Issue 649 / April 8th, 2025

PEAK OF FLIGHT NEWSLETTER

Apogee Components, Inc. / ApogeeRockets.com / Colorado Springs, CO

Why Your Rocket's Descent Position Might Be Wrong



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COVER PHOTO



Zephyr rockets with different flight paths. Only one is correct.

FEATURED ARTICLES



Why Your Rocket's Descent Position Might Be Wrong

A brief overview on the complexities of altimeter data, and why errors in your data may occur

Apogee Components, Inc.
4960 Northpark Dr.
Colorado Springs, CO 80918
1-719-535-9335
www.ApogeeRockets.com

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Managing Editor: Michelle Mason
Content Editor: Martin Jay McKee
Layout Design: Ogden Sikel

A special, unannounced rocket, launching its first test flight
Pueblo, CO



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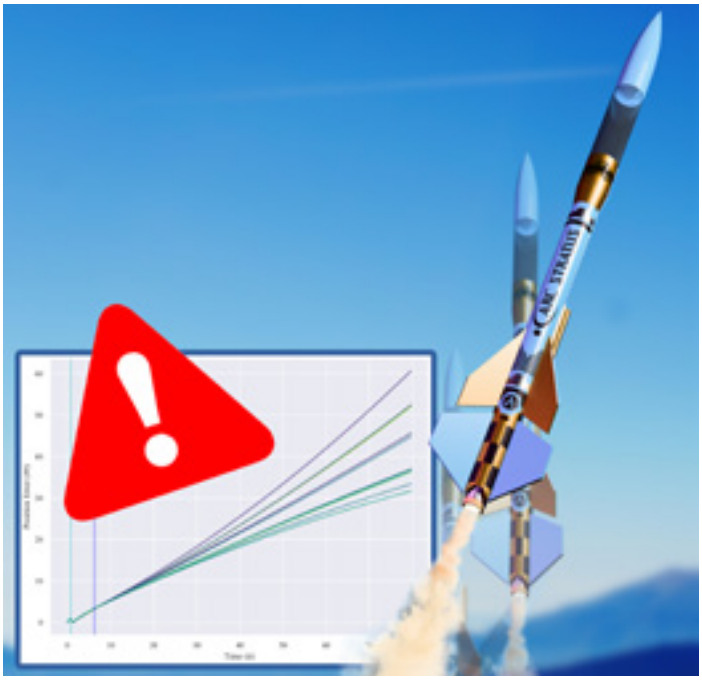
Why Your Rocket's Descent Position Might Be Wrong

Forward by Tim Van Milligan

Martin Jay McKee and I were talking about the reasons that the trajectories in ROCKSIM-PRO, based on the altimeter data from the **PerfectFlight Blue Raven** *(www.apogeerockets.com/Electronics-Payloads/Dual-Deployment/Blue-Raven-Altimeter)* and the **PerfectFlight Blue Jay Plus** (*www.apogeerockets.com/Electronics-Payloads/Dual-Deployment/Blue-Jay)* can look "off." I thought this would make a really great article for this newsletter. And Martin went off and wrote the definitive guide that explains every possible reason that non-GPS devices can give trajectories that "drift" from where they actually landed.

It was probably the best article I've ever seen, but it was very technical. Even a lot of it went over my head. But if you're interested in the technical nitty-gritty, I highly recommend reading that report.

What follows here is a short synopsis that gives you a simplified rendition of the full Technical Publication #30. I do admit that it was generated using an A.I., (including some of the images) but it was edited and massaged over by a human. I really recommend reading Martin's report if you want to go deep and really understand why in some situations, the data from a recording accelerometer on your model rocket may be off.





Want a Deep Dive?

If this topic fascinates you, Martin Jay McKee's article "Error Sources for Inertial Navigation Systems" is a fantastic technical introduction. It explains all the errors we've discussed—and many more—with graphs, equations, and clear explanations. It's a must-read for anyone serious about rocketry avionics.

