PEAK OF FLIGHT

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PEAK OF FLIGHT

Strategies for Composite Staging

By Tim Van Milligan

Here at Apogee, we have three different types of electronics that can be used for staging composite motors (see: www.apogeerockets.com/Electronics_Payloads/Staging). I thought I'd run through them in this article, so you can see what choices you have if you decide to launch your own two-stage rocket.

All of the electronics perform staging by firing off an igniter, which is installed in the motor of the upper stage. Therefore, they are independent of the bottom stage of the rocket.

Think of the "electronics" as a launch controller that rides in the top stage of the rocket. It supplies the electricity to set off the igniter in the motor. So besides the electronic circuitry board, the system has to include a battery, and the wires to bring the electricity from the battery to the igniter in the motor.

The electronic circuitry board is the brains of the system. It has to know when to send the electricity to the igniter in the motor. That is what this article is about, explaining the differences in the circuitry boards. So in the remainder of this article, when I mention things like: "timers", "altimeters", and "flight computers", what I'm really describing are the different types of circuitry boards that could be used in the rocket to fire off the igniter in the top stage of the rocket.

Timers

The timer is the simplest and least expensive option for staging composite propellant motors. A timer, as its name suggest, works by "counting" a set amount of time from a triggering event. It is like a countdown clock. Once it starts counting down, when it reaches zero, it will send electricity to the igniter, setting off the upper stage motor.

The "triggering event" is the important part. In the very simplistic timers of the past, the triggering event was a break-wire. As long as current flowed through the wire, the timer wouldn't start counting down. How they worked in reality was that a wire was attached from the rocket to the launch pad. When the rocket took off from the launch pad, the wire was broken (maybe burned through from the exhaust, or an electrical pin was pulled out of a socket by the motion of the rocket) and the countdown to the ignition of the upper stage was begun.

The drawback to the break-wire system is that it was too easy to trigger the system. For example, a motor chuff in the bottom stage could lift the rocket a few inches before dropping it back down on the launch rod. But it could have been high enough to start the timer in the upper stage going. Or, there could have been a misfire of the igniter in the bottom stage, and during the process of swapping out the igniter, the rocket was lifted up high enough to start the timer in the upper stage. The result was that the upper stage might ignite while the rocketeer was holding the rocket.

Therefore, most modern timers have some sophisticated sensors that try to filter out false triggering events.

The MiniTimer-4 from PerfectFlite (https://www.apogeerockets.com/Electronics_Payloads/Staging/PerfectFlite_MiniTimer4_Staging_Timer) uses an accelerometer on the circuitry board to sense a real launch of the rocket. This "sensing the launch" is

Figure 1: Mini-Timer-4 from PerfectFlite

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the triggering event that is used to start the countdown of the timer circuit. So the circuitry board must sense a real rocket launch before it starts counting down to zero when it fires off the second stage. It is very sophisticated, and even vibration, shaking the rocket, or it falling to the ground isn't enough to trick it.

Because it uses an accelerometer, the MiniTimer-4 can tell the difference between a positive acceleration, which occurs at lift-off, and a deceleration, which occurs when the rocket burns out and starts slowing down. Therefore, it can be configured to begin timing from detection of movement (ignition) or from burnout of the primary motor. Timing from ignition is typically used for igniting airstarts that overlap their burn with the primary motor (to provide increased initial thrust), and timing from burnout is used for delayed air-starts (for staggered ignition effects), staging, and recovery device deployment.

For staging, it is better for the triggering event to be from "burnout," where the rocket starts decelerating. This is for safety reasons. It is possible to misread the burn time of the motor and program in a wrong time for the staging point. If this happens, the upper stage could be arcing over and fire while the rocket is horizontal or aimed downward. This is very dangerous and should be avoided. To prevent this, you would set the timer to trigger on the deceleration of the motor, and keep the time low. Zero seconds would be the safest, since the upper stage would then ignite almost immediately at burnout of the first stage.

