Post Flight Report

Rocket Team

University of Minnesota Twin Cities

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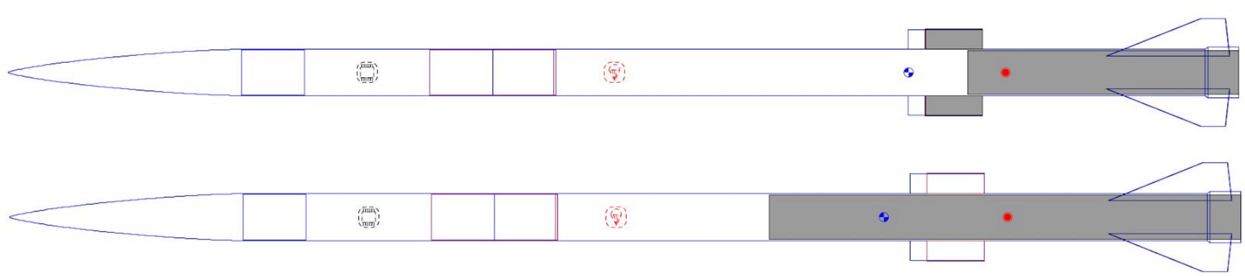
Executive Summary:

This year, the Rocket Team at the University of Minnesota participated in the Minnesota Space Grant Consortium's high power rocket contest. Our entry into the contest consisted of a lightweight 54mm minimum diameter rocket designed to reach the same altitude on two motors that were "as different as possible." Our motor choices were the aerotech J90W and the CTI K2045VM, since this motor combination had the highest combined motor coefficient of any feasible motor choices.

Design history:

Cluster Design

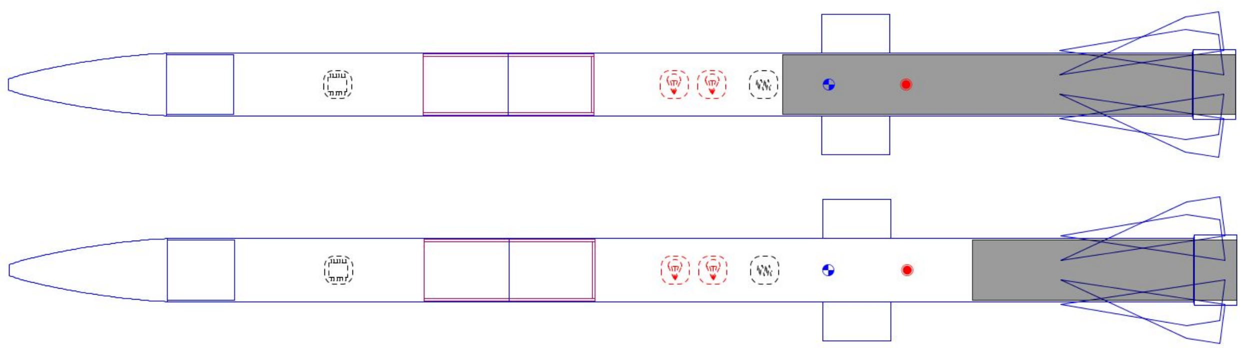
Immediately following the release of the rules at the end of August, we began designing and simulating various ideas for our competition rocket. After evaluating at the scoring formula, it became apparent that an intelligent motor selection and a high average apogee would allow for for significant performance benefits compared to a more precise but lower apogee design. We also were very hopeful to avoid utilizing airbrakes or a similar active system, due to the major difficulties experienced with the electronics portion of last year's contest. Our initial designs focussed on maximizing the average apogee term, using that to make up for somewhat less than ideal motor coefficients. The first successful design we came up with was a 54mm minimum diameter fully passive rocket that flew to ~8000 ft on a K1440 and a J140 with two 24mm-1G E31 "takeoff assist motors." By routing the ejection charges of both E31s into the main body tube, we were able to utilize the J140 despite the fact that it lacks a motor ejection. It would have utilized single separation point dual deployment. Depending on how average thrust would have been calculated in the scoring formula, (we assumed total impulse divided by total burntime) we expected our design to achieve a figure of merit of approximately 180,000. Unfortunately, at the end of September, it was announced that clusters were no longer allowed due to safety concerns.