You can read Martin's in-depth article on this topic here:

www.ApogeeRockets.com/Rocket-Books-Videos/Pamphlets-Reports/Error-Sources-for-Inertial-Navigation-Systems



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Figure 1: Screenshot from RS-PRO showing a replayed flight using data from a Blue Raven Altimeter. Note that the rocket seems to land miles away from the launch pad.



Introduction

Imagine this: your rocket launches beautifully. The motor roars, the air whistles past, and your altimeter logs every millisecond of ascent with impressive precision. You download the data, eager to relive the flight in RockSim-Pro's new **"Replay the Flight"** feature *(www.apogeerockets.com/Peak-of-Flight/Newsletter648).* And everything looks great... until you reach the descent phase. Suddenly, the position drifts far from where the rocket actually landed, and the flight trajectory in RS-PRO doesn't match reality.

That's the mystery many rocketeers face when using flight computers equipped with Inertial Measurement Units (IMUs). These sensors promise to track the rocket's position and orientation using built-in accelerometers and gyroscopes. And, to be fair, they do a fantastic job—at first. But once the parachute deploys, something changes. Errors creep in. The data becomes unreliable. This article explores why that happens, drawing heavily on insights from Martin Jay McKee's excellent deep dive technical report, titled "Error Sources for Inertial Navigation Systems (or Why Is My Flight Data Wrong?)"

The IMU's Promise—and Its Limits

An IMU typically includes three accelerometers (measuring motion in the X, Y, and Z directions) and three gyroscopes (measuring



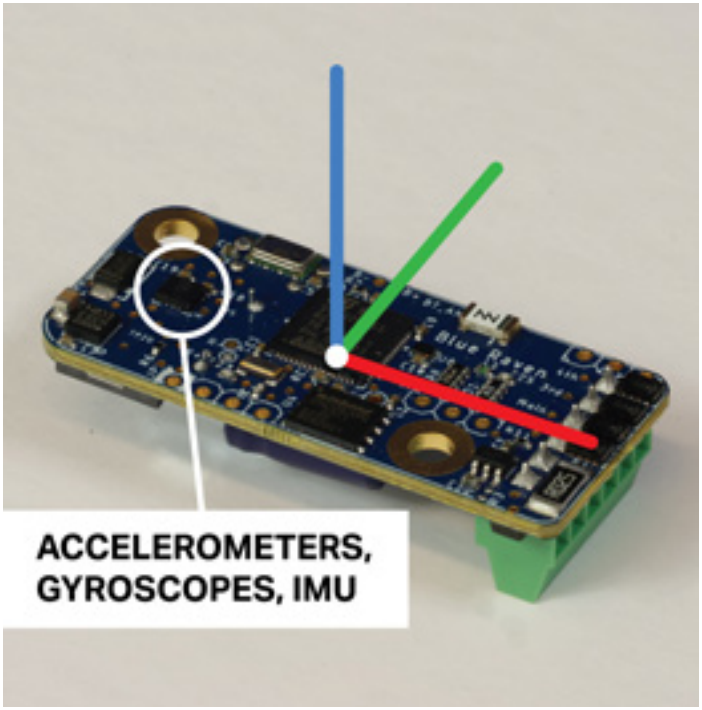


Figure 2: Photo of the Blue Raven, with callouts pointing to the Accelerometer and the Tilt-axis gyros.

rotation around those axes). These sensors allow you to track how your rocket moves and rotates during its flight. The data they provide is used to estimate speed, orientation, and—by integrating that data over time—position.

And that's the crux of the issue: integration. To get from acceleration to velocity, and from velocity to position, the IMU has to sum up tiny measurements over time. If every reading were perfect, this would work flawlessly. But unfortunately, no sensor is perfect, and small errors at every time step begin to accumulate.

Why the Ascent Looks Good

During the boost phase, everything works in the IMU's favor. The rocket is going mostly straight up. The time is short—maybe just a few seconds. The orientation doesn't change much, and the accelerations are strong and consistent. In this environment, even though the IMU has some inherent imperfections, they don't have much time to affect the results. In Martin's report, he shows that even with typical consumer-grade sensors, the estimated position can stay within a few meters of reality during ascent. That's accurate enough for most hobby needs.

