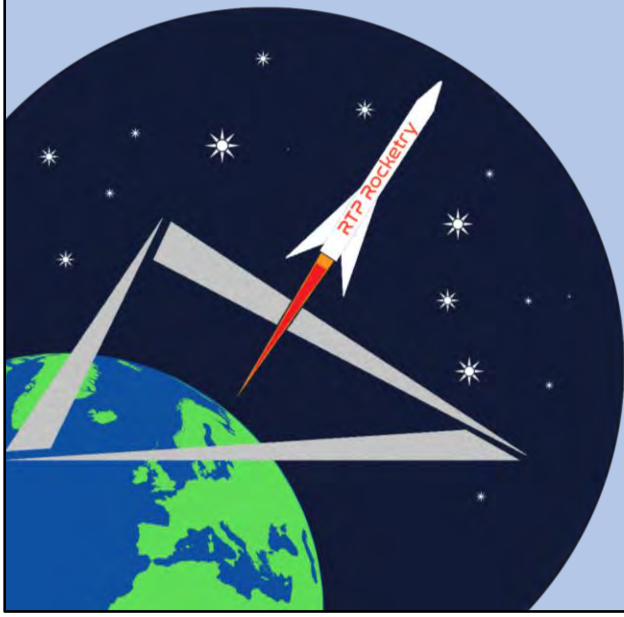


Cary Academy Rocketry Club

2021-2022 Design Review Presentation

Team 22-0000001419

Sponsored by:

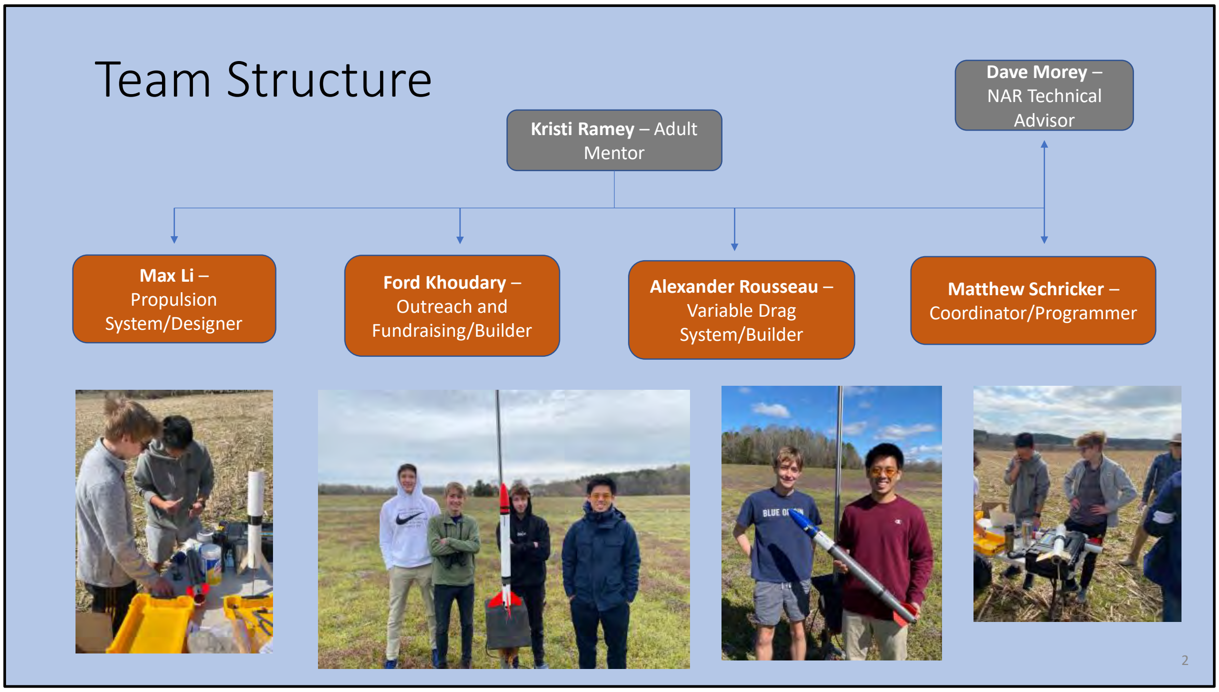
CARY ACADEMY

RALEIGH HAND TO SHOULDER CENTER

GRANDWELL SMART DISPLAY SOLUTIONS

1

Team Members: Matthew Schricker, Max Li, Alexander Rousseau, Ford Khoudary



- Our team is entirely student run with one adult mentor, Mrs. Ramey, who only provided non-technical help.
- Mr. Morey provided technical guidance and tools for launching.