	Name	Configuration	Velocity off rod	Apogee	Velocity at de...	Optimum delay	Max. velocity	Max. acceler...
!	Simulation 3	[K1440WT-7]	125 mph	8043 ft	1.62 mph	14.2 s	1511 mph	75.3 G
!	Simulation 5	[1211-J140-WH_LB...	50.7 mph	8009 ft	6.92 mph	10.2 s	576 mph	11.5 G

Spin design

Following this announcement, we immediately began redesigning the rocket to take this new information into account. Since the J140 was no longer able to be used for the low power motor, the decision was made to switch to the CTI J145. Unfortunately, this motor did not burn nearly as long as the J140 we had initially planned to use. As a result, we had to change our higher power motor to compensate. We used a CTI K2045 and canted fins in order to bleed off some energy into spin. This design did not achieve either the precision or the height of the cluster design, but it was able to achieve a better figure of merit than we deemed possible for us to achieve with airbrakes. This design was abandoned due to safety concerns. The highly canted fins and high maximum speed would likely result in a structural failure of the rocket.



	Name	Configuration	Velocity off rod	Apogee	Velocity at depl...	Optimum delay	Max. velocity	Max. acceleration
!	Simulation 9	[K2045Vmax-17]	65.3 m/s	5216 ft	16.8 m/s	12.7 s	586 m/s	102 G
!	Simulation 13	[699-J145-SK-LB-19A-9]	26.2 m/s	4664 ft	16 m/s	9.76 s	216 m/s	24 G

Air ducts

At one meeting, the possibility of using an “air augmented rocket” design was proposed. This design would have utilized a smaller section of 4 or 6 inch diameter phenolic tubing as a highly backswept ring fin, in such a way that the opening of the duct was just barely above the back edge of the motor mount/main body tube. For the higher power motor, a motor mount extension would be screwed on to the motor retainer on the main body tube. In theory, for the lower power flight, the high speed exhaust passing through the duct would in effect pull air from the atmosphere through the duct, increasing the amount of reaction mass. This is known to work best with a shaped duct, which has a shape somewhat similar to (but operating differently than) a normal convergent-divergent nozzle. Due to the greatly increased drag produced after burnout, we would have been unable to use a shaped duct. We focused on this design for a while, trying to come up with better ways to test such a design.

It was during this time period that the motor announcement was made. After examining the new selection of motors, it became readily apparent that the combination of a J90 and a K2045 would provide the highest feasible combined motor coefficient for us, with a value of 45.25. Several other combinations would have given better motor coefficients, including the combination of an I55 and a J1520 (motor coefficient 76.5) and the combination of a K1440 and a J90 (motor coefficient 53.7). We determined that an all passive design would not be able to get close enough on either of the other combinations. As a result, we decided to order our motors immediately since Apogee had only two K2045s left in stock. We ordered our motors on February 8th, before we had finished optimizing our design.

Final design

When we began simulating rockets on the K2045 and J90 to analyze stability, it became very clear that the duct was completely unnecessary. Without the duct, the designs returned to our initial minimum diameter fully passive plans. Minor optimizations were required to bring it to the final flight design. Most notably, we decided to make use of a relatively thick subsonic airfoil design and greatly decrease the fin sweep. This allowed us to keep drag quite low within the subsonic regime, but produce significant wave drag during the supersonic portion of the flight. The nose cone was also optimized for decent subsonic performance, but terrible supersonic performance.

