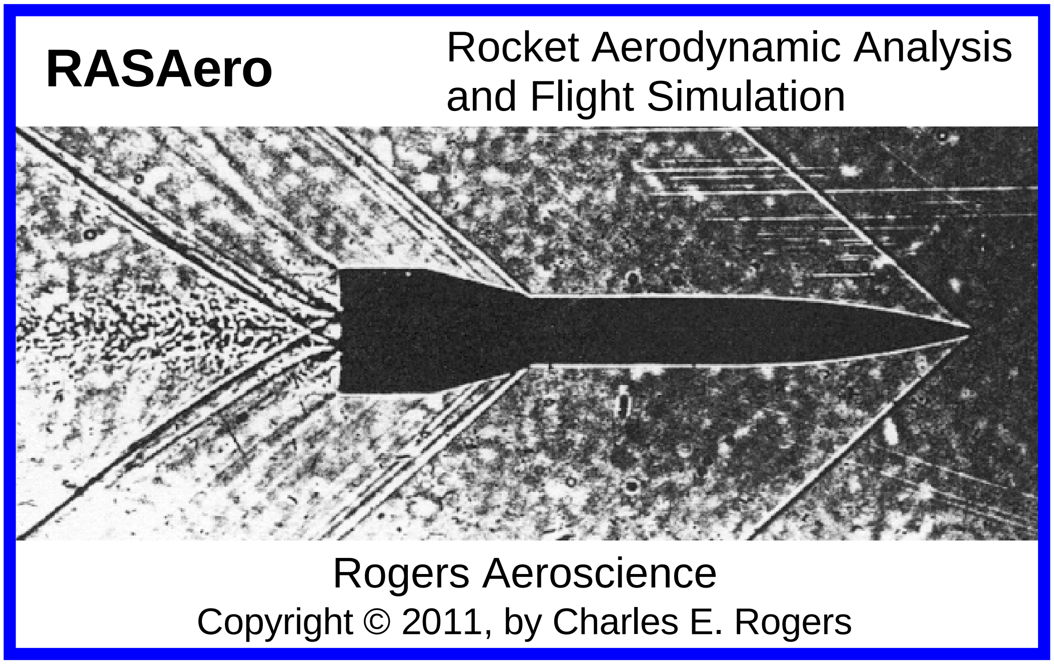

RASAero

Rocket Aerodynamic Analysis
and Flight Simulation

Rogers Aeroscience

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Rogers Aeroscience RASAero Aerodynamic Analysis and Flight Simulation Program

Users Manual

Version 1.0.2.0

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The RASAero Aerodynamic Analysis and Flight Simulation Program

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

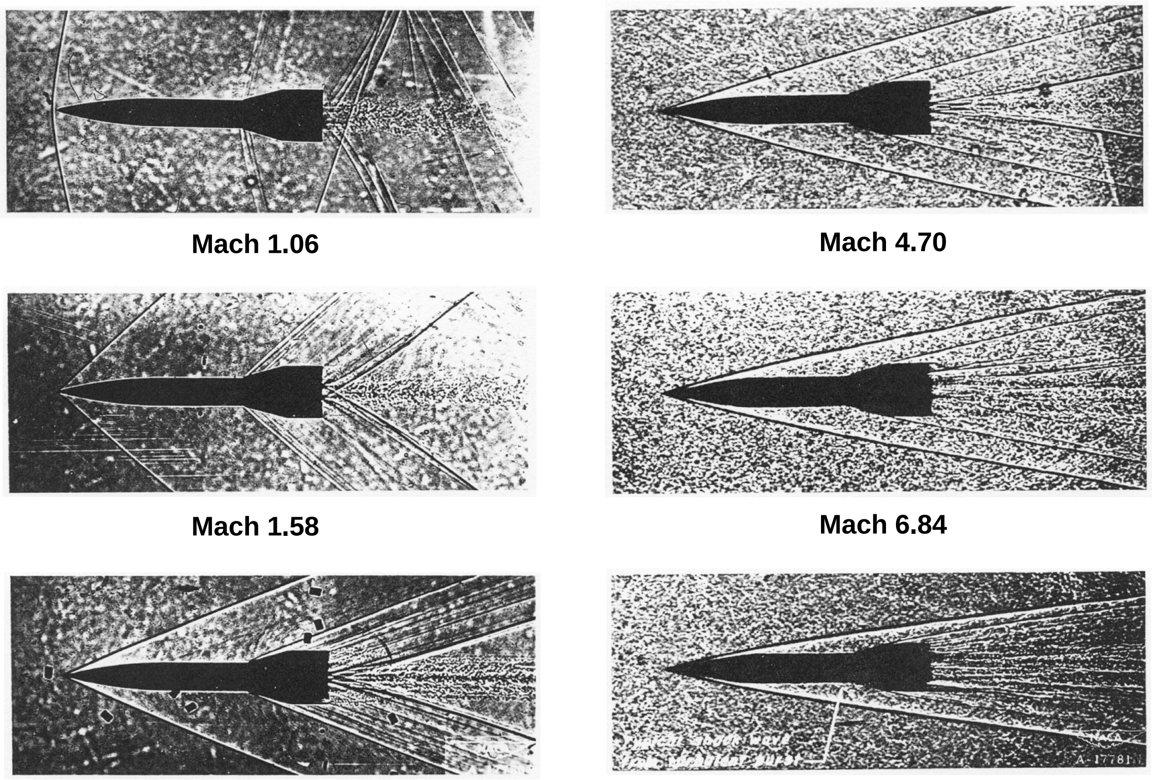
The RASAero aerodynamic prediction methods are the most accurate available for model, high power, and amateur rockets, and are of equivalent accuracy to professional engineering method aerodynamic analysis codes used for missiles, sounding rockets, and space launch vehicles.

The RASAero 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 (CNalpha) at low angles of attack, inclusion of the body in the presence of the fins interference factor (Kbf) 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 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.

The RASAero aerodynamic prediction methods and the RASAero software have been calibrated against NACA and NASA wind tunnel model, free-flight model and sounding rocket data, published professional aerodynamic data for missiles, and several professional engineering method aerodynamic analysis programs, against which RASAero has demonstrated equivalent numerical accuracy.

An example of the predictive accuracy of the RASAero software is presented in Figures 1 and 2. Figure 1 presents shadowgraphs (similar to Schlieren photographs) of a gun-launched ballistic free-flight model in flight in a supersonic-hypersonic wind tunnel, showing the formation of shock waves, Mach waves, and expansion fans around the rocket shape at supersonic and hypersonic Mach numbers. Figure 2 shows a comparison of the RASAero predicted drag coefficient at zero degrees angle of attack with the supersonic and hypersonic drag coefficient data at zero degrees angle of attack from the ballistic free-flight wind tunnel model test data. The excellent predictive accuracy of the RASAero software from subsonic to supersonic to hypersonic Mach numbers, all the way out to Mach 10 can be seen in Figure 2. The RASAero software has similar predictive accuracy for rocket drag coefficient up to Mach 25. Additional examples of the predictive accuracy of the RASAero software are presented in Figures 3-5.

NACA RM A53D02
Free-Flight Ballistic Wind Tunnel Model
(Shadowgraphs - Similar to Schlieren Photographs)



Mach 1.06 **Mach 4.70**

Mach 1.58 **Mach 6.84**

Mach 2.91 **Mach 10.0**

Figure 1 – Gun-launched ballistic free-flight model in a supersonic-hypersonic wind tunnel.

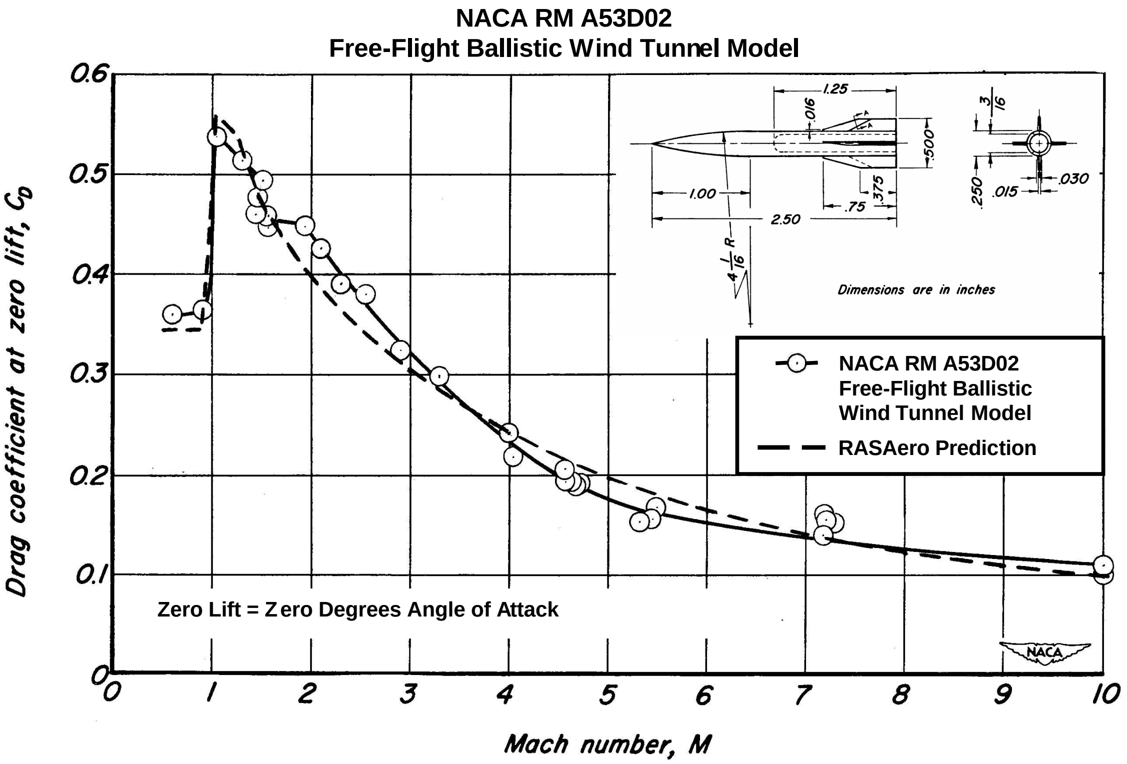


Figure 2 – Ballistic free-flight wind tunnel model test data, RASAero predicted drag coefficient.

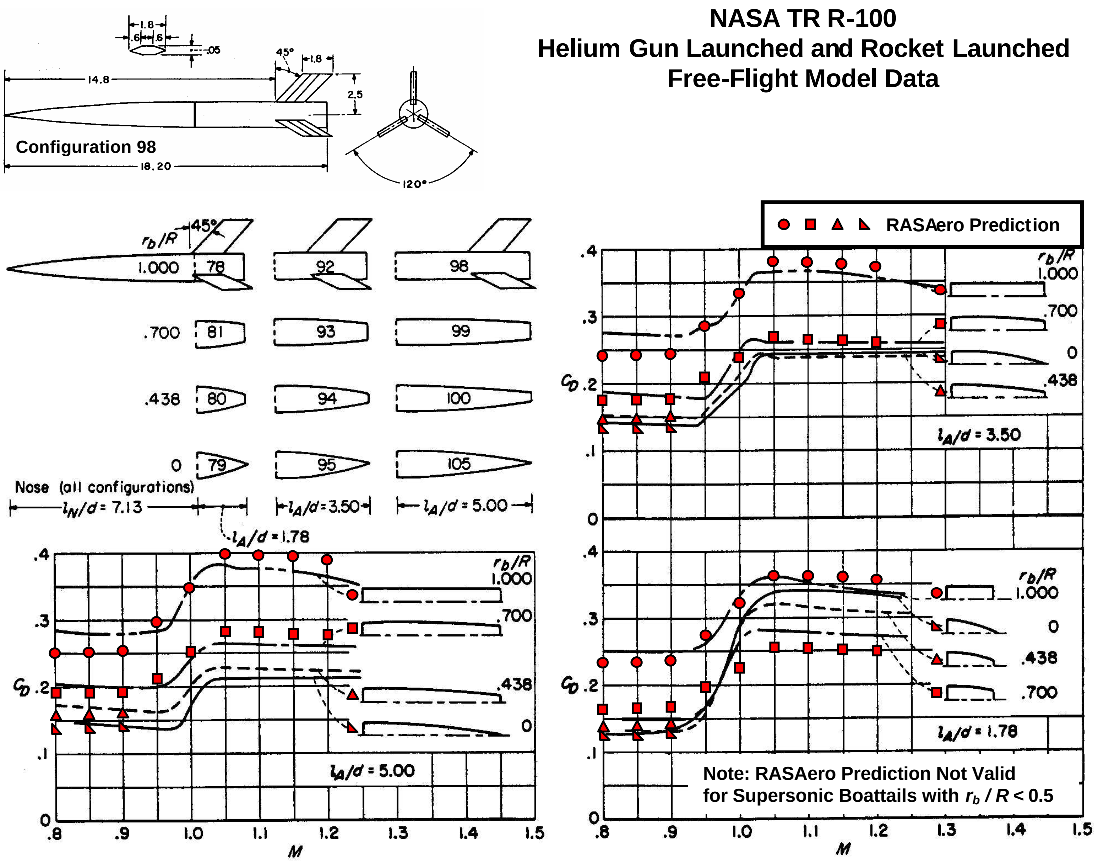


Figure 3 – Helium gun launched and rocket launched free-flight model data, RASAero predicted drag coefficient.

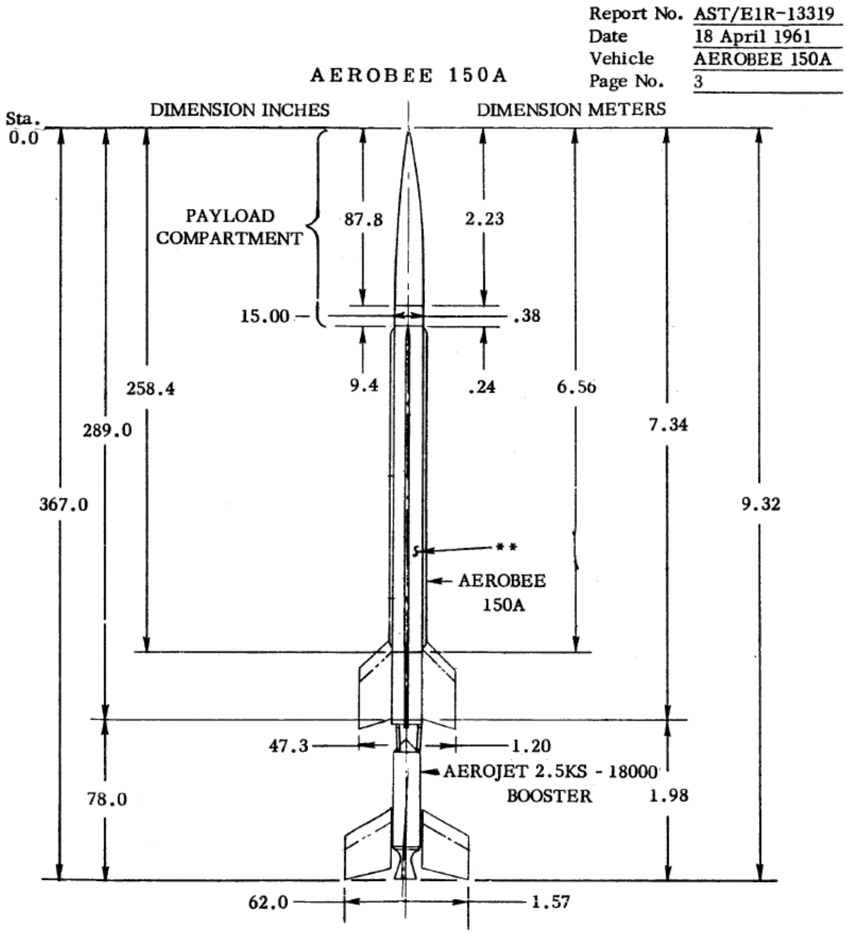
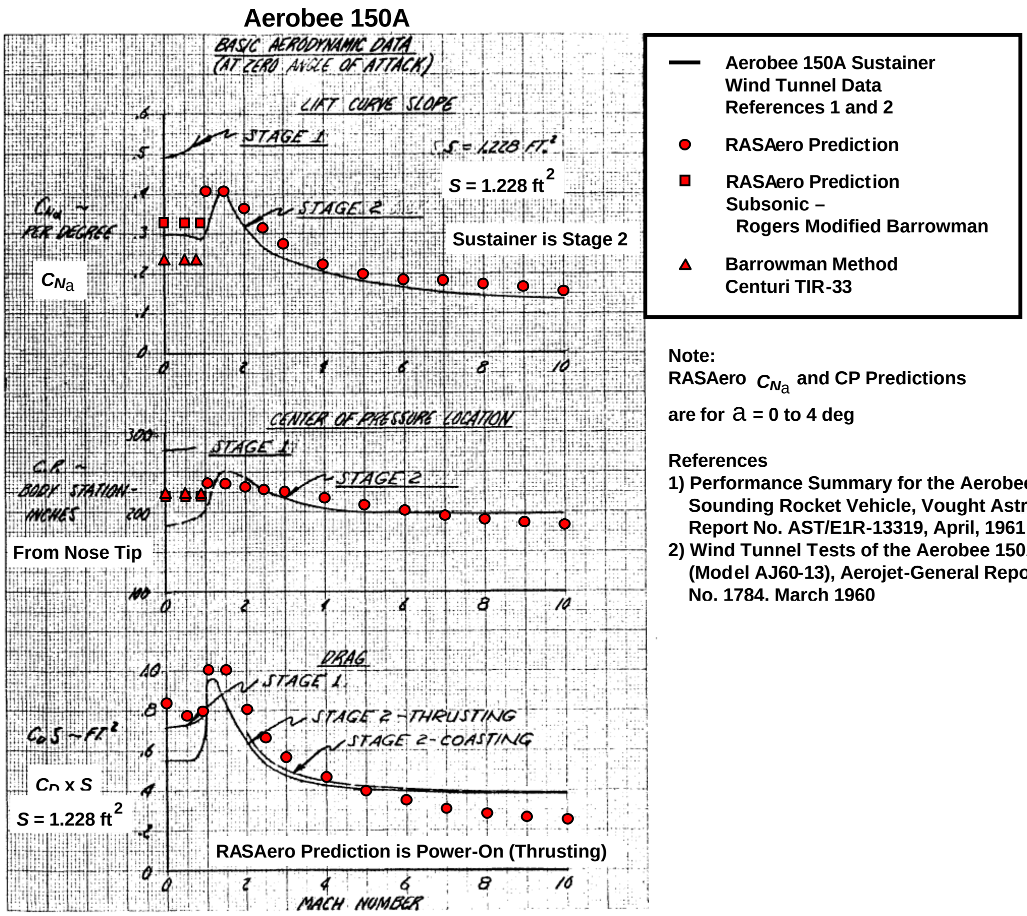


Figure 4 – Aerobee 150A sounding rocket.



Note:
RASAero C_{Na} and CP Predictions are for a = 0 to 4 deg

References

1) Performance Summary for the Aerobee 150A Sounding Rocket Vehicle, Vought Astronautics Report No. AST/E1R-13319, April, 1961

2) Wind Tunnel Tests of the Aerobee 150A (Model AJ60-13), Aerojet-General Report No. 1784. March 1960

Figure 5 – Aerobee 150A wind tunnel data, RASAero aerodynamic predictions.

Three flight simulation options are available in the RASAero software. A 1 degree-of-freedom straight-up flight simulation, a 2 degrees-of-freedom trajectory simulation, and a 3 degrees-of-freedom trajectory simulation with wind that includes dynamic stability and weathercocking of the rocket into the wind. All of the flight simulations include ballistic or parachute recovery, with a recovery event at apogee (typically a small drogue parachute) and a recovery event at a user-specified altitude above the ground (main parachute). Which flight simulation method is used is internally selected by the program based on whether the user has selected a straight-up (0 deg) launch angle, a non-zero launch angle to fly a downrange trajectory, and whether a wind speed has been specified.

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 based on the inputted 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 1, 2, and 3 degrees-of-freedom flight simulation results are also produced, including the recovery phase of the flight.

The accuracy of the RASAero flight simulation altitude predictions for high power rockets is shown in Table 1, where RASAero flight simulation altitude predictions are compared with barometric altimeter, optical tracking, and accelerometer-based altitude flight data for a representative set of high power rockets. RASAero rocket files (.alx1 files) for most of these rockets are included in the RASAero software download.

Rocket	Motor	Diameter (in)	Flight Data	Altitude (ft)	RASAero Predicted Altitude (ft)	Percent Error
Our Project R Rocket	R17971	10.500	Time to Apogee from Onboard Video (See Note 1)	94000	102402	8.94%
Proteus 6	P9381 (Loki-EX)	6.000	Integrated Accelerometer Data (See Note 2)	85067	86799	2.04%
Full Metal Jacket - BALLS 005	O10000 Kos	4.000	Optical Track	37981	38820	2.21%
Full Metal Jacket - Black Rock-6	O10000 Kos	4.000	Optical Track	30038	32646	8.68%
Kline-Rogers L500 Rocket	L500 Ace	2.260	Optical Track	24771	26485	6.92%
Laser/LOC-2.1	J125	2.260	Optical Track	15818	14868	-6.01%
Laser/LOC-2.1	J125	2.260	Optical Track	13219	14616	10.57%
Torrent	M1850GG (AMW)	4.000	Barometric Altimeter	12807	13852	8.16%
Rabia	L1080BB (AMW)	3.000	Barometric Altimeter	12745	12777	0.25%
Hubbub	L1080BB (AMW)	4.024	Barometric Altimeter	10750	10883	1.24%
Rabia – Short Fin Can	L730 (CTI)	3.126	Barometric Altimeter	10584	10376	-1.97%
Blister	K1075GG (AMW)	3.000	Barometric Altimeter	9026	8347	-7.52%
Raven	J570W (AT)	1.750	Barometric Altimeter	8815	9288	5.37%
EZI-65 J125	J125	3.998	Optical Track	8068	7436	-7.83%
Ion Drive	K550W (AT)	4.000	Barometric Altimeter	8027	8642	7.66%
Cancer Descending	M1297W (AT)	6.000	Barometric Altimeter	6188	6328	2.26%
Byrum	J570W (AT)	3.000	Barometric Altimeter	5732	5280	-7.89%
EZI-65 J100	J100	3.998	Optical Track	5671	6472	14.12%
Caliber Isp 05 ARO-414	I285 (CTI)	3.100	Barometric Altimeter	5085	4842	-4.78%
Caliber Isp 05 ARO-414	I285 (CTI)	3.100	Barometric Altimeter	4930	4831	-2.01%
McGarvey	J350W-L (AT)	3.000	Barometric Altimeter	4246	4862	14.51%
EZI-65	J450ST (AMW)	4.000	Barometric Altimeter	3965	4214	6.28%
Caliber Isp 04 AVTC Team 3	I205 (CTI)	3.100	Barometric Altimeter	3964	3871	-2.35%
Gibb	I284W (AT)	3.000	Barometric Altimeter	3913	4310	10.15%
Caliber Isp 04 AVTC Team 1	I205 (CTI)	3.100	Barometric Altimeter	3837	3943	2.76%
Caliber Isp 04 AVTC Team 2	I205 (CTI)	3.100	Barometric Altimeter	3710	3871	4.34%
Thunder & Lightning	I284W (AT)	3.100	Barometric Altimeter	3577	3989	11.52%
					Average Error =	3.25%

81.5% of Flights

Error < 10%

40.7% of Flights

Error < 5%

Note 1: Altitude based on time to apogee from onboard video (Reference: Postflight Analysis of the OuR Project R Rocket Flight, *High Power Rocketry* magazine, July 1997). From onboard video rocket spin rate 0.26-0.37 revolutions/sec. RASAero flight simulation based on 3.5 degree coning angle from onboard video.

Note 2: Altitude based on integration of onboard accelerometer data. Altitude based on the average of the apogee altitude from the two onboard accelerometers. Rocket also included barometric altimeter and GPS unit. Data from barometric altimeter and GPS unit stopped above 46000 ft. Integrated accelerometer data agreed well with barometric altimeter data up to 46000 ft, barometric altimeter data agreed well with GPS data below 46000 ft during parachute descent.

Table 1 – Comparison of RASAero altitude predictions with high power rocket barometric altimeter, optical tracking, and accelerometer-based altitude flight data.

