

# SKY AERO v.7.6.1

## User's Manual

---

*By: Armando Fuentes, Charles Hoult, Hien Tran and Michael Tong*

*Mar 02, 2014*

## Table of Contents

1.	Getting Started.....	1
2.	Input Tables.....	2
2.1.	Geophysics and Geodesy .....	2
2.2.	Wind Model .....	3
2.3.	Initial and Final Conditions.....	5
2.4.	Events/Phases and Durations .....	6
2.5.	Parachute and integration step sizes.....	8
2.6.	Stages.....	9
2.7.	Miscellaneous .....	12
3.	Running and Analyzing the Simulation .....	13
3.1.	Running SKYAERO .....	13
3.2.	Analyzing the Results .....	13
3.3.	Using SKYAERO to Adjust Launcher Settings .....	14
3.4.	Using SKYAERO for Other Applications.....	14
4.	FAQ.....	16

## 1. Getting Started

SKYAERO is a point mass time-event trajectory and rocket performance simulation. SKYAERO is capable of simulating up to 3-stages, and both drogue and main chute phases.

To simplify operation of the program, SKYAERO has been color-coded. The color usage and their meanings are defined in the following text and Figure 1. Green and Orange filled cells represent the titles, headers and symbols. Magenta filled cells represent the inherent physics of the problem (physical constants etc). Gray filled cells provide guidance to the users on how to operate SKYAERO. Light blue filled cells represent the required user inputs. White filled cells are calculated values by SKYAERO (based on user inputs and standard physics).

Title/Symbol	Natural Constants
Header	User Inputs
	Advisory Material
Outputs	

Figure 1 - Color-coded scheme of SKYAERO.

Some may wonder why this type of program was created and developed in Microsoft Excel VBA (Visual Basic for Applications) rather than C, Matlab, or other programming language. With SKYAERO's input and output Microsoft Excel interface, users can operate the software with no programming background or knowledge. Further, this program readily and easily accepts thrust curve data for motor and rocket's drag profile with input tables. This program was generated for its simplicity, accessibility, ease-of-use and accuracy.

When running the simulation users may feel that the simulation is taking longer than expected. This is normal! Visual Basic calculates slower than other programming languages. As a "rule of thumb" (for this program), if the simulation lasts more than 10 minutes, it should be aborted. Unfortunately, once the run begins, there is no way to stop it through the standard ~~tabular~~ interface. However, the program can be stopped directly from the source code using, standard computer operation techniques; alt + break or "Esc" key. The other alternative is to start the task manager (ctrl+alt+delete) and shut down MS Excel. On average, simulations take less than 5 minutes to compute (depending on step sizes, number of stages employed and the computer's overall capable performance).

Before starting any work, the users must **enable Macros** (the default setting has Macros disabled). If macros are disabled, follow the instructions provided with MS Excel and enable them. To access Excel's (Visual Basic) programming tools, you will need to enable and select the Developer's tab.

## 2. Input Tables

Prior to running SKYAERO, the users must input/fill in all tables that are applicable their problem. Failure to fill in the tables properly may result in a degradation in accuracy of the results or an error message. The number of tables required to be filled out depends on the number of stages required for the simulation. **Note that SKYAERO uses English units exclusively.**

### 2.1. Geophysics and Geodesy

The first table the users encounters is mostly completed and is shown below in Figure 2. The only required input is the launch site surface temperature in degrees Fahrenheit. The Fahrenheit temperature is converted to degrees Rankine when SkyAero begins its calculations. The input temperature is actually measured at 2 meters, or about 6 ft, above the ground level.

Physical and other Constants			
Parameter	Value	Units	Notes
standard gravity (g)	32.1740	ft/s <sup>2</sup>	
R <sub>EP</sub> (polar)	20855437.3000	ft	<b>Polar Earth Radius</b>
R <sub>EE</sub> (equatorial)	20925597.9000	ft	<b>Equatorial Earth Radius</b>
T <sub>P</sub> (polar)	27900.0000	ft	<b>Polar Tropopause Altitude</b>
T <sub>E</sub> (equatorial)	52500.0000	ft	<b>Equatorial Tropopause Altitude</b>
Specific Gas Constant (R)	1716.0000	ft lb <sub>f</sub> /slug °R	Gas Const=ant for Air
γ	1.4050		Heat Capacity Ratio (Cp/Cv) for Moist Air
P <sub>SL</sub>	2116.2290	lb/ft <sup>2</sup>	Pressure @ SL
alpha	-0.0036	deg/ft	Tropopause Temperature Lapse Rate
pi	3.1416		
Earth Equatorial radius	20925597.9000		
Earth Polar radius	20855437.3000		

Atmospheric Constants		
Parameter	Value	Notes
deg to rad	0.0175	pi/180
Sea Level Mass Density, sl/ft <sup>3</sup>	0.0022	
Sea Level Temperature, deg R	566.4386	
Tropopause Altitude, ft	39190.8680	
Launch Site Temperature, deg F (at 6ft AGL)	100.0000	
Tropopause Pressure, lb/ft <sup>2</sup>	477.0892	
Tropopause Temperature, deg R	426.6762	

Figure 2 - Physical and Atmospheric Constants Tables.