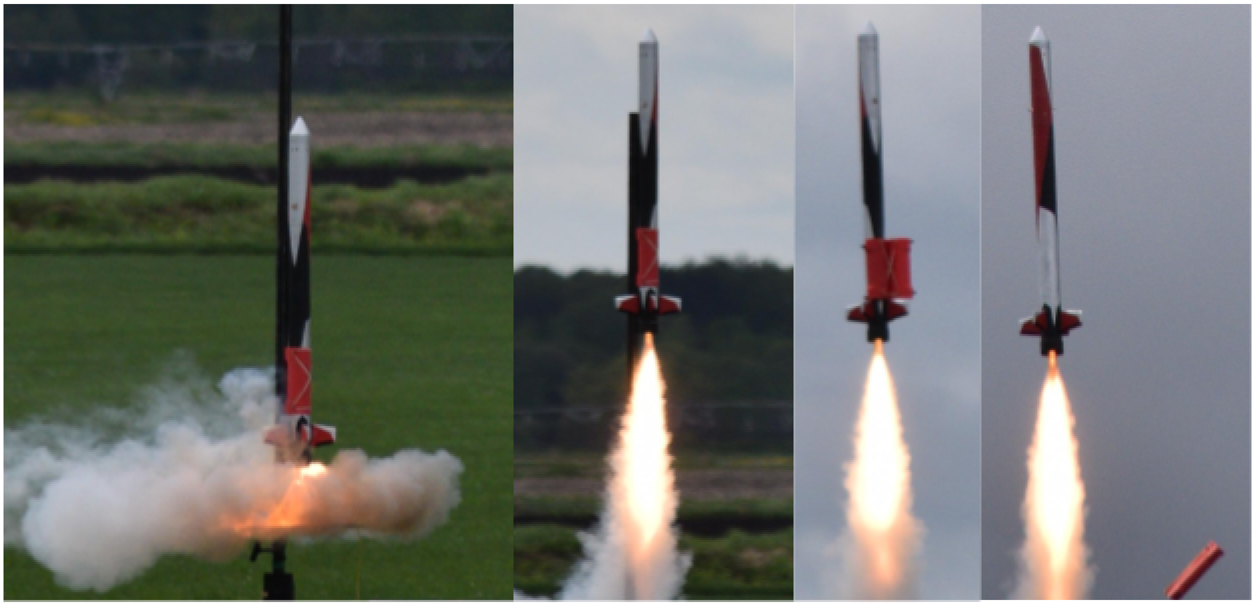
Flight Performance Comparison:

Competition flight videos can be found at https://z.umn.edu/UMNRTcompvid

Flight:	Aerotech J90	CTI 1408K2045
Apogee:	6587	6500
Apogee (predicted)	~6800	~6800
Maximum velocity (processed stratologger)	~686 ft/s = mach .61	~1926 ft/s = mach 1.71
Maximum acceleration (processed stratologger, *highly* suspect)	317.5 ft/s/s = 9.87 g	Data interpolation fails badly. Simulations optimized with real flight data show a maximum acceleration of 101G.
Gross Liftoff Mass (includes rail guides)	~2020g	~2460 g

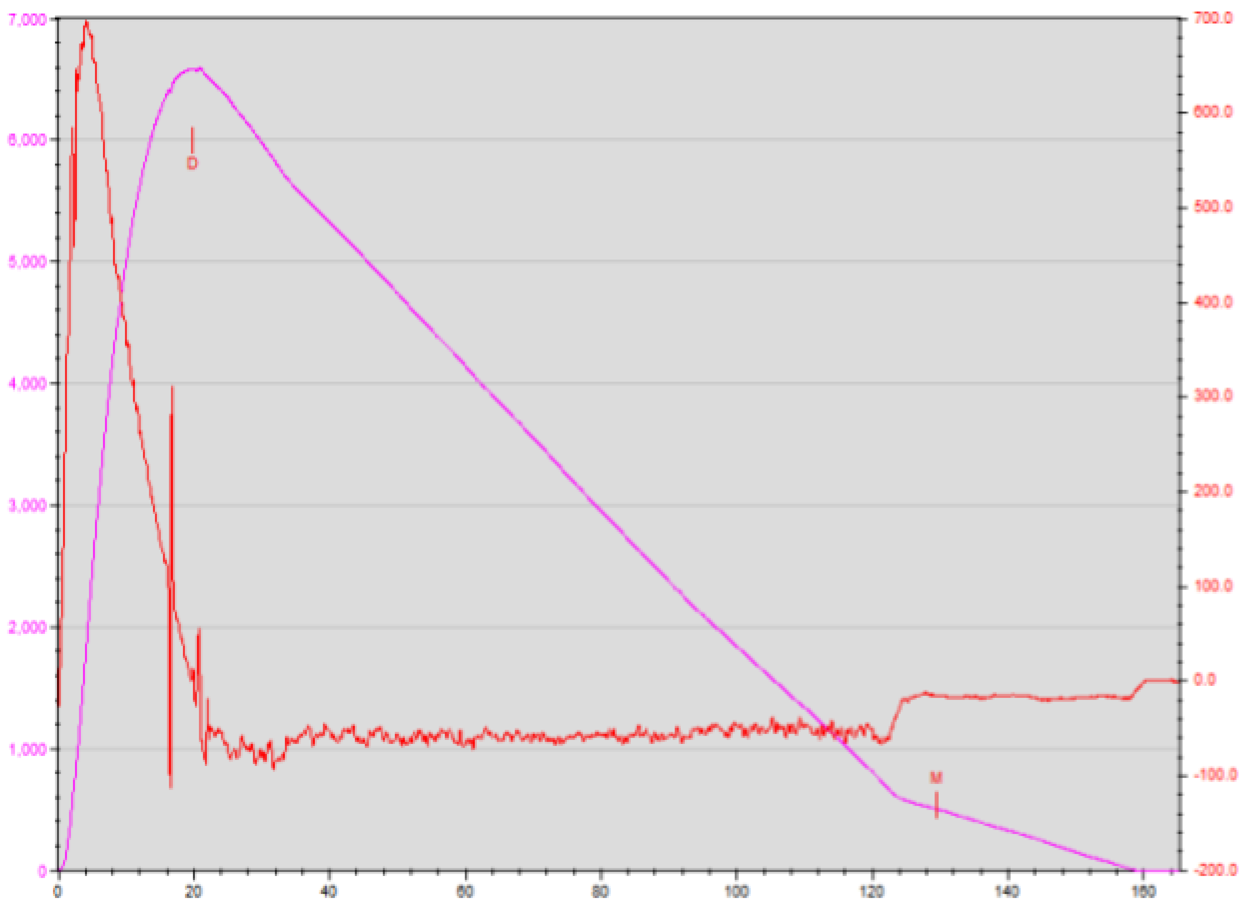
J90 Flight:

Our first flight of the day was on the Aerotech J90. This flight went absolutely perfectly. The rail guides separated quickly after liftoff, taking less than a quarter second between leaving the rail and completely leaving the rocket.



Flyaway rail guides in action: these four sequential pictures of the J90 flight show the rail guides working exactly as intended.
Photo cred: Max Jetzer (flickr.com/photos/max-q)

The boost phase proceeded nominally as well, and the rocket reached an apogee of 6587 as determined by the stratologger data.



Stratologger data for the J90 flight. Altitude (ft) is in pink, velocity (ft/s) is in red.

At apogee, the stratologger charges went off, separating the rocket and deploying the drogue chute.

The moment of drogue deployment, as seen from our onboard camera (downward facing on left, upward facing on right)

The rocket then descended under drogue, with an average descent rate of 58 ft/s. Once the rocket descended past 700 feet, the stratologgers triggered the two archetype rocketry cable cutters, allowing the main chute to deploy. Unfortunately the rocket was swinging too much to get any good pictures of the deployment itself, once the tumbling calmed down we were able to clearly see the correctly deployed main chute (red & green, on the left) as well as the drogue chute hanging below (small orange blob on the right) :

Under main, the rocket descended at a rate of 17.53 ft/s. This is slightly slower than anticipated, meaning that this parachute had a higher Cd than a slightly smaller parachute of the same design that had been tested in a wind tunnel by our IREC recovery team. This validates the use of this particular ultra-thin mill ripstop nylon.

After landing, the rocket was unfortunately dragged along the ground by the parachute due to a slight wind. Our camera prism became scratched, worsening the video quality for our next flight.

K2045 Flight:

Our next flight was on a CTI K2045VM motor. This flight was successful, but it did have several hiccups. The motor lit almost instantaneously, and the rocket left the pad in 0.09 seconds (according to simulations). The rail guides did not fare as well for this flight, and were destroyed by in-flight forces. However, they did serve their purpose well.