As can be seen in Table 1, for this representative set of high power rocket barometric altimeter, optical tracking, and accelerometer-based altitude flight data, for 81.5% of the flights the RASAero flight simulation altitude prediction is within +/- 10% of the flight data, and for 40.7% of the flights the RASAero flight simulation altitude prediction is within +/- 5% of the flight data.

Entering and Running a Rocket on RASAero

Main Input Screen

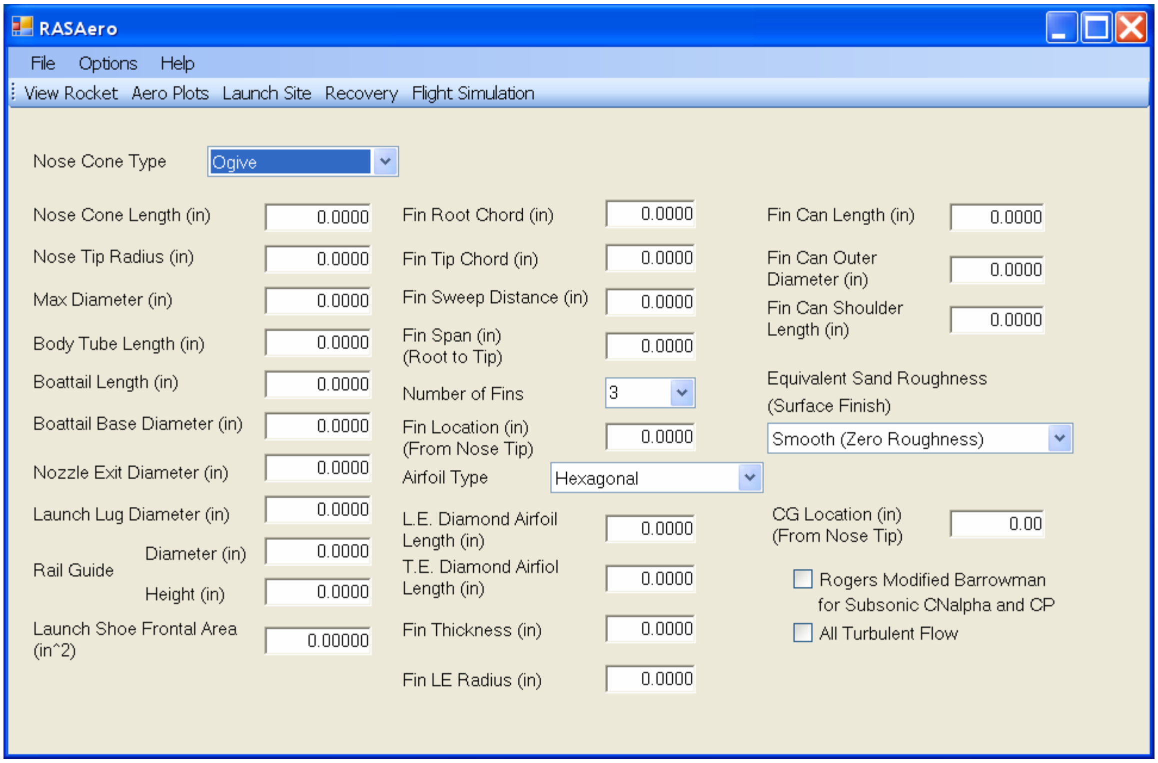
After double clicking on the RASAero icon on the computer desktop, the RASAero Main Input Screen, which includes the rocket geometry body and fin inputs, will appear as presented in Figure 6. The main header bar on the RASAero Main Input Screen includes the options for View Rocket (a scale drawing of the rocket), Aero Plot (plots of aerodynamic data for the rocket), Launch Site (launch site elevation and temperature, launch angle and wind speed), Recovery, and Flight Data (the RASAero flight simulation). For a new rocket the user starts filling in the input fields and then runs the rocket as described in later sections. To load an old, previously saved rocket, click on <File>, and then <Open>, and then select the file to be opened. Some example rockets are stored in the Examples directory in the /My Documents/RASAero directory. After the input data for the rocket is entered, 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, the rocket can be saved by selecting <File>, and then <Save> or <Save As> tab to save the rocket under the old name or a new name. All RASAero rocket files have the extension .ALX1, and are stored in the /My Documents/RASAero directory.

Rocket Geometry Inputs

The RASAero Main Input Screen also functions as the Rocket Geometry Data Input Screen. This is where the rocket geometry is entered. The rocket geometry inputs consist of Body Inputs and Fin Inputs.

Body and Fin Inputs

The Rocket Body and Fin Geometry Inputs on the Main Input Screen are shown in Figure 6. The Body and Fin Inputs geometry definitions are presented in Figures 7-10. Currently the RASAero software accepts geometry for single stage rockets with a single set of fins. In addition to the standard nose cone-body tube-fins geometry shown in Figure 7, a fin canister can also be added to the rocket as shown in Figure 8. Figures 9 and 10 show the additional body geometry input definitions when a boattail is added to the rocket. All dimensions are in inches.



Nose Cone Type: Ogive

Nose Cone Length (in) 0.0000
Nose Tip Radius (in) 0.0000
Max Diameter (in) 0.0000
Body Tube Length (in) 0.0000
Boattail Length (in) 0.0000
Boattail Base Diameter (in) 0.0000
Nozzle Exit Diameter (in) 0.0000
Launch Lug Diameter (in) 0.0000
Rail Guide Diameter (in) 0.0000
Rail Guide Height (in) 0.0000
Launch Shoe Frontal Area (in^2) 0.00000

Fin Root Chord (in) 0.0000
Fin Tip Chord (in) 0.0000
Fin Sweep Distance (in) 0.0000
Fin Span (in) (Root to Tip) 0.0000
Number of Fins 3
Fin Location (in) (From Nose Tip) 0.0000
Airfoil Type: Hexagonal
L.E. Diamond Airfoil Length (in) 0.0000
T.E. Diamond Airfiol Length (in) 0.0000
Fin Thickness (in) 0.0000
Fin LE Radius (in) 0.0000

Fin Can Length (in) 0.0000
Fin Can Outer Diameter (in) 0.0000
Fin Can Shoulder Length (in) 0.0000
Equivalent Sand Roughness (Surface Finish): Smooth (Zero Roughness)
CG Location (in) (From Nose Tip) 0.00
☐ Rogers Modified Barrowman for Subsonic CNalpha and CP
☐ All Turbulent Flow

Figure 6 – RASAero Main Input Screen, rocket geometry body and fin inputs.

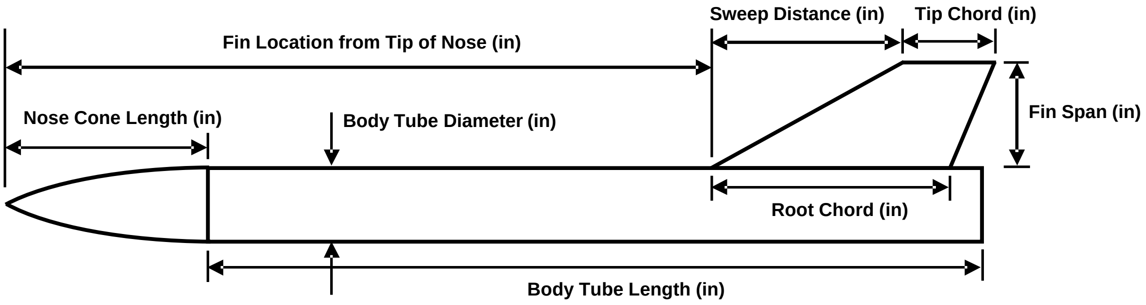


Figure 7 – Rocket body and fin input geometry definitions.

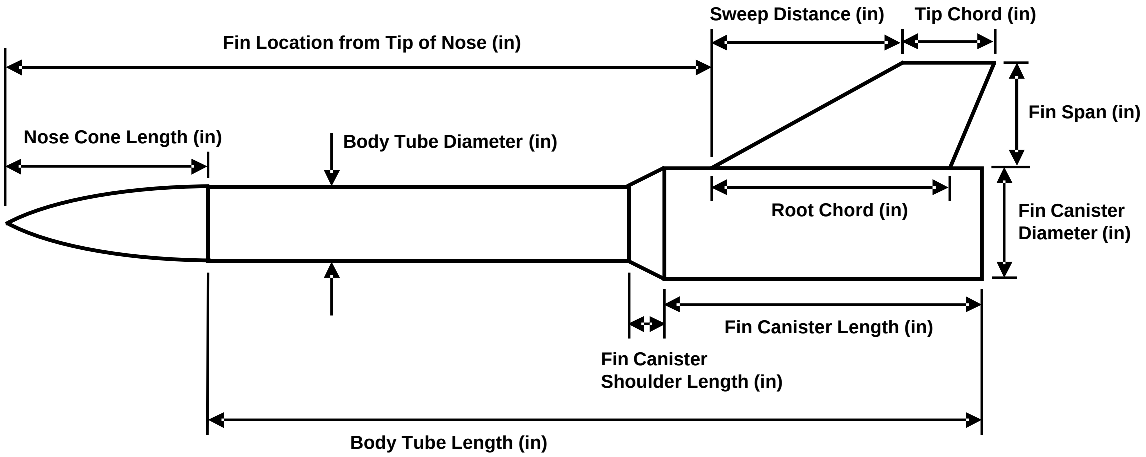


Figure 8 – Rocket body and fin input geometry definitions with a fin canister.

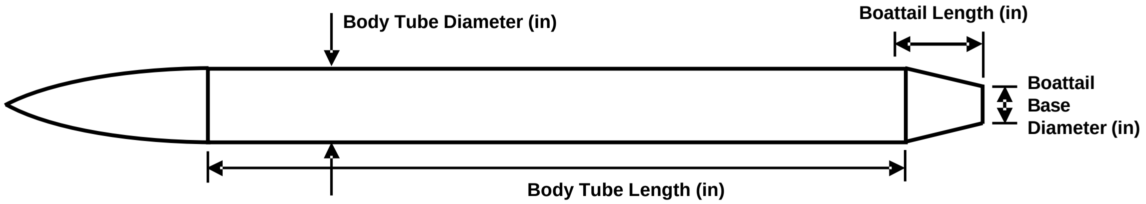


Figure 9 – Rocket body input geometry definitions with a boattail.

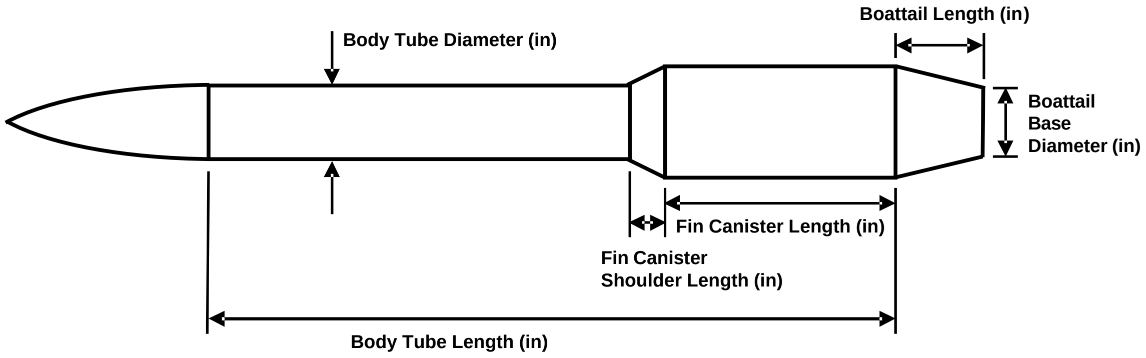


Figure 10 – Rocket body input geometry definitions with a boattail and a fin canister.

Some additional notes on the body and fin input geometry:

a) Nose cone shape options are tangent ogive, conic, or Von-Karman ogive. The nose cone length is entered; the diameter of the base of the nose cone does not have to be entered as it is equal to the body tube diameter.

b) A spherical blunt tip can be added to the nose cone by inputting a nose bluntness radius. The radius that is inputted is the radius of the sphere at the tip of the nose. For a sharp nose tip, the nose bluntness radius input is left at the default value of zero.

c) As shown in Figures 7 and 8, the body tube length is from the base of the nose cone to the bottom of the body tube if no fin canister is present, and from the base of the nose cone to the bottom of the fin canister if a fin canister is present.

d) As shown in Figures 9 and 10, when a boattail is added to the rocket the body tube length is from the base of the nose cone to the top of the boattail. The boattail length and base diameter are entered. As shown in Figure 10, a boattail can be added to a fin canister. The boattail upper diameter does not need to be entered, it is set to the rocket body tube diameter if no fin canister is present as shown in Figure 9, or it is set to the fin canister outside diameter if a fin canister is present as shown in Figure 10.

e) If no fin canister is present, the default input value of zero is used for the fin canister length, outer diameter, and shoulder length.

f) If no boattail is present, the default input value of zero is used for the boattail length and base diameter.

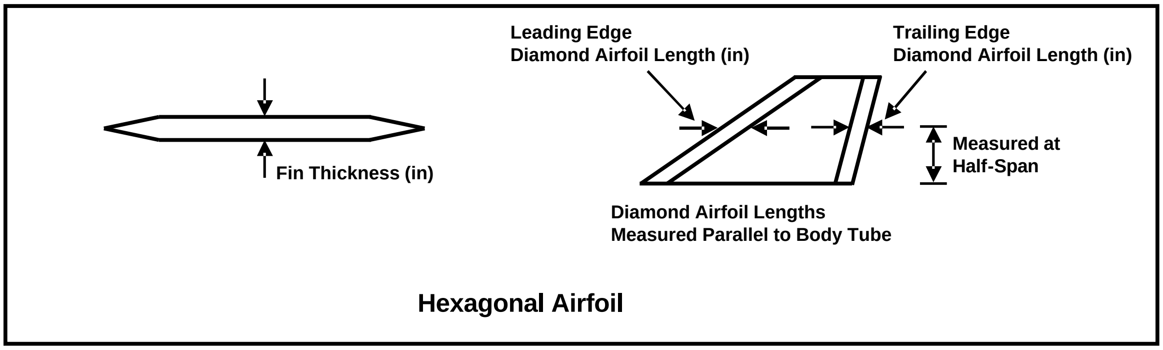
g) Nozzle exit diameter is entered for calculating the change in base drag when the rocket motor is on for determining the power-on drag coefficient. If the nozzle exit diameter is not known, it can be set to the default input value of zero, in which case the power-on drag coefficient will be equal to the power-off drag coefficient. The rocket motor exhaust helps to pressurize the base area of the rocket reducing base drag, thus typically the power-on drag coefficient is lower than the power-off drag coefficient. The RASAero flight simulation uses the power-on drag coefficient during the boost phase of flight, and the power-off drag coefficient during the coast phase of flight.

h) The fin span is measured from the root of the fin to the tip of the fin, as shown in Figures 7 and 8.

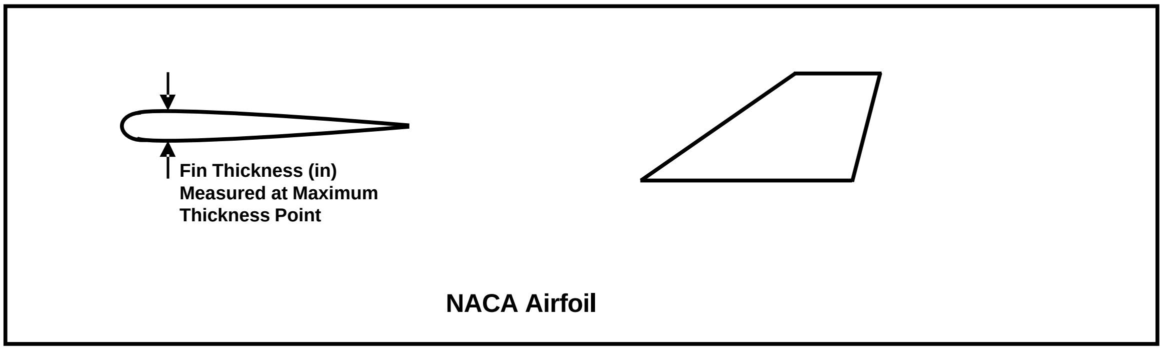
i) The number of fins is selected by selecting a number from the Fin Count input. Currently the RASAero software allows 3 or 4 fins to be used.

Fin Airfoil Inputs

The fin airfoils that can be selected in RASAero are shown in Figures 11a through 11c. 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 11a through 11c. If a fin airfoil geometry input is not needed for a particular airfoil, then that geometry input will be grayed-out on the input screen and 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.

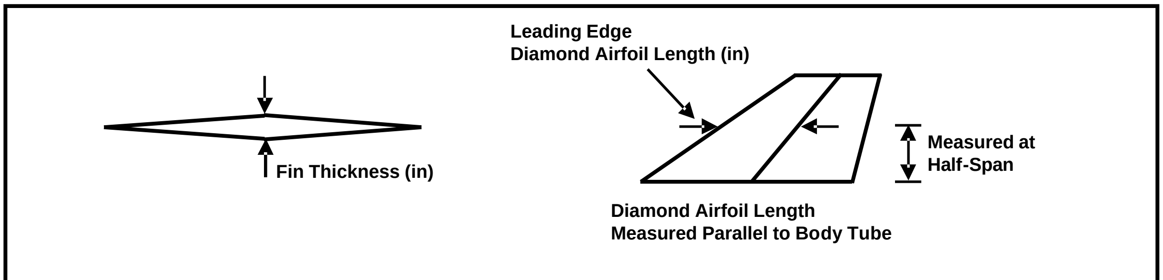


Hexagonal Airfoil

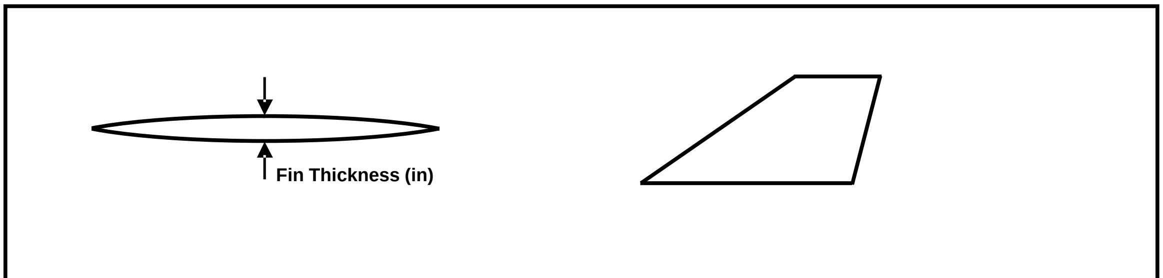


NACA Airfoil

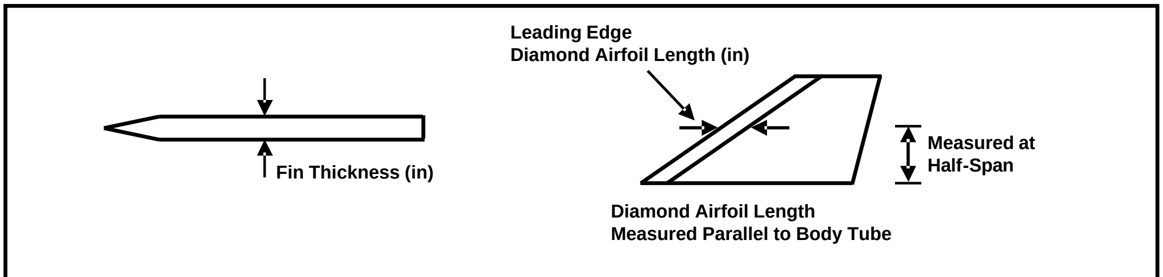
Figure 11a – Fin airfoil types and airfoil input geometry definitions.



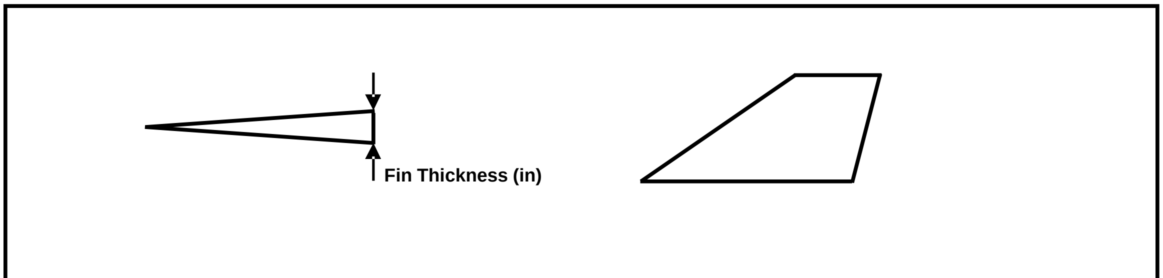
Double-Wedge Airfoil



Biconvex Airfoil

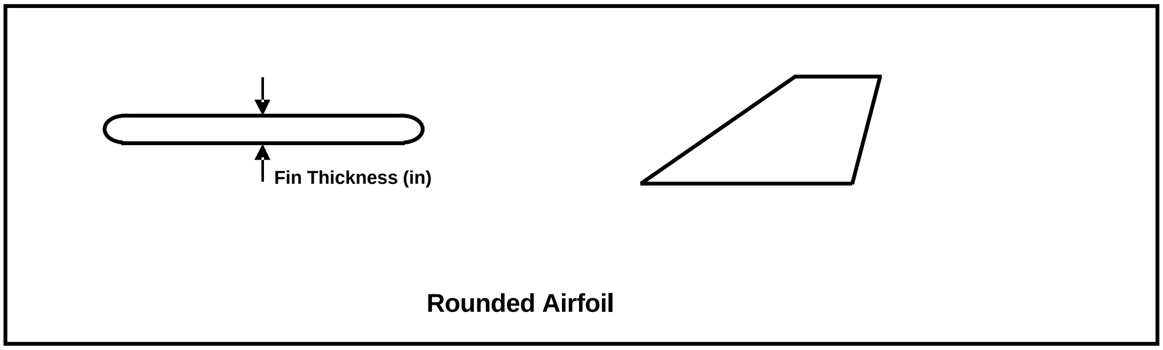


Hexagonal Blunt-Base Airfoil

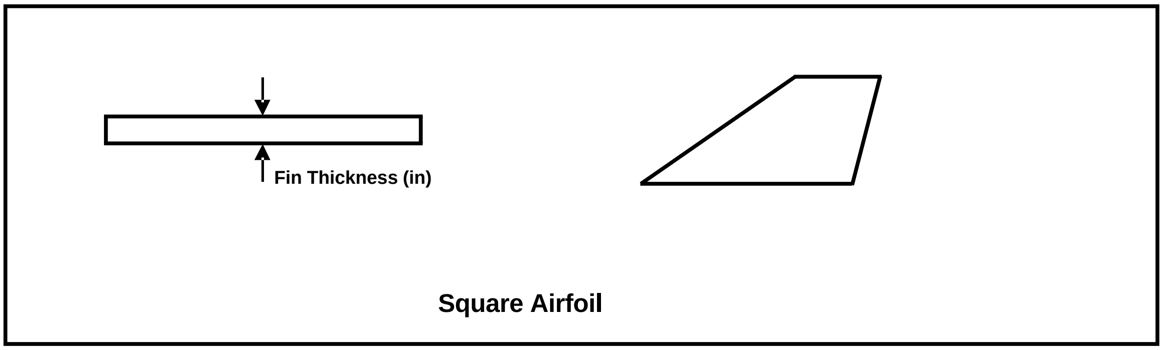


Single-Wedge Airfoil

Figure 11b – Fin airfoil types and airfoil input geometry definitions (Continued).



Rounded Airfoil



Square Airfoil

Figure 11c – 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 12. 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 13.

