



PEAK OF FLIGHT

N E W S L E T T E R

In This Issue

***The Top 5 Reasons
Why Your Altimeter and
Computer Simulations
Don't Agree***

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The Top 5 Reasons Why Your Altimeter and Computer Simulation Don't Agree

By Ken Karbon

Subtitle: And why you shouldn't worry about it

This article is an attempt to consolidate answers to the oft-asked question: "How come my altimeter measurement doesn't match my simulation?" Responses in the rocketry forums tend to coalesce around a few good suggestions as well as debates about simulation software A vs. simulation software B. I will try to avoid specific software features and instead focus on typical pitfalls that affect all simulations, flights, and correlation attempts.

Tim Van Milligan addressed some of these issues many years ago in previous *Peak of Flight* newsletters:

Maximum Simulation Accuracy - Part 1 (www.ApogeeRockets.com/education/downloads/Newsletter45.pdf)

Maximum Simulation Accuracy - Part 2 (www.ApogeeRockets.com/education/downloads/Newsletter46.pdf)

This article will provide an update to those articles with more examples and analysis. There is a wealth of flight data from today's altimeters and simulations, but for simplicity, I will focus on the quantity most everybody seems to monitor – maximum altitude.

From personal and professional experience, I know a little bit of what is going on behind the scenes in the rocket simulation hobby software. I wrote my own flight solver to compare with commercial codes. I also wrote the RockSim optimization add-on called SMARTSim that was sold by Apogee Components a few years ago (it is no longer available). The guts of the numerical simulations are pretty standard and follow well-established computer algorithms to solve the differential equations of rocket trajectory. With computers to do the iterative work, there is no need to use the simplifications of years ago, like constant values for thrust or drag.

Where things go awry are the inputs to the simulation (some the user can control, some he really cannot), the more complex internal models (like drag coefficient) and, importantly, the vagaries of real life flight performance. There is so much variation in all this that it is nearly impos-

sible to match sims and flights with much consistency. I hope this article will help set realistic expectations by way of simple examples. I ran across all of these problems at one time or another in my quest for perfect predictions.

Following are my "Top 5 Reasons Why Your Altimeter and Simulation Don't Agree." They are arranged in the order of what the typical rocketeer has the power to control (lowest to highest). Also, I give some suggestions for what can be done to improve the comparison, if at all possible.

Motor Data Files

You got a motor file from the internet. It must be correct, right? Nope. Motor data files (thrust curves) are found all over the place. They come installed with the simulation software. They are found on the manufacturers' websites. They are published by NAR and Tripoli. Members of forums share and distribute them. Due to the sheer volume, many are out of date, inconsistent, or flat out wrong. Unfortunately, the rocketeer doesn't even know it most of the time.

I was working on a correlation problem and wanted to make sure I was using the best available motor data. So, I went to www.Thrustcurve.org, which is a fantastic resource maintained by John Coker and Mark Koelsch and used by many rocketeers. I searched for the motor, and several data options appeared.

Four files were available for download, each of a different simulator format. The file formats may be different, but the data is the same, right? Or, the newer file is always best, right? Well, not in this case. Figures 1A and 1B on the next page show the most recent thrust curves for the same motor given in Format A and Format B. One file is the classic .eng format and the other is the richer .rse format. RockSim can use them both, which is a nice feature when digging into legacy data and motor comparisons.

Whoa. These two profiles are not even close. Just look at the average thrust values: 110N vs. 150N.

