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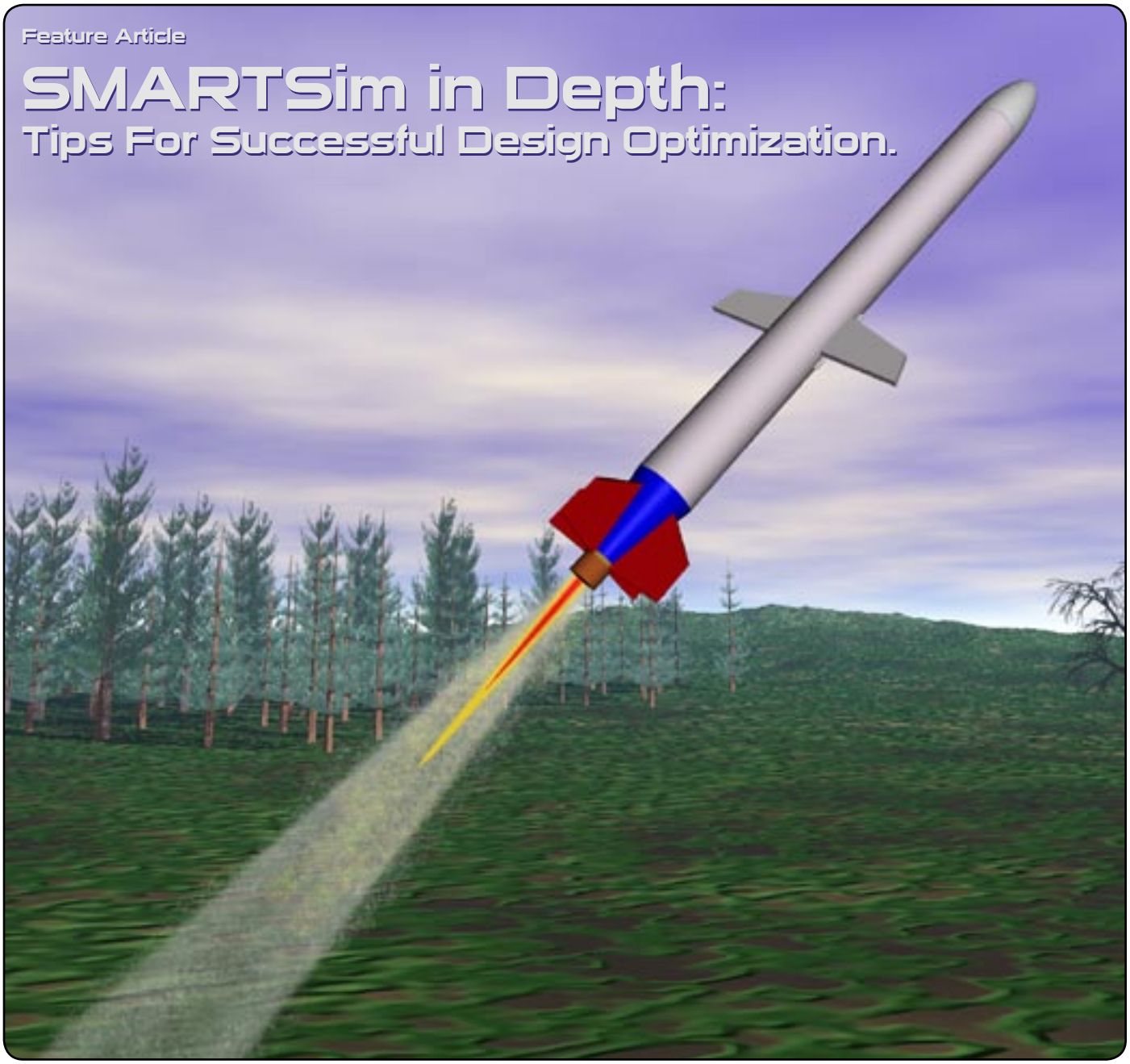
Feature Article

SMARTSim in Depth:
Tips For Successful Design Optimization.