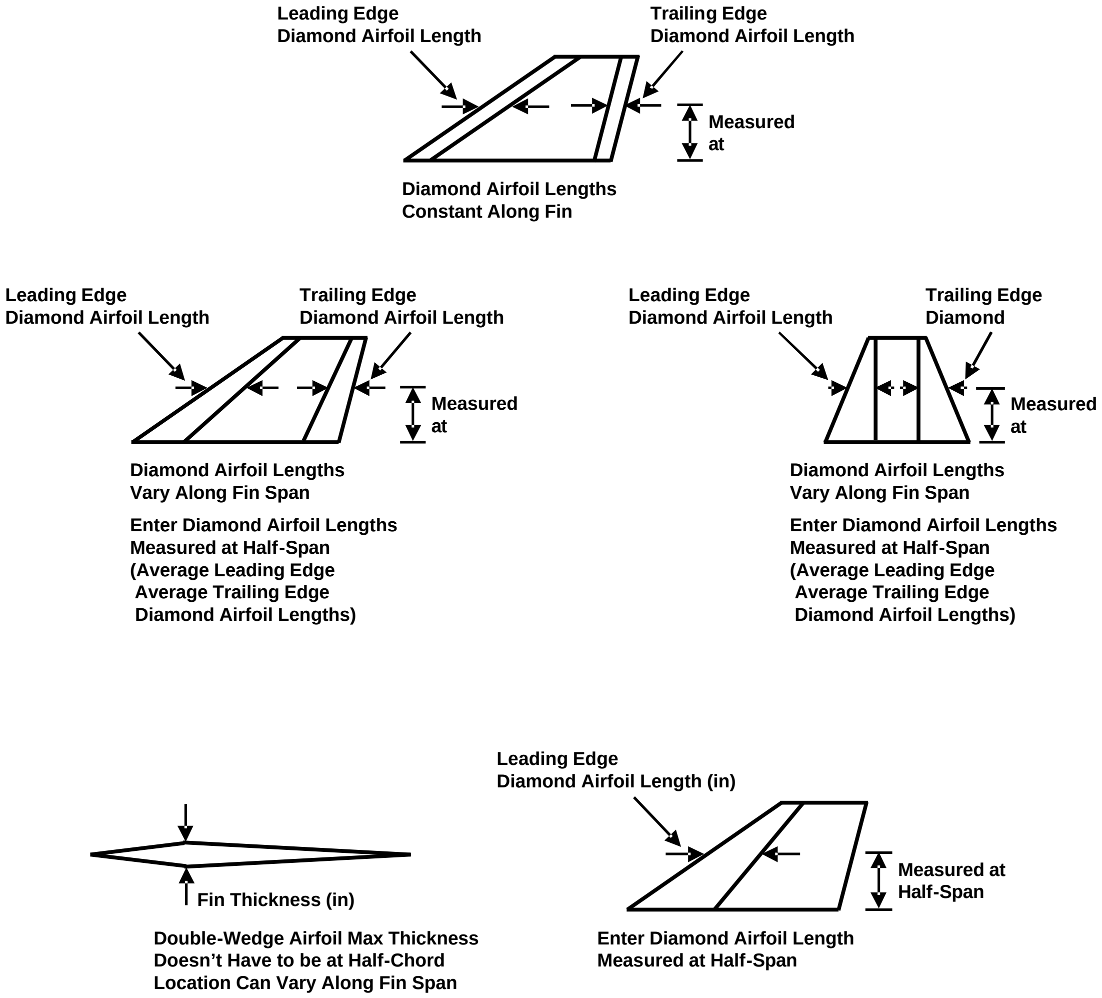


Figure 12 – Average leading edge and trailing edge diamond airfoil lengths used when the fin diamond airfoil lengths vary along the fin span.

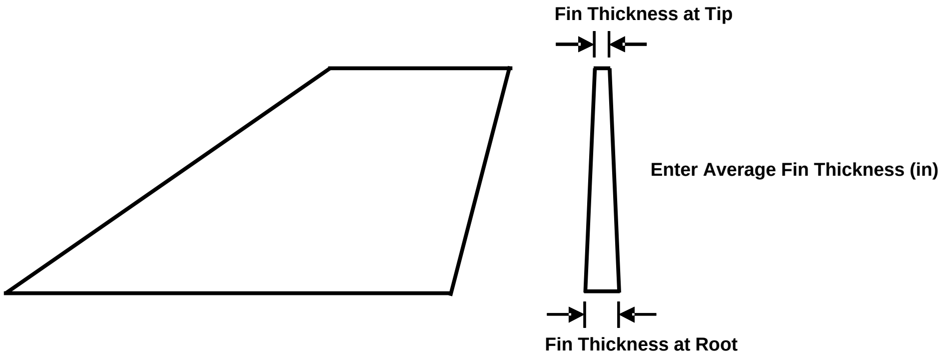


Figure 13 – Average fin thickness used when the fin thickness varies from the root of the fin to the tip of the fin.

Launch Lug, Rail Guide, and Launch Shoe Inputs

The RASAero software includes four options for rocket launch guides:

a) Rail Guides

b) Launch Lugs

c) Launch Shoes

d) None. (Tower-launched.)

Rail guide geometry inputs are presented in Figure 14. 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 calculates the drag based on two rail guides being mounted on the side of the rocket.

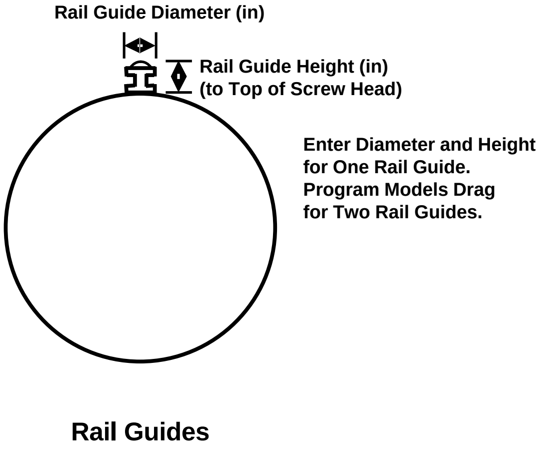
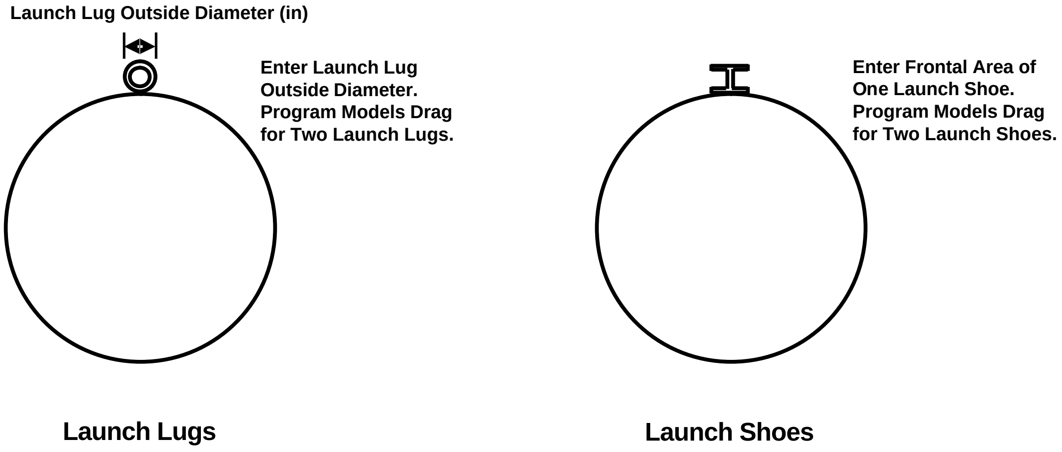


Figure 14 – Rail guide geometry inputs.

Launch lug and launch shoe geometry inputs are presented in Figure 15. For launch lugs the outside diameter of a single launch lug is entered, the software calculates drag based on two 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 calculates the drag based on two launch shoes being mounted on the side of the rocket.



Launch Lugs

Launch Shoes

Figure 15 – Launch lug and launch shoe geometry inputs.

Once a geometry input is made for a rail guide, launch lug, or launch shoe, the other guide/lug/shoe input boxes gray-out, and no input is allowed. Thus the rocket can have rail guides, launch lugs, or launch shoes, but not combinations of guides, lugs, and shoes.

If the rocket is tower launched (no rail guides, launch lugs, or launch shoes), then the default input value of zero is used for the guide/lug/shoe geometry 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 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 2.

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 2 – Equivalent sand roughness for a given surface finish selection.

Center of Gravity (CG) Input

The rocket liftoff Center of Gravity (CG) is entered in inches measured from the tip of the nose. If the rocket is flown with no wind, the CG input is an optional input and is not required for the flight simulation. The CG must be entered to have the rocket CG appear on the rocket drawing, if it is not entered only the subsonic Center of Pressure (CP) will appear. If no CG is entered, the value "0.00" is displayed. If the rocket is flown with a wind speed entered, then the liftoff CG is required to proceed with the flight simulation. The rocket CG is required when a wind is present for weathercocking of the rocket into the wind, and for the flight simulation static stability and dynamic stability calculations.

Rogers Modified Barrowman Method and All Turbulent Flow Options

On the RASAero Main Input Screen after the Rocket Body and Fin Geometry Inputs, option boxes are available for selecting the Rogers Modified Barrowman Method for subsonic center of pressure, and an option to select all turbulent flow. The default for the subsonic center of pressure calculations is the Barrowman Method as documented in Centuri Report TIR-33. The Rogers Modified Barrowman Method for subsonic center of pressure can be selected by checking the box. The Rogers Modified Barrowman Method includes a more accurate body normal force slope with angle of attack (CNalpha) 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 (Kbf) (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).

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 in-flight measured drag coefficient flight data for model and high power rockets that indicates that there is an immediate transition to fully turbulent flow for many model and high power rockets. This can be included in the aerodynamic predictions by selecting the Fully Turbulent Flow option by checking the Fully Turbulent Flow box.

View Rocket Scale Rocket Drawing

After the Rocket Body and Fin Geometry Inputs are entered on the RASAero Main Input Screen, View Rocket can be clicked on the main header bar which will present a scale drawing of the rocket. An example of a View Rocket scale drawing is shown in Figure 16. If the rocket liftoff Center of Gravity (CG) has been entered the liftoff CG will be displayed on the rocket drawing along with the rocket subsonic Center of Pressure (CP), as shown in Figure 16. If the rocket liftoff CG was not entered, only the subsonic CP will appear. This drawing can be printed out, or by pressing <Alt> <Prt Scr> the image can be copied for pasting into another file. Besides creating a scale drawing of the rocket, this feature also allows the user to check that the rocket geometry has been inputted correctly.

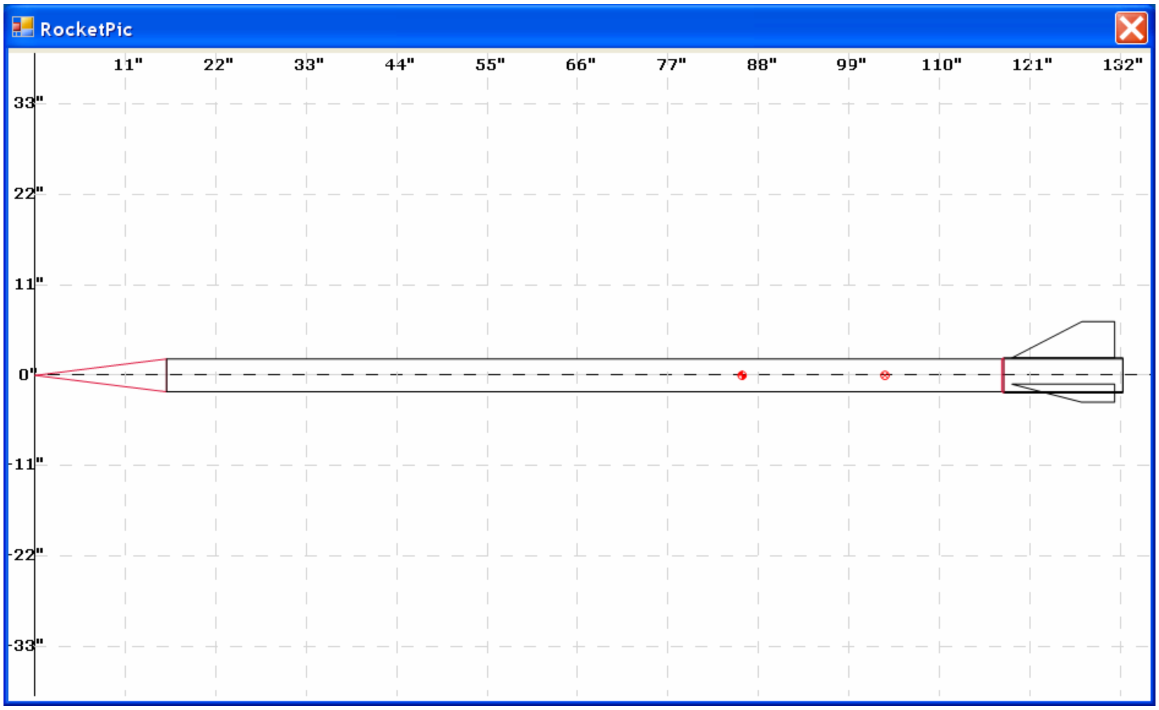
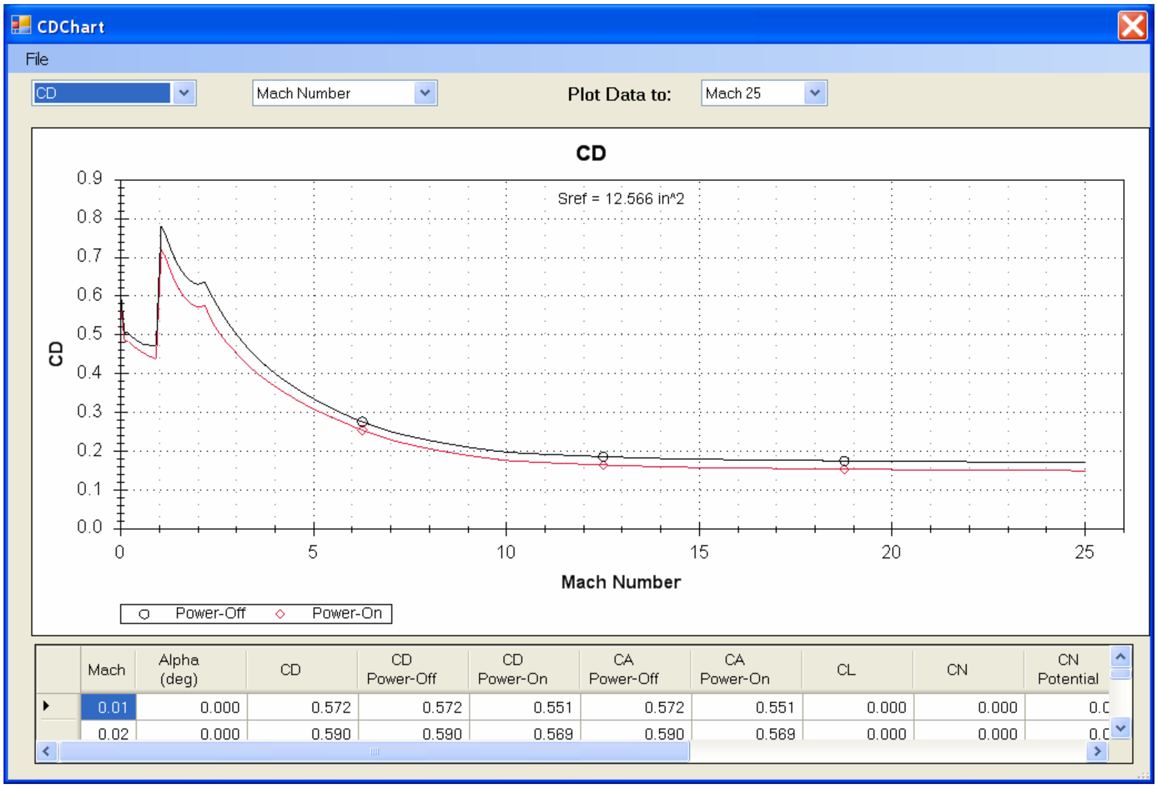


Figure 16 – Typical View Rocket scale rocket drawing.

Aero Plots

After the Rocket Body and Fin Geometry Inputs have been entered on the RASAero Main Input Screen, the aerodynamic analysis code built into RASAero can be run by clicking Aero Plots on the main header bar. Figure 17 presents a typical aerodynamic data plot generated by RASAero, the power-on and power-off drag coefficient (CD) versus Mach number.

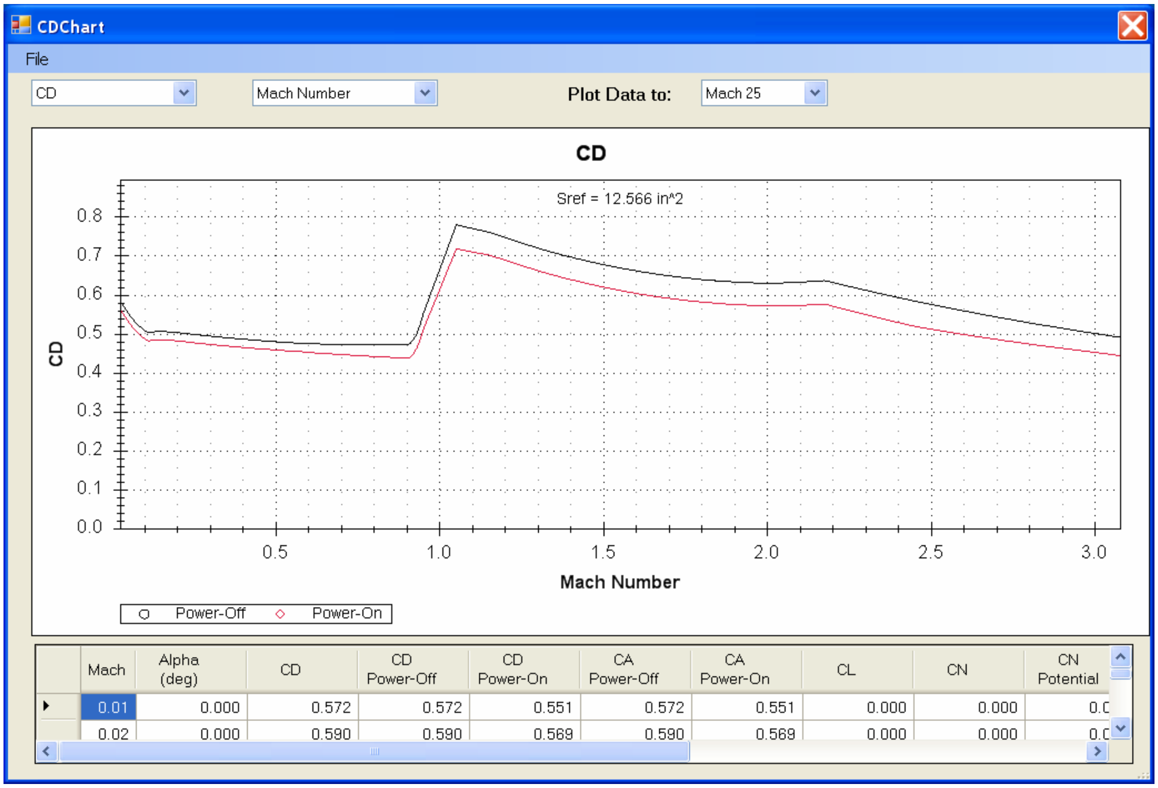


CD | Mach Number | **Plot Data to:** Mach 25

	Mach	Alpha (deg)	CD	CD Power-Off	CD Power-On	CA Power-Off	CA Power-On	CL	CN	CN Potential
▸	0.01	0.000	0.572	0.572	0.551	0.572	0.551	0.000	0.000	0.0
	0.02	0.000	0.590	0.590	0.569	0.590	0.569	0.000	0.000	0.0

Figure 17 – Aerodynamic data plot; power-on and power-off drag coefficient (CD) versus Mach number.

The aerodynamic data can be plotted to Mach 3, 5, 8, 10 or 25 by using the <Plot Data to:> pull-down menu. Additionally, holding down the left mouse button will cause a “lasso” to be formed as the cursor is dragged around the plot. 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 17 is blown up in Figure 18 using the “lasso” plot zoom-in feature to focus in on the data from Mach 0 to 3.

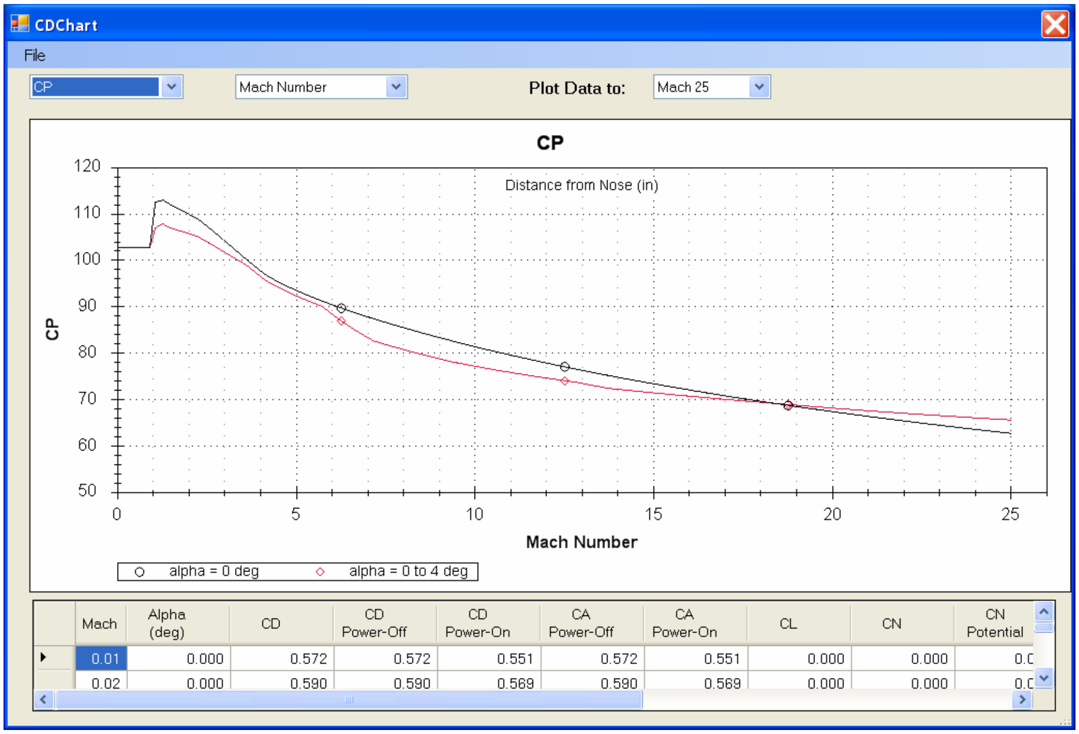


Plot Data to: Mach 25

Mach	Alpha (deg)	CD	CD Power-Off	CD Power-On	CA Power-Off	CA Power-On	CL	CN	CN Potential
0.01	0.000	0.572	0.572	0.551	0.572	0.551	0.000	0.000	0.0
0.02	0.000	0.590	0.590	0.569	0.590	0.569	0.000	0.000	0.0

Figure 18 – Blown-up plot using plot zoom-in feature of power-on and power-off drag coefficient (CD) versus Mach number, Mach 0-3.

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, or using the right down arrow the aerodynamic data can be plotted versus angle of attack. Figure 19 shows an aerodynamic data plot with the center of pressure (CP) selected to be plotted versus Mach number. Note in Figure 19 the substantial forward movement of the center of pressure with Mach number at high supersonic to hypersonic Mach numbers, an important effect for Mach 5 to Mach 6 sounding rockets which is accurately modeled in RASAero.



CP | Mach Number | **Plot Data to:** Mach 25

Mach	Alpha (deg)	CD	CD Power-Off	CD Power-On	CA Power-Off	CA Power-On	CL	CN	CN Potential
0.01	0.000	0.572	0.572	0.551	0.572	0.551	0.000	0.000	0.0
0.02	0.000	0.590	0.590	0.569	0.590	0.569	0.000	0.000	0.0

Figure 19 – Aerodynamic data plot; center of pressure (CP) versus Mach number.