Teamwork

Alexander Rousseau

- Designed the Variable Drag System (VDS)
- Helped build the body of the rocket
- Helped write this presentation

Matthew Schricker

- Designed the electronic parachute deployment system
- Worked with electronics: assembled Arduino set-up and coded flight computers
- Helped write this presentation

Max Li

- Propulsion engineer
- Designed rocket fins, centering rings, and lower body of the rocket
- Responsible for all 3-D printed parts

Ford Khoudary

- Reached out to local companies (i.e. Grandwell Industries) to get sponsors
- Led social media account and efforts
- Helped assemble the rocket

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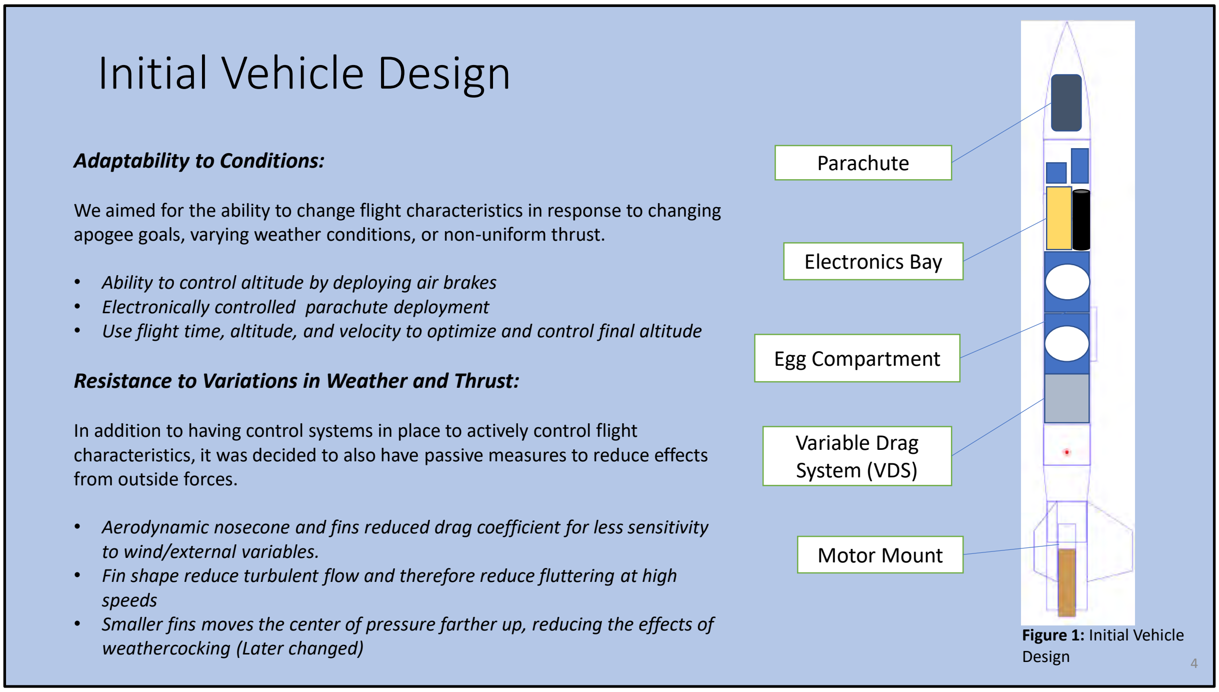
- The Cary Academy TARC team is a subset of the larger Rocketry Club, RTP Rocketry, which is ran by Matthew and Max
- The team met on Tuesday and Friday afternoons 2:30 – 3:30 to discuss and construct the launch vehicle's design
- We are a first-year team, and we stress teamwork throughout all our activities
    - No design change was signed off unless all four members agreed
    - Launches and meetings were attended by all members
    - Although members were given topic areas to gain expertise in, all members contributed in some way to all components of the vehicle



- A main goal of the TARC competition is the ability to hit precise altitudes, so we wanted a dynamic launch vehicle that can reach precise altitudes no matter the conditions.

- We had trouble avoiding weathercocking due to the large distance between our center of pressure and center of gravity
    - Initial plan had smaller fins to reduce weathercocking (this wasn't considered as a bad idea until the turbulent flow analysis)

- Eggs are in the center of the rocket to reduce shock from landing vertically.
    - Uses a BT-80 Apogee egg protector

- Autodesk Computational Fluid Dynamics (CFD) utilized to determine nosecone and fin shapes
    - Nosecone was

Launch Vehicle Summary

Full Length	749.4 mm
Diameter (upper body tube)	66 mm
Diameter (lower body tube)	56 mm
Mass	590-600 g
Motor Choice	F35W - 11
Parachute	609.6 mm diam.

