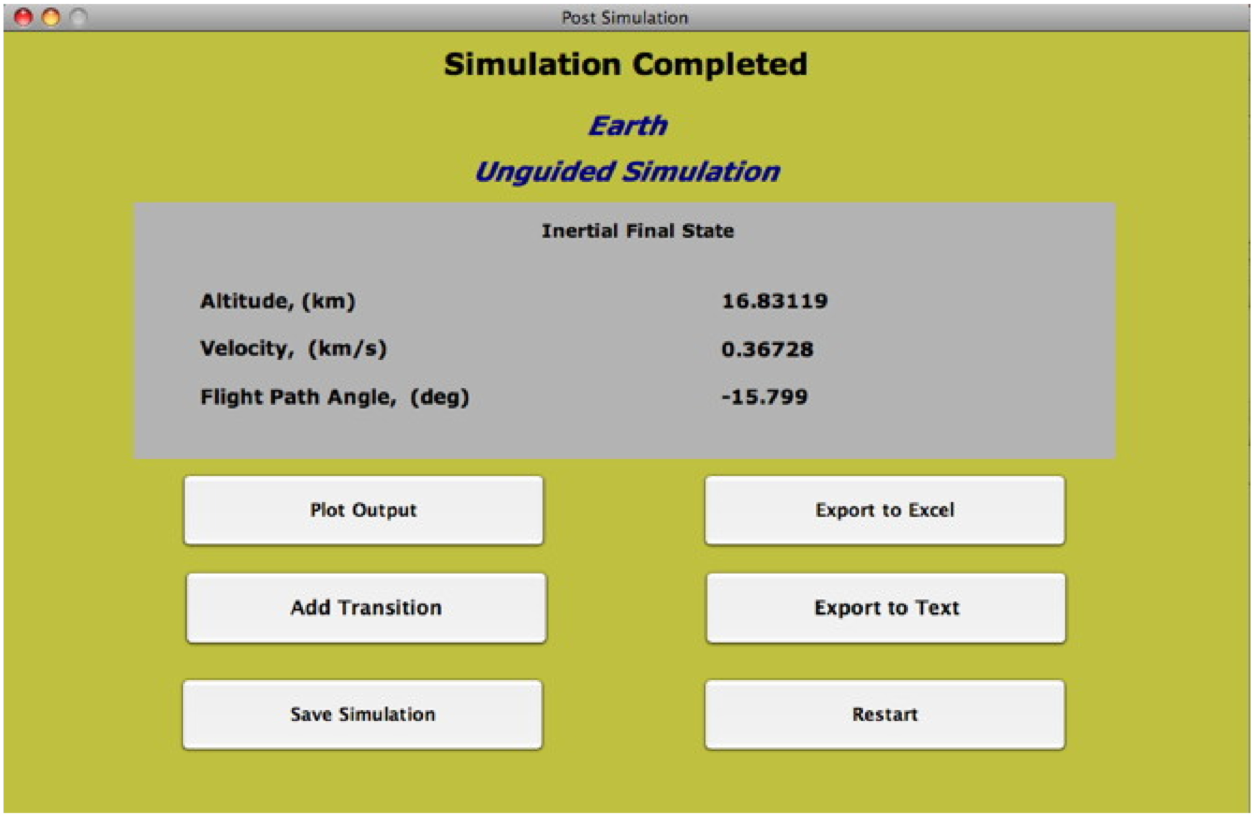

Figure 4-5 Post Simulation GUI - Unguided

- SAVE SIMULATION
  - Simulations must be saved in order use the "View Previous Simulation" option in the HyperPASS GUI. (See Section 5.3)

- PLOT OUTPUT – opens the Plot Output GUI
  - Allows the user to plot simulation output.
  - See Section 3.7.1for plotting options.

- EXPORT TO EXCEL
  - Allows the user to export selected output to an M/S Excel workbook.
  - See Section 5.4.1

- EXPORT TO TEXT
  - Allows the user to export simulation output into a delimited text (.txt) file.
  - See Section 5.5.1

- RESTART
  - Restarts HyperPASS

- ADD TRANSITION - opens the Add Transition GUI
  - The user can enter an infinite number of transitions in this manner.
  - This is an option if “Add Ballute” was not selected in the Simulation Parameters GUI.
  - Allows the user to add a transition anywhere in the previously completed simulation by changing any of the Vehicle or Guidance parameters.
  - “Transition time” is the time that the transition will begin. This value must be less than or equal to the total time of the previously completed simulation.
  - “Simulation time” is the duration of the simulation starting at the transition time.
  - Minimum and Maximum stopping conditions can be chosen as before.
  - After the transition simulation is completed, the Post Simulation GUI will be displayed again. The user can add an unlimited number of simulation transitions.

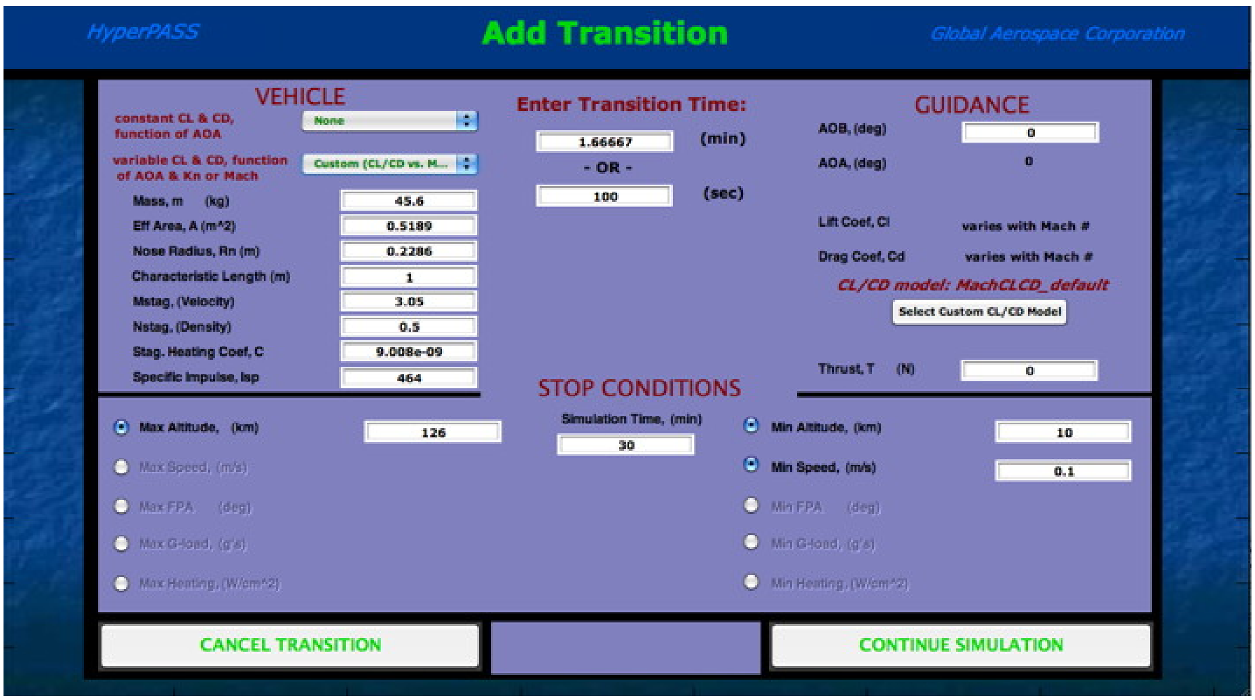

Figure 4-6 Add Transition GUI – Unguided

- CUT BALLUTE
  - This is an option if “Add Ballute” was selected in the Simulation Parameters GUI. (ADD TRANSITION is not a post simulation option in this case.)
  - Allows the user to release the ballute anywhere in the previously completed simulation.
  - “Ballute Cut Time” is the time that the ballute will be released. This value must be less than or equal to the total time of the previously completed simulation.

- "Simulation Time" is the time that the simulation will run after the ballute has been released.
- Minimum and Maximum stopping conditions can be chosen as before.
- After the ballute has been released and the simulation completed, the Post Simulation GUI will be displayed again.

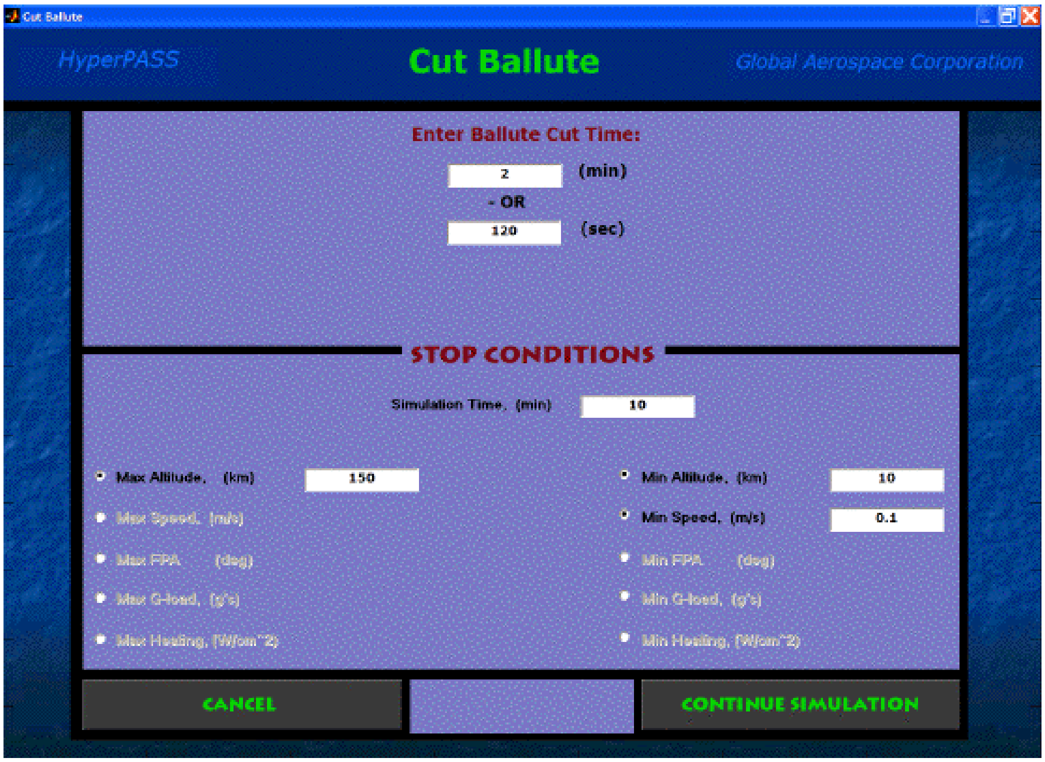

Figure 4-7 Cut Ballute GUI - Unguided

4.2.2 Guided Aerocapture Simulation

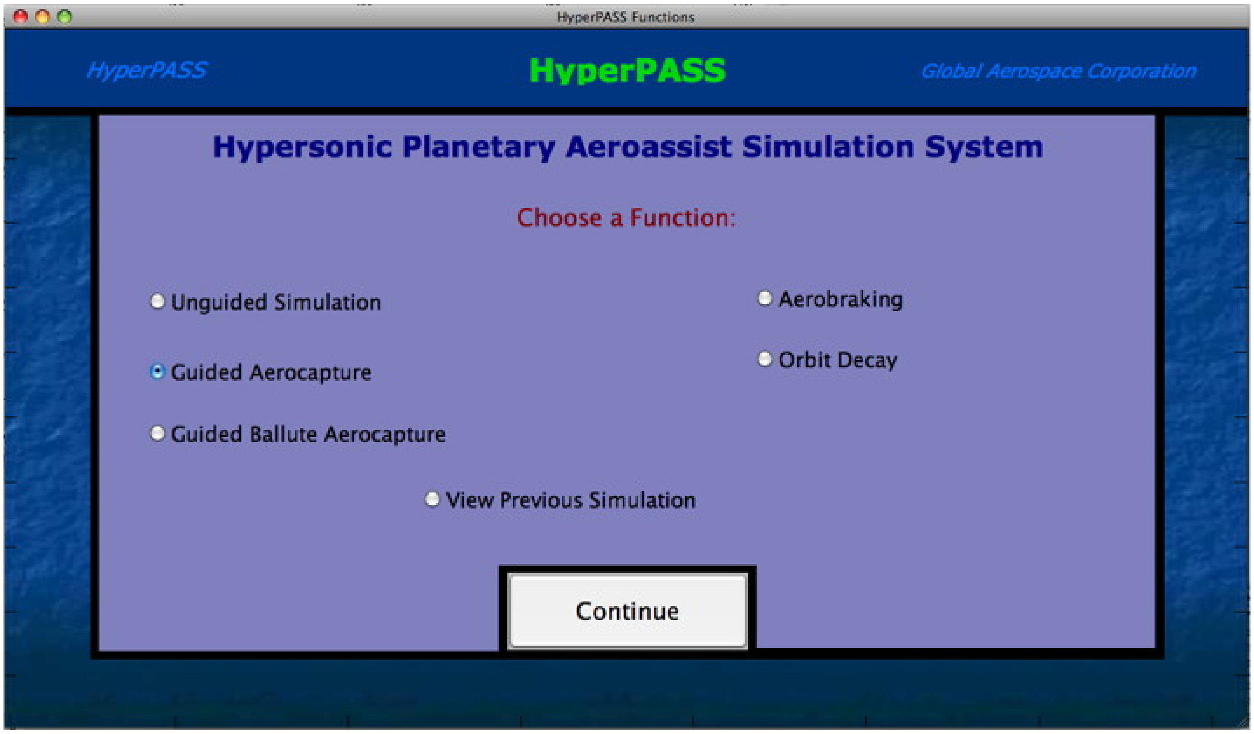

Figure 4-8 HyperPASS GUI – Guided Aerocapture

1. Select "Guided Aerocapture" in the HyperPASS GUI and press "Continue". The Mission Setup GUI will then appear.

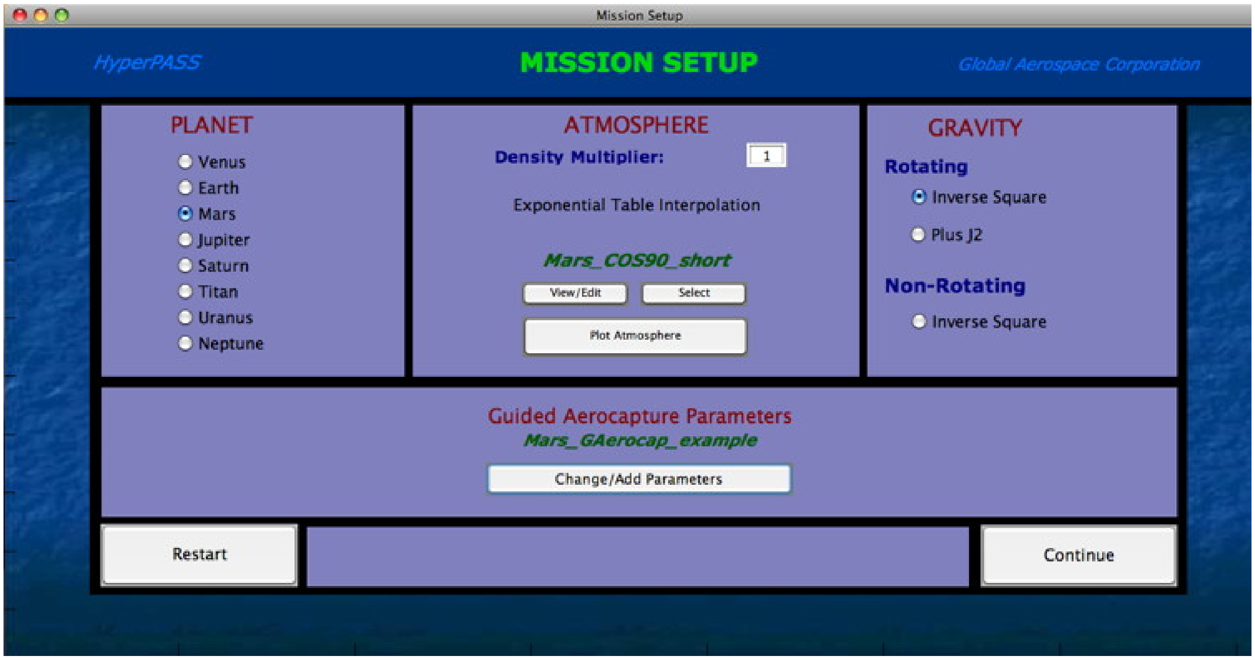

Figure 4-9 Mission Setup GUI – Guided Aerocapture

2. Select the desired "Planet" in the Mission Setup GUI. (See Section 8.2)

3. Select the desired "Atmosphere" model in the Mission Setup GUI. (See Section 8.4)

4. Select the desired "Gravity" (rotating or non-rotating) model in the Mission Setup GUI.

5. Press the "Change/Add" Parameters" Pushbutton in the Mission Setup GUI to open the Simulation Parameters GUI and view or change the simulation parameters. Save any changes (if it is desired to save the parameter set for future simulations) and press "Continue" to return to the Mission Setup GUI. Simulation parameters are given below:

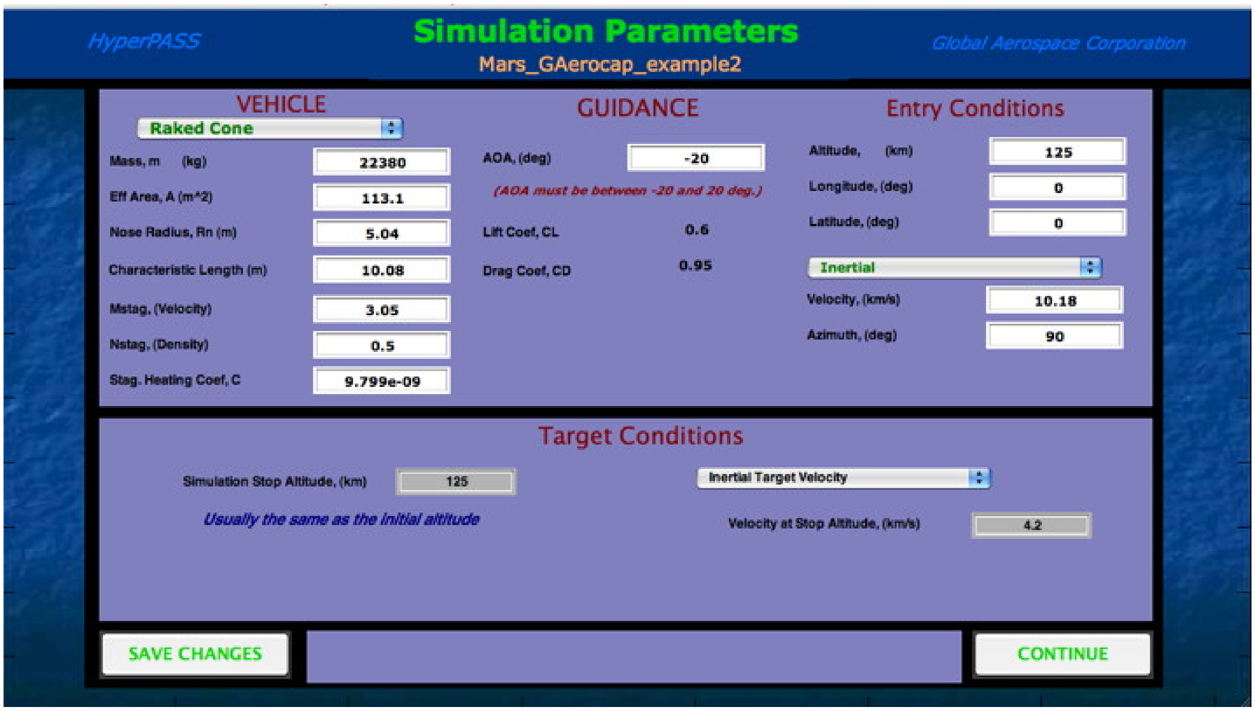

Figure 4-10 Simulation Parameters GUI – Guided Aerocapture

- VEHICLE
  - Type
    - None
    - Elliptical Raked Cone
    - Viking
    - Apollo
  - m
  - A
  - Rn
  - L
  - Mstag

  - Nstag
  - C

NOTE: If vehicle type is selected, the CL and CD are displayed as a function of vehicle angle of attack.