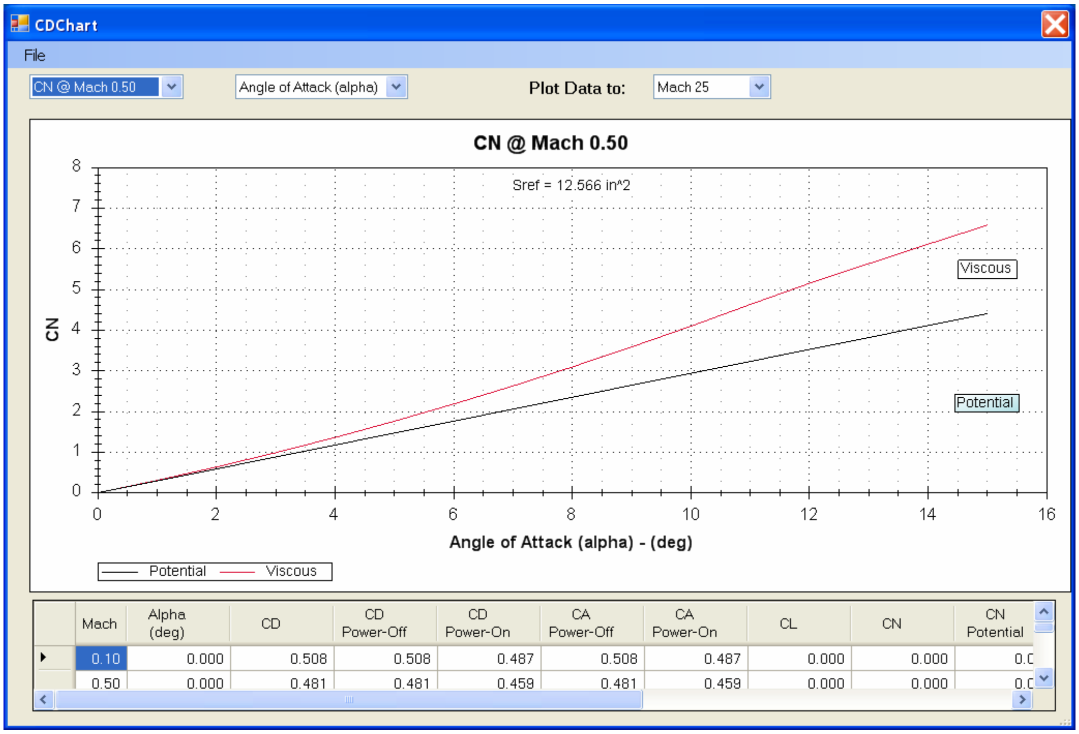
Figure 20 shows the power-off drag coefficient (CD) selected, and the plot versus angle of attack option selected, to plot the power-off drag coefficient (CD) versus angle of attack.

CD Power-Off | Angle of Attack (alpha) | **Plot Data to:** Mach 25

Mach	Alpha (deg)	CD	CD Power-Off	CD Power-On	CA Power-Off	CA Power-On	CL	CN	CN Potential
0.10	0.000	0.508	0.508	0.487	0.508	0.487	0.000	0.000	0.0
0.50	0.000	0.481	0.481	0.459	0.481	0.459	0.000	0.000	0.0

Figure 20 – Aerodynamic data plot; power-off drag coefficient (CD) versus angle of attack.

Figure 21 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 21), 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.



CN @ Mach 0.50

Angle of Attack (alpha)

Plot Data to: Mach 25

Mach	Alpha (deg)	CD	CD Power-Off	CD Power-On	CA Power-Off	CA Power-On	CL	CN	CN Potential
0.10	0.000	0.508	0.508	0.487	0.508	0.487	0.000	0.000	0.0
0.50	0.000	0.481	0.481	0.459	0.481	0.459	0.000	0.000	0.0

Figure 21 – Aerodynamic data plot; normal force coefficient (CN) versus angle of attack at Mach 0.5 using Rogers Modified Barrowman Method.

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

The aero plots can be printed out, or by pressing <Alt> <Prt Scr> the image can be copied for pasting into another file.

Launch Site Inputs

For running the RASAero flight simulation the Launch Site conditions are entered by clicking on Launch Site on the main header bar. Figure 22 shows the Launch Site inputs, consisting of:

a) Launch site elevation (ft) above sea level.

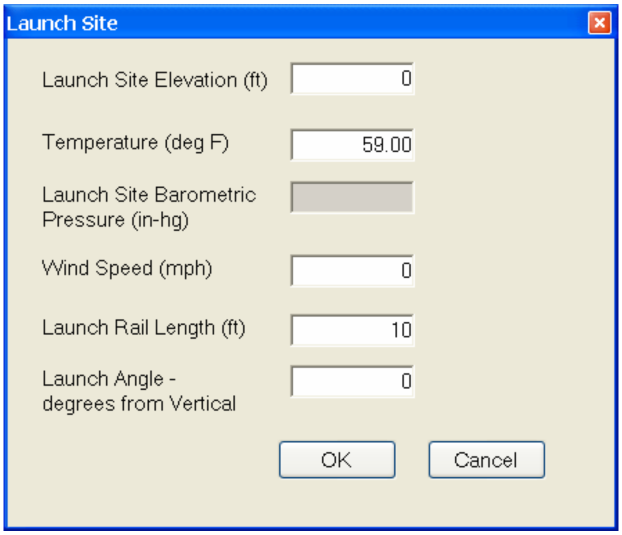
b) Temperature (deg F).

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.



Launch Site Elevation (ft) 0
Temperature (deg F) 59.00
Launch Site Barometric Pressure (in-hg)
Wind Speed (mph) 0
Launch Rail Length (ft) 10
Launch Angle - degrees from Vertical 0

Figure 22 – 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 .ALX1 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 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 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 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 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 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 the launch angle degrees from vertical and the wind speed determine what kind of flight simulation is run.

a) If the launch angle degrees from vertical is zero, and the wind speed is zero, a 1 Degree-Of-Freedom (1-DOF) straight-up flight will be flown.

b) If the launch angle degrees from vertical is non-zero, as an example 3 degrees from vertical, with no wind, then a 2 Degrees-Of-Freedom (2-DOF) trajectory flight will be flown.

c) For both the 1 Degree-Of-Freedom (1-DOF) straight-up flight and the 2 Degrees-Of-Freedom (2-DOF) trajectory flight, the rocket will fly at a constant zero degrees angle of attack.

d) If the launch angle degrees from vertical is non-zero, as an example 3 degrees from vertical, and a wind is present, the rocket will fly a 2-dimensional trajectory downrange, with the rocket oscillating in angle of attack around zero degrees angle of attack, weathercocking into the wind at launch. (3 Degree-Of-Freedom, 3-DOF mode.)

e) All of 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 the user inputs for launch angle and wind speed.

f) If a wind speed is inputted, and the rocket will fly with wheathercocking and dynamic stability, the rocket center of gravity (CG) is required, and a CG input box will appear on the bottom right-hand side of the Main Input Screen. If no wind speed is entered, then dynamic stability will not be turned on and no CG input is required to run the rocket.

When the flight simulation portion of the RASAero 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 flight simulation with wind, whethercocking, and dynamic stability, 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.

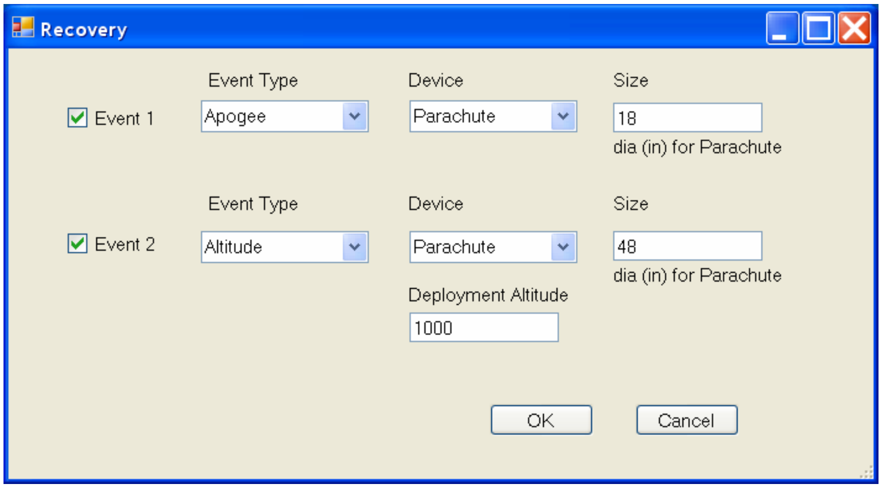
Recovery Inputs

The RASAero Recovery input screen is shown in Figure 23. Two recovery events are allowed, with options for the recovery device for each event. 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.



☑ Event 1
Event Type: Apogee
Device: Parachute
Size: 18
dia (in) for Parachute

☑ Event 2
Event Type: Altitude
Device: Parachute
Size: 48
dia (in) for Parachute
Deployment Altitude: 1000

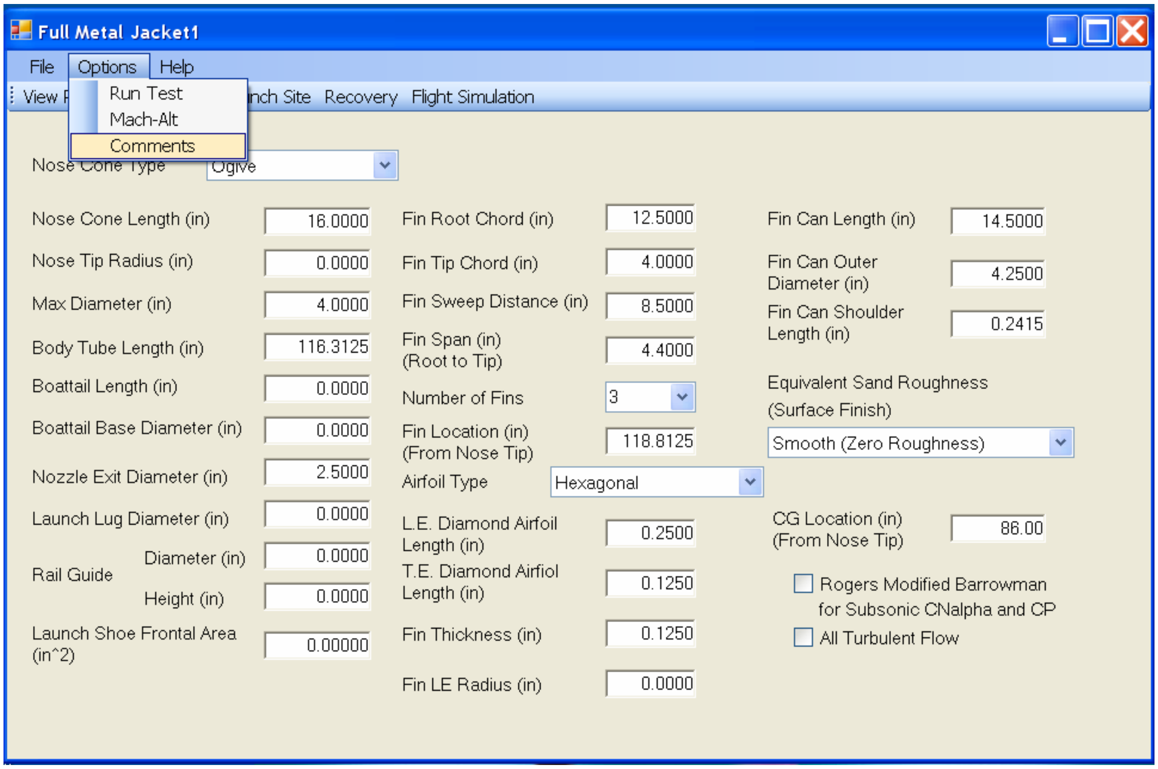
Figure 23 – Recovery inputs.

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 software.

Clicking OK saves the recovery inputs for the rocket.

Rocket Comments

As shown in Figure 24, comments can be entered for each rocket by clicking on <Options> on the main header bar, and then clicking on <Comments>.



Nose Cone Type: Ogive

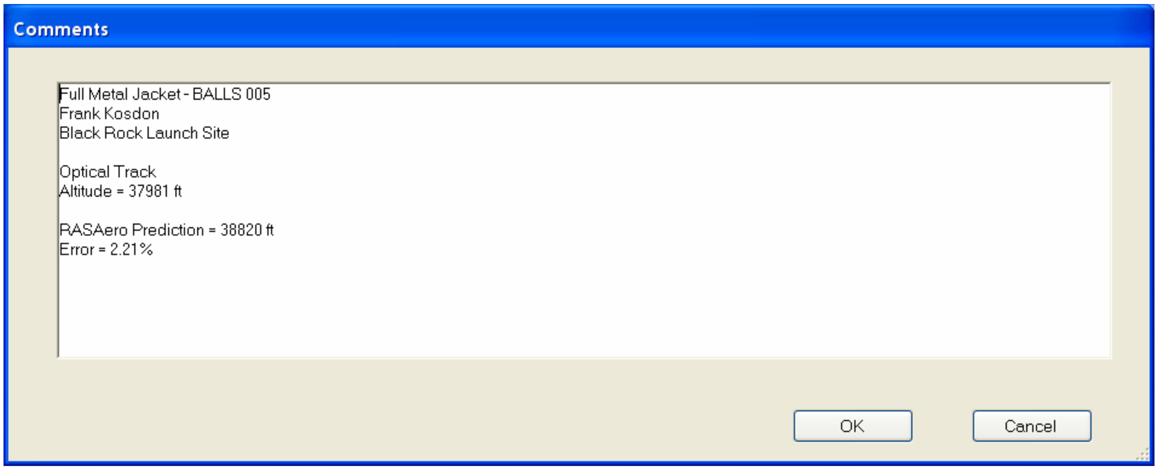
Nose Cone Length (in) 16.0000
Nose Tip Radius (in) 0.0000
Max Diameter (in) 4.0000
Body Tube Length (in) 116.3125
Boattail Length (in) 0.0000
Boattail Base Diameter (in) 0.0000
Nozzle Exit Diameter (in) 2.5000
Launch Lug Diameter (in) 0.0000
Rail Guide Diameter (in) 0.0000
Rail Guide Height (in) 0.0000
Launch Shoe Frontal Area (in^2) 0.00000

Fin Root Chord (in) 12.5000
Fin Tip Chord (in) 4.0000
Fin Sweep Distance (in) 8.5000
Fin Span (in) (Root to Tip) 4.4000
Number of Fins 3
Fin Location (in) (From Nose Tip) 118.8125
Airfoil Type: Hexagonal
L.E. Diamond Airfoil Length (in) 0.2500
T.E. Diamond Airfiol Length (in) 0.1250
Fin Thickness (in) 0.1250
Fin LE Radius (in) 0.0000

Fin Can Length (in) 14.5000
Fin Can Outer Diameter (in) 4.2500
Fin Can Shoulder Length (in) 0.2415
Equivalent Sand Roughness (Surface Finish): Smooth (Zero Roughness)
CG Location (in) (From Nose Tip) 86.00
☐ Rogers Modified Barrowman for Subsonic CNalpha and CP
☐ All Turbulent Flow

Figure 24 – Selecting Comments under Options.

The rocket comments input screen, with an example of rocket comments, is shown in Figure 25. 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 .ALX1 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 flight simulation altitude prediction is highly recommended by the RASAero authors.



Full Metal Jacket - BALLS 005
Frank Kosdon
Black Rock Launch Site

Optical Track
Altitude = 37981 ft

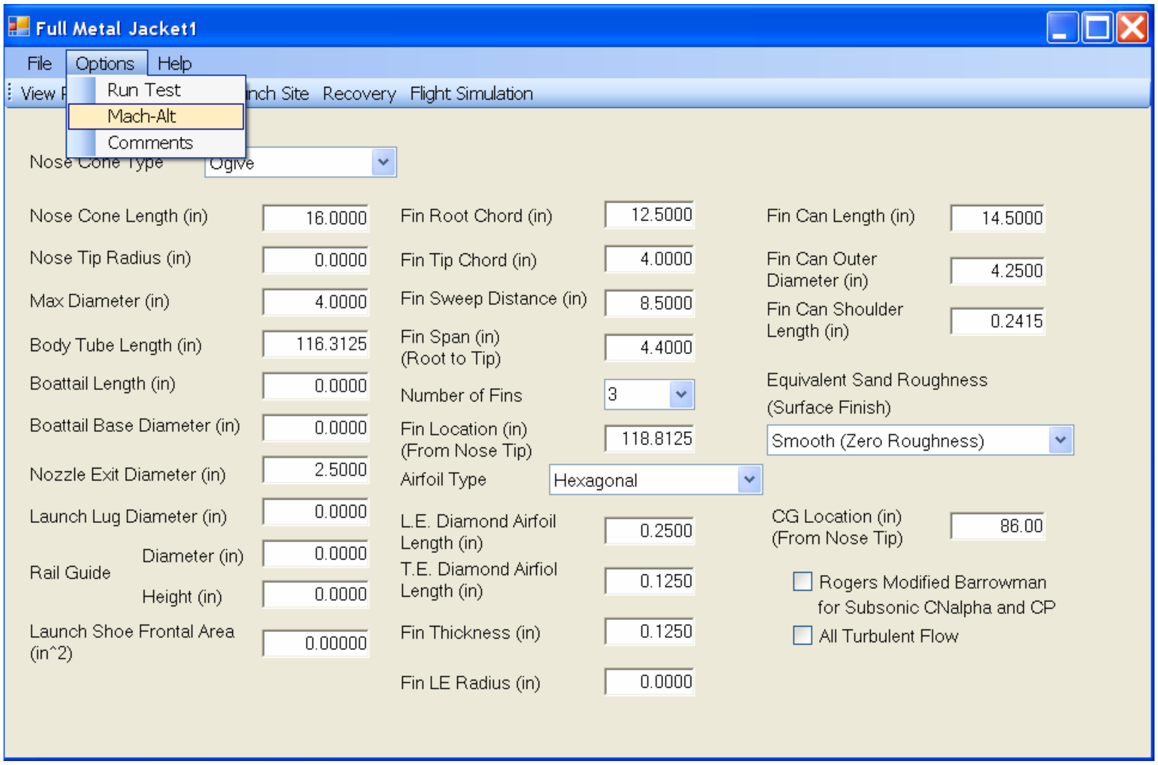
RASAero Prediction = 38820 ft
Error = 2.21%

Figure 25 – Rocket comments input screen.

Other Inputs

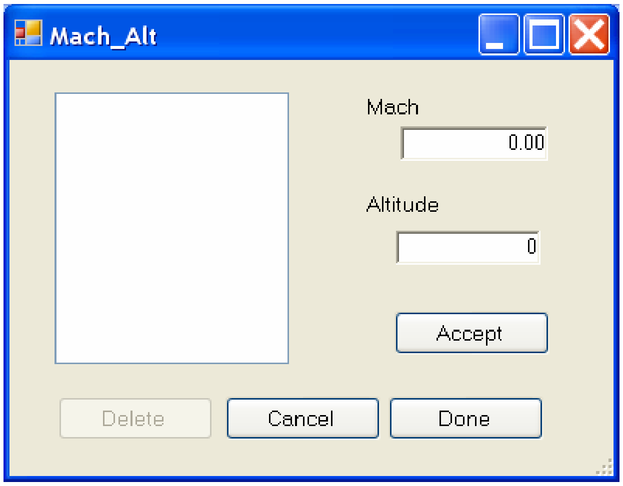
Mach-Alt Input for Matching Wind Tunnel or Flight Reynolds Number

The RASAero 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 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. As shown in Figure 26, under <Options>, <Mach-Alt> can be selected, after which the Mach-Alt input screen will appear, as shown in Figure 27.



Nose Cone Type: Ogive
Nose Cone Length (in): 16.0000
Nose Tip Radius (in): 0.0000
Max Diameter (in): 4.0000
Body Tube Length (in): 116.3125
Boattail Length (in): 0.0000
Boattail Base Diameter (in): 0.0000
Nozzle Exit Diameter (in): 2.5000
Launch Lug Diameter (in): 0.0000
Rail Guide Diameter (in): 0.0000
Rail Guide Height (in): 0.0000
Launch Shoe Frontal Area (in^2): 0.00000
Fin Root Chord (in): 12.5000
Fin Tip Chord (in): 4.0000
Fin Sweep Distance (in): 8.5000
Fin Span (in) (Root to Tip): 4.4000
Number of Fins: 3
Fin Location (in) (From Nose Tip): 118.8125
Airfoil Type: Hexagonal
L.E. Diamond Airfoil Length (in): 0.2500
T.E. Diamond Airfiol Length (in): 0.1250
Fin Thickness (in): 0.1250
Fin LE Radius (in): 0.0000
Fin Can Length (in): 14.5000
Fin Can Outer Diameter (in): 4.2500
Fin Can Shoulder Length (in): 0.2415
Equivalent Sand Roughness (Surface Finish): Smooth (Zero Roughness)
CG Location (in) (From Nose Tip): 86.00
☐ Rogers Modified Barrowman for Subsonic CNalpha and CP
☐ All Turbulent Flow

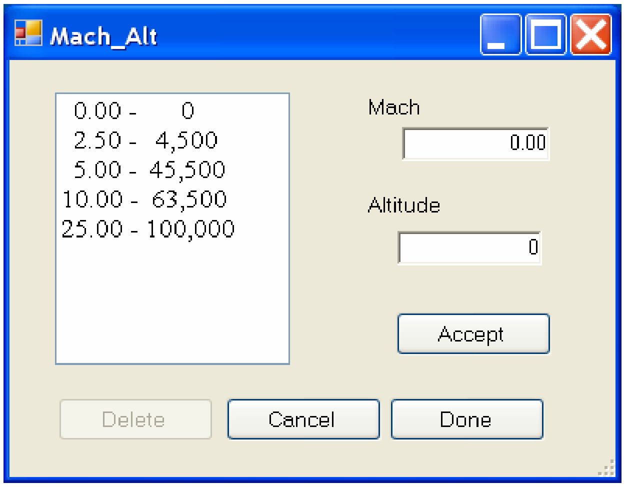
Figure 26 – Selecting the Mach-Alt input screen under Options.



Mach: 0.00
Altitude: 0

Figure 27 – Mach-Alt input screen.

Figure 28 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.



0.00 - 0
2.50 - 4,500
5.00 - 45,500
10.00 - 63,500
25.00 - 100,000

Mach: 0.00

Altitude: 0

Figure 28 – Typical Mach-Alt input.

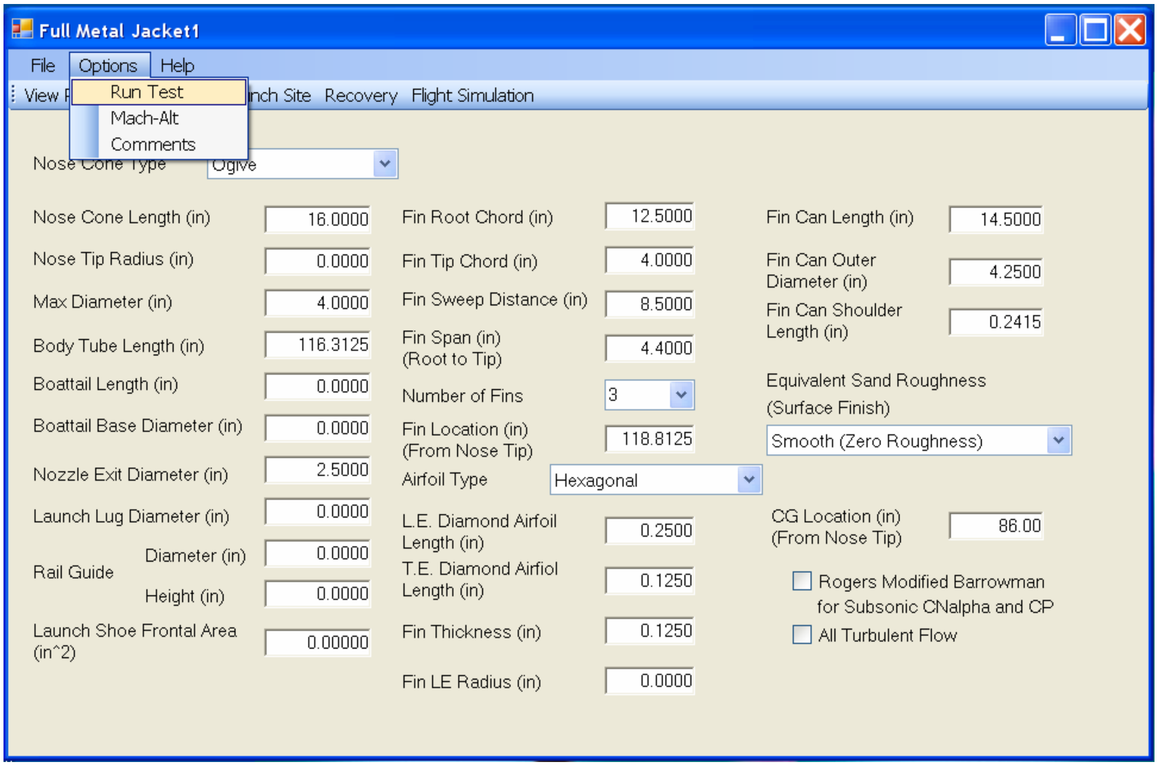
After the Mach-Alt points have been entered, the Reynolds number at each Mach number can be checked in the tabular output on the Aero Plots output screen (Reynolds number is to the far right), or in the Run Test file output. For a given Mach number a lower altitude increases Reynolds number, a higher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

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. As shown in Figure 29, under <Options>, <Run Test> can be selected, and then as shown in Figure 30 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>.



