Vanderbilt University Aerospace Design Lab Preliminary Design Review Presentation

November 6, 2015

VADL
VANDERBILT AEROSPACE DESIGN LABORATORY

Team

- Andrew Voss, President, Design Engineer
- Mitchell Masia, Vice President, Website Manager
- Robinson Rutherford, Treasurer, Design Engineer
- Justin Broughton, CFD, Design Engineer
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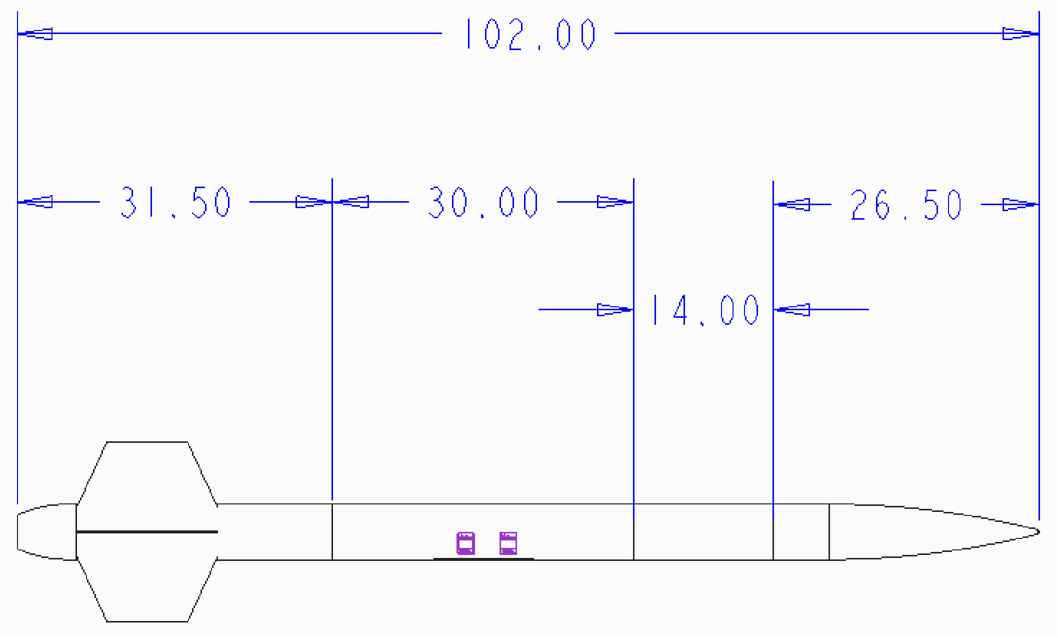
- Quinlan Monk, Design Engineer
- Dylan Shane, Design Engineer

Meeting Agenda

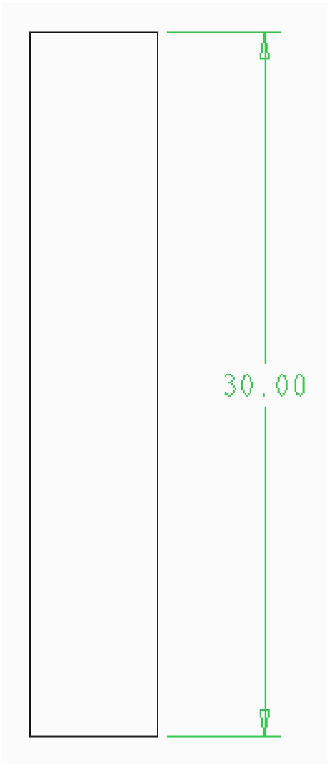
- Launch Vehicle Overview
- Flight Operations
- Vehicle Criteria
- Vehicle Systems
- Vehicle Safety and Verification
- Payload Systems
- Payload Verification and Testing
- Outreach
- Project Schedule
- Conclusions

Launch Vehicle Overview

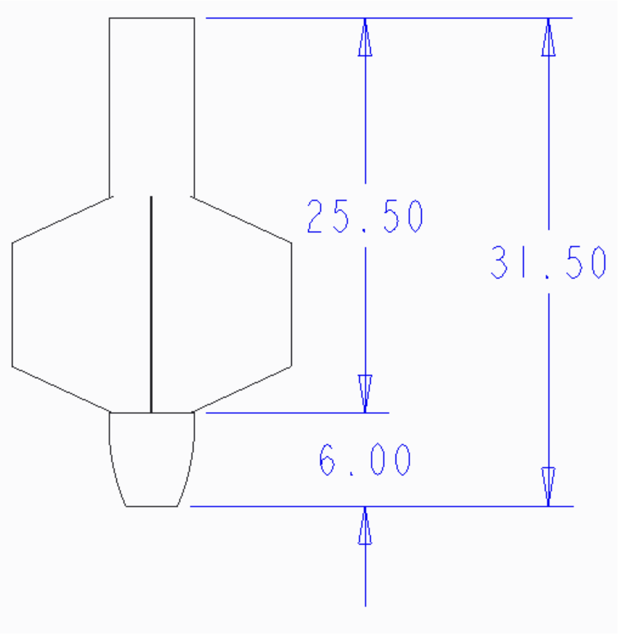
- Dimensions:
  - Overall Length = 102”
  - Outer Diameter = 5.5”
  - Inner Diameter = 5.3”
- Assembled Weight:
  - 37.9 lb



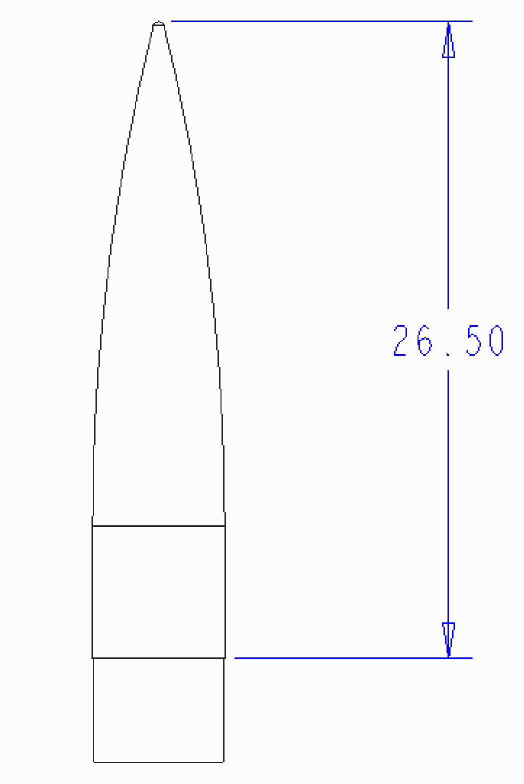
Launch Vehicle Overview – Sections



Payload Section



Tail Section



Nosecone

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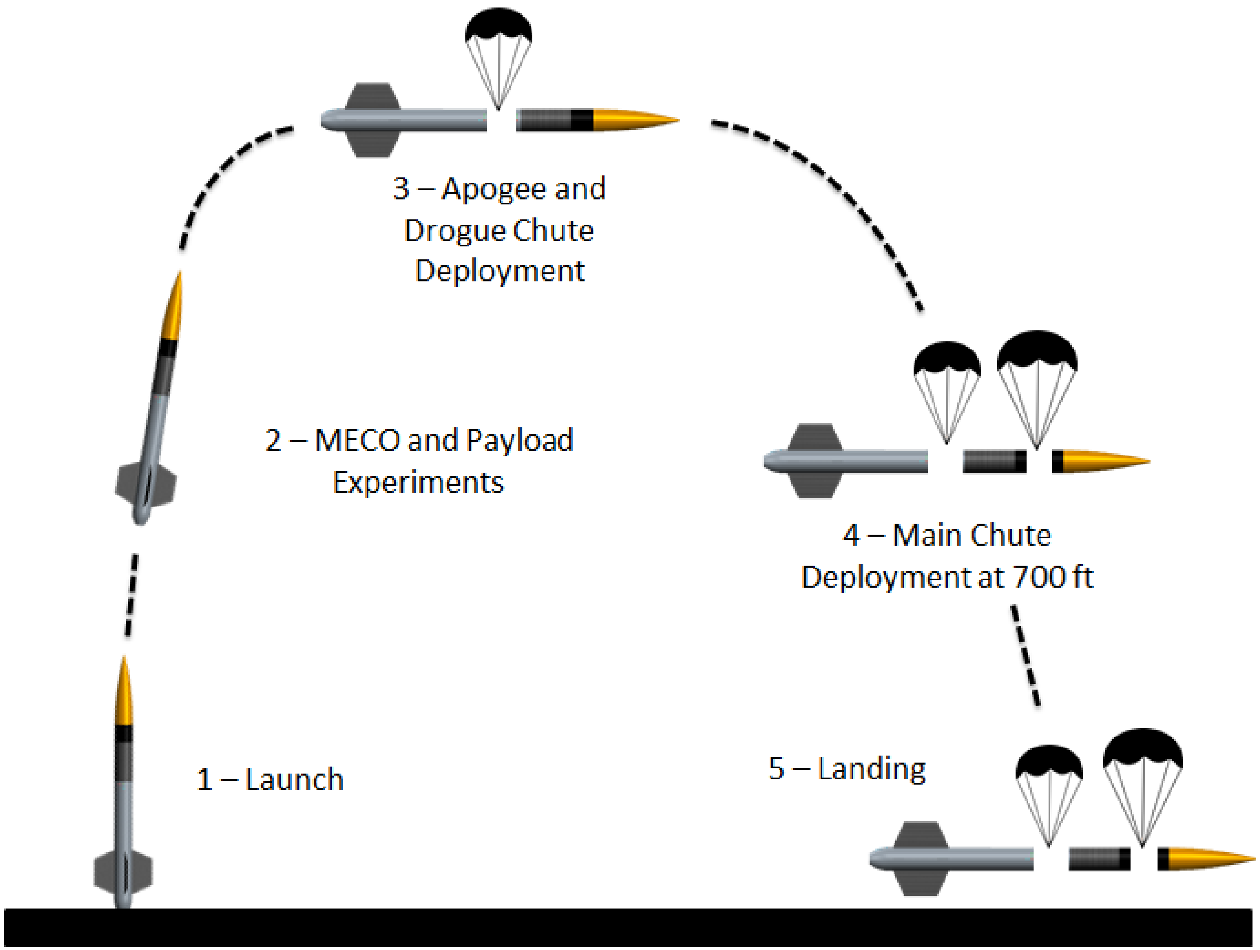
Flight Operations



