HALE Structures and Recovery Capstone Subteam: Active Roll Control

Final Report

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ABSTRACT

The High Altitude Liquid Engine Rocket (HALE) Structures and Recovery team has created an autonomous active roll control system for a full liquid engine rocket. The capstone's goal was to produce a complete workflow for developing active attitude control that was replicable for future HALE students. The team utilized ANSYS computational fluid dynamics, simulink simulation modeling, and mechanical hardware systems to create a fully functioning proof of concept prototype capable of sensing an induced roll moment, scanning aerodynamic data, then activating flight control surfaces to create a reactionary roll moment in opposition to the disturbance, bringing the overall moment to zero.

The final design included a complete CAD package for a fin-can assembly with integrated control surfaces, CFD based aerodynamic analysis, Simulink control models, and an Arduino based physical demonstration prototype. The CAD model provided a mechanical foundation for future integration with HALE rocket structures. CFD simulations were used to estimate the aerodynamic effects of flap deflection, while the Simulink model created a control environment for testing roll-damping behavior under simplified flight conditions. The Arduino prototype demonstrated the basic sensing-to-actuation process by using inertial measurement input to command physical control-surface motion.

The results showed that the project successfully established a functional workflow for active roll-control development. The simulation model demonstrated that the control logic could oppose roll disturbances, while the physical prototype confirmed that the core control process could be implemented on integrated hardware. Although the system is not yet flight proven, it provides HALE with a strong foundation for future work, including aerodynamic modeling, expanded testing, improved implementation, and eventual development toward more advanced attitude-control capabilities.

ACKNOWLEDGEMENTS

Major thanks to this project's sponsor, HALE, who have provided the opportunity and resources to make this possible. In addition, many thanks to Jonathan Messiers for his guidance as our sponsor mentor as well as Liam Kinnett and Austin Hays for sharing their technical expertise. Gratitude is owed also to the project supervisor, Dr. Elliot, who has been a dependant and helpful resource for any academic or team related questions. He has provided a well formulated structure to aid in the success of our project.

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1 BACKGROUND

1.1 Introduction

Oregon State University's High Altitude Liquid Engine (HALE) is a student-led rocketry team that has the long term goal of reaching the Karman Line (100 km altitude) with a liquid bi-propellent engine. This feat requires an exceptional level of technical complexity so the team is building up to the goal through their current development of a subscale rocket that will achieve a lower altitude. This subscale rocket uses passive aerodynamic control fins that will provide suitable stability throughout its flight. However, future higher altitude rockets developed by HALE have reason to move to an active aerodynamic control (AAC) system. AAC manages vehicle motion by utilizing actuated control surfaces that manipulate surrounding freestream air to produce a desired control input.

AAC would provide the capability to correct trajectory errors that occur from issues such as asymmetry in the rocket or uncontrollable factors such as wind. These issues can scale to create larger errors as the duration of engine burn time and altitude increase [1]. Additionally, higher altitudes and a skewed trajectory will cause a very large dispersion radius making rocket recovery difficult and limiting possible launching locations. AAC will also provide the ability to neutralize the roll of the rocket, creating smooth onboard footage and reducing sensor noise.

This document will cover this project's design process, proposal, and solution towards development of an AAC system for a rocket. It will also include some potential ways to improve the design as well as where to start when continuing to expand its capabilities.

1.2 Project Scope

This project's primary focus is aimed at starting AAC development through documented research findings, simulation results, control software, and mechanical design solutions. This will result in a significant headstart when a similar system is being designed into a future HALE rocket. We will produce a 3-D printed prototype fin-can that demonstrates AAC so that primary deliverables such as mechanical designs and software can be realized and tested for functionality. The primary scope constraint of this project is limiting the control authority to roll. This is due to the extensive simulation and programming expertise that pitch/yaw control introduces [2]. Despite this, the physical design and hardware will be suited for pitch/yaw control to make results from this project more relevant for the future.

2 DESIGN PROCESS

The design process for this project began with a sit-down discussion with the HALE team and its sponsors. The main issue identified was that CETUS currently has no capability for active attitude control during flight. Once launched, the rocket is essentially uncontrolled aerodynamically, which limits its ability to correct unwanted motion. This can reduce flight performance, create poor onboard footage, and make telemetry more difficult to interpret. Video is important for sponsor engagement, outreach, and recruitment, while clean telemetry is important for vehicle analysis, survivability, and team safety. Since the initial CETUS rocket is already nearly complete and ready for launch, the objective shifted away from redesigning the current vehicle and instead focused on developing a quantitative design and research foundation for a future version of CETUS.

The project scope was intentionally limited to active roll control early in the design process to keep the project focused and achievable. Full attitude control would require yaw, pitch, and roll control, which would greatly increase the software complexity of the project. However, the electrical and mechanical systems developed for roll control should remain similar enough to support future expansion into full attitude control. Because of this, the team focused specifically on roll-rate damping. The goal was to create stability during flight and reduce unwanted spin rather than fully guide the rocket. This constraint created a clear definition of success and helped determine the required deliverables for the capstone.

Once the problem and scope were defined, the next objective was to determine which control system would be used. Common designs already demonstrated by available online sources included canard-based systems, fin-mounted control flaps, and other active aerodynamic methods. Canard systems, as depicted in Figure 1, demonstrate strong control authority and relatively simple actuation. However, they require significant modifications to the forward section of the rocket and do not integrate as well with large fuselages, introducing additional structural and aerodynamic complexity.

Figure 1. Model rocket using forward canards for roll control, showing private implementation. Screenshot from Project Horizon [3].

Other methods, such as rollerons, were considered for their simplicity and reliability, but were passed over because of their limited application. While rollerons could help reduce roll, they would not provide a useful path toward future yaw and pitch control. From this comparison, the team chose a fin-mounted flap system as the most viable approach. This method uses small flaps placed along the trailing edge of the fins that rotate side to side, creating a moment when deflected into the airflow. It was chosen because it integrates well with the current rocket, minimizes redesign, and can be implemented as a replaceable subsystem, as shown in Figure 2.

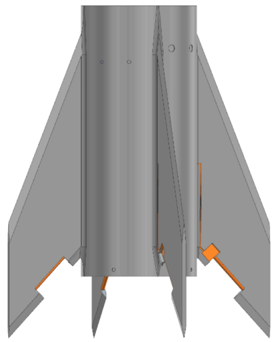

Figure 2. CAD model rocket fin can with servos integrated into the fins.

