Flight Readiness Report

Rocket Team

University of Minnesota Twin Cities

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Executive Summary:

The 2016-2017 Space Grant Midwest High-Power Rocketry Competition requires teams to build a high power rocket that reaches the same altitude on two rocket motors that are as different from each other as possible. Our rocket was designed in OpenRocket and reaches this goal through an entirely passive means. The rocket is 54mm minimum in diameter and is designed to fly on a CTI K2045VM and an Aerotech J90W. Due to the much longer coast phase of the K2045VM flight and the higher drag due to the higher velocity, we have simulated our design to less than a 100 foot difference in apogees. The low-mass minimum diameter design we are using allows us to reach an average apogee of above 6800 ft, greatly improving our flight performance. Our rocket uses 54mm canvas phenolic airframe from MAC Performance Rocketry. It will be 1.1m long, and its dry mass will be close to 1000 g. In order to reduce mass and drag, we will be using custom designed and manufactured flyaway rail guides.

Our rocket has an additively manufactured power-series nosecone. This nosecone has a built in pitot probe. This pitot probe is connected to our custom avionics system, which logs the data from the flight. This avionics system is based on the Raspberry Pi Zero computer, a small, lightweight, and low-cost ARM -based computer board. This Raspberry Pi Zero is also the basis of our camera system. We combine the camera module and a custom-manufactured acrylic prism in order to capture both upward and downward video during the flight. Our rocket is designed to be at least 2 calibers stable during all phases of the flight.

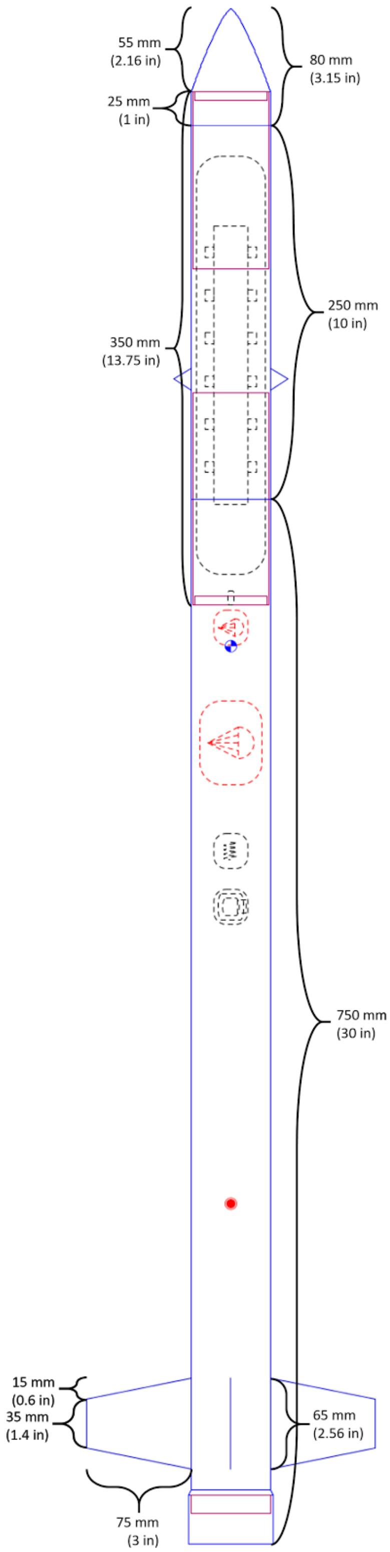
Introduction:

This is our entry into this year's Midwest High Power competition. The competition this year requires teams to build a rocket that will reach the same altitude on two motors that are as different as possible from one another, while also constructing their own noncommercial datalogging package to directly measure velocity during the flight, as well as detecting separation. Additionally, teams must collect both upward and downward video during the flight. Our designs were created using the rocket simulation software Openrocket.

Rocket design summary:

The rocket is a ultra light minimum diameter 54mm design, planned to fly on the Cesaroni K2045VM and the Aerotech J90W. No active system will be used to bring the rocket to the same apogees on both flights, only precise shaping and weighting of components. Components such as the fins and nosecone are designed to be aerodynamic at subsonic speeds, but produce significant wave drag at supersonic speeds. This helps us reach a high altitude on the J90W flight while bringing down the apogee on the K2045VM flight significantly.

Dimensional Specifications:



The rocket will use standard 54mm airframe tube (57.5mm OD). The rocket's airframe is split into a 10" upper section and a 28" booster section. The upper section of airframe is securely connected to both the nosecone and the coupler, giving it a total internal length of 15". The entirety of this upper section is used as the avionics bay, housing the two StratoLoggers and the custom flight computer.

The rocket's nosecone is a 3d printed PETG power series nosecone of shape parameter 0.749 and length 55mm. It has a 25mm long external shoulder designed to fit snugly over standard 54mm coupler. This shape is fairly low drag at subsonic speeds, but produces significant wave drag in the supersonic flight regime. The tip of this nosecone has a hole which will be used as the pitot pressure hole.

