WSGC Collegiate Rocket Competition Report
Wombat 1
Team Night Skies

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Rocket Design

Our rocket is based on a Formula 98 rocket kit manufactured by Rocketry Warehouse. To meet our design requirements, we asked the manufacturer to make the following changes to the kit:

- Increase the booster airframe length by 2 inches.
- Increase the payload airframe length by 6 inches.
- Increase the motor tube length by 5 inches to accommodate a tail cone.

We also made the following modifications:

- Eliminated the switch band.
- Shortened the electronics bay by 1".
- Shortened the nosecone by 1.5".
- Reconfigured the shape of the fins.

After modifications were done by the manufacturer and ourselves, the rocket was essentially scratch built with only the centering rings and the bulkheads remaining from the original design.

The decision to base our design on an existing rocket kit versus a scratch built design was necessitated by budgetary constraints. The cost of the kit and modifications came to $174.00. If purchased separately these same parts would have cost $354.00. By basing our rocket design on an existing manufactured kit we realized a $180.00 savings.

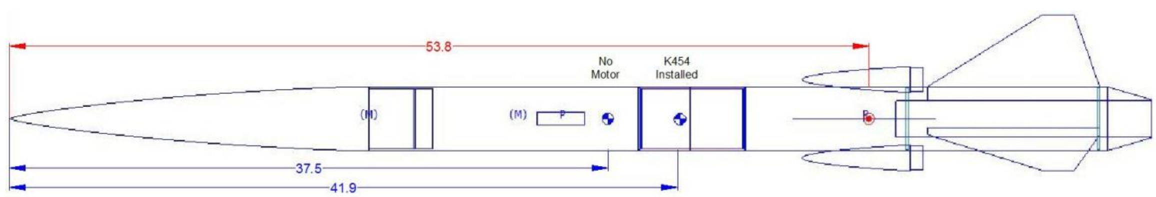

Figure 1: Basic Drawing of Rocket Design and Dimensions

Our final design is shown above. Critical design parameters are as follows:

- Diameter – 4"
- Overall Length – 71.5"
- Span diameter – 12.9"
- CP location – 53.8" from front of rocket
- CG_1 – 37.5" from front of rocket
- CG_2 – 41.9" from front of rocket
- Stability – 2.9 caliper with K454 motor

Payload Design

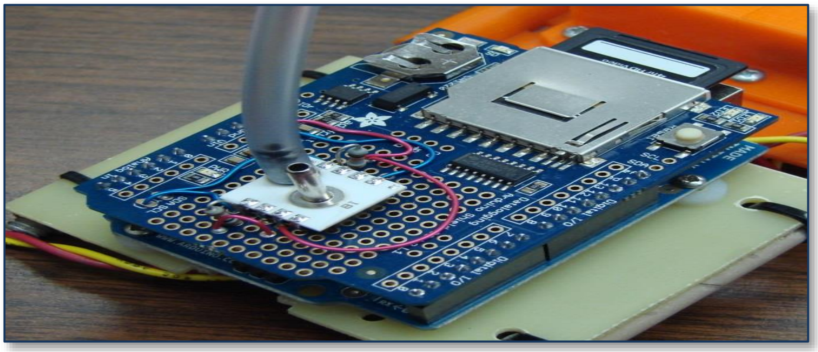

Figure 2: Differential Pressure Sensor

Our rocket contained two experimental payloads to assist us in determining its flight profile. Our first experiment used a pitot tube to determine the rocket's speed throughout the flight. The total pressure was sensed by the tube in the airstream outside the rocket and the static pressure was sensed in the altimeter bay. A differential pressure sensor manufactured by Silicon Microstructures Inc. converted the pressures to a digital signal. The differential pressure signal was read over its I^2C bus, time stamped and stored on a flash card by an Arduino microcomputer. The data collected during the flight was downloaded and analyzed to calculate the rocket's velocity during the flight.

Our second experiment would attempt to determine the rocket's velocity using the Doppler Effect. Two piezo-electric sounders were mounted on opposite sides of the airframe to emit a 2700 Hz tone during the rocket's flight. We recorded the sound on the ground using a 20" parabolic microphone and a Zoom H1 digital recorder. After the flight we analyzed the recorded audio using an audio spectrometer software package which determined the shifted frequency of the emitted tone. From this frequency shift we were able to calculate the rocket's speed during flight.