The atmosphere model is very similar to that used in the 1976 US Standard Atmosphere. Once a temperature profile has been established in an atmospheric region, e.g., the troposphere, then the perfect gas law and the condition of hydrostatic equilibrium are used to obtain the other state variables. The troposphere temperature profile uses the standard atmosphere lapse rate but passes through the measured launch temperature.

Tropopause altitude is found as a function of latitude from data in the Handbook of Geophysics<sup>1</sup>. The stratosphere temperature remains constant at its tropopause value.

The acceleration due to gravity at the geoid is modeled with a Potsdam equation<sup>1</sup> using latitude as its independent variable. Corrections for higher altitudes are based on an inverse square law. The shape of the earth is considered to be an ellipsoid of revolution, again using latitude as the independent variable.

## 2.2. Wind Model

Unlike many trajectory simulations, SKYAERO has the capability to account for wind. The wind model is based on Lewis' method<sup>2</sup>, which assumes the rocket instantly heads into the relative wind. Begin by clearing any old wind data from an earlier run. Then, if, a wind response is needed, press Generate Wind Profile. Values obtained by WIND CALCULATOR.xlsx can be input into SKYAERO. WIND CALCULATOR.xlsx can be found on Rocket Science and Engineering Technologies website<sup>3</sup>. WIND CALCULATOR.xlsx generates two sets of data, one for the North-South (N-S) component of the wind vector, and one for the East-West (E-W) component as shown in Figure 3b. The user simply types those values into the cells of the table of Figure 3b. The program calculates and populates the table of Figure 3a. The user also needs to know that he/she will need to run the program twice, once for in-plane wind, and again for cross-wind for a complete simulation.

---

<sup>1</sup> Adolph S. Jursa, Scientific Editor, "Handbook of Geophysics and the Space Environment", 3rd Edition, United States Air Force, 1985.

<sup>2</sup> Lewis, J.V., "The Effect of Wind and Rotation of the Earth on Unguided Rockets", Ballistic Research Laboratories Report No. 685, Aberdeen, March 1949.

<sup>3</sup> [www.rsandt.com](http://www.rsandt.com)

in-plane (TRUE) or cross-wind (FALSE) component, and (none) for no wind	FALSE
---	-------

Plus wind blows away from the launcher	Altitude (AGL), ft	Cross-Plane Wind Component, ft/s	$\Delta W / \Delta h$
	0.0000	0	-0.0923
<b>Clear Wind Profile</b>	5.0000	-0.461538462	-0.0923
	10.0000	-0.923076923	-0.0923
	15.0000	-1.384615385	-0.0923
<b>Generate Wind Profile</b>	20.0000	-1.846153846	-0.0923
	25.0000	-2.307692308	-0.0923
	23.5362	-2.172572777	-0.0923
	50.0000	-4.615384615	-0.0923
	55.0000	-5.076923077	-0.0923
	65.0000	-6	-0.0149

Figure 3a - Generate Wind Table and Wind Type Input.

Measured Wind data	Altitude (AGL), ft	N-S Wind Speed, fps	E-W Wind Speed, fps
Wind data from WIND CALCULATOR.xlsx go here	0.0000	0.0000	0.0000
	65.0000	-6.0000	-6.0000
	400.0000	-11.0000	-11.0000
	600.0000		
	650.0000		

Figure 3b - Wind Table of Input.

WIND CALCULATOR.xlsx generates a vector wind profile using data from two sources. Low altitude ( $150\text{ m} \approx 500\text{ ft AGL}$ ) vector winds are measured as near to launch time as feasible using a tethered pilot balloon (TPB)<sup>3</sup>. The higher altitude synoptic winds are obtained from the online National Weather Service data base for a location near the launch site. SKYAERO re-resolves the N-S and E-W profiles into in-plane and cross-plane profiles. Both are developed from the tabular data using linear interpolation.

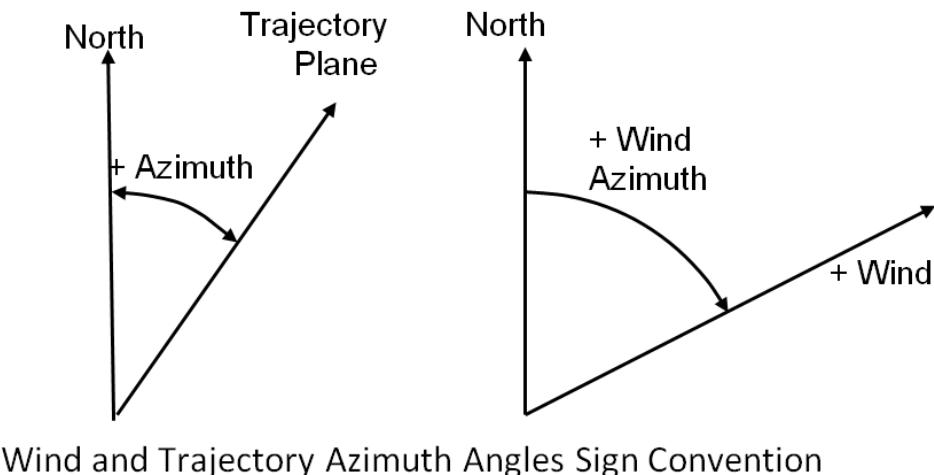


Figure 4 - Wind and Trajectory Azimuth.

