TAMU SRT-5: Theseus, the Half-Decade Pursuit of a Hybrid Rocket

Team 12 Project Technical Report for the 2018 IREC

Texas A&M University Sounding Rocketry Team *

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The Texas A&M University Sounding Rocketry Team has designed, built, and tested a hybrid-powered rocket standing 11.5 feet tall and measuring 8.4 inches in diameter, christened Theseus, to carry an 8.8 lbm 3U satellite to an altitude of 24,000 feet AGL. The team will be competing in the student researched and designed (SRAD) hybrid or liquid rocket propulsion system – 10,000 feet AGL apogee class of the Intercollegiate Rocket Engineering Competition at the 2018 Spaceport America Cup. The vehicle structure consists predominantly of a lament-wrapped carbon composite airframe with Aluminum 6061-T6 connecting bulkheads. Three foam core composite overwrapped fins, mounted to the airframe via a tip-to-tip layup, and a carbon fiber tail cone reduces the vehicle's overall drag during the coast phase of the trajectory (as confirmed by CFD and wind tunnel testing). On-board avionics consist of dissimilar redundant fight computers dedicated to initiating pyrotechnic events in the single chamber recovery bay for release of a 53 inch cruciform drogue and 120 inch toroidal main chute. Additionally the avionics contain on-board data acquisition and control for engine system measurements and oxidizer flow control. The entire electronics package utilizes a custom PCB board and laser cut acrylic levels making it compact and easily integrated with the vehicle. Theseus' payload utilizes digital image correlation to quantify the center of gravity shift of sloshing fluids stored in a hybrid or liquid rocket's oxidizer tank. The engine, a nitrous oxide (N_2O) & hydroxyl-terminated polybutadiene (HTPB) hybrid, designated MO-737 Nova-I, delivers a peak thrust of 737 lbf and operates in an impulse letter range of M to O. Team developed engine performance models and post processing codes allow for efficient and detailed analysis, characterization, and understanding of key engine operating principles and phenomena. To understand and predict the rocket's flight profile, the team has developed a 6 degree-of-freedom Monte-Carlo trajectory model that couples inputs from measured thrust data or engine performance models with variations in atmospheric parameters to determine a distributed spread of altitudes and landing locations. This vehicle is the culmination of lessons learned throughout the team's first four years of existence and will provide a platform for growth and innovation for years to come.

Nomenclature

a	Ballistic coefficient
A_{inj}	Cross sectional area of injector inlets
C_d	Drag coefficient of main parachute
F_{max}	Max opening force during main parachute inflation
g	Acceleration of gravity
G_{ox}	Oxidizer mass flux
H	Enthalpy
M	Mach number at the exit

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$\dot{m}$	Mass flow rate
m_{dry}	Mass of the rocket without fuel and oxidizer
n	Ballistic coefficient
P	Pressure
P_o	Stagnation pressure
R	Specific gas constant
$\dot{r}$	Regression Rate
T	Temperature
t	Time
V	Velocity of rocket during descent
γ	Specific heat ratio of air
ρ_{ox}	Oxidizer density

I. Introduction

The Texas A&M University Sounding Rocketry Team (SRT) is a student-run organization dedicated to developing its members' technical and professional skills through the design, analysis, manufacturing, and testing of hybrid rocketry systems. SRT is structured in a manner that emulates an industry environment helping members gain applicable experience through participation not only in technical reports and design reviews, but also hands-on engineering skills. Holding true to one of A&M's core values, selfless service, SRT also focuses on giving back to the community by serving as technical mentors to younger rocketry programs both at the collegiate and high school level. SRT promotes engineering and STEM through participation in numerous events throughout the year. The team's goal is to not only develop a cutting edge rocket team, but to also build a passion for rocketry and engineering in the next generation.

Academic Program

Texas A&M recognizes the Sounding Rocketry Team as an official University organization. This allows the team to utilize various University amenities such as: funding requests, financial system management, and university facilities. Although the University provides the team with a small amount of funding through funding requests (<10%), the team is responsible for raising their own budget through sponsorships and donations. Since the team is primarily engineering students, SRT utilizes many of the Dwight Look College of Engineering's facilities to house, manufacture, and test their rocketry systems. The team has access to three different testing facilities along with five separate machine shops within the A&M network.

