AIAA Glider Project Report - Analysis Discussion
Section 07 Group 1

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1 Introduction

The goal of this project is to explore the process of designing and creating an engineering solution entirely from scratch. Unlike previous assignments, such as the glider project, no pre-made design is provided. The task involves conceptualizing, developing, and building a fully functional model rocket.

The objective is to design and construct a small rocket powered by a C-6-5 rocket motor, which has a 10N-sec impulse, a 5-second delay, and a maximum allowable liftoff weight of 113 grams. The challenge includes not only achieving the highest possible altitude but also carrying an egg weighing at least 50 grams and ensuring it lands safely without breaking.

No materials are supplied for this project. Recycled materials can be used, and up to $10 can be spent on any special components required. The use of 3D modeling software and Cal Poly's 3D printing facilities is strongly encouraged for designing and producing parts for the rocket.

This project emphasizes creativity, engineering principles, and teamwork while encouraging critical thinking and innovation within practical constraints. It provides an opportunity to experience the full cycle of engineering design, from initial concept to final testing, while solving real-world challenges.

2 Methodology

Rocket Design Process

Day 1: Initial Design and Material Selection

Unlike the glider project, the rocket project had no initial design, requiring the team to start the design process from scratch.

On the first day, the team focused on discussing potential materials for the rocket, prioritizing factors such as weight, availability, and stability. Extensive research was conducted to determine the optimal center of gravity (CG) and center of mass (CM) ratio. After careful consideration, the team selected the following materials: aluminum cans for the body tube, cardboard for the fins, and either paper or 3D printed PLA for the nose cone.

Simultaneously, the team drafted multiple configurations for the rocket's body and the egg drop system. The goal was to maximize the rocket's apogee while staying within the weight limit. Several potential designs were proposed, with the team narrowing down a few that were theoretically optimal.

Day 2: Material Acquisition and Egg Drop System Prototyping

On the second day, the team acquired materials by collecting aluminum cans and other recyclable items from local sources. With the materials in hand, they began prototyping the egg drop system. Two designs were developed: one incorporating a crumple zone with a streamer function, and another featuring a cushion system for impact protection.

After testing these designs, the team decided to combine the two. The final egg drop system utilized the cushion mechanism for egg protection and streamers to increase drag during descent. Testing confirmed that this hybrid design was successful in safeguarding the egg.

Day 3: Detailed Design and Simulation with OpenRocket

The third day was dedicated to refining the rocket's design using OpenRocket software. The team inputted the material specifications and conducted simulations to optimize the body tube length, fin configuration, and nose cone shape. Through extensive trial and error, the final rocket design was determined, and construction could begin.

Once the prototype was assembled, stability tests were performed using the lasso method. These tests confirmed that the rocket's design was stable. Simultaneously, the egg drop system was reengineered for consistency in materials and weight distribution. Key improvements included:

- Standardizing the length of the straws and their distance from the outer radius of the polyethylene foam circles.
- Increasing the surface area and cant of the helicopter wings.
- Replacing the helicopter wing supports with more durable material (switching from paper to painter's tape).
- Streamlining the overall design for better functionality.

Day 4: Final Adjustments and Testing

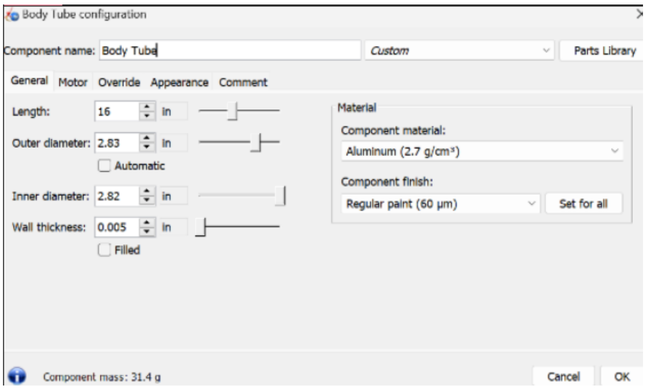
On the fourth and final day of design, the team focused on final adjustments to the rocket. They carefully considered the ratio of the body tube's radius to its length, overall weight distribution, and the structural integrity of the motor mount. After refining these elements, the final rocket design was completed.

