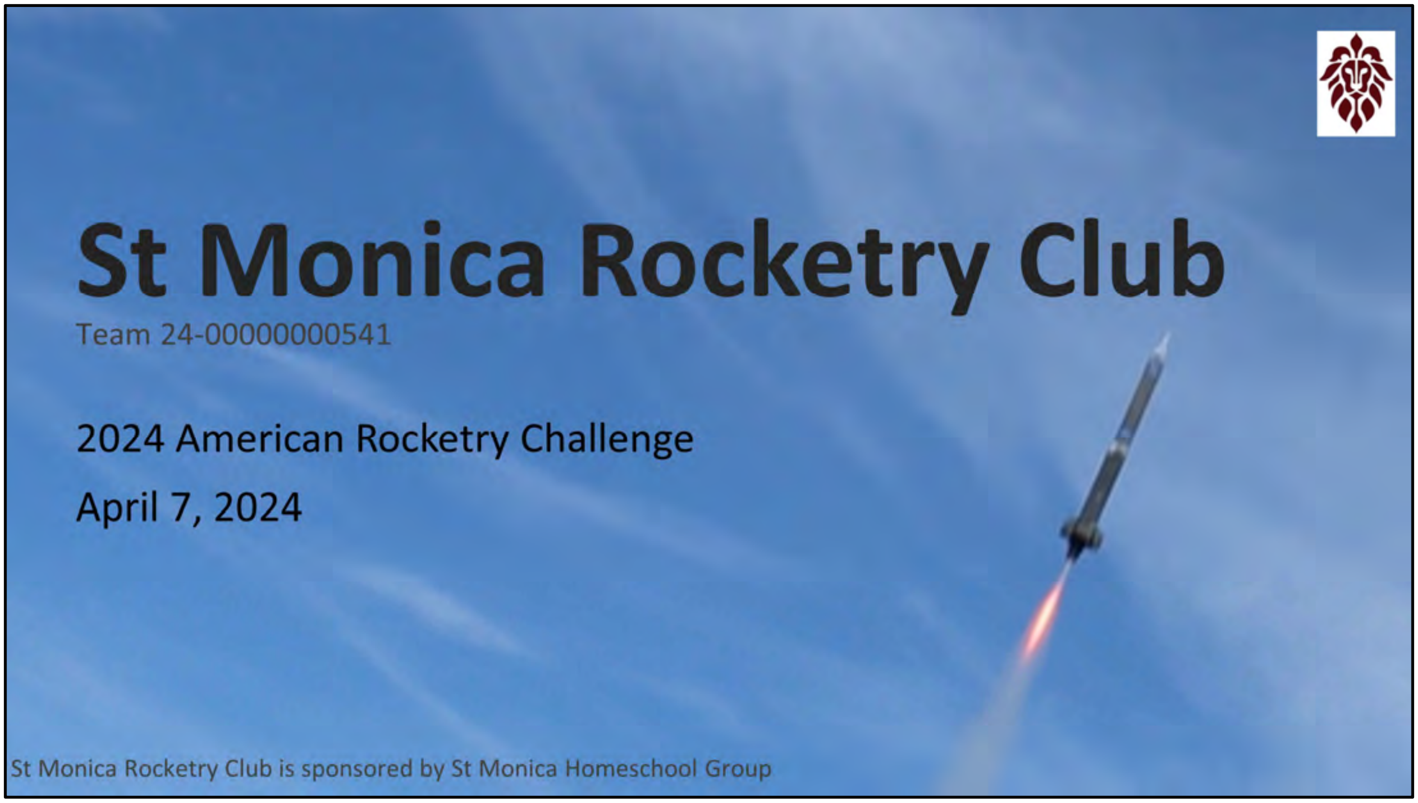

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2, Final Design: Brian

3, Rocksim: Patrick

4, Dynamic Stability: Patrick

5, Prototype Design: Sullivan

6, Prototype Test Flights: Sullivan

7, Construction Tooling: J.P.

