PEAK OF FLIGHT NEWSLETTER

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HOW TO DETERMINE TIME DELAY FOR STAGING

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PEAK OF FLIGHT

How to Determine Time Delay for Staging

By Tim Van Milligan

Say you have a high-power rocket with onboard electronics that will control when the upper stage motor will fire. At what point in the flight do you want that upper stage motor to fire? That is what we'll try to answer in this article.

The answer to the question is that "it depends."

Don't you hate that answer? I do too. But it is going to be based on what your criteria is for the launch. In other words, it depends on what your mission is and how much you're willing to risk the flight being unsafe.

For background, I'd point you to Advanced Construction Video #335 (https://www.apogeerockets.com/Advanced_Construction_Videos/Rocketry_Video_335), where I talked about the best time to stage a rocket in order to achieve the highest altitude. But that discussion was more about the "direct staging" technique, where you're using small black-powder motors. Direct staging is where the lower stage directly ignites the upper stage rocket engine. See also how 2-stage rockets work at https://www.apogeerockets.com/Tech/How_2-Stage_Rockets_Work

But if you have electronics on board that control when the upper stage fires, you have a lot more options. The option you have available with indirect staging (which is what this would be classified as), is that you can drop off the lower stage of the rocket as soon as it burns out, and the upper stage coasts upward a ways before igniting the upper stage motor. The advantage of this is you lose the weight of the lower stage quickly, and that allows the upper stage to have lower weight and drag, so it can coast higher into the sky.

So let's look at the mission you might possibly try to achieve. The most obvious one is for the rocket to achieve the highest altitude. This is what most people would want to do. But you might also have a mission to have the longest delay possible between the first and second stages igniting. This would be the longest "hang-time," creating an anxious anticipation for the upper stage to ignite. But at the same time, safety is by far the most important thing, so we won't allow the rocket to create an unsafe trajectory.

I propose this mission of longest hang-time because with the broad selection of rocket engines available to the rocketeer, the reality is that you can probably fly higher by using a single stage rocket. It is less complex, and you can optimize the flight easier. In my opinion, the only time you "really" have to stage a rocket to go higher is when you are maxed out by the availability of a larger rocket motor. As I write this, the largest currently certified rocket motor is an "O" motor. So if you wanted to go higher, you could stage two of those together, for some really extreme flights. But if some company made a "P-class" rocket motor, that would theoretically fly higher than staging two O-class motors together.

My point is that a mission to "fly the highest" is really best achieved by using a single stage rocket rather than using a multistage rocket.

When it comes down to it, because of choices of motors that are available, we need to look for a new mission to achieve with a two-stage rocket. So what is that mission? Most people fly multi-stage rockets because it is simply fun. That's why I do it. There is just something mesmerizing about seeing a two stage rocket take off.

And when those two-stage rockets air start, it is even more exciting. In my opinion, what makes an air start so thrilling is that anticipation of whether or not the upper stage ignites while the booster stage has already fallen away.

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About this Newsletter

You can subscribe to receive this e-zine FREE at the Apogee Components website www.ApogeeComponents.com, or by clicking the link here Newsletter Sign-Up

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As you're watching the rocket, you're thinking to yourself: "is it going to stage? If so, when? Come on now… when?" The tension rises and rises, right up to the point when you see that burst of smoke hanging in the sky to let you know the upper stage did fire and the rocket is continuing its beautiful flight.

So "hang time" is a pretty good mission… assuming everything works. Thankfully, the modern electronics that are available are getting really good at keeping things safe. For example, a lot of staging electronics have a tilt-angle system built into them that prevents ignition of the upper stage motor if the rocket is arcing over too much. This keeps the rocket from igniting when the pointy end is not going in a direction that you don't want. In other words, the electronics will save us from the worst case situation.

But we still have to set up the initial parameters to try to achieve our mission. This is not something that is built into the electronics' firmware. Not yet anyway…So it means that we as users have to determine when to stage the upper stage motor if everything is going as planned. And that is the fun part. Therefore, let's assume our mission is the longest hang time between when the booster stage falls away, and when the upper stage air starts.

This is still a complicated problem, because the rocket is always affected by the wind.

For starters, I ran a simulation in RockSim-Pro of the LOC Terrier Sandhawk model (https://www.apogeerockets.com/Rocket-Kits/Skill-Level-5-Model-Rocket-Kits/Terrier-Sandhawk) using the Aerotech H100 in both the first and second stages. The rocket was launch from an 8-foot rail, pointed straight up; with no wind blowing.

The way I set up the simulation was that the booster stage would drop off immediately after the propellant is consumed. The upper stage begins burning 5-seconds after the booster stage drops off. The actual configuration in RockSim-Pro is shown in Figures 1 and 2.

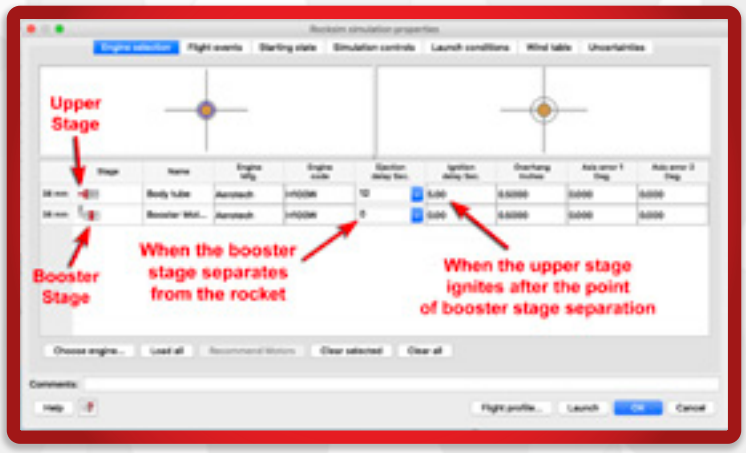

FIGURE 1: THE ENGINE SET-UP IN ROCKSIM-PRO

In Figure 1, this is the screen where we make our motor selection. There are two motors that need to be put into the rocket. The icons on the far left show you which stage they are. The top one is the upper stage, and the lower one is the booster stage.

You can see that I selected the H100W for both stages. On the ejection delay, for the upper stage, I selected a parachute ejection delay of 12 seconds. So if you were familiar with the naming convention of rocket motors, this

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would be a H100W-12. In actuality, the only available motor is the H100W-14. But it is an adjustable delay, so we can get it down to 12 seconds fairly easily.

For the booster stage, I have a H100W-0 motor. Unfortunately, in real life, we can't have a zero-second delay. But I need the 0-second delay, because that is what RockSim uses to control when the stages separate.

How do we do that in real life (make a zero second delay)? The answer is we use a technique called drag-separation (see https://www.apogeerockets.com/Advanced_Construction_Videos/Rocketry_Video_306). So this is possible too.