Subsequent testing verified the stability of both the rocket and the egg drop system. With all systems functioning as intended, the team proceeded to finalize the rocket assembly, ensuring that all components were securely attached and well-balanced. The completed rocket featured a streamlined body with an optimal fin configuration, a robust egg drop system, and a secure motor mount.

Materials

Body

The materials chosen to create the rocket were primarily chosen out of concern for the weight constraint of the project. Since the weight cap was 113 grams, and about 75 grams is made up by the motor and payload (egg), the team had to configure the body, fins, and nose cone with about 38 grams of material. To try and stay within this weight limit, the body is made of three thin aluminum soda cans that had a wall thickness of



Component name: Body Tube

Length: 16 in

Outer diameter: 2.83 in

☐ Automatic

Inner diameter: 2.82 in

Wall thickness: 0.005 in

☐ Filled

Component material: Aluminum (2.7 g/cm³)

Component finish: Regular paint (60 µm)

Component mass: 31.4 g

Figure 1: Final Body Tube Dimensions

about 0.005”, and which weighed about 16 grams each (after the ends had been cut off). These two cans were held together by painters’ tape at an overlapping joint near the center of the body.

Nose Cone

At first, our team considered a 3D printed nose cone since it would be more durable and could have been used as a part of the egg drop device used to keep the egg from cracking. However, after considering the weight capacity and deployment method of the egg once the engine fuse had gone off, it was no longer feasible to 3D-print the nose cone because no matter how densely printed, it would still add a significant amount of weight to our rocket and couldn’t confidently be detached once the fuse has gone off. Instead, the group opted for a nose cone made of heavier paper, as it was lighter – 4.125 grams – and could be cut and folded in such a way that the pressure from the fuse would push it out of the body, allowing for the payload to be deployed, yet sturdy enough for it to remain in place during the launch and flight.

Fins

The fins are made of cardboard. Cardboard was chosen for the fins because it is a rigid enough material to stay upright when launched, allowing the rocket to maintain stability and not produce extra drag, yet not so dense as to greatly affect the center of mass or the overall mass of the rocket. Cardboard is also easy to cut, allowing the team to create the angular shapes that fins typically have, such as the delta shape that the group chose for our rocket fins. The fins are fastened to the rocket body with hot glue.

Egg Drop

For the egg drop portion of the project, the team decided to place the egg between two circular pieces of polyethylene foam surrounded on four sides by plastic straws, and all held together by two rubber bands. This cage of foam and straws was designed to cushion the impact that the egg will undergo when it hits the ground after returning from its apogee. Attached to the edges of one of the foam pieces are streamers made of the same material as the nose cone. Since the polyethylene foam will mostly work to absorb the impact of the ground, the streamers were put in place to create drag on the way down to Earth, slowing the fall of the egg, and limiting its terminal velocity.

Motor

The motor is encased in a cardboard tube that travels up through the center of the rocket body, ending at the base of the egg drop device. The tube is held in place by two circular polyethylene pieces that have a hole carved out in the middle to allow the tube to pass through. The foam pieces are press-fit into the rocket body so that any pressure created by the fuse will travel upward to the egg drop device and deploy it, rather than escaping through cracks or other imperfections in the rocket body.

Stability Testing Method

To test the stability of the rocket, a method called the lasso test was primarily used. This process involved attaching a string to the rocket’s center of mass (CG) and swinging it in a circular motion to observe its behavior. Smooth, stable rotation was the goal, with an emphasis on avoiding dips, fluctuations, or erratic movements, which could indicate instability.

Before conducting physical tests, the rocket was designed using a program called OpenRocket. The design aimed to achieve at least 1 caliber of stability, meaning the distance between the rocket's center of gravity (CG) and center of pressure (CP) should be at least one body diameter of the rocket. This measure is critical in rocketry, as it ensures the CP is positioned behind the CG, which is necessary for straight and stable flight.

To meet this stability requirement, various aspects of the rocket's design were adjusted, with a significant focus on the fins, which play a crucial role in stability. Different fin shapes, including trapezoidal designs, were tested, and specific dimensions were modified:

- **Root Chord:** The length of the base of the fin where it attaches to the rocket body.
- **Tip Chord:** The length of the top edge of the fin, furthest from the rocket body.
- **Height:** The distance between the root chord and the tip chord, determining how far the fin extends outward from the rocket body.
- **Sweep Length:** The distance from the leading edge of the root chord to the leading edge of the tip chord, affecting the aerodynamic profile of the fin.
- **Sweep Angle:** The angle formed between the leading edge of the fin and the rocket body, influencing airflow dynamics.

