# DANIEL POE

## PROJECT PORTFOLIO

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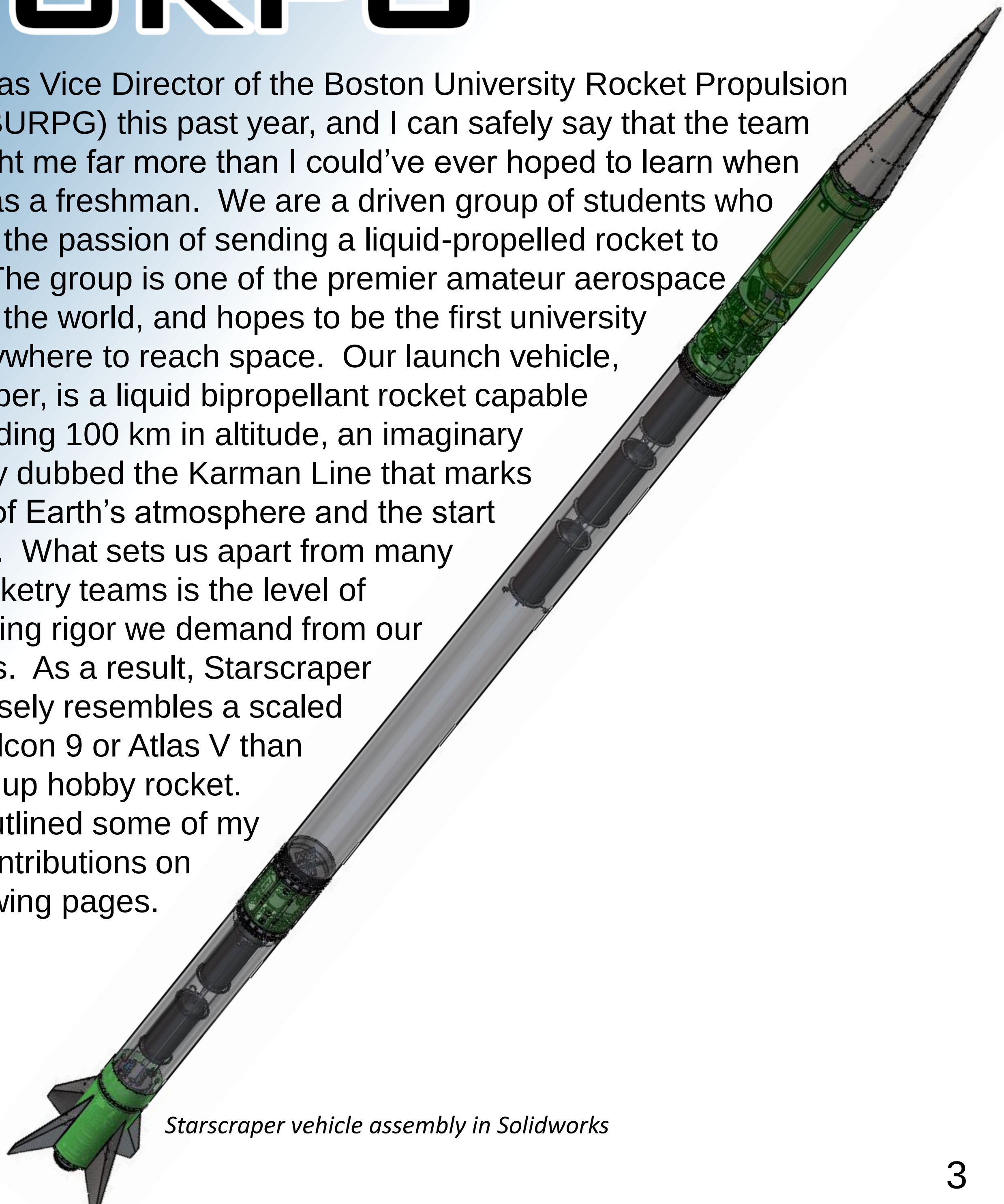
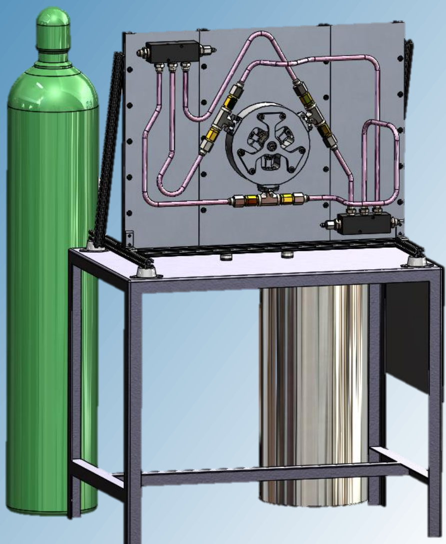
# BURPG

I served as Vice Director of the Boston University Rocket Propulsion Group (BURPG) this past year, and I can safely say that the team has taught me far more than I could've ever hoped to learn when I joined as a freshman. We are a driven group of students who all share the passion of sending a liquid-propelled rocket to space. The group is one of the premier amateur aerospace teams in the world, and hopes to be the first university team anywhere to reach space. Our launch vehicle, Starscraper, is a liquid bipropellant rocket capable of exceeding 100 km in altitude, an imaginary boundary dubbed the Karman Line that marks the end of Earth's atmosphere and the start of space. What sets us apart from many other rocketry teams is the level of engineering rigor we demand from our members. As a result, Starscraper more closely resembles a scaled down Falcon 9 or Atlas V than a scaled up hobby rocket. I have outlined some of my major contributions on the following pages.

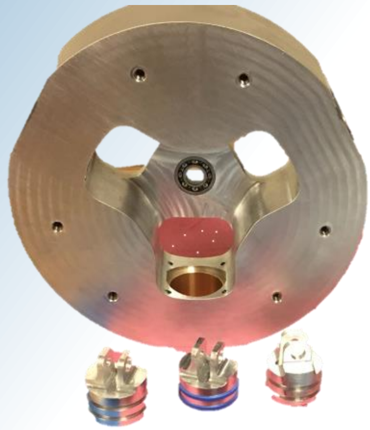


*Starscraper vehicle assembly in Solidworks*

# Rocket Engine Piston Pump



*Full CAD assembly of pump, test stand, pressurant bottle, water tank, and motor (behind panel)*

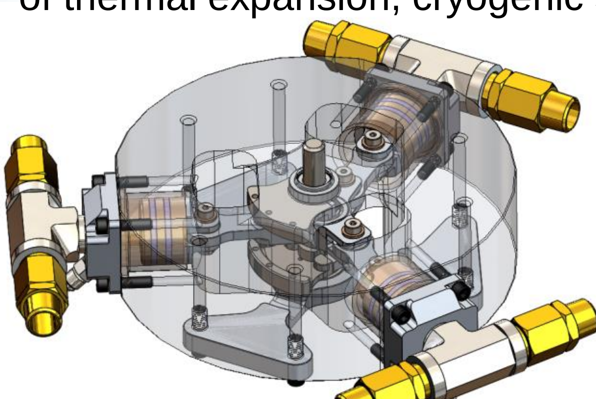


*Manufactured pump housing, pistons, and center linkage components*

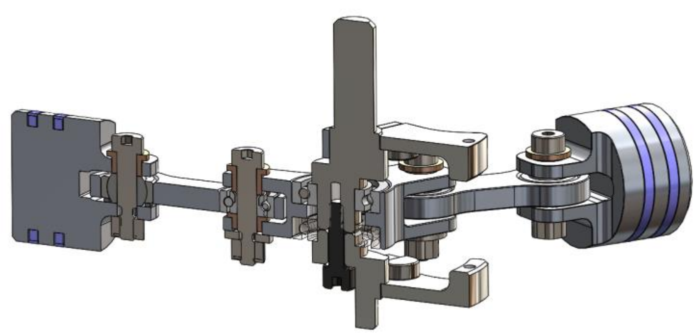
My senior capstone project group designed a piston pump for a liquid rocket engine. Group members include Doug Lescarbeau, Eric Loehle, Fedir Teplyuk, and Oleg Teplyuk.

The novelty of our pump stems from its operating environment. Plenty of piston pumps have been developed throughout history, but it would be difficult to find one that performs under the following conditions:

1. High pressure – liquid rocket engines operate at up to several thousand psi
2. High vibration environment – vicinity to any rocket engine guarantees extreme vibration
3. Cryogenic working fluid – requires materials to have matching coefficients of thermal expansion, cryogenic seals and check valves, etc.