- GUIDANCE
  - AOA
  - CL
  - CD

- ENTRY CONDITIONS
  - Altitude
  - Longitude
  - Latitude
  - Velocity
  - Azimuth

NOTE: Velocity options are planet relative, inertial or v-infinity. If planet relative is chosen, azimuth is also planet relative. If inertial is chosen, azimuth is also inertial. If a v-infinity is entered, azimuth is inertial and the initial velocity is calculated at the initial altitude.

- Target Conditions
  - Simulation Stop Altitude (usually the same as the entry altitude)
  - Target Options:
    - Planet Relative Target Velocity
    - Inertial Target Velocity
    - Target Apoapsis Altitude

NOTE: The chosen target option is achieved at the simulation stop altitude.

6. Press "Continue" in the Mission Setup GUI to start the simulation. A simulation progress window will be displayed while the simulation is running. When the simulation is completed, the Post Simulation GUI will appear. **See warning in Section 4.2 about prematurely starting a run before closing this GUI.**

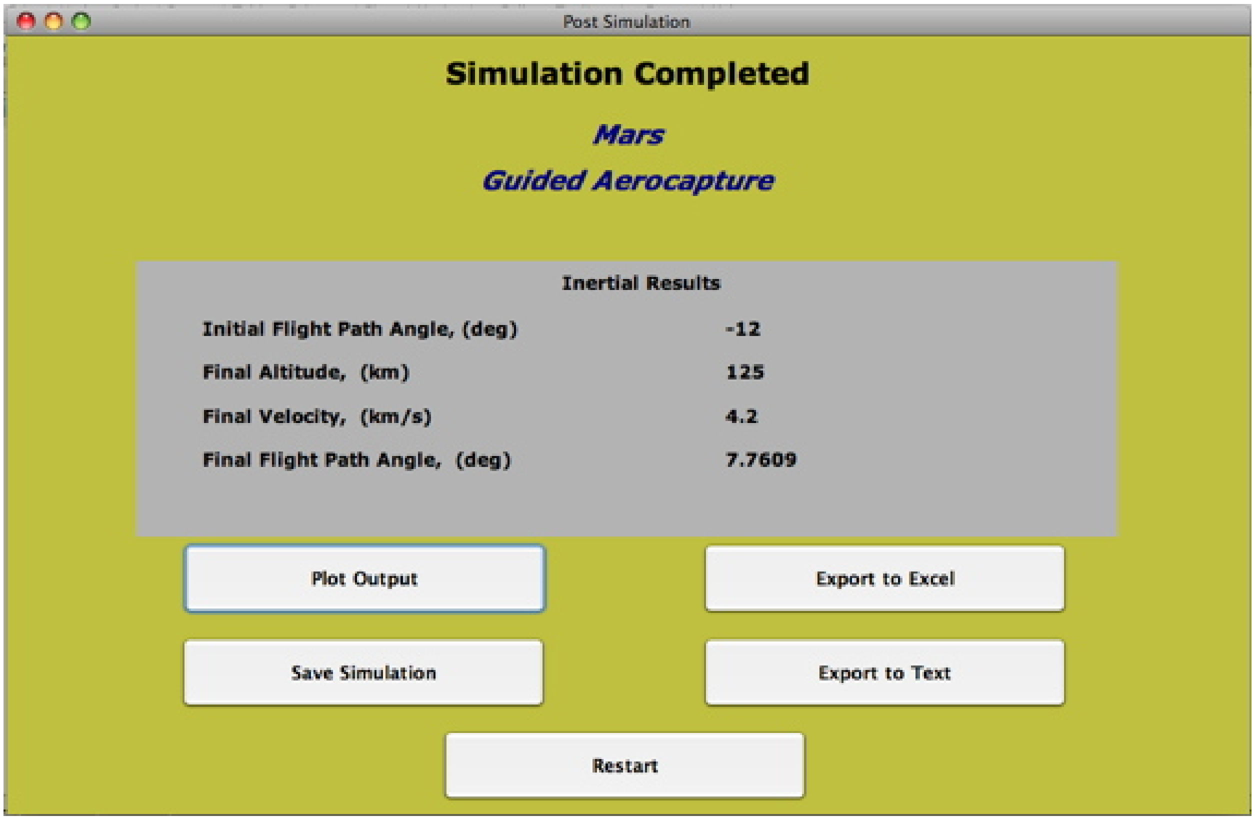

Figure 4-11 Post Simulation GUI – Guided Aerocapture

- SAVE SIMULATION
    - Simulations must be saved in order use the "View Previous Simulation" option in the HyperPASS GUI. (See Section 5.3)

- PLOT OUTPUT – opens the Plot Output GUI
    - Allows the user to plot simulation output.
    - See Section 3.7.1for plotting options.

- EXPORT TO EXCEL
    - Allows the user to export selected output to an M/S Excel workbook.
    - See Section 5.4.1.

- EXPORT TO TEXT
    - Allows the user to export simulation output into a delimited text (*.txt) file.
    - See Section 5.5.1

- RESTART
    - Restarts HyperPASS

4.2.3 Guided Ballute Aerocapture Simulation

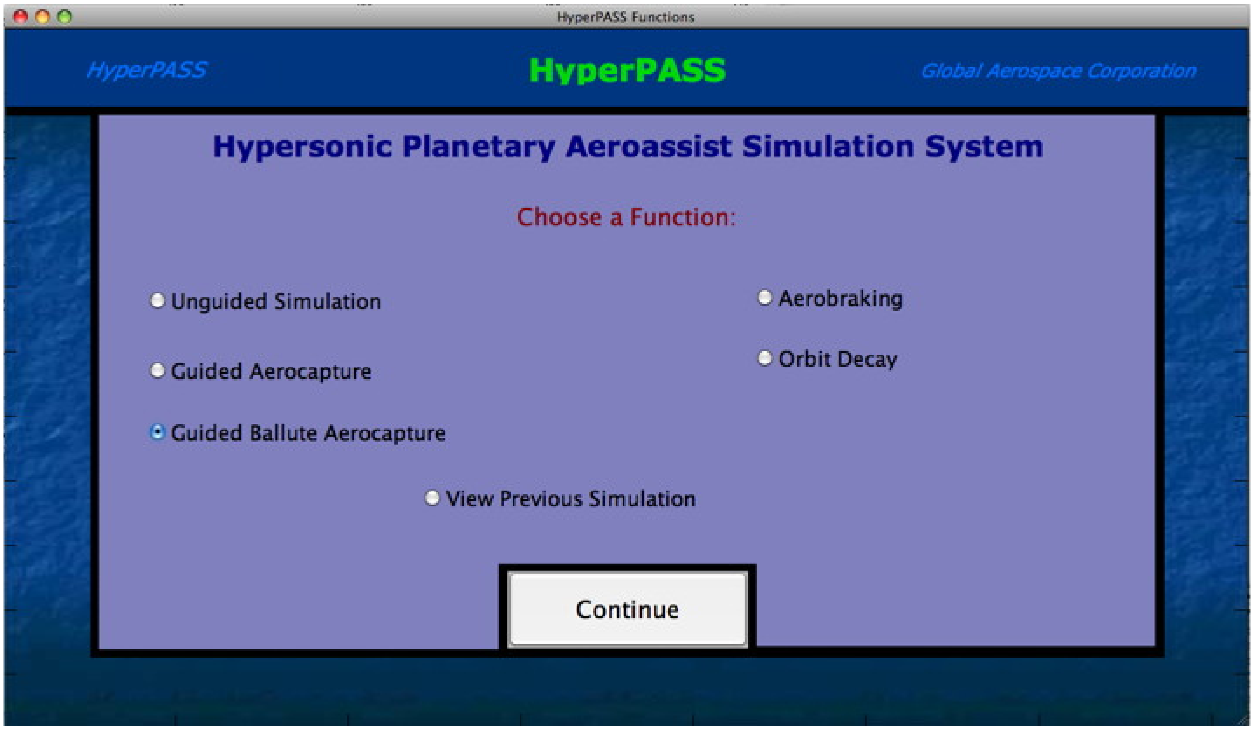

Figure 4-12 HyperPASS GUI – Guided Ballute Aerocapture

1. Select "Guided Ballute Aerocapture" the HyperPASS GUI and press "Continue". The Mission Setup GUI will then appear.

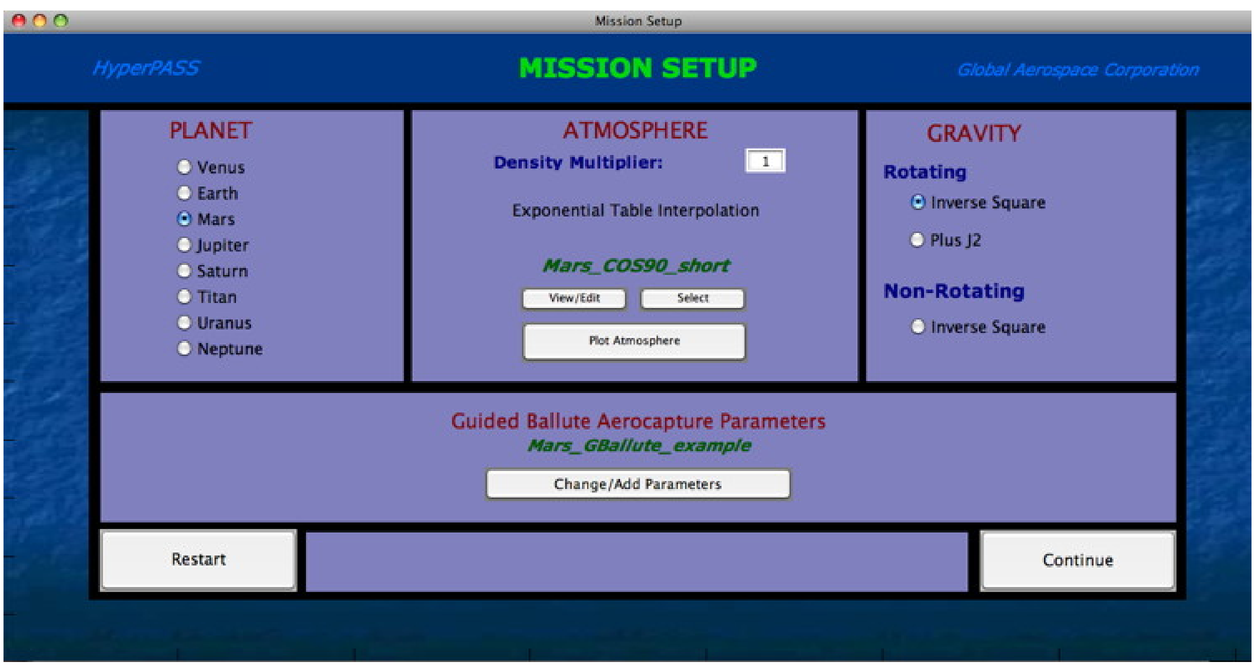

Figure 4-13 Mission Setup GUI – Guided Ballute Aerocapture

2. Select the desired "Planet" in the Mission Setup GUI. (See Section 8.2)

3. Select the desired “Atmosphere” model in the Mission Setup GUI. (See Section 8.4)
4. Select the desired “Gravity” (rotating or non-rotating) model in the Mission Setup GUI.
5. Press the “Change/Add” Parameters” Pushbutton in the Mission Setup GUI to open the Simulation Parameters GUI and view or change the simulation parameters. Save any changes (if it is desired to save the parameter set for future simulations) and press “Continue” to return to the Mission Setup GUI. Simulation parameters are given below:

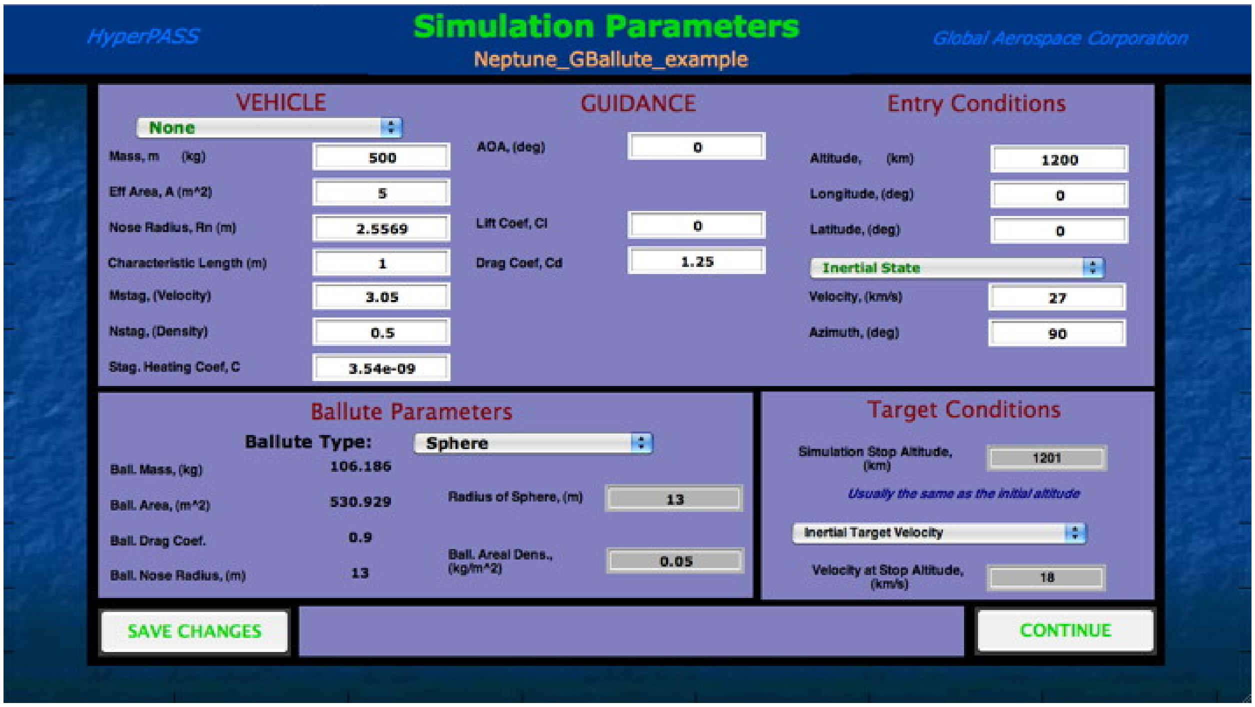

Figure 4-14 Simulation Parameters GUI – Guided Ballute Aerocapture

- VEHICLE
  - Type
    - None
    - Elliptical Raked Cone
    - Viking
    - Apollo
  - m
  - A
  - Rn
  - L
  - Mstag
  - Nstag
  - C

NOTE: If vehicle type is selected, the CL and CD are displayed as a function of vehicle angle of attack.

- GUIDANCE
  - AOA
  - CL
  - CD

- BALLUTE PARAMETERS
  - Type:
    - None
    - Sphere
      - radius of sphere
      - ballute areal density
    - Torus
      - d1 of torus
      - d2 of torus
      - ballute areal density
  - Ballute Mass
  - Ballute Area
  - Ballute Drag Coefficient (equals 0.9 for sphere and 1.37 for torus)
  - Ballute Nose Radius
  - Ballute Characteristic Length

NOTE: If "Sphere" or "Torus" is selected, the user must input the ballute dimensions and the areal density of the ballute material and HyperPASS automatically displays the corresponding ballute mass, ballute area, ballute drag coefficient and ballute nose radius. If no ballute type is selected, the ballute's m, A, CD, Rn and L are entered independently.

- ENTRY CONDITIONS
  - Altitude
  - Longitude
  - Latitude
  - Velocity
  - Azimuth

NOTE: Velocity options are planet relative, inertial or v-infinity. If planet relative is chosen, azimuth is also planet relative. If inertial is chosen, azimuth is also inertial. If a v-infinity is entered, azimuth is inertial and the initial velocity is calculated at the initial altitude.

- Target Conditions
  - Simulation Stop Altitude (usually the same as the entry altitude)
  - Target Options:
    - Planet Relative Target Velocity
    - Inertial Target Velocity
    - Target Apoapsis Altitude

NOTE: The chosen target option is achieved at the simulation stop altitude.