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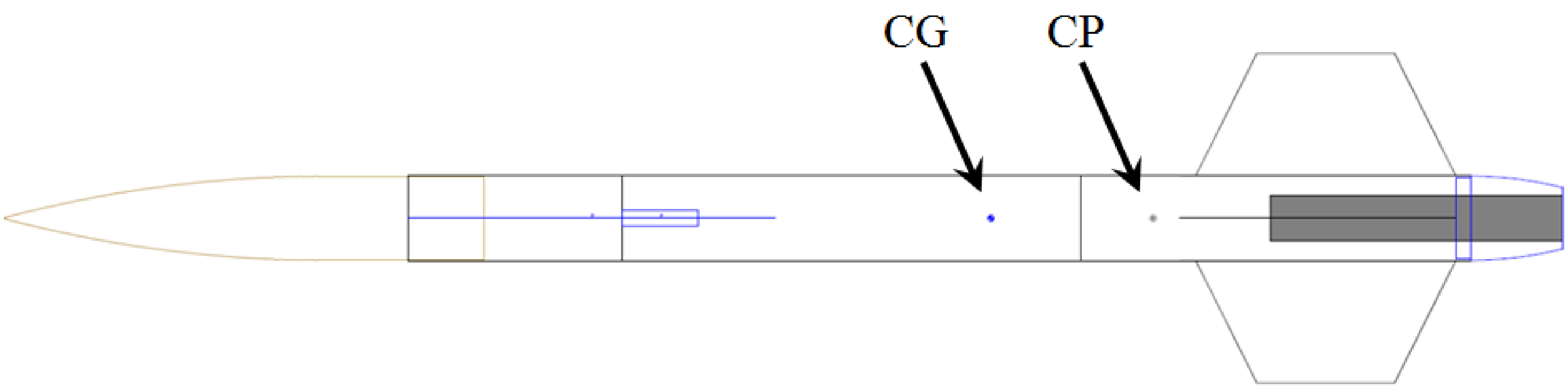
Vehicle Criteria – Stability

- Center of Gravity = 64.6”
- Center of Pressure = 75.2”
- Current Static Stability Margin = 1.91
  - Stability Margin greatly increased from last year
  - Use of lightweight carbon fiber



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Vehicle Criteria – Launch Parameters

- Thrust-to-weight Ratio
  - +12 average
- Rail Exit Velocity = 85 fps
- Predicted Maximum Velocity = 650 fps
- Predicted Apogee = 5300 ft AGL
  - Sufficient time for payload experiment

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Vehicle Systems

Propulsion System

Stability System

Structural System

Aerodynamic System

Recovery System

Propulsion System

- Cesaroni Pro75 L1720 Motor
  - Diameter = 75 mm
  - Total Weight =3341 g
  - Total Impulse = 3660 N-s
  - Max Thrust = 1947 N
    - 437.7 lbf
  - Burn Duration = 2 seconds
- 2 Aluminum Centering Rings
  - Secured to fins, motor sleeve, and outer body tube
  - Full Carbon Fiber Load Path

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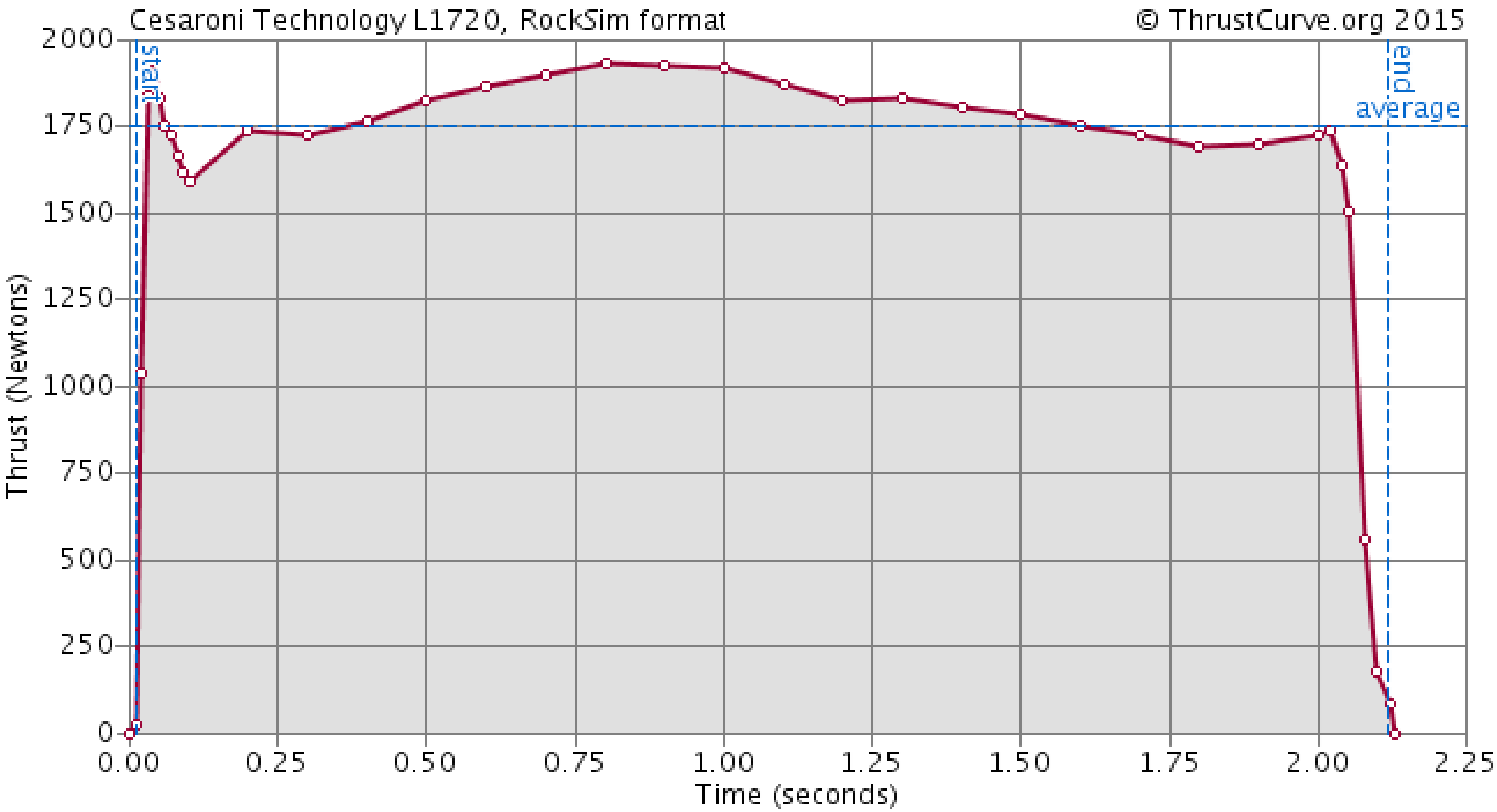
Propulsion System



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Vehicle Systems

Propulsion System

Stability System

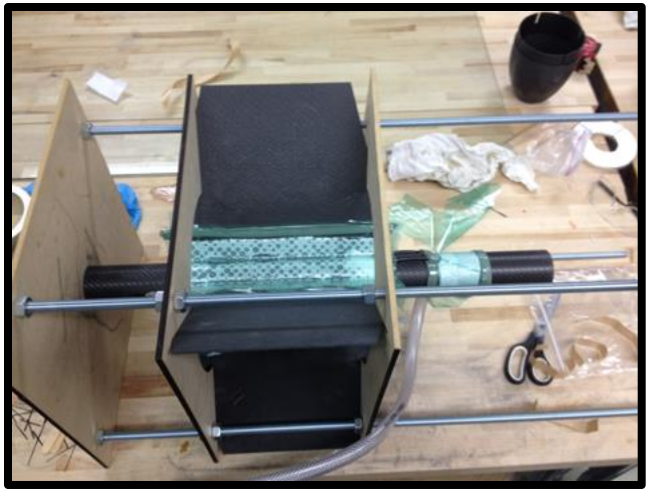
Structural System

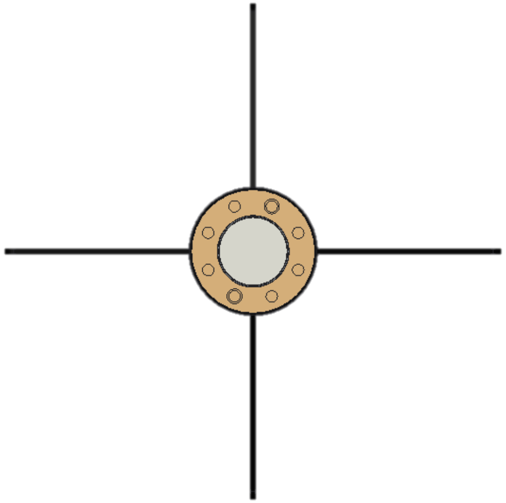
Aerodynamic System

Recovery System

Stability System

- Four Symmetric Fins
  - Fins provide stabilizing force to ensure straight flight
  - Team designed fin jig to ensure precision fin alignment
- Mass Adjustments – Final weights of each section determined





Vehicle Systems

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Structural System

5.5” Diameter Carbon Fiber as Rocket Body Tube

- Over an order of magnitude stronger in compression than blue tube
- Constructed out of high strength 3K 2x2 Twill Woven Carbon Fiber

2.5” Motor Tube – Thrust Transferred to Body Tube Through:

- 12” vacuum bagged carbon fiber fillets connecting ⅛” carbon fiber fins to motor sleeve and body tube
- Machined Aluminum Centering Rings bonded to sleeve, fins, and body tube

Sections joined with 1/16” carbon fiber coupler tube

- Secured with various fasteners

Structural System – Fins

- Four 1/8" Carbon Fiber Fins
  - Secured to outer carbon fiber body, motor tube, and centering rings with 2 plies of carbon fiber weave
  - Transfer load from motor tube to rocket body tube
  - Quasi-isotropic carbon fiber plates
- Geometries waterjet cut
- All Carbon Fiber filleting done in fin alignment tool for proper alignment

Vehicle Systems

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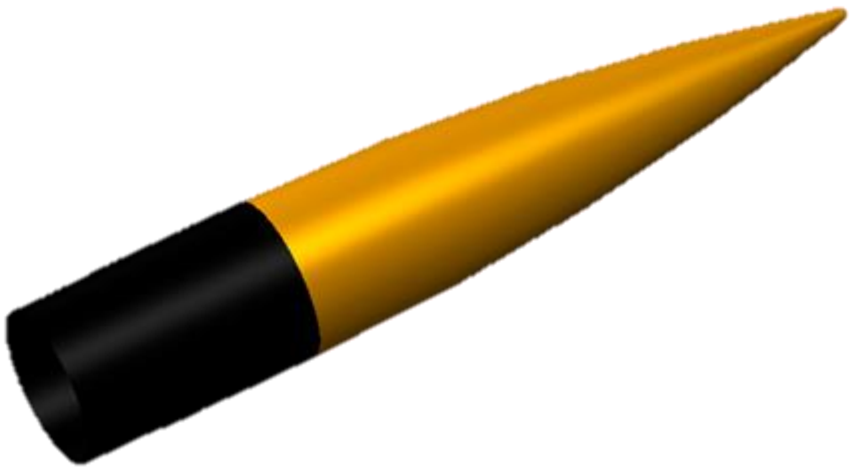
Recovery System

