Capstone

ENGR 415

Design Proposal

AIAA High Altitude Liquid Engine team - Structures and Recovery-D603

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March 9, 2026

I. Introduction

The High Altitude Liquid Engine (HALE) rocket team at Oregon State University is a student-led group developing a high-altitude, liquid-propellant launch vehicle consisting of a liquid rocket engine: MIRA and the launch vehicle: CETUS. After approximately eight years of development, the team expects to perform the first flight test of the current CETUS vehicle during a summer launch campaign in the Mojave Desert. The vehicle is approximately 22 ft (6.7 m) long with an 8 in (0.20 m) diameter and a sea-level thrust of 7100 N.

II. Scope

CETUS has no active aerodynamic control during powered flight. Observed roll during ascent can reduce the usefulness of onboard video and can complicate telemetry interpretation. Video footage is a critical outreach product for sponsor engagement and recruitment, while clean telemetry supports design iteration and safety reviews.

Because the flight-ready vehicle is effectively complete for its first launch, this capstone will not attempt major modifications to the current CETUS. Instead, the Structures and Recovery capstone subteam will design and prototype a working active attitude-control subsystem for the next iteration of the HALE rocket. The objective is a subsystem that is mechanically integrable, electrically realistic, and software-documented so that future HALE teams can flight-qualify it.

Full three-axis attitude control is outside the scope of a single-term subsystem build due to mechanical, software, and verification complexity. This project will therefore target roll stabilization only. The subsystem will use an onboard controller integrated with inertial sensors to estimate roll rate and command aerodynamic control surfaces that generate a counter-moment. The expected operating mode is roll-rate damping, rather than commanded roll maneuvers.

Project deliverables are defined to prevent scope creep and to make the subsystem hand-off clear for future HALE teams. In scope for this capstone are the following items:

- Define roll-control requirements in collaboration with HALE leadership.
- Design a mechanically feasible roll-control concept suitable for a large-diameter rocket fin set, emphasizing modularity, maintainability, and failure-tolerant behavior so that the vehicle remains stable despite failure.
- Develop a prototype controller package that reads an inertial measurement unit (IMU), computes a control command, and actuates one or more servos.
- Provide documentation for future teams, including mechanical drawings or CAD outputs, bill of materials, and a clear software repository with build instructions.

Items intentionally considered out of scope:

- Pitch and yaw control, trajectory guidance, and any full guidance system.
- Thrust vector control, reaction wheels, cold-gas thrusters, and other non-aerodynamic actuation methods.

- Flight integration on the first CETUS launch vehicle and any requirement for flight qualification within this capstone term.
- Closed-loop pointing of a payload gimbal; the subsystem will stabilize the vehicle roll rather than stabilize a camera directly.

III. Previous Approaches

Rockets roll for multiple reasons, including geometric asymmetries, motor thrust misalignment, and wind-induced side forces. Roll can be beneficial for passive stability in some designs, but it can be detrimental when a payload (such as a camera or antenna) requires consistent orientation.

Three recent projects demonstrate active aerodynamic roll control. Barnard presents a servo-actuated fin-flap concept where a trailing-edge control surface on an aft fin deflects into the airstream to generate an opposing roll moment [3]. Project Horizon demonstrates a canard-based roll control system using forward control surfaces to command roll while allowing aft fins to spin, aligning aerodynamically [5]. Arcadipane's thesis further documents an active roll-control system for a model rocket, including design implementation and experimental validation practices that translate well to subsystems for larger vehicles [2]. Our team analyzed all three concepts when choosing the control system, noting each method's validity. Barnard's approach, due to its simplicity and minimal impact on the rocket body, was identified as the most promising reference case for further study.

IV. Methodology

The structures and recovery HALE capstone consists of three primary requirements for sponsor satisfaction. The first is designing an effective mechanical system that can be emulated on each fin and act independently for future full attitude control. The second is a complete code package that interfaces with both the mechanical fin system and the on board sensors to move the flaps to actively damp roll. The final aspect for complete future integration will be a detailed set of CFD data tests to size both the servo motors and flap surface area required.