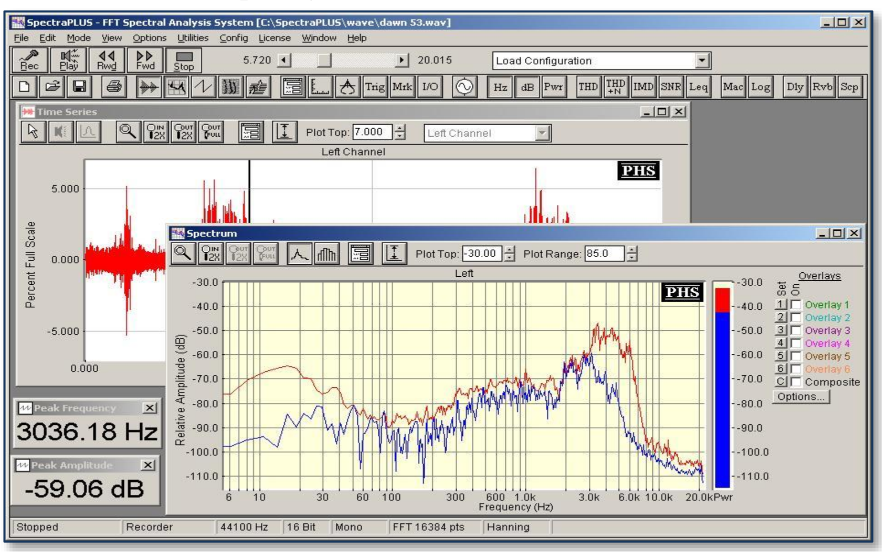

Figure 3: Recorded Data from Frequency Shift

Projected Flight Performance

After the rocket's construction was complete, it was weighed and the actual CG was measured. This data was added to our RockSim model to increase the accuracy of our flight simulations. RockSim predicted the following flight statistics when using a CTI K454 motor:

- Maximum acceleration: 223.7 Ft./s/s (7 g's)
- Maximum velocity: 312.2779 MPH
- Maximum altitude: 3,488 Ft.
- Time to burnout: 3.150 Sec.
- Time to apogee: 15.675 Sec.
- Optimal ejection delay: 12.525 Sec.

RockSim was also used to plot the predicted flight profile.

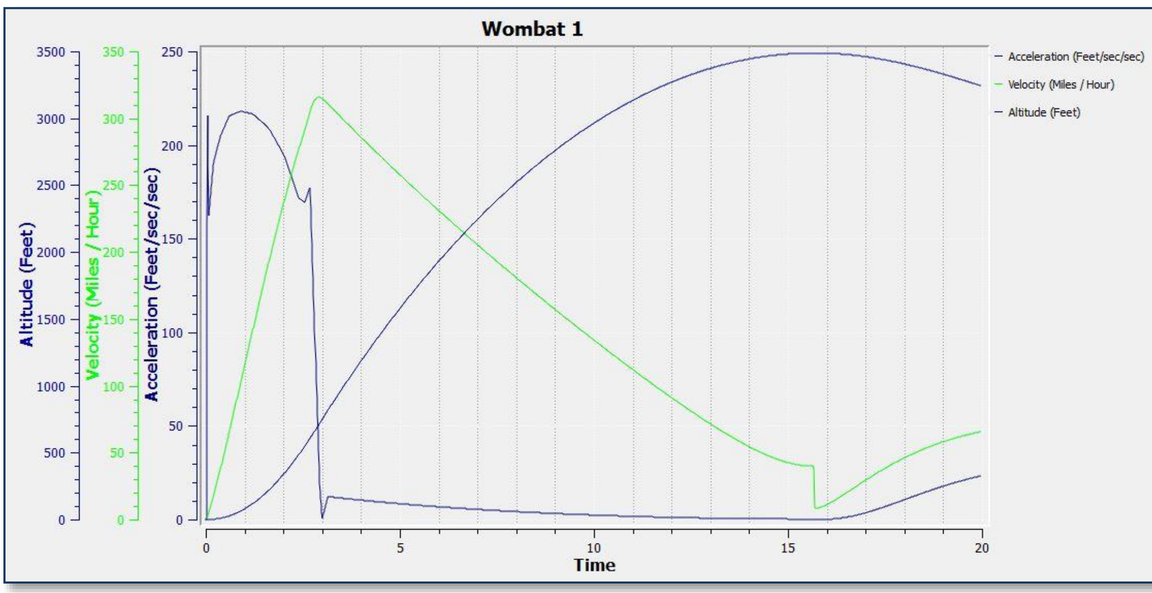

Figure 4: Projected Rocket Profile with RockSim Data

Rocket Construction

Figure 5: Fiberglass Tubing

Figure 6: Epoxy Adhesion to Tubing

With several pieces of fiberglass tubing, our adventure began. Starting with the fin can, we used a mixture of epoxy resin and hardener to hold together the individual pieces of the rocket. As an additional step, we also used expandable foam which was used to surround the motor tube and act as extra support for the fins.

We then began constructing the altimeter bay. For many on the team, this was the first experience they had with soldering.

Lastly, we assembled the nosecone and finished the rocket by drilling holes to relieve the pressure within the airframe. We also drilled holes to place sheer pins into the rocket, as a means to prevent drag separation.