The PET2+ Programmable Event Timer from Missile Works (https://www.apogeerockets.com/Electronics-Payloads/Staging/Missile-works-PET2-Timer) is similar to the MiniTimer4, but it has two timer circuits instead of one, so it can set off a second igniter in the rocket. This second event is typically to separate the stages of the rocket instead of relying on drag separation to pull the lower stage away from the upper stage. Let me explain this a little more.

Figure 2: PET2+ Programmable Event Timer from Missile Works

In a simple model rocket, particularly the Estes style two-stage rockets, the two sections of the rocket are joined together by a coupler that simply slides into the base of the upper stage. When the upper stage fires, the exhaust from the rocket motor pressures the area between the stages, and the lower stage slides away. This works fine on small rockets, but the drawback is that when you are on the ground and moving the rocket around, what happens when you pick up the rocket from the nose end? Right, the two stages separate because of gravity.

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When the rocket is larger, you may want to prevent this from happening so you can move or handle the rocket as a single unit without having the stages come apart accidentally. So you may decide to use shear pins between the stages to prevent them from coming apart during ground handling.

If you do that, now you need to come up with a way to separate the stages during flight. You might want to use a separate ejection charge that will break the shear pins, and positively blow the stages apart. In this case, a second timer could be used to fire off that additional ejection charge between the lower and upper stage. That is why the PET2+ timer has an additional hook-up for a second ejection charge.

This second circuit can also be used to fire off an ejection charge to deploy a parachute in the rocket. It can be a back-up to the rocket motor's ejection charge.

The PET2+ timer can also be used with a break-wire to further desensitize it against false trigger signals. So you could set it up to rely on two inputs in order to trigger it to start its countdown to launch of the second stage. If done this way, not only does it need to activate the break wire (or pull pin), it also has to sense acceleration in order to trigger.

The other difference in the PET2+ timer is that it has a 3-axis accelerometer instead of a single-axis accelerometer that is used in the MiniTimer4. This allows the circuitry board to be positioned in any direction within the rocket, instead of having to be mounted in an "up" direction.

Because of the extra igniter circuit and the 3-axis accelerometer, you have more control of the events occurring during the rocket flight. The downside of this is that programming the PET2+ timer is more complex, and can be a little confusing. My recommendation is that if you are new to staging of composite motors and want to use a Timer, that you choose the PerfectFlite Mini-Timer-4 because it will be less confusing to set up. But when you are needing the extra ignition circuit, get the PET2+ timer.

If you want to see an example flight of a two-stage rocket using a timer, watch my old YouTube video at: https://www.youtube.com/watch?v=M-RhzMFovAXM&feature=youtu.be

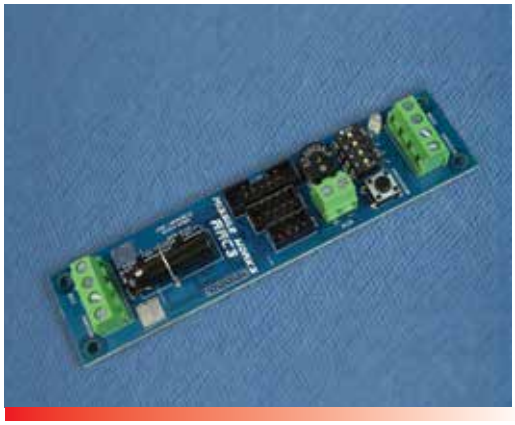

Figure 3: RRC2 Sport Altimeter

Altimeters

The RRC3 "Sport" altimeter from Missile-Works gives a little bit of extra versatility and safety when it comes to staging composite motors. On initial inspection, you might think that this is a simple dual-deployment altimeter. But it does

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have a third pyro channel that is designed for staging motors in flight.

The RRC3 uses a barometric sensor to know how high the rocket is at any point in the flight. It also has a timer circuit as well. These two inputs can be used to develop a logic loop to determine whether or not it is safe to fire off the igniter in the upper stage. So in a sense, you could think of the RRC3 as a simple "flight computer." I define a flight computer as a device that makes a decision on its own after being programmed prior to the flight.

This gives an extra margin of safety over the timers discussed previously. Here's how.