The Sounding Rocketry Team is primarily composed of Aerospace (75%) and Mechanical Engineering (25%) students. However, the team pursues numerous academic disciplines during recruiting because of the belief that a diverse organization offers a better depiction of an industry environment and allows for the development of more complex systems. This past year the team successfully recruited students from the departments of: Industrial Engineering, Mechanical and Manufacturing Engineering Technologies, Electrical Engineering, and Visualization. This holds true to SRT's commitment to building a diverse team that grows and utilizes each members' individual skills and passions. The team's goal is to provide an avenue for members to apply their academic knowledge to real world situations that helps them gain experience that will be applicable to careers in industry. SRT differs from a senior design courses in that it offers a more refined environment for design and testing continuity across many years (rather than a semester for each). The team also offers younger students the opportunity to develop their technical and communication skills early in their academic career.

Stakeholders

Although SRT is only five years old, it has developed a far reaching network that encompasses numerous stakeholders. These stakeholders can be classified into four categories (though many stakeholders fall into multiple categories): sponsors & donors, mentors, industry companies, and team members. As mentioned before, the team operates mainly on a sponsorship basis. Most sponsors make a one time donation that equates to recognition and associated team benefits. Figure 1 graphically depicts the academic, industry, and professional organization that have sponsored the SRT-5 team.

Figure 1. SRT-5 Sponsors

The dedication and passion required for participation on SRT frequently causes members to develop commitment for the team that carries on after graduation. In addition to the sponsors listed above, the team receives financial contributions from individuals and SRT alumni who want to help the team achieve their goals. The names of these supporters are listed below.

Evan Marcotte	Alex Pages	Gabe Aguilar	Tommy Arrington
Jeanette '85 & Gregory Doll	Michael Veneskey	Cristian Sanchez	Dayton Savage
	Randy Marek	Harry Spears	

The team could not achieve its rapid technical development without the support and guidance of their mentors. SRT works closely with the the members of Tripoli Houston, prefecture #002, and Tripoli Austin Area Rocketry Group, prefecture #054. Tripoli Rocketry Association mentors provide the team with valuable insight from their decades of combined experience and offers locations for test flights of the team's rocketry systems. The academic guidance given by the faculty at Texas A&M aids the team in developing many of the theoretical models that determine the physical attributes of the rocket and predict and characterize the performance of the vehicle. The growing SRT alumni network offers invaluable knowledge on how real industry companies are organized and how they handle issues similar to those faced by the team. All of these mentors directly influence SRT's technical and professional growth and contribute to the structure and operation of the team.

Figure 2. Supporting Tripoli Prefectures

SRT recognizes the role that industry plays on the organization. SRT parallels many aspects of the aerospace industry with the goal of developing its members for future positions in the field. As the team continues to mature, companies which hire former members will benefit from the experience gained during their tenure on the team. Figure 3 reports a selection of the companies with the largest concentration of former and current SRT members.

Figure 3. SRT Industry Outreach

The team requires a large commitment of at least 20 hours a week from it members. This time commitment on top of school, work, and personal time is no small feat. However, this dedication leads to great technical and professional growth unrivaled by any experience at Texas A&M. The team's members often develop a personal connection to the team as they see their projects that they've worked diligently at come to life. The team considers its members vital stakeholders because of this personal investment, and owes much of its success to their hard work and dedication.

Team Structure

The Sounding Rocketry Team typically consists of 30 dedicated students ranging from freshman to graduate students. SRT has created an organizational structure to manage its numerous and diverse members and to facilitate both individual and team advancement. This structure is flexible and evolves each year to account for areas in the design and testing process identified as points for improvement. For instance, the Testing and Operations team is a new sub-team that was developed to focus on improving the efficiency and effectiveness of the team. The SRT-5 team structure can be seen in Figure 4.