Continued on page 3

About this Newsletter

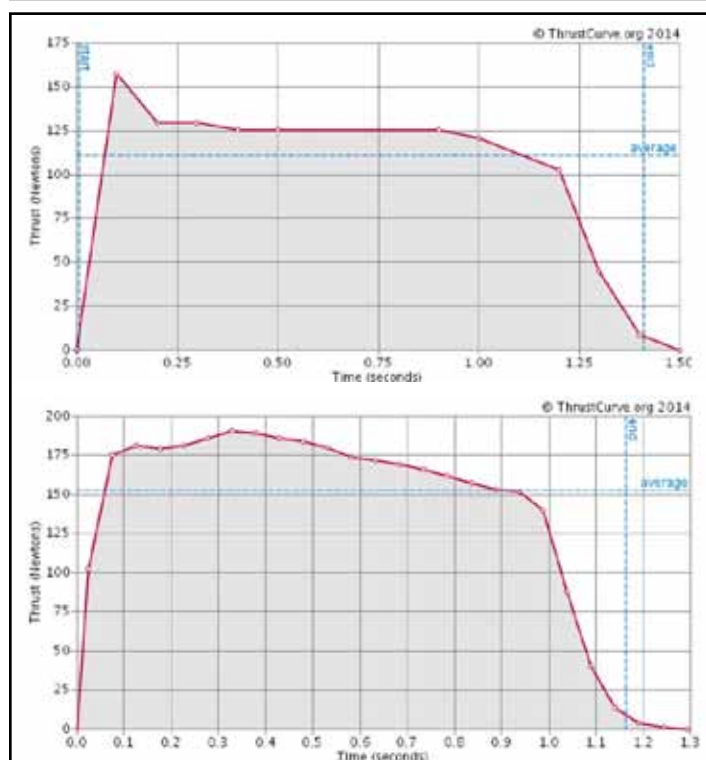
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Continued from page 2

Engine-Driven Gas-Dynamic Stabilization



Figures 1A and 1B above: Motor thrust curves for data Format A and data Format B.

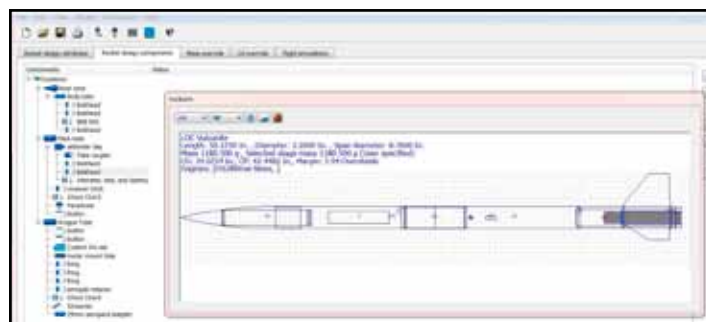


Figure 2: RockSim design file for motor data format comparison.

I plugged both files into RockSim and ran simulations on my dual deploy LOC Vulcanite design file. I created this design file with painstaking care and detail by measuring and weighing every part, adjusting finishes, and futzing with various simulation scenarios as seen in Figure 2.

For a basic 1D simulation, the results are shown in Figure 3.

Rocket	Simulation	Motor File	Max Altitude (ft)	Difference
LOC Vulcanite	Rocksim	Format A from Thrustcurve.org	1840	-
		Format B from Thrustcurve.org	2219	+ 21%


Figure 3: Variation in max altitude due to motor data files.

That's a 21% difference! I racked my brain for days trying to correlate my model with my altimeter. Not until I dug into the motor data did some clues appear about the possible sources of error. The moral of the story is that a bogus motor file will render your beautiful simulation file worthless. Most rocketeers assume the motor file is correct and beat themselves up over the other parameters in the model or criticize the simulation. The software is only as good as the data fed to it, and the motor data is most critical.

What can you do about it? Not much, unless you have your own motor thrust test stand or you scrutinize every single motor file in your database for accuracy. Since that is impractical, you just have to trust that the file author input the data correctly.


There is a way to quickly check motor file consistency. In this case of conflicting data for the same motor, I looked for some certification information. The Thurstcurve tool (again, awesome) reports that the official, certified impulse should be 172.9 N-s. Format A calculates to be 155.8 N-s,

Continued on page 4



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Continued from page 3

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and Format B is 177.8 N-s. Format B looks more correct.

In today's world of internet openness, collaboration, and sharing, anyone can add, edit, or upload information to a site like Thrustcurve.org. However, that freedom comes with a price. The end user must filter through the vast data and decide which information is best for his application.

Variation of Motor Thrust and Delays

Again from Thrustcurve.org, I searched for the Aero-tech G80. There were five data files to choose from, each with different thrust-time profiles. Hmm. I chose the first one in the list and inspected the NAR data sheet shown in Figure 4.