The fins are made of 6.67 mm thick carbon fiber with a Nomex-honeycomb core. The leading edge has a wooden dowel made of birch epoxied on, giving it a rounded leading edge. The trailing edge on each of the fins is a triangle shaped piece of basswood. The combination of leading and trailing edges in effect makes the fins a subsonic symmetric airfoil. A tip to tip fiberglass layup has been applied with fiberglass also covering the leading and trailing edges to ensure proper strength.

The four fins have a semi-span of 75 mm, which is larger than the diameter of the rocket. While going mach, it is recommended that there be four fins with a larger semi-span than the diameter to prevent the loss of stability during supersonic flight, referred to as "coning." The symmetric trapezoidal shape was sought after to avoid fin-flutter at high speed, as well as slightly increasing drag on the leading edge during the supersonic portion of the flight on the K2045VM. The root chord was chosen such that the fins would have a large area to bond with the surface of the airframe.

Construction

Fins

The fins are primarily made from a carbon fiber/ nomex honeycomb sandwich composite. We cut the nomex honeycomb sandwich sheet to approximate shape using a hacksaw. The pieces were then tacked together with a glue stick and sanded into the final shape using a belt sander until they had identical outer profiles.

The fins have an airfoil cross section. To make the rounded leading edge, a ¼" round wooden dowel was scraped down to a semicircular cross section. To make the trailing edge, a ¼" by ½" cross section wooden board was sanded into a tapered profile. Both the dowel and the trailing edge were cut to the correct length before being attached to the leading and trailing edges of the nomex honeycomb fin body.

The fins were first tacked onto the body with a thin layer of Glenmarc G5000 Rocketpoxy while being held in alignment by two laser cut plywood fin jigs. They were then filleted (.5" radius) with a thick layer of Rocketpoxy. After this had cured, a tip-to-tip fiberglass layup as well as encompassing both the leading and trailing edges was applied to all fins, and the entire assembly vacuum bagged for increased strength, bonding, and decreased weight.

Nosecone

The nosecone is 3D printed in PETG on a Lulzbot TAZ6. 3D-printing was preferred over molding or subtractive processes because it combines precise control over shape with quick turnaround times and the ability to produce unique geometries and infill. PETG's excellent layer bonding and high strength make it an excellent material for the fabrication of rocketry components. Note the hole in the top of the nose cone, as this will be the pitot tube. Two coats of acetone-thinned West Systems epoxy were applied and later sanded until smooth. The epoxy coat filled in between the layers allowing the surface finish to be more uniform. The nosecone was flown on both of our test flights, proving its suitability for the task.

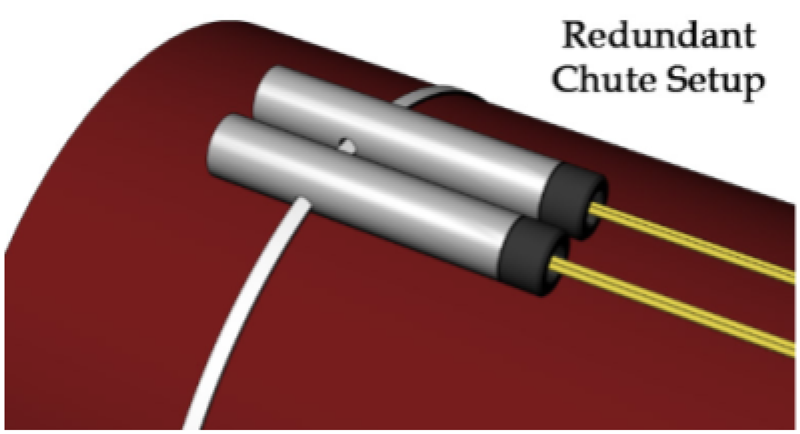
Booster Recovery Attachment Point

The booster recovery attachment point was made from a 30mm section of canvas phenolic coupler and a sheet of 1/16" G10-FR4 fiberglass. The G10-FR4 was water-jetted into two pieces, the bulkhead with holes and a cross brace. Small notches were cut so that all three pieces, the two fiberglass pieces and the coupler, would dry fit together snugly. Some filing was needed to make it fit perfectly. Once fit, JB-Weld heat resistant epoxy was used to bond the three, with an internal fillets to boost the strength. The edges were sanded until the system fit snugly inside the body tube. The attachment point is held in place with four removable 4-40 oval undercut Philips screws.

Rocket Recovery

The drogue chute is a commercial Top Flight Recovery 12” thin mill hexagonal parachute. Our main chute is a student-constructed, 30” diameter 2:1 ellipsoid design, made of 1.0 oz thin-mill nylon. The main and drogue chutes are both packed into the same 8”×8” piece of nomex flame protector. 15 feet of ¼” 1500# test kevlar cord are used for the shock cord. It is attached to the upper section bulkhead with a U-bolt and to the lower section via a 30mm section of 54 mm coupler with a bulk plate. The booster recovery attachment bulkhead has large holes to allow the motor ejection charge to pass through.