This decision reflects a structured down-selection process where multiple concepts were evaluated based on feasibility, complexity, and fit with project expectations. After the general concept had been established, the team moved into mechanical design and began determining how to physically build the system with electrical components, gears, and already-machined fins. Each team member created a CAD-modeled concept for integrating the servos and flaps into the fuselage and fins. The first concept embedded the servos directly in the fins, permanently fixing the machines in place with epoxy. This minimized moving parts but made the system difficult to remove, repair, or iterate. The second concept placed the servos in the fin can with indirect linkage far from the MIRA 2 engine, helping maintain lower temperatures and more available space. However, this option introduced gear backlash and added more moving parts. The third design placed the servos inside the fin can with direct linkages to the flaps at the base of the fin. This combined the strengths of both previous systems because the servos could still be replaced while maintaining a more direct connection to the flap. As a result, this option minimized mechanical complexity and reduced potential failure points.

In parallel with mechanical development, a series of CFD-based simulations were run using ANSYS. By modeling the fin can, the rocket was simulated in flight at different flap angles, producing data on moments and forces in each axis. From this data, a set of appropriate roll reaction rates could be created to simulate expected flight cases. This provided a base layer of information for the code package to run from. The software side was developed following advice from Austin Hays, from the SCRT research project at Oregon State University on February 18, 2026. The program was created using Simulink and exported to C++ to autonomously control the servo-operated flaps.

Overall, the design process followed a clear progression. It began with defining the problem and scope, researching existing designs, producing multiple variants, and ultimately selecting the working system based on feasibility and HALE expectations. The concept was then developed through CAD modeling, CFD-based simulation, and software planning. The final design is a flapped-fin control system using servos mounted in the fin can, controlled by onboard IMU and sensor data, and validated through simulated testing.

3 DESIGN PROPOSAL – First Term

3.1 Introduction

This chapter shows the final design of the active aerodynamic control system that was selected during the first term of this project. While Chapter 2 described the design process of the selected system, this chapter describes the implementation of the system. The system design focuses on improving the stability of the HALE (High Altitude Liquid Engine) rocket during its ascent. This chapter will discuss the final mechanical configuration of the system, the analysis to support the system, and the major design changes made throughout the implementation process.

3.2 Final Design Overview

The final selected design for the control system is made up of fin-mounted control surfaces that use active control to generate corrective aerodynamic moments. Each of the four control tabs is mounted along the trailing edge of each fin and rotates about a hinge located at the leading edge of the control tab. When deflected, the tabs modify the local airflow, generating a roll-correcting moment about the rocket's axis.

To operate the control tabs, four servos are placed inside the fin can and connected to the tabs via a direct drive system. Placing the servos inside the fin can reduce their exposure to aerodynamic heating and external damage. A worm drive linkage system was considered for its reduced mechanical backlash, but was ultimately rejected due to the added complexity.

This control system has been designed to operate as a closed-loop system using data from the onboard sensors. An internal measurement unit (IMU) provides the data for the rate of roll and orientation, which is then processed by the flight computer to determine the required deflection of the control tabs. The system actuates the control tabs accordingly based on this response.

3.3 Mechanical Design and Load Path

The physical design of this system is centered around a hinge shaft that runs along the span of each tab. This shaft is inserted in the leading edge of the tab, which allows the trailing edge to deflect aerodynamic forces. This hinge shaft is supported by two bearings embedded in the root and tip of the fin. This dual bearing support system improves the structural integrity of this design and minimizes deflection and vibrations experienced during operation.

Torque generated by the deflection of incoming aerodynamic forces is transmitted directly to the hinge shaft, which redistributes this load across the control tab and into the servo motors. The use of a direct drive linkage system minimizes mechanical slop, ensures consistent response under load, and transfers load to the servos efficiently.

During the ascent of the rocket, the load path begins at the control tabs due to aerodynamic forces. These forces are then directly transferred to the hinge shaft and into the servo motor and servo motor bracket. The mounting brackets for the servos are integrated into the structure of this fin can, allowing a smooth distribution of forces into the main frame. This design reduces the overall stress caused by the system and improves the durability of the vehicle.

Placing the servos inside the fin can rather than outside also centralized the mass of the system within the vehicle, reducing the impact of the rocket's moment of inertia, further improving stability.

3.4 Engineering Analysis and Justification

A thorough aerodynamic analysis has been performed to confirm the effectiveness of the active aerodynamic control system. CFD simulations using ANSYS Fluent have been performed to model the airflow of the fin can with varying control tab deflections. These simulations have given our team estimates of pressure distribution and moment generated by the control system.

The results from the ANSYS simulations prove that even small deflections of the control tabs will produce a significant moment, changing the rolling behavior of the rocket. This determines that the rocket will be capable of actively correcting the roll control during its ascent.

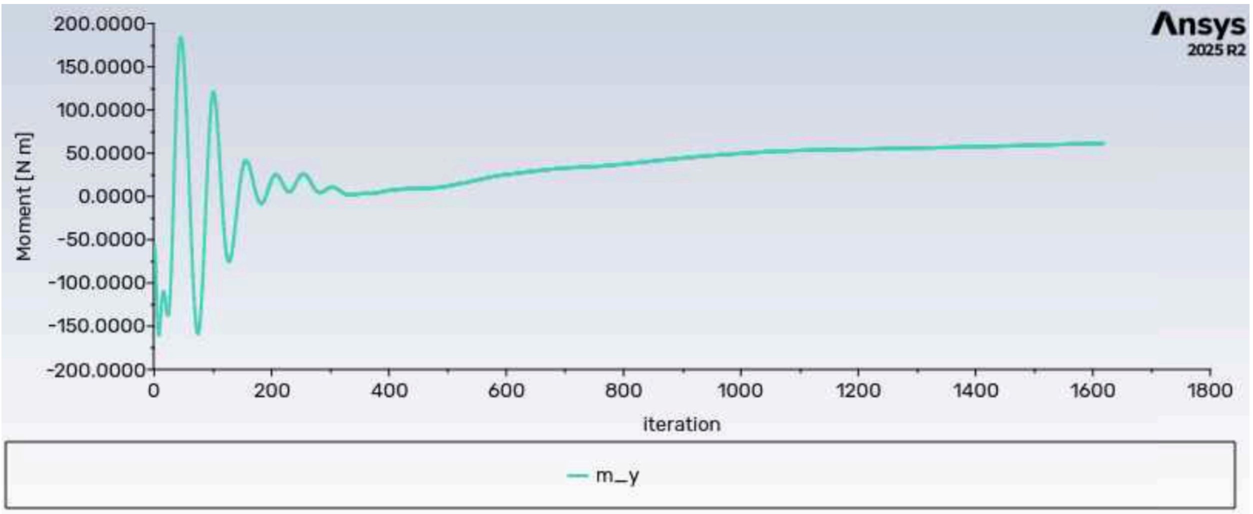

Figure 3. ANSYS Fluent simulation of moment

4 Design Solution

The final design solution for this capstone project was an active aerodynamic control system for the HALE rocket. This system used movable control surfaces mounted on the rocket's fins to generate a corrective roll moment during flight. This project was divided into four major parts, including ANSYS CFD, Simulink, CAD, and integration.