Two data sets fed into WIND CALCULATOR.xlsx to obtain the N-S component wind and E-W component wind. For more information on this topic you can refer to the materials posted on C. Hoult's website<sup>3</sup>.

Now that the wind data set of two components are obtained, SKY AERO will generate a wind profile as a function of altitudes linearly interpolating the wind data obtained. To use, all the user needs to do is type "true" (in-plane), "false" (cross-wind) or "none" (no wind). A linear interpolation curve is the straight line between two data points. Ideally the more data points we obtained in the field the better the accuracy of the wind profile is. To generate the table simply use the buttons in Figure 3.

Now that the user knows how to use the tables, it is important to briefly describe the use of the in-plane wind or cross-wind component. The wind model is used to predict the landing location of the rocket in the presence of winds.

SKY AERO has the ability to account for desired landing location by providing elevation and azimuth rocket launch angles. In order to achieve this, the wind vector is broken into two constituents, namely the in-plane wind and cross-wind directions with respect to the desired trajectory plane, and an impact point due to each wind component is calculated. A trigonometric calculation is carried out to determine the necessary launch angles to land at a desired location.

### 2.3. Initial and Final Conditions

The initial and final conditions table require the user to input values for initial conditions (including launch site data) and final goals. The launcher can be either static or mobile. An example of mobile launch would be a rocket being dropped-off from an airplane at some designated altitude. The inputs are the altitude at the launch site, velocity, geodetic latitude which will be defined later, initial range for whichever launch option is used, the initial launch elevation angle, and the initial yaw wave number, which will be defined later. In all cases, the initial position vector passes through the launch site.

You may be wondering what the geodetic latitude and yaw wave number are. There are two types of latitudes, geocentric and geodetic. Below is a definition of both:

Geocentric latitude: defined as the angle between the equatorial plane and a radius vector from the center of the Earth.

Geodetic latitude: defined as the angle between the equatorial plane and a vector normal to the Earth's geoid.

The yaw wave number<sup>4</sup> refers to a kind of spatial domain frequency that is a consequence of the rocket's moment of inertia and aerodynamic stability. This number will usually be provided by the structures or mass properties team. Figure 5 shows a lay-out of this input table. Cartesian coordinate axes are used. Subscript x is for the horizontal direction, and z for the vertical.

#### Initial and Final Conditions

Parameters	Value	Units	Notes
Initial Altitude (MSL)	1898.00	ft	Launch Location Altitude (MSL)
Initial Range	0.00	ft	
Initial Vx	0.00	ft/s	Velocity in x-axis at launch
Initial Vz	0.00	ft/s	Velocity in z-axis at launch
initial Quadrant Elevation Angle (QE)	85.00	deg	Quadrant Elevation Angle. Not used for first stage after parachute stabilized phase.
Physical Launcher Length	12.00	ft	Physical launcher length. Not used for first stage after parachute stabilized phase.
Initial Yaw Wavelength	350.00	ft	Pitch / Yaw Wavelength
Desired Impact Altitude (MSL)	1898.00	ft	Landing Altitude
Desired Trajectory Azimuth	0.00	deg	
Geodetic Latitude	34.00	deg	Launch Latitude
Pitch/Yaw Wavenumber	0.0180	rad/ft	Pitch/Yaw Wavenumber at Launch
Launch site g	32.1392	ft/sec <sup>2</sup>	g at Launch Latitude at MSL
Launch Site Earth radius	20902678.3940	ft	
Simulation Launcher Length	23.5362	ft	

Pitch-Yaw Wave Number3.doc

Launcher Length for Sounding-Rocket Point-Mass Traj. Sim.pdf

Figure 5 - Initial and Final Inputs.

## 2.4. Events/Phases and Durations

In a time-event simulation, events are when something important happens. Adaptive events depend on how the simulation evolves, such as time leaving the launcher rail, apogee and impact. Many events occur at a scheduled time. Examples are ignition and second stage separation from the first stage. Whenever the equations of motion change, such as when leaving the launcher rail or igniting an upper stage, an event must be inserted. Also, if the rocket's inert mass or drag curve changes, such as with parachute deployment, an event will be needed.

<sup>4</sup> Hoult, C.P., "The Pitch/Yaw Wave Number (rev.3)", Rocket Science and Engineering Technologies. 2009. <http://rsandt.com/media/The Pitch-Yaw Wave Number3.doc>

A phase is just everything between two adjacent events. For example, first stage coasting could begin with first stage burnout and end with parachute deployment.