6. Press "Continue" in the Mission Setup GUI to start the simulation. A simulation progress window will be displayed while the simulation is running. When the

simulation is completed, the Post Simulation GUI will appear. **See warning in Section 4.2 about prematurely starting a run before closing this GUI.**

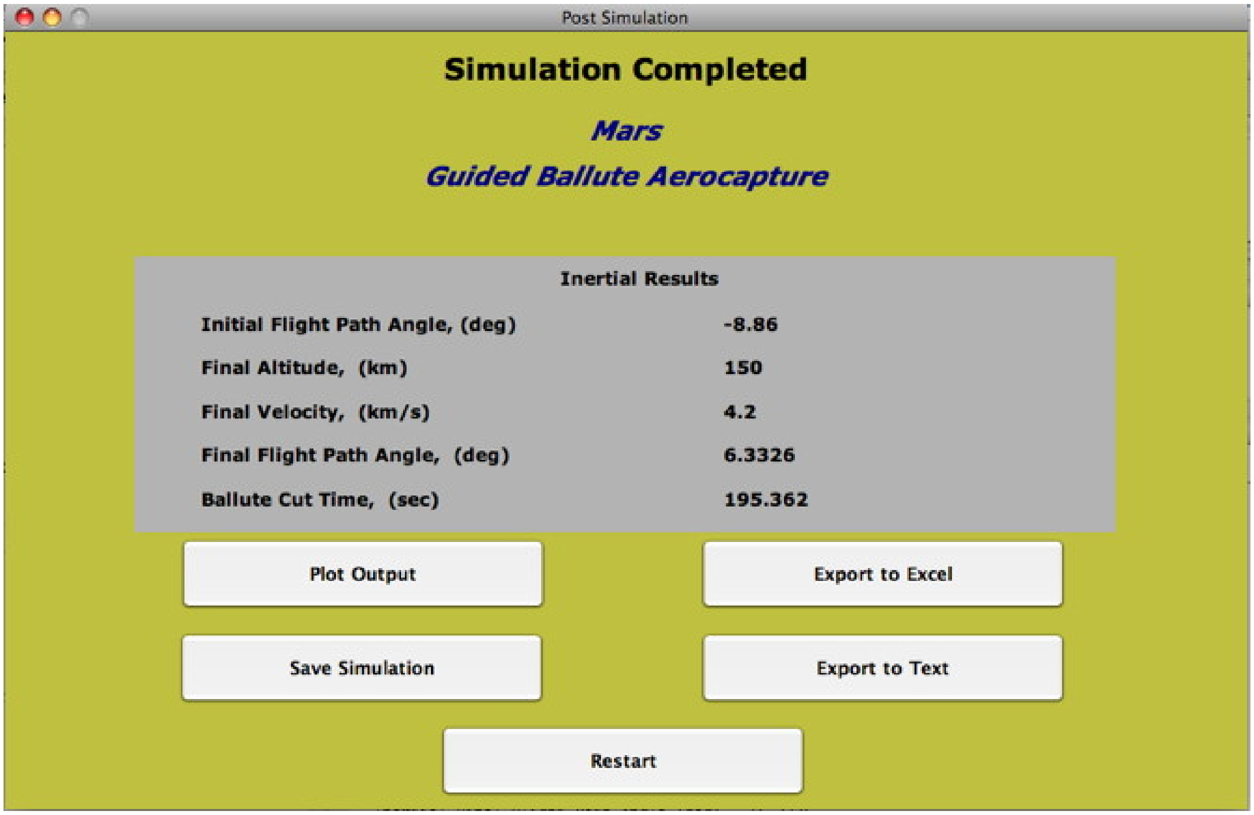

Figure 4-15 Post Simulation GUI – Guided Ballute Aerocapture

- SAVE SIMULATION
  - Simulations must be saved in order use the "View Previous Simulation" option in the HyperPASS GUI. (See Section 5.3)

- PLOT OUTPUT – opens the Plot Output GUI
  - Allows the user to plot simulation output.
  - See Section 3.7.1 for plotting options.

- EXPORT TO EXCEL
  - Allows the user to export selected output to an M/S Excel workbook.
  - See Section 5.4.1

- EXPORT TO TEXT
  - Allows the user to export simulation output into a delimited text (*.txt) file.
  - See Section 5.5.1

- RESTART

- Restarts HyperPASS

4.2.4 Aerobraking Simulation

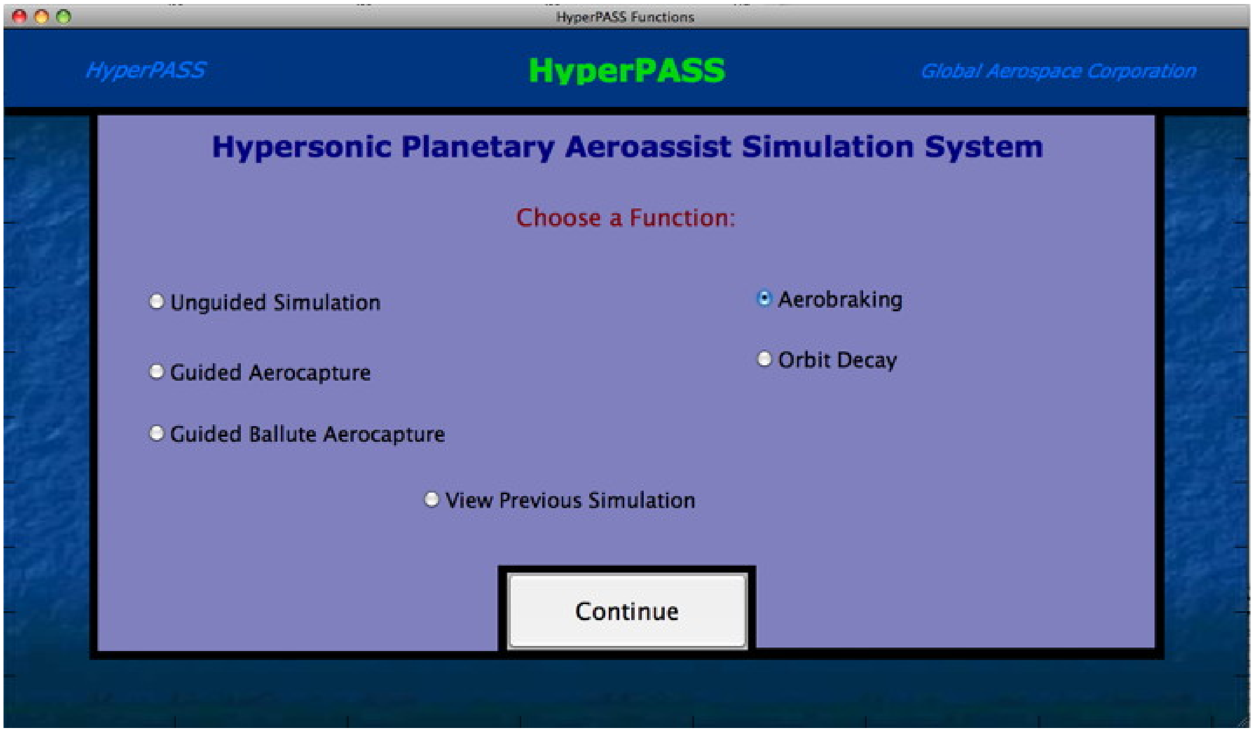

Figure 4-16 HyperPASS GUI – Aerobraking

1. Select "Aerobraking" in the HyperPASS GUI and press "Continue". The Mission Setup GUI will then appear.

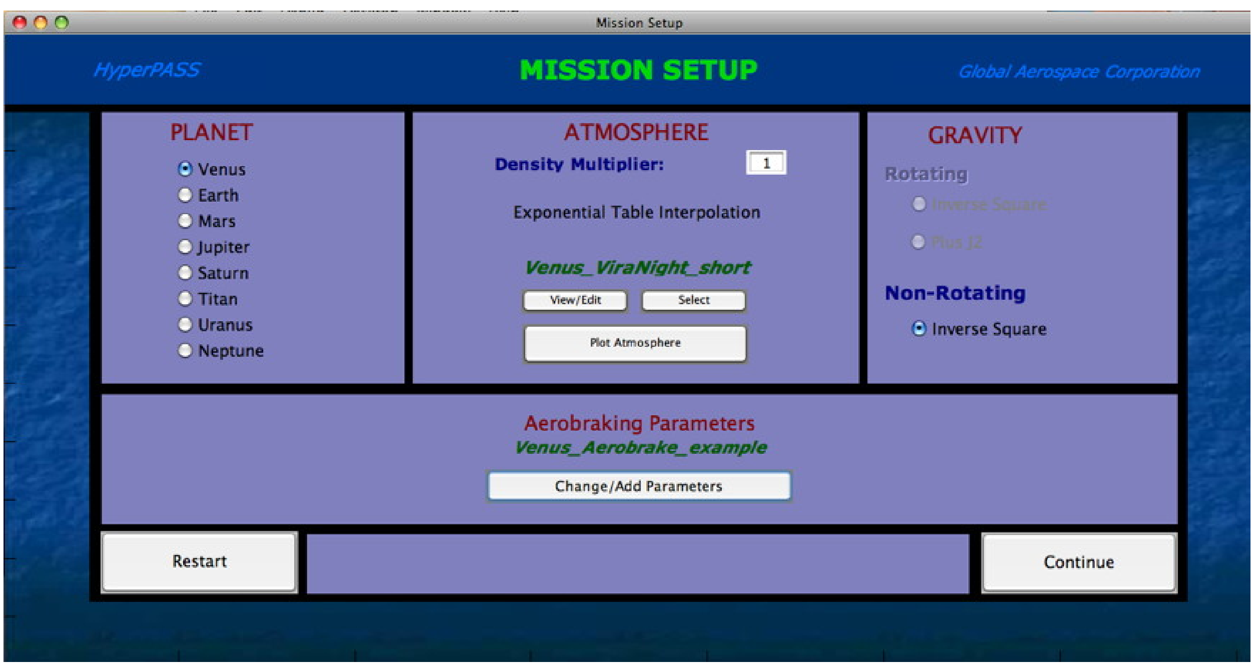

Figure 4-17 Mission Setup GUI – Aerobraking

2. Select the desired "Planet" in the Mission Setup GUI. (See Section 8.2)

3. Select the desired "Atmosphere" model in the Mission Setup GUI. (See Section 8.4)

4. The "Gravity" model is automatically set to the inverse-square model and the simulation is performed using the non-rotating planet/atmosphere.

5. Press the "Change/Add" Parameters" Pushbutton in the Mission Setup GUI to open the Simulation Parameters GUI and view or change the simulation parameters. Save any changes (if it is desired to save the parameter set for future simulations) and press "Continue" to return to the Mission Setup GUI. Simulation parameters are given below:

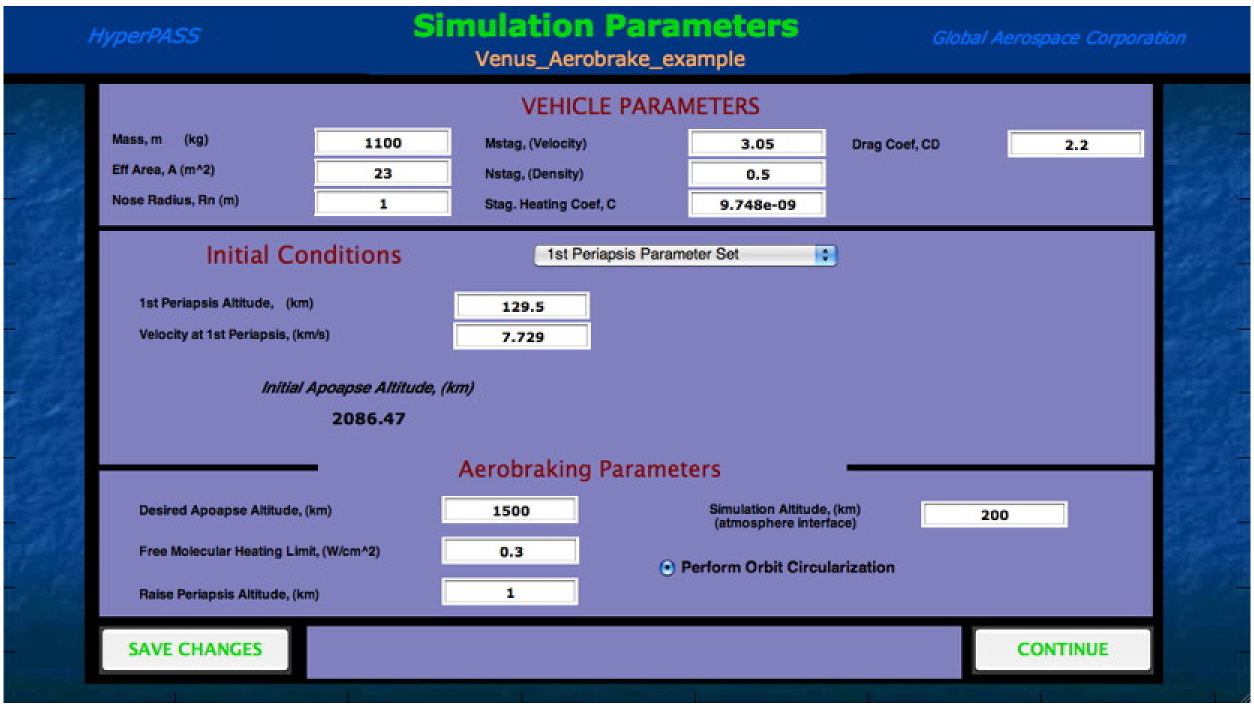

Figure 4-18 Simulation Parameters GUI – Aerobraking

- VEHICLE PARAMETERS
  - m
  - A
  - Rn
  - Mstag
  - Nstag
  - C
  - CD

- INITIAL CONDITIONS – 2 parameter set options
  - 1st Periapsis Parameter Set (no delta-V maneuvers performed prior to aerobraking)

        - 1st Periapsis Altitude
        - Velocity at 1st Periapsis
    - V-infinity Parameter Set (orbit insertion delta-V and lower periapsis delta-V maneuvers performed prior to aerobraking)
        - V-infinity
        - Initial Periapsis Altitude
        - Initial Semi-major Axis
        - Initial Orbit Period
        - 1st Aerobraking Periapsis Altitude

NOTE: The initial apoapsis altitude is automatically recalculated and displayed if initial conditions are changed. The initial semi-major axis and the initial orbit period are calculated simultaneously, so if either value is changed the other is calculated and displayed.

- AEROBRAKING PARAMETERS
    - Desired Apoapsis Altitude
    - Free Molecular Heating Limit
    - Raise Periapsis Altitude
    - Simulation Altitude
    - Perform Orbit Circularization (optional)

NOTE: If “Perform Orbit Circularization is selected, HyperPASS will perform a circularization maneuver when the desired apoapsis altitude is achieved.

6. Press “Continue” in the Mission Setup GUI to start the simulation. A simulation progress window will be displayed while the simulation is running. When the simulation is completed, the Post Simulation GUI will appear. **See warning in Section 4.2 about prematurely starting a run before closing this GUI.**

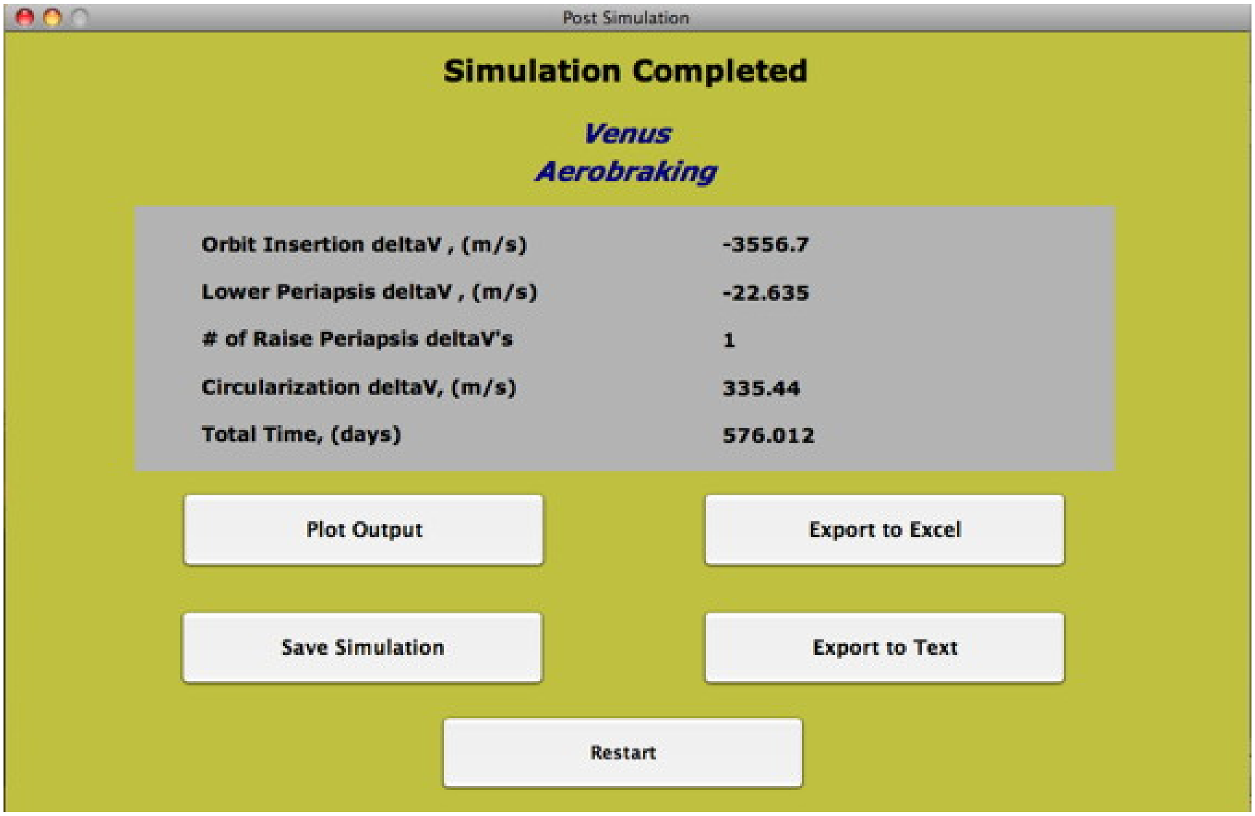

Figure 4-19 Post Simulation GUI – Aerobraking

- SAVE SIMULATION
  - Simulations must be saved in order use the "View Previous Simulation" option in the HyperPASS GUI. (See Section 5.3)

- PLOT OUTPUT – opens the Plot Output GUI
  - Allows the user to plot simulation output.
  - See Section 3.7.2 for plotting options.

- EXPORT TO EXCEL
  - Allows the user to export selected output to an M/S Excel workbook.
  - See Section 5.4.2

- EXPORT TO TEXT
  - Allows the user to export simulation output into a delimited text (*.txt) file.
  - See Section 5.5.2

- RESTART
  - Restarts HyperPASS

4.2.5 Orbit Decay Simulation

1. Select “Orbit Decay” in the main HyperPASS GUI and press “Continue”. The Mission Setup GUI will then appear.

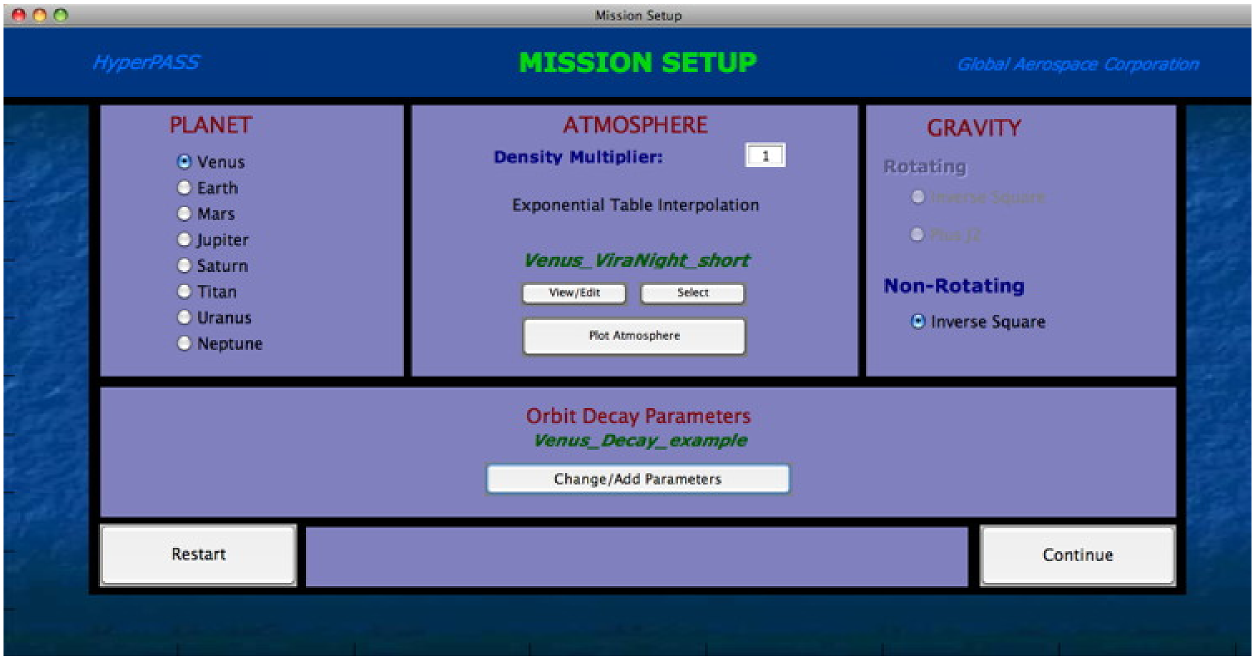

Figure 4-20 Mission Setup GUI – Orbit Decay

2. Select the desired “Planet” in the Mission Setup GUI. (See Section 8.2)

3. Select the desired “Atmosphere” model in the Mission Setup GUI. (See Section 8.4)

4. The “Gravity” model is automatically set to inverse-square model and the simulation is performed using the non-rotating equations of motion.