The predicted landing speed will be approximately 21 ft/s for the K2045VM flight and 20 ft/s for the J90W flight. Both landing speeds are well below the 24 ft/s safety limit. Instead of a traditional dual-deploy setup with two separation points, a system involving two redundant Archetype Rocketry Cable Cutters will be used. This system will allow us to deploy both a main and a drogue from a single separation point, saving mass and space. Both the drogue and main will be attached to the same shock cord at much different positions, and both released at apogee. Once ejected, the drogue chute will freely inflate like a normal parachute, but the main parachute will be retained inside the nomex blanket by a zip tie. At our desired main deployment altitude, the cable cutters will be activated by a signal from the Stratologgers, cutting the zip tie and deploying the main chute.This deployment setup is fully redundant, since only one of the cable cutters must deploy in order to sever the zip tie.



cable cutter layout image (credit: http://aeroconsystems.com/)

Four 0-80 shear pins will be used on the separation point to ensure that no drag separation occurs between the booster and the upper avionics section. The entire recovery process was used in both preliminary test flights. All eight e-matches, four from each flight, were ignited during the flight. Both the drogue and the main were successfully deployed during each test flight.

Materials Selection

Our strategy for reaching the same height with both motors relies on making the rocket as light as possible. Materials were selected accordingly. Most notably, a carbon fiber-Nomex honeycomb composite was used for fins. The material has incredible stiffness for its weight. It is also incredibly low density. Both factors make this material ideal for fins.

The body tube is canvas phenolic. This material is water-resistant, making it superior to alternatives such as Blue Tube. It also has similar cuttability and sandability to wood, making it superior to fiberglass, carbon fiber, or Kevlar in regards to workability. It has significantly better impact strength than standard Kraft Phenolic tubing, and excellent bond strength with epoxy.

The nose is 3D-printed out of PETG (Polyethylene terephthalate glycol-modified). This material has the strongest layer bonding of any commercially available 3D printable filament, giving it the high strength needed to withstand the rigors of supersonic flight.

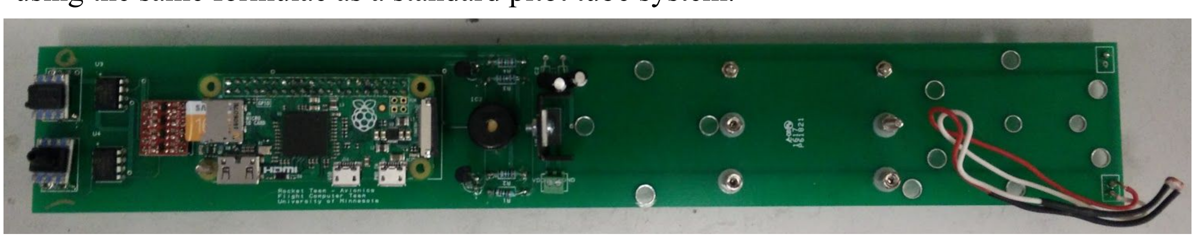
Changes since PDR

There have been no major design changes since the PDR. The Flyaway rail guides were redesigned to be more resilient as well as offer more support to the rocket on the rail. Additionally, the main parachute was enlarged to bring the rocket down at a safer speed.

Avionics Systems Design

Our deployment avionics consist of two redundant Perfectflite Stratologger CF dual deployment altimeters. Our custom avionics system is based around the Raspberry Pi Zero computer. This computer runs our camera system, pitot-tube system, and our separation detection system. The camera used is the Raspberry Pi Camera Module V2.1, which is capable of capturing 1080p60 video. This video will eventually be converted into two separate 1080×960 videos, one consisting of the upward video, the other of the downward video.

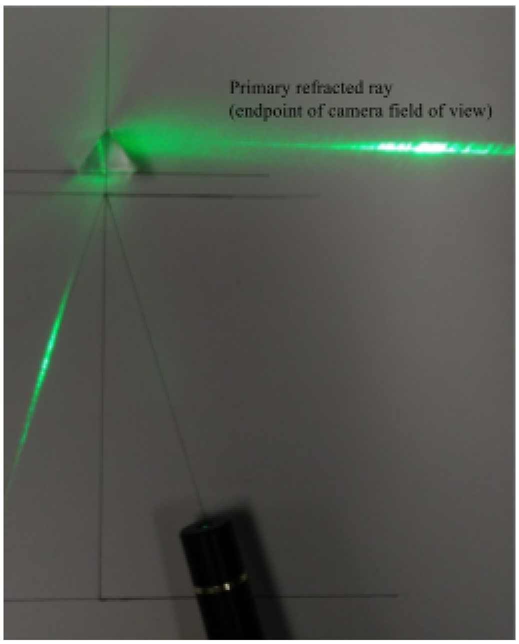
The Raspberry Pi collects data from two pressure sensors, one connected to the hole at the front of the nosecone, the other to a static pressure sensor. This setup allows us to calculate velocity using the same formulae as a standard pitot tube system.