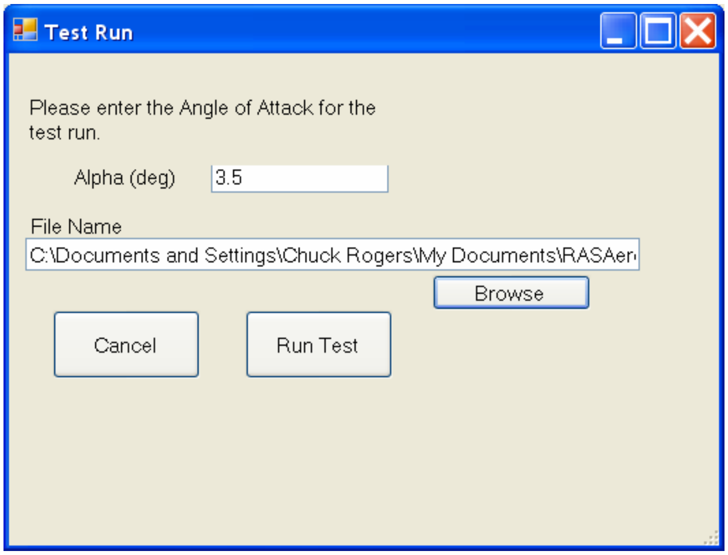
Nose Cone Type: Ogive

Nose Cone Length (in) 16.0000
Nose Tip Radius (in) 0.0000
Max Diameter (in) 4.0000
Body Tube Length (in) 116.3125
Boattail Length (in) 0.0000
Boattail Base Diameter (in) 0.0000
Nozzle Exit Diameter (in) 2.5000
Launch Lug Diameter (in) 0.0000
Rail Guide Diameter (in) 0.0000
Rail Guide Height (in) 0.0000
Launch Shoe Frontal Area (in^2) 0.00000

Fin Root Chord (in) 12.5000
Fin Tip Chord (in) 4.0000
Fin Sweep Distance (in) 8.5000
Fin Span (in) (Root to Tip) 4.4000
Number of Fins 3
Fin Location (in) (From Nose Tip) 118.8125
Airfoil Type Hexagonal
L.E. Diamond Airfoil Length (in) 0.2500
T.E. Diamond Airfiol Length (in) 0.1250
Fin Thickness (in) 0.1250
Fin LE Radius (in) 0.0000

Fin Can Length (in) 14.5000
Fin Can Outer Diameter (in) 4.2500
Fin Can Shoulder Length (in) 0.2415
Equivalent Sand Roughness (Surface Finish) Smooth (Zero Roughness)
CG Location (in) (From Nose Tip) 86.00
☐ Rogers Modified Barrowman for Subsonic CNalpha and CP
☐ All Turbulent Flow

Figure 29 – Selecting the Run Test input screen under Options.



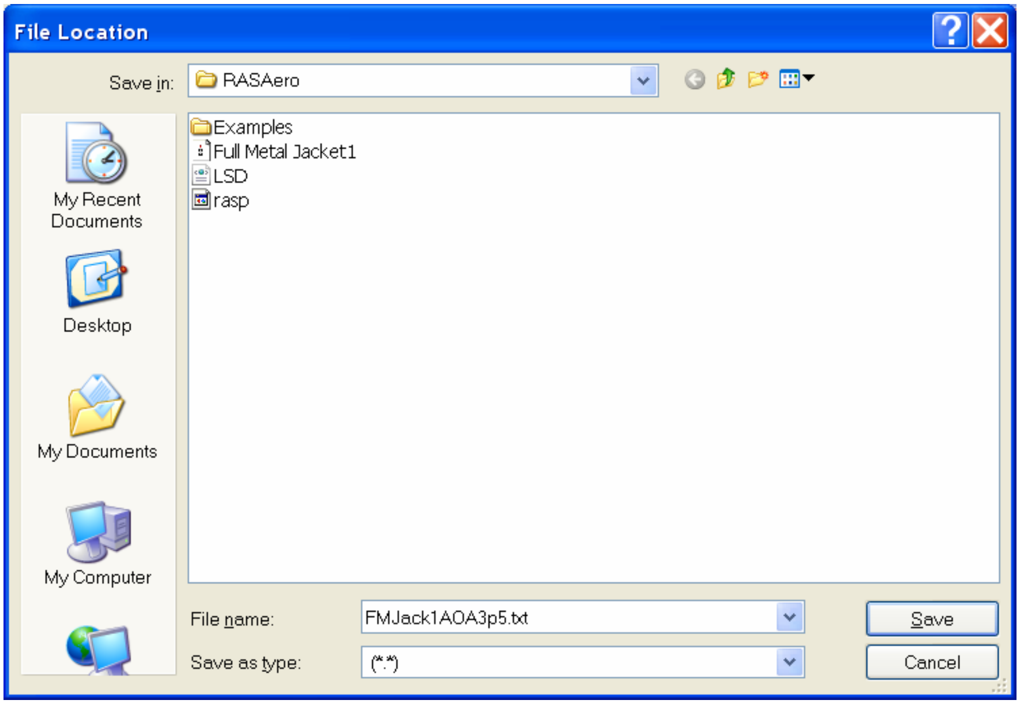
Please enter the Angle of Attack for the test run.

Alpha (deg) 3.5

File Name
C:\Documents and Settings\Chuck Rogers\My Documents\RASAer

Figure 30 – Run Test input screen.

The Run Test output file name can be entered on the file name line shown in Figure 30, 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 31. The default directory for the Run Test output file is the /My Documents/RASAero 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 31 the Run Test output file can be stored in various file formats with various file extensions.



Save in: RASAero

File name: FMJack1AOA3p5.txt

Save as type: (*.*)

Figure 31 – 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 32.

```
Subsonic
Mach 0.01 to 0.90


Mach  Alpha  CD      CD     Body   Body    Body    Fin    Fin     Fin   Rail  Reynolds No
      Zero   Power   Power  Frict  Press   Base    Frict  Inter-  Base  Guide
      deg    Off     On                            &Press ference       Launch
                                                                         Lug
                                                                         Launch
                                                                         Shoe

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  Alpha
      0-4    0-4
      deg    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
```

Figure 32 – 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
      Zero   Power   Power
      deg    Off     On

0.95  0.00   0.554   0.513  74378180


Mach  CN     CP
      Alpha  Alpha
      0-4    0-4
      deg    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

0.95   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
```

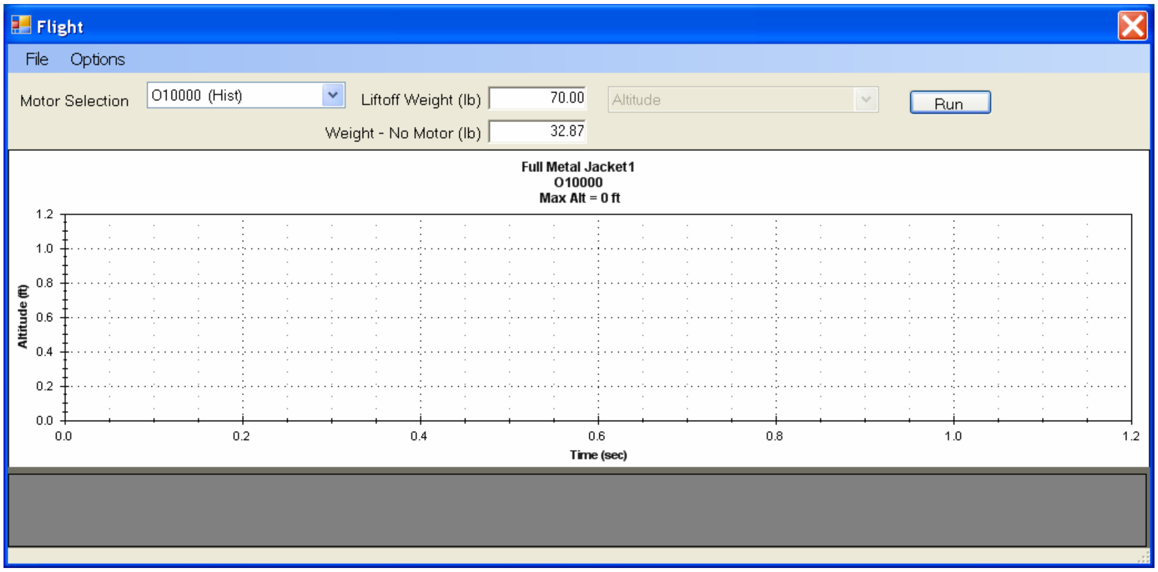
Figure 32 – Run Test output file format (continued).

```
Supersonic-Hypersonic
Mach 1.05 to Mach 25

Mach  Alpha  CD      CD     Body    Nose    Body   Fin     Fin   Fin    Fin   FinCan Rail  Reynolds No
      Zero   Power   Power  Frict   Wave    Base   Frict   Wave  Inter- Base  Wave   Guide
      deg    Off     On                                          ference             Launch
                                                                                     Lug
                                                                                      Launch
                                                                                     Shoe

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  Alpha
      0-4    0-4
      deg    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