5. Press the “Change/Add” Parameters” Pushbutton in the Mission Setup GUI to open the Simulation Parameters GUI and view or change the simulation parameters. Save any changes (if it is desired to save the parameter set for future simulations) and press “Continue” to return to the Mission Setup GUI. Simulation parameters are given below:

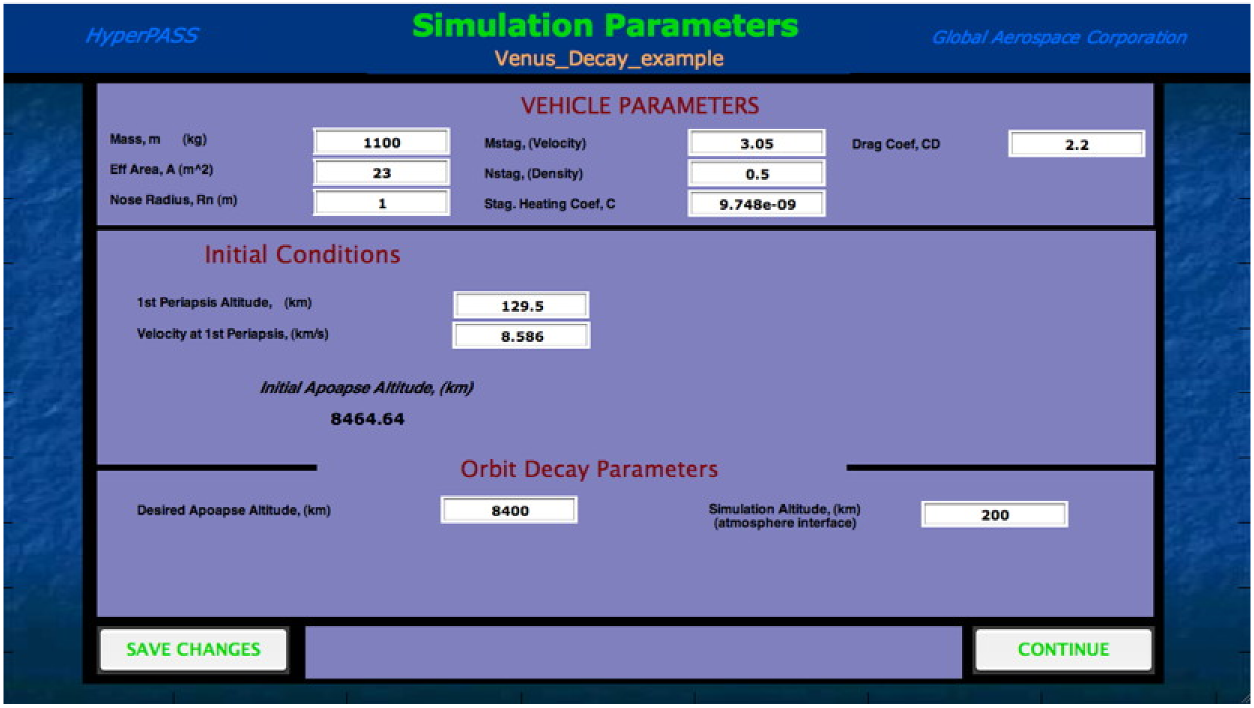

Figure 4-21 Simulation Parameters GUI – Orbit Decay

- VEHICLE PARAMETERS
  - m
  - A
  - Rn
  - Mstag
  - Nstag
  - C
  - CD

- INITIAL CONDITIONS
  - 1st Periapsis Parameter Set (no delta-V maneuvers performed prior to aerobraking)
    - 1st Periapsis Altitude
    - Velocity at 1st Periapsis

NOTE: The initial apoapsis altitude is automatically recalculated and displayed if initial conditions are changed.

- ORBIT DECAY PARAMETERS
  - Desired Apoapsis Altitude
  - Simulation Altitude

6. Press "Continue" in the Mission Setup GUI to start the simulation. A simulation progress window will be displayed while the simulation is running. When the simulation is completed, the Post Simulation GUI will appear. **See warning in Section 4.2 about prematurely starting a run before closing this GUI.**

Figure 4-22 Post Simulation GUI – Orbit Decay

- SAVE SIMULATION
  - Simulations must be saved in order use the "View Previous Simulation" option in the HyperPASS GUI. (See Section 5.3)

- PLOT OUTPUT – opens the Plot Output GUI
  - Allows the user to plot simulation output.
  - See Section 3.7.3 for plotting options.

- EXPORT TO EXCEL
  - Allows the user to export selected output to an M/S Excel workbook.
  - See Section 5.4.3

- EXPORT TO TEXT
  - Allows the user to export simulation output into a delimited text (*.txt) file.
  - See Section 5.5.3

- RESTART
  - Restarts HyperPASS

5 Output Options

5.1 Plot Data

Selecting “Plot Data” in the Post Simulation GUI opens the Plot Output GUI. For complete lists of output data available for plotting (See Section 3.7).

5.2 Editing Plots

Plots are created using MATLAB. MATLAB contains a variety of options for editing plots. For more information on editing plots, open the MATLAB Help Navigator by selecting “Help ▸ MATLAB Help” from the menu at the top of the MATLAB Command Window. Search for “using plot editing mode” under the “Search” tab.

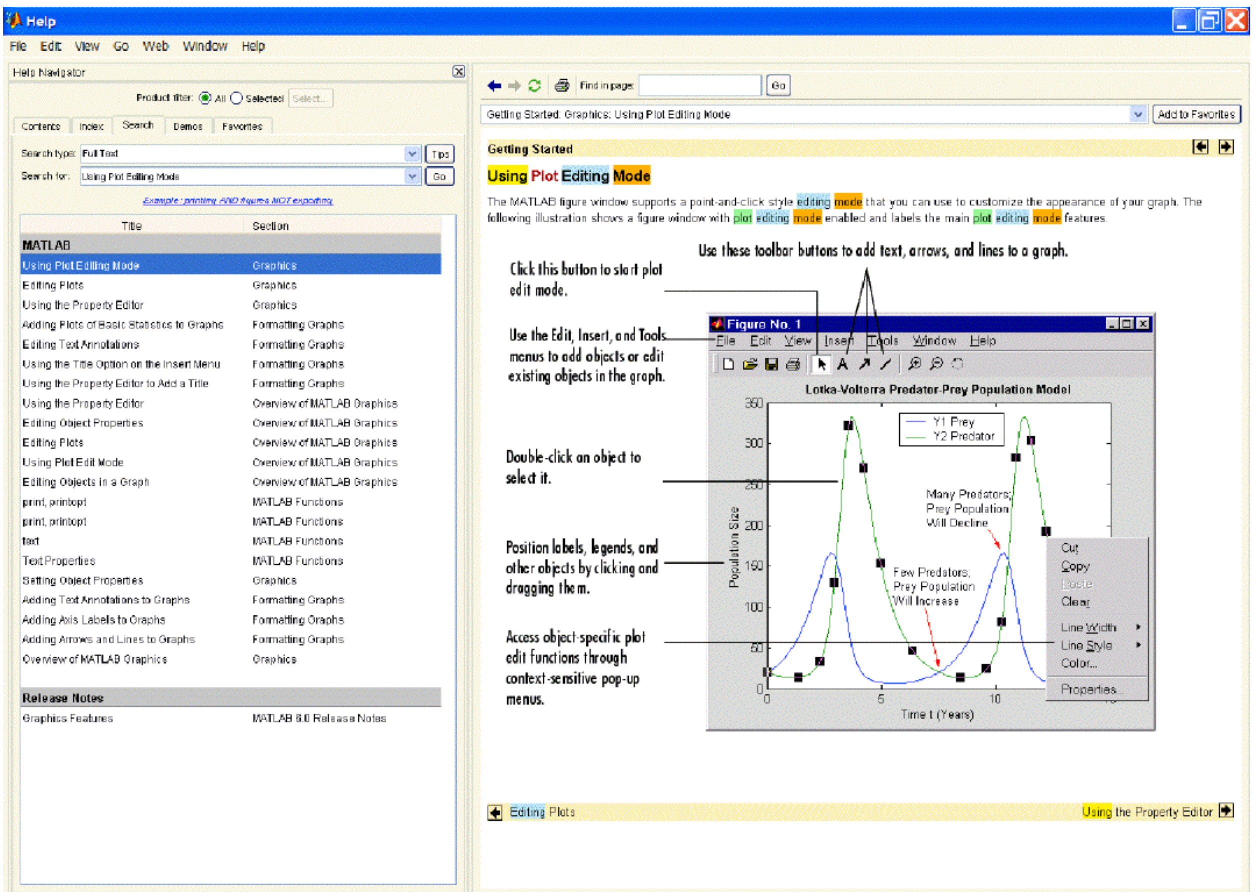

Figure 5-1 MATLAB Help Window (Courtesy of MathWorks)

5.3 Saving Output

Selecting “Save Output” in the Post Simulation GUI saves the simulation so that it can be viewed again later. The user will be prompted to enter a name for the saved simulation… DO NOT change folders while saving (HyperPASS automatically opens the correct folder for saved simulations). Use the "View Previous Simulation" option in the HyperPASS GUI to reload a chosen saved simulation. After the saved data is reloaded, the Post Simulation GUI will be displayed as if the simulation was just completed.

5.4 Export to Excel

This option is only available on Windows (PC) systems with M/S Excel installed.

Selecting "Export to Excel" in the Post Simulation GUI, allows the user to export the simulation data to a M/S Excel workbook. The user will be prompted to enter a name for the new Excel workbook… it is recommended that the workbook be saved outside the HyperPASS program, although a folder labeled "Excel Output" does exist just in case.

NOTE: *Currently "Export to Excel" is limited when compared to the "Export to Text" option. For complete data export, it is highly recommended that "Export to Text" is used instead. The text data can then easily be imported into external programs such as Excel.*

5.4.1 Unguided, Guided Aerocapture, & Guided Ballute Aerocapture

The user selects what output parameters to export using the Export Excel GUI. Output parameters include most parameters that are available for plotting (See Section 3.7.1). Two separate worksheets will be created in the Excel workbook, one containing the simulation data (output) and another containing the vehicle parameters.

All of the Excel workbooks will include mission setup information such as planet, atmosphere file, gravity model, and vehicle parameters in addition to the output parameters.

Figure 5-2 Select Data To Export

5.4.2 Aerobraking

All output data is exported to an M/S Excel workbook. Output parameters include all parameters that are available for plotting (See Section 3.7.2). Three separate worksheets will be created in the Excel workbook, one containing the simulation data (output), another containing the vehicle parameters, and the other containing the delta-V maneuver data.

5.4.3 Orbit Decay

All output data is exported to an M/S Excel workbook. Output parameters include all parameters that are available for plotting (See Section 3.7.3). Three separate worksheets will be created in the Excel workbook, one containing the simulation data (output), another containing the vehicle parameters, and the other containing the delta V maneuver data.

5.5 Export to Text

Selecting "Export to Text" in the Post Simulation GUI, allows the user to export the simulation data to a delimited text (*.txt) file. The user will be prompted to enter a name for the new text file. It is recommended that the file be saved outside the HyperPASS program, although a folder labeled "Text Output" does exist just in case.

All of the text files will include mission setup information such as planet, atmosphere file, gravity model, and vehicle parameters in addition to the output parameters.

NOTE: *Currently "Export to Excel" is limited when compared to the "Export to Text" option. For complete data export, it is highly recommended that "Export to Text" is used. The text data can then easily be imported into external programs such as Excel.*

5.5.1 Unguided, Guided Aerocapture, & Guided Ballute Aerocapture

Output parameters include all parameters that are available for plotting (See Section 3.7.1). Two separate worksheets will be created in the Excel workbook, one containing the simulation data (output) and another containing the vehicle parameters.

5.5.2 Aerobraking

All output data except for deltaV information is exported to a delimited text file. All deltaV information is displayed in the MATLAB Command Window at the end of a simulation and can be copied and pasted into a text file, if so desired.

5.5.3 Orbit Decay

All output data is exported to a delimited text file. Output parameters include all parameters that are available for plotting (See Section 3.7.2).

6 Examples

The following examples can be viewed by selecting "View Previous Simulation" in the HyperPASS GUI. The user may also choose to run the example simulations himself, by entering the data specified in the following tables.

6.1 Example 1: Unguided Aerocapture

Example 1: Unguided Aerocapture	
Function	Unguided
Planet	Titan
Atmosphere	Titan_Hunten
Gravity/Rotation	Inverse-square (non-rotating)
Simulation Parameters	Titan_Aerocapture_Ex1
Vehicle Type	Viking

6.2 Example 2: Unguided Ballute Aerocapture

Example 2: Unguided Ballute Aerocapture	
Function	Unguided
Planet	Neptune
Atmosphere	Neptune_Hall
Gravity/Rotation	Inverse-square (rotating)
Simulation Parameters	Neptune_Ballute_Ex2
Vehicle Type	none
Ballute Type	Sphere
Ballute Cut Time	432 sec

6.3 Example 3: Unguided Entry-Descent-Landing

Example 3: Unguided Entry-Descent-Landing	
Function	Unguided
Planet	Earth
Atmosphere	Earth_US1976
Gravity/Rotation	Inverse-square (rotating)
Simulation Parameters	Earth_Landing_Ex3
Vehicle Type	none

6.4 Example 4: Guided Aerocapture

Example 4: Guided Aerocapture	
Function	Guided Aerocapture
Planet	Mars
Atmosphere	Mars_COS90_short
Gravity/Rotation	J2 (rotating)
Simulation Parameters	Mars_GAerocap_Ex4
Vehicle Type	Elliptical Raked Cone

6.5 Example 5: Guided Ballute Aerocapture

Example 5: Guided Ballute Aerocapture	
Function	Guided Ballute

	Aerocapture
Planet	Mars
Atmosphere	Mars_COS90_short
Gravity/Rotation	Inverse-square (rotating)
Simulation Parameters	Mars_GBallute_Ex5
Vehicle Type	none
Ballute Type	Sphere

6.6 Example 6: Aerobraking

Example 6: Aerobraking	
Function	Aerobraking
Planet	Venus
Atmosphere	Venus_ViraNight_short
Gravity/Rotation	Inverse-square (non-rotating)
Simulation Parameters	Venus_Aerobrake_Ex6

7 Glossary

PARAMETER	TYPE	DESCRIPTION	APPLICABLE FUNCTIONS	SYMBOLS & ABBREVIATIONS
1st aerobraking periapsis altitude	INPUT	Periapsis altitude where aerobraking will start. If the V-infinity parameter set is selected (Aerobraking only), a lower periapsis deltaV will be performed to achieve this 1st aerobraking periapsis altitude.	Aerobraking, Orbit Decay	
acceleration force (binormal)	OUTPUT	Binormal or lateral acceleration (g-load) over time.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**a_w , g-load (binormal)**
acceleration force (magnitude)	OUTPUT	Magnitude of acceleration (g-load) over time.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**g-load**
acceleration force (normal)	OUTPUT	Normal acceleration (g-load) over time.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**a_n , g-load (normal)**
acceleration force (tangential)	OUTPUT	Tangential acceleration (g-load) over time.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**a_s , g-load (tangential)**
altitude	INPUT	Initial altitude (above planet surface) of vehicle. Value should typically be the planet's atmosphere interface.	ALL	
altitude	OUTPUT	Height of vehicle above the planet surface (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
angle of attack	INPUT	Initial angle of attack of the vehicle. Value should be between -90 and 90 degrees if no vehicle type is selected. If a vehicle type is selected, the corresponding angle of attack range is displayed.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**AOA**
angle of attack	OUTPUT	Angle of attack of the vehicle (over time). Value will be constant unless changed during an Unguided simulation (this is done by adding a transition).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**AOA**
angle of bank	INPUT	Initial angle of bank of the vehicle. Value should be between -180 and 180 degrees.	Unguided	**AOB**
angle of bank	OUTPUT	Angle of bank of the vehicle (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**AOB**
angular momentum - X	OUTPUT	Angular momentum in the inertial X-direction (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**hX**
angular momentum - Y	OUTPUT	Angular momentum in the inertial Y-direction (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**hY**
angular momentum - Z	OUTPUT	Angular momentum in the inertial Z-direction (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**hZ**
angular momentum (magnitude)	OUTPUT	Magnitude of angular momentum (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**h**
apoapsis altitude	OUTPUT	Apoapsis altitude of each orbit. (highest altitude of orbit)	Aerobraking, Orbit Decay	
Apollo - vehicle type	INPUT	If selected, HyperPASS displays the CL and CD as a function of user entered AOA.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
atmospheric altitude vs. density	INPUT	A preexisting model may be selected, or the user may enter his own.	ALL	
atmospheric density	OUTPUT	Atmospheric density (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**ρ (density)**
azimuth	INPUT	Initial flight path azimuth angle of the vehicle. The user has the choice of entering this value in either the planet relative or inertial frame. Value should be between 0 and 360 degrees.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
ballute area	INPUT	Effective area of the ballute.	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	**A_ballute**
ballute areal density	INPUT	Density of the ballute material.	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	
ballute cut time	INPUT	Time to release the ballute. This value is only needed if "Cut Ballute" is selected after performing an Unguided simulation. This value is determined iteratively when running a Guided Ballute simulation.	Unguided (if "Add Ballute" is selected)	
ballute cut time	OUTPUT	Time of ballute release. This value is determined iteratively when running a Guided Ballute simulation.	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	
ballute drag coefficient	INPUT	Drag coefficient of the ballute	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	**CD_ballute**
ballute mass	INPUT	Mass of the ballute (this value does not include vehicle mass).	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	**m_ballute**
ballute nose radius	INPUT	Nose radius of the ballute.	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	**Rn_ballute**
ballute type	INPUT	The user has the following options: Sphere or Torus. If one of these types is selected, the user must input the ballute dimensions and the areal density of the ballute material and HyperPass automatically displays the corresponding ballute mass, ballute area, ballute drag coefficient and ballute nose radius. If no ballute type is selected, the ballute's m, A, CD, and Rn are entered independently. See Sphere and Torus for more information.	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	
clock angle	INPUT	Clock angle of thrusting vector.	Unguided	
cone angle	INPUT	Cone angle of thrusting vector.	Unguided	
continuum heating	OUTPUT	Stagnation point (continuum) heating rate over time.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**Q_{stag}**
continuum heating at periapsis	OUTPUT	Stagnation point (continuum) heating at each periapsis.	Aerobraking, Orbit Decay	
d1 of torus	INPUT	Torus ballute dimension - distance from center of torus to the center of the torus's tube.	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	**d1**
d2 of torus	INPUT	Torus ballute dimension - diameter of the torus's tube.	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	**d2**
delta-V magnitude	OUTPUT	Magnitude of each raise periapsis deltaV performed during Aerobraking.	Aerobraking	
desired apoapse altitude	INPUT	Aerobraking and Orbit Decay simulations will stop once this apoapse altitude is achieved.	Aerobraking, Orbit Decay	
drag coefficient	INPUT	Initial coefficient of drag. Value can be entered manually if no vehicle type is selected. If a vehicle type is selected, the drag coefficient is calculated and displayed as a function of initial angle of attack.	ALL	**CD**
drag force	OUTPUT	Drag (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**D**
effective area	INPUT	Effective cross sectional surface area of the vehicle.	ALL	**A**
elapsed time	OUTPUT	Time of each periapsis pass.	Aerobraking, Orbit Decay	
flight path angle	INPUT	Initial flight path angle of the vehicle. The user has the choice of entering this value in either the planet relative or inertial frame. This value is determined iteratively when running a Guided Aerocapture or Guided Ballute Aerocapture simulation. (Value is typically a negative).	Unguided	**γ , FPA**