Table 1: Vehicle Parameters

- Upper tube diameter chosen to allow adequate room for all payloads and recovery hardware
- Length was chosen to properly house all components and satisfy TARC requirement
- Electronically released hexagonal nylon parachute
- Based on the simulations, the parachute was chosen due to its ability to carry the vehicle within the TARC time frame

Figure 2: Assembling Electronics at Qualification Launch

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- Rocksim was used to do the initial calculations on projected rocket apogee and time

- The design of having a larger BT-80 tube (66 millimeters diameter) on top of a shorter BT-70 tube (56 mm) stemmed from the design requirement for two separate body tubes
  - Smaller BT-70 tube completes the minimum length requirement of 6 inches and holds the F35W-11 motor and fins
  - Larger BT-80 tube fits the eggs perfectly and holds all electronic components.

- A mass range was given due to the differences in size of eggs

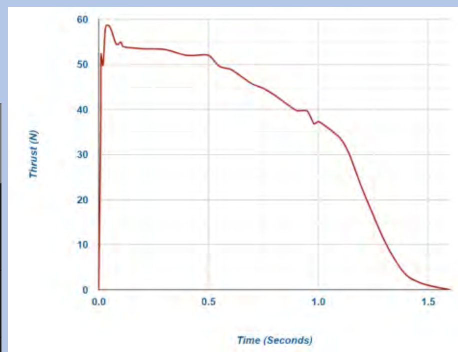
- The team decided to minimize falling time as much as possible: electronic systems can't control the rocket during this phase
  - Therefore, it was opted to choose a slower burning motor that accelerates less, and a smaller parachute for a faster falling vehicle

Performance Requirements/Motor Selection

- Having a higher predicted altitude is preferable: Variable Drag System (VDS) can reduce altitude if needed
- High thrust to weight ratio gives margin of error for mass assumptions and allows for more mass elsewhere

Motor Name	Burn Time	Total Impulse (N-S)	Max Thrust (N)	Motor Length (mm)	Propellant Mass (g)	Price ($/2pack)	Notes
F35W-11	1.6	57.1	55.2	95	30.0	$34.23	Perfect combination of high burn time and high motor impulse
F51-10NT	1.0	55.1	76.5	95	26.5	$34.23	Very high max thrust, lots of stress on vehicle
F62-10FJ	0.8	47.7	73.1	95	32.2	$34.23	Short burn time, too low total impulse
F39T-6	1.3	50	59.6	70	22.7	$34.23	Total impulse is too low for consistent overshooting

Table 2: Score chart of motors considered for launch vehicle



Graph 1: Time vs Thrust of an F35W-11 Motor

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- Table shows a narrowed down list of motors we considered.
  - Full list of similar motors can be viewed on Apogee Components website: https://www.apogeerockets.com/Rocket-Motors/AeroTech-Motors/24mm-Motors-Reload-Propellant-Kits/24-60-Motors-Reload-Propellant-Kits/Aerotech-24mm-Propellant-Kit-F35W-11

- The F35W-11 provided the best compromise of total impulse and burn time to extend ascent time
  - Longer burn time allows for a longer ascent, meaning we can lessen descent time
  - Electronic systems can't control descent rate once parachute is deployed, so we aimed to minimize descent time

- Only reloadable motors were considered to reduce cost and increase reusability
- In order to increase reusability of the vehicle (reduce wear), engines with lower max thrusts were preferred
  - F35W-11 had this combination of high total impulse yet lower max thrust

Material Makeup

Component	Material
Nosecone – Figure #4	Polylactic Acid Filament
Payload Bay – Figure #4	Polylactic Acid Filament
Upper Body Tube	Cardboard
Lower Body Tube	Cardboard
Egg Holders	High Density Foam
Transition Piece	Hi-Impact Polystyrene
Centering Rings & Fins– Figure #3	Polylactic Acid Filament
Variable Drag System – Figure #5	Polylactic Acid Filament

Table 3: Construction Materials (Excluding electronics and motor)

Figure 3: Centering Rings & Fins

Figure 4: Nosecone and Payload Bay

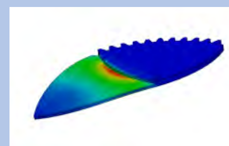

Figure 5: 3-D Model of Initial Design Variable Drag System Fin

- More than half of the vehicle is from 3-D printed polylactic acid filament.
- Although store-bought plastic has high-compression strength and an excellent strength-to-weight ratio, 3-D printed parts allowed for ease of customizations. 3-D parts also prints faster than what it takes for commercial parts to deliver.
- Our first launch resulted in catastrophic error and total loss of the vehicle. We had a second launch vehicle ready within a day due to these fast printing speeds.