4.1 Description of Solution

4.1.1 ANSYS

Computational Fluid Dynamics (CFD) was used to simulate how the control system functioned in flight. Its purpose was both to hone and validate design choices, as well as to gather predictive data to be used in our control loop. There are four main sections to this CFD simulation, CAD, geometry, mesh, and setup.

The CAD model had to be modified for compatibility with the CFD simulation. The main change was lengthening the cylindrical top end of the fin-can to 10 feet in order to better simulate upstream effects on our control system. Internal systems and mechanical features were not included in the CFD version of the CAD model due to having no effect on the aerodynamic profile of the fin-can. Additionally, a plug was modeled in the bottom of the fin-can to close the hollow cylinder to simulated airflow. This prevents a low pressure zone from forming where the engine bay and nozzle would be.

The geometry section involves setting up the CAD model for meshing and solving inside ANSYS. First, a rotation transformation was applied to all the control surfaces, allowing the deflection angle of these surfaces to be changed via a parameter value. Parameterizing this deflection angle was chosen instead of utilizing a dynamic mesh due to the unnecessary complexity a dynamic mesh brings. Then the enclosure was placed to have the inlet at the front of the 10 foot cylindrical extension with outwards and rearwards cushions of one meter and two meters respectively. These cushions were vital to encapsulate the interactive behavior between surrounding turbulated flow and distant less effected freestream flow.

The meshing section of CFD is often attributed to be the most impactful and difficult step in creating a CFD simulation that will produce realistic results. It involves creating finite volumes and surface elements within the simulation enclosure, simply put it is setting the simulation's resolution [4]. Meshing was set up to include localized refinement areas on the fins and control surfaces of the fin-can. This is due to the complex aerodynamic environment these areas create which require a higher resolution to yield realistic results. Figure 4 shows these refinement regions where smaller mesh sizes are seen around the fin-can and its direct area of influence.

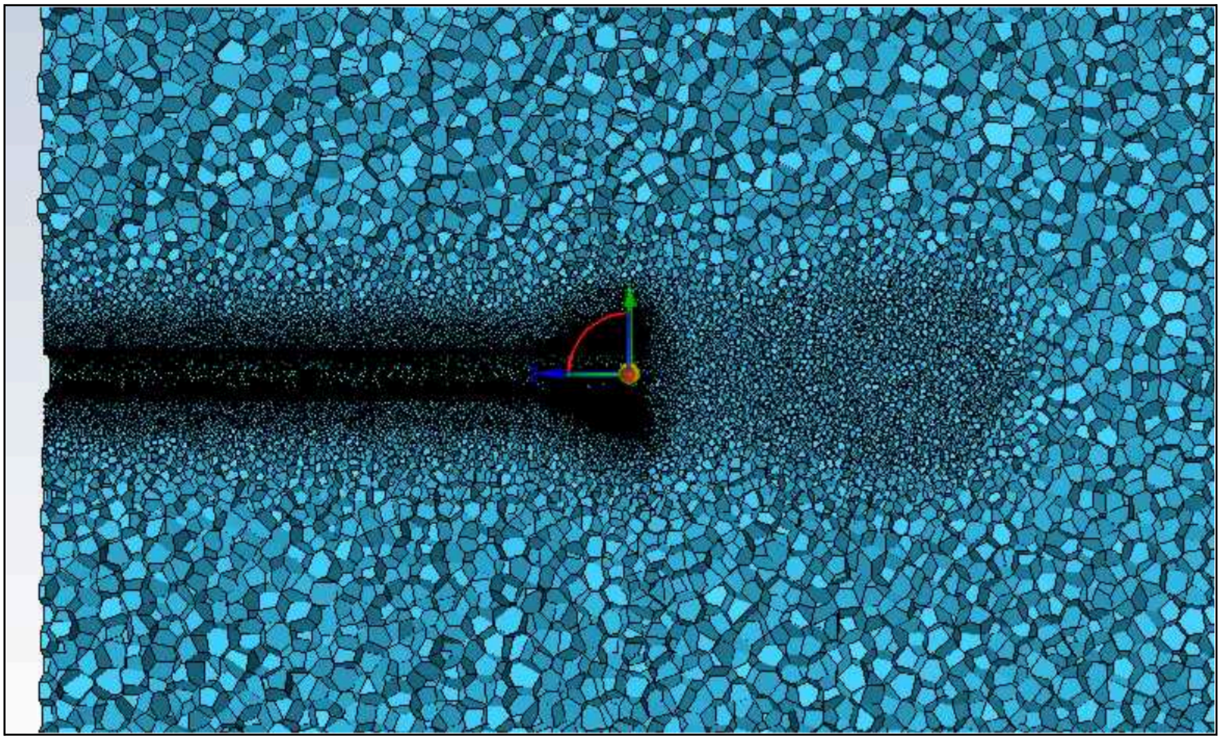

Figure 4. Cross sectional view of one million node mesh

Mesh resolution can be quantified by the total number of nodes in a model. A node is a discrete point where values such as velocity, pressure, or temperature are stored [4]. As the number of nodes increases (along with mesh resolution), the solution's accuracy will also increase, eventually converging to an answer. It is important to find a mesh resolution that balances the simulation accuracy with the computational resources available. This was done by completing a mesh refinement study which compares simulation results with total node count. Figure 5 shows this comparison and aided in our chosen mesh resolution of roughly one million nodes (third point from the left side of the graph).