PARAMETER	TYPE	DESCRIPTION	APPLICABLE FUNCTIONS	SYMBOLS & ABBREVIATIONS
free molecular heating at periapsis	OUTPUT	Free molecular (continuum) heating at each periapsis.	Aerobraking, Orbit Decay	Q_{fm}
free molecular heating limit	INPUT	If the free molecular heating rate exceeds this limit during Aerobraking, HyperPASS will automatically "back up" to the previous apoapse and perform a raise periapsis deltaV maneuver. The periapsis altitude change during this maneuver is determined by the user-entered raise periapsis altitude.	Aerobraking	
g-load	OUTPUT	See acceleration force.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	g-load
heading angle	INPUT	Vehicle flight path heading angle. Heading angle is not a user-entered input, instead the user inputs azimuth angle. (= 90° - azimuth)	ALL	ψ
inertial azimuth angle	OUTPUT	Flight path azimuth angle of the vehicle in the inertial reference frame (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
inertial flight path angle	OUTPUT	Flight path angle of the vehicle in the inertial reference frame (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
inertial velocity	OUTPUT	Speed of the vehicle in inertial reference frame (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
inertial velocity at periapsis	OUTPUT	Speed at each periapsis.	Aerobraking, Orbit Decay	
initial apoapse altitude	INPUT	Initial apoapse altitude is automatically calculated and displayed based upon the user-entered Aerobraking or Orbit Decay parameters. This is not a user-entered value.	Aerobraking, Orbit Decay	
initial orbit period	INPUT	Period of the initial orbit (prior to the lower periapsis deltaV maneuver and the start of aerobraking). This is an input when the V-infinity parameter set is selected for an Aerobraking Simulation. Initial semi-major axis and initial orbit period are calculated simultaneously, so changing one value will result in the other value changing as well.	Aerobraking (V-infinity parameter set)	P
initial periapsis altitude	INPUT	Periapsis altitude of the approaching V-infinity trajectory. The orbit insertion deltaV will be performed at this altitude to achieve the orbit described by the user-entered initial semi-major axis (or initial orbit period). This value should be above the simulation altitude. This is an input when the V-infinity parameter set is selected for an Aerobraking Simulation.	Aerobraking (V-infinity parameter set)	
initial semi-major axis	INPUT	Semi-major axis of the initial orbit (prior to the lower periapsis deltaV maneuver and the start of aerobraking). This is an input when the V-infinity parameter set is selected for an Aerobraking Simulation. Initial semi-major axis and initial orbit period are calculated simultaneously, so changing one value will result in the other value changing as well.	Aerobraking (V-infinity parameter set)	a
latitude	INPUT	Initial latitude in the planet reference frame. Value should be between 0 and 360 degrees.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	Φ
latitude	OUTPUT	Latitude position in the planet reference frame (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	Φ
lift coefficient	INPUT	Initial coefficient of lift. Value can be entered manually if no vehicle type is selected. If a vehicle type is selected, the lift coefficient is calculated and displayed as a function of initial angle of attack.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	CL
lift force	OUTPUT	Lift (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	L
longitude	INPUT	Initial East longitude in the planet reference frame. Value should be between 0 and 360 degrees.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	Θ
longitude	OUTPUT	East longitude position in the planet reference frame (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	Θ
mass	INPUT	Initial mass of the vehicle. When running a simulation involving a ballute, this is the mass of the vehicle without the ballute.	ALL	m
max altitude	INPUT	Maximum altitude stopping condition. The simulation will stop if this altitude is reached. This is an optional condition for Unguided Simulations only.	Unguided	
max FPA	INPUT	Maximum planet relative flight path angle stopping condition. The simulation will stop if this FPA is reached. This is an optional condition for Unguided Simulations only.	Unguided	
max G-load	INPUT	Maximum acceleration force magnitude stopping condition. The simulation will stop if this g-load is reached. This is an optional condition for Unguided Simulations only.	Unguided	
max heating	INPUT	Maximum stagnation point (continuum) heating stopping condition. The simulation will stop if this heating limit is reached. This is an optional condition for Unguided Simulations only. Aerobraking Simulations have a maximum free molecular heating limit, not to be confused with this continuum heating limit.	Unguided	
max speed	INPUT	Maximum planet relative speed stopping condition. The simulation will stop if this speed is reached. This is an optional condition for Unguided Simulations only.	Unguided	
min altitude	INPUT	Minimum altitude stopping condition. The simulation will stop if this altitude is reached. This is an optional condition for Unguided Simulations only.	Unguided	
min FPA	INPUT	Minimum planet relative flight path angle stopping condition. The simulation will stop if this FPA is reached. This is an optional condition for Unguided Simulations only.	Unguided	
min G-load	INPUT	Minimum acceleration force magnitude stopping condition. The simulation will stop if this g-load is reached. This is an optional condition for Unguided Simulations only.	Unguided	
min heating	INPUT	Minimum stagnation point (continuum) heating stopping condition. The simulation will stop if this heating limit is reached. This is an optional condition for Unguided Simulations only. Aerobraking Simulations have a maximum free molecular heating limit, not to be confused with this continuum heating limit.	Unguided	
min speed	INPUT	Minimum planet relative speed stopping condition. The simulation will stop if this speed is reached. This is an optional condition for Unguided Simulations only.	Unguided	
Mstag	INPUT	Velocity power coefficient for stagnation point heating calculation. See (***) for more information on heating calculations.	ALL	Mstag
new periapsis altitude	OUTPUT	Periapsis altitude resulting from each raise periapsis deltaV performed during Aerobraking.	Aerobraking	
nose radius	INPUT	Nose radius of vehicle. This value is used in the stagnation point heating calculation.	ALL	Rn
Nstag	INPUT	Atmospheric density power coefficient for stagnation point heating calculation. See Appendix for more information on heating calculations.	ALL	Nstag
old periapsis altitude	OUTPUT	Periapsis altitude just prior to each raise periapsis deltaV performed during Aerobraking.	Aerobraking	
orbit number (of deltaV)	OUTPUT	Orbit number of each raise periapsis deltaV performed during Aerobraking.	Aerobraking	
orbit period	OUTPUT	Duration of each orbit.	Aerobraking, Orbit Decay	
periapsis altitude	OUTPUT	Periapsis altitude of each orbit. (lowest altitude of orbit)	Aerobraking, Orbit Decay	

PARAMETER	TYPE	DESCRIPTION	APPLICABLE FUNCTIONS	SYMBOLS & ABBREVIATIONS
periapsis pass (#)	OUTPUT	Orbit number of each periapsis pass (starts with "1" at 1st aerobraking periapsis altitude).	Aerobraking, Orbit Decay	
planet radius	PLANET	Average radial distance from the planet's center to surface. This is not a user-entered input.	ALL	**R**
planet relative azimuth angle	OUTPUT	Flight path azimuth angle of the vehicle in the planet relative reference frame (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
planet relative flight path angle	OUTPUT	Flight path angle of the vehicle in the planet relative reference frame (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
planet relative velocity	OUTPUT	Speed of the vehicle in planet relative reference frame (over time).	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
planet rotational velocity	PLANET	The rotational rate of the specified planet (or moon). HyperPASS assumes that the atmosphere rotates with the planet. This is not a user entered input.	ALL	Ω
planetary gravitational constant	PLANET	Used for inverse-square gravity calculations. This is not a user-entered input.	ALL	μ, **GM**
radial distance (radius)	OUTPUT	Radial distance of the vehicle (over time), measured from the center of the planet.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**r**
radius of sphere	INPUT	Sphere ballute dimension - radius of spherical ballute.	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	
raise periapsis altitude	INPUT	Periapsis altitude change when a raise periapsis deltaV is performed. If the free molecular heating limit is exceeded during Aerobraking, HyperPASS will automatically "back up" to the previous apoapse and perform a raise periapsis deltaV maneuver.	Aerobraking	
Raked Cone - vehicle type	INPUT	Elliptical raked cone vehicle type (45 degree). If selected, HyperPASS displays the CL and CD as a function of user entered AOA.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
simulation altitude	INPUT	Altitude above which atmospheric density is insignificant (atmosphere interface). The higher this value, the longer it will take to perform Aerobraking and Orbit Decay simulations.	Aerobraking, Orbit Decay	
simulation stop altitude	INPUT	Altitude when simulation will terminate. Typically this is atmospheric interface altitude and is equal to the initial altitude. This is an input when running a Guided Aerocapture or Guided Ballute Aerocapture Simulation only.	Guided Aerocapture, Guided Ballute Aerocapture	
simulation time	INPUT	Time of simulation. Simulation time is an input when running an Unguided Simulation. If other simulation stopping conditions are specified, the simulation will run until any stopping condition is met or until the simulation time is reached.	Unguided	
specific impulse	INPUT	Specific impulse of the body fixed thrust.	Unguided	**Isp**
Sphere - ballute type	INPUT	If selected, the user must input the sphere dimension (radius of sphere) and the areal density of the ballute material and HyperPass will automatically display the corresponding ballute mass, ballute area, ballute drag coefficient and ballute nose radius. The ballute drag coefficient for the sphere is 0.9.	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	
stagnation heating coefficient	INPUT	Coefficient for stagnation point heating calculation. See for more information on heating calculations.	ALL	**C**
stagnation point heating	OUTPUT	Stagnation point (continuum) heating rate over time.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
stagnation point heating at periapsis	OUTPUT	Stagnation point (continuum) heating at each periapsis.	Aerobraking, Orbit Decay	Q_{stag}
target apoapse altitude	INPUT	This target (final) condition will be met at the simulation stop altitude when running a Guided Aerocapture or Guided Ballute Aerocapture Simulation. The Aerobraking and Orbit Decay Simulations will stop once this apoapse altitude is achieved.	Guided Aerocapture, Guided Ballute Aerocapture, Aerobraking, Orbit Decay	
target velocity (inertial)	INPUT	See velocity at stop altitude.	Guided Aerocapture, Guided Ballute Aerocapture	
target velocity (planet relative)	INPUT	See velocity at stop altitude.	Guided Aerocapture	
thrust	INPUT	Initial magnitude of thrust. Directional thrust can be entered by changing the body fixed thrusting cone and clock angles.	Unguided	**T**
thrust	OUTPUT	Magnitude of thrust. This value will be zero unless otherwise specified during an Unguided simulation.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	**T**
time	OUTPUT	Duration of simulation.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
time of deltaV	OUTPUT	Time of implementation of each raise periapsis deltaV performed during Aerobraking.	Aerobraking	
Torus - ballute type	INPUT	If selected, the user must input the torus dimensions (d1 of torus and d2 of torus) and the areal density of the ballute material and HyperPass will automatically display the corresponding ballute mass, ballute area, ballute drag coefficient and ballute nose radius. The ballute drag coefficient for the torus is 1.25.	Unguided (if "Add Ballute" is selected), Guided Ballute Aerocapture	
transition time	INPUT	Time to begin transition. This value is only needed if "Add Transition" is selected after performing an Unguided simulation.	Unguided	
vehicle	INPUT	The user has the following vehicle type options: Raked Cone, Viking, or Apollo. If one of these types is selected, HyperPass displays the CL and CD as a function of the user entered AOA. If no vehicle type is selected, the CL, CD , and AOA are entered independently.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
velocity	INPUT	Initial speed of the vehicle. The user has the choice of entering this value in either the planet relative or inertial frame.	ALL	**v**
velocity at 1st periapsis	INPUT	Speed at the user-entered 1st aerobraking periapsis altitude.	Aerobraking (1st periapsis parameter set), Orbit Decay	
velocity at stop altitude	INPUT	Target velocity is an input when running a Guided Aerocapture or Guided Ballute Aerocapture Simulation. This target (final) condition will be met at the simulation stop altitude. The user has the option to enter either a velocity at stop altitude or the target apoapse altitude.	Guided Aerocapture, Guided Ballute Aerocapture	
Viking - vehicle type	INPUT	If selected, HyperPASS displays the CL and CD as a function of user entered AOA.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture	
v-infinity	INPUT	Approaching v-infinity magnitude. If the user chooses to give a v-infinity speed, the initial (entry) velocity will be calculated at the user entered initial altitude.	Unguided, Guided Aerocapture, Guided Ballute Aerocapture, Aerobraking	**v-infinity**
Zonal Harmonic J2	PLANET	Planetary constant used in J2 gravity calculations. This is not a user-entered input.	ALL	**J2**

8 Appendices

8.1 Angle Geometry

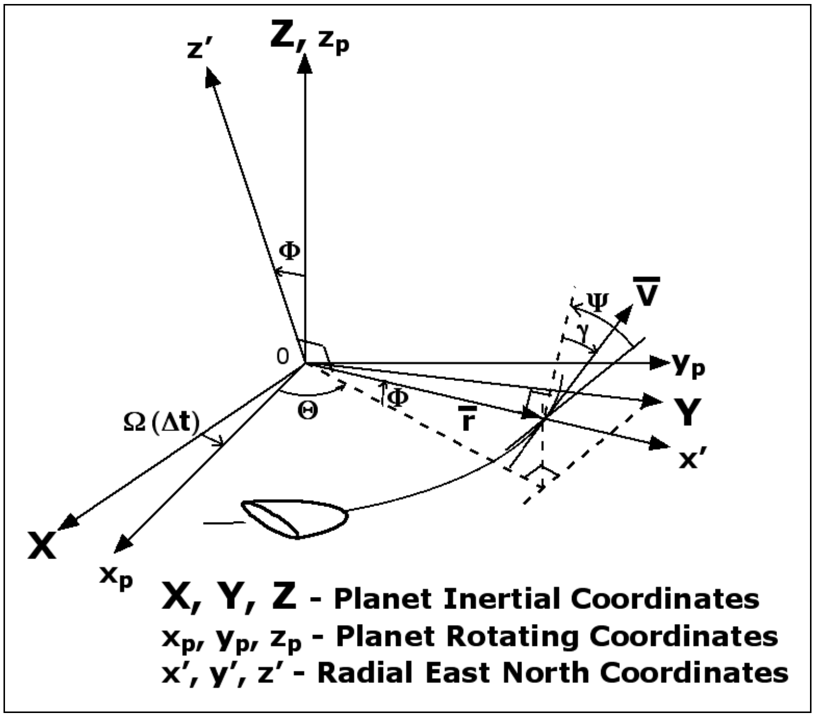

Figure 8-1 HyperPASS Coordinate Systems

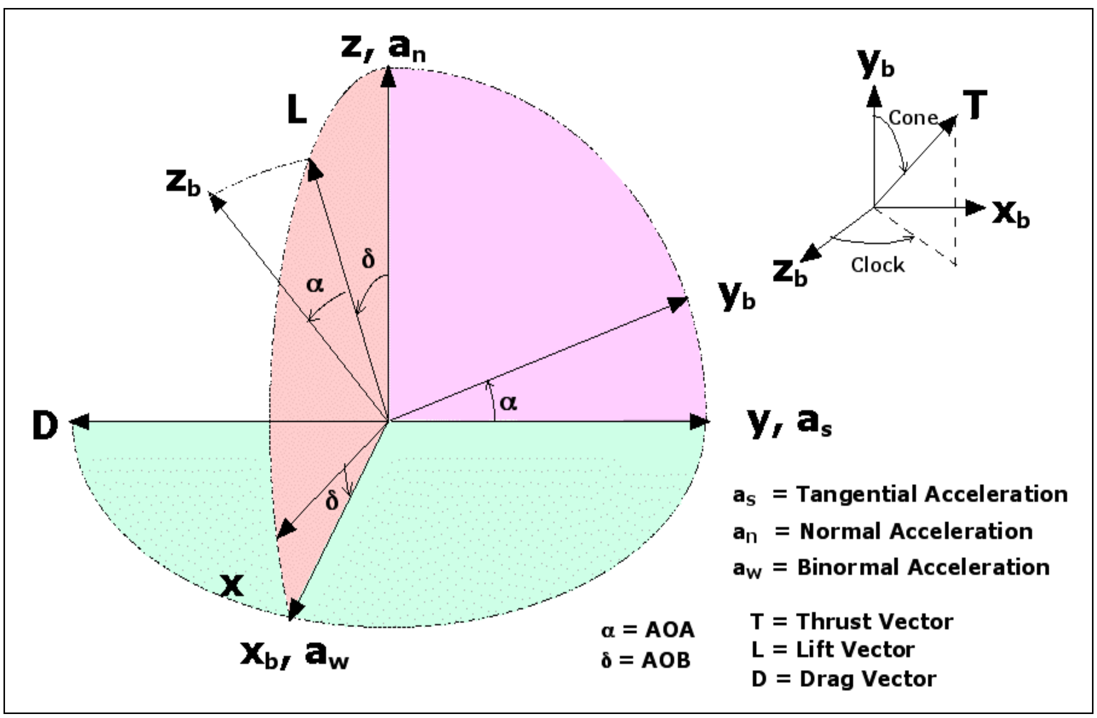

Figure 8-2 Vehicle Guidance Angles

8.2 Planetary Information

Planetary data for Saturn and Uranus will be documented in the next version of this user's manual.