The phases/events input table defines the number of stages of the rocket, and whether or not parachutes are present. A simple true and false logic is employed to determine which stages will be activated. Make sure to select true for coasting and power phase for each stage selected. Note that not all events of the stage need to exist. However; there are some which are essential. One example would be the first stage powered flight is needed for a two stage rocket but the first stage coasting flight can be omitted if the rocket goes straight to second stage ignition from first stage burnout. For more information, user needs to look up the document "Events and Phase(rev.3)"<sup>5</sup> on website<sup>3</sup>.

From the table in Figure 6, after inputting the launch logic, the user will input the duration times between two phases. The user can observe the start time and the end time of each event and check if the launch sequence is correct. Note that the final phase, which will be terminated by impact with the ground, should be given an input duration of 9999.0 seconds. The actual impact will occur much earlier, but this ensures that the simulation run does not stop itself prior to impact.

---

<sup>5</sup> Hoult, C.P., “Events and Phases(rev.3)”, Rocket Science and Engineering Technologies. 2013.  
[http://rsandt.com/media/Events\\_and\\_Phases\(rev3\).doc](http://rsandt.com/media/Events_and_Phases(rev3).doc)

**Phases/Events and Durations Input Table**

Event/Phase	Logic	Duration, sec	
1 - First Stage on Coasting Flight	FALSE	1.0000	Burn Time
2 - 1st Stage Coasting Stabilization Parachute	FALSE	10.0000	
3 - First Stage Powered Flight on launcher	TRUE	C85 for 1st stage total burn time	
4 - First Stage Powered (Free) Flight	TRUE	7.0800	
5 - First Stage Coasting Flight	TRUE	9999.0000	
6 - Second Stage Coasting Flight	FALSE		
7 - Second Stage Powered Free Flight	FALSE		
8 - Second Stage Coasting Flight	FALSE		
9 - Third Stage Coasting Flight	FALSE		
10 - Third Stage Powered Free Flight	FALSE		
11 - Third Stage Coasting Flight	FALSE		
12 - Coasting on Drogue Parachute	FALSE		
13 - Coasting on Main Parachute	FALSE		

TALO <sub>start</sub> , sec (assume initial time = 0)	TALO <sub>end</sub> , sec	Sequence stage
FALSE	FALSE	
FALSE	FALSE	
0.0000		OK
0.0000	7.0800	OK
7.0800	10006.0800	OK
FALSE	FALSE	
FALSE	FALSE	
FALSE	FALSE	
*TALO: Time After Lift-Off	SE	
SE	FALSE	
FALSE	FALSE	
FALSE	FALSE	
FALSE	FALSE	

Figure 6 - Events/Phases and Durations Input Table.

## 2.5. Parachute and integration step sizes

SKY AERO uses a fourth order Runge-Kutta numerical integrator. Below the events table, the user will encounter parachute inputs and time step inputs. The default delta t (dt or time step) for the flight is .05 seconds, which is pretty accurate except during parachute deployment. For this reason, the user is given the option of adjusting the times to ensure the simulation runs stably. Keep in mind that these shorter time intervals are only needed for a few seconds following parachute deployment. Large accelerations are encountered during parachute deployments, and if the step size is too large, the integration will be unstable. Input values are needed for the parachute diameters, deployment times, and, an inflation time constant. The time constant is the time required for the parachute to fully deploy. It is assumed that the parachute capture areas will follow an exponential behavior. One time constant is assumed for all

parachutes. Users are free to experiment with the values, but it is recommended to use the default value.

<b>dt</b>	0.0500	s	<b>General Integration Time Step</b>
<b>dt</b>	0.0010	s	<b>Time Step for Drogue Phases</b>
<b>dt</b>	0.0005	s	<b>Time Step for Main Chute Phase</b>

Figure 7 - Integration Time Steps.

SKY AERO provides for three parachutes. The standard drogue and main are used for recovery. But, for aircraft and balloon launches, a separate drogue is initially used to ensure the launch aircraft is at a safe distance away and the rocket is pointing vertically prior to stage ignition.

Parachute			
<b>DT<sub>MC</sub></b>	<b>FALSE</b>	s	<b>Main Chute Deployment Time</b>
<b>DT<sub>DC</sub></b>	<b>FALSE</b>	s	<b>Drogue Chute Deployment Time</b>
<b>τ</b>	2.0000	s	<b>Pre-ignition Chute Deployment Time</b>
<b>D<sub>MC</sub></b>	10.0000	ft	<b>Main Chute Diameter</b>
<b>D<sub>DC</sub></b>	3.0000	ft	<b>Drogue Chute Diameter</b>
<b>DD</b>	3.5000	ft	<b>Pre-ignition Phase Drogue Chute Diameter</b>
<b>Dt1</b>	<b>FALSE</b>	s	<b>Pre-ignition Phase Chute Deployment Time</b>

Cd main chute	0.8900	drag coefficient
Sref main chute	78.5398	reference area drag, ft^2
Cd drogue chute	0.8700	drag coefficient
Sref drogue chute	7.0686	reference area drag, ft^2
Sref for pre-ignition chute	9.6211	reference area drag, ft^2
Cd for pre-ignition chute	1.0000	drag coefficient

Figure 8 - Parachute Parameters.