8, Tail Cone Assembly: Danilo

9, Transition Assembly: Adam

10, Motor Selection: Mary

11, Descent Rates: Brian

12, Parachute Reefing Results: Sullivan

13, Determining Target Mass: Brian

14, Practice Flights: Peter

15, Qualification Prep: Brian

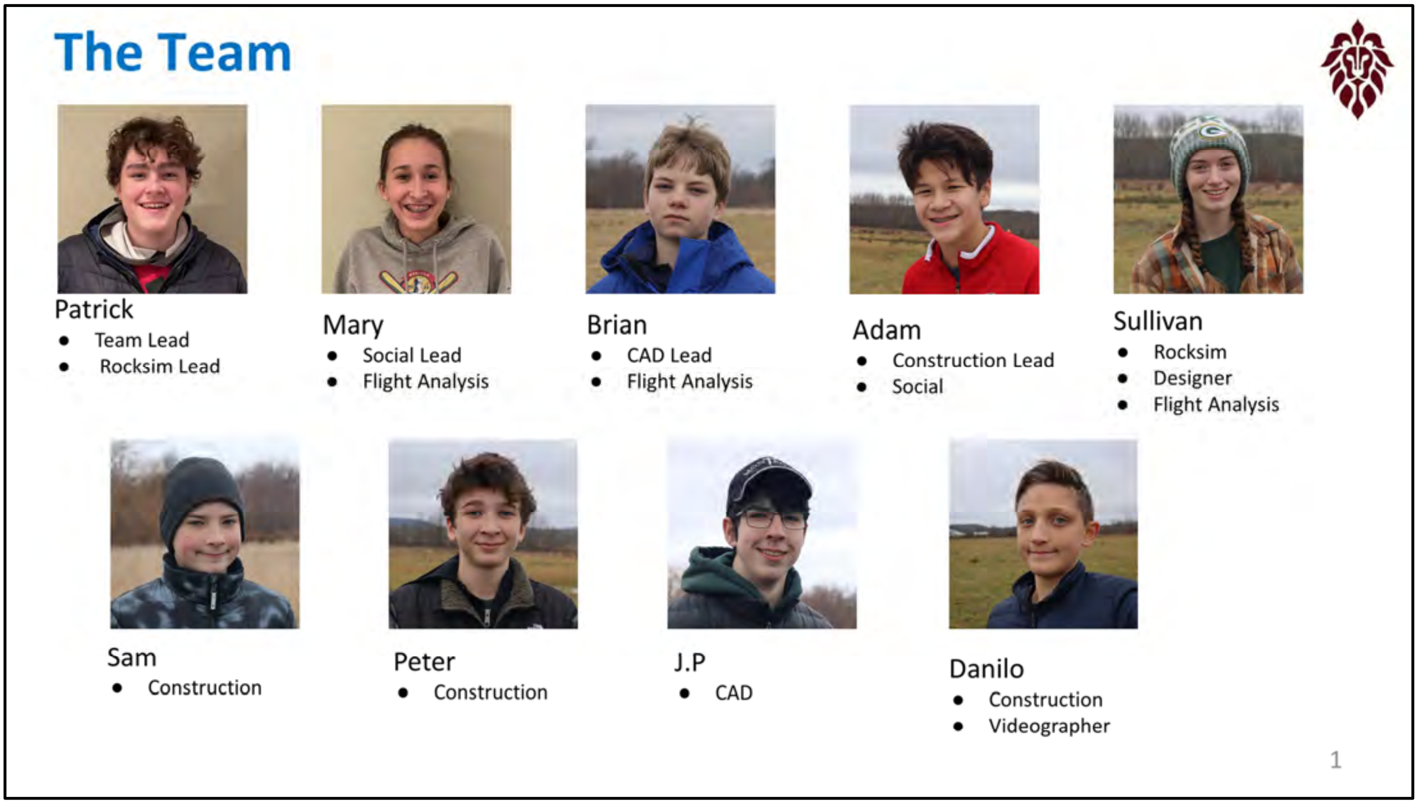
16, Qualification Flights: Brian

17, Time Management: Sam

18, Social Media: Mary

19, Lessons Learned: J.P./Adam/Peter

20, Appendix, Parts Listing: Sam

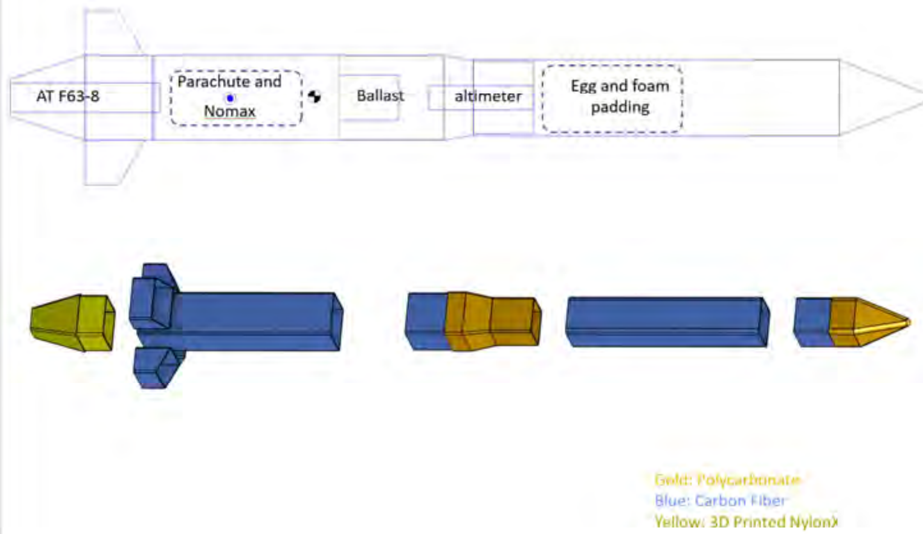


Hi, we are the St Monica Rocketry Club. We are all homeschooled and from the New York-Connecticut metro area. Our members' grades range from 7th to 11th. Some of our members are starting their second year of rocketry while others are starting their third or fourth year. Even though some of these members have only been here for a couple of years, our rocketry club has existed for 10 years with the same mentor.

What is unique about us is that even though we are educated at home, have different curriculums and are spread out over a large geographical area. We still share a common goal and love of math, rocketry, and science. One of the largest difficulties that we have had to tackle is effective communication. Due to our distance from each other we have made sure to work collaboratively by emailing, texting, collaborating on Google Docs, and meeting in-person every week.

Final Design

- Reusable launch vehicle
- 100% waterproof
- 100% of airframe components manufactured by team
- Unballasted mass of 487g
- Total length: 30 In.
- Stability margin of 1.35
- Parachute - Rocketman-24” TARC
- Uses Aerotech RMS 24/60 motor system

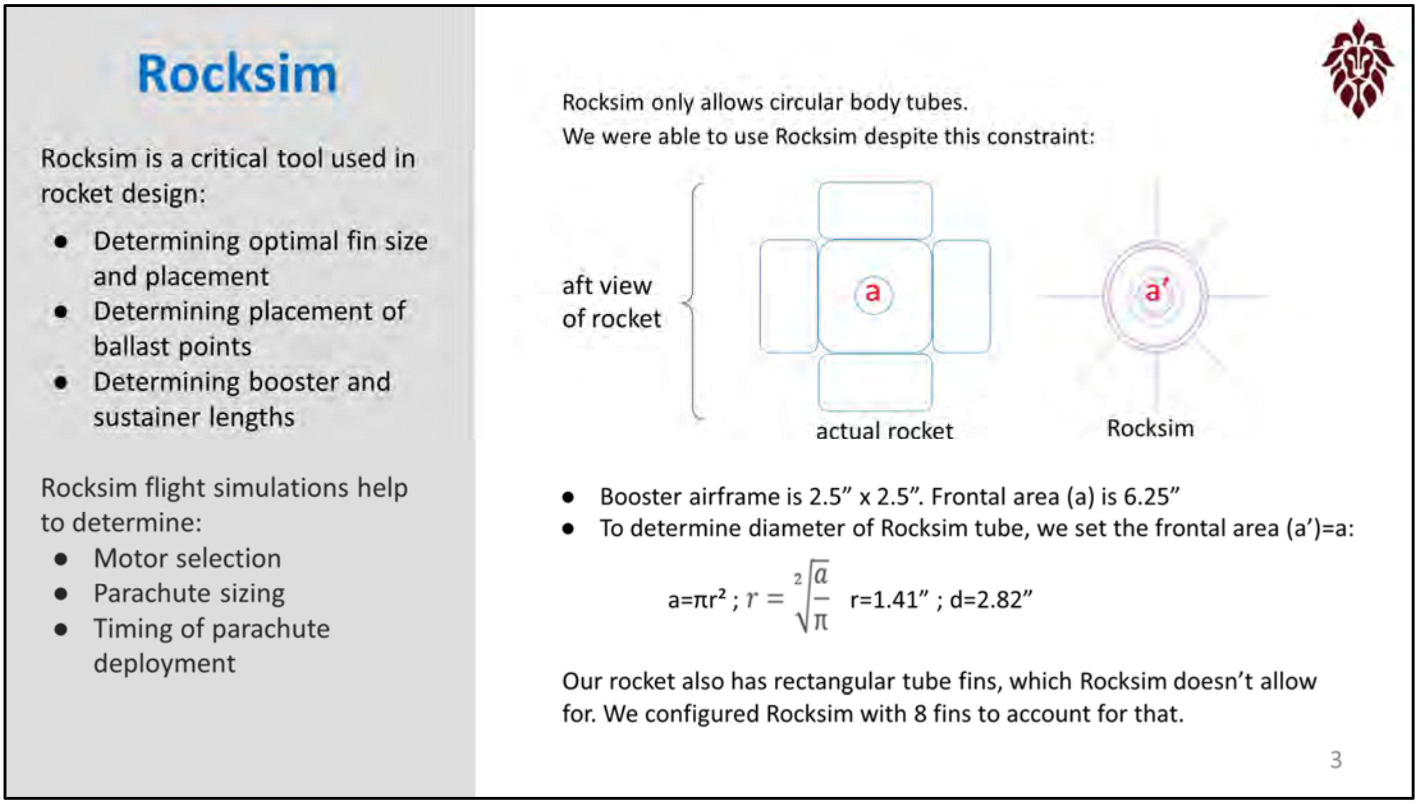


2

Our team has a square rocket, which some people think is a little weird. We chose this unusual design for our rocket while we were coming back from flying rockets in 2022. The conversation started with, “Hey wouldn’t it be funny if we had a square rocket?” The rocket from last year was square. It ended up flying really well, so we wanted to use that design as a starting point.

Last year the rocket was a bit too heavy to qualify. It flew really well, but during qualifying, we needed to have it be just a little bit lighter and we couldn’t remove any more weight. That was a major consideration this year – making components lighter. This is why we ended up vacuum forming parts – they are much lighter than 3D printed parts. Parts made using other methods proved to be flimsier.