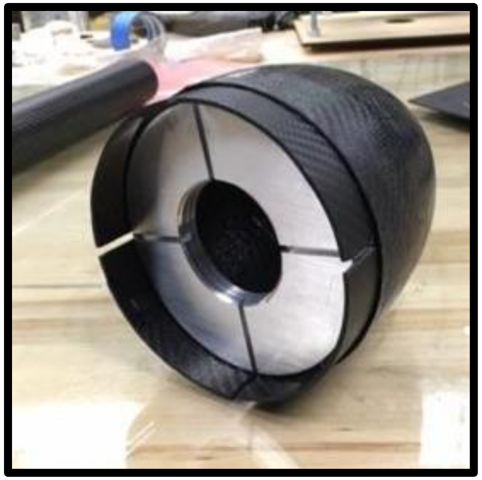
Aerodynamic System – Nose Cone

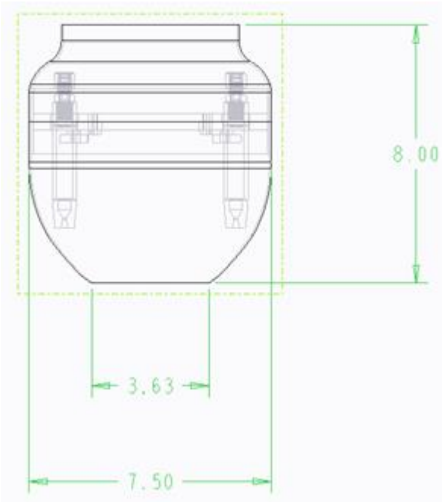
- Nose Cone –Long Tangent Ogive
  - Original Length = 22” (Overall), 21” (Exposed)
  - Lengthened to 26.5” to house main parachute
- Houses Main Parachute and Blast Caps



Aerodynamic System – Tail Cone

- Minimizes Drag
- Subscale Tail Cone Length = 5.5”
- Fabricated In-House
    - 2x2 twill carbon fiber
    - 2 piece split mold
- Lightweight
- Temperature Resistant
- Design will be altered for full scale to accommodate thrusters

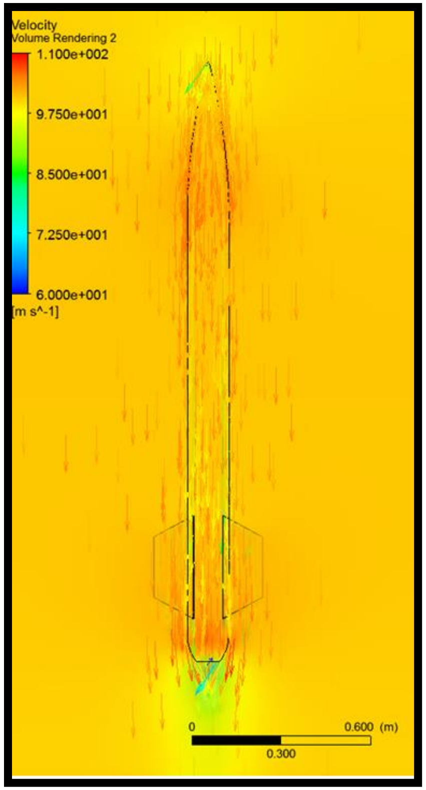


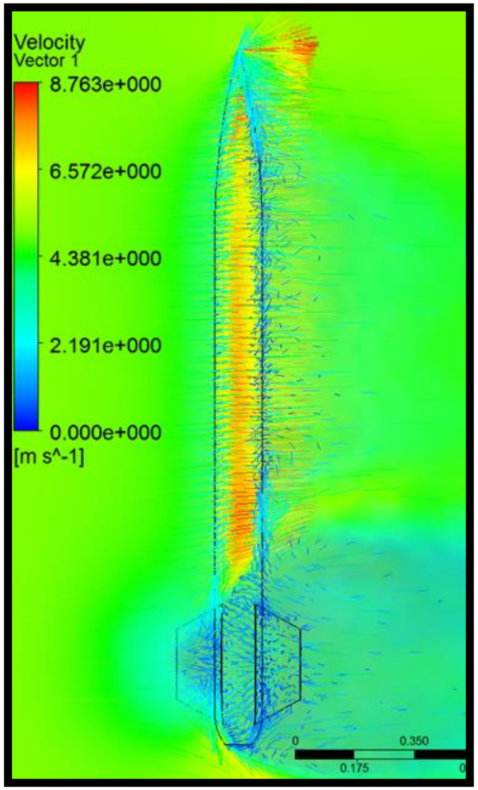


Analysis of Structural Protuberances

- Tail cone modifications
  - Changes to C_D and C_P

- Optimize tail cone with drag, center of pressure, and structural considerations





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Vehicle Systems

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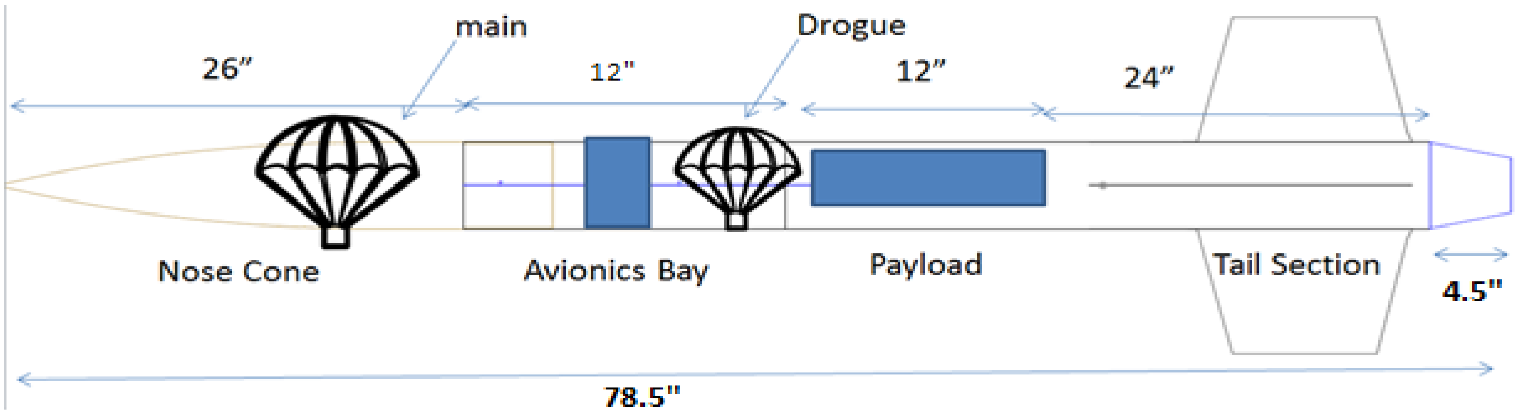
Recovery System

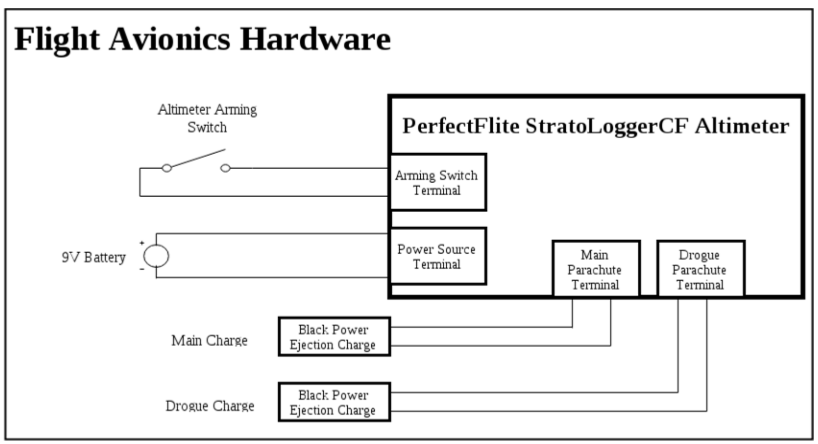
Recovery System – Overview



Recovery Schematic for Subscale Launch

Recovery System - Altimeters

- Altimeter Controlled Dual Deployment Scheme
  - Drogue at apogee
  - Main parachute around 700 ft
- Two Independent PerfectFlite StratoLoggerCF Altimeters



Recovery System - Separation

Two rocket separation events

- Forward event: Nosecone / Upper Body
  - Houses main chute
- Aft event: Upper Body / Payload Section
  - Houses drogue chute

Controlled detonation of 4F black powder charges

- 1.1 gram charge for drogue parachute
  - 0.549 gram charge minimum required, 2.0 margin
- 3.5 gram charge for main parachute
  - 1.8 gram charge minimum required, 1.94 margin

Three 4-40 nylon shear pins per separation

- 212 lb of force required

Recovery System – Parachutes

30” Drogue Parachute at Apogee

- Cd = 1.5
- 69 ft/s descent rate - predicted

12 ft Main Parachute around 700 ft

- Cd = 1.5
- 13.4 ft/s descent rate - predicted

Landing Energy of Largest Component

- Tail and Payload section, 24 lb
- 67 ft-lb kinetic energy at landing predicted

Recovery System - Parachutes

Drogue Parachute

- 30” diameter elliptical
- ½” tubular Kevlar shock cord, 30’
- 9 Nylon shroud lines, 43” length (86” continuous)
- ½” wide Kevlar harness near the ejection charges where fireproof material is needed
- 69 fps drogue descent

Main Parachute

- 12’ diameter elliptical
- ½” tubular Kevlar shock cord, 15’
- Nylon shroud lines, 200” length (400” continuous)
- 5/8” Kevlar harness near the ejection charges where fireproof material is needed
- 13.4 fps main descent

Recovery System – Avionics Bay

- Self contained avionics bay
  - Two altimeters
  - Batteries
  - Switches
- 1/4”-20 Aluminum rods
- U-bolts on both ends to attach to harnesses
- Two blast caps on bottom for drogue
- Mounts inside forward rocket section

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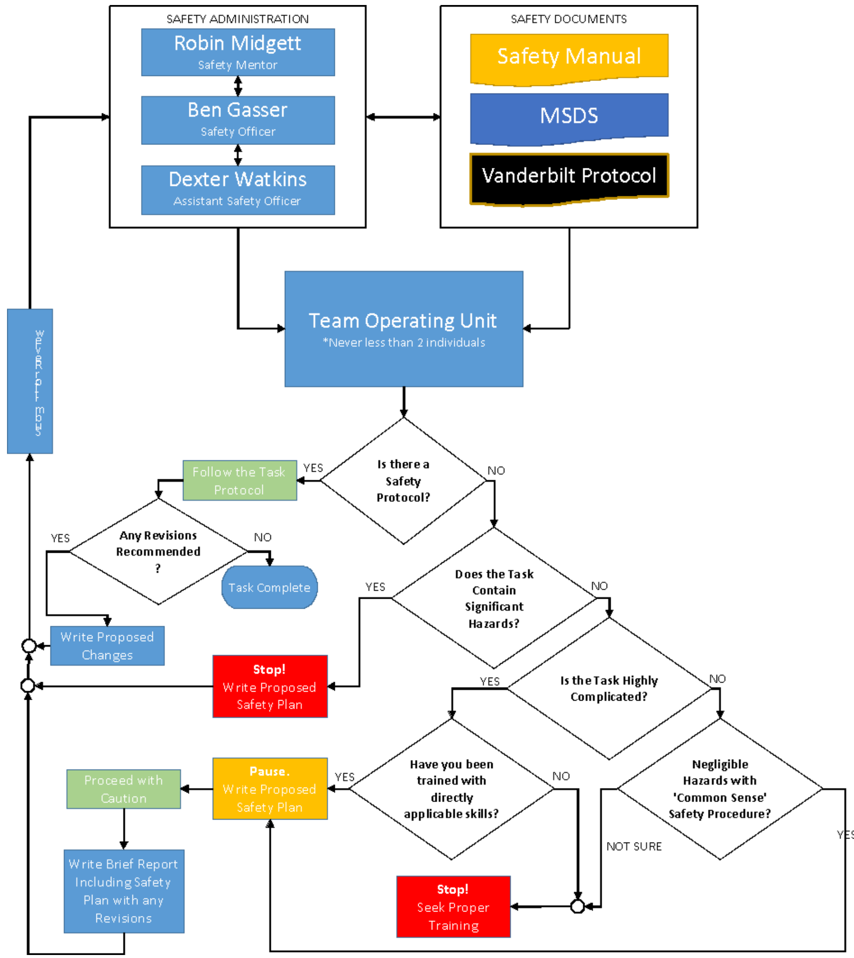
Vehicle Safety

