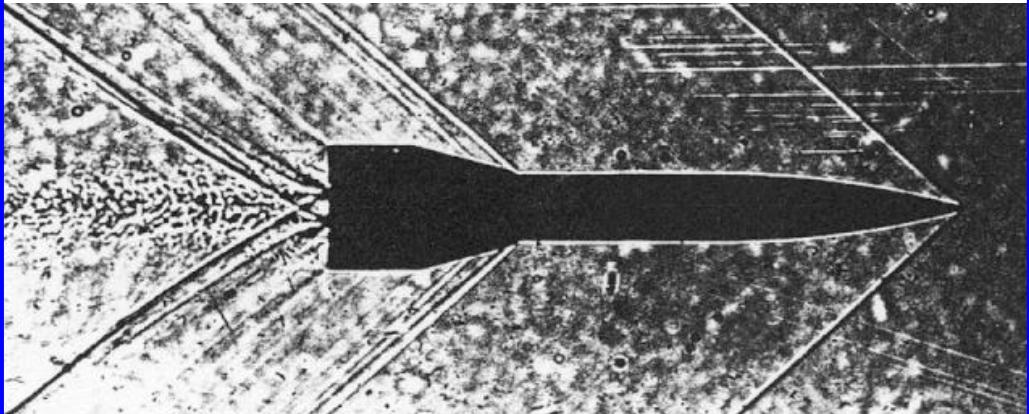


[www.rasaero.com](http://www.rasaero.com)

**RASAero II**

Rocket Aerodynamic Analysis  
and Flight Simulation Software



Rogers Aeroscience  
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**Rogers Aeroscience RASAero II Aerodynamic Analysis and  
Flight Simulation Program**

**Users Manual**

**Version 1.0.2.0  
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## The RASAero II Aerodynamic Analysis and Flight Simulation Program

RASAero II is a combined aerodynamic analysis and flight simulation software package for model rockets and high power rockets, amateur rockets, and sounding rockets. RASAero II can also be used for predicting aerodynamic coefficients for use in other flight simulation programs for orbital rockets.

The RASAero II aerodynamic prediction methods are the most accurate available for model, high power, and amateur rockets, and are of equivalent accuracy to professional engineering method aerodynamic analysis codes used for missiles, sounding rockets, and space launch vehicles.

The RASAero II aerodynamic predictions include drag coefficient at zero degrees angle of attack, drag coefficient with a non-zero angle of attack, lift coefficient and normal force coefficient with angle of attack, for both power-on (thrust phase) and power-off (coast phase). Center of pressure is predicted both as a function of Mach number and as a function of angle of attack. Aerodynamic coefficients are predicted for the subsonic, transonic, supersonic, and hypersonic flight regimes, from Mach 0.01 to Mach 25. For subsonic center of pressure the standard (for model and high power rockets) Barrowman method can be used, or the Rogers Modified Barrowman method can be selected which includes a more accurate body normal force slope with angle of attack ( $C_{N\alpha}$ ) at low angles of attack, inclusion of the body in the presence of the fins interference factor ( $K_{bf}$ ) left out of the Barrowman method, and body viscous crossflow for forward movement of the rocket center of pressure with angle of attack. The effects of fin sweep angle, fin airfoil, nose cone shape, and nose and fin bluntness are included in the transonic, supersonic and hypersonic aerodynamic predictions. Airfoil options include hexagonal, NACA, double wedge, biconvex, hexagonal blunt base, single wedge, rounded, and square leading edge airfoils. The drag from launch lugs, rail guides, and launch shoes is included. The rail guide drag model for model and high power rockets is particularly accurate. The forward movement of center of pressure at high supersonic to hypersonic Mach numbers is predicted, an important effect for fin-stabilized rockets flying up to and over Mach 3, where depending on fin design by Mach 5 the Center of Pressure can move up to 60-70% of the body length from the nose.

Two flight simulation options are available in the RASAero II software, a 2 degrees-of-freedom trajectory simulation with no wind, and a 3 degrees-of-freedom trajectory simulation with wind that includes dynamic stability and weathercocking of the rocket into the wind. If no wind is entered then the 2 degrees-of-freedom trajectory simulation is selected, if a wind is entered then the 3 degrees-of-freedom trajectory simulation with dynamic stability and weathercocking is selected. Thrust of the rocket motor is varied with altitude using the entered thrust curve, the altitude of the rocket, and the exit diameter of the rocket motor nozzle. All of the flight simulations include either ballistic or parachute recovery. If a parachute recovery is selected, there is a recovery event at apogee (deployment of a small drogue parachute or the main parachute), and if selected there is a recovery event at a user-specified altitude above the ground (deployment of the main parachute after descending on a drogue parachute).

When the flight simulation portion of the software is run, the aerodynamic coefficients for the rocket are calculated during each time step based on the rocket Mach number, angle of attack, Reynolds number based on the altitude of the rocket, and whether the rocket is flying in the motor thrust phase (power-on) or the coast phase (power-off). For the 3 degrees-of-freedom trajectory with dynamic stability and wind, both static and dynamic stability derivatives for the

rocket are calculated, including rocket aerodynamic damping coefficients and the jet damping coefficient from the rocket motor thrust during the powered flight phase.

A scale drawing of the rocket is produced by RASAero II based on the entered rocket geometry. Extensive plots of the aerodynamic data for the rocket are produced, with the rocket aerodynamic coefficients plotted versus Mach number and angle of attack. Extensive plots of the flight simulation results are also produced, including the recovery phase of the flight.

## Entering a Rocket into RASAero II

### Main Screen

To run the RASAero II software, the User double clicks on the RASAero II Icon on the computer desktop shown in Figure 1. After double clicking on the RASAero II icon on the computer desktop, the RASAero II Main Screen will appear as presented in Figure 2. For a new rocket the user immediately starts building the rocket by selecting a nose cone, and then adding a body tube. Fins and rail guides, launch lugs, or launch shoes are then added to the body tube. As will be detailed in later sections, a fin canister can be added with fins mounted on the fin canister, a boattail can be added at the base of the body tube, or one or two additional booster stages can be added.

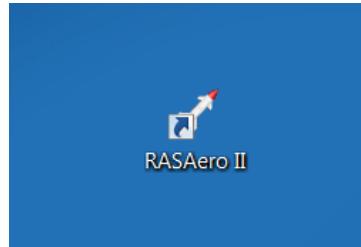


Figure 1 – RASAero II Icon on computer desktop.

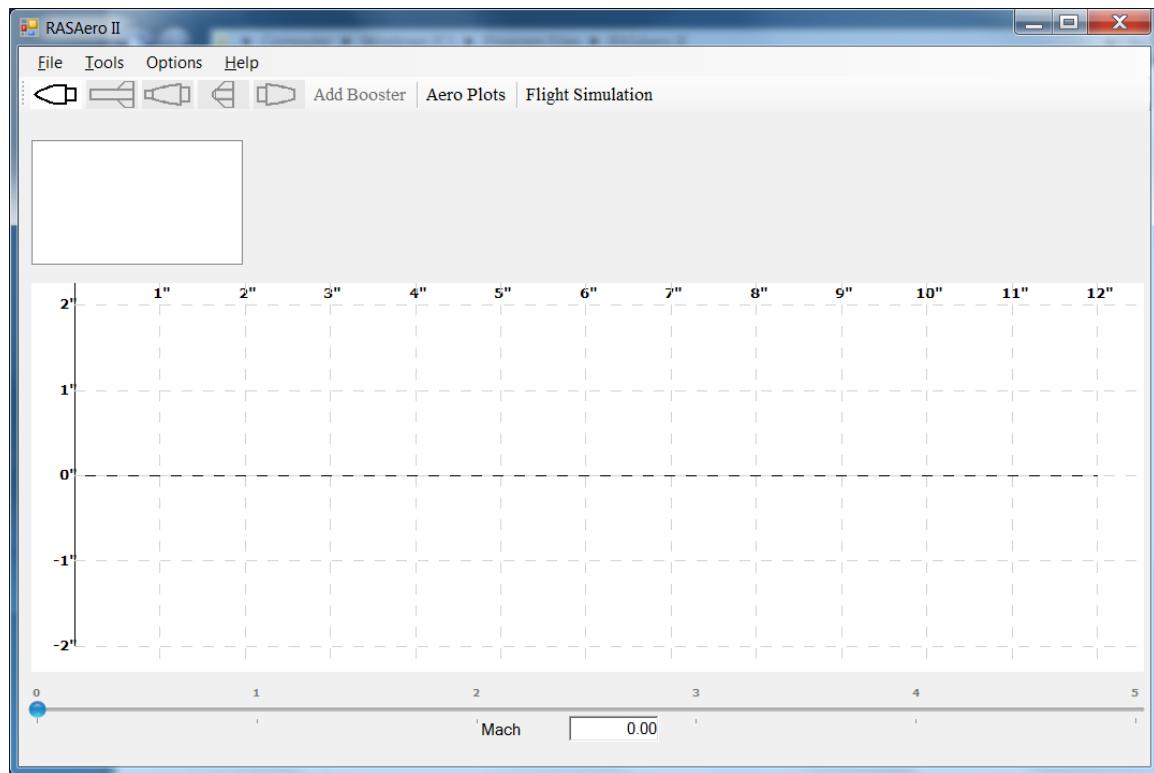


Figure 2 – RASAero II Main Screen.

As shown in Figures 3 and 4, to load an old, previously saved rocket, or to load a file from the previous RASAero software, click on <File>, and then <Open>, and then select the file to be opened.

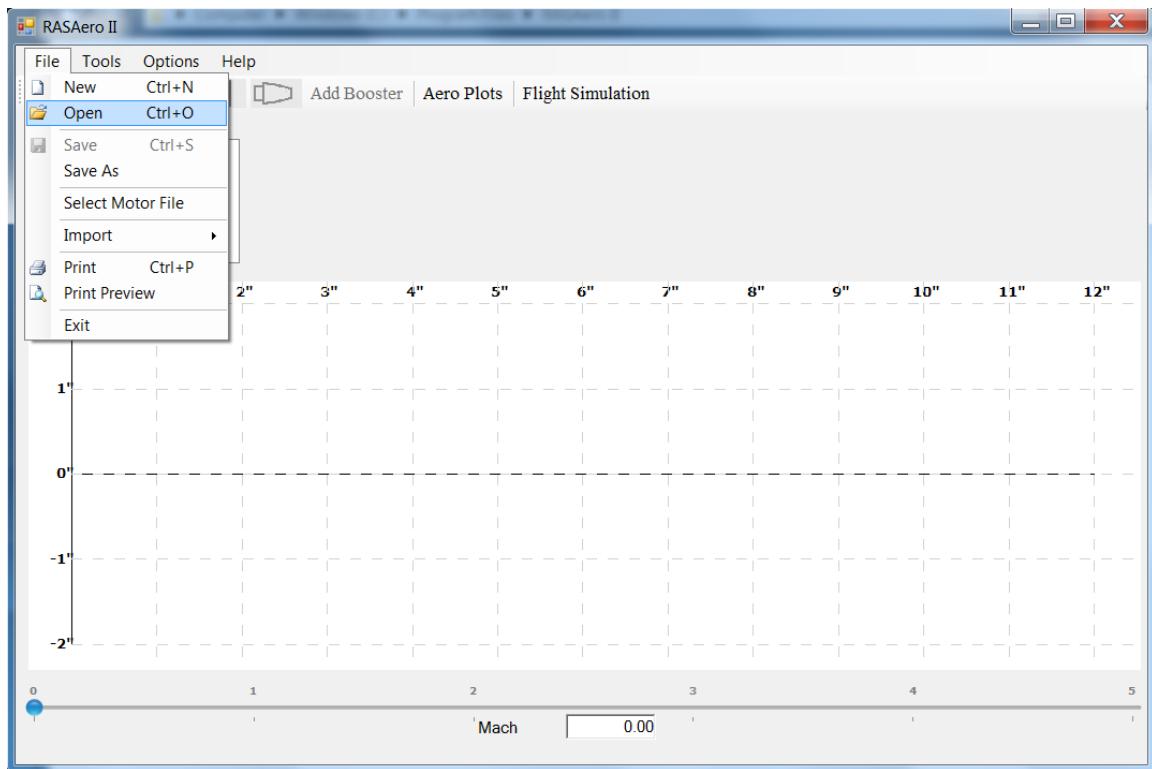


Figure 3 – Opening a file in RASAero II.

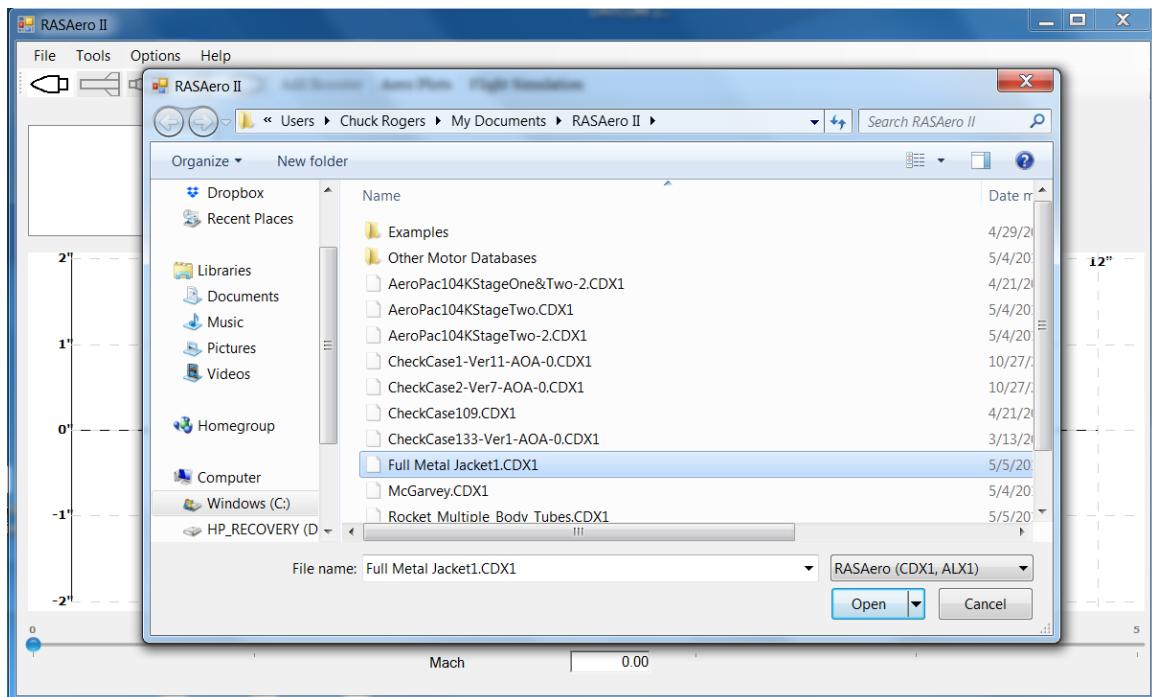


Figure 4 – Opening a file in RASAero II (continued).

Rockets saved on the previous RASAero software, saved as .ALX1 files, can be loaded into the RASAero II software, and then saved in the RASAero II .CDX1 file format.

The Select Motor File feature will be described in the RASAero II Rocket Motor Database and the User-Selected RASP Motor File sections.

As shown in Figure 5, and as will be detailed in a later section, RockSim rocket files (.RKT format files) can be loaded into RASAero II by selecting <File>, then <Import>, and then <RockSim> to load the RockSim file.

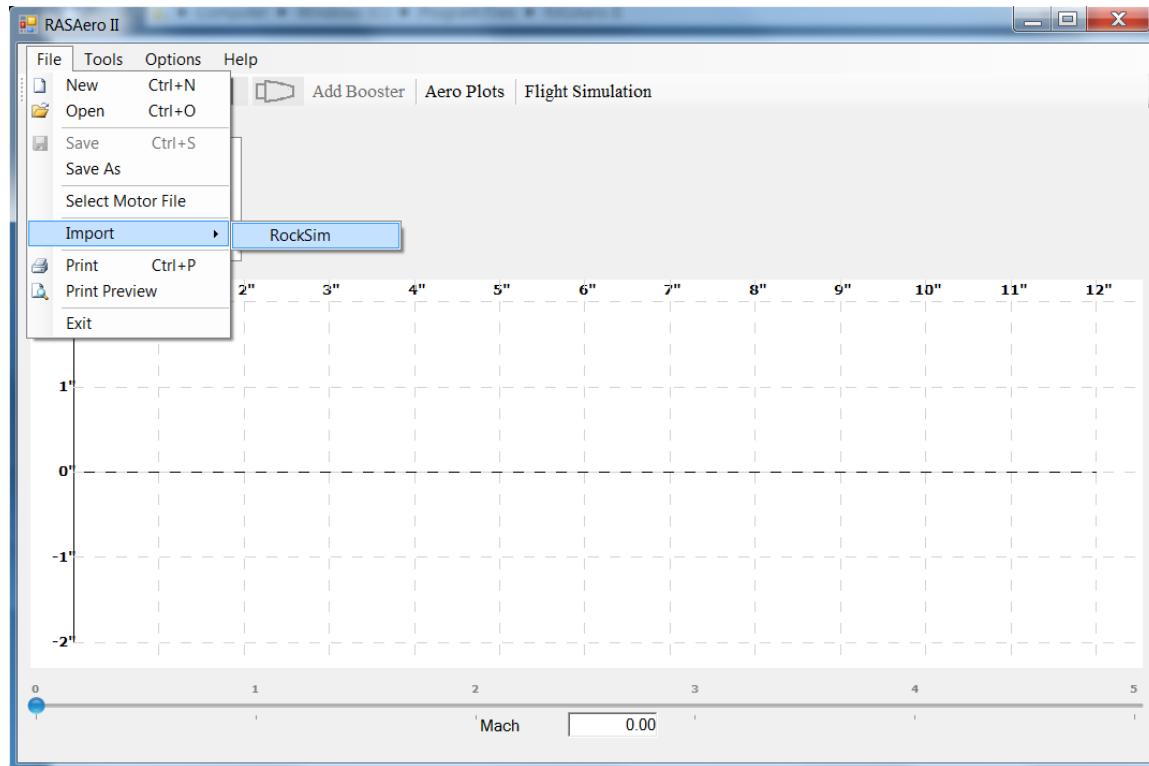


Figure 5 – Importing a RockSim file into RASAero II.

Some example rockets are stored in the Examples directory in the /My Documents/RASAero II directory.

After the input data for the rocket is entered, as will be detailed in later sections, or the input data for a previously saved rocket is modified, the rocket can then be run to generate aerodynamic data or to run the flight simulation. After the runs are completed, as shown in Figures 6 and 7 the rocket can be saved by selecting <File>, and then <Save> or <Save As> to save the rocket under the old name or a new name. All RASAero II rocket files have the extension .CDX1, and are stored in the /My Documents/RASAero II directory.

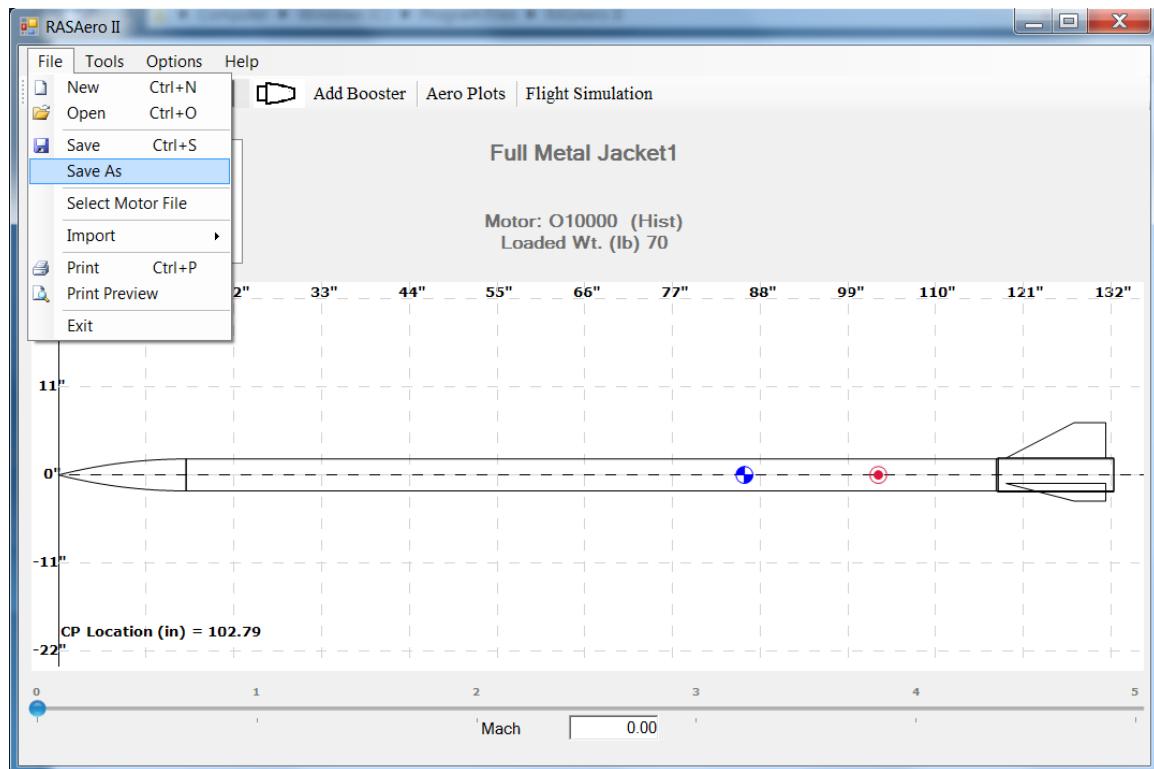


Figure 6 – Saving a rocket in RASAero II.

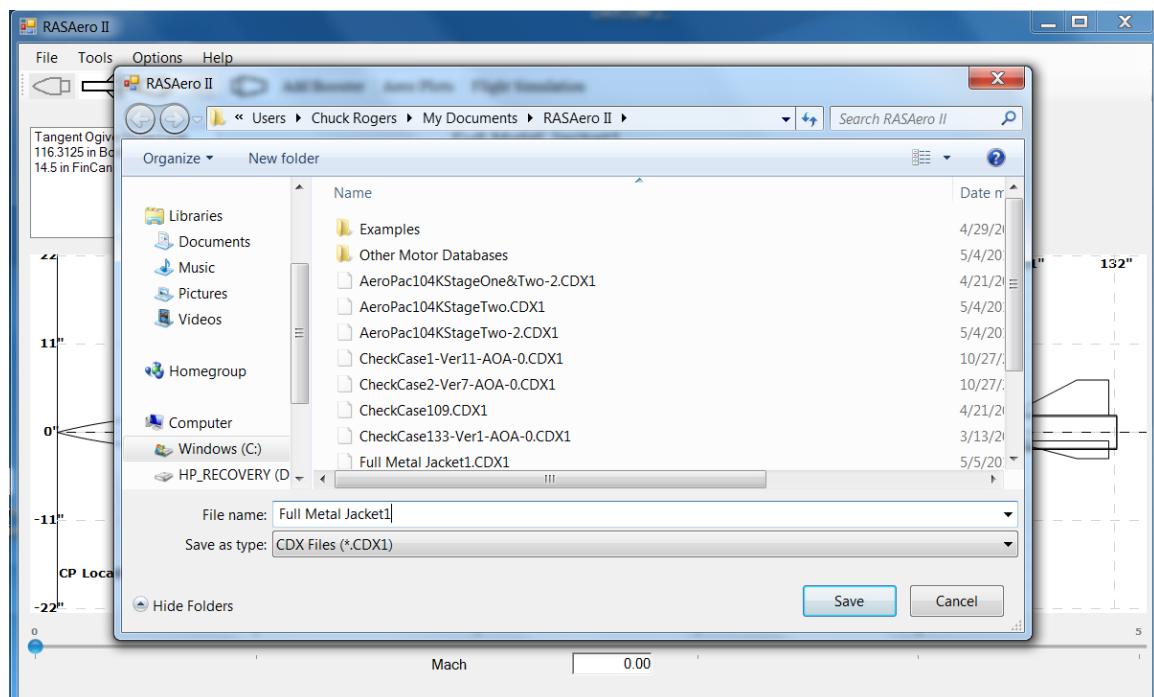


Figure 7 – Saving a rocket in RASAero II (continued).

## Nose Cone Inputs

To begin entering a new rocket into RASAero II, first the nose cone is entered by clicking on the Nose Cone Icon as shown in Figure 8. The RASAero II Nose Cone Inputs which are displayed after clicking on the Nose Cone Icon are shown in Figure 9. The available nose cone shapes are conical, tangent ogive, Von Karman ogive, power law, LV-Haack, parabolic, and elliptical. If the power law nose cone is selected, then the power law exponent “n” must be entered. The nose cone base diameter and length are entered, and a blunt (spherical) nose tip can be added by entering a nose tip radius. The inputs are saved by clicking on the <Save> button, or cancelled by clicking on the <Cancel> button.

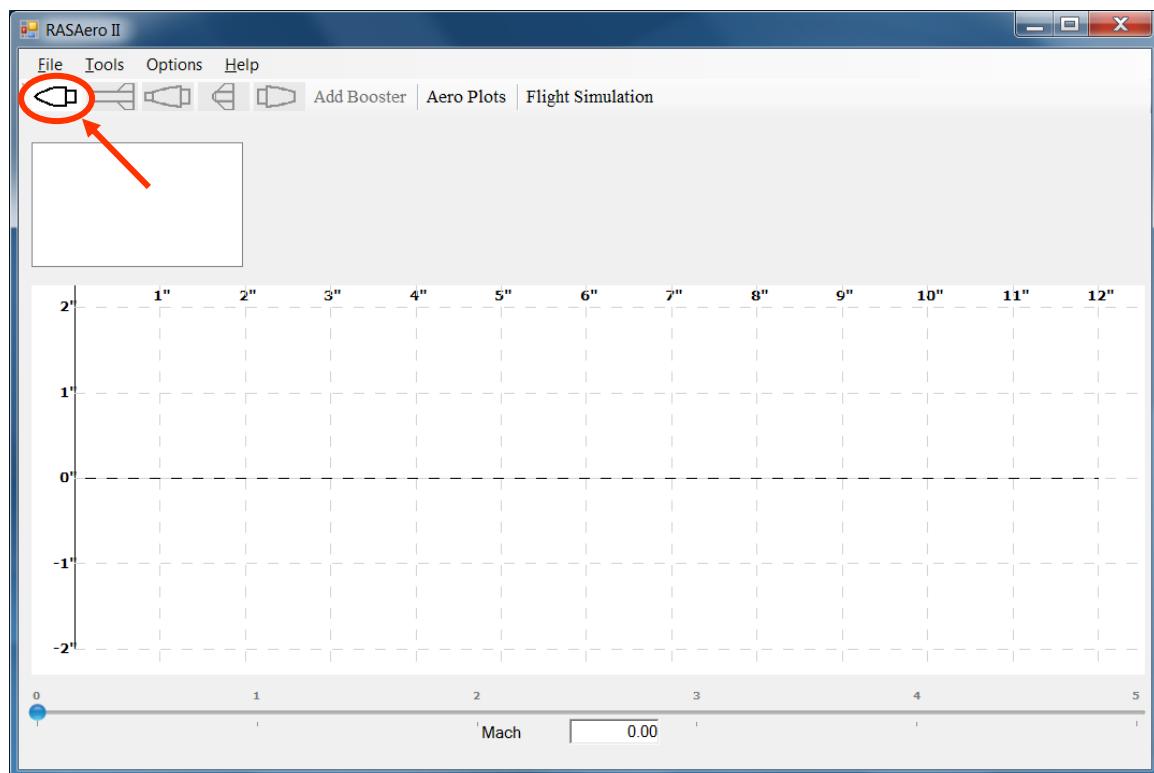


Figure 8 – Nose Cone Icon.

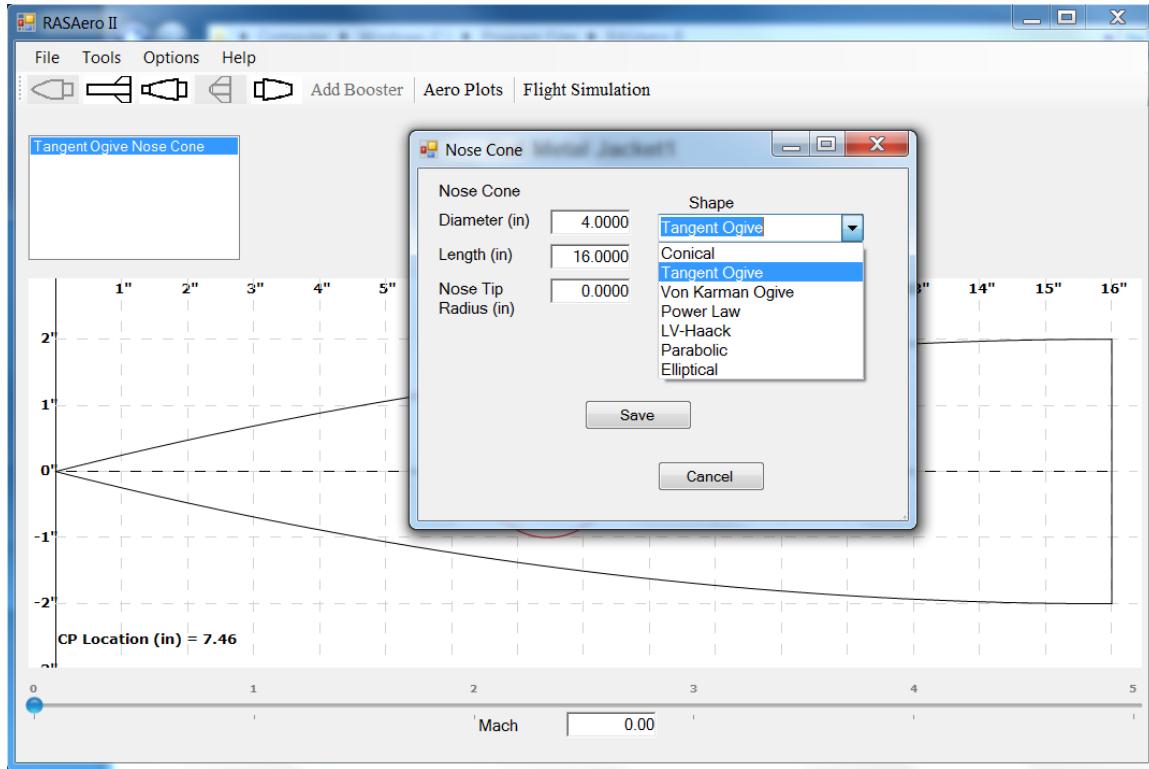


Figure 9 – Nose Cone Inputs.

### Body Tube, Fins and Rail Guide/Launch Lug/Launch Shoe Inputs

The rocket body tube is then added to the nose cone by clicking on the Rocket Body Tube and Fins Inputs Icon, as shown in Figure 10. Once the Rocket Body Tube and Fins Inputs Icon has been clicked on, the rocket Body Tube, Fins, Rail Guide/Launch Lug/Launch Shoe and Protuberance Inputs will appear as shown in Figure 11. The Protuberance Inputs will be described in the Protuberance Inputs section.

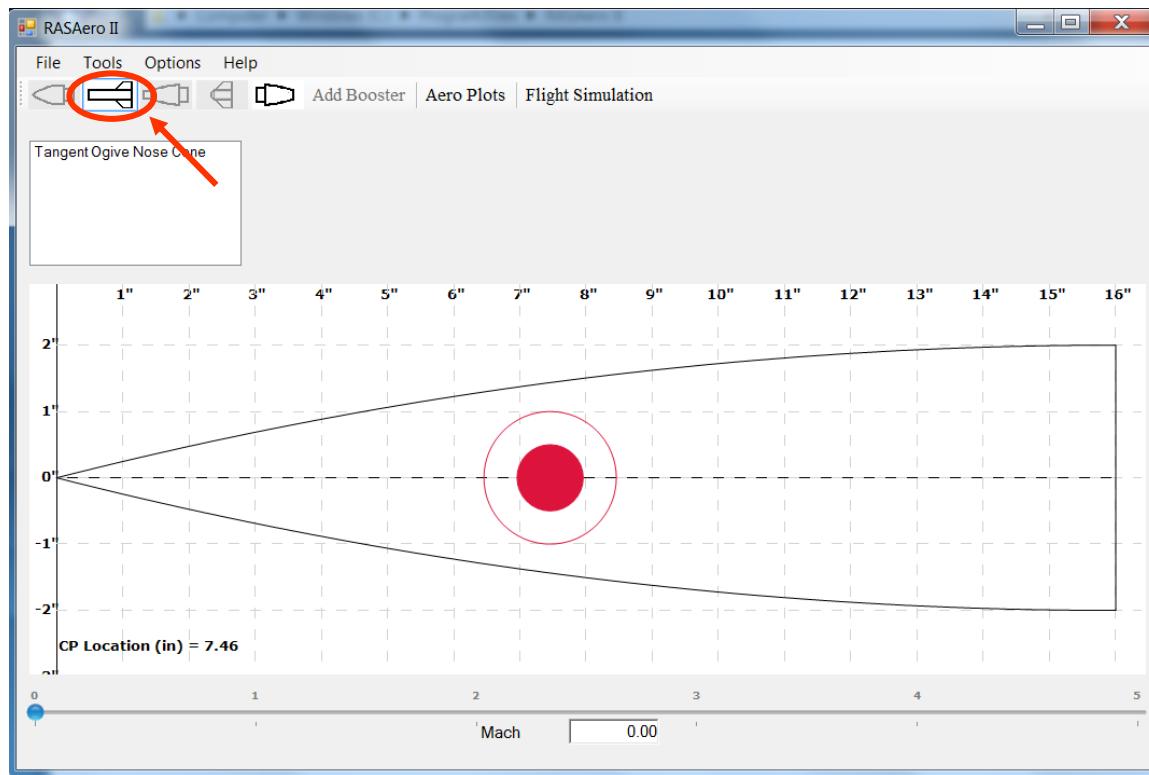


Figure 10 – Rocket Body Tube and Fins Inputs Icon.

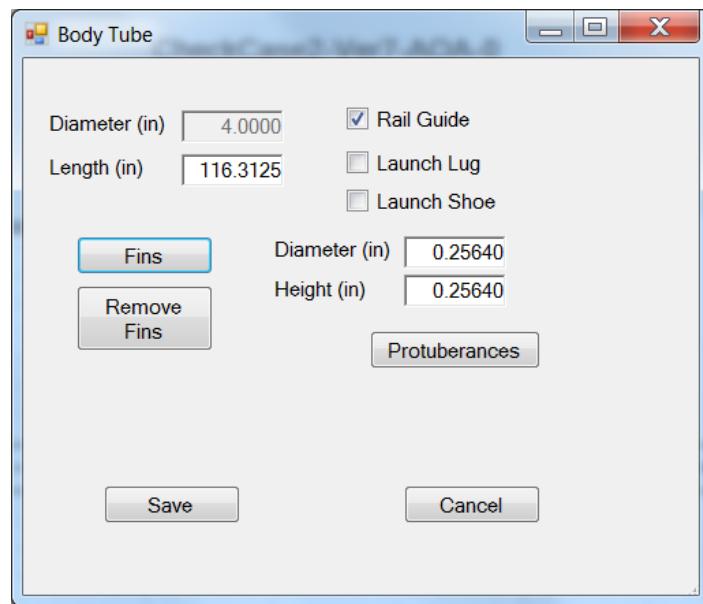


Figure 11 – Rocket Body Tube, Fins, Rail Guide/Launch Lug/Launch Shoe and Protuberance Inputs.

The Fin Inputs button is then clicked on, to open the Fin Inputs shown in Figure 12. If there are no fins on the body tube, the Fin Inputs button does not need to be clicked on, and no fins will be added to the body tube. The inputs are saved by clicking on the <Save> button, or cancelled by clicking on the <Cancel> button.

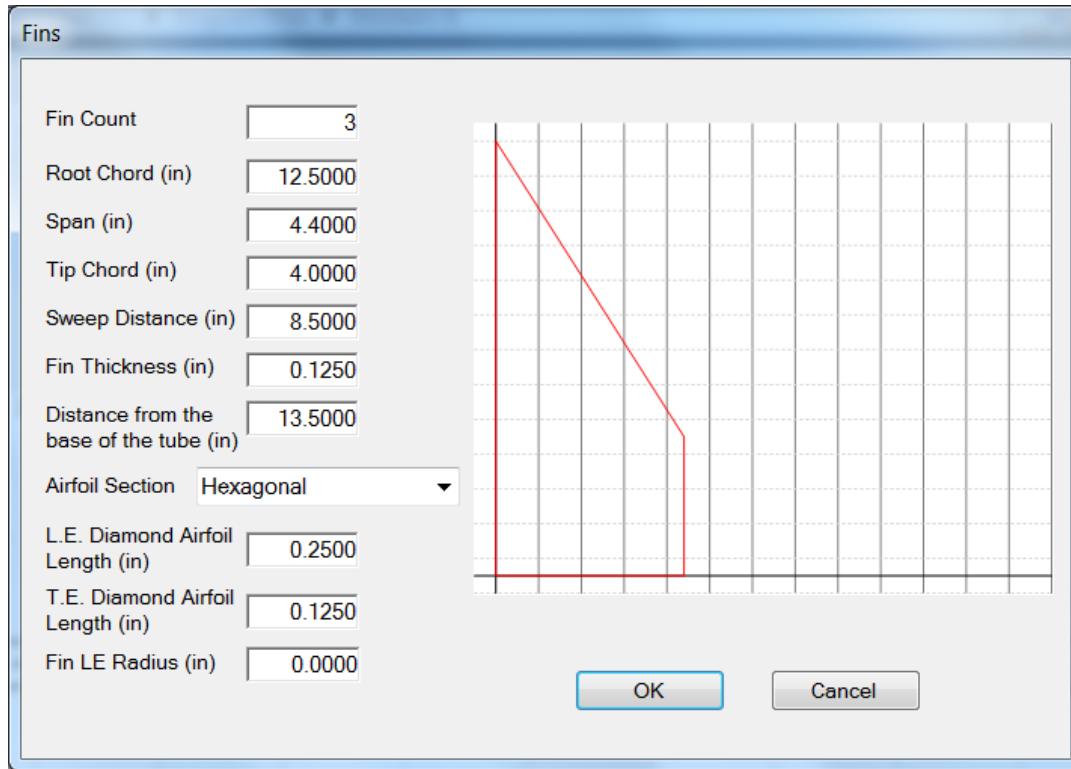


Figure 12 – Fin Inputs.

Note on the Fin Inputs shown in Figure 12, “L.E. Diamond Airfoil Length” is the Fin Airfoil Leading Edge Diamond Airfoil Length, and “T.E. Diamond Airfoil Length” is the Fin Airfoil Trailing Edge Diamond Airfoil Length, both of which will be defined in the Fin Airfoil Inputs section.

The Body and Fin Inputs geometry definitions are presented in Figure 13. All dimensions are in inches.

Note in the Fin Inputs in Figure 12, and the Fin Inputs geometry definitions in Figure 13, that the “Distance from the base of the tube (in)” input is for the start of the fin (where the fin leading edge intersects the body tube), and is the distance from the start of the fin to the bottom of the body tube.

The Fin Inputs are saved by clicking on the <OK> button, or cancelled by clicking on the <Cancel> button.

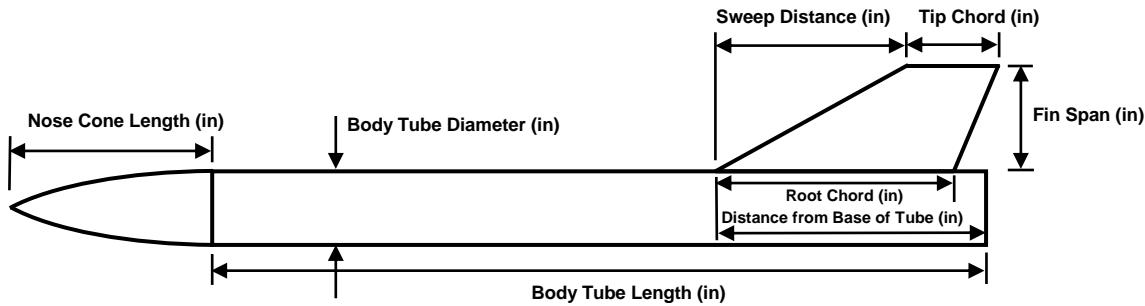


Figure 13 – Rocket Body and Fin Inputs geometry definitions.

### Fin Airfoil Inputs

The fin airfoils that can be selected in RASAero II are shown in Figures 14a through 14c. Hexagonal, NACA, double-wedge, biconvex, hexagonal blunt-base, single wedge, rounded, and square airfoils can be selected. Based on the airfoil selected, different airfoil geometry inputs are required which are described in Figures 14a through 14c. If a fin airfoil geometry input is not needed for a particular airfoil, then that geometry input will not be displayed on the input screen as no input is required. (Example; for the NACA airfoil the only input required is the fin thickness.) The leading edge diamond airfoil length and the trailing edge diamond airfoil length are measured parallel to the body tube.

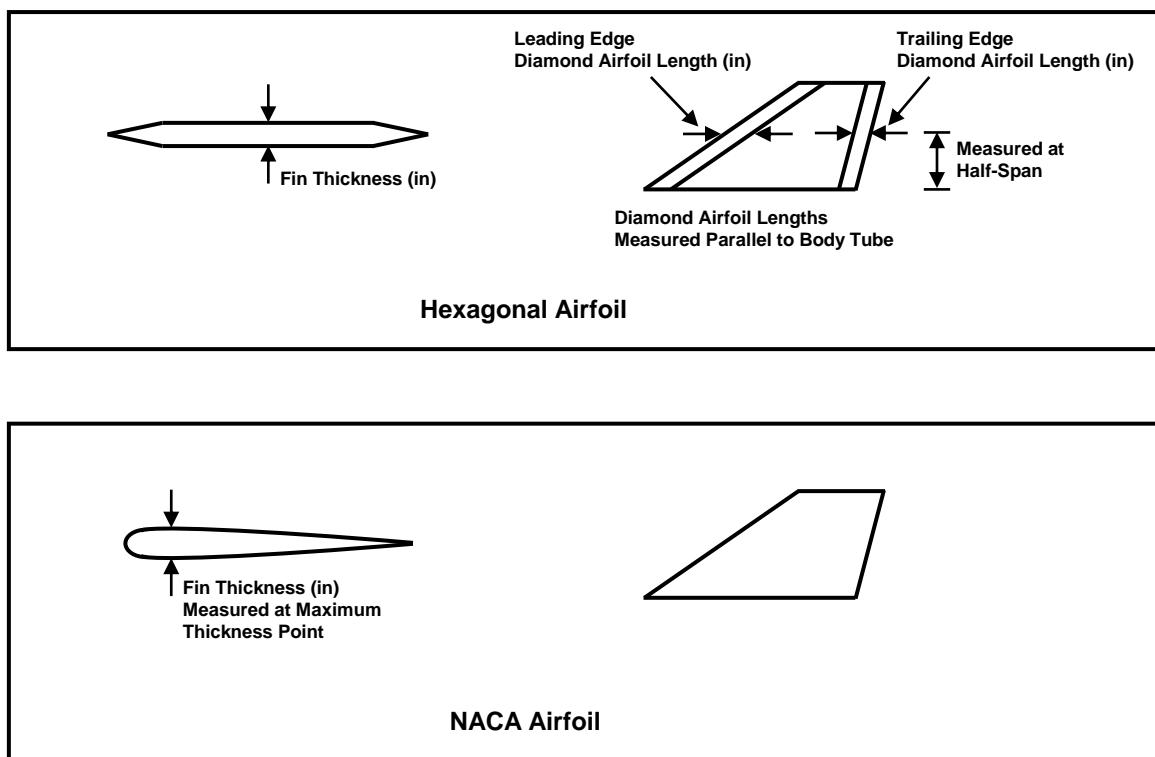


Figure 14a – Fin airfoil types and airfoil input geometry definitions.

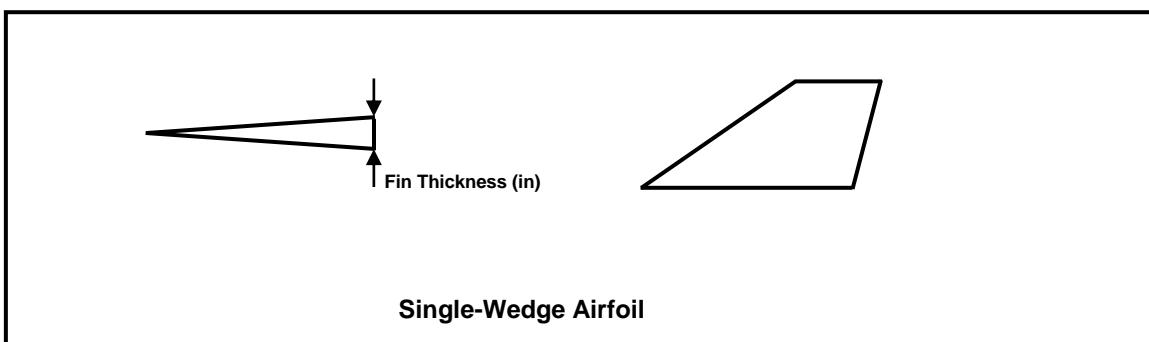
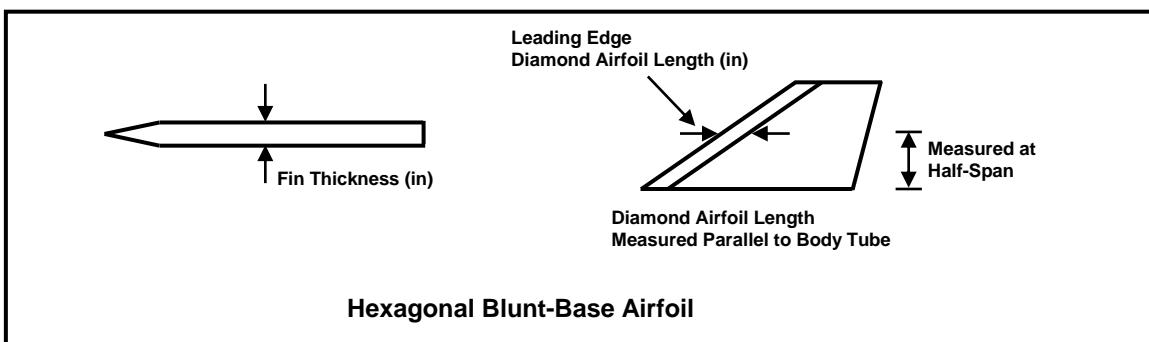
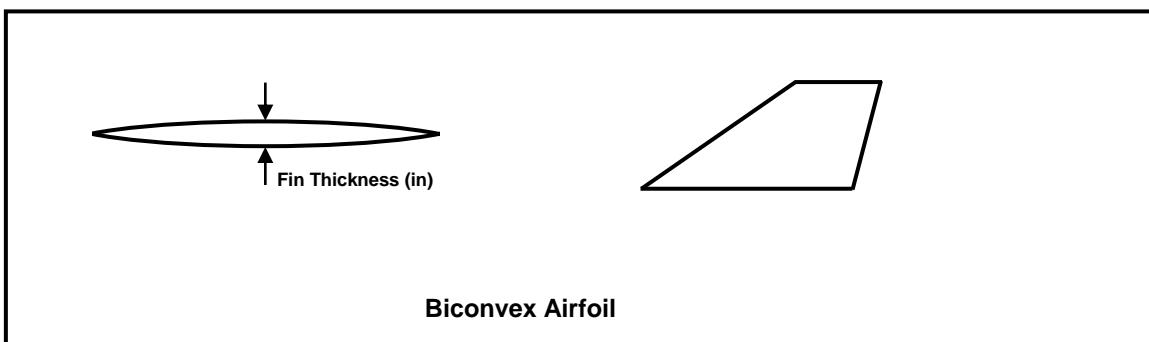
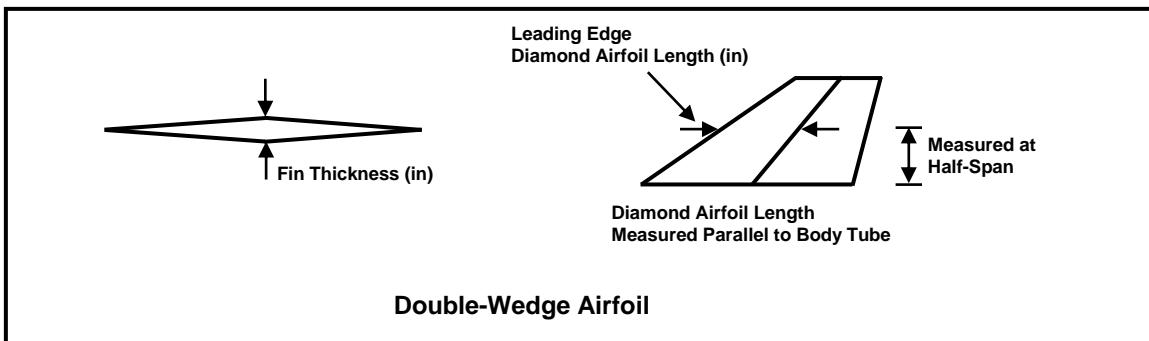


Figure 14b – Fin airfoil types and airfoil input geometry definitions (Continued).

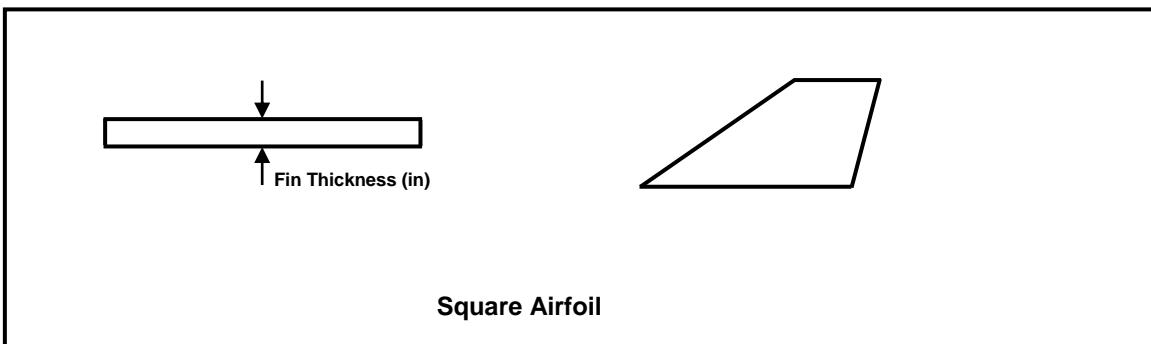
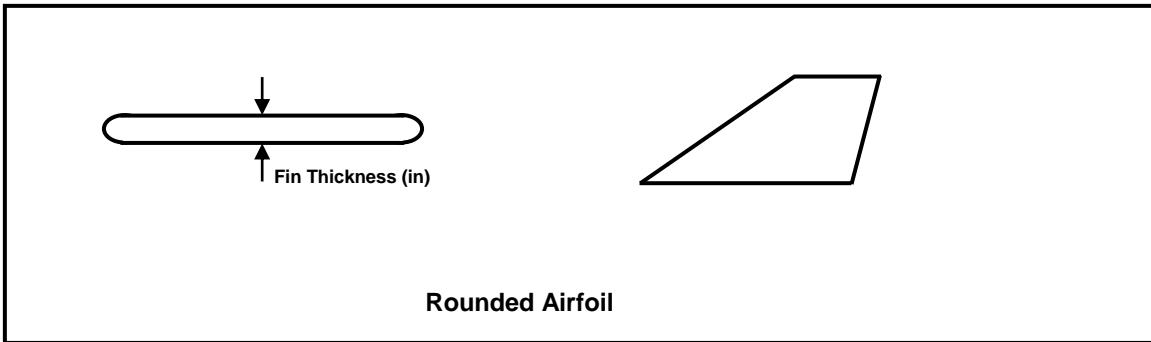


Figure 14c – Fin airfoil types and airfoil input geometry definitions (Concluded).

A blunt (rounded) leading edge can be added to any airfoil, with the exceptions of the NACA and Rounded airfoils which already have rounded leading edges, and the Square airfoil which specifically has a non-rounded leading edge. The blunt (rounded) leading edge is a cylindrical section added to the leading edge of the airfoil, with the radius of the cylindrical blunt (rounded) leading edge entered as the Fin LE (Leading Edge) Radius input. For a sharp (no bluntness) fin leading edge, the Fin LE (Leading Edge) Radius input is left at the default value of zero.

### **Fin Airfoil Inputs with Varying Leading Edge and Trailing Edge Diamond Airfoil Lengths**

When a leading edge and/or a trailing edge diamond airfoil length is required as a fin airfoil geometry input, and the fin leading edge and trailing edge diamond airfoil lengths vary along the fin span, the average leading edge diamond airfoil length and the average trailing edge diamond airfoil length are used as shown in Figure 15. If the fin thickness varies from the root of the fin to the tip of the fin, then the average fin thickness is used as shown in Figure 16.

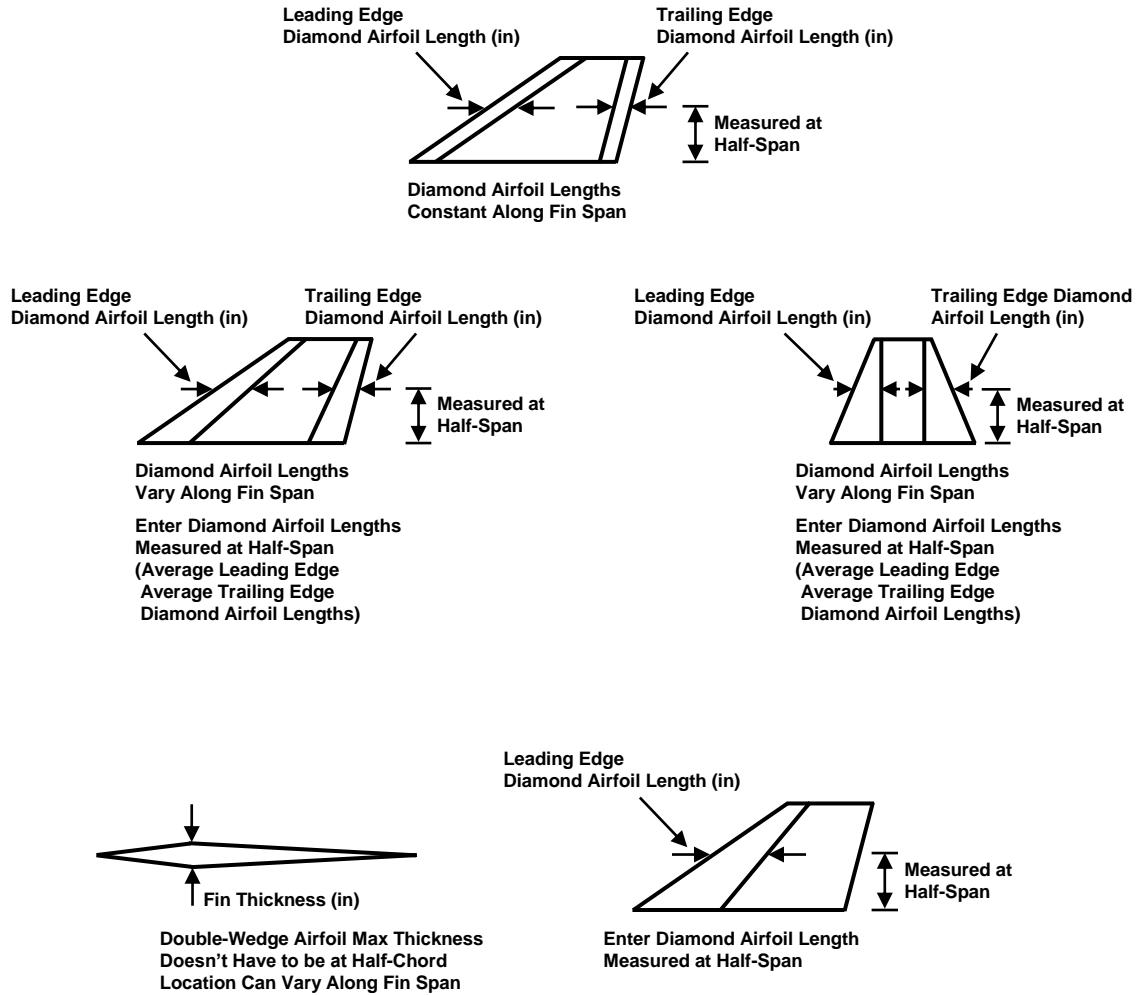


Figure 15 – Average leading edge and trailing edge diamond airfoil lengths used when the fin diamond airfoil lengths vary along the fin span.

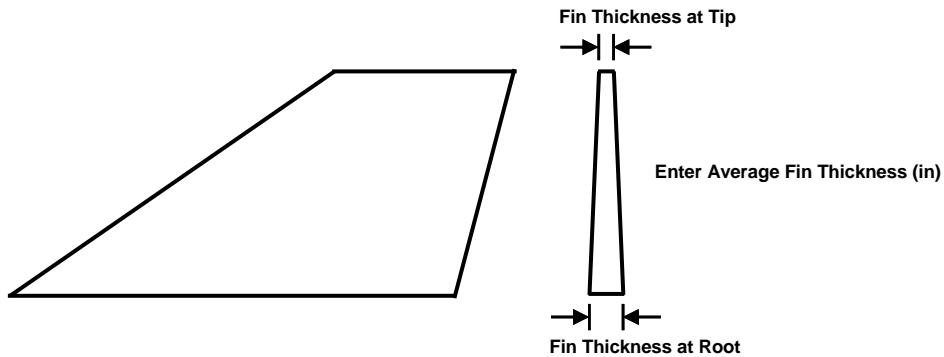


Figure 16 – Average fin thickness used when the fin thickness varies from the root of the fin to the tip of the fin.

## Adding Multiple Body Tubes

As shown in Figure 17, multiple body tubes can be added in a row on each stage of the rocket by clicking on the Rocket Body Tube and Fins Inputs Icon, as was shown in Figure 10, and adding a body tube. When the body tube is added, the Fins Inputs Icon is not clicked, and fins are not added. Figure 17 shows multiple body tubes added in a row for the rocket body.

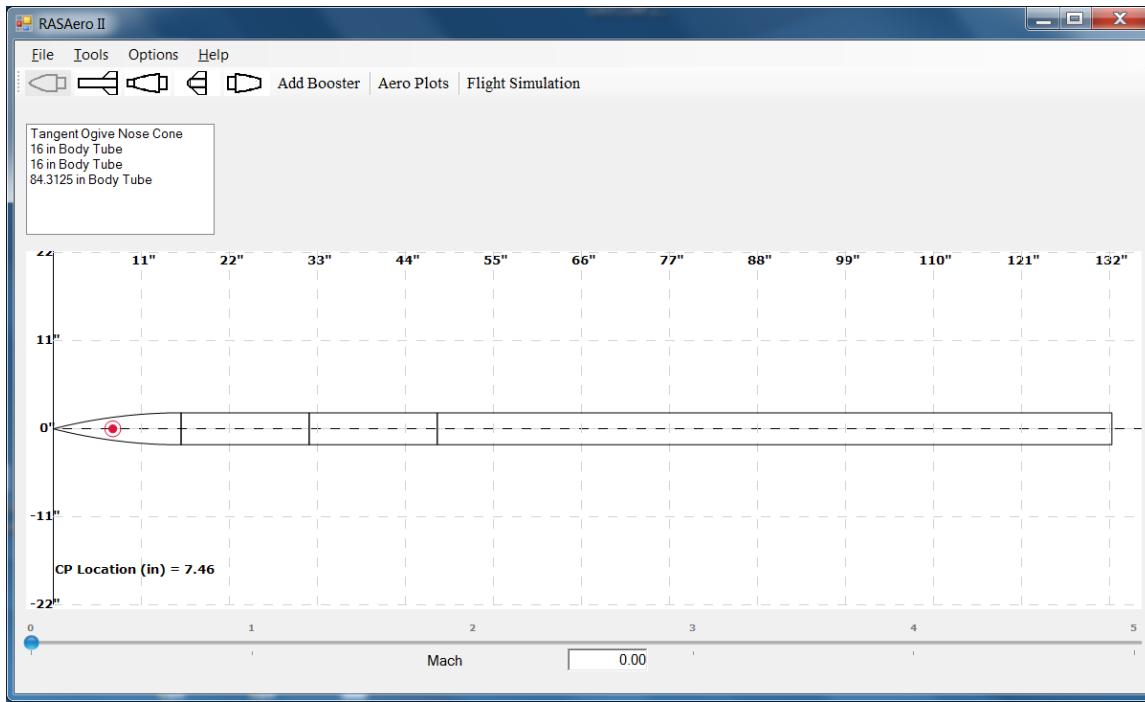


Figure 17 – Multiple body tubes added in a row for the rocket body.

Note that from an aerodynamic prediction standpoint having multiple body tubes in a row versus one single body tube of the same total length has no effect on the aerodynamic predictions for the rocket. Adding multiple body tubes can be used to build up the rocket from the individual body tube lengths which are planned to be used, or to create a more representative drawing of the rocket showing the separation point for the recovery system, and the payload bay, as examples.

Note that every time a body tube is added, a set of fins can be added anchored to that body tube by inputting fins for that body tube. Thus multiple sets of fins can be added to a single stage rocket, or each stage of a multi-stage rocket, by adding individual body tubes and inputting fins for each of the body tubes.

## Rail Guide, Launch Lug and Launch Shoe Inputs

The RASAero II software includes four options for rocket launch guides:

- a) Rail Guides
- b) Launch Lugs
- c) Launch Shoes
- d) None. (Tower-launched.)

To select a rail guide, the rail guide box is checked as shown in Figure 18.

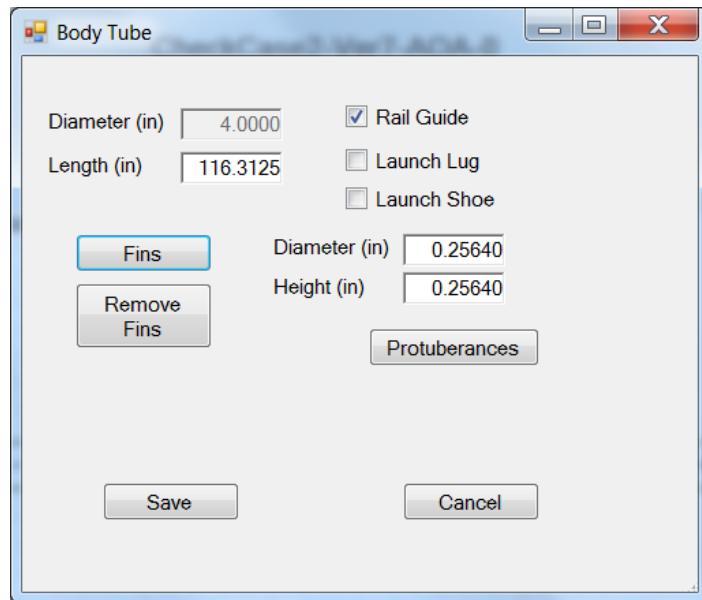


Figure 18 – Rail guide inputs.

The rail guide inputs geometry definitions are presented in Figure 19. The rail guide diameter, and the rail guide height measured to the top of the retaining screw, are entered. The diameter and height for a single rail guide is entered, the software then calculates the rail guide drag based on two of the rail guides being mounted on the side of the rocket.

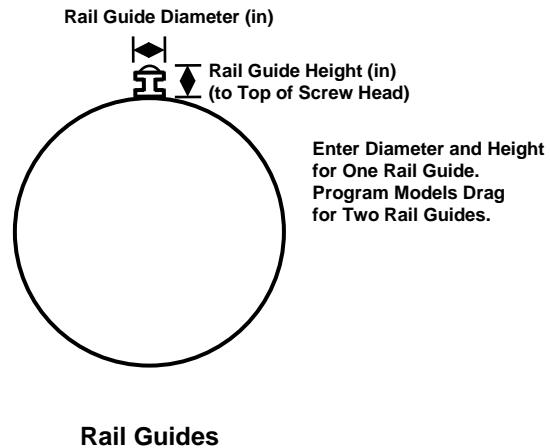


Figure 19 – Rail guide geometry inputs.

To select a launch lug, the launch lug box is checked as shown in Figure 20.

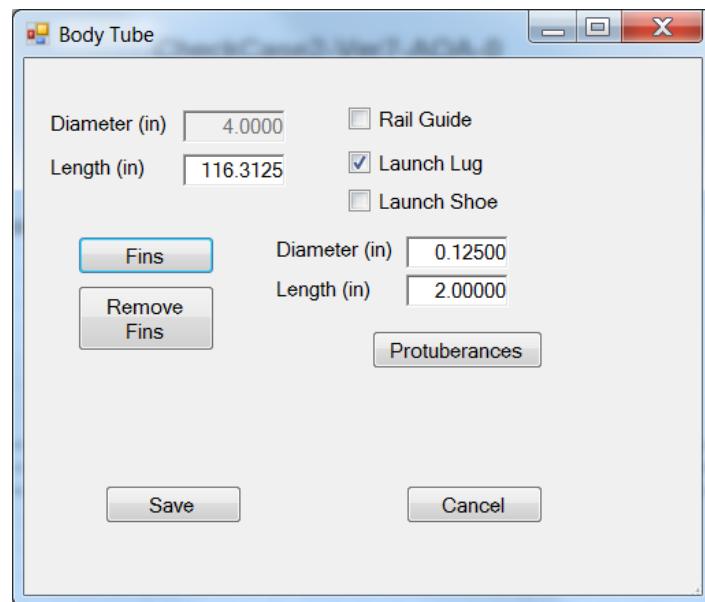


Figure 20 – Launch lug inputs.

To select a launch shoe, the launch shoe box is checked as shown in Figure 21.

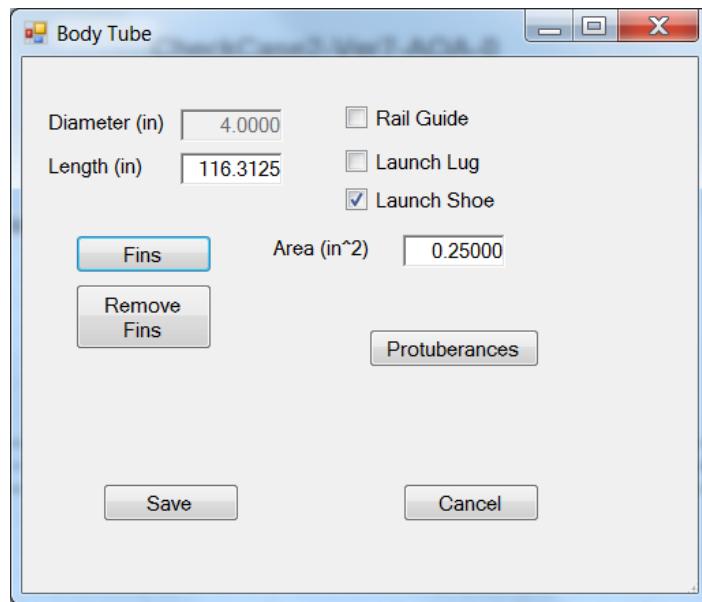


Figure 21 – Launch shoe inputs.

Launch lug and launch shoe geometry inputs are presented in Figure 22. For launch lugs the outside diameter and length of a single launch lug is entered. The software then calculates the launch lug drag based on two of the launch lugs being mounted on the side of the rocket. For launch shoes the frontal area of a single launch shoe is entered in square inches. The software then calculates the launch shoe drag based on two launch shoes being mounted on the side of the rocket.

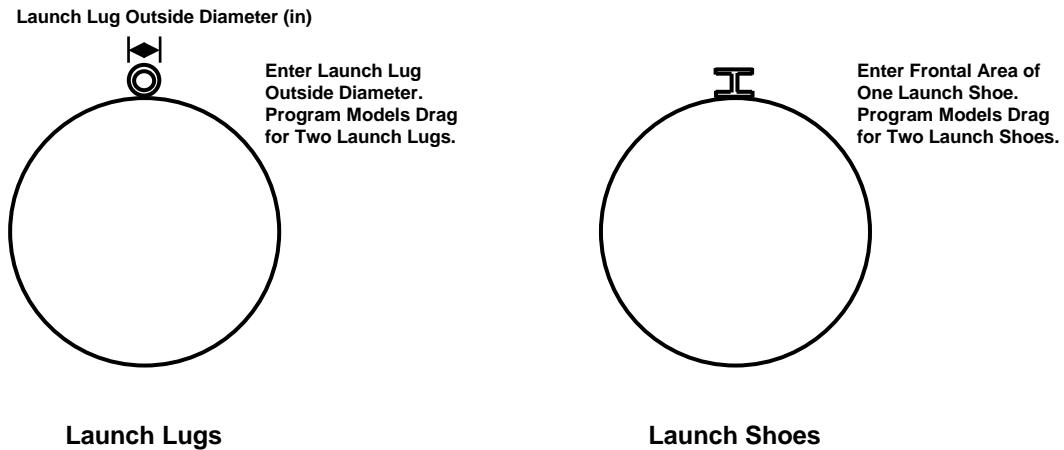


Figure 22 – Launch lug and launch shoe geometry inputs.

If the rocket is tower launched (no rail guides, launch lugs or launch shoes), then none of the rail guide/launch lug/launch shoe boxes are checked, as shown in Figure 23.