In the RRC3, you can make the altitude of the rocket as one condition of the trigger event. You would program this into the altimeter in advance of the flight. Therefore, the rocket would not fire the igniter unless the rocket reached a specific altitude. Why is this useful? Because if the rocket went unstable prior to reaching that altitude, it would not fire off the second stage. I really like this feature, because it really adds to the safety of the flight.

Say for example, the two-stage rocket lifted off and everything was going fine. But suddenly halfway through the burn of the first stage, the booster stage motor CATO's. The CATO might be so violent that the rocket veers off course and the rocket is pointed sideways. If you used a timer, it would not sense that anything was wrong, since it would assume that the motor just reached its burnout point. It would then fire off the second stage, which might be pointed horizontally when it ignites. This could be very bad.

But with the logic programmed into the altimeter to also look for a specific altitude, it would not fire off the second stage.

Going back to the above example, when the booster motor CATOs, the rocket will never reach the target altitude as the second triggering event needed to initiate the ignition of the upper stage. What would happen is that the altimeter would sense that something is wrong, and just revert back to its dual-deployment role. In other words, if the rocket turns horizontal unexpectedly due to the first motor CATO-ing, it would simply assume it reached its apogee point and initiate the charge to pop out the drogue parachute. And if the rocket was below the main deploy altitude, the altimeter will fire off that ejection charge too. I've seen a few flights where dual deployment altimeters have saved the day and brought back the rocket in safe condition so it is able to be launched again.

To use the RRC3 this way, you do have to do some homework before the flight. You have to know in advance what altitude the rocket should reach if everything was nominal with the trajectory. This is where you need to your launch simulations on the computer.

When you set up your simulation, you want to first find the worst case scenario that you are willing to live with in the launch. In my case, I first choose the motors as I normally would (see https://www.apogeerockets.com/Advanced_Construction_Videos/Rocketry_Video_32). Then I set up the launch conditions so that the rocket will arc over slightly during the flight; But not so much

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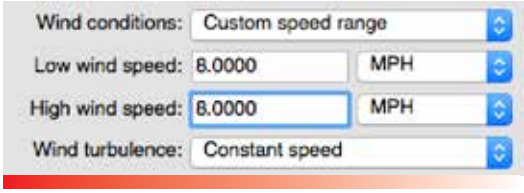

Figure 4: Simulation Properties

that the rocket would be unsafe. To make the rocket arc over, I add some wind to the simulation. This is done on the "Simulation Properties" screen in RockSim (https://www.apogeerockets.com/RockSim/RockSim_Information), which can be seen in **Figure 4**. I set the "Wind conditions" to "Custom Speed range" first, and then type in a wind speed of 8 mph for both the "Low wind speed" and "High wind speed values." I also set the "Wind turbulence" on the screen to "Constant speed." When you make these inputs, what RockSim does is to assume a constant wind of 8 mph. I also set the launch angle to be 5° from vertical (pointing away from spectators), which is the new safety recommendation from the NAR.

I typically perform all my simulations using these conditions, because that is about the wind speed for a typical launch day where I fly rockets. Under these conditions, the rocket will weathercock somewhat into the wind. And if you typed in positive numbers for the wind speed and the launch angle, then the rocket will be aimed into the wind when you launch it in the simulation. This is the worst case situation that I'm willing to live with.

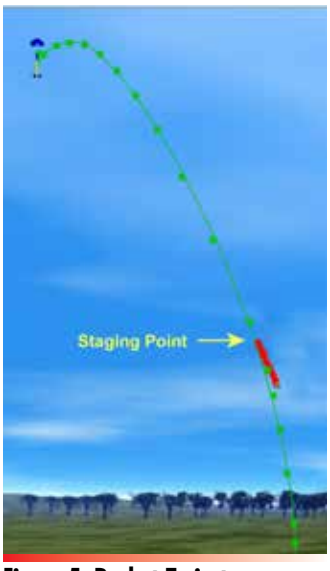

Figure 5: Rocket Trajectory

From this point, I run a simulation and look at a nominal trajectory as seen in the flight profile (see **Figure 5**). What I'm looking for is how straight the trajectory is, particularly the orientation of the rocket at the point where the second stage ignites. If that looks reasonable, then I'll see how far downrange the rocket is at the apogee point.