Typically, RockSim uses the separation as the trigger to fire the upper stage motor. But we want to delay that firing, because we want the upper stage to coast upward. Therefore, we'll put a number in the "Ignition delay" column for that motor. I randomly choose a 5 second delay. The number is arbitrary at this point -- I don't know what it will be, so I'm guessing. This is actually the "hang time" that we want to maximize.

RockSim-Pro is different from regular RockSim, in that you actually have to specify the separation trigger of the two stages. As I just said, normally the delay time of the booster motor (the H100W-0) is used to control the separation. But in the Pro version, there are actually a lot of options you can have that determine when separation occurs. So we have to make sure we specifically tell the software when we want separation to happen, and that is done on the "Flight Events" screen as shown in Figure 2.

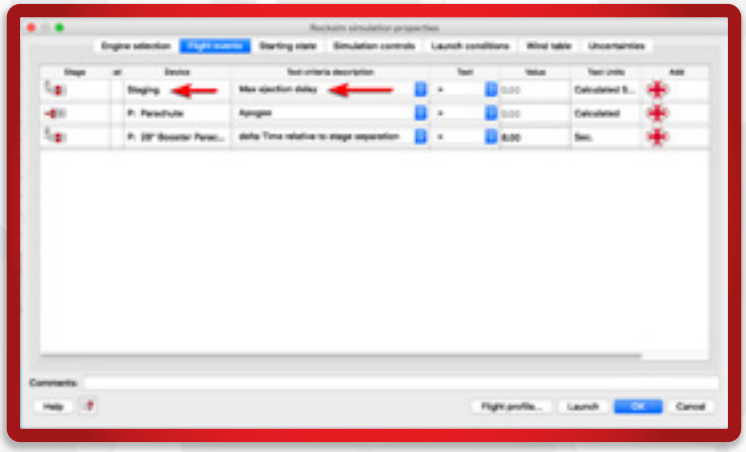

FIGURE 2: WHEN STAGING (THE SEPARATION OF THE THE PARTS) OCCURS MUST BE DEFINED IN ROCKSIM-PRO USING THE FLIGHT EVENTS FEATURE.

You see that the first row in the Flight Events chart is called "Staging." This is set to "Maximum Ejection Delay" in my example. What this setting means is that the delay charge of the rocket motor in the booster (the H100W-0) will be the triggering event. In essence, we are making it just like regular RockSim, and the trigger it uses for staging. But this trigger has to be specified in RockSim-Pro.

If you don't set it (like you forgot, or weren't paying attention), the default value of staging separation is "Stage Now."

This is bad… It means that as soon as you trigger the rocket to launch (by pushing the launch button), you are also telling RockSim-Pro to separate the booster and fire off

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the upper stage. Essentially, only the upper stage fires. And then you will wonder what went wrong. But it did exactly what was specified, which was to "stage now."

Everything else in the flight events, I'm ignoring for now. That information is when the parachutes are deployed. I'm not concerned about when the parachutes are ejected, as I just want to figure out the longest hang time for air starting (staging).

When I run the simulation, I get a screen as shown in Figure 3. This is the Launch Visualizer.

FIGURE 3: THE VIEW IN THE LAUNCH VISUALIZER SHOWS THE TRAJECTORY OF THE ROCKET. THERE IS NO WIND, SO THE ROCKET GOES STRAIGHT UP.

I always like to look at the Launch Visualizer flight profile, because it puts everything into perspective. I can see the flight in real time, and get an idea of what to expect. It also helps to debug the set-up conditions, such as if we left the flight event as "Stage Now" as opposed to the correct set-up of staging at max ejection delay.

The one thing we notice right away from the Launch Visualizer flight profile is that the rocket went nearly perfectly straight up. This makes sense, because I set the wind to zero. The thing of importance here is the apogee point is indicated by a green dot. The color of the dot is significant, because it tells us if the apogee point was within the weathercocking cone. This is exactly what we want to see. It is the criteria we set out as a "safe" launch. The rocket is going upwards and not traveling very far horizontally.

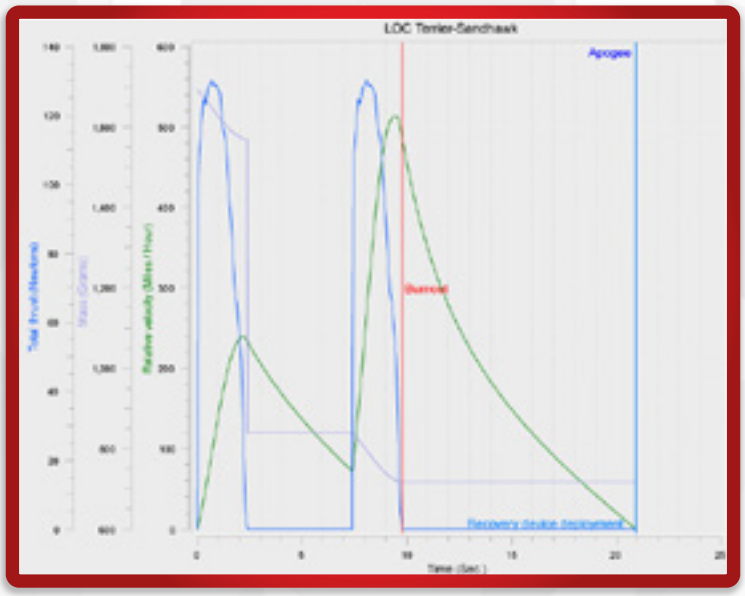

FIGURE 4: GRAPH OF THE SIMPLE SIMULATION WITH NO WIND

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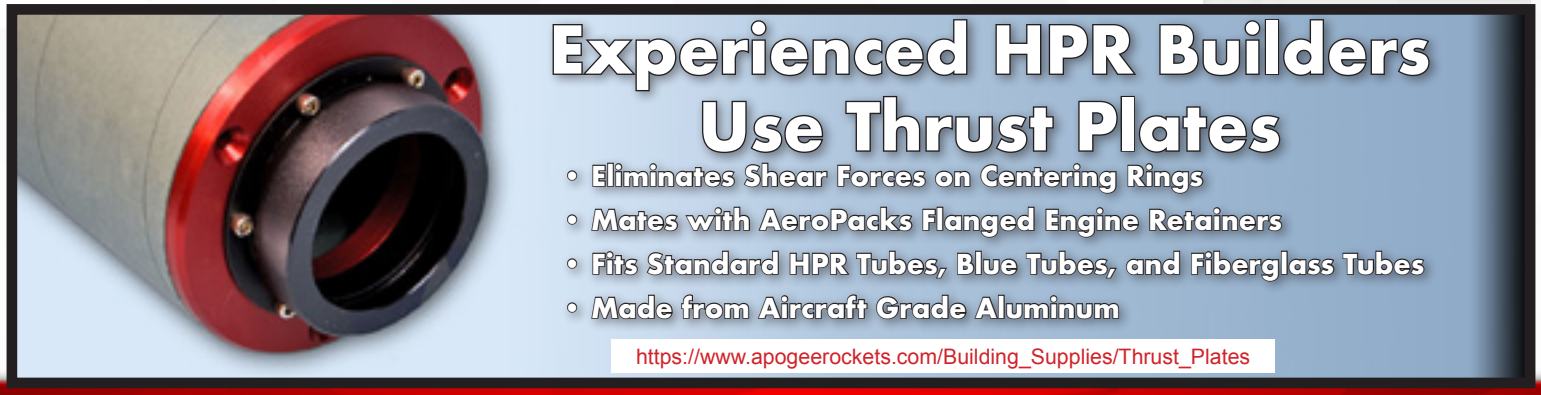