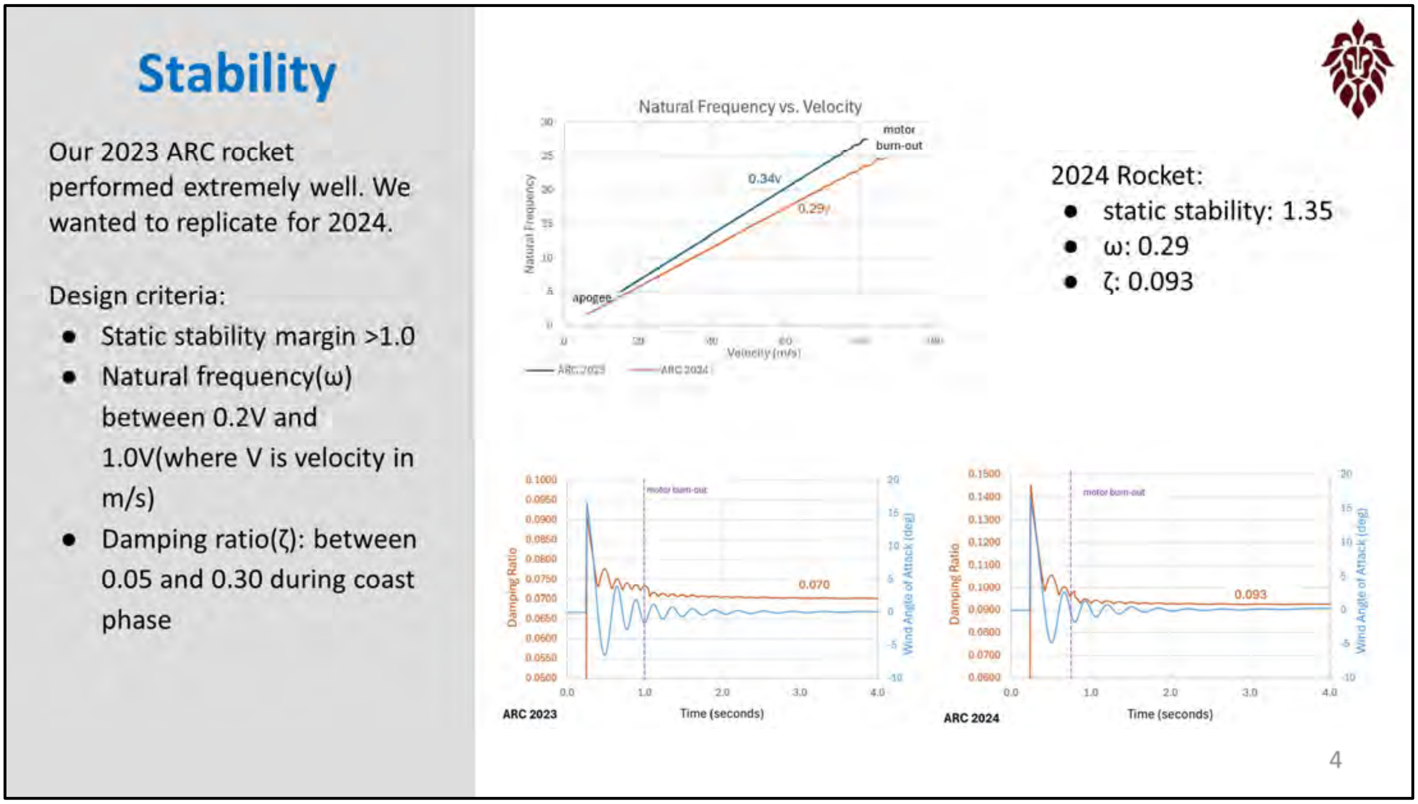
This final design was based on three initial prototypes.



In order to utilize Rocksim with a square rocket design, we tricked it into believing our rocket was circular. Although our approach was probably not perfectly accurate, we think it ended up being pretty close.

With the assistance of Rocksim we were able to build a very stable rocket with a ballast point right at the center of gravity (CG). Our rocket is stable when we keep the center of gravity at the desired spot. On one of our practice flights, the CG ended up being a fourth of an inch lower than the desired spot which ended up in an unstable flight.

We also used Rocksim to determine individual flight coefficients of drag (Cd) in a process called "Cd backtracking", as described in Apogee Peak of Flight Newsletter #130. Over the years, we have observed that a static stability margin of slightly over 1.0 is ideal for consistently good flights. This year we also started observing the dynamic stability of our rocket, which determines how quickly the rocket will correct to a straight path after a disturbance – we could not have performed this analysis without Rocksim.



This year we focused not only on static stability margin, but also dynamic stability as discussed in considerable detail in Apogee Components Peak of Flight Newsletter issues 192-197. The two variables that we wanted to closely replicate from our 2023 rocket were the natural frequency and damping ratio:

natural frequency: $\omega=\sqrt{(C_1/I_L)}$
damping ratio: $\zeta=C_2/(2\sqrt{C_1 I_L})$

where:

I_L=longitudinal moment of inertia
C_1=corrective moment coefficient
C_2= damping moment coefficient

Natural Frequency

- When natural frequency approaches 0.2V, "The rocket cannot respond to the moments applied by its fins with sufficient rapidity for safe and stable flight."
- A higher value results in the rocket being more easily disturbed.

Damping Ratio

- If the damping ratio is less than 1.0 (underdamped), the rocket will oscillate back and forth. The smaller the number, the faster the oscillations (i.e. higher natural frequency)
- If the damping ratio is greater than 1.0 (overdamped), the rocket will never come back to zero degrees angle of attack, creating higher drag.
- If the damping ratio is exactly 1.0 (critically damped), the rocket won't oscillate at all.

Prototype Design

Our design is not optimized for altitude

Design Goals:

- Stability
- Predictable in all types of weather
- Waterproof

The airframe is the same between all three prototypes, except fin size and placement.

Prototype #1	Prototype #2	Prototype #3
1.25″ x 2.5″ tube fins at base of booster	2.0″ x 2.0″ tube fins at base of booster	2.0″ x 2.0″ tube fins 2.5″ up from base of booster

When we designed prototypes this year, we first started off with our design from last year and tweaked it to fit the standards for this year's competition. After doing that, we realized that the fins on the rocket were too big which caused the center of pressure to be too low. To fix this problem, we came up with three designs, each featuring different fin sizes and placements. Although the different fin sizes and placements had the same static stability in Rocksim, we decided to build and fly them to determine which one performed the best.

Prototype Test Flights

- All three prototypes flew really well
- One crash - rocket undamaged and egg unbroken

Decision From Prototype Flights

- Prototype #1 was selected as final design
- Modifications needed to transition coupler (too tight of a fit)
- Vacuum forming seams on transition and nose cone need to be minimized

On November 18th, we test flew the three prototypes using Aerotech F51NT motors:

Flight#	Prototype#	Mass	Altitude (Feet)	Wind (mph)	Flight Observations
1	1	496	947	9	Straight up flight. Parachute did not deploy.
2	2	526	930	7	Flew straight
3	3	486	964	7	Slight angle off of launch rail
4	1	488	926	8	Straight flight

Another round of test flights for Prototypes #1 and #2 were flown before deciding on final design. We switched to the F63R motor.

Flight#	Prototype#	Mass	Altitude (Feet)	Wind (mph)	Flight Observations
1	1	520	782	6	Did not fly straight.
2	1	522	826	6	Straight flight
3	2	567	781	6	Straight flight
4	2	500	872	7	Straight flight

During our prototype test flights, we learned a lot from our failures and our successes. For instance, in our first flight the parachute did not deploy, and our rocket came down ballistically in one piece. From this flight, we learned that the coupler in our design was too tight and needed to be adjusted for the final design. We also learned from the way the rocket fell, horizontally, that it was extremely well balanced. Its horizontal descent caused more drag and therefore slower fall which allowed for the egg to be unharmed and the rocket to be undamaged.

