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APOGEE

PEAK OF FLIGHT

NEWSLETTER

Why Do Rockets Go Unstable?

By Tim Van Milligan

Every now and then, I get a letter that reads something like this:

"I just designed a rocket using your RockSim software. When I flew it this weekend, it went unstable. RockSim told me that my design was stable; so what went wrong?"

First off, let me say that "generally speaking" I get this question most often when the modeler is really pushing the performance of the model. That is, they are trying to reduce everything to a bare minimum so that the rocket achieves the highest altitude. Let me say that I can relate to this 100 percent. To me, this is engineering at its best. I like to see modelers doing this type of thing, and asking these types of questions. It tells me that they have a genuine desire to learn and become better modelers.

The answer to the question, however, is that there could have been a zillion things that could have happened. Since I wasn't there and didn't get to see the flight, it is hard for me to give you the reason.

But, let me give a list of things that have happened to some of my rockets. Yep, that's right. I've crashed a lot more rockets than you have. Here are some of the things that I now watch out for.

The first thing I always suspect are the fins. They are the cause to at least 80 percent of the rockets that go unstable.

1. Crooked or canted fins. If you have fins on your rocket that are not perfectly straight, they have the potential to cause unexpected lift forces to be generated.

2. Fins where the airfoils are different. If each fin on your rocket has a different airfoil, this would have the same effect as a crooked or canted fins. It generates non-uniform lift forces. The best airfoil on all the fins would be the teardrop shape (symmetrical). But if it isn't uniform on both sides, you have what is called a "cambered" airfoil. This is the same type of airfoil that is on the wing of an airplane; who's purpose is specifically to generate lift.

3. Forward fins. These are any fins placed on the model in front of the Center-of-Gravity (CG). They are always destabilizing if they generate lift. So it is critically important that they be made as small as possible, and that they be "perfectly straight" on the model. If they aren't, the model is probably going to be unstable.

4. Asymmetrical fin arrangements. The word asymmetrical means "not" symmetrical -- in other words fins that are not placed or spaced equal distances around the tube. It would also include having some fins on the rocket being bigger than others. In either case, what happens is that the lift force on one side of the rocket can be bigger than on the other side. This can cause the model to do loops if it is hit by a sudden gust of wind (on the wrong side of the model).

5. Fins that pop off during flight. When this happens, the result is that the lift forces around the rocket are not uniform. This makes the rocket do loops. And it is pretty easy to figure out after the flight if you're fortunate to find the parts afterward.

6. Loose fins. Even if the fins don't pop off during flight, the reason we don't tolerate loose fins on the rocket is that they can vibrate back and forth. This disrupts the airflow on one side of the model, and can cause it to go unstable. So never tape a fin onto a rocket, or permit someone else to do so. This is just asking for trouble.

7. Fin flutter. This condition is a lot like loose fins. But the difference is that the root edge of the fin is securely attached. Typically, it is caused by fins that are made from very thin material, or material that can flex. During flight, the fins twist. When this happens, the fin tip is at an angle of attack. That generates lift, and can cause the model to go unstable. If you ever hear of a rocket that buzzes as it goes up into the air; this is fin flutter.

8. Protrusions on the side of the rocket that act like fins. It doesn't have to look like a fin to act like one. Anything on the side of the rocket body tube can generate lift or drag forces

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when the model is at an angle of attack. It may be a canopy on a model that looks like a jet; or maybe a parasite glider that is there just to be boosted into the air. These forces are very difficult to predict; which is the main reason that RockSim does not allow things to be strapped to the sides of the tube.

9. Parachute that isn't fully inserted into the rocket, and flutters along-side of the rocket. This disrupts the smooth flow of air over the fins. I've seen this happen to a lot of younger modeler's rockets.

10. Loose nose cones that are canted in the tube. This is similar to the number 8 above, because a canted nose cone can generate more lift forces on one side of the rocket than the other.

11. CG shift during flight. This can happen on really light -- high performance models. On these models, the parachute sliding rearward in the tube can be enough to move the CG behind the Center-of-Pressure. This has happened to me several times during competition.

12. Air being ducted through the rocket, and out one side. This one isn't common, except for rockets that have jet intake scoops. You just have to watch out for the direction of the air coming out the back.

13. Putting the rocket high on the launch rod, instead of near the bottom. I see this one all the time. Most time it is because the launch rod is bent near the base, and you are trying to avoid that area. Or maybe there is crud on the rod. And it happens a lot on gliders, which have long tails that stand on the launch pad. The result is the same -- there isn't enough length of rod for the rocket to travel while it builds up to that critical flight speed. And as we all know, there is a minimum speed the rocket must be traveling at before the fins become effective at keeping it flying straight.