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- The Body tubes, transition piece, and egg holders are purchased directly from Apogee Components
- All other parts are 3-D printed using 3-D printers and supplies provided by our sponsor, Cary Academy
- Grandwell and Raleigh Hand to Shoulder Center both provided financial aid and materials
  - Grandwell provided electronic components used for the VDS and Parachute Deployment System (See slide 9,13)

Reducing Vehicle Drag & Turbulent Flow

Nosecone

- To maximize efficiency, nosecone was designed to have a low drag coefficient
- As drag is highly variable dependent on current weather conditions (pressure, humidity), high drag was avoided
- Nosecone was designed and optimized using Computational Fluid Dynamics

Fins

- Although having a slightly higher drag coefficient than elliptical wings, trapezoidal fins were chosen after a turbulent flow analysis of fins and tube above
- Trapezoidal fins gave more guidance at lower speeds in comparison to elliptical because of higher radius

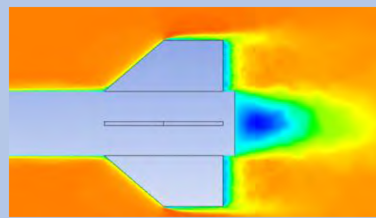

Figure 6: CFD analysis of fin design

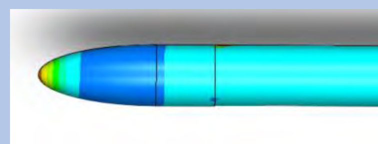

Figure 7: Pressure analysis of prototype elliptical nosecone

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In addition to optimizing the fins and nosecone design, other techniques were used in order to reduce drag and therefore increase capability

- Smooth any rough areas from 3-D printing
- Cover small gaps between tubes with caulk and secure temporary placements with electrical tape
- Paint the body tubes with a gloss paint

- After looking at studies on fin types and performing tests on different fin types, trapezoidal fins were chosen especially for their guidance in high winds
    - This could possibly be attributed to the lower "fluttering" chance than other fin types at subsonic speeds
    - Rectangle fins were especially bad at fluttering
    - By choosing trapezoidal fins, we reduced the thickness of our fins and therefore mass

- In comparison to other nosecone types, elliptical nosecones have the lowest coefficient of drag at subsonic speeds
    - This was confirmed by testing in the CFD wind-tunnel

Technical Design: Automatic Parachute Release

Design Overview:
The parachute release system uses a servo in addition with 3-D printed components and electrical components to release the parachute at apogee or at a target altitude. The nosecone (Figure 8) contains the parachute, and the nosecone door (Figure 9) closes over the nosecone, securing the parachute. A servo sits in the payload section (Figure 10), that holds and releases the door. The servo is controlled by an Arduino Teensy held in the payload section, and the parachute release is determined based on data from a BMP 355P Altimeter.

Figure 8: Nosecone

Figure 9: Nosecone Door

Figure 10: Payload Section

Reasons for using:
- Allows for perfect parachute deployment every flight, no matter the engine or weather conditions
- Can alter apogee through deploying parachute on ascent
- Programmable and customizable

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- When designing the nosecone, simplicity, mass, and drag were considered
  - The nosecone only has two moving parts: the servo and the door. For this reason, it is extremely reliable.
  - 3-D printing allowed us to make complex and lightweight structures that weren’t possible with regular casting or cutting techniques.
  - After a turbulent flow analysis at various flight speeds, an elliptical design was chosen to minimize drag coefficient

- An electronically ejected parachute reduces the need for repeated test flights for different conditions, as an exact ejection delay is generated autonomously per flight

The Three Stages of Parachute Deployment

Stage 1: Door and parachute held in position by the servo. Detecting for apogee.

Stage 2: Apogee detected and the servo spins, releasing the door.

Stage 3: The parachute is released and deployed.