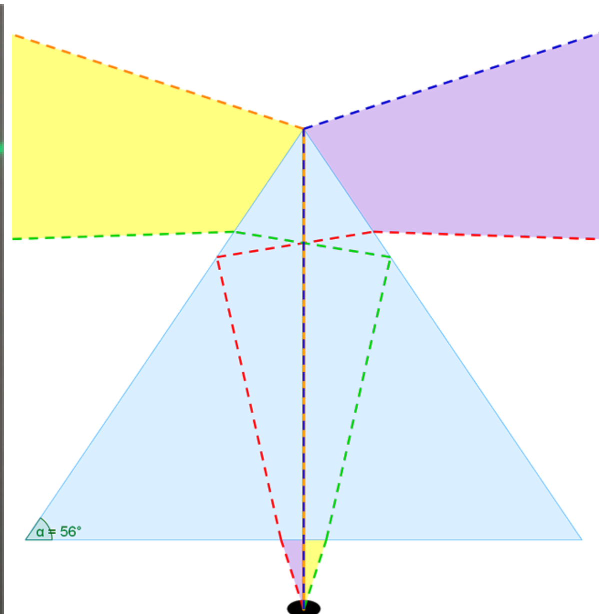


To save on av-bay space and mass, our av-bay was also designed to function as our sled. It includes CNC cut mounting holes for two stratologgers, three LiPo batteries, and a Jolly Logic AltimeterTwo mount.

Prismatic Lens System

The split-view prism is made from a ½" thick acrylic block. We have used a laser cutter to create the approximate shape of the split-view prism (an isosceles triangle with side angle 56°). We will sand and polish the three optical surfaces to bring them to the necessary surface finish.





These two images show the prism working. The left image shows the redirection of a laser beam entering the prism at the same angle as one edge of the camera's field of view. The image on the right is a dimensionally correct schematic of how the prism redirects the field of view.

We have tested the prisms using phone cameras, and have proven that they function as intended. The prisms still must be polished to a better optical quality prior to the competition.

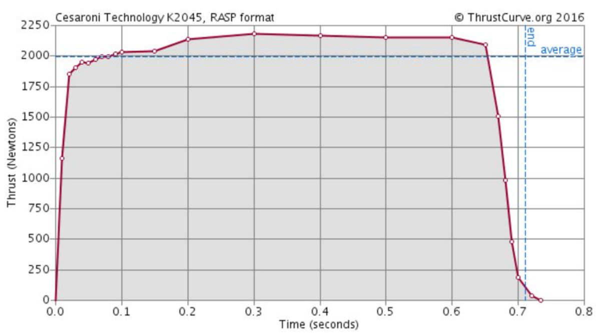
Separation detection

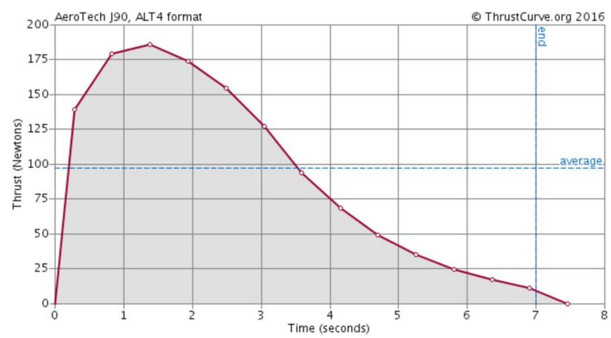
In order to fulfill the requirement of logging separation, we are using two photoresistors mounted directly beneath two holes in the coupler. Prior to ejection, the holes are covered up by the airframe tube. The photoresistors remain at high resistance. Upon separation, the light levels in the av-bay will significantly increase, causing the resistance of the photoresistors to drop. Our custom circuitry detects this and send a signal to the Raspberry Pi alerting it that separation has occurred. Ground testing has proven this system to be highly reliable.

Predicted Performance

We predicted the competition performance of our rocket using OpenRocket. Openrocket was also used to optimize the nosecone length and shape parameter to maximize apogee on the J90.