In my criteria for selecting rocket engines, I want the apogee point to be within a 20° cone, where the point of the cone is at the launch pad (see **Figure 6**). In the figure, the apogee point is outside the 20° cone, and therefore I'd consider this flight to be too much weathercocking. It is too far away from the launch site at apogee.

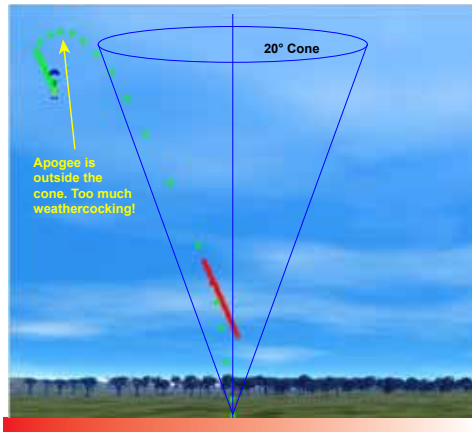

Figure 6: Weathercocking cone diagram

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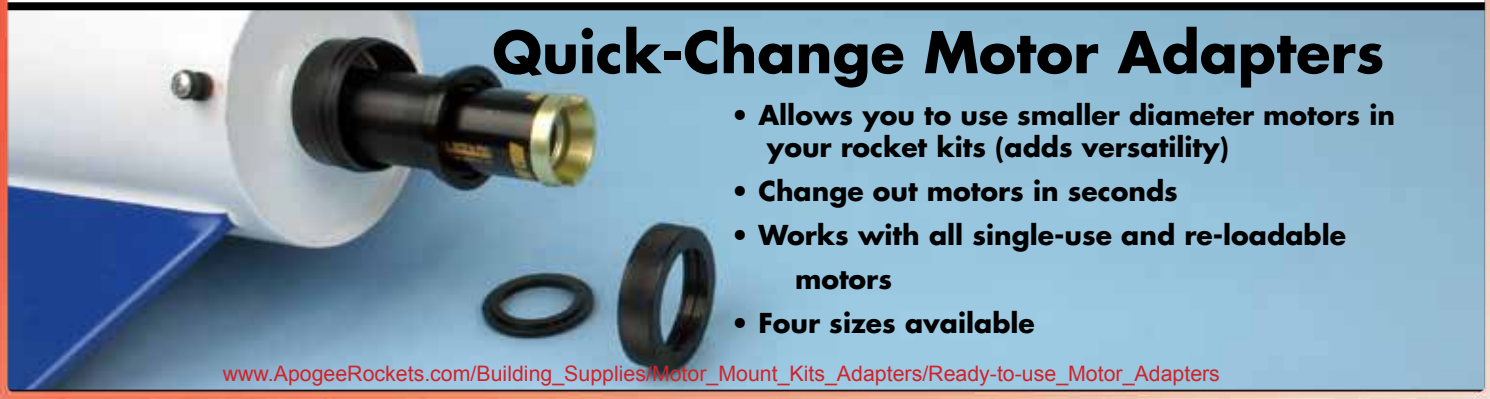

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RockSim doesn't automatically calculate the cone, so you'll have to do it manually. The formula for finding out whether or not the rocket is inside the 20° cone is in **Figure 7**.

$$\text{Angle} = \text{arc Tan}\left(\frac{\text{Distance from launch pad}}{\text{Apogee altitude}}\right)$$

Figure 7: Formula for determining weathercocking angle

You can get the values from the "Simulation Details" screen in RockSim. Scroll down to find the "Maximum range from launch site" and the "Maximum altitude." You have to verify the "Maximum range from the launch site" by looking at the 2D flight profile in RockSim, because the wind could actually make the rocket drift further downwind later on in the flight.