After the first round of test flights, our team reconvened to discuss the flights and concluded that prototype number three ought to be eliminated. This decision to eliminate prototype three was motivated by the crooked ascent of the rocket. After the second round of flights with prototypes one and two, we selected prototype one as our final design. The choice to make prototype one the final design was far from unanimous but was still clearly a majority. The reason it was such a hard decision was because ultimately both designs performed admirably.

Mandrels for the tubes were 3D printed. The 3D printer could not print one long piece, so we made four smaller pieces and glued them together on a wooden dowel to form the mandrels.

Mandrels for the tubes were 3D printed. The 3D printer could not print one long piece, so we made four smaller pieces and glued them together on a wooden dowel to form the mandrels.

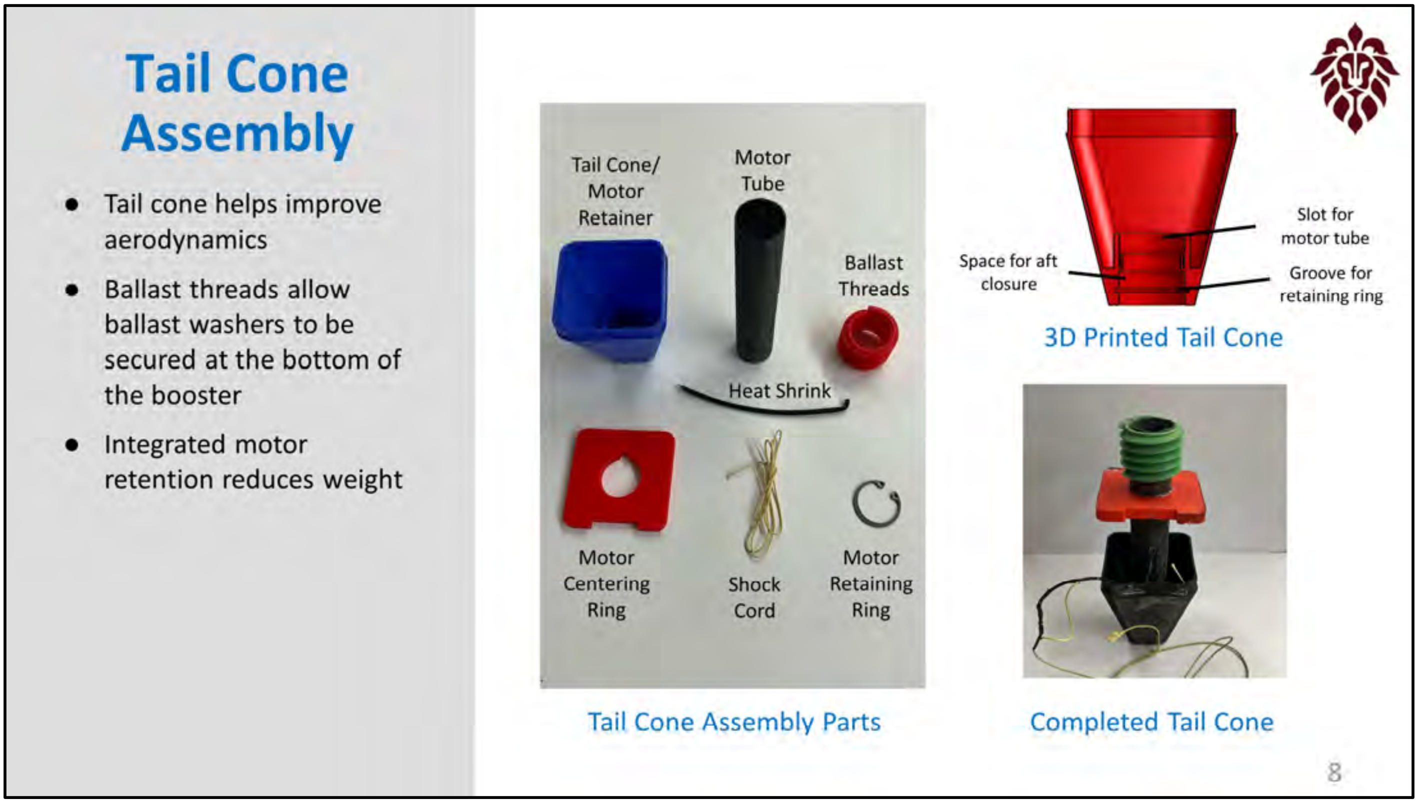
The vacuum forming process was used to make the ballast bays, altimeter bays, nose cones, and transitions.

Each mold was designed in CAD, then printed them out of CarbonX filament on the 3D printer. Using mold wax was really helpful in removing the part from the mold.

We made the hole jigs from 3D printed PLA. The drill would often move sideways, wearing away at the PLA and destroying the jig. We solved this problem by adding a metal insert into the hole in the jig.

We made the foam egg molds from wood and 3D printed parts. The molds were a challenge because we had to take them apart and put them together each time we built the foam protectors.

The fin jigs were designed in CAD and 3D printed out of PLA. Our team used the jigs to ensure that the fins were kept perfectly straight during assembly so the rocket would fly straight.

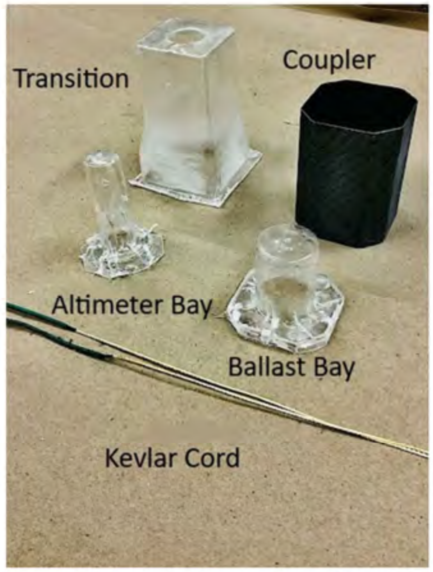


The integrated tail cone/motor retainer is a critical part of the design. Not only does it improve the aerodynamics of the rocket, but it also reduces the overall weight because a separate motor retainer is unnecessary.

We began with the motor tube being 3D printed, but it melted to the motor casing. We modified the design and used a motor tube made out of carbon fiber instead of the 3D printed version. We incorporated a ballast point in the booster. This included 3D printed threads that were glued onto the end of the motor tube. We then added the 3D printed ballast washers onto the threads and secured them in place with a 3D printed nut.