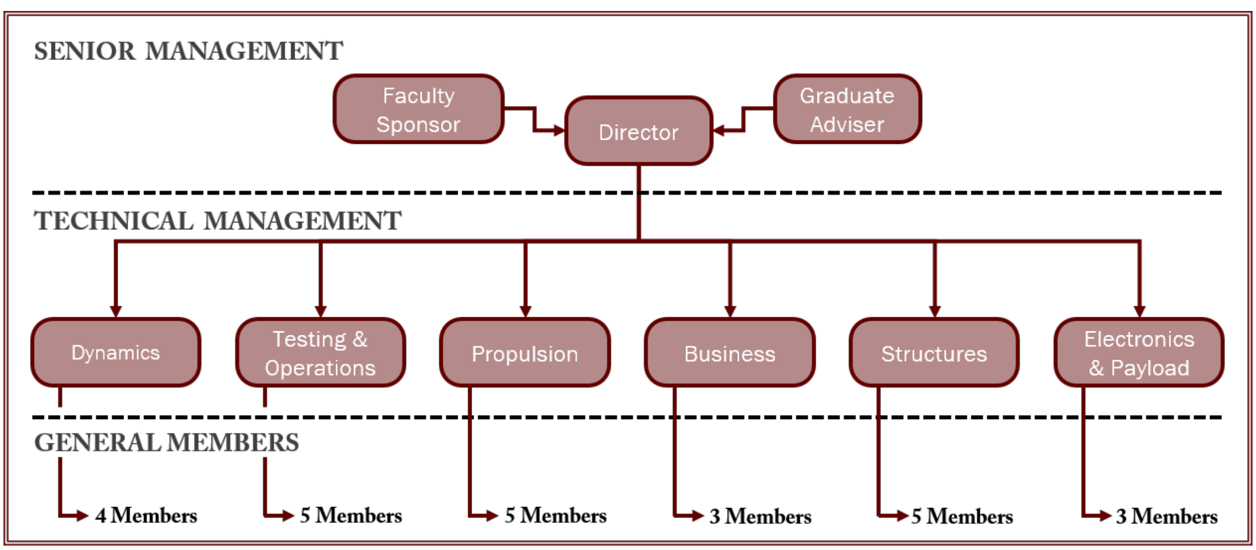

Figure 4. SRT-5 Organizational Structure

The senior management team consists of up to three people; a director, faculty sponsor, and graduate advisor. The director is a student with multiple years of team experience, and is extremely familiar with the overall management of the organization. The directors role is to set overall short and long term objectives, increase efficiency of each sub-team, and to implement methods for increasing team transparency regarding team progress. The director also functions as the safety manager. The faculty advisor provides oversight for major projects and counsels managers and members in all areas of rocket design and testing. The graduate adviser is a graduate level student with previous SRT experience whose role is to advise and assist the director in making top-level management decision, and to offer technical expertise to all members on the team.

The technical management team represents the leadership core of the Sounding Rocketry Team. Each sub-team has one manager and a specified number of members to complete their dictated goals and responsibilities. The Dynamics sub-team is tasked with creating trajectory models and designing the rocket's aerodynamic surfaces (nosecone, tail cone, fins). The Electronics & Payload sub-team is in charge of designing, programming, and building the rockets avionics and payload. The Structures sub-team role is to design, analyze, fabricate, and test all structural components of the rocket system and supporting infrastructure. This includes: manufacturing of new rockets and rocket components (body tubes, nose cone, fins, bulkheads, and recovery system), refurbishing of current rockets, and design and maintenance of the launch trailer and launch tower. The Propulsion sub-team is expected to research, design, test, and analyze hybrid propulsion system that will be used for the team's primary flight engine. The Testing and Operations sub-team is tasked with ensuring the effective, safe, and efficient testing and operation of all aspects of the hybrid rocket system. This includes system refurbishment, hybrid engine validation testing, system integration, and launch day operations management.

