How to Build a Rocket for L1 Certification (Vulpes II Rocket Launch)

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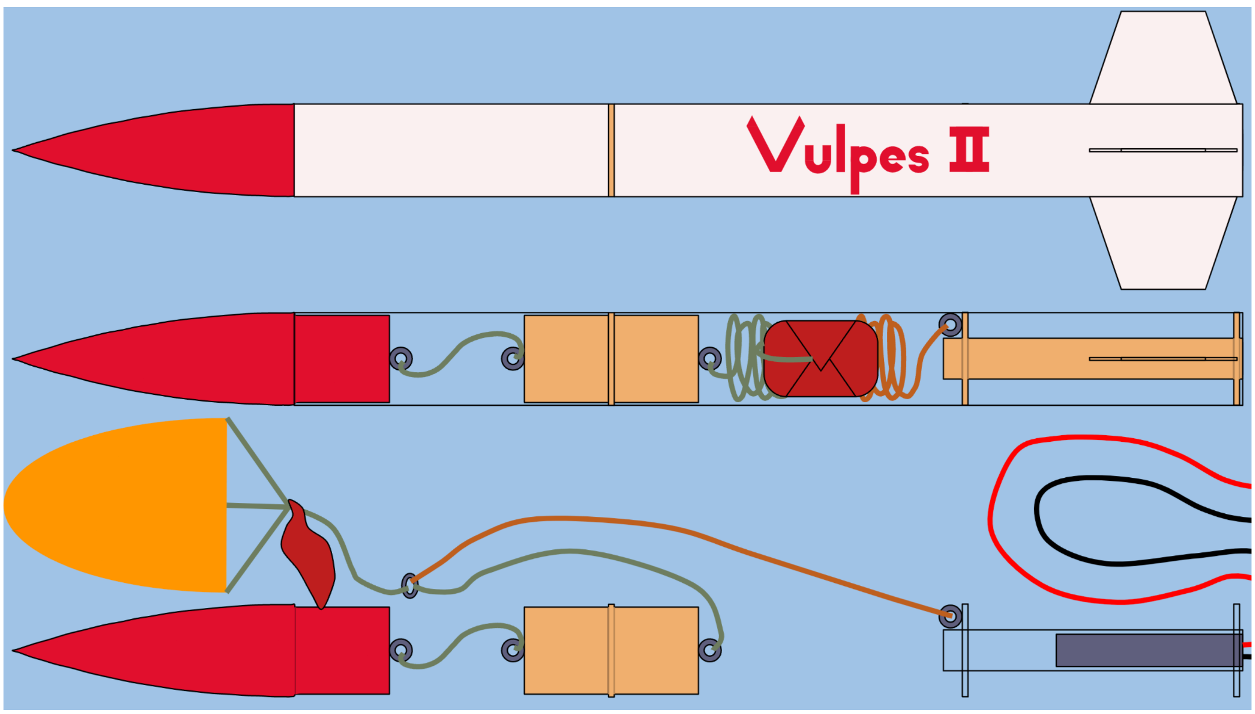
Announcement



Thumbnail of our most recent video, which can be found on YouTube at
https://www.youtube.com/watch?v=aXq2AdKqtJY

On January 14th, I launched the second hobby rocket I've ever built. The Vulpes II is an L1 certification rocket, meaning that it had to meet certain standards for me to obtain the certification to purchase H and I class high-power rocket motors. Getting to an estimated apogee of 430 meters and successfully separating, the Vulpes was recovered intact. The Vulpes' motor was single-use, but its intact structure means that all it would need is a new motor to launch again. Learn all about the Vulpes and how you can build your own L1 certification rocket in this Graviton Media video on YouTube or Odysee. An unedited video of the Vulpes' flight is also available on YouTube, Odysee, and TikTok. I hope you enjoy the videos!