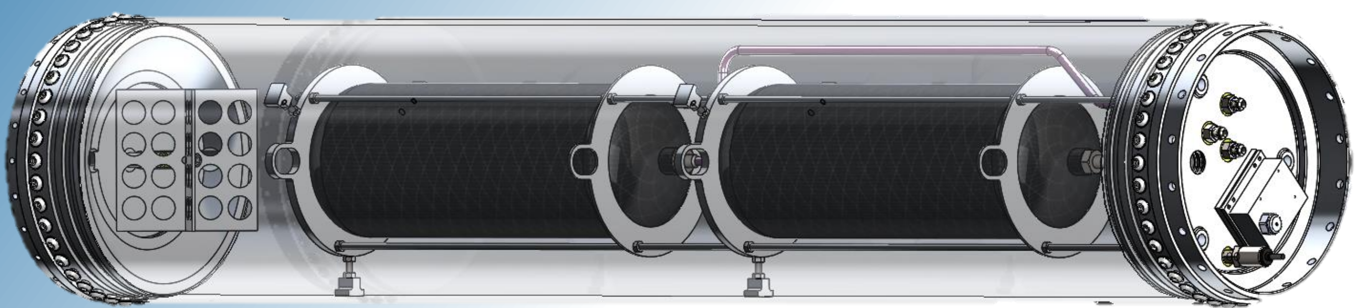


*Pump consists of the housing, pistons, and center linkage. The piston manifolds have check valves on their inlets and outlets to determine flow direction*



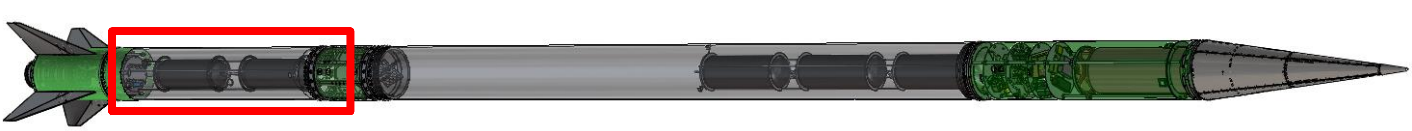
*The center linkage required extensive tribology research, and features spherical joints, misalignment bearings, adjustable counterweights, interference fits, and more*

# Liquid Rocket Fuel Tank



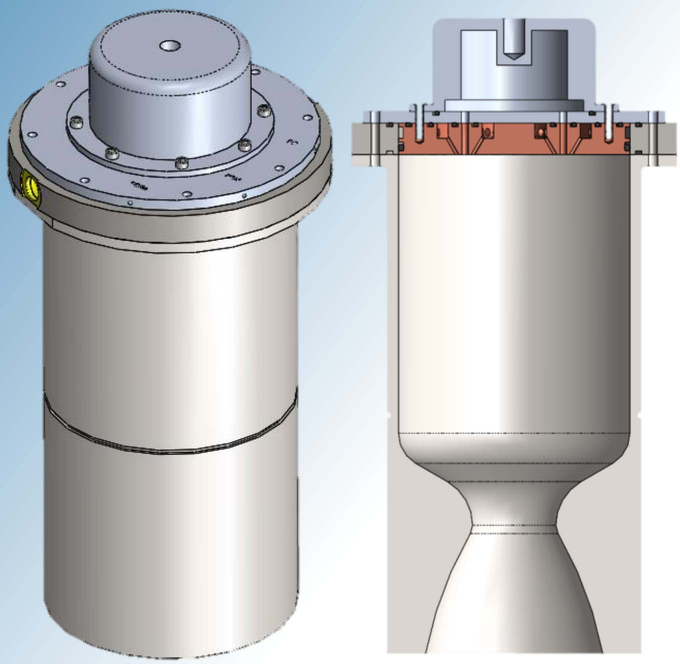
*Full assembly in SolidWorks*

- Designed a fuel tank fully integrated with the pressure-fed propulsion system on Starscraper
- Performed Finite Element Analysis in SolidWorks and ANSYS
- Rated for 900 psi.  Lowest safety factor: 1.3 (tank wall)
- Components: Tank wall, forward and aft bulkheads, pressure feed system and mounting structure, oxidizer passthrough, and slosh baffle
- Contains 20 gal of isopropanol + 5% ullage volume
- Acts as a structural segment of the rocket
- Manufacturing on hold for funding

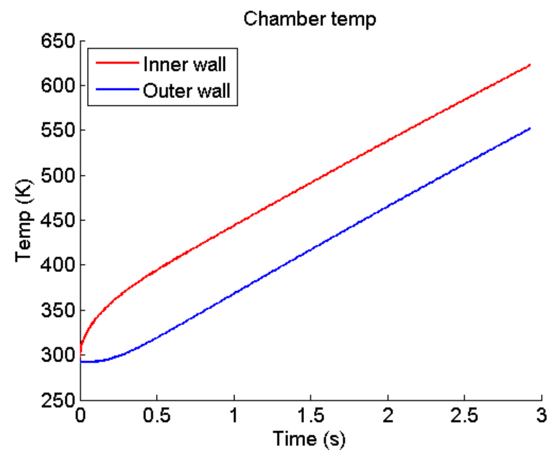


*Fuel tank location on the vehicle*

# Test Engine Thermal Analysis



*Single-piece steel test chamber*

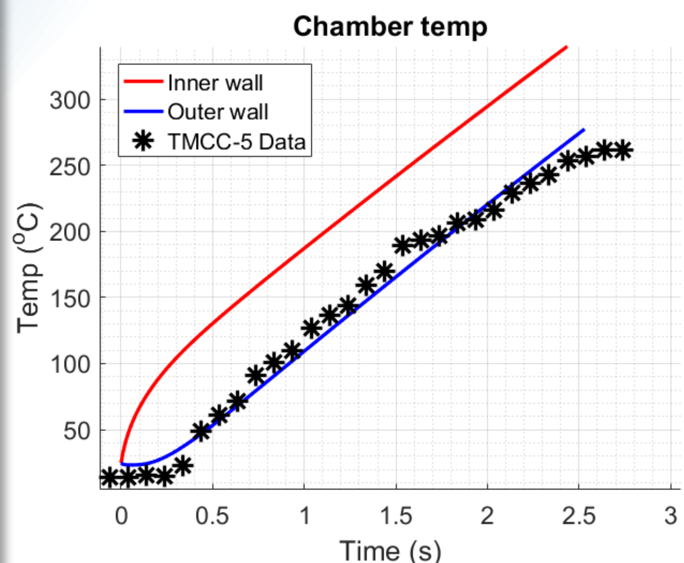



*2.9 sec to reach 350°C at thermal failure point*

- Wrote a 20+ term series solution for slab heating in MATLAB to approximate the thermal response of a heat-sink engine
- Used the Bartz correlation for hot gas convection to quantify heat transfer through the chamber
- Interfaced a thermocouple array to the existing ground support equipment to record test data for model validation
- Chamber design incorporates a groove to induce a benign failure mode

# Test Engine Thermal Analysis (cont.)

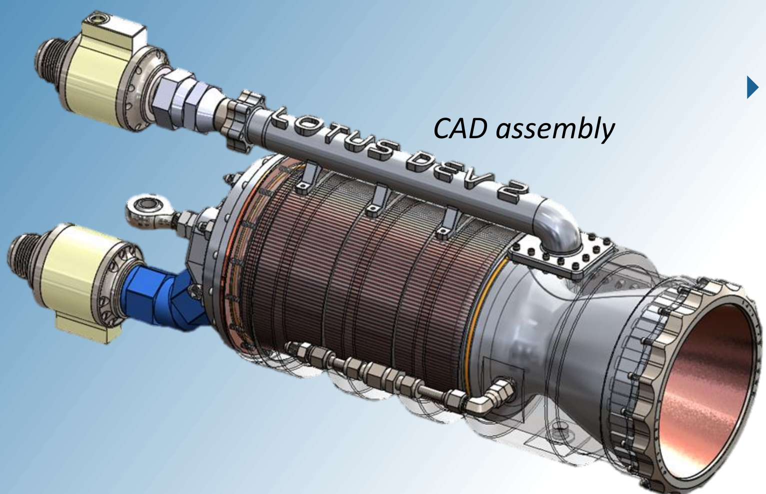
*Engine successfully hot fired on April 8th, 2017*