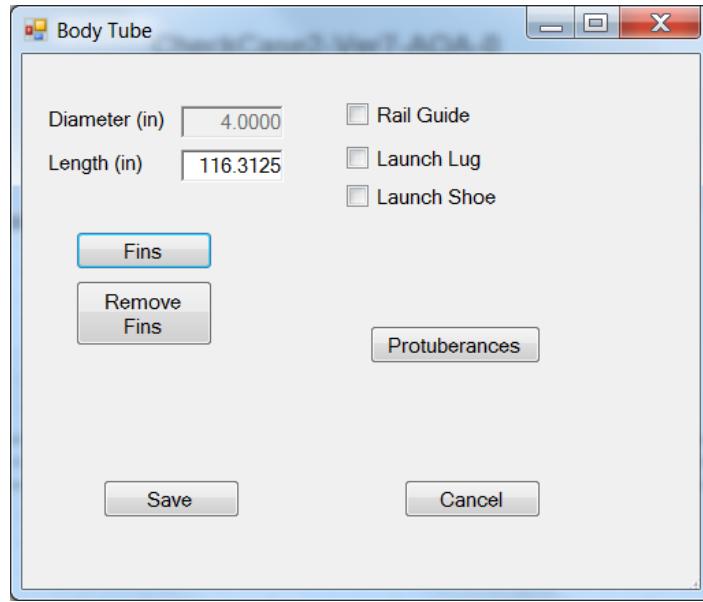


Figure 23 – No rail guides, launch lugs or launch shoes (tower launched).

The rail guide/launch lug/launch shoe inputs are saved by clicking on the <Save> button, or cancelled by clicking on the <Cancel> button.

When rail guides, launch lugs or launch shoes have been added to the rocket; rail guides, launch lugs or launch shoes will be added to the rocket drawing, as shown in Figure 24.

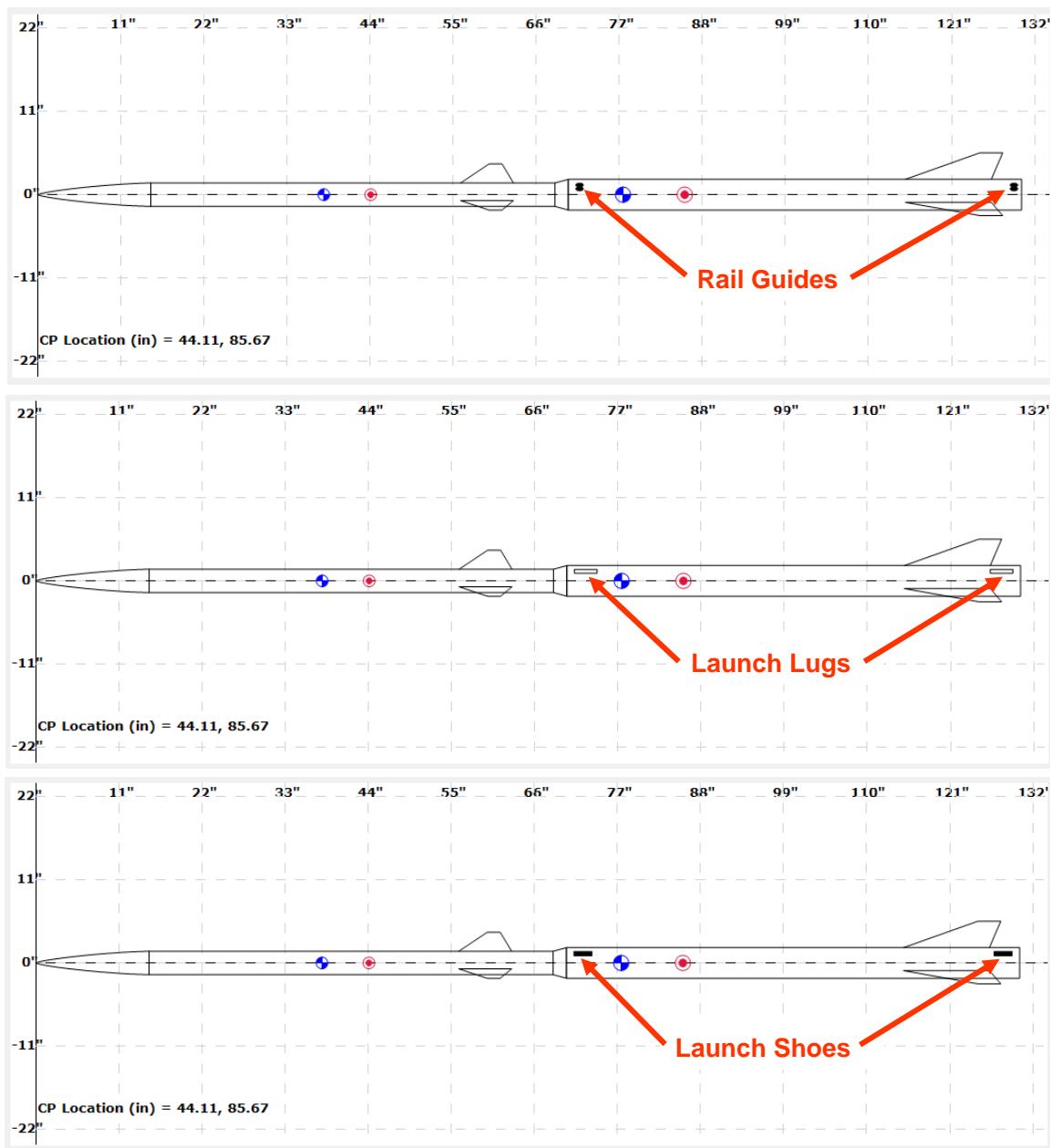


Figure 24 – Rail guides, launch lugs and launch shoes displayed on the rocket drawing.

## Protuberance Inputs

The RASAero II software includes four options for Protuberance Inputs:

- a) Streamlined – No Base Drag
- b) Streamlined – With Base Drag
- c) Inclined Flat Plate
- d) None.

The Protuberance Inputs are made by clicking on the Protuberances button shown in Figure 25, which opens the Protuberance Inputs shown in Figure 26.

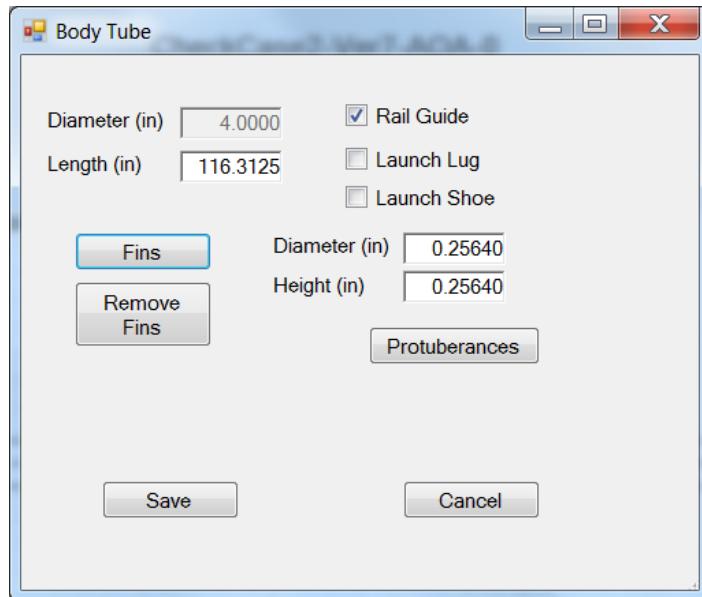


Figure 25 – Protuberances button to access Protuberance Inputs.

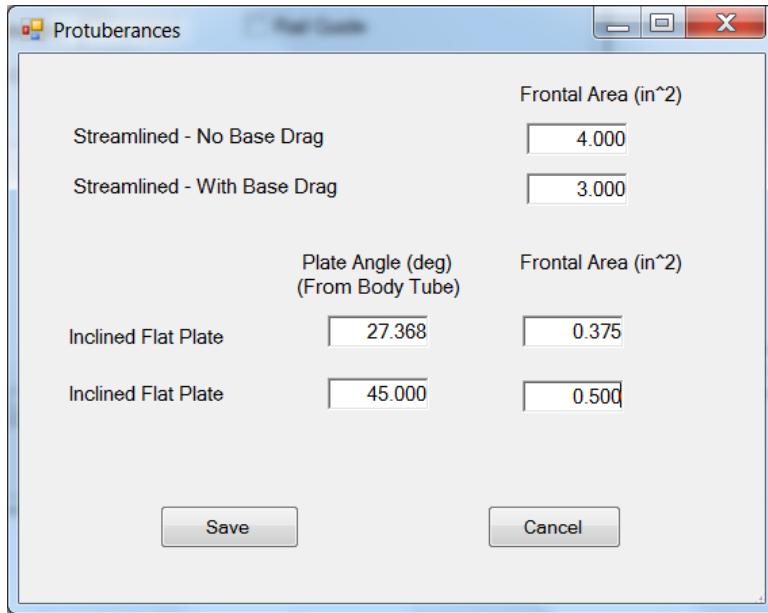


Figure 26 – Protuberance Inputs.

The plate angle of the inclined flat plate is measured from the body tube in degrees. It is the angle between the flat plate and the body tube, which will be less than 90 deg. (Although the RASAero II software allows a plate angle input of up to 90 deg, a vertical flat plate.) A plate angle of zero deg is the flat plate lying on the body tube, i.e., the flat plate is parallel to the body tube.

Note that protuberances can be added for each body tube and fin canister on the rocket. (The fin canister will be described in the Fin Canister Inputs section.)

If there are multiple Streamlined – No Base Drag Protuberances on a particular body tube or fin canister on the rocket, the frontal areas of all the Streamlined – No Base Drag Protuberances are added up for the total frontal area which is entered in the Protuberance Inputs shown in Figure 26. The same is done if there are multiple Streamlined – With Base Drag Protuberances on a given body tube or fin canister. For multiple Inclined Flat Plate Protuberances, the frontal areas are also added up for the total frontal area, but the frontal areas being added up must be for inclined flat plates with the same plate angle.

For no protuberances, the Protuberance Inputs are simply not accessed, and no protuberances are entered.

The Protuberance Inputs are saved by clicking on the <Save> button, or cancelled by clicking on the <Cancel> button.

Once protuberances have been entered, the protuberances can be removed by clicking on the Remove Protuberances button shown in Figure 27, which appears after protuberances have been entered and saved. This will remove all of the protuberances on that body tube or fin canister, but will not remove protuberances on other body tubes and fin canisters.

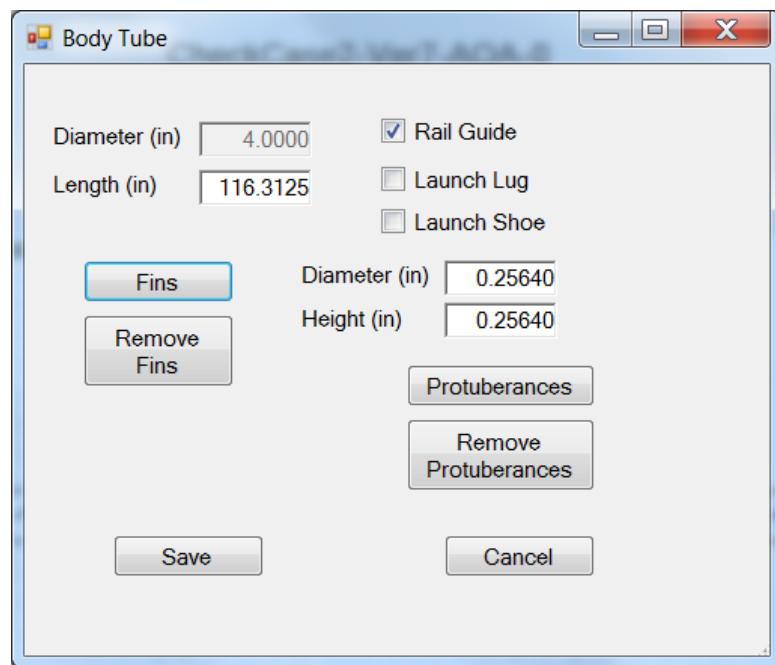


Figure 27 – Remove Protuberance button.

Examples of the different protuberance types are described in the paragraphs and figures which follow.

Streamlined – No Base Drag Protuberances are protuberances with a streamlined front end and a streamlined or boattailed aft end. An example is a missile raceway on a Corporal missile shown in Figure 28.



Figure 28 – Example Streamlined – No Base Drag Protuberance, a missile raceway.

Streamlined – With Base Drag Protuberances are protuberances with a streamlined front end, but a blunt (flat) back end which has base drag. An ullage rocket cover on an S-IVB stage on a Saturn IB launch vehicle, shown in Figure 29, is a good example of a Streamlined – With Base Drag Protuberance.

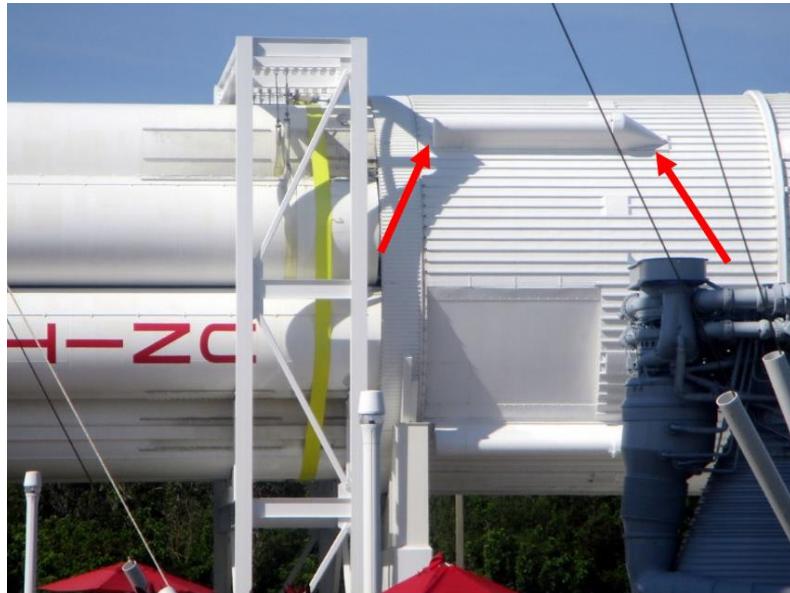


Figure 29 – Example Streamlined – With Base Drag Protuberance, ullage rocket cover on S-IVB stage on Saturn IB launch vehicle.

Camera shrouds, like the Cineroc camera shroud shown in Figure 30, can be modeled as a Streamlined – With Base Drag Protuberance.



Figure 30 – Cineroc camera shroud, modeled as a Streamlined – With Base Drag Protuberance.

An example of Inclined Flat Plate Protuberances are fin brackets, shown in Figure 31. The angle of the front inclined flat plate, measured relative to the body tube, is inputted as the plate angle. The frontal areas of all of the fin brackets are added up for the total frontal area, which is entered with the plate angle as the Protuberance Input for the fin brackets.



Figure 31 – Example Inclined Flat Plate Protuberances, fin brackets.

When Streamlined – No Base Drag, Streamlined – With Base Drag or Inclined Flat Plate Protuberances have been added to the rocket; Streamlined – No Base Drag, Streamlined – With Base Drag or Inclined Flat Plate Protuberance symbols will be added to the rocket drawing, as shown in Figure 32.

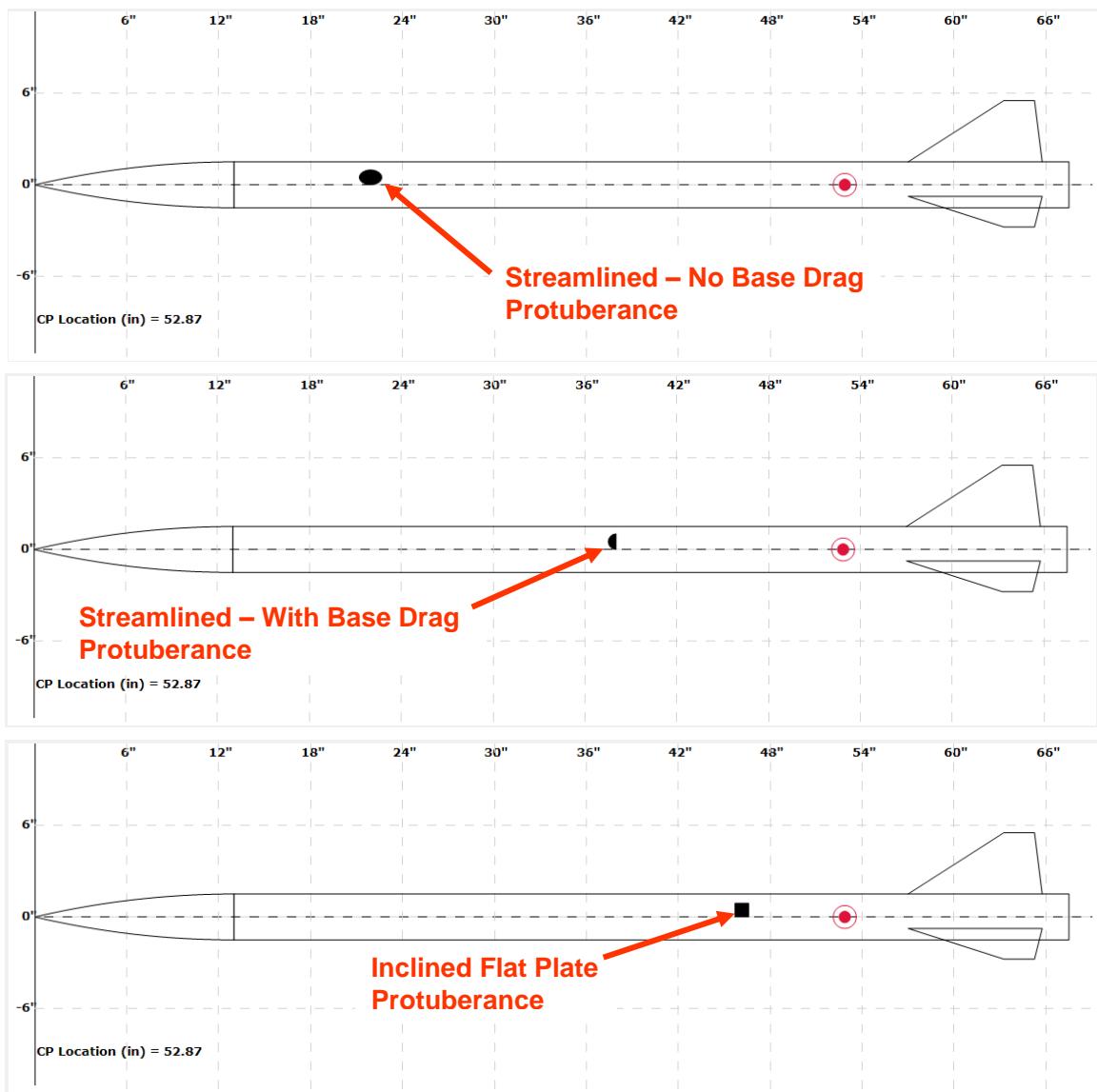


Figure 32 – Streamlined – No Base Drag, Streamlined – With Base Drag and Inclined Flat Plate Protuberances displayed on the rocket drawing.

## Transition Inputs

A transition can be added to a body tube by clicking on the Transition Icon as shown in Figure 33. The Transition Inputs are shown in Figure 34, with a rocket with a completed transition input and a body tube entered after the transition shown in Figure 35.

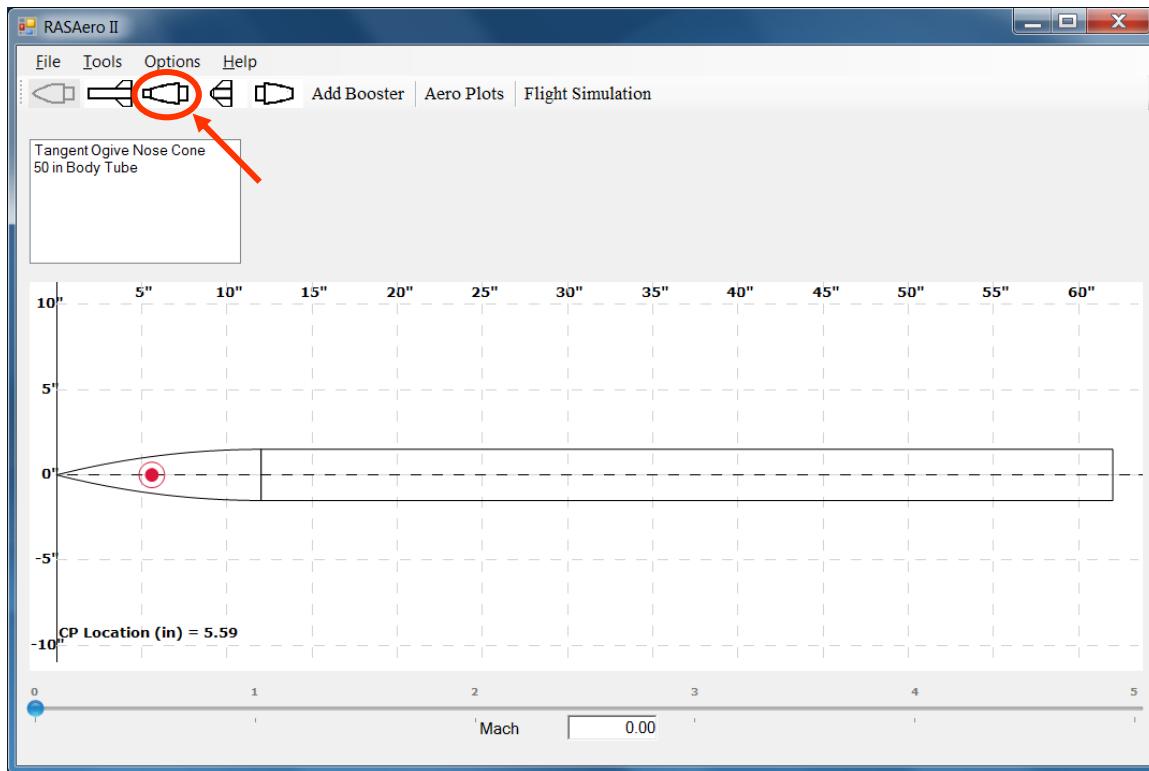


Figure 33 – Transition Icon.

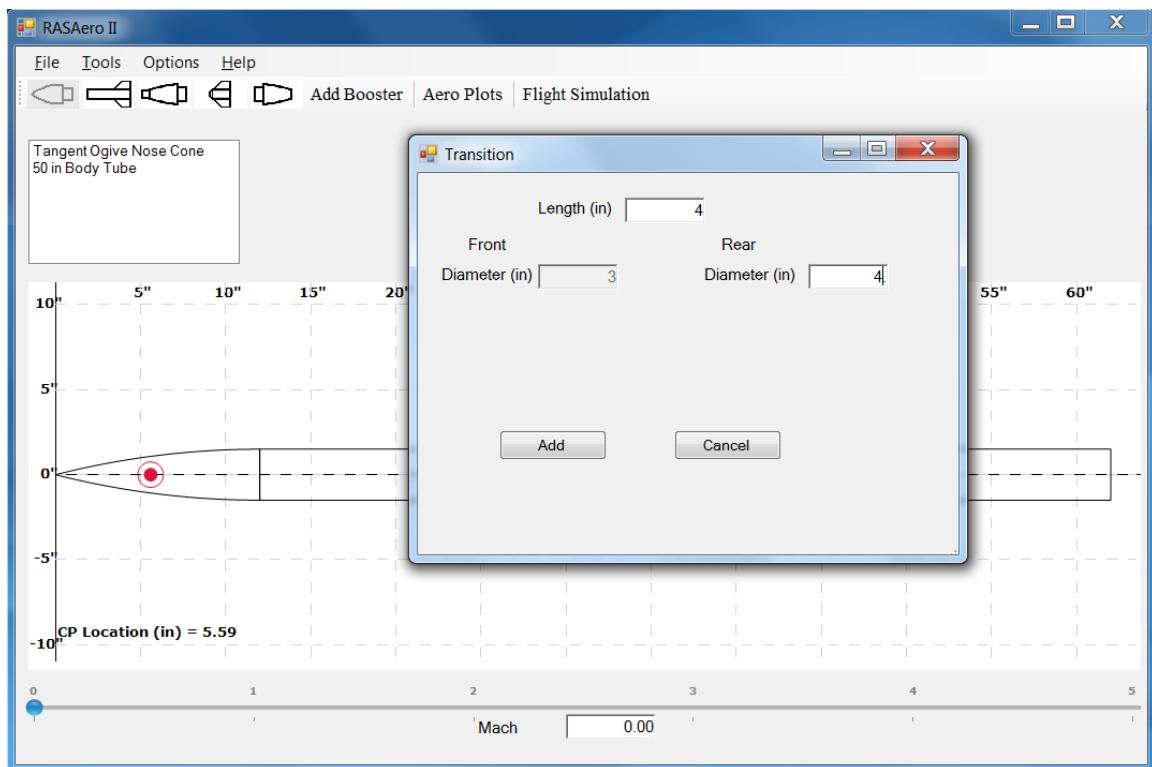


Figure 34 – Transition Inputs.

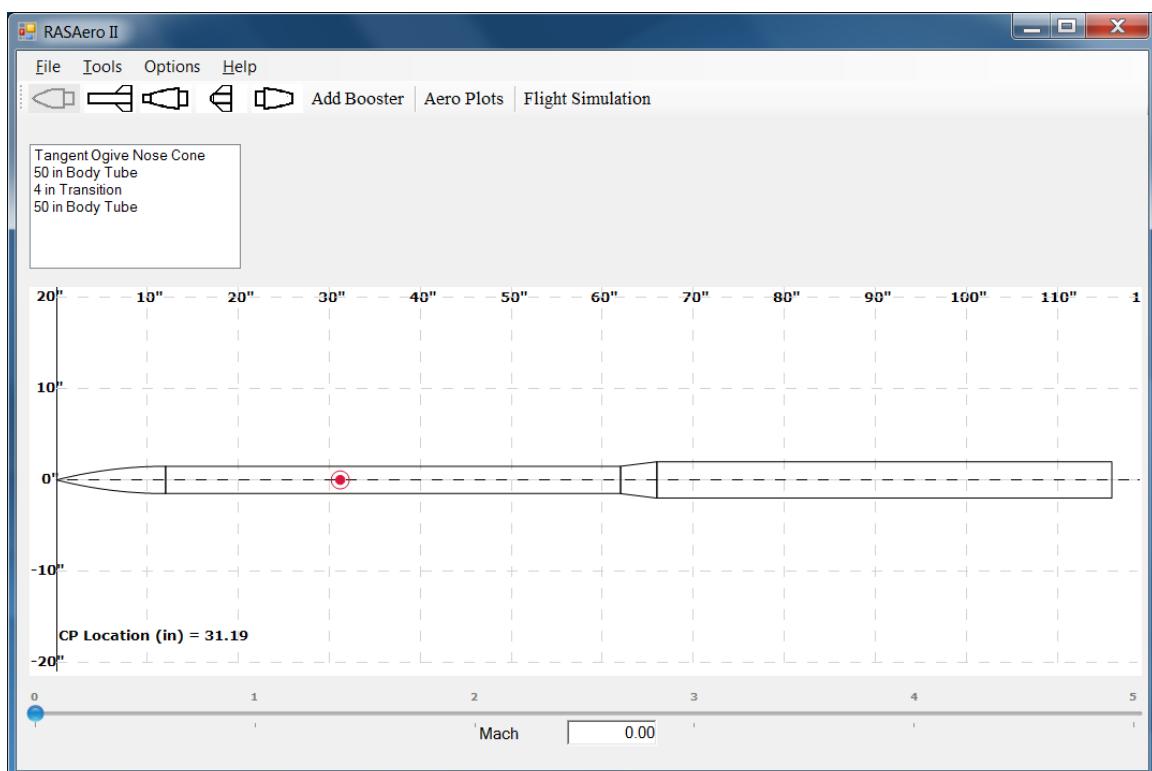


Figure 35 – Completed Transition Input.

## Fin Canister Inputs

A Fin Canister can be added to a body tube by clicking on the Fin Canister Icon as shown in Figure 36. The Fin Canister Inputs are shown in Figure 37, with the Fin Canister geometry definitions shown in Figure 38.

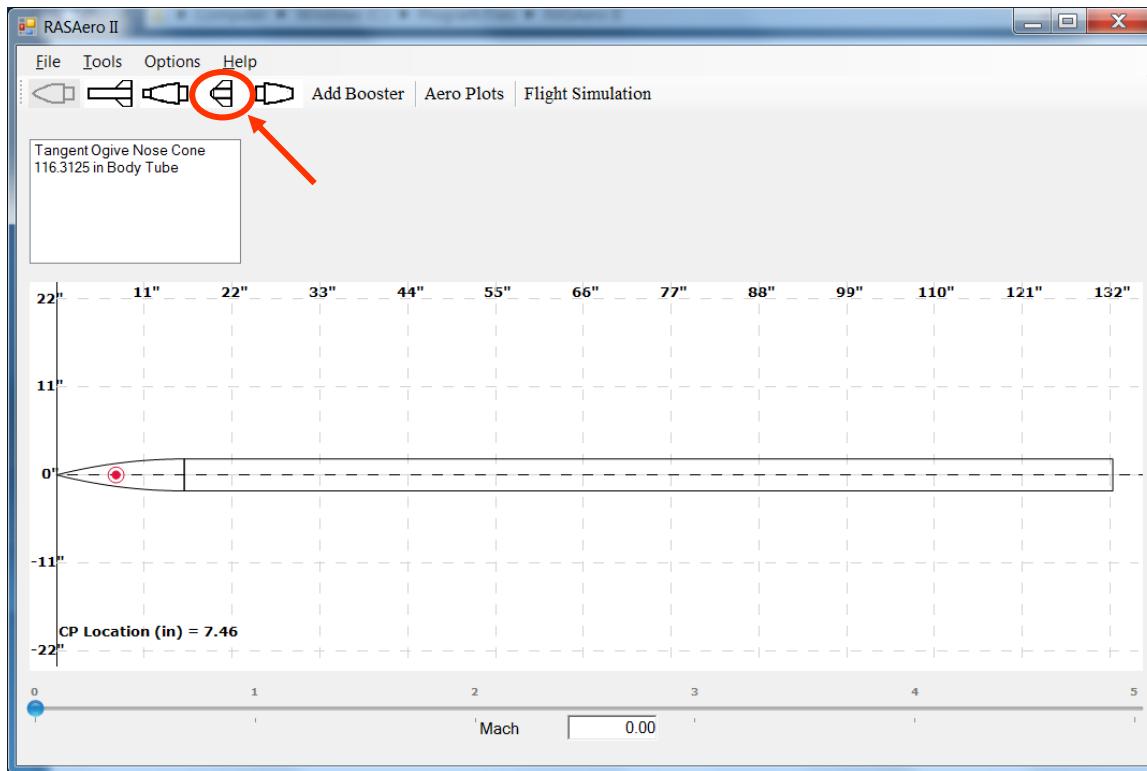


Figure 36 – Fin Canister Icon.

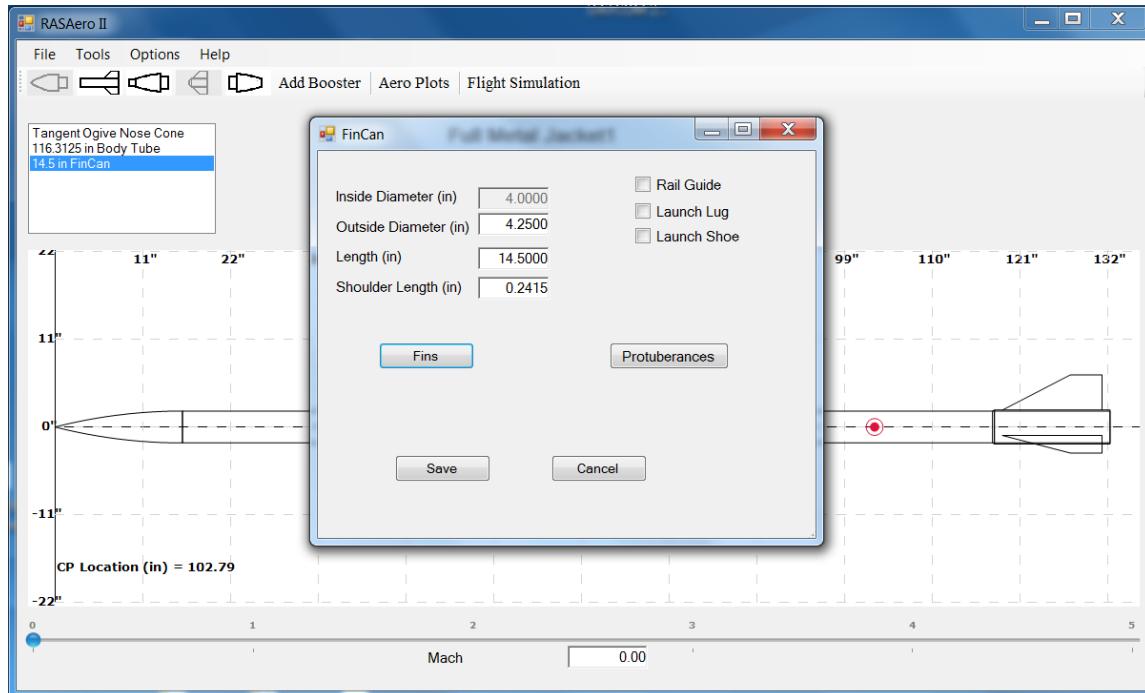


Figure 37 – Fin Canister Inputs.

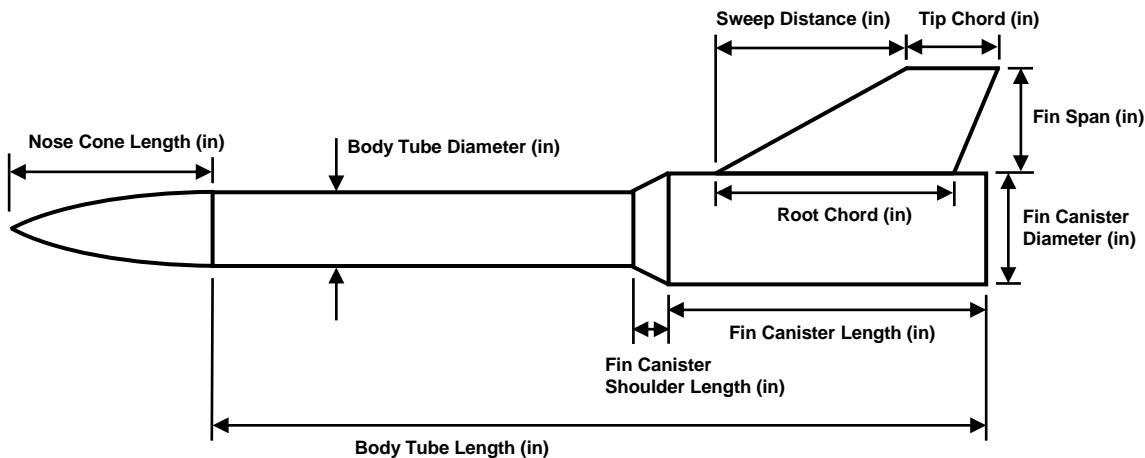


Figure 38 – Fin Canister geometry definitions.

Note as shown in Figure 38, the bottom of the fin canister is at the bottom of the body tube, the fin canister length then defines the location of the fin canister shoulder. Note in Figure 37 that there is a Fin Inputs button on the fin canister input screen, the Fin Inputs button is clicked on to enter the Fin Inputs for the fins which are mounted to the fin canister.

The Fin Canister Inputs are saved by clicking on the <Save> button, or cancelled by clicking on the <Cancel> button.

## Boattail Inputs

A boattail can be added to the bottom of the rocket by clicking on the Boattail Icon as shown in Figure 39. The Boattail Inputs are shown in Figure 40, with the Boattail geometry definitions shown in Figure 41.

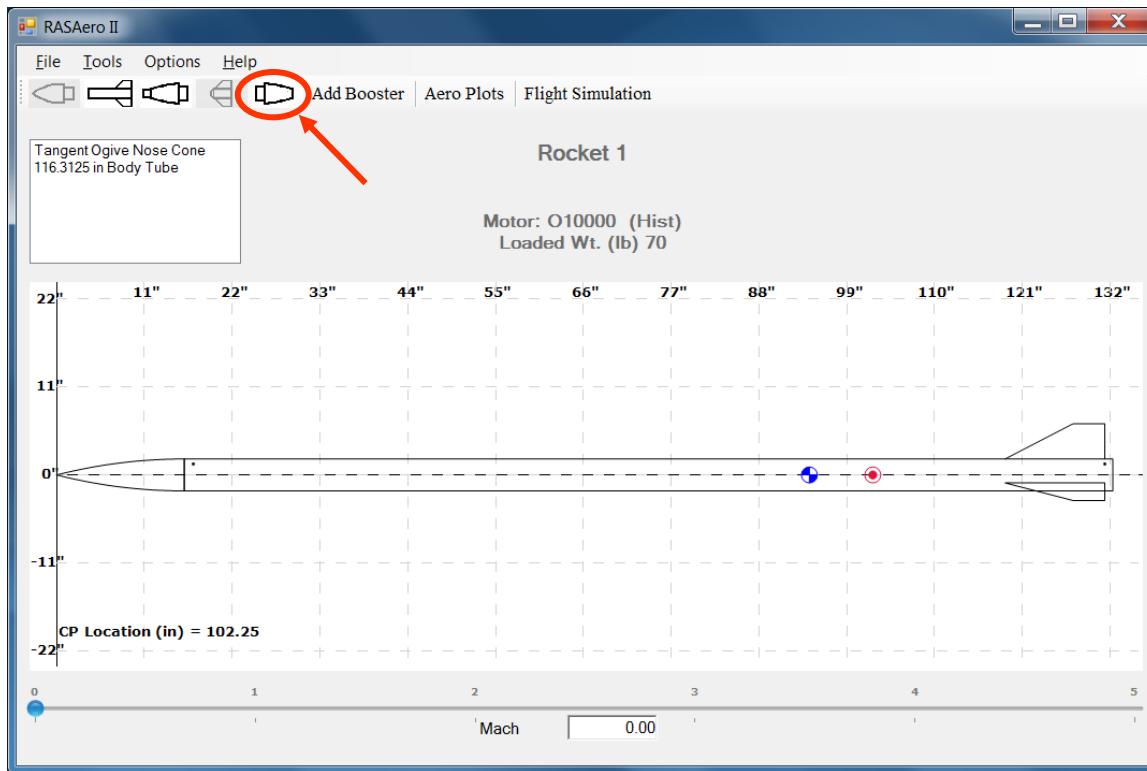


Figure 39 – Boattail Icon.

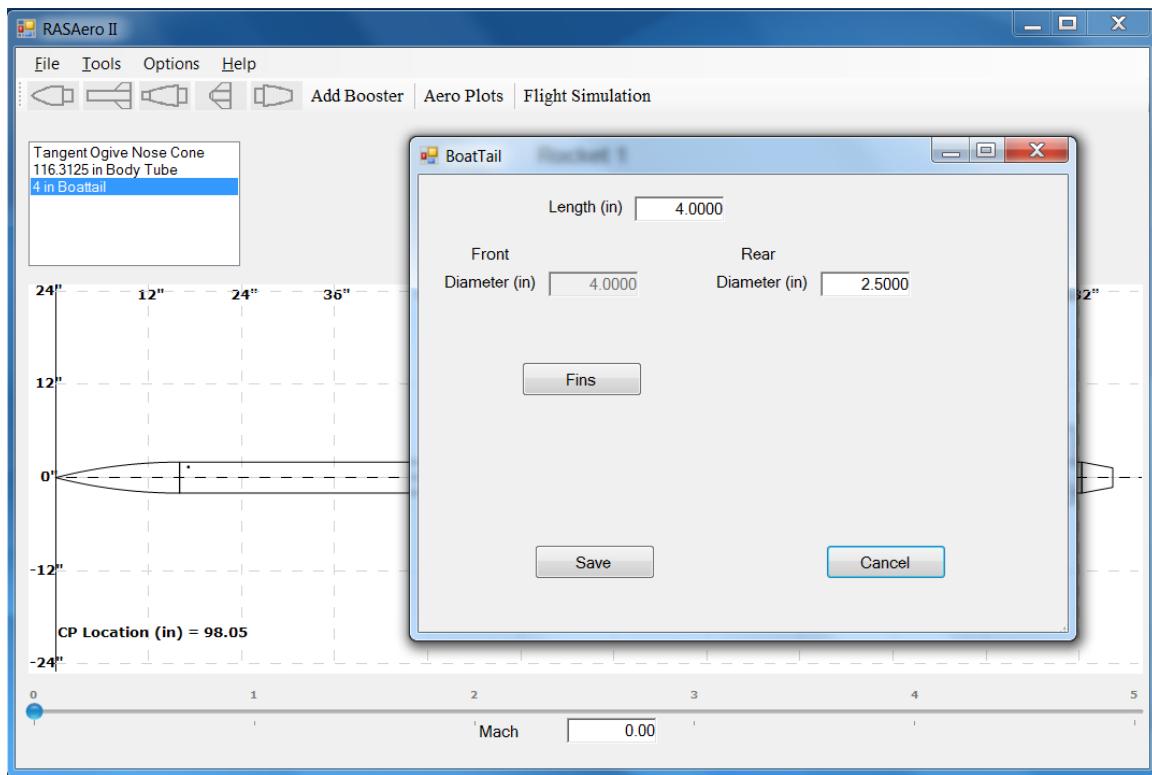


Figure 40 – Boattail Inputs.

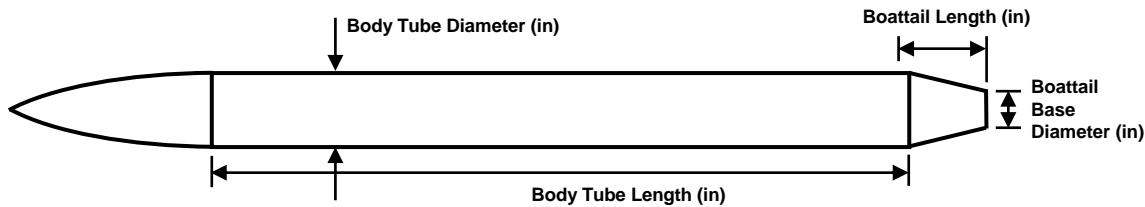


Figure 41 – Boattail geometry definitions.

The Boattail Inputs are saved by clicking on the <Save> button, or cancelled by clicking on the <Cancel> button.

## Editing, Inserting or Deleting Rocket Components

Rocket components which have already been entered can be edited by double clicking on the rocket component in the upper left-hand rocket component box, which will open the input for that rocket component, as shown in Figure 42. By clicking the right-hand mouse button on the rocket component in the upper left-hand rocket component box, the Edit, Insert, or Delete rocket component options will be displayed, as shown in Figure 43.

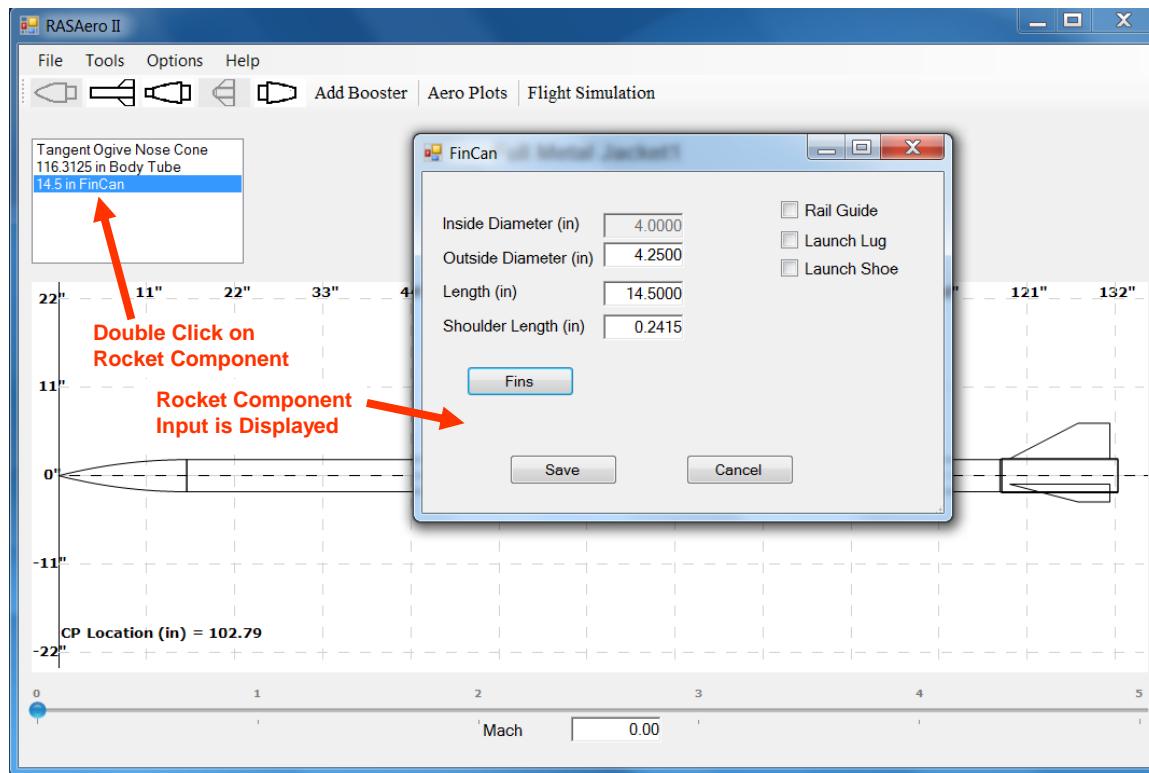


Figure 42 – Double clicking on rocket component to edit rocket component.

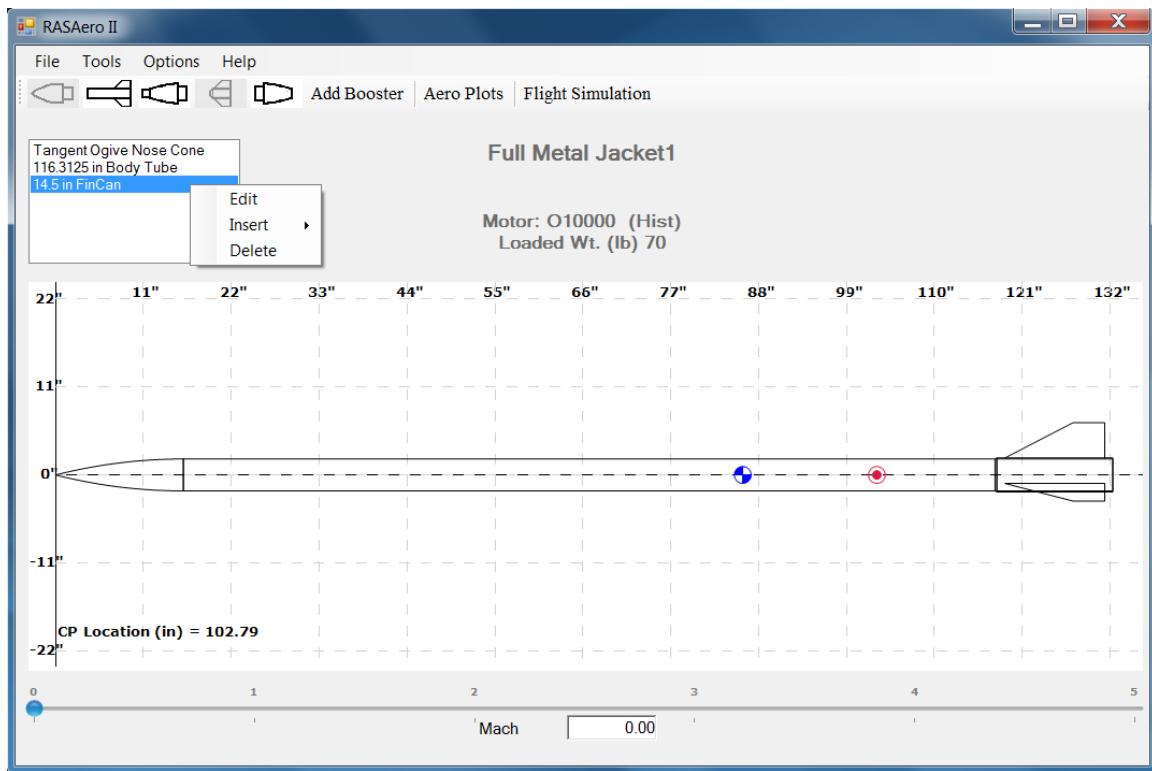


Figure 43 – Edit, Insert, or Delete options for rocket components.

If the Edit option is selected, the input for the rocket component will be opened, and the rocket component can be edited.

If the Delete option is selected, the user will be asked to confirm that the selected rocket component should be deleted as shown in Figure 44, and then the rocket component will be deleted.

If the Insert option is selected, the user then selects which rocket component type to insert, as shown in Figure 45. The component will be inserted ahead of the original component which the right-hand mouse button was clicked on, which is highlighted, as shown in Figure 45.

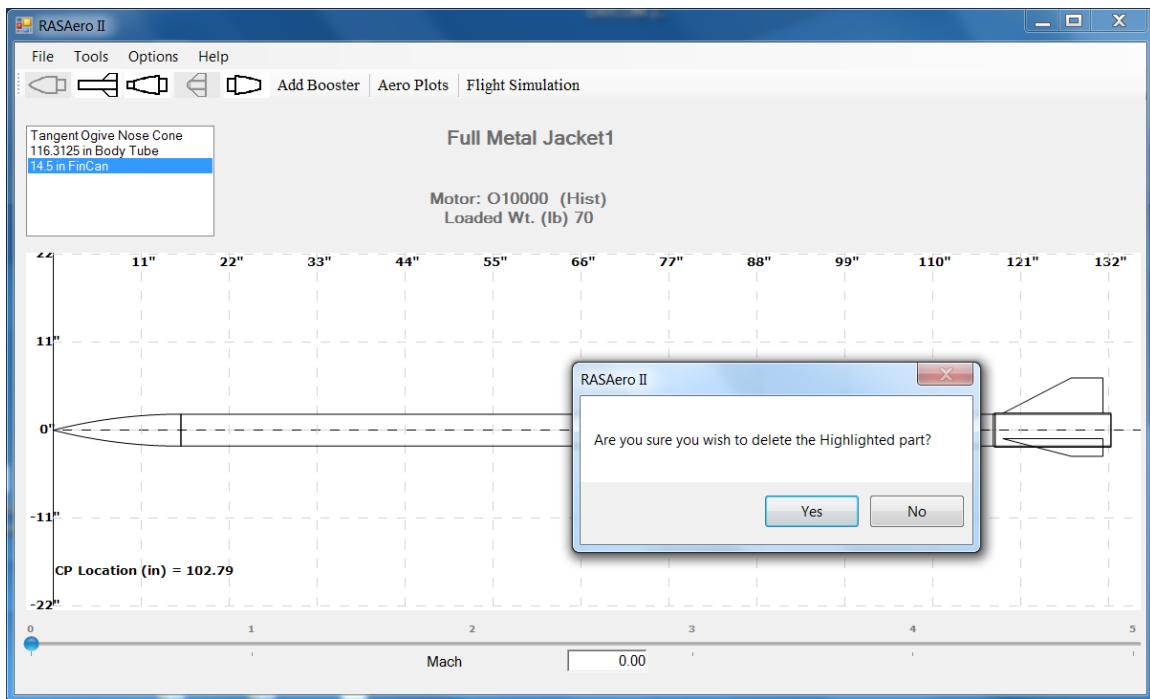


Figure 44 – Delete option; confirming that the selected rocket component should be deleted.

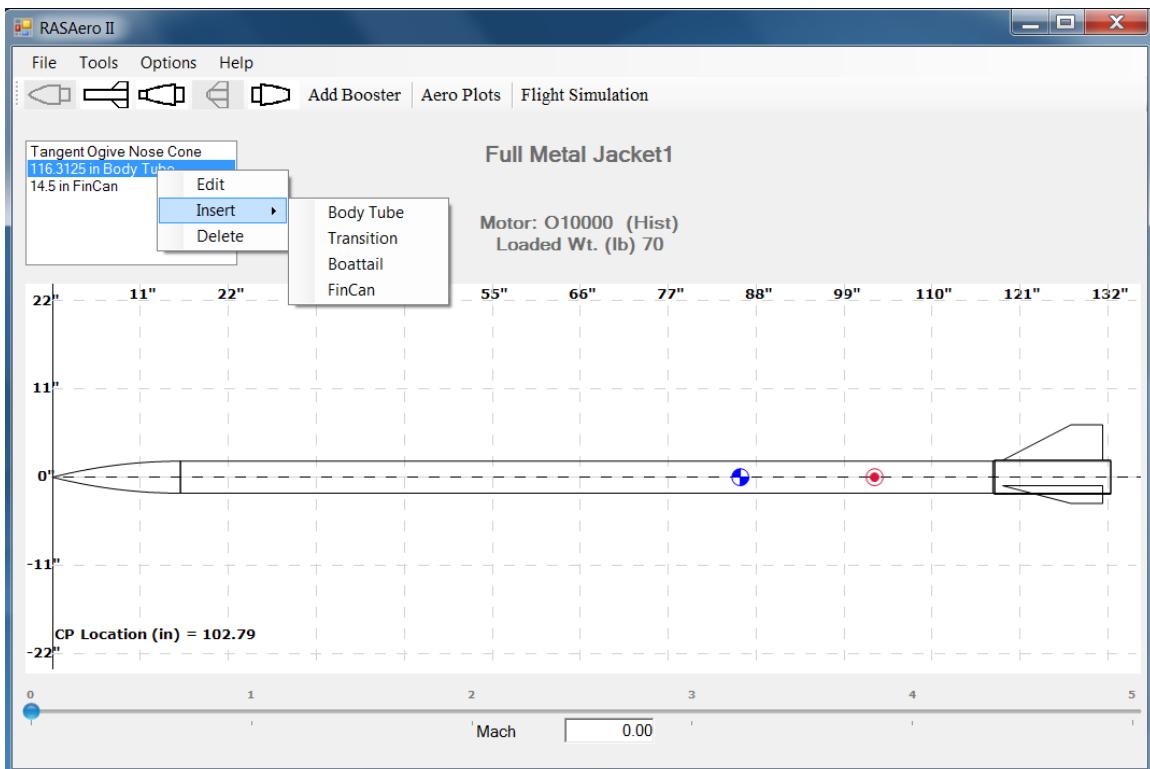


Figure 45 – Insert options for rocket components.

## Adding a Booster Stage with a Nested Upper Stage

On many two stage high power rockets, the upper stage mounts into the booster stage by having the upper stage motor case extend beyond the bottom of the upper stage, so that the motor case slides into the front of the booster stage. (Sometimes with a sleeve on the motor case.) Thus part of the upper stage is nested within the booster stage, with part of the upper stage (the portion of the motor case extending below the bottom of the upper stage) not exposed until the upper stage separates from the booster stage. This is known as a nested upper stage, which the RASAero II software can handle using the inputs described below.

To add a booster to a nested upper stage, first a very slight boattail is added to the upper stage. The length of this very slight boattail is the length of the upper stage which will nest within the front of the booster stage.

Figures 46-48 show the very slight boattail being added to the upper stage. Note that the boattail rear diameter is only 0.01 inches less than the boattail front diameter.

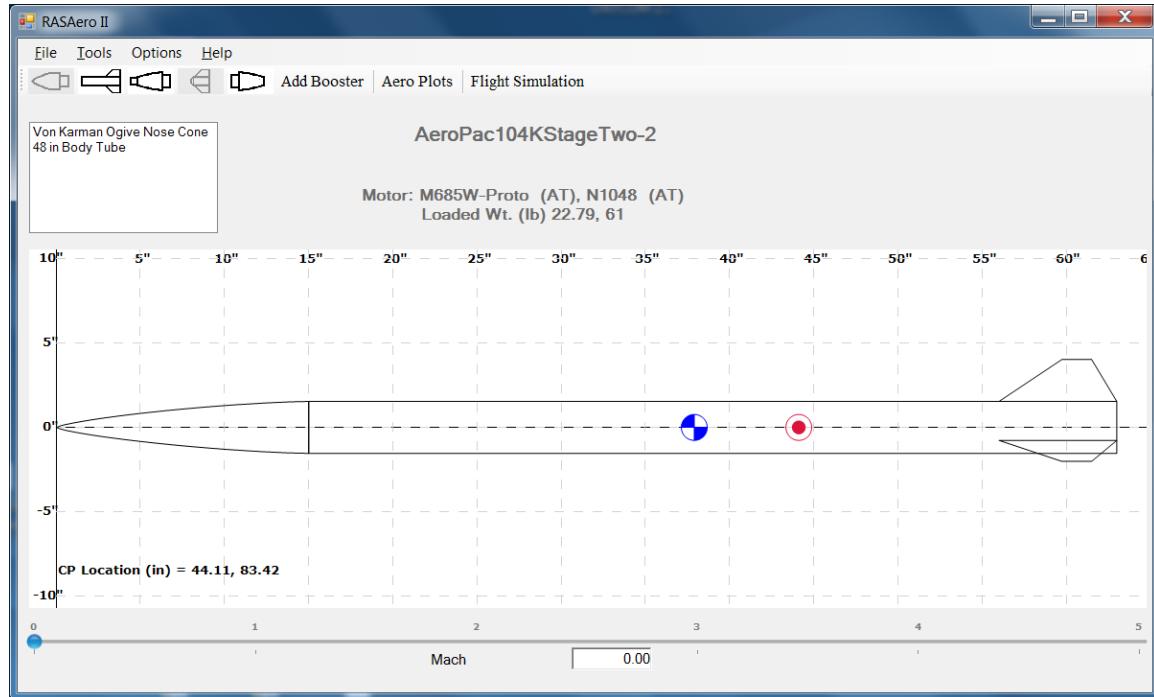


Figure 46 – Upper stage before addition of very slight boattail.

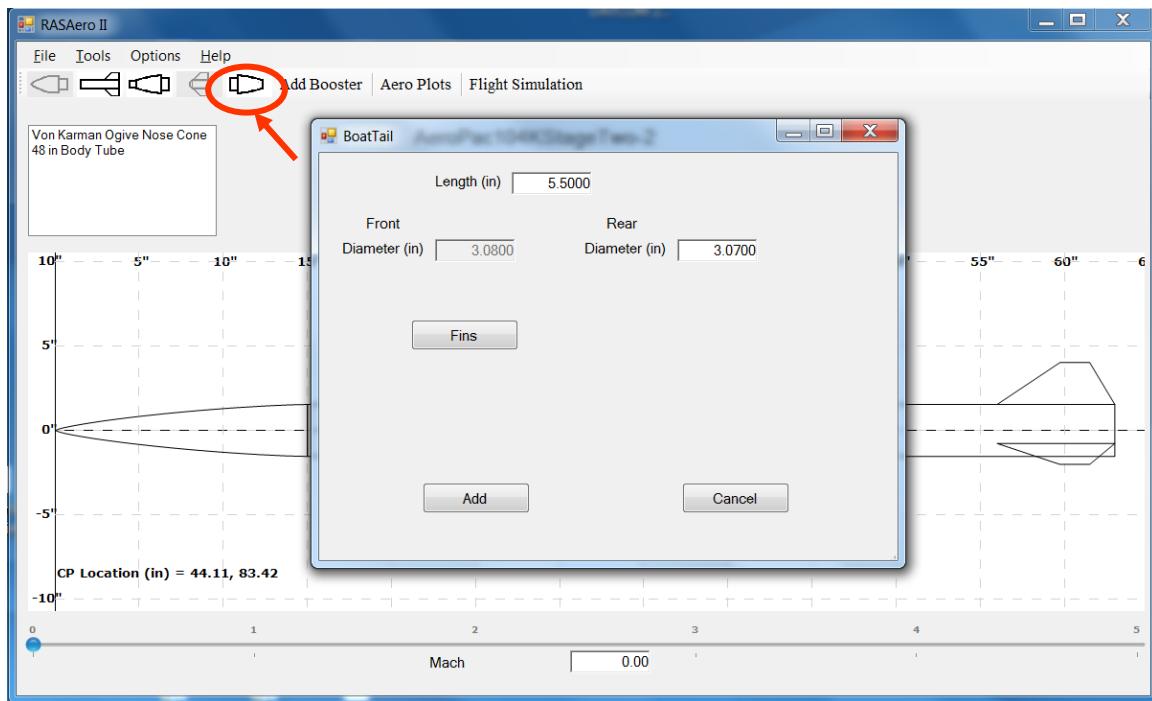


Figure 47 – Very slight boattail being added to upper stage.  
Note that rear diameter of boattail is only 0.01 inches less than front diameter of boattail.

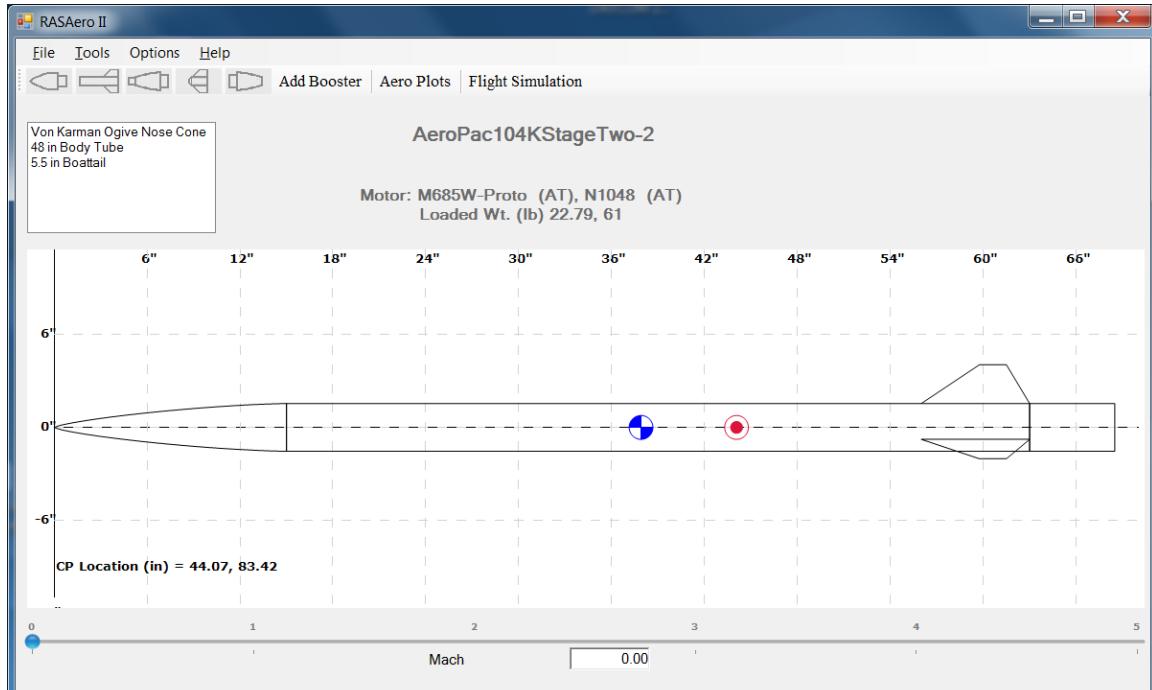


Figure 48 – Upper stage with very slight boattail added.  
Very slight boattail will be portion of upper stage that will nest within booster.

The aerodynamic prediction methods in RASAero II will treat this very slight boattail as a boattail, but the boattail is so slight (the rear diameter is only 0.01 inches less than front diameter) that from an aerodynamic prediction standpoint the very slight boattail will be equivalent to adding an extra body tube section.

The booster stage is then added to the rocket by clicking on the Add Booster button as shown in Figure 49, with the Booster Inputs shown in Figure 50.

In the RASAero II nomenclature for a two stage rocket, the upper stage is called the sustainer stage, and the booster stage is called the booster stage. As will be presented in the Aero Plots and Flight Simulation sections, the aerodynamic data and portions of the flight simulation for each stage will be labeled as Sustainer and Booster.

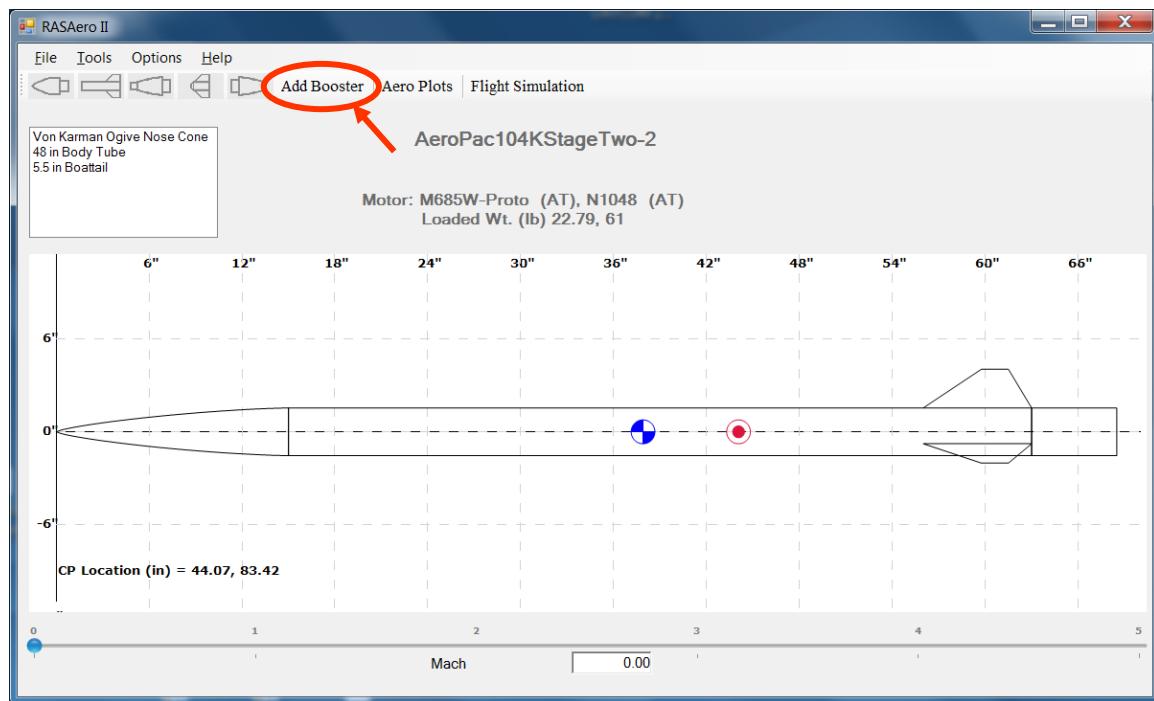


Figure 49 – Add Booster button for adding a booster stage.

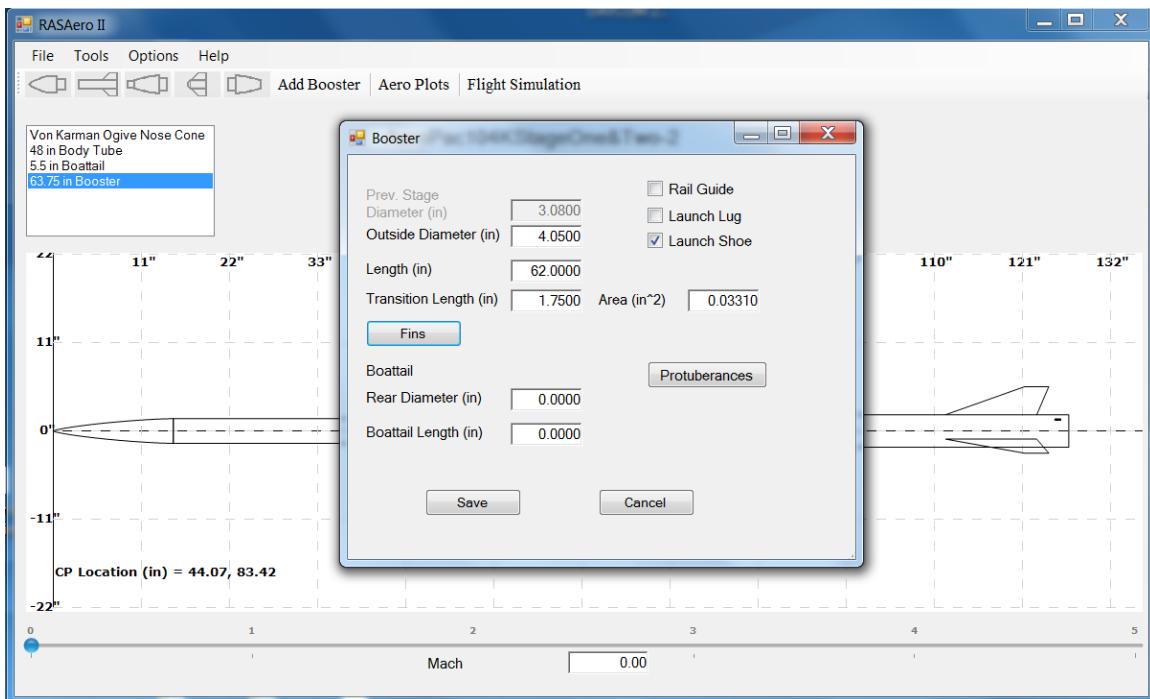


Figure 50 – Booster Inputs.

Again note that when a booster stage has been added to a rocket, the original rocket becomes the sustainer stage.

For the Booster Inputs, all of the inputs used for a regular single stage rocket are repeated. Note in Figure 50 that the diameter of the previous stage is grayed-out (the front diameter of the boattail), as the diameter is already set by the previous stage which has already been entered. The diameter of the booster stage is then entered, and if the booster stage diameter is different than the previous stage diameter the transition length is entered for the conic transition between the two stages. If the two stages have the same diameter, the transition length input disappears as it is not needed (no transition is required).

Figure 51 shows the two stage rocket (sustainer and booster), with the nested sustainer stage, with the Add Booster Inputs completed.