In addition to adjustments to the fin design, the length of the rocket body was modified to improve stability. By balancing these variables in OpenRocket, the CP was positioned appropriately behind the CG to achieve at least 1 caliber of stability.

After finalizing a design in OpenRocket that met stability requirements, the rocket was fabricated, and the lasso test was performed to confirm its stability before proceeding with the launch.

Figure 2: Bottom View

Figure 3: Front View

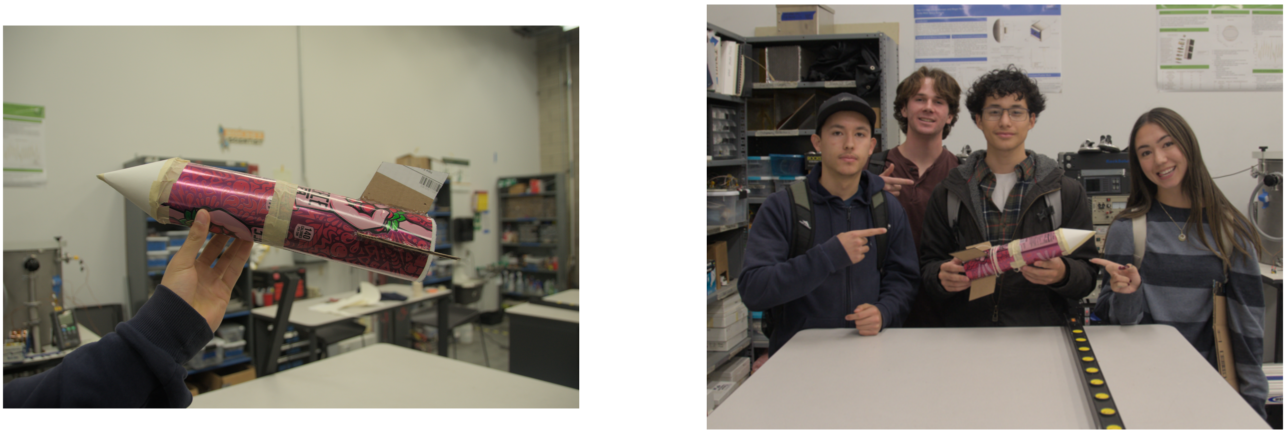


Figure 4: Side View

Figure 5: Humans for Scale

Figure 6: Cirrus Prototype v1 Pictures

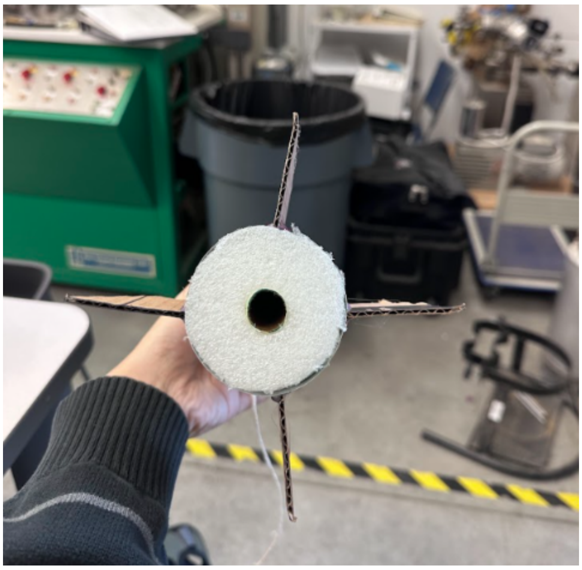


Figure 7: Bottom View

Figure 8: Side View

Figure 9: Cirrus Prototype v2

3 Results

Egg Testing

Prototype Number	**Height**	**Flight Time (seconds)**	**Damage Taken**
1	3 flights of stairs	1.73	1 cracked straw
2	3 flights of stairs	1.96	1 cracked straw
2.1	1 table	unknown	Broken egg

Table 1: Egg Testing Data

Rocket Stability Testing

Prototype Number	**Length of String**	**Pass/Fail**
1	6ft	Pass
2	26ft	Pass

Table 2: Rocket Stability Testing

Changes Made Between Prototypes

Egg 1 to egg 2: standardized the length of the straws and their distance from the outer radius of the Polyethylene foam circles, increased the surface area of helicopter wings, replaced helicopter wing supports with sturdier material (paper to painter's tape)

Rocket 1 to rocket 2: increased length of body tube by 4.5", replaced the interior mechanisms egg 1 to egg 2, installed the motor mount, installed the rocket mount, increased the fin count from 3 to 4, decreased the fin area.