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
```

Figure 32 – Run Test output file format (concluded).

Running the RASAero Flight Simulation – Flight Data

To run the flight simulation of the rocket, click on Flight Data on the main header bar. The Flight Data Screen will appear, as shown in Figure 33.



Motor Selection: O10000 (Hist)
Liftoff Weight (lb): 70.00
Weight - No Motor (lb): 32.87

Full Metal Jacket1
O10000
Max Alt = 0 ft

Figure 33 – RASAero flight simulation Flight Data Screen.

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

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

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

The RASAero 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 authors recommend that the original version of the rasp.eng file, and subsequent versions of the file, be archived as new motors are appended to the file.

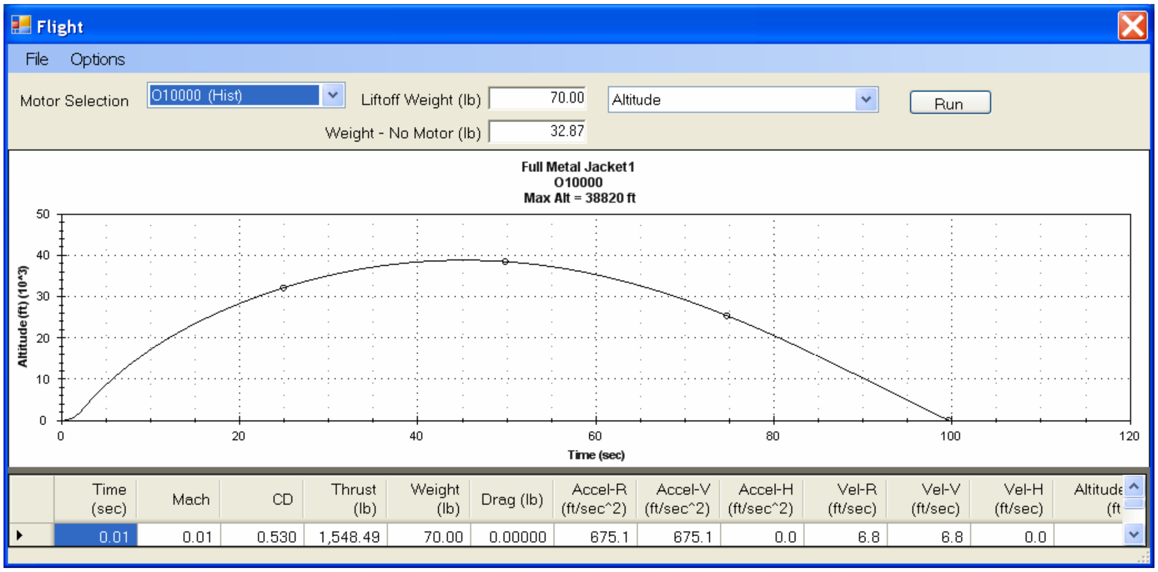
For advanced users creating their own RASP format motor data the ThrustCurve.org web site (http://www.thrustcurve.org/) has detailed information on the RASP motor file format at http://www.thrustcurve.org/raspformat.shtml . The ThrustCurve.org web site also has extensive resources and applets for creating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

A menu-driven option for entering motor data will be added to a future version of RASAero. In the meantime the RASAero authors have scoured all of the available motor databases, and in terms of current production model and high power rocket motors, the authors feel that RASAero has the best production motor database of any model or high power rocket flight simulation program available.

After the motor has been selected from the motor selection menu, the rocket weight is entered. The weight loaded is the liftoff weight of the rocket. The weight empty is the weight of the rocket with no motor. (Note, this IS NOT the burnout weight of the rocket, it is the weight of the rocket with no motor.) The user can specify the weight loaded (liftoff weight), and the software will calculate the weight empty of the rocket. Or the user can specify the weight empty of the rocket, and the software will calculate the weight loaded of the rocket. An advantage of entering the weight empty of the rocket is that once the weight of the rocket is measured and entered with no motor (weight empty), as different motors are selected the software automatically calculates the new weight loaded (liftoff weight) of the rocket.

An important note from the RASAero authors is to emphasize the importance of actually measuring the rocket weight loaded (liftoff weight) when doing comparisons of the predicted altitude with the rocket altitude measured by onboard altimeters. The liftoff weight estimated by the rocketeer and the actual measured liftoff weight can differ considerably, which will cause errors in the comparison of the predicted altitude with the onboard measured flight altitude. Typically rocketeers will underestimate the rocket weight, meaning the rocket actually flew at a higher weight than the weight used in the flight simulation, lowering the actual altitude and making the flight simulation appear to overestimate the altitude of the rocket. When doing comparisons between a flight simulation and the actual rocket onboard measured altitude from an altimeter package, the authors strongly recommend that the rocket weight loaded (liftoff weight) be measured just prior to flight, with the ignitors uninstalled. These weight measurements are typically done at the Range Safety table when checking in the rocket for flight.

After the motor is selected, and the weight loaded or the weight empty are entered, the RASAero flight simulation is run by clicking on <Run>. The resulting altitude plot and tabular output are shown in Figure 34. (This rocket was flown without recovery to a ballistic impact.)

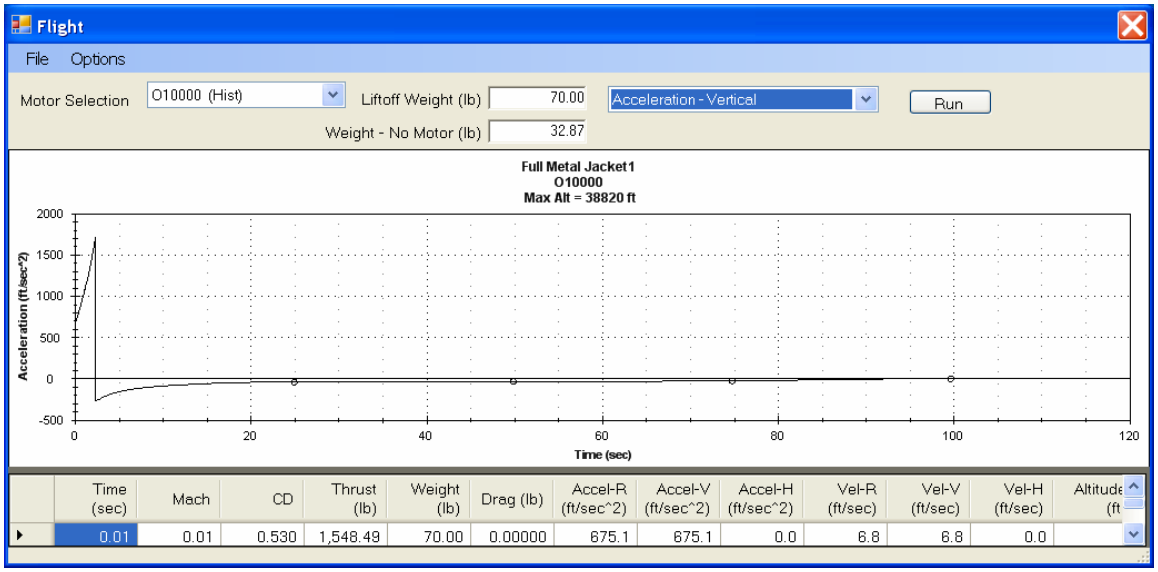


Motor Selection O10000 (Hist)
Liftoff Weight (lb) 70.00
Weight - No Motor (lb) 32.87
Altitude

Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
0.01	0.01	0.530	1,548.49	70.00	0.00000	675.1	675.1	0.0	6.8	6.8	0.0	

Figure 34 – RASAero flight simulation output, altitude plot and tabular output.

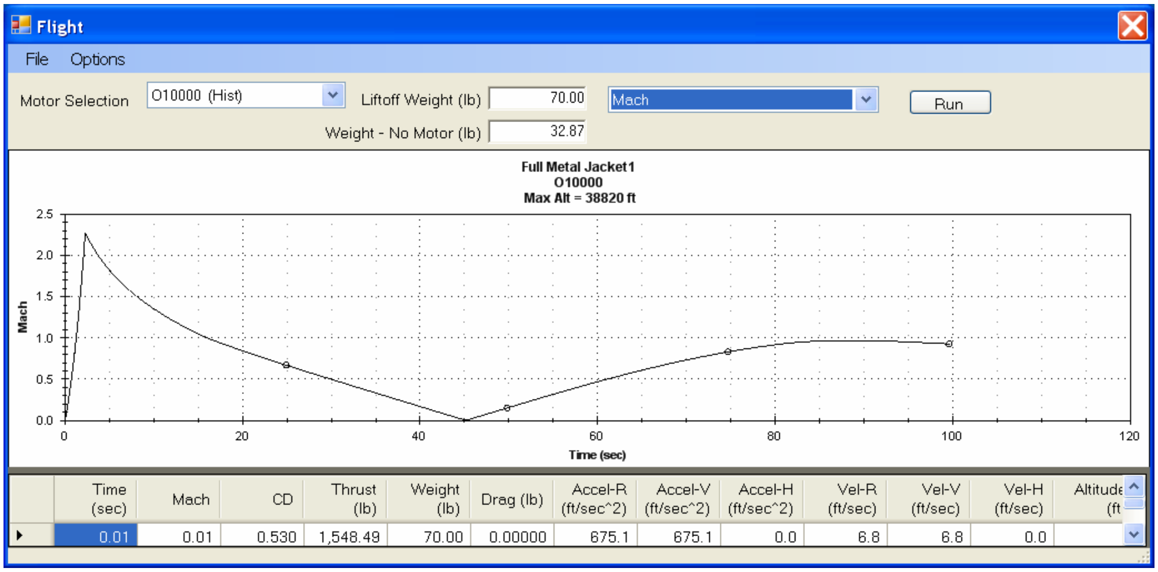
Different plots can be selected, such as altitude, Mach number, acceleration, velocity, downrange distance, drag coefficient, etc., versus time, by selecting the parameter to be plotted using the down arrow on the Flight Data screen. As examples, Figure 35 presents vertical acceleration versus time, and Figure 36 presents Mach number versus time.



Motor Selection O10000 (Hist)
Liftoff Weight (lb) 70.00
Weight - No Motor (lb) 32.87
Acceleration - Vertical

Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
0.01	0.01	0.530	1,548.49	70.00	0.00000	675.1	675.1	0.0	6.8	6.8	0.0	

Figure 35 – RASAero flight simulation output, vertical acceleration versus time.



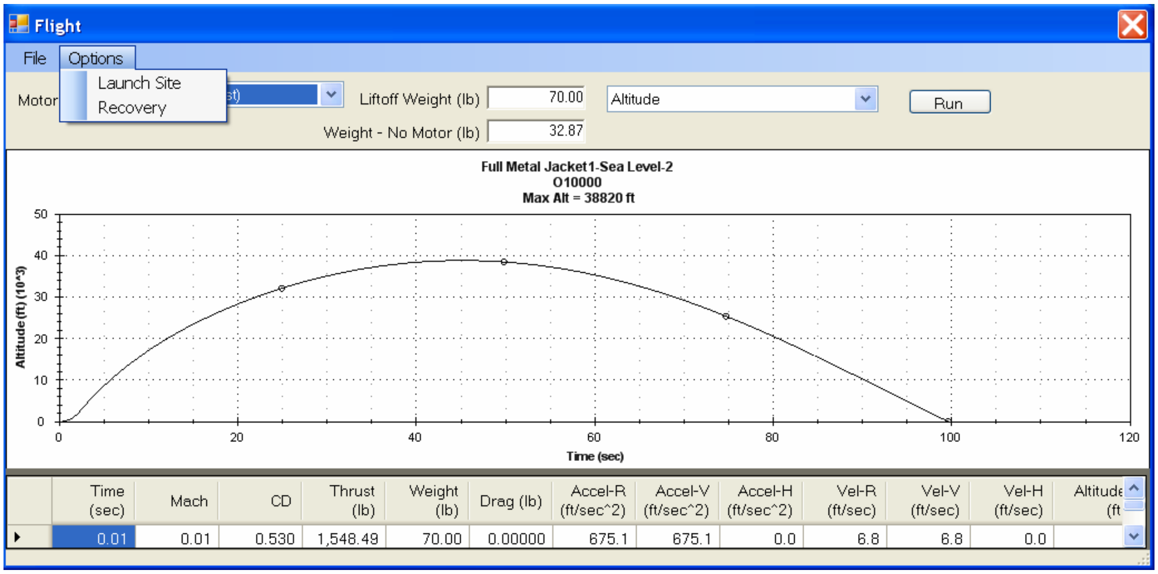
Motor Selection O10000 (Hist)
Liftoff Weight (lb) 70.00
Weight - No Motor (lb) 32.87
Mach

Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
0.01	0.01	0.530	1,548.49	70.00	0.00000	675.1	675.1	0.0	6.8	6.8	0.0	

Figure 36 – RASAero flight simulation output, Mach number versus time.

The RASAero flight simulation output plots can be printed out, or by pressing <Alt> <Prt Scr> the image can be copied for pasting into another file.

The Launch Site and Recovery inputs can be changed within the Flight Data Screen by clicking on <Options>, and then selecting <Launch Site> or <Recovery> as shown in Figure 37. When <Launch Site> or <Recovery> is selected, the Launch Site or Recovery input screen will appear and the Launch Site or Recovery inputs for the flight simulation can be changed without having to return to the Main Input Screen. When <Run> is pressed on the Flight Data Screen the rocket flight simulation will be re-run with the new Launch Site or Recovery inputs.



Liftoff Weight (lb) 70.00

Weight - No Motor (lb) 32.87

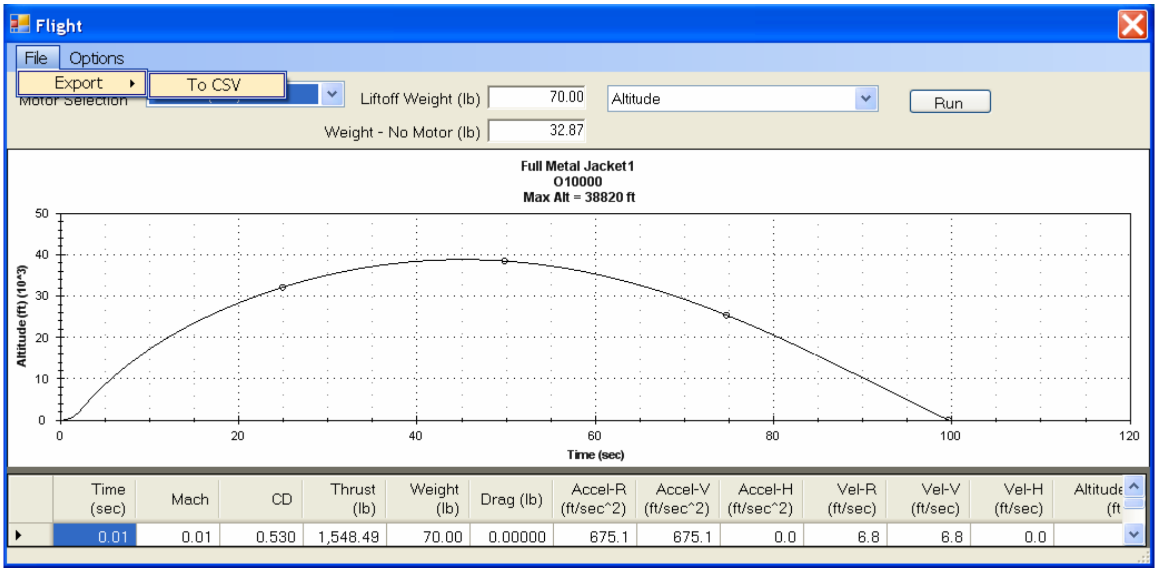
Altitude

Full Metal Jacket1-Sea Level-2
O10000
Max Alt = 38820 ft

Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
0.01	0.01	0.530	1,548.49	70.00	0.00000	675.1	675.1	0.0	6.8	6.8	0.0	

Figure 37 – Accessing the Launch Site or Recovery input screens from within the Flight Data Screen. Launch Site or Recovery inputs can be changed without having to return to the Main Input Screen.

After a flight simulation run is completed, 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 Data Screen as shown in Figure 38.



Liftoff Weight (lb) 70.00

Weight - No Motor (lb) 32.87

Altitude

Full Metal Jacket1
O10000
Max Alt = 38820 ft

Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
0.01	0.01	0.530	1,548.49	70.00	0.00000	675.1	675.1	0.0	6.8	6.8	0.0	

Figure 38 – Exporting flight simulation tabular output data to an Excel file.

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 39. The liftoff Center of Gravity (CG) of the rocket was measured preflight, and was located 40.19 in from the nose of the rocket. The RASAero rocket file for this rocket (CalIsp1.alx1) is located in the /My Documents/RASAero/Examples directory.

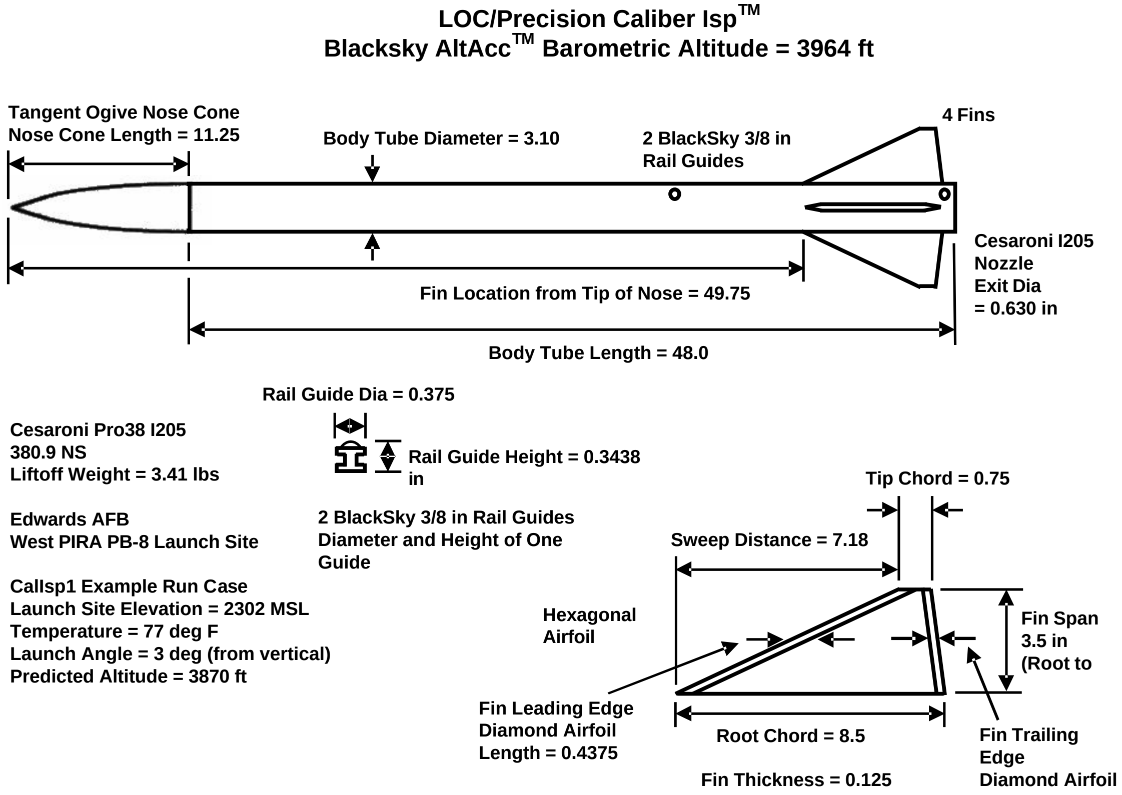
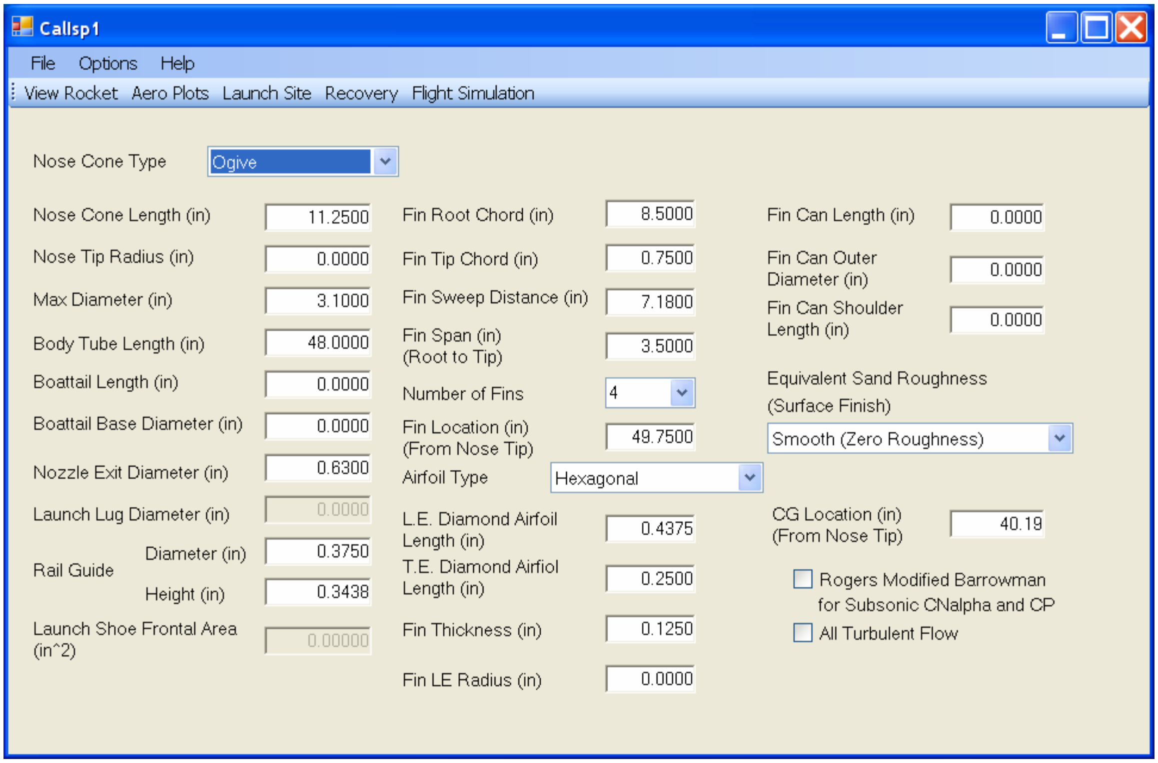


Figure 39 – Example Rocket 1, LOC/Precision Caliber ISP rocket on a I205 rocket motor.

The RASAero Main Input Screen with the rocket geometry input data for the LOC/Precision Caliber ISP rocket is presented in Figure 40.