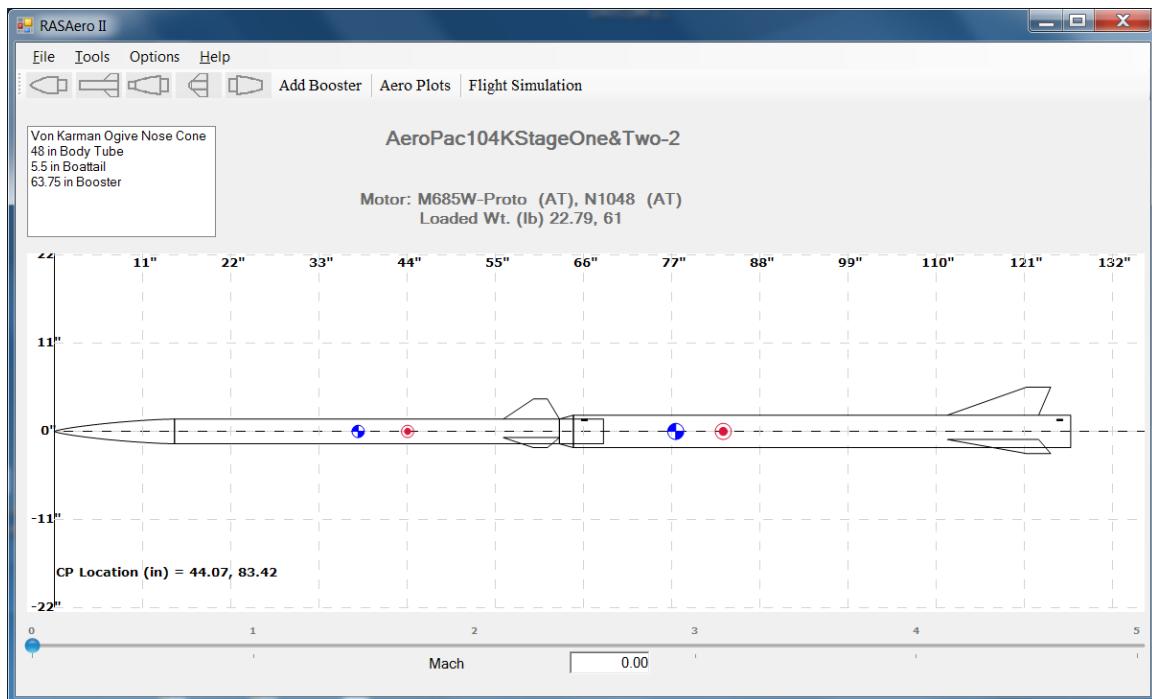


Figure 51 – Two stage (sustainer and booster) rocket, with nested sustainer stage, with Add Booster Inputs completed.

Note in Figure 51 that the booster starts at the top of the very slight boattail, and the very slight boattail is the portion of the sustainer stage which is nested in the booster.

A booster stage is treated as a rocket component, and can be edited by double clicking on the booster component in the upper left-hand rocket component box, which will open the Booster Stage Inputs. Or, by clicking the right-hand mouse button on the booster component in the upper left-hand rocket component box, the booster stage can be edited. By clicking the right-hand mouse button on the booster component in the upper left-hand rocket component box, the boosted stage can be deleted.

A good technique for checking that the nested sustainer (upper) stage has been implemented correctly is, without saving the file, to remove (delete) the booster and see from the Rocket Drawing what the sustainer (upper) stage looks like, to make sure it has the correct configuration. This is shown in Figures 52 and 53. Again, after removing (deleting) the booster, do not save the file. (Or perform this test on a copy of the file.)

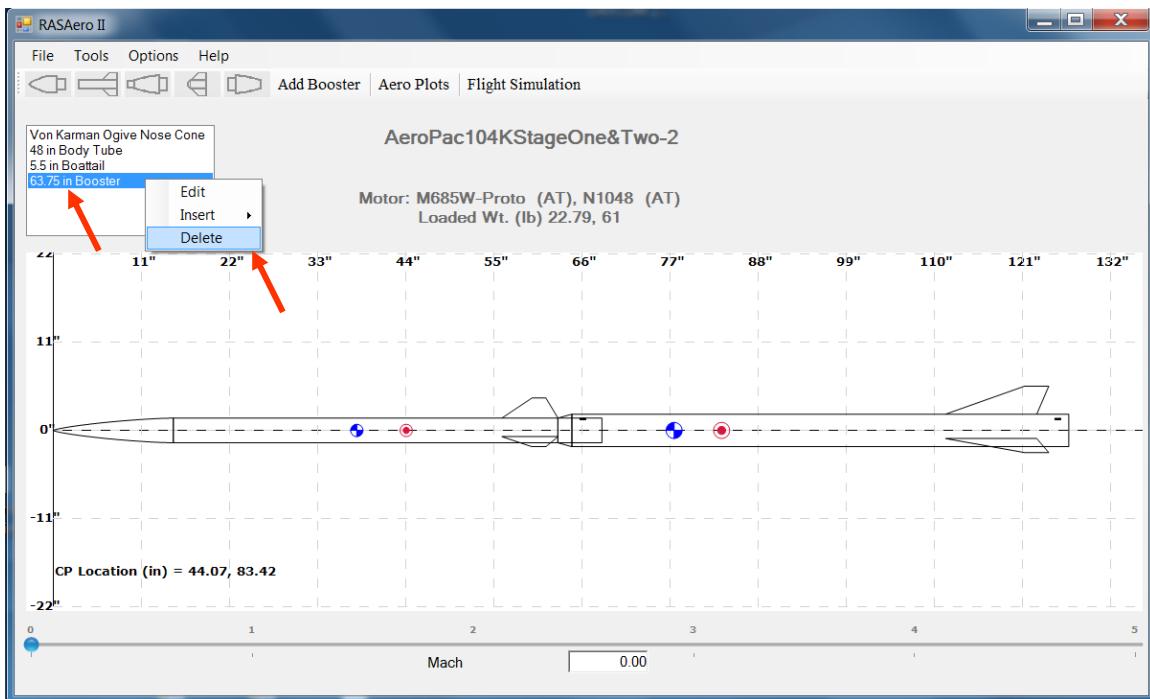


Figure 52 – Check that the nested sustainer configuration is correct by deleting the booster stage.  
(Do not save the file after performing this check, or perform this check on a copy of the file.)

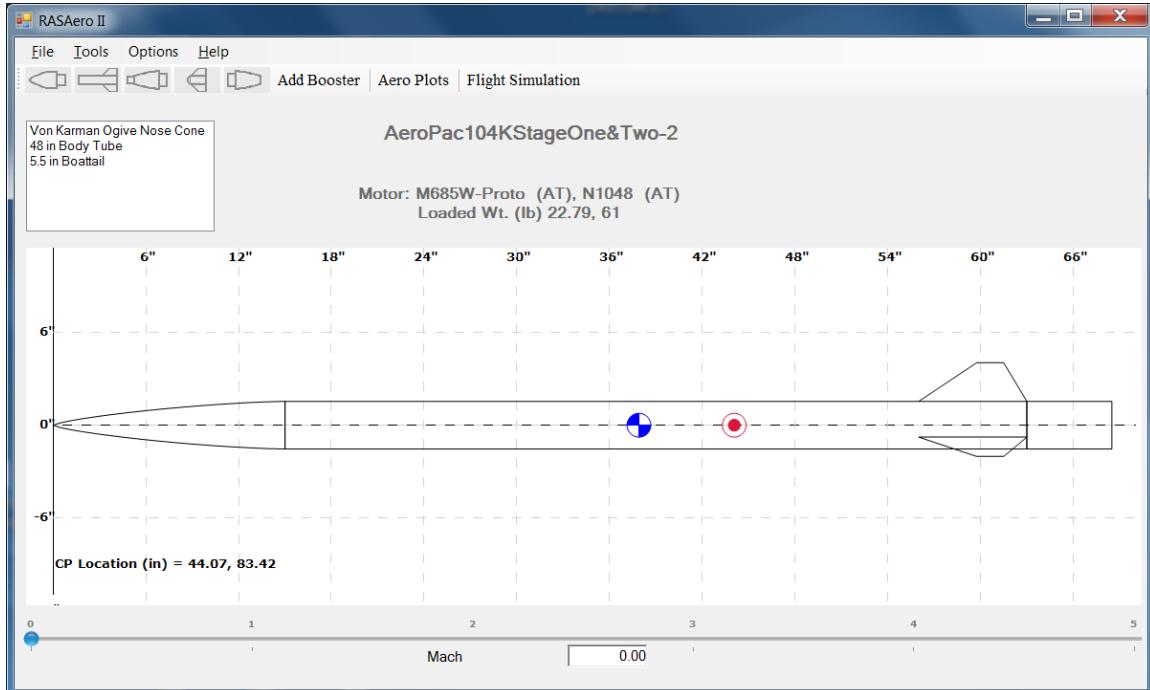


Figure 53 – Check complete; booster deleted, sustainer remains, sustainer configuration is correct.

## Adding a Booster Stage that Does Not Have a Nested Upper Stage

When a booster stage is added that does not have a nested upper stage, the booster stage is added to the rocket by clicking on the Add Booster button as shown in Figure 54.

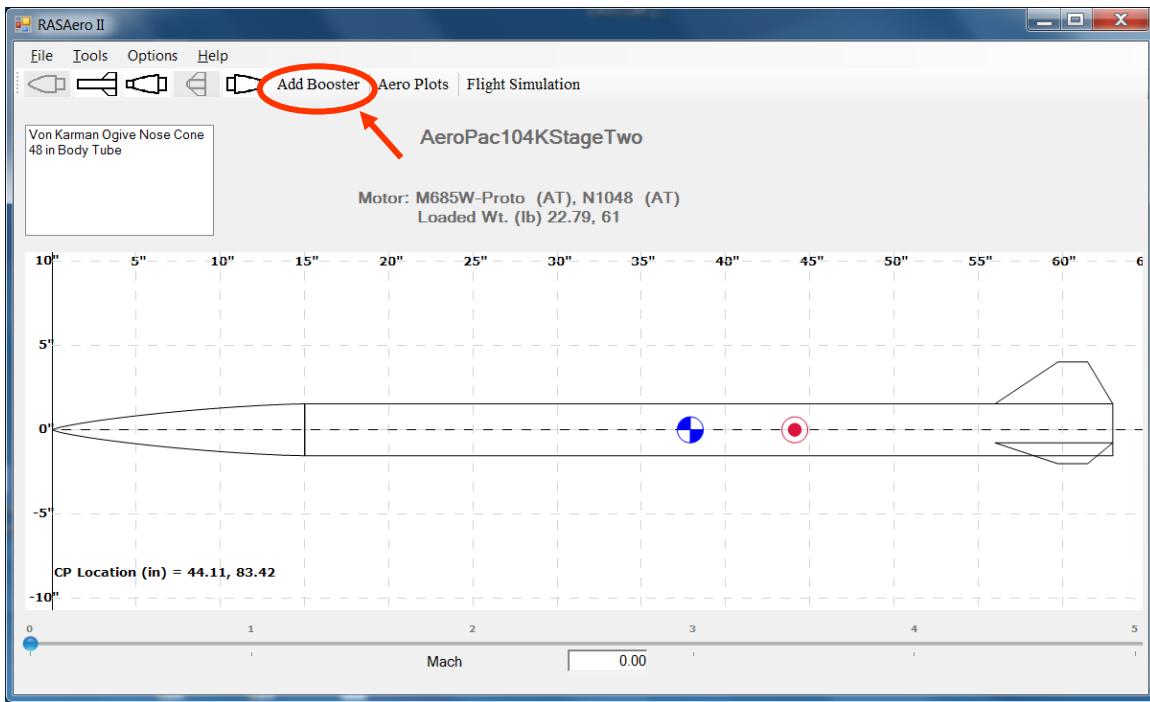


Figure 54 – Using Add Booster button to add a booster stage.

Typical Booster Inputs are shown in Figure 55.

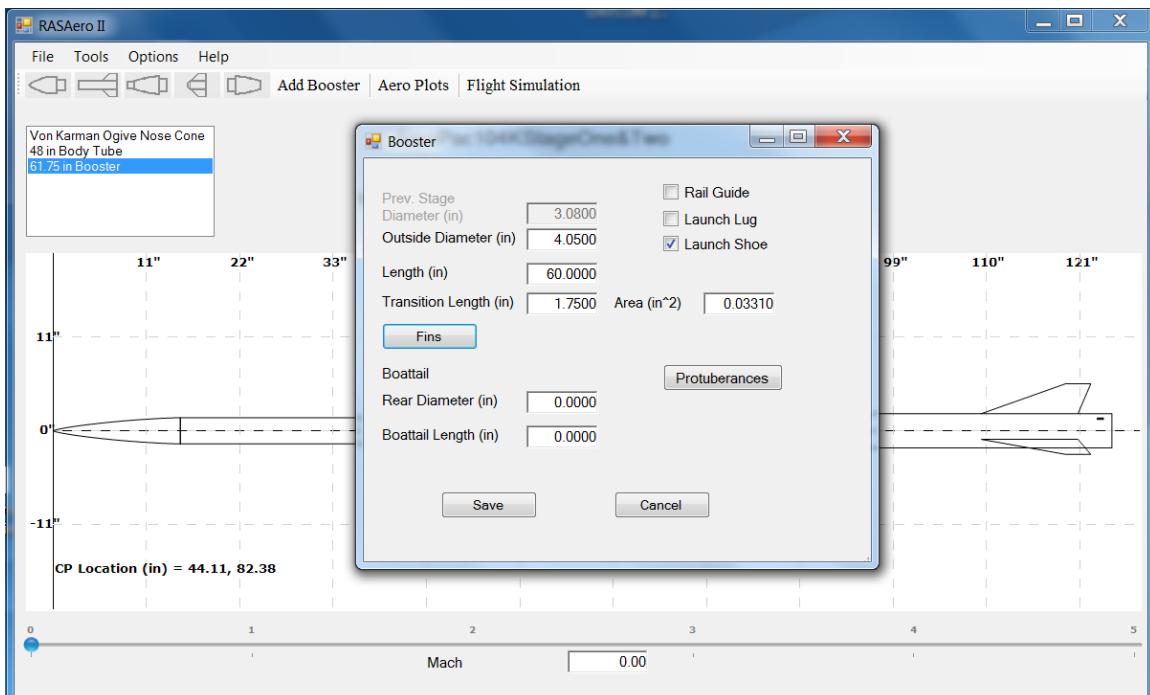


Figure 55 – Typical Booster Inputs.

In addition to high power rockets which may not have a nested upper stage, adding a booster stage that does not have a nested upper stage is used when running launch vehicles on RASAero II to generate aerodynamic data for ascent to orbit trajectory simulations, which will be described in the later Running a Launch Vehicle on RASAero II to Generate Aerodynamic Data for Ascent to Orbit Trajectory Simulations section. The separation plane between stages on a launch vehicle are typically modeled as a non-nested upper stage with a booster added.

Again note that when a booster stage has been added, the original rocket becomes the sustainer stage.

For the Booster Inputs, all of the inputs used for a regular single stage rocket are repeated. Note in Figure 55 that the diameter of the previous stage is grayed-out (the diameter is already set by the previous stage which has already been entered), the diameter of the booster stage is entered, and if the booster stage diameter is different than the previous stage diameter the transition length is entered for the conic transition between the two stages. If the two stages have the same diameter, the transition length input disappears as it is not needed (no transition is required).

Figure 56 shows a two stage rocket (sustainer and booster) with a non-nested upper stage with the Add Booster Inputs completed.

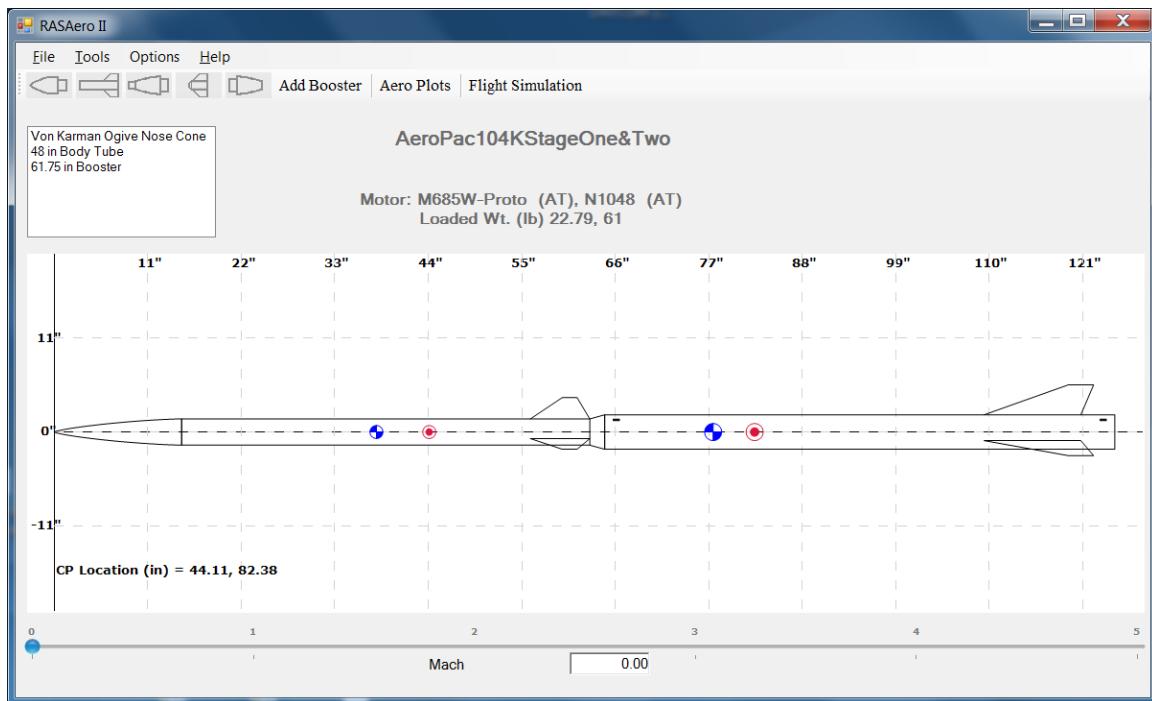


Figure 56 – Two stage (sustainer and booster) rocket with a non-nested upper stage with Add Booster Inputs completed.

A booster stage is treated as a rocket component, and can be edited by double clicking on the booster component in the upper left-hand rocket component box, which will open the Booster Stage Inputs. Or, by clicking the right-hand mouse button on the booster component in the upper left-hand rocket component box, the booster stage can be edited. By clicking the right-hand mouse button on the booster component in the upper left-hand rocket component box, the boosted stage can be deleted.

As before a good technique for checking that the sustainer (upper) stage has been implemented correctly is, without saving the file, to remove (delete) the booster and see from the Rocket Drawing what the sustainer (upper) stage looks like, to make sure it has the correct configuration. This is shown in Figures 57 and 58. Again, after removing (deleting) the booster, do not save the file. (Or perform this test on a copy of the file.)

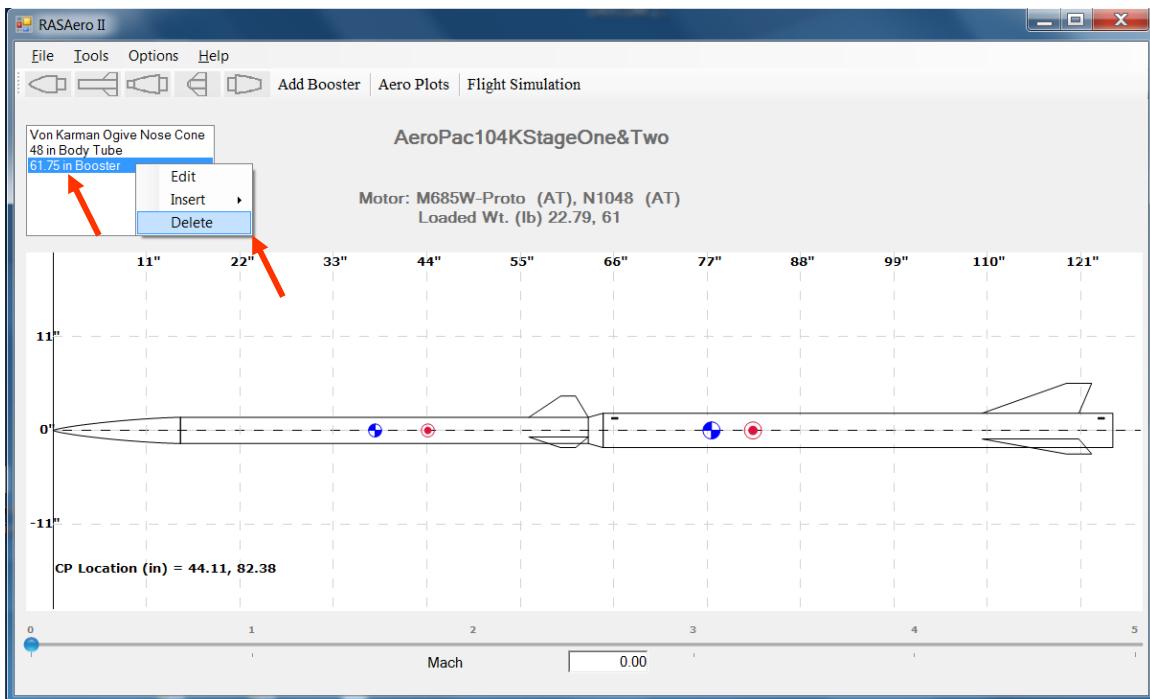


Figure 57 – Check that the sustainer configuration is correct by deleting the booster stage.  
(Do not save the file after performing this check, or perform this check on a copy of the file.)

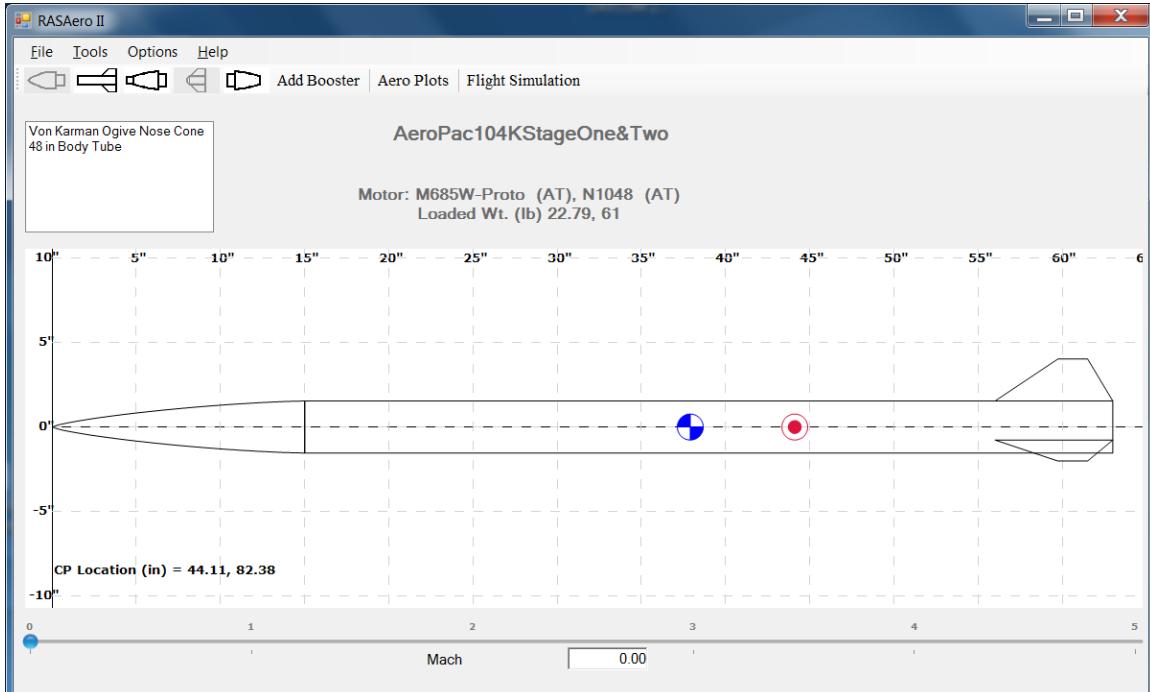


Figure 58 – Check complete; booster deleted, sustainer remains, sustainer configuration is correct.

RASAero II can handle up to three stages (sustainer – booster – booster). A completed three stage rocket is shown in Figure 59.

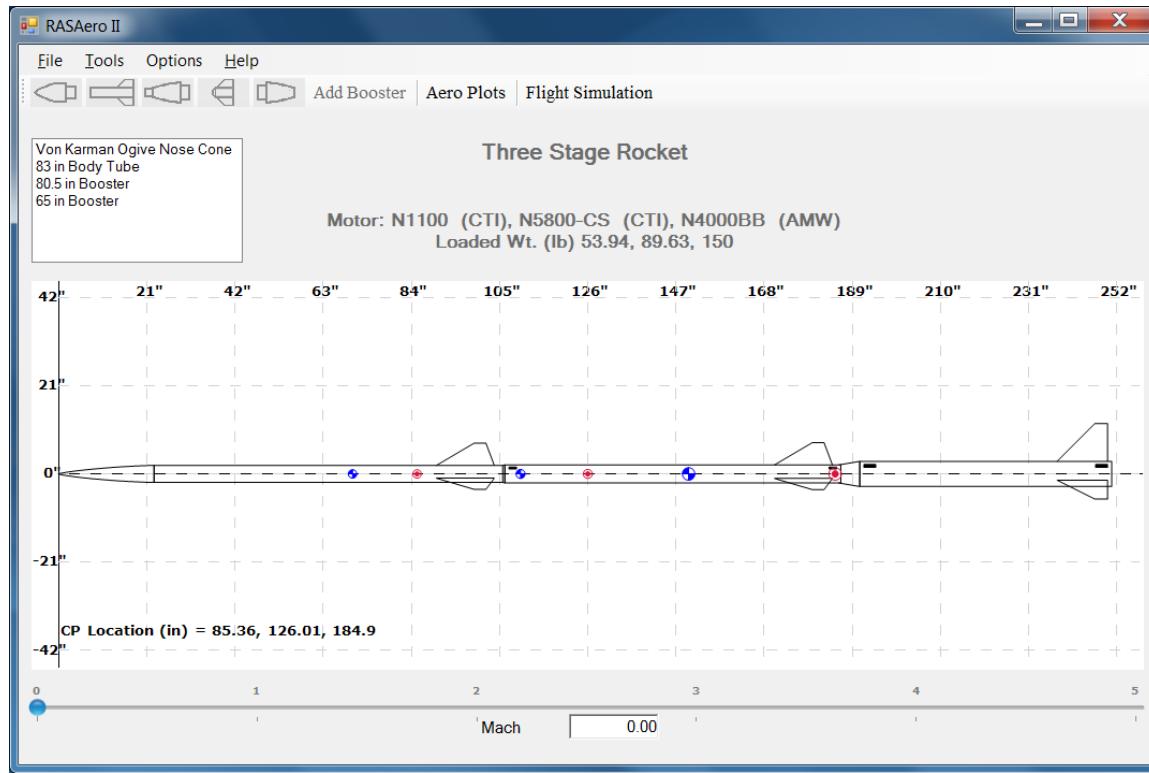


Figure 59 – Three stage rocket (sustainer – booster - booster) entered into RASAero II.

RASAero II is a combined aerodynamic analysis and flight simulation software package for model rockets and high power rockets, amateur rockets, and sounding rockets. RASAero II can also be used for predicting aerodynamic coefficients for use in other flight simulation programs for orbital rockets.

### **Running an Orbital Launch Vehicle on RASAero II to Generate Aerodynamic Data for Ascent to Orbit Trajectory Simulations**

While RASAero II currently does not run ascent to orbit trajectories, RASAero II can be used to generate aerodynamic data for orbital launch vehicle configurations. The RASAero II predicted aerodynamic coefficients can be used as inputs for other flight simulation programs for orbital launch vehicles for ascent to orbit trajectories.

RASAero II can be used to run trajectories for the lower stages of orbital launch vehicles to compare the actual delta-v from RASAero II to the ideal delta-v from the Tsiolkovsky ideal rocket equation, to determine the delta-v losses (gravity and drag losses) for the lower stages. Once these delta-v losses have been determined, they can be used in hand calculations or spreadsheets to subtract the delta-v losses from the ideal delta-v for each stage, to come up with

an estimate for the total delta-v for the lower stages. The ideal delta-v can then be calculated for the upper stages (which can have small or negligible delta-v losses compared to the ideal delta-v), to come up with an estimate for the payload to orbit of the launch vehicle.

The Minotaur I orbital launch vehicle, and the Minotaur I orbital launch vehicle modeled in RASAero II to obtain aerodynamic prediction data, are presented in Figure 60.

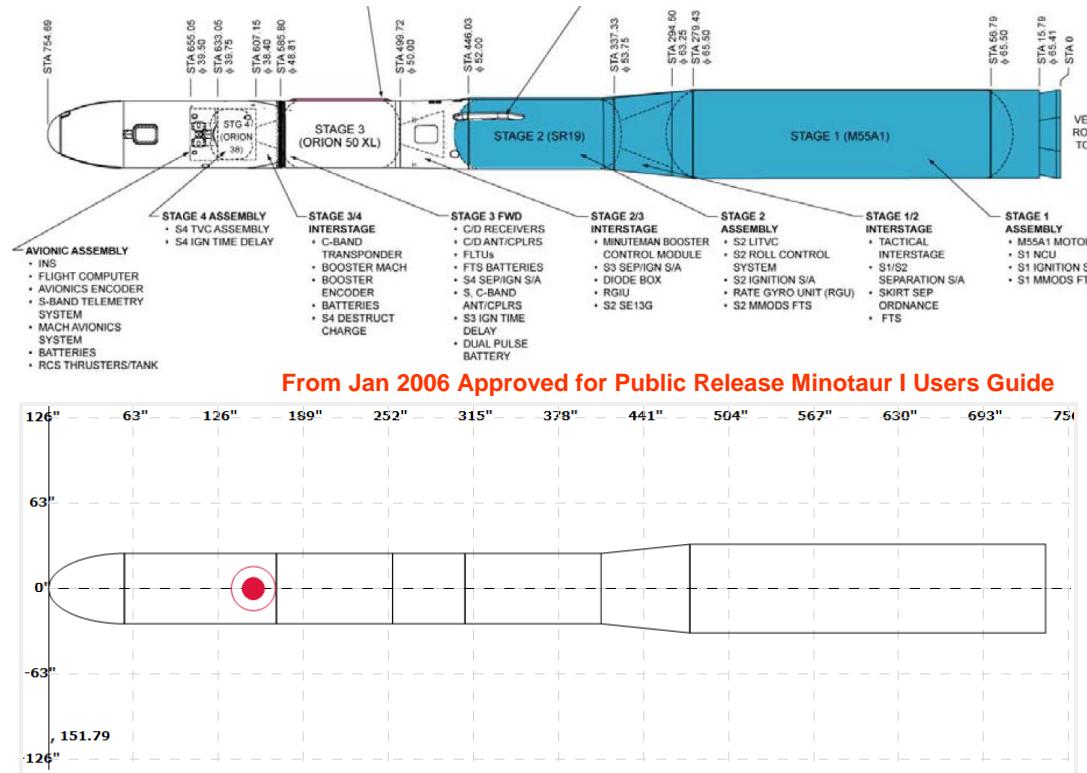


Figure 60 – Minotaur I orbital launch vehicle, and Minotaur I orbital launch vehicle modeled in RASAero II to obtain aerodynamic prediction data.

As a note when an orbital launch vehicle has multiple nozzles (multiple liquid rocket engine nozzles, or as on the Minotaur I a single solid rocket motor on Stage-1 with multiple nozzles), the nozzle exit areas of the multiple nozzles are added up to obtain the total nozzle exit area, and then this total nozzle exit area is converted to a single nozzle with the same nozzle exit area, and then the nozzle exit diameter for this single nozzle is entered into RASAero II for the stage for the power-on drag coefficient calculations.

Note that aerodynamic data can be generated for an orbital launch vehicle in RASAero II without entering any Center of Gravity (CG) data. After the rocket geometry data is entered, on the Rocket Drawing the Center of Pressure (CP) for each stage will be displayed, but no CG will be displayed, as shown in Figure 60.

The first stages of almost all orbital launch vehicles have no fins, but for a booster stage RASAero II requires fins to be entered. In general on RASAero II for each body tube fins do not

need to be added, and the sustainer stage can have no fins if a very forward Center of Gravity (CG) is entered so that the rocket will be aerodynamically stable and thus will run on the RASAero II Flight Simulation. But RASAero II requires fins to be added to booster stages. The solution is to enter very small fins to the booster, shown for the Minotaur launch vehicle in Figure 61. From an aerodynamic prediction standpoint these very small fins have a negligible effect on the predicted aerodynamics for the launch vehicle. To run the launch vehicle on the RASAero II Flight Simulation the launch vehicle must be aerodynamically stable, so with the very small fins on the booster a very forward CG for the booster must be entered.

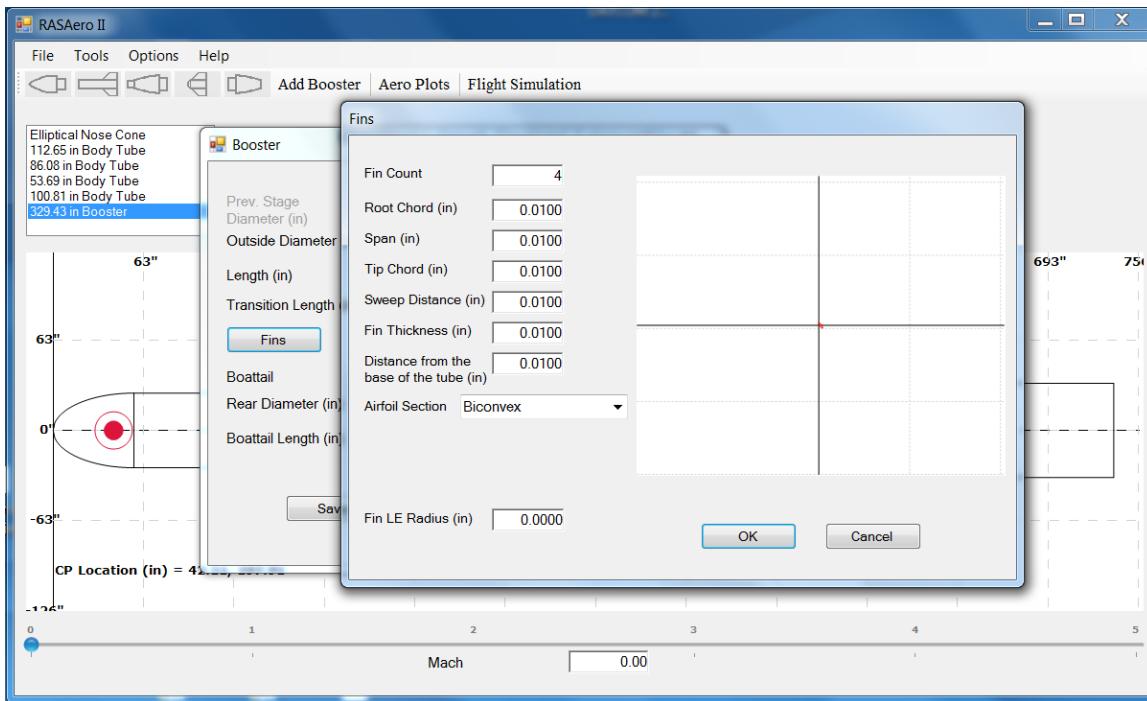


Figure 61 – Minotaur I orbital launch vehicle; very small fins added to booster (Stage-1), as RASAero II requires fins on the booster.

For a trajectory to be run for the launch vehicle on the RASAero II Flight Simulation CG data must be entered for each stage, and each stage must have the CG ahead of the CP. As the actual launch vehicle will be actively stabilized with a guidance system, it will not be aerodynamically stable. To run the launch vehicle on the RASAero II Flight Simulation, a very forward CG must be entered for each stage to ensure that each stage of the launch vehicle will be aerodynamically stable.

It is also important to have No Wind in the Launch Conditions Inputs when running an orbital launch vehicle trajectory on RASAero II. This will have the orbital launch vehicle fly the trajectory at zero degrees angle of attack, and the RASAero II dynamics models will be turned off, as they are not applicable as the actual launch vehicle will be actively stabilized with a guidance system.

## Additional RASAero II Inputs

### Equivalent Sand Roughness (Surface Finish) Input

The surface roughness of the rocket can be specified using the Equivalent Sand Roughness (Surface Finish) Input. The RASAero II Equivalent Sand Roughness (Surface Finish) Input, which is located under the Options Tab, is shown in Figure 62.

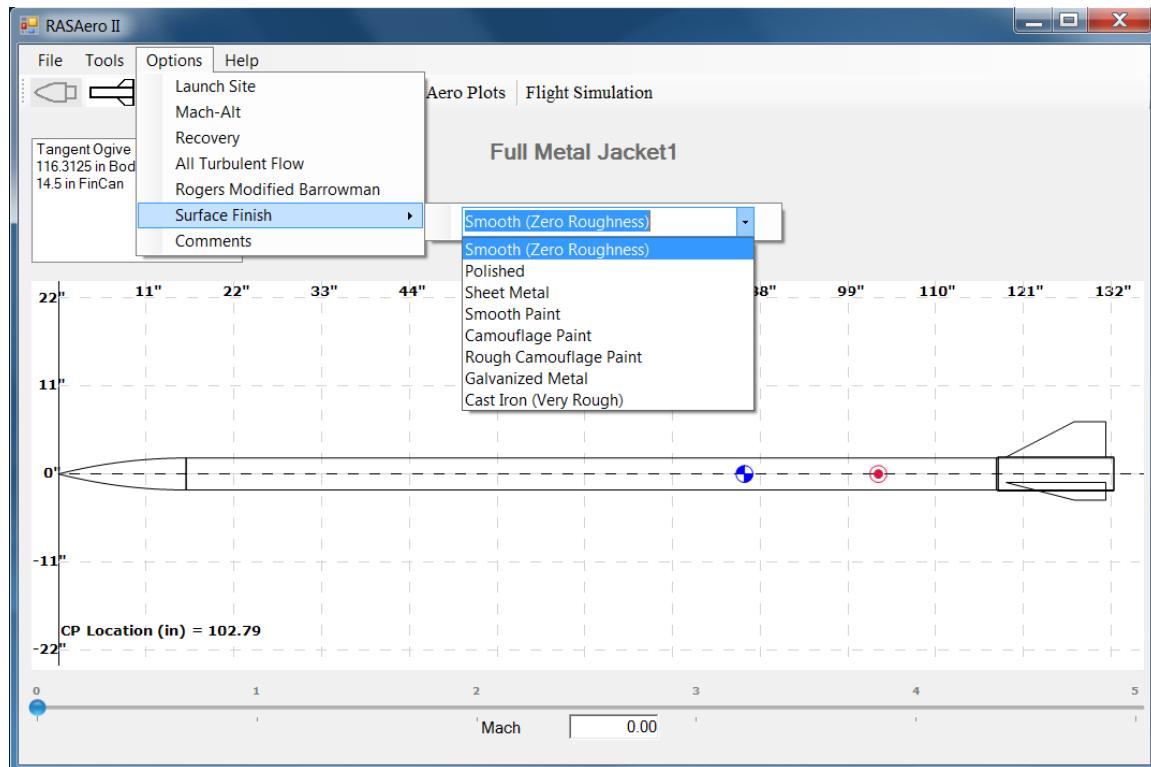


Figure 62 – Equivalent Sand Roughness (Surface Finish) Input.

The default input is Smooth (aerodynamically smooth – zero roughness). Varying levels of surface roughness can be entered by using the pull-down menu. The equivalent sand roughness for each level of smoothness which can be entered is presented in Table 1.

Equivalent Sand Roughness Surface Finish Selection	Equivalent Sand Roughness (in)
Smooth (Zero Roughness)	0.0
Polished	0.00005
Sheet Metal	0.00016
Smooth Paint	0.00025
Camouflage Paint	0.0004
Rough Camouflage Paint	0.0012
Galvanized Metal	0.006
Cast Iron (Very Rough)	0.01

Table 1 – Equivalent sand roughness for a given surface finish selection.

## Rogers Modified Barrowman Method Option

Under the Options Tab on the RASAero II Main Screen the option is available to select the Rogers Modified Barrowman Method for subsonic center of pressure.

The default for the subsonic center of pressure calculations is the Barrowman Method as documented in Centuri Report TIR-33. If the Rogers Modified Barrowman Method is not checked, then the Barrowman Method will be used for the subsonic center of pressure calculations.

Figure 63 shows the Rogers Modified Barrowman Method Not Checked (Not Selected), thus the default Barrowman Method will be used for the subsonic center of pressure.

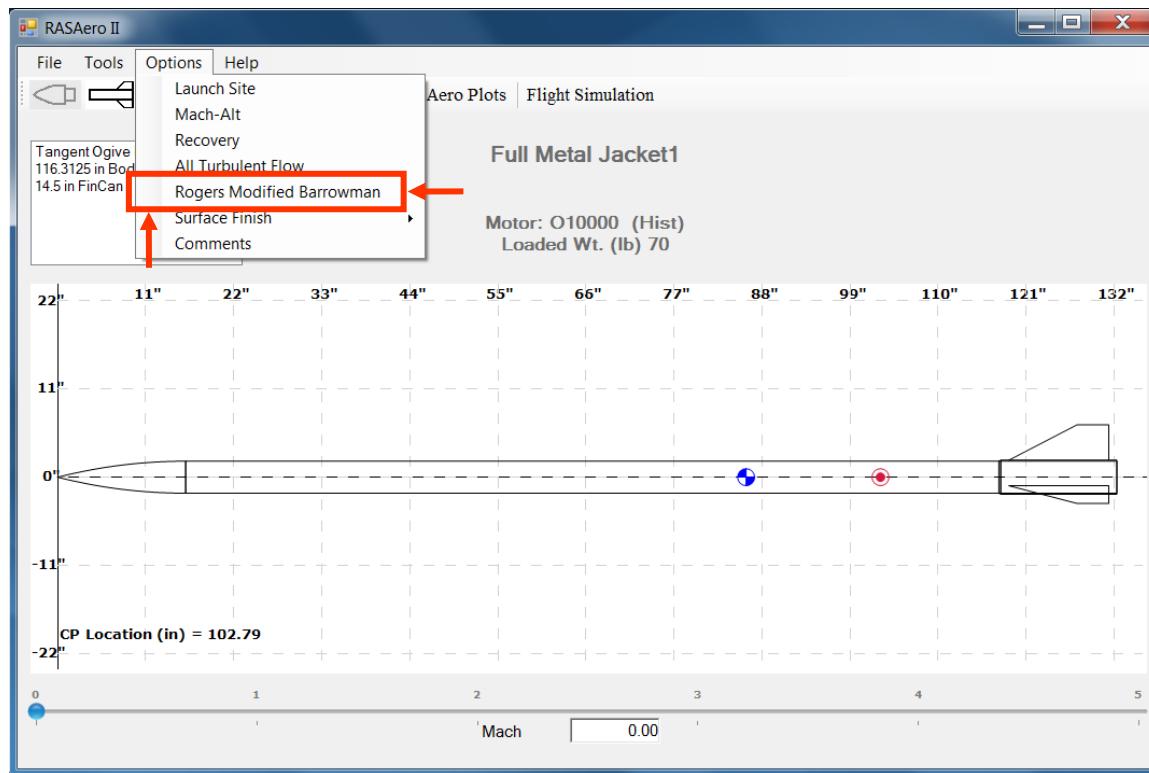


Figure 63 – Rogers Modified Barrowman Method Not Checked (Not Selected), default Barrowman Method will be used for subsonic center of pressure.

Figure 64 shows the Rogers Modified Barrowman Method Checked (Selected), thus the Rogers Modified Barrowman Method will be used for the subsonic center of pressure.

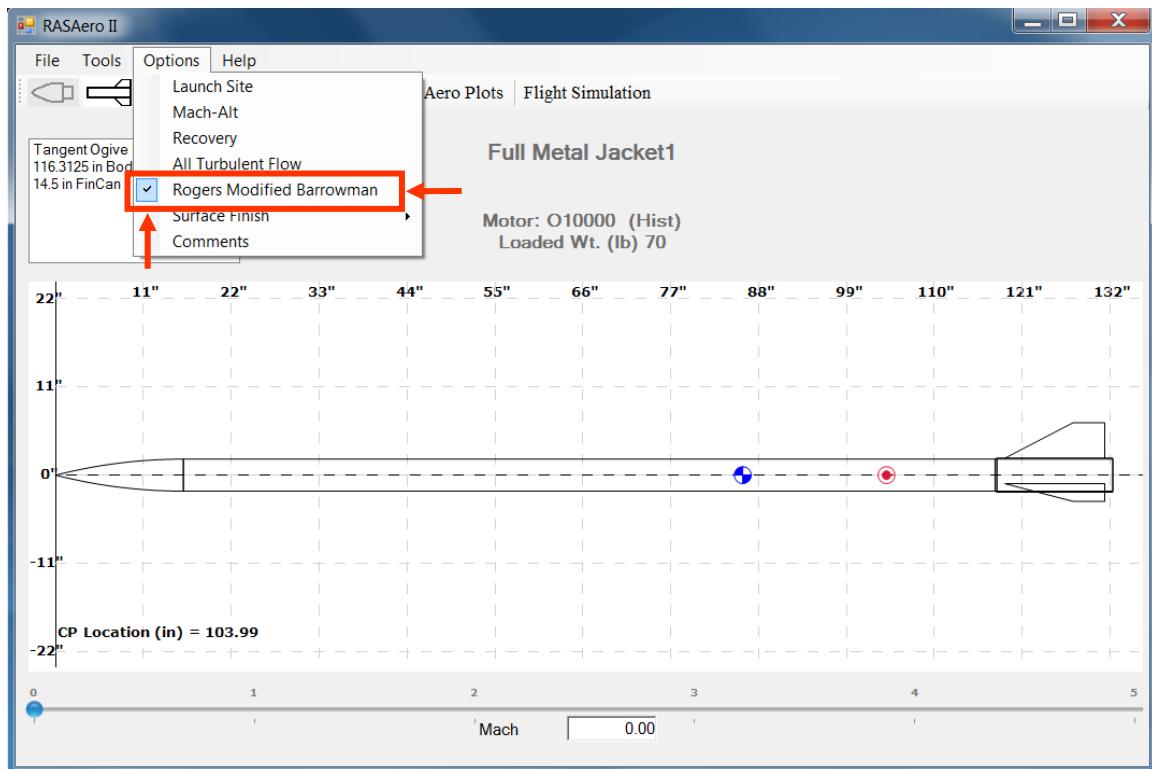


Figure 64 – Rogers Modified Barrowman Method Checked (Selected), Rogers Modified Barrowman Method will be used for subsonic center of pressure.

The Rogers Modified Barrowman Method includes a more accurate body normal force slope with angle of attack ( $C_{N\alpha}$ ) at low angles of attack by including the influence of the body tube cylinder (left out of the Barrowman Method), includes the body in the presence of the fins interference factor ( $K_{bf}$ ) (left out of the Barrowman Method), and includes body viscous crossflow using the Jorgensen Method for the forward movement of the rocket center of pressure with angle of attack (not included in the Barrowman Method).

### All Turbulent Flow Option

Under the Options Tab on the RASAero II Main Screen the option is available to select All Turbulent Flow.

In the RASAero II aerodynamic drag predictions the default for the skin friction calculations is laminar flow, transition to turbulent flow, and turbulent flow, with the flow transition Reynolds number used being the flat plate value of 500,000. There is some in-flight measured drag coefficient flight data for high power rockets, especially near and above Mach 3 where there is thermal damage to the rocket, or when there is a poorly faired-in transition between rocket stages, which indicate that there is an immediate transition to fully turbulent flow. An immediate transition to fully turbulent flow can be included in the aerodynamic predictions by selecting the All Turbulent Flow Option.

Figure 65 shows All Turbulent Flow Not Checked (Not Selected), thus the default laminar flow, transition to turbulent flow, and turbulent flow will be used for the skin friction calculations in the aerodynamic drag predictions.

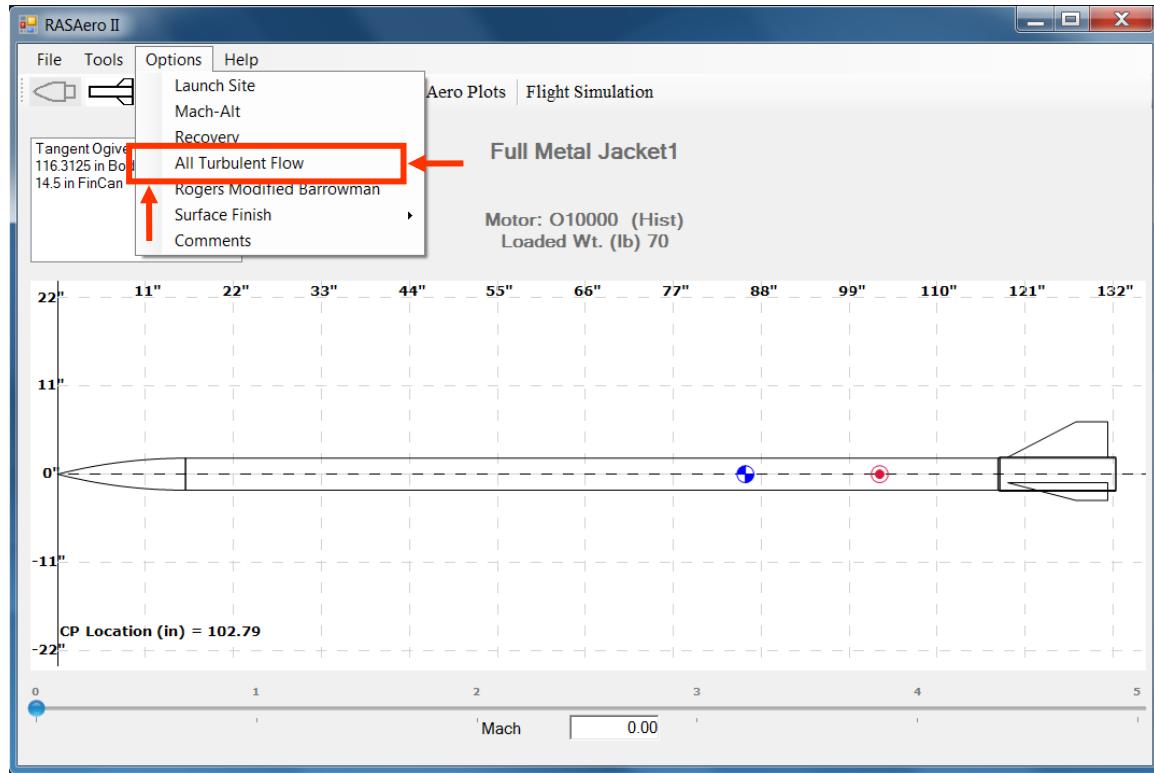


Figure 65 – All Turbulent Flow Not Checked (Not Selected), default laminar, transition to turbulent, and turbulent will be used for aerodynamic drag predictions.

Figure 66 shows All Turbulent Flow Checked (Selected), thus an immediate transition to fully turbulent flow (all turbulent flow) will be used for the skin friction calculations in the aerodynamic drag predictions.

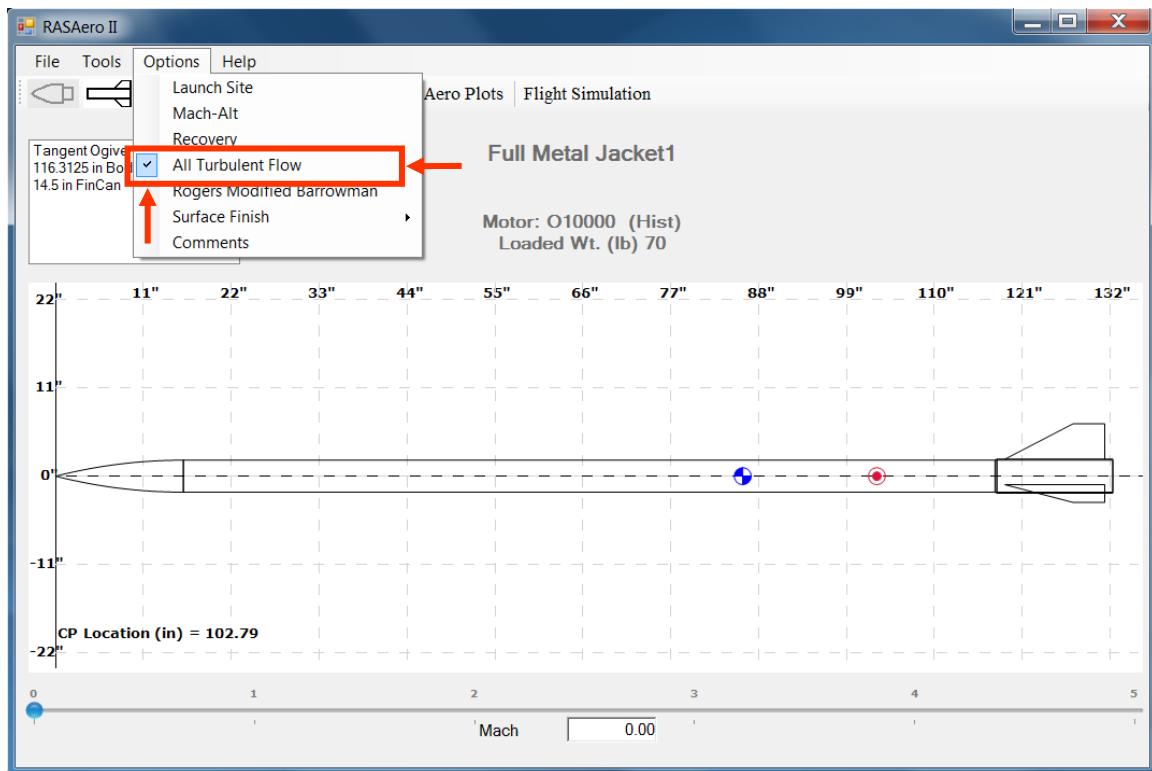


Figure 66 – All Turbulent Flow Checked (Selected), immediate transition to fully turbulent flow (all turbulent flow) will be used for aerodynamic drag predictions.

### Loading a Rocket File from the Previous RASAero Software

As noted in an earlier section, .ALX1 format rocket files from the previous RASAero software can be loaded into RASAero II. After clicking on <File> and then <Open>, both .ALX1 format (RASAero format) and .CDX1 format (RASAero II format) files will be displayed, and can be selected to be opened in RASAero II. When the file is saved in RASAero II, it will be saved in the RASAero II .CDX1 format.

### Importing a RockSim File into RASAero II

RASAero II has the feature of being able to import RockSim files, which can then be run on RASAero II. Only the external geometry of the rocket is imported from RockSim into RASAero II, none of the rocket internal components in RockSim are carried over to RASAero II.

As shown in Figure 67, RockSim rocket files (.RKT format files) can be imported into RASAero II by selecting <File>, then <Import>, and then <RockSim> to load the RockSim file. .RKT RockSim format files will be displayed, and can be selected to be converted and opened in RASAero II.

Example RockSim files which can be imported into RASAero II are included in the Examples directory in the /My Documents/RASAero II directory.

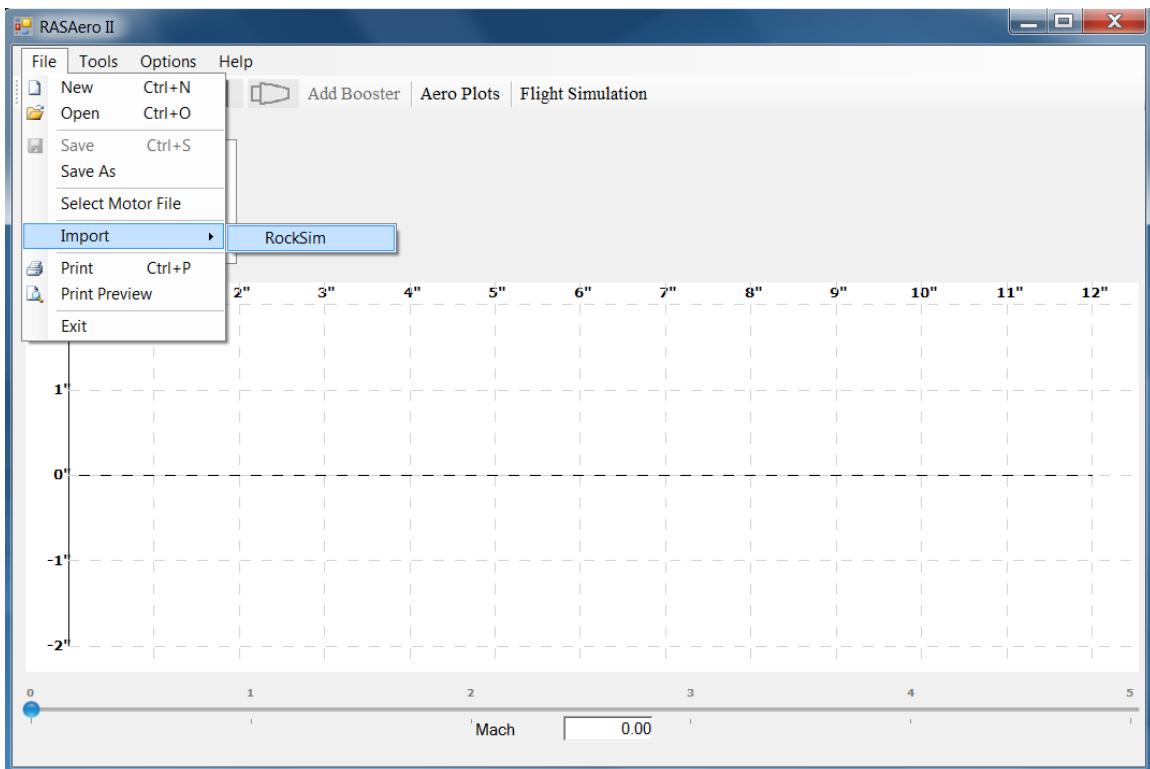


Figure 67 – Importing a RockSim file into RASAero II.

### **Important Note**

When the RockSim file has been imported into RASAero II, the warning message shown in Figure 68 will be displayed before the rocket is displayed. Clicking on <OK> will retract the message and display the rocket. As noted in the message, because RASAero II has many more fin airfoil options than RockSim, the actual airfoils on the fins of the rocket may have been approximated in RockSim by other airfoils. The airfoils must now be changed to the correct airfoils in RASAero II. Rail guides and launch shoes in RockSim may have been approximated by launch lugs, or the rail guides and launch shoes may have been left off the rocket. The rail guides and launch shoes must now be entered into RASAero II.

It is important to note that if the User does not go back and check the airfoil inputs and the rail guide and launch shoe inputs, the erroneous RockSim inputs will be transferred over to RASAero II, and RASAero II will run with the erroneous inputs.

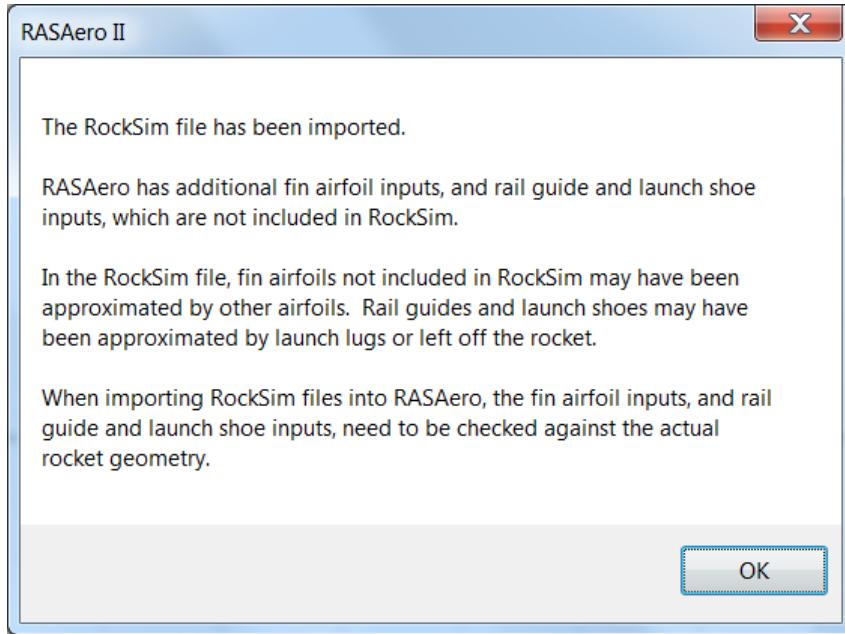


Figure 68 – Importing a RockSim file into RASAero II warning message.

Figure 69 shows a RockSim file example rocket (AeroPac104KStageOne&Two.RKT) from the /My Documents/RASAero II/Examples directory after being imported into RASAero II. Note that while the external geometry of the rocket has been imported, the rocket motors that were loaded into the rocket and the rocket Center of Gravity (CG) information have not been transferred over from RockSim, and will have to be re-entered into RASAero II. Likewise, the rocket lift-off and burnout weights, loaded and unloaded weights, are not transferred over from RockSim, and will have to be re-entered into RASAero II.

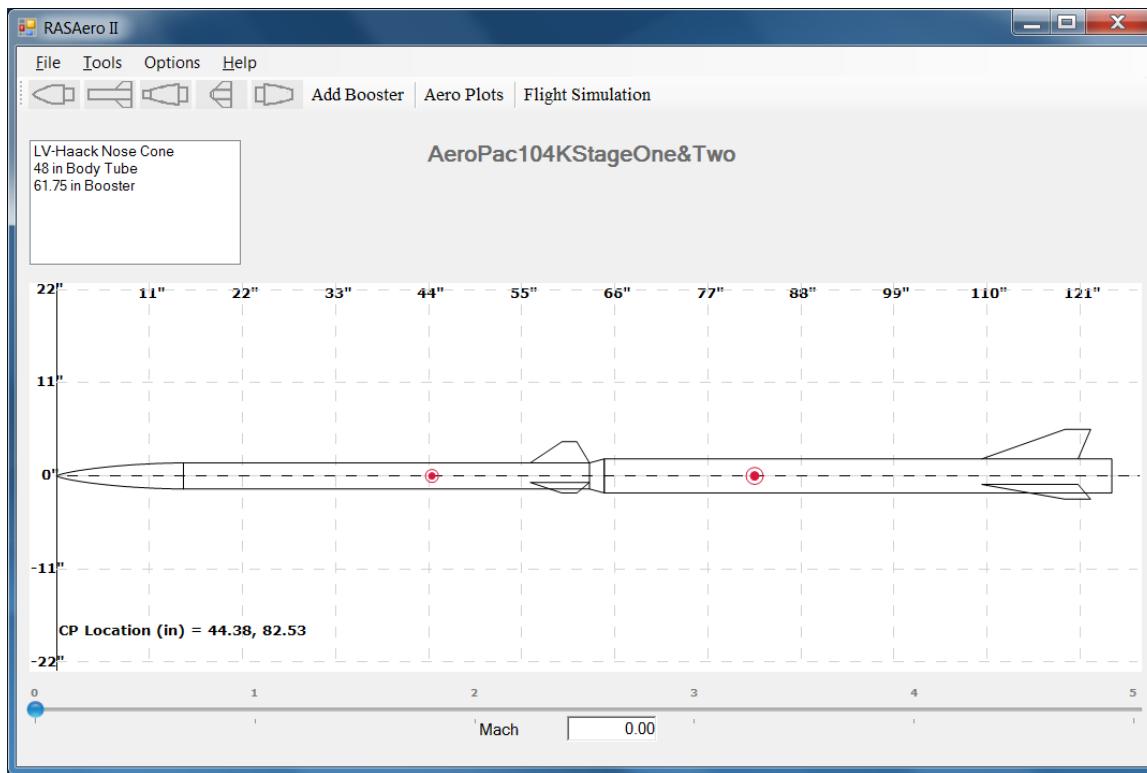


Figure 69 – Example RockSim file rocket imported into RASAero II.

If some aspects of the rocket geometry in the RockSim file are not compatible with RASAero II, then the warning message shown in Figure 70 will be displayed, informing the User that RASAero II was unable to import the RockSim file. The rocket will then have to be manually entered into RASAero II.

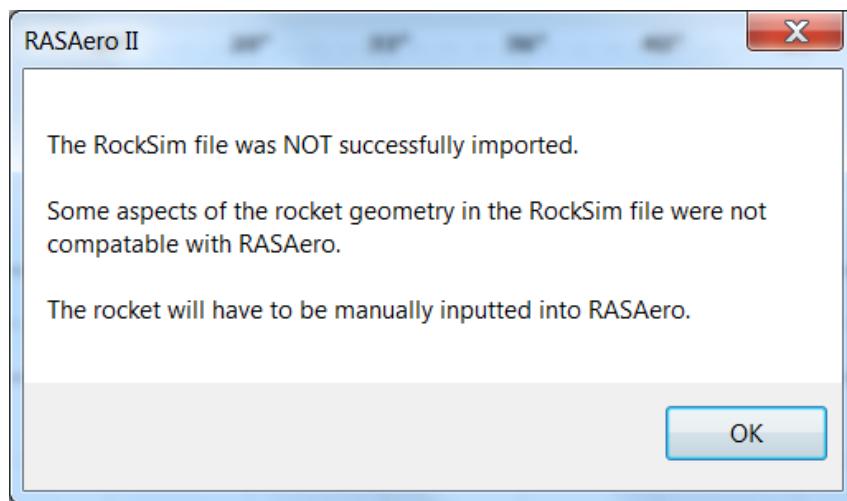


Figure 70 – Warning message for RASAero II being unable to import a RockSim file because of some rocket geometry incompatibility with RASAero II.

## Scale Rocket Drawing

As the Rocket Body and Fin Geometry Inputs are entered into RASAero II, a scale rocket drawing is created on the Main Screen. The rocket Center of Pressure (CP) of each stage will be displayed, which will shift depending on whether the default Barrowman Method is used, or the Rogers Modified Barrowman Method has been selected. Once the rocket Center of Gravity (CG) data has been entered (detailed in a later section), and the rocket motors have been added (detailed in a later section), the rocket CG is displayed and the rocket motors which have been loaded are displayed. The dot on the slider bar at the bottom of the scale rocket drawing can be moved to different Mach numbers; the CP of the rocket as displayed on the drawing will shift to the new CP location based on the new Mach Number.

Besides creating a scale drawing of the rocket, the scale rocket drawing also allows the User to check that the rocket geometry has been entered correctly.

Example scale rocket drawings on the RASAero II Main Screen are presented in Figure 71 for a single stage rocket, and in Figure 72 for a two stage rocket.

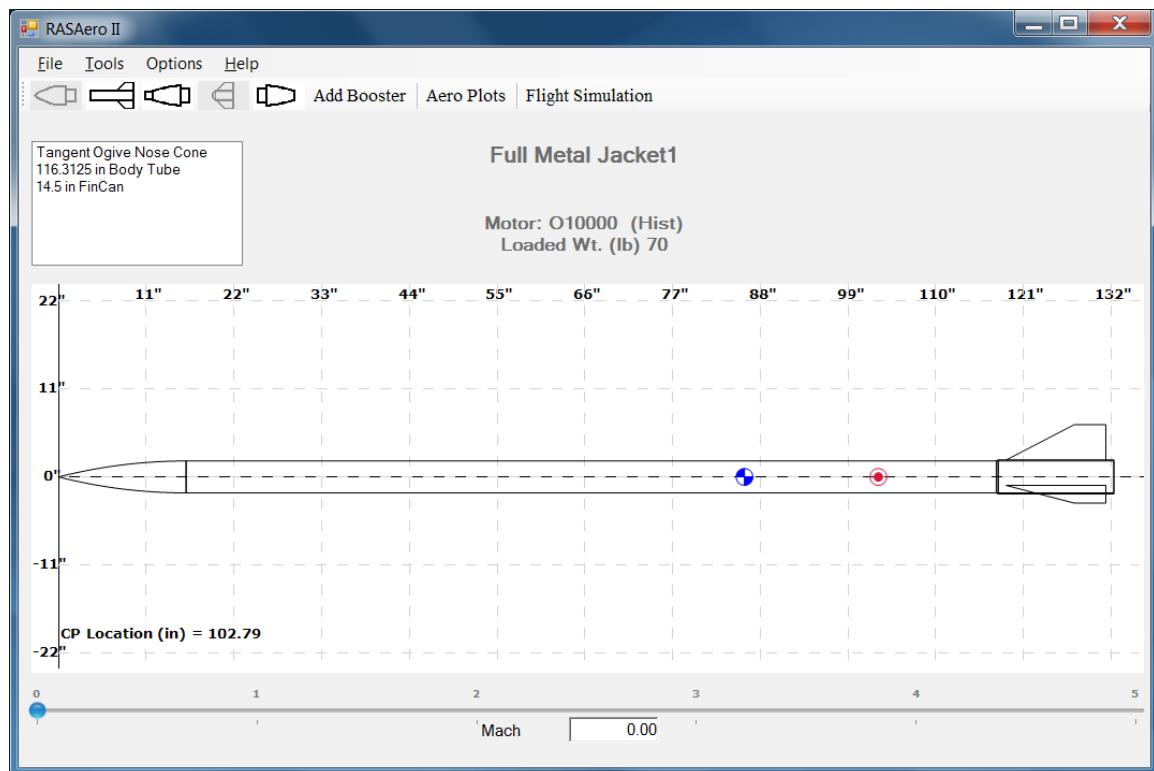


Figure 71 – Scale rocket drawing on the RASAero II Main Screen for a single stage rocket.