- Follow sound/proven construction methods
- Follow safety flowchart at all times for hazardous materials and equipment
- Two pre-competition, progressive launches
  - Incrementally design and test components
  - Increase rocket complexity for each launch
- Follow thorough checklists during launches
  - Update checklists as needed

Vehicle Safety – Protocol



Vehicle Safety – Testing

Ground Based Testing

- Carbon Fiber Compression Testing
- Altimeter Testing
- Simulated launch
- Deployment Testing

Flight Tests

- Subscale launch November 14
- Fullscale by late February

Vehicle Safety – Testing

Carbon Fiber Compression Testing

- 12” body section tube loaded to 17.5 kip without failure
- Safety factor of over 40 for predicted launch conditions

Altimeter Testing

- Altimeters prepped, armed and placed in vacuum chamber
- Simulate ascent by reducing pressure
- Simulate descent by restoring pressure to atmospheric
- Ensures altimeter functionality and data collection

Vehicle Safety – Testing

Deployment Testing

- Test for smooth fits between couplers and body tubes.
- Fully assemble rocket
  - Live charges and parachutes packed properly
  - Shear pins as used for launch inserted
- Place rocket in horizontal position
- Manually deploy charges
- Ensures proper functionality of recovery system
  - Reveals potential problems

Vehicle Safety – Testing

Flight Tests

- Two launches before competition
  - Subscale launch to be completed on November 14
  - Full scale launch to be completed by late February
- Incremental design approach
  - Increase complexity of rocket each launch
- Verify drag coefficient
- Ensure stable flight and safe recovery

Vehicle Safety – Pre-Launch

- Significant Pre-Launch Vehicle Verification Steps
  - Confirm safe and stable launch pad setup
  - Verify all avionics equipment to ensure safe deployment of recovery system
  - Inspect all rocket structures
  - Abide by the High Powered Rocket Safety Code for motor handling, usage, and inspection
  - Maintain safe distances at launch

Vehicle Verification - Pre-Launch

- Significant Pre-Launch Vehicle Verification Steps
  - Weigh Complete Rocket
  - Determine the Location of the Center of Gravity
  - Update Simulations with Actual Launch Vehicle Weight
  - Confirm that the Accelerometers are Logging Data
  - Confirm GoPro flow visualization system is on and recording

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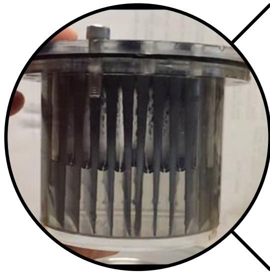
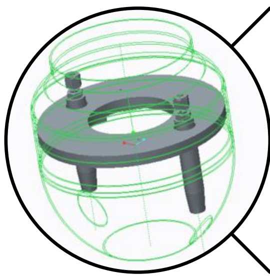
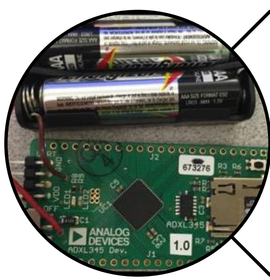
Payload Systems - Overview



Liquid Fuel Delivery System



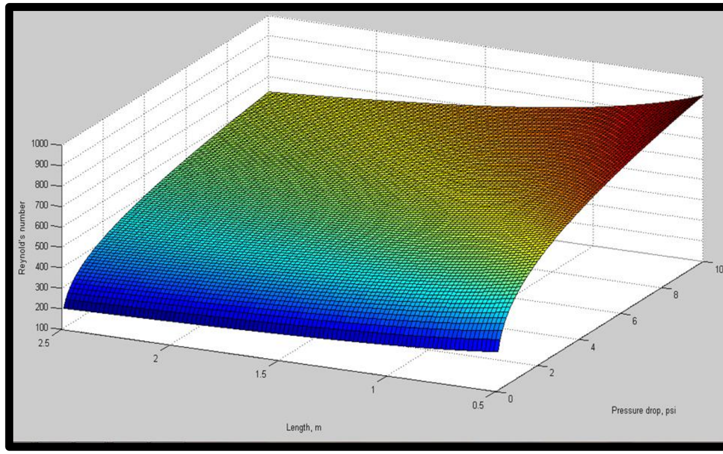
Performance Analysis of a Hydrogen Peroxide Monopropellant Thruster



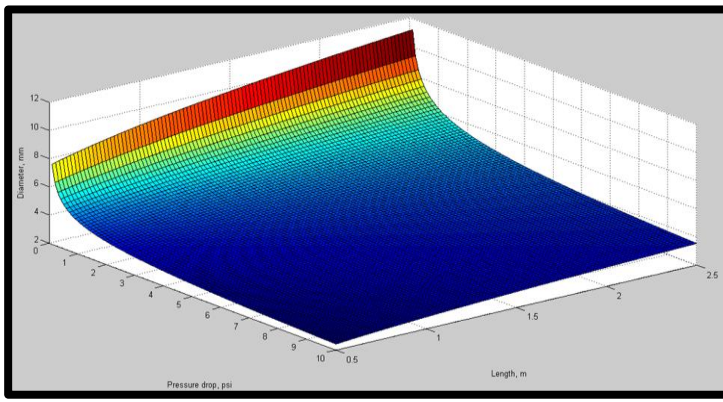
Structural Analysis of the Rocket Body

Fuel System – Fuel Delivery

- The system must deliver fuel at ~450 psi
- Must fit within the confines of the rocket
- Must provide a small response time to controls



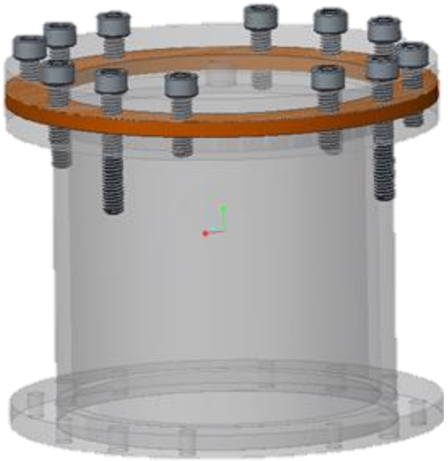
Laminar Flow Verification

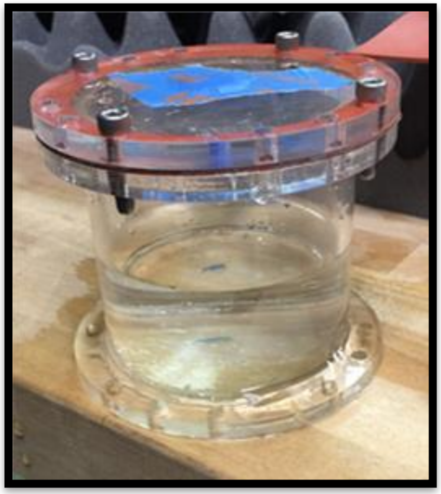


Diameter Calculation

Fuel System – Fuel Tank

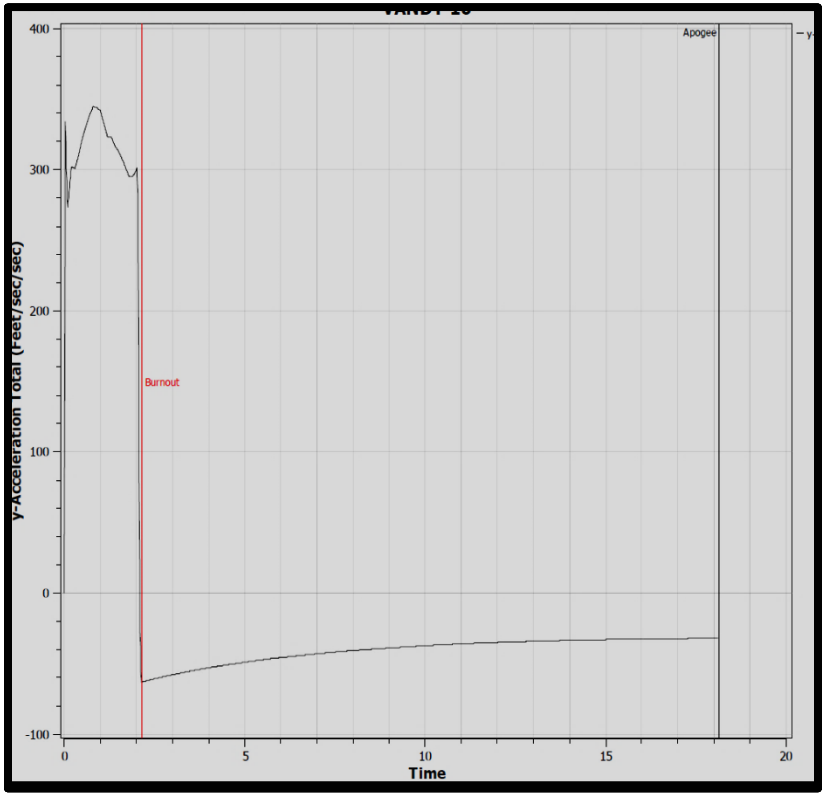
- Transparent prototype fuel tank provides flow visualization
- This serves to verify Slosh Abatement System functionality
- Imitates final pressure vessel design





Fuel System – Acceleration Conditions

- At Main Engine Cut-Off deceleration will be around -2g's
- Causes liquid stacking on upper side of fuel tank away from fuel pickup
- Thrusters fire directly after MECO for ~5s



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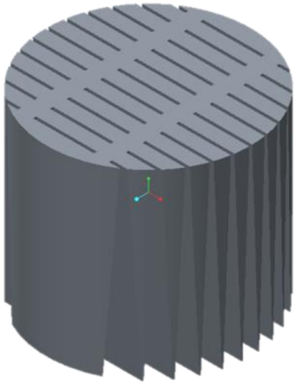
Fuel System – Slosh Abatement System

