Launch Vehicle 4 Airframe

Maseeh College of Engineering and Computer Science
PORTLAND STATE UNIVERSITY

Team Members: William Bleichner, Matthew Bradbury, James Foley, Melissa McEntire, Catherine Spivey

Sponsor: Portland State Aerospace Society

Project Objective Statement

The mission of this capstone is to make a complete CAD design of the LV4 rocket airframe and isogrid propellant tanks to meet the requirements of the Base 11 Space Challenge before the Launch Readiness Report deadline in June 2021.

Introduction and Motivation

The Portland State Aerospace Society is participating in the Base11 Space Challenge, a competition to be the first student group to use a liquid-propelled, single-stage rocket to get to space (100 km above Earth) within three years. This project required determining if the PSAS LV3.1 modular airframe technology could be scaled up to meet the needs of their next generation rocket, LV4, and if their proposed isogrid propellant tanks would meet their requirements. Both must also match manufacturing capabilities. The current requirements are:

- Length:Diameter ratio of 27.6:1
- Velocity of 28.41 m/s at the launch rail
- Maximum acceleration of 6.658 g's
- Dynamic pressure of 94.410 kPa
- Optimal apogee between 100 and 150 km.

Passthrough Modules

- Designed to be a modular solution for use as the camera module, RCS module and the regular passthrough modules.
- 3D printed window covers get affixed to the various window ports not in use for each respective module, while other 3D printed components allow for the affixing of various components such as fuel/propellent pipes, compressed Nitrogen gas nozzles, wiring and onboard flight cameras.

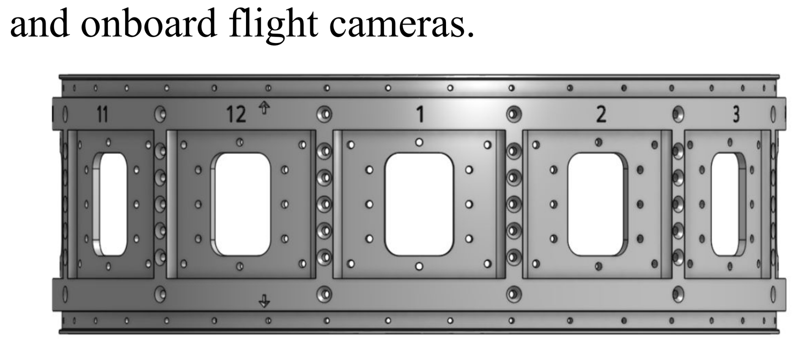

Figure 1: Empty passthrough module.

Racepipes

Four external body racepipes will allow for the transportation of compressed nitrogen, liquid oxygen, and isopropyl alcohol propellant to their respective modules throughout the rocket body

Acknowledgments

We would like to thank: Portland State Aerospace Society, Dr. Yi, Peter McCloud, Dr. Recktenwald, Dr. Zareh, and Andrew Greenberg. Supported in part through NASA and Oregon Space Grant Consortium, Cooperative Agreement 80NSSC20M0035.
PSU Mechanical & Materials Engineering Department

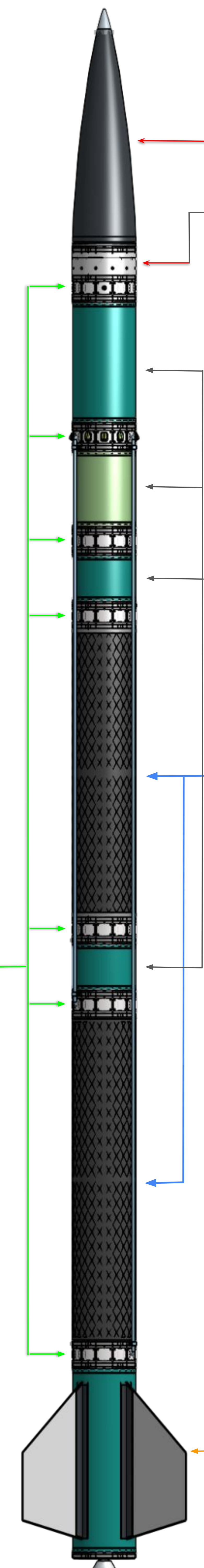

Figure 2: Version 3 (V3) of Portland State Aerospace Society's Launch Vehicle 4 (LV4) airframe.

Nose cone and ERS (Electromechanical Recovery System)

- The nose cone's initial design was for LV3.1. It utilizes a Von Karman ogive, which is an equation driven curve that is parameterized for its length.
- LV4's nose cone parameters changed from LV3.1 in OD but also in length based on the MDO specifications.
- The ERS has not yet been designed for LV4, so the module redesign from LV3.1 consisted only of matching LV4's 12 in. OD, and changing some features to accommodate the larger size.

N2, Avionics, and Spacer Modules

- Initial design of this and other composite modules was constructed with a rudimentary composite layup based on LV3.1. For V2, the composite modules have more refined composite layers to match the contours of the coupling rings, current layer thickness parameters, and inclusion of a 3-D printed fairing at the coupling ring junctions.
- In the N2 module, COTS nitrogen tank is included, with a representative mass of the RCS plumbing.
- In the Avionics module, the length has been reduced and a cradle containing a representative avionics package is included.
- Spacer modules provide more space than a passthrough module for internal components.