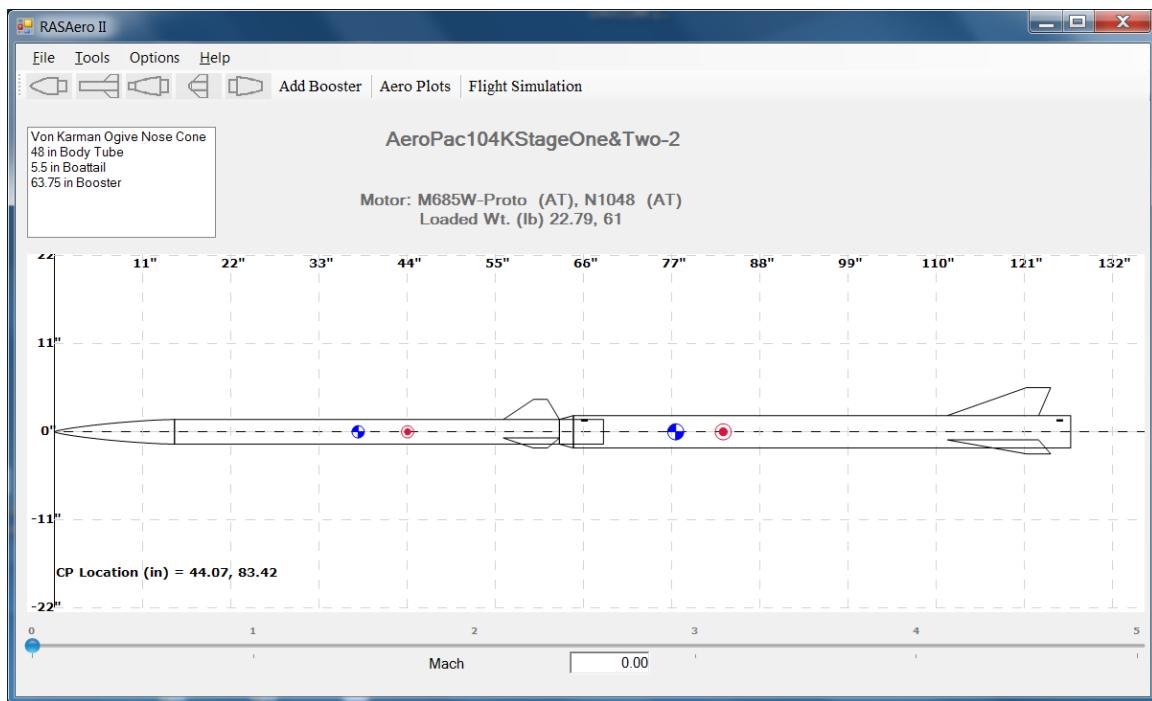


Figure 72 – Scale rocket drawing on the RASAero II Main Screen for a two stage rocket.

As shown in Figure 73, the scale rocket drawing can be printed out by selecting <File>, <Print> or <Print Preview>. The Print Preview screen as ready to be printed out is shown in Figure 74.

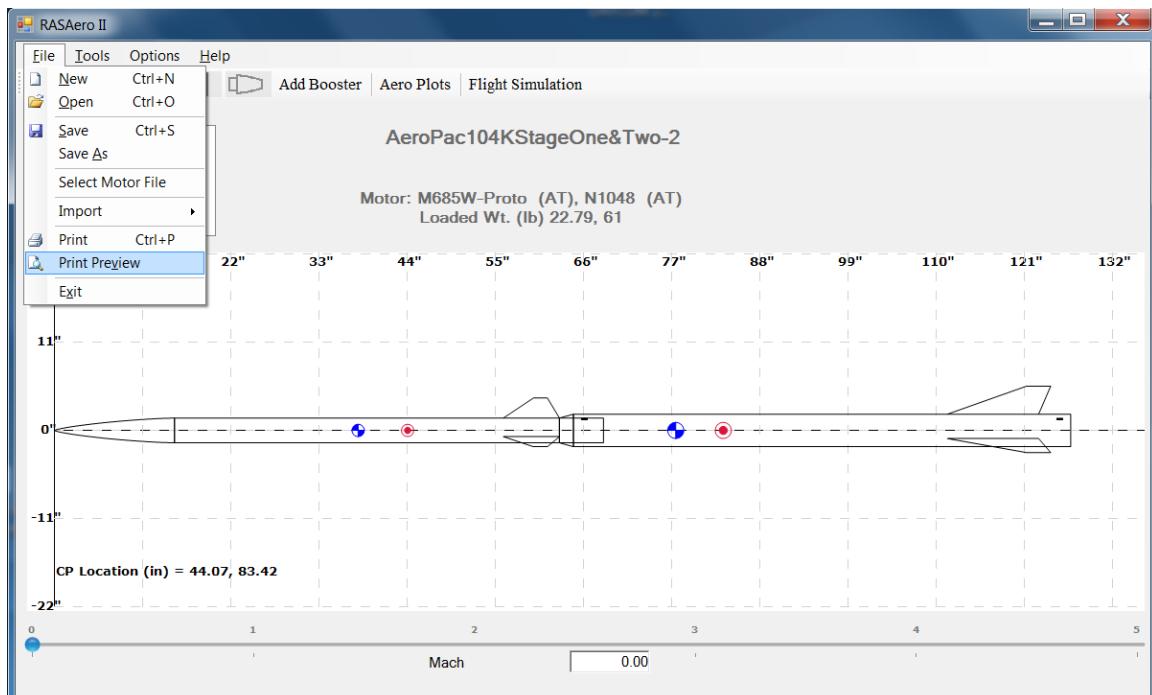


Figure 73 – Printing out the scale rocket drawing by selecting Print or Print Preview.

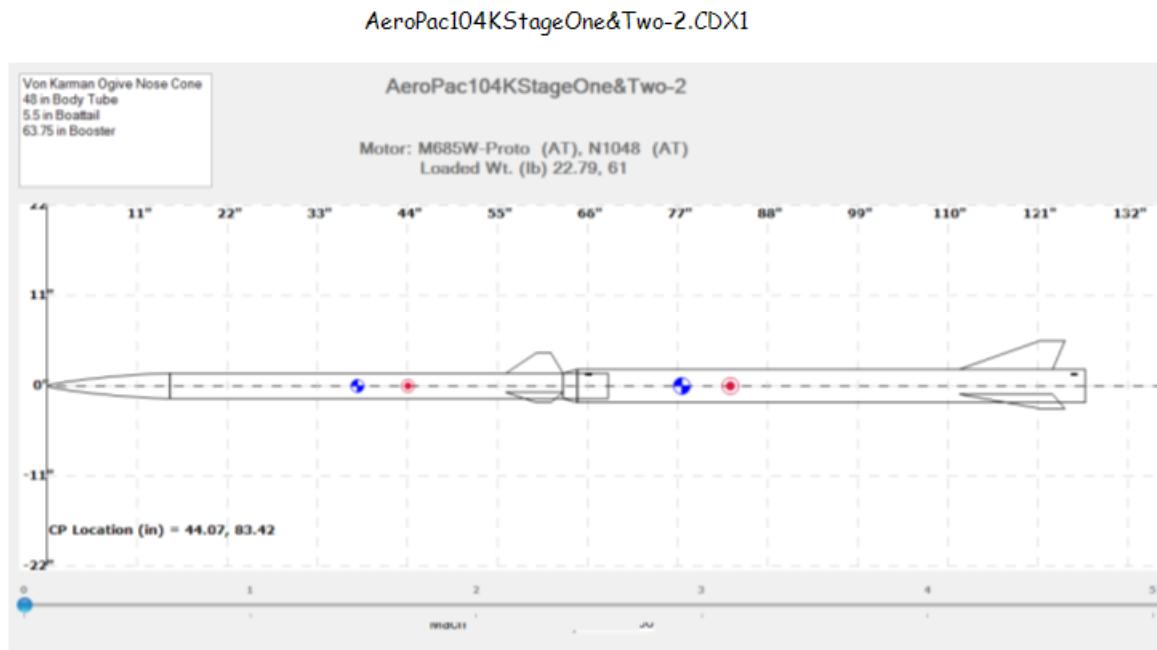


Figure 74 – Print Preview for the scale rocket drawing.

## Aero Plots

After the rocket has been entered into RASAero II, the aerodynamic analysis code built into RASAero II can be run by clicking the Aero Plots button as shown in Figure 75, which will generate aerodynamic data plots for the rocket.

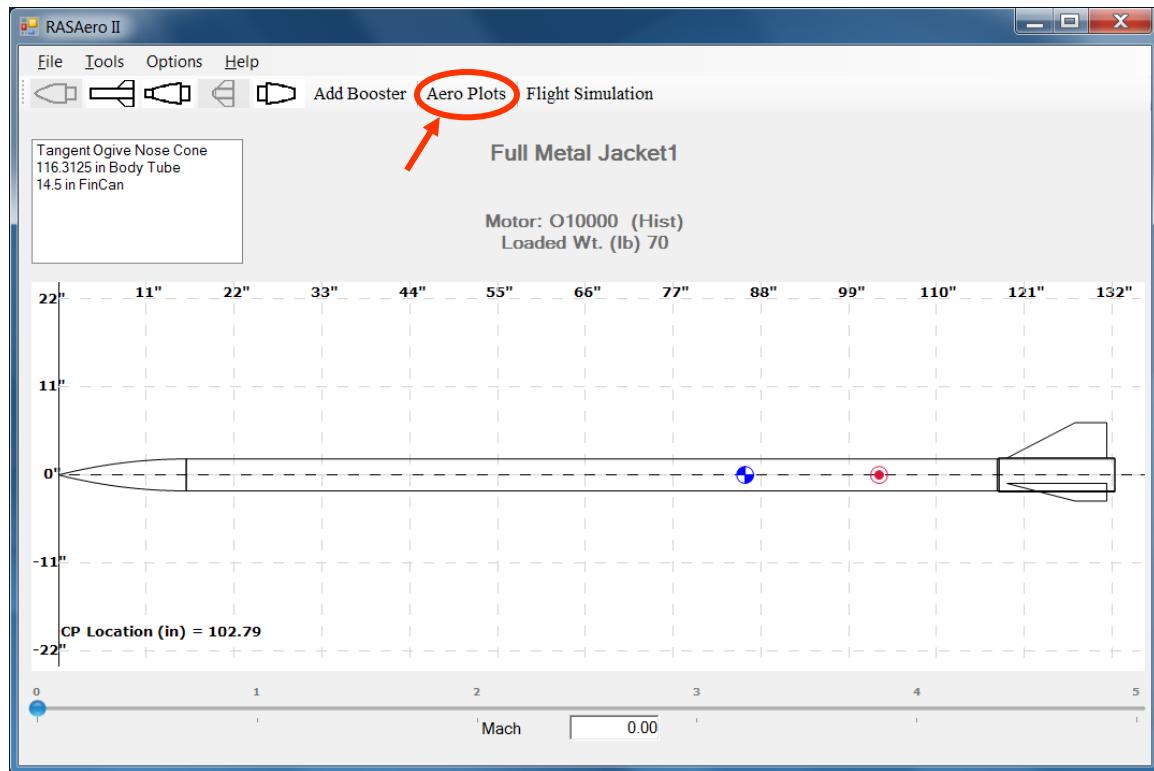


Figure 75 – Aero Plots button for generating rocket aerodynamic data plots.

Figure 76 presents a typical aerodynamic data plot generated by RASAero II, the power-on and power-off drag coefficient (CD) versus Mach number.

The reference area for the aerodynamic data generated by the RASAero II software is the maximum cross-sectional area of the rocket body, and is displayed on the Aero Plot plots labeled as "Sref" in square inches.

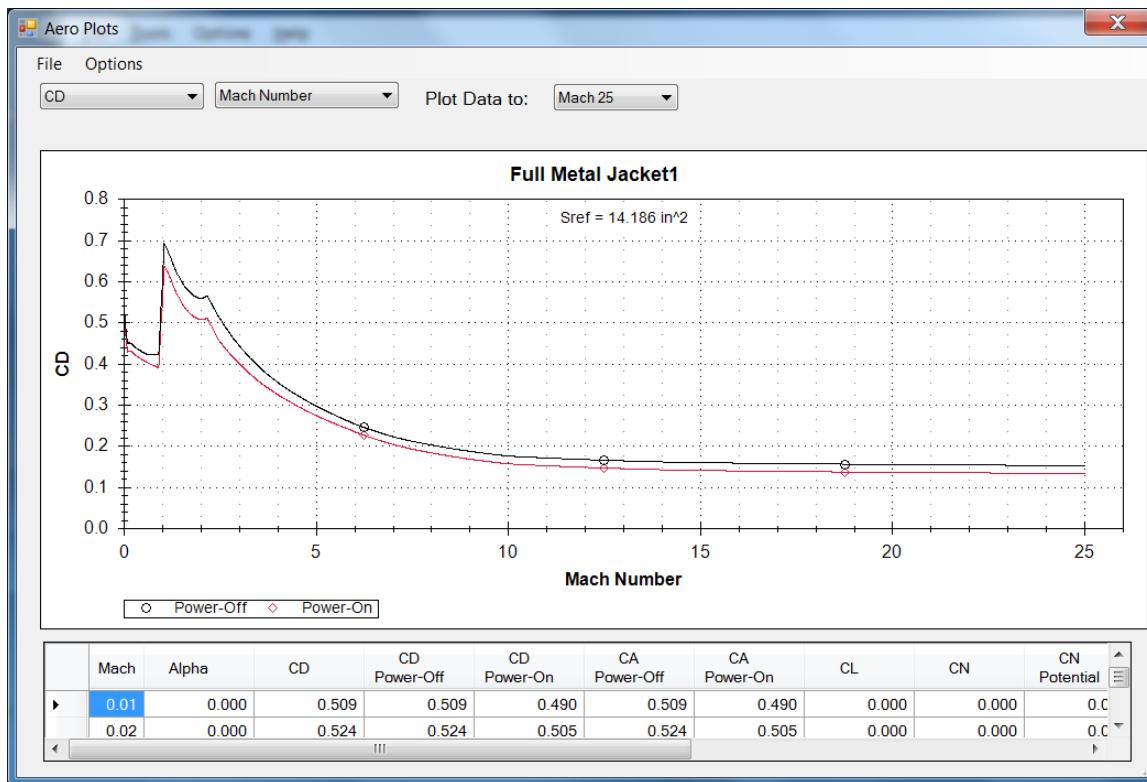


Figure 76 – Aerodynamic data plot; power-on and power-off drag coefficient (CD) versus Mach number.

In addition to the specific aerodynamic data plotted in the aero plot, all of the aerodynamic data for the rocket is also presented in the tabular output below the plot as a function of Mach number.

As shown in Figure 77, the aerodynamic data can be plotted to Mach 3, 5, 8, 10, or 25 by using the <Plot Data to:> pull-down menu. After being selected to be plotted to Mach 3 in Figure 77, the aerodynamic data is plotted to Mach 3 in Figure 78.

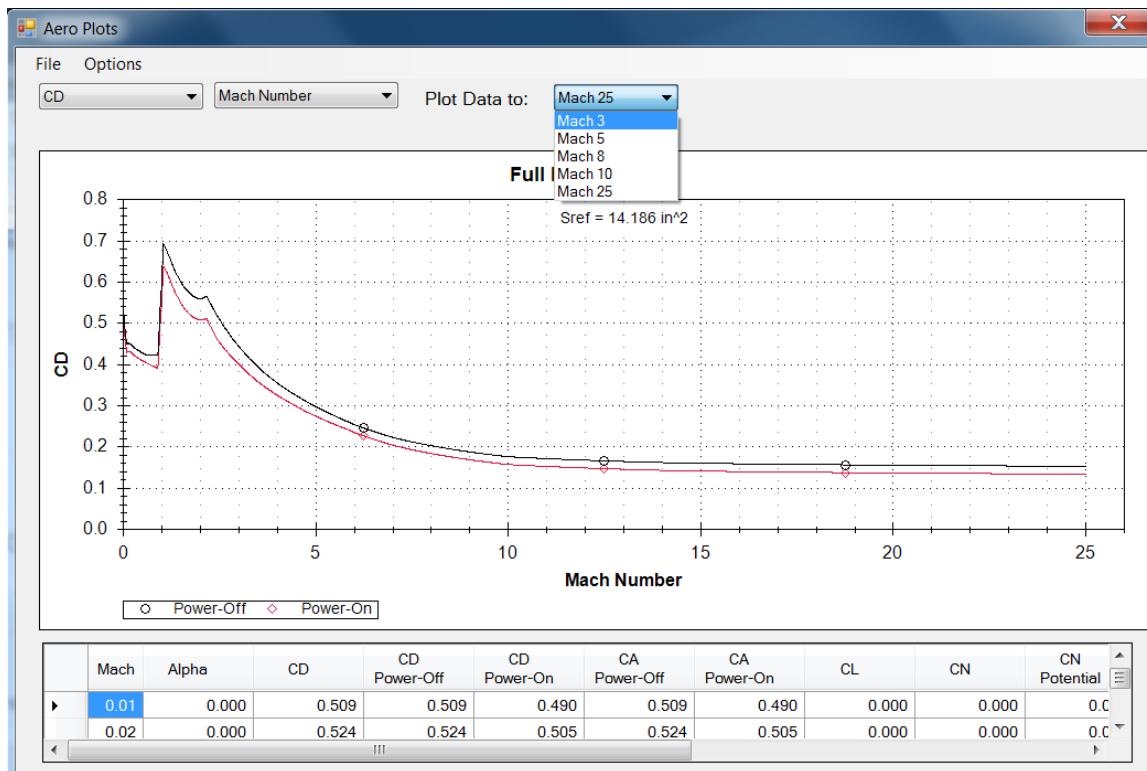


Figure 77 – Plotting aerodynamic data to Mach 3, 5, 8, 10, or 25 by using pull-down menu.



Figure 78 – Aerodynamic data plot; power-on and power-off drag coefficient (CD) versus Mach number, after being selected to Mach 3, plotted Mach 0-3.

Additionally, holding down the left mouse button will cause a “lasso” to be formed as the cursor is dragged around the plot, as shown in Figure 79. This square “lasso” allows portions of the aero plot be “zoomed in” (blown up). The power-on and power-off drag coefficient (CD) versus Mach number plot shown in Figure 77 is “lassoed” in Figure 79, and is shown after being blown up in Figure 80, showing the aerodynamic data plot zoomed-in to focus in on the Mach 0 to 5 aero data.

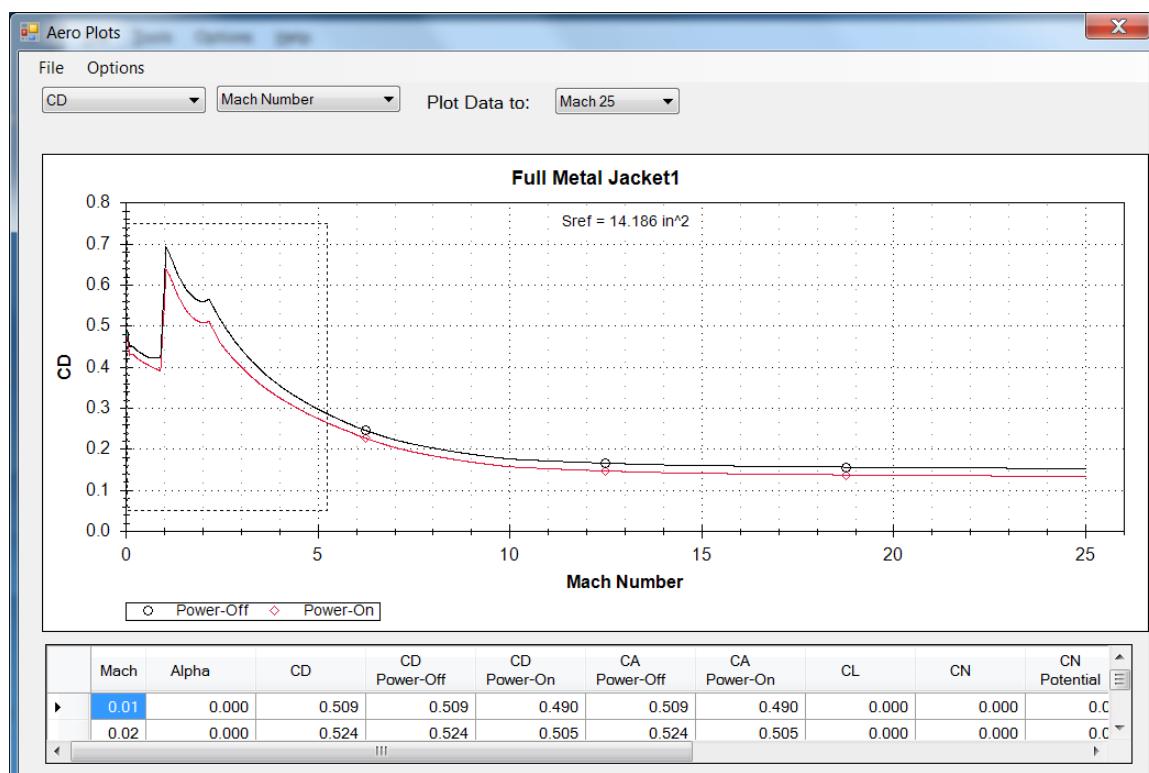


Figure 79 – Mach 0-5 aerodynamic data being “lassoed” and blown-up from Mach 0-25 aerodynamic data plot.

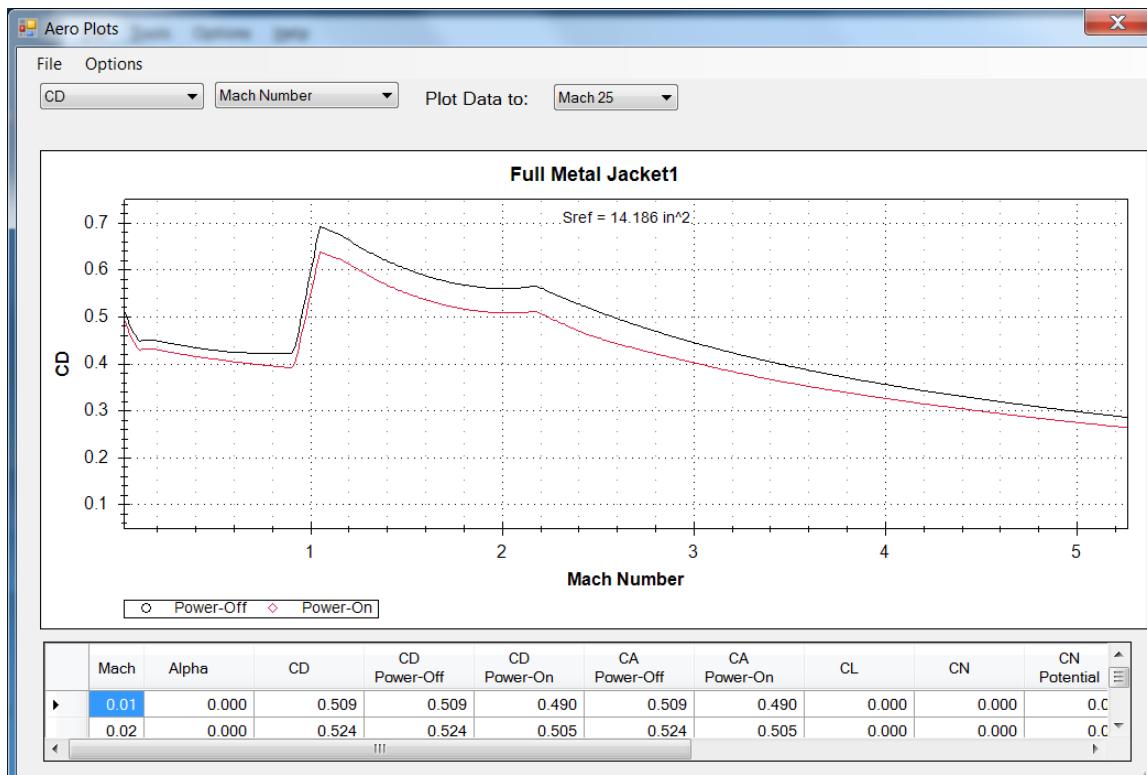


Figure 80 – Mach 0-5 aerodynamic data after being “lassoed” and blown-up from Mach 0-25 aerodynamic data plot.

Using the left down arrow on the plot selection inputs on the Aero Plots screen, different aerodynamic data can be selected versus Mach number for the plots, the aerodynamic data which can be plotted versus Mach number is shown in Figure 81. Using the right down arrow the aerodynamic data can be plotted versus angle of attack, the aerodynamic data which can be plotted versus angle of attack is shown in Figure 82.

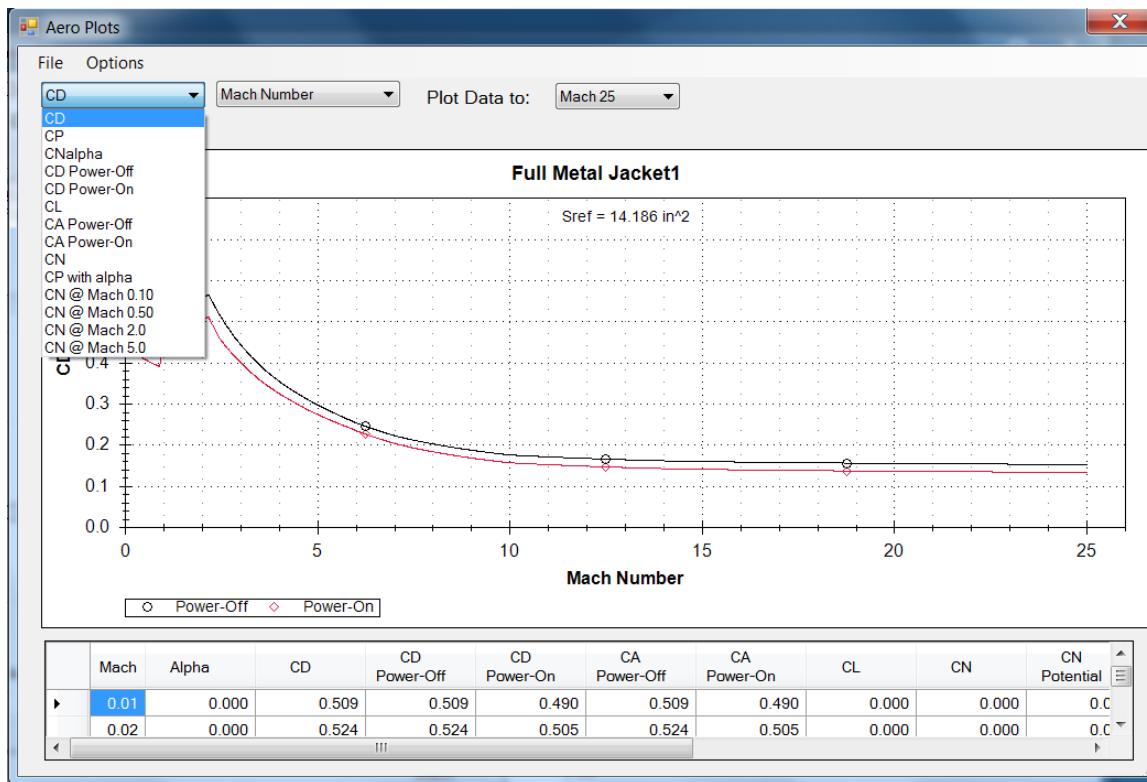


Figure 81 – Aerodynamic data which can be plotted versus Mach number.

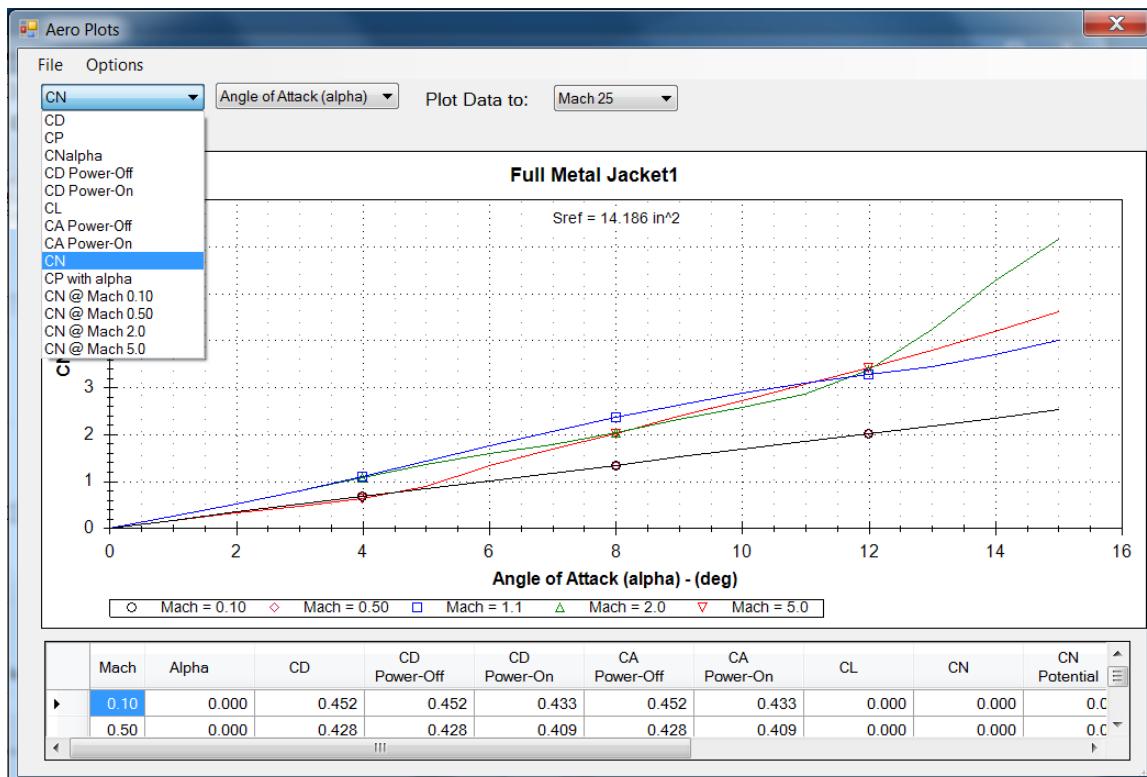


Figure 82 – Aerodynamic data which can be plotted versus angle of attack.

Figure 83 shows an aerodynamic data plot with the center of pressure (CP) selected to be plotted versus Mach number. Note in Figure 83 the substantial forward movement of the center of

pressure with Mach number at high supersonic to hypersonic Mach numbers, an important effect which is accurately modeled in RASAero.

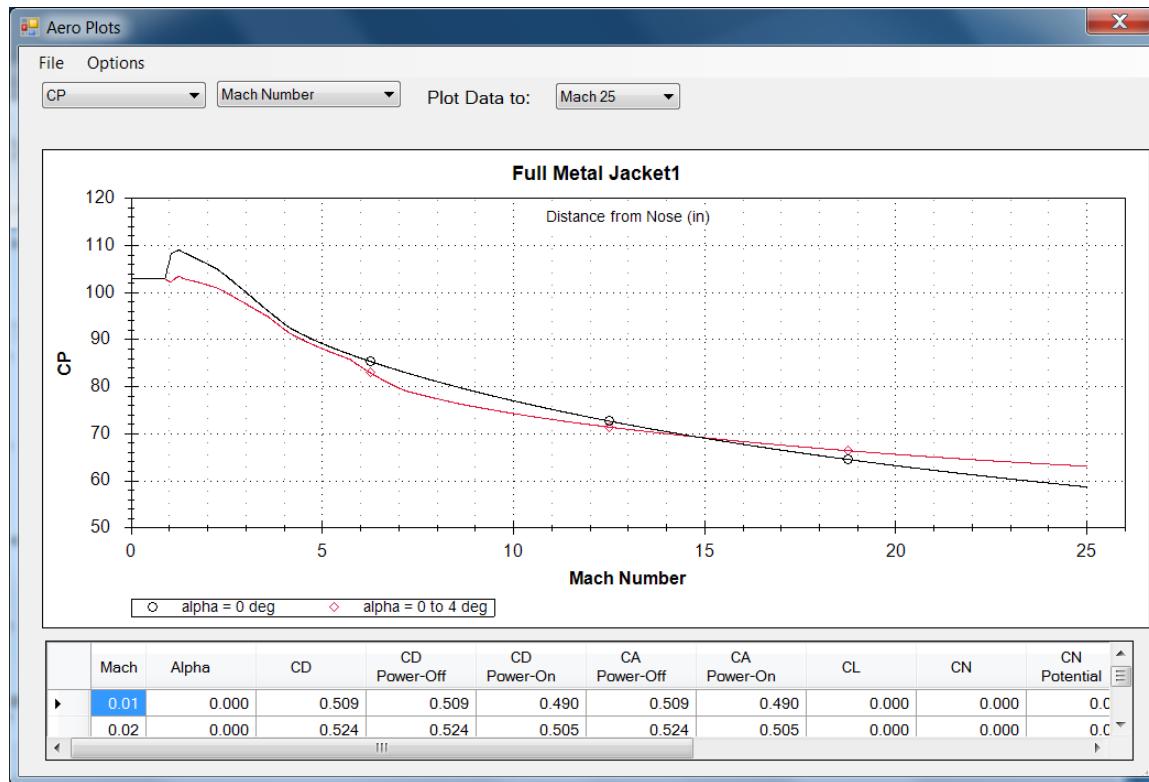


Figure 83 – Aerodynamic data plot; center of pressure (CP) versus Mach number, Mach 0-25.

Figure 84 shows the power-off drag coefficient (CD) selected, and the plot versus angle of attack option selected, to plot the power-off drag coefficient (CD) versus angle of attack.

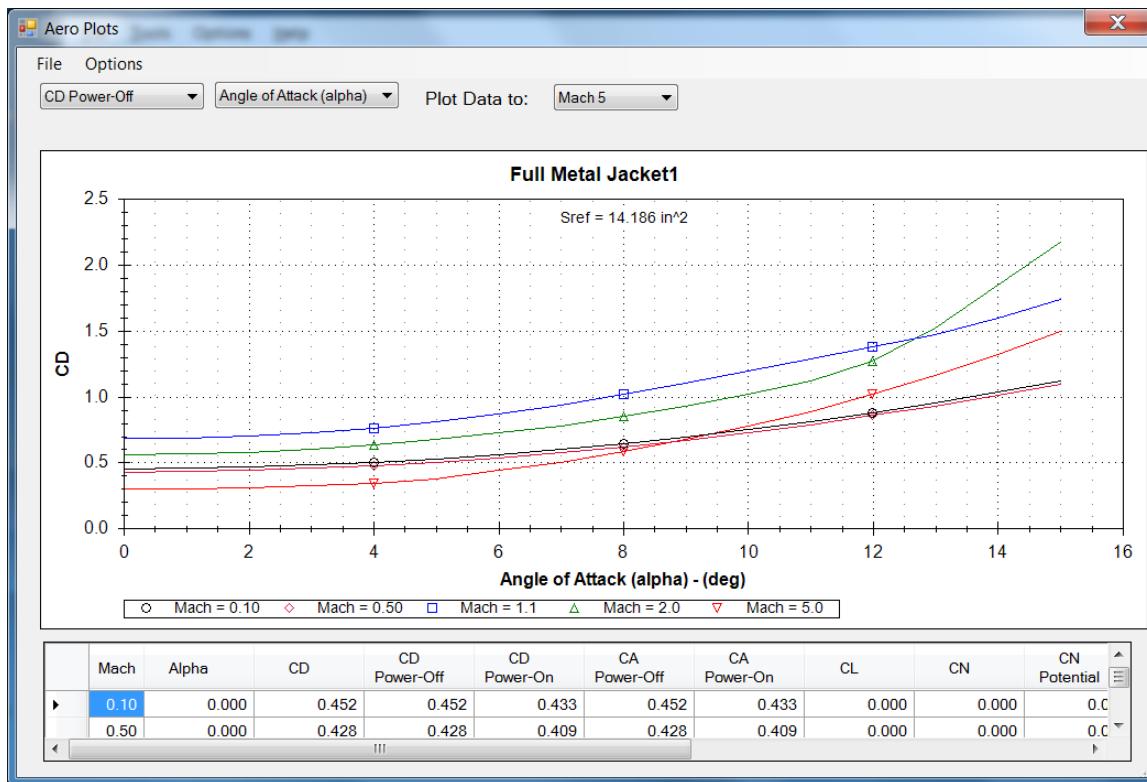


Figure 84 – Aerodynamic data plot; power-off drag coefficient (CD) versus angle of attack.

Figure 85 shows the normal force coefficient (CN) selected to be plotted versus angle of attack at Mach 0.5, with the Rogers Modified Barrowman Method option turned on. Note the additional normal force generated by viscous crossflow (labeled Viscous in Figure 85), an aerodynamic effect not included in the Barrowman Method. The Barrowman Method predicts Potential normal force only, with the Rogers Modified Barrowman Method having improved Potential normal force predictions with increased accuracy, in addition to adding the Viscous normal force not included in the Barrowman Method.

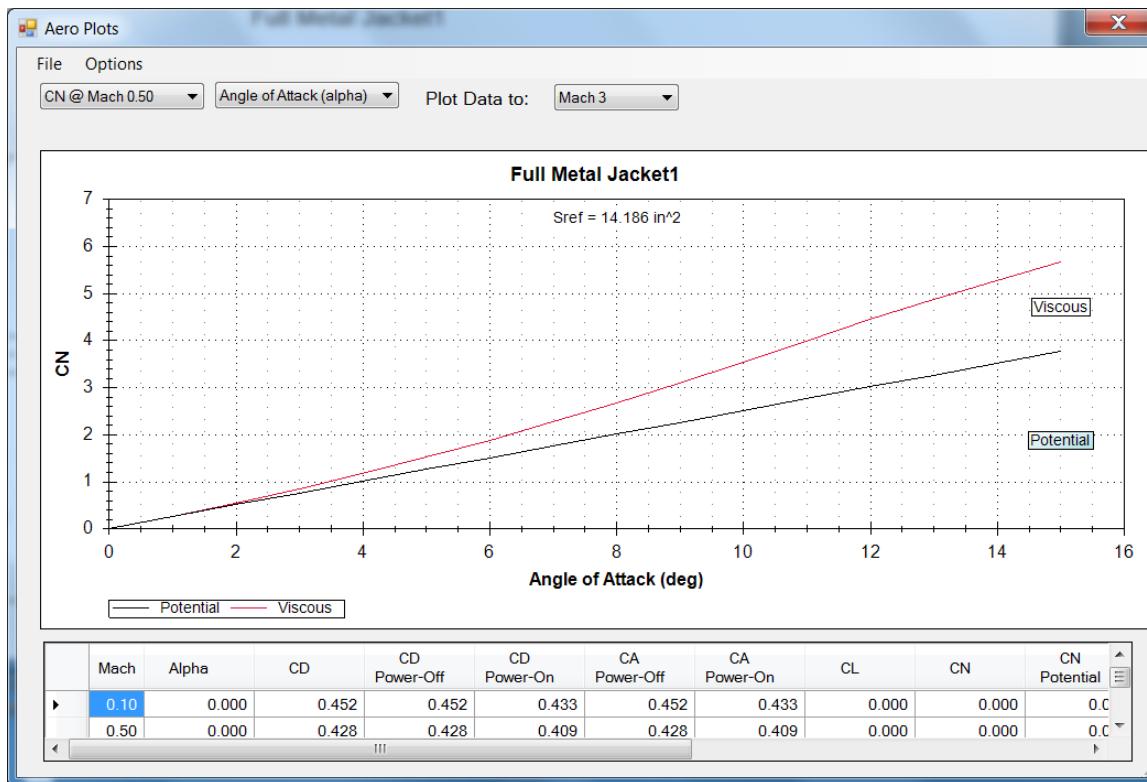


Figure 85 – Normal force coefficient (CN) versus angle of attack at Mach 0.5 using Rogers Modified Barrowman Method.

For a multi-stage rocket, like the rocket shown in Figure 86, when the Aero Plots button is clicked on as shown in Figure 86, the “Sustainer” and “Sustainer plus Booster” buttons will appear. The Sustainer plus Booster aerodynamic data will be plotted if Sustainer plus Booster is selected, as shown in Figure 87 and Figure 89; the Sustainer only aerodynamic data will be plotted if Sustainer only is selected, as shown in Figure 88 and Figure 90.

The reference area for the aerodynamic data for each stage is the maximum cross-sectional area of the rocket body for that stage, and is displayed on the Aero Plot plots labeled as “Sref” in square inches. Note in Figure 87 and Figure 89 that the reference area (Sref) for the aerodynamic data for the Sustainer plus Booster is the maximum cross-sectional area of the Booster (the stage with the larger diameter), and the reference area is lower for the smaller in diameter Sustainer only stage, as shown in Figure 88 and Figure 90.

If the rocket is a three stage rocket as shown in Figure 91, then “Sustainer”, “Sustainer plus Booster”, and “All Stages” buttons will appear on the Aero Plots screen as shown in Figure 92.

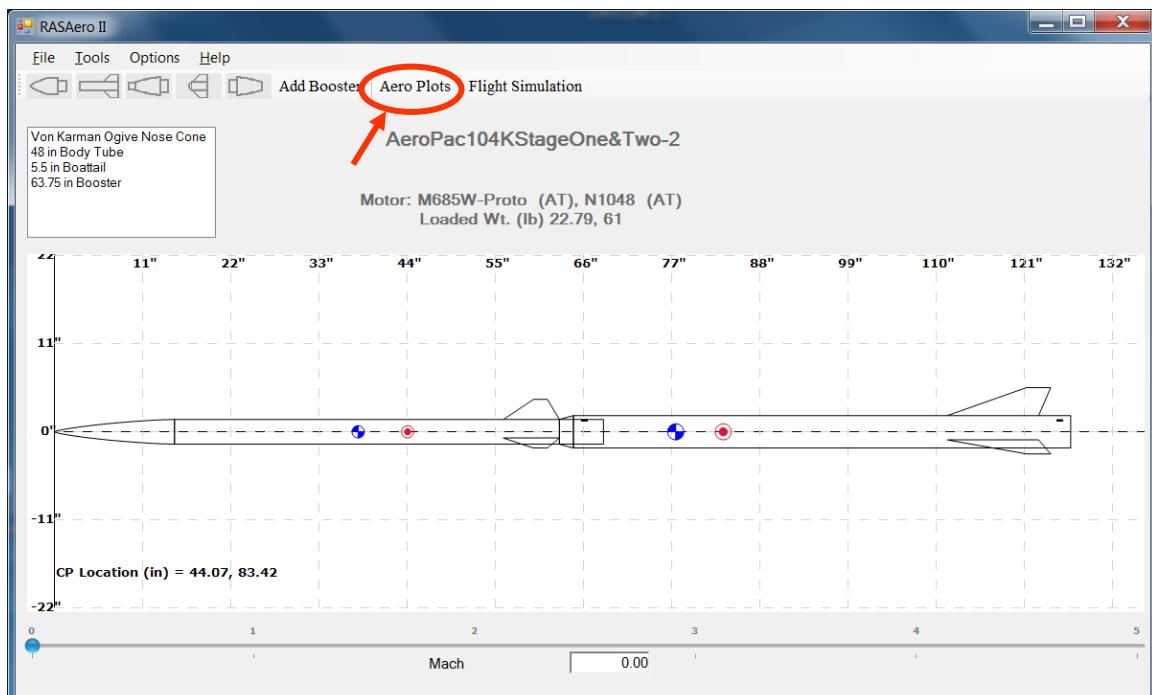


Figure 86 – Aero Plots button selected for two stage rocket in RASAero II.

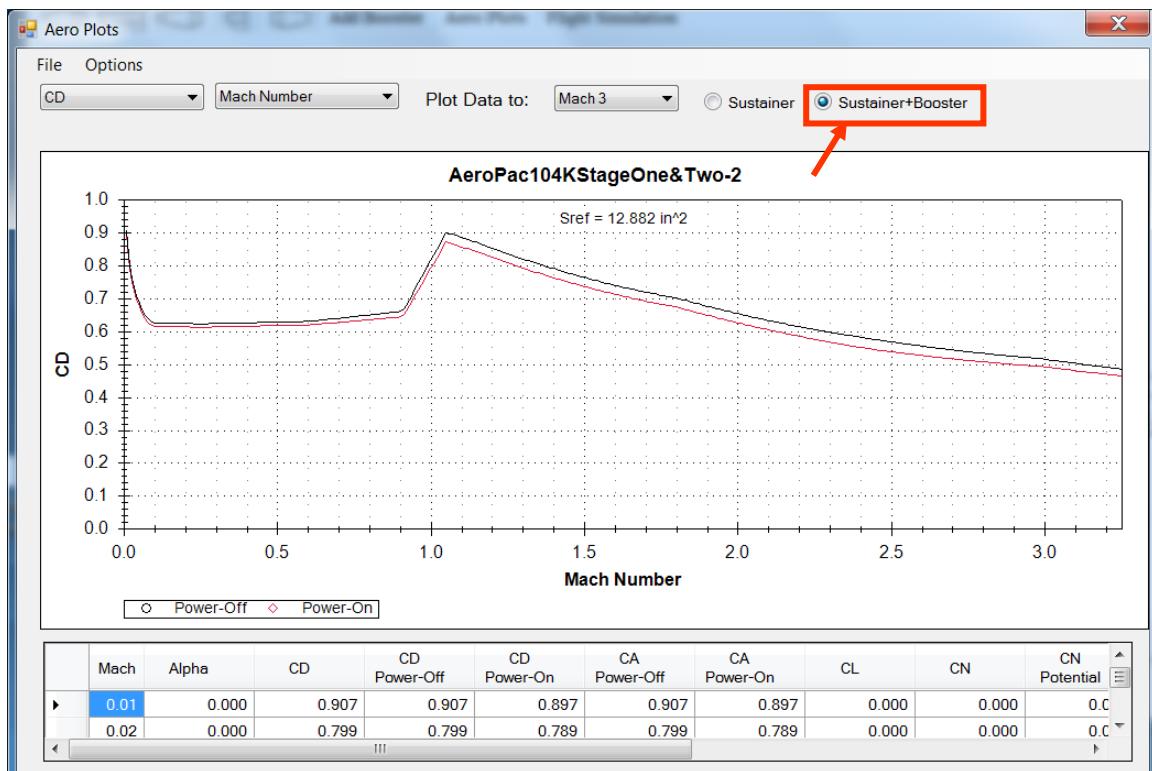


Figure 87 – Sustainer plus Booster power-on and power-off drag coefficient (CD).

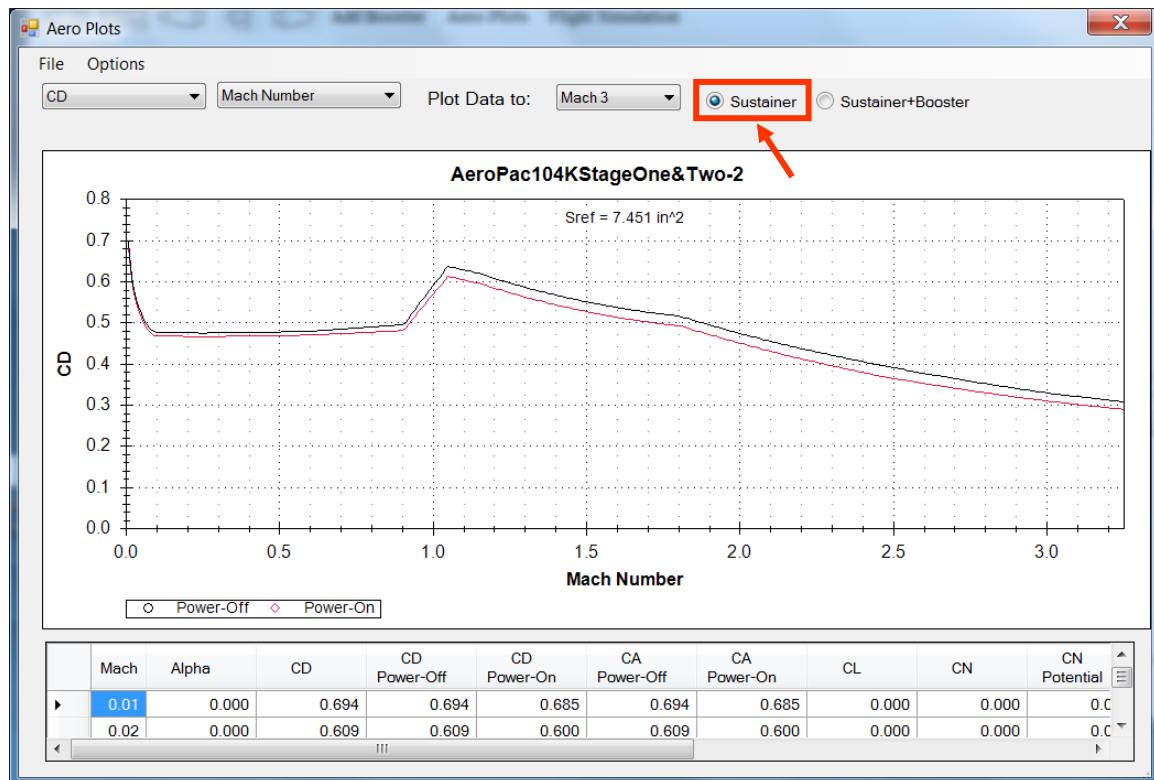


Figure 88 – Sustainer only power-on and power-off drag coefficient (CD).

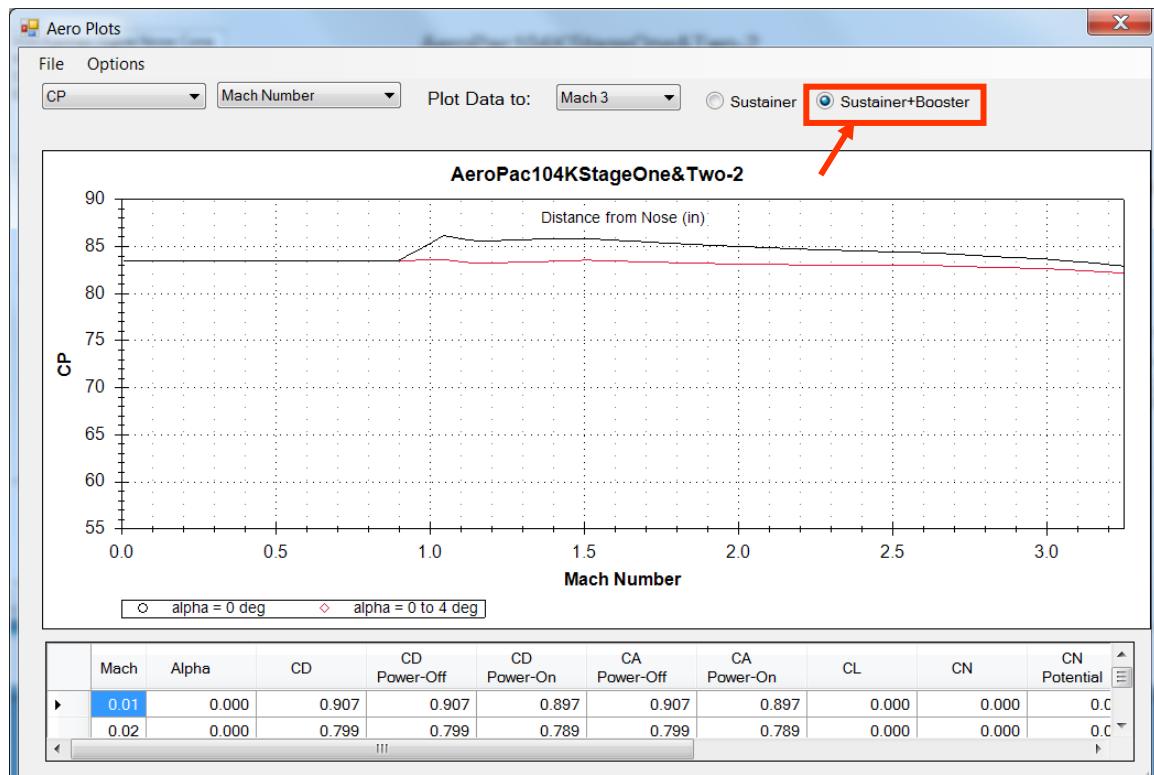


Figure 89 – Sustainer plus Booster center of pressure (CP) versus Mach number.

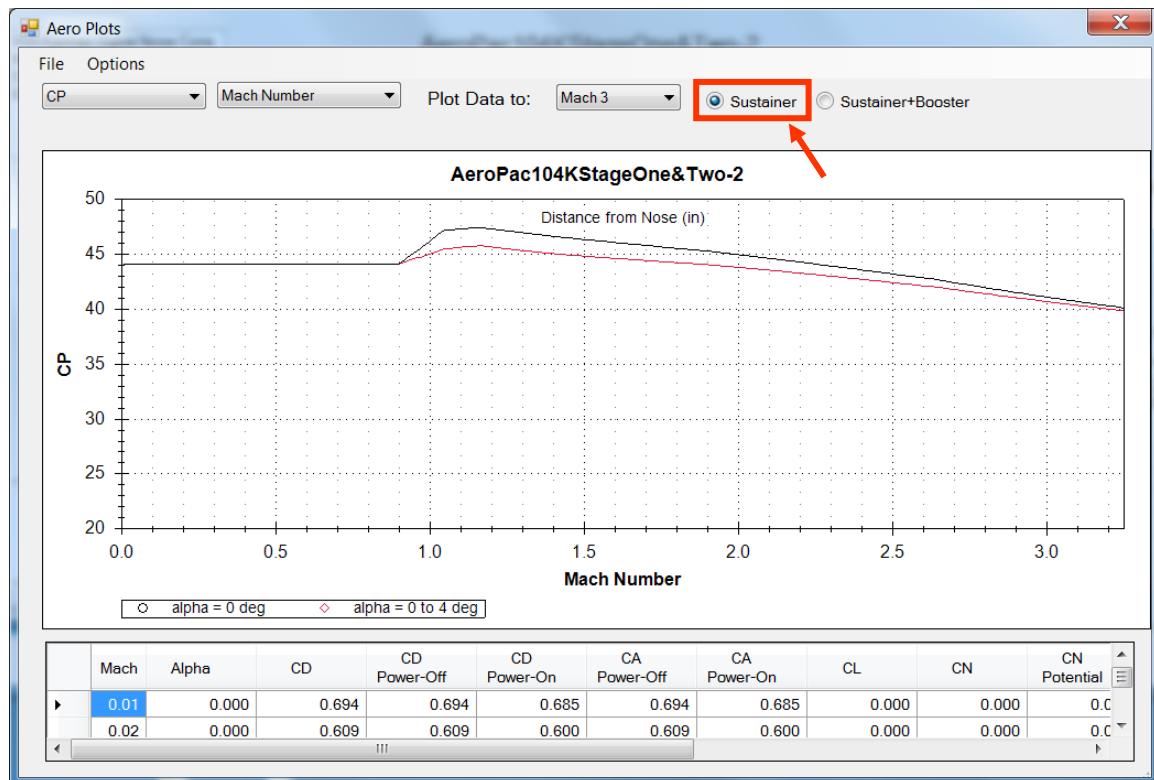


Figure 90 – Sustainer only center of pressure (CP) versus Mach number.

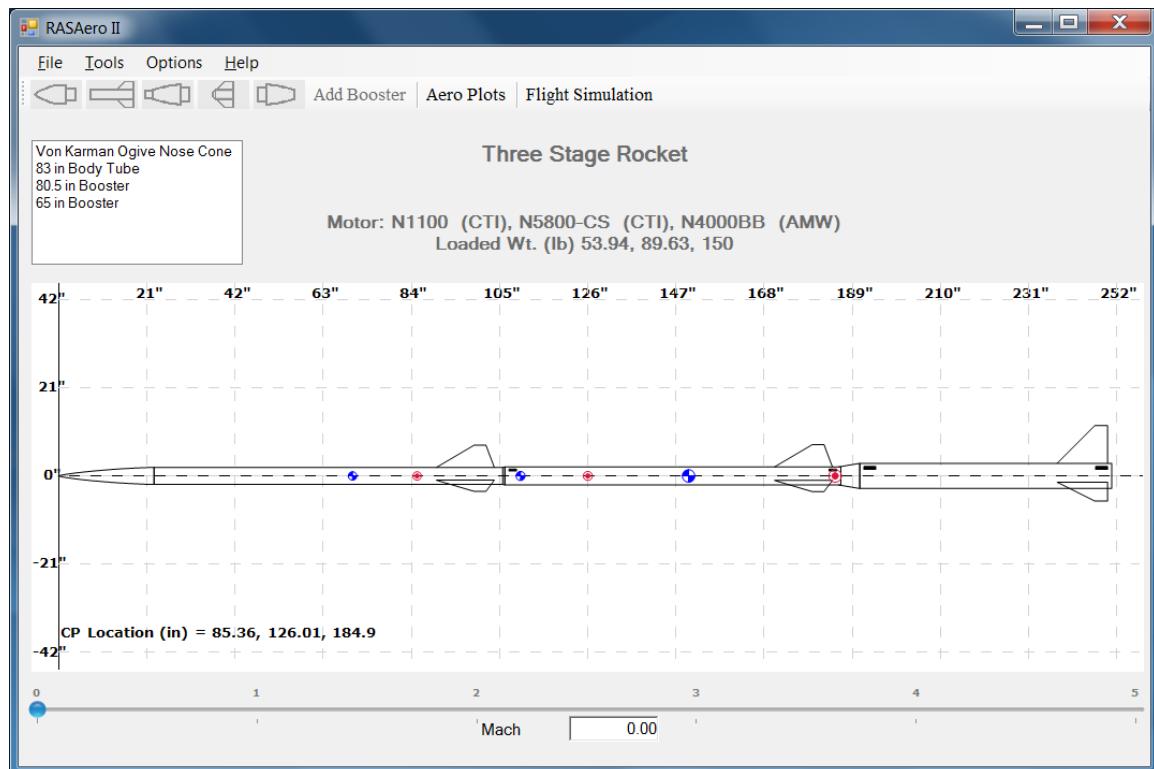


Figure 91 – Three stage rocket (sustainer – booster - booster) entered into RASAero II.

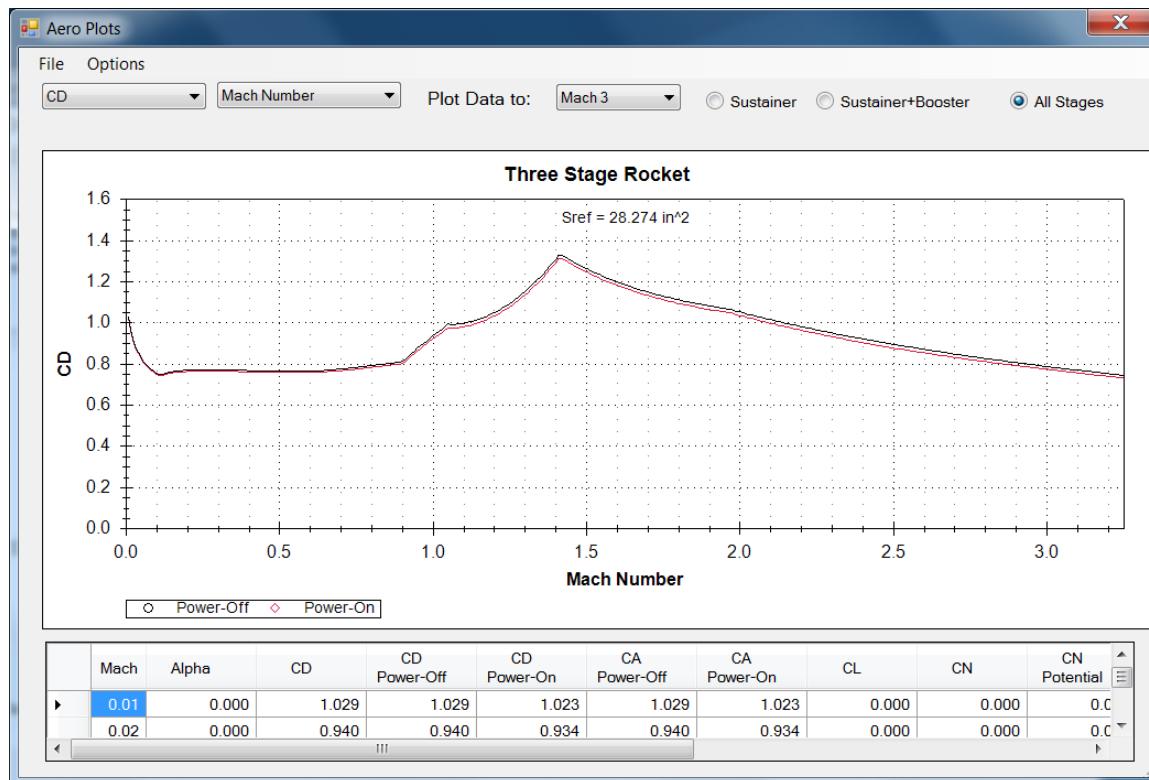


Figure 92 – Three stage rocket; All Stages power-on and power-off drag coefficient (CD).

By pressing <Alt> <Print Scrn> the Aero Plot image can be copied for pasting into another file.

As shown in Figure 93, the Aero Plot can be printed out by selecting <File>, <Print> or <Print Preview>.

As shown in Figure 94, the Aero Plot aerodynamic data can be exported to an Excel CSV file by selecting <File>, <Export>, <To CSV File>.

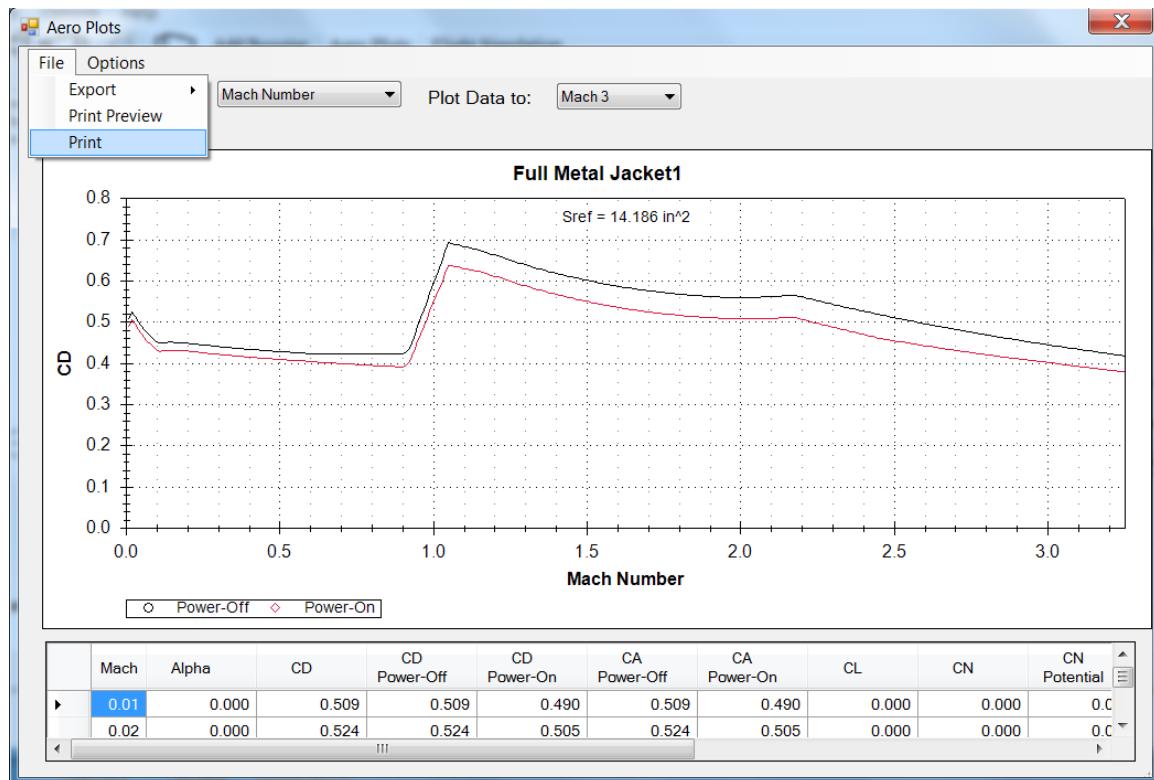


Figure 93 – Printing out an Aero Plot by selecting Print or Print Preview under File.

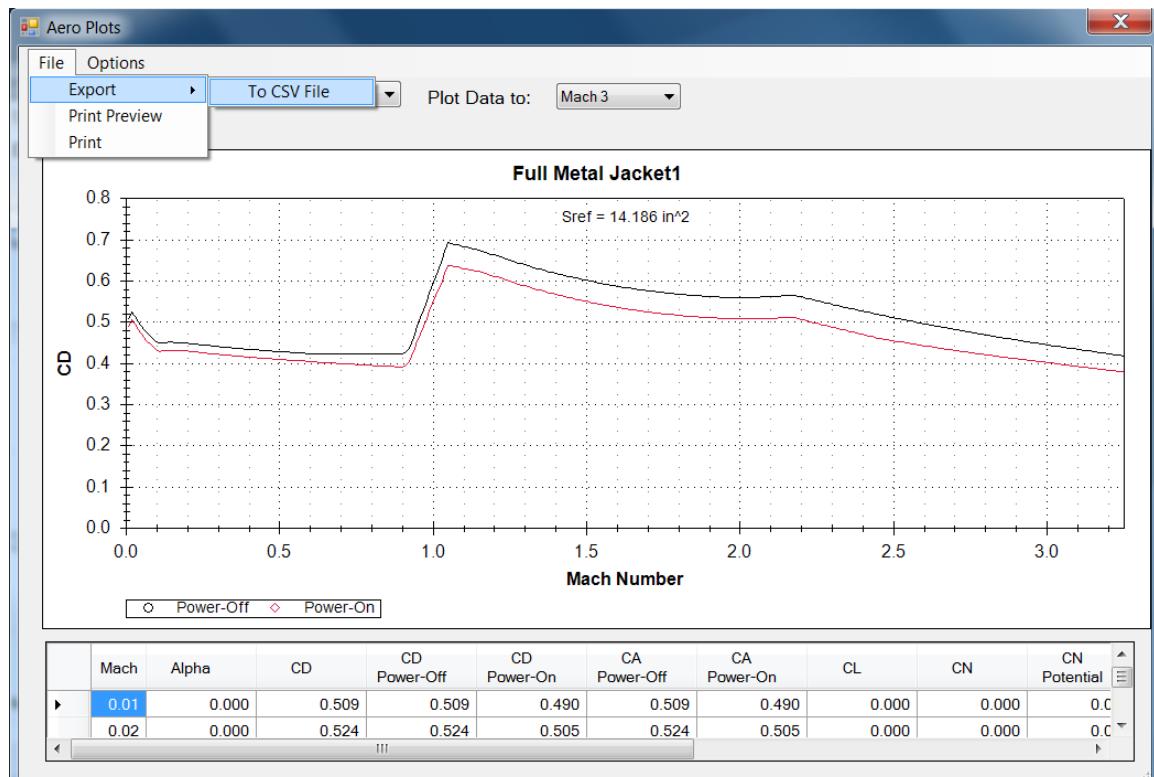


Figure 94 – Exporting Aero Plot aerodynamic data to an Excel CSV file.

## Launch Site Inputs

For running the RASAero II flight simulation the Launch Site conditions are entered by selecting Launch Site under the Options Tab on the RASAero II Main Screen, as shown in Figure 95. Figure 96 shows the Launch Site inputs, consisting of:

- a) Launch site elevation (ft) above sea level.
- b) Temperature (deg F).
- c) Launch site barometric pressure (in-hg). This is not a mandatory input, and can be left blank. Note that this is the barometric pressure at the launch site, like the atmospheric pressure measurement obtained from a weather station or an airport.
- d) Wind speed (mph). Positive wind speed is a headwind, which the rocket will weathercock into, and which will blow the rocket on a parachute back towards the launch pad. Negative wind speed is a tailwind, which will blow the rocket on a parachute away from the launch pad.
- e) Launch rail length (ft), (or launch rod length).
- f) Launch angle, degrees from vertical. Zero degrees is straight-up. A positive launch angle is angled downrange away from the launch controller and crowd.

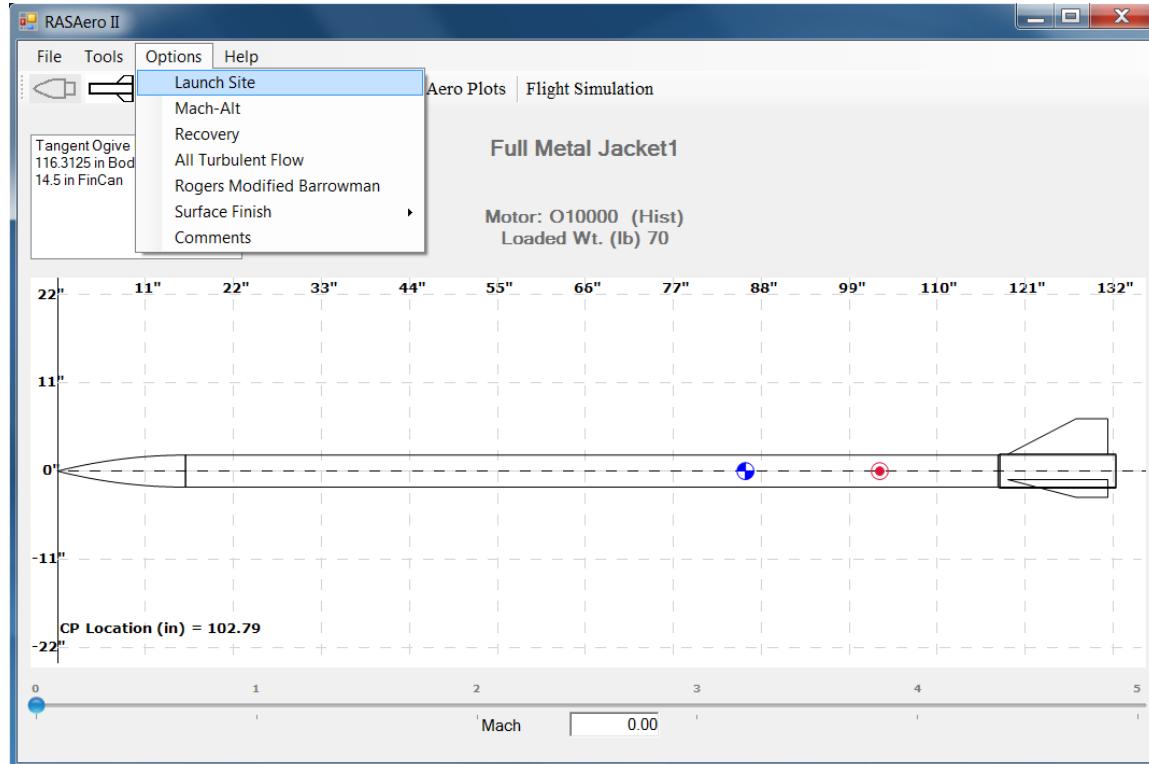


Figure 95 – Selecting Launch Site Inputs under the Options Tab to enter launch site conditions.