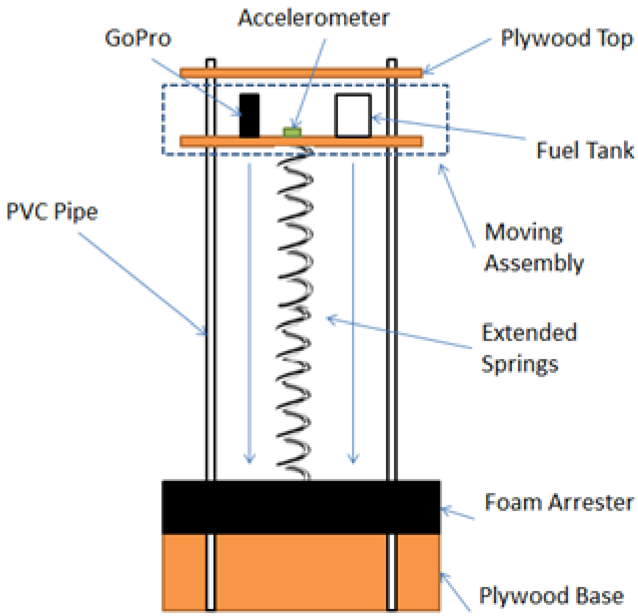
- Slosh Abatement System prevents air from entering fuel lines

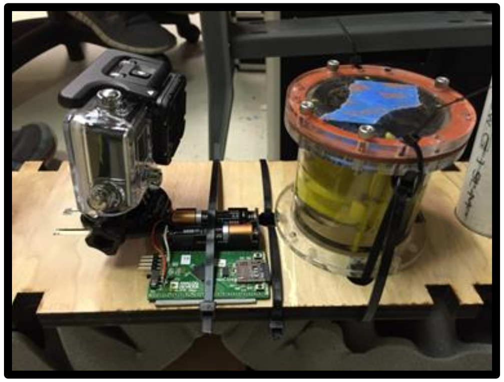


- GoPro Camera is mounted next to the fuel tank to provide flow visualization

Fuel System – VADL Drop Test Stand

- Spring and gravity accelerated platform
- Simulates negative gravity environment encountered after MECO





Fuel System – Test Stand Results

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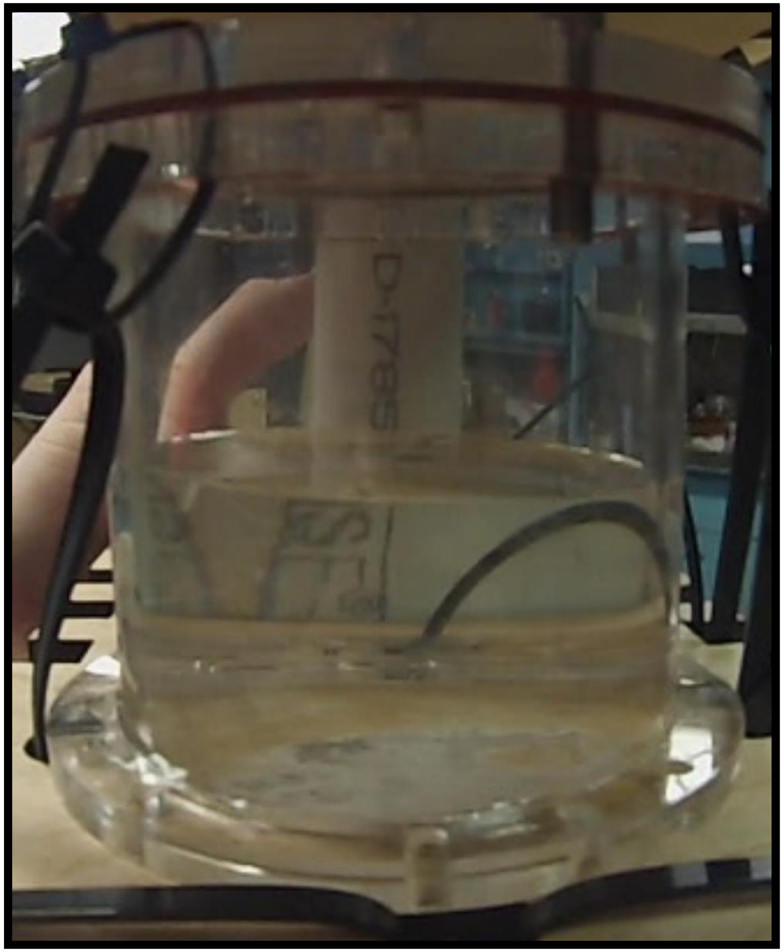
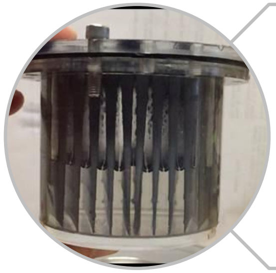


Fuel System – Test Stand Results

Payload Systems - Overview



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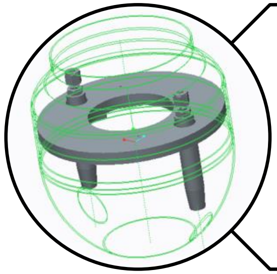

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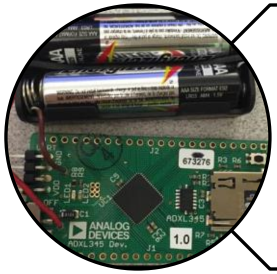
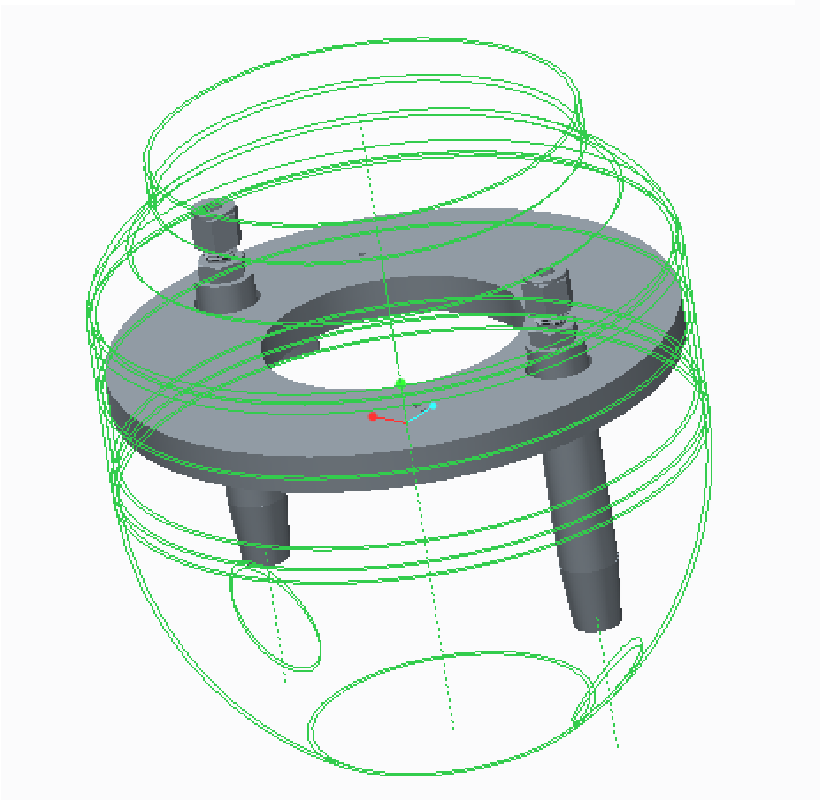
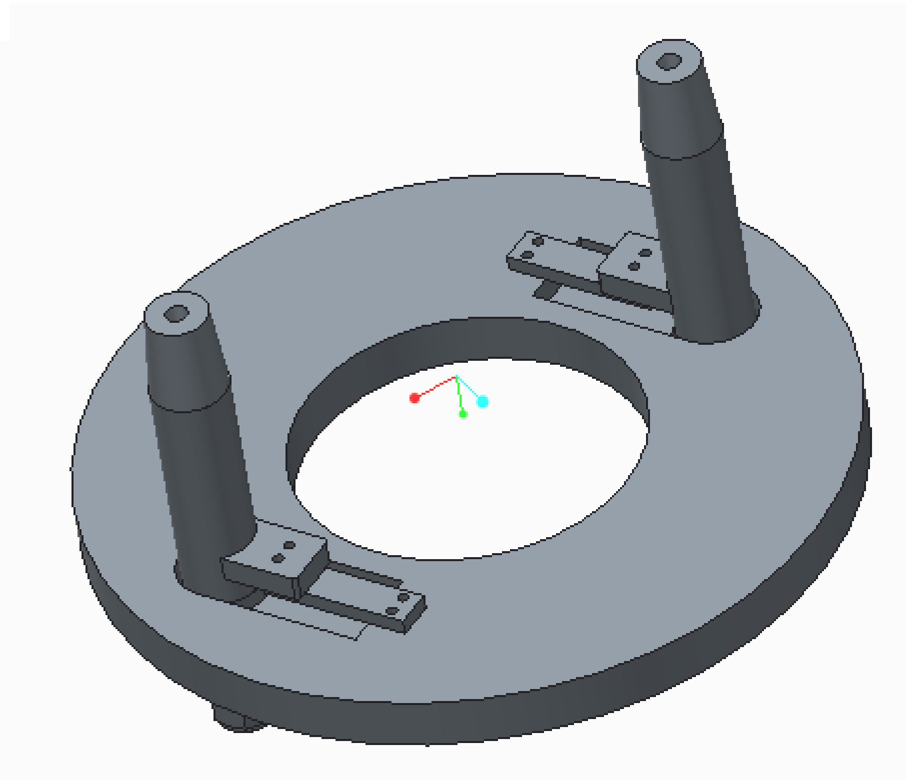


Structural Analysis of the Rocket Body

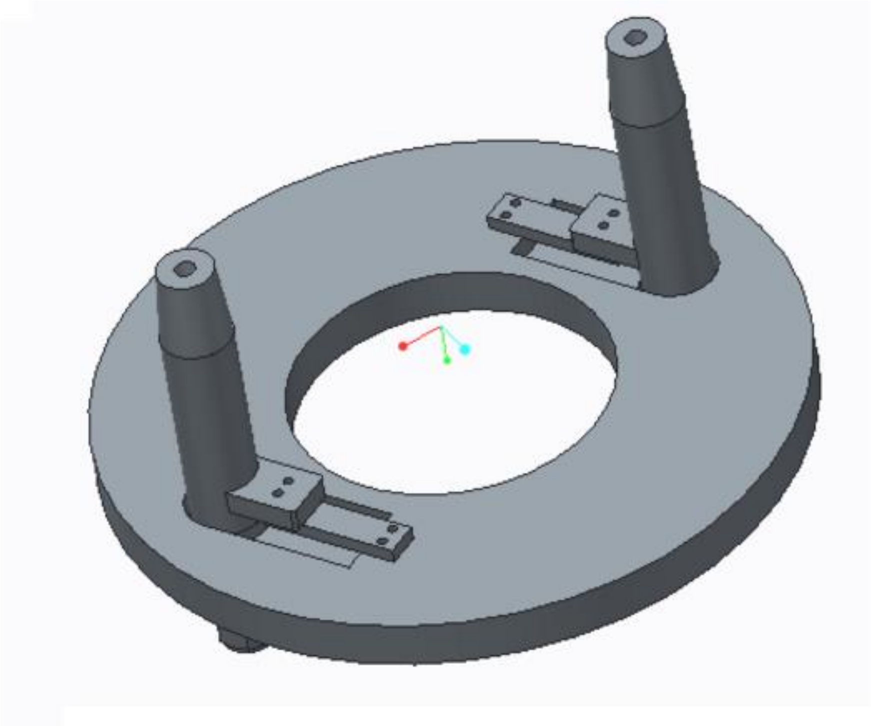
Thruster – Assembly Design





Thruster – Placement

- Originally planned to mount external thrusters
- Dimensions and propellant requirements allow internal placement
- Internally mounting thrusters will
  - Decrease drag
  - Decrease buffeting of the thrusters



