Design Proposal for MIME Capstone Design 2022
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Team 803

HALE Structures and Integration Team

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1. Introduction:

The High Altitude Liquid Engine Team (HALE) has the ambition of flying the first student-built and designed liquid propellant rocket past the Karman line of 100 kilometers as part of the Base 11 Space Challenge. This final goal is expected to be completed one or two years from now with the development of the engine and all the structural components needed for the rocket still being tested, designed, and manufactured. The goal of current HALE subteams is to design subscale components and an overall subscale rocket for testing and analysis. Development of the subscale rocket will help create a successful full scale rocket build in future capstone generations. As part of the HALE team, the structures and integration subteam's main goal is to design the basic structural components of the subscale rocket and design an integration solution so each subteam's design components can be incorporated into the rocket.

2. Project Scope

The challenge of designing an efficient and capable rocket for subscale and future full scale development falls on the structures and integration team. The goal of this team is to design the subscale rocket structural components including the nosecone, fins, bulkheads, and airframe. The team will also design the integration structure for the rocket as other subteams including propulsion, pumps, valves, tanks, avionics, and ejection must have their designed capstone components in the rocket for testing and later launches.

The unique challenge of the High Altitude Liquid Engine team is essential to producing better engineers as the problems encountered by each subteam will test both undergraduate and graduate expertise and education. Each subteam member will gain valuable experience with computer aided design, composite materials, and large team communication skills that will be useful to have in the professional world. Facing these challenges as a group will help create more well rounded engineers capable of tackling any challenge no matter the complexity. Oregon State University and NASA have given significant funds to the HALE team because of the valuable undergraduate experience it provides with real world application for future professional engineers.

3. Design Process:

There have been no previous structures and integration capstone teams that have worked on the HALE. Other AIAA project teams such as The Experimental Sounding Rocket Association (ESRA) and The Oregon State High Altitude Rocket Team (HART) have had years of experience with rocket design and integration that will be useful for the design process and analysis required to develop a capable subscale rocket design. However, different teams have different mission objectives which will impact the overall design solution. HART's solid engine rocket is designed for reaching 150,000 ft compared to HALE's ambition of reaching 100 km or 328,000 ft. There are different design decisions necessary for the difference in engine types and speed of the rockets while ascending to vastly different heights. The team has been designing the structural components of the rocket for efficiency at the specific mission parameters and customer requirements essential for the final design decisions.

3.1 Nose Cone:

When designing the nose cone it was important to account for the high temperature buildup on the tip of the nose cone as the rocket cuts through the atmosphere at transonic and supersonic speeds. The main part of the nose cone will be made of fiberglass and the tip made of a high melting point metal. To account for this the team came up with different material selection options for the tip of the nose cone and geometric shapes. The two main material options for the tip of the nose cone that were selected during the design process include aluminum and titanium due to their high melting points and high thermal conductivity. The main geometric nose cone considerations are Von Karman conical shape and elliptical shape. Von Karmen conical performs better at transonic to supersonic speeds while elliptical performs better at subsonic speeds [2].

3.2 Fins:

The fins of the rocket ensure stability and drag performance at high speeds as the dynamic pressure and relationship between center of gravity and pressure act on the rocket. When considering the design of fins there are two main considerations including geometric shape and material selection. After looking at both industry and previous approaches on other AIAA projects the options include carbon fiber, aluminum, or a hybrid of the two. Carbon fiber provides the high structural stiffness and strength required for the mission and client while weighing less than aluminum. Aluminum fins provide good strength for fin structure and can perform better at high temperatures: however it weighs more than carbon fiber and moves the center of gravity closer to the butt of the airframe causing stability issues. The hybrid option uses an aluminum honeycomb stressed skin structure with carbon fiber layers on top providing the best of both material properties. The geometries for the fins include elliptical, clipped delta swept, and trapezoidal. Elliptical fins perform best at the high speeds; however, they are very hard to manufacture correctly. Trapezoidal fins behave well at high speeds and help move the center of pressure higher on the airframe. This allows for less bending stress on the airframe due to the tug-of-war phenomenon between the center of gravity and pressure on the airframe. Manufacturing trapezoidal fins is easier than elliptical fins but still poses a challenge. Clipped delta swept fins behave well at high speeds and the geometry allows for an easier manufacturing process [1]. Compared to elliptical and trapezoidal fin performance, clipped delta swept fins also provide a low coefficient of drag while having roughly the same high performance and stability as elliptical and trapezoidal fins.