Isogrid Fuel Tanks

- This is the first time PSAS will fly a liquid-fueled rocket and the first time using an isogrid design. This design was adapted from existing designs used by NASA. The tanks serve as pressure vessels as well as structural members for the airframe.
- The isogrid pattern will be machined into aluminum cylinders using a CNC, then insulated with a spray foam and finally wrapped in carbon fiber. Each tank is made in two parts and welded together at the center. The tanks have flat end caps with an isogrid pattern machined on the outer surface.
- The tanks were challenging to make in CAD and had extra design consideration for manufacturability.

Arc Clamps, Launch Lugs, Racepipe Clamps

- The arc clamps are a scaled up version of the arc clamps from LV3.1 and were updated for the thinner walls.
- The launch lugs will be built in to the arc clamps. The initial design for the launch lugs was based on the launch lug created prior. They were updated with an enclosed slot to hold the brackets and pins to hold in place. Fillets were added based on FEA results to provide strength.
- Racepipe clamps were created and are also built into arc clamps.

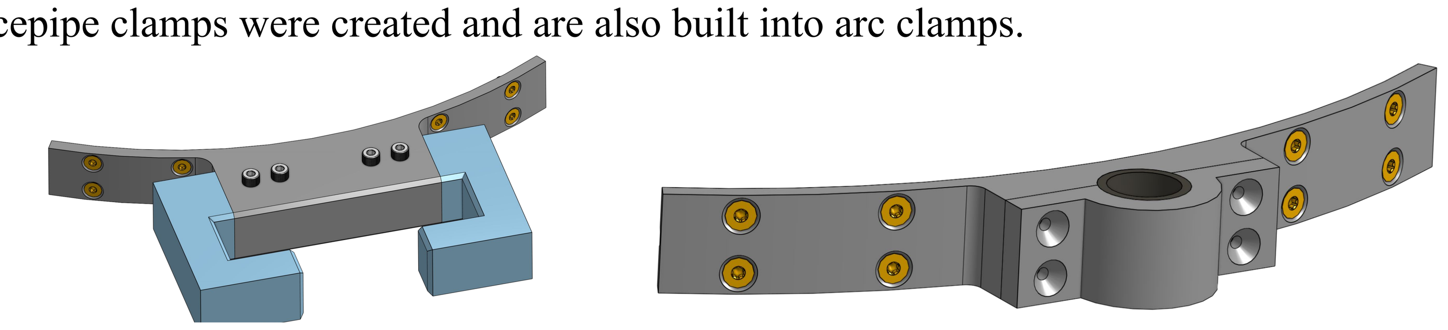

Figure 3: Arc clamps, LEFT: with built-in launch lugs. RIGHT: with built-in racepipe clamp for 0.5 inch diameter racepipe

Fins and Engine Module

- Initial design used scaled up fins and rudimentary composite layup based on LV3.1.
- The fin dimensions have been reduced to better match the surface area used in MDO. The composite modules have more refined composite layers to match the contours of the coupling rings, current layer thickness parameters, and inclusion of a 3-D printed fairing at the coupling ring junctions.

FEA and CFD

- FEA simulations for the static hanging weight of the rocket supported by the arc clamp launch rail lugs produced maximum stress concentration values on the lugs of approximately 22.4 ksi, and the fin assembly at maximum pressure. Iterative designs were made to satisfy factors of safety between 2 and 4.