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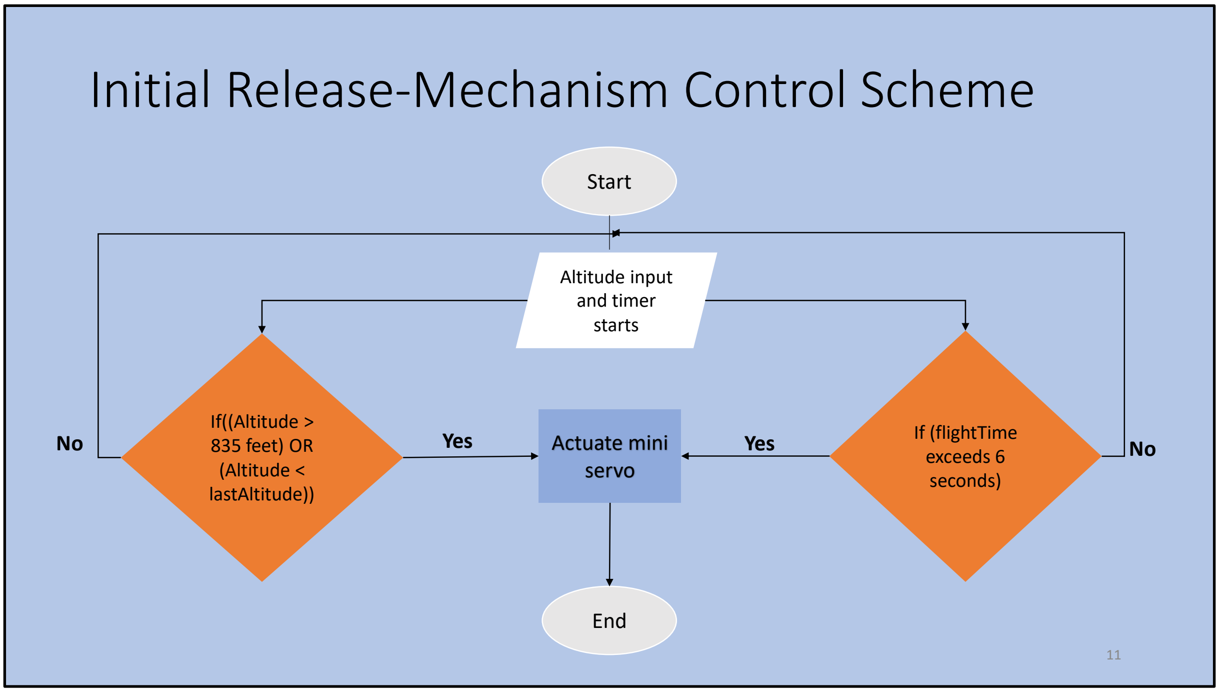
- The door was designed to pop off with only the pressure from the parachute inside
  - This was deemed risky, however, as in non-optimal situations the door would stay on from wind pressure. Therefore, springs were later added.



- As soon as the altimeter records an altitude above the initial altitude, the program will start.
- Then the program will check for two things, the altitude and the time.
- When the altitude is less than the last recorded altitude, the parachute deploy. This is detecting for the launch vehicle's apogee during flight
- If the launch vehicle exceeds the goal apogee, the parachute will also deploy to slow it down
- If for some reason the altimeter fails, which has occurred before and caused catastrophic losses, the servo will also spin after 6 seconds of flight time to ensure the safety of bystanders and have a safe recovery. This is our failsafe.

System Level Trade Study

Many alternative designs were considered during the development of the Electronic Parachute System. As the functionality of this system is integral to the success of the launch vehicle. Extensive research was carried out to ensure the best solution was pursued. Below is a brief introduction into alternative systems that were considered for implementation.

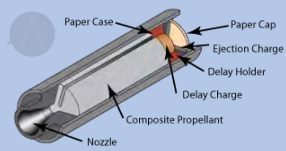


Figure 10: Classic Ejection Charge

Figure 11: Linear Actuator

Options		Nosecone Deployment		Linear Actuator		Classic Ejection Charge	
Categories	**Weights**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**
Deploy Speed	10.00%	7	0.7	3	1.50	9	0.5
Controllability	40.00%	10	2.5	10	1.25	2	2.5
Simplicity	15.00%	10	1.5	5	2.00	10	0.75
Mass	25.00%	7	1.75	4	1.75	8	1
Manufacturability	10.00%	9	0.9	6	0.60	5	0.4
Total Score:		**7.4**		**7.1**		**5.15**	

Table 4: Comparison of Different Deployment Systems

Linear Actuator
- A full actuation of the linear actuator took approximately 4 seconds, far too long for a rocket that needs quick reaction times
- Electronically controlled but heavy and complicated.
- Required 12 volts, which would require excessive space and electronic layout
- Took a long time to ship and was expensive; non-repeatable process if damaged

Ejection Charge
- Although not dynamic like the other options, a classic ejection charge was considered mainly for its simplicity
- In sub-scale demonstrations, the ejection charge proved adapt at deploying the parachute every time.
- It took many launches to gain some control over when in relation to apogee it deployed

Electronic Nosecone Deployment
- By utilizing ground tests and pressure chambers, the altitude-based nosecone deployment proved its preciseness
- In addition, a nosecone could be 3-D Printed in less than 5 hours, much shorter shipping times than the linear actuator system.
- Better precision and autonomous capabilities than the classic ejection charge

Technical Design: Variable Drag Flaps

Design Overview:

In order to achieve TARC's altitude and time goals, the variable drag system (VDF) was implemented to dynamically change the drag of the vehicle.

