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ROCKETDOGS

POST FLIGHT PERFORMANCE REPORT

University of Minnesota Duluth

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Executive Summary

The RocketDogs design team competed in the Wisconsin Space Grant Consortium's Regional Rocket Competition on April 27, 2013. The goal of the competition was to reach an apogee of 3000 ft as accurately as possible. The rocket had to include an electronic parachute deployment system, a competition altimeter, and be recovered in flyable condition.

The RocketDogs team designed a rocket that utilized a one-time rotating air brake that was to be activated by a microprocessor, using in-flight data to determine when the brake needs to deploy, if at all. The air brake is spring loaded and released by a solenoid. The electronic parachute ejection system was controlled by the team's own altimeter. At apogee, the altimeter was set to ignite the blast charges to deploy the parachute.

The first launch of the rocket was successful with the exception of two occurrences: the parachute was deployed using the motor backup ejection system, as the blast charges did not fully ignite; and a wire to the solenoid became loose before flight (likely during pre-flight assembly), disabling the air brake. The rocket reached an altitude of 3124 ft and was recovered in flyable condition near the launch site. This launch used an I540 motor.

The second launch of the rocket was successful in almost every aspect and should be used by the competition to calculate the score the RocketDogs team receives. The rocket reached an apogee of 2885ft, electronically deployed its parachute at apogee, activated the brake, and was recovered in flyable condition. The reason this flight was less successful than predicted is due to the use of an I216 motor to circumvent the possibility of receiving a defective I540 motor. Programming for the microcontroller was set specifically for the I540 motor, and was set to start comparing the actual coast phase to an ideal one at 1.2s, the end of the boost phase for an I540 motor. As the I216 has a thrust phase over twice as long, the controller started comparing in the middle of the boost, and consequently calculated a large error. This resulted in a premature deployment of the air brake, explaining the lower maximum altitude.

When the I216 motor data and a brake time of five seconds were input to the governing equations the control system was built upon, the rocket was expected to reach an apogee of 2896 ft. This proves that the governing equations were accurate. Had an I540 motor been used as intended, and knowing the equations are accurate, the team is confident the apogee would have been within ten feet of 3000 ft. The control system programming was not changed between launches due to oversight and time constraints.

The rocket performed as expected, but there are many improvements that could be made to the rocket for future design competitions. The primary lesson learned from the competition is that a test launch should be conducted and that the rocket should be more adaptable to changing parameters on launch day. There were also many positive aspects to the design which made it successful. The simple and reliable air brake design, accurate flight models and control system, and robust nature of the rocket build made the flights—particularly the second—successful.

Team Summary

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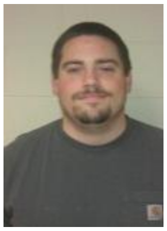			
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Design Summary

The final design of the rocket is a 3 in outer diameter, 65.63 in length body with a one-time deployed air brake built weighing 6 lbs. The rocket was constructed using components purchased from reputable high powered rocketry suppliers. An Arduino microprocessor uses in-flight data sampled during flight to electronically deploy the air brake based on a developed flight model. The final assembled rocket is shown below in Fig. 1.

Figure 1: Assembled Rocket

The air brake, made using a selective laser sintering process from glass impregnated nylon, is designed as a tear drop shape located behind the rear fins when in the undeployed position. When activated, solenoids release a spring loaded section which separates the teardrop into two parts and exposes flat surfaces normal to the rocket's flight path in order to increase drag. The recovery system consisted of a single 60 in. rip-stop nylon chute deployed by black powder canisters deployed electronically at apogee, and was designed to employ a delayed motor backup ejection, if required.

Launch

The RocketDogs team launched twice at the competition. The launches were within 125 ft and 115 ft of the desired apogee and recovered in flyable condition. The launches themselves will be discussed in detail in their own sections. Figure 2 shows the rocket leaving the launch rail during the first launch.

Figure 2: RocketDogs Rocket Leaving the Launch Rail

Flight analysis was done by collecting data from the two on board altimeters, a Stratologger Pro and a Raven III. The data collected from altimeters is accurate. This is because the two altimeters gathered flight data independently and their values for apogee and time of apogee are within 0.01 percent of one another.