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SMARTSim In Depth: Tips For Successful Design Optimization

By Kenneth J. Karbon

Introduction

In a previous issue of the *Peak of Flight Newsletter* (http://www.apogeerockets.com/education/downloads/Newsletter130.pdf), an overview of SMARTSim software was given along with a couple basic applications. This article is geared to power users of RockSim and SMARTSim and will go into more detail on the features, strengths, and limitations of the codes. Additional examples and tips for efficient and successful SMARTSim usage are also provided.

Know Your Limits

First of all, what do you want to achieve in your rocket design? SMARTSim gives you three options:

1. "Desired" solves for the input that produces a known or desired value in the response. This is also known as "backtracking", "goal seeking", or "root finding."
2. "Maximize" finds the input to produce the largest local value in the response. Optimum mass is a prime example.
3. "Minimize" finds the input to produce the smallest local value in the response.

The solution you are trying to achieve must exist in the "design space." The choice of rocket, engines, delays, weather conditions, and etc. all dictate the limits of the RockSim solution. You must have some intuition about the values you want to optimize or backtrack before you use SMARTSim to zero in on the answer. Some simulation results will converge nicely, while others are simply impossible.

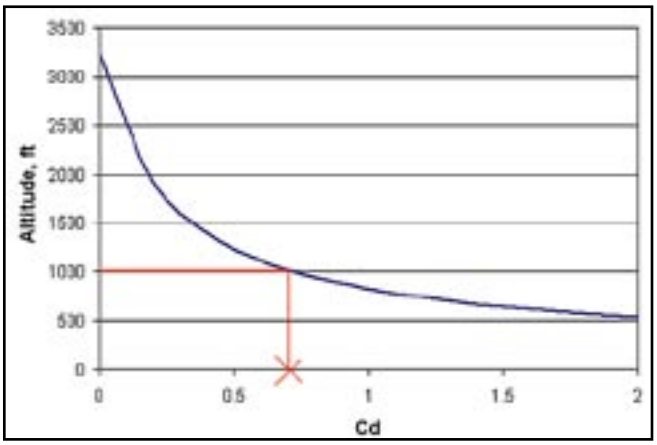

Figure 1: Altitude vs. Cd. The backtracking solution to 1000 feet is around Cd = 0.7.

Consider the classic backtracking example from the previous article. Figure 1 shows a graph of altitude vs. drag coefficient for a given RockSim design. Achievable altitudes in the simulation are essentially between 500 and 3200 feet when varying C_d. If you seek a desired altitude of say 4000 feet, SMARTSim will try to find it, but it will likely converge to a meaningless result, like a negative C_d. SMARTSim (or RockSim running in the background) could also diverge to a very large or very small number.

Also note that the graph has no optimum value. If you tried to Maximize or Minimize altitude versus C_d in SMARTSim, an error message would appear saying that a solution could not be bracketed. That is because SMARTSim searches for "local" minima and maxima, meaning a peak or valley must exist in the function. Figure 2 shows a good example of an optimum launch angle that finds the maximum altitude. Keep in mind that the design space may include several maxima/minima (including small "wiggles"), but SMARTSim can only find one at a time.

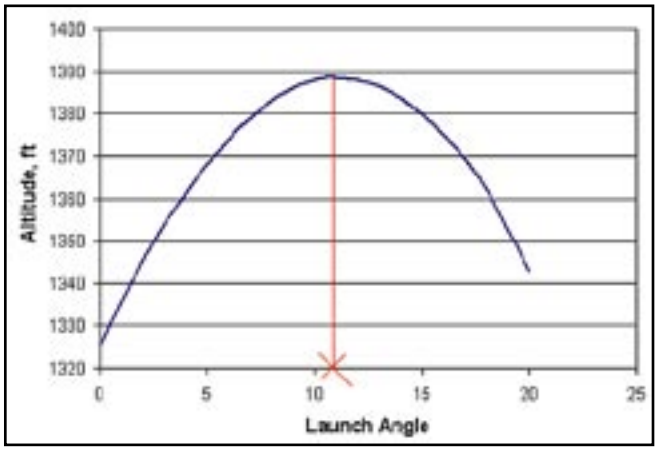

Figure 2. The optimum launch angle for maximum altitude is around 11 degrees.