- *Actuated by a 180-degree mini-servo*
- *All components are 3-D printed using a composite polymer*
- *Designed for use during the coast phase after motor burnout, allowing the vehicle to compensate for variations in weather and motor burn characteristics*
- *By placing blades perpendicular to airstream, calculated drag coefficient increases by a factor of 1.27*
- *Printed slots mechanically stop over-rotation by the servo*

VDF Components:
- *Teensy 3.6 Microcontroller*
- *Adafruit BMP 355P Altimeter*
- *SG90 Continuous Micro-Servo*

Figure 12: Second Air Brakes Prototype

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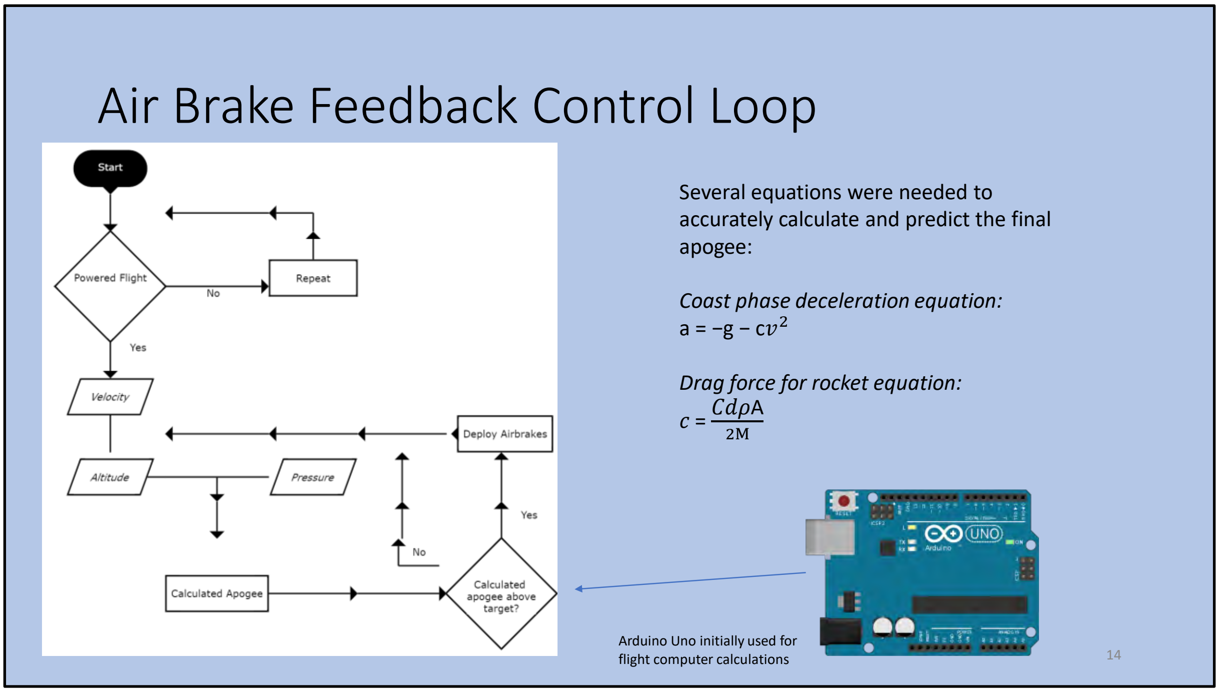
- The VDF was intended to respond to outside variables during the ascent of the vehicle
- Using CFD analysis, a 3-D printed fin were able to withstand forces equal to a 170-mph flight, well over our maximum speed. For this reason, lightweight and easily manufacturable 3-D Printing was chosen for the material



- Arduino checks for powered flight, and then calculates the apogee using a combination of the velocity, altitude, and pressure

- System uses a PID controller (Position, Integral, Derivative), in order to effectively calculate apogee and correct for any variations in velocity

- a is the vertical component of acceleration, g is the acceleration due to gravity, and v is the vertical component of velocity. The constant c represents the vehicle's unique drag characteristics.
    - A is the cross-sectional area of the vehicle, Cd is the coefficient of drag of the vehicle, and m is the mass of the vehicle after burn.