Motor Selection

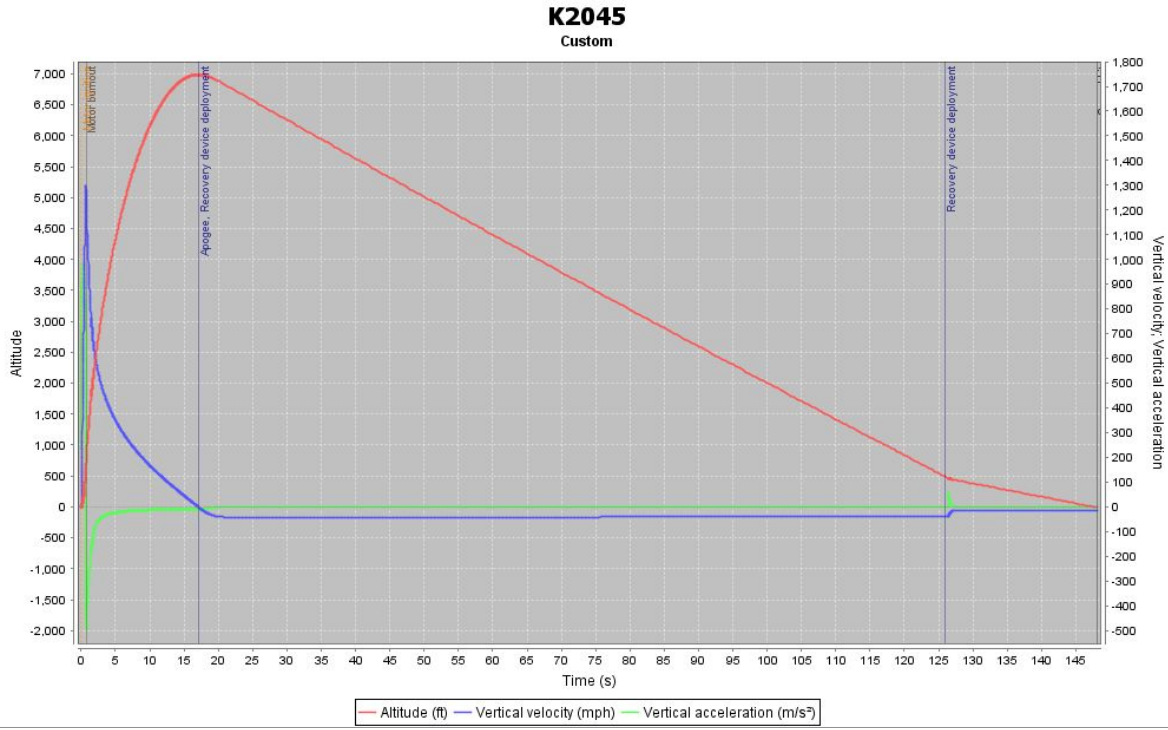


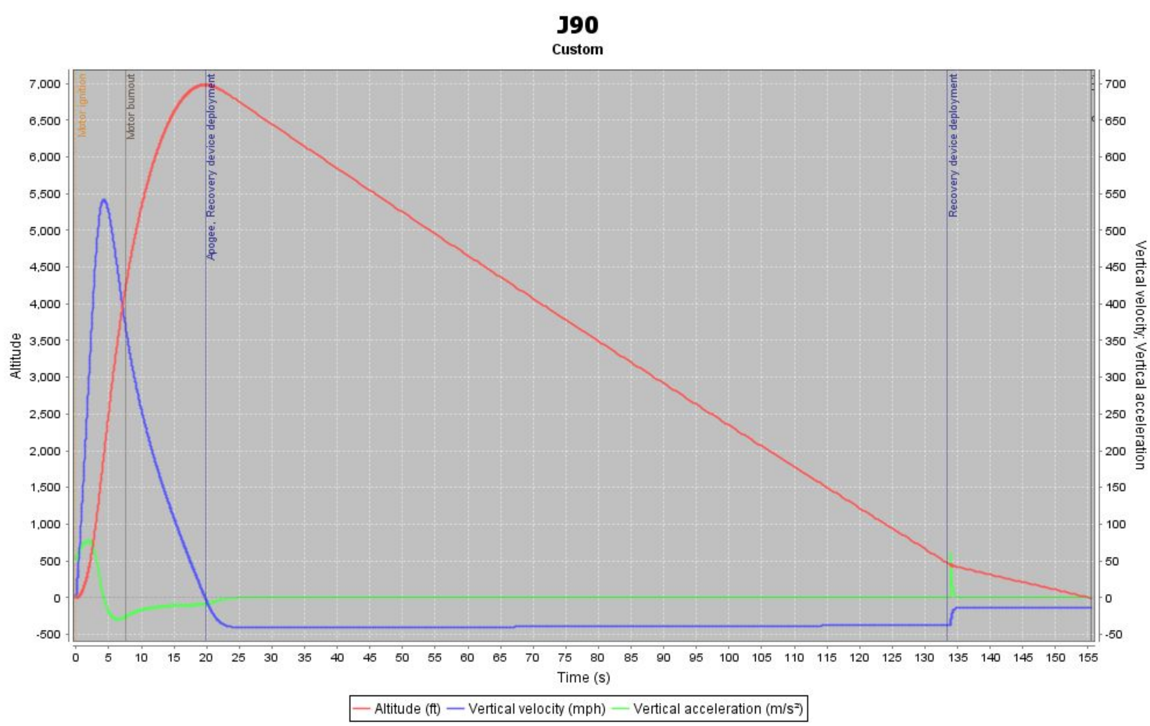


To achieve a large figure of merit, the choice of motors is critical. We have chosen the Aerotech J90W as the lower-powered motor. The J90W is a 54 mm White Lightning c-slot geometry motor with an average thrust of 90 Newtons, a max thrust of 188 Newtons, and a burn time of 6.9 seconds giving it 707 Newton-Seconds of total impulse.

The Cesaroni K2045VM Vmax was chosen as the higher-powered motor. The K2045VM is a 54 mm 4 grain BATES geometry motor with an average thrust of 2,045 Newtons and a max thrust of 2,231 Newtons. The burn time is 0.691 Seconds, giving it a total impulse of 1407.6 Newton-Seconds. The two motors combine to give us a scoring formula numerator of 45.2, the second highest of any allowable J-K combination. The only better combination is a J90W with a CTI K1440. However, the K1440 was rejected due to space and mass considerations.