When testing the egg drop prototypes, the initial prototype proved substantial in protecting the egg from breaking. It was observed that the helicopter wings did not produce the amount of drag or spin to increase the flight time as hoped so when drafting the second prototype, the surface area and cant of the helicopter wings were increased and the supports were changed to a sturdier material (from paper to painter's tape). The common theme among the egg drop prototype tests was broken and cracked straws. Ideally, the material of the straws would be replaced but due to budget and time constraints the material remained the same.

Figure 10: Post Launch Celebratory Picture with George

Launch Results

Cirrus successfully launched after a last minute change: increasing the diameter of the straw being used as a launch lug. Cirrus achieved a flight time of 9.52 seconds, with its apogee being measured at 48 and 46 degrees. In addition to this amazing performance, the egg survived! The combination of these amazing stats netted Cirrus a remarkable 2nd place in the competition.

4 Analysis/Discussion

Comparing Configuration to Competition

Previous Competitions

As pointed out by the wonderful Kendra B. all have the privilege of access to footage of previous Aero121 competition rockets. A reel was posted on December 3, 2022 to the Cal Poly Aero instragram page showcasing a myriad of rocket designs as well as their launches. As such, preliminary comparisons can be made.

A very striking similarity can be quickly recognized regarding the egg recovery mechanism and means of decreasing descent velocity: some configuration of rotary blades. As described previously in this report, this rocket's egg mechanism consists of 4 blades, straws, and cushion disks. The first year Aeros of years past seem to also have settled on this alternative to any form of parachute. Another similarity notable similarity—although somewhat uncomfortable and obfuscated by low video quality—was the implementation of soda cans as the primary body tube component. Midway through the video, a rocket launches that bears a striking similarity in body characteristics to this ''s rocket, although those involved with the composition of this paper and project would hope for a more successful trajectory than that pictured.

Differences. Differences Galore. Whether its a more streamlined body design with supports, larger fins, or general size variation one need not look far to find differences between the rockets of yesteryear and this group's rocket. However, the most alarming observation that was made is the utter lack of utilization of the motor's built in ejection charge, or perhaps the utter lack of feasibility of using the ejection charge. Regardless of what the cause was, none of the rockets shown in the footage had a recovery mechanism that was successfully ejected by the charge. Needless to say this raises some concerns as the survivability of this groups' egg depends on the carriage and blades deploying from inside the body.

Ultimately, it would be disingenuous to draw conclusions on the efficacy of our rocket based on these previous designs as their results more or less speak for themselves. Furthermore its uncertain wether the 2022 competition and the 2024 competition have the same task constraints. However, this group was still able to gleam fulfilling morsels of learning from what many ought regard as sacred footage

Current Competition

In a room full of peers and competition this team's rocket stands a head above: literally. The easiest comparison to draw is a difference in height. Specifically looking within the section 07 lab group, the height of other groups' rockets appear to be under a foot, while Cirrus stands at a towering 20". Of course this necessitates more variation in dimensions from the diameter to the fin shape: more differences. Beyond the aforementioned massive disparity in body length Cirrus also stands out with its relatively unique egg recovery methods. Other projects in its class were designed with crumple zones or an inverted skirt that increases drag, electing to forgo the ejection charge, using the body and its associated components as further insulation.

Although differing in brands and diameter, every group in Cirrus' section utilized aluminum beverage cans for some part of the body. Anywhere from 1 to 3 cans were sourced and converted into body components. One need only look to the abundance, convenience, and resilience of the aluminum beverage can to understand why the groups involved sought to procure them. Continuing the similarity of component materials is cardboard, used extensively across groups for fins—likely due to how rigid it is relative to its weight. Of course one must not overlook how easily available recycled cardboard is.

Analysis of results:

Upon the day of launch Cirrus PERFORMED. Not only did the egg survive the treacherous drop, but Cirrus earned a second place position for both Air Time and Peak Angle. This group would happily conclude that Cirrus was in fact flight stable, while noting that it did spiral upon its ascent.