System Level Trade Study

Figure 13: Outward Airbrake

Options		3-Bladed VDF		Rotating Fins		Outward Airbrake	
Categories	**Weights**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**
Actuation Speed	15.00%	8	1.20	10	1.50	4	0.5
Projected Area	25.00%	7	1.75	5	1.25	10	2.5
Simplicity	25.00%	8	2.00	5	2.00	3	0.75
Mass	25.00%	7	1.75	8	1.75	4	1
Manufacturability	10.00%	7	0.70	6	0.60	4	0.4
Total Score:		**7.4**		**7.1**		**5.15**	

Table 5: Comparison of VDS Systems

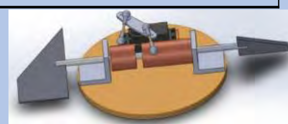


Figure 14: Rotating Fins

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Similar to the electronic parachute system, the team considered many designs when creating the variable Drag System

- 3-Bladed Variable Drag Flaps allowed for quick actuation speed and simplicity. In addition, it was easily 3-D printed and programmable.
- Although the rotating fins had the quickest actuation time out of all the designs, it was the least functional in terms of projected area. It also had the most mass and hardest programming.
- The outward airbrake had a slow actuation time (bad for a quick moving rocket) and had overall bad values across the board.

Accounting for Varying Goal Apogees, Weather Conditions, and Motor Performance

Through a combination of the launch vehicle's autonomous systems, peak apogee and total flight time can be altered

Electronic Parachute System:

- Duration of descent (most unpredictable part of flight) can be altered by varying parachute deployment time
- No matter the weather, system will deploy at goal altitude or apogee
- Depending on option chosen before liftoff, vehicle will be stopped at either 775 or 835 feet by system

Variable Drag Flaps:

- System smooths over any motor performance variations by actuating/not actuating fins according to calculated apogee
- Controls ascent based on goal altitude (either 835 or 775)
- **During qualification flights, VDF contributed to rocket having a 99.2 percent accuracy rate when achieving apogee**

Figure 15: Air Brake Internal Set Up

Figure 16: Air Brakes Fully Deployed

- Autonomous systems were utilized in order to stop any variations caused by external variables in the flights

Results of 1st Flight

As the first flight resulted in the launch vehicle making an uncontrolled descent to the ground (Fig. 5), the team realized we needed to re-think many of our systems. After analyzing the wreckage, several points of design failure were identified, leading to a re-design of certain components.

Failure identified from wreckage and flight data	Changes implemented for second flight
Faulty failsafe in code. By time failsafe activated, launch vehicle was in a nosedive and door was unable to open correctly.	• Failsafe re-designed to detect apogee using past altitude values • Program refresh rate changed to every 0.1 seconds, as opposed to every 0.6
Insufficient force to open door in downwards and upside-down orientations:	• Springs added to parachute compartment for extra pressure against parachute
Thrust puck for motor was attached to fins for support: Instead of being glued, it was decided to have the fins interlock with the thrust puck for support. As a result, potential thrust lost was lost by zippering the cardboard body tube. (Fig. 6)	• Both the thrust puck and fins were glued in using a plastic epoxy
Launch vehicle too heavy: unwieldy nickel battery led to off center COM (Center of Mass) and low apogee	• Changed to significantly lighter 9V battery with a lighter charger cord

Table 6: List of Failures/Changes After First Launch

Figure 17: Wreckage of Launch Vehicle Resulting from Faulty Parachute Mechanism

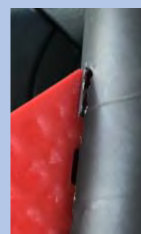

Figure 18: Evidence of Body Tubes Being Zippered By Fins

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- Although first flight was a failure, it gave us lots of valuable data that helped us improve the launch vehicle
- Due to the fast printing of 3-D Printers, our second launch vehicle was ready in less than a day after being completely lost before
    - Several components were iterated upon during this period

Subsequent Data Collection

Second Flight:

- Nominal Ascent
- Max. Altitude was 635 feet
- 39 second flight

Third Flight:

- Nominal Ascent
- Max. Altitude: 689 feet
- 40 second flight

Both flights had a perfect parachute deployment exactly at apogee!