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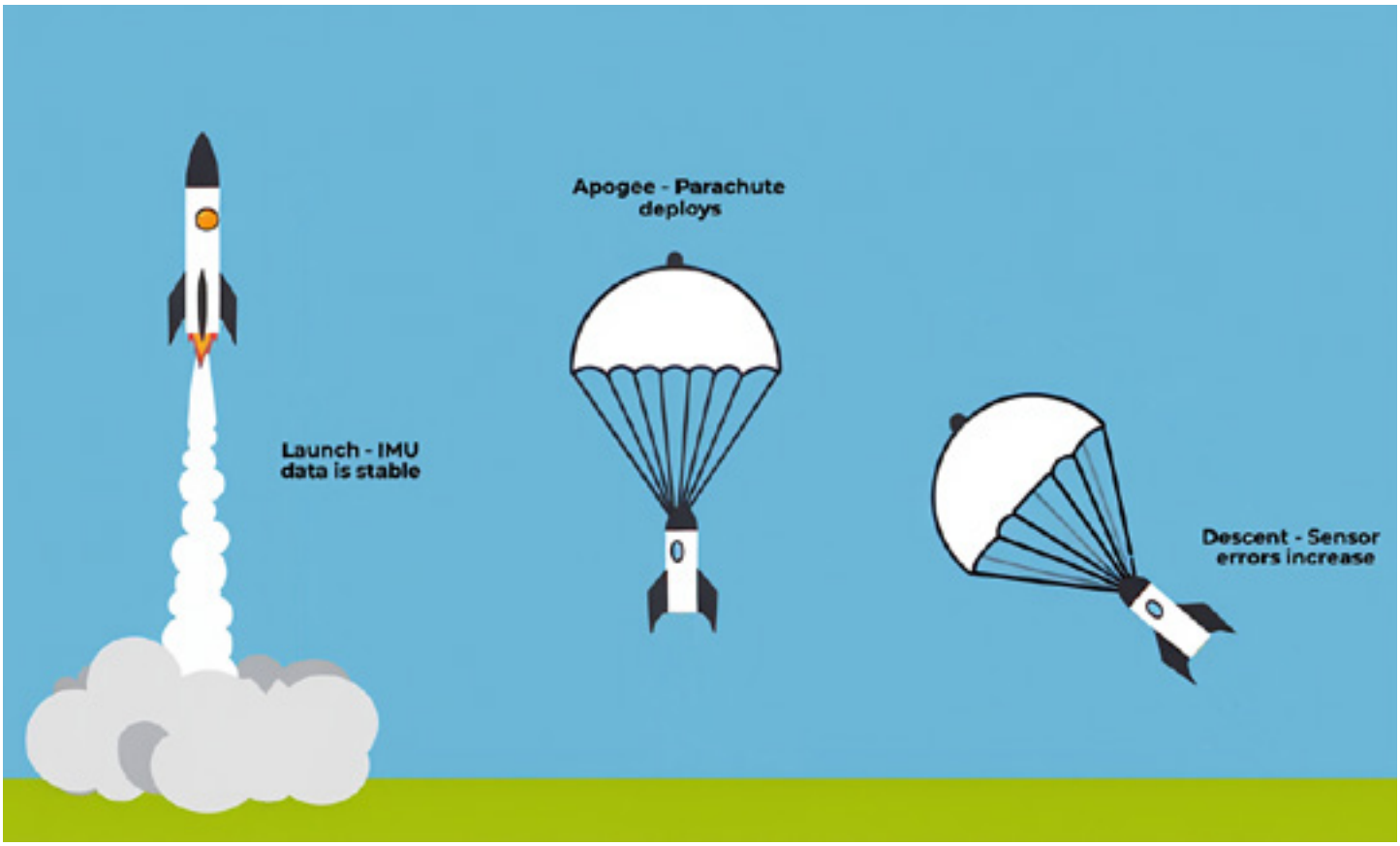


Figure 3: The typical rocket journey: boost phase, parachute deployment, and parachute descent. During boost, the data is stable. But after the chute deploys, we see lots of errors.