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If the rocket was going too far horizontally, the apogee point would be outside the weathercocking cone. This would be indicated in the Launch Visualizer as a red colored apogee point. This is bad. We don't want to see a red colored apogee point. So from this one simple screen, we can easily tell if our setup yielded a safe trajectory.

But I want to see more information, so I'm also plotting a graph of some of the flight data, as shown in Figure 4.

This shows the thrust of the rocket, the mass, and the velocity of the rocket. It is a bit confusing, so I'll break it up so you can understand what I'm trying to see.

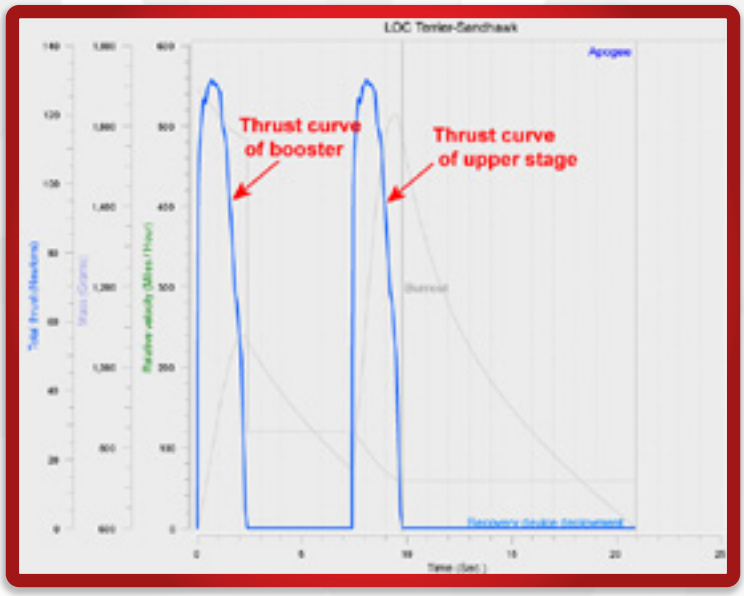

FIGURE 5: THE THRUST CURVES OF THE TWO MOTORS IN THE ROCKET

In Figure 5, I've isolated just the thrust curves of the rocket.

You'll notice that the two bumps are identical. They have the same shape, same peak thrust, and same duration. And that makes sense, because both stages in the rocket used the H100W motor.

In Figure 6, we see the Mass curve isolated.

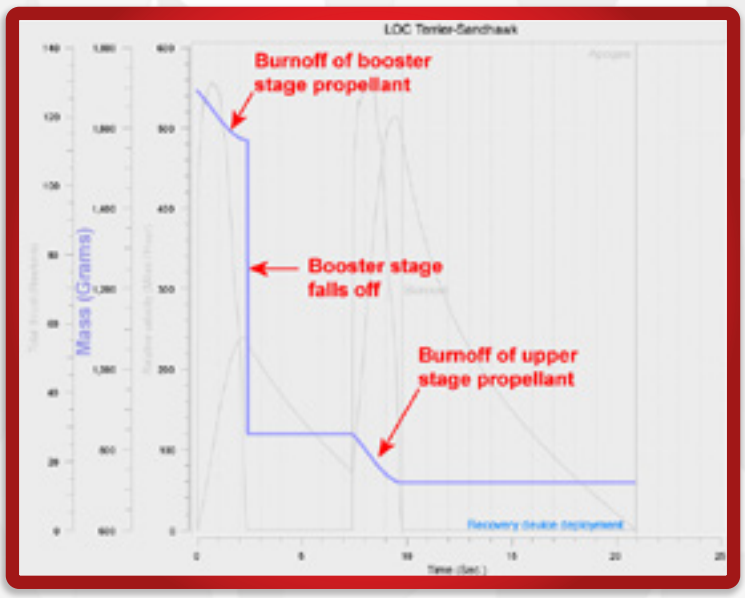

FIGURE 6: THE MASS OF THE ROCKET PLOTTED FROM LIFT-OFF TO APOGEE

I wanted to see the mass curve as shown in Figure 6, because I wanted to verify that in the behind-the-scenes of RockSim-Pro, it was calculating everything correctly. And it does look good.

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This plot shows how the rocket is losing weight as it travels upwards. Right at time-zero, the rocket begins losing weight. Why? Because the propellant is being burned off by the rocket motor. It gradually reduces weight, right up to the point of the burnout of the booster stage. Then, it dramatically falls off a cliff, as shown by the vertical line around 2.3 seconds. Why is this? Because the booster stage completely separated from the rocket. This is exactly what I was looking for. It is verification that the stage did drop away correctly.

Then we get a flat horizontal line from 2.3 seconds to around 7.3 seconds. This is the coasting phase of the upper stage, before the motor ignites. It is horizontal, because the rocket is not losing weight during this time period.

At 7.3 seconds, the graph again shows a gradual decline in mass to right before 10 seconds. This is because the upper stage motor is burning off propellant. And then finally after 10 seconds, the mass remains the same until the end of the data. Again, this is normal, as nothing is falling off the rocket.

Finally, in Figure 7, we see the velocity of the rocket isolated in the graph.