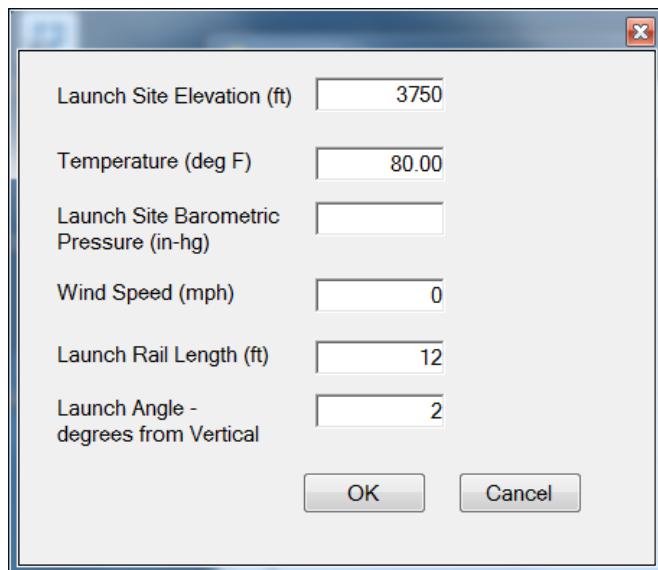


Figure 96 – Launch Site Inputs.

Clicking <OK> will save the launch site conditions, which are saved in the rocket file with the rest of the data for the rocket (the .CDX1 file). For a new rocket, the last launch site conditions used will initially be displayed, and then can be changed to the launch site conditions needed for the current rocket. It's a good idea to verify for each rocket and for each rocket flight simulation run that the correct launch site elevation and temperature are being used for the launch site conditions, as the launch site elevation in particular has a strong effect on the altitude of the rocket.

Generally, the typical flight simulation run on RASAero II is run using the launch site elevation and the launch site temperature. Few model or high power rocketeers measure barometric pressure at the launch site. The launch site elevation feature in RASAero II assumes a standard day, and internal to the program provides the launch site atmospheric pressure based on the elevation of the launch site. Thus all the user needs to know and enter into the software is the elevation of the launch site, and the temperature. Actual measured temperature is preferred, but the general temperature experienced at the launch site can be used. Thus most users will run the RASAero II flight simulation using the launch site elevation and the typical temperature at the site. The launch site barometric pressure can be left blank.

If, for engineering purposes, the user wishes to run the flight simulation from sea level on a standard day, the user can enter a launch site elevation of zero ft, and a temperature of 59 deg F, the sea level standard day conditions.

The atmosphere model in the RASAero II flight simulation uses the launch site elevation (or an entered barometric pressure and the launch site elevation), to anchor a model of atmospheric pressure (used for variation of thrust with altitude) as a function of altitude, the launch site temperature input anchors a model of temperature (from which speed of sound is calculated) as a function of altitude, and the launch site pressure and temperature are used to calculate the atmospheric density at the launch site, which then anchors a model of the atmospheric density

(used to calculate the aerodynamic drag on the rocket) as a function of altitude. The atmosphere models extend to 1,000,000 ft altitude, and is based on the 1976 US Standard Atmosphere.

For advance users, the barometric pressure as obtained from a weather station or airfield, or measured at the site, can be input in the program. Note that barometric pressure is the pressure that would be present at sea level, based on the measured pressure at the site, which then based on the elevation of the site is adjusted back to the sea level value based on a standard variation of pressure with altitude. Thus the elevation of the launch site is still required when entering the barometric pressure. This feature was built into RASAero II so that the easiest to obtain atmospheric pressure, the barometric pressure from a weather station or airfield, can be inputted into the program.

Note that entering a wind speed, or not entering a wind speed, (wind or no wind), will determine what kind of flight simulation is run.

- a) If no wind speed is entered, then a 2 degrees-of-freedom trajectory simulation with no wind will be run, with no dynamic stability and no weathercocking.
- b) If a wind speed is entered, then a 3 degrees-of-freedom trajectory simulation with wind will be run that includes dynamic stability and weathercocking of the rocket into the wind.
- c) The above flight simulation modes are selected internal to the software and are transparent to the User. The selection of the flight simulation mode is based on whether the User has entered a wind speed or not.

When the flight simulation portion of the RASAero II software is run, the aerodynamic coefficients for the rocket are calculated during each time step based on the rocket Mach number, angle of attack, Reynolds number based on the altitude of the rocket, and whether the rocket is flying in the motor thrust phase (power-on) or the coast phase (power-off). For the trajectory simulation with wind, with dynamic stability and weathercocking included, both static and dynamic stability derivatives for the rocket are calculated, including rocket aerodynamic damping coefficients and the jet damping coefficient from the rocket motor thrust during the powered flight phase.

## Recovery Inputs

The RASAero II Recovery inputs are entered by selecting Recovery under the Options Tab on the RASAero II Main Screen, as shown in Figure 97. Figure 98 shows the Recovery Inputs.

Two recovery events are allowed. Typical recovery sequences are as follows:

- a) No recovery, flight through apogee, ballistic descent to impact. To select this option, leave both Event 1 and Event 2 boxes unchecked. (Or Event 1 and Event 2 boxes can be checked, but for the recovery device select None.)
- b) Main parachute at apogee. Check Event 1, for Event Type specify Apogee (apogee deployment), select parachute for Device, and then specify the parachute diameter.
- c) Drogue parachute at apogee, main parachute at a selected altitude (example 1000 ft above ground level). Check Event 1, for Event Type specify Apogee (apogee deployment), select parachute for Device, and then specify the parachute diameter. Check Event 2, for Event Type specify Altitude (deployment at a specified altitude above the ground), enter the deployment altitude above ground level, select parachute for Device, specify the main parachute diameter.

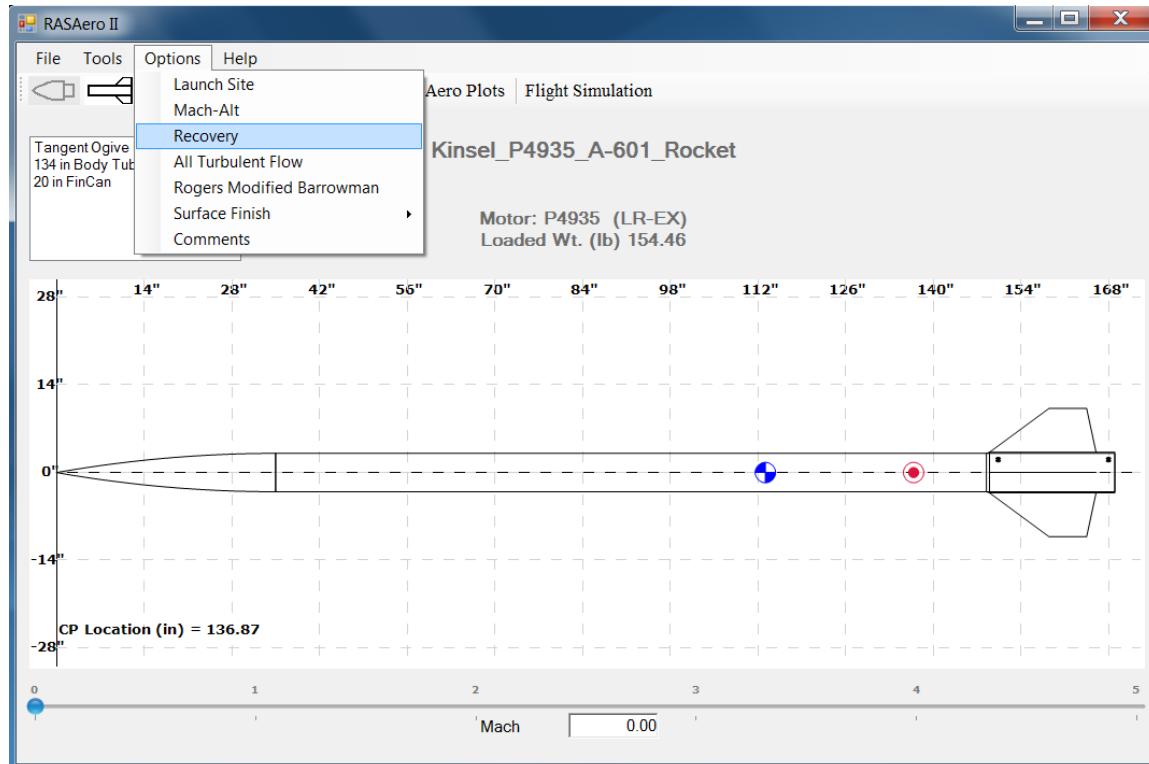


Figure 97 – Selecting Recovery inputs under the Options Tab.

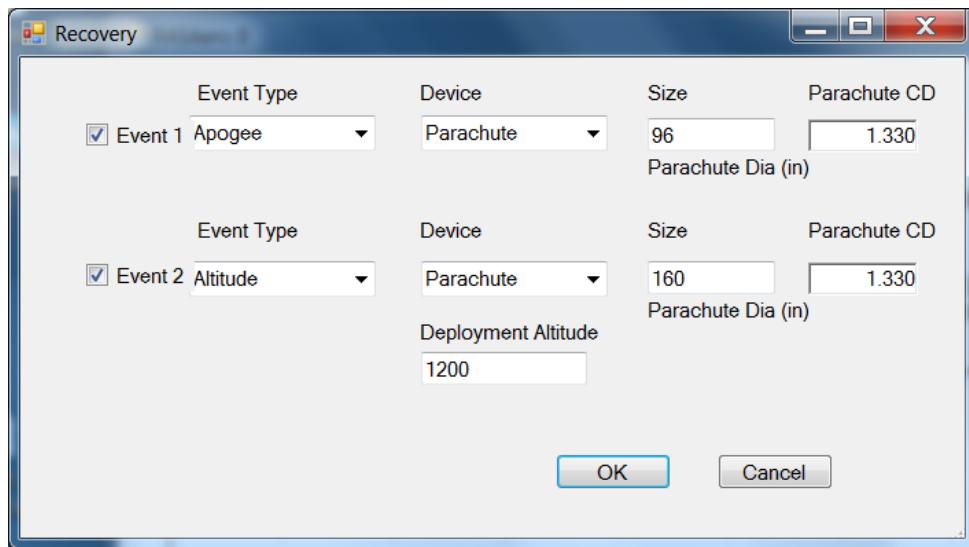


Figure 98 – Recovery inputs.

Note that the diameter of the parachute is the diameter with the parachute laid flat on the ground. This is the way most model and high power rocket parachutes are measured, and is the reference area convention used to develop the parachute drag coefficient data used in the RASAero II software.

Note the default parachute drag coefficient (CD) of 1.33 is based on a study of high power rocket descent rates as a function of parachute size, but the User has the option of entering his own parachute CD based on descent rate flight data for the parachute being used.

Clicking <OK> saves the Recovery inputs for the rocket.

## Rocket Comments

Comments can be entered for the rocket by selecting Comments under the Options Tab on the RASAero II Main Screen, as shown in Figure 99. Figure 100 shows the Comments input screen with an example of some rocket comments. After the rocket comments are entered, they are saved by clicking on <OK>. Note that the comments are saved with the rocket in the rocket .CDX1 file.

Saving comments for each rocket, describing any unique features of the rocket, and in particular noting altimeter altitude measurements for comparison with the RASAero II flight simulation altitude prediction is highly recommended by the RASAero II authors.

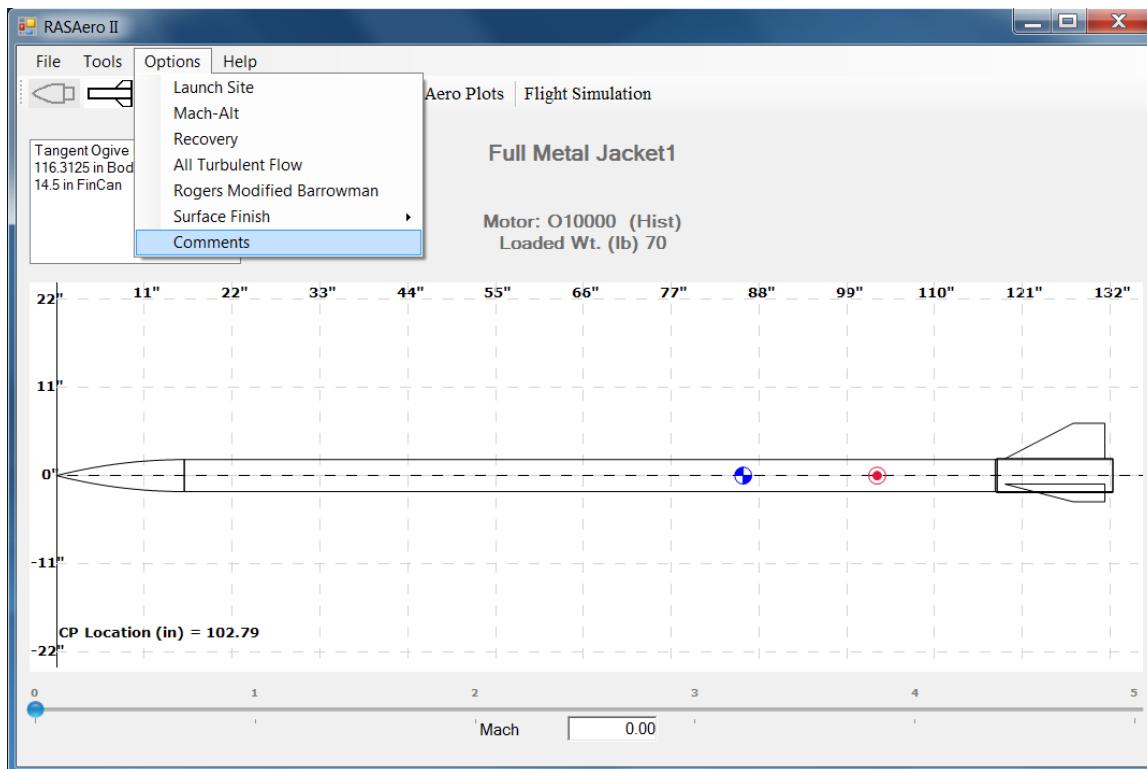


Figure 99 – Selecting Comments inputs under the Options Tab.

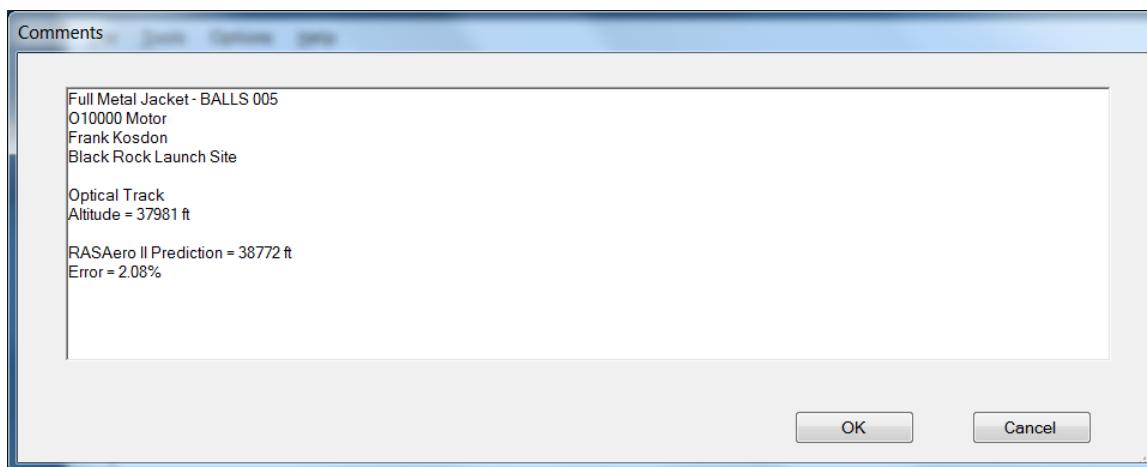


Figure 100 – Rocket Comments input screen.

## **Other Inputs**

### **Mach-Alt Input for Matching Wind Tunnel or Flight Data Reynolds Number**

The RASAero II aerodynamic predictions which are displayed on the Aero Plots screen output and are included in the Run Test output file (described in the next section) are based on the rocket Reynolds number as a function of Mach number calculated at sea level. When making comparisons with wind tunnel data and flight data where there is a specified Reynolds number that goes with each test condition or flight condition Mach number, the Mach-Alt function in RASAero II allows the user to specify a particular altitude for a particular Mach number, with linear interpolation between the Mach-Altitude points, so that the rocket aerodynamics are predicted using the correct Reynolds number at each Mach number test point. The Mach-Alt option is only used with Run Test, and is typically used to do comparisons with wind tunnel data to match the Reynolds number for a particular Mach number from the wind tunnel tests.

Note that the Mach-Alt input only affects the altitude and Reynolds number used when generating the Run Test output file. It has no effect on flight simulation runs.

For rocket flight simulation runs, the Mach number at the beginning of the time step, and the altitude of the rocket at the beginning of the time step, are always used to calculate the rocket Reynolds number. The Mach-Alt input has no effect on the rocket flight simulation runs, and no entry is required in the Mach-Alt input to perform flight simulation runs.

The Mach-Alt option can be selected under the Options Tab on the RASAero II Main Screen, as shown in Figure 101. After the Mach-Alt option is selected, the Mach-Alt input screen will appear, as shown in Figure 102.

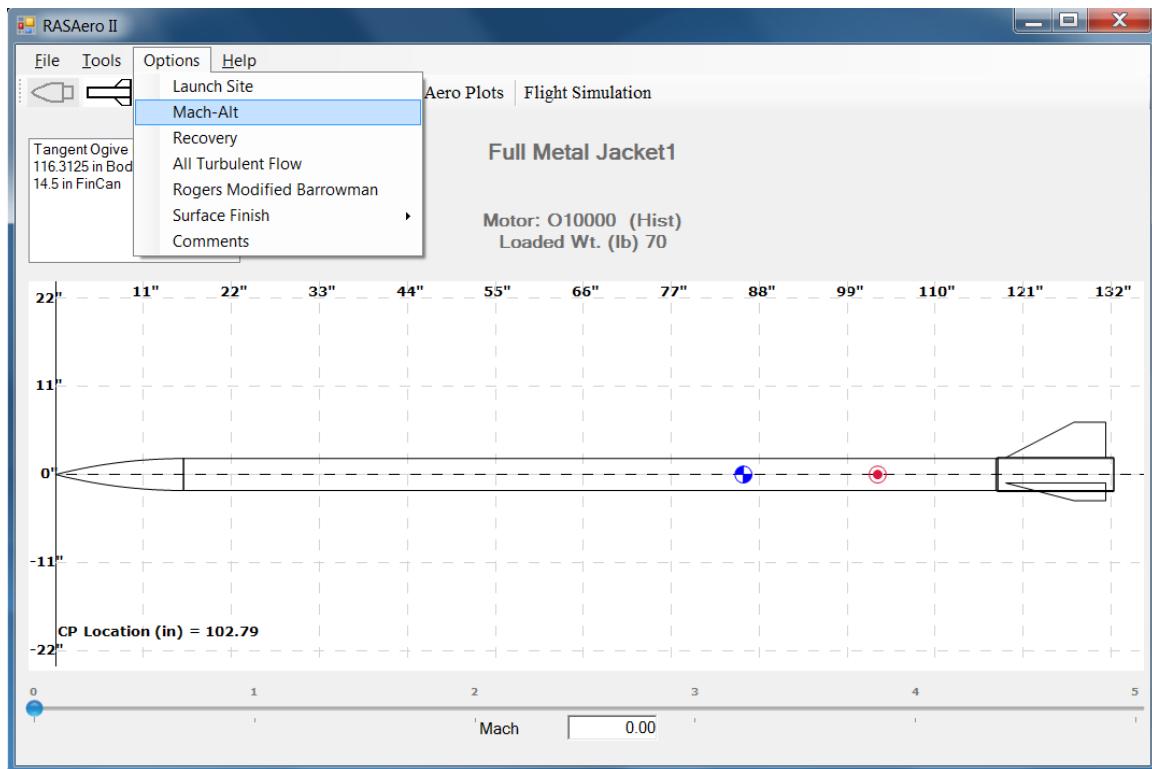


Figure 101 – Selecting Mach-Alt option under the Options Tab.

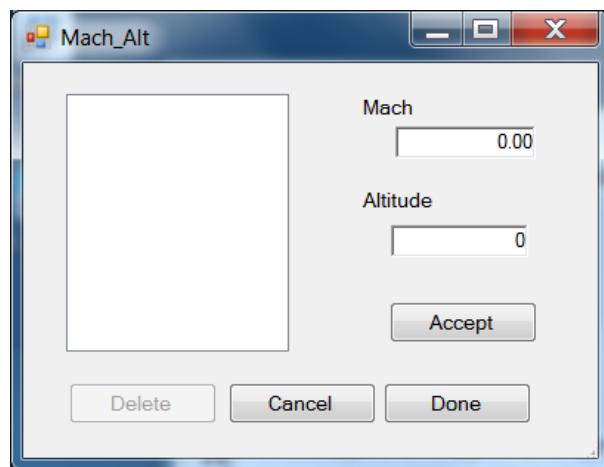


Figure 102 – Mach-Alt input screen.

Figure 103 shows a typical entry of Mach-Altitude on the Mach-Alt input screen, in this case to match the Reynolds number at several Mach number points along the trajectory of a sounding rocket. The first Mach-Alt point is always at Mach 0, and the final Mach-Alt point is always at Mach 25.

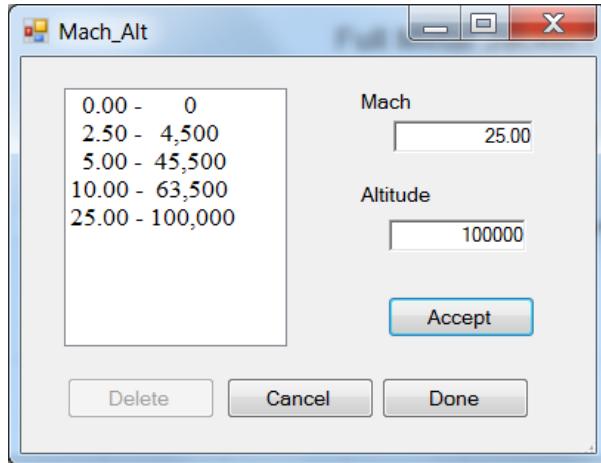


Figure 103 – Typical Mach-Alt input.

After the Mach-Alt points have been entered, the Reynolds number at each Mach number can be checked in the tabular output on the Aero Plots output screen (Reynolds number is to the far right), or in the Run Test file output. For a given Mach number a lower altitude increases Reynolds number, a higher altitude decreases Reynolds number.

Note that the default is no Mach-Alt points are entered, and for the Aero Plots output screen and tabular output and the Run Test output file the rocket aerodynamic predictions are run with the Reynolds number calculated at sea level.

For the rocket flight simulation runs, the Mach number at the beginning of the time step, and the altitude of the rocket at the beginning of the time step, are always used to calculate the rocket Reynolds number. The Mach-Alt input has no effect on the rocket flight simulation runs, and no entry is required in the Mach-Alt input to perform flight simulation runs.

## Run Test

In the Aero Plots output screen, the tabular output for the rocket aerodynamic predictions are presented for 0, 2, and 4 degrees angle of attack. To generate aerodynamic predictions for the rocket at any angle of attack between 0 deg and 15 deg, the Run Test option can be used.

The Run Test option can be selected under the Tools Tab on the RASAero II Main Screen, as shown in Figure 104. After the Run Test option is selected, the Run Test input screen will appear, as shown in Figure 105 for a single stage rocket, and Figure 106 for a two stage rocket.

In the Run Test input screen, a user-selected angle of attack can be specified and a tabular output file for the aerodynamic prediction run will be created when the user clicks on <Run Test>.

Note for a two stage rocket as shown in Figure 106, the User can select to run with both stages (Sustainer plus Booster), or Sustainer only. The aerodynamic data will be generated for the Sustainer plus Booster, or Sustainer only, based on the selection.

For single stage and two stage (and three stage) rockets, it is important to have the correct nozzle exit diameter for each stage to get the correct power-on drag coefficient (CD) for each stage. The nozzle exit diameter for each stage should copy over from the Flight Simulation input screen (covered in a later section), but the User may have changed the rocket motors selected, so it is a good idea to confirm that the correct nozzle exit diameters are present before running the aero data using Run Test.

The Run Test output file name can be entered on the file name line shown in Figure 105 and Figure 106, or the <Browse> button can be used to locate the directory the file will be stored in and to enter the file name, as shown in Figure 107. The default directory for the Run Test output file is the /My Documents/RASAero II directory. Typically the Run Test output file is stored as a Text file (.txt), and can be read using the WordPad or NotePad programs, although as shown in Figure 107 the Run Test output file can be stored in various file formats with various file extensions.

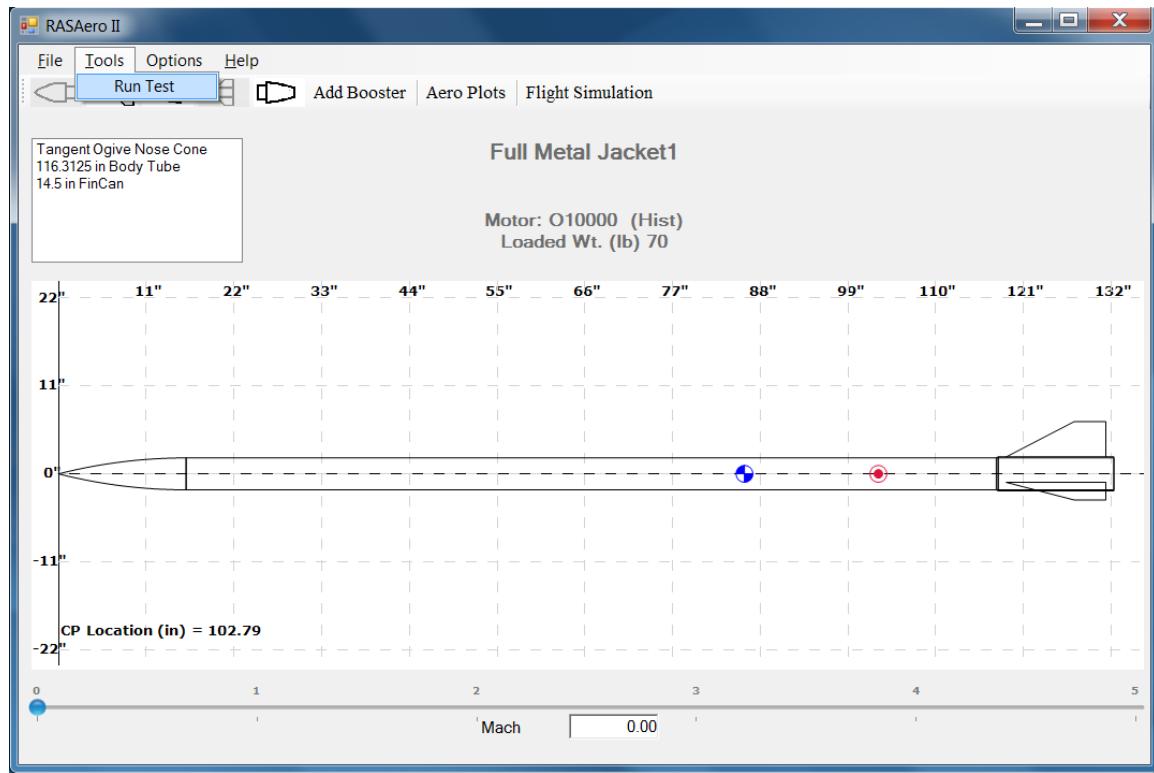


Figure 104 – Selecting the Run Test option under the Tools Tab.

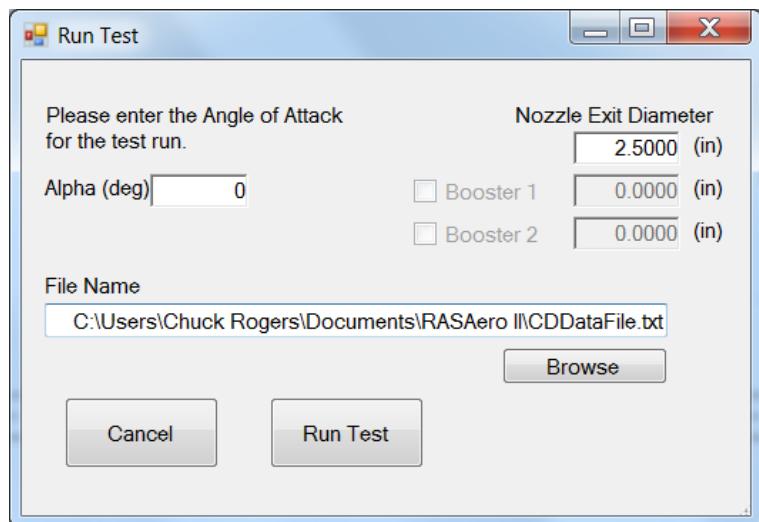


Figure 105 – Run Test input screen for a single stage rocket.

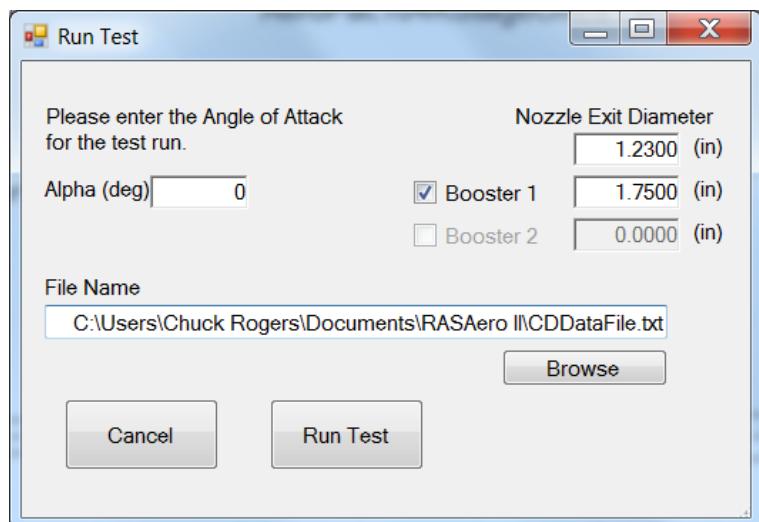


Figure 106 – Run Test input screen for a two stage rocket.

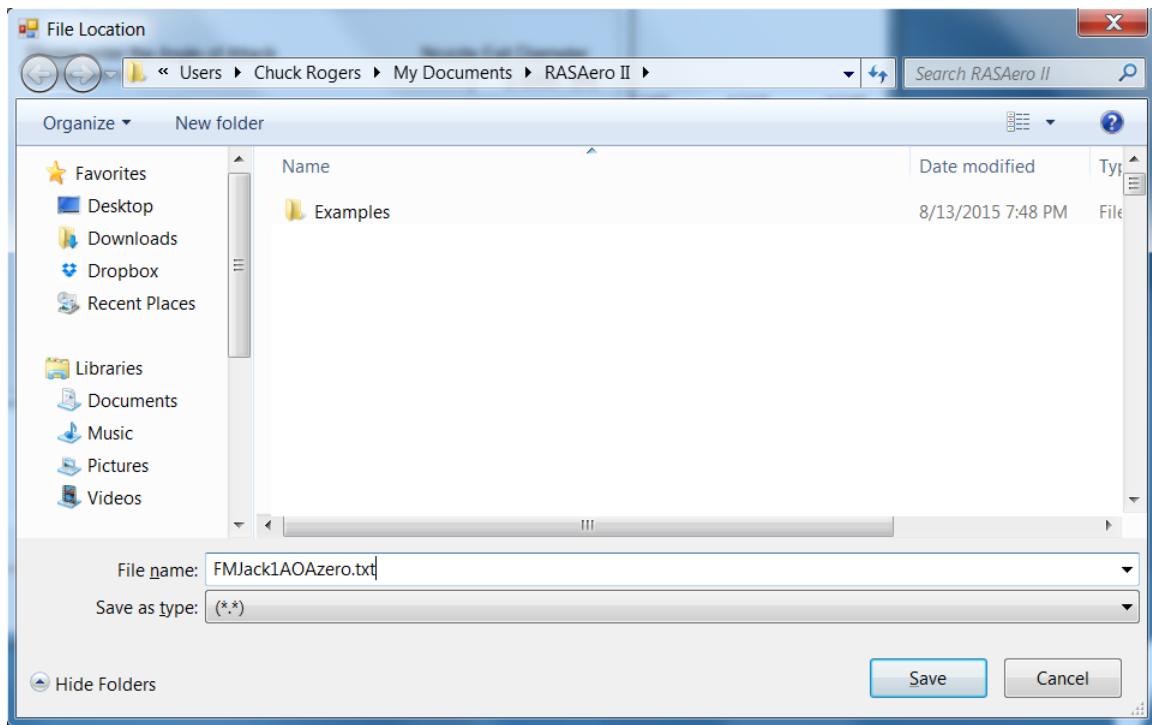


Figure 107 – Using the Browse-Save File option to locate the directory and set the file name and extension for the Run Test output file.

Using the Run Test option the rocket will be run to Mach 25 at the angle of attack that was specified. The Run Test output also provides additional breakdown in the components of the aerodynamic drag and normal force of the rocket. The rocket aerodynamic drag by rocket component and by drag type, potential and viscous normal force, and the power-on and power-off lift and drag and axial force and normal force of the rocket are included in the Run Test output file, as shown in Figure 108.

Subsonic  
Mach 0.01 to 0.90

Mach	Alpha	CD	CD	Body	Body	Body	Fin	Fin	Fin	Pro-	Reynolds	No
	deg	Power	Power	Frikt	Press	Base	Frikt	Inter-	Base	tuber-		ance
		Off	On				&Press	ference				
0.50	0.00	0.481	0.459	0.306	0.026	0.057	0.050	0.042	0.000	0.000	39146410	
Mach	CN	CP										
	Alpha	0-4										
	0-4	deg										
Mach	Alpha	CN	CN									
	deg	Potent-	Viscous									
		ial										
Mach	Alpha	CN	CP									
	deg	Total	Total									
Mach	Alpha	CL	CD	CN	CA							
	deg	Power	Power	Power	Power							
		Off	Off	Off	Off							
Mach	Alpha	CL	CD	CN	CA							
	deg	Power	Power	Power	Power							
		On	On	On	On							
0.50	19.51	98.115										
0.50	3.50	1.028	0.143									
0.50	3.50	1.172	98.619									
0.50	3.50	1.140	0.553	1.172	0.482							
0.50	3.50	1.141	0.532	1.172	0.461							

Note: Protuberance CD is Total of Rail Guide, Launch Lug, Launch Shoe, Streamlined No Base Drag, Streamlined With Base Drag, and Inclined Flat Plate Protuberances, if present.

Figure 108 – Run Test output file format; rocket aerodynamic drag by rocket component and drag type, potential and viscous normal force, and power-on and power-off lift and drag and axial force and normal force.

Transonic  
Mach 0.91 to 1.04

Mach	Alpha	CD	CD	Reynolds	No
deg		Power	Power		
	Off	On			
0.95	0.00	0.554	0.513	74378180	
Mach	CN	CP			
Alpha	0-4				
0-4	deg				
Mach	Alpha	CN	CN		
deg		Potent-	Viscous		
		ial			
Mach	Alpha	CN	CP		
deg		Total	Total		
Mach	Alpha	CL	CD	CN	CA
deg		Power	Power	Power	Power
	Off	Off	Off	Off	Off
Mach	Alpha	CL	CD	CN	CA
deg		Power	Power	Power	Power
	On	On	On	On	On
0.95	19.94	101.059			
0.95	3.50	1.054	0.143		
0.95	3.50	1.198	101.600		
0.95	3.50	1.162	0.628	1.198	0.556
0.95	3.50	1.164	0.587	1.198	0.515

Figure 108 – Run Test output file format (continued).

Supersonic-Hypersonic  
Mach 1.05 to Mach 25

Mach	Alpha	CD	CD	Body	Nose	Body	Fin	Fin	Fin	Fin	Other	Pro-	Reynolds	No
	deg	Power	Power	Frict	Cone	Base	Frict	Wave	Inter-	Base	Body	tuber-		
		Off	On		Wave				ference	Drag	Wave	ance		Drag
2.00	0.00	0.631	0.572	0.189	0.059	0.163	0.037	0.067	0.031	0.000	0.084	0.000	156585600	
Mach	CN	CP												
	Alpha	0-4												
0-4		deg												
Mach	Alpha	CN	CN											
	deg	Potent-	Viscous											
Mach	Alpha	CN	CP											
	deg	Total	Total											
Mach	Alpha	CL	CD	CN	CA									
	deg	Power	Power	Power	Power									
		Off	Off	Off	Off									
Mach	Alpha	CL	CD	CN	CA									
	deg	Power	Power	Power	Power									
		On	On	On	On									
2.00	20.64	105.712												
2.00	3.50	1.131	0.127											
2.00	3.50	1.258	105.798											
2.00	3.50	1.217	0.709	1.258	0.633									
2.00	3.50	1.221	0.650	1.258	0.575									

Note: Other Body Wave Drag CD is Wave Drag of Transition Sections, Reducers, Fin Canisters, and Boattails, if present. It is the part of the Body Wave Drag that is not Nose Cone Wave Drag, which is printed out in a separate column.

Note: Protuberance CD is Total of Rail Guide, Launch Lug, Launch Shoe, Streamlined No Base Drag, Streamlined With Base Drag, and Inclined Flat Plate Protuberances, if present.

Figure 108 – Run Test output file format (concluded).

## RASAero II Rocket Motor Database

An extensive selection of currently produced model and high power rocket motors is included in the RASAero II motor selection menu. Some historical rocket motors marked with (Hist) are also included, for comparison of the RASAero II flight simulation predicted altitude with historical optical tracking and barometric altimeter altitude data.

RASAero II uses the RASP motor file format. The RASP motor file can be found in the /My Documents/RASAero II directory, with the file name rasp.eng.

Advanced users familiar with the RASP motor file format can add rocket motor data from other sources, or input their own rocket motor data, in particular for rocket motors they have developed and built themselves in programs like the Tripoli EX (Tripoli Research) program. The new rocket motor data can be appended at the end of the rasp.eng file, and the rocket motor will show up in the motor selection menu in alphabetical order.

The RASAero II authors recommend that before editing the rasp.eng file, that the user saves a copy of the original rasp.eng file in a separate directory in case the file is corrupted during editing. The RASAero II authors recommend that the original version of the rasp.eng file, and subsequent versions of the file, be archived as new rocket motors are appended to the file.

For advanced users creating their own RASP format motor data the ThrustCurve.org web site (<http://www.thrustcurve.org/>) has detailed information on the RASP motor file format at <http://www.thrustcurve.org/raspformat.shtml>. The ThrustCurve.org web site also has extensive resources and applets for creating and manipulating RASP format motor files.

Rocket motor nozzle exit diameter is not saved with the RASP motor data (it is not part of the RASP motor data format), and is instead saved with the rocket stage (Booster or Sustainer) in the .CDX1 file.

The rocket motor nozzle exit diameter is not only used to determine the power-on drag coefficient (CD) for each stage, it is also used to vary the thrust with altitude for each stage.

RASAero II varies the thrust with altitude for the rocket motor in each stage based on the nozzle exit area of each stage calculated from the entered nozzle exit diameter, based on the assumption that the thrust curve data in the rasp.eng file is sea level thrust curve data. RASAero II then compares the atmospheric pressure at altitude from the Flight Simulation atmosphere model to sea level atmospheric pressure, and based on the nozzle exit area determines the increase in thrust at altitude.

Again, RASAero II assumes the thrust curve in the rasp.eng file is a sea level thrust curve. More sophisticated Users generating their own thrust curve data can correct their thrust stand thrust data to sea level to get more accurate altitude predictions from RASAero II.

## User-Selected RASP Motor File

If the user does not wish to use the default RASAero II RASP motor file (rasp.eng located in the /My Documents/RASAero II directory), then a user-selected RASP motor file can be selected by selecting Select Motor File under the File Tab on the RASAero II Main Screen, as shown in Figure 109. The motor file is then selected as shown in Figure 110 by clicking on the RASP motor file, and then <Open>, to select the motor file.

Note that the user does not have to select the default RASAero II RASP motor file (rasp.eng located in the /My Documents/RASAero II directory) the first time RASAero II is run. The first time RASAero II is run, the software will automatically load the default rasp.eng motor file, and will continue to load the default rasp.eng motor file for all subsequent runs unless Select Motor File is selected.

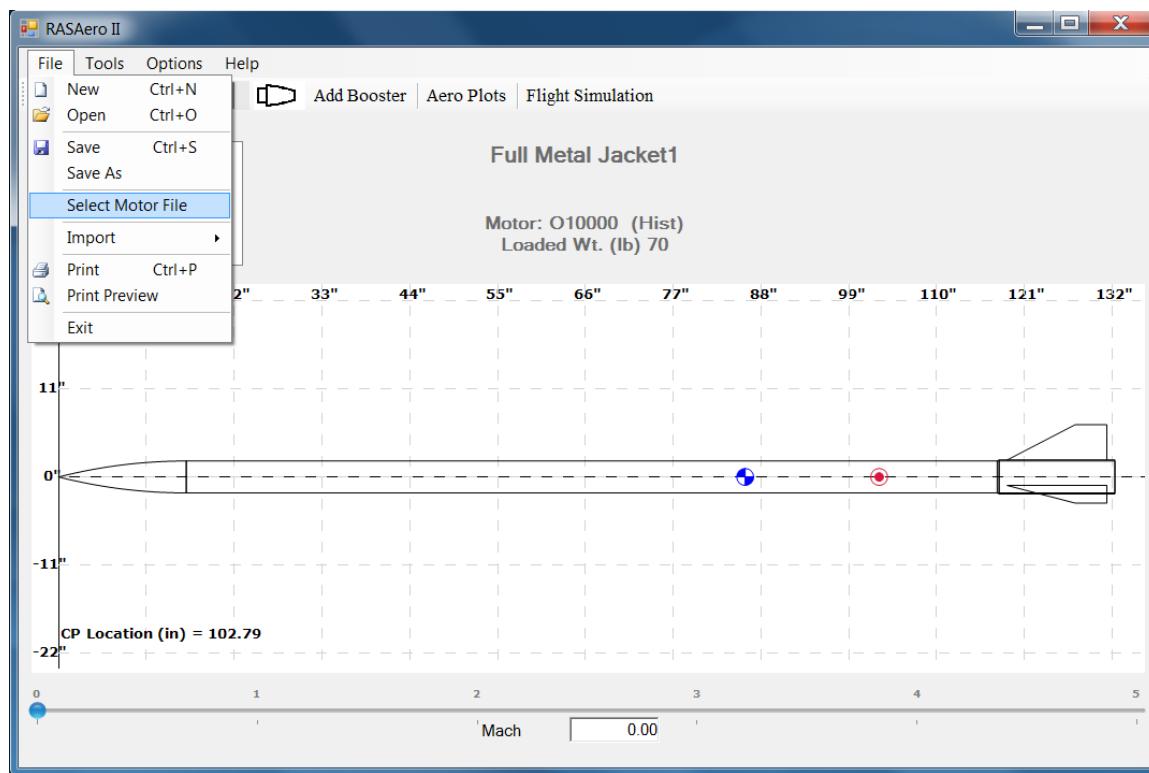


Figure 109 – Select Motor File for user-selected RASP motor file.

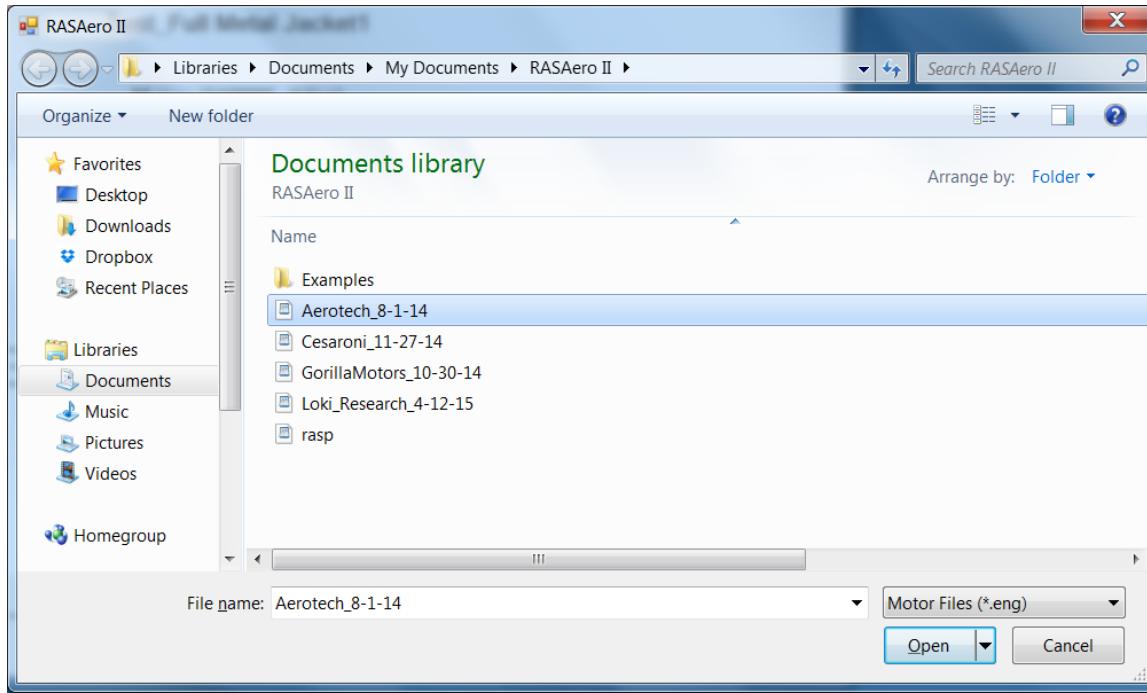


Figure 110 – Selecting the RASP motor file.

For selecting a RASP motor file RASAero II will first open the /My Documents/RASAero II directory, although by browsing other directories can be selected. User-selected RASP motor files can be located in and pulled from any directory, but the RASP motor file must remain in that directory to be found by RASAero II for subsequent Flight Simulation runs. If the RASP motor file is moved out of that directory, or if the directory itself is moved, then RASAero II will not be able to find the motor file, and the error message shown in Figure 111 will be displayed. Thus the user should consider keeping their user RASP motor files in the /My Documents/RASAero II directory, as the location of this directory will not change as long as RASAero II is installed.

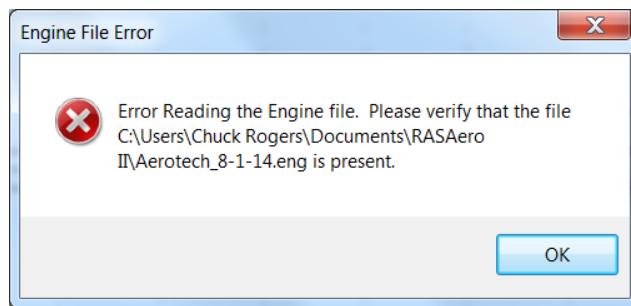


Figure 111 – Error from user-selected RASP motor file being moved from it's previous location.

### **Important Note**

If the user never uses Select Motor File to select a user-selected RASP motor file, RASAero II will always use the default RASAero II RASP motor file (rasp.eng located in the /My Documents/RASAero II directory). Once a user-selected RASP motor file is selected using Select Motor File, then that user-selected RASP motor file will be used for all subsequent RASAero II Flight Simulation runs until a new user-selected RASP motor file has been selected, or the original RASAero II RASP motor file (rasp.eng located in the /My Documents/RASAero II directory) is selected.

The user-selected RASP motor file is not saved with the rocket. The last RASP motor file used is used for all subsequent RASAero II Flight Simulation runs, until the RASP motor file selection is changed.

If a user-selected RASP motor file has been selected, and if the motor for a later rocket is not in that motor file, the error message shown in Figure 112 will be displayed.

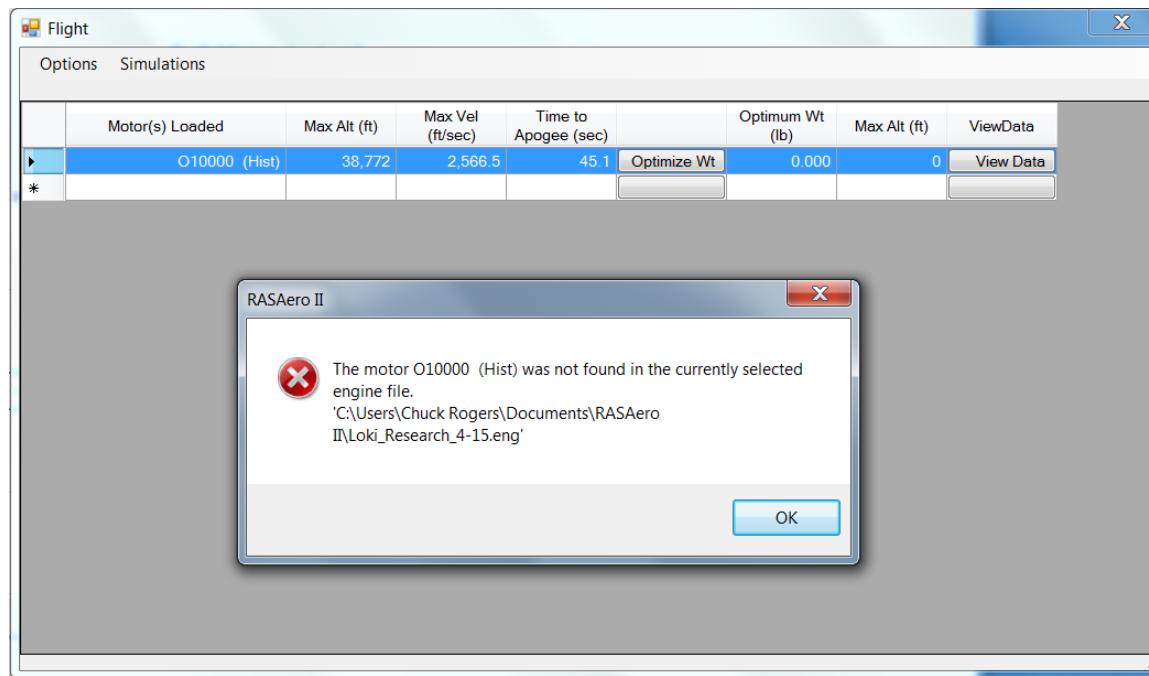


Figure 112 – Error from a later rocket needing a motor not in the last user-selected RASP motor file.

The user-selected RASP motor file needed by the rocket, or the default RASAero II rasp.eng RASP motor file if used by the rocket, will then need to be selected for the rocket Flight Simulation to be run.

### **Important Note**

Note that rather than loading in different user-selected RASP motor files, the user can add the desired rocket motor data to the default RASAero II rasp.eng file (located in the /My Documents/RASAero II directory), by appending the motor data at the end of the rasp.eng file. Then Select Motor File never needs to be used, all of the motor data will be in the default RASAero II rasp.eng file, which will automatically be selected for every RASAero II Flight Simulation run.

If a user-selected RASP motor file has previously been selected, and the user wishes to return to the default RASAero II rasp.eng file (located in the /My Documents/RASAero II directory), then the default rasp.eng file can be selected by using Select Motor File as shown in Figure 113, after which the default rasp.eng file will be used for all subsequent RASAero II Flight Simulation runs.

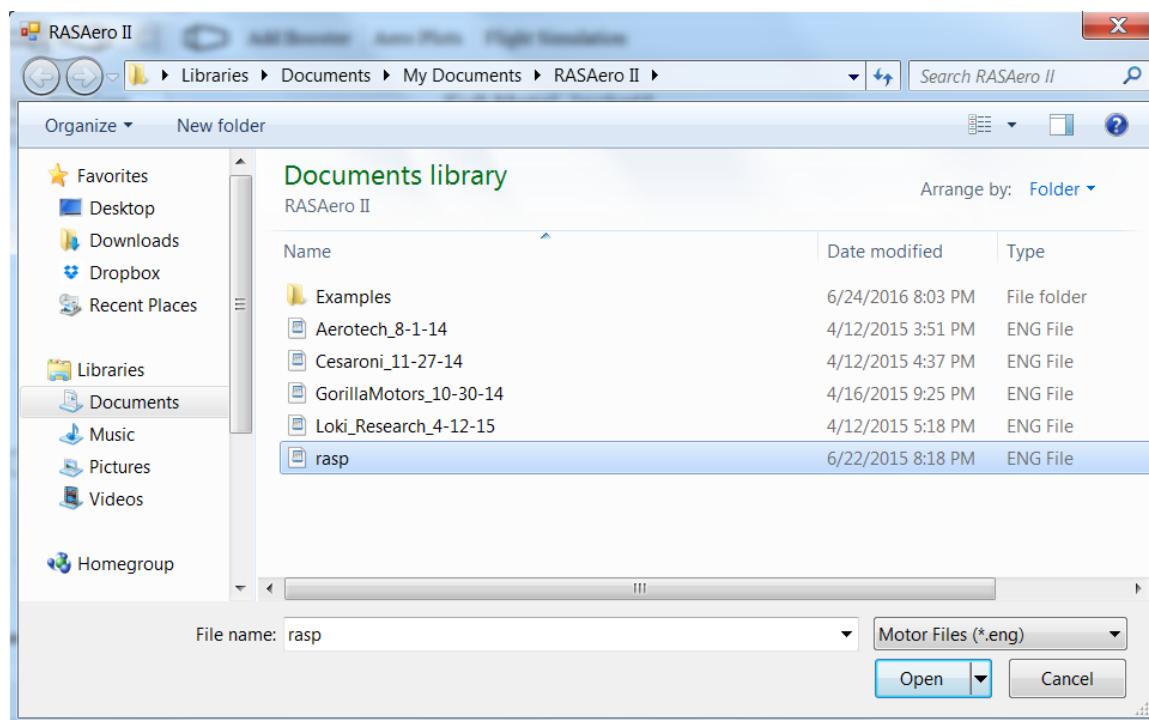


Figure 113 – Using Select Motor File to select the default RASAero II rasp.eng RASP motor file.

## Running the RASAero II Flight Simulation

To run the RASAero II Flight Simulation for the rocket, the first step is to click on the Flight Simulation button shown in Figure 114. After clicking on the Flight Simulation button, the Flight Screen will be displayed as shown in Figure 115. The Flight Screen shown in Figure 115 is for a single stage rocket.

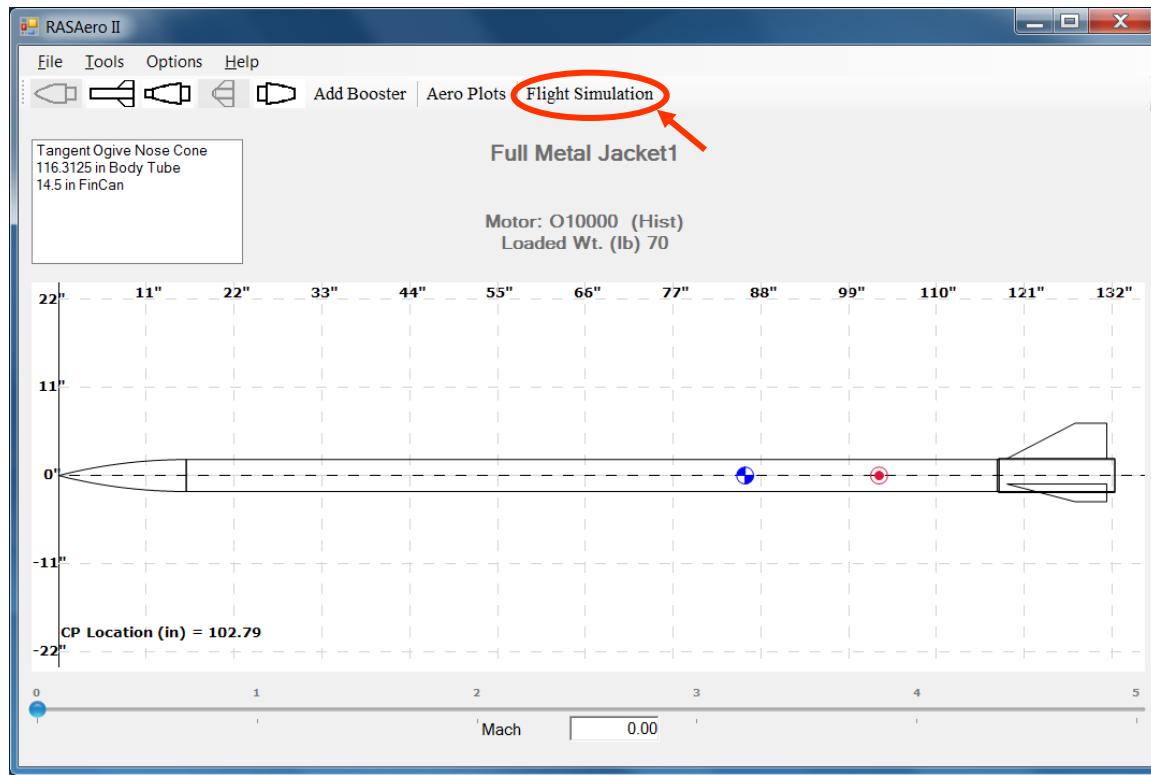


Figure 114 – Flight Simulation button for accessing Flight Screen and running Flight Simulation.

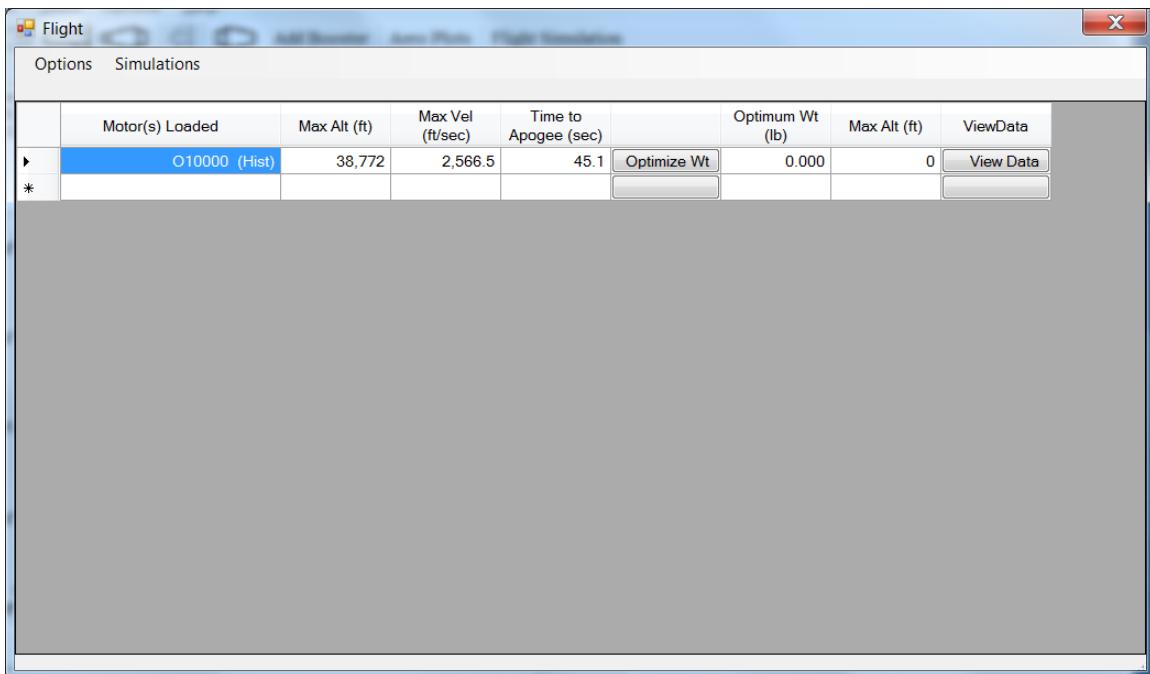


Figure 115 – Flight Screen for running Flight Simulation for a single stage rocket.

To open the motor selection for the rocket, and to enter the lift-off weight, lift-off center of gravity (CG), and nozzle exit diameter, as shown in Figure 116 the User must double click on the Motor(s) Loaded cell to access the FlightDataEntry Screen.

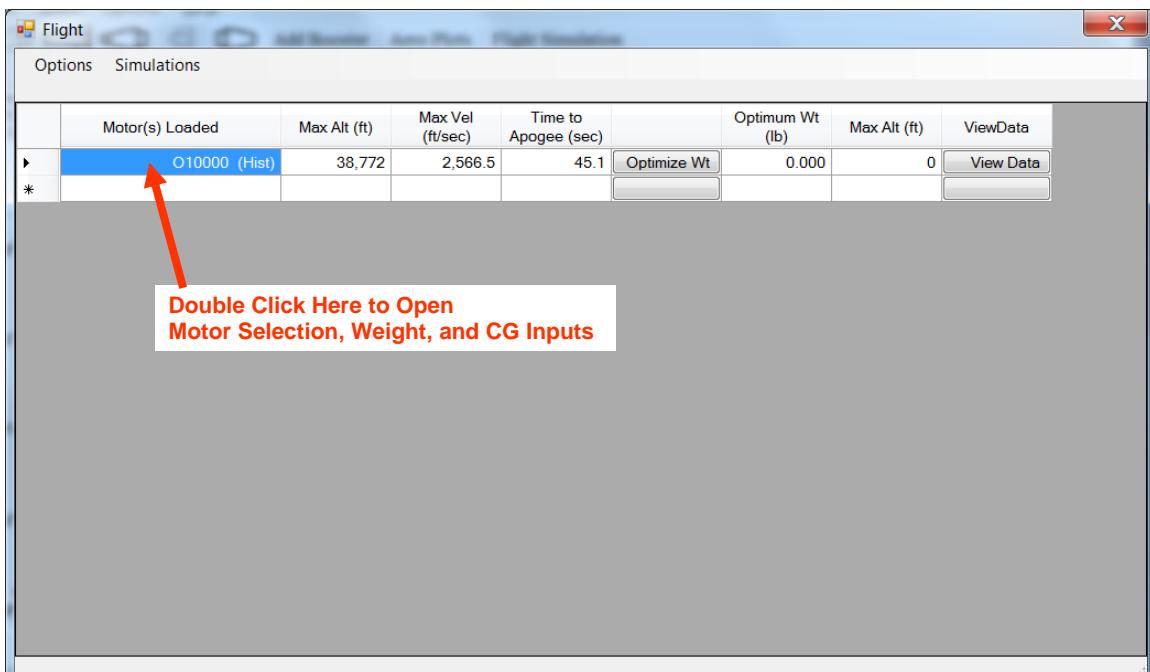


Figure 116 – Double clicking on Motor(s) Loaded cell to access FlightDataEntry Screen to enter motor selection, lift-off weight, lift-off center of gravity (CG), and nozzle exit diameter.

The FlightDataEntry Screen for entering the motor selection, and for entering the lift-off weight, lift-off center of gravity (CG), and nozzle exit diameter inputs, shown for a single stage rocket, is presented in Figure 117.

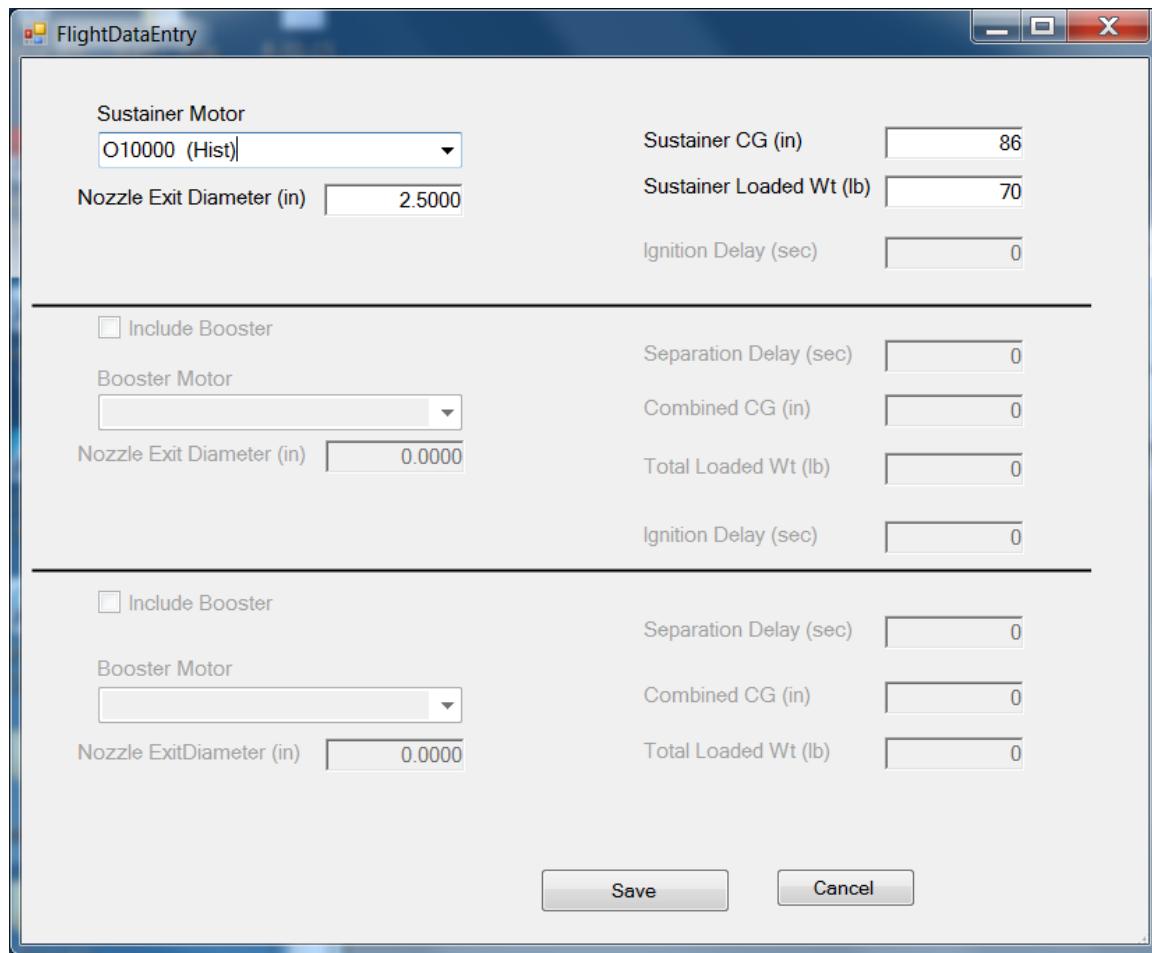


Figure 117 – FlightDataEntry Screen for entering motor selection, lift-off weight, lift-off center of gravity (CG), and nozzle exit diameter, for a single stage rocket.

The Sustainer CG (in) and Sustainer Loaded Wt (Weight) lb inputs on the FlightDataEntry Screen in Figure 91 are the lift-off center of gravity (CG) and the lift-off weight. As this is a single stage rocket, the Sustainer stage is the only stage, the Sustainer stage is the rocket.

The rocket motor for the rocket is selected on the FlightDataEntry Screen using the pull-down motor selection menu as shown in Figure 118 for a single stage rocket.

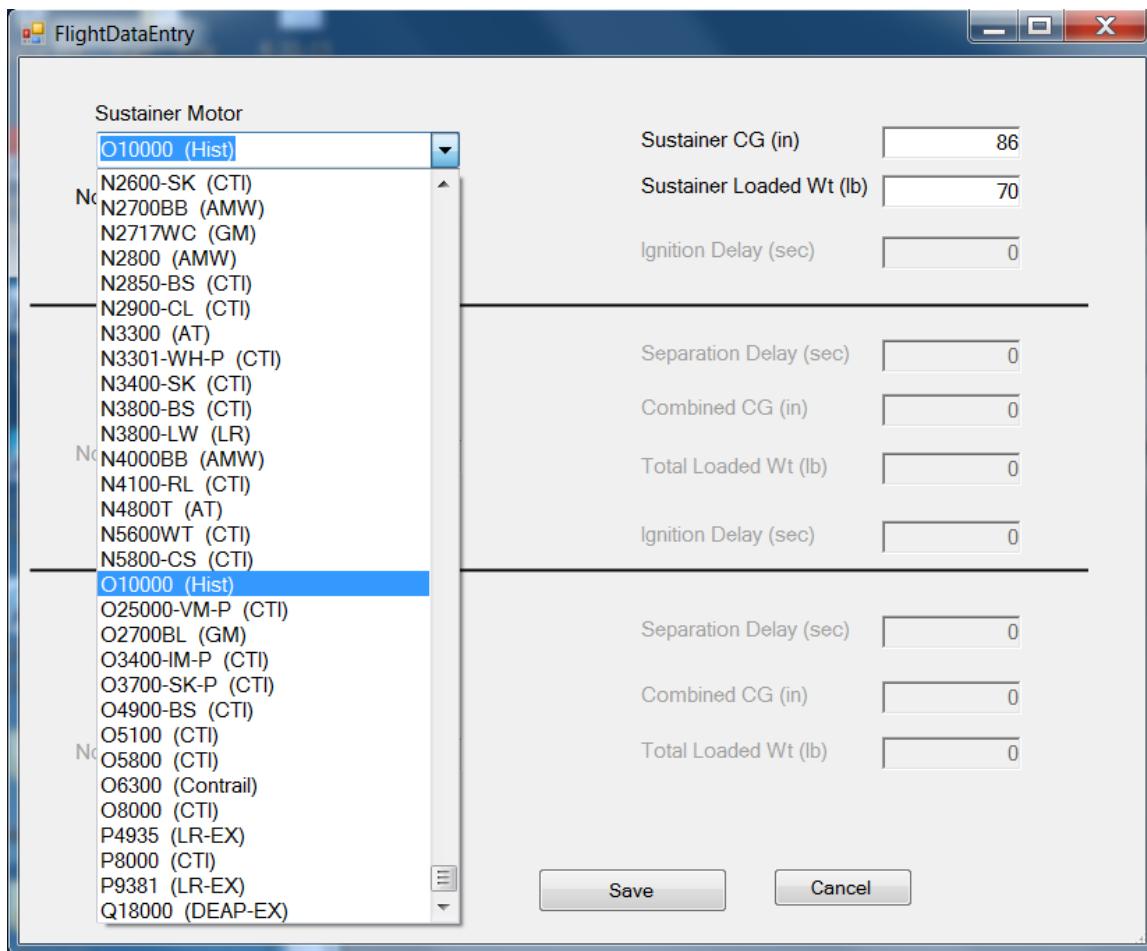


Figure 118 – Rocket motor selection menu for selecting a rocket motor for the rocket.