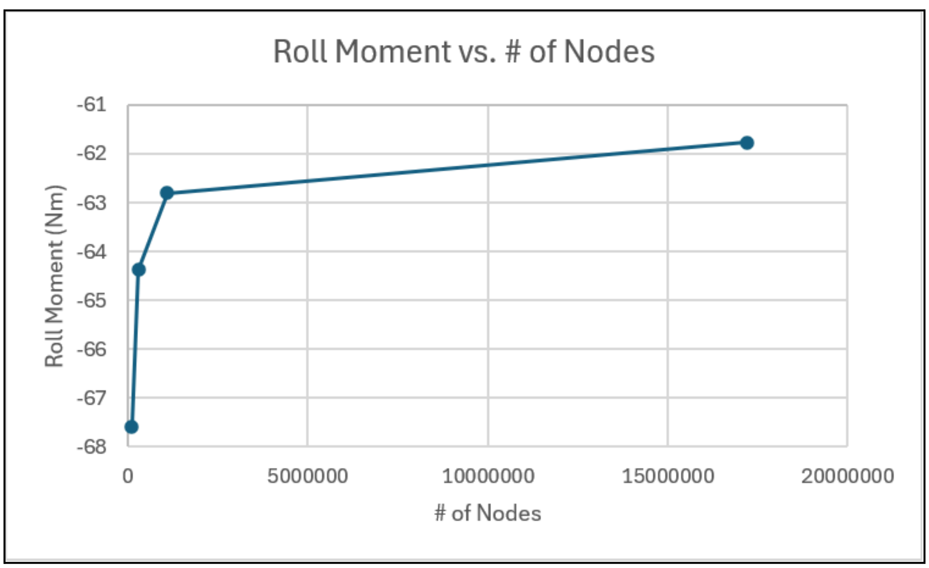

Figure 5. Mesh refinement study

The setup portion of the CFD simulation involves final adjustments to solver settings before running calculations. All enclosure boundaries were set to "pressure far-field" to simulate the fin-can being in an open atmosphere. Energy equations were turned on and solver type had to be changed to "density-based" due to flight regimes going past the compressible flow threshold (mach greater than 0.3). The turbulence model used was "SST k-omega" which is the aerospace industry standard for external flows and supersonic shock interactions [5]. The equation offers high accuracy within flow separation conditions, which will translate to continued precision even in the case of a control surface stall [5].

4.1.2 Simulink

The Simulink was split into two models, simulation and arduino application. The simulation model was developed to test the feasibility of an active roll control system using counteracting moments before transferring it to hardware and the real world. It provided a controlled environment to demonstrate that a moving flap command could generate a reactive roll rate to dampen in-flight instability. The model utilized four major systems to predict roll control: a built in simulink dynamics block, a feedback loop controller, actuator control, and a scope setup for visually determining the accuracy of the system.

The primary feedback variable contained within the simulation model constituted the roll rate feedback. The controller measures the evaluated roll rate against the desired roll rate which is zero for complete dampening and subsequently passed through a multitude of both hardware and software constraints before producing a resulting flap command. This flap command was then fed back into the basis of the model as a resulting command moment. This reactive moment could then be monitored via a scope command which demonstrated the accuracy of the system once disturbances similar to those seen during flight had been issued, as shown in Figure 6.

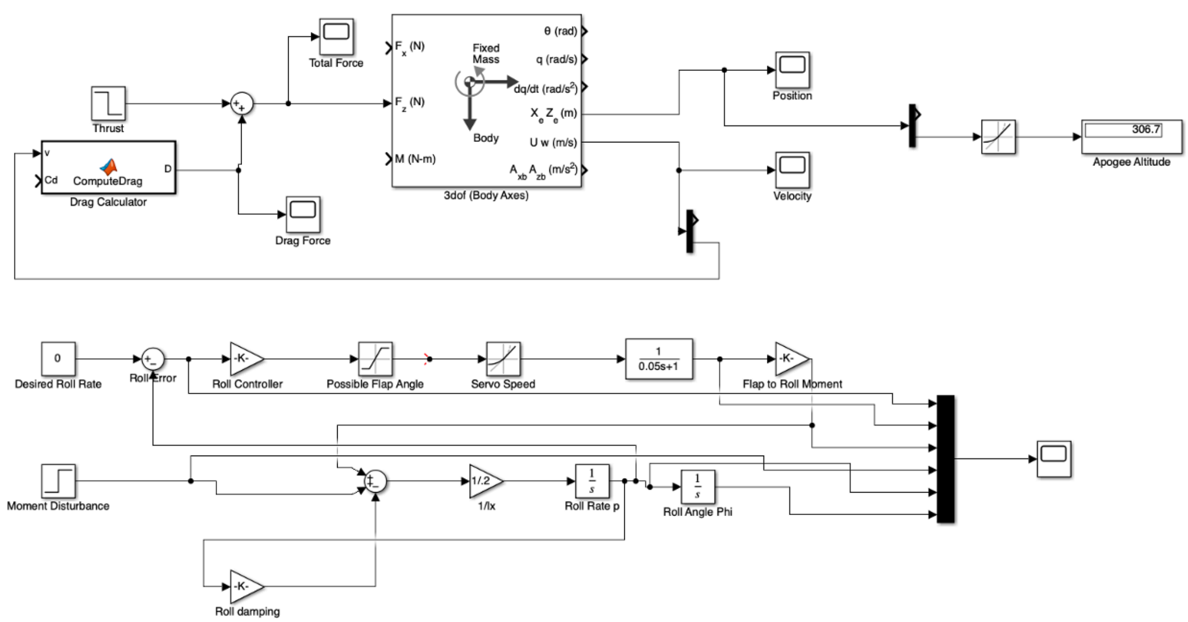

Figure 6. Preliminary demonstration of a Simulink Setup. Note this is not an actual or complete model.

The Simulink simulation model relied on the data collected from the ANSYS setup in the form of a data table. It would take specific measurements and calculations performed, and match them accordingly to the perceived roll moment collected from data. It was this data table that provided the suppleness of the reaction as it provided the data and context required for how intensely the resulting moment needed to be to maximally reduce the roll.

The arduino version was developed to physically demonstrate the capabilities of the simulation system. Transferring the capabilities of active roll control on the computer to the real world and testing the actual feasibility of the entire workflow. The arduino model tested the capabilities of transferring the control loop to an active actuator. The physical version utilized the servos and measurement microcontroller evaluated in the integration as illustrated in Figure 7.