*Thermocouple data closely match temperatures predicted by the thermal model*

- The test engine, Iron Lotus, serves as a platform to verify performance prior to igniting the more complex and expensive flight engine

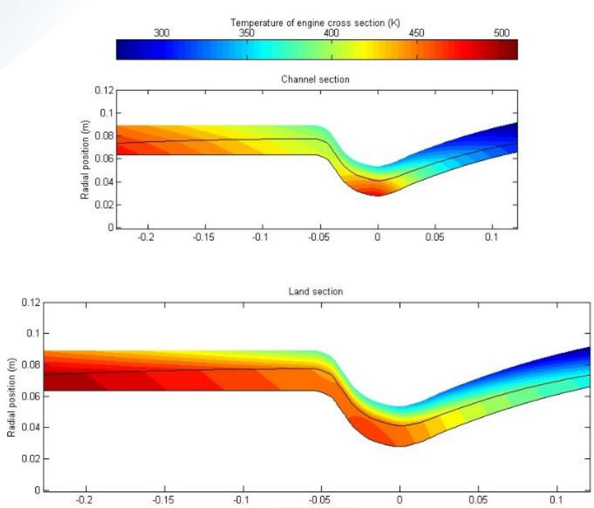
# Flight Engine Regenerative Cooling



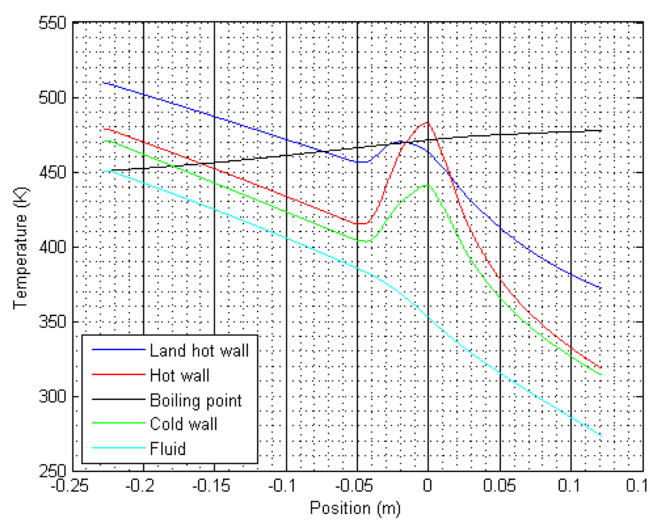

*CAD assembly*

*Copper chamber and aluminum saddle after machining. Regen channels clearly visible*

- Modified a finite element heat transfer model based on the Bartz, Serghides, and Gnielinski correlations in MATLAB for BURPG's flight engine, Lotus Dev 2 (LD2)
- Designed fuel channels for regenerative cooling, which involves cold fuel running along the outside of the chamber to prevent it from melting
- Determined an optimal film cooling layout

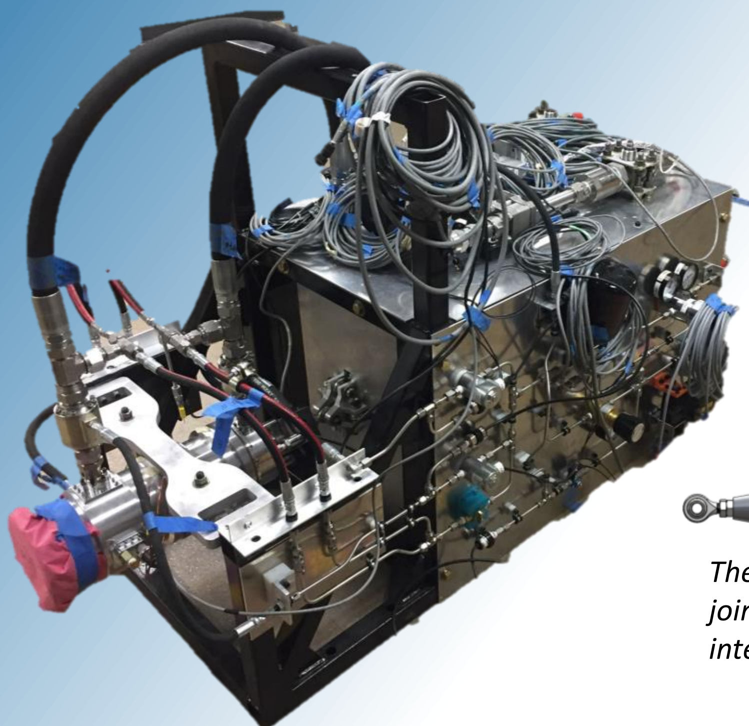



*Temperature contours in engine profile*




*Steady-state temperatures vs axial position*

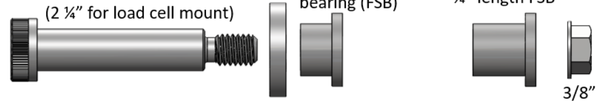
# Test Stand Thrust Structure



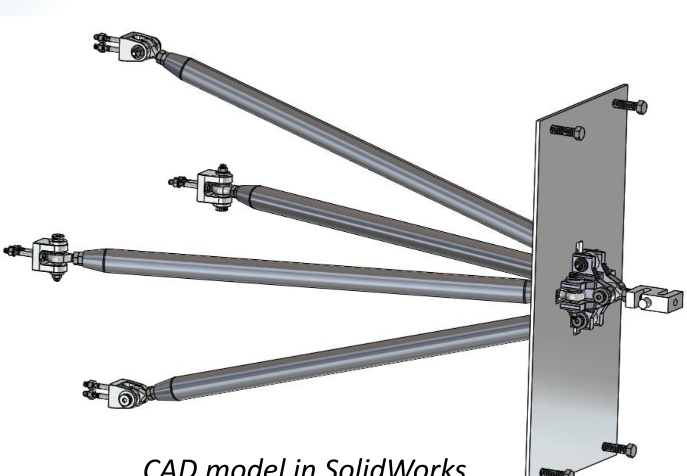
*Fully assembled test stand. Engine clevis and thrust plate visible behind LD2 engine*

*Rod end ball joint fits snugly on engine clevis*

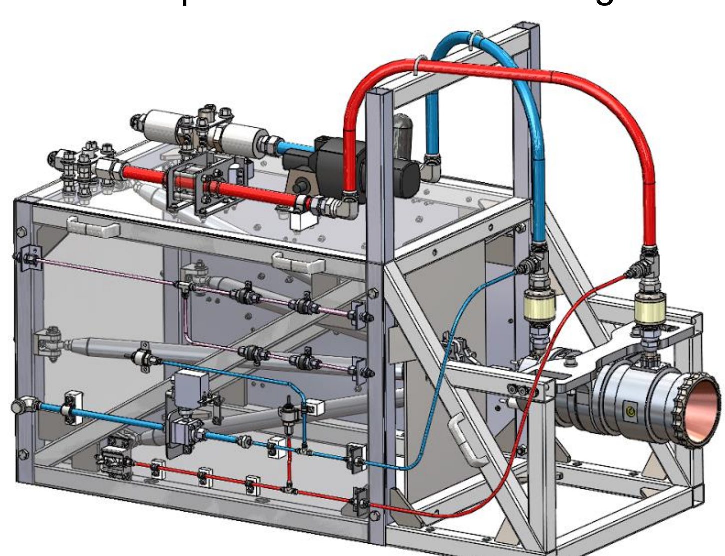
*The thrust beams are held securely with rod end ball joints connected to shoulder bolts passing through interference-fit flanged sleeve bearings*




- Designed a thrust structure for BURPG's horizontal test stand
- Main beams are turnbuckles. The rod end ball joints have right handed threads on one side and left handed threads on the other, allowing for easy length adjustment without disassembly
- Sized for a 10,000 lbf rocket engine in anticipation of BURPG testing larger engines in the future