Figure 7: Epoxy for Construction

Figure 8: Expandable Foam

Figure 9: Team Photo

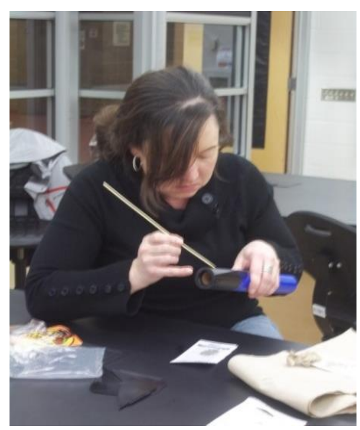

Figure 10: More Epoxy Construction

Competition Flights

April 5, 2014, a day that will not soon be forgotten. It was warmer than usual, the kind of day one relishes after a long harsh winter. It was sunny and a crowd was beginning to gather. The cars were pulling in steadily, and by 9:00 am, Parking Lot E of the Richard Bong Recreational Area was flooded with the joyful exuberance of the day's fliers, judges, and spectators. Men, women, and children had come, from coast to coast, to this small park in Wisconsin to feast their eyes on one thing, the flight of the Wombat 1.

A ragtag team of Rocketeers approached the launch pad, rocket slung proudly over their shoulders; this was it. The crowd cheered their names as Team Night Skies walked ever forward, heads held high. The theme from *Chariots of Fire* played in synchrony with their footsteps. The rocket was quickly and calmly set up. The sounders were sounding, the altimeters were calculating, the Pitot tube was, was … well, it was doing something, I'm sure, *pitoting, maybe… pressuring?* Regardless, this rocket was ready for liftoff! Fifteen minutes passed and in those fifteen minutes the Wombat 1 soared, popped its chutes, landed gracefully, and was hurriedly carried back to the judges. The data was slow to transfer. The crowd bit their nails; the nerves were beginning to creep up on them. This was their team; this was what they had come to see. Finally, the results were in, Team Night Skies had elevated to 3,051ft, a near perfect flight! No? That was the wrong altimeter, you say? The competition altimeter read higher than that? Oh, right, sorry about that then, "ahem"; what I meant to say was, Team Night skies had elevated to 3,348ft, which is still respectable and something that they're very proud of! At once, the nervous silence was overtaken by a deafening roar from the crowds. They had done it, ladies and gentlemen; Team Night Skies had really done it!

OK. So, I may have embellished a little bit of that story. But Team Night Skies really was and is a ragtag group of Rocketeers, and I really did hum the theme from *Chariots of Fire* as we walked out, and our rocket really did soar to 3,348ft, and, most importantly, we really did have as much fun as I tried to convey in that last paragraph. Thankfully, we were afforded the opportunity to fly a second time, achieving an even better altitude of 2,815ft and a much improved recovery time, roughly a twelve minute improvement. We were able to improve upon our initial flight with some quick thinking. We had to work with what we had available, so by adding some duct taped tools and padding it with gloves and pajamas we were able to reduce our altitude. Better still, both of our experiment, the Doppler shift and a Pitot tube, respectively, worked very well and closely resembled the data received via the Raven III altimeter, as will be shown in the following pages.

Doppler Shift Experiment

Experiment Design

This experiment attempted to determine the velocity of our rocket by measuring the Doppler shift of a tone emitted from two piezo-electric sounders on the rocket. The sounders were mounted on two sides of the rocket near the aft end. Each sounder emitted a ~3200 Hz tone at 100db. As the rocket accelerated off the launch pad, the emitted tone was recorded using a 20” parabolic microphone and a digital recorder. Data analysis was performed using audio spectrograph software and Excel.

Results

The recorded wave file was examined using an open source spectral analysis program called Spectran (www.weaksignals.com). The resultant waterfall graph is shown below.