Launch & Flight Analysis





Our Openrocket simulations using this software predict an apogee of 6983 for the J90W motor and 6991 for the K2045VM motor. The J90W will reach a peak velocity of mach .72, but the K2045VM will reach a peak speed of mach 1.74. After burnout, the rocket will coast to apogee. The K2045VM burns out after 0.7 s, followed by a 16.4 s coast phase. The J90W burns out after 7.3 s, followed by a 12.2 s coast period.

The following table shows the apogee, peak velocity, peak mach number, and peak acceleration on both the K2045VM and the J90W:

Motor:	Apogee:	Velocity (ft/s)	Velocity (Mach)	Acceleration (g):
K2045	6991	1901	1.73	103
J90	6983	797	0.72	8.5

Simulated test flights

The rockets test flew on Saturday, March 4. Unfortunately, our custom avionics were not complete at that time, but our dual-deployment system was fully operational. Since we only had enough competition motors to do one test flight on each, it was decided to test fly the worst case scenario in terms of mass in order to find a lower bound on our figure of merit.. The ballast came to a total of 382 grams, which was significantly heavier than we had budgeted for avionics. As a result, the simulated performance for this configuration was lower than our expected competition performance. Our pre-flight simulation produced the following predictions:

Motor:	Apogee:	Velocity (ft/s)	Velocity (Mach)	Acceleration (g):
K2045	7069	1855	1.65	100
J90	6675	726	0.65	8.7

The simulation was repeated at the launch site using the correct wind speed (12 mi/hr) and produced the following data:

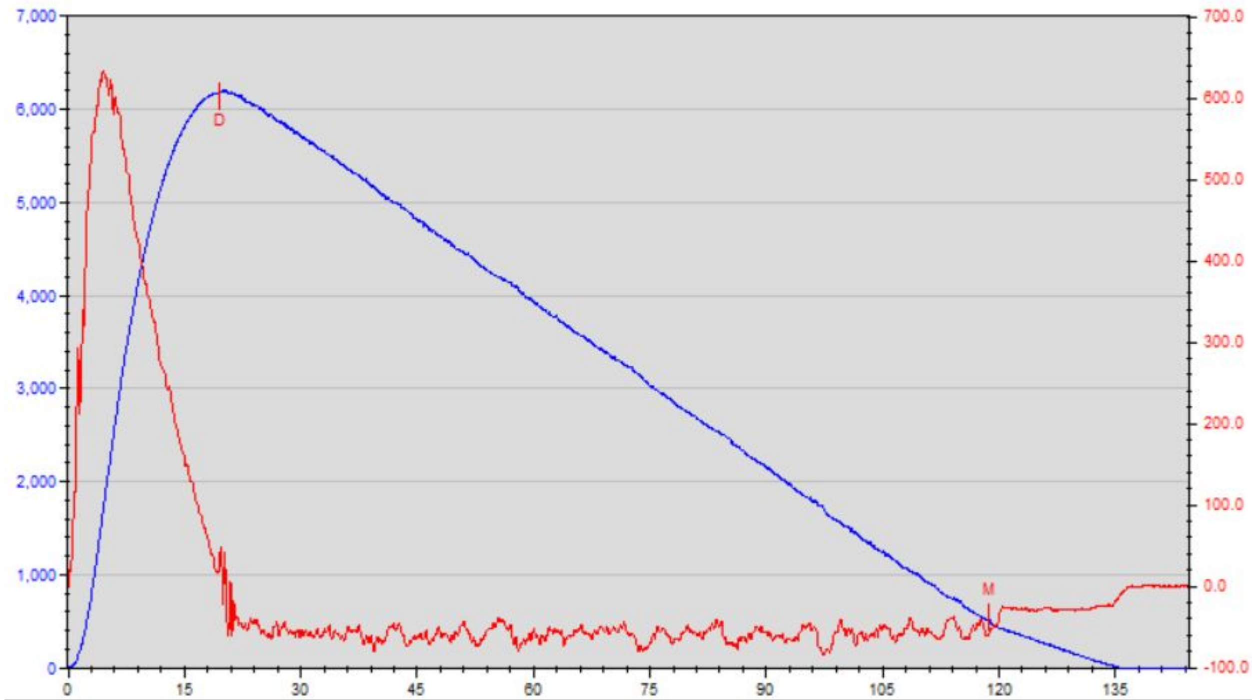
Motor:	Apogee:	Velocity (ft/s)	Velocity (Mach)	Acceleration (g):
K2045	7058	1864	1.64	100
J90	6452	724	.64	8.7

Operation assessment

J90 flight

Overview

The rocket first flew on the J90, with a gross lift off weight of 2114 g including the flyaway rail guides. The following graph shows the data from the J90 test flight, with altitude (ft) shown in blue and velocity (ft/s, extrapolated) shown in red.



Boost phase

The rocket left the rail at a safe speed with only minor weathercocking. High average winds, overstability of the rocket, and heavy nose weight contributed to the weathercocking. The competition flights will be considerably lighter than the test flight, decreasing the likelihood of this happening again. The flyaway rail guides functioned exactly as expected, peeling away quickly after the rocket left the rail. Burnout occurred 6.9s after ignition.

Coast phase

The rocket then coasted to apogee, which it reached at 19.5s. The rocket only reached an apogee of 6199' AGL according to our stratologger data.