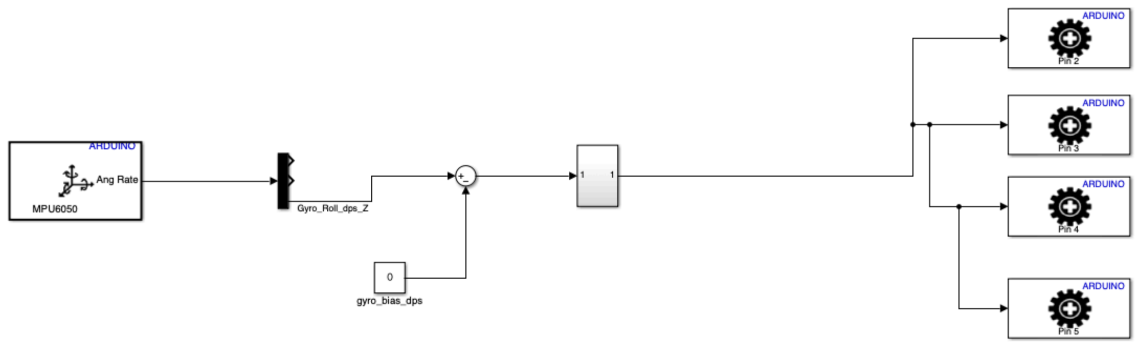

Figure 7. Arduino compatible roll control model with blackbox subsystem.

The real world system replicated the general flow and logic of the simulation version while implementing some key differences. Instead of inducing a fake roll attempt to facilitate the program's reaction, sensors collected measured inertial data that could then be fed through the feedback loop instead. This allowed the arduino version to serve as a full hardware demonstration for future HALE rockets, fully integratable with more advanced sensors and a complete workflow.

4.1.3 CAD

The CAD portion of this project was used to create the overall design and physical layout of the active roll control system, and to determine how the servos, control tabs, and linkages function. The final CAD design used four control tabs mounted on each of the four fins. Each of these control tabs was designed to rotate about a direct shaft linkage mounted on the servos.

The CAD model defined the side and placement of the control surfaces relative to the existing fins. Because the fin can thickness is limited, the design had to account for the size of the servos and linkages. The control tabs were designed to account for the clearance between the outer edge of the fins and the fin can structure. This step was particularly important to ensure the reliability of the moving parts.

Overall, the CAD design proves that an active aerodynamic control system can be physically integrated into the current design of the HALE rocket fin-can. Furthermore, this design can be implemented without requiring major changes to the engine, body tube, or overall vehicle structure. This CAD model has also provided a clear layout for future implementation and refinement.

4.1.4 Integration

The integration portion of this project focused on combining the microcontroller, measurement unit, and servos into a single working demonstration. The purpose of this hardware integration was not to flight qualify the system fully, but to demonstrate that the active aerodynamic roll control system is functional and responds to real inputs.

This hardware demonstration used an Arduino Uno as the main microcontroller, an MPU 6050 as the inertial measurement unit (IMU), and four micro servos to control the deflection of the control tabs. The IMU measures inertial changes in the fin-can body, and the Arduino then processes this signal and commands the servos to respond accordingly.

The power integration was an important design for the hardware demonstration. The Arduino and servo motors were both powered by different batteries and voltage-regulated systems. This was done so the servos would not interfere with the Arduino or overload the onboard power supply. Buck converters were used on each of the two LiPO batteries to step the voltage down to a usable level. All of the grounds were connected together to provide the same reference for each component, which is necessary for the PMW servo signals to function correctly.

The final integrated system showed that the active roll control system can respond to real roll inputs. This system connected each of the components together to create one working system.

4.2 Project Results

4.2.1 CFD Results

CFD simulations were focused around inputting environmental conditions and outputting values that could be used in the control loop of our AAC system's avionics. The two environmental conditions that were set as inputs were pressure and mach, which can both be obtained via onboard sensors. The control surface deflection angle was also an input and due to this project only including roll control, is constant across all four surfaces. The primary output of the simulation was the moment generated around the roll-axis by the deflected control surfaces.

Using simulated flight data from the CETUS rocket, a lookup table of these corresponding environmental, geometry, and control output values was generated. This table found the resulting roll moment generation from a "high" and "low" control surface deflection per pressure and mach data point during the rocket's ascent. Figure 8 shows a small section of this lookup table to aid in comprehension.

			Control Surface Deflection		
		High		Low	
Pressure	Mach	Angle	Moment	Angle	Moment
100352	0.238515	5	-2.94254	1	-0.53627
99425.21	0.335826	3	-3.31164	1	-1.09401
98194.17	0.434533	3	-5.38715	1	-1.85033
96665.13	0.534485	1	-2.85517	0.5	-2.19429
94847.55	0.635536	1	-4.15664	0.5	-3.57807
92753.96	0.737512	1	-5.01634	0.5	-5.64196
90399.85	0.840255	0.75	-5.03136	0.25	-8.22179
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 8. Section of lookup table

Due to the high computational demands of the CFD simulation, the table was limited to solving one point per 0.4 seconds of flight data. The use of this table necessitates interpolation between pressure/mach values as well as control surface angles and their corresponding rolling moment. In order to use interpolation across deflection angles, linear relationships needed to be proven. Figures 9, 10 demonstrate linear relations between roll moment and deflection angle at subsonic and supersonic velocities. Figure 11 demonstrates linear relations between roll moment and mach at a constant control surface deflection angle.