Below is a rough transcript of the video based on the script I wrote for it:

> This is the Vulpes II rocket. It's my second hobby rocket, and it's my L1 certification rocket. At nearly five feet long and over three pounds, this rocket used an H class motor to reach an apogee of 1400 feet and safely return to earth. The principles used to design the structure and plan the flight of the Vulpes were crucial to its success. I'd like to tell you more about my rocket and these principles so that you too can get into hobby rocketry.
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> Let's start with a look at the Vulpes' structure from tip to tail. This rocket consists of two main tubes that hold all the equipment it needs to launch and land safely. I'll start with the upper body tube, a hollow, 38-centimeter tube of cardboard that connects the nose cone to the tube coupler. On its own, this tube didn't serve much purpose for January's flight other than connecting these two more-important pieces together and holding them in place. However, were I to fly the Vulpes again, it would come in handy as a place to store the rocket's payload. In January, the Vulpes had no payload—I will discuss what its mission was later—but some of my fellow hobbyists that flew rockets of similar design included payloads like an experimental GPS tracking system and a live snail. The fact that both of these delicate machines—one technological and one biological—survived their flights suggests that the upper body tube does fairly well for holding a payload.
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> When it comes to a rocket's nose cone, there's a reason they all look so similar: their shape greatly impacts the aerodynamics of the rocket. Drag forces from air resistance slow a rocket down as it flies, decreasing its capacity for height, speed, or payload mass. A simple approximation of drag comes from the equation: $Fd = \frac{1}{2}\rho v^2 Ac_d$ "force equals one half times the density of air times the velocity of the rocket squared times the cross-sectional area of the rocket times the drag coefficient." Generally, a rocket's mission will demand a certain velocity and diameter from the craft, so the main factor to minimize is the drag coefficient. This term is a unitless number that is quite mathematically complicated to determine, involving pressure drag (which conforms well to the previous equation) but also friction drag (which relates to air running along the length of a body) and a whole host of other factors like the behavioral differences between sub- and super-sonic air flow, the roughness of a body's surface, and the boundary layers of air around a body. Trust me, this is a whole field that one can research, so I don't have time to discuss it today. The important part is that a shape known as a tangent ogive does pretty well at minimizing the drag coefficient for hobby rockets, so that is the shape I used for the Vulpes' nose cone. Mathematically, this shape comes from taking a section of a circle like this and rotating it about an axis, creating a shape that starts at a point and broadens out to become flush with the upper body tube. Just by looking at it, one can tell that it is aerodynamic, as it pushes the air out of the way with minimal backward force on itself.

The Vulpes' nose cone is made of acrylic, and attaching it firmly to the upper body tube and the rest of the rocket is important, because the aerodynamic shape of the cone would make it incredibly dangerous coming down without a parachute. First, the cone is friction fitted as tightly as possible to the tube; then, it is tied to a strong shock cord that attaches it to the tube coupler at the other end; and finally, a screw is drilled through the tube and cone. This triple insurance made the cone extra secure.

The wooden tube coupler and its two bulkheads sit on the other end of the upper body tube. This device is quite simple, attaching the upper body tube to the lower body tube tightly enough for them to stay together during ascent, but loosely enough for the separation event to successfully deploy the recovery system. Like the nose cone, the coupler is friction fitted tightly to the upper body tube and a screw is drilled through it. On this side of the coupler, I wanted everything to stay firmly together during the flight. The other side of the coupler, attached to the lower body tube, is where a balancing act between tight and loose comes into play. The rule of thumb for the Vulpes is to make the coupler tight enough that the rocket stays together while lifted by its upper body tube but comes apart when shaken up and down. This step required some careful modification to the coupler by adding or removing layers of tape to slightly adjust its diameter and friction fit. The lower half of the coupler is connected to another shock cord that attaches it to the recovery system. Unlike the Vulpes I, which splits into two pieces and falls in two pieces, the Vulpes II splits in two but both halves remain attached to a single parachute.

Now, the lower body tube. This is a cardboard tube with the same diameter and twice the length of the upper body tube. The lower body tube houses the Vulpes' all-important recovery system, which consists of a 76-centimeter parachute and its burn protection. Further, it contains the Vulpes' motor, the driving force of the rocket that allows it to fly in the first place.