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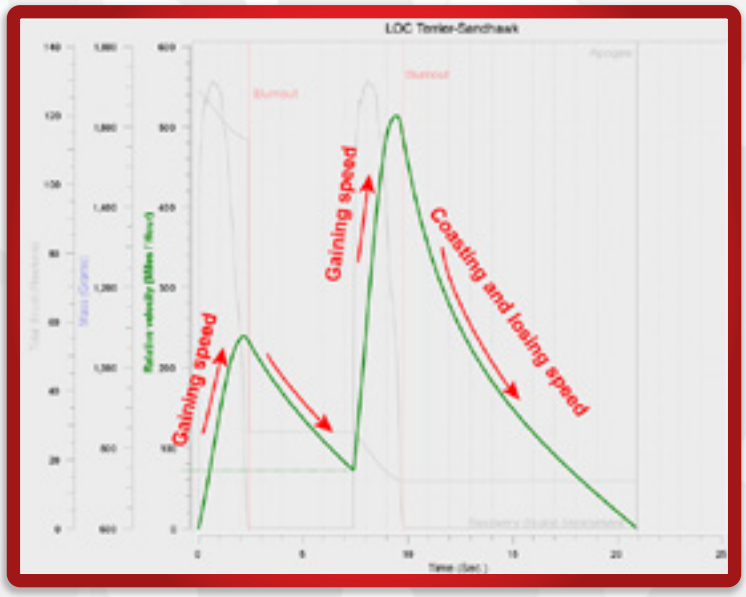

FIGURE 7: THE VELOCITY GRAPH. NOTICE THAT THE ROCKET DOESN'T SLOW DOWN TO ZERO SPEED DURING THE FIRST COASTING PHASE.

The lines tell us that twice during the flight, the rocket gains speed. The first is during the booster motor burn, and the second during the upper stage motor burn. This is as expected.

It also loses speed twice during the flight. First after the booster stage is done burning, at which time it is coasting upwards. The second time is when the upper stage motor burns out, and it coasts all the way up to apogee, where the speed drops down to zero.

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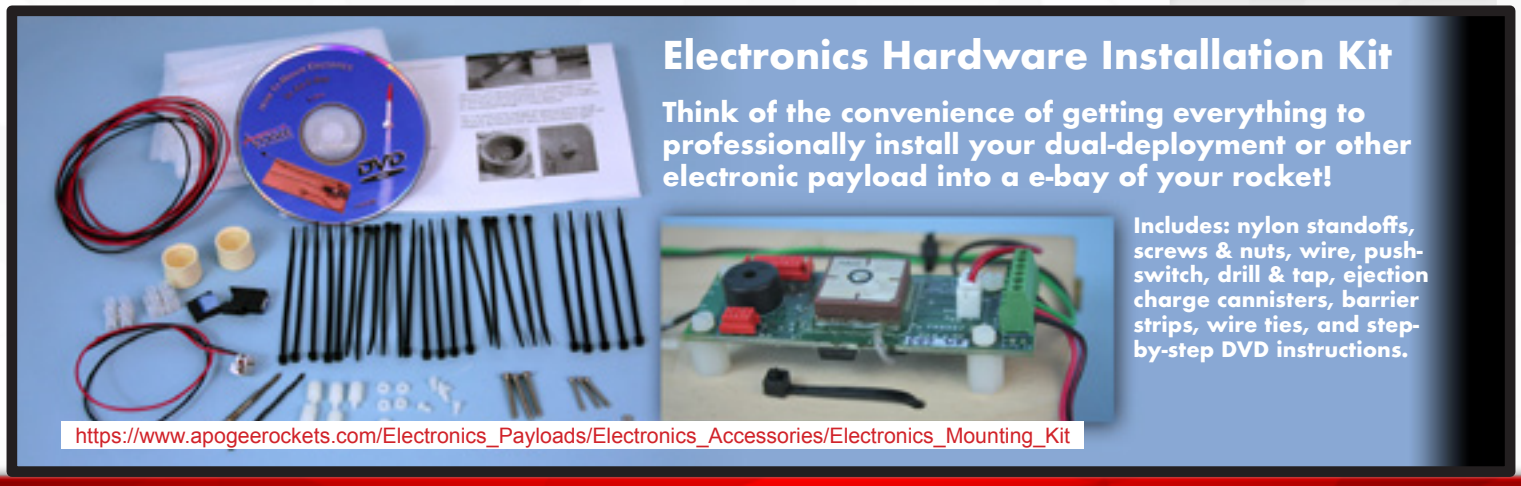

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What is important to notice from this graph is that the rocket doesn't coast down to zero mph during the first coasting phase. If you extend the lowest speed to the index on the left, you can see that the slowest speed the rocket reached at around 7.3 seconds was approximately 76mph. That's still moving at a pretty good speed.

What this tells us is that the rocket could have coasted longer, and we could have had a longer "hang time" during the flight. That is what we want to maximize, after all.

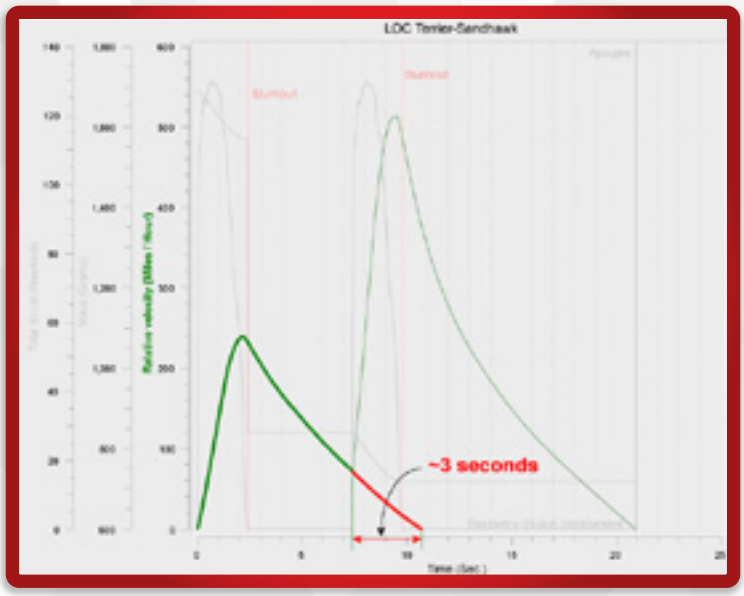

FIGURE 8: THE THICK RED LINE IS OUR EXTRAPOLATED GUESS AS TO HOW MUCH LONGER THE ROCKET COULD HAVE COASTED.

How much longer? This is where we have to make what is called an "extrapolation." This is what engineers do all the time. We look at the data, and we see if we can guess where the rocket would have coasted to zero miles per hour. This is shown in Figure 8.

From the velocity curve as shown in Figure 8, we try to extrapolate to the point where the rocket might have slowed down to zero during the first coast phase.

We have to try to match the curvature of the line during the coasting phase, which is what I did. It turns out that this is almost an extra three seconds of coasting that the rocket could have done.

We originally guessed at a 5 second coasting phase, and now we can add another 3 seconds to that, for a total of 8 seconds.

However…

The problem with this simulation is that there was no wind. How often do you fly with no wind? Never, right?

What happens if there is wind during the flight? The rocket starts to weathercock, of course. That means it starts to go horizontal as well as vertical.

Figure 9 shows the Launch Visualizer screen of the same simulation, but this time with a 4mph constant breeze coming out of the west.