From the data sheet, you can see that 10 motor samples were fired, and the average and standard deviation

Data File #	Engine	Total Impulse	Max Thrust	Avg. Thrust	Burn Time	Delay Time	Initial Weight	Fired Weight
071125W03	G80-7T	135.2	116.2	73.5	1.762	5.77	127.7	58.7
071125W04	G80-7T	140.5	115.6	78.3	1.704	5.75	127.4	59.1
071125W05	G80-7T	140.3	116.6	81.6	1.679	5.86	127.6	59.2
071125W06	G80-7T	135.4	101.8	77.2	1.691	6.13	127.5	59.4
071125W07	G80-10T	138.1	106.1	78.2	1.693	9.16	127.9	59.2
071125W08	G80-10T	139.9	118.8	76.9	1.748	8.12	127.5	59.2
071125W09	G80-10T	137.1	104.9	79.3	1.684	10.00	128.4	59.3
071125W10	G80-13T	135.4	102.1	77.1	1.706	12.39	129.0	59.5
071125W11	G80-13T	131.5	100.5	76.5	1.665	12.59	129.6	59.8
071125W12	G80-13T	133.0	102.2	77.6	1.681	13.58	129.4	59.9
Average		136.64	108.5	77.6	1.701		128.2	59.3
Std Dev		3.096	7.400	2.080	0.031			
Std Dev %		2.3%	6.8%	2.7%	1.8%			
Range	Indicated	Actual	Actual	Actual	Actual	Average		
7	5.5 to 8.5	5.77	5.75	5.86	6.13	5.88		
10	8.0 to 12.0	9.16	8.12	10.00		9.09		
13	10.4 to 15.6	12.39	12.59	13.58		12.85		

Figure 4: The NAR's G80 data sheet

tion (σ) is given for each motor characteristic. The standard deviation indicates the amount of variation from the mean. 99.7% of the population is expected to fall within plus or minus three standard deviations. The average total impulse of the motor is 136.64 N-s, but it is possible to get an extreme motor that is 9.3 N-s (-3σ) short of that, giving a total impulse of only 127 N-s. Also note that the 7 second delay can range from 5.5 to 8.5 seconds per Aerotech.

These variations result in different performance every time you fly a rocket, even with the same motor. The motor burn may also be affected by temperature, humidity, age, and oxidation, further widening the range of flight results. The following example shows how the manufacturer's motor variability may show up in your altimeter measurement.

I downloaded the motor file and read it into RockSim EngEdit. EngEdit is a great tool to inspect motor data and create new thrust profiles. Consider Figure 5 to be an "average" G80 motor.

I then edited some points to produce a new thrust



Figure 5: Average G80 thrust curve

Continued on page 5

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Continued from page 4

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Figure 6: A -3σ G80 thrust curve. In this curve, the power output has been reduced by approximately 9 N-s.

curve with about 3σ less total impulse and average thrust as seen in Figure 6.

I simulated both motors in RockSim using my Madcow DX3 design file. For the average impulse motor, I picked the delay on the high end, 8.5 s. For the lower impulse motor, I picked a delay on the low end, 5.5 s. Figure 7 shows the results.

Rocket	Motor	Simulation	Impulse (N-s)	Delay (s)	Max Altitude (ft)	Difference
Madcow DX3	Aerotech G80-7	Rocksim	136	8.5 (max)	1621	-
			126 (-3σ)	5.5 (min)	1451	-10%

Figure 7: Effect of manufacturer's motor burn variation on altitude.

The lower impulse combined with a short delay that prematurely stops the coast to apogee results in a rocket flight with 10% less altitude. This is a flight issue, not a simulation issue. Your computer gives the same answer every time.

What can you do about? Again, not much, if you fly one motor at a time. Researchers trying to collect good flight data will average several tests in a short time period and choose motors from the same package or batch to limit variability.

Weather, Wind, and Weather Cocking

Elevation of the launch site, temperature, humidity, and barometric pressure affect the density of the air and Mach

number. The latitude of your launch site affects the gravitational constant. Many simulators allow you to input these values. If you are serious about correlating your sim to the flight, you should measure these values at your launch site or retrieve them from the hourly reports of a weather webpage.

Figure 8 shows the change in simulated altitude by varying the weather inputs one by one across some extreme ranges. The changed parameter from the baseline run is highlighted in blue in the table.