Table 8-1 Planetary Information

Planet/ Moon	planet radius, R (km)	rotational velocity, (rad/s)	gravitational parameter, GM, (km^3/s^2)	J2 (Oblateness)	atm. composition	surface gravity constant, (m/s^2)
Venus	6,051.80	-2.9924E-07	324,858.5988	4.458E-06	CO_2 96.5% N_2 3.5%	8.87003
Earth	6,378.14	7.2921E-05	398,600.433	0.001082627	N_2 78.08% O_2 20.95% Ar 0.93% CO_2 0.04%	9.80665
Mars	3,396.20	7.0776E-05	42,828.3100	0.001960454	CO_2 95.70% N_2 2.70% Ar 1.60%	3.71317
Jupiter	71,492.00	1.7585E-04	1.266865E+08	0.014736008	H_2 89.8% He 10.2%	24.78652
Saturn	60,268.00	1.6379E-04	3.793100E+07	0	H_2 96.3% He 3.25% CH_4 0.45%	10.44289
Titan	2,575.00	0.0000E+00	8,978.2000	0	N_2 98.4% CH_4 1.6%	1.35405
Uranus	25,559.00	-1.0124E-04	5.794000E+06	0.003343430	H_2 82.5% He 15.2% CH_4 2.3%	8.86933
Neptune	24,764.00	1.0834E-04	6.835107E+06	0.034104740	H_2 80% He 19.0% CH_4 1.0%	11.14561

8.3 HyperPASS Vehicle & Ballute Models

8.3.1 Elliptical Raked Cone (vehicle)

Elliptical Raked Cone is a vehicle model available during Unguided, Guided Aerocapture, and Guided Ballute Aerocapture simulations. When Elliptical Raked Cone is chosen, the CL and CD are calculated and displayed based on the user-entered angle-of-attack (AOA). Once the AOA is chosen, the CL, CD, and AOA are fixed for the simulation.

8.3.2 Viking (vehicle)

Viking is a vehicle model available during Unguided, Guided Aerocapture, and Guided Ballute Aerocapture simulations. When Viking is chosen, the CL and CD are calculated and displayed based on the user-entered angle-of-attack (AOA). Once the AOA is chosen, the CL, CD, and AOA are fixed for the simulation.

8.3.3 Apollo (vehicle)

Apollo is a vehicle model available during Unguided, Guided Aerocapture, and Guided Ballute Aerocapture simulations. When Apollo is chosen, the CL and CD are calculated and displayed based on the user-entered angle-of-attack (AOA). Once the AOA is chosen, the CL, CD, and AOA are fixed for the simulation.

8.3.4 45^0 Half-Cone (vehicle)

The 45^0 Half-Cone is a vehicle model available during Unguided simulations only. When 45^0 Half-Cone is chosen, the axial and normal force coefficients are calculated for the user-entered angle-of-attack (AOA). Once the AOA is chosen, the CL and CD vary during the simulation based on the varying Knudsen Number value and fixed AOA.

Ref: Mitcheltree, R. A., et. al, "Aerodynamics of the Mars Microprobe Entry Vehicles," AIAA Paper 97-3658, 1997.

8.3.5 Sphere (vehicle or ballute)

Sphere is a vehicle model available during Unguided simulations only. When Sphere is chosen, the AOA and CL are set to zero and the CD varies during the simulation as a function of both Knudsen number and Mach number. For continuum flow (Kn < 0.001), we use a CD vs. Mach model for supercritical Reynolds numbers.

Ref: Nebiker, R. R., "Feasibility Study of an Inflatable Type Stabilization and Deceleration System for High-Altitude and High-Speed Recovery," Goodyear Aircraft Corporation, Akron, OH, 1961.

Sphere is also a ballute model available during Unguided and Guided Ballute Aerocapture simulations. When Sphere Ballute is chosen the ballute mass is calculated from user-entered sphere radius and material areal density values. For an Unguided simulation, the AOA and CL are set to zero and the CD varies during the simulation as a function of both Knudsen Number and Mach Number. When Sphere Ballute is chosen for a Guided Ballute Aerocapture simulation, the AOA and CL are set to zero and the CD is set to 0.9 (i.e. for Guided Ballute simulations the CD is constant, not a function of Kn or Mach.

8.3.6 Torus (vehicle or ballute)

Torus is a vehicle model available during Unguided simulations only. When Torus is chosen, the AOA and CL are set to zero and the CD varies during the simulation as a function of Knudsen Number.

Ref: Riabov, V. V., "Numerical Study of Hypersonic Rarefied-Gas Flows About a Torus," AIAA Paper 98-0778, 1998.

Torus is also a ballute model available during Unguided and Guided Ballute Aerocapture simulations. When Torus Ballute is chosen the ballute mass is calculated from user-entered torus dimensions and material areal density values. For an Unguided simulation, the AOA and CL are set to zero and the CD varies during the simulation as a function of Knudsen Number. When Sphere Ballute is chosen for a Guided Ballute Aerocapture simulation, the AOA and CL are set to zero and the CD is set to 1.37 (i.e. for Guided Ballute simulations the CD is constant, not a function of Kn or Mach).

8.4 Atmosphere Models

8.4.1 Venus

The atmosphere temperature profile used for Venus atmosphere models is from,
Hunten, D. M., et. al, “Venus,” University of Arizona Press, Tuscon, AZ, 1983.
Venus_ViraDay and Venus_Longuski use the Subsolar/Noon model and Venus_ViraNight uses the Antisolar/Midnight model.

8.4.1.1 Venus_ViraDay

Ref: Venus COSPAR 1986, (41 data points)

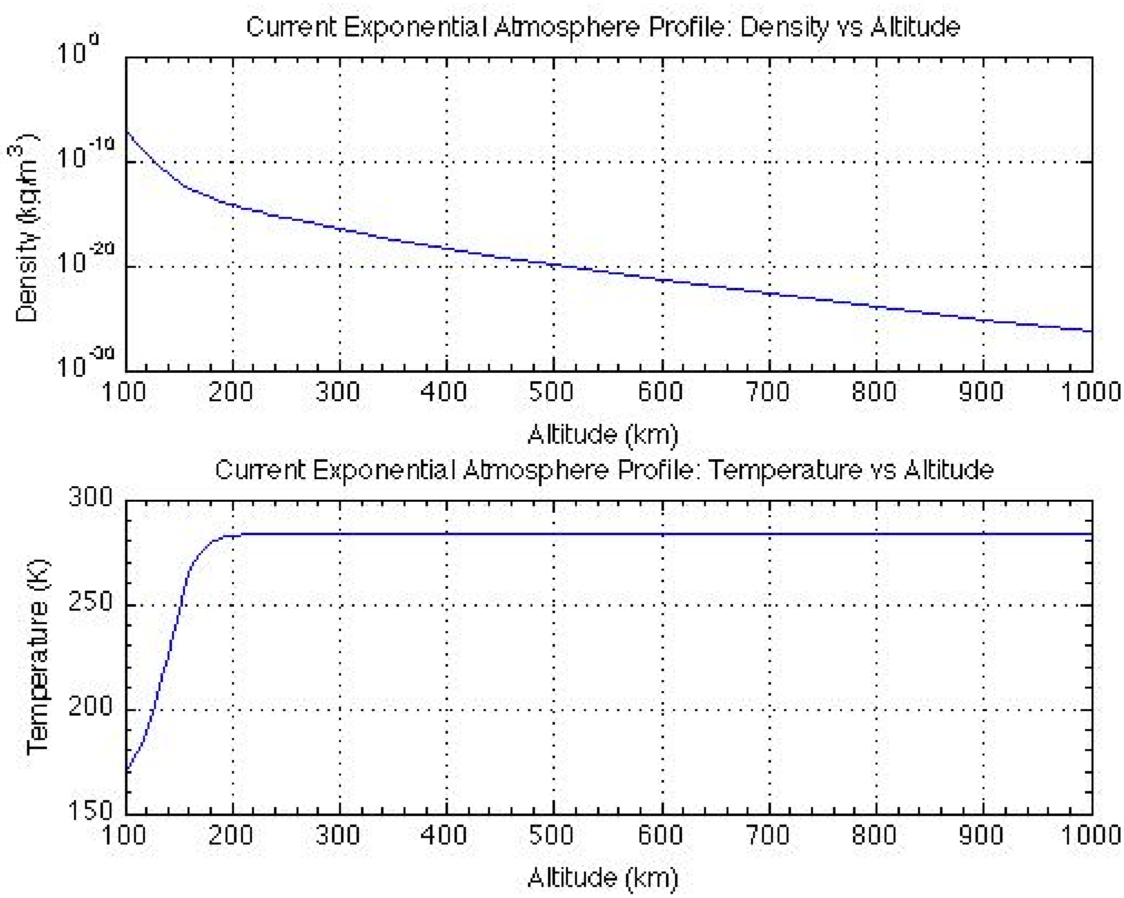

Figure 8-3 Venus_ViraDay Atmosphere

8.4.1.2 Venus_ViraNight

Ref. Venus COSPAR 1986, (121 data points)

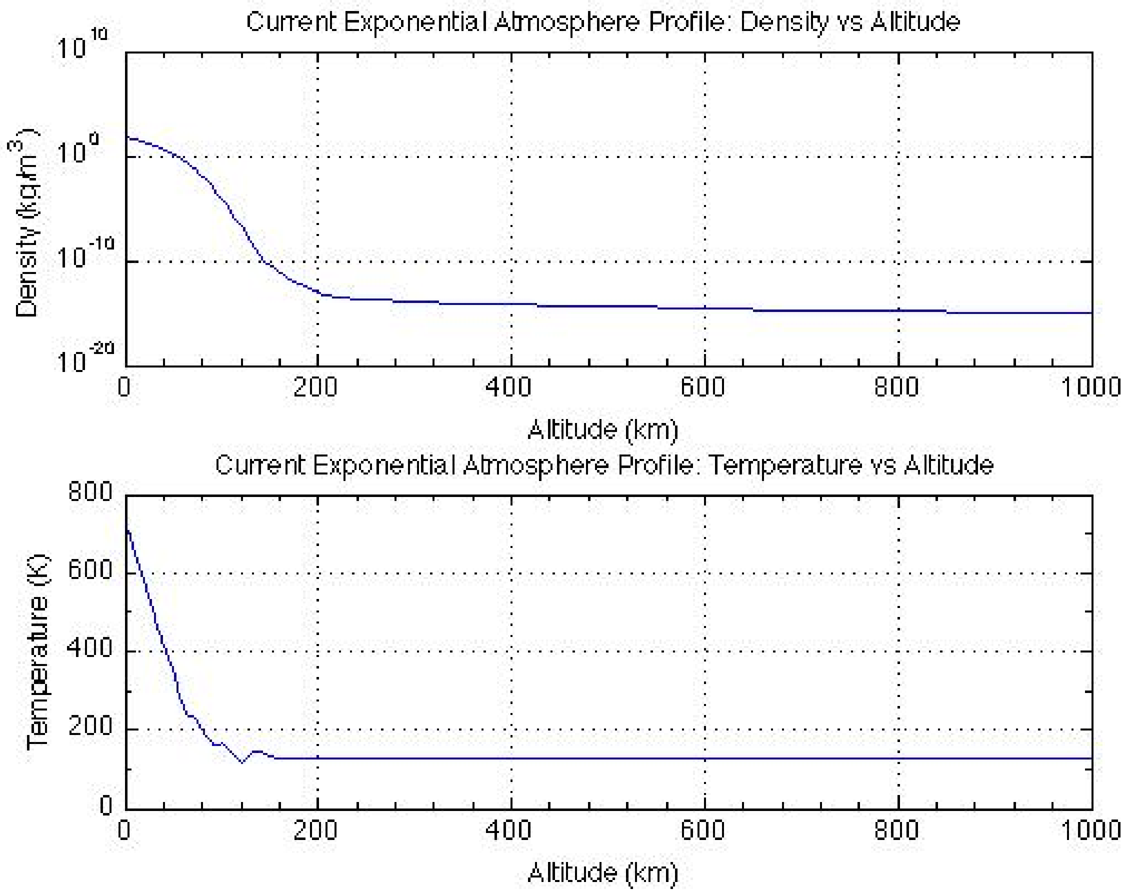

Figure 8-4 Venus_ViraNight Atmosphere

8.4.1.3 Venus_ViraNight_short

This is a shortened version (21 data points) of the Venus_ViraNight atmosphere model. In this version, there is a greater altitude change between each data point in the table. Ref: Venus COSPAR 1986

8.4.2 Earth

8.4.2.1 Earth_MSISE90

(46 data points) Ref: http://www.spenvis.oma.be/spenvis/ecss/ecss07/ecss07.html run for mean solar activity levels (F10.7 =(F10.7)avg = 140, Ap = 15) averaged over diurnal and seasonal-latitudinal variations.

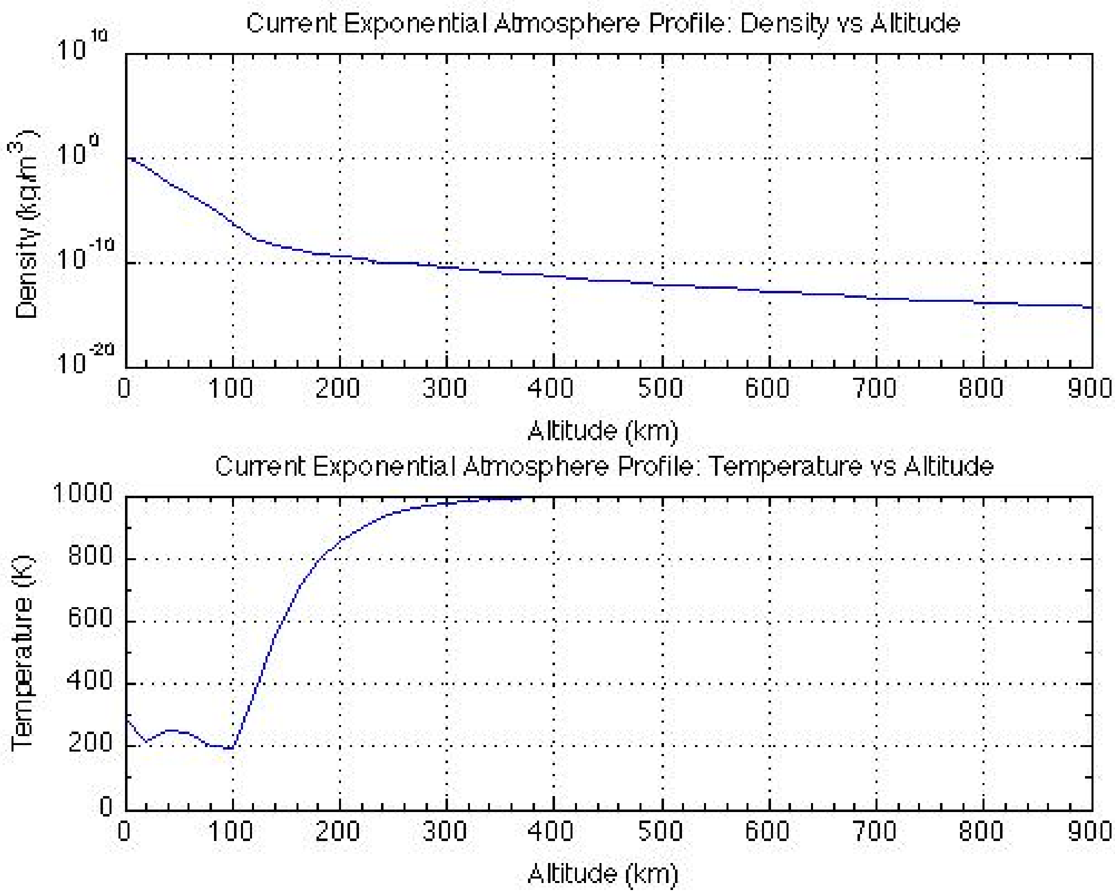

Figure 8-5 Earth_MSISE90 Atmosphere

8.4.2.2 Earth_US1976

(21 data points) Ref: US Standard Atmosphere 1976

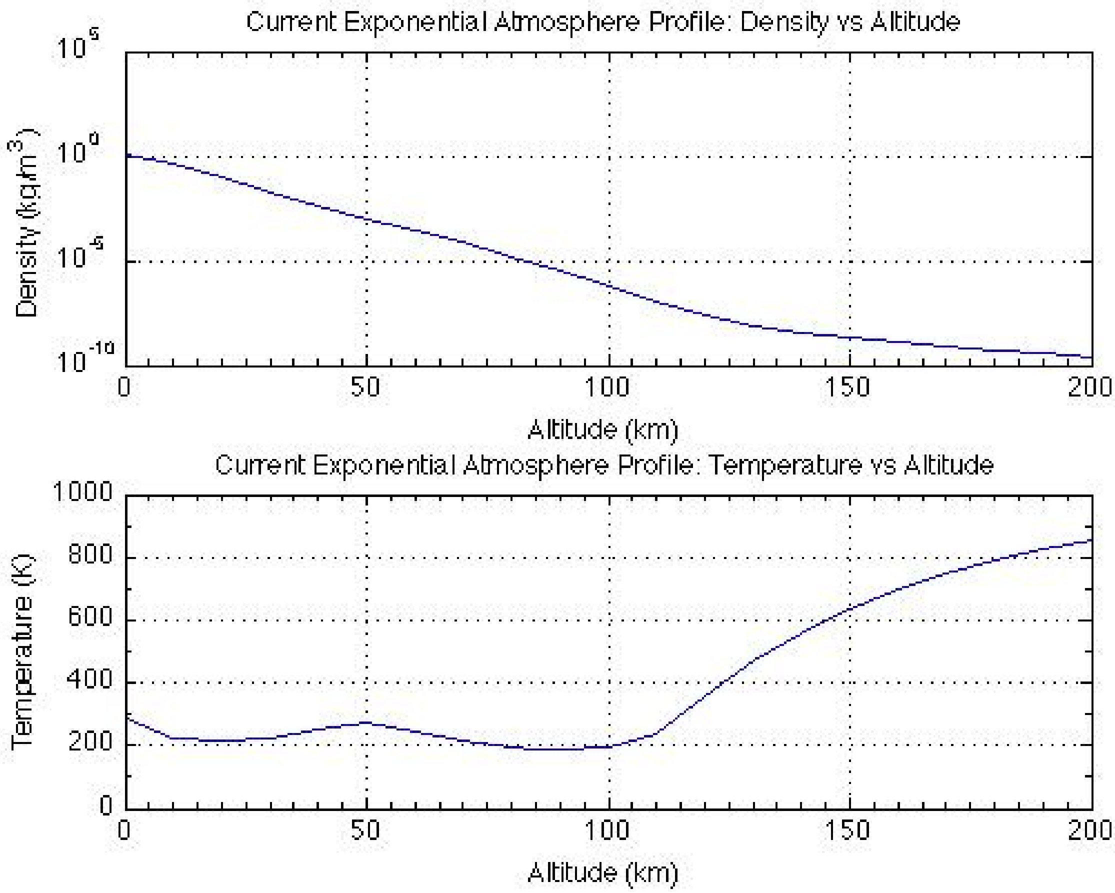

Figure 8-6 Earth_US1976 Atmosphere

8.4.3 Mars

8.4.3.1 Mars_COSPAR90

(154 data points) Ref: "The Mars Atmosphere: Observations and Model Profiles for Mars Missions", David. E. Pitts et al., NASA Johnson Space Center report JSC-24455, 1990.