SMARTSim treats RockSim as a "black box" by calling it as a subroutine. It does not know beforehand the functional form of the input and response. The proceeding figures are among thousands of possibilities. In equation form, the RockSim "function" can be written this way:

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y = ROCKSIM(x)

Where x is the input and y is the response.

For a given simulation, no solution may exist, or many solutions may exist, depending on what you ask for. Figure 3 shows potential functions and SMARTSim outcomes.

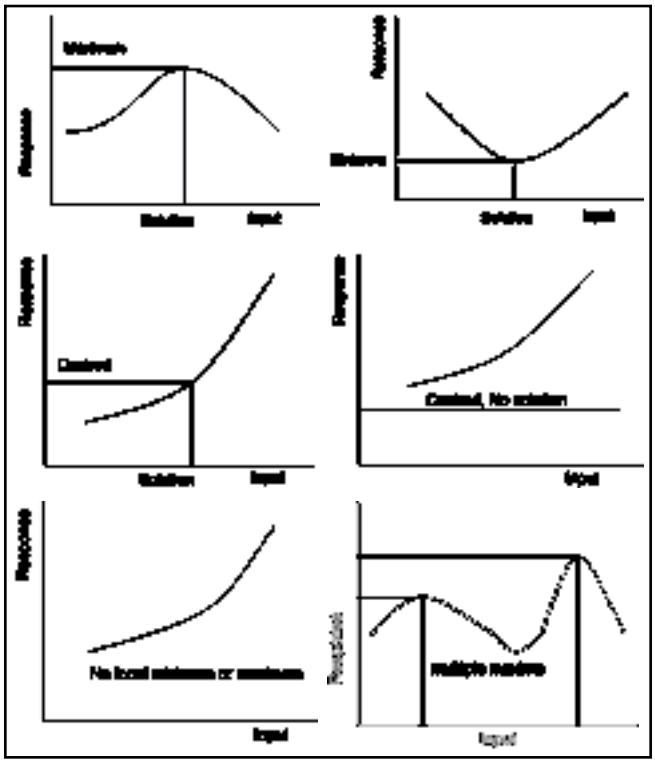

Figure 3. Possible outcomes from SMARTSim, depending on the input/response functional relationship.

Lastly, understand the differences between Desired, Maximize, and Minimize as they pertain to RockSim simulations. For example, if you want "on the pad recovery", you may think to "Minimize" landing range with launch angle. Actually, the correct choice is a "Desired" range of zero. The reason is that RockSim calculates positive and negative range from the launch pad. There is no valley in the function. See Figure 4.

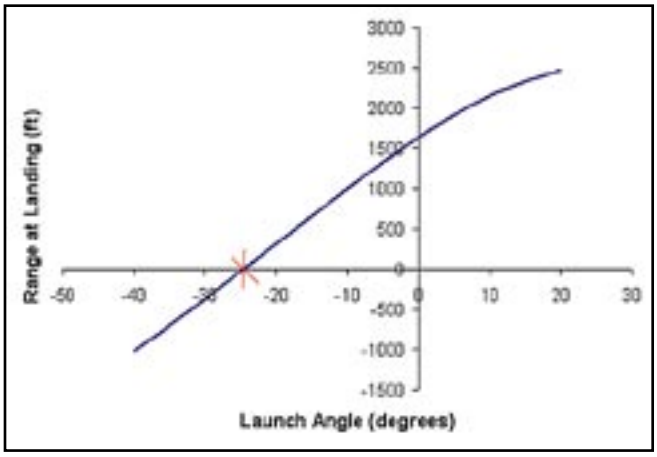

Figure 4. A desired landing range of zero ("on the pad recovery") is achieved with launch angle = -25 degrees

SMARTSim Numerics

In the previous figures, I manually generated the data from RockSim. I first ran some simulations to figure out the range of values to capture a solution. I then changed the input variable in small increments to make a smooth curve. For each new simulation, I modified the input in the RockSim GUI and retrieved the result from the simulation details, writing all values on a piece of paper. Finally, I typed in and plotted the data in a spreadsheet to find the solution. This process was repetitive, time consuming, and prone to mistakes.