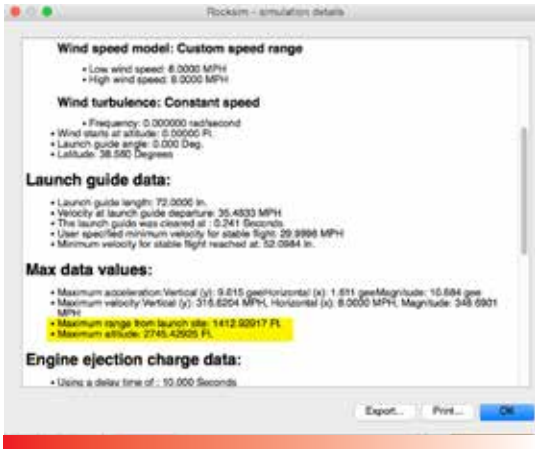

Figure 8: Max Flight Values

Figure 8 can be used as an example. When you plug in these numbers into the equation, you get the completed formula in **Figure 9**.

$$\text{Angle} = \text{arc Tan}\left(\frac{1412.92\text{ ft}}{2745.43\text{ ft}}\right)$$

$$\text{Angle} = \text{arc Tan}\ (0.514646)$$

$$\text{Angle} = 27.23°$$

Figure 9: Completed Formula

Since 27° is greater than our allowable tolerance of 20°, we know that this is not a good situation for launching the rocket. What are you to do at this point? Great question. The answer is that you have to go back and pick different rocket engines for the model, or change the ignition delay in the simulation.

In this example, I had a delay of three seconds between the burnout of the

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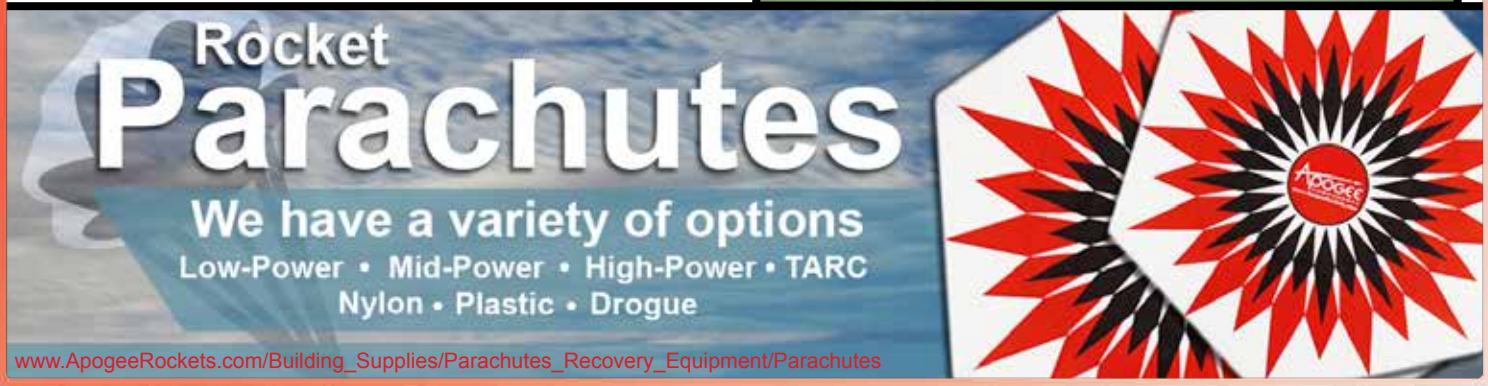

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booster motor and ignition of the upper stage. During this time, the rocket was slowing down and turning into the wind. So when the upper stage ignited, the rocket was pointed away from vertical. As mentioned previously, the safest situation is for a zero second delay between the burnout of the first stage and ignition of the second.

What I'd do in this situation would be to re-run the simulation without a delay between the firings of the two rocket motors.