## 2.6. Stages

The next tables are those pertaining to thrust, drag, and weight data about each stage. There are 3 of these tables, one for each stage simulated. The first inputs required are the weight of the structure, payload, and propellant for each stage in Figure 9. The thrust table in Figure 10 is composed of two input columns. One is for time from ignition and the other is for sea level/vacuum thrust. These values are obtained from the motor manufacturer, test or thrustcurve.org in Figure 11. An alternative source is the NAR data base at National Association of Rocketry website<sup>6</sup>. It is important to realize that the motor manufacturer will always give thrust at sea level, not vacuum. It is the responsibility of the user to input the correct thrust. The other columns are calculated values and need not be modified. See figure below for reference.

<sup>6</sup> www.nar.org

### Stage 1 (1st rocket section)

Parameters	Value	Value if stage present	Units	Notes
$W_p$	10.0000	10.0000	lb	Propellant Weight
$W_s$	41.0000	41.0000	lb	Structure Weight
$W_{PL}$	10.0000	10.0000	lb	Payload Weight Attached to Stage 1
$t_b$	7.0800	7.0800	s	Motor Burn Time
tdelay	0.0000	FALSE	s	Delay to Fire First Stage Motor
tseparate	FALSE	FALSE	s	Launch to 1st Stage Separation

Figure 9 - Weight Parameters.

The burn time, delay time and separation time are input in the duration column of Phases/Events and Durations Input Table. The motor burn time is obtained from the powered flight duration time. As an example, see Figure 11, for this motor the burn time is 7.08 second. The delay time for first stage exists when the rocket is air-launched. It is the duration time between the aircraft release or separation from a lower stage to the ignition of the motor. The separation time is the time from the lower stage motor burn out to the separation of the lower stage.

Diagram illustrating the flow of data from the Thrust and Drag Data table to the Drag Coefficient table, and finally to the nozzle exit area and total vacuum impulse tables.

**Thrust and Drag Data:**

Thrust and Drag Data	Aero Tech M1939	Is the Input Vacuum Thrust?	Reference
Time,s	Time+ignition	Sea Level/Vacuum Thrust Input, lbs	Vacuum Thrust, lbs
0.0000	0.0000	0.0000	0.0000
0.0500	0.0500	84.7183	120.0593
0.1000	0.1000	169.4365	204.7775
0.2000	0.2000	338.8731	374.2141
0.2600	0.2600	440.5350	475.8760
0.7800	0.7800	476.6100	511.9510

**Drag Coefficient:**

Sref power on phase	0.2131	reference area drag, ft <sup>2</sup>	
Sref coast phase	0.2131	reference area drag, ft <sup>2</sup>	
Mach No.	Power on Cd	Base Press. Coeff.	Power off Cd
0.0000	0.6904	0.0040	0.6907
0.1000	0.4862	0.0052	0.4866
0.2000	0.4619	0.0055	0.4623
0.3000	0.4477	0.0057	0.4481
0.4000	0.4369	0.0058	0.4374

**Nozzle Exit Area and Total Vacuum Impulse:**

Nozzle Exit Area, ft <sup>2</sup>	0.0167	
Total Vacuum Impulse, lb-sec	2542.8346	for corresponding stage
Vacuum Isp, sec	254.2835	for corresponding stage

**Drag data from DRAG COEFFICIENT3.2.xls go here**

Figure 10 - Thrust and Drag Inputs.

The drag tables are to the right in Figure 10 and require three inputs: Mach number, power-on drag coefficient, and base pressure coefficient. These inputs can be tabulated using Excel file, DRAG COEFFICIENT3.2.xls, from website<sup>3</sup>. DRAG COEFFICIENT3.2.xls contains codes used to estimate sounding rocket zero lift drag coefficients. Ideally, the aerodynamics group will provide them but more often than not they will only provide power-off drag as a function of Mach, and the base pressure. To obtain the power-on values simply work backwards using the equations in the Power of Cd column as shows below.

$$Cd_{off} = Cd_{on} + Cp_{base} \frac{A_{e-nozzle}}{S_{ref_{on}}}$$

All this comes about due to the way thrust and drag are defined. The pressure area integral is book kept under thrust during burning but is considered part of drag while coasting. It's just subtraction, addition, and some division.

Immediately below the thrust table there are three cells. These are the exit area of the engine nozzle, and total impulse and vacuum Isp. The user must provide the exit area.