Note as shown in Figure 119 that once a rocket motor has been selected, and the FlightDataEntry Screen is Saved, the rocket motor will appear in the Motor(s) Loaded cell on the Flight Screen.

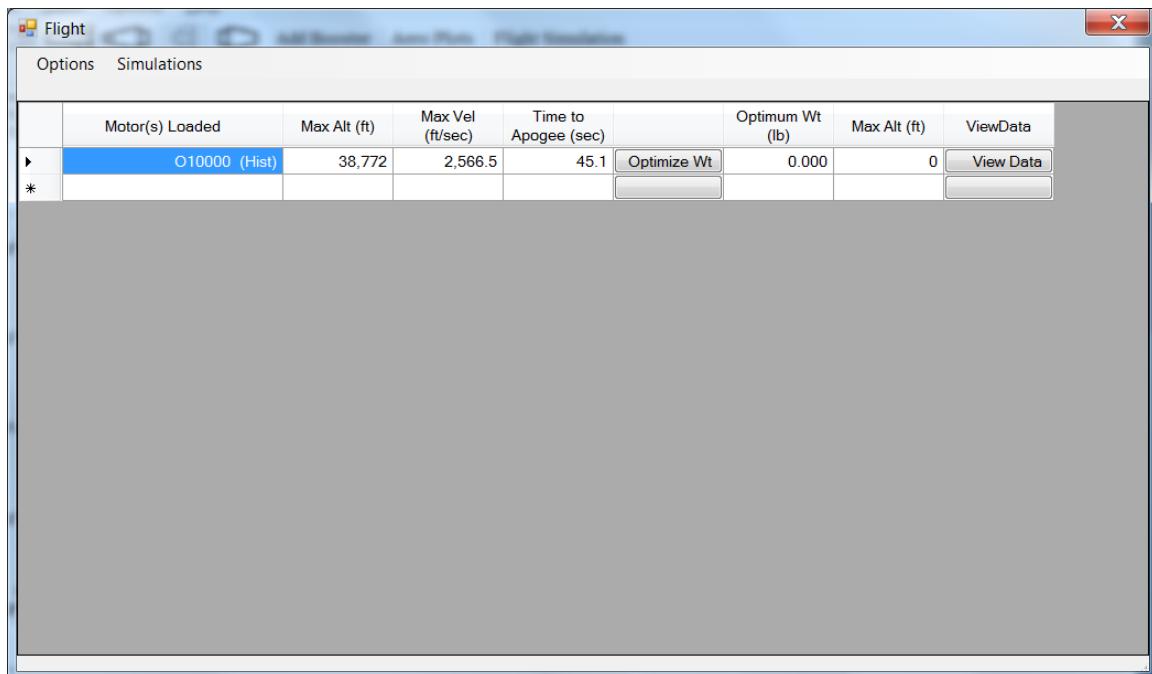


Figure 119 – Motor successfully loaded, now appears in Motor(s) Loaded cell on Flight Screen.

The Flight Screen for a two stage rocket is shown in Figure 120. Note that two motors are displayed in the Motor(s) Loaded cell, as this is a two stage rocket. The left motor is the Sustainer motor, the right motor is the Booster motor.

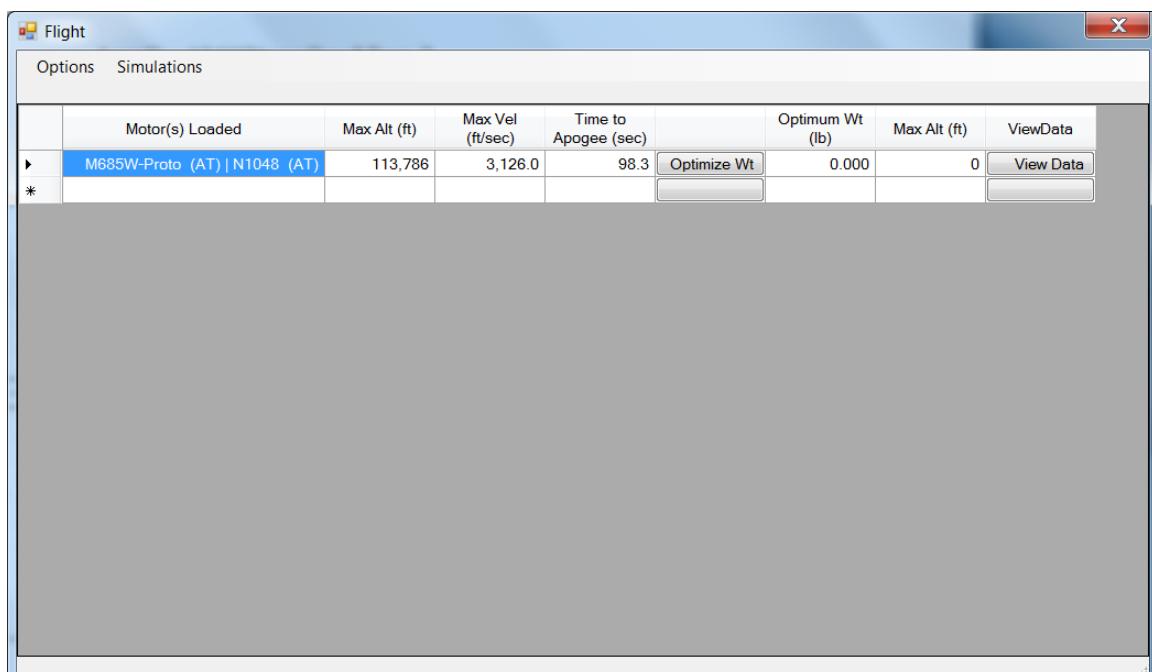


Figure 120 – Flight Screen for a two stage rocket, with two motors in the Motor(s) Loaded cell.

Figure 121 shows the FlightDataEntry Screen for a two stage rocket, with Sustainer and Booster motor selection and nozzle exit diameter, Sustainer and Booster lift-off weight and lift-off center of gravity (CG), and the separation delay on the Booster and ignition delay on the Sustainer. The separation delay on the Booster allows the User to specify that the Booster and Sustainer will coast together for the specified number of seconds after Booster burnout before the Booster separates. The Sustainer ignition delay is the time delay after the Booster separates, where the Sustainer by itself coasts, before the Sustainer motor is ignited. Including the Booster separation delay and the Sustainer ignition delay allows various delay staging strategies to be implemented for increased altitude.

Note in Figure 121 that if the User does not want to include the Booster, and wants to fly the Sustainer as a single stage rocket, the Include Booster box can be un-checked, and the rocket will be flown as a single stage rocket using the Sustainer.

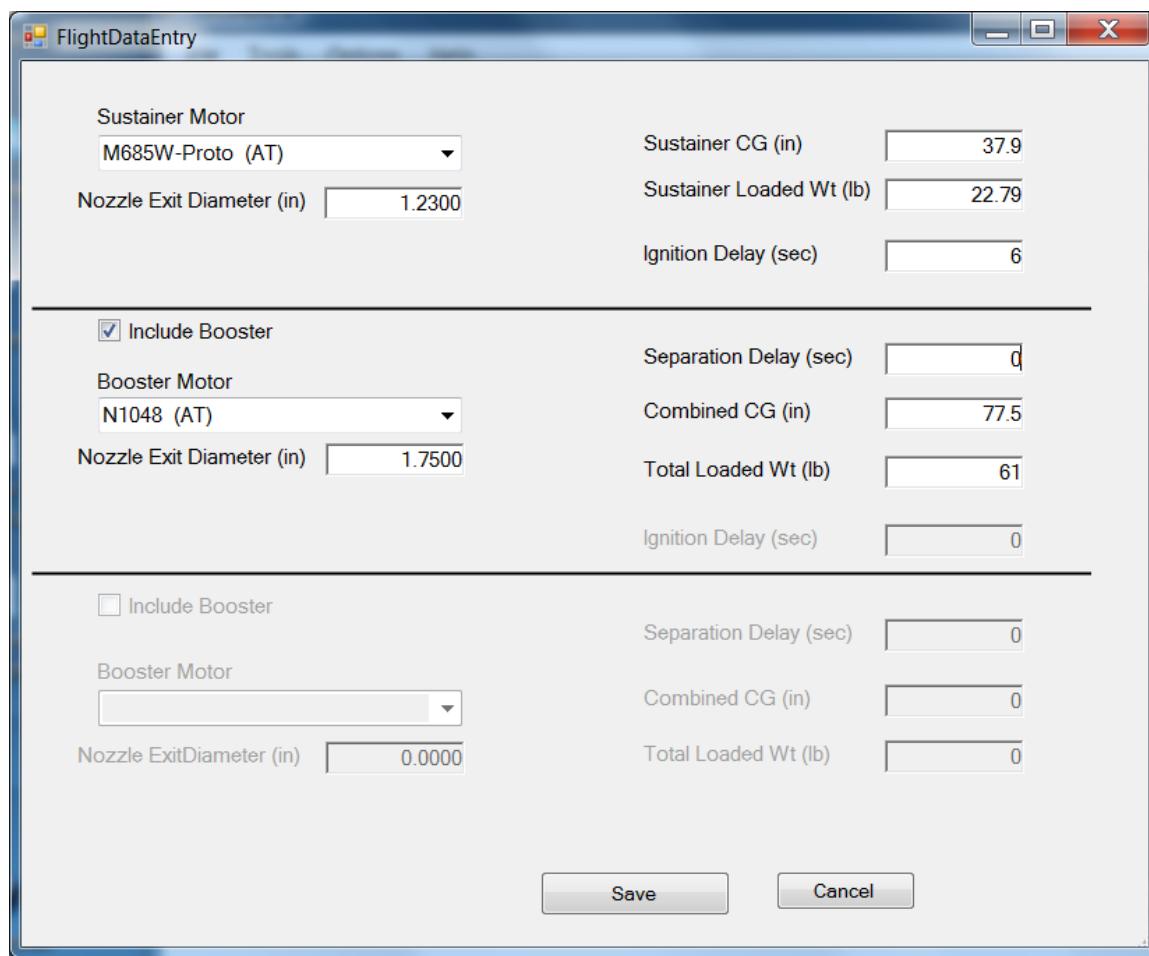


Figure 121 – FlightDataEntry Screen for a two stage rocket, with Sustainer and Booster motor selection and nozzle exit diameter, Sustainer and Booster lift-off weight and lift-off center of gravity (CG), separation delay on the Booster and ignition delay on the Sustainer.

The Launch Site Inputs and Recovery Inputs, covered in earlier sections, can also be accessed from the Flight Screen, under the Options Tab, as shown in Figure 122. The Launch Site Inputs and Recovery Inputs Screens appear the same as when accessed from the Main Screen, and the inputs will be saved when the inputs on the Flight Screen are saved. Most RASAero II Users access the Launch Site Inputs and the Recovery Inputs from the Flight Screen under the Options Tab when running Flight Simulations from the Flight Screen.

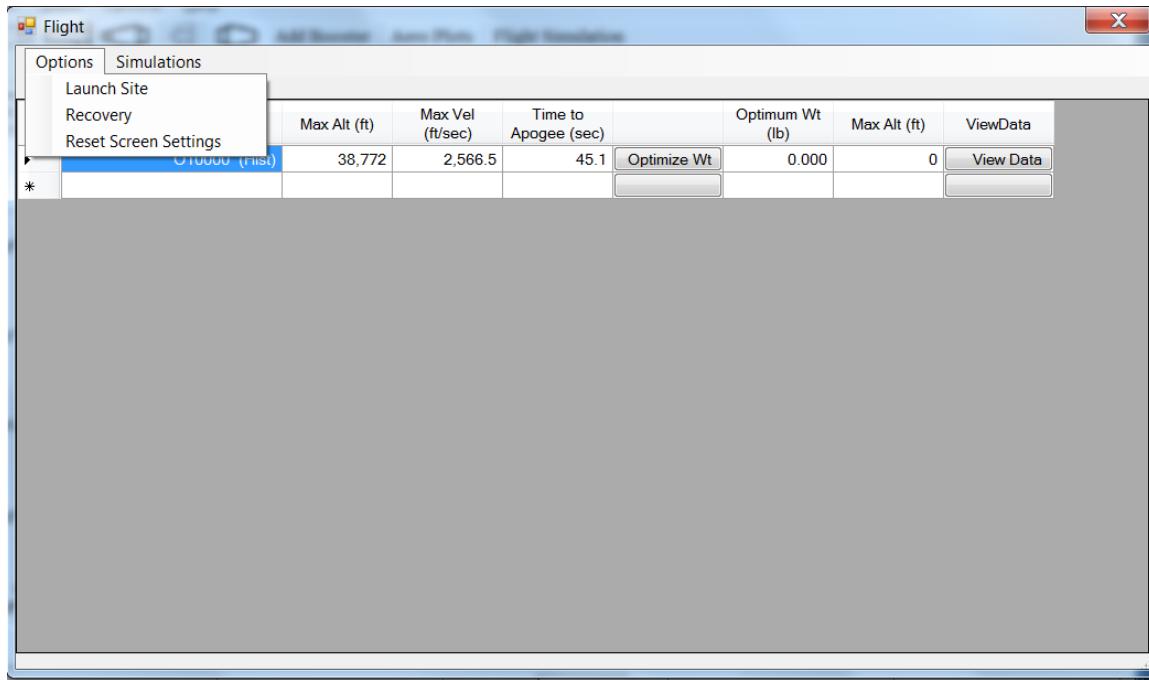


Figure 122 – Accessing the Launch Site Inputs and Recovery Inputs from the Flight Screen using the Options Tab.

The Flight Simulation is run by highlighting the line of the specific Flight Simulation the User wants to run, and then under the Simulations Tab, selecting Rerun Selected Simulation as shown in Figure 123.

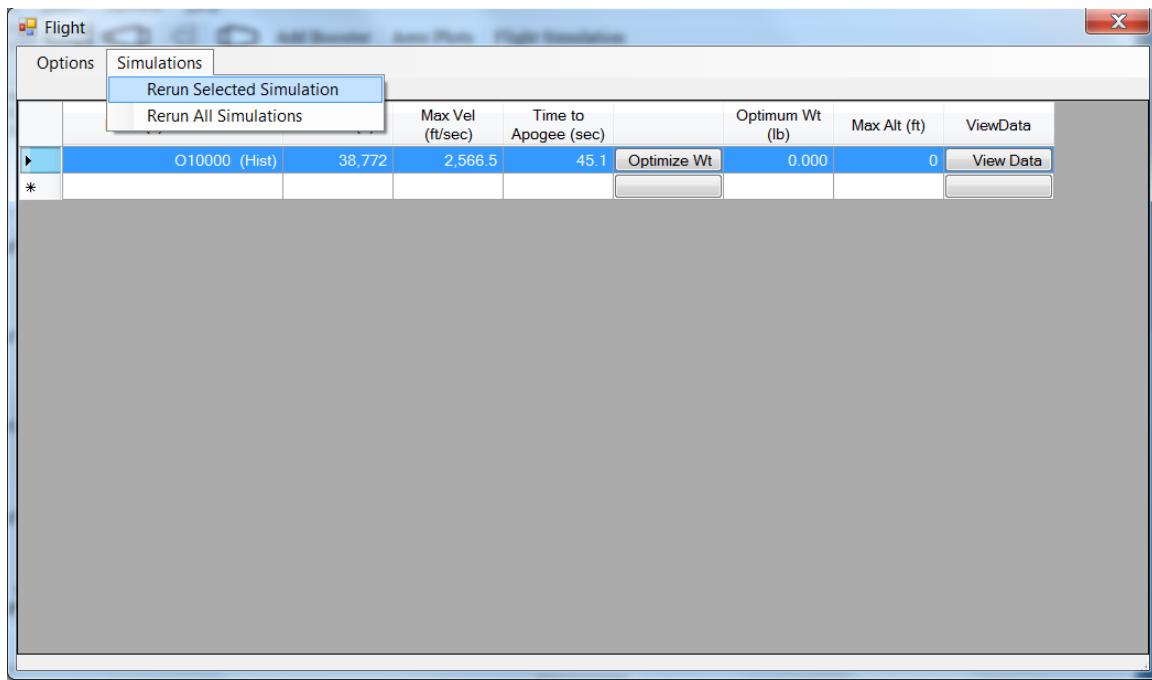


Figure 123 – Running the Flight Simulation for the rocket by selecting Rerun Selected Simulation under the Simulations Tab.

With the Flight Simulation completed, the summary flight data for the Flight Simulation is displayed as shown in Figure 124, and the Flight Simulation plots and tabular data can be accessed by clicking on the View Data button, as shown in Figure 124.

	Motor(s) Loaded	Max Alt (ft)	Max Vel (ft/sec)	Time to Apogee (sec)		Optimum Wt (lb)	Max Alt (ft)	ViewData
▶	O10000 (Hist)	38,772	2,566.5	45.1	Optimize Wt	0.000	0	<input type="button" value="View Data"/>
*								<input type="button" value="View Data"/>

Figure 124 – Summary flight data after running Flight Simulation, accessing plots and tabular data by clicking on View Data button.

The altitude plot and the Flight Simulation complete tabular data are then displayed, as shown in Figure 125. The Max Altitude of the rocket is always displayed beneath the title of the rocket on the altitude plot, and the additional plots which follow.

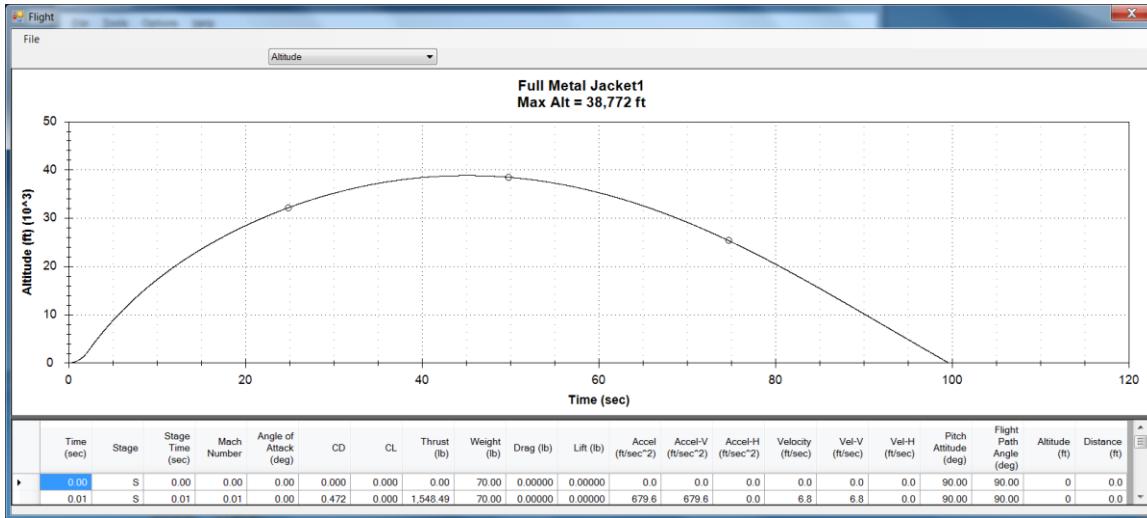


Figure 125 – Altitude plot and Flight Simulation tabular data after using View Data to display Flight Simulation plots and data for the rocket.

The tabular data includes all of the output variables from the Flight Simulation. The Flight Simulation output variables can be individually plotted as shown in Figure 126, by using the pull-down menu. All of the Flight Simulation variables in the tabular output can be plotted, as shown in Figure 126.

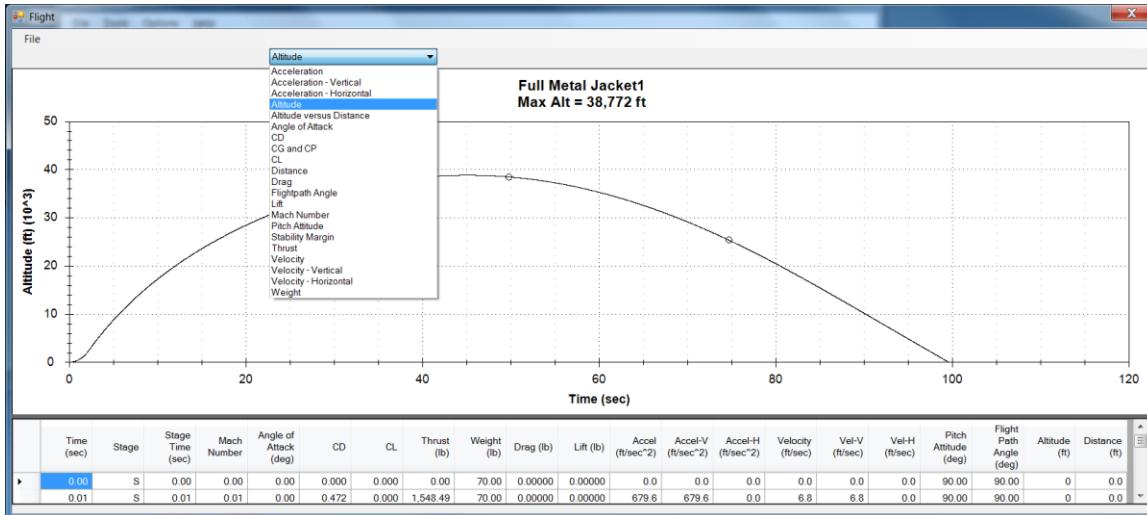


Figure 126 – Flight Simulation variables which can be plotted.

Some additional example Flight Simulation plots are presented in Figure 127-129. Figure 125, presented previously, presents the altitude versus time for an example rocket. Note that this particular example rocket has no recovery system, so the rocket flies a ballistic no recovery flight to impact. Figure 127 presents acceleration versus time, Figure 128 presents Mach number

versus time, and Figure 129 presents center of gravity (CG) and center of pressure (CP) versus time.

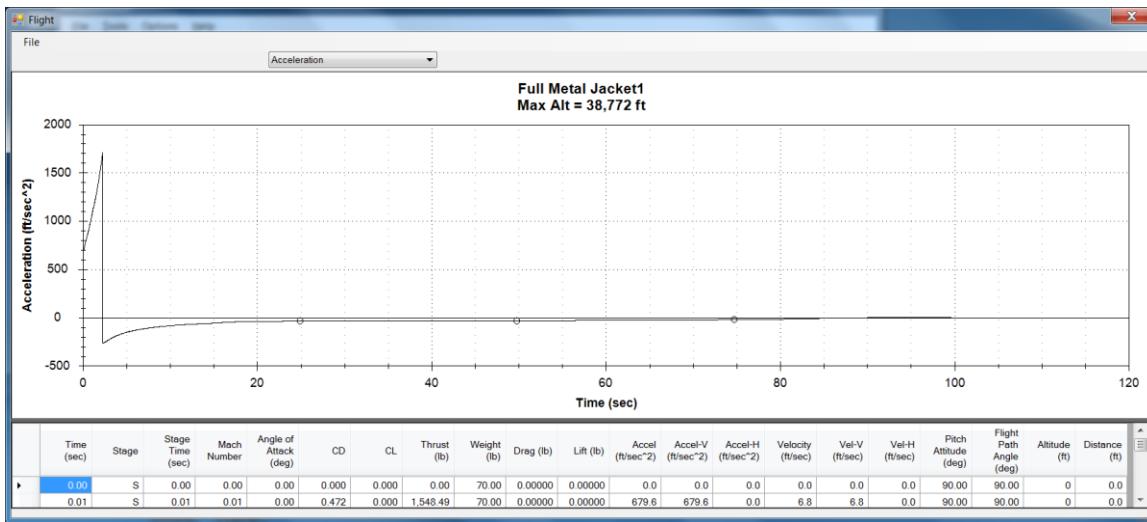


Figure 127 – RASAero II Flight Simulation output plot, acceleration versus time.

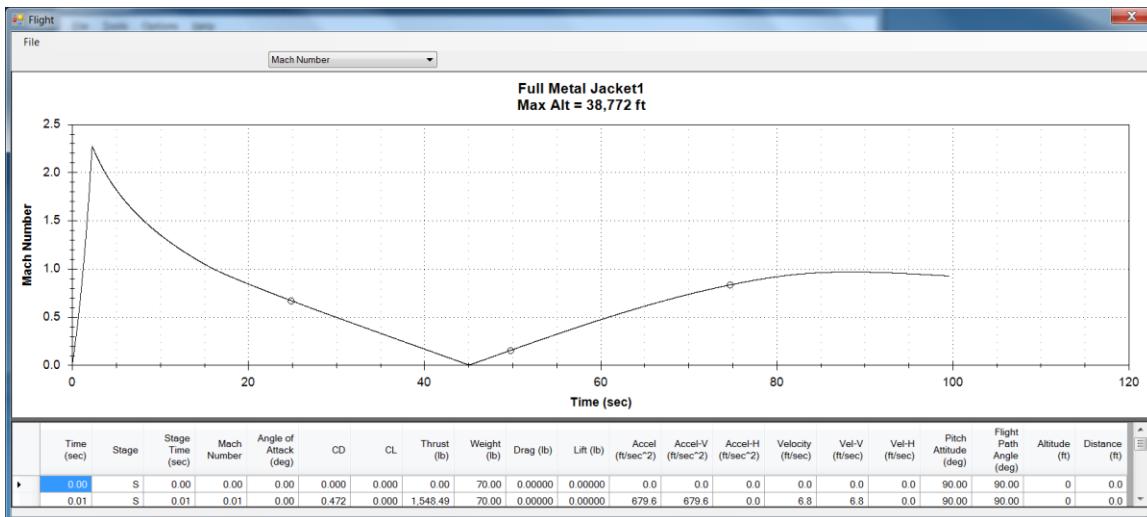


Figure 128 – RASAero II Flight Simulation output plot, Mach number versus time.

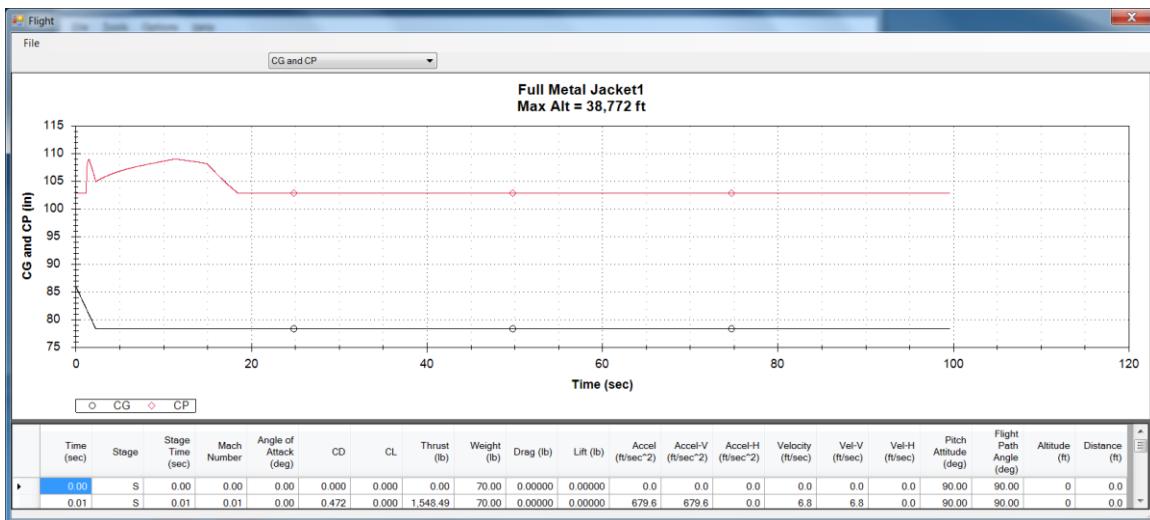


Figure 129 – RASAero II Flight Simulation output plot, center of gravity (CG) and center of pressure (CP) versus time.

By pressing <Alt> <Print Scrn> the RASAero II Flight Simulation output plot image can be copied for pasting into another file.

As shown in Figure 130, the Flight Simulation tabular output data can be exported to an Excel (.CSV) file by selecting <Export> and <To CSV> under <File> on the Flight Simulation output screen. As shown in Figure 131, when exporting to an Excel (.CSV) file, the user can select the time increment for the data in the file from the options of 0.01 sec (the default), 0.10 sec, 0.50 sec and 1.0 sec.

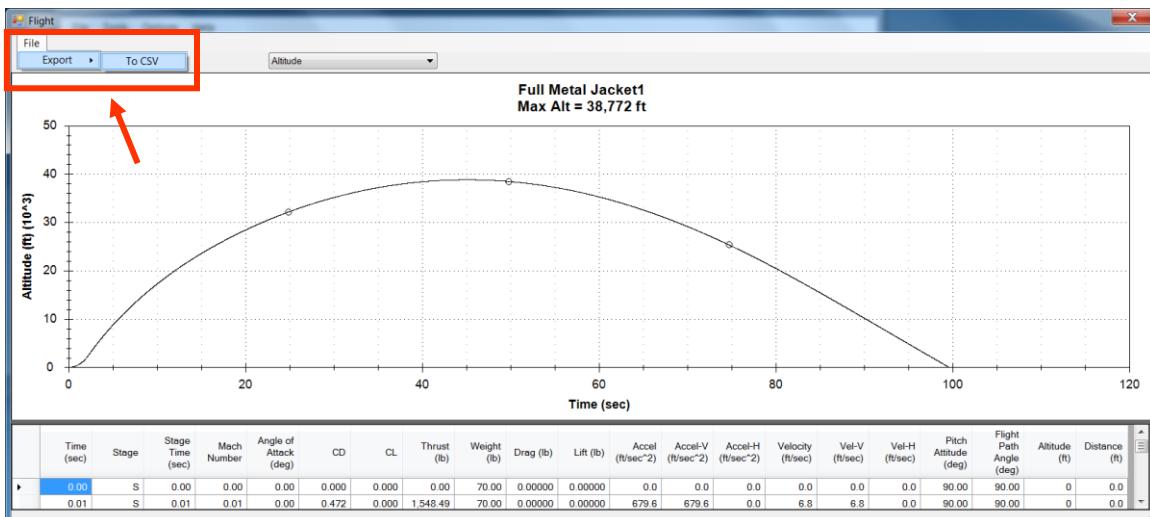


Figure 130 – Exporting the Flight Simulation tabular output data to an Excel file.

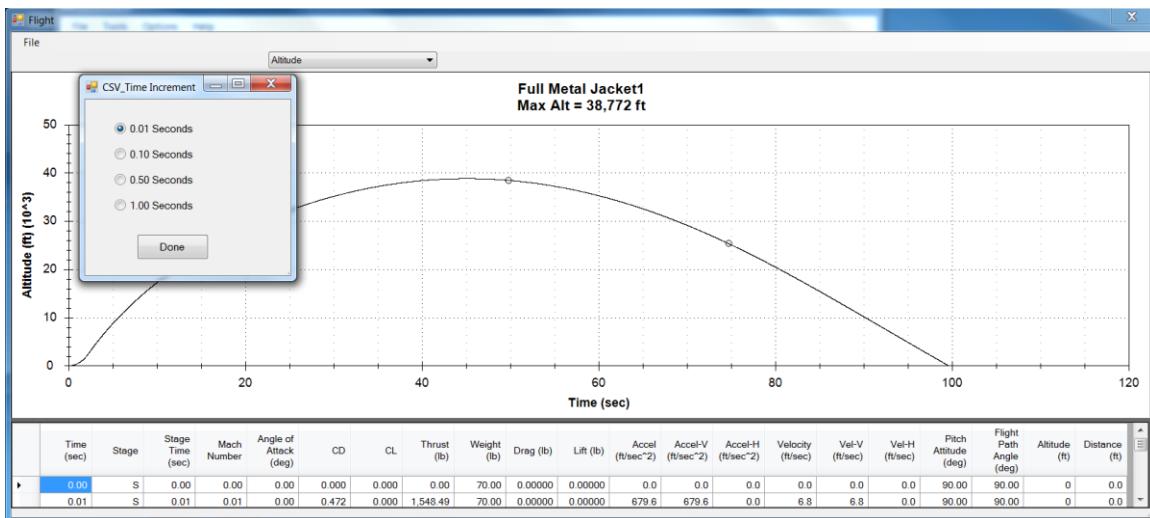


Figure 131 – Selecting the time increment for exporting the Flight Simulation tabular output data to an Excel file.

The Optimum Weight of the rocket can be determined by clicking on the Optimize Wt (Optimum Weight) button as shown in Figure 132. The resulting Optimum Weight for an example rocket, and the max altitude at that Optimum Weight, are presented in Figure 133.

Note that for many larger high power rockets, and sounding rockets, the optimum weight is typically the lowest possible weight of the rocket. RASAero II will stop the optimum weight flight simulation trajectory iterations once the weight has gotten down to the motor loaded weight from the rasp.eng file, i.e., there is no weight left for the rocket airframe and other rocket systems. This optimum weight equal to the motor loaded weight will be displayed, even though it is an unrealistic weight. The optimum weight may be below any realistic weight for the rocket, again, RASAero II will display the optimum weight, the User will have to check and determine whether the rocket could actually be built for such a low weight.

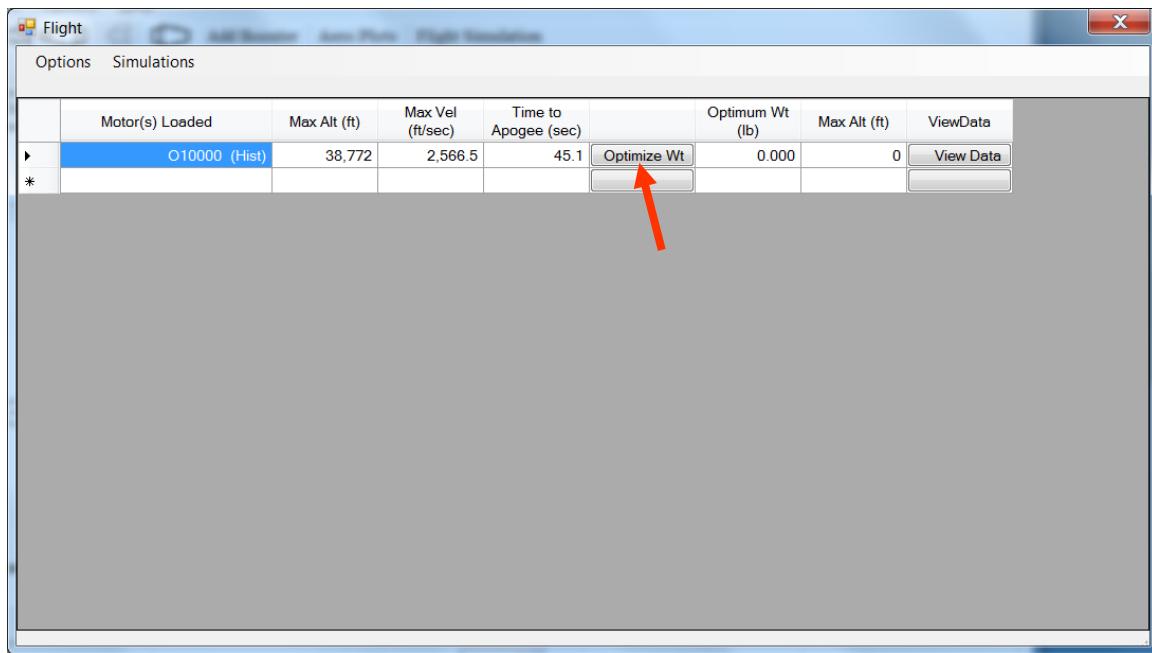


Figure 132 – Determining the Optimum Weight of the rocket by clicking on Optimize Wt (Optimum Weight) button.

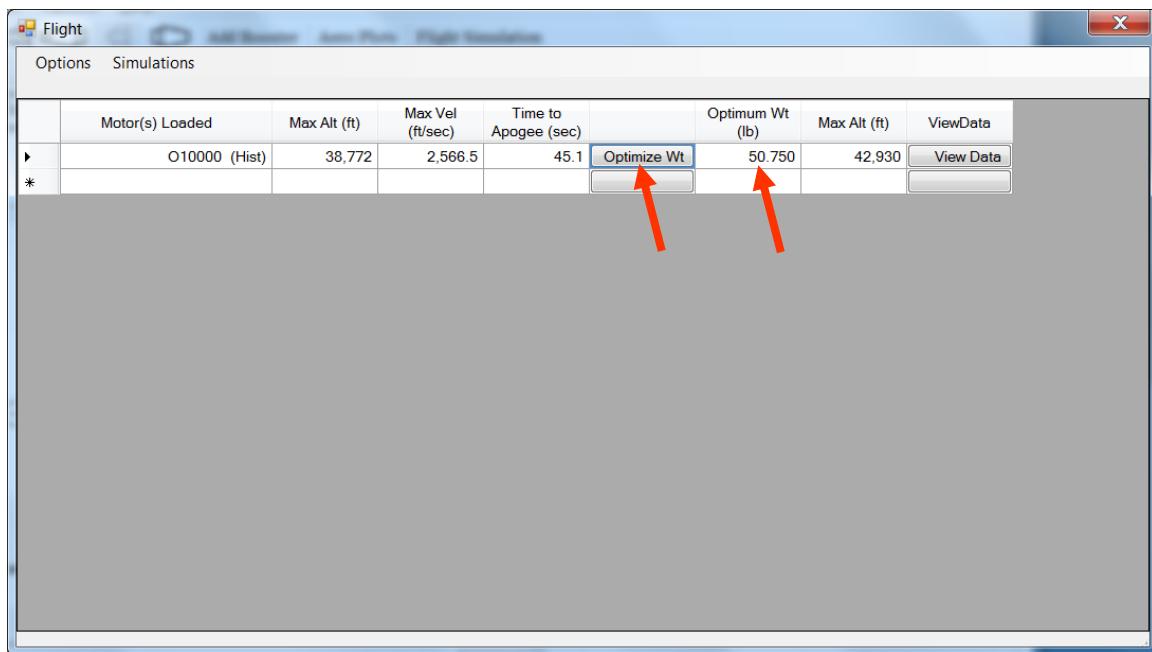


Figure 133 – Optimum Weight, and Max Altitude at the Optimum Weight.

## Running a Boosted Dart on RASAero II

For running a Boosted Dart on RASAero II (an unpowered Sustainer stage which coasts after separating from the Booster), the Boosted Dart is entered as a Sustainer stage.

When running the RASAero II Flight Simulation, when it is time to enter the Sustainer stage motor, the “Dart (NoThrust)” motor is selected out of the RASAero II motor database, as shown in Figures 134 and 135.

The Nozzle Exit Diameter is also set to 0.0 inches for the Sustainer stage with the “Dart (NoThrust)” motor, as shown in Figure 135.

When the “Dart (NoThrust)” motor is selected for the Sustainer stage, and the Sustainer stage Nozzle Exit Diameter is set to 0.0 inches, the Boosted Dart will have no thrust, and the Boosted Dart will have the correct power-off drag coefficient (CD).

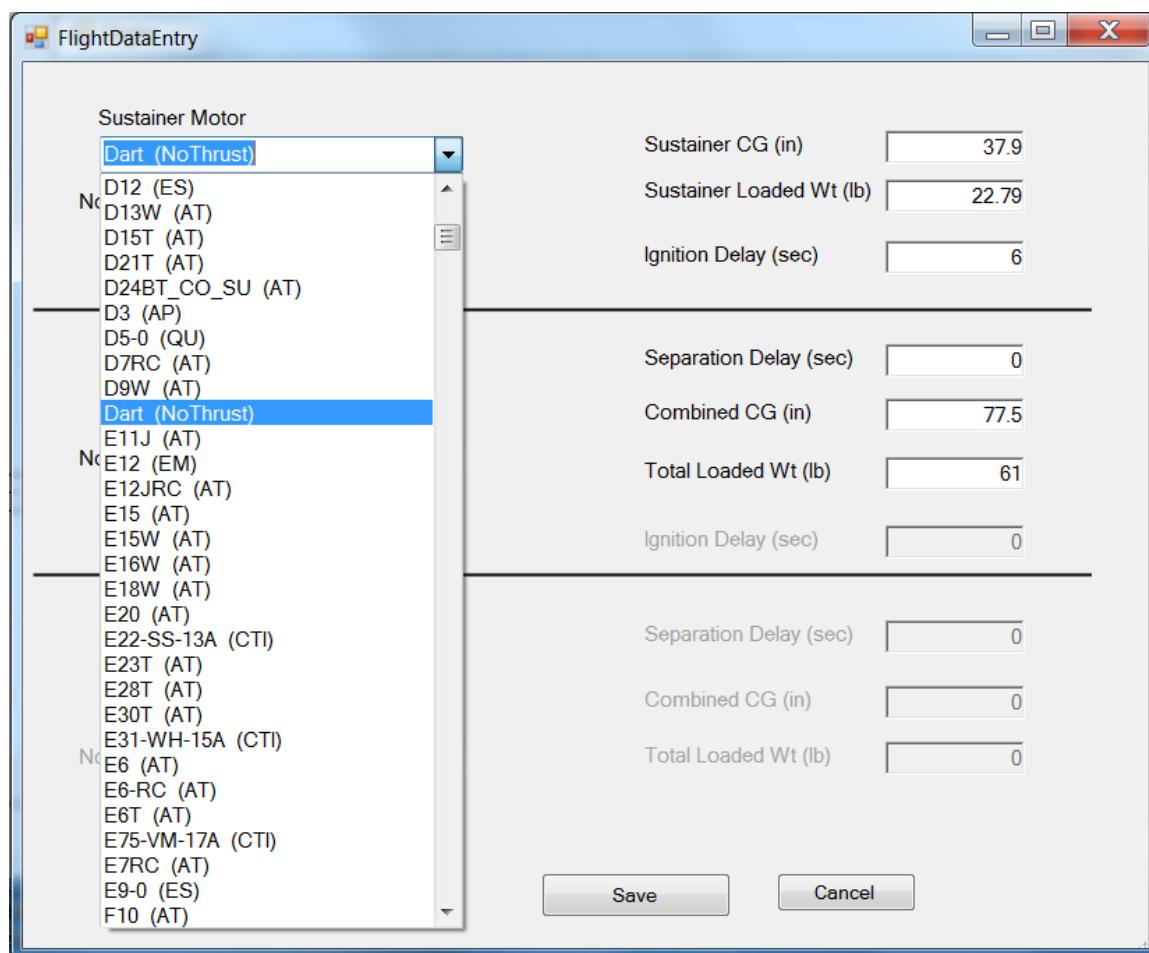


Figure 134 – Entering the “Dart (NoThrust)” motor for the Sustainer stage for a Boosted Dart.

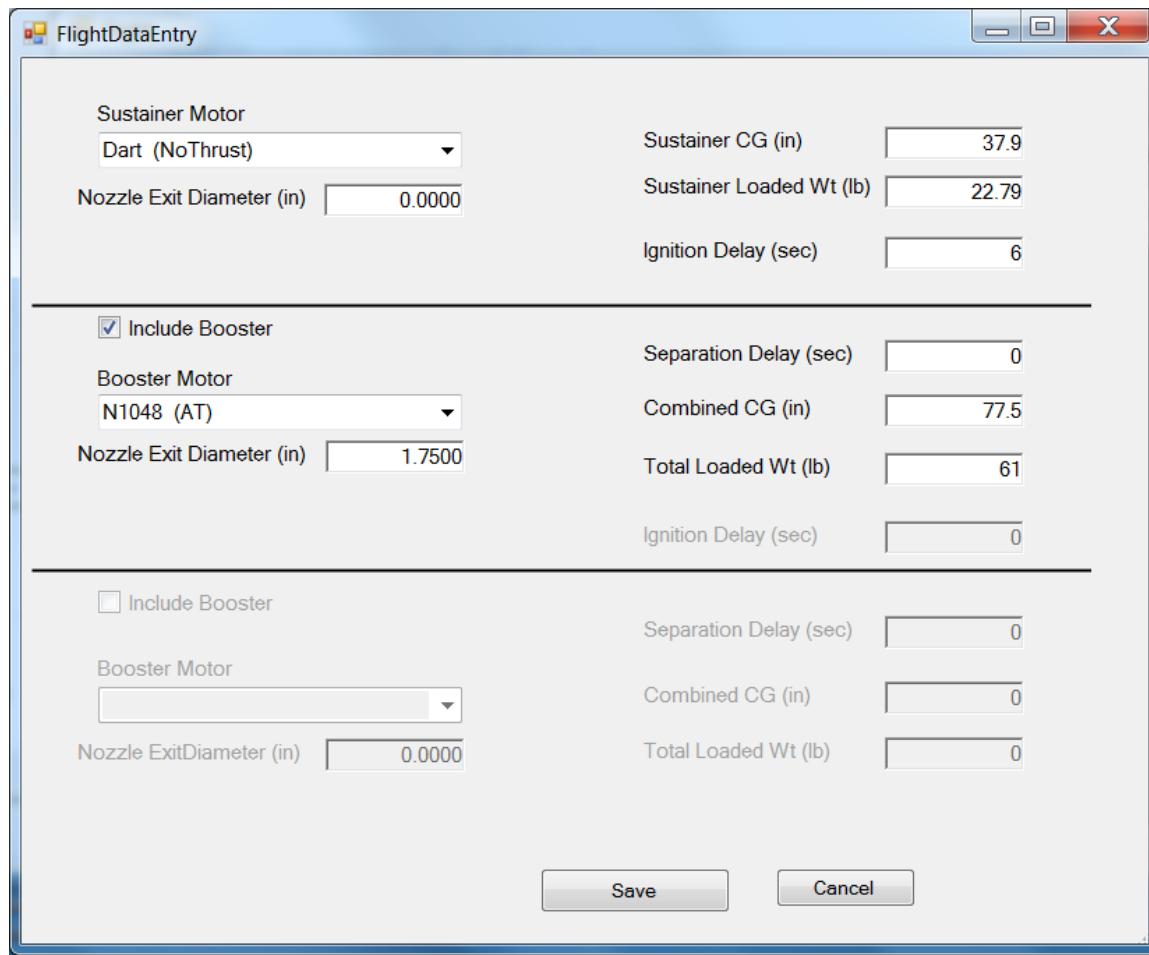


Figure 135 – “Dart (NoThrust)” motor entered, and Nozzle Exit Diameter set to 0.0 inches, for the Sustainer stage for a Boosted Dart.

## Marginal Stability and Unstable Rocket Warnings

The RASAero II Flight Simulation has built-in checks for rocket marginal stability, and for when a rocket goes unstable. Stability margin is CP – CG (distance measured from the nose, CG should be ahead of CP), divided by the rocket max diameter. Positive stability margin means the rocket CG is ahead of the CP, the rocket is stable. The RASAero II recommended stability margin for Subsonic Mach numbers is a stability margin of 1.0 calibers, for Transonic and Supersonic Mach numbers the recommended stability margin is 2.0 calibers. The RASAero II Flight Simulation checks for these stability margins only at low angles of attack (less than 5 degrees angle of attack) because the rocket can have momentary marginal stability right off the launch rail with wind, and at high angles of attack at low velocity going through apogee.

If during the RASAero II Flight Simulation the stability margin of the rocket at Subsonic Mach numbers falls below 1.0 calibers, or for Transonic and Supersonic Mach numbers falls below 2.0 calibers, for angles of attack less than 5 degrees, the Marginal Stability warning message shown in Figure 136 will be displayed. The rocket will run on the Flight Simulation, but it is recommended that the user go back and check the CG and CP and assess whether to make changes to the rocket. The Marginal Stability warning message will be displayed after the rocket Flight Simulation run, and when the View Data button is clicked on to view the Flight Simulation plots and tabular data.

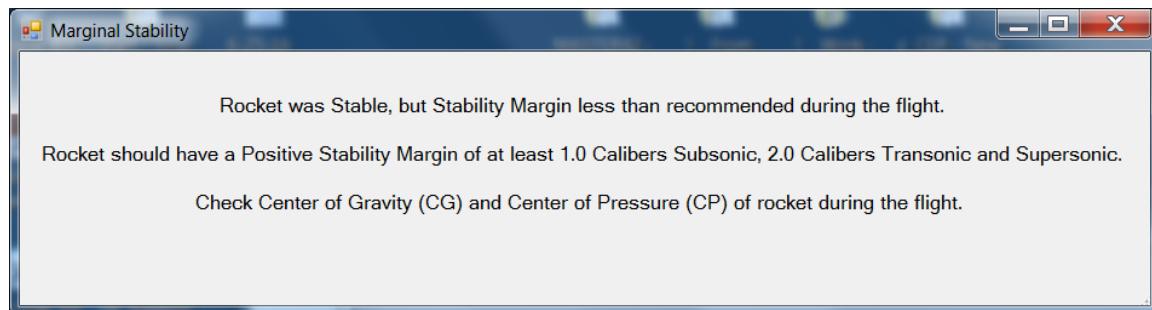


Figure 136 – Rocket Marginal Stability warning message.

If during the Flight Simulation the rocket goes unstable (CP is ahead of CG), even momentarily, the Unstable Rocket warning message, shown in Figure 137, will be displayed, and the Flight Simulation will stop at the point where the rocket went unstable. The Flight Simulation output plots and tabular data will only plot and print the Flight Simulation data to the point where the rocket went unstable and the Flight Simulation stopped.

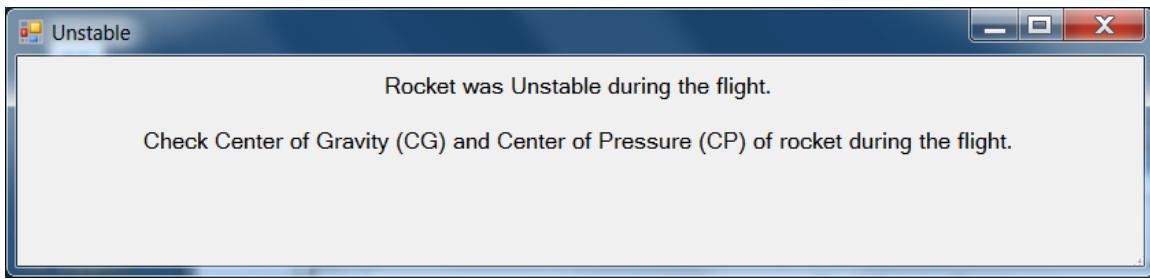


Figure 137 – Unstable Rocket warning message.

The Unstable Rocket warning message will be displayed after the rocket Flight Simulation run, and when the View Data button is clicked on to view the Flight Simulation plots and tabular data.

### Tips for Two Stage Rockets and Mach 3 and Mach 3+ Rockets

From comparisons of the RASAero II Flight Simulation altitude predictions with flight data, some tips have been determined to increase the accuracy of the RASAero II altitude predictions for two stage and Mach 3 and Mach 3+ rockets.

For two stage rockets where there is an increase in diameter from the Sustainer stage to the Booster stage, as shown in Figure 138, comparisons with flight data have shown that the expansion section from the smaller diameter to the larger diameter inevitably causes the flow to trip to turbulent flow on the Booster. Thus the Booster will have All Turbulent Flow, and for a conservative altitude prediction it is recommended to run the rocket with the All Turbulent Flow option selected.

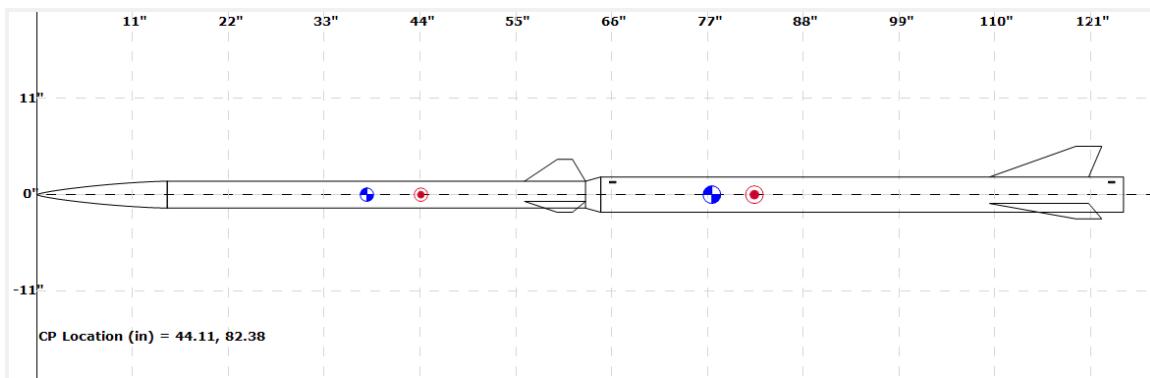


Figure 138 – Two stage rocket with an increase in diameter from the Sustainer stage to the Booster stage which should be run with All Turbulent Flow selected.

Comparisons between RASAero II altitude predictions and flight data have been performed for many rockets flying near and over Mach 3, and most of these rockets were recovered after flight with thermal damage on the surface of the rocket from aerodynamic heating. This thermal

damage roughs up the surface of the rocket, causing the flow on the rocket to immediately trip to All Turbulent Flow. Additionally, the surface roughness of the rocket, after there has been thermal damage from aerodynamic heating, is more appropriately modeled by the Rough Camouflage Paint surface roughness setting, rather than other smoother surface roughness settings.

For rockets run on RASAero II, it is recommended for Mach 3 and Mach 3+ rockets that the settings of All Turbulent Flow and Rough Camouflage Paint for surface roughness be used for a more accurate altitude prediction.

## Example Rocket 1

The first example rocket is a 3.10 in diameter I205 powered LOC/Precision Caliber ISP rocket with rail guides. The rocket geometry inputs, rocket motor used, launch site and launch angle data, and the rocket weight are presented in Figure 139. The liftoff center of gravity (CG) of the rocket was measured preflight, and was located 40.0 in from the nose of the rocket. The RASAero II rocket file for this rocket (CalIsp1.CDX1) is located in the /My Documents/RASAero II /Examples directory.

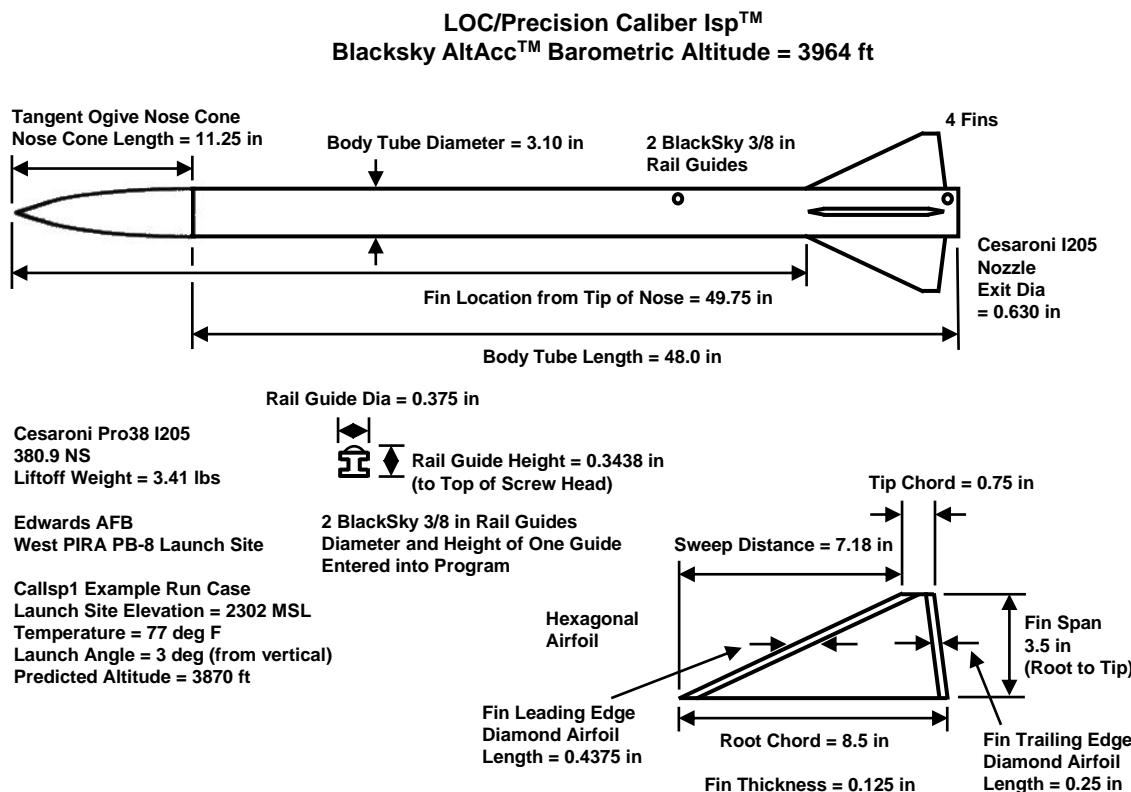


Figure 139 – Example Rocket 1, LOC/Precision Caliber ISP rocket on an I205 rocket motor.

The RASAero II Main Screen with the scale rocket drawing for the LOC/Precision Caliber ISP rocket (Example Rocket 1) is presented in Figure 140.

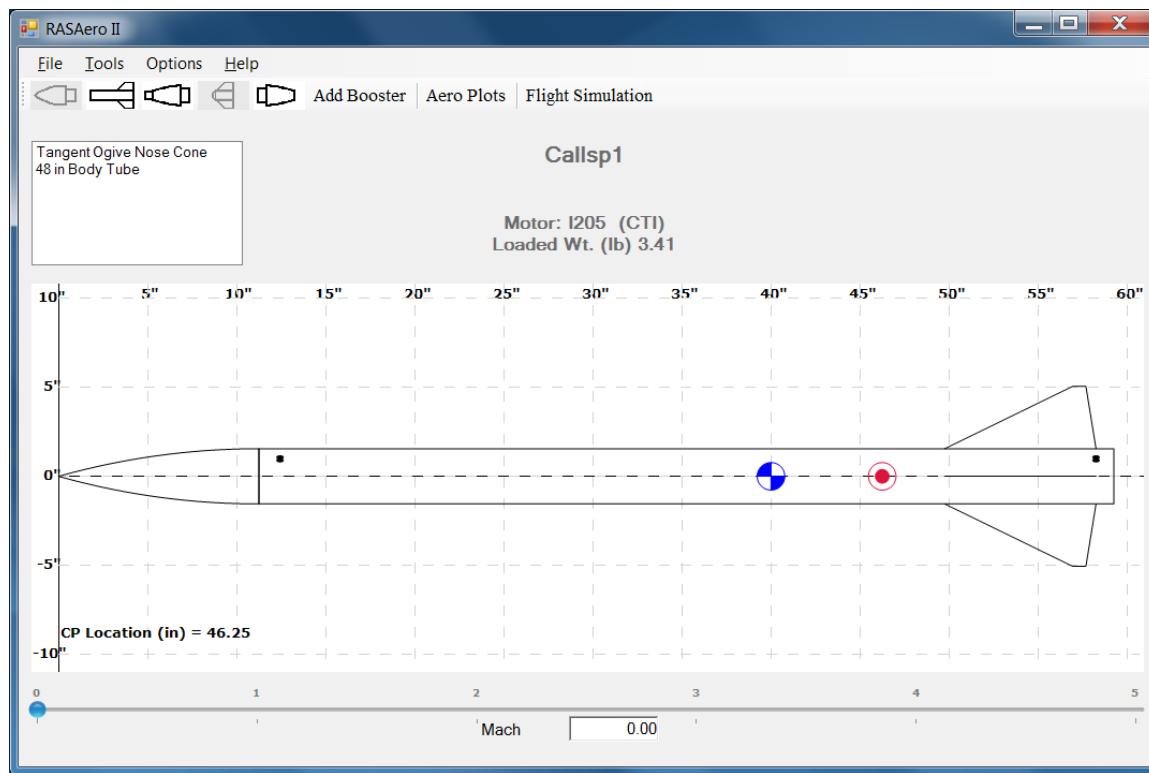


Figure 140 - RASAero II Main Screen with scale rocket drawing for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

The Nose Cone Inputs, the Body Tube and Rail Guide Inputs, the Fin Inputs, and the Surface Finish Input for the LOC/Precision Caliber ISP rocket are presented in Figures 141-144.

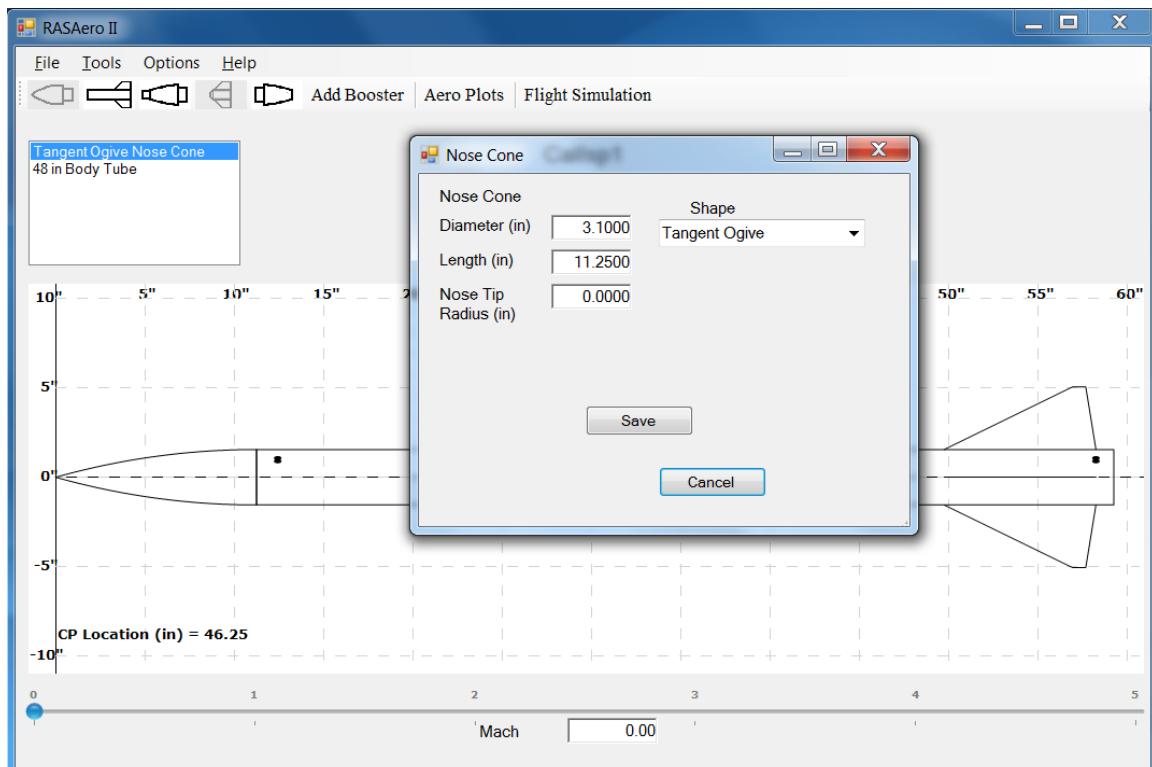


Figure 141 – Nose Cone Inputs for LOC/Precision Caliber ISP rocket (Example Rocket 1).

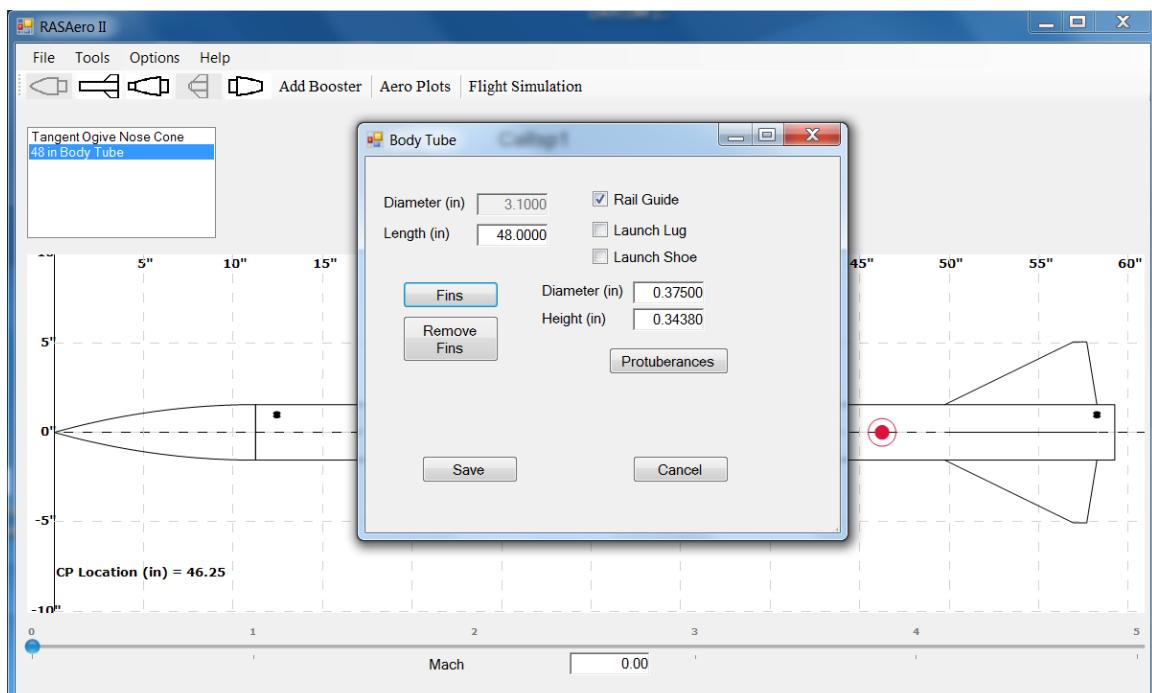


Figure 142 – Body Tube and Rail Guide Inputs for LOC/Precision Caliber ISP rocket (Example Rocket 1).

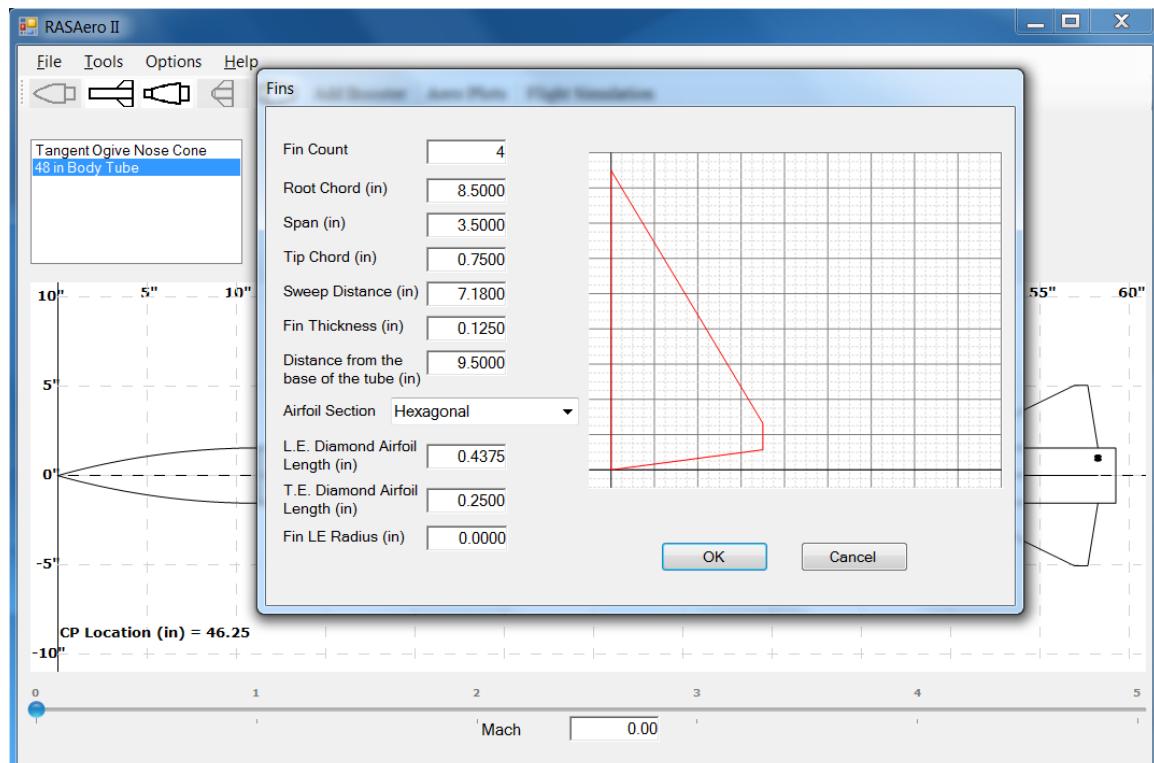


Figure 143 – Fin Inputs for LOC/Precision Caliber ISP rocket (Example Rocket 1).