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FIGURE 9: WHEN WIND IS ADDED, THE ROCKET STARTS TO WEATHERCOCK (TURN INTO THE WIND).

Again, the Launch Visualizer shows you a lot of information that can help you decide if you have your launch set up to meet your objectives.

In this image, we can see the red ground path of the rocket, showing how far away from the pad it is at any point in time. On the bottom of the screen, you see the current time of 20.77 seconds, and in the top left corner, we can see both the altitude and the distance the rocket is from the launch pad. Currently, the rocket is 1445 feet, due west of the launch pad. It doesn't look like much from this perspective, but that's actually a good distance away.

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We also see the white smoke trails of the rocket motor. They are off from the green-line trajectory path because the wind has blown them towards the east.

What is neat to see is the upper stage smoke trail. Just like in real life, the smoke starts where the airstart kicks in.

I've also noted where the booster burnout point is. You might be asking how I can tell where that point is? Again, I'm extrapolating from the given information. I can see where the smoke trail ends from the booster stage. I then just moved that point leftward to the trajectory line. That's how I know where the booster stage separates from the upper stage.

The most important thing to notice though, is the green dot of the apogee point. Since it is green, and not colored red, we know that it is inside the weathercocking one. I didn't even need to turn on the option to display the weathercocking cone. Just the color of the dot alone tells me all that I need to know.

What did I need to know? That this was a safe flight.

At this point, we can start to play around with the ignition delay of the upper stage to maximize the "hang time" of the rocket. When we increase the ignition delay, we'll come back to the Launch Visualizer screen and just check to see if that apogee point is green or red. If it is green, we're good. And if it is red, then we need to dial the ignition delay time downward until it is green.

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FIGURE 10: FLIGHT WITH A 6-SECOND IGNITION DELAY

Figure 10 shows the simulation where the ignition delay time was increased from 5 seconds to 6 seconds. Everything else stayed the same (straight up launch, 4mph wind from the west). You can see from the red dot that the flight was unsafe. The apogee point is outside of the weathercocking cone, and the rocket is going too far horizontally. At this time in the flight, it is now 1914.0 feet westward from the launch pad.

So for this particular simulation, the maximum hang time (the ignition delay) that we can tolerate is somewhere between 5 and 6 seconds. You can see from Figure 10 that the red dot is pretty close to the edge of the weathercocking cone. From that piece of information, I'd guess that the maximum hang time we could use is closer to 6 seconds than to 5 seconds.

What you'd have to do to confirm that is to run another simulation, at say 5.7 seconds.

But if you want more safety, defined as a straighter flight path, you'd probably dial it back down to 5 seconds.

To kind of recap, you could have any delay time set on your electronics from 0 to almost 6 seconds. The lower the time number, the straighter the flight because it wouldn't weathercock as much as it slows down. The higher the number, the more hang-time it has to build up anticipation in the spectators. Ultimately it is your choice, but I recommend you err on the side of safety.

It gets more complicated…

Now that you know the process to figure out the maximum time you could use for your ignition delay, you would start adding into your simulations other criteria. For example, this would be considered a "complex flight" by NAR and Tripoli launch rules -- it's high power, and a two stage rocket. The NAR would like you to point the launch rail at least 5° away from the spectator line for added safety.

Now you also need to know where the spectator line is on the launch field. But you still have probably 180° of azimuth (compass direction) to play with. So it does get a bit more complex.

There are lots of other variables too, like the wind direction and velocity.

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The best thing to do is probably run the simulations on the field, right before you launch. At that point, you know where the spectator line is, and you can measure the winds on the field. From that, you can adjust the launch angle, and the azimuth direction the pad is pointed.

While RockSim-Pro only runs on a desktop machine, if you have a phone, you can run the simulations described here using the online cloud-based Launch Visualizer that is at https://www.RockSim.com. All you need is cell phone service to connect to the website to run your simulations. It allows you to dial in on your set-up for safety, and so that you can achieve your mission.

Conclusion

Can you think of additional ways to get the rocket to weathercock less so you could use a longer ignition delay time? There are probably a few more things we could do here, like adjusting the CG of the rocket by moving electronics around to different locations, and doing things like spinning the rocket a lift-off.

That is the beauty of a program like RockSim-Pro and the Launch Visualizer at RockSim.com. You can set up some really complex simulations to try to optimize your rocket for the mission you want to achieve. It is a tool that makes you a better and safer rocketeer.

I hope you give it a try today.

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Additional Information

Apogee Staging Timer: https://www.apogeerockets.com/Electronics-Payloads/Staging/Simple-Timer-for-Staging

About The Author:

Tim Van Milligan (a.k.a. “Mr. Rocket”) is a real rocket scientist who likes helping out other rocketeers. He is an avid rocketry competitor and is Level 3 high power certified. He is often asked what is the biggest rocket he’s ever launched. His answer is that 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 an 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 also the author of the books: *Model Rocket Design and Construction*, *69 Simple Science Fair Projects with Model Rockets: Aeronautics* and publisher of the “Peak-of-Flight” newsletter, a FREE ezine newsletter about model rockets. You can email him by using the contact form at https://www.apogeerockets.com/Contact.

Sledge Hammer Rocket Plan

Download the ***RockSim*** design file for the Sledge Hammer at:
https://www.apogeerockets.com/Peak-of-Flight-Rocket-Plans

Sledge Hammer Parts List

10168 - (1) Slotted AT-56 (BT-70 tube)
10198 - (1) AT-66 (BT-80 tube)
12022 - (1) Motor Mount Kit 29/BT-70
13529 - (1) Stand-off Rail Guide (56mm-to-66mm)
13531 - (1) Universal Rail Guide
14092 - (1) ⅛" x 4" x 18" Basswood Sheet
17081 - (1) Blow mold transition from 66mm-to-56mm
20080 - (1) PNC-66
24020 - (1) Estes 29mm screw-on retainer
29093 - (1) 24" Nylon parachute
30326 - (5 ft) 300-lb Kevlar shock cord

Order parts at:
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Sledge Hammer *By Tim Van Milligan*

Color scheme and decoration by Derek Villar

About the Design

For this plan, I wanted to design a rocket that had multiple diameter tubes in order to give it a different shape from a normal rocket. A few years back, I created a blow-mold transition for the TARC teams that had design rules that required a transition. So that blow-molded transition was a natural component for this design. If I think about it, this rocket design probably would have been a good example for a TARC rocket. It flies on a single 29mm diameter motor, which allows for dozens of motor options for the rocket. You should download the RockSim file so you can simulate the rocket on your own launch field.