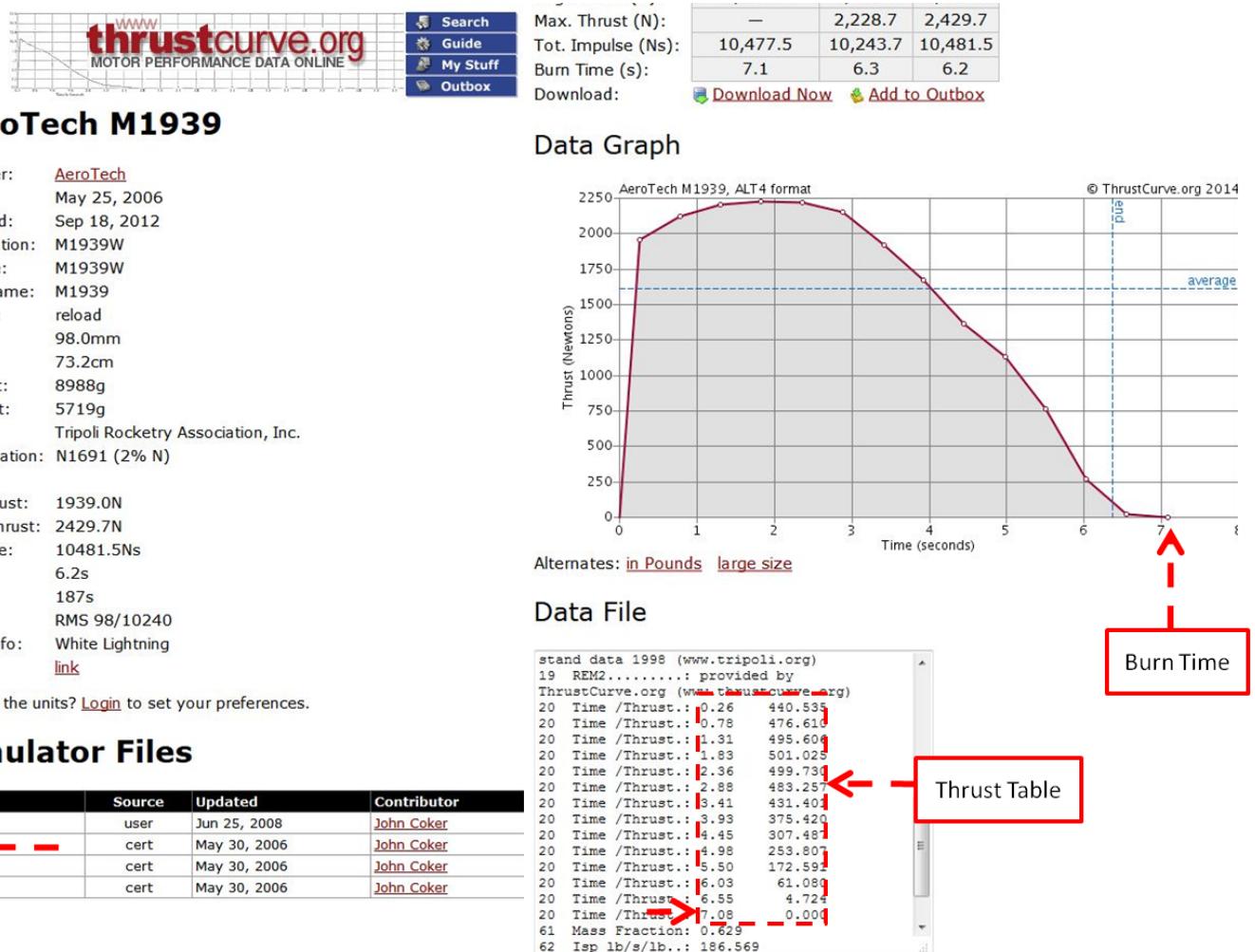


Figure 11 - Data from Thrustcurve.org.

## 2.7. Miscellaneous

The table in Figure 12 summarizes the weight and mass for each stage and at each phase. This table is to help user to re-check their input values and settings before running the program. Figure 13 is the table for the simulation monitor. It helps users track the simulation progress.

**Phases Weight and Mass Data**

Phase	Initial Weight, lb	Initial Mass, sl	Final Weight, lb
1 - First Stage on Coasting Flight	#N/A	#N/A	#N/A
2 - 1st Stage Coasting Stabilization Parachute	#N/A	#N/A	#N/A
3 - First Stage Powered Flight on launcher	61.0000	1.8959	61.0000
4 - First Stage Powered (Free) Flight	61.0000	1.8959	51.0000
5 - First Stage Coasting Flight	51.0000	1.5851	51.0000
6 - Second Stage Coasting Flight	#N/A	#N/A	#N/A
7 - Second Stage Powered Free Flight	#N/A	#N/A	#N/A
8 - Second Stage Coasting Flight	#N/A	#N/A	#N/A
9 - Third Stage Coasting Flight	#N/A	#N/A	#N/A
10 - Third Stage Powered Free Flight	#N/A	#N/A	#N/A
11 - Third Stage Coasting Flight	#N/A	#N/A	#N/A
12 - Coasting on Drogue Parachute	#N/A	#N/A	#N/A
13 - Coasting on Main Parachute	#N/A	#N/A	#N/A

Figure 12 - Weight and Mass Summary.

Monitor	TRUE	Press Esc or Break key to stop the simulation then click End button	
	Current value	Initial	Final
Event/Phase		3 - First Stage Powered Flight on launcher	N/A
Time, sec			0.0000 10006.0800
Mach number			0.0000 N/A
Altitude, ft			1898.0000 1898.0000
Range, ft			0.0000 N/A

Figure 13 - Simulation Monitor.