Once you get your motors selected and the

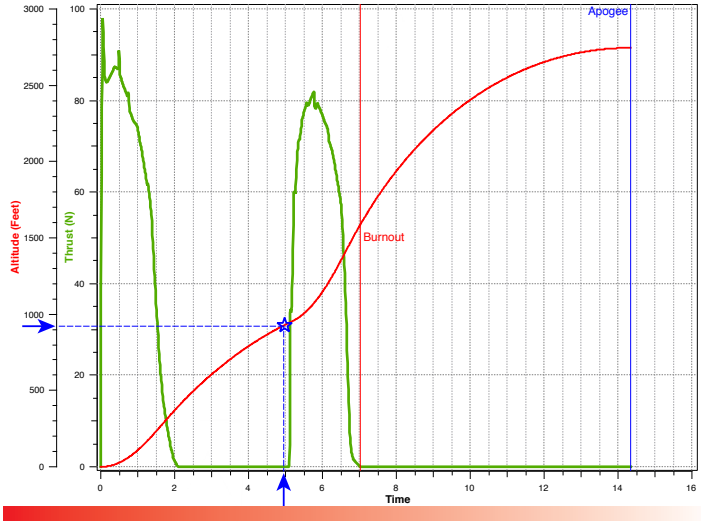

Figure 10: Thrust and Altitude graph

apogee point in the cone of acceptable weathercocking, you can start to program your RRC3 altimeter for the staging. For this, you'll need to go back to your RockSim simulations and dig out some data from the graphs of the flight data.

Figure 10 shows a graph of thrust (the green line) and Altitude (the red line) versus time. The two motor firings are represented by the two big peaks in the thrust line on the graph. What you want to get from this graph is the altitude of the rocket just before the second motor ignites. I put a little blue star on the graph showing the point that is important. This point occurs just before 5.0 seconds into the flight (measured from first motion of the rocket). At this point in time, the rocket is a little over 900 feet in altitude. Let's call it 920 feet.

Once you have this data, you can program the altimeter. These are the inputs that the altimeter must see in order to assume that the trajectory is nominal, and it is safe to fire off the igniter that

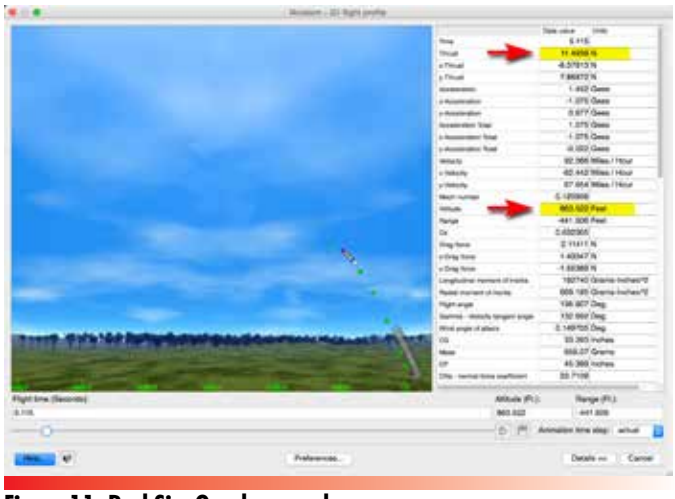

Figure 11: RockSim Graph example.

will get the second stage burning.

Say for example the actual launch looked like **Figure 11**. I've hi-lighted the two important numbers. At time 5.115 seconds, the second motor is just starting to come up to thrust (it has 11.4939 Newtons at this point). But it is only at 863.5 feet in altitude at this time. So the RRC3 would know that it didn't meet the criteria for a safe launch; and it wouldn't fire off the ignit-

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er to get the second stage going. What would happen is that it would just assume it was being used for dual deployment and fire off the deployment ejection charges at the appropriate points in the flight.

It is a nice feature, but remember you have to do your simulations before the flight so you know the criteria to program the RRC3 Altimeter.

Gyro Sensors

The TeleMega (https://www.apogeerockets.com/Electronics_Payloads/Dual-Deployment/TeleMega) is the next step up in sophistication and additional safety for the launch. It is more sophisticated because it has a total of six pyro channels to set off igniters, and it has additional sensors to take in data. Besides having an accelerometer, barometric sensor and a timer, it has a GPS antenna for position data, a magnetic sensor to know which way is north, and a 3-axis gyroscope.

Like the RRC3, the TeleMega can be programmed to make decisions during the flight based on the information it takes in from its sensors. That makes it in my opinion, a flight computer.