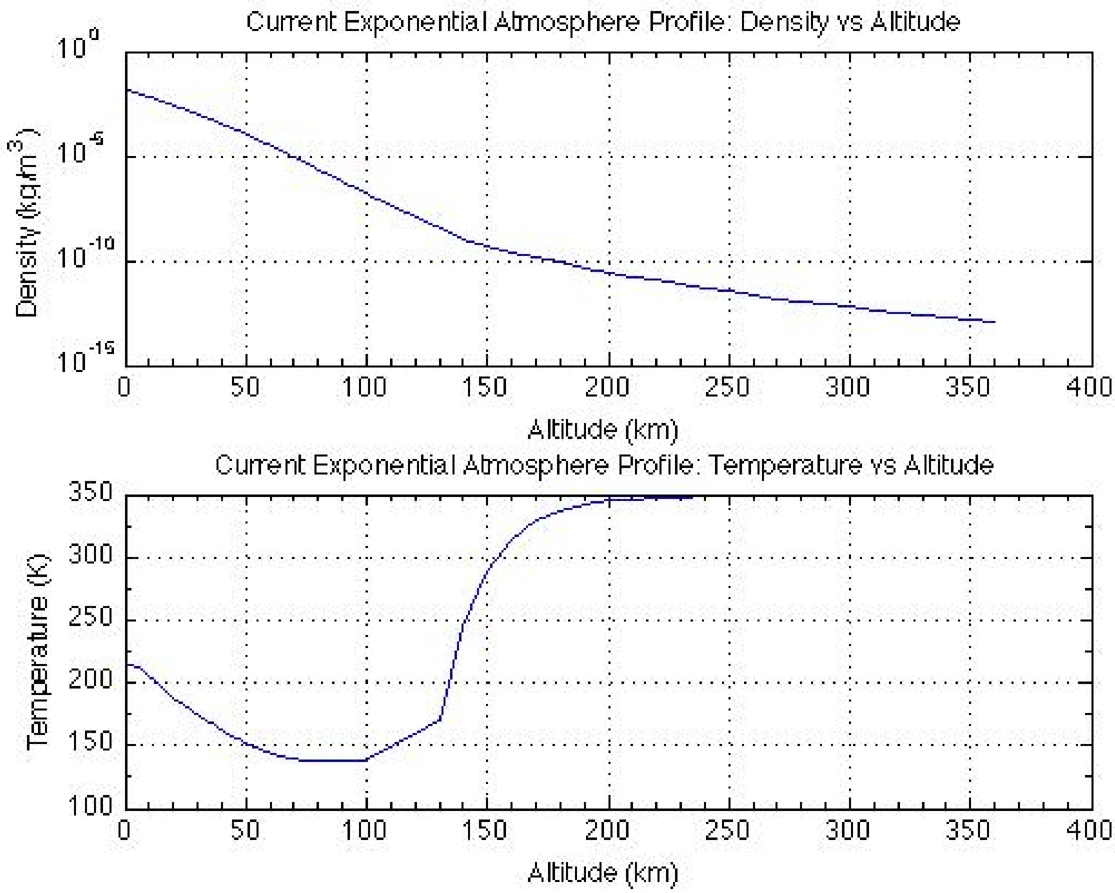

Figure 8-7 Mars_COSPAR90 Atmosphere

8.4.3.2 Mars_COS90_short

This is a shortened version (21 data points) of the Mars_COSPAR90 atmosphere model. In this version, there is a greater altitude change between each data point in the table. Ref: "The Mars Atmosphere: Observations and Model Profiles for Mars Missions", David. E. Pitts et al., NASA Johnson Space Center report JSC-24455, 1990.

8.4.4 Jupiter

The atmosphere temperature profile used for Jupiter_Orton and Jupiter_Longuski atmosphere models is from the Galileo Probe Atmospheric Structure Instrument: Jovian Upper Atmosphere (Ref: http://atmos.nmsu.edu/PDS/data/gp_0001/data/asi/upperatm.lbl, http://atmos.nmsu.edu/PDS/data/gp_0001/data/asi/upperatm.tab)

8.4.4.1 Jupiter_Orton

(111 data points) Ref: Atmospheric Structure in the Equatorial Region of Jupiter, November 23, 1981, Glenn S. Orton

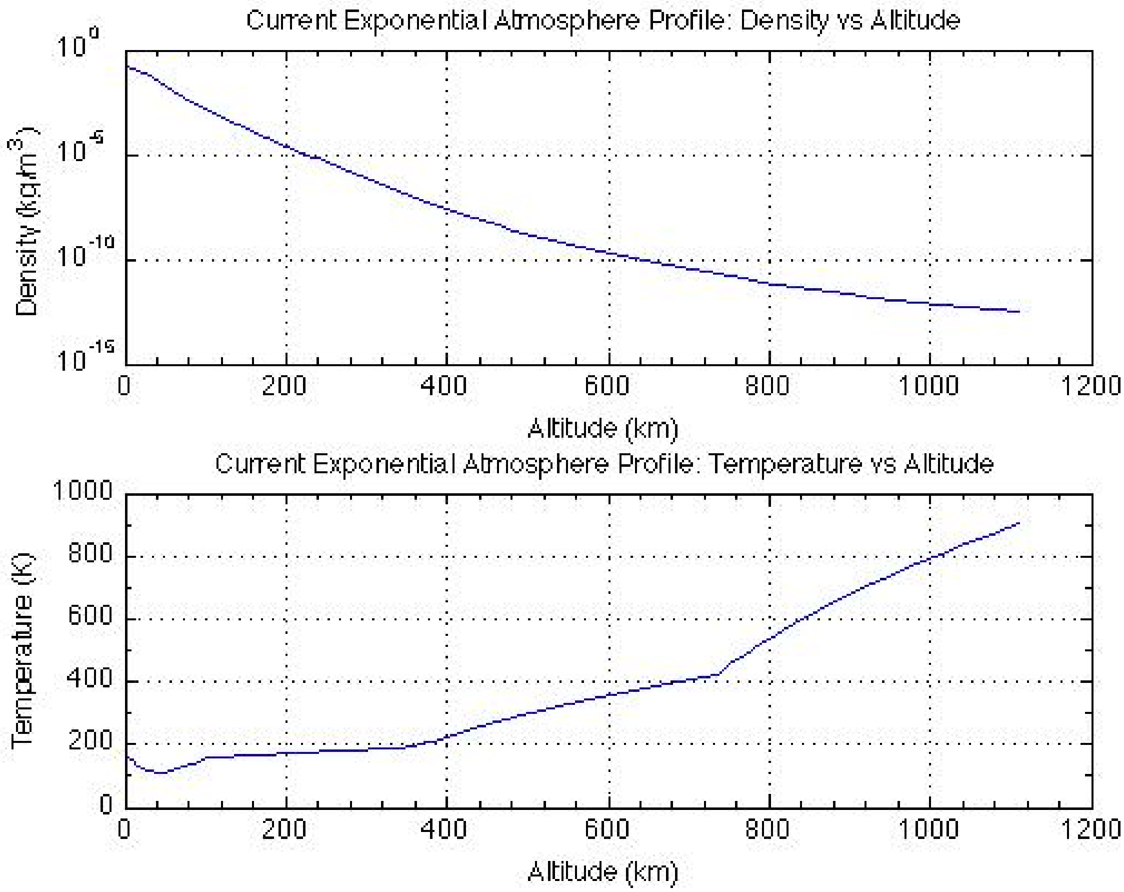

Figure 8-8 Jupiter_Orton Atmosphere

8.4.4.2 Jupiter_Orton_short

This is a shortened version (21 data points) of the Jupiter_Orton atmosphere model. In this version, there is a greater altitude change between each data point in the table. Ref: Atmospheric Structure in the Equatorial Region of Jupiter, November 23, 1981, Glenn S. Orton

8.4.4.3 Jupiter_Longuski

(21 data points) Ref: Longuski, James M., Puig-Suari, Jordi, Mechalas, M., "Aerobraking Tethers for the Exploration of the Solar System," Acta Astronautica, Vol. 35, No. 23, pp. 205-214, 1995.

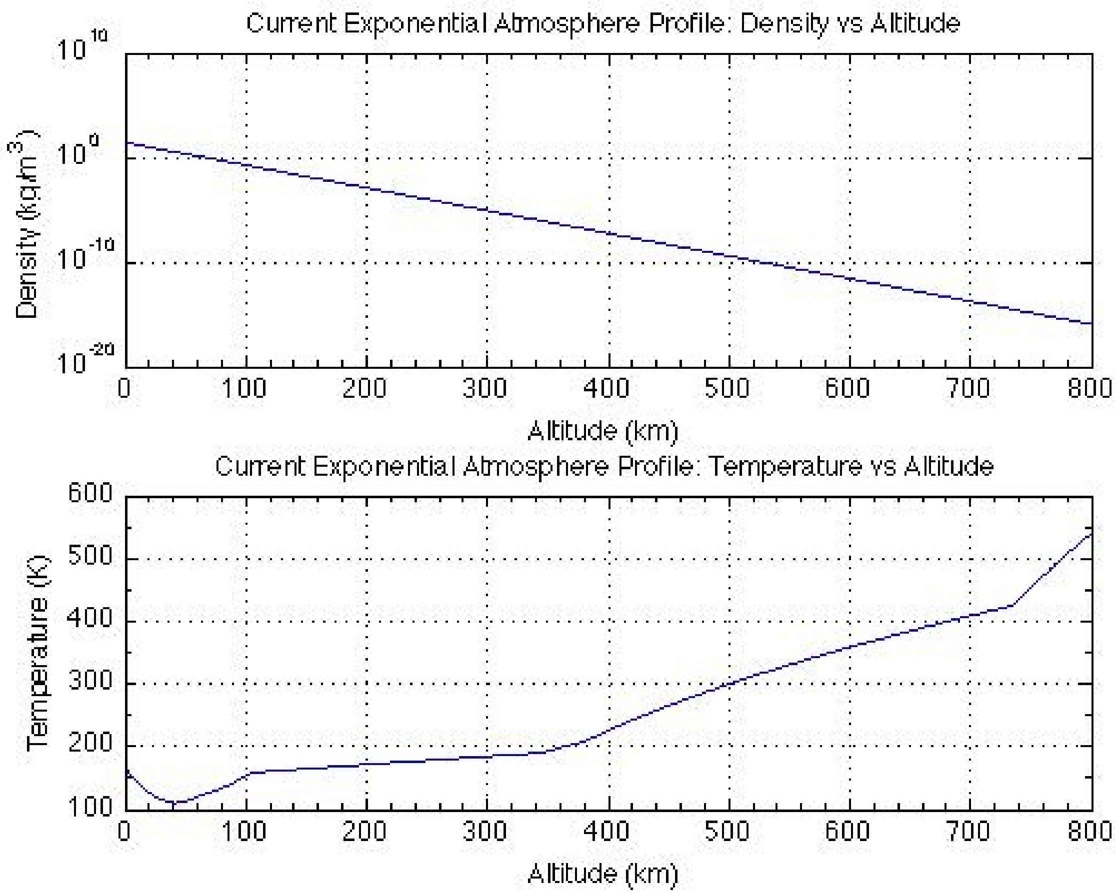

Figure 8-9 Jupiter_Longuski Atmosphere

8.4.5 Saturn

8.4.5.1 Saturn_Longuski

(21 data points) Ref: Longuski, James M., Puig-Suari, Jordi, Mechalas, M., "Aerobraking Tethers for the Exploration of the Solar System," Acta Astronautica, Vol. 35, No. 23, pp. 205-214, 1995.

The atmosphere temperature profile used for the Saturn_Longuski atmosphere models is: Moses, J. I., "Photochemistry of Saturn's Atmosphere," Icarus 143, pp. 244-298, 2000.

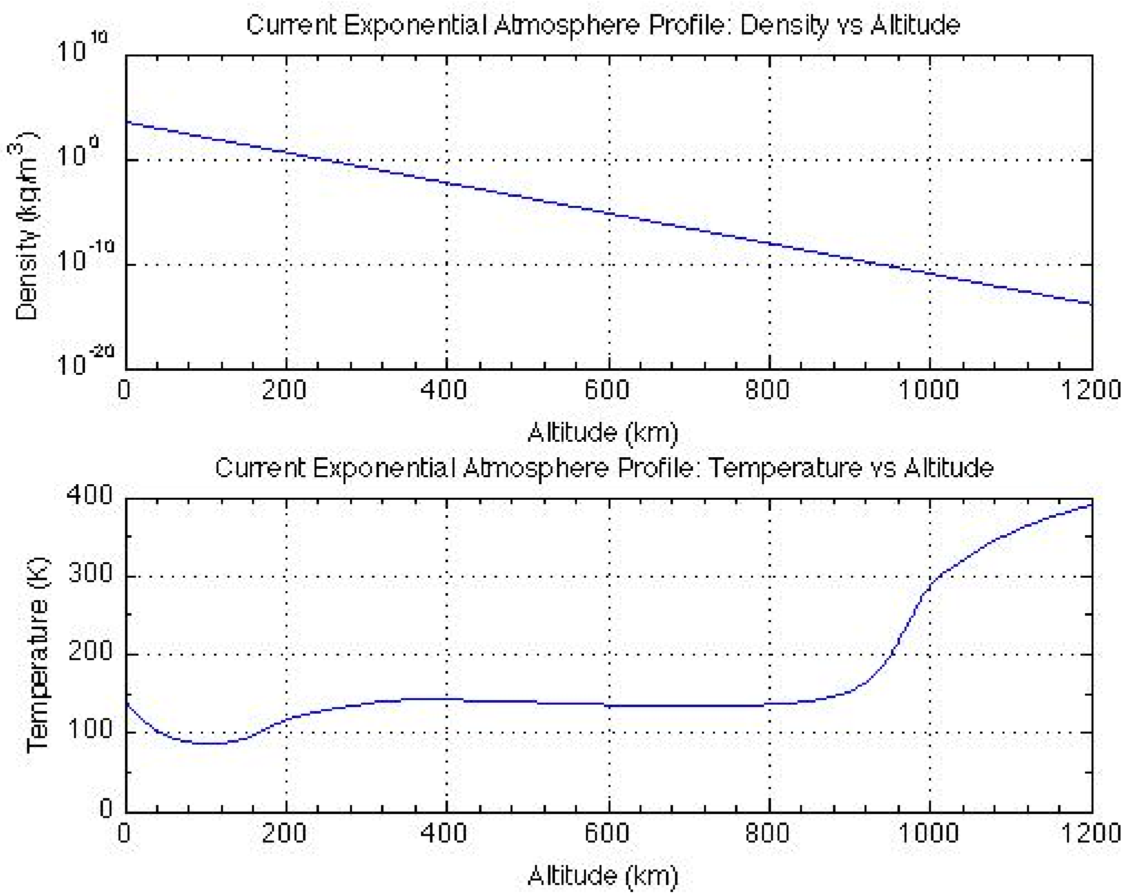

Figure 8-10 Saturn_Longuski Atmosphere

8.4.6 Titan

The atmosphere temperature profile used for the Titan_Hall, Titan_Hunten, and Titan_Longuski atmosphere models is: Hunten, D. M., Prepared for NASA AMES RC Preliminary Draft, 1981, modified by GAC in 2004 to account for appropriate radius and gravity.

8.4.6.1 Titan_Hall

(11 data points) Ref: Hall, Jeffery L.

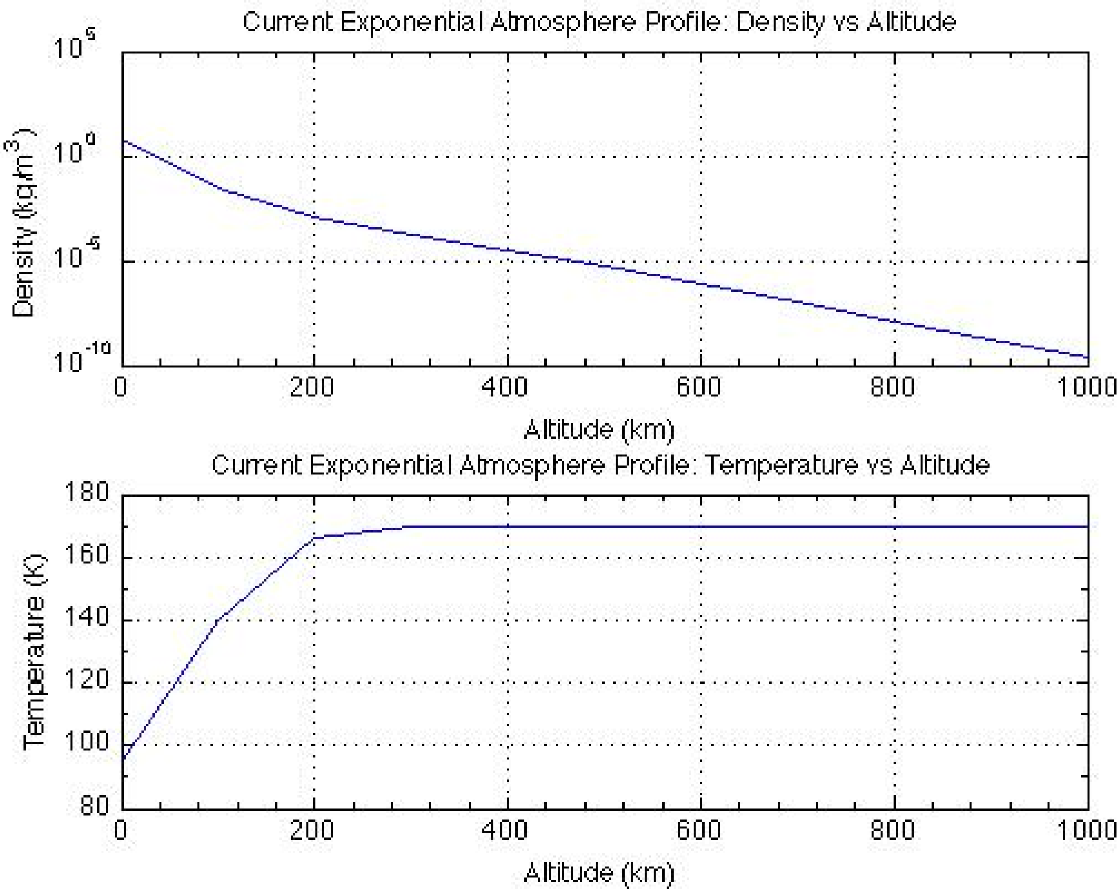

Figure 8-11 Titan_Hall Atmosphere

8.4.6.2 Titan_Hunten

(1521 data points) Ref: Prepared for NASA AMES RC Preliminary Draft, 1981, modified by GAC in 2004 to account for appropriate radius and gravity.