In preparing the Vulpes for launch, its parachute is wrapped up in two kevlar heat blankets and tied to the coupler and the motor's upper centering ring to keep it attached to both halves of the rocket after separation. The cord tied to the centering ring also has a protective kevlar sheath. Further, a couple handfuls of cellulose recovery wadding, or "dog barf," as hobbyists call it, is placed in the tube on top of the upper centering ring. Finally, the parachute is packed on top of this wadding and the upper body tube is attached to the lower body tube via the coupler. The purpose of all of the kevlar and wadding is to prevent any component of the recovery system from burning or breaking during separation, an event I will talk more about shortly.

The Vulpes' fins are attached to the exterior of the lower body tube. Fins on a rocket aren't just for show; they help the rocket stay upright while flying. If you've ever tried to balance a pencil on your finger, you'll know it's hard to keep a long object upright while applying force from below. A rocket has the same problem.

However, it has another source of force that can prevent it from destabilizing: drag. Yes, that inconvenient drag force can actually help a rocket stabilize by pushing on its fins. Imagine if the Vulpes were to tilt slightly as it flew. All of a sudden, its fins would be showing a long, diagonal cross-section to the air. As the air hit the fins, it would push them sideways against the direction of the tilt. Since the Vulpes' center of gravity is above its fins, this drag force would provide torque to kick the Vulpes back into an upright position. That's why fins and their placement are important to a hobby rocket. Without fins, or with fins too high up on a rocket, drag forces can't provide the proper torque to prevent tilting.

The last component of the Vulpes is its motor. Being skinnier than the body tube itself, the motor requires a motor tube fixed to the center of the Vulpes by two centering rings. The motor I used for this launch was an H class motor. Hobby rocket motors are designated by class from A to O in increasing order of total impulse. Total impulse is a measure of momentum transfer and has the units Newtons times seconds, or an amount of force exerted over a period of time. This is a useful metric for rockets, since their final heights are ultimately determined by how much upward thrust they receive and for how long. In general, the greater the total impulse, the greater the final height*. A motors have between 1.25 and 2.5 Newton-seconds of total impulse, B motors 2.5 to 5, and each successive class is twice as powerful as the last.

The Vulpes' motor was a Cesaroni motor designated 229-H255-14A. This designation lists three important facts about the motor, as well as its class. First, the motor has 229 Newton-seconds of impulse. Glancing again at the motor classification table, this puts the motor right in the middle of the H class. Second, the motor has an average thrust of 255 Newtons. This varies a little bit over the course of its firing, as can be seen by its force profile. Finally, the motor has an adjustable, 14-second delay grain. This part is quite important. The delay grain acts like a fuse to a small explosion inside the lower body tube. This explosion creates enough pressure to pop off the coupler and eject the recovery system from the tube during the separation event. Thus, this explosion is what triggers the release of the parachute. When the motor finishes firing after 0.9 seconds, the delay grain's timer starts, so the separation event has to be timed in terms of seconds after the motor finishes firing. Ideally, the separation event occurs just after apogee to slow the rocket's descent. According to OpenRocket simulations, the optimal delay to time separation correctly for the Vulpes' flight was 7 seconds. Therefore, I used a plastic drill to file down the adjustable delay grain to 7 seconds to prepare the motor for flight.

With that, the Vulpes is ready to fly. The motor is placed in the motor tube and secured with two screws, rail buttons are drilled into the lower body tube so that the rocket can sit upright on the launch rail, and an igniter is placed in the bottom of the motor to be remotely triggered from a safe distance back. 5 4 3 2 1—liftoff.