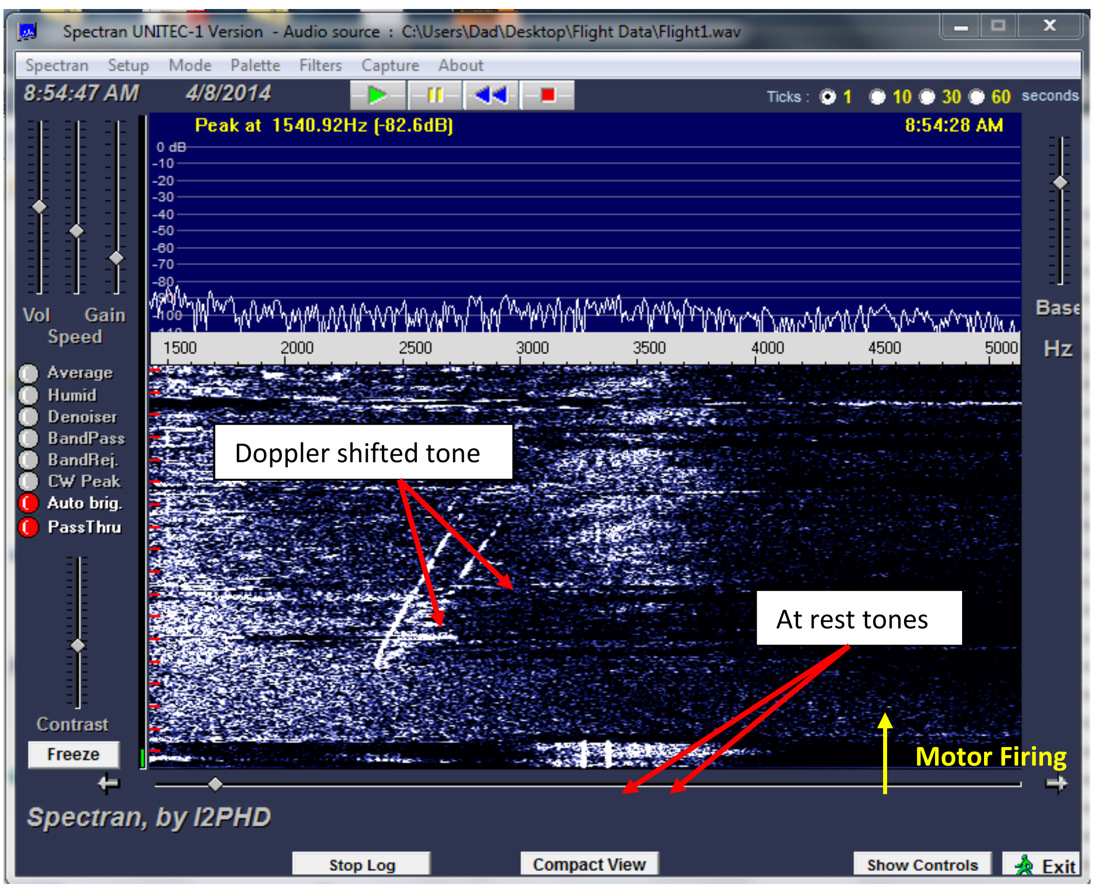

Figure 11: Doppler Shift Analysis Data

The program logs the peak frequencies and Excel was used to plot the results. The initial 3 seconds of audio were drowned out by the rocket motor noise. After nine seconds the rocket had arced over and the tones were no longer heard. The frequency data was converted to velocity using the formula $V = C * \left({}^{Fs}\!/_{Fo} - 1 \right)$ where:

Fs = Frequency of the source
Fo – Observed Frequency
C = Speed of Sound
V = Velocity

Excel was used to graph the resultant velocities.