Descent: Where It All Falls Apart

Then comes the parachute deployment. The rocket slows down dramatically, and a new kind of motion begins. The rocket swings back and forth, it spins, it bobs in the air. And the descent takes much longer—perhaps 20 or 30 seconds or more. It's this combination of long duration and erratic motion that causes the IMU to lose its grip on reality.

Let's break down some reasons, as explained in Martin's report.

Gyroscope Drift and Bias

Gyroscopes measure how fast something is rotating. But real-world gyros don't return perfect data. Even when sitting still, they often report a small rotational rate—this is called bias. If your rocket's computer thinks it's turning—even when it's not—that error gets added to the orientation calculation every moment of the flight. Over time, this leads to a phenomenon called drift, where the calculated orientation slowly diverges from the true orientation. Under a parachute, when the rocket is actually swinging and rotating, this drift grows even faster.

In the full report, you'll read that even a small bias in the gyro—say, 8 degrees per second—can lead to tens of degrees of orientation error in just 10 seconds. And once the orientation estimate is wrong, then the accelerometer data (which relies on





knowing the correct orientation) becomes unreliable too. In figure 1, which shows the flight path of a rocket using altimeter data, we think that the accelerometer thought the down direction was the wind drift direction. So it calculated that there was a 9.8 m/s acceleration (gravity) pushing it down range. If the electronic device gets confused as to which way is down, you can get some very large drift distances during descent.

Accelerometer Noise and Random Walk

While good, accelerometers are also imperfect. They pick up not just actual motion, but also random vibrations, sensor noise, and even heat-related variations. The accelerometer reads this random vibration as actual motion, even though everything may be rock-steady and there is no parachute swaying. These tiny errors are summed up over time—just like the gyro errors—leading to incorrect estimates of velocity and, eventually, position.

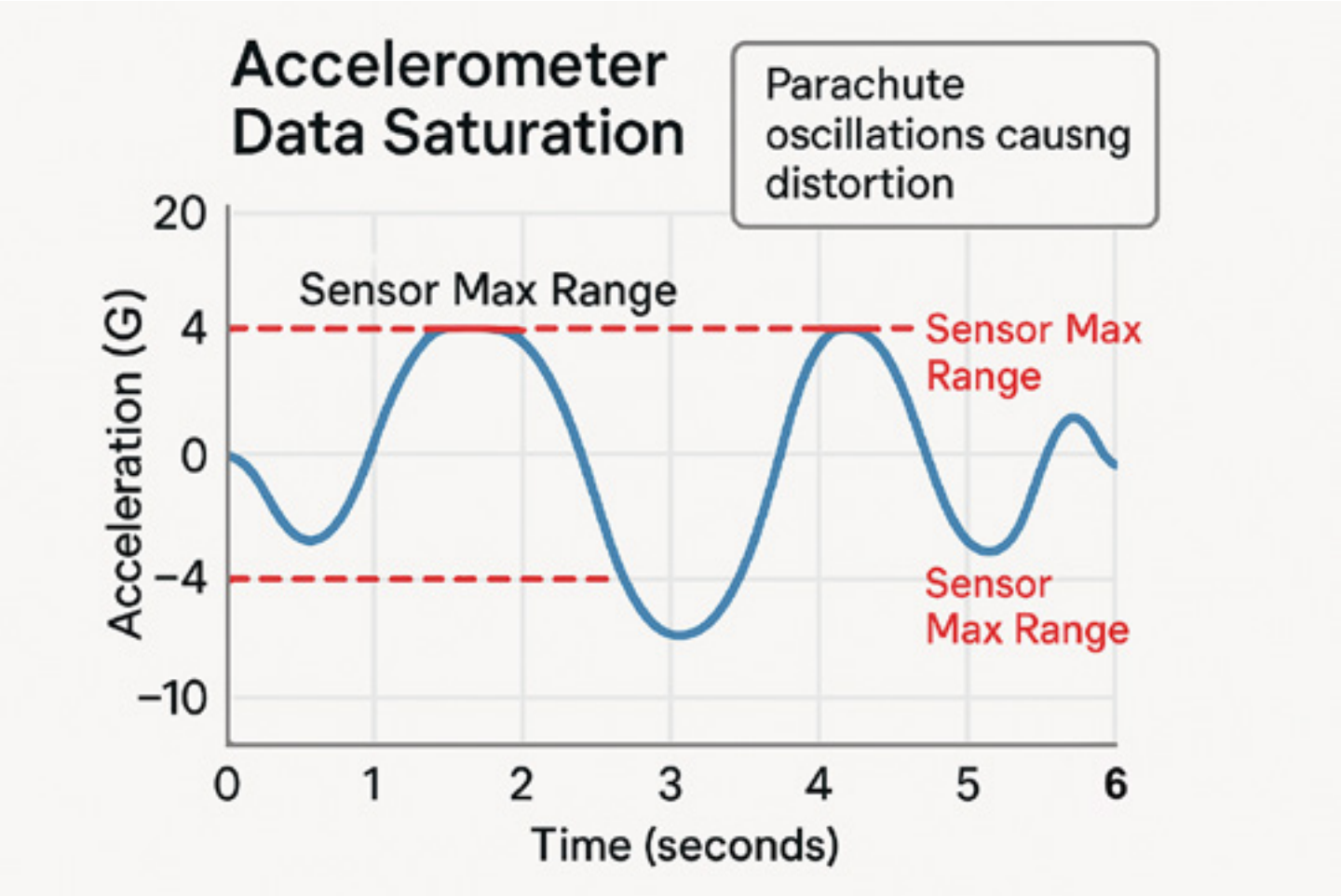
Another sneaky issue is random walk—a type of drifting bias in accelerometers and gyros that slowly changes over time. Unlike a fixed bias that can be calibrated out, random walk is unpredictable and accumulates like a drunkard stumbling in random directions. On a long descent, it adds up.