Here is a sample flight (on an E23-5 motor) from the Launch Visualizer that you can look at from any view angle to get an idea of what it is like: https://rocksim.com/apis/nUtZ7v21f?img=LVgifs-8.gif

I think with the parts listed here, this would probably make this a skill level 3 design. However, all the tubes have to be cut down to their proper lengths, so that would bump this up to a skill level 4 on our complexity level. You'll also have to cut the basswood fins to the proper size, as well as to get them to fit on the blank sheet of wood. The pattern sheet for the fins shows the fins broken into two halves that are to be glued together prior to attaching them on the rocket. I oriented the wood grain on the rear panel at a different angle in order to put the wood grain parallel to the rear edge so that it is a little easier to finish the model. There is a suggested layout of the fin panels so that they all fit on a single sheet of basswood.

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Sledge Hammer Rocket Plan

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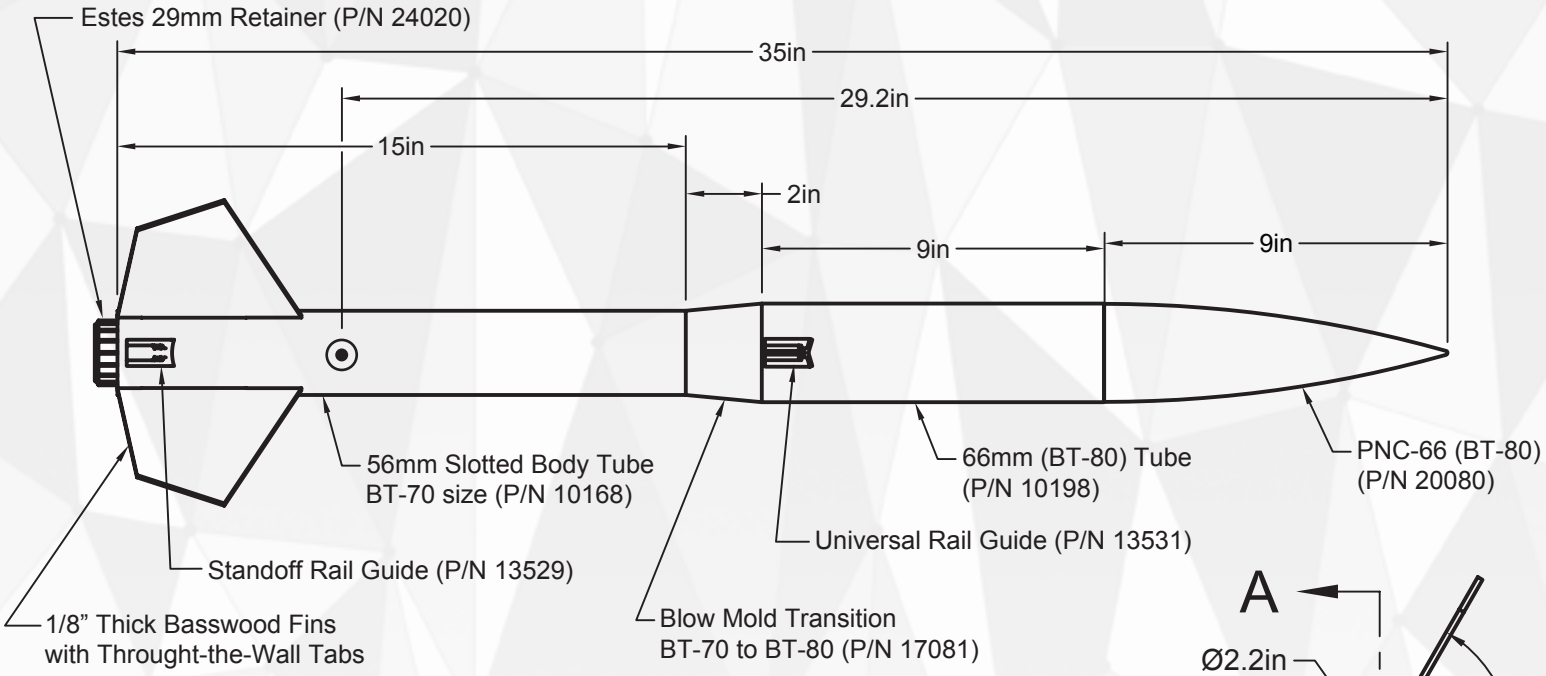