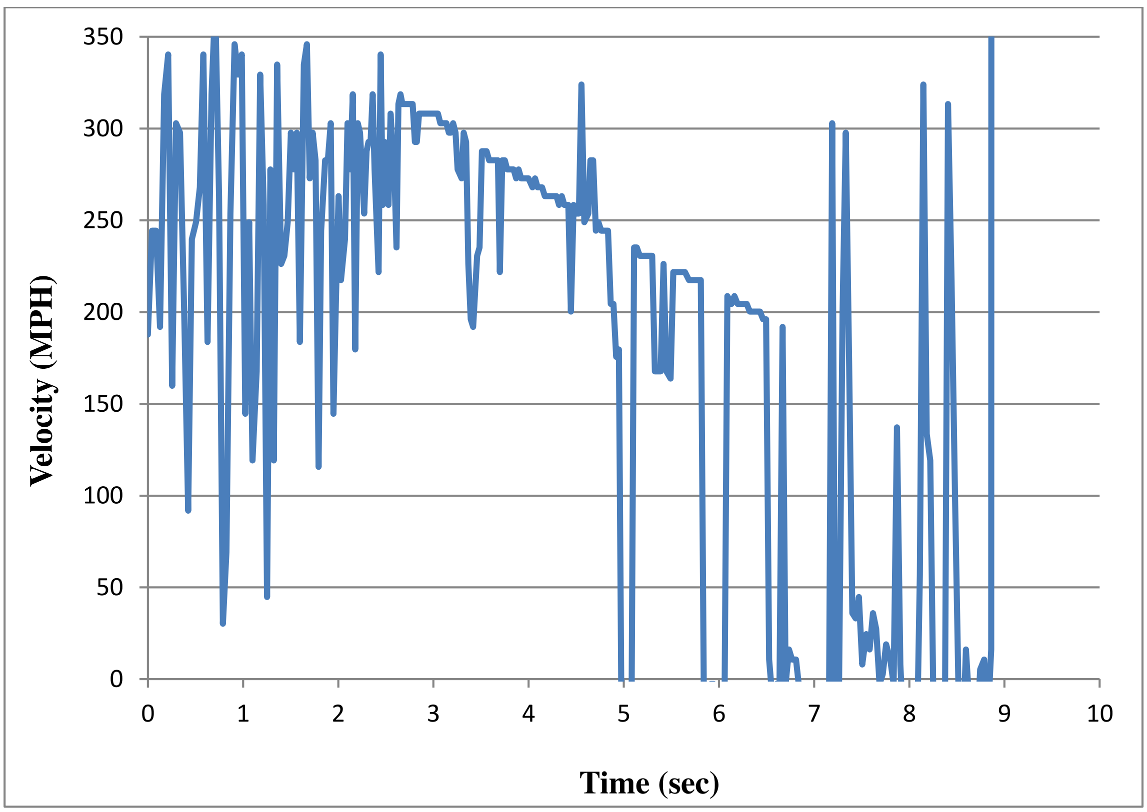

Figure 12: Graph of Velocity

Our initial comparison of the two data sets showed a substantial error in the Doppler data. Further analysis showed the error was due to the time it took for the sound emitted by the sounders to travel to the receiver. When the traverse time of the emitted signal was taken into account the error was eliminated.

The graphic below shows the two data sets overlaid on the same graph.

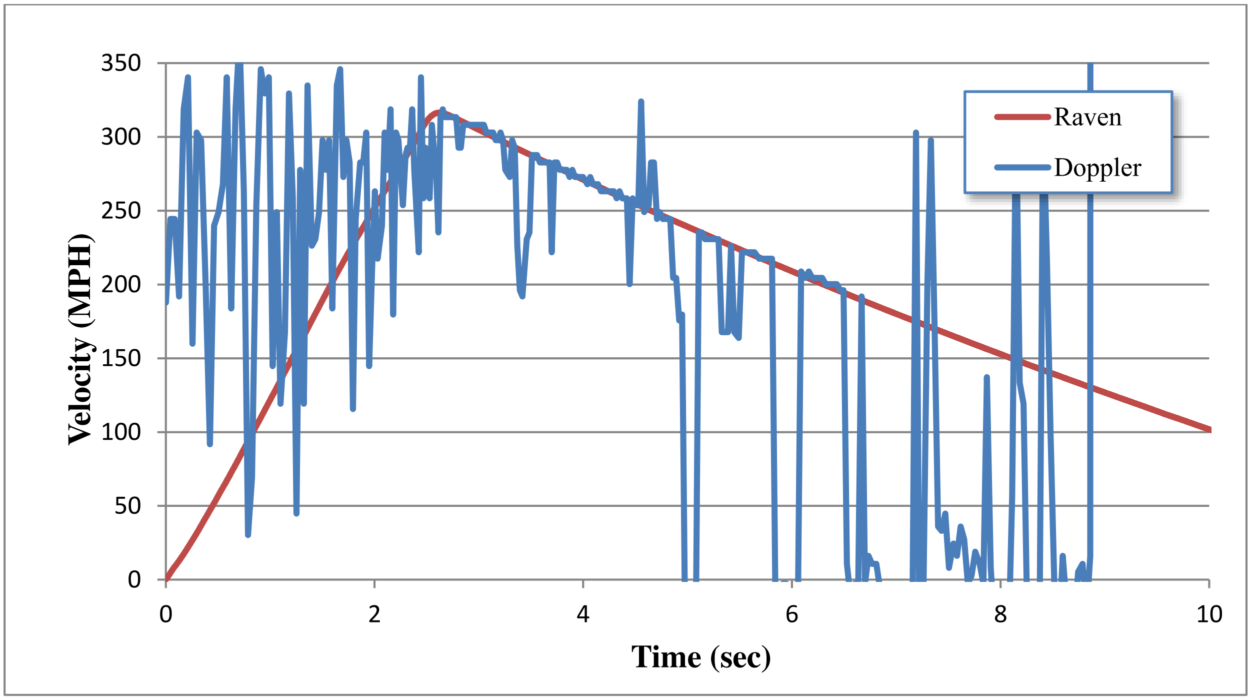

Figure 13: Comparison Chart of Raven and Doppler Data

As the chart shows, there is very strong correlation between the velocity data logged by the Raven altimeter and the Doppler data.

Pitot Tube Experiment

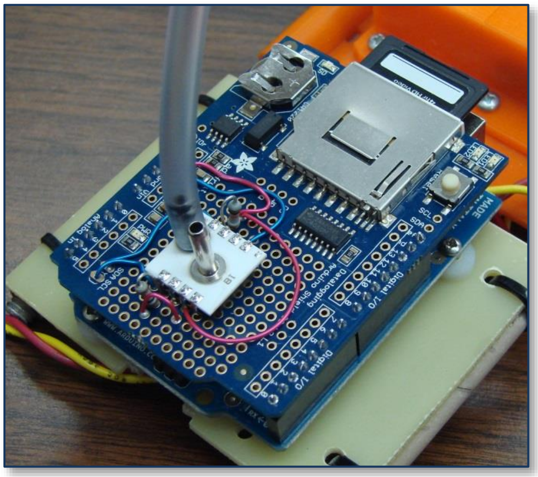

Figure 14: Arduino Microcomputer

Our second experiment also measured the rocket's velocity using a Pitot tube. A single port tube was placed outside the airframe to measure the dynamic pressure during the flight. The pressure from this tube was routed to the high side of a differential pressure transducer. The low side of the transducer was left open to sense the static pressure inside the altimeter bay. The resultant differential data was logged to a flash card using an Arduino microcomputer.