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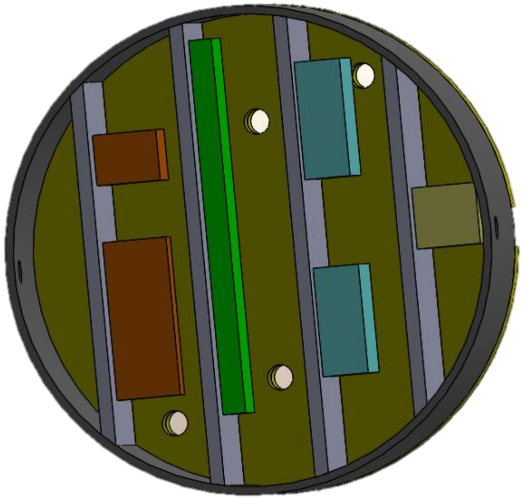
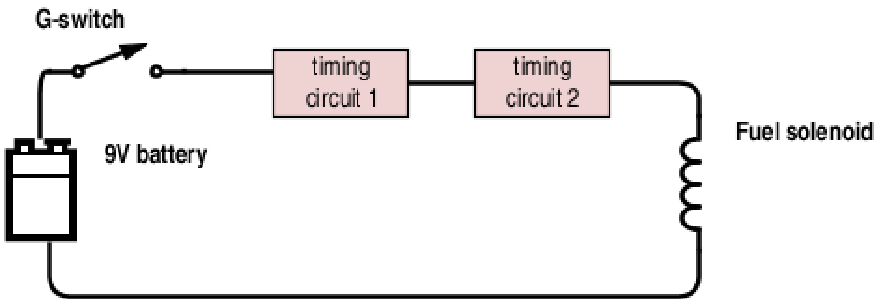
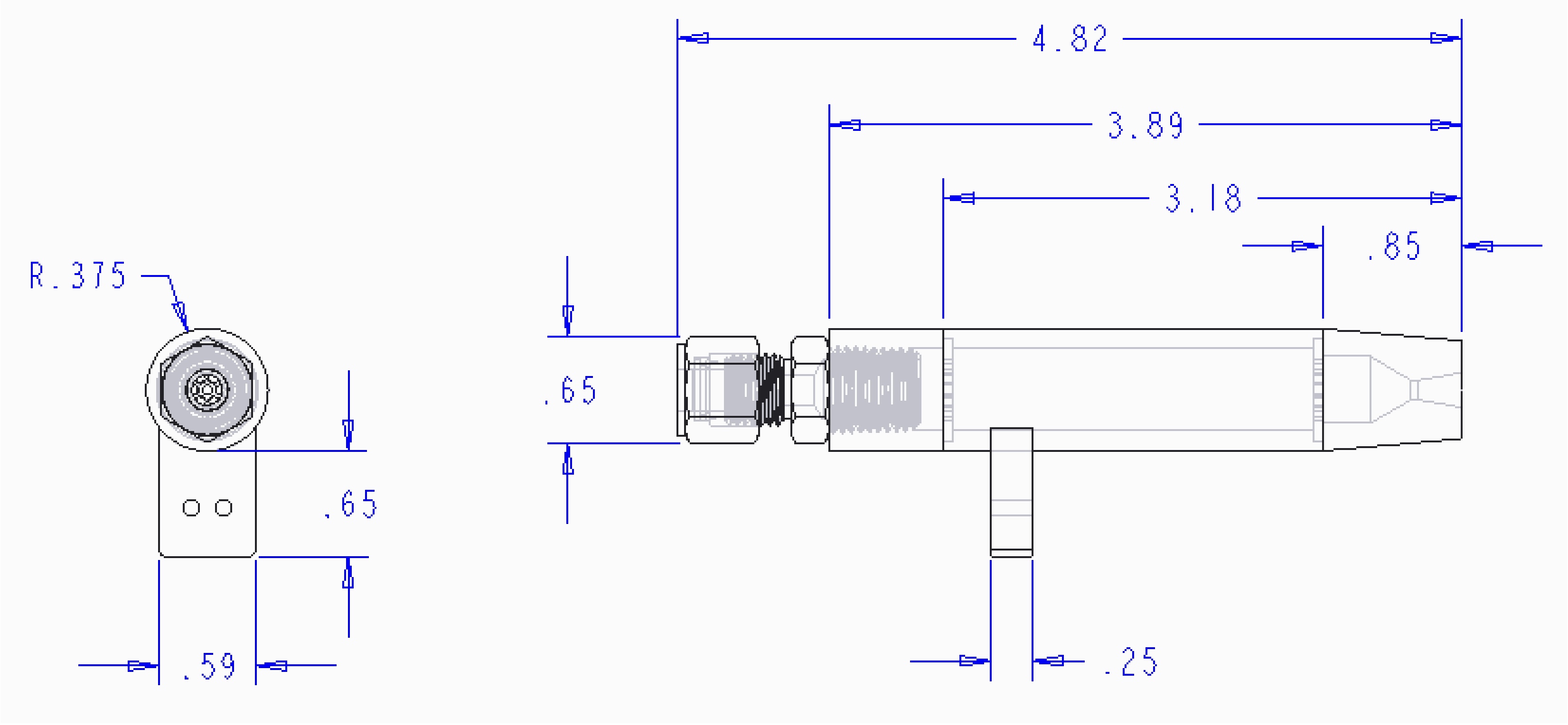
Thruster - Instrumentation

- Dedicated payload electronics
  - Custom PCB controls fuel delivery to thruster
  - RDAS collects strain, acceleration, temperature data
  - Measures thrust on active thruster and drag on both thrusters
  - Pylon strain gauges
  - Thermocouple inside combustion chamber
- New design this year to better utilize lateral space