Nose Cone Type: Ogive

Nose Cone Length (in): 11.2500
Nose Tip Radius (in): 0.0000
Max Diameter (in): 3.1000
Body Tube Length (in): 48.0000
Boattail Length (in): 0.0000
Boattail Base Diameter (in): 0.0000
Nozzle Exit Diameter (in): 0.6300
Launch Lug Diameter (in): 0.0000
Rail Guide Diameter (in): 0.3750
Rail Guide Height (in): 0.3438
Launch Shoe Frontal Area (in^2): 0.00000

Fin Root Chord (in): 8.5000
Fin Tip Chord (in): 0.7500
Fin Sweep Distance (in): 7.1800
Fin Span (in) (Root to Tip): 3.5000
Number of Fins: 4
Fin Location (in) (From Nose Tip): 49.7500
Airfoil Type: Hexagonal
L.E. Diamond Airfoil Length (in): 0.4375
T.E. Diamond Airfiol Length (in): 0.2500
Fin Thickness (in): 0.1250
Fin LE Radius (in): 0.0000

Fin Can Length (in): 0.0000
Fin Can Outer Diameter (in): 0.0000
Fin Can Shoulder Length (in): 0.0000
Equivalent Sand Roughness (Surface Finish): Smooth (Zero Roughness)
CG Location (in) (From Nose Tip): 40.19
☐ Rogers Modified Barrowman for Subsonic CNalpha and CP
☐ All Turbulent Flow

Figure 40 - RASAero Main Input Screen with rocket geometry input data for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

Figure 41 shows the View Rocket scale drawing for the LOC/Precision Caliber ISP rocket. The View Rocket scale drawing confirms that the rocket geometry has been correctly entered, and provides a scale drawing of the rocket which can be copied and pasted into other documents.

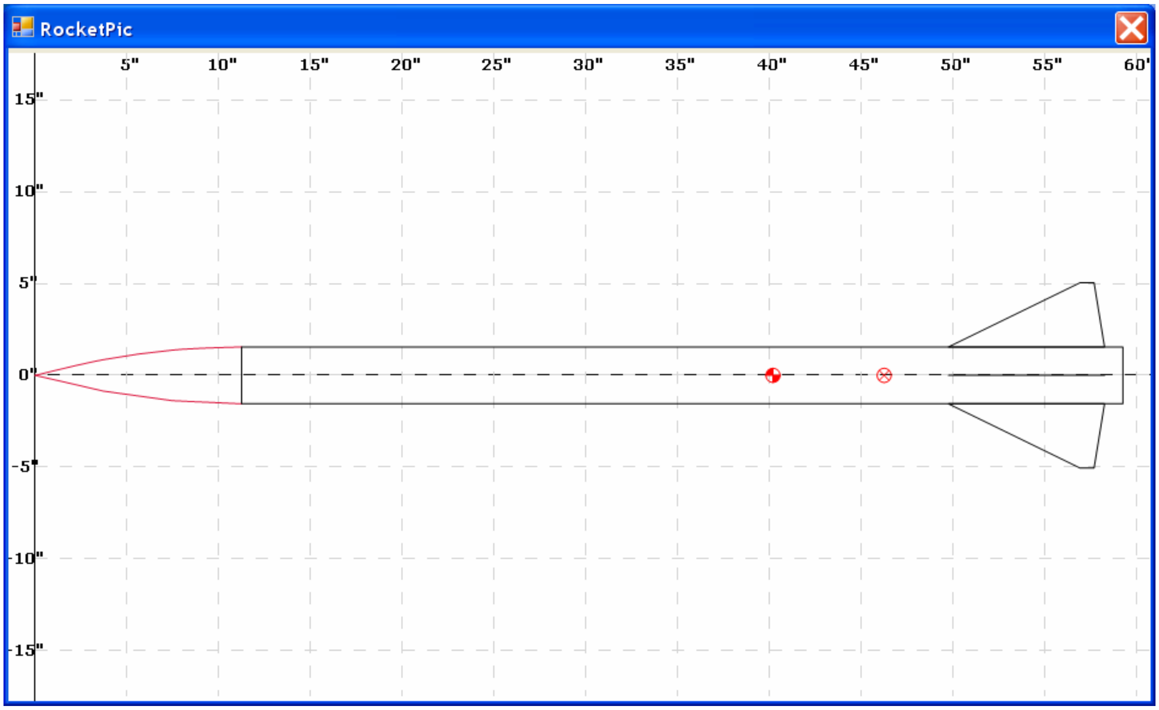
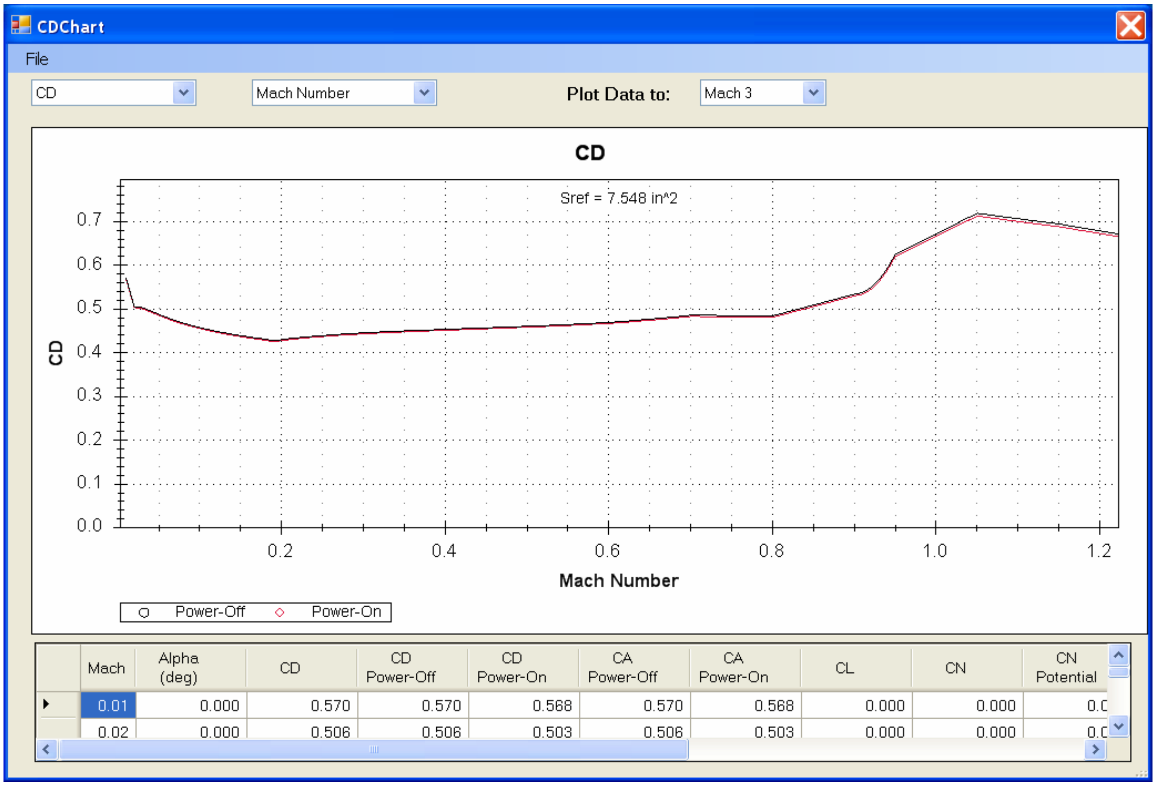


Figure 41 – RASAero View Rocket scale rocket drawing for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

Figure 42 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.



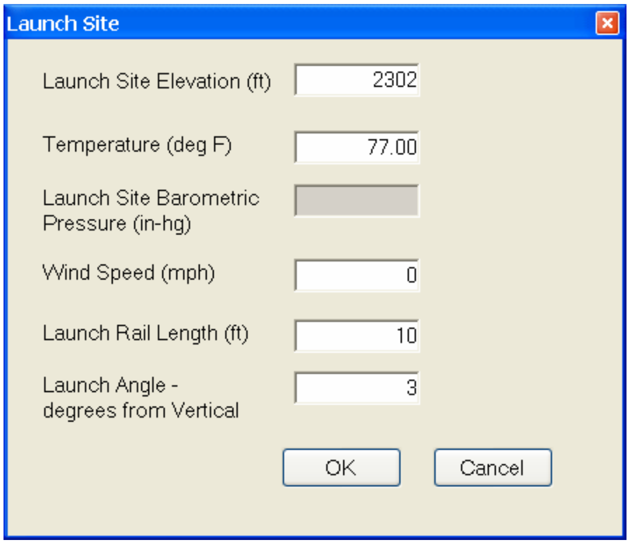
CD | Mach Number | Plot Data to: Mach 3

Sref = 7.548 in^2

	Mach	Alpha (deg)	CD	CD Power-Off	CD Power-On	CA Power-Off	CA Power-On	CL	CN	CN Potential
▸	0.01	0.000	0.570	0.570	0.568	0.570	0.568	0.000	0.000	0.C
	0.02	0.000	0.506	0.506	0.503	0.506	0.503	0.000	0.000	0.C

Figure 42 – Aerodynamic data plot for the LOC/Precision Caliber ISP rocket (Example Rocket 1); power-on and power-off drag coefficient (CD) versus Mach number, Mach 0-1.2.

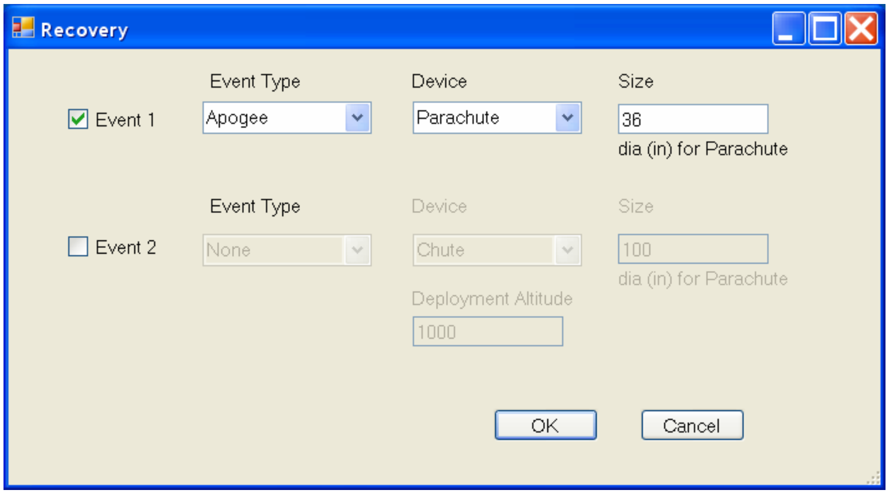
Figure 43 shows the launch site data for the LOC/Precision Caliber ISP rocket. The rocket was flown on Edwards AFB, with a launch site elevation of 2302 ft. The launch site temperature at the time of launch was 77 deg F. The rocket was launched with a launch angle 3 deg from vertical from a 10 ft long launch rail. Wind speed is set to zero for this example run.



Launch Site Elevation (ft)	2302
Temperature (deg F)	77.00
Launch Site Barometric Pressure (in-hg)	
Wind Speed (mph)	0
Launch Rail Length (ft)	10
Launch Angle - degrees from Vertical	3

Figure 43 – Launch site input data for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

The recovery system inputs are shown in Figure 44. The rocket was flown with a 36 in diameter parachute which was opened at apogee.

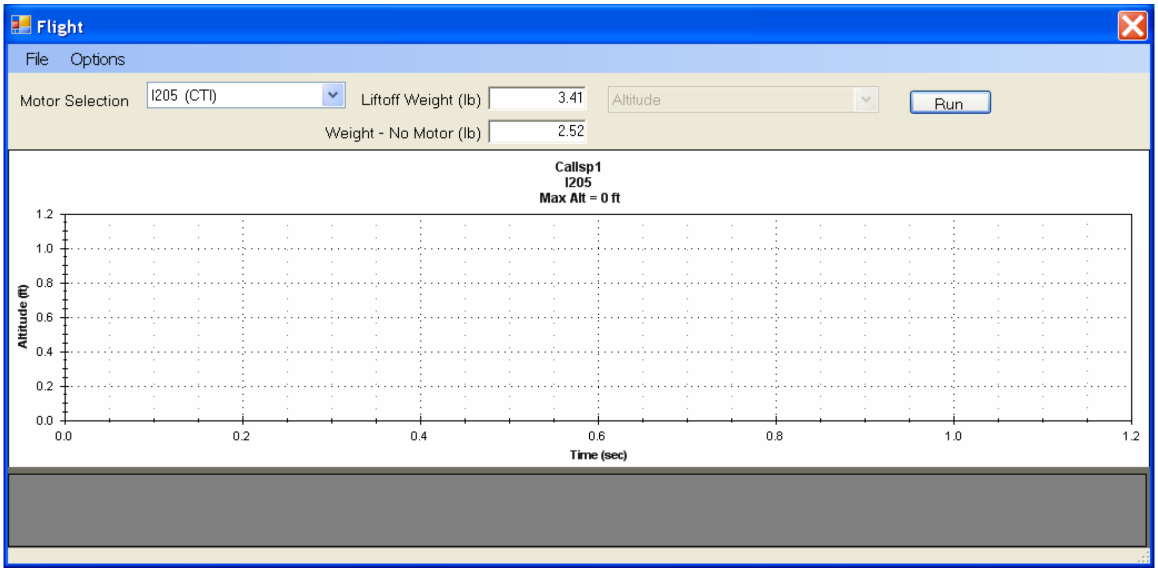


☑ Event 1
Event Type: Apogee
Device: Parachute
Size: 36
dia (in) for Parachute

☐ Event 2
Event Type: None
Device: Chute
Size: 100
dia (in) for Parachute
Deployment Altitude: 1000

Figure 44 - Recovery system input data for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

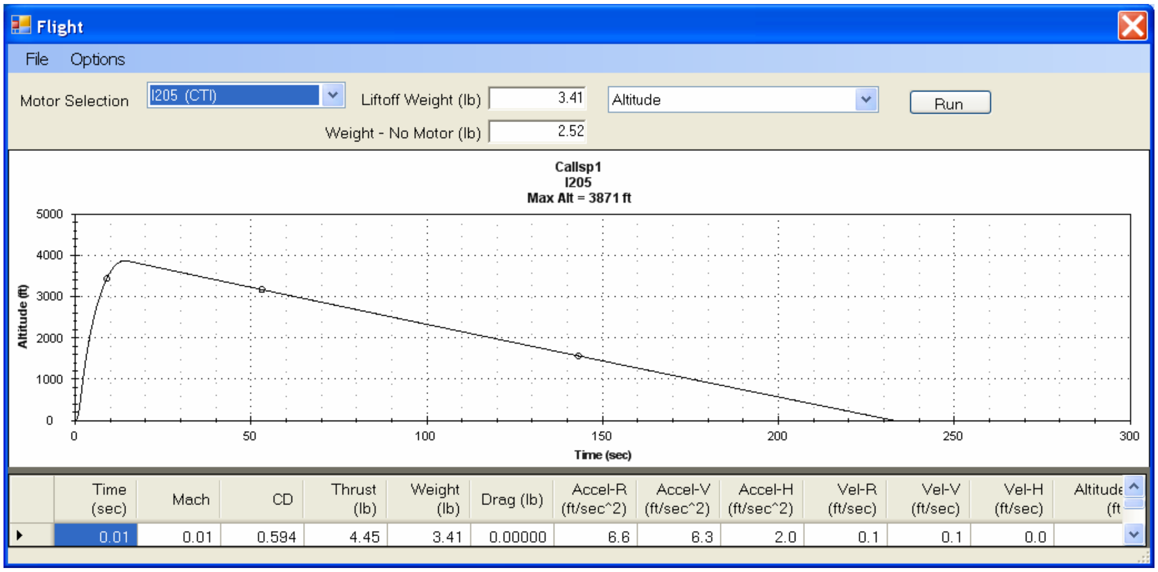
The RASAero flight simulation Flight Data Screen input data for the LOC/Precision Caliber ISP rocket (Example Rocket 1) are presented in Figure 45. The rocket was flown on a Cesaroni Technology Incorporated (CTI) I205 rocket motor, which was selected from the motor selection menu. The rocket loaded weight with motor (the liftoff weight) as flown was 3.41 lb.



Motor Selection: I205 (CTI)
Liftoff Weight (lb): 3.41
Weight - No Motor (lb): 2.52

Figure 45 – Flight simulation Flight Data Screen input data for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

The RASAero flight simulation for the rocket is run by clicking on <Run>, with the altitude versus time plot for the completed flight simulation run shown in Figure 46. The altitude versus time plot in Figure 46 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 flight simulation predicted altitude is 3871 ft, an error of only -2.35% compared to the actual barometric altimeter measured altitude.



Motor Selection: I205 (CTI)
Liftoff Weight (lb): 3.41
Weight - No Motor (lb): 2.52
Altitude

Callsp1
I205
Max Alt = 3871 ft

Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
0.01	0.01	0.594	4.45	3.41	0.00000	6.6	6.3	2.0	0.1	0.1	0.0	

Figure 46 – RASAero flight simulation Flight Data Screen with 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 47. 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 flight simulation predicted acceleration and velocity are shown in Figure 48. For acceleration note the similarly shaped plot of acceleration versus time, with a peak acceleration of almost 500 ft/sec^2. For velocity note the similarly shaped plot of velocity versus time, with a peak velocity of just over 700 ft/sec.

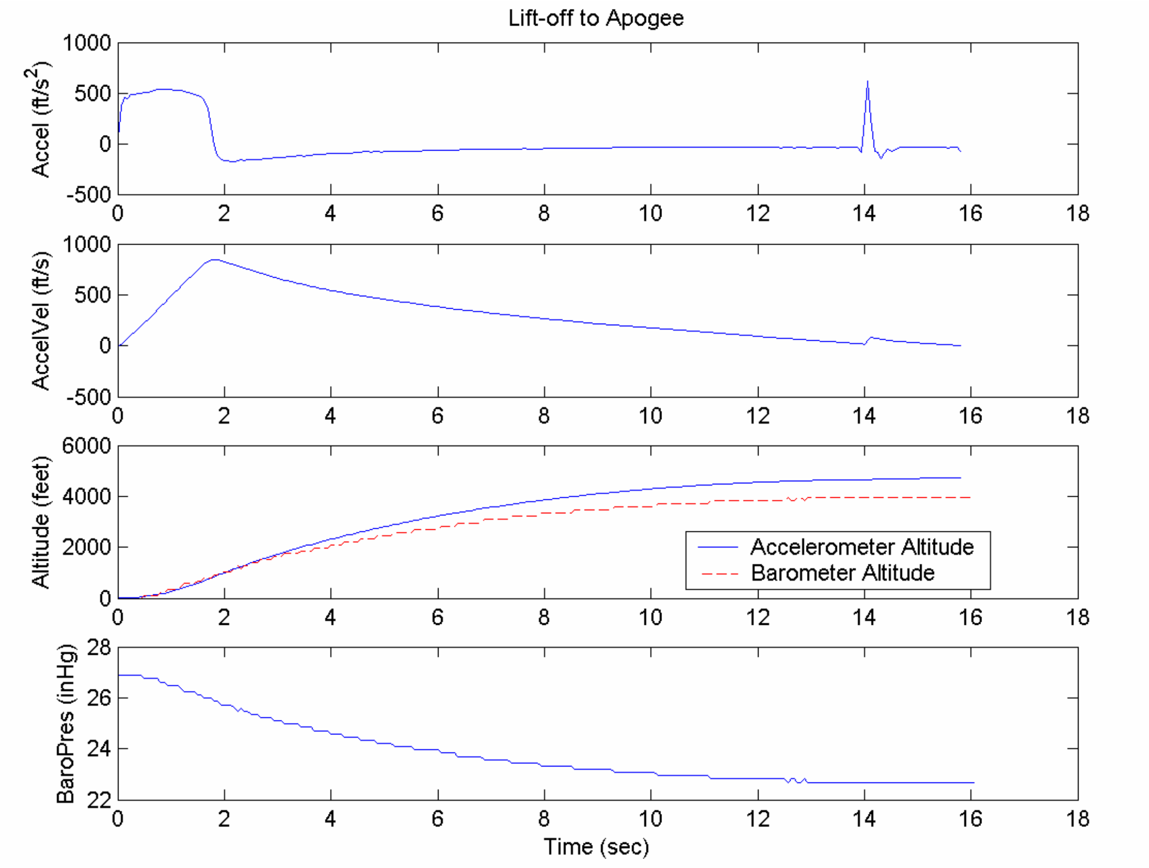
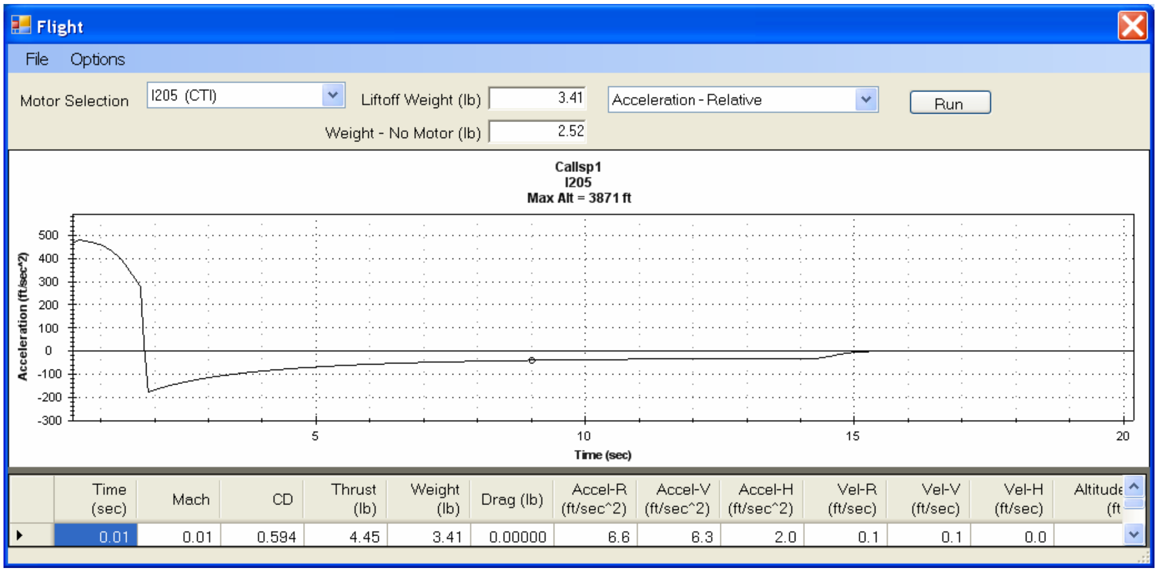
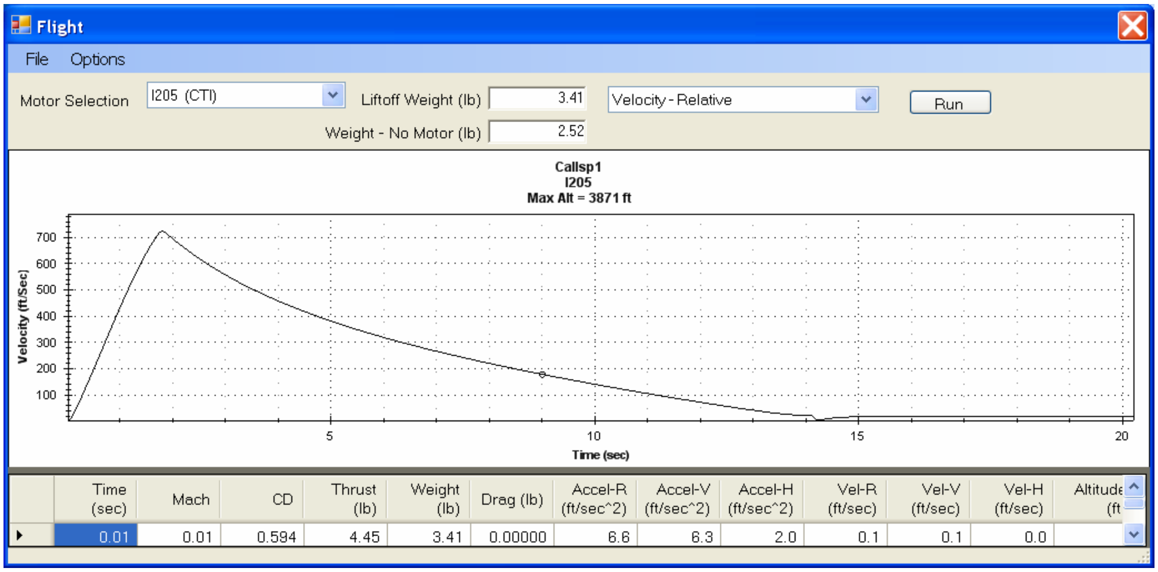


Figure 47 – Measured axial acceleration, accelerometer-based velocity, on-board measured barometric pressure, barometric altimeter altitude and accelerometer-based altitude for the LOC/Precision Caliber ISP rocket (Example Rocket 1).



Motor Selection: I205 (CTI)
Liftoff Weight (lb): 3.41
Weight - No Motor (lb): 2.52
Acceleration - Relative

Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
0.01	0.01	0.594	4.45	3.41	0.00000	6.6	6.3	2.0	0.1	0.1	0.0	



Motor Selection: I205 (CTI)
Liftoff Weight (lb): 3.41
Weight - No Motor (lb): 2.52
Velocity - Relative

Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
0.01	0.01	0.594	4.45	3.41	0.00000	6.6	6.3	2.0	0.1	0.1	0.0	

Figure 48 – RASAero flight simulation predicted acceleration and velocity for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

Figure 49 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 flight simulation predicted altitude versus time on a similar time-scale through apogee is presented in Figure 50. Again note the similarly shaped plot, in this case of altitude versus time through apogee.

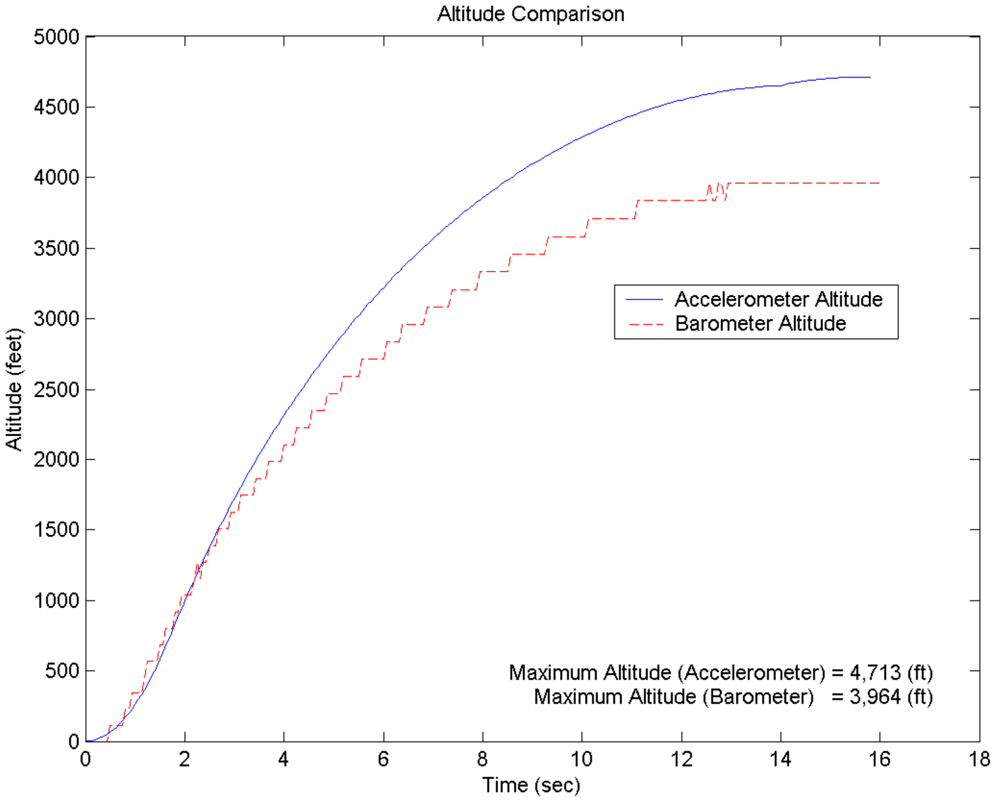
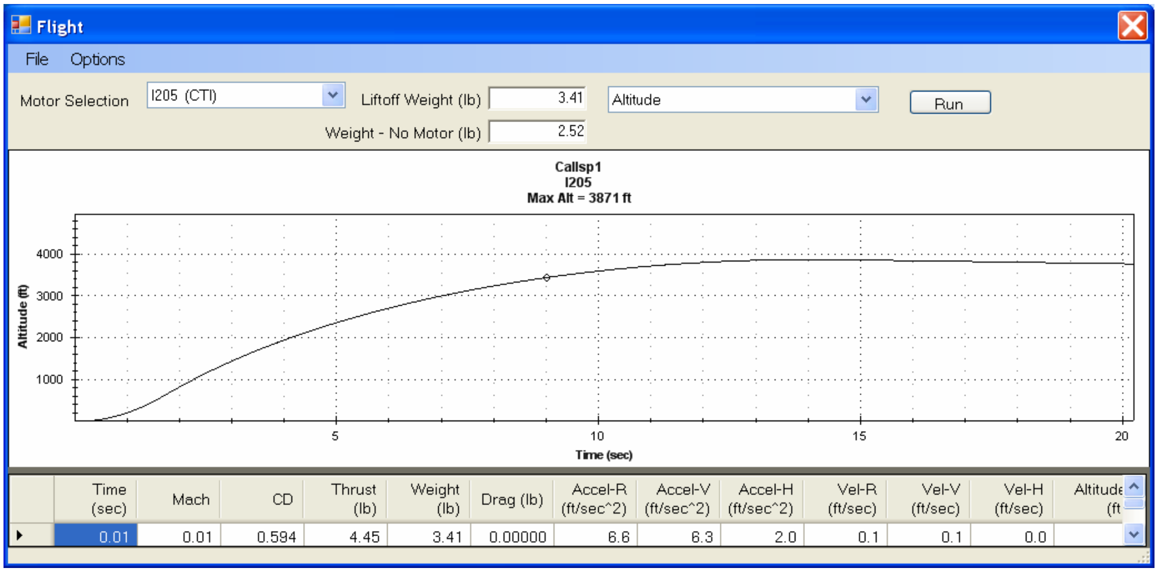


Figure 49 – Barometric altimeter altitude and accelerometer-based altitude for the LOC/Precision Caliber ISP rocket (Example Rocket 1).



Motor Selection: I205 (CTI)
Liftoff Weight (lb): 3.41
Weight - No Motor (lb): 2.52
Altitude

	Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
▸	0.01	0.01	0.594	4.45	3.41	0.00000	6.6	6.3	2.0	0.1	0.1	0.0	

Figure 50 – RASAero flight simulation predicted altitude versus time plotted through apogee for the LOC/Precision Caliber ISP rocket (Example Rocket 1).

As noted previously the RASAero flight simulation predicted altitude of 3871 ft has an error of only -2.35% compared to the barometric altimeter measured altitude of 3964 ft.

Figure 51 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 flight simulation prediction for altitude versus time from launch through apogee to landing, including the parachute descent, was presented in Figure 46, and is presented again in Figure 52. Note the similarly shaped plot of altitude versus time from launch through apogee, and then the parachute descent to landing. The RASAero flight simulation predicted parachute descent time is 218.83 sec, an error of only -9.20% in the parachute descent time from apogee.