Transition Assembly

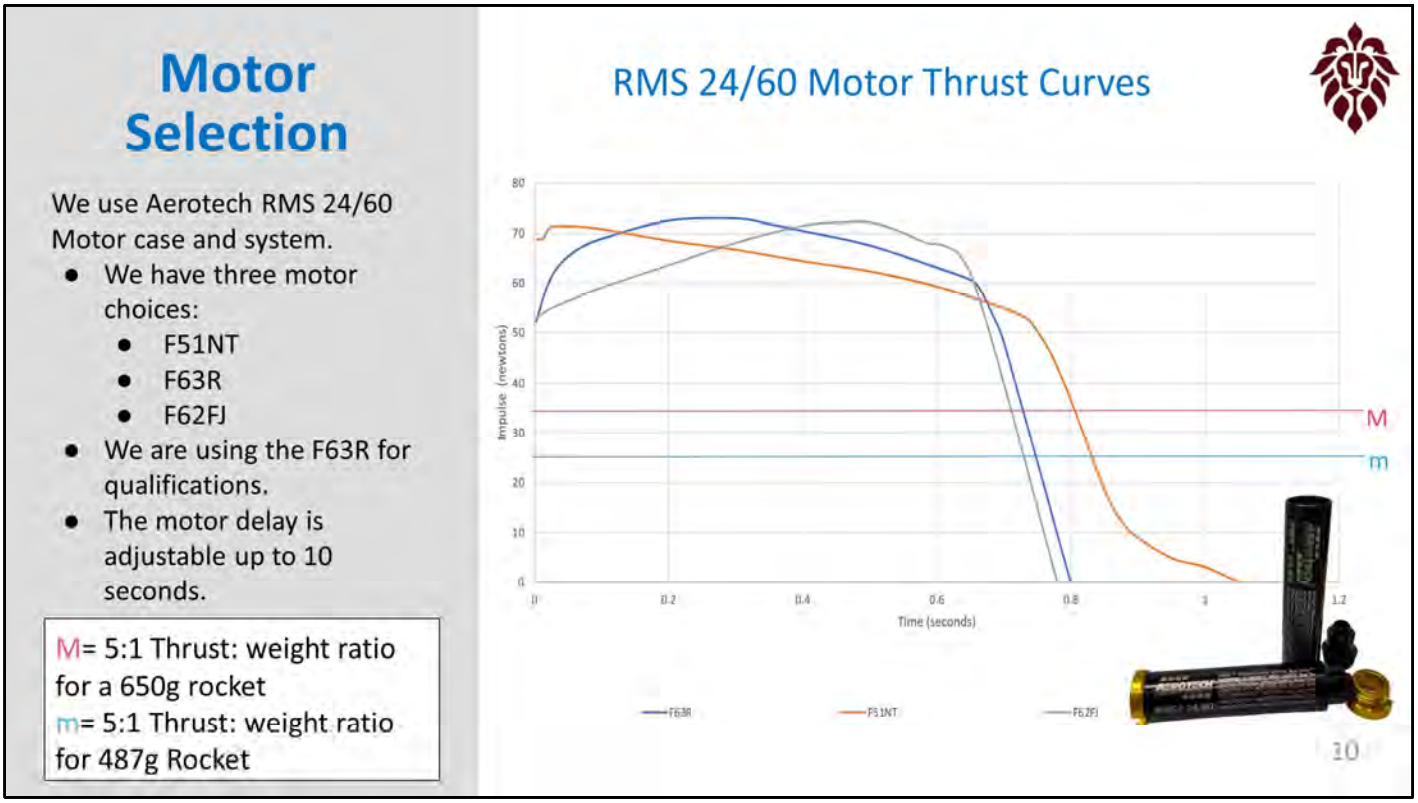
- Vacuum formed parts help reduce the weight significantly
- The mass of the assembly is 62g which is 22.5g lighter than last year
- Coupler corners are chamfered which reduces “binding” in the booster



Vacuum formed parts are much more difficult to make as opposed to the 3D printed ones; however, it was worth it, because it allowed us to reduce the weight of the transition assembly from last year’s design.

The vacuum formed parts enabled us to add up to 163g of ballast while still maintaining a stable rocket. This gave us a lot of flexibility in how we ballasted the rocket and what motors we used.

When constructing the transition assembly, we were very careful to completely seal the aft end in order to protect the altimeter from ejection gasses that could potentially harm it.

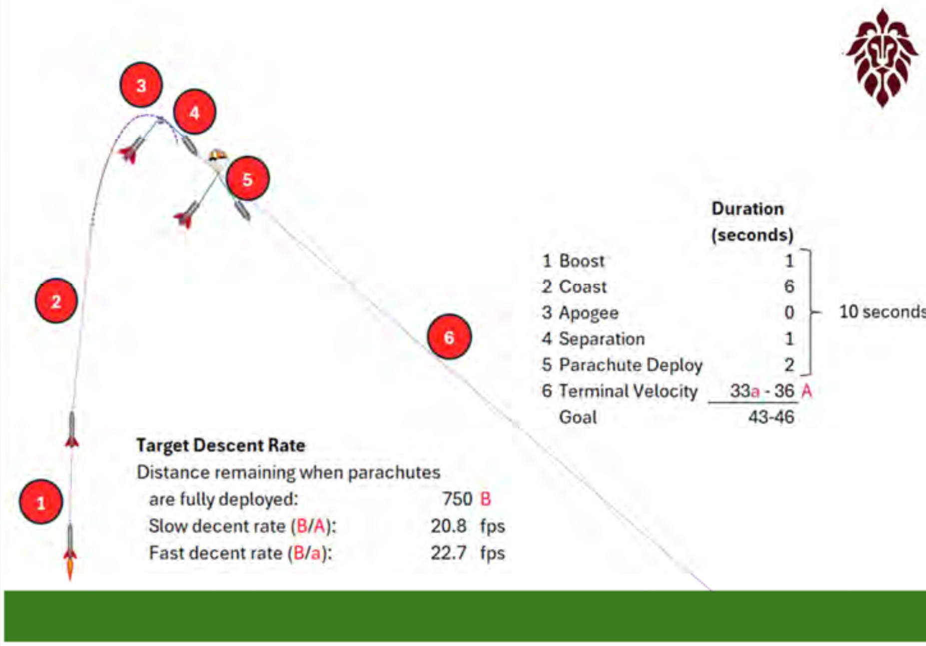


Our motor was quite awesome in many ways. Our motor case fits three different motors, giving us flexibility and margin for different altitudes. The F63R motor that we used for qualification flights had a slightly higher impulse than the F62FJ but a slightly lower impulse than the F51NT. Finals will require a different altitude, and this motor case will allow for a change in motors. If the F63R motor does not have enough impulse for us for the 850 ft target, we could use the F51NT instead. If the F63R has too much impulse for the 800 ft target, we could use the F62FJ instead. This motor system allows our team to get to the optimal qualification height, but also the flexibility to achieve different altitudes.

All three of the motors that we used are well above the minimum 5:1 thrust-to-weight ratio required for a safe flight. In fact, they were among the highest thrust motors on the approved motor list. Having a high thrust motor lessens the effect of windy conditions.

Descent Rates

- It takes on average 10 seconds for the parachute to deploy
- The average altitude at deployment is 750 ft
- In order to hit the target duration, our descent rate needs to be between 20.8fps and 22.7fps



11

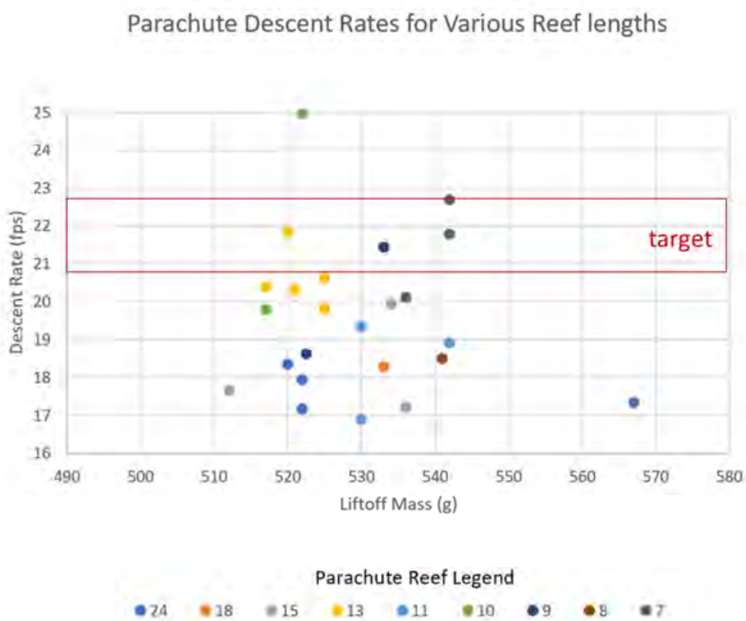
Descent rates are the rates of how fast the rocket falls. To calculate this rate, we take the altitude of the rocket and divide it by the amount of time that it was in the air. The reason this was useful was that we could use it to find a descent rate that brought the rocket to the ground in the time frame.