Before I continue, you might be wondering why I flew the Vulpes in the first place. As I mentioned, rocket motors are designated from A to O in order of increasing total impulse. Since rocket motors can be dangerous if handled incorrectly, and since this danger only rises with a higher total impulse, the companies that sell motors have adopted a self-regulatory scheme in partnership with national hobby rocketry associations to prevent injuries and accidents. This means that the largest motor an uncertified member of the public can purchase is a G motor, a motor with less than 160 Newton-seconds of total impulse. An L1 certification, however, unlocks H and I motors to the hobbyist, representing a four times increase in total impulse to 640 Newton-seconds. This allows for the creation of rockets that can reach higher altitudes and carry more mass for scientific equipment. To earn an L1 certification, a hobbyist "must build, launch and successfully recover a rocket using a certified HPR motor in the H to I impulse range." Typically, this is done under the supervision of a certified mentor. Afterall, you need someone certified to buy one of these motors for you in the first place. Rice Eclipse Rocketry Team has a program to certify its members by supervising them and providing them with an H class motor. This is the program I participated in to build and launch the Vulpes and earn my L1 certification.

As an L1 rocket, the Vulpes II was not required to contain any electronics equipment—that's a requirement for more-complex, L2 certification rockets. Therefore, I can't know exactly how the flight unfolded in terms of the timing of events and precise measurements of the rocket's motion. However, OpenRocket simulations and video recordings of the flight paint a decently accurate picture.

After the motor ignition, the first second of the Vulpes' flight was powered, meaning that its motor was actively providing thrust. Within a second, the Vulpes reached its top speed of about 140 meters per second. Its peak acceleration during this period was briefly 22 gees. Not all payloads would be able to survive such massive acceleration, so care must be taken when designing a rocket to ensure that its payload can actually survive its launch.

After that second, the Vulpes experienced 7 seconds of unpowered flight. It would be tempting to describe this period as a "free-fall" or "ballistic" trajectory. However, those descriptions ignore the significant drag force that acted on the rocket, at times more strong than gravity itself. During this period, the Vulpes quickly shed its momentum as it climbed to an altitude of 430 meters. Here, it finally ran out of steam and started coming back down. At the same time, the delay grain's time ran out, triggering the explosion that separated the rocket and released its recovery system.

The descent phase of the flight that followed was relatively gentle compared to the extreme forces and accelerations involved in the previous few seconds. Here, the Vulpes drifted to the ground at a rate of 7.5 meters per second and landed in the grass near Hearne Airport's runway. After a few other rocket launches, the range was clear for me to go pick up my rocket and bring it back. While a simple task for a small rocket, recovery can become a challenge with larger rockets that reach higher altitudes. Often, these rockets don't remain in sight through their flights, and they drift far from their launch sites. Thus, these large rockets need GPS tracking systems so that their builders can drive out to the locations they land to recover them.

Finally, to get my certification, I had to show my rocket to a Tripoli official so that he could confirm that it was undamaged. Even seemingly small issues like a broken fin can suggest serious problems with the engineering of a rocket, such as picking a parachute too small for a rocket's mass. It's not pickiness, Tripoli needs to make sure you know what you're doing before giving you your certification. Fortunately, the Vulpes II returned to earth without a scratch on it, so it passed inspection. A few weeks for paperwork, and I had my L1 certification.

Building and launching the Vulpes II was an incredible experience. As part of Rice Eclipse, I got to work alongside a bunch of other amazing hobbyists seeking their own certification. Further, the atmosphere at a launch site—typically a small, non-commercial airport—is quite exciting, as many people come to launch their rockets and show off their hard work. It's a great community of people that share an interest in rocketry. Besides that, building the Vulpes taught me a lot of engineering principles that I can use for building later, more-advanced rockets or for working a future job. If you're interested in engineering, I would highly recommend hobby rocketry to hone and improve your skills. Getting an L1, then higher certifications, are great, concrete goals to work towards. The sense of accomplishment you'll feel after a successful launch is also a great reward.

Here's footage of a test of Eclipse's Titan II Engine from two different angles. If you liked this video, please consider liking and subscribing, and if you have any questions for me, feel free to ask in the comments below.

Sources:
Video links: https://www.youtube.com/watch?v=aXq2AdKqtJY, https://odysee.com/@GravityMax:6/how-to-build-a-rocket-for-l1:d?r=CZXkFaQbqihmueWm4xp657QewkdPor84
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