V. Mechanical Design Process

In order to design a working mechanical servo/fin flap interface, each member came up with and modeled a simple version as is demonstrated in Figure 1. The requirements were that it be relatively simple, have a low number of gear parts, and be very reliable in its construction. The two primary locations were either in the fin can or embedded within the fin itself. The question then became how to connect to the servo with as much precision as possible while also mitigating backlash.

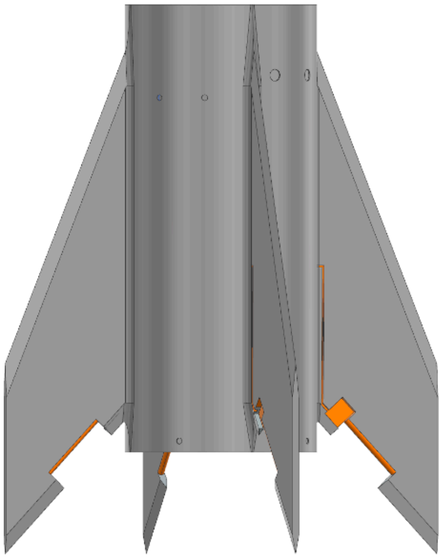

Figure 1. CAD model rocket fin can with servos integrated into the fins.

This first method as demonstrated by BPS Space [3] is far and away the cheapest and least complex option for the servos. It embeds into the rocket, connecting directly to the fins. This minimizes the amount of moving parts and mechanical pieces to only the absolutely necessary, allowing for the least possibilities of failure. However, it must have a channel carved into the fin that runs directly from the servo up into the fin can and must then be epoxied into place. This means that once inserted, the servos are permanent and fused to the fin can, bad for any iterative method. The second issue is the vast increase in manufacturing complexity and analysis. Running stress analysis with any computer program is significantly more complicated, and making such a complex shape with carbon fiber is beyond the manageable scope of our team or HALE's.

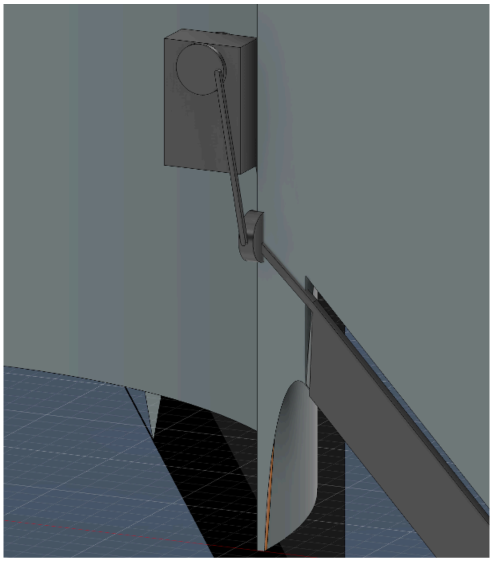

Figure 2. CAD model rocket fin can show a rotary servo method with servos placed inside the can.

This second option introduces placement within the fin can itself. This would put it directly next to the high powered engine where surrounding temperatures are approximately 300 Kelvin. This temperature implies that if not in direct contact with the engine, placement here is possible. If further temperature decrease is required, air intake vents placed above will funnel ambient air into the fuselage and allow for temperate cooling. This demonstrated rotary system would allow for precise control, and high redundancy with two arms being utilized on either side of the motor. However, it would be far removed from the flap itself and has a higher number of moving parts, creating more complexity, more possible failure points, and greater overall weight.