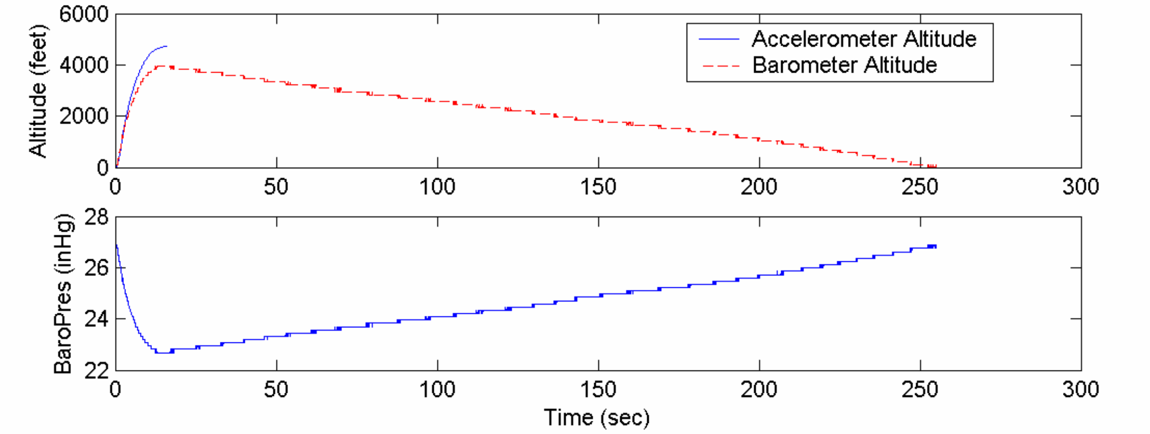
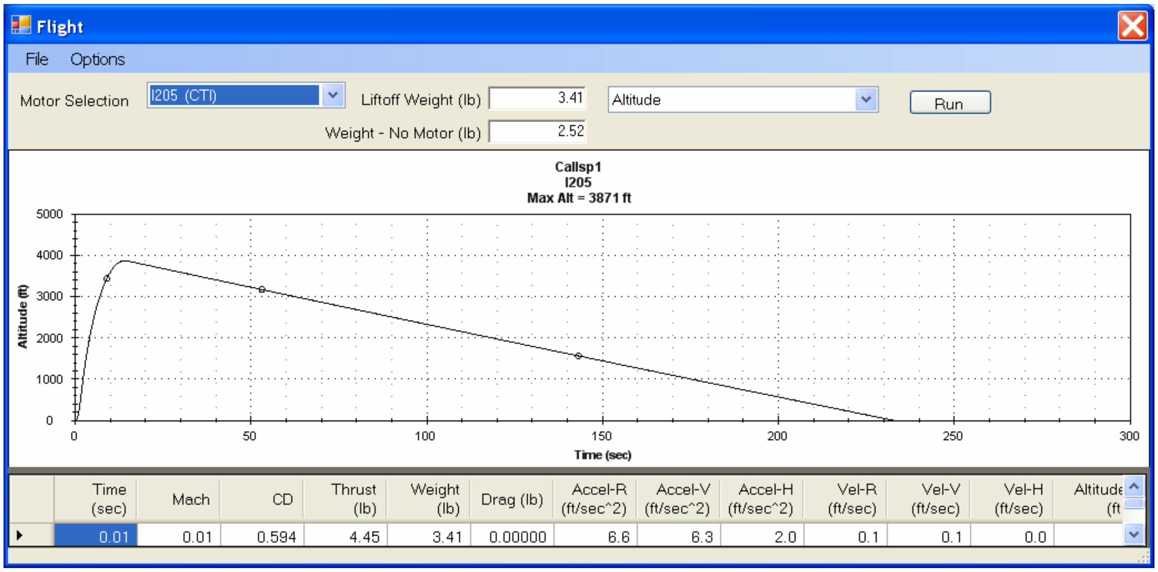


Figure 51 – On-board measured barometric pressure and barometric altimeter altitude from launch through apogee to landing, including the parachute descent, for the LOC/Precision Caliber ISP rocket (Example Rocket 1).



Motor Selection: I205 (CTI)

Liftoff Weight (lb): 3.41

Weight - No Motor (lb): 2.52

Altitude

Callsp1
I205
Max Alt = 3871 ft

Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
0.01	0.01	0.594	4.45	3.41	0.00000	6.6	6.3	2.0	0.1	0.1	0.0	

Figure 52 – RASAero 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 53. The Full Metal Jacket - Flight 3 configuration rocket was tower launched, and thus had no rail guides, launch lugs, or launch shoes. The RASAero rocket file for this rocket (Full Metal Jacket1.alx1) is located in the /My Documents/RASAero/Examples directory.

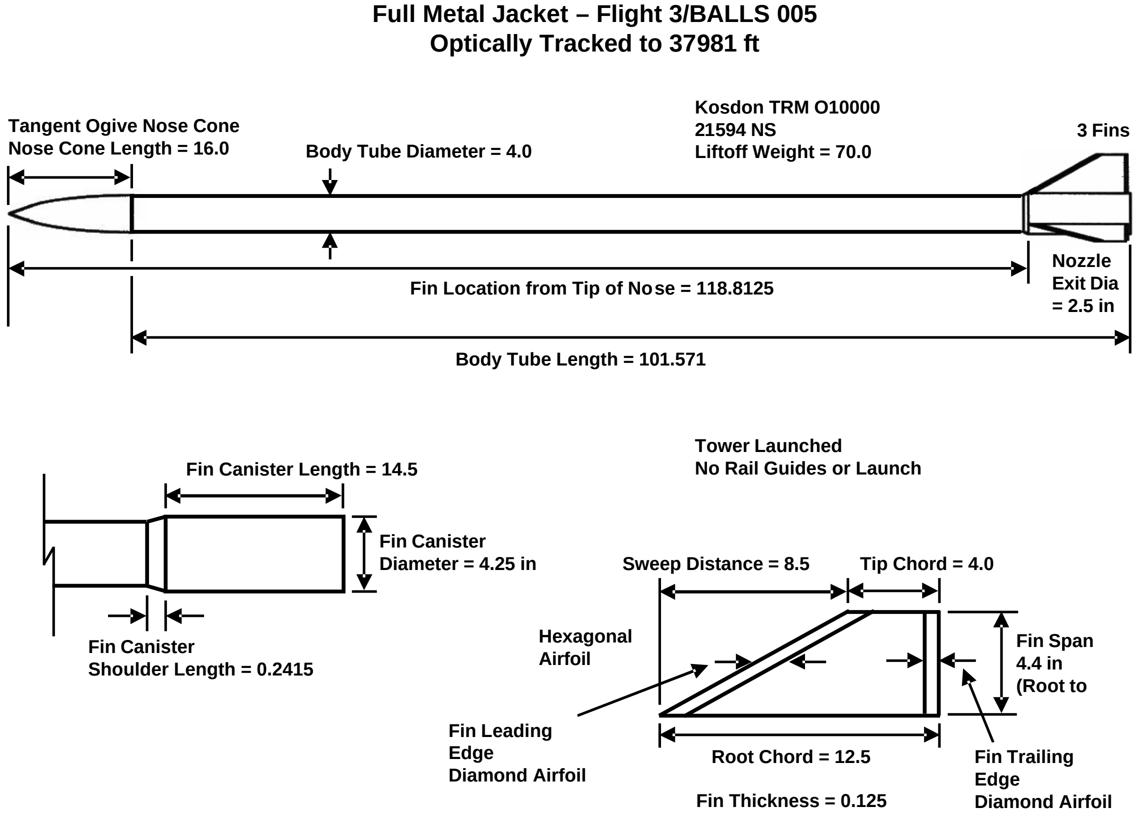
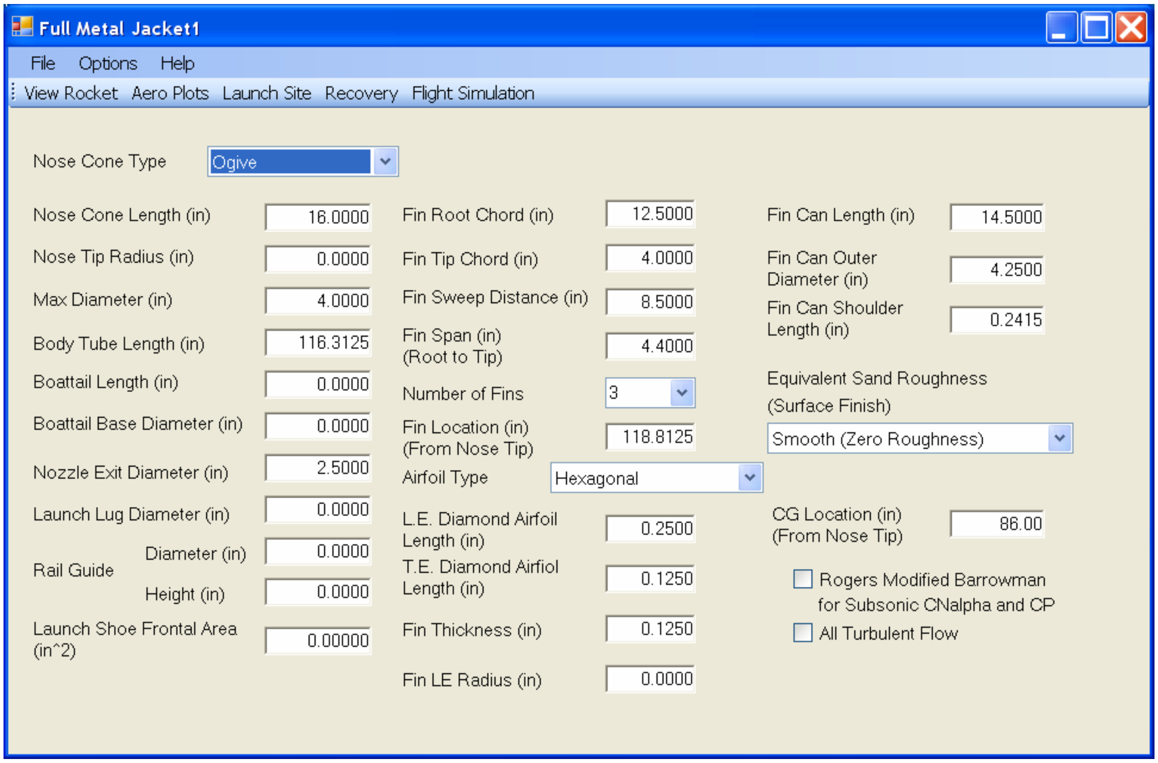


Figure 53 – Example Rocket 2, Full Metal Jacket - Flight 3 configuration rocket, powered by O10000 rocket motor, optically tracked to 37981 ft.

The RASAero Main Input Screen with the rocket geometry input data for the Full Metal Jacket - Flight 3 configuration rocket is presented in Figure 54.



Nose Cone Type	Ogive
Nose Cone Length (in)	16.0000
Nose Tip Radius (in)	0.0000
Max Diameter (in)	4.0000
Body Tube Length (in)	116.3125
Boattail Length (in)	0.0000
Boattail Base Diameter (in)	0.0000
Nozzle Exit Diameter (in)	2.5000
Launch Lug Diameter (in)	0.0000
Rail Guide Diameter (in)	0.0000
Rail Guide Height (in)	0.0000
Launch Shoe Frontal Area (in^2)	0.00000
Fin Root Chord (in)	12.5000
Fin Tip Chord (in)	4.0000
Fin Sweep Distance (in)	8.5000
Fin Span (in) (Root to Tip)	4.4000
Number of Fins	3
Fin Location (in) (From Nose Tip)	118.8125
Airfoil Type	Hexagonal
L.E. Diamond Airfoil Length (in)	0.2500
T.E. Diamond Airfiol Length (in)	0.1250
Fin Thickness (in)	0.1250
Fin LE Radius (in)	0.0000
Fin Can Length (in)	14.5000
Fin Can Outer Diameter (in)	4.2500
Fin Can Shoulder Length (in)	0.2415
Equivalent Sand Roughness (Surface Finish)	Smooth (Zero Roughness)
CG Location (in) (From Nose Tip)	86.00

☐ Rogers Modified Barrowman for Subsonic CNalpha and CP

☐ All Turbulent Flow

Figure 54 - RASAero Main Input Screen with rocket geometry input data for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2).

Figure 55 shows the View Rocket scale drawing for the Full Metal Jacket - Flight 3 configuration rocket. The View Rocket scale drawing confirms that the rocket geometry has been correctly entered, and provides a scale drawing of the rocket which can be copied and pasted into other documents.

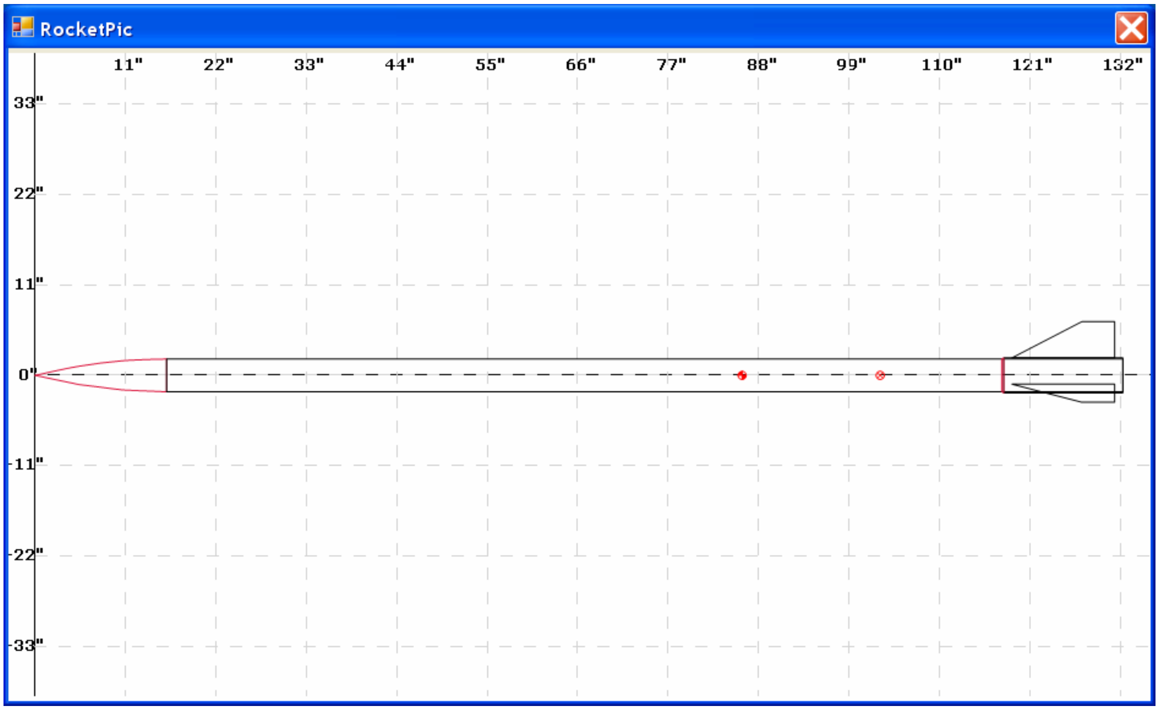
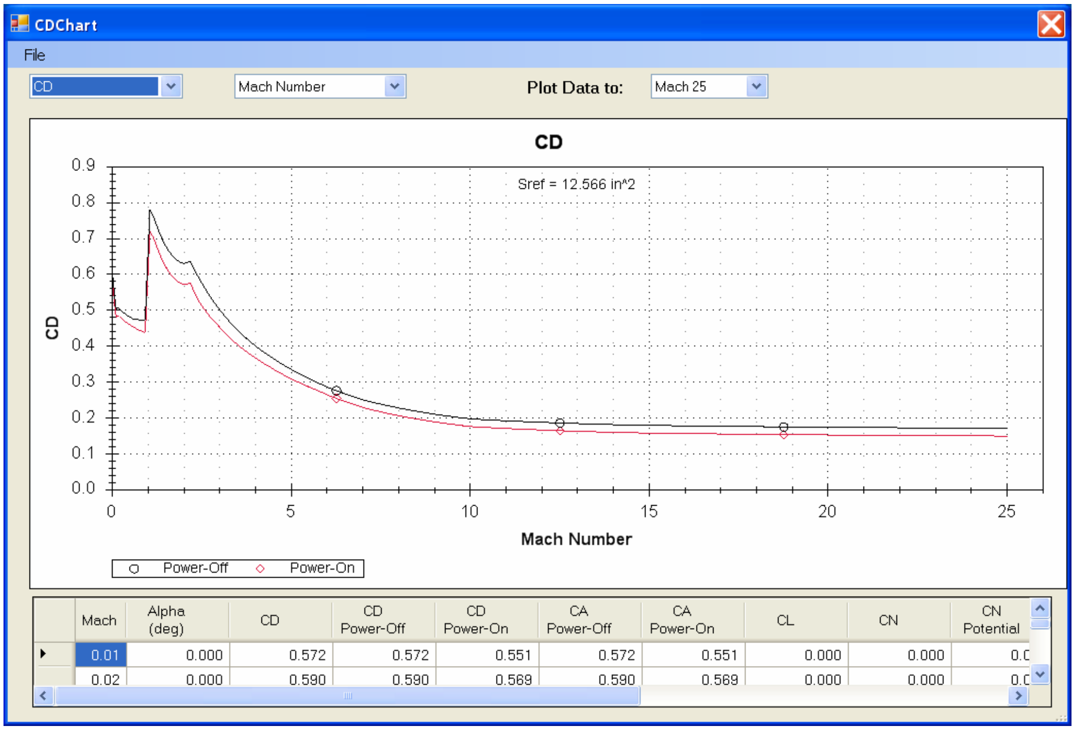


Figure 55 – RASAero View Rocket scale rocket drawing for the Full Metal Jacket - Flight 3 configuration rocket. (Example Rocket 2).

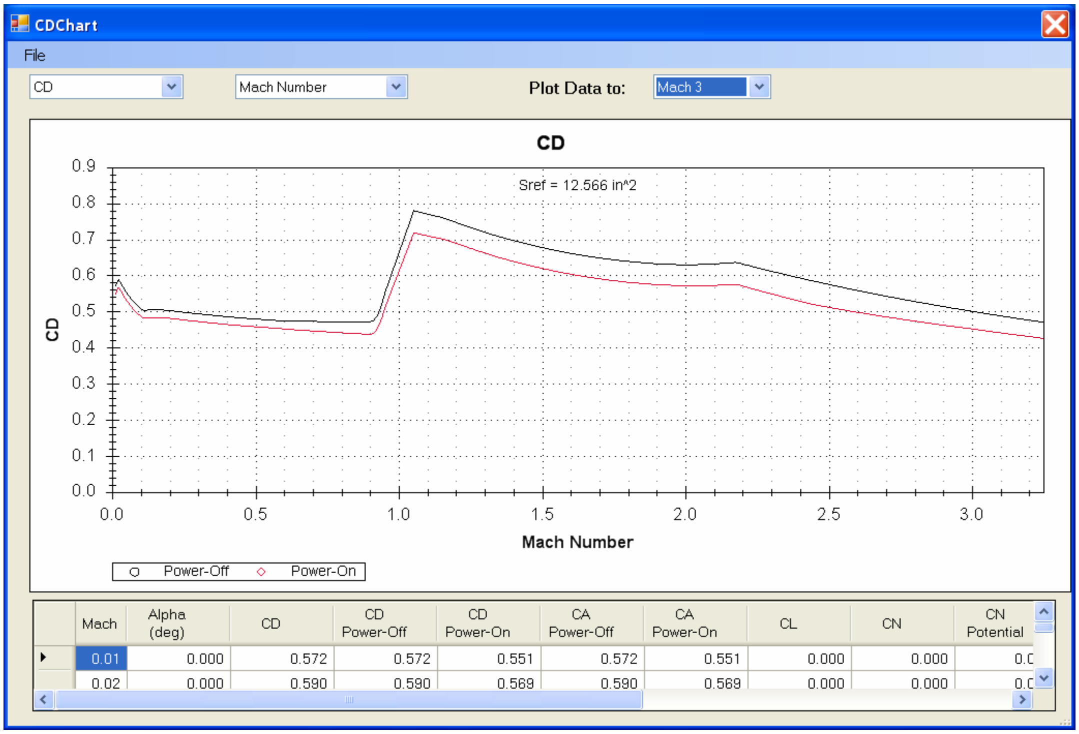
Figures 56 and 57 show one of the aerodynamic data plots for the Full Metal Jacket - Flight 3 configuration rocket, the power-on and power-off drag coefficient (CD) versus Mach number. Note that with the large nozzle exit diameter (nozzle exit area) used on this rocket, a 2.5 in nozzle exit diameter 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 56 is the initial aerodynamic data plot generated by the software where the aerodynamic data is plotted for Mach 0-25, and in Figure 57 the <Plot Data to:> pull-down menu has been used to plot the data for Mach 0-3.



CD | Mach Number | Plot Data to: Mach 25

Mach	Alpha (deg)	CD	CD Power-Off	CD Power-On	CA Power-Off	CA Power-On	CL	CN	CN Potential
0.01	0.000	0.572	0.572	0.551	0.572	0.551	0.000	0.000	0.0
0.02	0.000	0.590	0.590	0.569	0.590	0.569	0.000	0.000	0.0

Figure 56 – 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.

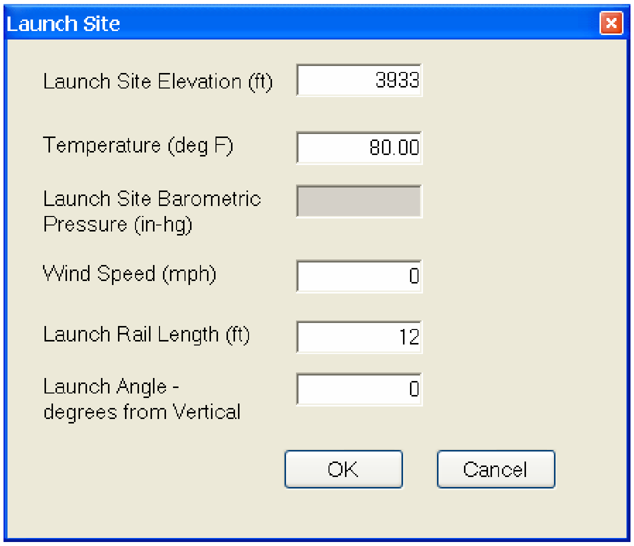


CD | Mach Number | Plot Data to: Mach 3

Mach	Alpha (deg)	CD	CD Power-Off	CD Power-On	CA Power-Off	CA Power-On	CL	CN	CN Potential
0.01	0.000	0.572	0.572	0.551	0.572	0.551	0.000	0.000	0.0
0.02	0.000	0.590	0.590	0.569	0.590	0.569	0.000	0.000	0.0

Figure 57 – 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.

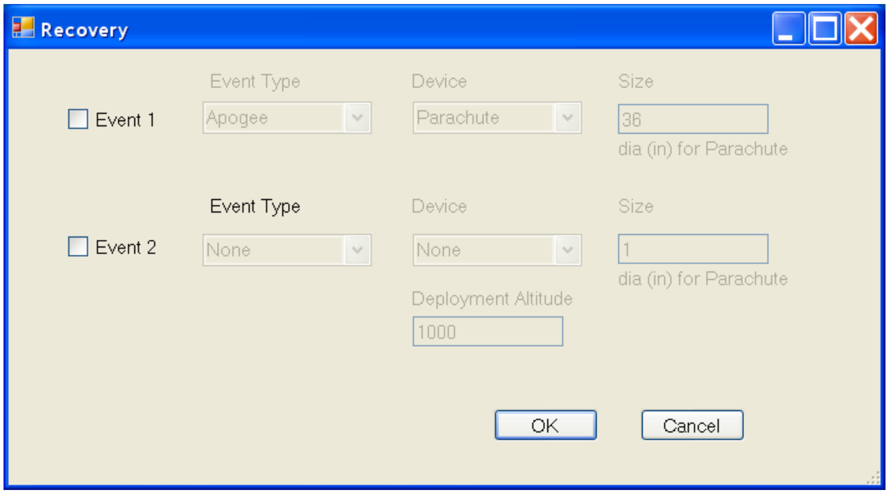
Figure 58 shows the launch site input data for the Full Metal Jacket - Flight 3 configuration rocket. The Flight 3 configuration of the Full Metal Jacket rocket was flown from the Black Rock Desert Dry Lakebed launch site, with a launch site elevation of 3933 ft. The launch site temperature at the time 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.



Launch Site Elevation (ft): 3933
Temperature (deg F): 80.00
Launch Site Barometric Pressure (in-hg):
Wind Speed (mph): 0
Launch Rail Length (ft): 12
Launch Angle - degrees from Vertical: 0

Figure 58 – Launch site input data for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2).

The recovery system inputs are shown in Figure 59. 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.)



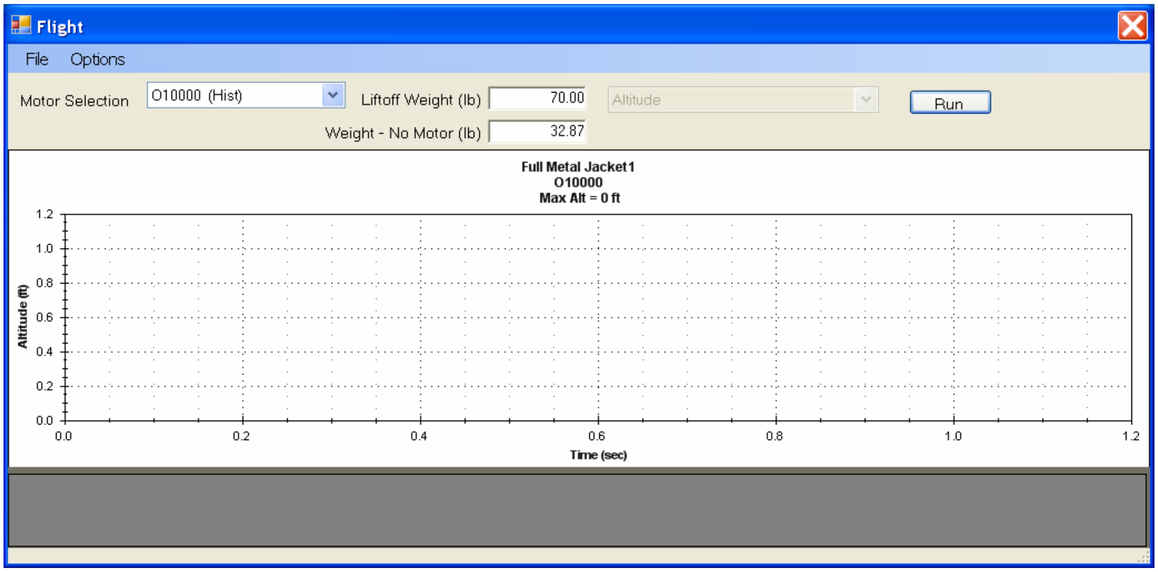
Recovery

	Event Type	Device	Size
☐ Event 1	Apogee	Parachute	36 dia (in) for Parachute
☐ Event 2	None	None	1 dia (in) for Parachute

Deployment Altitude
1000

Figure 59 - Recovery system input data for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2).

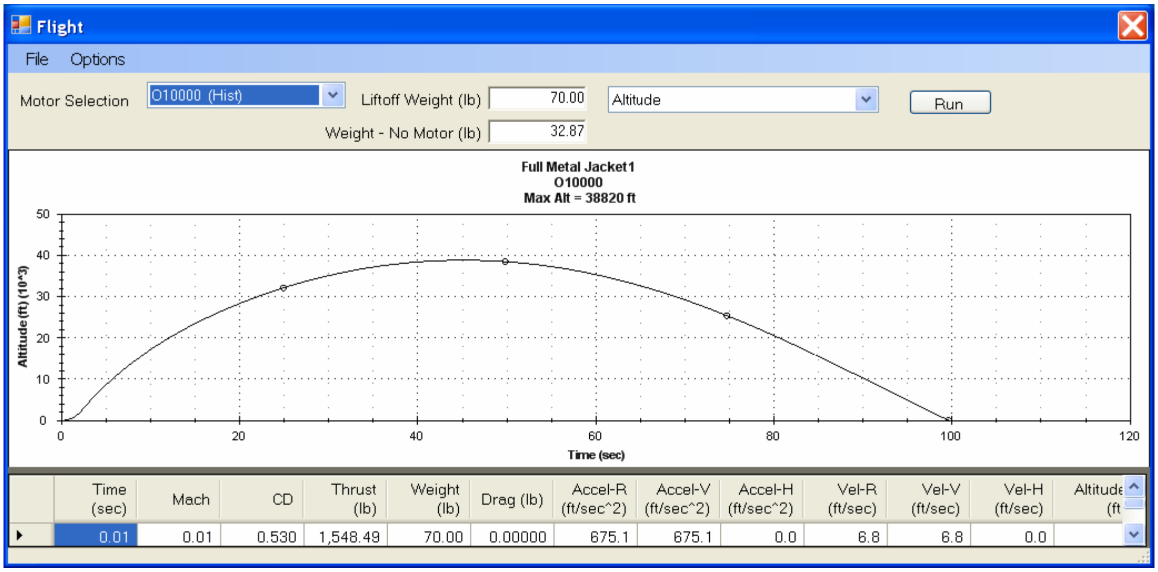
The RASAero flight simulation Flight Data Screen input data for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2) are presented in Figure 60. The rocket was flown on a Kosdon O10000 rocket motor, which was selected from the motor selection menu. The rocket loaded weight with motor (the liftoff weight) as flown was 70 lb.



Motor Selection: O10000 (Hist)
Liftoff Weight (lb): 70.00
Weight - No Motor (lb): 32.87

Figure 60 – RASAero flight simulation Flight Data Screen input data for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2).

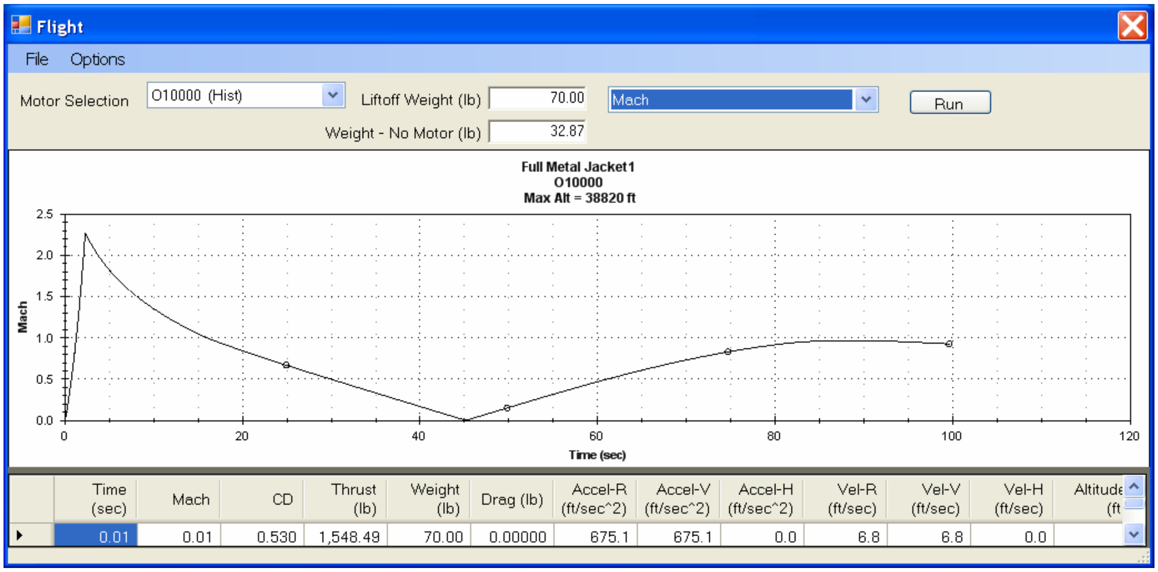
The RASAero flight simulation for the rocket is run by clicking on <Run>, with the altitude versus time plot for the completed flight simulation run shown in Figure 61. The Mach number versus time plot from the flight simulation run is presented in Figure 62, showing that the rocket reached Mach 2.27. The altitude versus time plot for the flight shown in Figure 61 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.)



Motor Selection: O10000 (Hist)
Liftoff Weight (lb): 70.00
Altitude
Weight - No Motor (lb): 32.87

Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
0.01	0.01	0.530	1,548.49	70.00	0.00000	675.1	675.1	0.0	6.8	6.8	0.0	

Figure 61 – RASAero flight simulation Flight Data Screen with flight simulation output for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2), altitude versus time.



Motor Selection: O10000 (Hist)
Liftoff Weight (lb): 70.00
Weight - No Motor (lb): 32.87
Mach

	Time (sec)	Mach	CD	Thrust (lb)	Weight (lb)	Drag (lb)	Accel-R (ft/sec^2)	Accel-V (ft/sec^2)	Accel-H (ft/sec^2)	Vel-R (ft/sec)	Vel-V (ft/sec)	Vel-H (ft/sec)	Altitude (ft
▸	0.01	0.01	0.530	1,548.49	70.00	0.00000	675.1	675.1	0.0	6.8	6.8	0.0	

Figure 62 – RASAero flight simulation Flight Data Screen with flight simulation output for the Full Metal Jacket - Flight 3 configuration rocket (Example Rocket 2), Mach number 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 38820 ft, an error of only +2.21% compared to the optically tracked altitude.