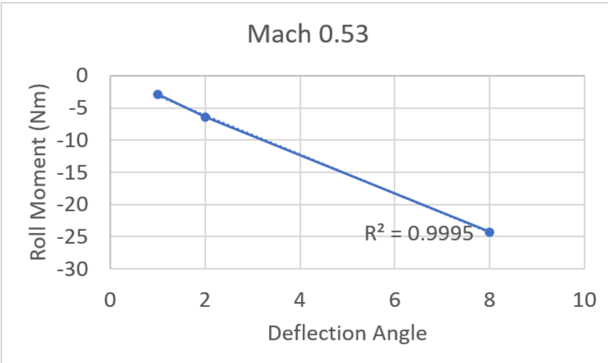

Figure 9. Relations at mach 0.53

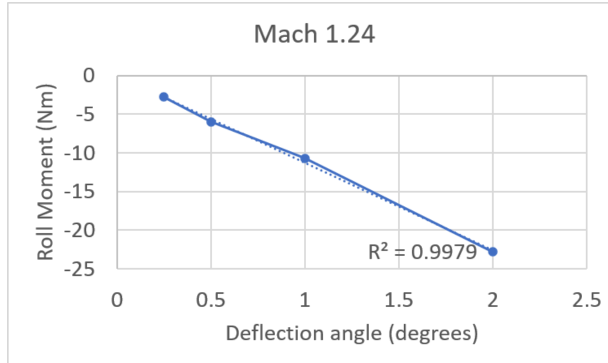

Figure 10. Relations at mach 1.24

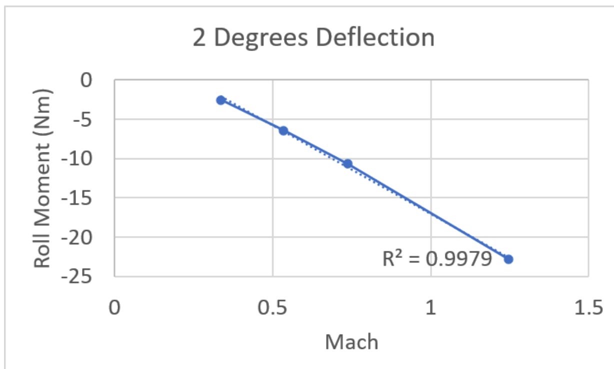

Figure 11. Relations a 2 degrees deflection

This lookup table is what grounds the control loop to the physical world through CFD simulation results. It enables a higher efficiency method of control by allowing the control loop well placed guesses of how the rocket will respond at any given point with any given input.

4.2.2 Simulink Results

The simulink simulation results showed a clear relationship between active induced roll control moment, reactionary moment, and overall roll rate as the system continuously effectively dampened to zero. This proves that the simulation operated as expected, limiting the reactionary moment to a physically capable range, which helped prevent unnatural phenomena or artifacts.

The primary result attained from the Simulink model demonstrated that ANSYS computational fluid dynamic data could be combined with real hardware integration to produce accurate physical results. The roll rate response acted in accordance with the ANSYS table to push the rocket back to equilibrium after the disturbance was applied as shown in Figure 12, illustrating that the modeled control surfaces successfully provided corrective moment maneuvering.

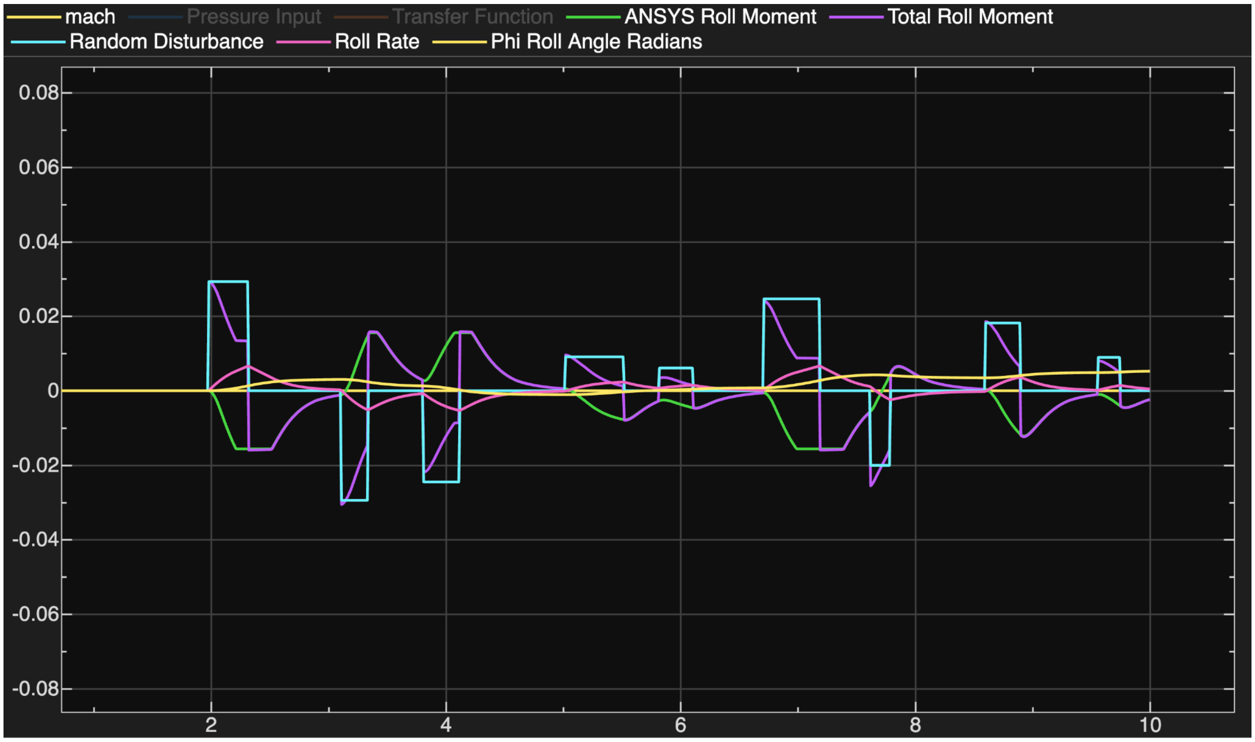

Figure 12. Simulink simulation data with a 10 second disturbance scenario demonstrating that the roll rate continuously returns to 0.

The simulation also demonstrated the need for realistic actuator limits that bound the model to attainable limits when implemented into the arduino model. The arduino model results successfully demonstrated that the control logic could be transferred and implemented with sensors and data inputs. The embedded system was capable of reading sensor inputs, processing control logic, and issuing reactionary roll commands to servos. This proved that the model was not entirely theoretical and was fully capable of implementation with future HALE rockets.

The arduino results were most useful as a proof of concept for the simulation and code. The prototype showed that the system could operate in real time with real world sensory inputs at a basic benchlevel test. Flight testing was never accomplished due to the research and development nature of the capstone. But it did show a complete bridge between ANSYS, simulation, and future flight capable design. Figure 13 demonstrates the fins movements when different spin angles and intensities were applied.

Figure 13. Fin-can prototype used for bench-level roll-control demonstration. The silver cylindrical body was manually rotated to show the black control surfaces responding in the opposing direction.