LOC Vulcanite, CTI 1216, RockSim						
Elevation (ft)	% Relative Humidity	Temperature (°F)	Pressure (in Hg)	Degrees Latitude	Max Altitude (ft)	Difference
0	0	75	31	45	5985	Baseline
5280	0	75	31	45	6518	8.9%
0	90	75	31	45	6022	0.6%
0	0	32	31	45	5713	-4.5%
0	0	75	29	45	6224	4.0%
0	0	75	31	0	5989	0.1%

Figure 8: Effect of weather parameters on the sim.

Humidity and latitude have minor impact on this model. The others have a noticeable effect and are worth getting right in your simulation. The weather can also change the burn of motors. To the best of my knowledge, hobby sim software doesn't comprehend that when computing on the thrust curves.

Simulation software allows for wind and launch angle, turning your 1D flight into 2D or 3D. Launch angle is easily measured with an inclinometer. You can measure wind at the ground and input it to your simulation, too. However, the real world wind boundary layer and winds aloft are not so easy to determine. What you feel on the ground is not the same as what is happening up in the air. Even if you had these detailed wind profile measurements from a reporting station, most hobby software that I know of can't deal with it.

Continued on page 6



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Continued from page 5

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We have all seen rockets that flew arrow straight on one day take a hard turn off the rail on another day. Perhaps they were hit with a wind gust. You can't predict the instantaneous environmental conditions from Mother Nature.

Figure 9 shows the effects of wind and angle on a simulation. I think most of the software under predicts the amount of weather cocking, horizontal range, and altitude loss with non-zero launch angle or non-zero wind. I don't have a lot of data to prove this, but many anecdotes from my own experience.

Rocket	Motor	Simulation	Wind (mph)	Launch Angle (degrees)	Max Altitude (ft)	Difference
LOC Vulcanite	CTI I216	Rocksim	0	0	5985	-
			15	0	5847	-2.3%
			0	15	5584	-6.7%

Figure 9: Effect of wind and launch angle on altitude.

Drag Coefficient

Everybody knows that C_d is critical for simulations. You usually need to rely on other people to figure it out for you, unless you have access to a wind tunnel (See *Peak-of-Flight* newsletter Issue #345 - *Exploring Rocketry Using Research Wind Tunnel* at: www.ApogeeRockets.com/education/downloads/newsletter345.pdf) or good Computational Fluid Dynamics (CFD) models to measure it directly. Drag coefficient can also be backed out from ballistic tests and accelerometer data (see *How to Determine the Drag Coefficient of Your Rockets* in *Peak-of-Flight* Newsletter issue #303, which can be downloaded at: www.ApogeeRockets.com/education/downloads/newsletter303.pdf). You do have some control of this value in simulations, however, mainly by way of the software algorithms that you choose.

I extracted CD vs. Mach number curves from "Software A" and "Software B" for my modified Blackhawk 38. I built both design files as similar as possible and selected "pol-

ished" finishes. After that, I let the native drag coefficient calculators in "Software A" and "Software B" take over and do their own thing. For ease, I chose only the powered-on curves as shown in the following graph. Also included is a line of constant $CD = 0.75$, which is a common default single value drag coefficient used by hobbyists. See Figure 10.

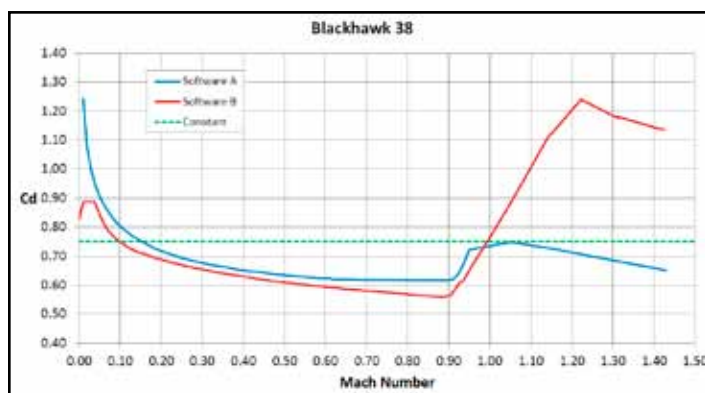


Figure 10: Different drag coefficient models

All is well until Mach 1.0 when the two software diverge wildly in CD prediction. I am not versed in supersonic rocket aerodynamics, so I can't judge which one is more accurate. I am just pointing out the possible variation in the simulation's end result.