Overall, the performance was extremely pleasing, receiving the 5th longest flight time and 10th highest angle out of 22 rockets. Important to note is that only 13/22 eggs survived.

A noticalble trend developed among the other groups and their rockets: the absence of utilization of ejection charges. Any observer would easily make this inference, that all groups elected to go for an insulation or crumple zone approach to keeping the eggs safe. However, one must also consider that much like with what happened with Cirrus' launch, their ejection charge approach might not have come to fruition. When comparing this years rocket competition and the previous year's footage it appears as though in both competitions the ejection charges were not thouroughly used.

Section	Team	Time	Angle1	Angle2	Egg safe	
3	24K Magic	3.59	18	15	Y	
	Alejandro^2	4.59	10	11	Y	
	F35	3.03	1	1	Y	
	Team Mantis	10.49	54	50	N	
4	S4 - Team 1	8.04	54	40	N	
	S4 - Team 2	7.7	31	33	N	
	S4 - Team 3	3.73	18	18	N	
	S4 - Team 4	2.92	12	14	Y	
5	Drag Queens	10.22	62	59	N	
	Airborne Maveriks	0.5	1	1	Y	
6	S6 - Team 1	10.1	65	70	Y	1st
	S6 - Team 2	8.92	48	45	N	
	S6 - Team 3	8.95	48	46	N	
	S6 - Team 4	15.28	54	54	N	DQ for streamer
7	S7 - Team 1	9.42	48	45	Y	2nd
	S7 - Team 2	3.45	16	16	Y	
	S7 - Team 3	0	0	0	Y	
	S7 - Team 4	2.5s	3	4	Y	
8	Peter's Angels	6.5	40	39	Y	
	The Wright Stuff	2.67	6	4	Y	
	The SLO Thinkers	5.33	26	22	N	
	C2K2	7.12	42	40	Y	3rd

Figure 11: Competition Launch Results

How Two Do a Do Over

Design Improvements

The designers behind Cirrus decided that the primary improvement to the design would be to reduce the diameter of the egg safety mechanism such that it falls out of the tip of the body with less friction. As was seen in the launch, while the ejection charge was sufficient to knock off the nose cone, it was insufficient in ejecting the egg holding cylinder. This proposed solution could be further supplemented via the inclusion of pressure sealing components to direct the ejection charge's pressure exclusively into what is intended to eject.

Furthermore, the team would like to more strictly define numerically the stage of the rocket in development after each work day. Basically giving it a prototype number to better track its progress, and of course take pictures to help document the development.

Test Plan Improvements

Rumors were spread and— of course—heard about one group present having already tested their rocket, through some unspecified means. If it were allowed and safe, the designers behind Cirrus propose that a hypothetical future improvement would be to pool the 10 dollar budget with another group and using this 20 dollars to buy 3 additional motors for 15 dollars. Then build a prototype and test before the competition. This would yield an excess of crucial and invaluable data.

Project Improvements

- Reduce Ejection Charge Delay - The group reasons that because the egg drop component of the project necessitates a weight so near the optimal maximum of the given motors rockets are doomed to apogees too low to facilitate a proper ejection phase: by the time the lengthy 5 second delay has elapsed it is likely the rocket will have made contact with the ground again. The issue with no ejection charge
- Straighten Launch Structure - On the day of the competition the launch structure was notably tilted, not being perfectly perpendicular to the ground, which this team believes hindered the potential maximum heights of all rockets involved. The presumed reason behind this impeding tilt is for safety, which ultimately was just lack of enough cable for the ignition sequence. This team wooed hope that in future competitions this issue is accounted for, allowing for enough distance to safely launch the rockets straight up.

5 Conclusion

The construction of Cirrus involved extensive trial and error, leading to significant insights into aerodynamics. The process began with the assembly of the rocket's structure, which consisted of three stacked Peace Tea cans. Data from the Open Rocket simulation was then used to refine the fin shape and optimize weight distribution. By implementing trapezoidal fins, the team effectively reduced the rocket's drag, allowing it to ascend smoothly through the air. A crucial aspect of the project was designing a mechanism to prevent the egg from cracking. After thorough testing, the designers successfully developed an egg-drop component that protected the egg and fit neatly within the rocket's body. Overall, this project not only deepened our understanding of rocket design but also highlighted the importance of resilience and innovation in engineering.