Overall, the simulation and arduino simulink models validate the feasibility of roll control and eventually full attitude control in HALE's future rocket designs. The simulation model proved that ANSYS CFD data could be implemented into a feedback loop capable of controlling the movement of a rocket. While the arduino model proved that that same logic could be applied to physical hardware. Together, these results provide a clear workflow for future teams in HALE to incorporate active aerodynamic control into their rocket.

4.2.3 CAD Results

The CAD results have shown that the active aerodynamic roll control system can be physically modeled and implemented into the current design of the fin-can in a realistic way. This model has also proven that the control surfaces can be added to the fins, keeping the original geometry and shape. The CAD modeling has also helped identify the main mechanical constraints of the design, including the placement of the servos and the alignment and clearance of the linkage shaft.

The main result from the CAD model is that the system can be designed as a fin-can subsystem. This ensures that the system can be designed around the existing geometry of the fin structure without requiring a full redesign. The CAD model has also made it much easier to communicate with the Structures & Recovery subteam by physically showing how the control tabs, linkages, and servos all work together.

This portion of the project has also highlighted areas of improvement for future reiterations. These include stronger servo mounting brackets, a more detailed bearing support system with an improved linkage geometry. Although these improvements would need to be made before flight testing, the CAD design allowed our team to reach the project goal of creating and obtaining a physical design model of the active roll control system.

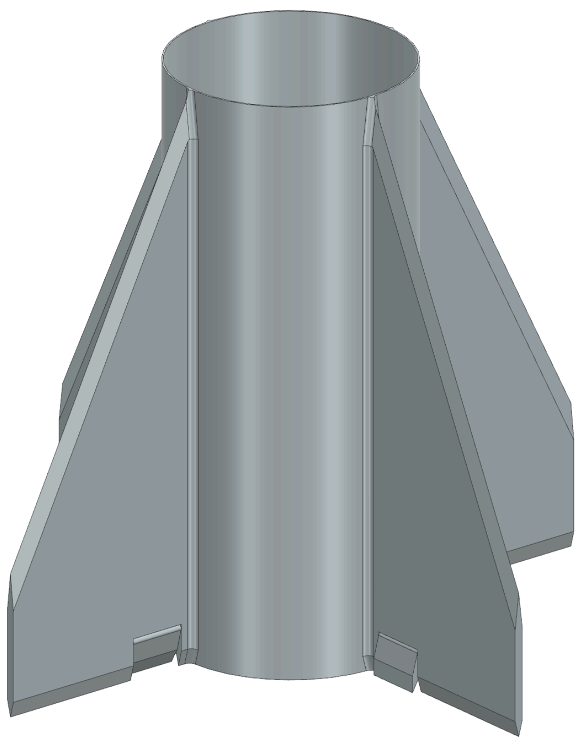

Figure 14. Finalized CAD model

4.2.4 Integration Results

The hardware integration has successfully demonstrated the basic function of our team's active roll control system. The working hardware system allowed the Arduino, IMU, and servos to integrate into one working system. This has shown that the active control system can respond to inertial inputs and respond using control tabs.

After evaluating the working hardware integration, several areas of improvement were found. These areas of improvement include servo response speed, vibration sensitivity, wiring management, and mechanical backlash. This prototype has shown a working design concept of our system, but a flight-ready model would require stronger components with higher reliability.

Figure 15. Fully integrated fin-can

5 LOOKING FORWARD

5.1 CFD

The inclusion of pitch/yaw control will require a significant increase in complexity of the CFD simulation setup. This is due to control expanding from just one axis (roll) to 3 axes (pitch, yaw, roll). One way CFD could be used in creating a full attitude control system is by solving for aerodynamic forces for a range of control surface deflections on a single fin. Each quadrant of the rocket would then have a range of simulated aerodynamic forces as their control surface deflects. These forces could then be coupled with each other via a control loop to create a pitch/yaw/roll maneuver. Additionally, since all four fins are ideally symmetrical, the solutions for one quadrant could be mirrored to the others to cut computation time.

A second task for future development is to create a more complete CFD specific model of the rocket as it would yield significant increases in simulation fidelity. Two primary missing features from this project's model are a nose cone and raceways. These features will create shockwaves, turbulence, and even asymmetries all of which will create upstream effects for the control system.

5.2 Simulink

One of the most difficult and important endeavors for future teams when continuing this research will be the incorporation of more advanced attitude control systems. The current model is fully ready for mach number, pressure, and altitude sensor incorporation with pitch and yaw also being easily addable into the workflow. However, this only applies to damping as all components are designed to set the roll moment to a specific level. For full in-flight control capable of being able to turn and fly to a specific location or point fixed in the sky, major revisions to the current design will need to be performed. As it stands, full attitude dampening is well within reach using this capstone's workflow and progress. To incorporate pitch and yaw, future students would need to expand the ANSYS simulations to more actively reflect the differences in modeling while also creating a method to mix all six degrees of freedom into four servo commands.

5.3 CAD

Future development of the CAD model should focus on turning the design concept into a flight-ready design, ready for integration into the HALE rocket. The current design model shows the general placement and structure of the control tabs, servo location, and linkage system, but future teams may want to refine these for serviceability, manufacturability, and strength. A major improvement that could be made to the design is improving the linkage system between the servos and the control tabs. The current design concept proves that a direct linkage system is practicable, but improving alignment and reducing backlash will improve aerodynamic handling and reduce deformation.

5.4 Integration

Future integration should focus on implementing the flight hardware into the HALE rocket's current avionics system. The demonstration uses an Arduino-based system to actuate the servos and measure sensor response, but the future version should be designed to be used with HALE’s GEMMA flight computer.

6 CONCLUSIONS

The primary objective of this project was to design, analyze, and validate an AAC system that could provide roll control for a large high altitude rocket. To do so the team chose to integrate trailing-edge control surfaces into the rearwards stabilization fins. Efforts have yielded CAD models, CFD simulation data, simulink control loops, integration processes, and a demonstration model. Lessons and results will be passed onto HALE for use in the continuation of AAC development.

With respect for public health and safety in mind, important details around the control loop were kept out of this document. This is due to this project fitting under the definition, and restrictions, of a guided missile system under ITAR regulation. Additionally, by limiting the sensor types to IMUs we ensured guidance was only possible in the upwards direction with damping being the only capable form of movement.

Overall, the project successfully created a structured path for developing active attitude control within HALE. The team produced a working proof-of-concept for roll damping, demonstrated the basic relationship between sensing, control logic, and actuation, and created deliverables that future teams can expand on. While full attitude control would require major additional work, this project provides an important first step toward that long-term goal.