3.3 Bulkheads:

The bulkheads of the rocket body are crucial for structural integrity as they hold the internal stresses developed within the airframe and allow for stability of subteam components such as the engine, valves, pumps, tanks, avionics, and ejection systems. The two main structural configurations of the bulkheads include interior skeleton frame and exterior skeleton frame. The Interior skeleton frame approach allows the bulkheads to provide most of the structural support within the airframe. The bulkheads in this approach are responsible for protecting the inner components, tubing, and airframe. Using the exterior skeleton frame the bulkheads are used as a containing compartment for all components within the rocket. The airframe will provide the main structural support, the airframe will also take most of the internal forces and stress using this approach. There are three ways to design the insertion system of the bulkheads including slide-in, cut, and single body. Slide-in approach has bulkheads designed so they simply slide into the butt of the airframe with exterior bolts to secure the internal structure. Components cannot be accessed or modified while inside the airframe with this approach. The cut approach is when many section cuts on the airframe will be opened on hinges with components placed into each bulkhead compartment. The bulkhead sections will already be secured into the frame allowing for structural integrity. The single body approach is when the bulkheads will be placed in a single larger bulkhead casing that can be placed into the frame allowing for the airframe to be untouched and individual components to be accessed and adjusted as necessary [3].

4. Design Proposal:

4.1 Nose Cone:

The design of the nose cone is a critical component for rocket performance and mission success. If the nose cone gets too hot or produces too much drag on fins the rocket will not reach the desired height or could breakup in the atmosphere. Based on the transonic and supersonic speeds at which the rocket is expected to be traveling, the Von Karman nose cone shape was selected with an Aluminum nose cone tip. The Von Karmen shape provides the lowest drag coefficient and using the Haack series equation the complex geometry of the nose cone can be plotted and designed accurately. The aluminum nose cone tip was selected because of the relatively high melting point of the material properties and the high expected temperature on the tip. Aluminum was also selected because the material is more machinable than titanium and more available in the current supply chain. The aluminum nose cone tip will be threaded into the fiberglass frame of the nose cone for simple integration. As seen in **Figure 1** the NX CAD design of the nose cone is presented.

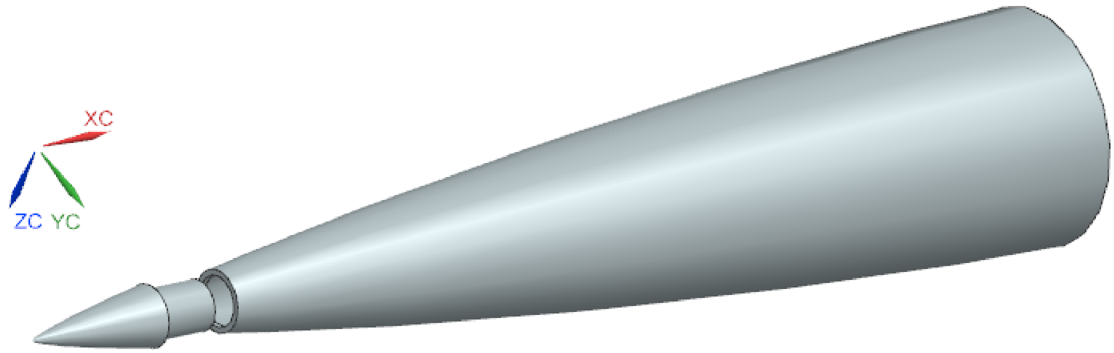

Figure 1: The nose cone tip and main structure showing threaded tip for nose cone integration.

4.2 Fins:

The design of the fins is important for rocket stability and drag performance. Based on the options for fin design geometries using four clipped delta swept fins as seen in **Figure 2**, were selected for the rocket. For the speeds the rocket will be traveling at, elliptical and trapezoidal fins have slightly better performance characteristics. Clipped delta swept fins are much easier to manufacture and considering the lack of experience with manufacturing within the team using clipped delta swept fins will save time and still provide high fin performance. The curvature of an elliptical fin is complex and hard to correctly lay up with composite materials and manufacture considering the team's manufacturing inexperience. Trapezoidal fins are efficient devices for rocket stability at high speeds but also too hard to manufacture correctly. The customer requirements and expectations show trapezoidal and elliptical fins are not needed due to their various complexities and lack of outstanding performance characteristics compared to the clipped delta swept fins.