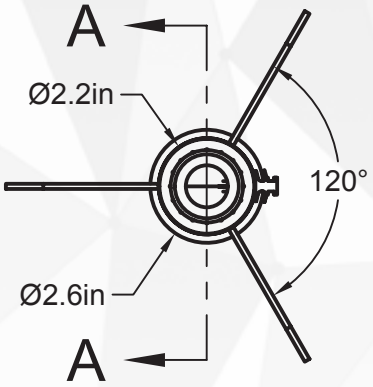

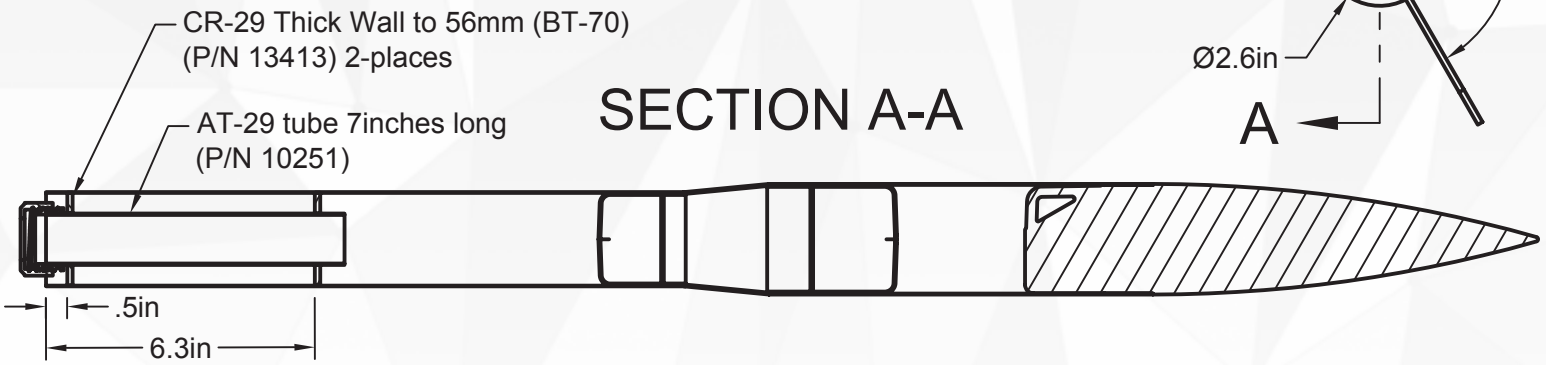

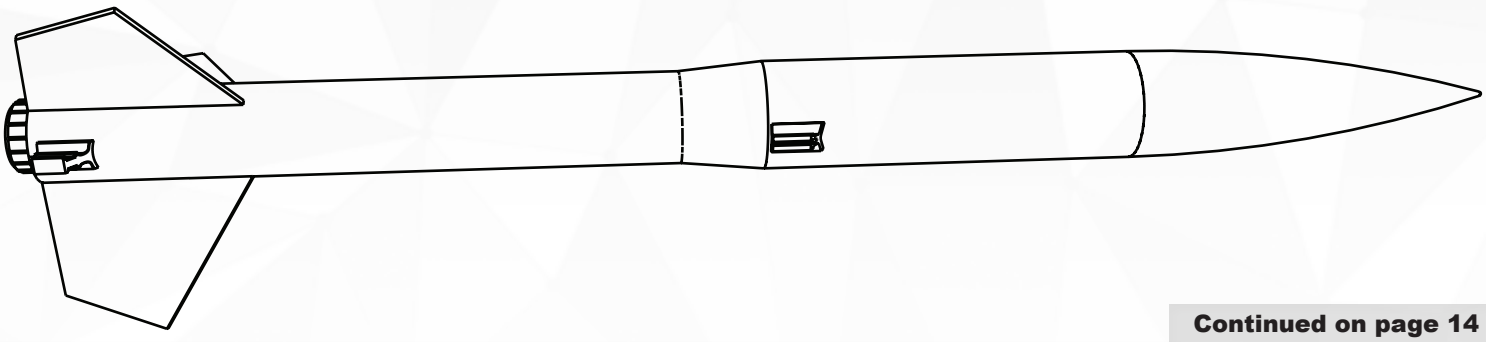

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Sledge Hammer Rocket Plan

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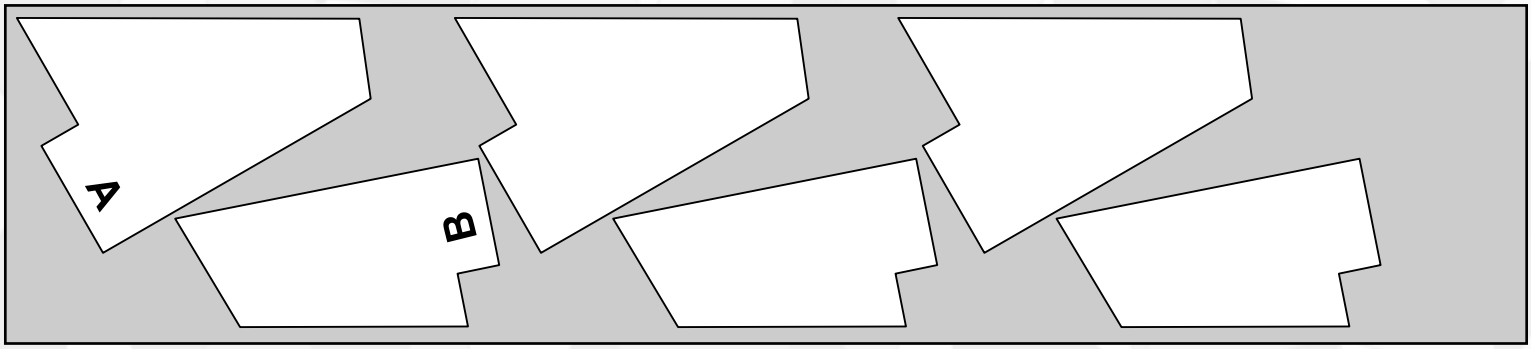
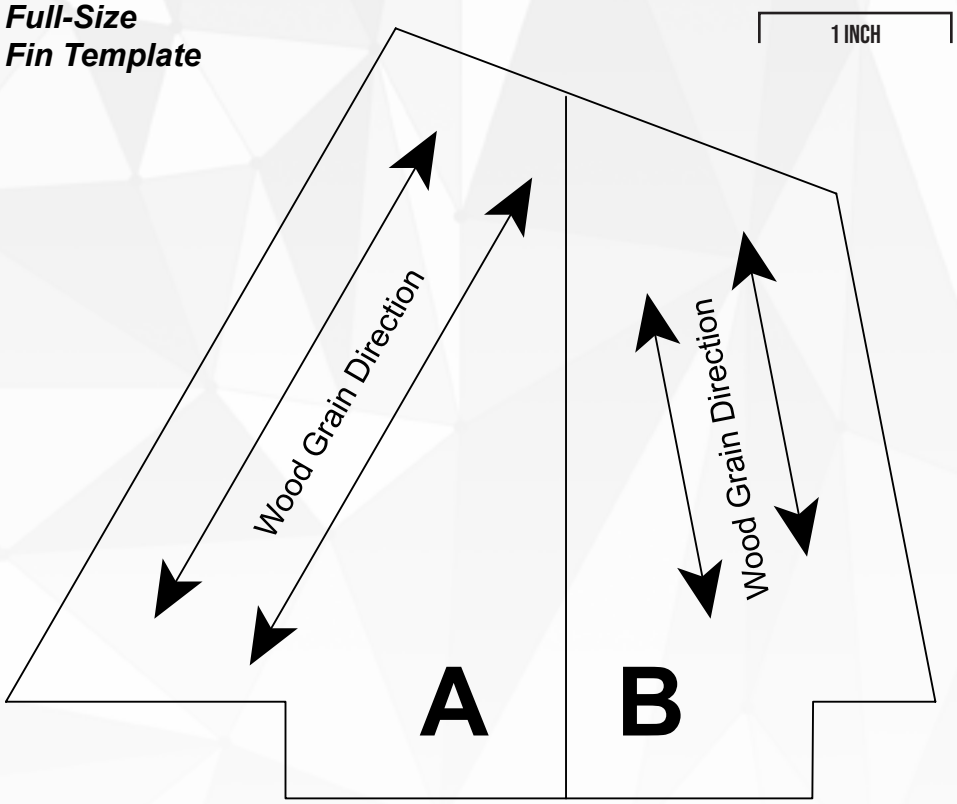
Suggested Layout of Fin Panels