14. Rocket binding on the launch rod. This is similar to the one above. The rocket hangs up for just a moment; decreasing its speed. When it lets go, now it isn't traveling fast enough.

15. Getting entangled in the igniter clips; preventing it from lifting off smoothly. Again, anything that slows the rocket while it is on the rod may be a detriment to the stability of the flight.

16. Piston launchers come with their own problems. When the rocket is traveling upward on the piston and it reaches the stop before popping off is the most common problem. In effect, the rocket comes to rest for a brief instant, and then pops off the piston assembly. Because it is basically starting from rest, the fins of the rocket are not effective at all. So if you are using a piston launcher, just be careful. Better yet, mount the rocket inside a tower launcher too. That way, when it pops off the piston, it has the guidance of the tower while the rocket builds up speed again.

17. Insufficient thrust level. If your rocket is heavy, and you're using a low thrust motor, you need to be extra cautious. Run your RockSim simulations, and see what the lift-off speed is when the rocket clears the rod. If it isn't up to the minimum lift-off speed; try a motor with more initial thrust.

18. A strong gust of wind right when the rocket clears the rod. We blame a lot of unstable flights on this; although it is preventable. Just like number 17 above, run your RockSim simulations; but with a high wind speed. See what happens to the flight.

19. A nose cone that pops off in flight. This one is obvious when it occurs, and usually happens on larger diameter models. And there is a reason nose cones suddenly pop off during high speed flights. It is because the internal pressure inside the rocket is greater than the outside air pressure. So there is a force trying to push the nose cone out of the tube. It is easily solved with a pressure relief hole.

20. Rod whip. We blame this one for a lot of unstable flights too. If there is wind, we can see the rod waving about. This movement adds a velocity component that isn't anticipated. But a lot of times, we use this excuse when there isn't any wind at all. What we think my be occurring is that as the rocket is traveling upward, it is somehow flexing the rod. There needs to be some high-speed movies made to actually determine what is happening, and if this is a legitimate reason for the model to go unstable.

21. Canted thrust line. This may occur when the motor mount is cocked inside the rocket body tube. Because the motor is pushing in a different direction than the rocket wants to move; it causes it to go unstable.

22. Off-axis thrust lines. This is different than a canted thrust line, but the effect can be the same. One kit in particular uses an off-axis thrust line. That is the Estes skill level 5 Space Shuttle. The motor is straight along the length of the model,

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but is offset from the centerline. This is because the orbiter is creating lift forces that counteract the off axis thrust. But if you tried to fly the External Tank by itself, it will do cartwheels across the sky.

23. CG that is off-axis. This one is rare, unless the CG is way off to one side. It is usually caused by something heavy on one side of the model (maybe a payload inside the rocket that has a heavy battery against one side of the tube).

24. Nozzle Erosion. I have a good friend that thinks this is the cause of a lot of unexplained unstable flights. The theory is that the gases coming out the rocket are eating at the sides of the nozzle. If the erosion of the nozzle isn't uniform, then you'll get a vectored thrust. This would cause the rocket to go unstable. I think there is a lot of legitimacy in this theory, particularly for black powder motors that have clay nozzles. I don't know if it occurs on composite motors that use a phenolic nozzle. The problem can be alleviated by using a longer launch rod. Because if the model is traveling fast enough, the fins can cancel out the effect.

25. Side wall failure. This is actually a motor cato. A tiny pin-hole develops near the base of the motor, which vents hot exhaust gases out one side. It always leaves physical evidence that can be seen after the flight. There isn't anything you can do to prevent it, but it can be used to explain why the flight went unstable.

26. Short Rockets. This is where it gets really tricky. Short rockets are less "dynamically stable." That is, they are more easily disturbed from the flight path, and they take longer to correct back to straight flight. In my opinion, there is something (one of the other causes listed above), that triggers the model onto its course of instability. Figuring out what that is will be difficult because the design of the model makes it tend to be less stable to begin with. See the related article in e-zine newsletter #86.

27. Very long rockets can flex. This means that the nose is flying in one direction, while the tail and motor are going in a different direction. The NAR super-roc competition can really be fun to watch because of this fact.

That's my list of causes of rockets going unstable. As you might guess, most of them are preventable. It takes care and patience during the construction of the model, and setting it up to fly.

If you have any others causes, please send them to me, and I'll add them to this list. By knowing the things that can go wrong, we modelers can try to prevent them from happening in the first place.

Also, there are some things that you can do to enhance the stability of the rocket. Those things are listed in my book *"Model Rocket Design and Construction."* Check it out, and see if any of those methods might fit your situation.