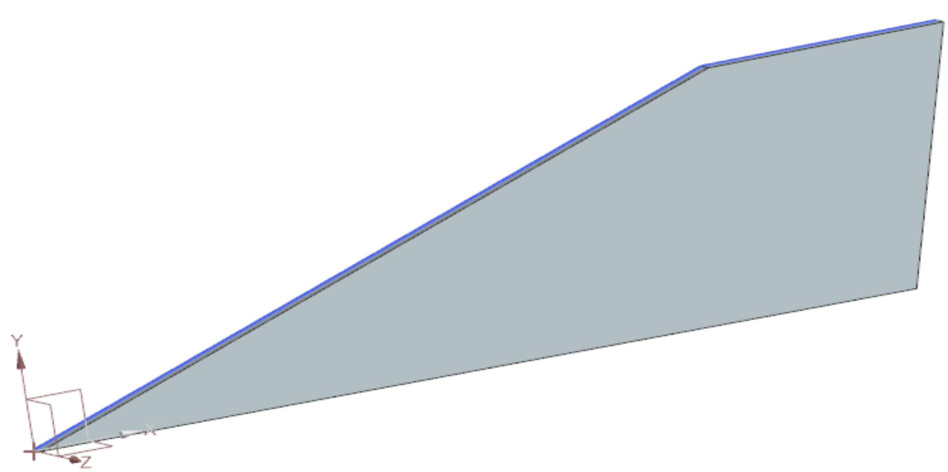

Figure 2: One of four clipped delta swept fins designed for HALE subscale rocket.

4.3 Bulkheads:

The bulkhead combination selected for the HALE subscale rocket that will best fit with the customer requirements of easy integration are internal skeleton frame and single body approach. The internal skeleton frame was selected because the components within the rocket airframe will be better protected and using a single body approach works best in this pair combination. The components of the bulkheads must be able to withstand large stresses during flight, and will, therefore, be made of aluminum to handle the high forces and changing temperature from the atmosphere and frozen cryogenic fluid from the valves. Rods made of nylon will also be placed parallel down the internal airframe as structure to help better handle the stress and make sure the contents of each component are secure in place within the bulkhead apparatus. As seen in **Figure 3** the full bulkhead section is shown from bottom to top of the rocket.

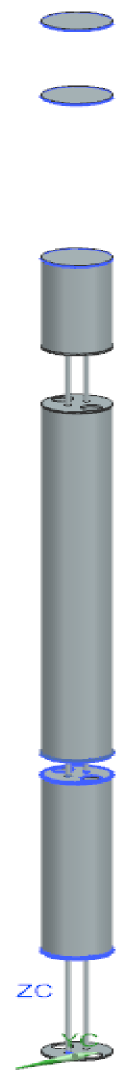

Figure 3: Bulkhead sections shown for the whole rocket with each component's compartment.

4.4 Rocket Integration:

With each sub-team's components designed, the integration aspect of the rocket must now be considered. Stuffing each HALE subteam's devices into the single body bulkheads has proven successful. Having preliminary dimensions and masses that are subject to change the team has made a diagram for full assembly integration as seen in **Figure 4**. The original airframe was donated from Innovative Composite Engineering. The airframe is approximately 7.3 ft in length with a diameter of 6.5 in. The airframe body tube is made of S2 fiberglass composite material and will house the components of each subteam within the bulkheads. Due to the expanded dimensions of length and mass from each subteam it was decided to expand the airframe another 6 ft and cut off any unnecessary lengths beyond that. As the diagram shows each sub team's components will fit within the expanded airframe comfortably while also taking into consideration each designed structural component of the rocket.