Failure of rocket	Changes implemented for next flights
Electronics too heavy, leading to lower apogee than anticipated	• Electronic board switched to the Arduino Teensy (15 grams lighter) • Battery switched to a significantly lighter Lipo battery
Centering ring bent out of shape mid-2nd flight	• Added supports to 3D model

Table 7: List of Failures/Changes After Second Launch

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- Flight data tells us that there was a lost in thrust 1.2 seconds into the second flight: We attribute this to the centering ring bending and henceforth wasting thrust

- Both flights verified the functionality of the parachute system, we were confident that it would work for qualifications

- Altitudes had to be corrected due to temperature
    - Altitude = Altimeter * (273.15 + Local temp (C)) / 288.15

Qualification Flights

Flight #	Max Altitude (ft)	Time (s)	Total Points
1	841	32	42
2	Unverified	29	Disqualified
3	827	12	Disqualified

Table 8: Qualification Flight Summary

Figure 19: Team Picture at Bahama, NC

Next Steps:

- Flight-test new code that results in a 17% faster reaction time
- Reduce mass of 3-D printed components
- Create a function of velocity, altitude, and projected apogee.
- Launch in non-optimal conditions (i.e. winds higher than 13 mph) to test variable drag system's calculations in high wind

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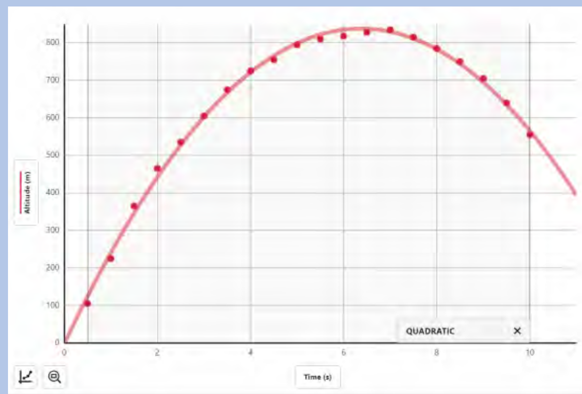
- Although VDF system worked very well in getting a 99.2 percent accuracy rate with the altitude, parachute deployment failed in last flight
    - 2nd flight was disqualified due to pieces falling off.
    - 3rd Flight had a catastrophic failure with the parachute system, resultingly, entire vehicle was lost

- First qualification flight had the parachute unfurl very late, leading to a large jolt with the electronics: This is possibly what led to the accident in the last flight

- We're going to keep on testing and make sure our systems are foolproof next year!

Analyzing Flight Data

- Rocket hit the altitude target with an accuracy of 99.2 percent.
- Parachute unfurled way too late on first flight, leading to lower time score
- Parachute system is very unreliable, further testing will need to be completed
- By using the VDF, we were successfully able to alter the final apogee and get on target
- Although the vehicle was a bit over-stable in the high winds, the VDF was able to smooth out any variations



Graph 2: Flight data from 3rd failed flight – no parachute release detected

Lessons Learned and Conclusion

- Just a single line of code can end a whole launch!
- Electronics are a MUST for future competitions: the ability to dynamically change the goal apogee with the click of a button is vital
- Simulations will not model launches accurately – *same goes for mathematical equations*
- Start doing test launches earlier, and set deadlines for team objectives to be met
- Don't stick with a design just because of personal pride, always search for a better iteration
- **Engineering is the process of constant improvements. Good enough is never the right answer.**

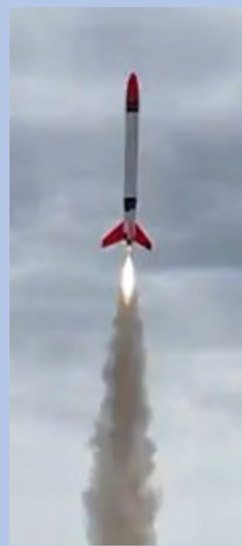


Figure 21: First Successful Launch

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- As it was our first time in the competition and first time using electronics like the Arduino, we had a lot of teething problems in the beginning. Shown by the VDF, however, electronics are extremely helpful in determining final altitude

- Although our team will not qualify for further competition due to disqualifications of two out three launches, we noticed very positive trends in recorded altitudes
    - Adding up both recorded qualifications launches results in a 99.2 percent accuracy rate when it comes to altitude
    - Descent rate and parachute release needs to be worked on, as that was our biggest problem throughout the competition

- We had expected for the rocket to overshoot our target apogee by a fair margin according to simulations
    - Real world results tended to be a little bit shorter than the simulated apogee, probably because of external factors

- We aim to launch earlier for next year to better test out our electrical components and gain data