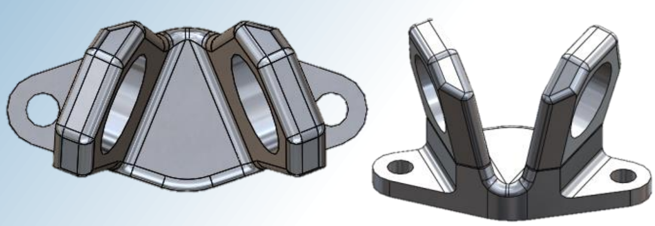
*CAD model in SolidWorks*



*CAD model of full test stand showing internal thrust structure*

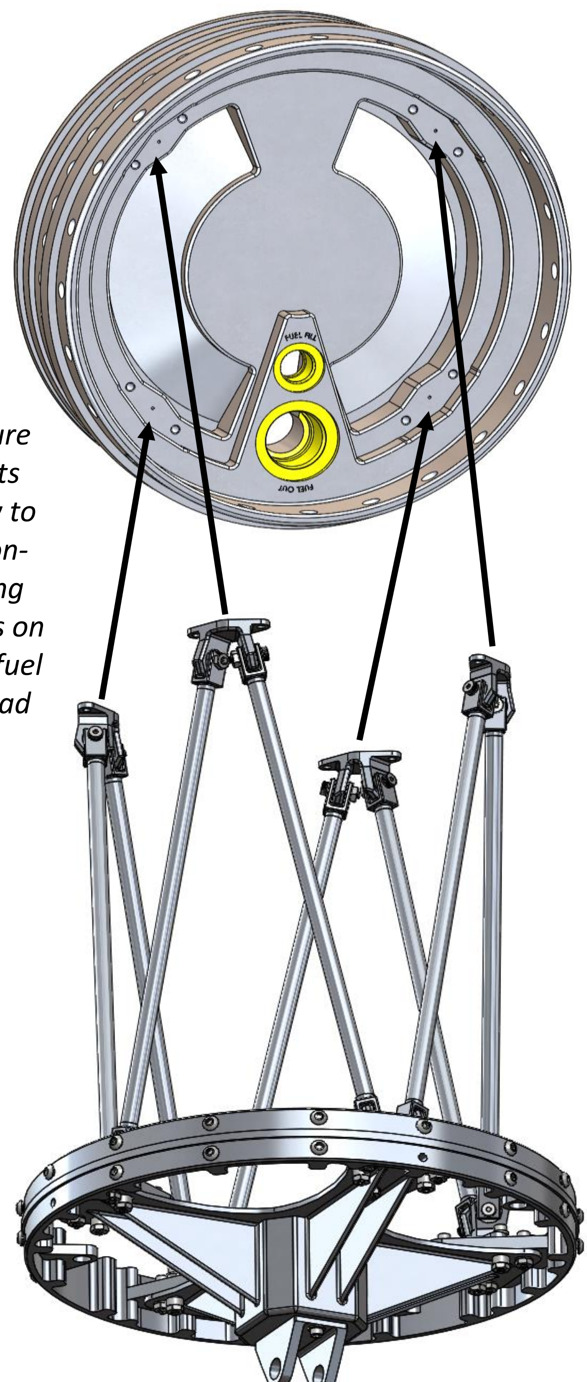
# Vehicle Thrust Structure

- Designed a new thrust structure for the Starscraper flight vehicle – old design relied on welded joints, which we chose to avoid for ease of assembly
- Clamp-ups are similar to those used on the test stand thrust structure
- Main beams are turnbuckles – allows for easy length adjustment without disassembly.  They are sized to take the full thrust load of LD2 axially as well as the moment caused by the engine assembly and plumbing during storage/transport



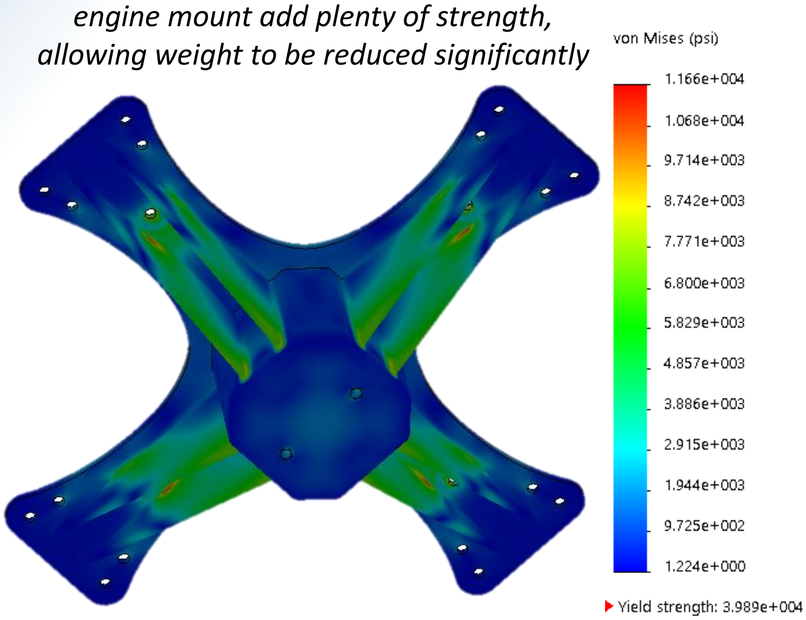
*The 8 load transfer units (4 on bulkhead, 4 on engine mount) will have 3/16" spherical joints press fit in to avoid static indeterminancy*

*Structure mounts directly to location-defining features on the aft fuel bulkhead*

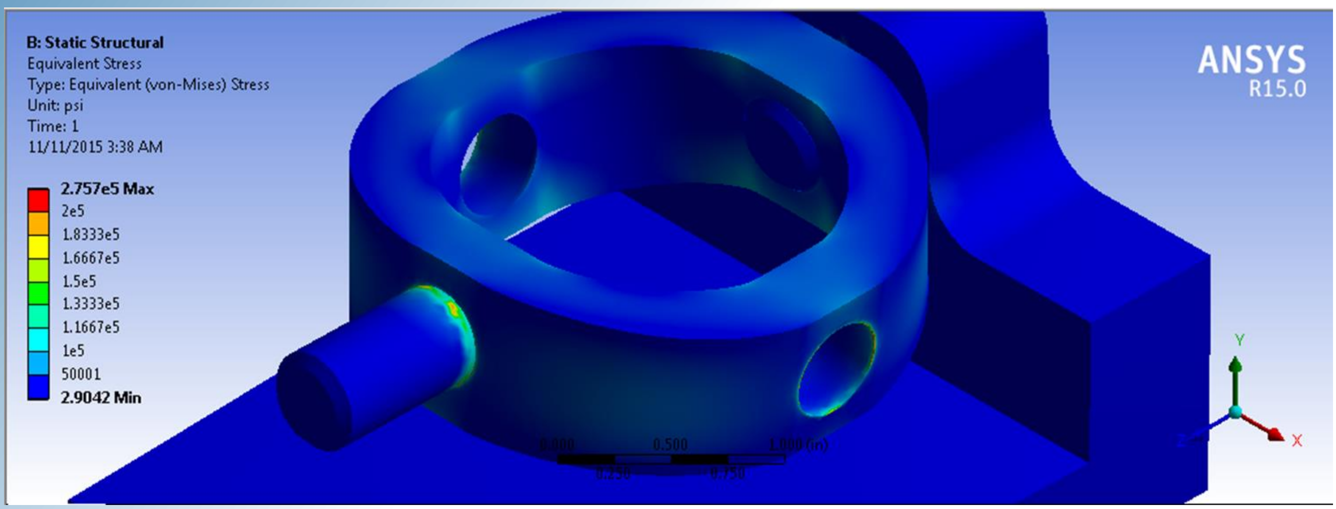



*Thrust structure CAD model*

*Dual braces on each of the arms of the engine mount add plenty of strength, allowing weight to be reduced significantly*