### 3. Running and Analyzing the Simulation

#### 3.1. Running SKYAERO

Running SKYAERO is very simple. After filling-out every blue-colored cell simply scroll all the way down until you see a rectangle containing two buttons. One is for running the simulation and the other for erasing the old values. Erasing any old values prior to running a new simulation is recommended.

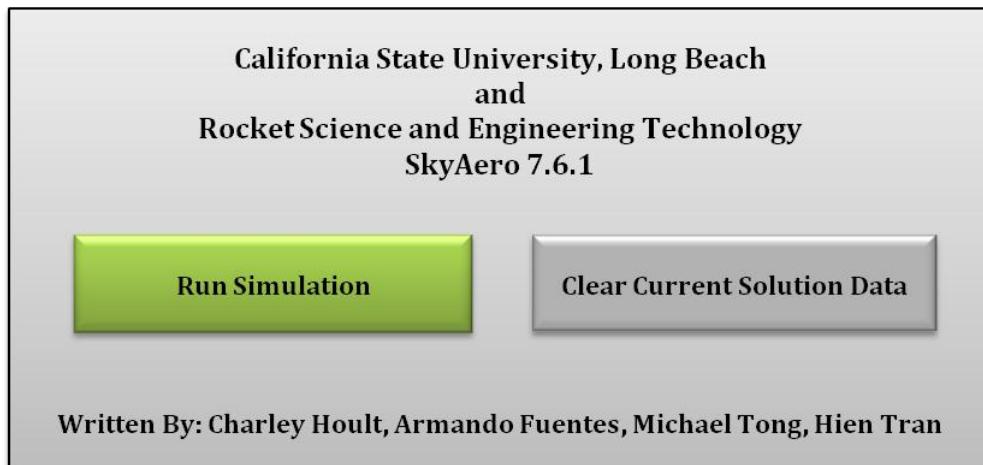


Figure 14 - Simulation Controls.

#### 3.2. Analyzing the Results

The results obtained are stored in a sheet called “Solution”. Here the user will be able to see all the necessary output values at different times and to make sure that at each time the rocket is in the right phase. The values shown are the state vector elements as a function of time after liftoff (TALO): Vertical velocity, inertial horizontal velocity, relative horizontal velocity, range, mass, and altitude. Other results include the initial wind speed followed by a correction factor and then the actual simulated speed. In other words, the simulated speed is the true wind speed after applying a correction factors<sup>7,8</sup>. The user can also look at the flight path angle, acceleration, thrust, drag, Mach number, dynamic pressure, etc.

At the far right, values at critical events are presented. From these columns the user can choose to plot any variables and graphically analyze the results. Some important graphs have already been done and are shown in other sheets.

<sup>7</sup> Hoult, C.P., “Finite Inertia Corrections to the Lewis Method Wind Response”. Aerospace Corp. I.O.C. A79-5435-44, 1979

<sup>8</sup> Hoult, C.P., “Launcher Length for Sounding Rocket Point-Mass Trajectory Simulations”. Journal of Spacecraft and Rockets, Vol. 13, No. 12, Dec 1976, pp 760-761.

### 3.3. Using SKYAERO to Adjust Launcher Settings

SKYAERO has a wind model that can be used to predict the impact point of the rocket. This is a very useful tool but incomplete. The user must next be able to use the code to adjust the launcher angles to achieve the desired impact point. This is done by using the sheet called “launcher angles”. Here the user will run a sequence of simulations and use those values as inputs. First, run SKYAERO at 90 degrees and obtain the impact point due to each wind component. Repeat the procedure, but with zero winds and by varying the elevation angle. Do as many as you like making sure to go between 82 and 90 degrees. The last two inputs are the desired impact locations. Fill those out and you will obtain the necessary elevation and azimuth angles needed to accomplish it. See Figure 15.

From QE = 90°	from SKYAERO	from SKYAERO	from Flt Ops	from Flt Ops	Cross-Plane Wind Compensatory Tilt Angle $T_c$ , deg
Cross-Plane Wind-Induced Impact Displacement, ft	Impact Point Range, ft	Tilt Launch Angle, deg	Desired In-Plane Impact Point Component, ft	Desired Cross-Plane Impact Point Component, ft	
1396	0	0	2000.00	0	-4.598359283
	611.4	2			
	1217.3	4			
	1814.6	6			
	2401.1	8			

from SKYAERO in-plane wind	from SKYAERO in-plane wind	In-Plane Wind Compensatory Tilt Angle $T_i$ , deg	Total Tilt Angle, $T_T$ , deg	Total QE, degrees	True Launcher Azimuth, deg
Impact Point Range, ft	Tilt Launch Angle, deg				
1270.6	0	2.139090909	5.071549863	84.9284501	-65.05282548
1954.1	2				
2284.1	3				
3508.3	7				

Figure 15 – Launcher Settings Input Table.