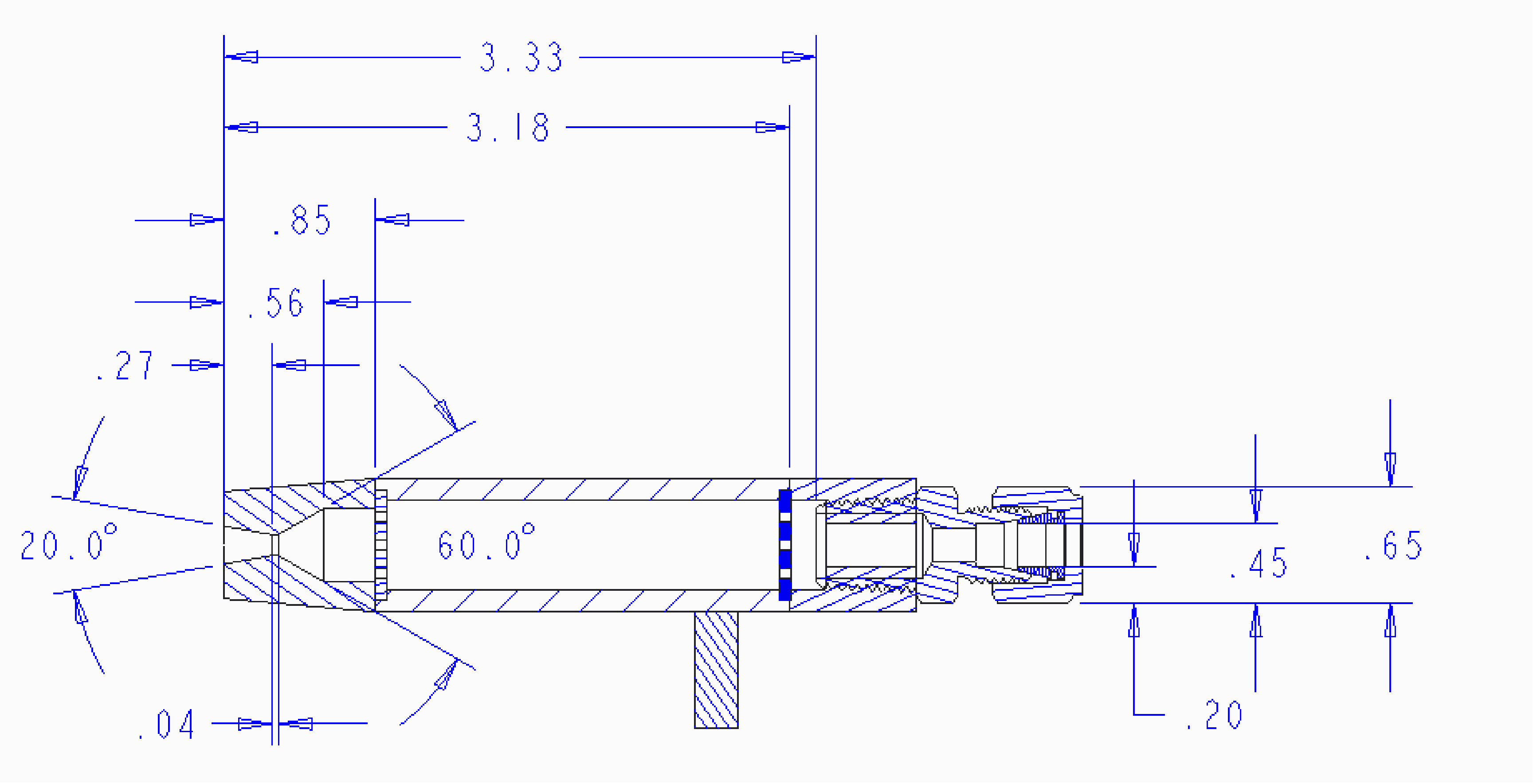




Thruster – External Geometry

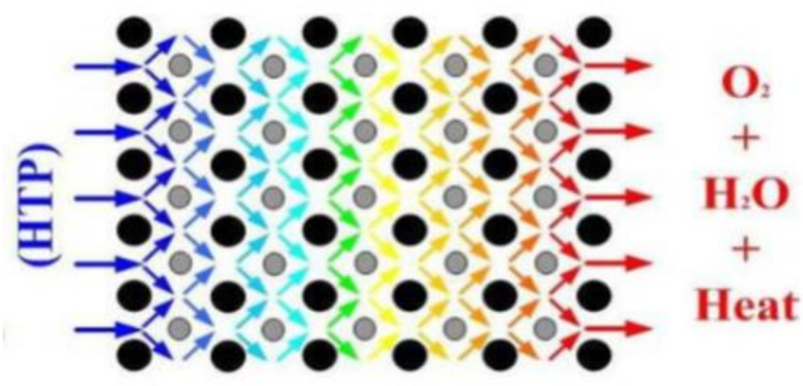


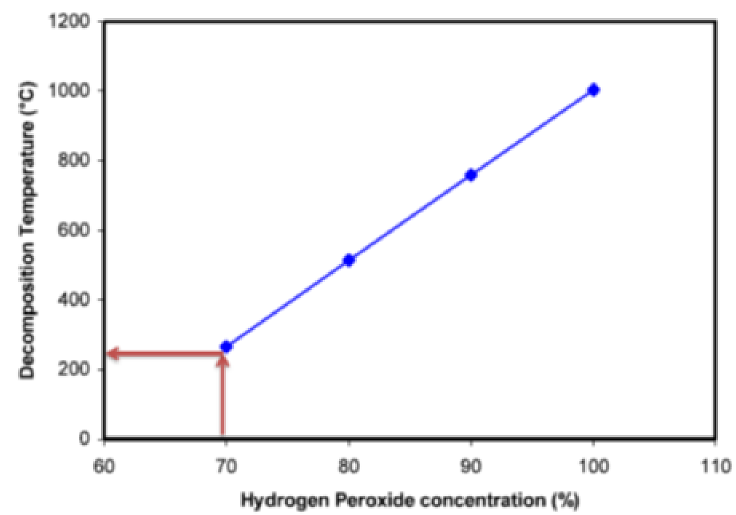
Thruster – Internal Geometry



Thruster – Decomposition Efficiency

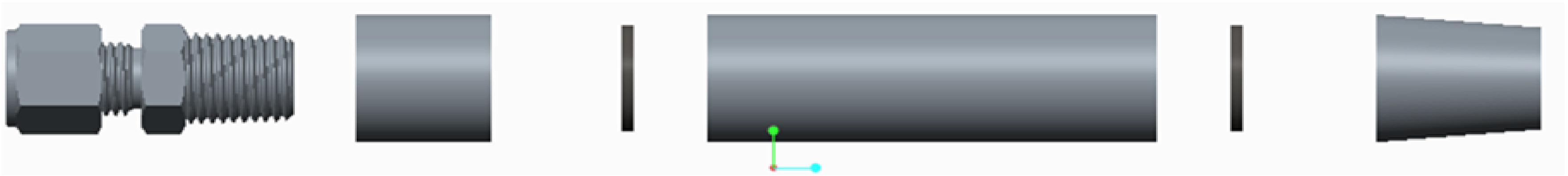
- High-pressure fuel injection and atomization
- Iridium catalyst allows for 'cold start' of thruster
- Iridium catalyst very effective when decomposing HTP, expect full dissociation





Thruster - Optimization

- Nozzle Optimization
  - Theoretically optimized
  - Thrust calculations
    - Ground based testing to confirm
    - Test facility under construction
  - Three-section modular design
    - Allows replacement/alteration of subsections



Thruster - Optimization

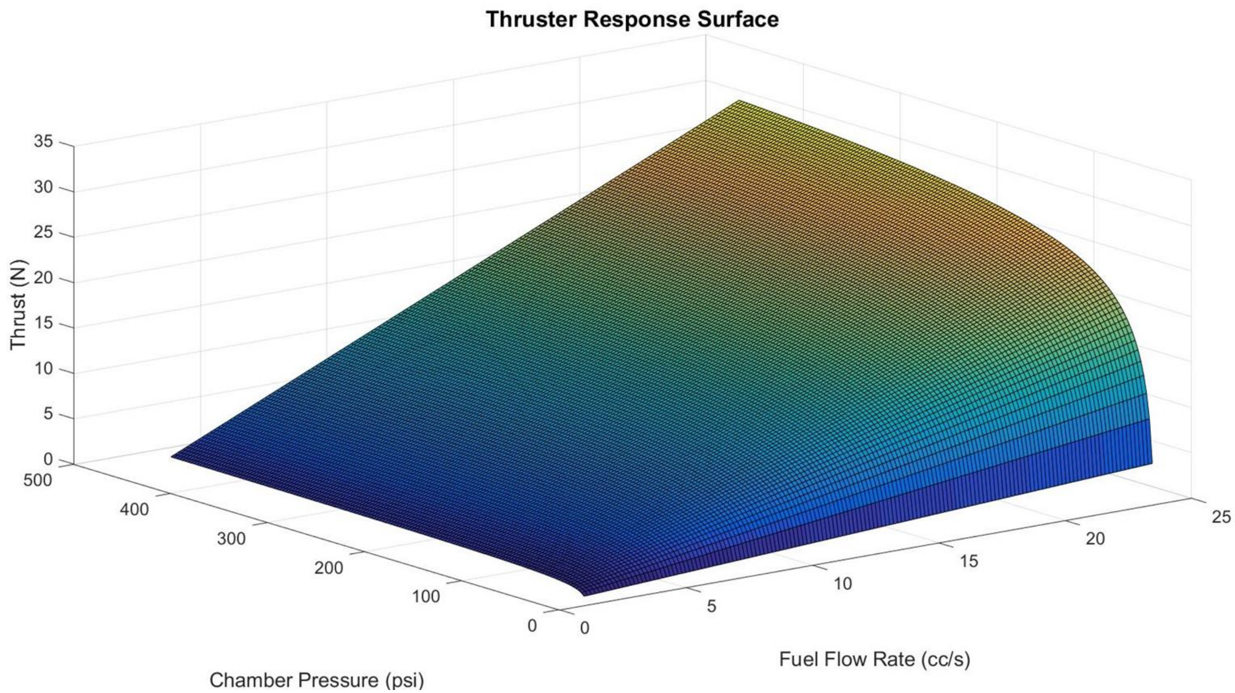
Simulation tool was created in Matlab

- Uses isentropic flow equations to predict thrust output
- Determines dimensions of converging-diverging nozzle
- Used for parametric study of the thruster design

Thruster – Parametric Study

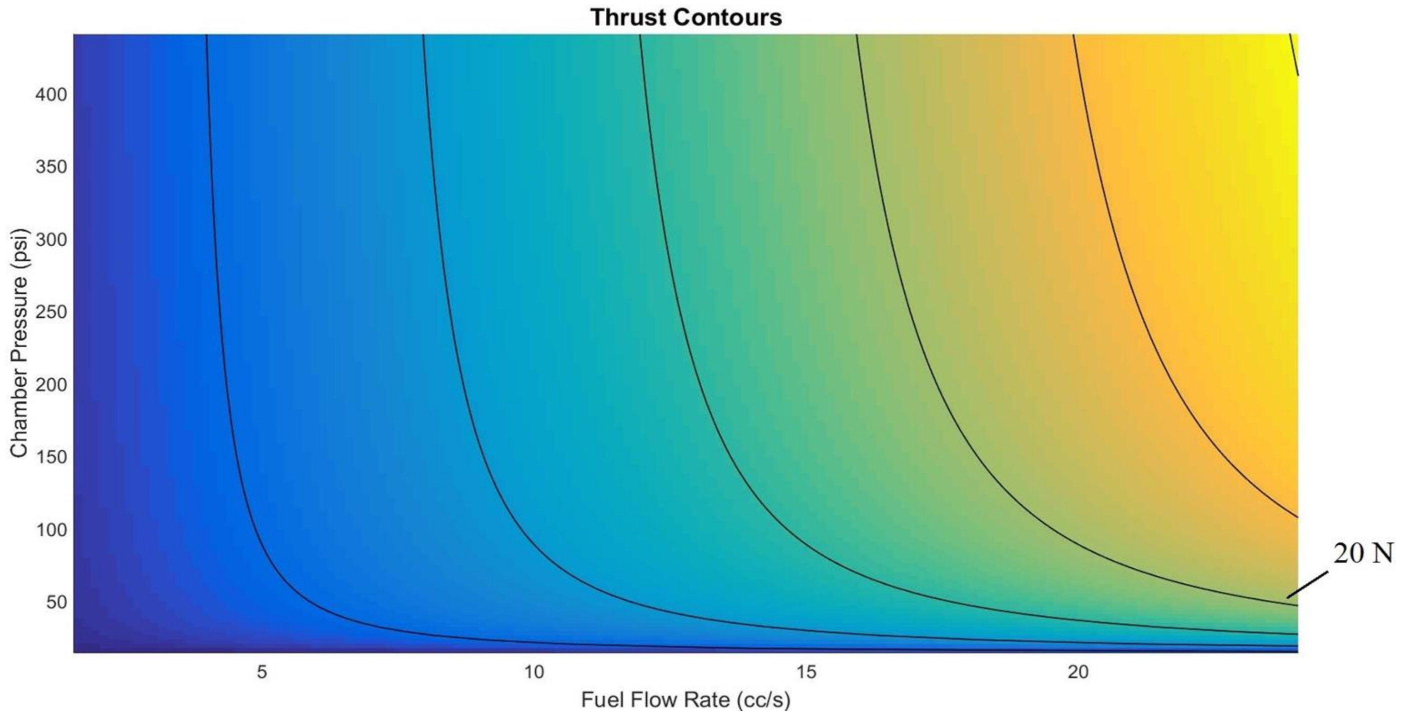
Thrust plotted as a function of:
- Chamber Operating Pressure
- Fuel Flow Rate

Plot generated assumes:
- Complete dissociation
- Adiabatic (no heat loss)



Thruster – Parametric Study

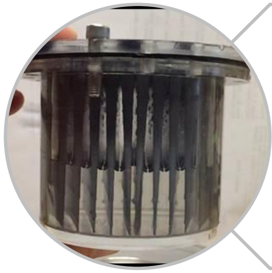
- Contours of constant thrust (black lines) show combinations of pressure and flow rate to produce a given thrust



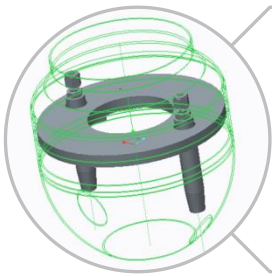
Thruster – Study Conclusions

- Fuel flow rate acts as a ‘scaling factor’ for thrust output
  - (i.e. thrust scales linearly with flow rate)
- Chamber operating pressure more complex
  - Nozzle efficiency varies non-linearly with pressure
  - Operating pressure in the catalyst bed affects the decomposition efficiency
- Operating pressure should be varied during ground testing to arrive at an optimized design