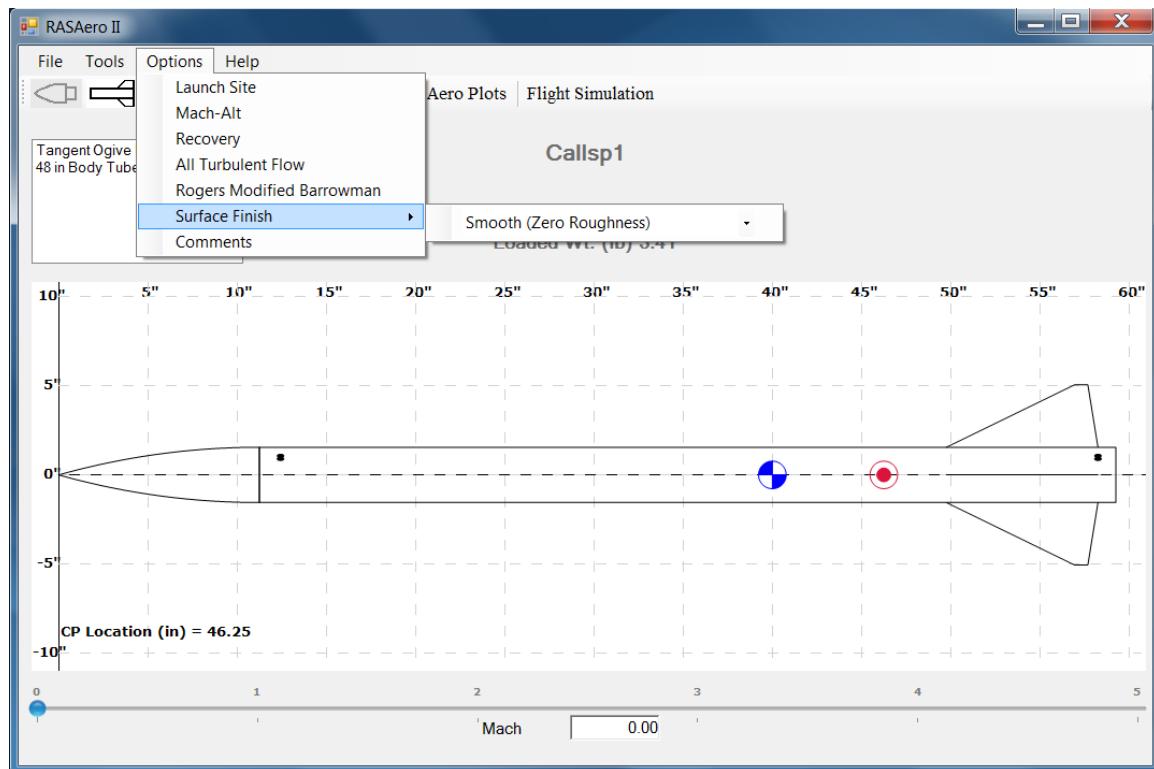


Figure 144 – Surface Finish Input for LOC/Precision Caliber ISP rocket (Example Rocket 1).

Figure 145 shows one of the aerodynamic data plots for the LOC/Precision Caliber ISP rocket, the power-on and power-off drag coefficient (CD) versus Mach number. As the rocket flight was subsonic, the zoom in feature has been used to zoom in the plot to Mach 0 to 1.2. Note that because of the small nozzle exit diameter (nozzle exit area), there is little difference between the power-on and power-off drag coefficients. The start of the transonic drag rise at approximately Mach 0.90 can be seen in the plot.

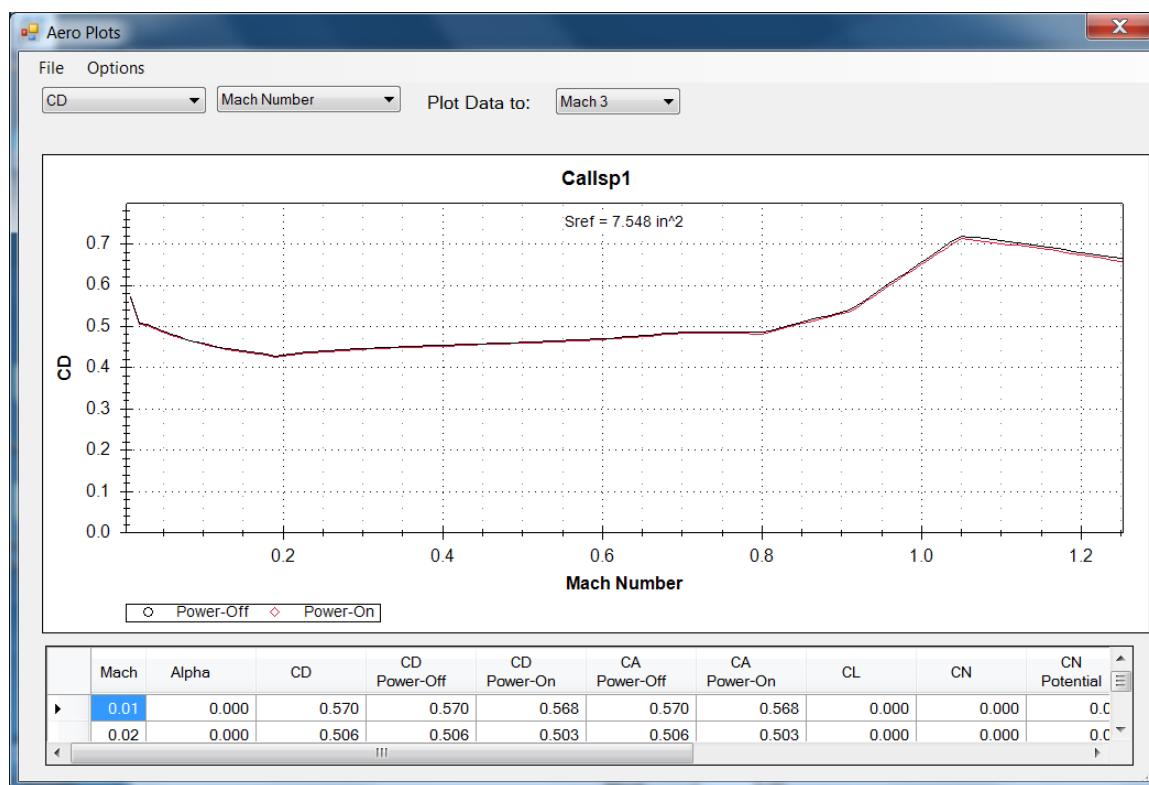


Figure 145 – Aerodynamic data plot for LOC/Precision Caliber ISP rocket (Example Rocket 1); power-on and power-off drag coefficient (CD) versus Mach number, Mach 0-1.2.

Figure 146 shows the launch site data for the LOC/Precision Caliber ISP rocket. The rocket was flown on Edwards AFB, with a launch site elevation of 2302 ft. The launch site temperature at the time of launch was 77 deg F. The rocket was launched with a launch angle 3 deg from vertical from a 10 ft long launch rail. Wind speed is set to zero for this example run.

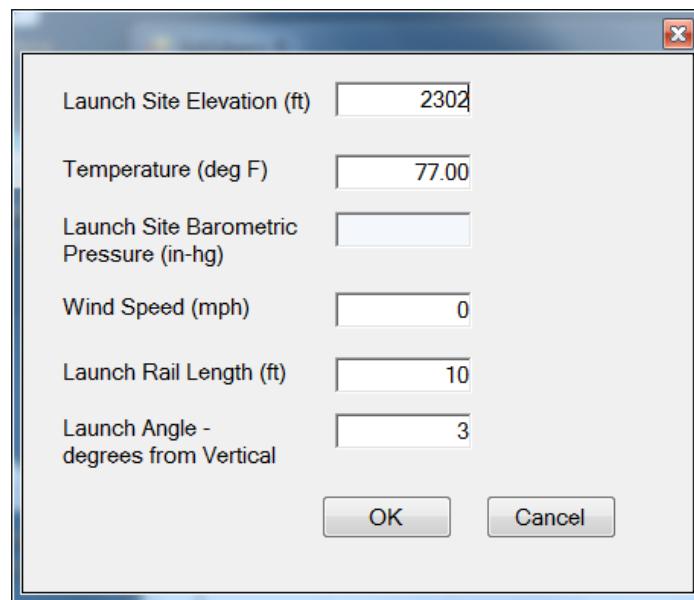


Figure 146 – Launch site input data for the LOC/Precision Caliber ISP rocket  
(Example Rocket 1).

Figure 147 shows the recovery system inputs for the LOC/Precision Caliber ISP rocket. The rocket was flown with a 36 in diameter parachute which was opened at apogee.

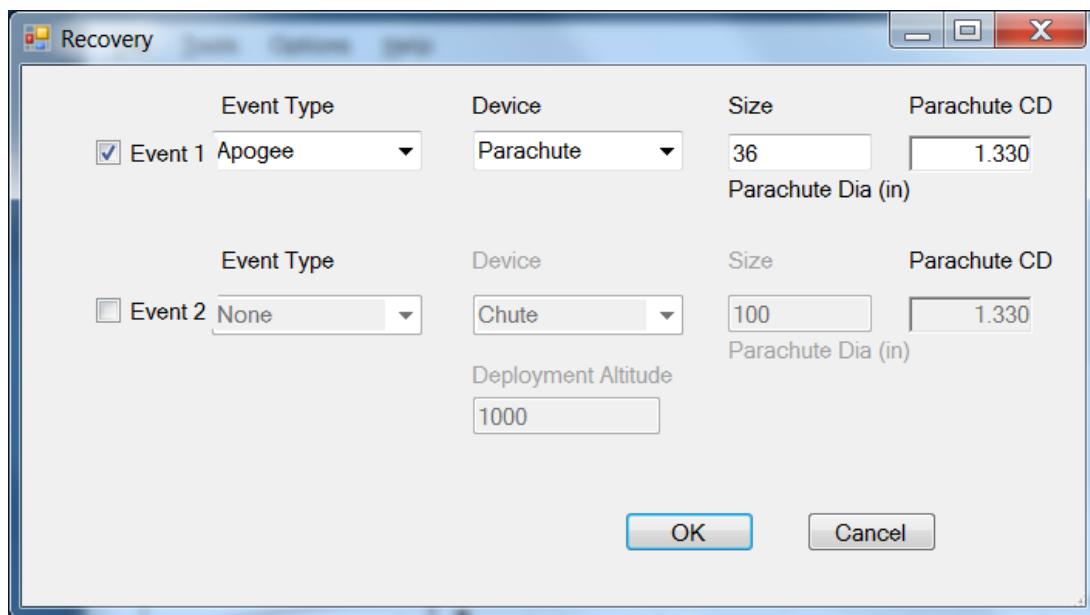


Figure 147 - Recovery system input data for the LOC/Precision Caliber ISP rocket  
(Example Rocket 1).

The RASAero II Flight Simulation FlightDataEntry Screen showing the input data for the LOC/Precision Caliber ISP rocket (Example Rocket 1) are presented in Figure 148. The rocket was flown on a Cesaroni Technology Incorporated (CTI) I205 rocket motor, which was selected from the motor selection menu. The rocket loaded weight with motor (the liftoff weight) as flown was 3.41 lb. The liftoff center of gravity (CG) of the rocket was measured preflight, and was located 40.0 in from the nose of the rocket

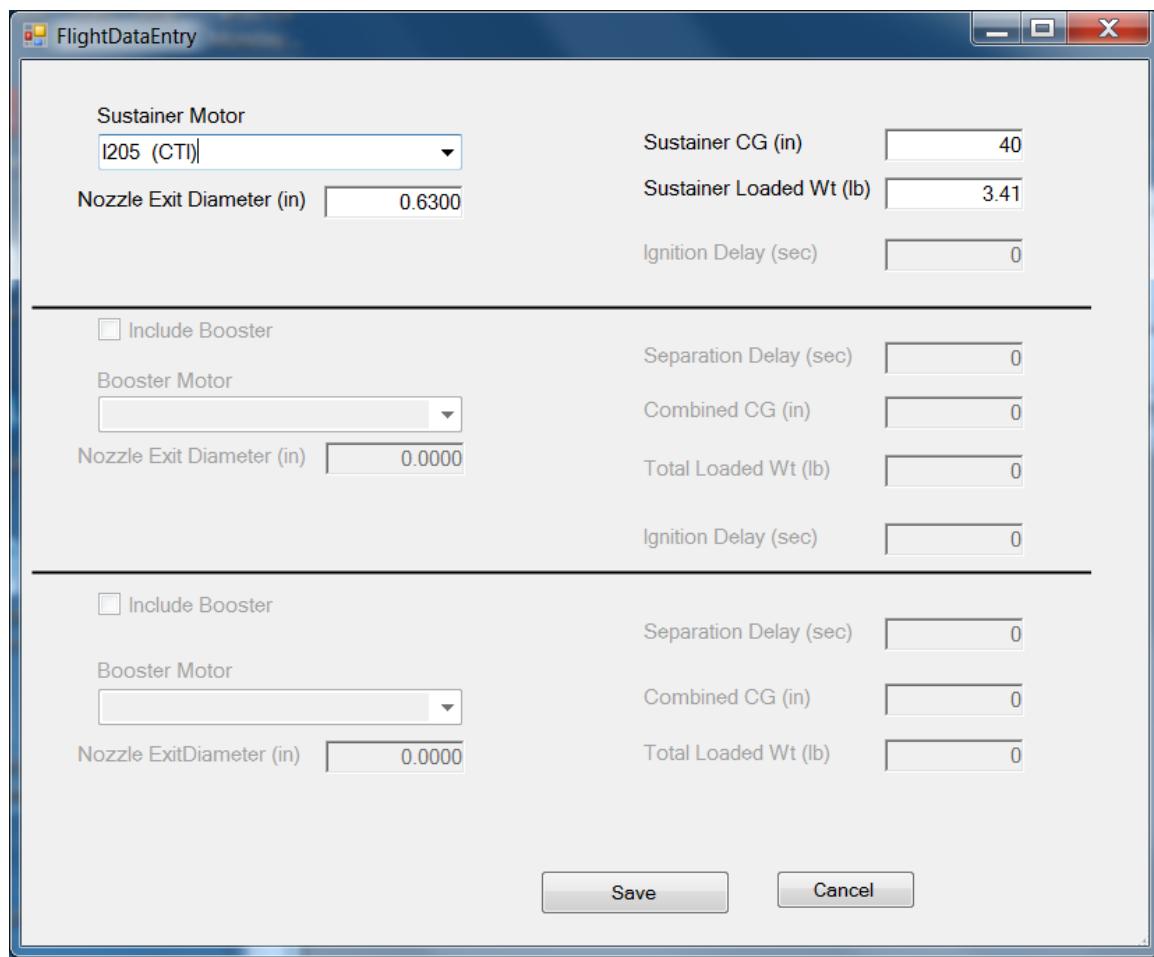


Figure 148 - Flight Simulation FlightDataEntry Screen for LOC/Precision Caliber ISP rocket (Example Rocket 1) with selected CTI I205 motor, lift-off center of gravity (CG), lift-off weight, and motor nozzle exit diameter.

The summary flight data from the RASAero II Flight Simulation for the LOC/Precision Caliber ISP rocket (Example Rocket 1) with the CTI I205 motor is presented in Figure 149. The altitude versus time plot presented in Figure 150 shows both the powered flight and coast to apogee, with apogee occurring at approximately 14 sec, and then the rocket descent on the parachute. The actual altitude the rocket reached, measured by an on-board barometric altimeter, was 3964 ft. The RASAero II flight simulation predicted altitude is 3876 ft, an error of only -2.22% compared to the actual barometric altimeter measured altitude.

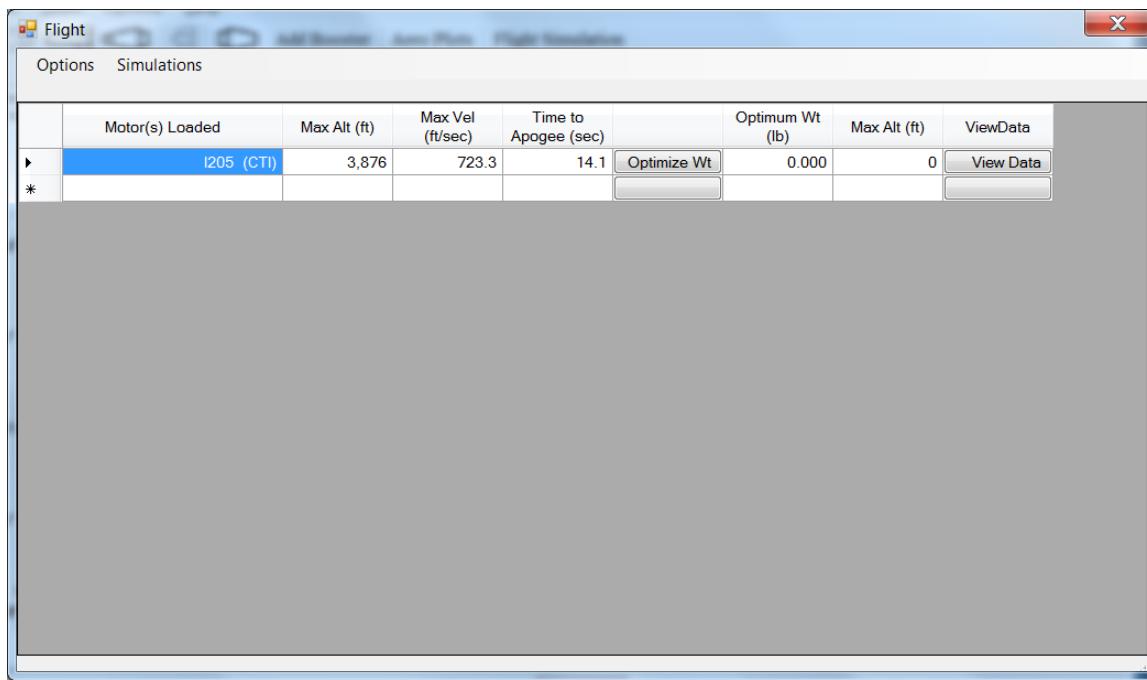


Figure 149 – RASAero II Flight Simulation summary flight data for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

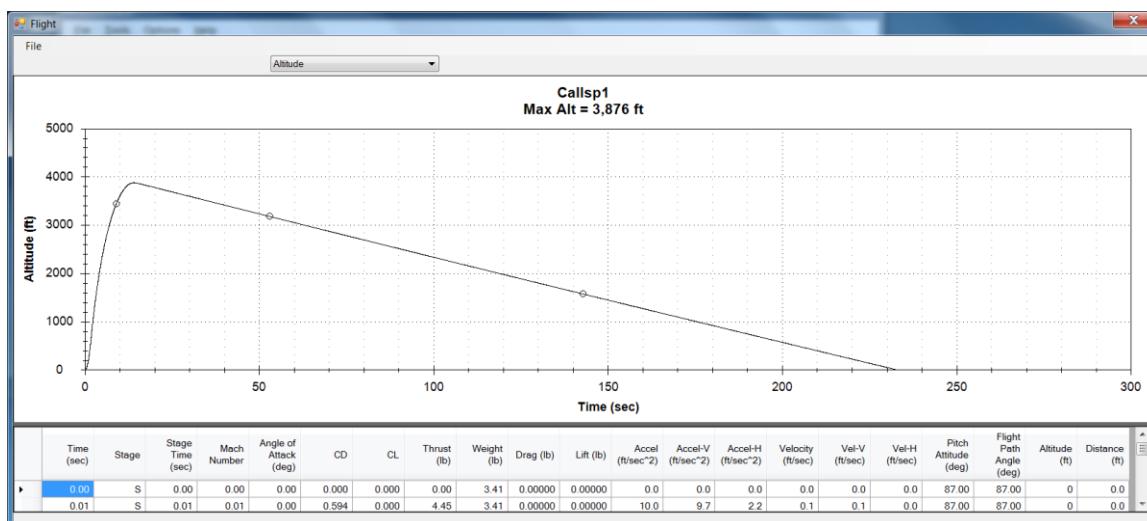


Figure 150 – RASAero II Flight Simulation output for the LOC/Precision Caliber ISP rocket (Example Rocket 1), altitude versus time for powered flight and coast to apogee, rocket descent on parachute.

The LOC/Precision Caliber ISP rocket (Example Rocket 1) carried a Blacksky AltAcc accelerometer and altimeter instrumentation unit, which included a barometric altimeter and an axial accelerometer. The on-board measured axial acceleration, accelerometer-based velocity, on-board measured barometric pressure, barometric altimeter altitude and accelerometer-based altitude for the LOC/Precision Caliber ISP rocket are presented in Figure 151. In the early part of the flight the accelerometer-based altitude and velocity are considered more accurate than the barometric altimeter altitude due to the absence of any pitot tube and pressure lag corrections to the on-board measured barometric pressure. At apogee the barometric altimeter altitude is considered more accurate than the accelerometer-based altitude, due to trajectory and attitude effects not taken into account in the 1-dimensional integration (assuming a straight-up flight) of the body axial acceleration data. For comparison the RASAero II flight simulation predicted acceleration and velocity are shown in Figure 152. For acceleration note the similarly shaped plot of acceleration versus time, with a peak acceleration of almost 500 ft/sec<sup>2</sup>. For velocity note the similarly shaped plot of velocity versus time, with a peak velocity of just over 700 ft/sec.

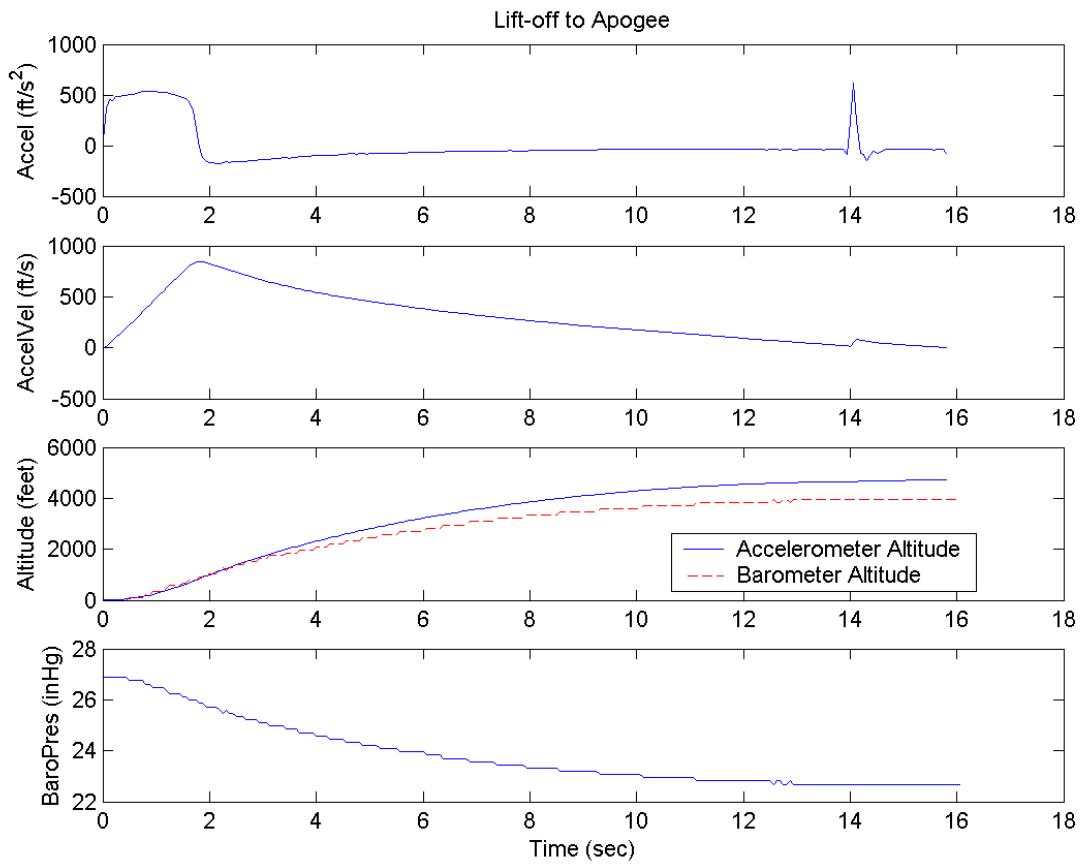


Figure 151 – Measured axial acceleration, accelerometer-based velocity, on-board measured barometric pressure, barometric altimeter altitude and accelerometer-based altitude for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

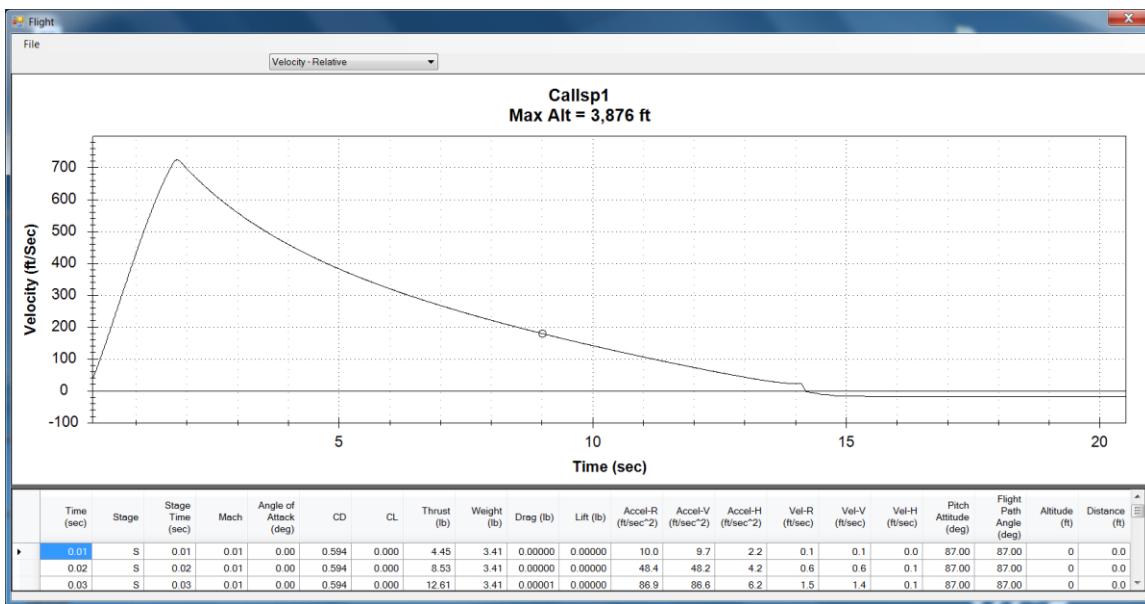
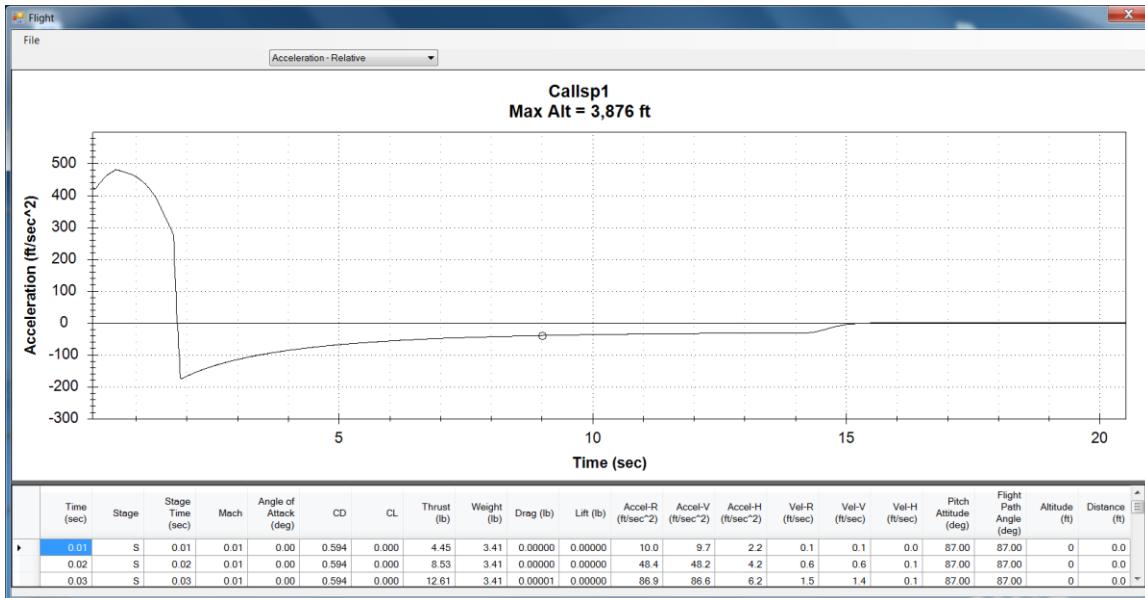


Figure 152 – RASAero II flight simulation predicted acceleration and velocity for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

Figure 153 presents a summary plot of the barometric altimeter altitude and the accelerometer-based altitude for the LOC/Precision Caliber ISP rocket. Again at apogee the barometric altimeter altitude is considered to be more accurate than the accelerometer-based altitude. For comparison the RASAero II flight simulation predicted altitude versus time on a similar time-scale through apogee is presented in Figure 154. Again note the similarly shaped plot, in this case of altitude versus time through apogee.

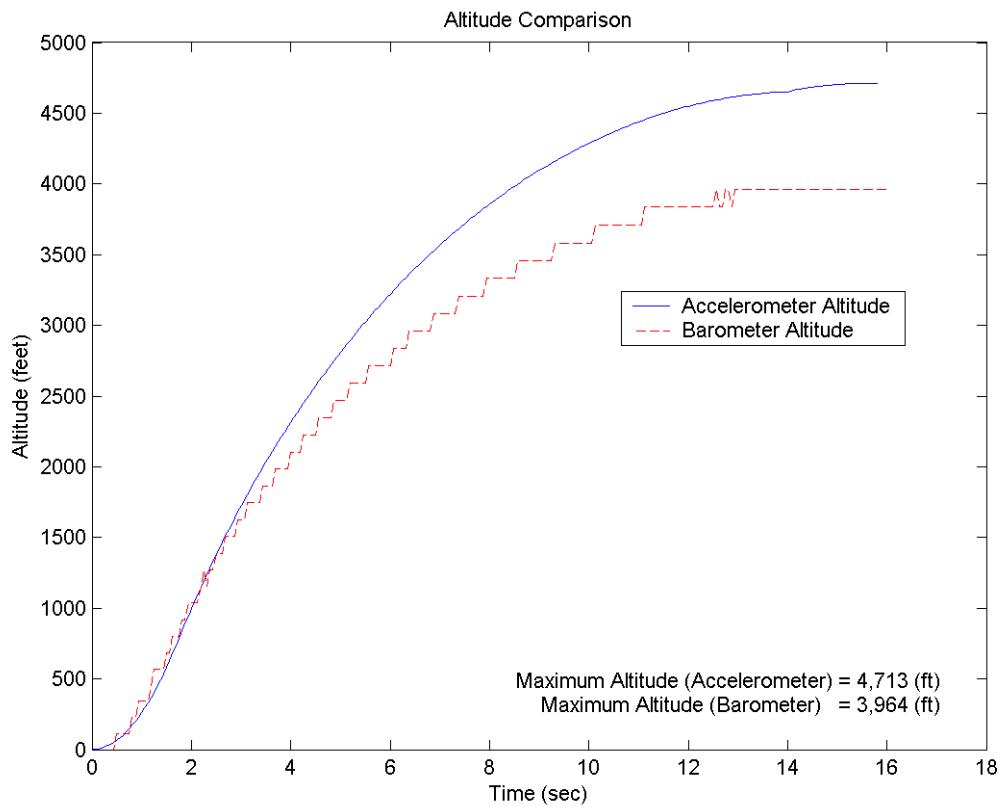


Figure 153 – Barometric altimeter altitude and accelerometer-based altitude for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

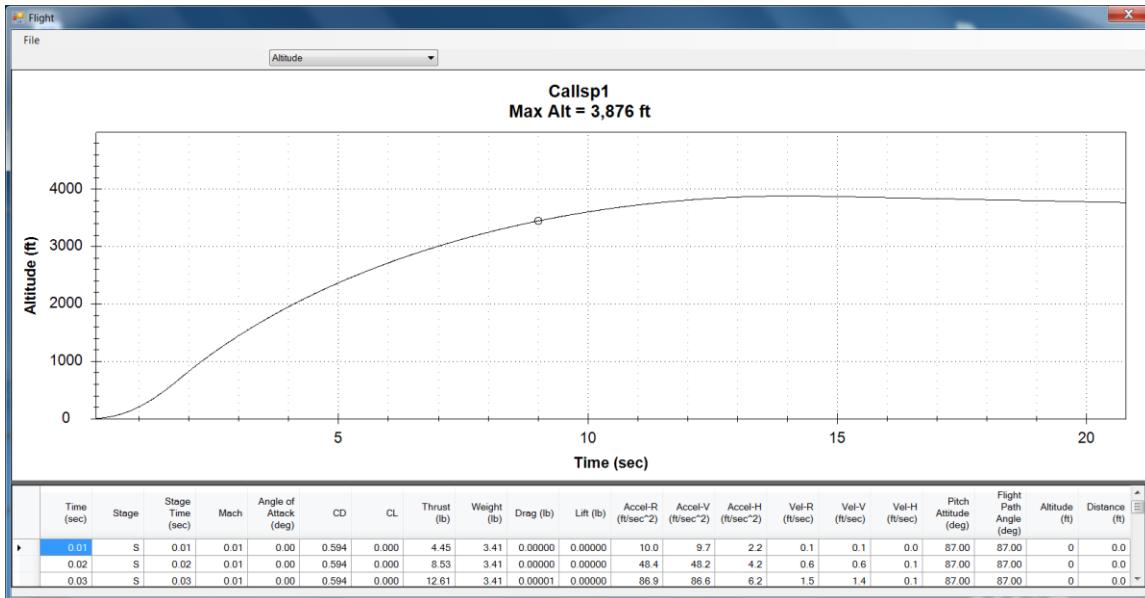


Figure 154 – RASAero II flight simulation predicted altitude versus time plotted through apogee for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

As noted previously the RASAero II flight simulation predicted altitude of 3876 ft has an error of only -2.22% compared to the barometric altimeter measured altitude of 3964 ft.

Figure 155 presents the on-board measured barometric pressure and the barometric altimeter altitude from launch through apogee to landing, including the parachute descent. From apogee to landing the parachute descent time based on the barometric altimeter altitude was 241 sec. The RASAero II flight simulation prediction for altitude versus time from launch through apogee to landing, including the parachute descent, was presented in Figure 150, and is presented again in Figure 156. Note the similarly shaped plot of altitude versus time from launch through apogee, and then the parachute descent to landing. The RASAero II flight simulation predicted parachute descent time is 218.71 sec, an error of only -9.25% in the parachute descent time from apogee.

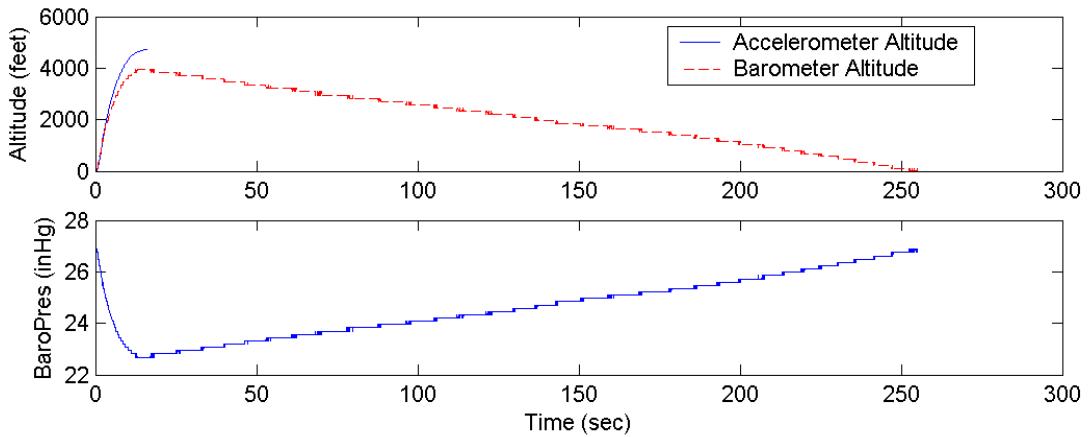


Figure 155 – On-board measured barometric pressure and barometric altimeter from launch through apogee to landing, including the parachute descent, for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

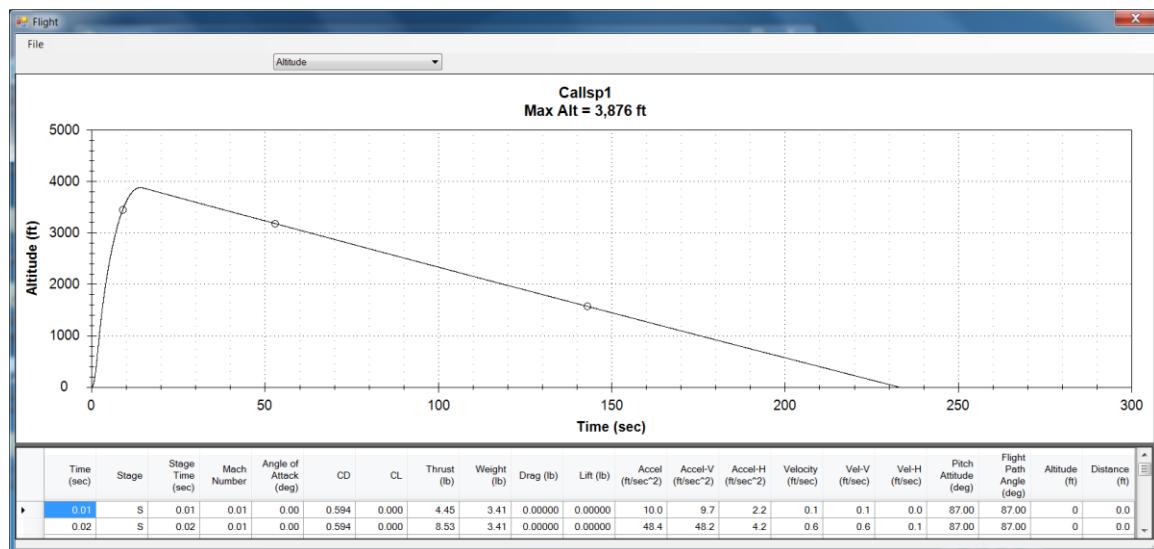


Figure 156 – RASAero II flight simulation predicted altitude versus time through apogee to landing, including the parachute descent, for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

## Example Rocket 2

The second example rocket is the O10000 powered Full Metal Jacket - Flight 3 configuration rocket, which was optically tracked to 37981 ft at the BALLS 005 launch. The rocket geometry inputs, rocket motor used, launch site and launch angle data, and the rocket weight are presented in Figure 157. The Full Metal Jacket - Flight 3 configuration rocket was tower launched, and thus had no rail guides, launch lugs, or launch shoes. The RASAero II rocket file for this rocket (Full Metal Jacket1.CDX1) is located in the /My Documents/RASAero II/Examples directory.

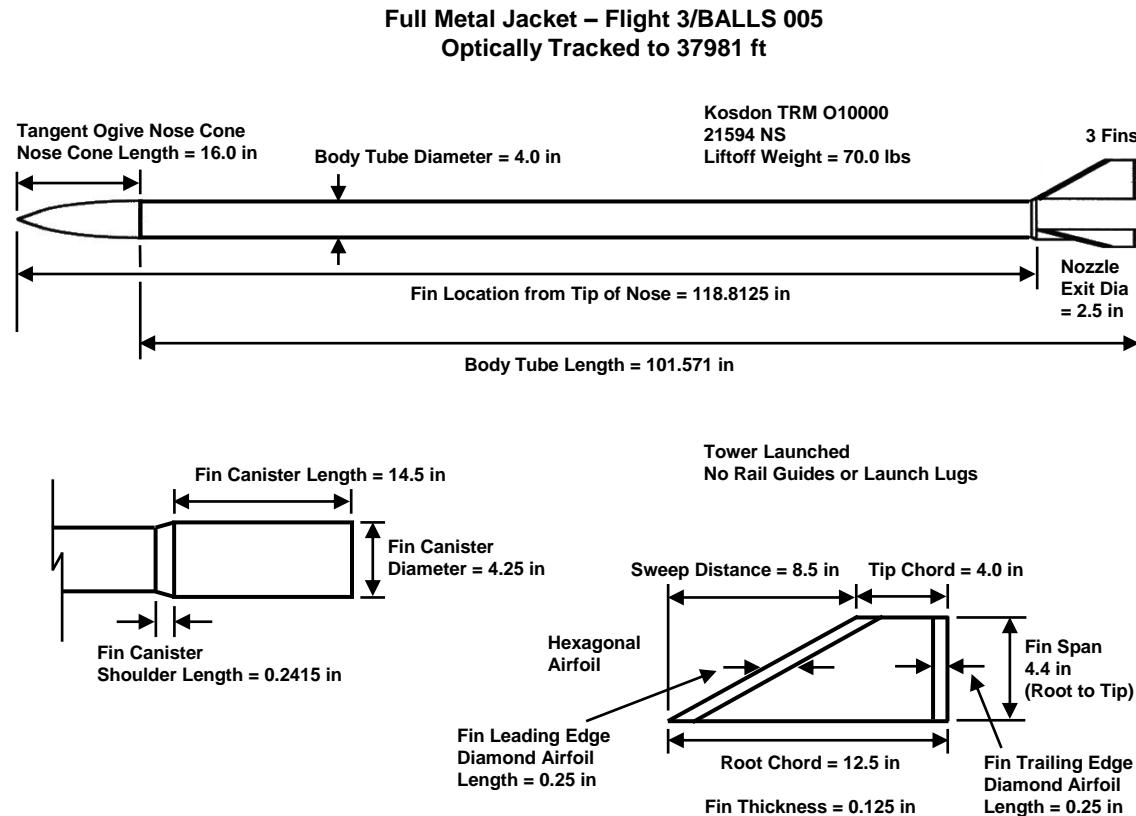


Figure 157 – Example Rocket 2, Full Metal Jacket - Flight 3 configuration rocket, powered by O10000 rocket motor, optically tracked to 37981 ft.

The RASAero II Main Screen with the scale rocket drawing for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2) is presented in Figure 158.

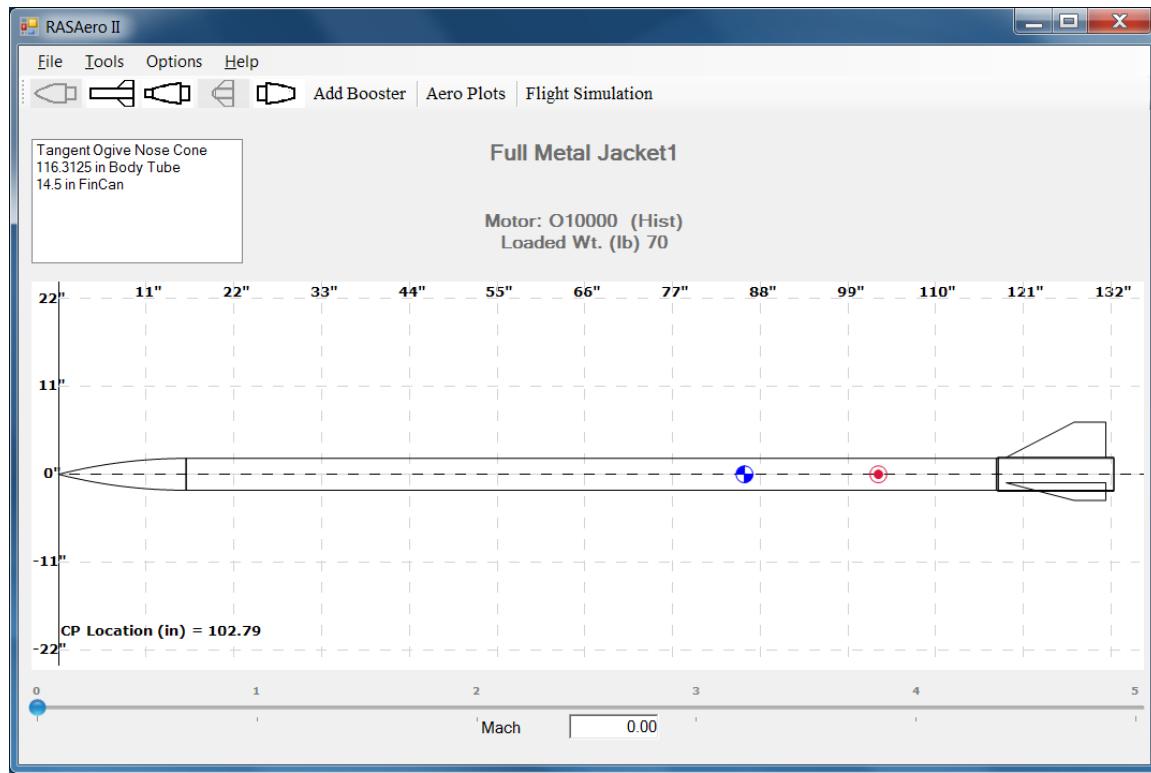


Figure 158 - RASAero II Main Screen with scale rocket drawing for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2).

The Nose Cone Inputs, the Body Tube Inputs, the Fin Canister Inputs, the Fin Inputs on the Fin Canister, and the Surface Finish Input for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2) are presented in Figures 159-163.

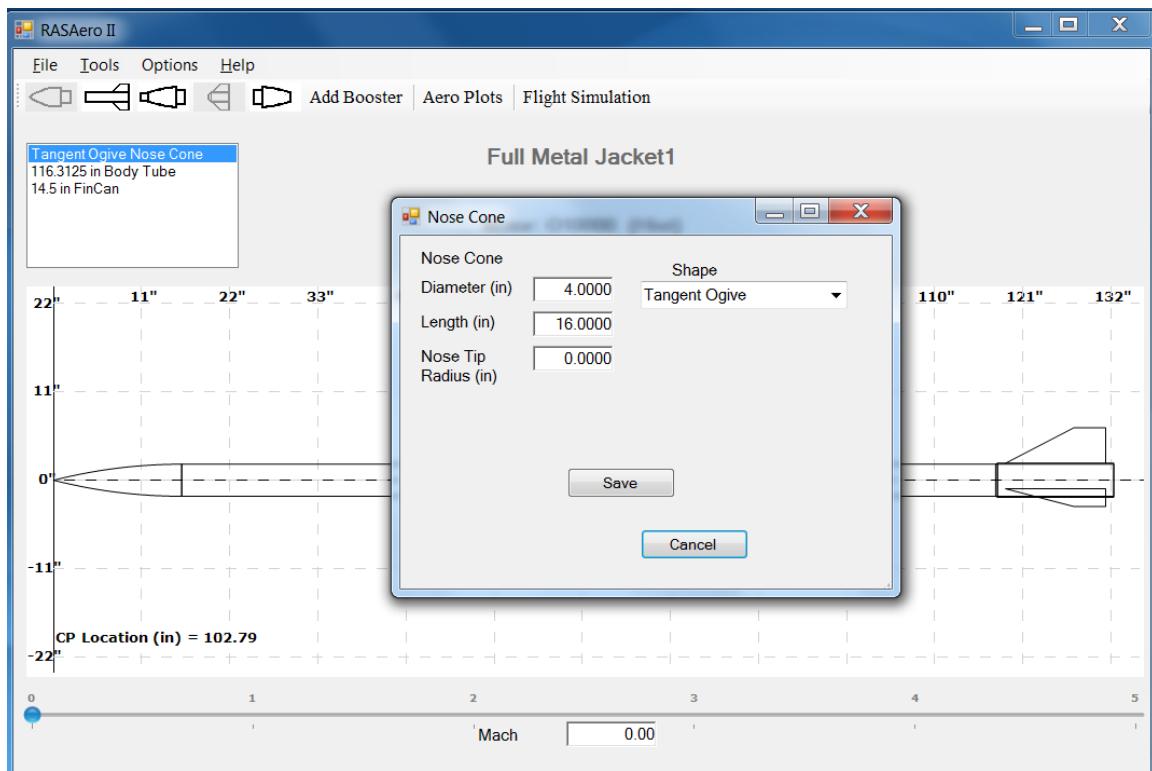


Figure 159 – Nose Cone Inputs Full Metal Jacket - Flight 3 configuration (Example Rocket 2).

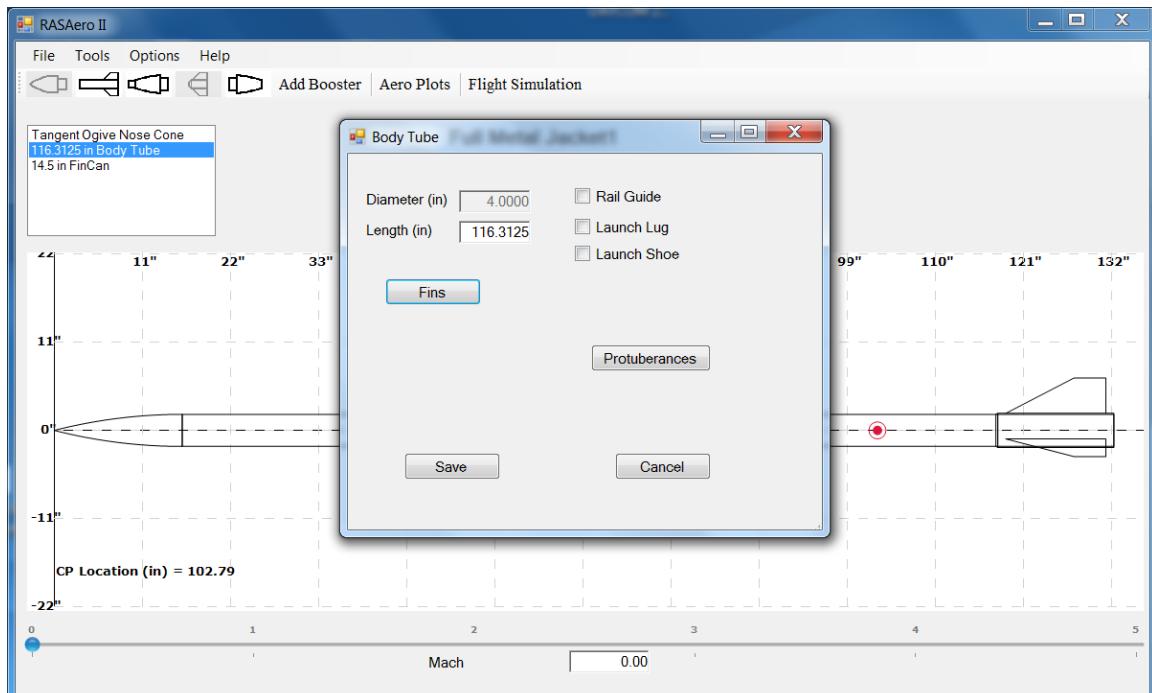


Figure 160 – Body Tube Inputs for Full Metal Jacket - Flight 3 configuration  
(Example Rocket 2).

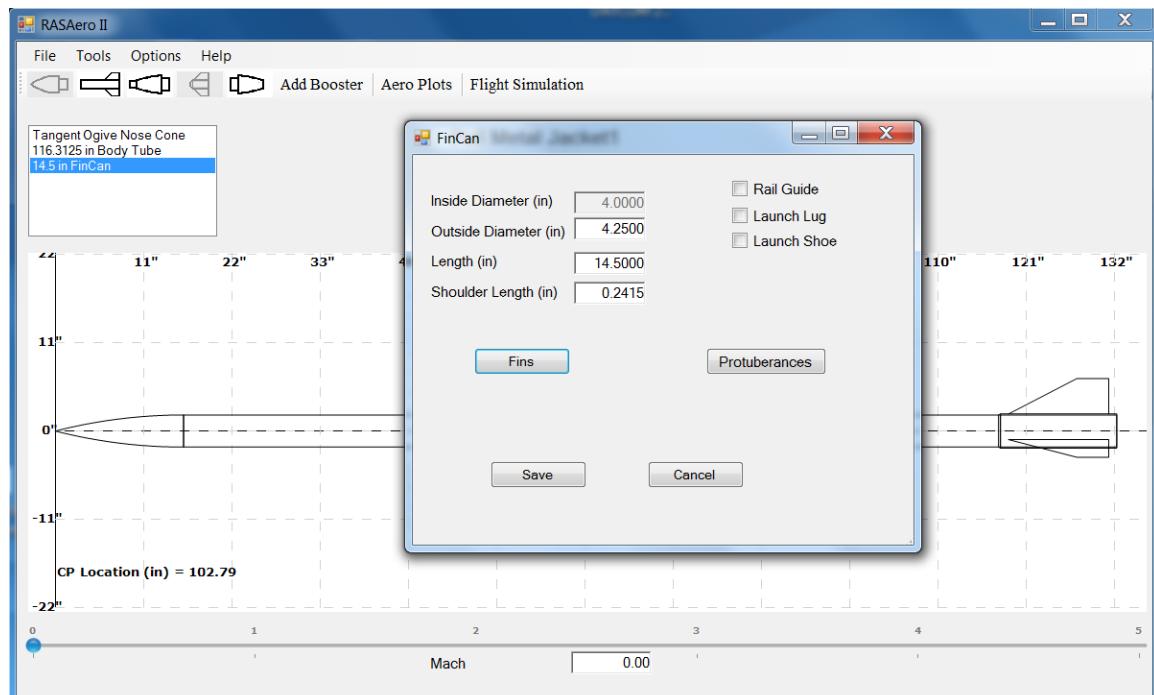


Figure 161 – Fin Canister Inputs Full Metal Jacket - Flight 3 configuration (Example Rocket 2).

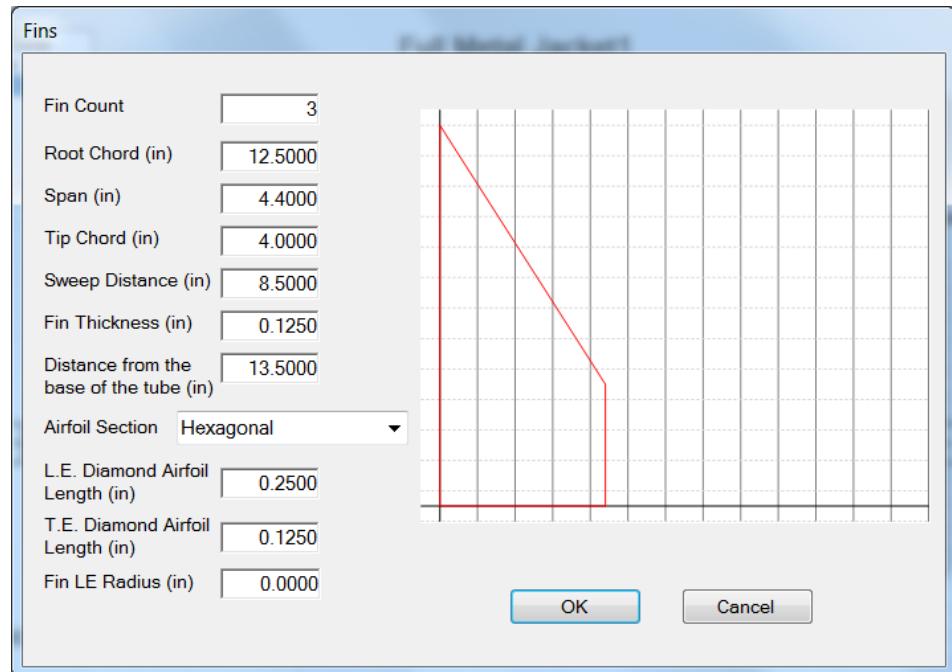


Figure 162 – Fin Inputs for Fins on Fin Canister for Full Metal Jacket - Flight 3 configuration (Example Rocket 2).

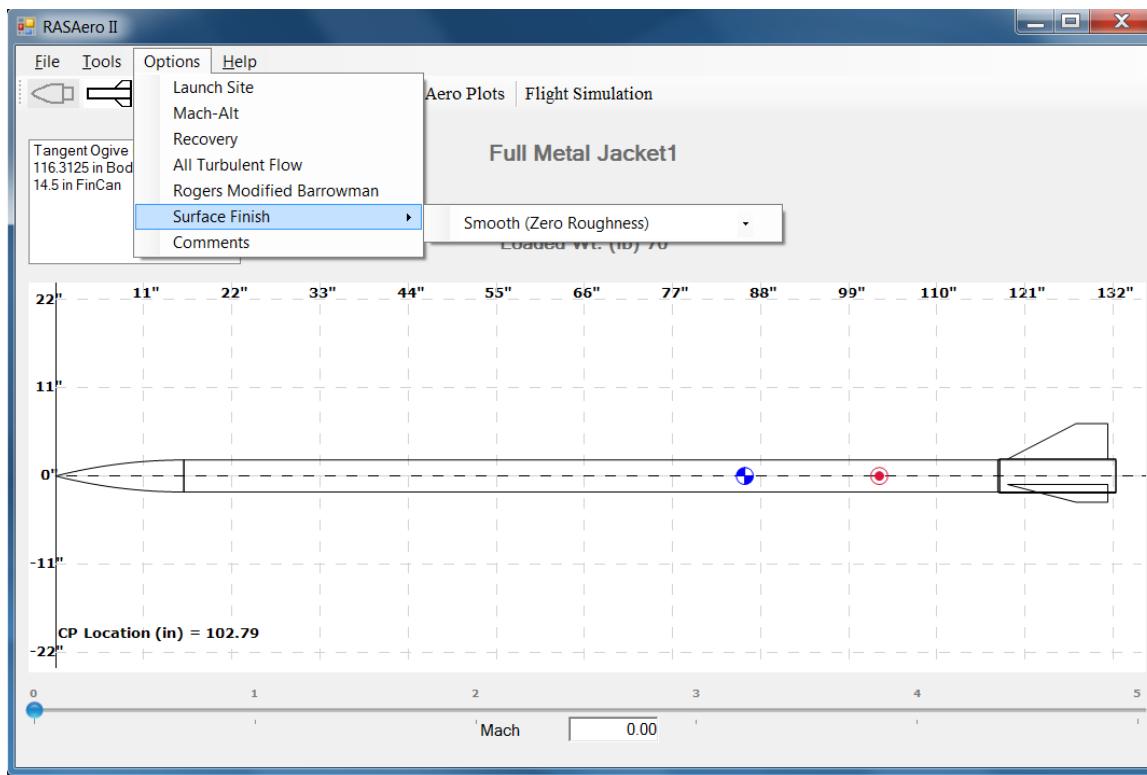


Figure 163 – Surface Finish Input for Full Metal Jacket - Flight 3 configuration  
(Example Rocket 2).

Figures 164 and 165 show one of the aerodynamic data plots for the Full Metal Jacket - Flight 3 configuration rocket, the power-on and power-off drag coefficient (CD) versus Mach number. Note that with the large nozzle exit diameter (nozzle exit area) used on this rocket, a 2.5 in nozzle exit diameter compared to the 4.25 in diameter base area of the rocket, that there is a noticeable decrease in the power-on drag coefficient compared to the power-off drag coefficient. Figure 164 is the initial aerodynamic data plot generated by the software where the aerodynamic data is plotted for Mach 0-25, and in Figure 165 the <Plot Data to:> pull-down menu has been used to plot the data for Mach 0-3.

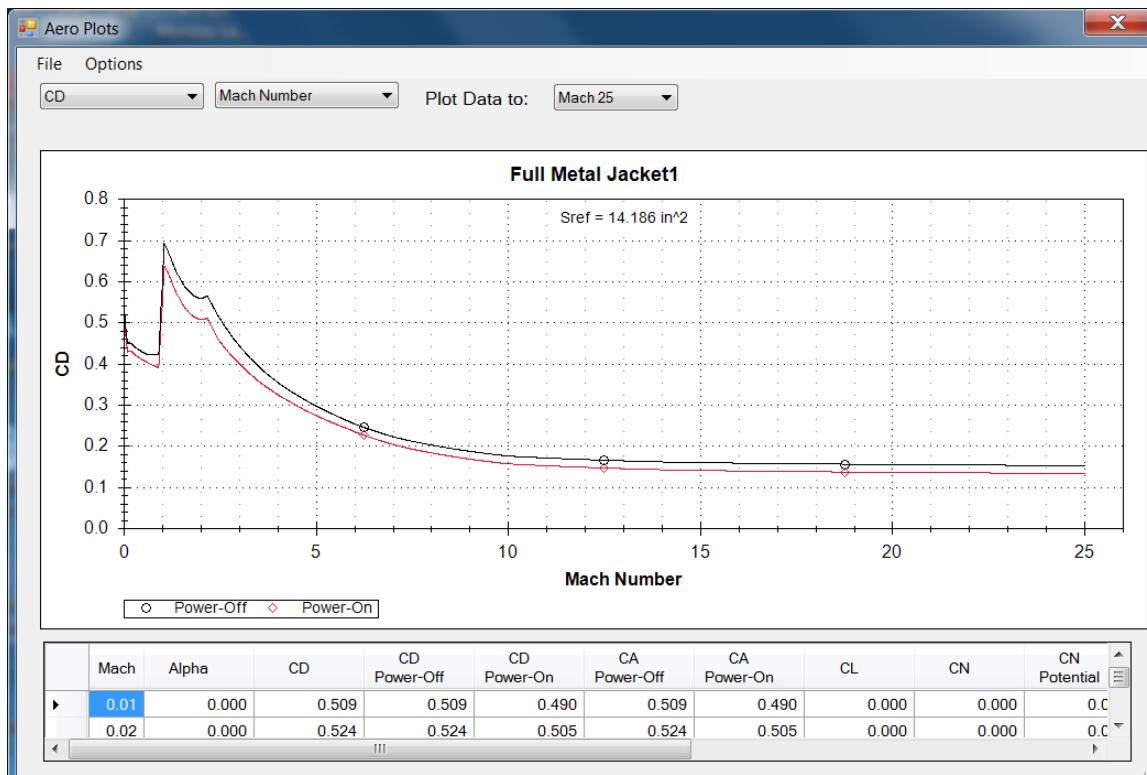


Figure 164 – Aerodynamic data plot for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2); power-on and power-off drag coefficient (CD) versus Mach number.

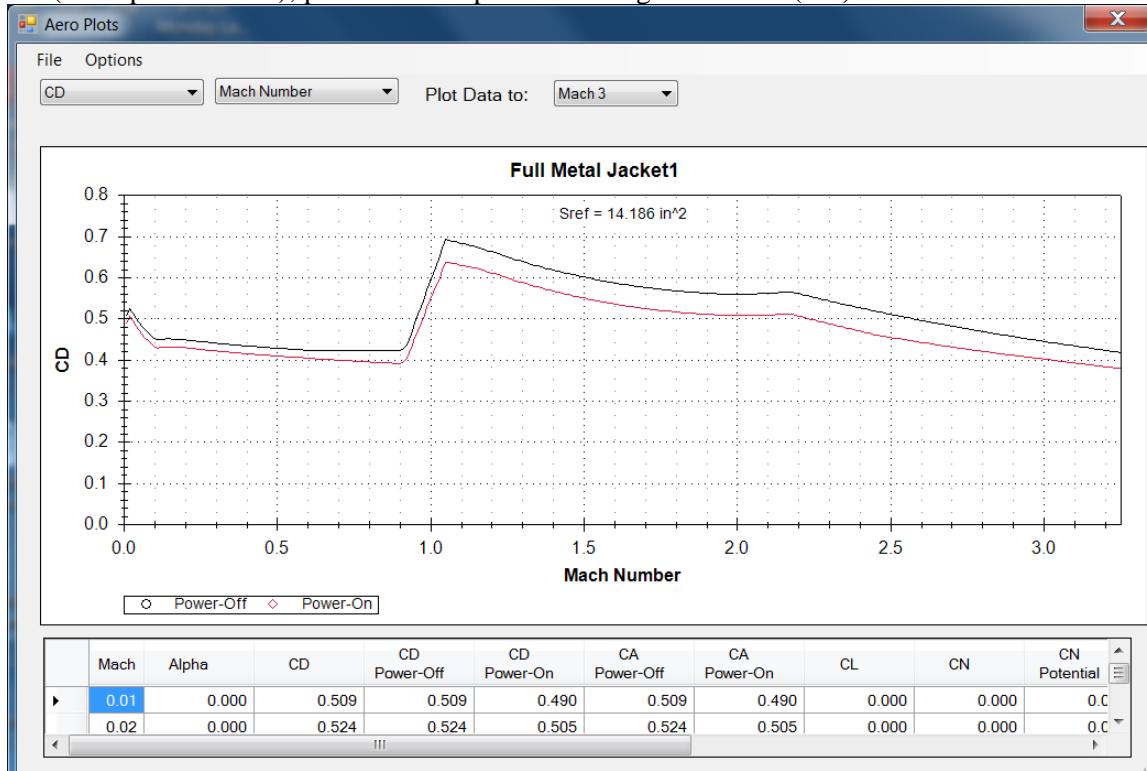


Figure 165 – Aerodynamic data plot for the Full Metal Jacket - Flight 3 configuration rocket; power-on and power-off drag coefficient (CD) versus Mach number, Mach 0-3.

Figure 166 shows the launch site input data for the Full Metal Jacket - Flight 3 configuration rocket. The Flight 3 configuration of the Full Metal Jacket rocket was flown from the Black Rock Desert Dry Lakebed launch site, with a launch site elevation of 3933 ft. The launch site temperature at the time of launch was 80 deg F. For this flight simulation the launch angle is set to zero deg from vertical, with the wind speed set to zero mph. The launch tower was 12 ft tall.

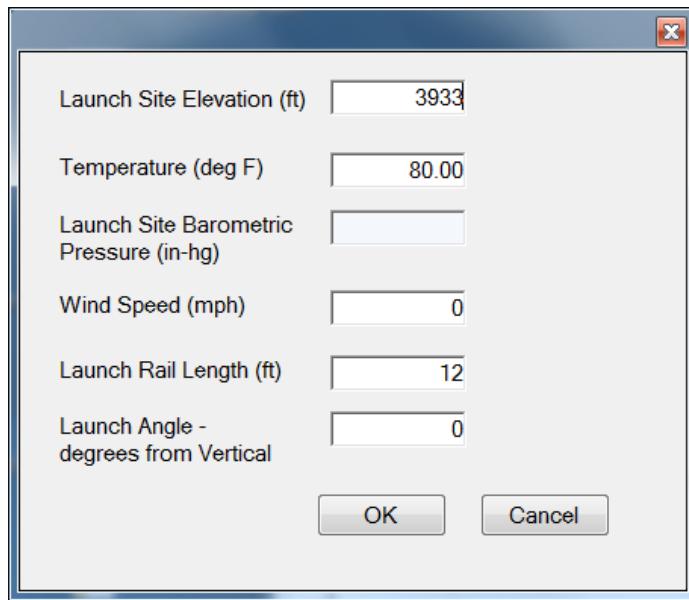


Figure 166 – Launch site input data for the Full Metal Jacket - Flight 3 configuration rocket  
(Example Rocket 2).

The recovery system inputs are shown in Figure 167. The Full Metal Jacket - Flight 3 configuration rocket had a small parachute, but since no parachute descent or landing data were recorded, and the primary flight data of interest was the peak altitude of the rocket measured by optical tracking, for this flight simulation the No Recovery ballistic descent to impact option was selected, by not checking either of the Recovery Event 1 or Event 2 boxes. (No Recovery Event, coasting flight through apogee, ballistic descent to impact.)

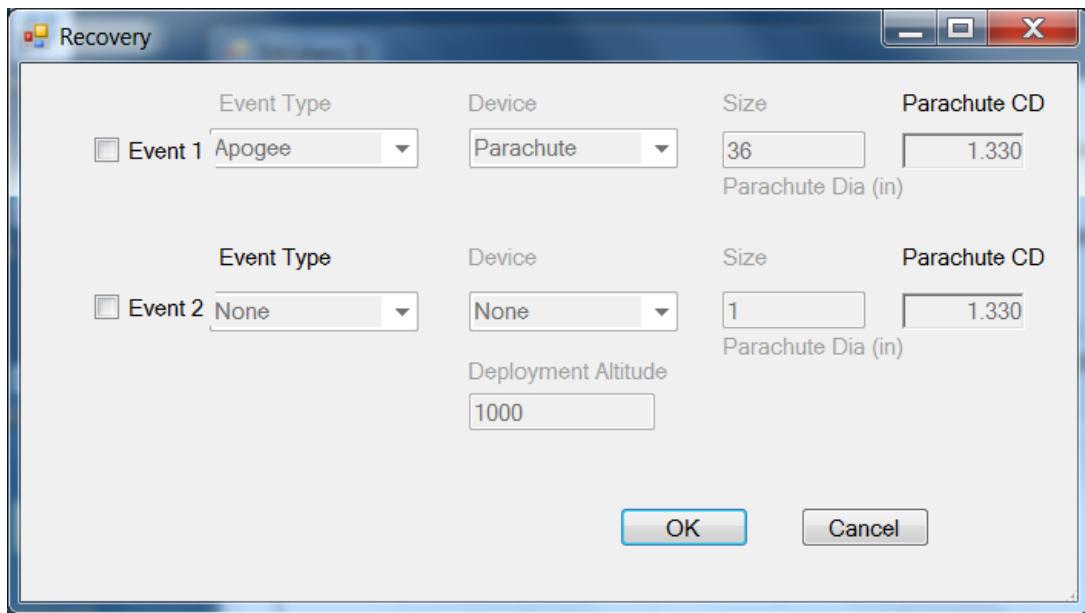


Figure 167 - Recovery system input data for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2).

The RASAero II Flight Simulation FlightDataEntry Screen showing the input data for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2) are presented in Figure 168. The rocket was flown on a Kosdon O10000 rocket motor, which was selected from the motor selection menu. The rocket loaded weight with motor (the liftoff weight) as flown was 70 lb.