First Launch

The first launch used an I540 motor and the target was to reach an apogee of 3000ft. Shown in Fig. 3 is the graph of the data collected by the PerfectFlite SL100 StratoLogger altimeter during the flight. The graph displays the altitude above ground level (AGL) and the instantaneous velocity plotted against time through the flight, as well as when the altimeter deployed the parachute. Of note is the discontinuity of the data at the apogee of the flight. This discontinuity is caused by the altimeter firing ejection charges when the rocket reaches apogee, causing an increase in pressure to separate the rocket and release the parachute. Due to a failure to ignite both canisters of gunpowder, the rocket did not separate at apogee as intended. Instead, the parachute deployed under the pressure from the backup motor ejection 4 s later. The unstable descent of the rocket begins at approximately 20 s. The cause of this instability was the parachute being deployed after apogee and then becoming tangled in its own chords. The parachute fully deployed at approximately 32 s, providing a smooth final descent.

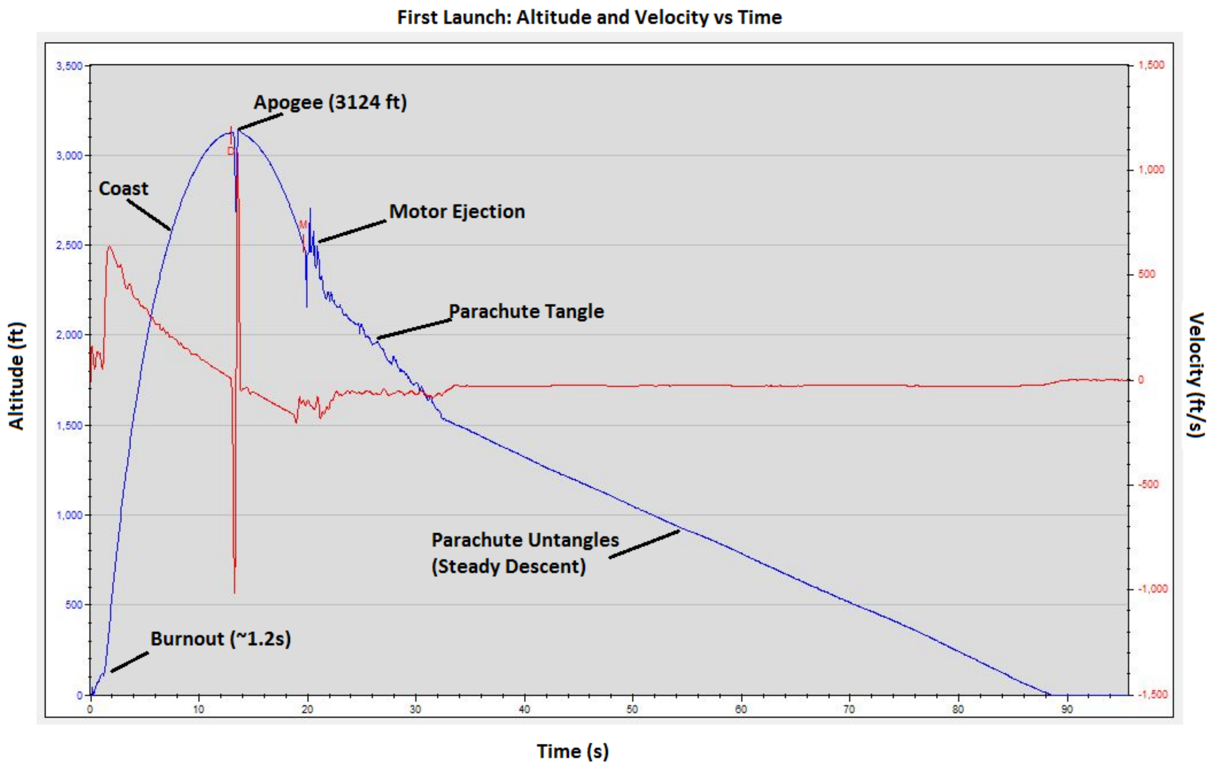

Figure 3: Graph of first flight, StratoLogger data, altitude (blue) and velocity (red) vs. time.

Shown in Table 1 are the key parameters extracted from the first rocket flight, both simulated and measured. The apogee of the rocket was recorded by the Raven III altimeter at 3124 ft, or 124 ft away from the intended height. The primary reason for this error is due to the air brake never deploying in flight; it was discovered during post-flight inspection that a wire had seemingly become disconnected during the assembly process. The disconnected wire was supposed to be connected to the solenoid for deploying the air brake; therefore, the air brake could not deploy when needed. The calculations found an apogee of 3140 ft if the brake did not deploy and if there was no wind whatsoever. This is 16 ft above the recorded apogee for the first flight, with wind speeds of approximately 10 mph. Also of importance is the descent rate of the rocket being higher than predicted. This was the result of the parachute not completely open due to an entanglement issue with the shock chord.

Table 1: First flight parameters.