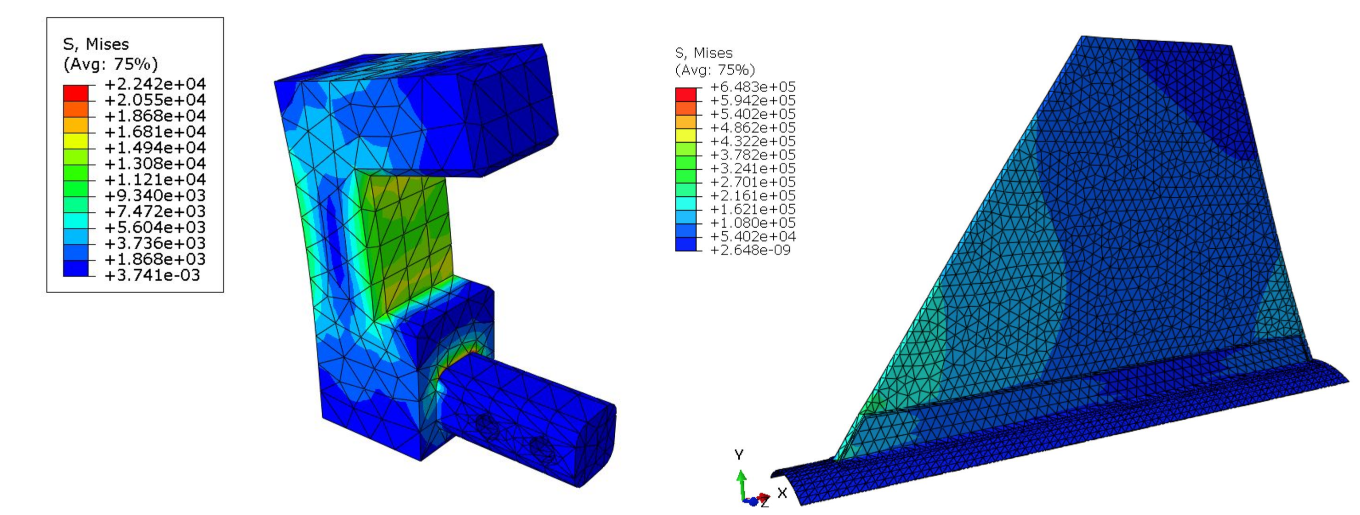

Figure 4: FEA simulations of LV4 launch lug (left) and fin assembly (right).

- Computational Fluid Dynamics (CFD) simulations were run to determine optimal fin and nose cone shapes. A diamond trapezoid fin shape returned the lowest drag force of 45.9 N and lowest frontal pressure of 5.8 psi when traveling at maximum dynamic pressure.

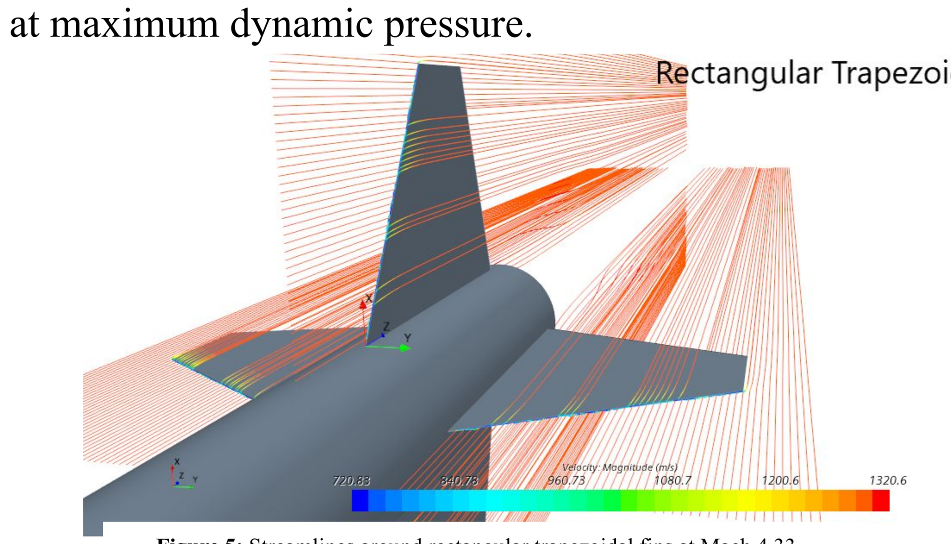

Figure 5: Streamlines around rectangular trapezoidal fins at Mach 4.33

- Nose cone CFD returned a predicted drag coefficient of 0.042 and a drag force of 290.6 N. This confirms researched data that the current nose cone shape is optimized for the predicted supersonic regime.

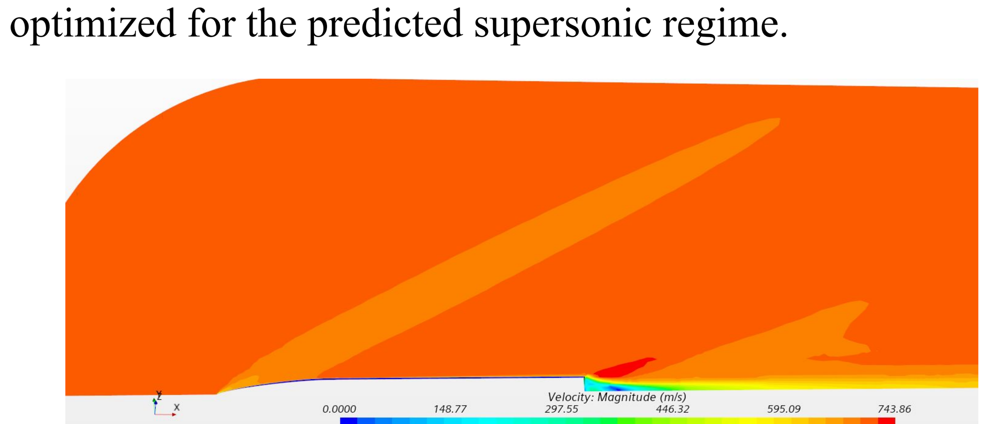

Figure 6: Velocity scene of the nose cone showing bow shock from the CFD simulation using Star CCM+.

Lessons Learned / Future Work

- COVID played a major role in changing the scope of this project. The team was unable to meet so the project was focused on design and simulations.
- The continuation of FEA analysis can focus on optimizing the rocket module connections. Future CFD work can be done to optimize center of pressure location. This could include fin optimization and a change of nose cone shape.
- Future teams can begin physical testing and begin the process of mass reduction where possible.