Luckily, SMARTSim does not operate in this brute force manner. If it did, the software would be called "DumbSim." Instead, it uses efficient numerical methods to zero in on the solution with a minimum number of calls to the RockSim simulation solver. You do need to provide initial "Upper" and "Lower" guesses to start the process, but more on that later.

When solving for a "Desired" value, SMARTSim offers two root finding algorithms as shown Figure 5. The Secant Method is best for smooth, well behaved functions (altitude

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vs. drag, for example) and will converge quickly. If the function is not well behaved, the technique can diverge.

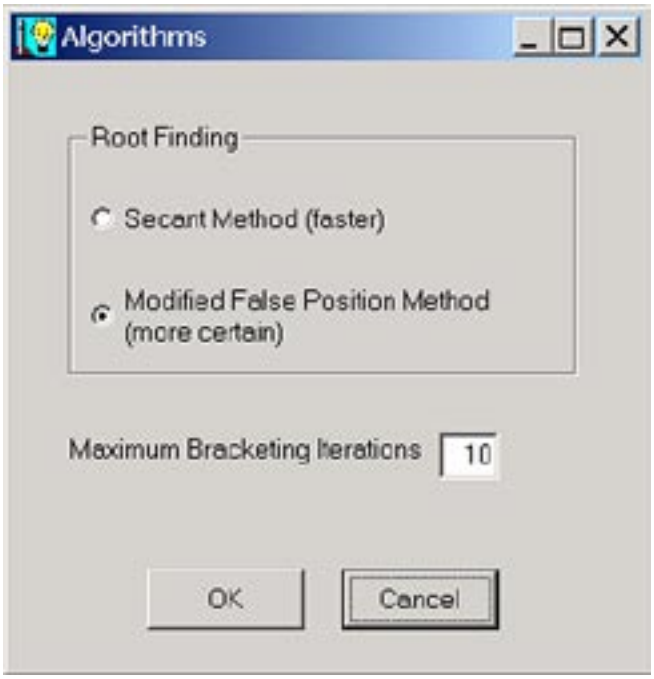

Figure 5. Algorithms menu

The Modified False Position Method is more certain because it first tries to roughly "bracket" the solution and keeps it bracketed throughout the iterations. This "safer" method will usually converge more slowly to the final result.

There is only one algorithm for "Minimize" or "Maximize", but the same bracketing concept applies. The bracketing operation expands outward from the initial guesses and tries to identify if a solution is possible. If it is, then the iterations kick in and the algorithm marches to the precise solution. If no solution is bracketed, SMARTSim will stop and give a warning. The bracketing tries are adjustable, but the default of ten is usually plenty. Evaluation of the initial guesses and the bracketing operations occur during iteration "0" as in Figure 6.

Getting Off to a Good Start

The software requires two initial guesses for the input variable to start the algorithms. If using the predefined Scenarios, SMARTSim automatically places the current value as the "Lower Guess" and some sort of multiple of this as the "Upper Guess". If using a user-defined Scenario, then

Iteration	Input	Response
7	4.807060	2,235.981264
6	4.807060	2,235.981264
5	4.824161	2,235.979458
4	4.762900	2,235.968804
3	3.819660	2,229.714964
2	3.819660	2,229.714964
1	3.819660	2,229.714964
0	-6.180340	0.000000
0	10.000000	2,084.906266
0	20.000000	1,371.608893
0	20.000000	1,371.608893
0	10.000000	2,084.906266

Figure 6. A converged maximizing solution. The initial guesses and bracketing test are performed as "iteration 0" before marching to the solution.

the saved values are entered accordingly. You can edit the guesses at any time prior to launching the calculations.

Carefully consider the initial guesses, because they are crucial to the success of SMARTSim! The default values may not always work for your particular problem. It is wise to choose the guesses to be close to, and bracket, a probable solution. (Recall from the first section of this article that you already have some idea of the result you want to achieve.) Otherwise, the calculations may converge slowly, converge to a non-physical result, or cause RockSim to blow up with crazy numbers. Keeping the upper and lower guesses fairly close together also ensures that the bracketing routine will not overshoot any local minima or maxima and mistakenly tell you that no solution is possible.