To test the impact of these CD profiles while keeping everything else constant, I dug up the venerable wRASP32 program. wRASP has the nice feature of allowing you to input your own drag curve and not rely on a simple constant value or the programmer's hard-coded algorithms. I ran the simulations as seen in Figure 11 on my modified Wildman Blackhawk 38 design.

The max altitude difference due solely to Software A

Continued on page 7



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Continued from page 6

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Rocket	Motor	Simulation	Cd Prediction	Max Altitude (ft)	Difference
Blackhawk 38	Aerotech J570	wRASP32	Software A	14,900	-
			Software B	13,490	-9%
			0.75	13,899	-7%

Figure 11: Effect on altitude due to drag coefficient models

and Software B drag coefficient estimates is almost 10% and will be greater the longer the flight is supersonic.

Rocketeers like to tune the constant C_D such that the simulated altitude matches the altimeter measurement. This is fine, provided all the other inputs (motor file, motor variation, weather, mass, etc.) are simulated exactly as the real flight conditions. This is hard to do, so the backtracked C_D often becomes a catch-all fudge factor for everything wrong in the correlation. Also, the tuned C_D can vary depending on motor, since different motors will put the rocket through different regimes of the C_D vs. Mach curve.

Rocket Mass

Rocket mass has a huge impact on simulations and is completely under your control! Weigh your parts individually and override the default values in the software. Don't forget the contribution from glue, paint, and hardware. It all adds up quickly. Even better, weigh and balance the rocket in flight-ready condition (including wadding, ematches, ejection charges, adapters – everything!) and override the calculated values for overall rocket mass and center of gravity.

Figure 12 is a simplified RockSim model I made of my

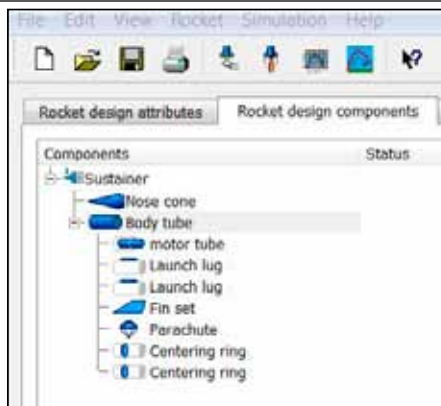


Figure 12: Simplified design file for quick simulations.

Madcow DX3 using construction parts from the data-base. I wanted to do quick altitude checks before the build. The design file includes just enough parts for drag, motor, flight, and recovery prediction. RockSim calculated the mass to be 438 g.

Once I built the rocket, however, it included a Kevlar cord, nomex blanket, motor retainer, swivel, eyescrew, 2-part foam, glue, and paint that were unaccounted for in the original simulation file. There are also likely differences in the part mass or densities between reality and the component database in the software. The real rocket weighs 693 g. Figure 13 shows the impact.

So, before you complain about Brand X simulation, weigh your rocket first. This one is on you!

Rocket	Motor	Simulation	Mass (g)	Max Altitude (ft)	Difference
Madcow DX3	Aerotech G64	Rocksim	438 (approx.)	1604	-
			693 (actual)	1391	-13%

Figure 13: Simulated altitude with approximate and actual rocket mass.

Continued on page 8

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Continued from page 7

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Bonus – Maybe Your Altimeter is Wrong

Physical tests and measurements are not perfect. There is an old engineering saying, “Everybody trusts the test except the guy who did it.” That is because the guy who did the measurements knows the assumptions and limitations of the equipment, but the receiver of the test data usually does not. In my day job, I have the need for particular airflow measurements. The hardware test apparatus, precision, and data reduction are fraught with problems. The CFD simulation is quicker and more accurate. I know the pros and cons of both methods, and for this kind of airflow test, the simulation gives a better result.

I have little knowledge of altimeters or electronics, so I am just speculating, here. Is the \$20 altimeter as good as the one that costs \$300? Does the altimeter that suffers a hard landing or a dunk in the lake work as good as the day it was new? Do altimeters advertised to simply clip unprotected on the shock cord suffer from flight anomalies and pressure spikes? To an electronics newbie like me, these seem like reasonable questions to ask.