Team Management Strategies

The core tenants of SRT's multi-faceted management strategy are communication, accountability, and technical competence. SRT utilizes digital, oral, and written forms of communication. Digital communication is primarily done via the Slack platform. In addition to team wide channels (chat rooms with added functionality), each sub-team manages its own channel for relevant discussion and to answer questions from other members. To promote collaboration and information transfer the team meets once a week at a general meeting. At these meetings each sub-team presents a weekly-update to the entire team about the accomplishments and setbacks of the previous week, short-term goals for the upcoming week, and any relevant information the other sub-teams may find pertinent. The updates are created and presented on a rolling basis each week so each member of every sub-team has the opportunity to improve their technical presentation and public speaking skills. In addition to the general meeting, the management team meets once a week to ensure each sub-team's weekly goals and tasks are aligned with the master schedule developed at the beginning of the semester. These meeting are prefaced by weekly-update memos to the director. This allows the director to set the meeting agenda and gather information on the overall team progress. The team produces a large quantity of written documentation to successfully operate (instructions sheets, media, published reports) all of which are stored on a shared working directory in a university-based Google Drive suite. Google Drive serves as the primary document storage directory and is vital to the teams operations.

To hold members and managers accountable a variety of systems of checks have been established by the team. The first of which has already been discussed, the weekly presentations. Each sub-team must clearly state the tasks they intended to complete the previous week, the current status of that task (complete, in progress, incomplete), and the current weeks tasks. This holds members accountable for their actions and informs the team of their personal progress on their assigned tasks. The team has also implemented checks on critical design and software changes. Any 3D-model changes or updates must be approved by the team-designated CAD reviewer, and affected sub-team's managers. Once approved the change must be uploaded into the master assembly by the CAD reviewer. Software changes are logged and stored via GitHub with live updates being broadcasted on the team's Slack. Before a final change is implemented into the master file it must be approved at a monthly software change review meeting (SCR). The SCR meetings are intended to screen all changes in attempt to prevent any test or launch failure due to software.

Every year the team produces a design report to serve as a platform for technical documentation. This catch-all document is meant to contain complete information pertaining to all design and managerial decisions made during the SRT-5 team. The report contains: basic team demographics (composition of team academic background, sub-team sizes, number of males & females, etc.), managerial advice, the team's master schedules, reasoning behind design decisions, analysis performed on designs, results from test verification of individual components, and results from full-system testing. The intent of the design report is to serve as a reference for future teams to reflect upon when making design or managerial decisions. The goal is to have a robust document that could offer sufficient information such that a new team could operate without input from any previous members.