The combination of initial guesses and requested result determines the accuracy and efficiency of the SMARTSim solution. Even though the numerical algorithms are robust and can overcome an impractical starting point, it is still smart to keep the initial guesses reasonable and realistic. Cd

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guesses of 0.0 and 1.0 are much better than –100 and 100.

A Strong Finish

SMARTSim is an iterative procedure, so it needs to know when to stop calculating. Use the radio buttons in the "Convergence Criteria" frame to select which variables are monitored during the solution. For root finding to a desired value, choose the "Input Variable", "Response Variable", or "Both." The solution will stop if the change from one iteration to the next or bracketing interval is less than the tolerance(s) specified. Choosing "Both" is a more precise way of generating a solution but may require more iterations to converge.

For Minimization/Maximization, only the Input variable is monitored. The tolerance in the text box is considered a fractional value that is then multiplied by the input variable, so it is wise to keep this number fairly small (typically smaller than the needed tolerance for root finding). In theory, this number can be as small as the square root of the computer's machine precision (about 3E-08 for the double precision floating point operations of RockSim and SMARTSim). If the tolerance is too large, the solution will converge without reaching the "true" minimum or maximum.

Please note that these are "absolute tolerances", meaning they have the same units as the variables. Again, knowing the approximate range of answers is very important. Depending on the desired level of accuracy and choice of units, the user may wish to change the default values. If you get the same answer with smaller and smaller tolerances, then a precise and unique solution has been found.

SMARTSim is also stopped if the "Maximum Number of Iterations" is reached. This parameter acts as a safety check to stop the calculations if SMARTSim oscillates or the user specified impractical convergence criteria. The default value is 20. Most well posed, root finding problems will converge to within several significant digits in 10 iterations or less. Minimization/maximization may take 20+. If you are uncertain of the relationship between the input and response variables, then set this value to a smaller number (even zero) to see the simulation trend. Increase the number again when you are ready to converge to a desired solution.

A Good Example From A SMARTSim User

The following case summarizes some of the key issues in this article. A user reported to me that he was having trouble with SMARTSim while attempting to optimize fin semi-span to maximize altitude. I also struggled with a solution until I thought more carefully about the limits of the simulation and the initial guesses.

I went back to RockSim and tinkered with the fin size. With very small semi-span (0.1 inches), the rocket went unstable and crashed after achieving a low altitude in the simulation. (The 2D flight profile in RockSim was key in recognizing this result.) I then changed the semi-span to a very large size (30 inches). The result was a model with high drag that achieved another low altitude in the simulation. See Sims 0 and 1 in Figure 7.

The solution was now bracketed with two low altitudes, so an optimal value had to lie somewhere in between! I turned the problem over to SMARTSim for the fine-tuning. Using the big and small fins as initial guesses, the software found a maximum altitude of 1509 ft using an optimum semi-span of about one inch as in Figure 8. Sim number 2 in Figure 7 shows the result confirmed again in RockSim. This example illustrates the importance of understanding the RockSim simulation, bounding the solution, and giving good guesses to SMARTSim.

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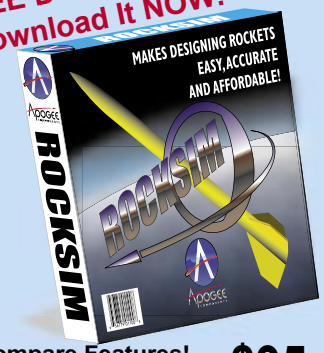

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Helpful Hints

Sim #	Engines loaded	Max. Altitude (Feet)	Comments	Results
0	[E15-7]	98.64	small semi-span, unstable	
1	[E15-7]	604.01	large semi-span, high drag	
2	[E15-7]	1510.82	semispan = 0.98 in (calculated by smartsim)	

Figure 7. RockSim simulations with small fins, big fins, and optimum fins

This article concludes with some tips to alleviate common problems and make your SMARTSim solutions more efficient and accurate.

1. When using old or unfamiliar designs with SMARTSim, first open the rkt file in RockSim and "recalculate all simulations." Save the file to ensure that all the features and formats are up to date with your latest version and preferences. In the SMARTSim Settings menu, verify that the RockSim console executable also reflects the same version.