First Flight	Expected	Actual	
	Calculations	StratoLogger	Raven III
Apogee (ft)	3000	3126	3124
Max Velocity (ft/s)	585	650	-
Max Acceleration (g)	15.63	-	29.67
Time of Apogee (s)	12.41	13.1	13.12
Air Brake Deploy (s)	5.63	No	
Motor	I540	I540	
Parachute Deployment	Altimeter	Motor Eject	
Descent Rate (ft/s)	24	26.8	
Flyable Recovery	Yes	Yes	

Second Launch

The second flight was successful as all the systems worked correctly and should be used by the judging committee in the scoring of the RocketDogs Team. Figure 4 is the graph of the data collected by the PerfectFlite SL100 StratoLogger altimeter during the flight. It displays the altitude above ground level (AGL) and the instantaneous velocity plotted against time through the flight, as well as when the altimeter deployed the parachute.

At the beginning of the flight, the motor takes a relatively long amount of time to burnout. The coast was smooth. When the rocket reached apogee, the blast caps deployed the parachute and the rocket separated. The parachute fully opened shortly after and the rocket began its smooth descent. It was then recovered in flyable condition near the launch site.

There is evidence of the air brake deploying at 5 s, as the voltage recorder on the microprocessor shows a signal was sent to the brake at that time. There is also a distinct decrease in the velocity that cannot be easily seen in Fig. 4 but is noticeable in the data set. Only a relatively small decrease in velocity was expected as the design of brake only increased the overall drag of the rocket by 50 percent according to computational fluid dynamic analysis.

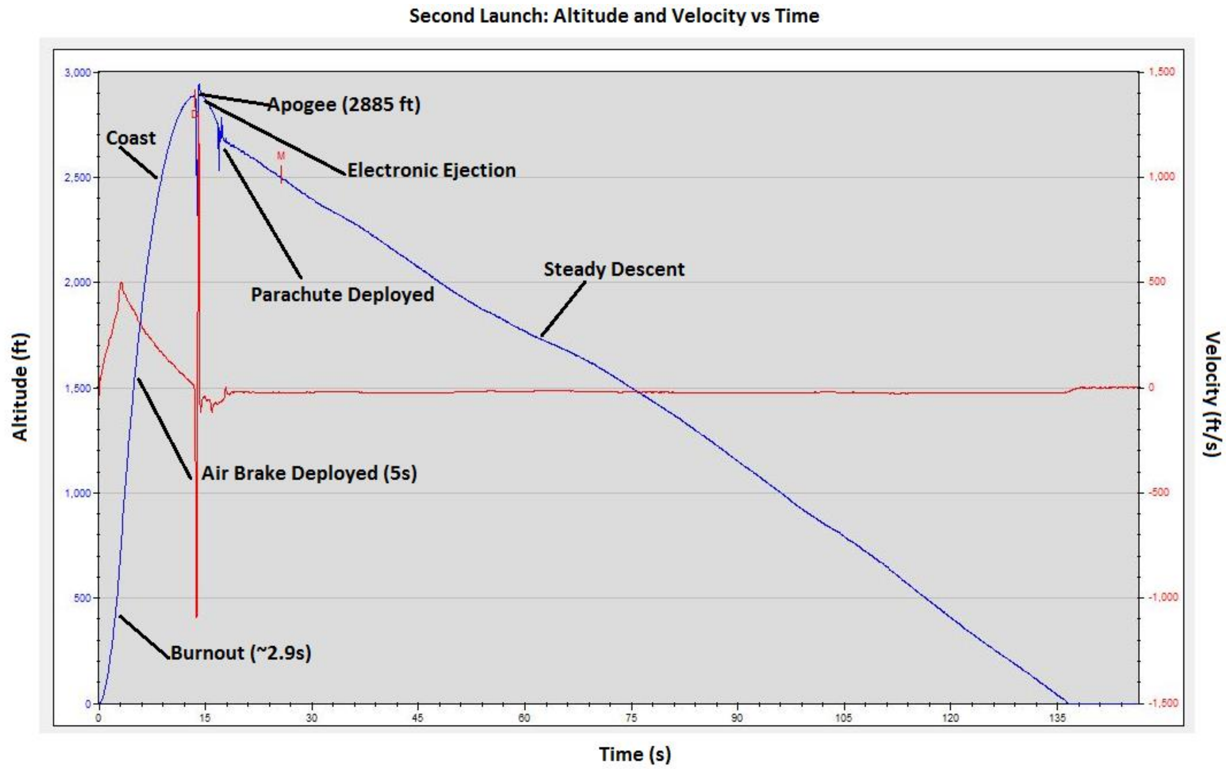

Figure 4: Graph of second flight, StratoLogger data, altitude (blue) and velocity (red) vs. time.