# TVC Ring Joint



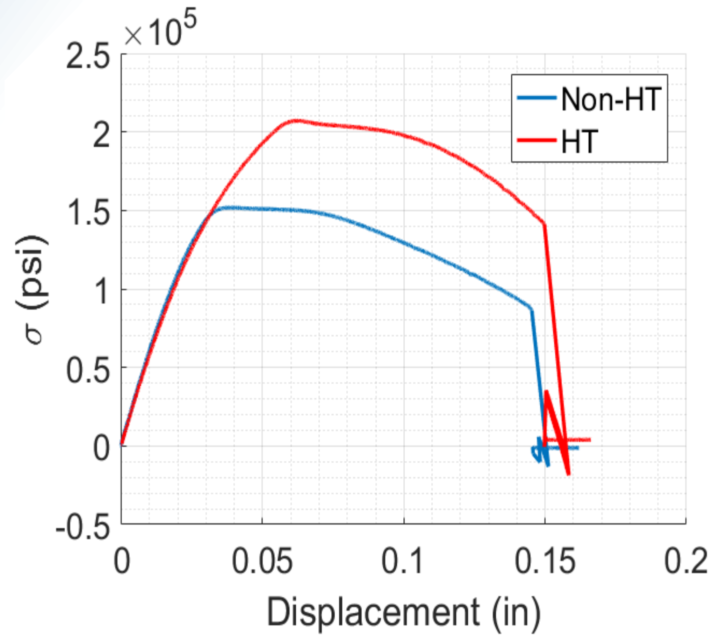

*Finite Element Model in ANSYS*

- Designed a gimbal joint with two other BURPG members
- Allows the vehicle to be actively stabilized by thrust vector control
- Transmits 2500 lbf to the vehicle
- Connects engine to aft structure
- Rotates about two independent axes for pitch and yaw control

*Gimbal joint prototype*

# TVC Ring Joint (cont.)

- Design requirements induce non-trivial manufacturing methods, which include interference fits, wire EDM, and heat treating
- In-house heat treating increased the UTS of 15-5 PH steel by over 50,000 psi
- Requires further modification to be compatible with new thrust structure

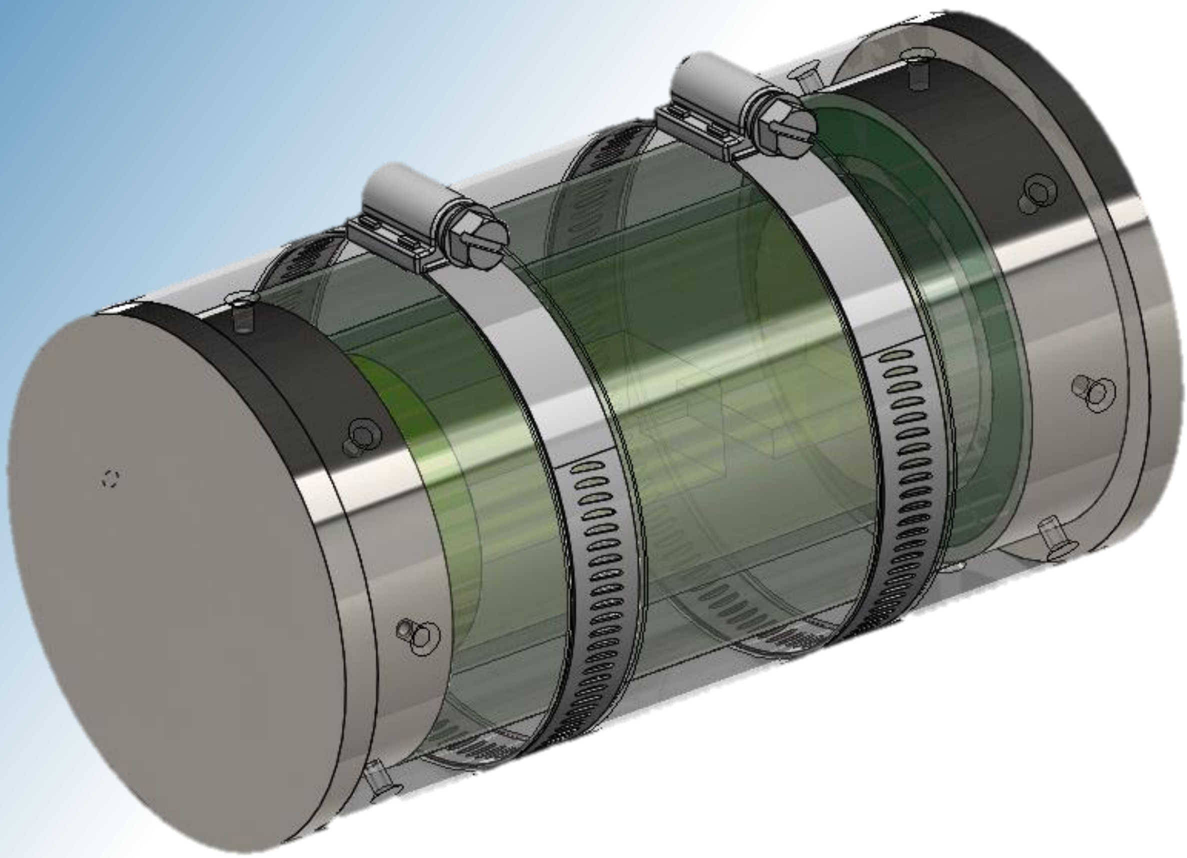



*Tensile testing results for heat treated and non-heat treated steel samples*

*Heat treated steel after tensile testing*

*Non-heat treated steel after tensile testing*

# Flight Data Recorder Housing



- Designed a black box to house a flight data recorder storing information not transmitted by live telemetry during Starscraper’s flight to space
- Robust dual shell construction protects sensitive electronics
- Analyzed impact loads and thermal response during reentry to ensure that the housing will survive a fall from space
- Served as a project leader and held weekly/biweekly meetings with new members

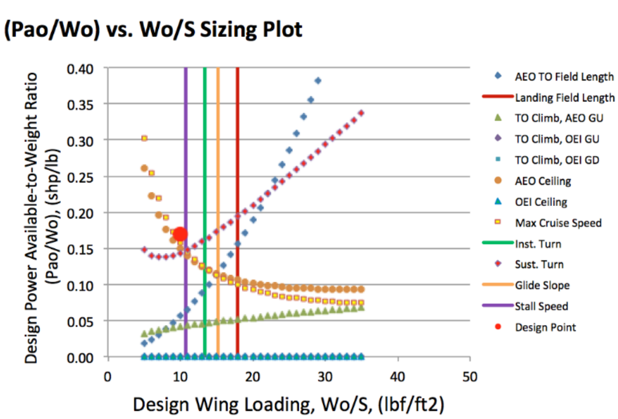
# Aerobatic Aircraft

*Lycoming AEIO-540 engine*

*CAD model in SolidWorks*

- Completed a conceptual design for an aerobatic aircraft as part of a five-member team in BU’s aircraft performance and design class
- The aircraft has two configurations: it meets light sport aircraft (LSA) requirements when using a Lycoming AEIO-360 engine and a fixed-pitch propeller, and can be used as an unlimited-class high performance aerobatic aircraft by swapping in a Lycoming AEIO-540 engine with a constant-speed propeller and moving the wing forward on the airframe

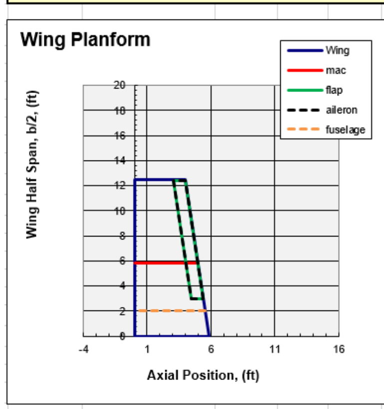
*Wing loading driven by intersection of stall speed and max cruise speed at varying power to weight ratios*

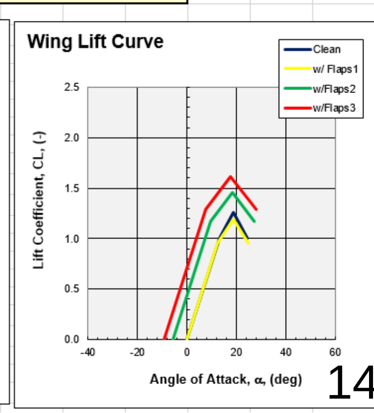



*Enhanced lift summary*

**Flap Design Summary**

| | Flaps1 | Flaps2 | Flaps3 | Takeoff | Landing | Units |
|---|---|---|---|---|---|---|
| Type of TE Flaps | plain | plain | plain | plain | plain | - |
| LE Flaps | No | No | No | No | No | - |
| Flap Area / Wing Area, Swf/Sw | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | - |
| Flap Deflection Angle, δf | 0.00 | 20.00 | 40.00 | 10.00 | 40.00 | deg |
| Flap Chord / Wing Chord, cf/c | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | - |
| Flap Span / Wing Span, bf/b | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 | - |
| CL,max | 1.157 | 1.972 | 2.113 | **1.564** | **2.113** | - |
| ΔCDo, flaps | 0.0000 | 0.0214 | 0.0571 | **0.0107** | **0.0571** | - |