7 REFERENCES

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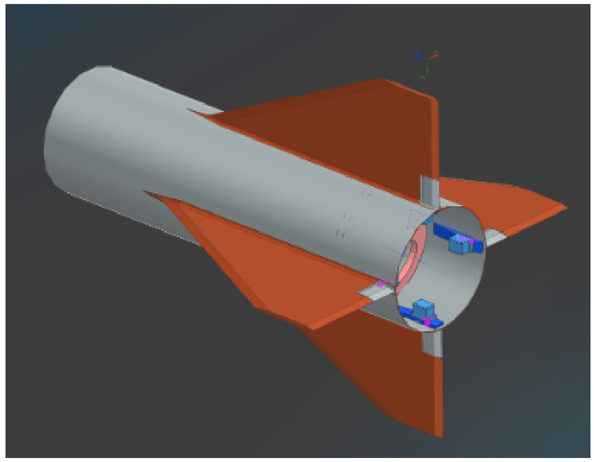
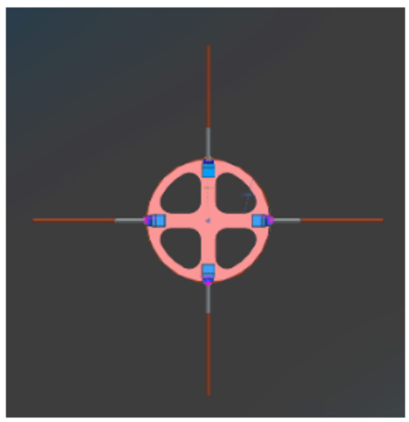
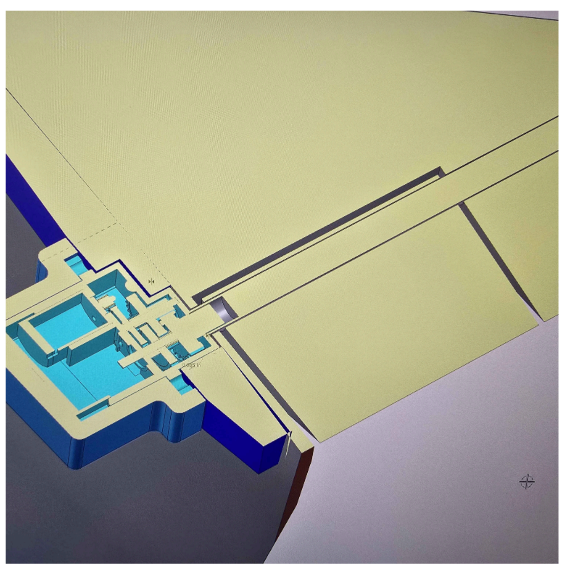
8 APPENDICES

8.1 Appendix A: CAD Package







8.2 Appendix B: House of Quality

House of Quality
ENGR 416

Team Number: AIAA.08.B

Team Description: HALE – Structures and Recovery – Active Aerodynamic Control

CR#	CR description using complete sentences	Weight (100 total)	Matching Engineering Specification	Targets with Tolerances
1	System must provide stable ascent trajectory within atmosphere	30	Actuator torque must be sufficient for supersonic velocities	Max torque ≥ 0.8 Nm
			Pitch and yaw disturbance moments	Pitch/yaw moments ≤ 10% of roll moment
			Roll response settling time	Settling time ≤ 0.5s within ±5 %
			Maximum generated rolling moment	Max roll moment ≤ 5 Nm
2	System must be capable of limiting vehicle roll rate	15	Maximum roll rate limit	Roll rate ≤ 5 deg/s
			Capability to generate sufficient torque around the roll axis	Torque≥ 0.5 Nm (above mach 0.1)
3		20	Structural load and vibration survivability	Factor of safety ≥ 2.0
	The system must survive launch			
			Limit heat transfer from engine	Servo max temperature ≤ 55 C
4	Must operate within onboard power limits	15	Power consumption	Average ≤10 W
5	System must limit mass as much as possible	20	Limit maximum mass	Mass ≤ 1.5 kg
	Sum (should be 100)	100		

All Team Members:

Printed Name	Signature	Date
1. Gavin Branch	Gavin B.	05/17/2026
2. Clay McLeod	C.McLeod	05/17/2026
3. Ethan Shingleton	Ethan Shingleton	05/17/2026

Sponsor Mentor Signatures:

Printed Name	Signature	Date

1. Jonathan Messiers 5/17/2026
2.
3.

8.3 Appendix C: Bill of Materials

Item	Part #	Description	Material	Qty	Units	Weight (g)	Supplier	Unit Cost	Total Cost	Notes
1	MKS-HV6150	High Voltage Digital Servo (10.9 Kg/cm @ 8.4 V)	Aluminum	4	ea	16.4	MKS	$71.49	$285.96	Final intended actuator; cheaper servo may be used for testing.
2	Gemma V2 Flight Computer	Flight computer	PCB	1	ea	8	Adafruit	$9.95	$9.95	Final vehicle avionics uses Gemma based flight computer
3	SEN0142	IMU	PCB	1	ea	3	DigiKey	$12.90	$12.90	Angular rate sensing
4	Turnigy 2S 850mAh	Servo Battery (2S LiPo)	LiPo	1	ea	55	HobbyKing	$9.99	$9.99	Power servos
5	O0002010-3 Metal horn package (2 ct)	Servo Horn/Arm	Aluminum	2	pkg	8	MKS	$12.99	$25.98	Servo output to linkage
6	Custom	Conrol Tab	Carbon Fiber	4	ea	15	Custom	$10.00	$40.00	Lightweight control surface
7	3x50mm Inner Hinge Pin(4)	Hinge Pin	Aluminum	2	pkg	11.2	McMaster-Carr	$6.60	$13.20	Control tab hinge
8	MR63-ZZ (4 ct)	Mini Support Bearings	Chrome Steel	2	pkg	0.5	amainhobbies	$6.99	$13.98	Supports hinge shaft
9	3S 18650 Pack (11.1 V)	Flight computer battery	Li-Ion	1	ea	50	DigiKey	$9.95	$9.95	Avionics power
10	1528-4494-ND	Adafruit Barometer	PCB	1	ea	1	DigiKey	$6.95	$6.95	Altitude sensing
Total				19		282			$428.86	