Here are some letters and feedback that we got about this article:

Jay King writes:

> 16. Piston launchers come with their own problems. When
> the rocket is traveling upward on the piston and it reaches
> the stop before popping off is the most common problem.
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> then pops off the piston assembly. Because it is basically
> starting from rest...

This is a very interesting comment Tim. If literally true, then the fact that the piston moves is of no consequence to flight performance. My theory is that as the piston stops the rocket's inertia contributes to the speed with which it "pops" off the pad.

This would be a fascinating R&D project. One would need to fully instrument and/or observe a piston launcher to monitor a) piston velocity and acceleration b) piston pressure c) rocket velocity and acceleration.

I suspect that moving pistons are only marginally more effective than stationary pistons. That the majority of performance enhancement comes from a) the pressure increase "popping" the rocket off the pad and b) the absence of a large launch rod or tower and the corresponding reduction in friction.

One could do a great DOE (Design of Experiments) study to see which parameters really matter and fine tune them for optimum performance. I do not have the time but I offer this idea to anyone with the inclination and imagination to do the work.

Thanks for the fine weekly newsletter. --- Jay King

Dan Miner writes:

People who have studied for a level 2 certification will also note a variation to your #11 - CG shift during flight. This is usually thought of regarding hybrid motors where the (typically) very long motor with (liquid) oxidizer tank can be partially in front of the CG at initial motor ignition. As the liquid oxidizer is consumed, the CG shifts backwards until the level of the oxidizer is exactly equal to the momentary CG location. (After which the CG will move forwards again.)

However, this could happen in theory with rockets that have relatively long solid fuel/oxidizer motors that are not end burning. An example could be the Aerotech 38/1080 (J570W). (I think the Apogee Micro Motor B2 is and "end burn" motor so it would not be affected by this.)

If at the moment of ignition, the rocket CG is behind the CG of the motor fuel, then as the fuel burns, then the CG will shift backwards. (Again, assuming the motor is NOT an end burn motor.) I believe a "normal" looking rocket could easily be designed that would meet this criteria.

Ed Pearson writes:

Hi. Thank you for a nice, comprehensive list on why model rockets may go unstable. If someone asked me that question, I bet I would have come up with only 1/3 of your list.

What about old engines or poor engines whose thrust has deteriorated or are not up to the markings? Too small fins obviously is a cause, but should have been caught by RockSim, and probably is worth a footnote rather than a list item.

Am sure that cutting it tight (reducing the distance between CG & CP), trying to optimize performance, contributes greatly to unstable models when other factors that wouldn't ordinarily have crossed the line kick in. And you have listed many of these contributors that usually manifest themselves with less than perfect flights using wider margins but because of trying to optimize cross the stability threshold instead. Really good job and point you make.

Thank you again. -- Ed Pearson (NARHAMS section member).

Ian Johnston writes:

You discussed excrescence drag, but I don't think you mentioned launch lugs. It is particularly important on models where the payload bay is a larger diameter than the motor tube - eg egg lofters. In this case it is often convenient to mount one lug on the payload bay, and the other part way out on a fin, and this obviously leads to 2 excrescences on one side of the vehicle.

Keep up the good work, I always enjoy your articles and have in fact just been following your advice on press releases (Issue #19), to prepare a release covering a series of rocket workshops I am running for the UK National Science week later this month

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Scott Orr writes:

It doesn't have to flex--just flying at a non-zero angle of attack makes the body, in effect, into a fin (LaBudde's paper from last year covered this topic), which has the effect of shifting the CP forwards, making it more like the cardboard-cutout approximation the further off zero the rocket gets. In my case, where I've tried with competition streamer or parachute models to stuff a wide streamer or parachute into a narrow but moderately long body, I've had this problem (at least, I'm fairly sure this was the problem); bigger fins help (anything that passes the cardboard-cutout test shouldn't be affect by this problem).

This is worst on windy days (when the rocket will weathercock--in theory, it's not a problem at all in perfectly calm weather), which is why you often hear experienced rocketeers advise against flying a long, skinny rocket (like the Mean Machine) in this weather.

About the Author:

Tim Van Milligan is the owner of Apogee Components (http://www.apogeerockets.com) and the curator of the rocketry education web site: http://www.apogeerockets.com/education. He is also the author of the books: "*Model Rocket Design and Construction*," "*69 Simple Science Fair Projects with Model Rockets: Aeronautics*" and publisher of the FREE e-zine newsletter about model rockets. You can subscribe to the e-zine at the Apogee Components web site, or sending an email to: ezine@apogeerockets.com with "SUBSCRIBE" as the subject line of the message.