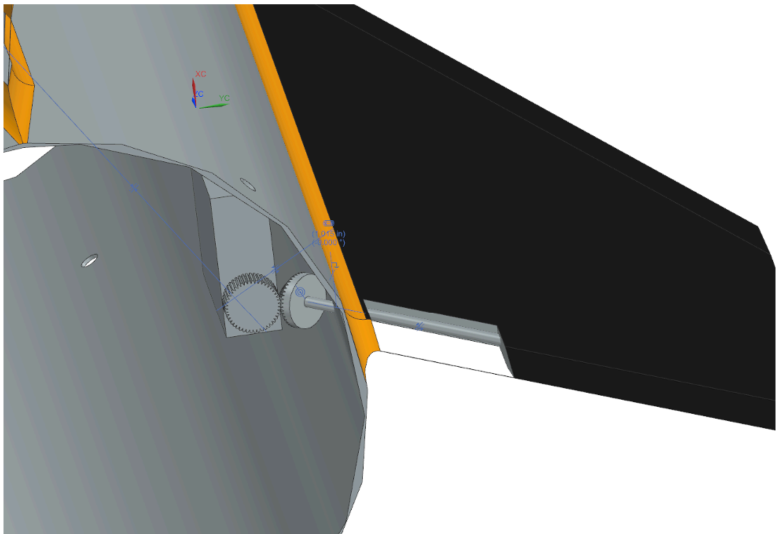

Figure 3. CAD modeled fin can showing direct linkage between flaps and servos with servos placed inside fin can.

Figure 3 effectively combines the two systems, placing the servos inside the fin can while also allowing for more direct contact to the flap, thereby reducing the number of moving parts and ensuring manufacturing efficiency. It is lighter and more compact, being directly approved by sponsors after offering all three options. Unfortunately, the presented gear system will create backlash and interfere with the needed precision. So two alternative methods have been offered: worm gears and direct servo connection. Worm gears create a screw-like gear-servo connection that generates precise control with no tolerance between, ensuring incredibly fine tuned control. While a direct servo connection provides that same level of fine control with more unknowns. Depending more on the servo itself and how it has been designed to connect to other components, it is simpler but harder to market as a complete product to the sponsors. Both methods will be evaluated and prototyped, with the current expectation being direct servo connection.

VI. Code Design Process

Arguably the most complex component, the pseudocode has been written below and will be translated into c++ over the course of the next term:

Pseudo Code:

```
● Prepare Sensors
    ○ Read gyro body rates
    ○ Read accelerometer body measurements
    ○ Remove bias estimations
    ○ Apply filters
● Attitude
    ○ Use gyro rates to compute quaternion changes over time step
    ○ Update quaternion using previous quaternion and change in quaternion
    ○ Normalize quaternion
● Build Attitude Transform
    ○ Convert quaternion into body to world rotation matrix (ENU)
● World Frame Translational Acceleration
    ○ Rotate accelerometer vector from rocket view to world view
    ○ Incorporate Earth's gravity
● Integrate Motion
    ○ Update world frame velocity using world frame acceleration
    ○ Update world frame position using world frame velocity
● Dynamic Pressure for Roll Authority
    ○ Estimate air density
    ○ Estimate speed
    ○ Compute dynamic pressure
    ○ Use dynamic pressure to create roll damping commands to fins
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This is just a set of building blocks created initially from Austin Hays (SCRT research project, Oregon State University, February 18th, 2026) which has been altered for this specific situation. More research into the dynamic physics and quaternion aspects along with trial and error will be necessary to write the code from this point forward.

VII. CFD Design Process

To size the servos and motors, an iterative design study will be performed. Using the CFD software, Ansys Fluent, a CAD fin can and section of the fuselage will be modeled. Specifications such as the expected mach number, altitude, and flap angle of deflection will then be incorporated. Ansys will then be capable of calculating both the moment and forces on the fin from geometry and air flow. This will create an iterative method through calculated trial and error that gains a specific required maximum force on the fins and a reasonable area to generate that torque. The servos can then be chosen given these new computer tested specifications.

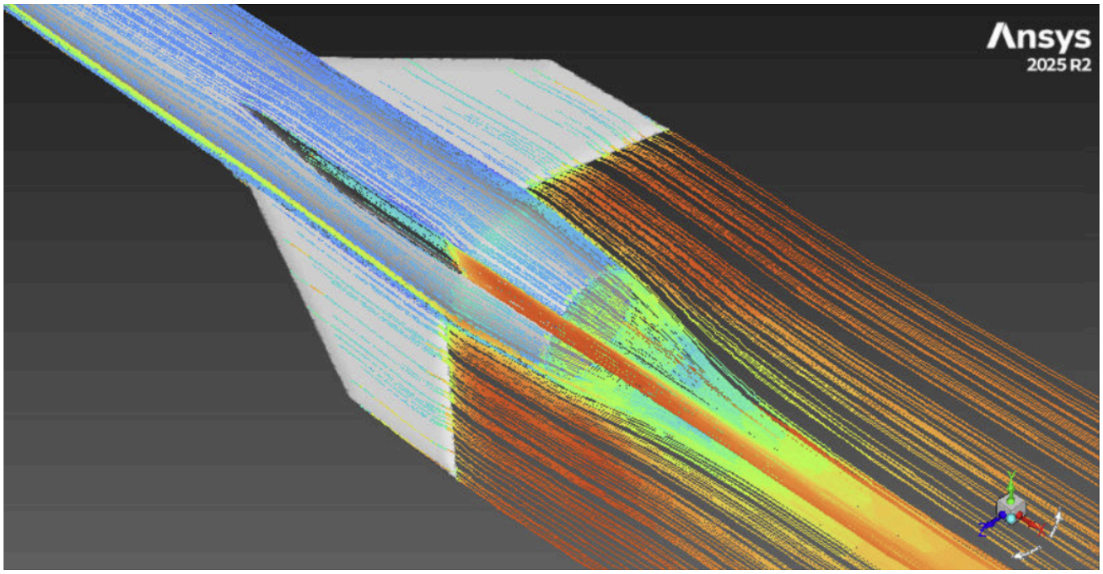

Figure 4. Ansys computational fluid dynamics software modeling 3D airflow around fin can without flaps. Shows velocity of airflow increasing from blue to red.

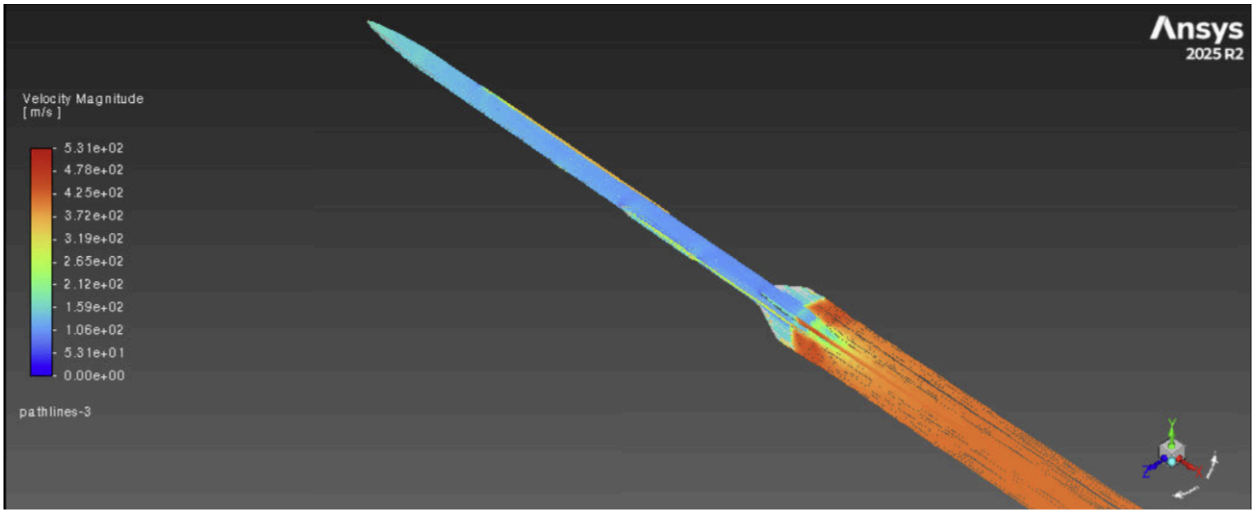

Figure 5. Ansys computational fluid dynamics software modeling 3D airflow around the CETUS rocket body without flaps installed.

Figures 4 and 5 demonstrate the software in use with the rocket modeled without fin flaps installed. Airflow is simulated around the body, allowing aerodynamic force data to be collected. By varying flap length and width and repeating the analysis, clear trends and design relationships can be established, enabling calculation of the resulting torques. These torque requirements can then be used to select servos with adequate moment capacity. With an appropriate factor of safety applied, the final design could then be integrated into CETUS.