For more details on how altimeters work, see Norman Dziedzic’s excellent series of *Peak-of-Flight* articles:

- *How do electronic altimeters work? Part 1* ([www.](http://www.ApogeeRockets.com/education/downloads/newsletter240.pdf)

[ApogeeRockets.com/education/downloads/newsletter240.pdf](http://www.ApogeeRockets.com/education/downloads/newsletter240.pdf))

- *How do electronic altimeters work? Part 2* ([www.](http://www.ApogeeRockets.com/education/downloads/newsletter242.pdf)

- *How Altimeters Work - Part 3* (www.ApogeeRockets.com/education/downloads/newsletter257.pdf)

Norman indicates that 5%-10% altimeter error is possible depending on calibration of variables such as temperature.

“Peak Recording” altimeters beep or display the maximum altitude and velocity for quick reporting of the flight performance. However, this doesn’t tell the whole story. Figure 14 shows the potential pitfalls of peak recording altimeters. There is a pressure spike likely due to an ejection event at 9 seconds. Because of the spike, the apogee is reported as 1117 ft. In actuality, the correct apogee is more like 925 ft. Without scrutinizing the complete time history of the measurements, you can reach the wrong conclusion from your altimeter.

I have a particular altimeter that seems to give MORE altitude than my simulations, no matter what I do to correlate. I diligently input mass, weather, and launch conditions

Continued on page 9

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Continued from page 8

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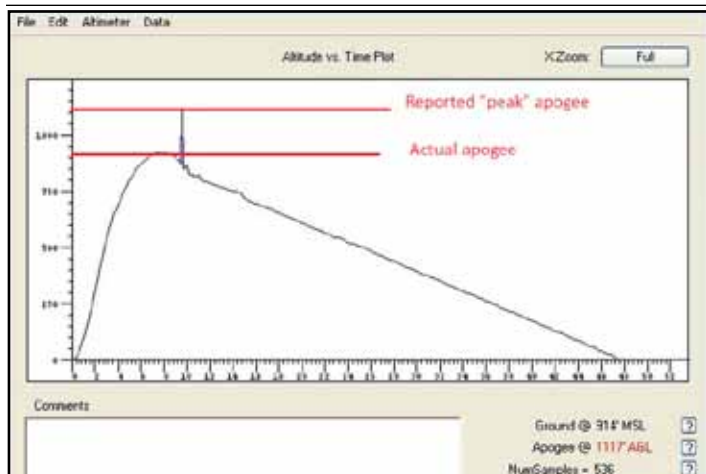


Figure 14: False peak altitude reported by altimeter.
Courtesy of www.rocketryforum.com

to the simulation. Even with the best case rocket finish for lowest drag, the predicted altitude is often less than what the altimeter reports. This is totally opposite to what most hobbyists experience. It makes me feel good that I attained great heights, but I am a bit skeptical of the data!

Upon startup, my altimeter in question measures the local ground elevation and adjusts its altitude calculation from the sea level reference. Where I fly in the Midwest, the launch site elevation is around 600 ft. above sea level. However, the altimeter always says that my launch site is 300 ft. above sea level. That is a 50% discrepancy, and the rocket hasn't even left the pad, yet! I don't know if this is a problem or not during flight, but it seems odd. I am now repeating some flights with different altimeters to see if there is a consistent pattern to this.

Conclusions

This article presents five major sources of error in correlating simulations to altimeter measurements. Variations


can occur on both sides, both in the predictions and in the actual flight data. Much of the variation is really out of the control of most casual hobbyists. Just one parameter error can easily lead to a 10% discrepancy. Get a couple things wrong and the errors compound. So, ask yourself, how "accurate" do you really expect a pre-flight simulation to be?

Computer simulations are a great way to eliminate prototypes and virtually cycle through many parameter iterations before committing to a build. Bad or unsafe designs are quickly weeded out. However, absolute prediction is nearly impossible. Unless you have a lot of R&D time on your hands, striving for better than 10% correlation is a futile endeavor in my opinion. Claims of excellent correlation may also be more luck than reality. I use simulations mainly to get in the ballpark for a safe lift-off velocity, ejection delay, maximum altitude, and drift. These are the answers I need most for a successful day at the launch site. I don't worry too much if the real results don't match exactly.


About the Author:

Ken Karbon is a rocketeer from Michigan. He works in the auto industry, specializing in aerodynamics and CFD simulation.





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Penny shown for size comparison

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