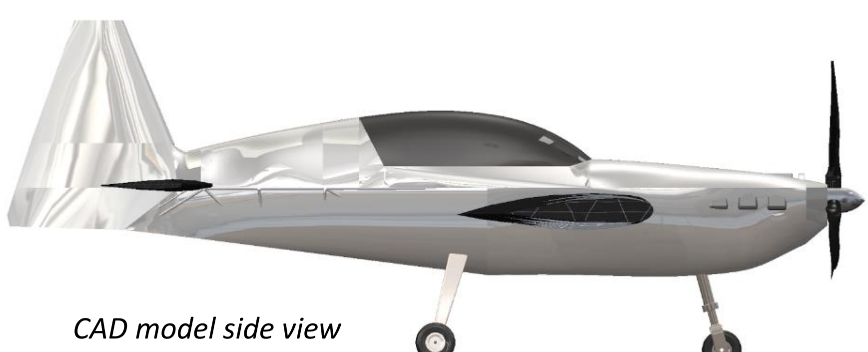


# Aerobatic Aircraft (cont.)

- Individual contributions included wing sizing, enhanced lift design, horizontal and vertical stabilizer design, engine selection, stability analysis, and CAD modeling of the fuselage, canopy, tail, nose gear, and wing ribs
- As an aspiring aerobatic pilot, this project hit close to home
- Won best in-class design award for the Fall 2017 semester

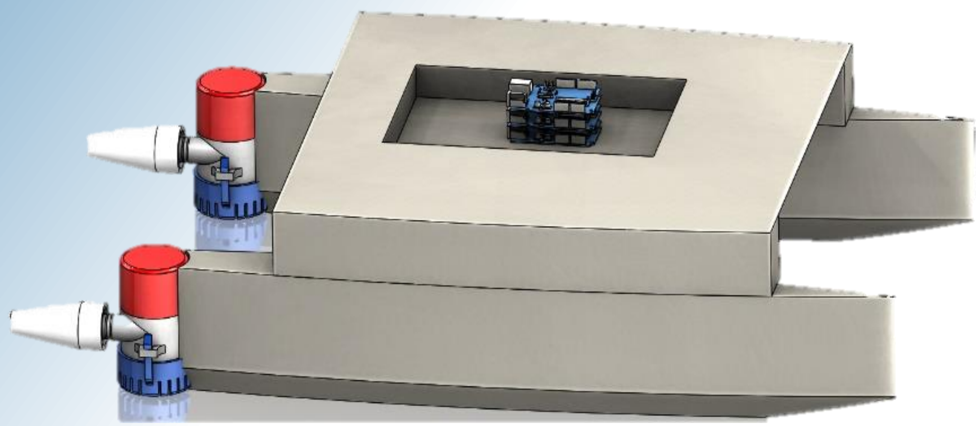
*Practicing maneuvers over Plum Island before a competition*



*CAD model side view*

# Roving Acoustic Sensor Platform

Designed, tested, built, and raced a US Navy-inspired remotely controlled boat in a team of four students as part of an engineering product design course at Boston University



*Boat CAD model from SolidWorks*

- Thrust provided by two X-Bee/Arduino-controlled bilge pumps with FDM 3D printed nozzles
- Hulls shaped out of rigid foam with laser-cut acrylic templates
- An intuitive joystick controller and thin ogive hulls gave our boat impressive performance
- Our team finished first place out of four in-class teams


*Rachel Avioli (ENG '18) with the winning boat. Photo featured in BU Today*

# Flight Computer

*Photograph taken at the destination of a 332 nautical mile cross-country flight planned with the custom program*

- Developed an electronic version of the mechanical E6-B flight computer in MATLAB
- Used the code for planning multiple general aviation flights under VFR
- User inputs the planned waypoints, desired track, wind speed and direction at the appropriate altitudes, as well as the airspeed and fuel consumption specific to the make and model of aircraft
- Output includes the wind correction angle, heading, ground speed, distance, and time in minutes to complete each leg of the flight in addition to a conservative estimate of the fuel burn

# Flight Computer (cont.)

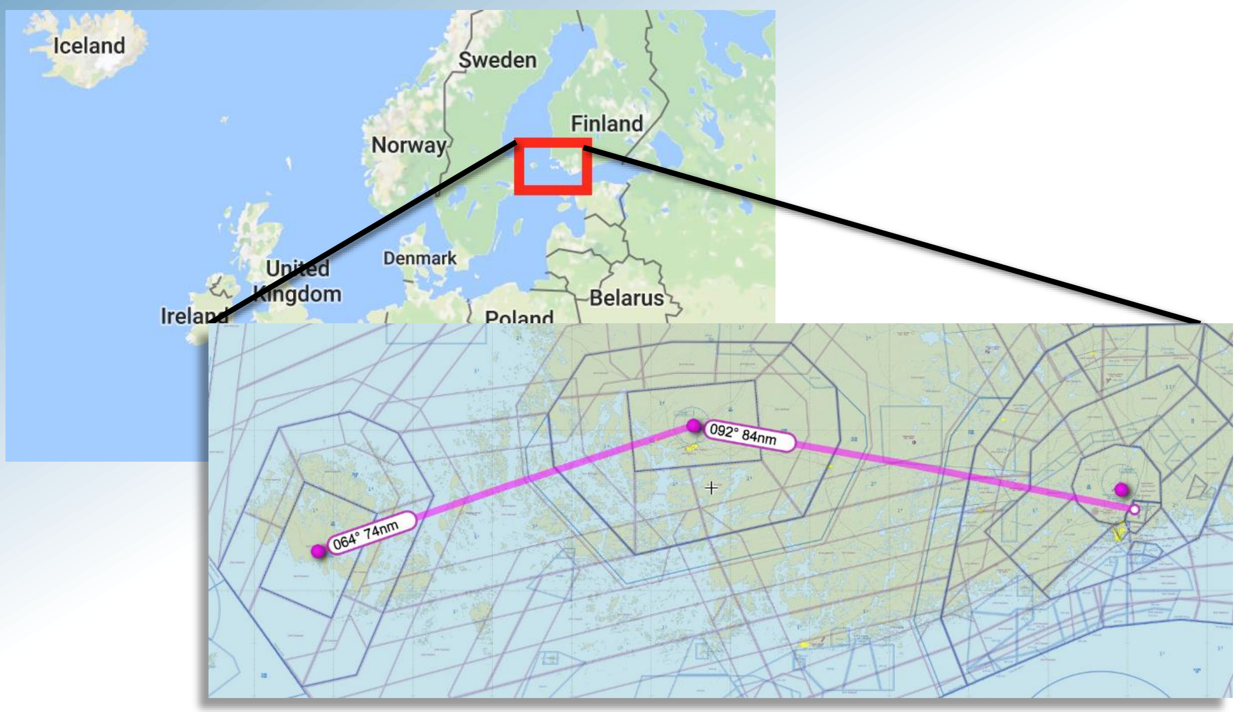



*Image from Google Maps*

*EFMA – EFHF return flight path from skyvector.com*

```
EDU>> E6B
WCA: -11    Heading: 43    GS: 128.41    Distance: 12    Time: 5.7    Fuel burn: 0.7
WCA: -10    Heading: 54    GS: 132.74    Distance: 11    Time: 5.0    Fuel burn: 0.6
WCA: -9    Heading: 55    GS: 138.68    Distance: 4    Time: 1.8    Fuel burn: 0.2
WCA: -9    Heading: 55    GS: 138.68    Distance: 11    Time: 4.8    Fuel burn: 0.6
WCA: -10    Heading: 54    GS: 141.49    Distance: 10    Time: 4.3    Fuel burn: 0.5
WCA: -10    Heading: 54    GS: 141.49    Distance: 16    Time: 6.8    Fuel burn: 0.8
WCA: -10    Heading: 54    GS: 141.49    Distance: 11    Time: 4.7    Fuel burn: 0.6
WCA: -2    Heading: 100    GS: 152.43    Distance: 13    Time: 5.2    Fuel burn: 0.6
WCA: -2    Heading: 100    GS: 147.54    Distance: 13    Time: 5.3    Fuel burn: 0.6
WCA: 0    Heading: 102    GS: 148.00    Distance: 10    Time: 4.1    Fuel burn: 0.5
WCA: 2    Heading: 104    GS: 147.54    Distance: 17    Time: 7.0    Fuel burn: 0.8
WCA: 2    Heading: 104    GS: 147.54    Distance: 6    Time: 2.5    Fuel burn: 0.3
WCA: 2    Heading: 104    GS: 147.54    Distance: 16    Time: 6.6    Fuel burn: 0.8
WCA: -5    Heading: 60    GS: 144.75    Distance: 12    Time: 5.0    Fuel burn: 0.6
WCA: -9    Heading: 348    GS: 119.63    Distance: 4    Time: 2.1    Fuel burn: 0.3
Total distance: 166 Nm    Total time: 70.9 min    Total fuel burn: 10.5 gal
```

*Sample code output for the above route written in MATLAB*

# SPACEX

Worked as a Summer 2017 Test Equipment Engineering Intern for the Falcon Booster Stand (FBS, shown in background image) team. SpaceX tests every Falcon 9 and Falcon Heavy first stage on FBS before launching it.