Integration Error: The Nature of the Beast

Martin's report emphasizes that integration is a double-edged sword. It's how we get position from acceleration—but it's also how every little error snowballs. Imagine trying to measure a long hallway using a ruler that's just slightly off. Even if it's only wrong by a millimeter, that mistake gets multiplied every time you move it. After 100 measurements, you're way off.

That's exactly what happens during parachute descent. The rocket's motion is slow and unpredictable. The sensors do try to keep up, but the longer it goes on, the more the errors start to pile up. The report shows in simulations that descent position estimates can easily drift by dozens or even hundreds of meters, even within idealized scenarios.





Other Sneaky Problems

Sensor Saturation

If the rocket swings too violently, the sensors can saturate—they reach their maximum measurable value and can't go any higher. When that starts to happen, the IMU "clips" the motion and records incorrect data. Some sensors even misbehave after saturation, reporting inverted or frozen values. That invalid data can throw the entire position estimate into chaos.

Cross-Axis Sensitivity

IMUs are designed to measure in three perfectly perpendicular directions. But in reality, they're never perfectly orthogonal (or 90° to each other). The result of this, is that a bit of motion in one axis can bleed into another. This subtle error, which we call cross-axis sensitivity, adds yet another layer of confusion during complex parachute motions experienced during flight.

Figure 4: If the amplitude of the acceleration exceeds the sensor's range, it will clip off the peak, and underestimate the true acceleration. This is Sensor Saturation.