2. If your are not interested in landing conditions, then end the RockSim simulation at apogee or when the recovery device deploys. Otherwise, unnecessary descent computations will take place during the SMARTSim iterations and slow down the solution.

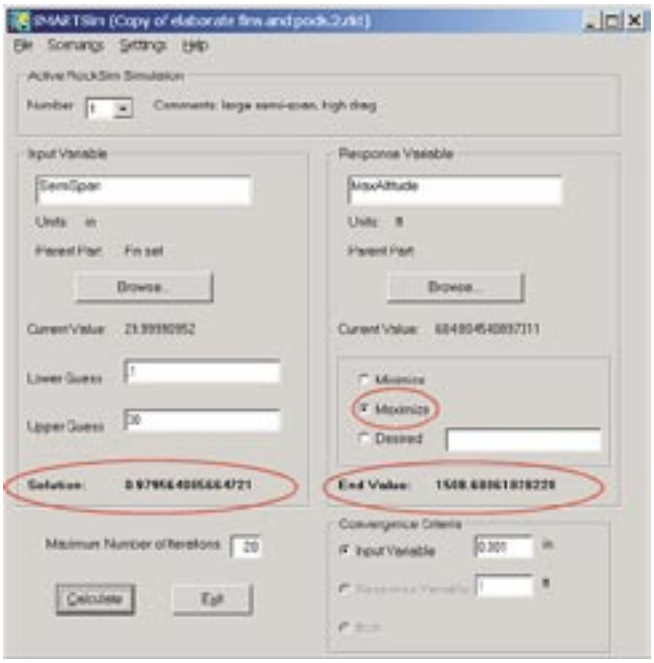

Figure 8. SMARTSim solution to optimum fin size for maximum altitude

3. When using mass variables, be sure to use the mass override feature either on the entire rocket or a component of interest. This disables the RockSim automatic mass computations and gives SMARTSim a fixed number to work with.

4. Often when you verify a result in RockSim using a solution from SMARTSim, the answer is not exactly the same. This is because the SMARTSim calculations use all 15 digits (double precision) that may be stored in the XML rkt file. By contrast, the RockSim GUI text boxes accept a limited number of digits.

5. SMARTSim acts on just one set of simulation results in the rkt file. Make sure the "Active RockSim Simulation" is set to the appropriate number.

6. In RockSim version 7, variable launch conditions and competition settings are present. These features can alter the simulation data in random fashion. Rerunning identical simulations can lead to different results each time. Since the physics, equations, and results are not constant, SMARTSim may have difficulty in converging to one answer. To avoid non-convergence, set to zero (or constant values) all the adjustable wind and thermal parameters in the launch conditions of RockSim. Also uncheck the random competition settings. Alternatively, increase the convergence criteria for the input and response variables in SMARTSim.

7. The Scenarios automatically search through the rkt file to find the "correct" variables to describe an event. If the variable is a part characteristic, the scenario will search for the first occurrence of the part name. By default, RockSim will use repeated, generic names for parts, which SMARTSim cannot distinguish. To use your own scenarios effectively, you should give unique names to the parts of your model, such as "Front Body Tube", "Drogue Parachute", or "Nose Mass." Use these names consistently in all design files so that your SMARTSim scenarios are universal.

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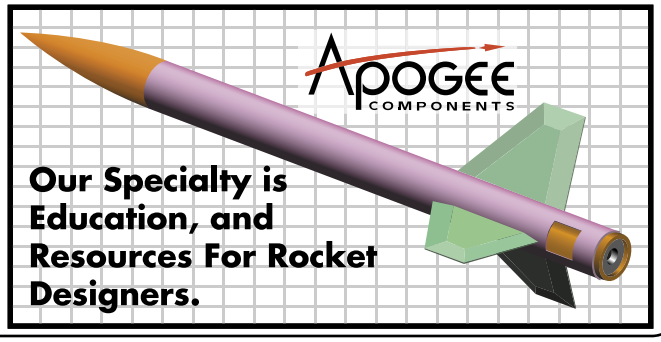
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