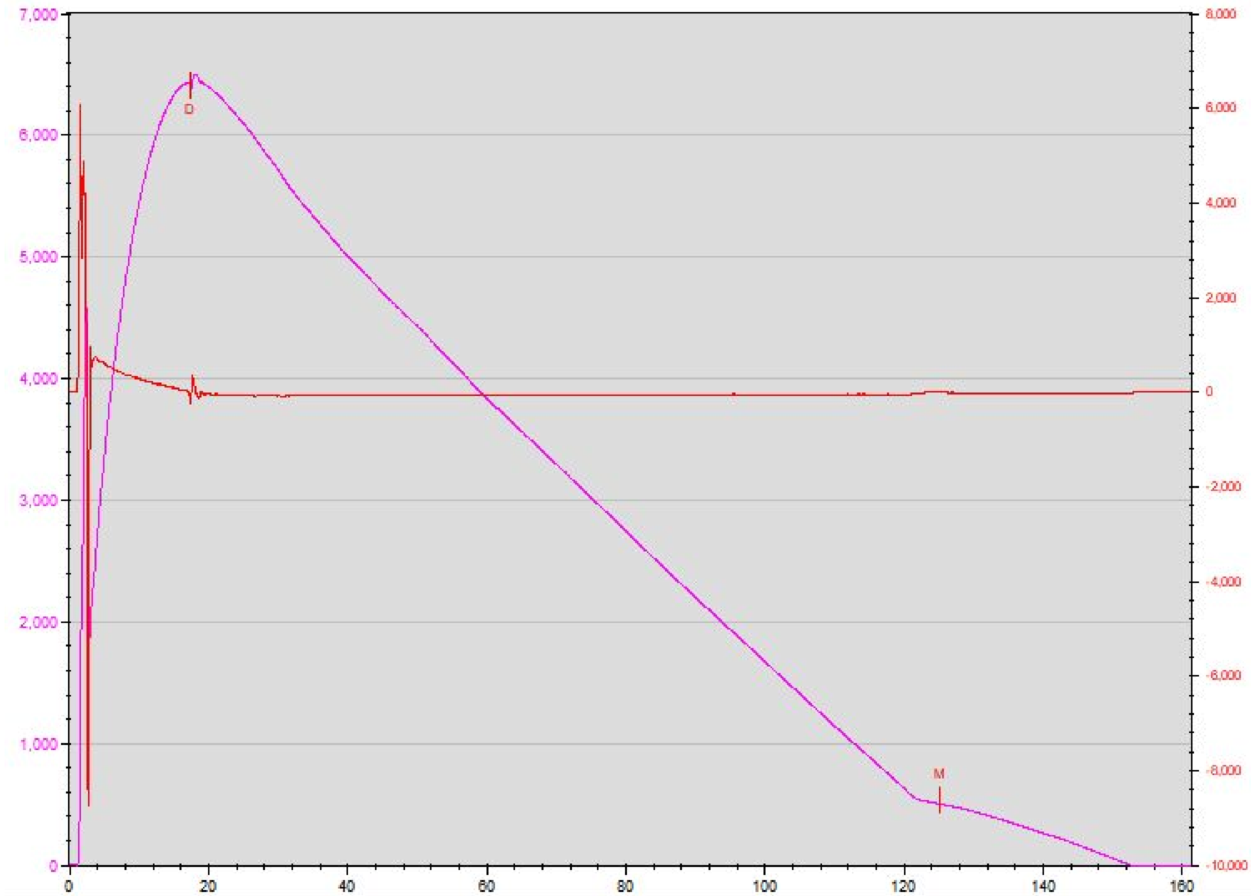
Photo cred: Max Jetzer flickr.com/photos/max-q

During the coast phase of flight, the rocket passed into a cloud. Water condensed on the acrylic prisms used to split the camera view, and since the prisms rely on total internal reflection to split the view, they didn't work very well at all. Water droplets on one of the two outer surfaces will lead to distortion in both views. As a result, the video is very hard to make out. Fortunately, it is still possible to verify that the chutes have deployed.

The drogue deployed at apogee, and the rocket descended at an average rate of 55.2 ft/s. This was somewhat unexpected, since the empty mass was higher than during the J90 flight, yet it descended slower. We suspect this was caused by increased tumbling of the booster section because the more massive casing would move its center of gravity back more, decreasing its stability.

At 700 feet, the main chute was successfully deployed by stratologger.

Under the main chute, the rocket descended at a rate of 18.1 ft/s. This was again less than we predicted.



Comparison to predictions

Our rocket was predicted to reach an apogee of approximately 6800 feet on the J90, yet it only reached 6587. It was predicted to reach the same apogee of 6800 on the K2045, but only reached 6500. In our simulations, we noticed that surface finish has a relatively significant effect on apogee. However, surface finish did not have a significant effect on *relative* apogee. When we painted the rocket, we unfortunately caused a significant increase in the surface roughness of the rocket. However, our overall performance in terms of our figure of merit was not greatly decreased, since our apogees stayed relatively close together.