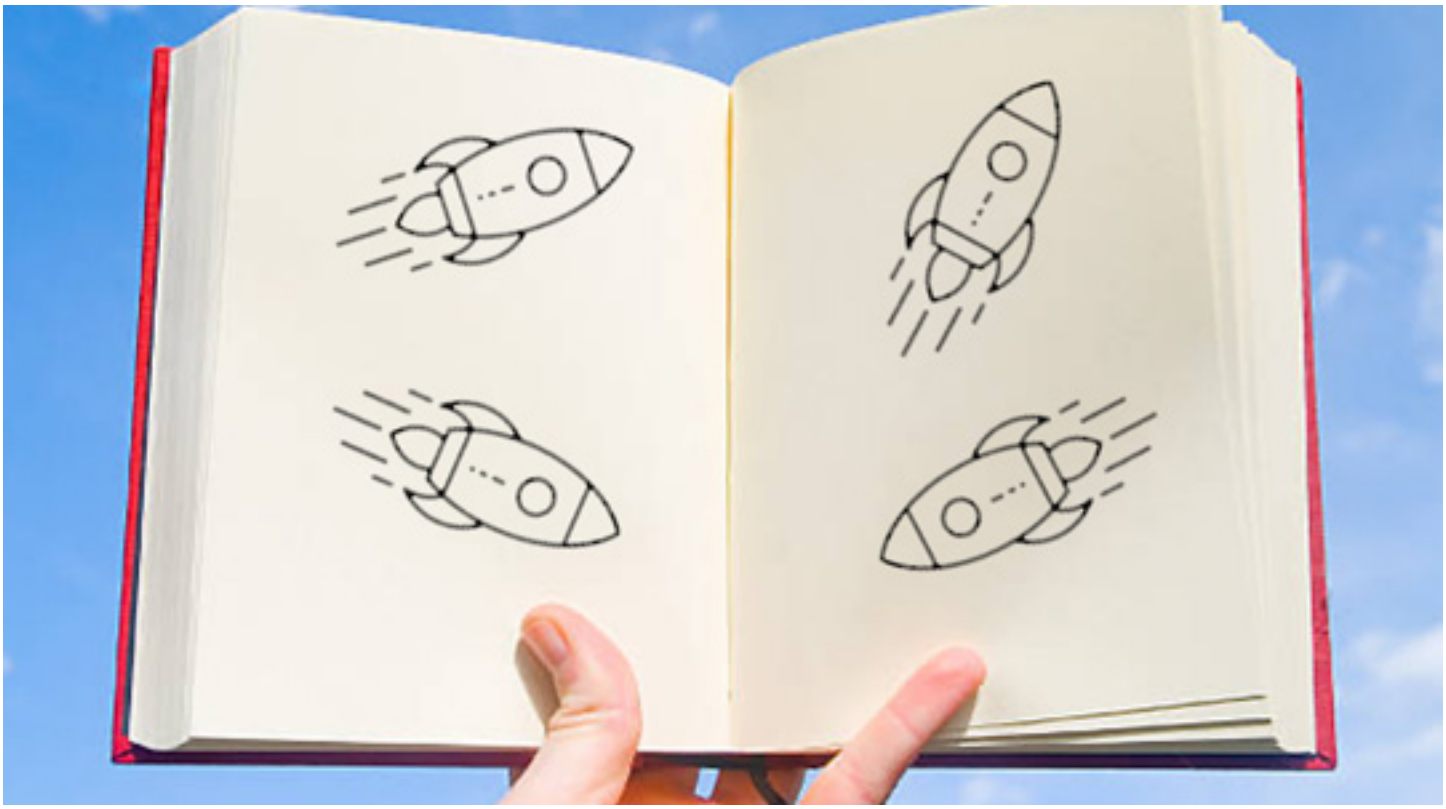




Figure 5: The sample rate determines the number of snapshots of the rocket's orientation. There is no data between frames, which can lead to position or speed errors.

Quantization and Sampling Rate

Even if a sensor were perfectly accurate, it can only take measurements at discrete time steps. Martin illustrates this using quantization error—the difference between continuous motion and the IMU's "snapshot" view of it. An IMU sampling at 50 Hz (50 snapshots per second) sees your rocket's motion as a flipbook—missing details between frames. Faster sampling (100+ Hz) helps but can't eliminate the gaps.

So, What Can Be Done?

There are several strategies to reduce errors, but none are perfect. **Calibration** is essential. Most flight computers do some form of automatic calibration before flight. This helps, but doesn't fix errors that develop mid-flight.