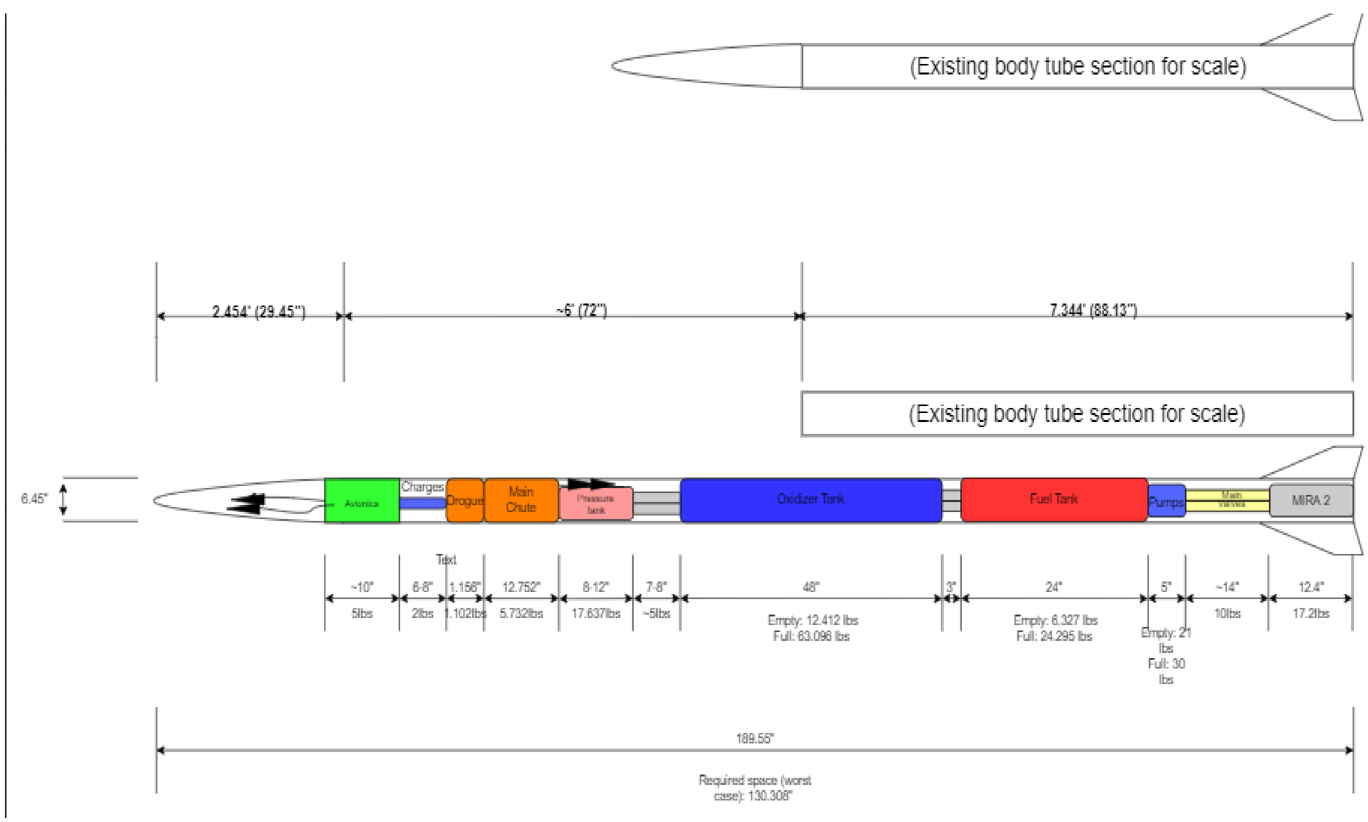

Figure 4: HALE subscale rocket integration diagram using known dimensions.

5. Conclusion:

The design and integration of the rocket has optimized over the past nine weeks as more research and approaches were analyzed. The current design of components and integration structure are on track to meet the customer requirements and HALE's ambition. From this point, increased optimization of fin dimension components and final length and mass values from each subteam will be confirmed to get a better picture of the final integration structure of the rocket. The path forward looks exciting as the ideas the team has designed will become reality within the coming weeks and help launch one of the most comprehensive and exciting rocket programs on behalf of Oregon State University, NASA, and the American Institute of Aeronautics and Astronautics (AIAA) community.

References:

[1] Fraley, E. R. (2018). *Design, Manufacturing, and Integration of Fins for 2017-2018 Osu Esra 30k Rocket* (thesis).

[2] Iyer, A., & Pant, A. (2020). A REVIEW ON NOSE CONE DESIGNS FOR DIFFERENT FLIGHT REGIMES. *International Research Journal of Engineering and Technology (IRJET)*, *07*(08), 3546–3554.

[3] Lostoski, M., Schwenning, M., & Szucs, J. (2016). (tech.). *Structural Design and Fabrication of a Rocket* (pp. 1–54). Akron, OH: The University of Akron.