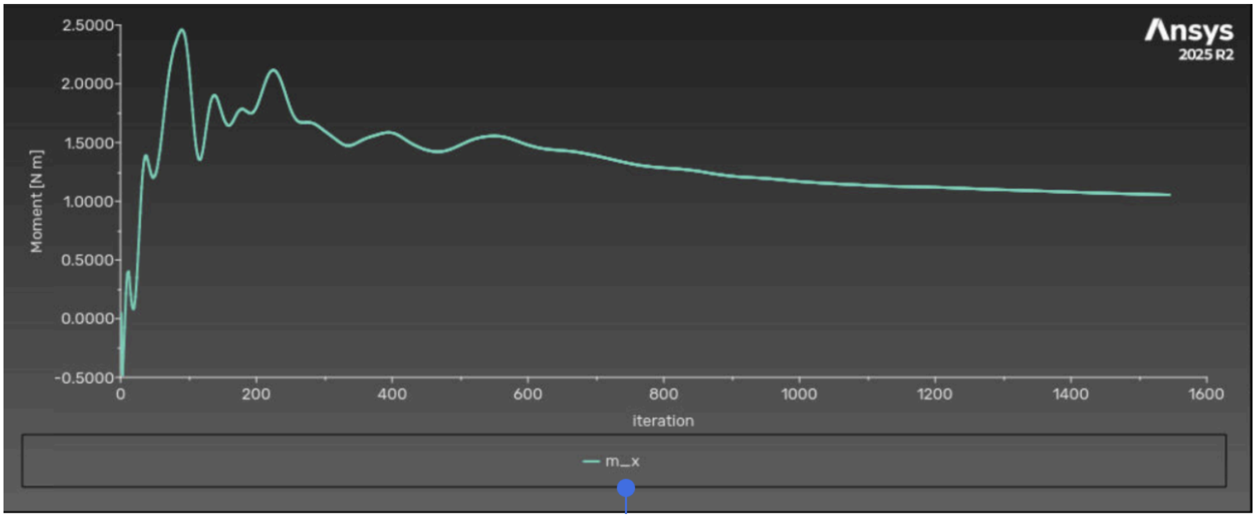

Figure 6. Ansys computational fluid dynamics software plotting the moment about the x axis.

VIII. Mechanical Prototype

In agreement with sponsor stipulations, the final system will be four servos, independently mounted within the fin can near the engine. They will then be connected either by worm gears, or direct servo connection to a shaft placed at the top of the fin flap. The servos will be mounted with a manufactured carriage, screwed into the frame and cooled either by airflow provided by current systems or naca ducts strategically placed higher up the fuselage. There will be a “brain” consisting of actuator, MCU, and IMU placed in close proximity somewhere above the engine in a location of HALE’s choosing, while the sensors will be the avionics package already integrated into CETUS, with location and movement data being provided to this subsystem for roll reaction. The sensors must be placed in close proximity to the center of gravity for accurate data inference.

IX. Stakeholders

HALE, being such a complex rocket, has a large web of interested parties. The Structures and Recovery capstone subteam consists of Gavin Branch specializing in finite element control, Clay McLeod supporting aerodynamic reasoning, and Ethan Shingleton providing trained CAD experience. Dr. Elliot Clement provides academic oversight and ensures alignment with Capstone Design requirements. HALE stakeholders include the club sponsor, Jonathan Messiers, and the chief engineer, Jeremy Robinson, who will define integration constraints and acceptance criteria for transitioning the subsystem to future CETUS vehicles. Dr. Blunck provides program-level supervision and safety expectations. Additional stakeholders include the broader HALE membership that will inherit and maintain the subsystem and any range safety personnel who review modifications before flight.

X. Constraints, Risks, and Assumptions

<u>Constraints:</u>

The prototype budget is limited to approximately $300, which restricts component selection and the number of iterative builds. The team's embedded software experience is starkly lacking, but the subsystem regardless requires sensor acquisition, control logic, and reliable servo actuation. Schedule constraints are driven by the academic term and HALE integration timelines.

Assumptions:

HALE will provide access to basic fabrication tools, materials, and mentorship for machining or composite work. The vehicle architecture will allow an auxiliary controller and sensor suite to be integrated without major redesign of avionics power distribution or wiring harnesses.

Risk:

Scope creep will be controlled by explicitly limiting the project to roll-rate damping. Structural or aerodynamic failure of a fin modification will be mitigated by conservative linkage design, basic stress checks, and staged testing that begins with low-risk prototype tests before any higher-speed evaluation. Actuator authority risk will be mitigated by estimating hinge moments and selecting servos with margin, then validating response under representative loads. Software and wiring reliability risk will be mitigated through code version control, simple fault-handling, strain relief, locking connectors, and test logs that document failures and fixes. Environmental impact will be mitigated by limiting component size and number, creating reliable redundancy.

XI. Conclusion

This capstone proposes a practical active roll-control subsystem for future HALE CETUS vehicles, focused specifically on roll-rate damping through fin-mounted aerodynamic actuation. The proposed design emphasizes a mechanically efficient gear system, an autonomous code package, and an iterative CFD-informed sizing process to support actuator selection and subsystem integration. As shown in the mechanical concepts and preliminary CFD results, the project is structured to balance performance, manufacturability, and reliability while remaining within the team’s budget, schedule, and technical constraints. This work will provide HALE with a credible foundation for future refinement, qualification, and eventual flight integration.

XII. References

[1] 3dxin, n.d., "Aim-9X Sidewinder Missile—FAQ," Superhive Market (formerly Blender Market), https://superhivemarket.com/products/aim-9x-sidewinder-missile/faq (accessed Jan. 23, 2026).

[2] Arcadipane, A., 2012, "Active Roll Control System for a Model Rocket: Design, Realization and Testing," M.S. thesis, Università degli Studi di Palermo, Palermo, Italy. Available: https://github.com/Newaysfactory/RocketRollControlSystem/blob/bdbeac04deca785c7c1af28e353de0f743dcc631/Thesis_2.3%20-%20Active%20roll%20control%20system%20for%20a%20model%20rocket%20-%20Design%20implementation%20and%20experimental%20validation.pdf (accessed Jan. 23, 2026).

[3] Barnard, J., 2024, "Supersonic Aerodynamic Control," YouTube (BPS.space), May 11, 2024, https://www.youtube.com/watch?v=6eH-t6LYYkk (accessed Jan. 23, 2026).

[4] Nakka, R., n.d., "Introduction to Rocket Design—Fins," Richard Nakka's Experimental Rocketry Web Site, https://www.nakka-rocketry.net/RD_fin.htm (accessed Jan. 23, 2026).

[5] Project Horizon, 2025, "I Built a Rocket That Uses Canards for Roll Control," YouTube, Dec. 16, 2025, https://www.youtube.com/watch?v=y531cVPWTlE (accessed Jan. 23, 2026).

[6] Science Learning Hub, 2011, "Rocket roll control," University of Waikato, https://sciencelearn.org.nz/resources/387-rocket-control (accessed Jan. 23, 2026).