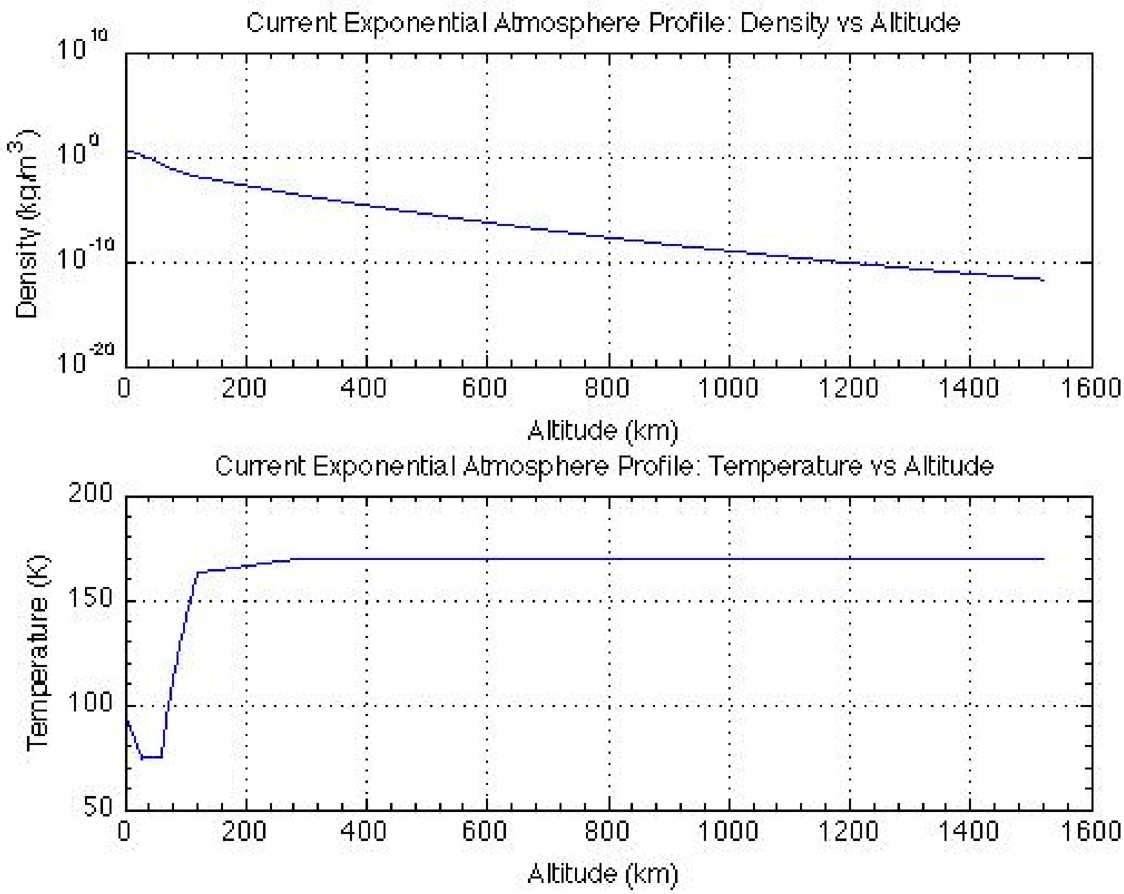

Figure 8-12 Titan_Hunten Atmosphere

8.4.6.3 Titan_Longuski

(1521 data points) Ref: Longuski, James M., Puig-Suari, Jordi, Mechalas, M., "Aerobraking Tethers for the Exploration of the Solar System," Acta Astronautica, Vol. 35, No. 23, pp. 205-214, 1995.

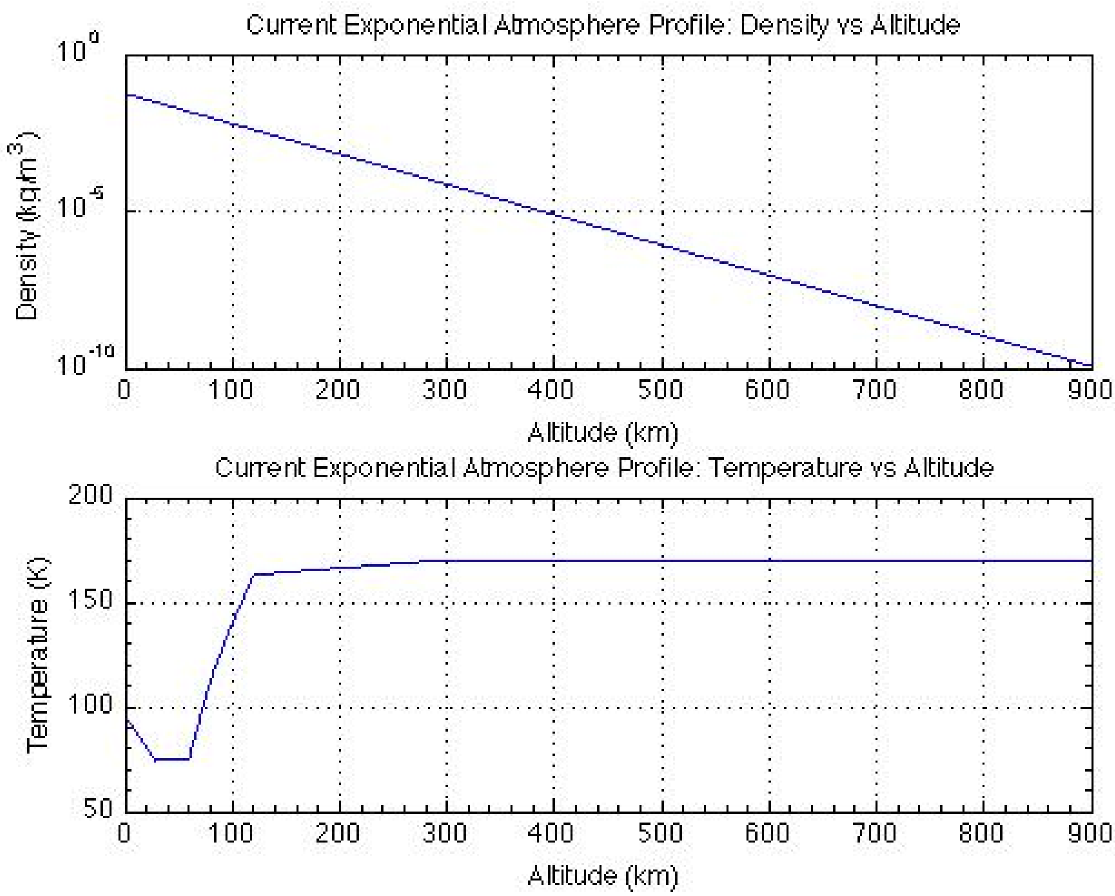

Figure 8-13 Titan_Longuski Atmosphere

8.4.7 Uranus

8.4.7.1 Uranus_Longuski

(21 data points) Ref: Longuski, James M., Puig-Suari, Jordi, Mechalas, M., "Aerobraking Tethers for the Exploration of the Solar System," Acta Astronautica, Vol. 35, No. 23, pp. 205-214, 1995.

The atmosphere temperature profile used for the Uranus_Longuski atmosphere model is,
Ref: Lunine, J. I., "The Atmospheres of Uranus and Neptune," Annu. Rev. Astron. Astrophys., No. 31, pp. 217-263, 1993.

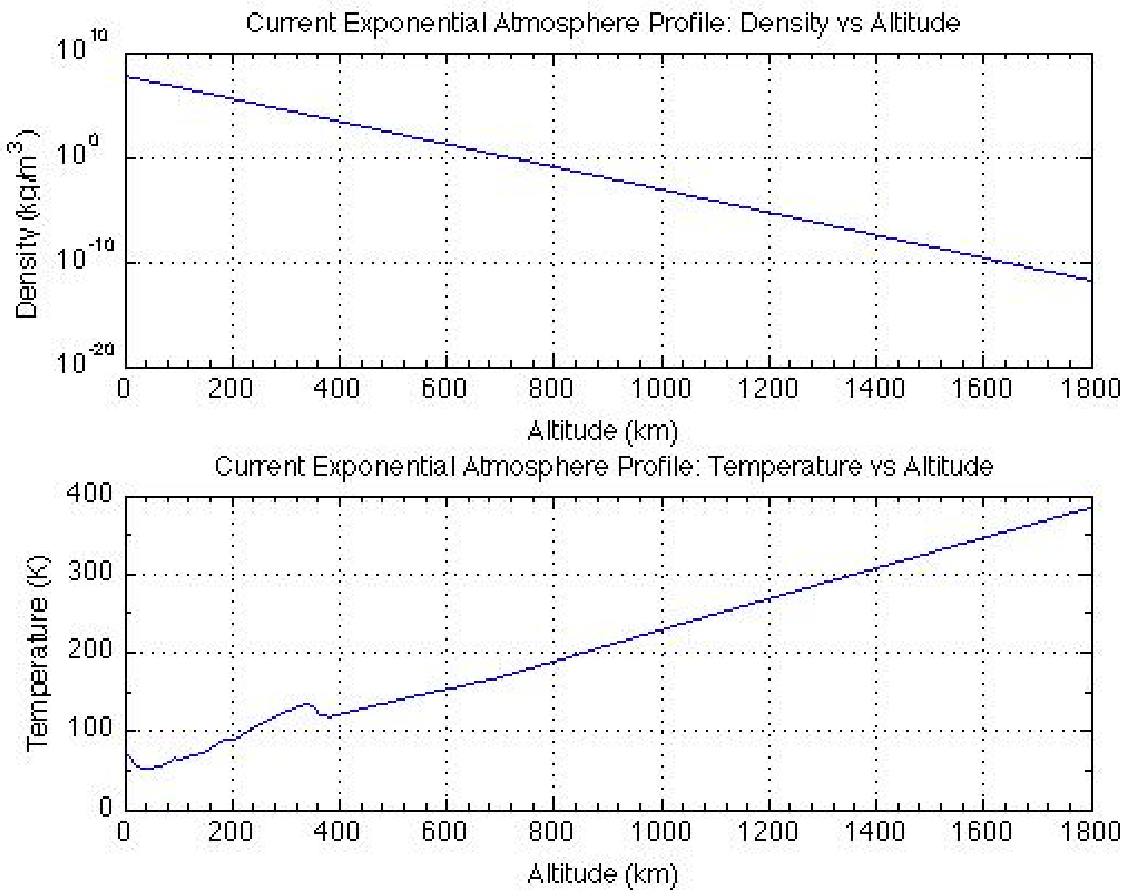

Figure 8-14 Uranus_Longuski Atmosphere

8.4.8 Neptune

The atmosphere temperature profile used for Neptune_Hall and Neptune_Longuski atmosphere models is,
Ref: Lunine, J. I., "The Atmospheres of Uranus and Neptune," Annu. Rev. Astron. Astrophys., No. 31, pp. 217-263, 1993.

8.4.8.1 Neptune_Hall

(21 data points) Ref: Hall, Jeffery L. and Lee, Andrew K., "Aerocapture Trajectories for Spacecraft with Large Towed Ballutes", AAS 01-235.

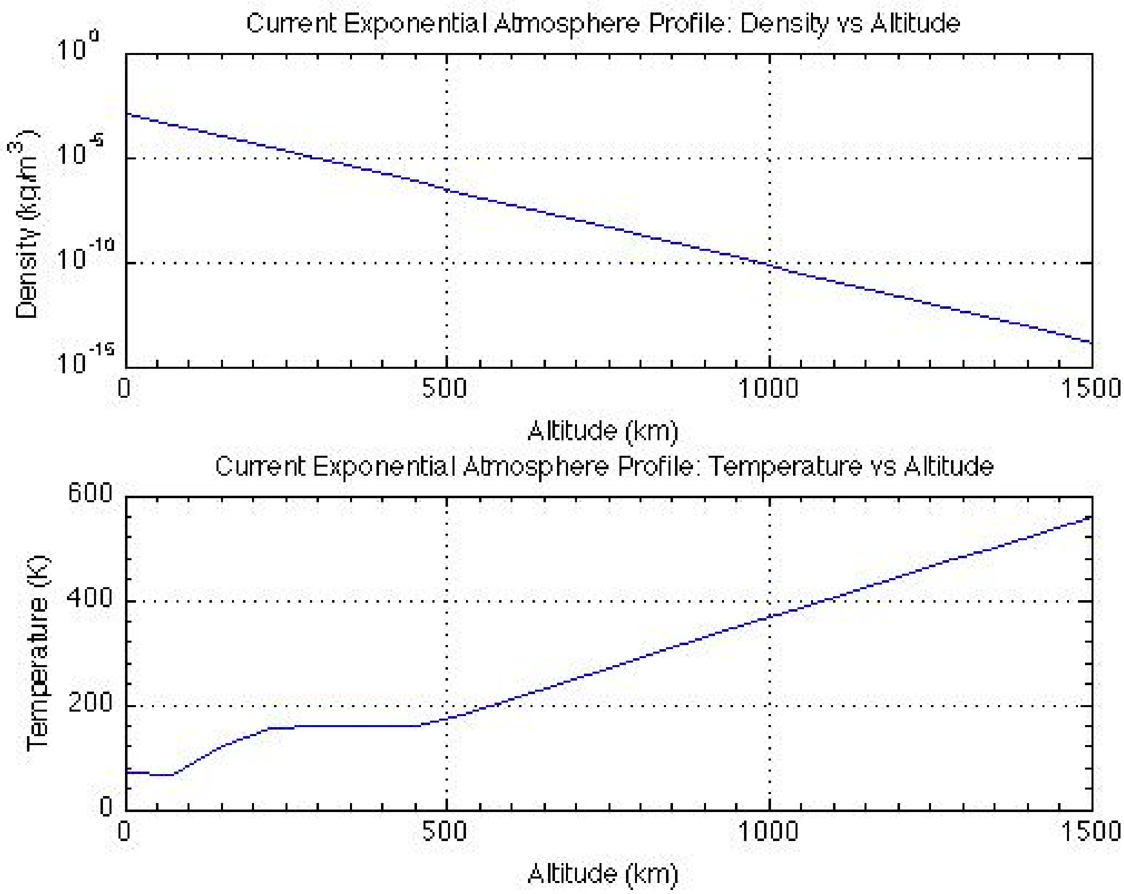

Figure 8-15 Neptune_Hall Atmosphere

8.4.8.2 Neptune_Longuski

(21 data points) Ref: Longuski, James M., Puig-Suari, Jordi, Mechalas, M., "Aerobraking Tethers for the Exploration of the Solar System," Acta Astronautica, Vol. 35, No. 23, pp. 205-214, 1995.

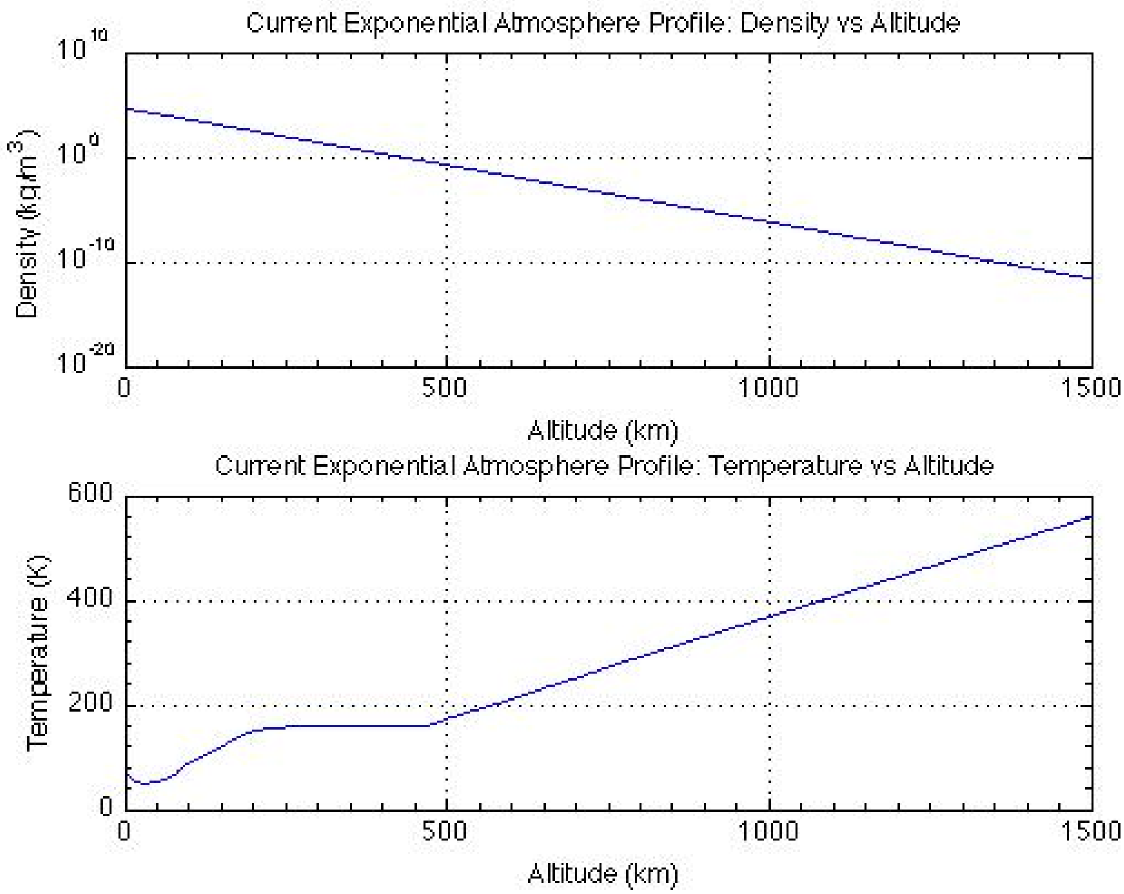

Figure 8-16 Neptune_Longuski Atmosphere

8.5 Heating Equations

Refer to the Glossary for symbol definitions.

8.5.1 Stagnation Point Heating

The equation for Stagnation Point Heating, also called Continuum Heating, is shown below.

$$Q_{stag} = \frac{C}{\sqrt{Rn}} \rho^{Nstag} v^{Mstag}$$

where,
$\boldsymbol{Q_{stag}}$ is the stagnation point heating rate in W/cm^2
$\boldsymbol{v}$ is velocity in m/s
$\boldsymbol{C}$ is the stagnation point heating rate coefficient, kg$^{1/2}$/m
ρ is density in kg/m^3
Rn is the vehicle nose radius in meters

8.5.2 Free Molecular Heating

The equation for Free Molecular Heating is shown below.

$$Q_{fm} = \left(\frac{1}{2}\rho v^2\right) \times 10^{-4}$$

where,
$\boldsymbol{Q_{fm}}$ is the free molecular heating rate in W/cm^2

8.6 Knudsen Number

$$Kn = \lambda / L$$

where,
λ is the mean free path, m
L is the characteristic length of the vehicle, m

The mean free path is the average distance between molecular collisions in the atmosphere. Its value is calculated based on the atmosphere conditions and composition. For more information on calculating mean free path:
Bird, G. A., "Molecular Gas Dynamics and the Direct Simulation of Gas Flows," Clarendon Press, Oxford, New York, 1994.

9 Addendum

TBD