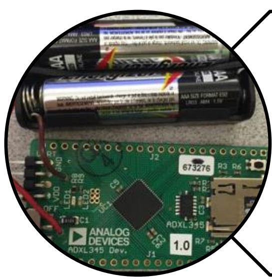
Payload Systems - Overview



Liquid Fuel Delivery System



Performance Analysis of a Hydrogen Peroxide Monopropellant Thruster



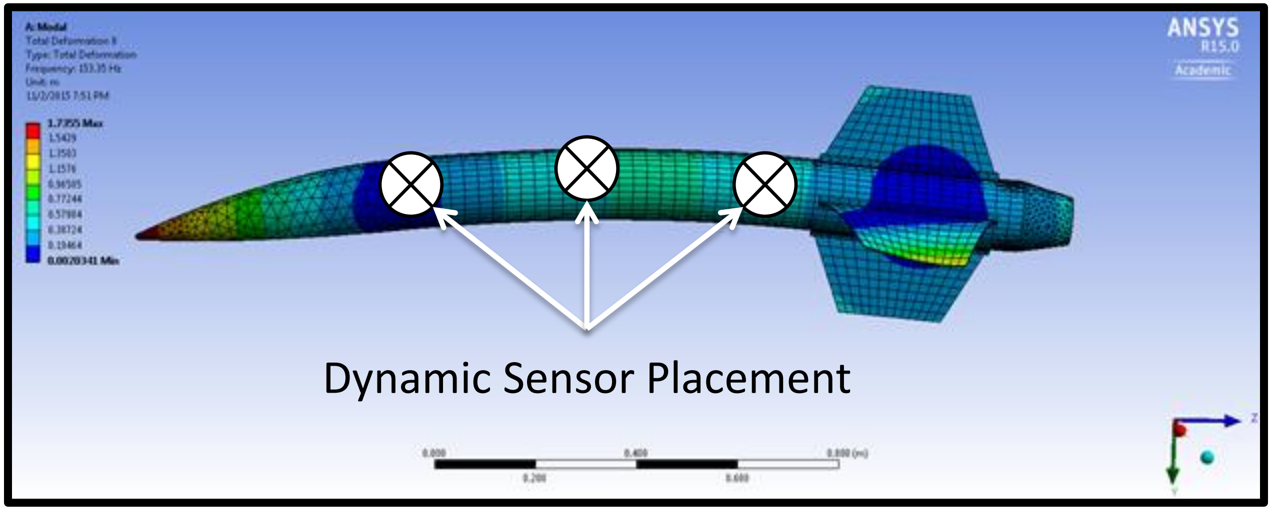
Structural Analysis of the Rocket Body

Structural Analysis

Develop a finite element model of the launch vehicle that captures the material behavior of the custom built carbon fiber

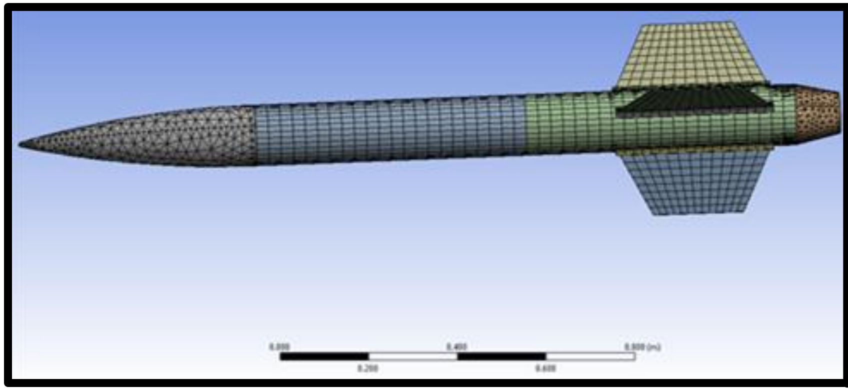
Dynamic sensing of vehicle accelerations during flight and during ground-based tap tests will be used to validate the finite element model

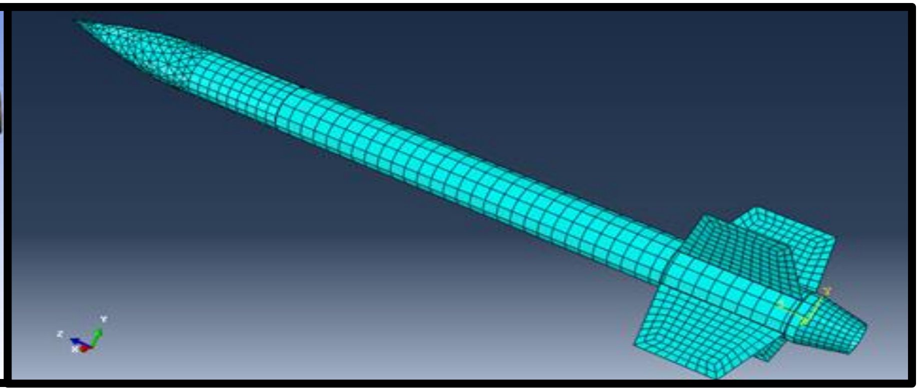
A validated finite element model will be used to analyze stresses that occur during launch



Structural Analysis – FEM's

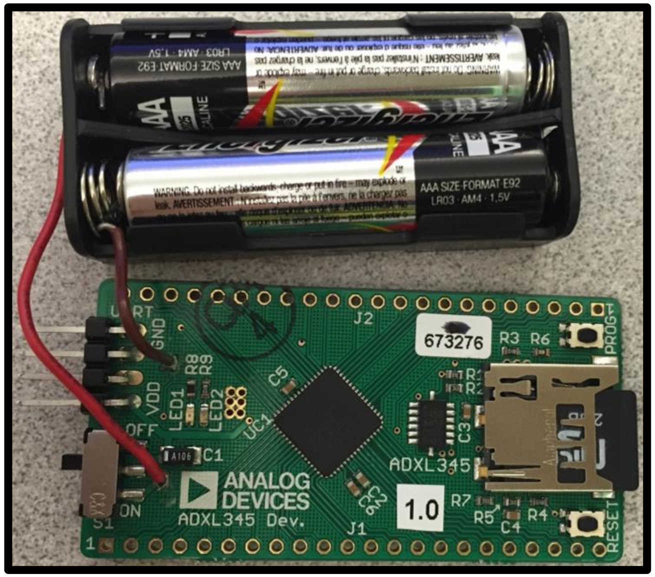
- Models developed to reflect mass and stiffness properties of the launch vehicle
- Two models developed in ANSYS and Abaqus to minimize error and compare modeling techniques
- Models will be validated with flight and tap test data to compare modal properties





Structural Analysis – Flight System

- Analog Devices ADXL345 Datalogger Development Board
  - ADXL345 three-axis accelerometer
  - ADuC7024 microcontroller



Structural Analysis – Integration

Three accelerometers mounted in the rocket

Avionics bay

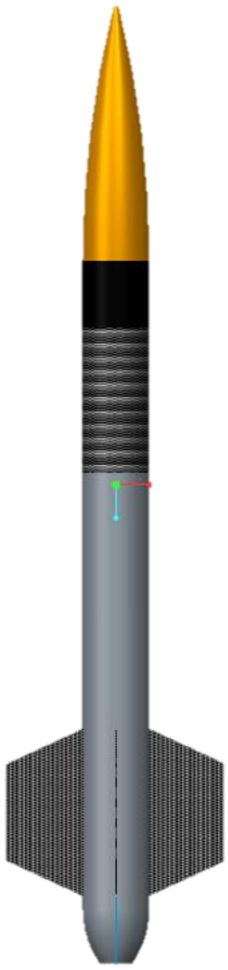
- Mounted in forward section
- Fixed to wall with epoxy

Payload Section

- Fixed to aluminum plate with epoxy
- Plate rigidly fastened into bulkhead

Tail Section

- Attached to curved carbon fiber section with epoxy
- Carbon fiber section riveted into rocket body tube



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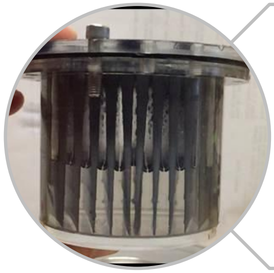
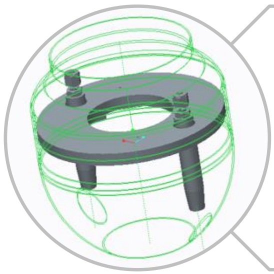
Payload Systems - Overview



Liquid Fuel Delivery System



Performance Analysis of a Hydrogen Peroxide Monopropellant Thruster

Structural Analysis of the Rocket Body

Meeting Agenda

- Launch Vehicle Overview
- Flight Operations
- Vehicle Criteria
- Vehicle Systems
- Vehicle Safety and Verification
- Payload Systems
- Payload Verification and Testing
- Outreach
- Project Schedule
- Conclusions

Payload Verification and Testing

Slosh Abatement Testing through Flow Visualization

- Ground based thruster tests
- Ground based drop testing
- Flight based results

Ground Based Monopropellant Thruster Testing

- Thruster verification
- Fuel supply verification
- Instrumentation verification

Structural Analysis Testing

- Finite Element Modeling
- Flight based test to verify accuracy of FEM

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Outreach

- Generate excitement and interest in STEM and aerospace
- Cover Newton's laws and aerodynamic forces and their role in a rocket launch
- Create a fun, hands-on learning environment
- Introduce engineering and the engineering design cycle
- Measure our effectiveness through pre- and post-assessments

Outreach - Schedule

- Percy Priest Elementary -- 2nd, 3rd, and 4th graders
- Love Circle & Solar Sails Series
- Prospective: John Early Museum Magnet Middle School
- Prospective: Whitecreek Academy for Renewable Energy
- Prospective: Nashville Adventure Science Center

Meeting Agenda

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Project Schedule – Gantt Chart

GANTT project

Name	Begin date	End date
NASA requirements	8/17/15	4/29/16
Proposal	8/17/15	9/11/15
Prepare proposal	8/17/15	9/9/15
Proposal due	9/11/15	9/11/15
Proposal awards	10/2/15	10/2/15
PDR Q&A	10/7/15	10/7/15
Website up	10/23/15	10/23/15
PDR	10/26/15	11/6/15
Team PDR contributions	10/26/15	11/4/15
Proofing and posting	11/4/15	11/6/15
CDR	1/1/16	1/15/16
Team CDR contributions	1/1/16	1/13/16
Proofing and posting	1/13/16	1/15/16
FRR Q&A	2/3/16	2/3/16
FRR	3/1/16	3/14/16
Team FRR contributions	3/1/16	3/12/16
Proofing and posting	3/12/16	3/14/16
LRR	4/13/16	4/13/16
LAUNCH DAY	4/16/16	4/16/16
PLAR	4/29/16	4/29/16
Avionics I	10/1/15	11/30/15
Examine old avionics bay	10/1/15	10/8/15
Research new components	10/9/15	10/16/15
Procure altimeters and arming switches	10/17/15	10/24/15
Shock testing -- switches and altimeters	10/25/15	11/1/15
Construct bay	11/2/15	11/10/15
Deployment tests	11/11/15	11/13/15
Subscale	11/14/15	11/14/15
Altimeter data collection & analysis	11/15/15	11/22/15
Mods/testing of bay	11/23/15	11/30/15
Avionics II	1/16/16	2/13/16
Retest altimeters, arming switches	1/16/16	2/8/16
Deployment testing	2/8/16	2/13/16
Aerodynamic Systems	9/1/15	2/14/16
Nose cone	10/1/15	11/13/15
Tail cone	9/1/15	2/14/16
Data Acquisition	10/15/15	2/21/16
Analyze existing system	10/15/15	11/5/15
Identify areas for optimization	11/5/15	12/1/15

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Meeting Agenda

Conclusions

- Liquid sloshing research, onboard structural analysis, and small-scale monopropellant thruster payloads present unique challenges where future contributions can be made

- Incremental improvements enable a developmental program that will yield substantial contributions to future USLI teams

Final Questions