We flew many practice flights and observed that it took about 10 seconds for the parachute to fully deploy and that the rocket was about 70 feet from apogee when the parachute did deploy. If we flew to exactly 820 feet, this results in the parachute being fully deployed at 750 feet. We started off using a 7 second delay for our F63R motor. We noticed that the motor ejection occurred slightly before apogee several times, so we increased the delay to 8 seconds.

At Finals, the descent rates must change because the time is the same while the height is changed to be either 800 or 850 feet. for the 800-foot flight, we must decrease our descent rate to go slower so that we make the time frame. For the 850 flight, we must increase it to go faster.

Parachute Reefing Results

- We used the Rocketman 24" TARC parachute
- We adjusted descent rates by reefing the shroud lines to different lengths (measured from the edge of the canopy)

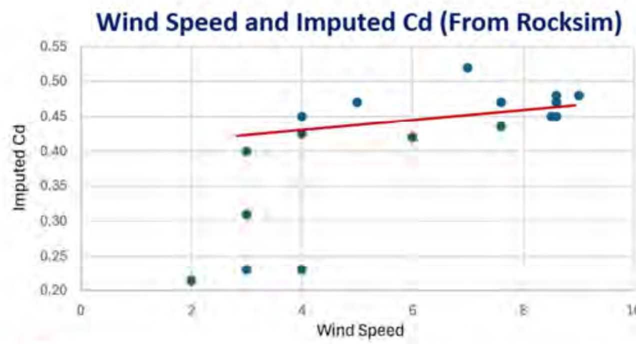


12

The parachute we used for nearly all our flights was the Rocketman 24" TARC parachute. We ended up going with the Rocketman 24" TARC parachute because the 18" had a descent rate that was too quick. Our 24" parachute had a descent rate that was slightly too long, so we remedied this by reefing our shroud lines. We measured the reef from the edge of the parachute's canopy to the point of the reef. The smaller the number, the more extreme the reef. We created a graph of all the reefing data from our practice flights to compare what was the best reefing length. Since the descent rate should be impacted by mass, we included that in the graph as well. Our hypothesis was that higher masses result in faster descent rates. The result of our analysis is that we will have to significantly reef our parachute in qualifying flights, as well as at Finals. The red box indicates our desired descent rates for qualifying flights, which was calculated on slide 11.

Determining Target Mass

- Flight data from practice flights were used to determine the mass of the rocket
- Utilizing Rocksim, we imputed the Cd for each flight
- For each day that we flew, we constructed a Flight Matrix
- This matrix was developed by running simulations until we reached the desired 820 feet



Flight Matrix

Temperature	52 F
Pressure	29.54 In Hg
Humidity	50 %
Cloud Cover	50 %

Mass (g) needed to achieve 820 ft

Cd \ Wind Speed	4	6	8	10
0.51	505	504	503	502
0.48	519	519	517	516
0.45	532	532	531	530
0.42	545	545	544	543
0.39	558	557	556	555
0.36	570	570	568	567
0.33	582	581	580	579
0.30	593	590	590	589

Apogee Peak of Flight Newsletter #130 describes different methods for determining a rocket's Cd:

a. Test the model in a wind tunnel (do not have)
b. Perform Computational Fluid Dynamics (not smart enough)
c. Use a recording altimeter (too lazy)
d. Re-run Rocksim with new Cd until we get the required altitude- a.k.a. Cd backtracking (WINNER)

In the first chart, we plotted our imputed Cds, determined by Cd backtracking, for observed nominal practice flights. We ended up with a pretty tight group of Cds using this method and felt pretty confident that simulations with a range of between 0.43 and 0.48 were going to be accurate. Surprisingly, wind speed did not have as great of an impact as we would have thought.

Instead of taking a computer to the field and running simulations before each flight, we develop a Flight Matrix before each flight day. Using this one chart, we can quickly adjust the ballast of our rocket based on observed wind speeds at the time of the launch.

Practice Flights

- We flew a total of 26 practice flights on 5 separate days
- All the rockets for the practice flight used F63R motors but we changed the delay from 7 to 8 seconds (purple line)
- The parachute folding technique was changed after the 2/24 flights to a "z" fold for quicker deployment (red line)
- Rocketman 24" parachute used on all flights except for flight #5 on 3/9

Date	Flt#	Booster#	Mass (g)	Reef	Descent Rate (fps)	Apogee (ft)	Duration (s)	Imputed Cd	Comments
2/10/2024	1	1	522	24	17.9	850	52	0.72	wiggled off rail
2/10/2024	2	1	533	24	18.3	818	50	0.43	straight flight
2/10/2024	3	2	536	24	17.2	795	n.a	0.45	weathercocked. Stuck in tree for 2 weeks
2/10/2024	4	1	534	24	19.9	805	45	0.61	small wiggle
2/24/2024	1	1	525	13	20.6	794	41	0.48	didn't fly straight
2/24/2024	2	0	518	13	n/a	820	30	0.45	
2/24/2024	3	0	520	13	21.8	825	44	0.45	
2/24/2024	4	0	521	13	20.3	800	44	0.48	
2/24/2024	5	0	517	13	20.4	809	43	0.47	
3/2/2024	1	0	512	15	17.7	869	55	0.22	perfect flight
3/2/2024	2	0	529	13	n/a	n/a		n/a	drag separation
3/2/2024	3	0	532	13	15.5	745	46	0.40	straight flight
3/2/2024	4	0	525	13	19.8	855	50	0.23	straight flight
3/2/2024	5	0	530	11	19.4	794	42	0.32	did not fly straight
3/2/2024	6	0	530	11	16.9	853	54	0.23	
3/2/2024	7	0	542	11	18.9	798	47	0.31	
3/9/2024	1	0	516	10	n/a	na	n/a	n/a	unstable flight - crash
3/9/2024	2	1	522	10	25.0	782	n.a	0.52	lots of wiggles. Not weathercocking
3/9/2024	3	1	517	10	19.8	840	48	0.44	
3/9/2024	4	1	523	9	18.6	816	58	0.47	
3/9/2024	5	1	524	0	26.9	832	39	0.42	RM 18 parachute. Wiggle off rail
3/16/2024	1	3	533	9	21.4	841	46	0.45	straight flight
3/16/2024	2	3	541	8	18.5	817	50	0.49	straight flight
3/16/2024	3	3	542	7	21.8	795	44	0.53	angled off of rail
3/16/2024	4	3	536	7	20.1	828	46	0.48	straight flight
3/16/2024	5	3	542	7	22.7	788	38	0.54	straight flight. Not sure why so low.

We tried to fly our rocket quite a bit for multiple reasons. The main reason to fly as much as we did was to perfect and validate the design and to make adjustments when needed.

Another obvious reason was to see how our rocket could perform in many different weather conditions.