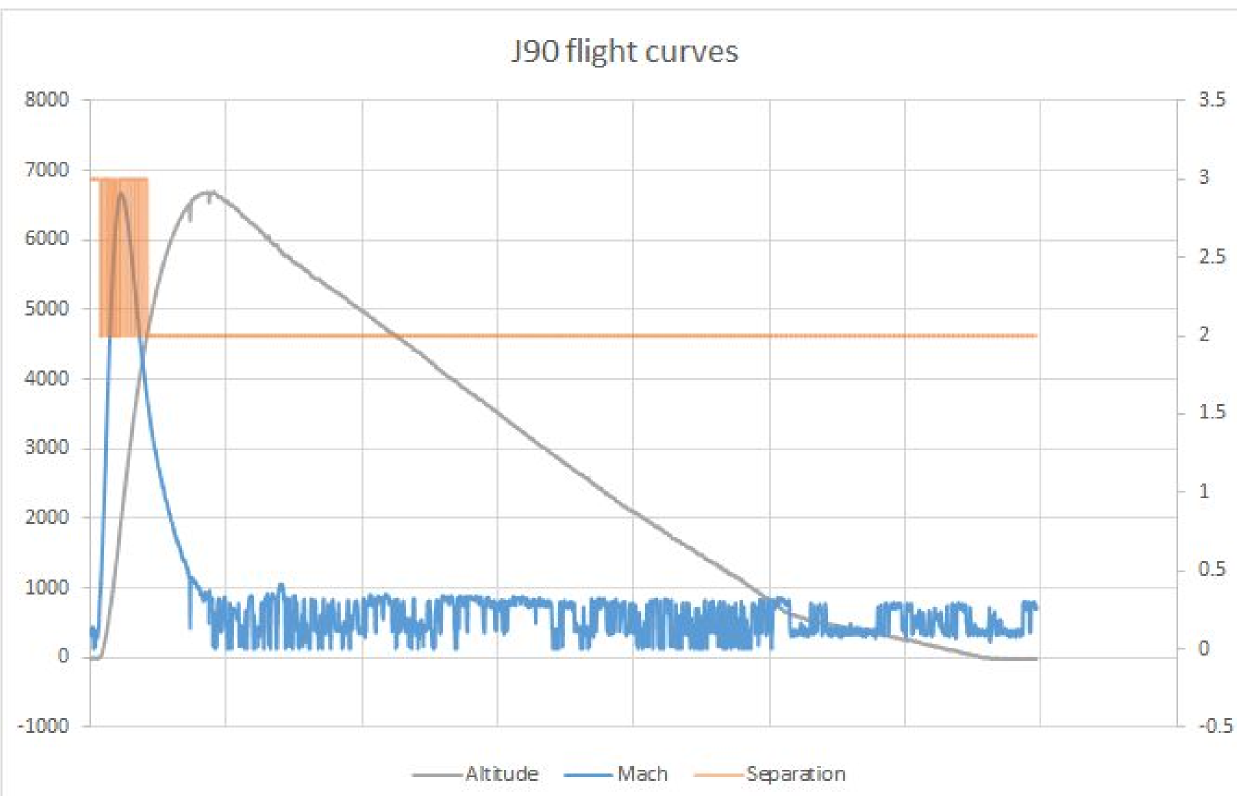
Our maximum velocities are fairly close to what we predicted. The maximum acceleration of the J90 is also quite close to what we predicted, though there are large uncertainties on that value. However, due to the supersonic noise induced during the K2045 flight, we could not directly evaluate the stratologger data. Instead, we eliminated the questionable data points and used graphing software to determine a function that closely modeled the good data points. We then simply found the maximum value of the derivative of this function. The number we came up with was a fairly close match with our simulations as well.

Unfortunately, the function did not model the details at the beginning of the k2045 launch well enough for us to extrapolate any reasonable acceleration data. We had initially considered using a Raven3, but our simulations predicted that we would be going above 100 G, which is above the limit of the Raven3's accelerometer. So in order to determine the approximate maximum acceleration, we made minor modifications to our simulations until they matched the real life competition flight data that we did have. The simulation software then gives us what we assume to be fairly accurate acceleration data.

Custom Avionics Data Analysis

Our custom avionics package was based around the Raspberry Pi Zero computer because of its extremely compact size and powerful functionality. The flight computer was performing several functions simultaneously throughout the duration of both flights. It was capturing video from the camera module, collecting sensor data from the pitot-static system, and monitoring the separation detection system.