It is the 3-axis gyroscope on the TeleMega that adds additional safety for staging. Because of the information supplied by the gyro, the TeleMega can tell how far from vertical the rocket is pointing throughout the flight. So you can simply program it to prevent the ignition of the upper stage if the rocket tilts too far from vertical. This makes it a little more versatile, because you don't necessarily have to re-run your RockSim simulations right before launch if the weather conditions have changed from what you anticipated.

The accelerometer data can also be used to find the speed of the rocket at any point in the flight. This allows for another trigger-event parameter to be used in making a decision to ignite the second stage. Essentially, you could set a minimum speed for the rocket to achieve in order for the TeleMega to set off the igniter to the second stage motor. What this does is to allow for uncertain events to occur, and still be safe for the second stage to be ignited.

For example, say we set the trigger event to include both a minimum speed for staging at 15 meters/second, and that the orientation of the rocket to be less than 5° from vertical. Under these criteria, you could still have a safe flight if the booster stage motor CATO's halfway through its burn. Imagine this scenario: the rocket lifts off successfully and then BOOM, the booster motor lets go. But the upper stage is thrown forward (upward) and it is still traveling over 15m/s. The TeleMega would still go ahead and fire off the second stage motor and allow the upper stage to continue on as if nothing unusual happened below it.

Note: I've been talking like CATO's happen all the time, but in reality, they are extremely rare. I just used this as an extreme corner-case example to show what might be possible.

As mentioned previously, the TeleMega has six pyro channels. So it is possible to perform some really complex flight effects with the device, such as parallel staging additional motors on the outside of the second stage's core motor.

TripleFire

The TripleFire is a radio control interface that provides 3 pyro channels and can also be used for staging rockets or for air starts. What makes it unique is that it puts the human

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www.apogeerockets.com/RockSim/RockSim_Information

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back into the loop by allowing the staging decision to be made on the ground and transmitted to the rocket by a commercial RC transmitter.

This can be good or bad. On the positive side, you are in direct control of the rocket so you can decide for yourself when staging can occur. But on the negative side, the events in a flight happen very quickly and there sometimes isn't enough time to respond by throwing the panic switch. And unfortunately, humans are easily tricked by false information or by being distracted. If people were 100% accurate with their decisions, then an RC airplane would never crash. But yet they do…

Conclusion

In this article, I tried to lay out the options you have with the different electronic devices that we offer for staging. Each device has both its positive and negative attributes, so please consider them before making a choice. Sometimes the best choice is to use multiple devices.

Previous Articles on Staging Composite motors:

Newsletter #91 - Electronic staging of composite propellant rocket motors. This article shows the differences between staging black-powder motors, and composite propellant motors. (www.ApogeeRockets.com/Education/Downloads/Newsletter91.pdf)

Newsletter 216 - Simulating staging using the RockSim software (www.ApogeeRockets.com/Education/Downloads/Newsletter216.pdf)

Newsletter 229 - How to set up staging and air starting in the RockSim software (www.ApogeeRockets.com/Education/Downloads/Newsletter229.pdf)

Newsletter #289 - This article shows a few ways of mounting the electronics within the rocket (www.ApogeeRockets.com/Education/Downloads/Newsletter289.pdf)

Newsletter #364 - Staging Composite Motors (www.ApogeeRockets.com/Education/Downloads/Newsletter364.pdf)

Newsletter 382 - Multi-staging with a cluster engine configuration (www.ApogeeRockets.com/Education/Downloads/Newsletter382.pdf)

About the Author

Tim Van Milligan (a.k.a. "Mr. Rocket") is a real rocket scientist who likes helping out other rocketeers. Before he started writing articles and books about rocketry, he worked on the Delta II rocket that launched satellites into orbit.

He has a B.S. in Aeronautical Engineering from Embry- Riddle Aeronautical University in Daytona Beach, Florida, and has worked toward a M.S. in Space Technology from the Florida Institute of Technology in Melbourne, Florida. Currently, he is the owner of Apogee Components (http:// www.apogeerockets.com) and the curator of the rocketry education web site: http://www.apogeerockets.com/educa- tion/. 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 a FREE e-zine newsletter about model rockets.

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