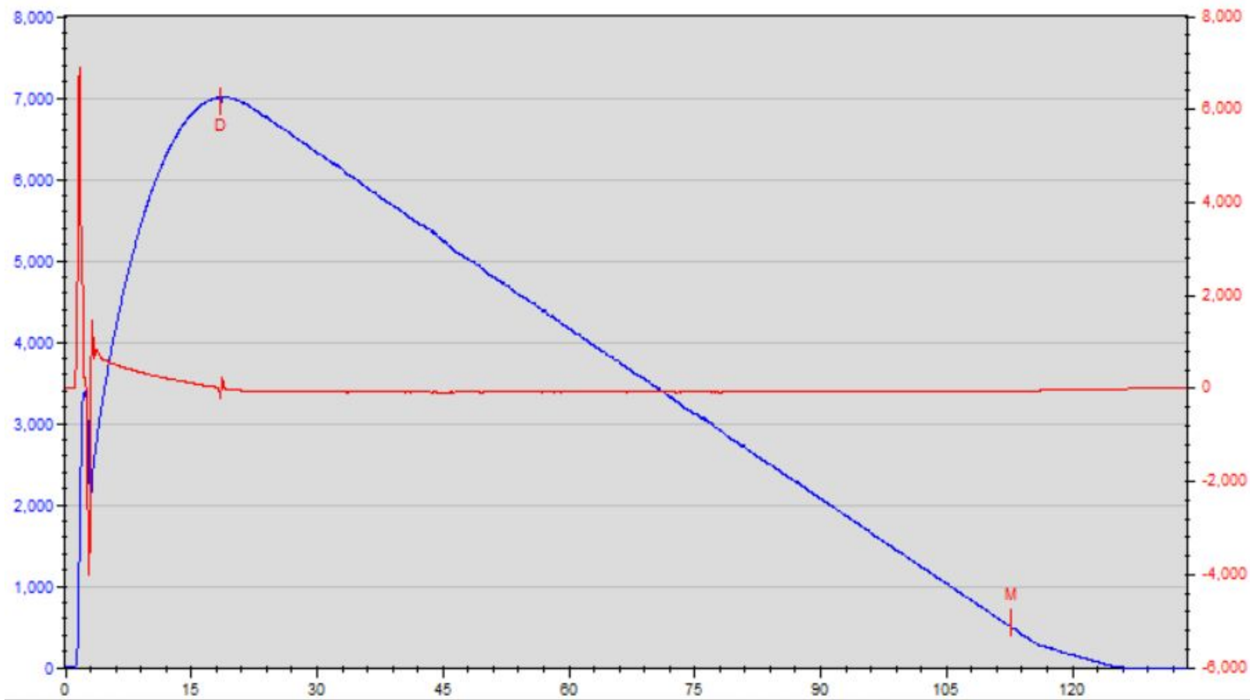
Recovery analysis

The drogue chute deployed exactly as it was supposed to, and left the nomex bundle just fine. The cable cutters held the main chute wrapped up inside the parachute protector until 500 feet AGL, at which point they deployed the main chute. A combination of optical tracking and a radio beacon was used to locate the rocket after it had landed. No damage occurred to any component as a result of this flight.

K2045 flight

Overview

After the successful recovery of the rocket, everything was repacked and flown again on the K2045, with a new gross lift-off weight of 2552g including the rail guides. The following graph shows our altitude (ft) in blue, and our velocity (ft/s, extrapolated) in red. You can see the anomalous readings caused by mach effects close to the beginning of the flight.



Boost phase

The rocket left the rail at a more than safe speed, and the flyaway rail guides served to keep the rocket attached to the rail during the liftoff phase. At some point after the rocket left the rail, the flyaway rail guides were destroyed. It is suspected that the flyaway rail guides fell away from the rocket but were briefly caught in the supersonic exhaust produced by the motor. The rocket burned out at 0.7s at an altitude of approximately 2500 feet.

Coast phase

At this point, the rocket was travelling at mach 1.65, and experienced an extreme amount of drag. The coast phase lasted until 17.5 seconds into the flight, at which point the rocket reached apogee and the drogue charges fired.

Recovery analysis

The recovery portion of the flight proceeded nominally. The drogue deployed properly at apogee, and the main deployed properly at 500 feet.

Performance

J90

During the flight, the rocket continuously weathercocked as the altitude increased. This continuous weathercocking effect served to decrease our apogee more than predicted by simulations, which assume a constant wind speed at all altitudes. In reality, we would expect wind speed to increase with increasing altitude. Data from the stratologgers show that our peak velocity was approximately 640 ft/s. Analysis of data provided by the stratologgers showed that our speed under main was slightly over the limit imposed by the competition.

K2045

The rocket reached an apogee of 7008’ AGL according to our stratologger data. This flight was much less affected by the changing wind speeds than the J90 flight was due to the fact that the K2045 burns out much lower and at a much higher speed than the J90. Analysis of data provided by the stratologgers showed that our speed under main was slightly over the limit imposed by the competition. Unfortunately, we do not have a peak velocity measurement for this particular flight, because we were using barometric altimeters. Our expected acceleration of 100 G would max out the accelerometer in a Raven3, so it was decided to use two stratologgers due to their higher reliability.