### 3.4. Using SKYAERO for Other Applications

This section will elaborate on SKYAERO’s ability to analyze rockets launched from other than a static launcher on the ground. This depends on the creativity and the engineering judgment of the user. Some examples for mobile launching are dropping a rocket from an airplane or balloon and launching the rocket from a moving vehicle. SKYAERO can also be used for projectiles, such as dropping supplies from an airplane.

When dropping a rocket off an airplane, initially the rocket is suspended from a small pre-ignition chute to control launch angle and to safely separate rocket from airplane. The way to

use this feature is very simple. Simply type true in first stage on coasting flight and false for the launcher, if appropriate, type true in first stage coasting on parachute. Also, input the altitude,  $V_x$ , and  $V_z$  of the rocket at it releases from airplane. Typically  $V_z$  will be zero since the airplane will likely be moving horizontally.  $V_x$  will be the speed of the airplane unless an initial boost is given to the rocket. The altitude must be the MSL value at which the rocket is dropped.

Singular perturbations are used at ignition. This is done by assuming a small launch rail length, 3 inches or so, and calculating a simulation launcher length based on the pitch/yaw wave number. This procedure will fix the flight angle of the rocket until it has enough vertical acceleration and speed to move upwards. If this is not done, the velocity in the vertical direction will be negative after launching and the new flight angle values will also be negative, meaning the rocket will head into the ground. This phenomenon is due to the point mass assumption, and which cannot simulate the rotational effects of the vehicle. To get accurate results, the user must use the correct pitch/yaw wave number, which will reflect the rocket deployment altitude (as a function of density).

Another use for this feature is that of a rocket being launched while suspended from a balloon. This has, in fact, been done many times starting with the Rockoon project in the early 1960s. The simulation would simply use a very high launch altitude (think Mt. Everest) and a zero length (maybe 3 inches) physical launcher rail length. The singular perturbation additional rail length that's already in the code will keep things going ok, as when launching while descending from a parachute.

These are two examples of some options that SKYAERO can simulate. The analyst must keep in mind the limitations and advantages of the code and as such apply some sound engineering judgment to the results obtained.

## 4. FAQ

Q: I do not have as many Thrust-Time points as the table allows.

A: *No problem! SKYAERO will run the simulation based on what the user can provide (similarly for the drag-mach table).*

Q: I do not know the temperature or altitude of the launch site?

A: *Search the values on the internet or simply assume a standard value of 85F and 4320 feet for Utah. Or, assume a Standard Atmosphere value of 59°F at sea level*

Q: How does the Standard Atmosphere pressure compare with that in SKYAERO?

A: *Except at sea level the pressure in SKYAERO at any given altitude will not be in agreement to pressure in Standard Atmosphere table so don't panic.*

Q: I run SKYAERO and Excel stops working, what am I to do?

A: *Some people have encountered problems with SKYAERO and Excel. This was mainly due to the operating software, in this case Windows Vista. SKYAERO has run in Windows XP, Vista, and 7 satisfactorily, but as always, Windows Vista seems to conflict in some rare instances. If this occurs just do what you can and attempt to run the code directly from visual basic editor.*

Q: Can I modify the source code?

A: *Sure, simply access visual basic editor and add or delete any appropriate content.*

Q: Is the program susceptible to float point errors?

A: *It was discovered that sometimes Excel had trouble with the increments in time, which often resulted in numbers such as .0500009990000. These errors would make it difficult to locate certain time dependant events. The best solution is to round the values down to whatever accuracy the user wants. This was done for the time vector and it satisfactorily fixed the problem.*

Q: How do I compute the pitch/yaw wave number, and why does it matter?

A: *Go onto rsandt.com website, select reports and go to Pitch-Yaw Wave Number section or search for it (ctrl+f). It's important to an accurate simulation when the rocket is moving slowly right after ignition. The errors in the instantaneous head-into-the relative wind may be approximately corrected with singular perturbation solutions whose independent variable uses the Pitch-Yaw Wave Number.*

Q: How do I find the burn time?

A: *Go to the thrust-time table or graph in Figure 11, and lookup the time when thrust goes to zero.*

Q: What are the requirements to run SKYAERO?

A: *The requirements are the computer with minimum Excel 2003, the understanding of a rocket's flight, the creativity and the engineering judgment.*

Q: What are other tools need for SKYAERO? Can SKYAERO be used without them?

A: *The two tools are WIND CALCULATOR.xlsx and DRAG COEFFICIENT3.2.xls. The can be found on rsandt.com. SKYAERO can be run without the above tools with the user provide their own wind profile and drag profile.*

Q: How can I make sure the solutions are valid?

A: *First, the user needs to run a validation with a simple test case. This test case can be from a published data or a conducted flight test.*

Q: I encountered an error. What does it mean? What do I do?

A: *Sometimes when an input value is incorrect Excel will display error message. Most of the time, it is an overflow error or division by zero error. It will most likely be a function evaluating a division by zero value or Excel not working fine. To fix this problem make sure your inputs are corrected and make sense, and then re-run Excel.*