The differential pressure transducer was calibrated before the flight so we could convert the digital output of the transducer to engineering units. The resultant graph and transfer function are shown below.

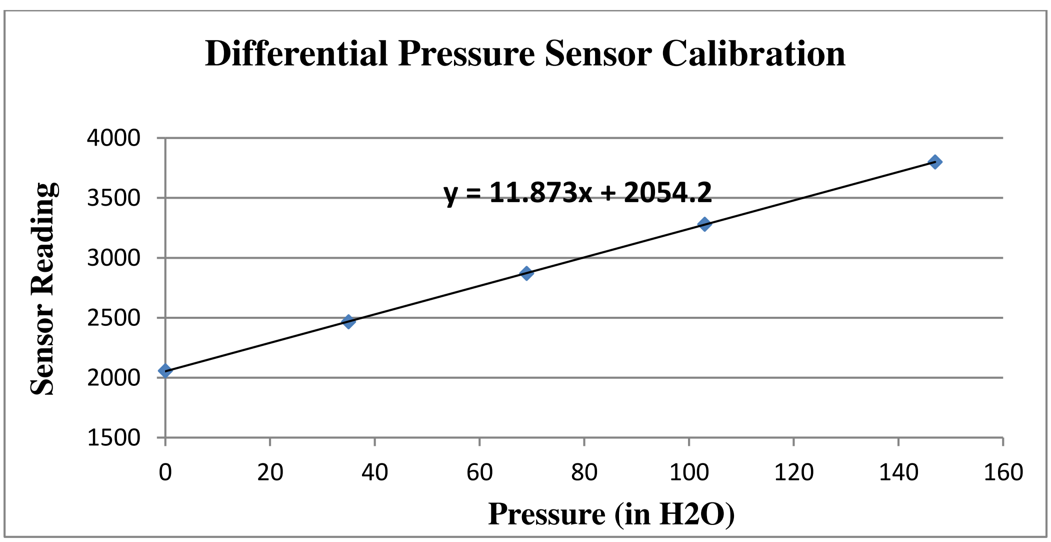

Figure 15: Prefight Calibration Data

Using this calibration data we could plot the Pitot tube pressure recorded during the flight.

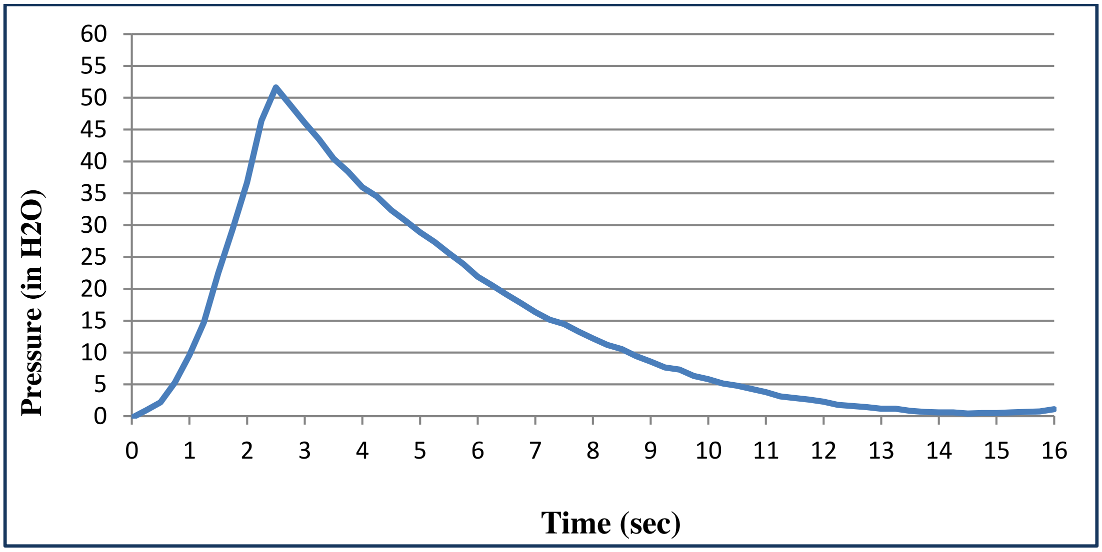

Figure 16: Pitot Tube Pressure During Flight

Next we converted the pressure data to velocity using the formula $V = \sqrt{\frac{2 * \Delta P}{\rho}}$ where:

V = Velocity
$\triangle$P = Differential Pressure
ρ = Density of Air

Overlaying the Pitot tube velocity with the velocity reported by the Raven altimeter yielded an almost perfect match.