Projects included:

- Stand pneumatics upgrades
- Vehicle control pneumatics
- TEA-TEB ignition system pneumatics upgrades
- Mechanical lockouts for ground/vehicle fluids interfaces
- Vehicle COPV gas loading

Missions affected:

CRS 12

OTV 5

Iridium 3

KoreaSat 5A

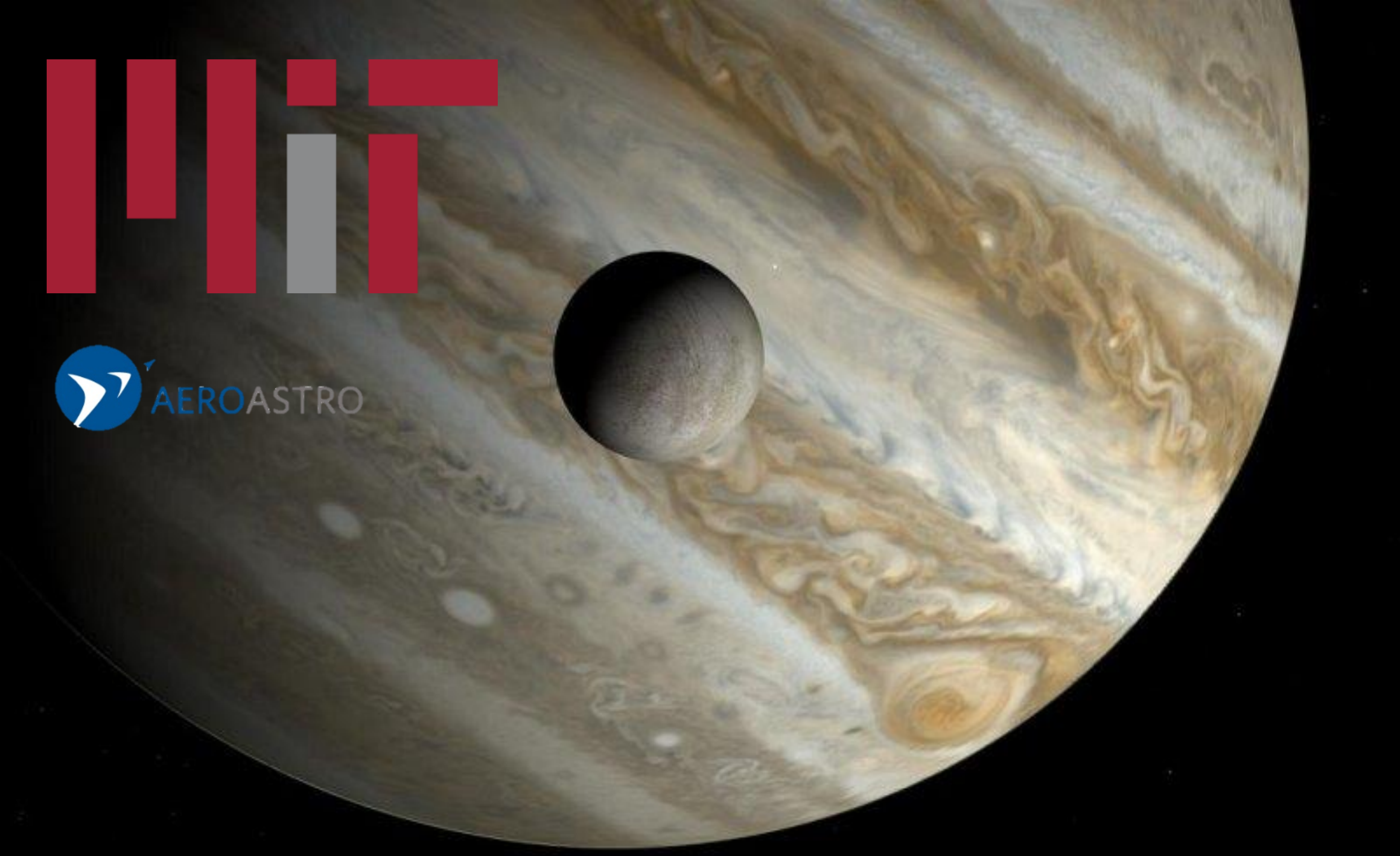
Zuma

FH Demo

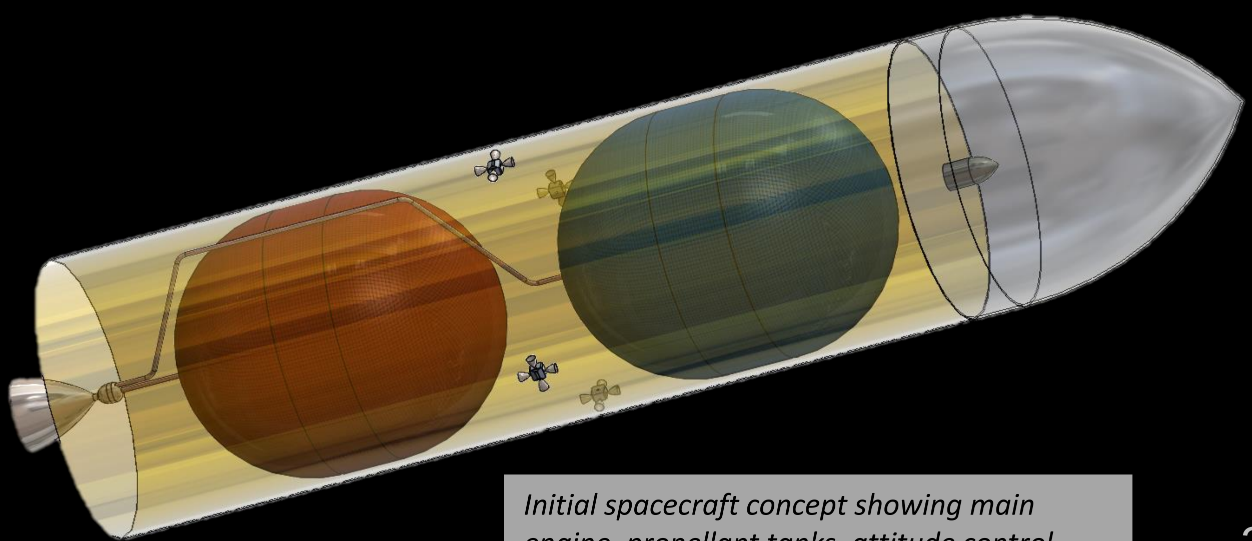
Hispasat

Iridium 5

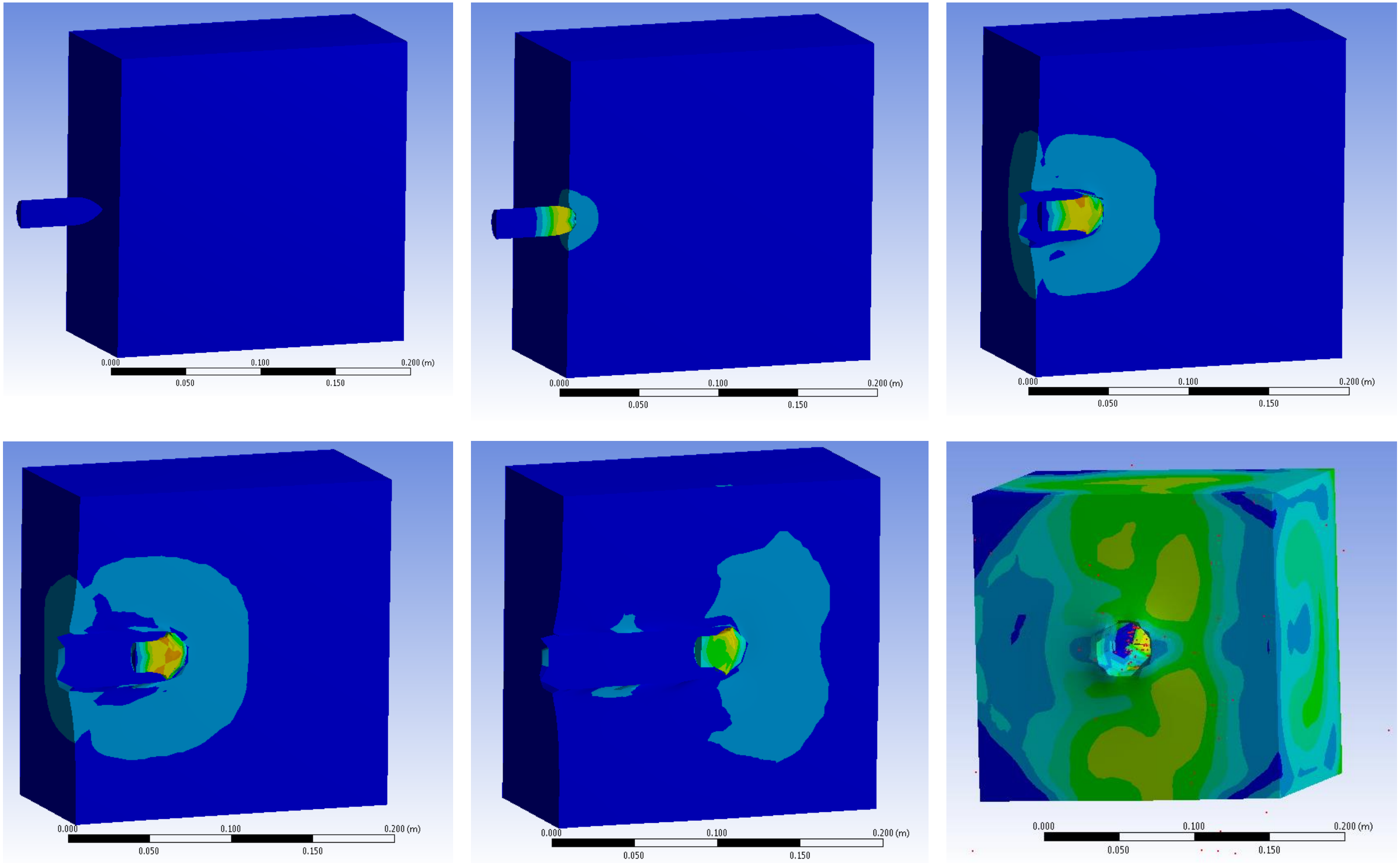
CRS 14



Conducted preliminary analysis and created a conceptual spacecraft design to investigate the possibility of sending a penetrator probe to an icy moon such as Europa (shown in background image in front of Jupiter. Photo courtesy of NASA/JPL). If the project receives funding, I will continue researching it at MIT's Space Systems Lab (SSL) as a Master's student. The proposal calls for building a prototype and air-dropping it into the ice sheets of Antarctica.



*Initial spacecraft concept showing main engine, propellant tanks, attitude control thruster modules, and tungsten penetrator*

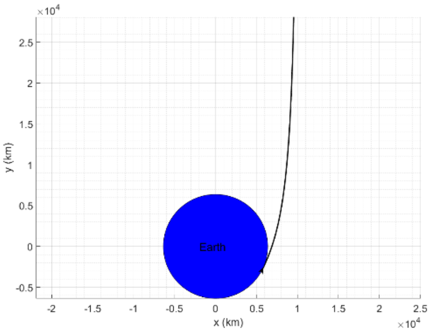



Hypervelocity impact simulations in ANSYS reveal that the stresses involved in a collision directly from orbit are unsurvivable. Retropropulsion would add another 1.43 km/s of required ΔV to the spacecraft, but would allow the payload to remain intact.

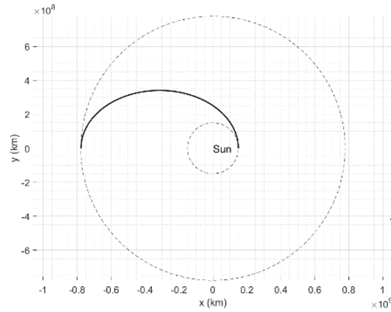
The propulsion system uses NTO and MMH as propellants because they are hypergolic, i.e. ignite spontaneously on contact. This greatly simplifies the engine design because it eliminates the need for an ignition system. The nozzle is vacuum-expanded and radiation cooled.

*Main engine CAD model*

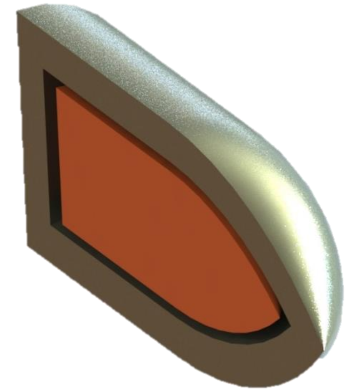
| Propulsion technical overview | |
|---|---|
| **Fuel** | Monomethyl hydrazine (MMH) |
| **Oxidizer** | Nitrogen tetroxide (NTO) |
| **O/F ratio** | 1.7 |
| **Thrust** | 250 lbf |