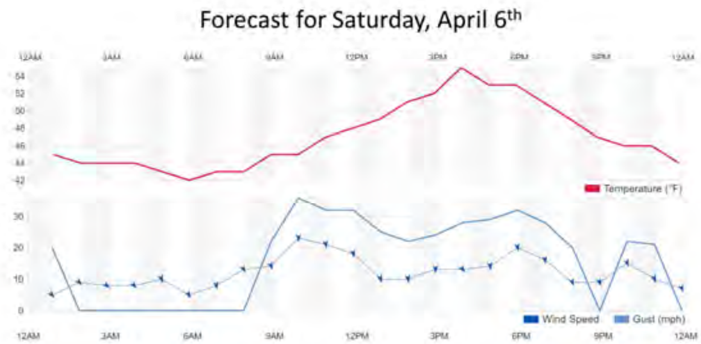
Flying different versions of the same rocket also helped us determine which were the best.

Flying frequently helped us with team bonding and teamwork necessary to be efficient while preparing and flying the rocket.

In order to prepare the rocket for flying, we collected a lot of data and made observations on the day we were flying such as: temperature, humidity, wind speed, and cloud coverage.

Qualification Prep

- We built the Flight Matrix based on the weather forecast for Saturday April 6
- It was the last day and we had to qualify in 12 mph winds
- We had never flown in these types of winds before.
- We ballasted our rocket assuming that the Cd was 0.50



Flight Matrix

Temperature	45 F
Pressure	29.73 In Hg
Humidity	47 %
Cloud Cover	80 %

Mass (g) needed to achieve 820 ft

Cd	8	10	12	14
0.54	481	479	477	475
0.51	497	495	493	492
0.48	512	511	509	507
0.45	526	525	523	522
0.42	540	539	537	535
0.39	553	551	550	548

Wind Speed

15

Normally we meet on Mondays but because of Easter we had to meet on Friday, the day before qualifying. This was good because the weather forecast was very current.

We prepared the rocket on Friday night so that we could fly as soon as possible on Saturday. For the people that were going to be there for the flights, we also assigned jobs like packing the parachute, recovery, motor preparation and taking notes.

Qualification Flights

- On Saturday, the first flight was very bad and landed in the swamp
- The next few flights were good, but we still needed to dial in a little bit
- Once we started to think about qualification flights, we decided to do one more flight and again we landed a rocket in the swamp
- Once we retrieved the rocket, we started qualification flights and got our best flights of the season

April 6, 2024; Durham CT

Flt#	Mass (g)	Reef (inches)	Apogee (ft)	Duration (s)	Score	Comments
1	497	7	582	32	282	Huge weathercock. Lost to the swamp
2	497	7	866	56	86	Straight flight
3	509	5	868	44	48	Straight flight
4	524	5	842	40	34	Straight flight
5	530	5	832	46	12	Straight flight. Swamp/Tree
6	534	5	826	42	11	Qual 1
7	536	5	823	49	17	Qual 2
8	535	5	815	47	8	Qual 3

Loading rocket

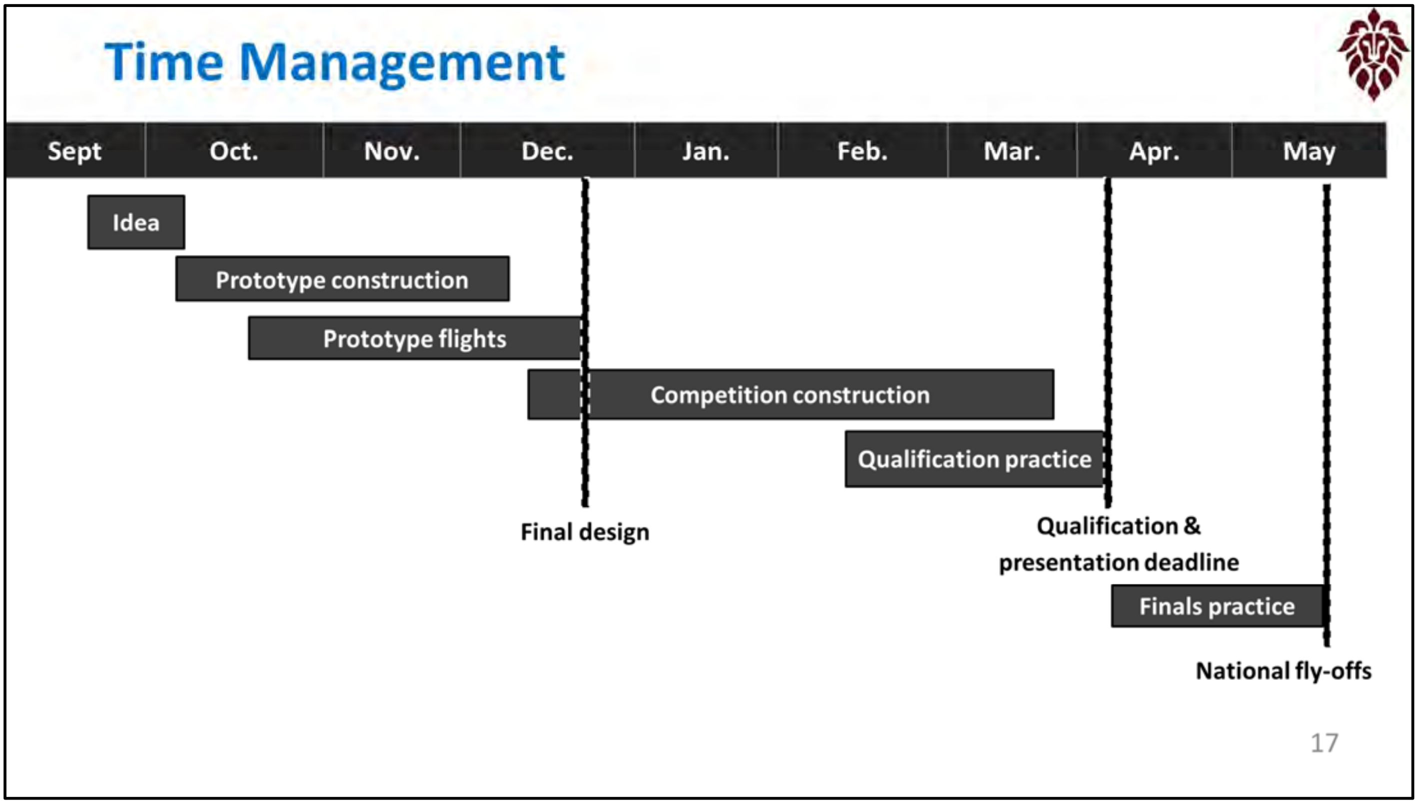
Celebratory pizza after 3rd qualifying flight

16

The weather was as predicted: cold, overcast, and very windy.

On the first flight we lost our best booster to the swamp, but thankfully had another rocket prepared. The severe winds caused us to lose that rocket to the swamp as well, but only temporarily. We were able to recover it from atop a tree. When we returned to the field, we learned that other than landing in the swamp, the flight went really well so we decided to do our first qualification flight. Amazingly, we got a score of 11! After this, we chose to do our other qualification flights and got very good scores on all three of them.

After a very challenging day, we think that our chances of being invited to Finals are great. We overcame a lot of adversity by everyone working together as a team.