Conclusions

Our performance in this test flight gives a Figure of Merit of 193,543. This is less than we expect to achieve at the actual competition due to this being a worst case scenario test flight. Through a decrease in mass in both the avionics bay due to various changes including replacing

9v with lithium ion batteries it is expected to increase the hight of the J90 and decrease the height of the K2045 thus increasing the Figure of merit. Additionally, these test flights showed us that we needed to use a larger main chute. We also expect to add weight to the J90 flight to account for the difference in weight of the two motors, also increasing figure of merit.

Safety

Pre-flight Checklist

1. Inspect all shock cord connection points for upper and lower sections.
2. Inspect all wiring connections on avionics sled.
3. Inspect all wiring connections and zip-tie attachments.
4. Test all battery voltages.
5. Connect batteries to the avionics.
6. Power all avionics on to test proper wiring
7. Power all avionics off
8. Inspect static pressure ports in altimeter bay.
9. Mount camera and ensure it is fixed in place facing the PLS.
10. Insert avionics sled into upper section.
11. Fold main parachute into the body tube, attach zip tie with both zip tie cutters.
12. Wire all charges to the terminals
13. Tape tracker to shock cord
14. Insert upper section into lower section.
15. Insert shear pins.
16. Assemble motor
17. Install motor.
18. Attach flyaway rail guide.
19. Place rocket on launch rail.
20. Power up Raspberry Pi
21. Arm Stratologgers
    a. Turn on primary
    b. Wait for proper beep signals
        i. Listen for three sequential beeps repeating
    c. Turn on backup
    d. Wait for proper beep signals
        i. Listen for three sequential beeps repeating
22. Visual inspection
23. Photograph(s) of rocket on pad.
24. Photograph(s) of team members with rocket.
25. Launch!

Post-flight Checklist

1. Locate rocket
2. Inspect rocket for any damage
3. Check that there are no remaining live charges
4. Take a picture of the rocket
5. Power off electronics
6. Disconnect spent charges from electronics
7. Bring recovered rocket to post flight check in table
8. Give Altimeter 2 to competition official
9. Retrieve all flight Data

Budget

Competition Fee	1		$400.00		$400.00	
Travel (estimated)	1		$400		$400	
Nylon Threaded Rod, 1/4-20, 2'	2	2' section	$3.74		$7.48	McMaster
Nylon nuts, 1/4-20	1	100 pack	$6.47	$6.00	$6.47	McMaster
stainless steel square tubing, .5" side	1	6" section	$5.11		$5.11	McMaster
Stainless steel undercut 4-40 philips oval head screws, 3/16"	1	100 pack	$5.21		$5.21	McMaster
Silver coated stainless steel 6-32 socket head screw	1	5-pack	$7.42		$7.42	McMaster
Screw switch	5		$2.95	?	$14.75	Missile Works
Turnigy Nano-Tech 2S 300 mAh LiPo	4		$4.63		$18.52	HobbyKing
Turnigy basic balance charger	1		$4.81	$8.31	$4.81	HobbyKing
Lime green 1.0 oz Ripstop Nylon, Calendered	1	yd (×58")	$6.95		$6.95	RipstopByTheRoll
Crimson 1.0 oz Ripstop Nylon, Calendered	1	yd (×58")	$6.95	$2.67	$6.95	RipstopByTheRoll
carbon fiber plate, 100*500*1mm	1		$16.19	$0.00	$16.19	Ebay
0-80 nylon screw, 1/4"	1	pack of 100	$7.66		$7.66	McMaster
Vented 1/4-20 socket head screw	1	5 pack	$5.71	6?	$5.71	McMaster

6" ×6" cast acrylic sheet, 7/16" thick	1		$7.05		$7.05	McMaster
Kevlar cord 100#	12	ft	$0.33		$3.96	Apogee
Kevlar cord 1500#	30	ft	$0.97	$4.86	$29.10	Apogee
54mm Phenolic 57" section	1		$54.95	$0.00	$54.95	MAC performance rocketry
3.9" Phenolic 1ft section	1		$17.85	$0.00	$17.85	MAC performance rocketry
Wildman 54mm FWFG VK Nosecone	1		$29.00		$29.00	MAC performance rocketry
54mm Coupler tube	1	6" section	$7.95		$7.95	MAC performance rocketry
1010 rail buttons	2	2-pack	$3.50		$7.00	Offwego
eye bolt	2		$1.50		$3.00	offwego
cable cutter	2		$30.00	$9.27	$60.00	fruity chutes
quick lok slimline retainer system	2		$36.76	$10.50	$73.52	giant leap rocketry
CTI K2045	2		$113.94		$227.88	Apogee
Raspbery Pi Zero camera bundle	1		$39.95		$39.95	Adafruit
Aerotech 54-852 casing	1		$73.00		$73.00	Offwego
Aerotech 54mm extended open forward closure	1		$41.99		$41.99	Offwego
Aerotech J90W	2		$72.99		$145.98	Offwego
TOTAL:					$1377.00	