| **Chamber pressure** | 500 psi |
| **$I_{sp}$** | 329.6 sec |
| **A/A*** | 185 |
| **Chamber material** | Inconel 718 |




*Earth escape trajectory*




*Hohmann transfer to Jupiter*



*Simplified RTG CAD model: Tungsten shell with red-hot plutonium inside*

Assuming a launch vehicle could provide the initial 13.86 km/s of ΔV, the spacecraft would need to generate 6.514 km/s to decelerate and change trajectory planes to intercept Europa's orbit around Jupiter, 0.559 km/s to fall into a capture orbit around Europa, and 1.43 km/s to slow down from orbit (8.5 km/s total). With a propellant mass fraction of 93%, the spacecraft can generate 8.75 km/s of ΔV.

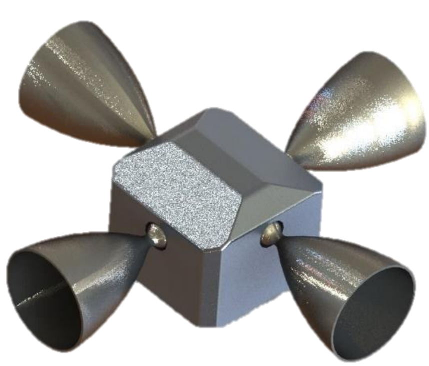
| RTG technical overview | |
|---|---|
| **Fuel** | Plutonium 238 |
| **Fuel mass** | 5.77 lbm |
| **Initial heat output** | 1487 W |
| **Half life** | 87.7 years |
| **Shell material** | Tungsten |
| **Max. shell temperature** | 829 $^{o}$C |
| **Chamber material** | Inconel 718 |

The RTG serves two main purposes:

1. Provides power to spacecraft systems.
2. Ice penetrator: Not only is it heavy enough to achieve a decent kinetic impact, it also is a nuclear-powered heater that will continue to bore through the ice until it breaches through, allowing sensors to measure the composition of Europa's liquid ocean.

Tungsten was chosen as the shell material because of its excellent radiation shielding, high strength, and resistance to high temperatures.

The reaction control system (RCS) fine-tunes the spacecraft flight trajectory.



*RCS module CAD model*

| Attitude control technical overview | |
|---|---|
| **Fuel** | Monomethyl hydrazine (MMH) |
| **Oxidizer** | Nitrogen tetroxide (NTO) |
| **Thrust** | 4 lbf/thruster |
| **Modules** | 4 (2 redundant) |
| **Degrees of Freedom** | Roll, pitch, yaw, axial settling |
| **Nozzle exit diameter** | 1” |
| **Chamber material** | Inconel 718 |