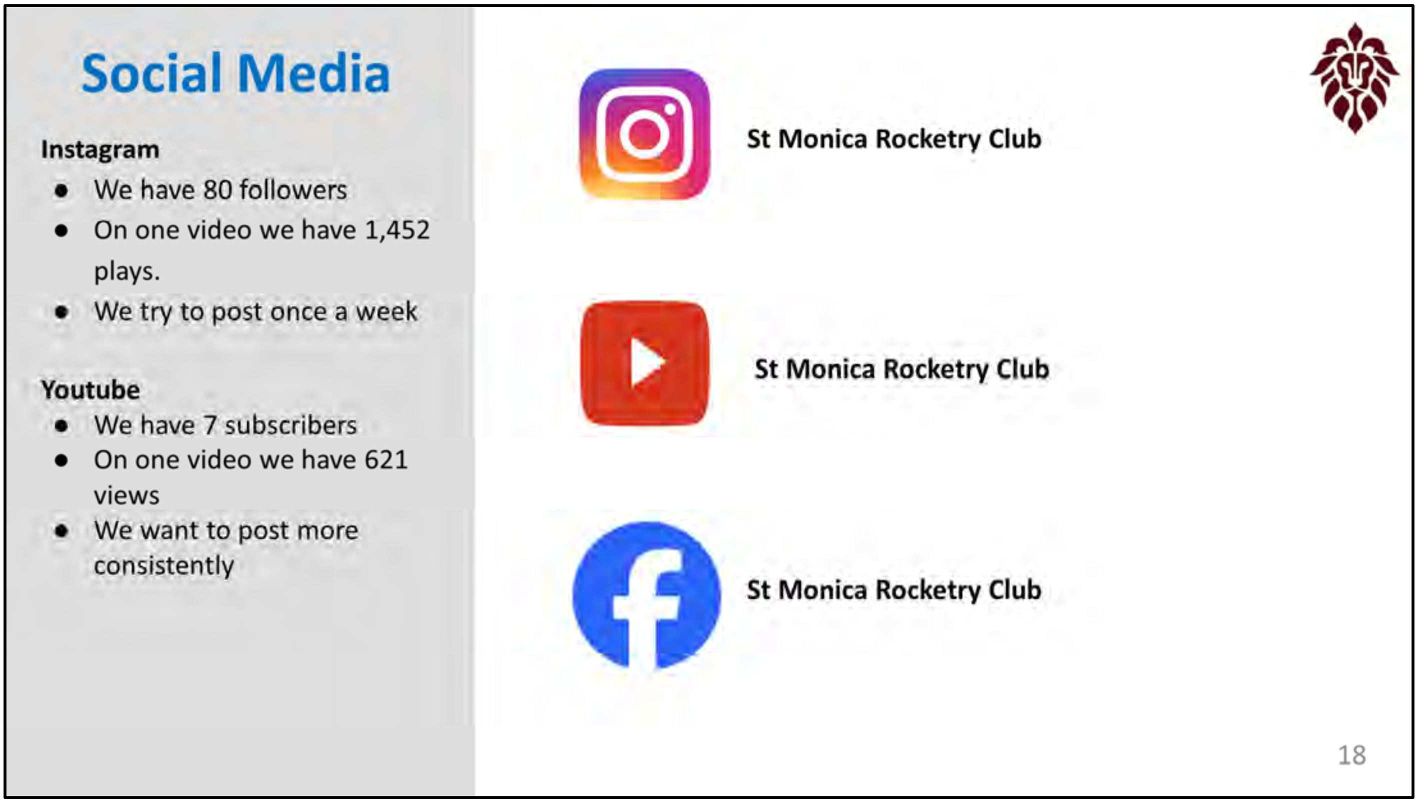
It was critical to manage time effectively to stay on track. The uniqueness of the design was an additional challenge to keeping to our timeline. Our mentor constantly reviewed our schedule with the team during weekly meetings to help us stay on course.

Without the focus on time management, the project would not have been successful. More specifically, it was critical to set milestone goals to make the qualification deadline. Below is more detail on each time segment of the project:

Ideas - Our team decided to do a square rocket and to create a unique presentation for it.

Prototype - The team worked in CAD making nose cones, couplers, tail cones, and tools along with 3D printing and vacuum forming. The team also worked in Rocksim designing the rocket.

Competition - We worked on our presentation while also vacuum forming and constructing more body tubes. We built three more rockets based on the final design. The team has flown every Saturday since mid-February to dial in the rocket for qualifications.



On Instagram we started with 15 followers! Then as a team we started making more videos and posting more consistently to cause more interest in our account. We started gaining followers and now we have 80 followers. Our goal is to have around 200 followers by Nationals. We recently started a YouTube account. We have only 7 subscribers but hope to gain about 200 before nationals. We hope to, as a team, spread the word to family, friends, and to our Homeschooling group about our wonderful platforms. Our social media group has learned a lot about making our content more interesting to our group of followers.

Lessons Learned and Future Changes

Lessons Learned:

- Effective time management
- Principles of rocketry
- Proficiency in construction tools, software, and social media
- Effective communication
- Flexibility

Future Changes:

- Time management
- Better communication skills
- Adaptability

19

We have not done a presentation before, so making one was a big challenge this year.

Scheduling was a problem that was hard to fix, as many of the team members have jobs and live a long distance from our meeting place. We did not understand the importance of working outside of the team meetings on the presentation until the last few weeks. During the last few weeks, the team pulled together to finish the presentation.

We learned to use many new programs for the first time for the presentation to include, Google Docs, Sheets, Slides, Adobe PhotoShop and Excel. For construction, new tools were introduced like the vacuum forming machine. Learning these programs and tools took more time than estimated. In the future, we need to continue to work on how we communicate with each other and be open to ideas from all members of the team.

Appendix: Parts List

Part	Material	Source/ Manufacturer	Mass (g)
Sustainer			
Nose cone	Polycarbonate	St. Monica's	13.8
Nose cone coupler - 3"	Carbon fiber	St. Monica's	15.8
Sustainer body tube - 12"	Carbon fiber	St. Monica's	46.1
Plastic rivets	Nylon	McMasters	-
Egg Protector	Foam	St. Monica's	15.6
Egg	Egg	Hen	54.7
Glue			4.0
Subtotal			**150.0**
Transition			
Transition	Polycarbonate	St. Monica's	17.9
Transition coupler - 3.25"	Carbon fiber	St. Monica's	17.5
Altimeter compartment	PETG	St. Monica's	4.7
Ballast compartment	PETG	St. Monica's	5.6
Shock cord	200lb kevlar	Ebay	0.1
Heat shrink tubing		Ebay	0.1
Plastic rivets	Nylon	McMasters	-
Altimeter			7.4
Glue			16.7
Subtotal			**70.0**

Part	Material	Source/ Manufacturer	Mass (g)
Booster			
Booster tube	Carbon fiber	St. Monica's	43.4
Booster tube fins (4)	Carbon fiber	St. Monica's	34.3
Rail buttons & fasteners	Delrin	Railbuttons.com	4.0
Tail cone	NylonG filament	Matterhackers	21.7
24mm motor tube - 5"	Carbon fiber	St. Monica's	7.1
Snap ring	Steel	McMasters	1.5
F63 motor and case	Aluminum	Aerotech	82.2
12" x 12" nomex protector	Nomex	Rocketman	**10.9**
24" TARC parachute	Nylon	Rocketman	28.0
Parachute swivel	Steel	Ebay	3.0
1/2" split rings	Stainless steel	Amazon	1.4
Shock cord - 5 feet	200lb kevlar	Ebay	2.0
Glue			27.5
Subtotal			**267.0**
Total			**487.0**

20

Parts Details:

- We used carbon fiber parts – 210g/in² 3k carbon fiber. A West System epoxy was used (105 resin and 207 hardener)
    - Two layers were used to make the airframe tubes
    - Three layers were used to make the tube fins
    - Two layers were used for the Motor tube
    - Three layers were used to make the Couplers
- Vacuum formed nose cone and transition; used .06" polycarbonate (From Home Depot)
- Vacuum formed altimeter bay and ballast bay; used .75mm PETG sheet from Vaquform
- Tail cone was created using either CarbonX or CarbonG filament from Matterhackers
- Flex Foam-iT III from Smooth-On was used to make the Foam Egg protector