Table 2 shows the key parameters extracted from the rocket flight, both simulated and measured. The apogee of the rocket for the competition use was 2885 ft, or 115 ft away from the intended altitude. The primary reason for this error is due to the air brake deploying itself at the first opportunity presented during in-flight calculations by the control system. This calculation error was certainly a result of a different motor being used that had a notably longer burn-time than the motor the rocket was designed for. The in-flight control system was built to begin sampling at the end of the burn time of the I540 motor. The change of rocket motor from the I540 to the I216 changed the burn time for the same amount of propellant from 1.2 sec to 2.9 sec, introducing a huge sampling error into the data points.

However, this flight provided the data necessary to prove that the rocket control system was working as designed. The control system used the first 4 s of altimeter data to project a flight curve and calculate when to deploy the brake. After four seconds had passed, the system was allowed to activate the brake. Since burn time was so much longer for the I216, the projected flight curve had an apogee far exceeding 3000 ft so the system deployed the brake immediately at 5.5 s. A voltage feed showed that the brake deployed at 5.5 s and a drop in the velocity is also apparent at this point.

When the programming was changed to include the I216 motor data, the rocket was predicted to hit an apogee of 2896 ft without wind. This is very close to actual apogee of 2885 ft and verifies that the model is accurate.

Table 2: Second Flight Data

Second Flight	Expected	Actual	
	Calculations	StratoLogger	Raven III
Max Altitude (ft)	3000	2887	2885
Max Velocity (ft/s)	502.1	500	-
Max Acceleration (g)	5.49	-	-
Time of Apogee (s)	13.52	13.5	-
Air Brake Deploy (s)	7.12	5.5	
Motor	I216	I216	
Parachute Deployment	Altimeter	Altimeter	
Descent Rate (ft/s)	24	20.57	
Flyable Recovery	Yes	Yes	

Overall, the second flight was successful. An apogee of 2885ft was reached, the air brake deployed when the programming told it to, the parachute was deployed electronically, and the rocket was recovered in flyable condition.

Figure 5 shows the recovery of the rocket in the field. The rocket is structurally sound with no parts critically damaged.

Figure 5: Field Recovery of the Rocket

The photographs show the lower half of the rocket in one piece and in good condition. The rocket also did not drift far from the launch pad. Figure 6 shows the approximate location where the rocket was recovered for each flight.

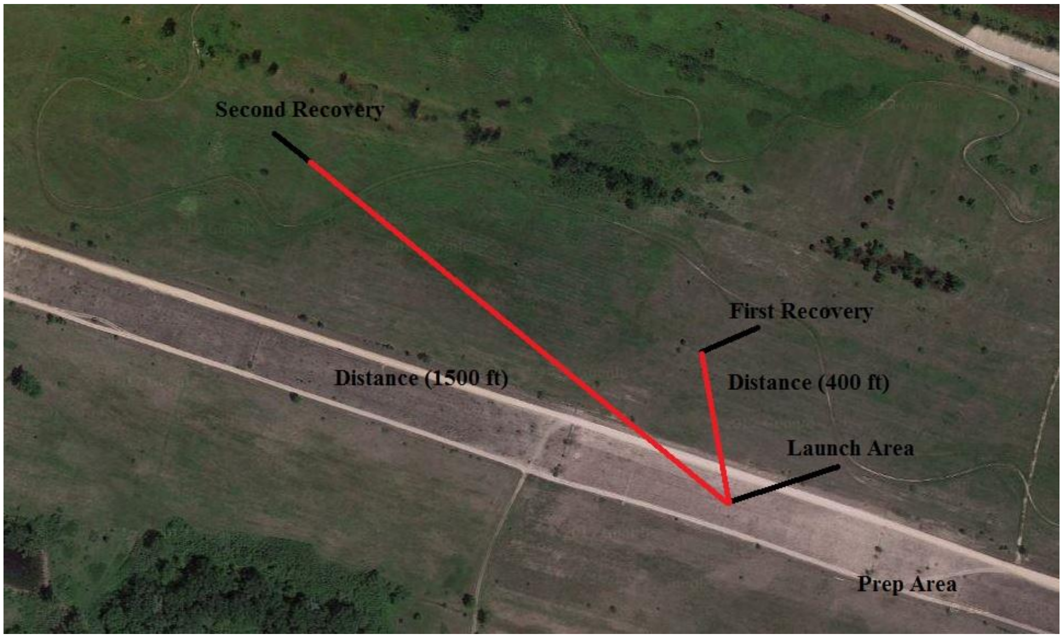

Figure 6: Recovery locations of the rocket

Lessons Learned

While the flights were successful, particularly the second, there are valuable lessons to be learned for future rocket design competitions. While the one-time air brake design worked well in many regards the flights still could have been more accurate and there are improvements that could be made. A list of the lessons learned through the design and launch is as follows:

- Finalize the design concept early to ensure proper testing can be performed
- Make the rocket's weight more easily adjustable between flights
- Make the control system inputs more easily adjustable between flights
- Arrive at competition ready to fly
- Have a standard, repeatable method for packing the blast charges, wadding, and parachute, to reduce error and ensure repeatability
- Use machine screws or rivets to attach the nosecone to the airframe
- Have a test launch to test everything as a system
- Check continuity for all electrical components of the control system when on launch pad
- Properly seal between the electronics bay and ejection sources
- Create a simple active control system. Include everything possible in simulation and modeling, but make the rocket do as little actual calculations as possible

While it is easy to point out what wrong during the flights, there were also many facets of the rocket that performed well and should be included in future designs. A list of the items that helped ensure a successful flight is as follows:

- Testing of the parachute ejection system. Had the gunpowder calculator been trusted blindly, there wouldn't have been enough pressure to eject to the parachute in flight
- Using a simple, reliable air brake that deployed dependently and symmetrically. Other teams with air brakes had unsuccessful flights due to catastrophic failures
- Testing the air brake design in a wind tunnel helped prove that the brake was stable
- The use of a jig that was cut on a water jet table during the assembly of the fins helped the rocket maintain stability and fly true
- Testing the telemetry electronics in a vacuum chamber
- Multiple coats of paint and clear coat helped the rocket stay clean after impact with the ground
- Using components that were well beyond the strength requirement and having a robust build helped the rocket survive impact and be recovered in flyable condition

Budget

Table 3 shows the design team's budget for the competition.

Table 3: Rocket Design Expenditures

Rocket Design Budget			
Item	**Quantity**	**Cost/Quant.**	**Cost**
Motor	4	$36.25	$145.00
Body Tube (Fiberglass)	3	$97.95	$293.85
Nose Cone (Polypropylene)	1	$19.95	$19.95
Centering Ring	5	$6.39	$31.95
Motor Mount Tube (Fiberglass)	1	$28.00	$28.00
Fins	4	$19.15	$76.60
Electronics Bay	1	$37.95	$37.95
Parachute	1	$73.95	$73.95
Miscellaneous Hardware	1	$217.67	$217.67
Brake Assembly	1	$1,589.00	$1,589.00
Registration Fee	1	$375.00	$375.00
Car Rental for Competition	1	$72.00	$72.00
Travel Mileage (est.)	900	$0.30	$270.00
Hotel (2 nights)	4	$101.00	$404.00
Altimeter	1	$80.00	$80.00
Miscellaneous Electronics	1	$127.52	$127.52
Epoxy	6	$5.00	$30.00
Micro-controllers	1	$60.00	$60.00
Solenoids	1	$50.00	$50.00
RockSim (software)	1	$149.35	$149.35
		Total	$4,131.79

A majority of funds went to the brake assembly. The high cost was due to the printing of multiple brakes using the SLS manufacturing process. There was also a learning curve and different design considerations which added considerably to the total amount.

Conclusion

The RocketDogs team designed a rocket with a one-time use air brake that would be deployed based on data gathered in flight, and was used in the regional rocket design competition hosted by the Wisconsin Space Grant Consortium. The RocketDogs team achieved the competition objectives of reaching an apogee as close to 3000 ft as possible, electronically deployed the parachute recovery system, and recovered the rocket in flyable condition. In addition to the competition objectives, the RocketDogs team was able to deploy their rocket's air brake when the control system was designed to do so. The launches also verified that the flight models used in simulations were accurate.

The first launch was successful in that it reached an apogee of 3124 ft, but a wiring failure caused the electronic parachute deployment system and the solenoid which activated the air brake to fail. The rocket was recovered successfully. The second launch was successful in all phases of its flight. The rocket reached an apogee of 2885 ft. Due to the validated accuracy of the governing equations, the team is confident that the second flight could have been within ten feet of 3000 ft had an I540 been used. The different burn rates for the motor and the way the control system was programmed caused a significant error in the projected flight path and skewed the calculation results determining the air brake deployment time.

The RocketDogs team feels it has competed successfully and the University of Minnesota Duluth looks forward to sending teams to future competitions. Many lessons, positive and negative, were taken from the experience and will be implemented in future designs.