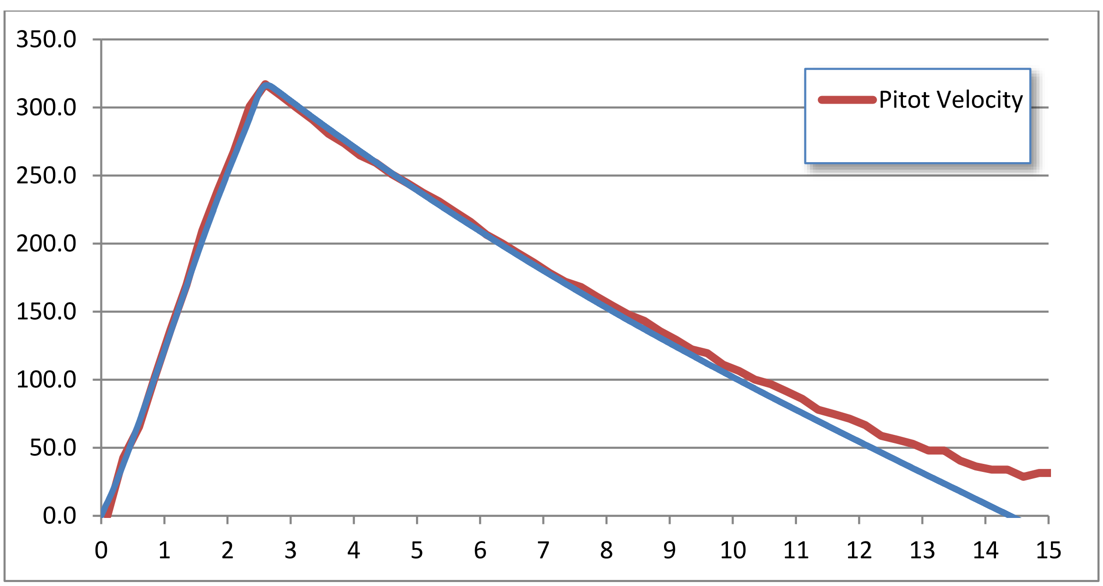

Figure 17: Comparison of Pitot tube Velocity to Raven Altimeter

Using the data from the Pitot tube, the rocket's acceleration and altitude was calculated. The calculated data was graphed with the corresponding data from the Raven altimeter and is shown below. Again there is strong correlation between the two data sets.