1/8” X 4” X 18” Basswood Sheet

Full-Size Fin Template



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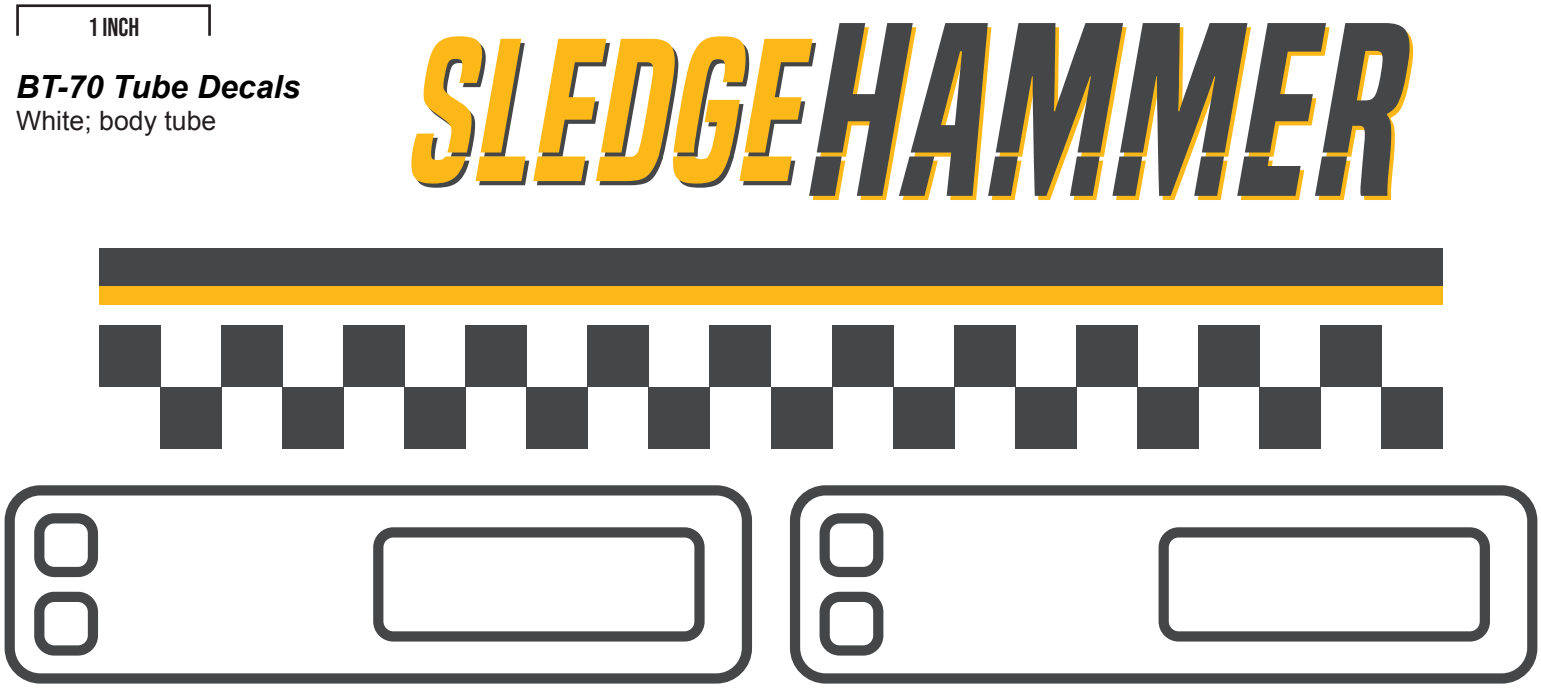
1 INCH

BT-70 Tube Decals
White; body tube



Fin Decals
White; 6 total, one for each side of the fin

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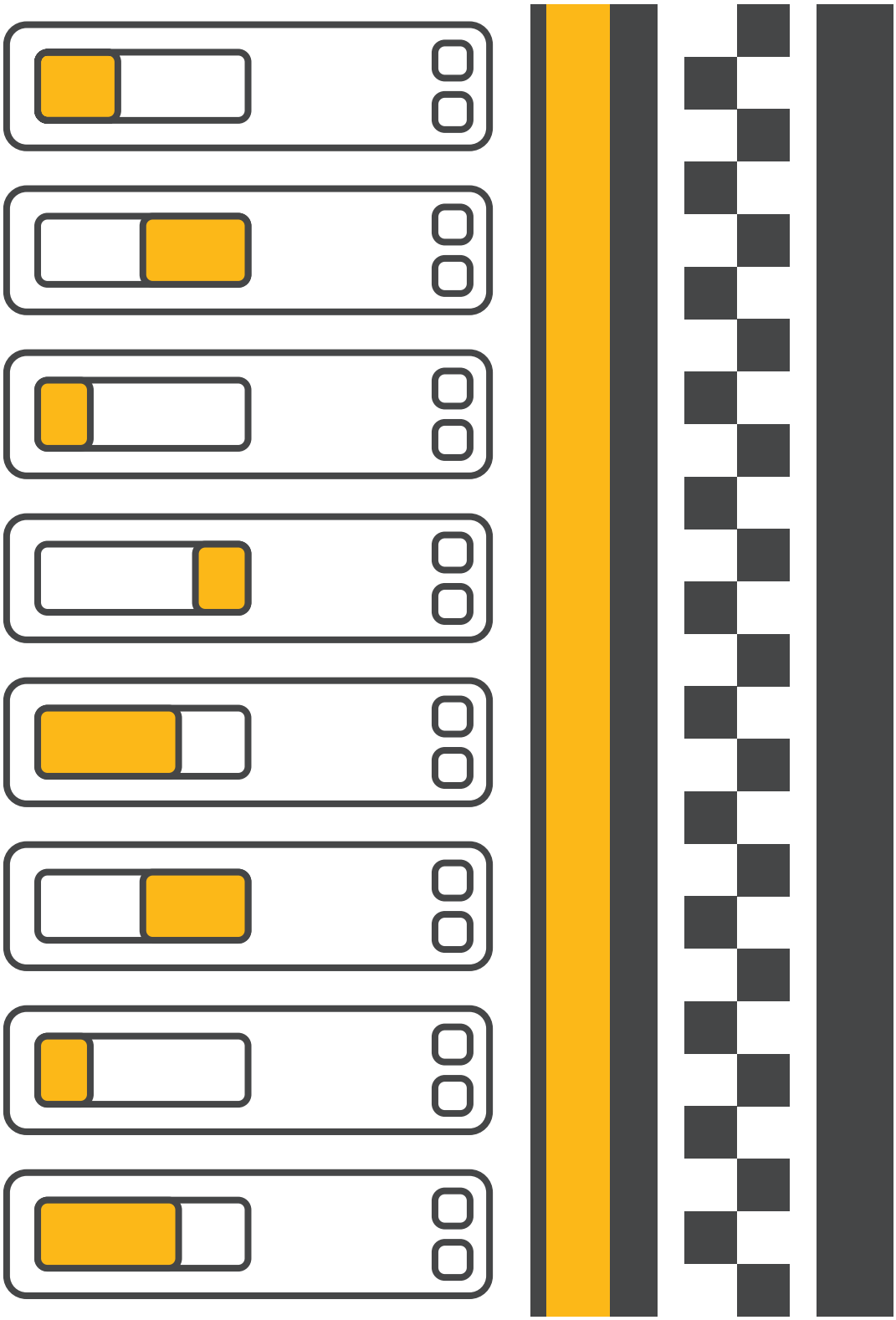
1 INCH

BT-80 Tube Decals
White; body tube