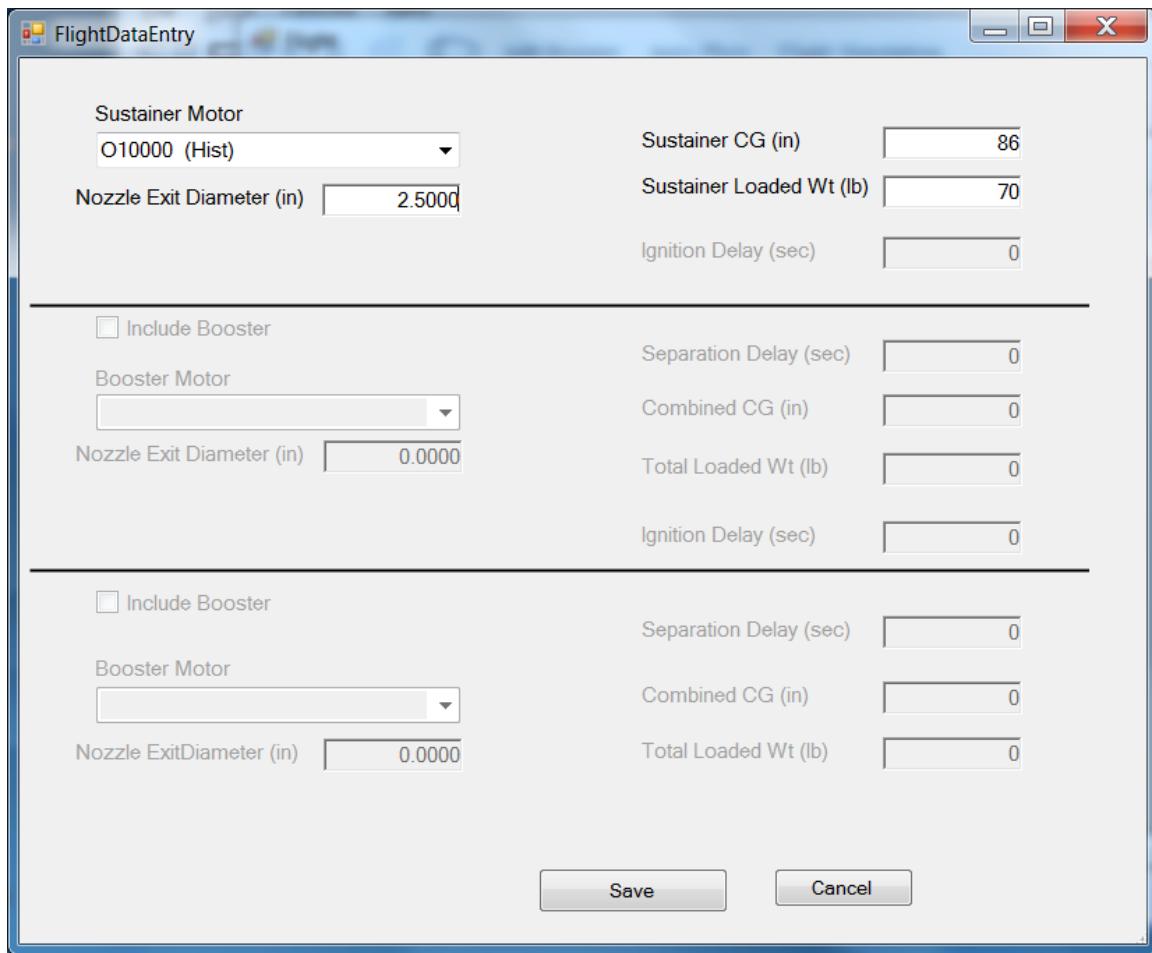


Figure 168 - Flight Simulation FlightDataEntry Screen for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2) with selected Kosdon O10000 motor, lift-off center of gravity (CG), lift-off weight, and motor nozzle exit diameter.

The summary flight data from the RASAero II Flight Simulation for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2) with the Kosdon O10000 motor is presented in Figure 169. The altitude versus time plot is presented in Figure 170, which shows the powered flight and coast to apogee, the coast through apogee, and the ballistic flight to impact since no recovery event was specified. (No recovery, ballistic flight to impact.)

The Mach number versus time plot is presented in Figure 171, showing that the rocket reached Mach 2.27.

The center of gravity (CG) and center of pressure (CP) versus time is presented in Figure 172.

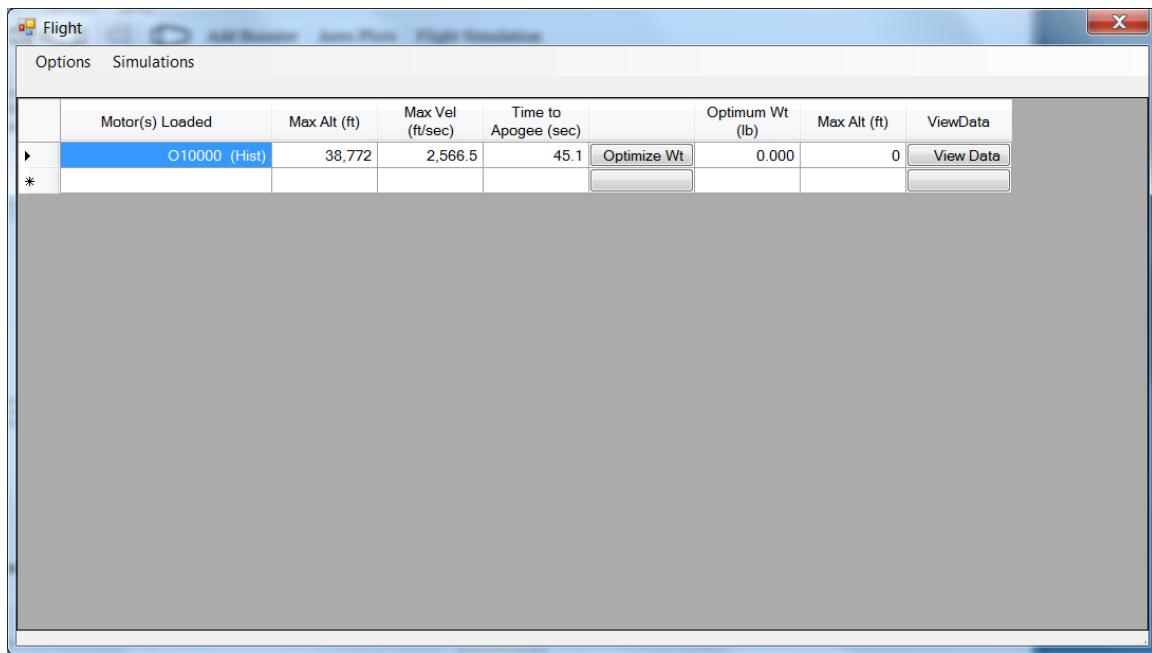


Figure 169 – RASAero II Flight Simulation summary flight data for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2).

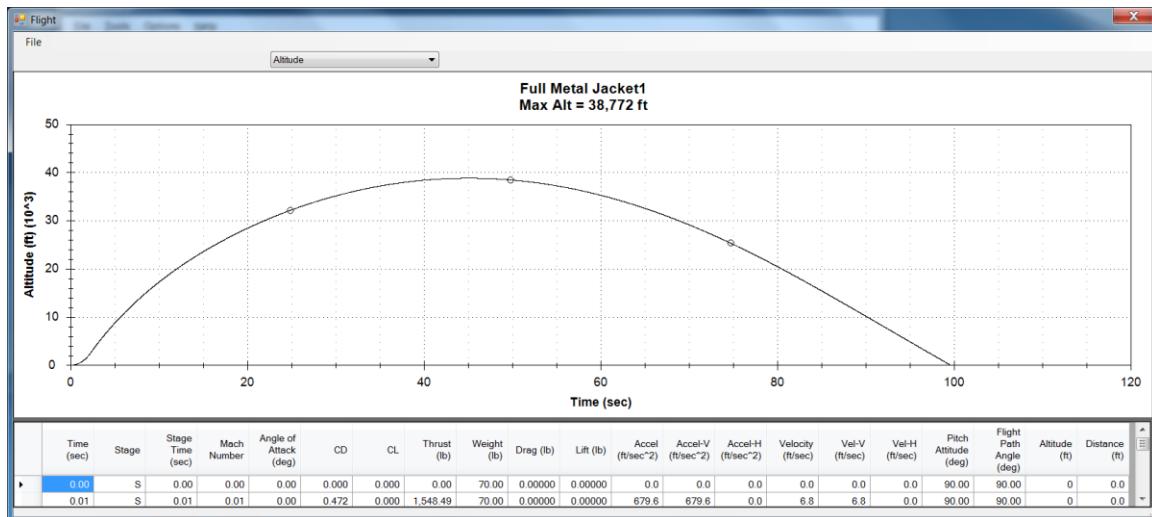


Figure 170 – RASAero II Flight Simulation output for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2), altitude versus time for powered flight and coast to apogee, ballistic descent to impact.

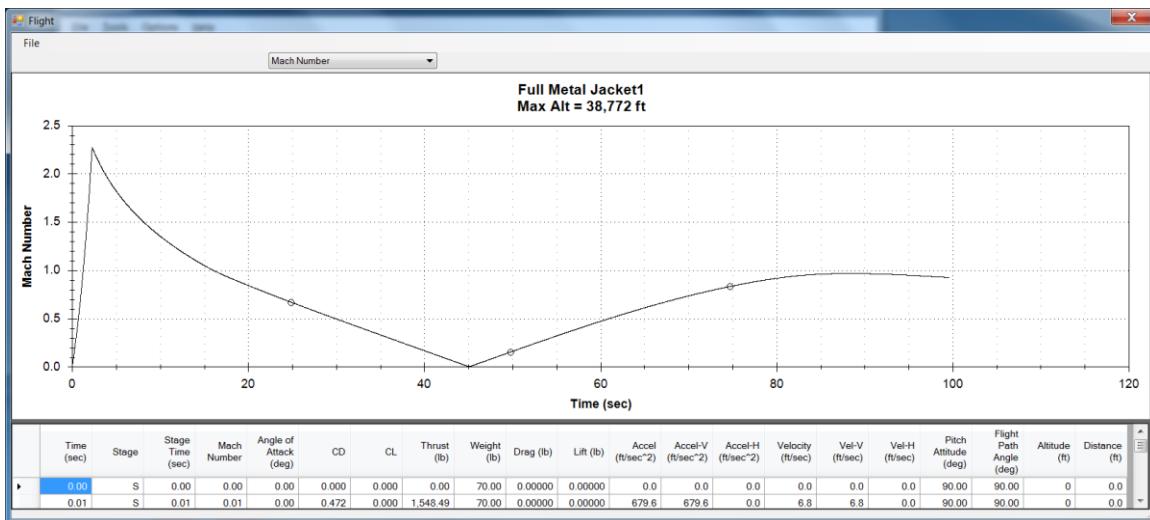


Figure 171 – RASAero II Flight Simulation output for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2), Mach number versus time for powered flight and coast to apogee, ballistic descent to impact.

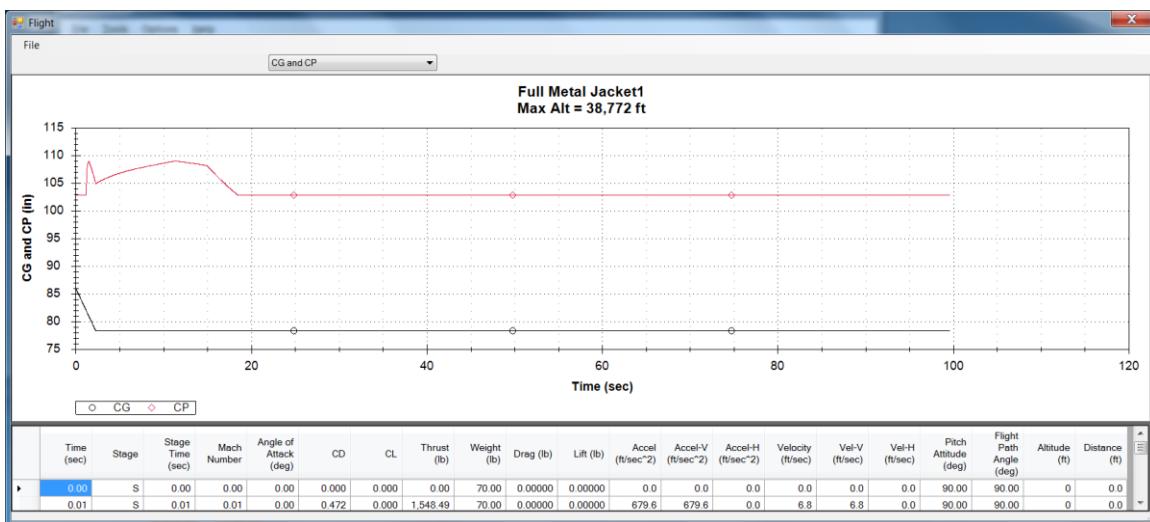


Figure 172 – RASAero II Flight Simulation output for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2), center of gravity (CG) and center of pressure (CP) versus time.

The Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2) was optically tracked to an altitude of 37981 ft. The altitude predicted by the RASAero flight simulation is 38772 ft, an error of only +2.08% compared to the optically tracked altitude.

### Example Rocket 3

The third example rocket is a two stage rocket, the AeroPac 104K Carmack Prize Rocket, which won the Carmack prize for the first rocket to use Global Positioning System (GPS) data to measure an apogee altitude for the rocket over 100K ft. The rocket reached an altitude of 104659 ft, 17.1 miles downrange from the launch site, as measured by GPS data. The RASAero II rocket file for this rocket (AeroPac104KStageOne&Two-2.CDX1) is located in the /My Documents/RASAero II/Examples directory.

The RASAero II Main Screen with the scale rocket drawing for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3) is presented in Figure 173. This rocket used a nested upper stage, where the upper stage motor case extended beyond the bottom of the upper stage, so that the motor case could slide into the front of the booster stage. The Comments inputs for the rocket are presented in Figure 174.

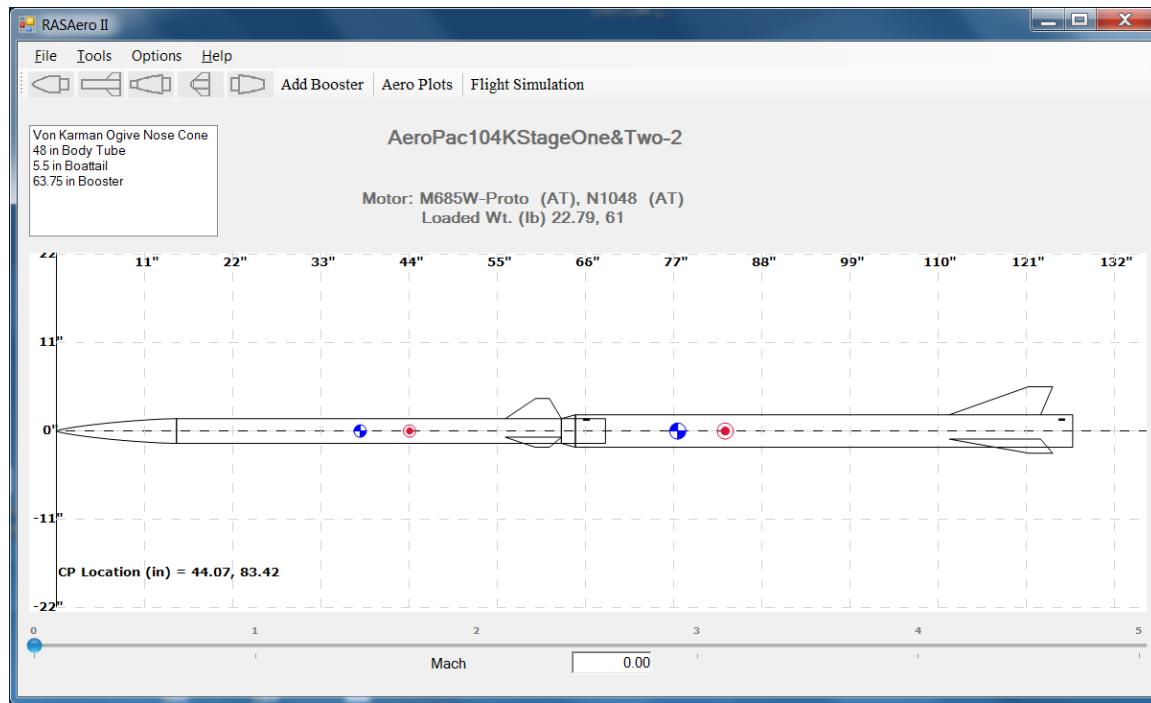


Figure 173 - RASAero II Main Screen with scale rocket drawing for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

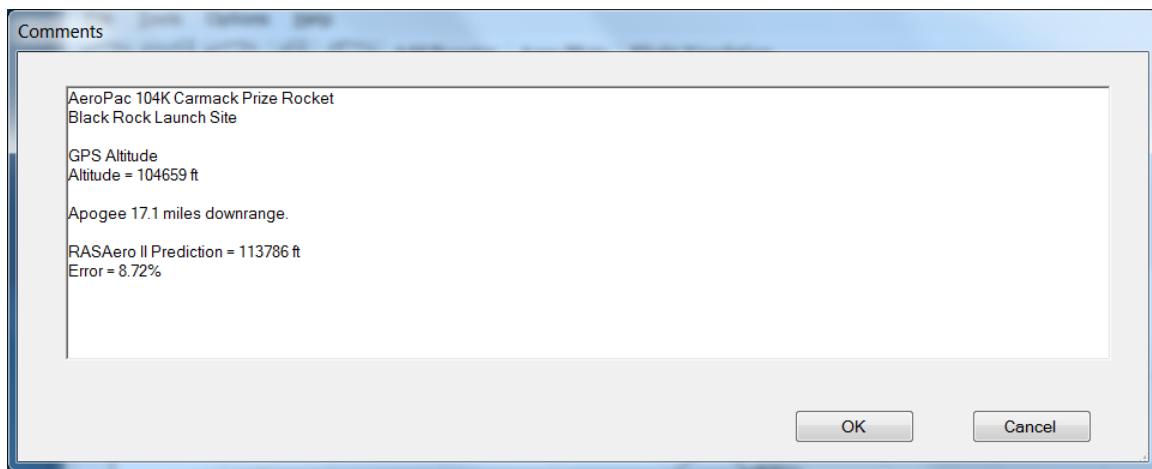


Figure 174 – Comments Input for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

The Nose Cone Inputs, the Sustainer Body Tube Inputs, the Sustainer Fin Inputs, the Sustainer Boattail Inputs to allow the upper stage to nest in the front of the Booster, the Booster Body and Launch Shoe Inputs, the Booster Fin Inputs, and the All Turbulent Flow and Surface Finish Inputs for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3) are presented in Figures 175-181.

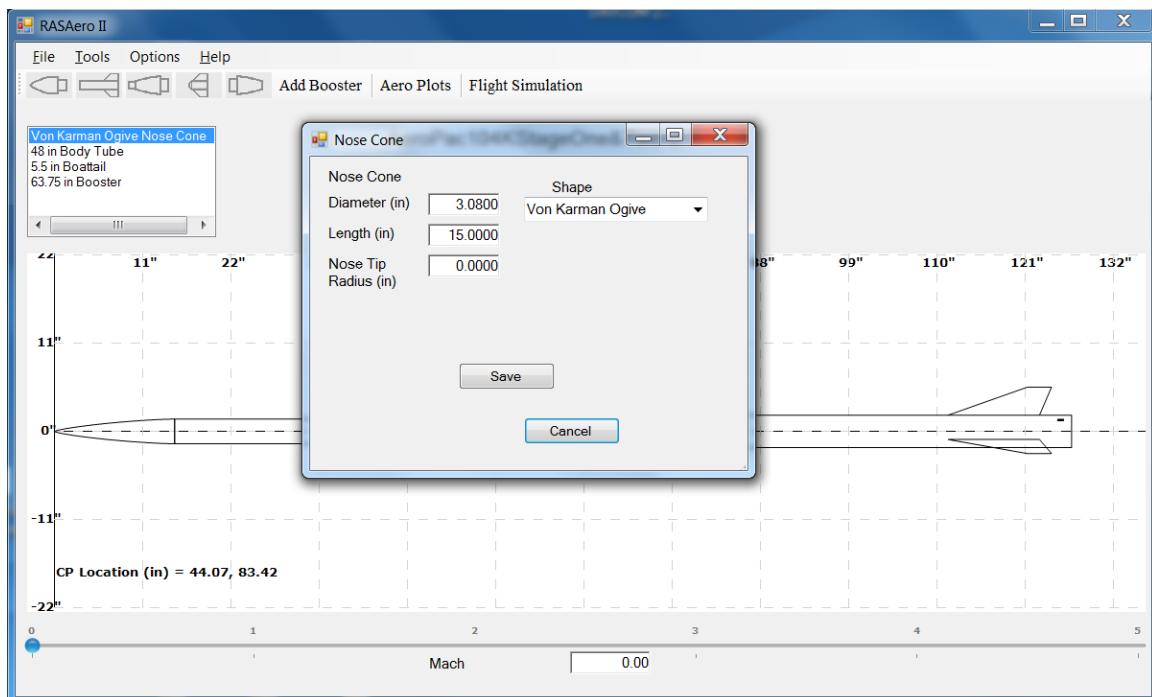


Figure 175 – Nose Cone Inputs for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

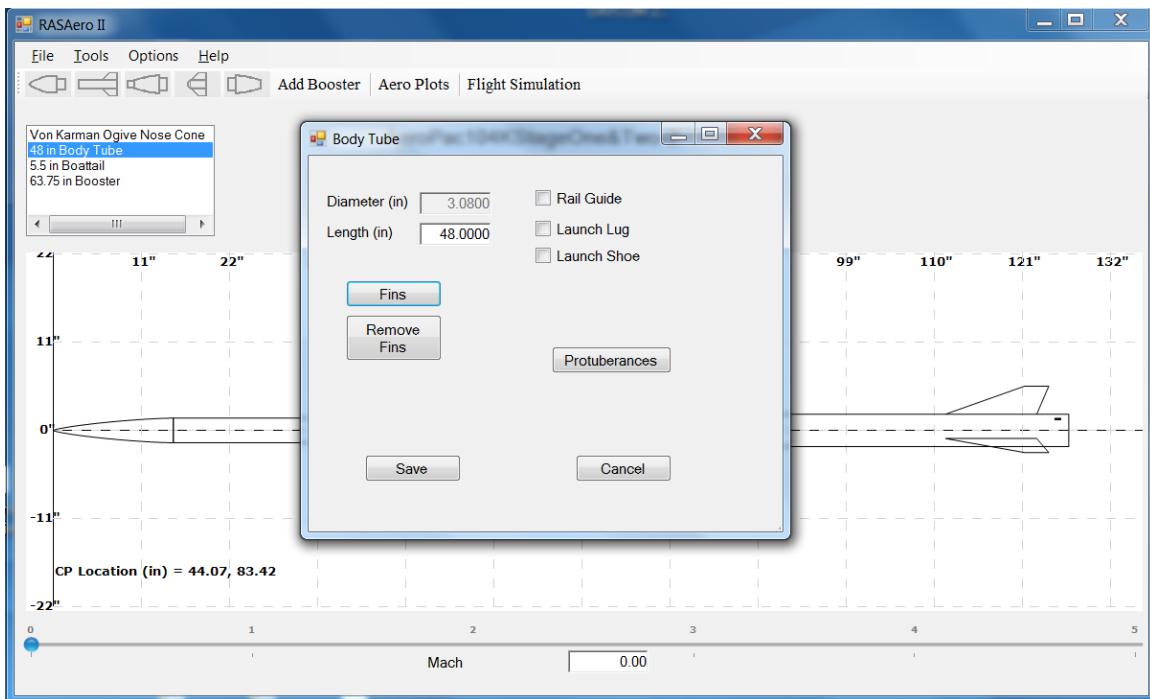


Figure 176 – Sustainer Body Tube Inputs for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

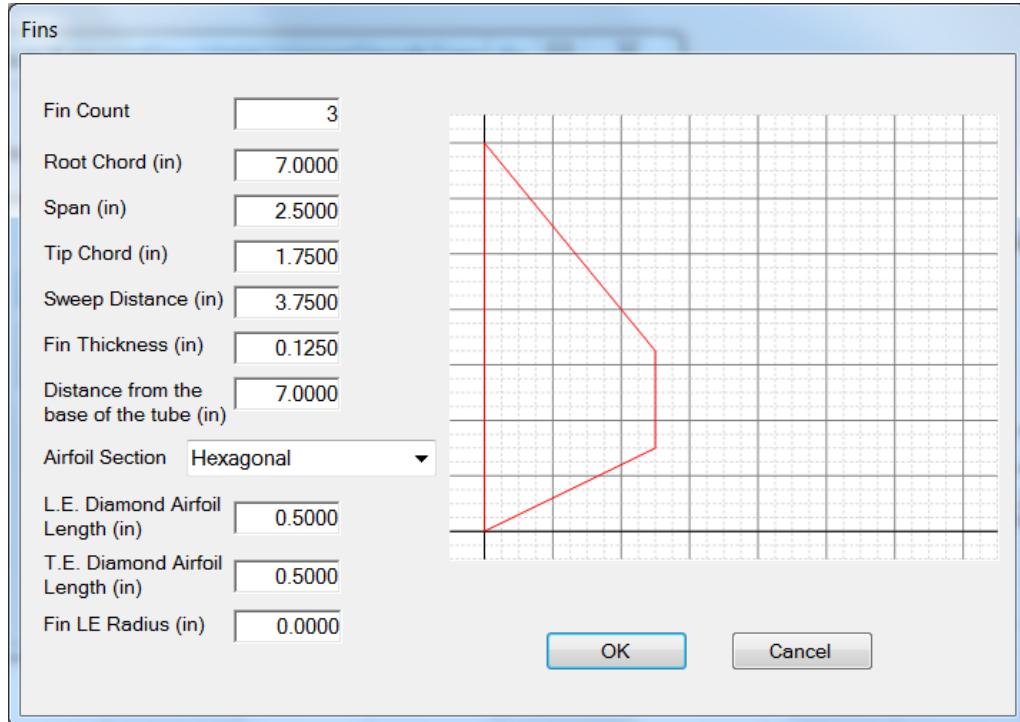


Figure 177 – Sustainer Fin Inputs for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

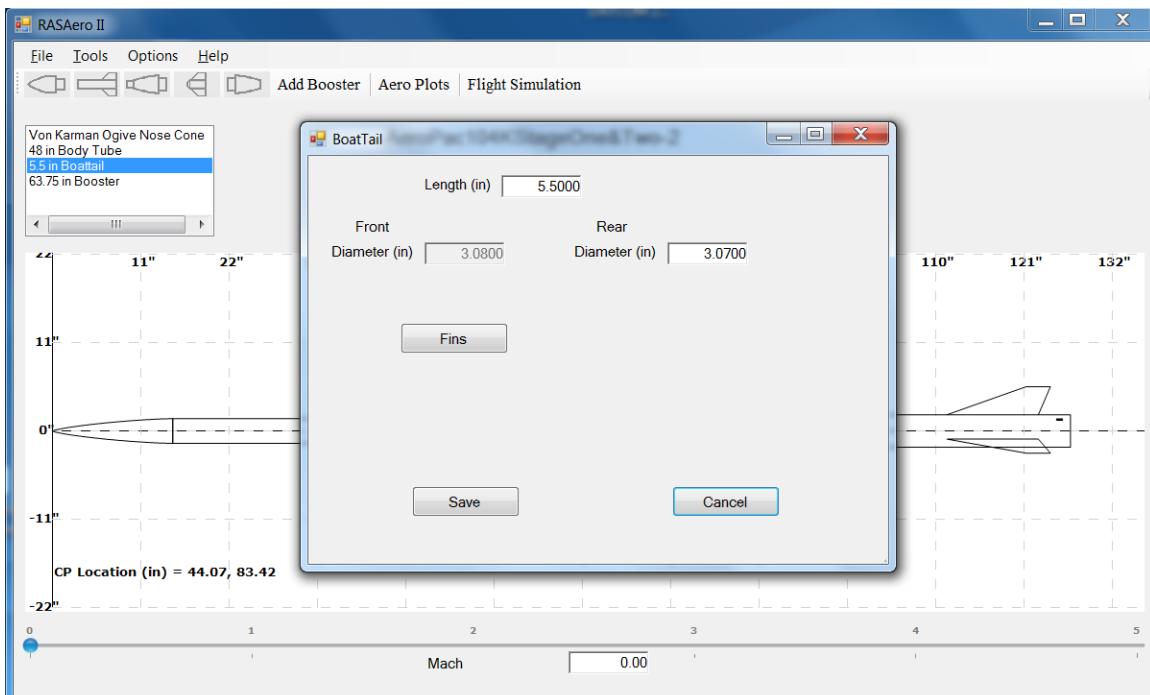


Figure 178 – Sustainer Boattail Inputs to allow the Sustainer stage to nest in the front of the Booster stage for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

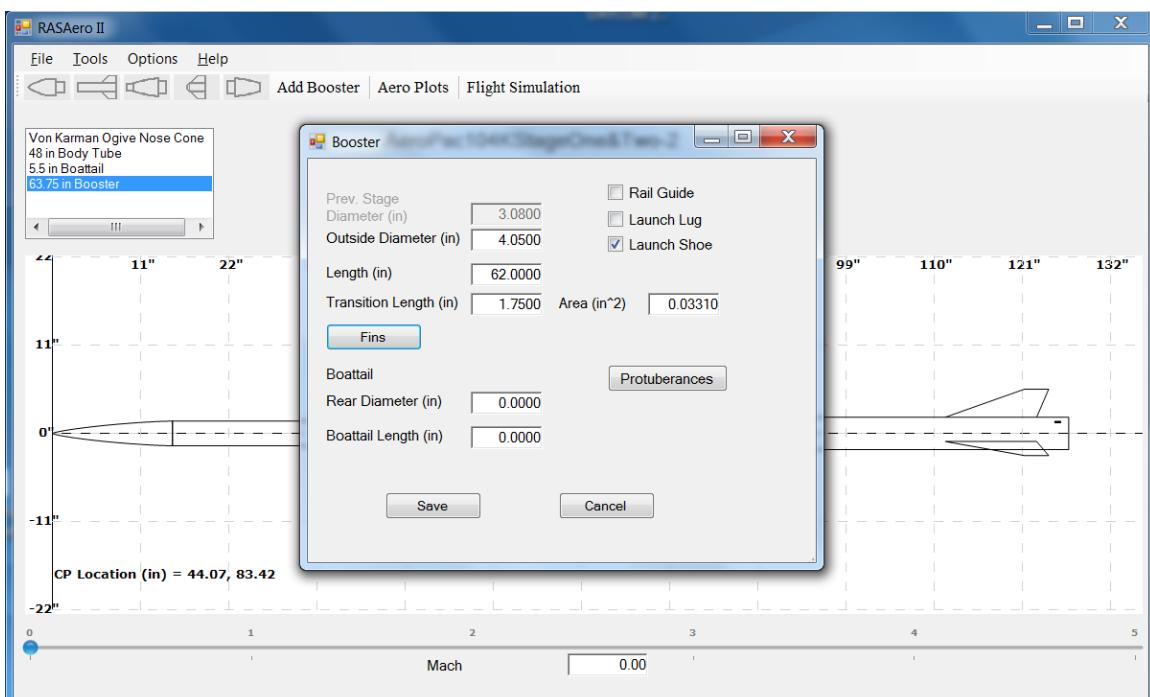


Figure 179 – Booster Body and Launch Shoe Inputs for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

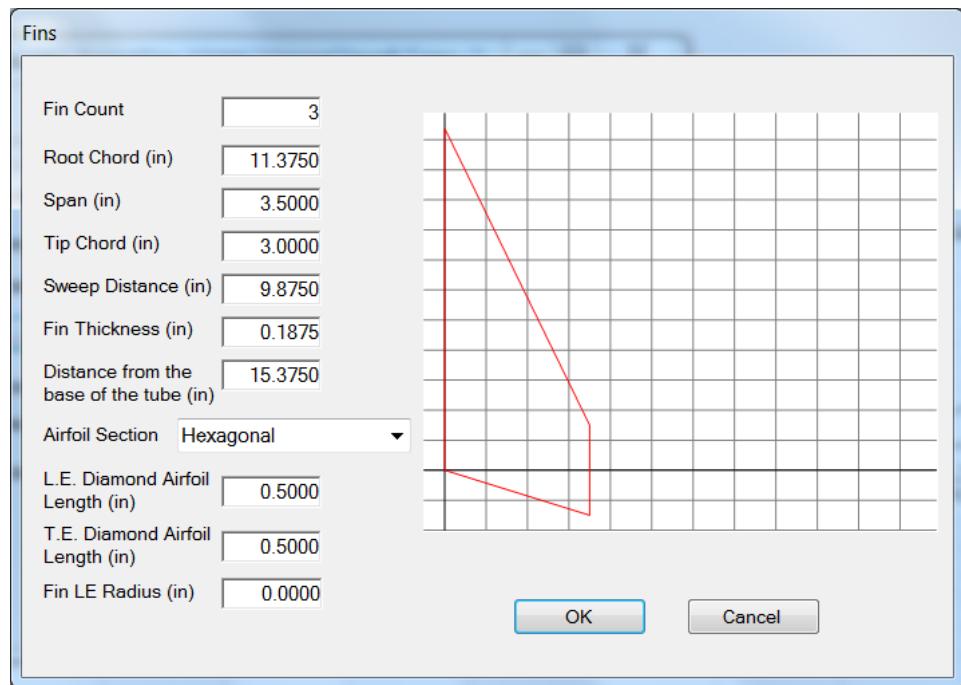


Figure 180 – Booster Fin Inputs for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

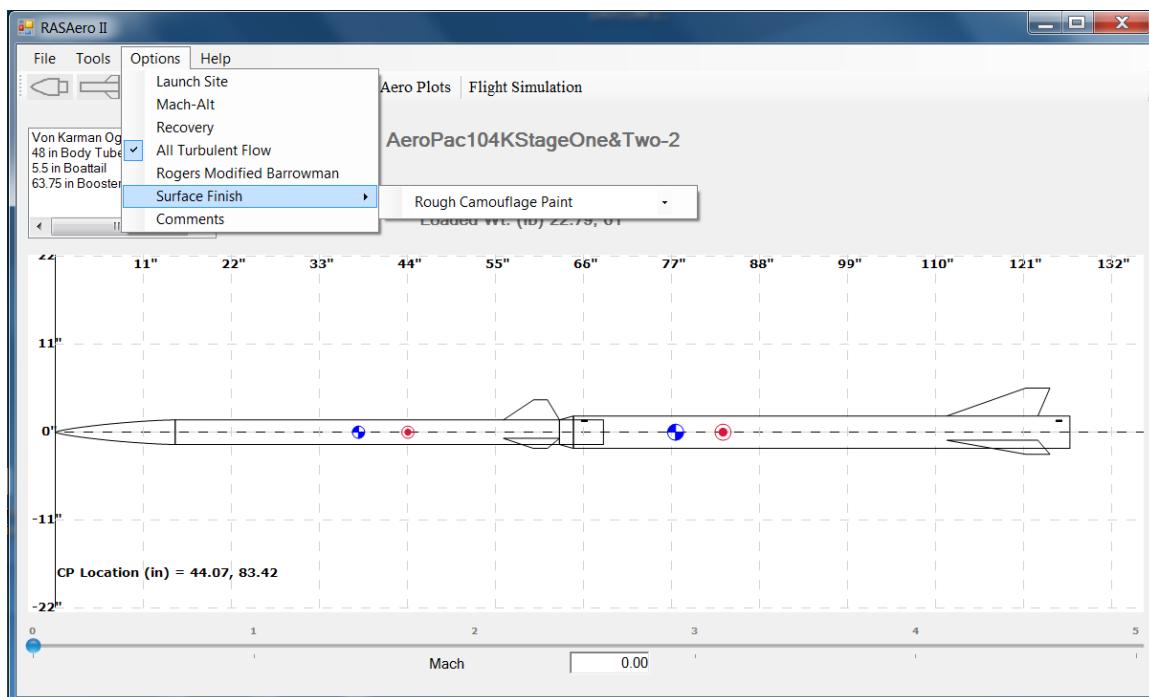


Figure 181 – All Turbulent Flow Selected, and Surface Finish Input for two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

There was aerodynamic heating damage on the Sustainer stage from flight over Mach 3 that was discovered when the Sustainer stage was recovered. Based on this observed aerodynamic heating damage and the resultant increase in surface roughness of the rocket, the All Turbulent Flow option and a Surface Finish Input of Rough Camouflage Paint was selected for the rocket.

Figures 182 and 183 show the power-on and power-off drag coefficient (CD) versus Mach number for the Sustainer plus Booster, and Sustainer only, for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

Figures 184 and 185 show the center of pressure (CP) versus Mach number for the Sustainer plus Booster, and Sustainer only, for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

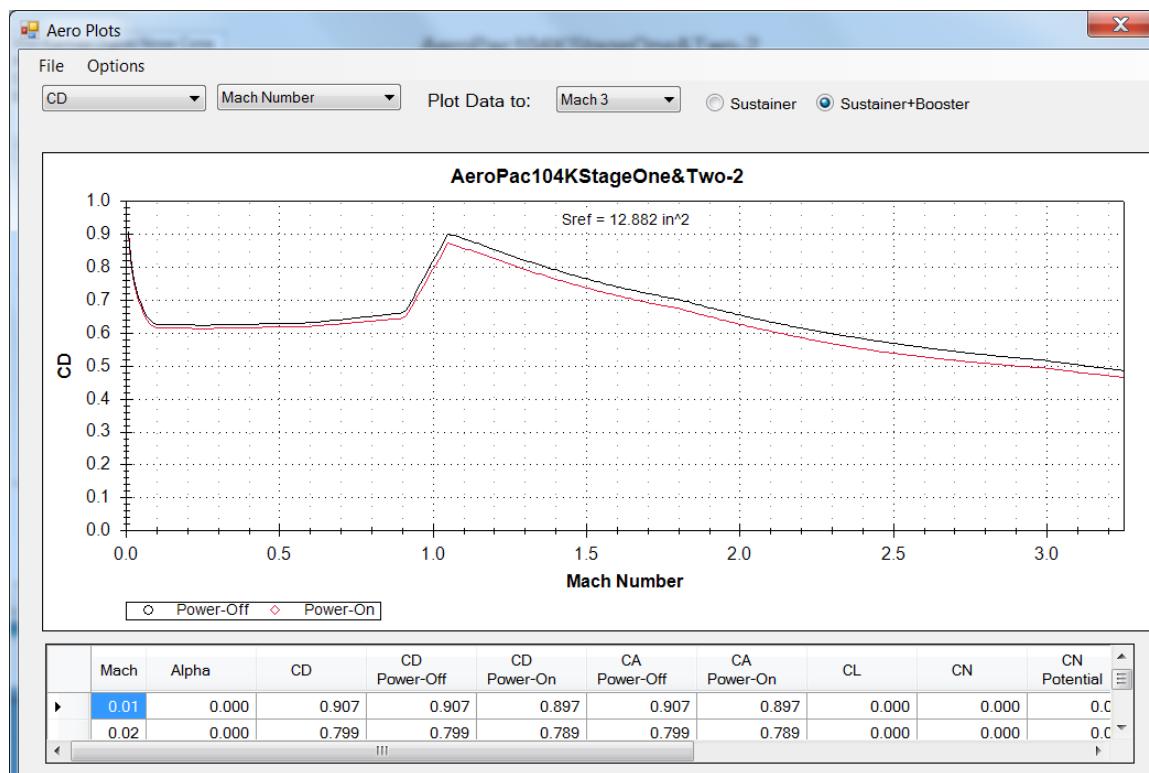


Figure 182 – Power-on and power-off drag coefficient (CD) versus Mach number for Sustainer plus Booster for the AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

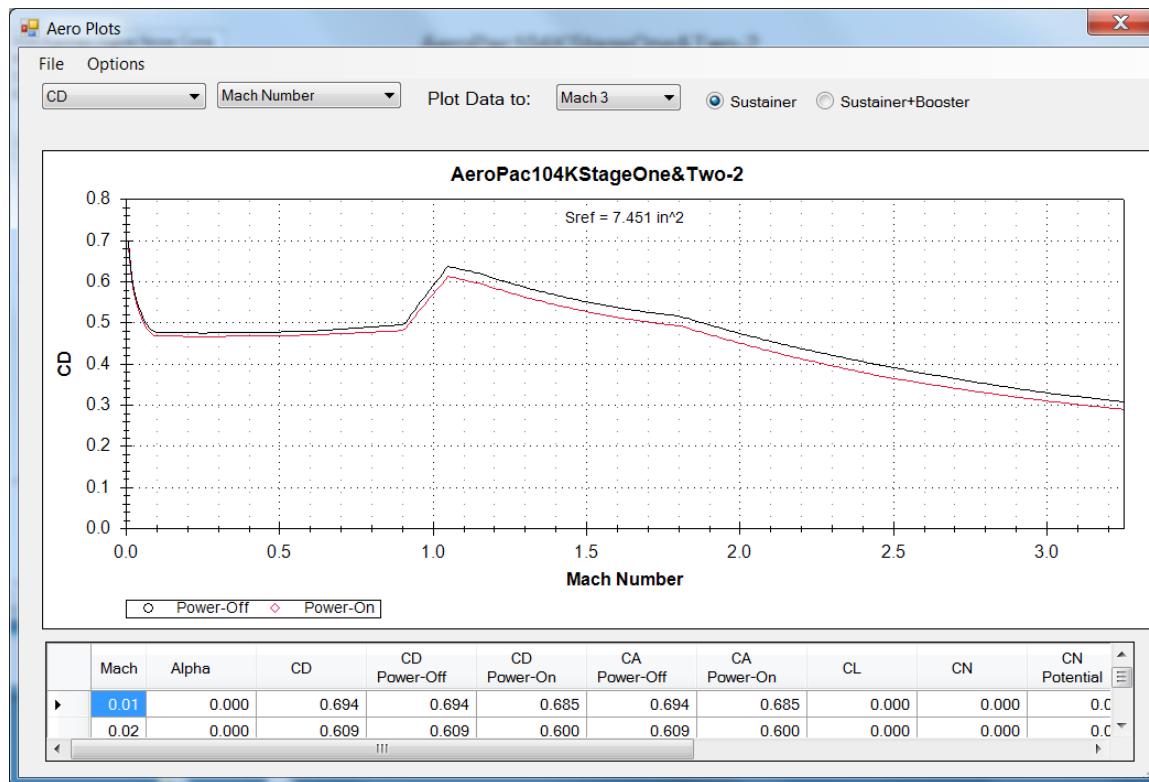


Figure 183 – Power-on and power-off drag coefficient (CD) versus Mach number for the Sustainer Only for the AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

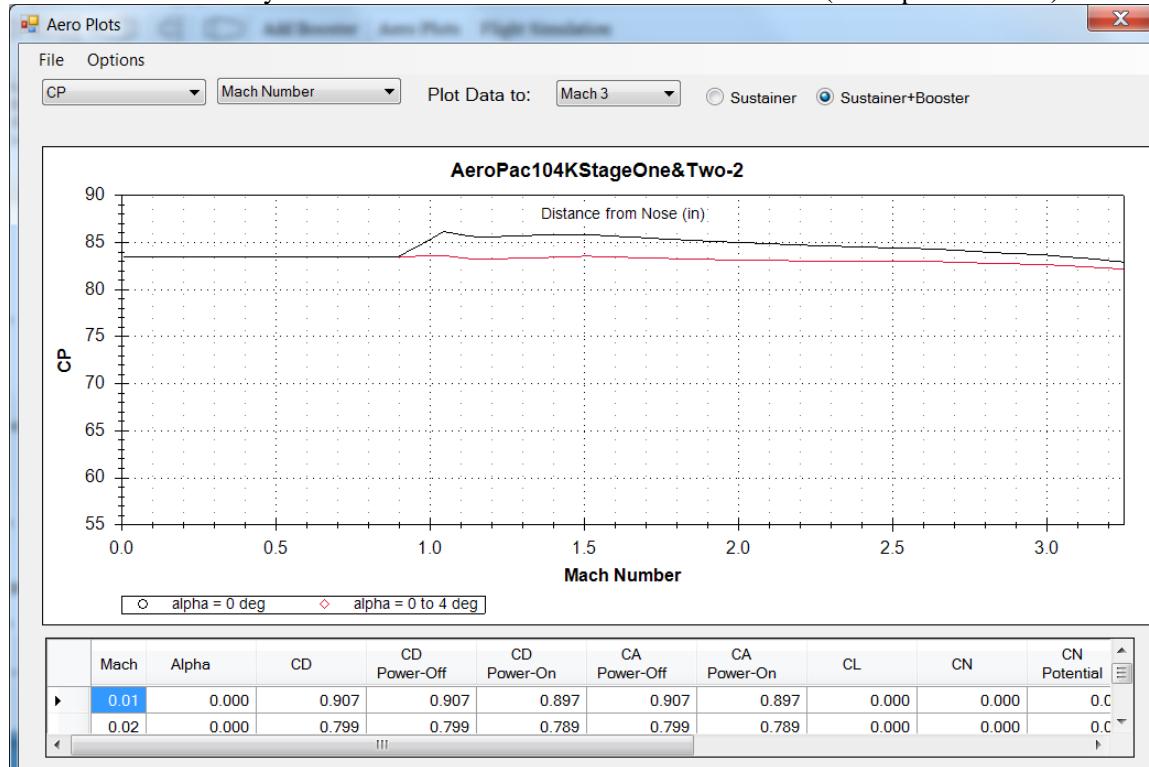


Figure 184 – Center of pressure (CP) versus Mach number for the Sustainer plus Booster for the AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

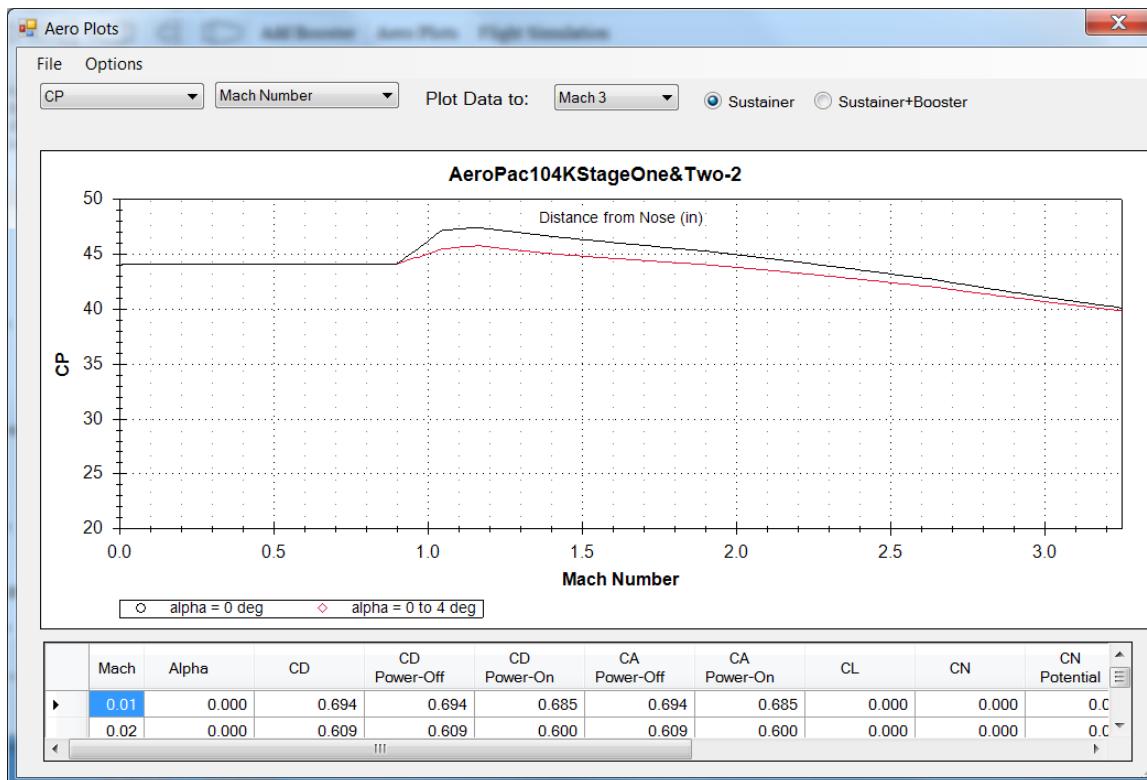


Figure 185 – Center of pressure (CP) versus Mach number for the Sustainer Only for the AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

Figure 186 shows the launch site input data for the two stage AeroPac 104K Carmack Prize Rocket. The rocket was flown from the Black Rock Desert Dry Lakebed launch site, with a launch site elevation of 3750 ft. For this flight simulation the launch site temperature was set to 80 deg F. The wind speed was set to zero mph. The launch rail was 12 ft long. The Launch Angle was adjusted through a series of flight simulation runs until the downrange distance at apogee of 17.1 miles from the launch site was reached. A Launch Shoe guide broke off from the rocket while it was moving up the launch rail, lowering the Launch Angle by an amount that could not be determined post-flight. Note from the RASAero II flight simulation run that a Launch Angle 7.64 degrees from vertical was required to match the downrange distance at apogee of 17.1 miles recorded in the GPS flight data.

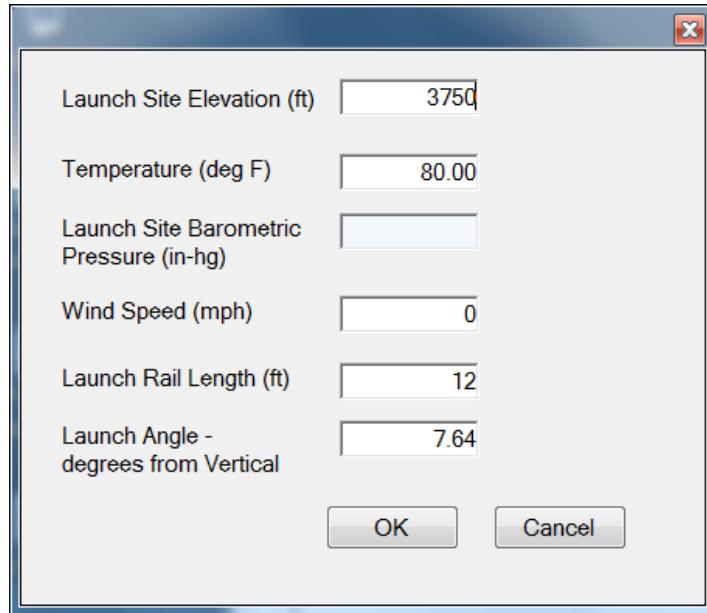


Figure 186 – Launch site input data for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

The recovery system inputs for the AeroPac 104K Carmack Prize Rocket are shown in Figure 187. Since the RASAero II flight simulation runs were run to determine the Launch Angle required to reach the 17.1 miles downrange distance at apogee, the rocket was run with the No Recovery ballistic descent to impact option, by not checking either of the Recovery Event 1 or Event 2 boxes. (No Recovery Event, coasting flight through apogee, ballistic descent to impact.) This allowed a more accurate determination from the flight simulation runs of the downrange distance at apogee.

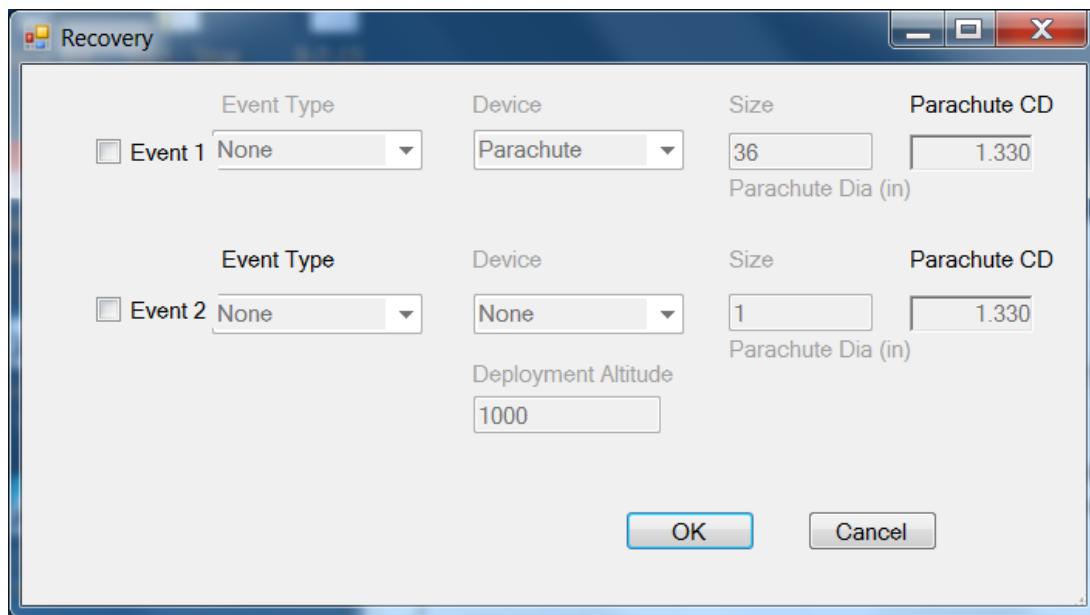


Figure 187 - Recovery system input data for the AeroPac 104K Carmack Prize Rocket  
(Example Rocket 3).

The RASAero II Flight Simulation FlightDataEntry Screen showing the input data for both the Sustainer and Booster Stages for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3) are presented in Figure 188. Note the ignition delay on the ignition of the Sustainer motor, which was based on in-flight measured axial acceleration from the flight.

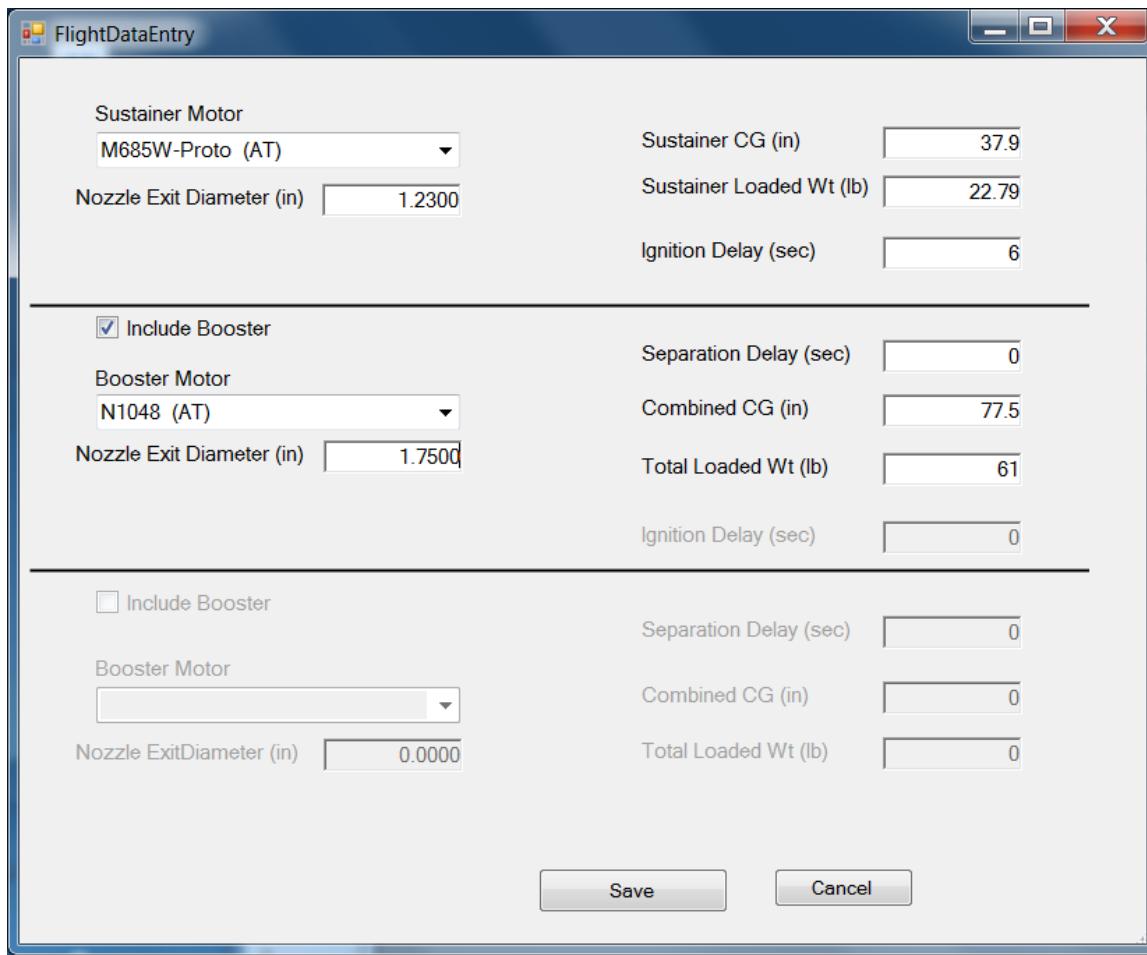


Figure 188 - Flight Simulation FlightDataEntry Screen showing data for both Sustainer and Booster Stages for the AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

The summary flight data from the RASAero II Flight Simulation for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3) is presented in Figure 189. The altitude versus time plot is presented in Figure 190, which shows the powered flight and coast to apogee, the coast through apogee, and the ballistic flight to impact since no recovery event was specified for this flight simulation.

The Mach number versus time plot is presented in Figure 191, showing that the rocket reached Mach 3.14.

The thrust versus time plot for the flight, blown up to focus in on the burn time of the rocket motors, is presented in Figure 192.

The center of gravity (CG) and center of pressure (CP) versus time is presented in Figure 193, and the stability margin in calibers (CG – CP) / D versus time is presented in Figure 194.

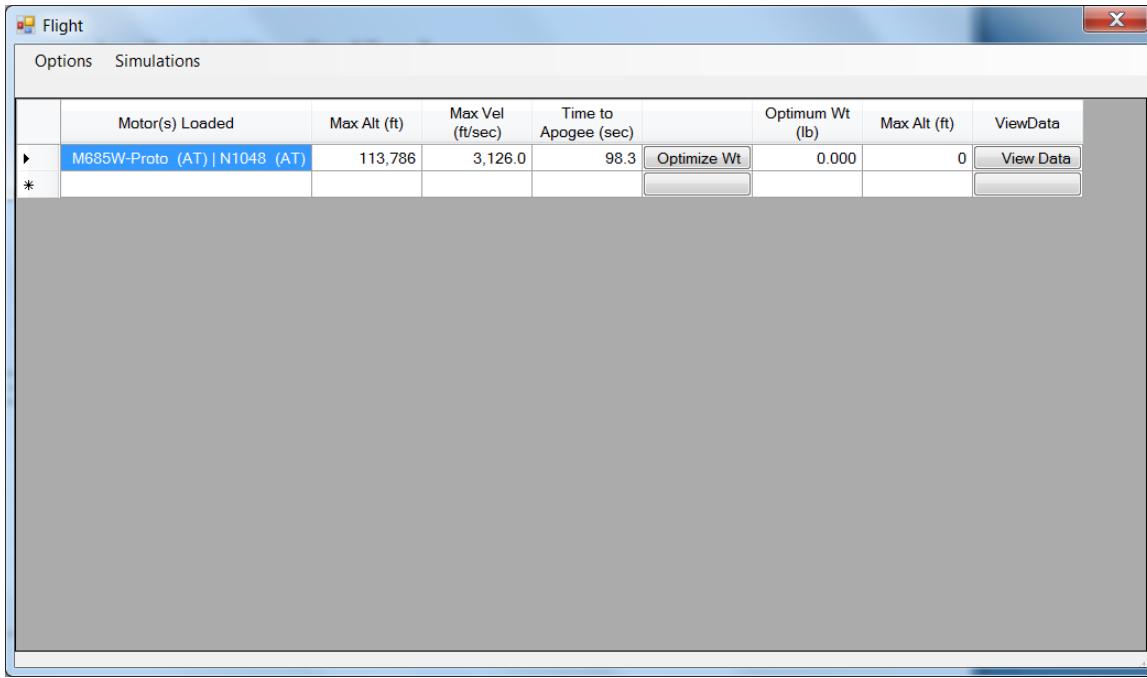


Figure 189 – RASAero II Flight Simulation summary flight data for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3).

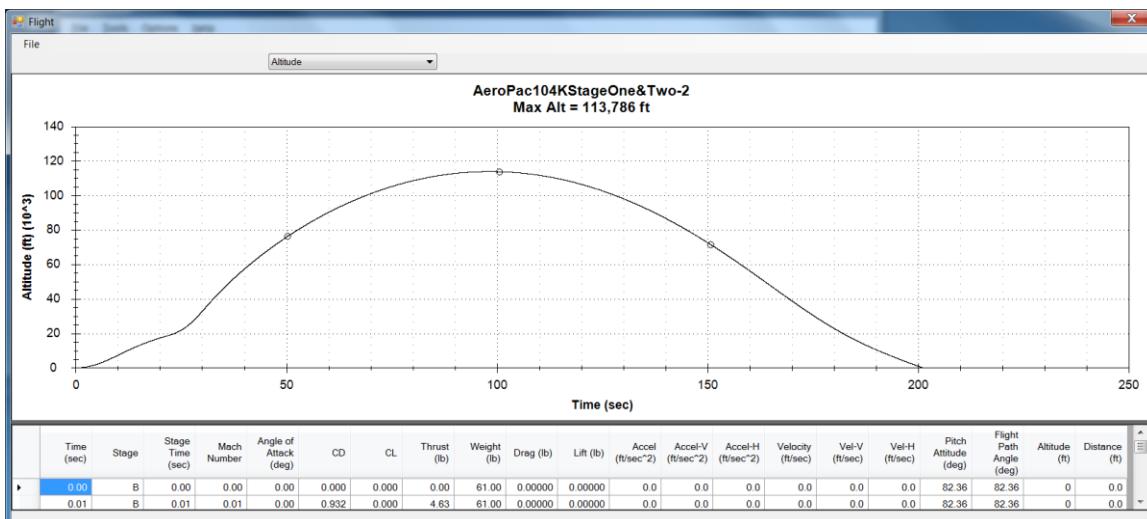


Figure 190 – RASAero II Flight Simulation output for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3), altitude versus time for powered flight and coast to apogee, ballistic descent to impact.

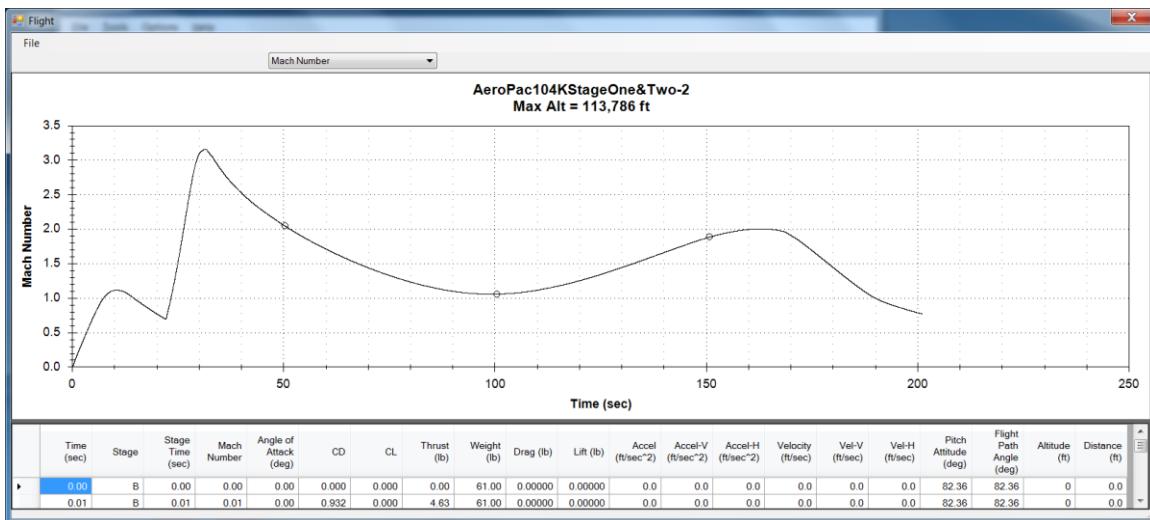


Figure 191 – RASAero II Flight Simulation output for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3), Mach number versus time for powered flight and coast to apogee, ballistic descent to impact.

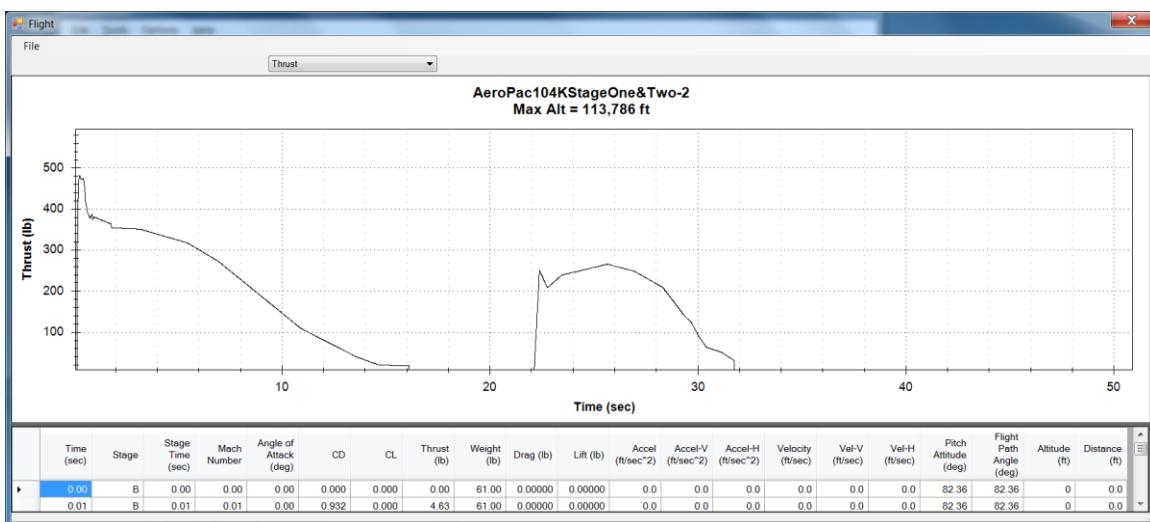


Figure 192 – RASAero II Flight Simulation output for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3), thrust versus time.

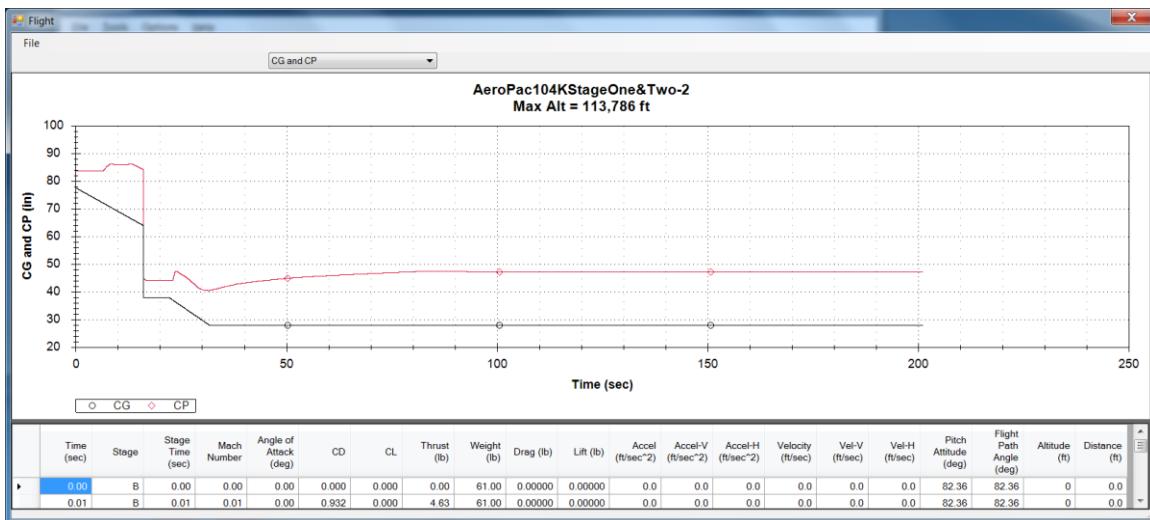


Figure 193 – RASAero II Flight Simulation output for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3), center of gravity (CG) and center of pressure (CP) versus time.

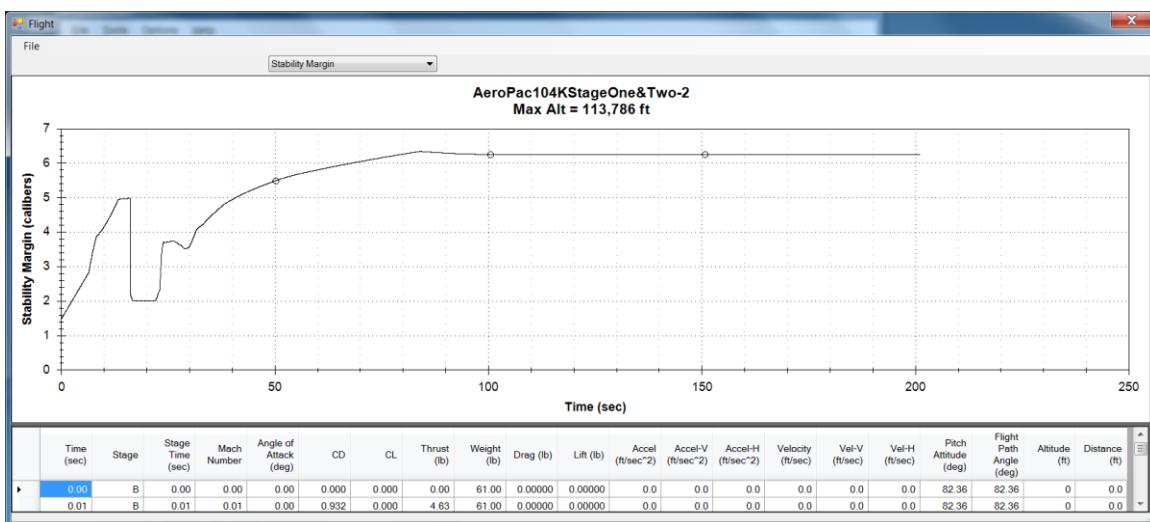


Figure 194 – RASAero II Flight Simulation output for the two stage AeroPac 104K Carmack Prize Rocket (Example Rocket 3), stability margin in calibers versus time.

The actual apogee altitude for the upper (Sustainer) stage of the AeroPac 104K Carmack Prize Rocket at the apogee point 17.1 miles downrange from the launch site based on GPS data was 104659 ft. The RASAero II flight simulation predicted apogee altitude for the upper (Sustainer) stage at the apogee point 17.1 miles downrange from the launch site was 113786 ft, an error of +8.72% compared to the GPS flight data.