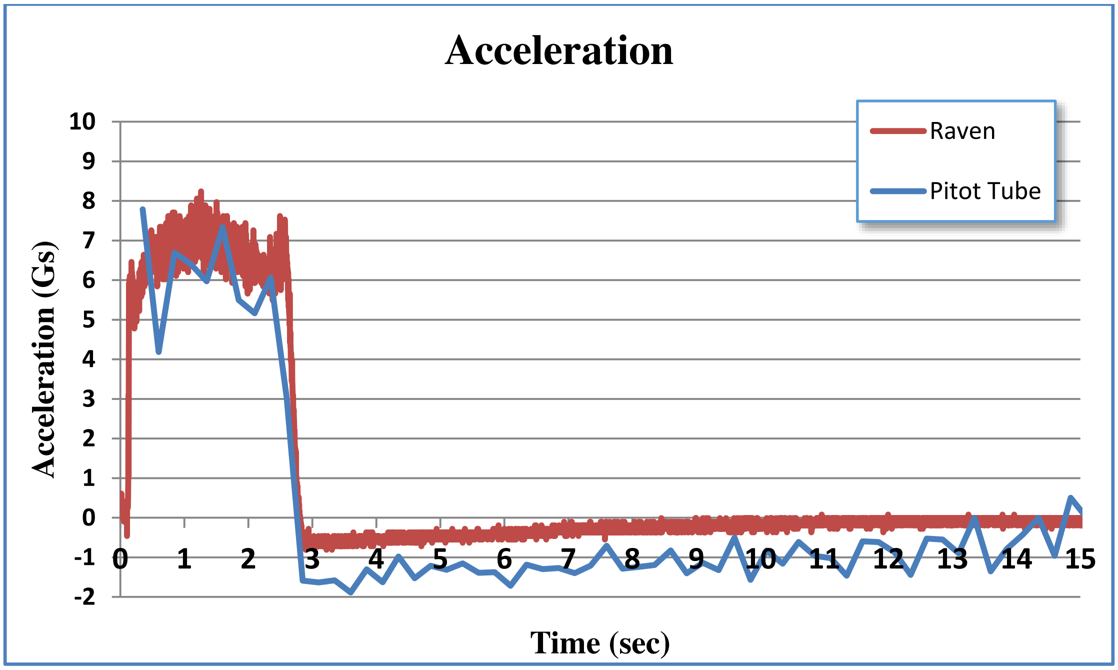

Figure 18: Acceleration Comparison of Raven and Pitot tube

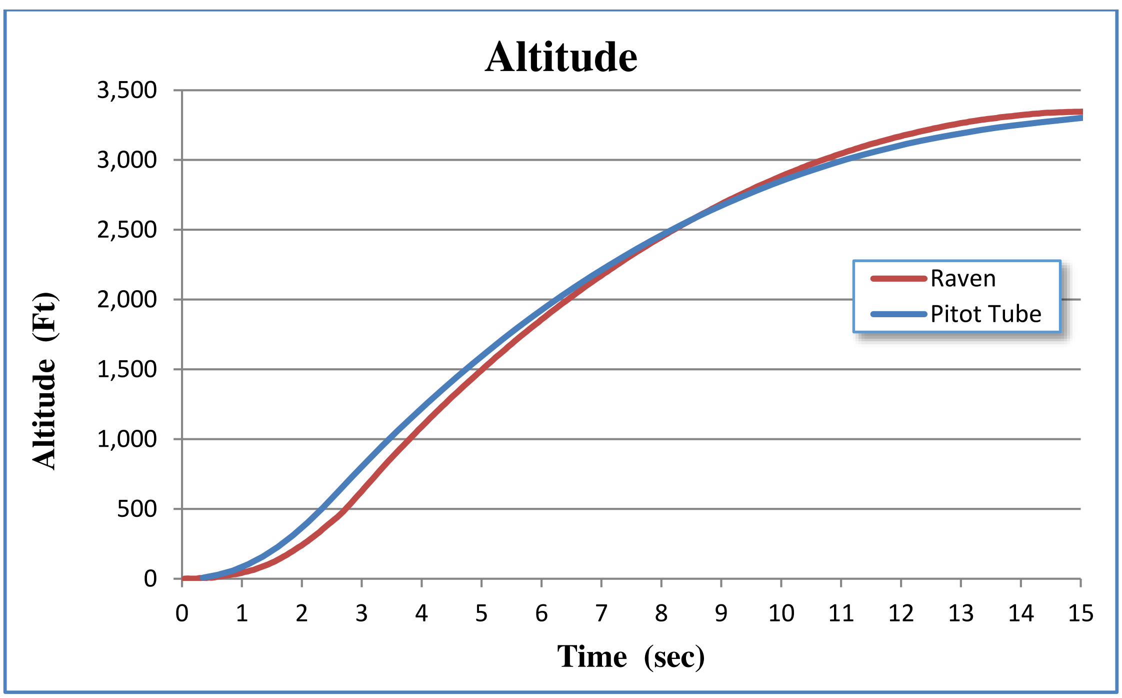

Figure 19: Altitude Comparison of Raven and Pitot tube

Conclusion

Data from both the Doppler and Pitot tube experiments matched closely to the data downloaded from the Raven altimeter. The Doppler experiment was hampered by the motor noise and the directional nature of the piezo-electric sounders but the limited data we collected provided a proof of concept for this technique.

Closing

Participating in the WSGC 2014 Collegiate High-Powered Rocketry Competition was a new and great experience for all members of Team Night Skies. This was a field of study that we had very little knowledge of prior to this competition. It gave us the opportunity to explore the fields of technology, science and innovation. Only one of us is majoring in the science field, so it was an expansive introduction into this field for our other two members and also gave our team a unique perspective. This competition also helped us develop our cooperation and interpersonal skills; working on a team and helping each of us to develop our leadership skills. Our team was also proud to be able to represent a gender that did not have much representation in this competition. We had two females on a team of three members. In addition, this has had a valuable experience for students who have an interest in working for NASA or any other company in the aerospace engineering sector. The entire competition was a great learning opportunity and experience and served as the platform from which we will continue to build our newly found love of rocketry.

It was an exciting process to see our rocket come to life. Each step along the way advanced our understanding and education of rocketry, from the starting stages, to the initial design plan, to the fabrication of our beloved Wombat 1, and finally being able to successfully launch our rocket. This was a truly life changing experience as, without this competition, we probably would have never gained this knowledge. This experience has led us to appreciate rocketry so much more than we ever would have expected, and we would like to extend a great thanks to all involved with this completion for presenting us with an opportunity to participate. Thank You.

Budget

University of Wisconsin - Sheboygan
Rocket Competition Budget

Rocket				
Formula 98 rocket kit				
Standard Kit	$	139.99		
Manufacturer changes to kit	$	35.00		
Motor Retainer	$	55.00		
Shipping	$	16.65	$	246.64
Altimeter			$	165.00
Altimeter sled			$	30.99
Misc. Hardware			$	50.00
Lead ballast weights x3			$	54.11
50" Parachute			$	79.95
Experiments				
Pitot tube holder			$	29.44
Power Connectors			$	3.99
Differential Pressure Sensor			$	34.70
Arduino data logger shield			$	32.24
Cast eyebolt & tubing for pitot tube			$	17.83
Piezo-electric sounder & batteries			$	16.77
Rocket Motor Reloads				
K454 Reloads x2	$	114.99	$	229.98
Total Budgeted Cost			**$**	**991.64**