Filtering can reduce the noise. Simple methods like averaging multiple samples, or more advanced digital filters (IIR/FIR), can

smooth out the worst of the jitters. But filtering can't remove drift—it only masks the symptoms.

Sensor Fusion is the gold standard. By combining IMU data with barometric and GPS readings, a flight computer can cross-check and correct itself. Some of the more advanced electronic payloads have multiple sensors for this specific purpose. And techniques like the Kalman Filter use math to blend these data sources, taking advantage of the IMU's responsiveness and the GPS's long-term stability. Still, these methods are complex and not foolproof. And as rocketry electronics evolve, this sensor fusion will be ever more available and more popular.

Post-flight Analysis can help make sense of messy data. Software tools like RS-Pro or MATLAB can reprocess the raw sensor values after the fact, applying corrections and smoothing filters to produce more believable flight paths.

A Model That's Wrong… but Still Useful

In the end, we must remember the wise words of statistician George Box: "All models are wrong, but some are useful." Your rocket's IMU data is a model—a reconstruction of what happened. It will never be perfect. But if you understand where it shines (boost phase) and where it struggles (descent phase), you can use it wisely.

So next time your rocket's track in RS-PRO's replay the flight feature looks like it landed in the next county, don't panic. The ascent data is likely still solid. That is the important part anyway. And if you want accurate landing positions, consider using a dedicated GPS tracker that doesn't rely on IMU integration at all. RS-PRO can read that data as well.

Want to Learn More?

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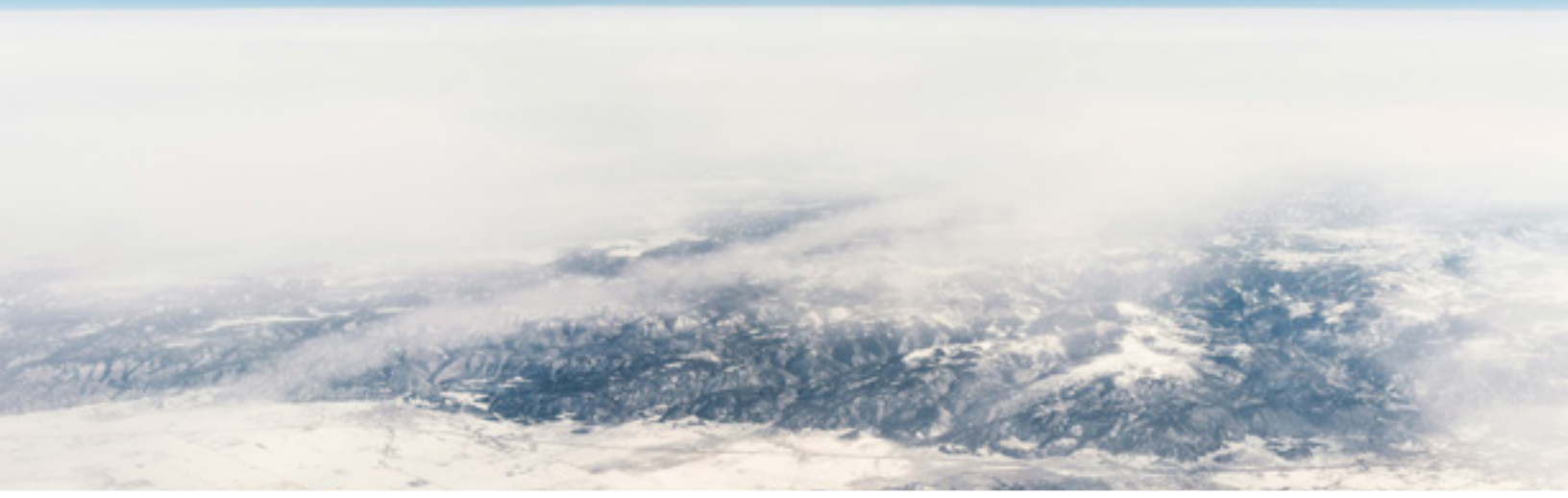
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Apogee Components, Inc.
4960 Northpark Dr.
Colorado Springs, CO 80918
719-535-9335

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