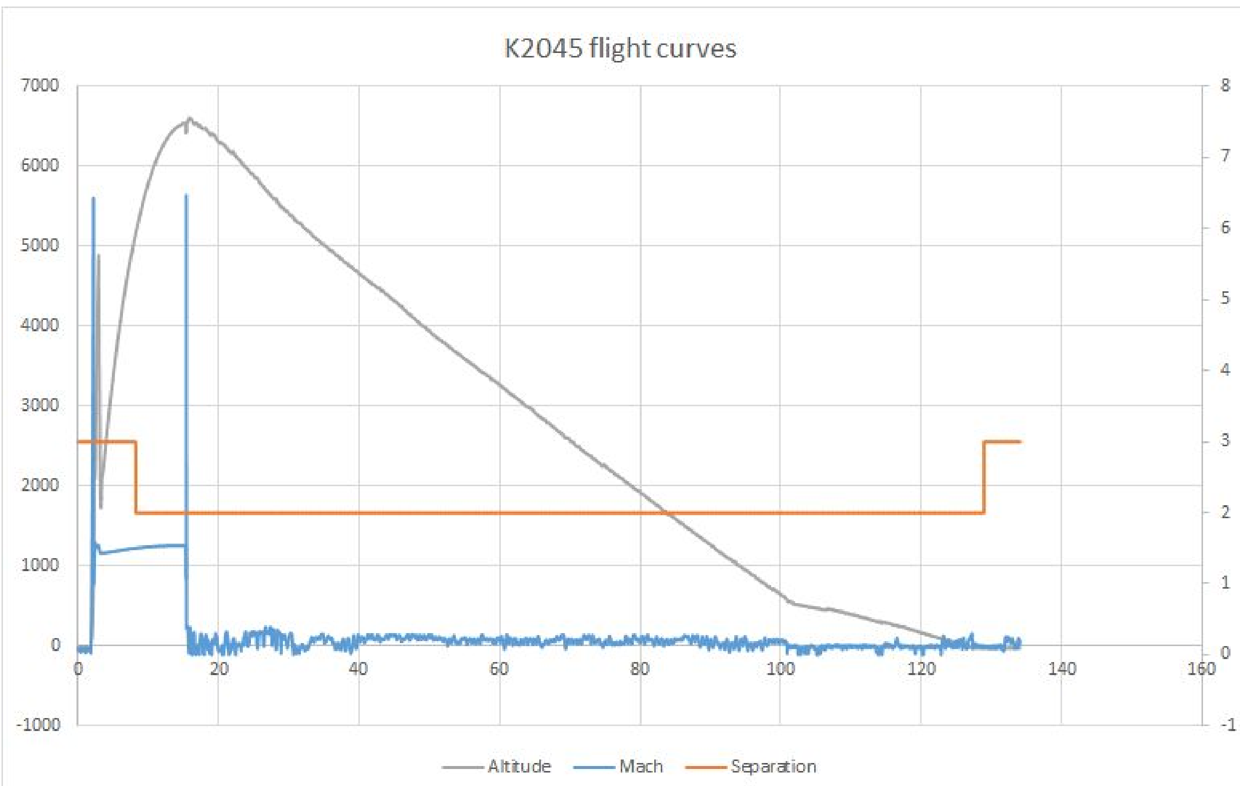
Sensor data charts:



Since we had a static pressure sensor on the board, we decided to convert the pressure data to altitude in order to check our results. The data was not temperature compensated at all, so our result of 6690 ft differs slightly from that reported by the stratologger. However, this is only 1.5% off.

Something is quite wrong with the velocity measurement, since we certainly did not go mach 2.91 on the J90. We suspect there is a problem either with the pitot formulas we are using or there's a problem with the differential pressure sensor. We're still working on determining the root cause of the problem.

There were additional issues with our separation detection mechanism. The night before the launch, during our integration runthrough, we realized that the photosensors had been placed on the wrong side of the board and would be covered up by our threaded rods if they weren't resoldered. Both photoresistors were successfully desoldered, but only one was able to be put back on the right side of the board. The photoresistor that was attached may have also been damaged by the heat of the soldering iron.



The velocity data from the K2045 flight is almost entirely garbage. It initially rises to a value of 6.5, then drops down to 1.00 before jumping up to a relatively stable value of 1.5, where it remains until apogee. Obviously, this is not at all realistic. We suspect that the differential pressure sensor may have blown out due to the high pressures experienced during supersonic flight.