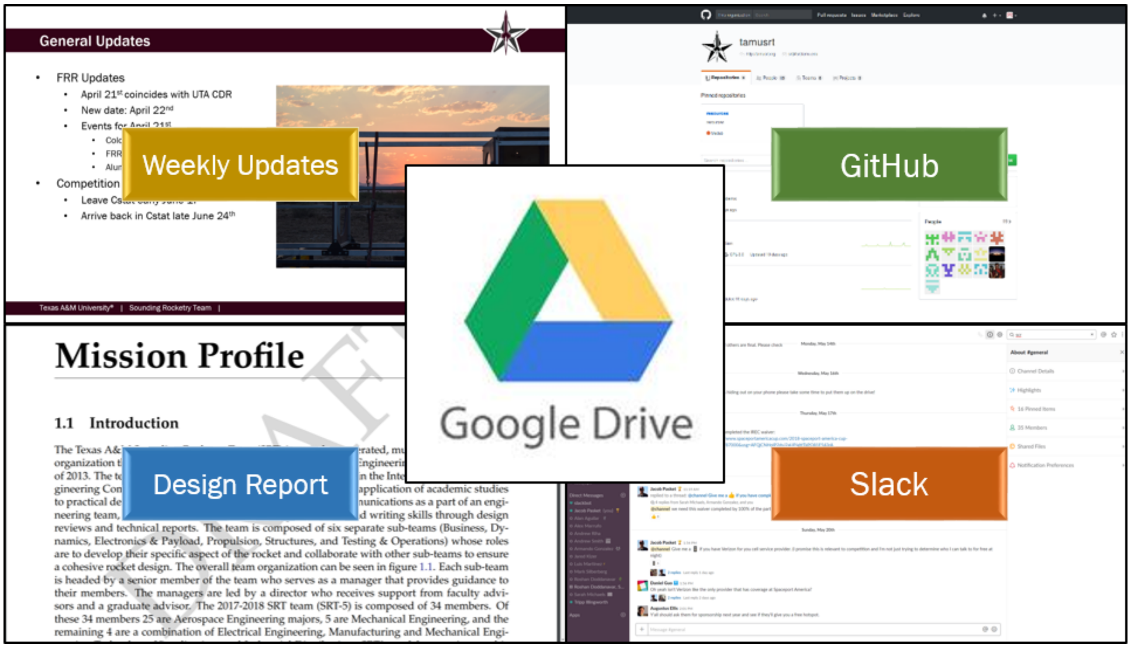

Figure 5. SRT-5 Management Strategies

II. System Architecture Overview

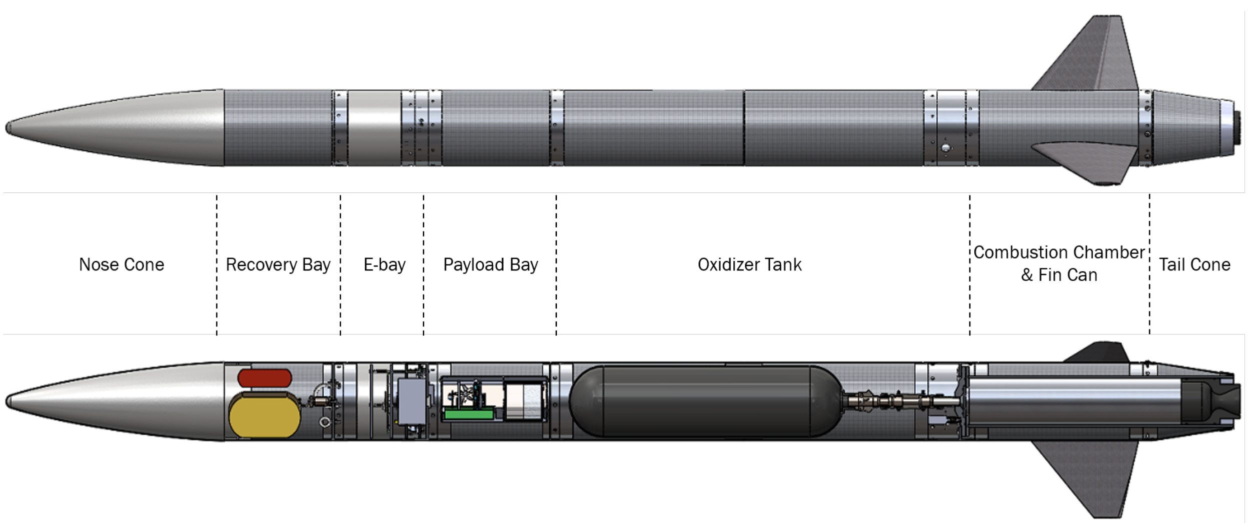

Figure 6. SRT5 Competition Rocket - Theseus

Theseus is SRT's 4th hybrid-rocket and the chosen competition rocket for IREC 2018. Theseus is an iteration of the Daedalus vehicle (IREC 2017) and incorporates many of the lesson's learned from the team's experiences at the previous competition. Simplicity, user-friendly operation, modularity and robustness were emphasized through the design phase to create a work-horse rocket that can be used by the team for many years to come. In the following sections, the design decisions, analysis and manufacturing methods are discussed for all of the airframe and engine components.

Table 1. Theseus Specifications

Overall Rocket Parameters	Measurement
Airframe Length	136.4 in
Airframe Diameter	8.42 in
Fin Span	21.58 in
Vehicle Weight	97.2 lbs
Propellant Weight	22.5 lbs
Liftoff Weight	128.5 lbs
Propulsion Type	SRAD Hybrid
Stages	1

III. Hybrid Propulsion System

Overview

MO-737 Nova-I is a 737-pound, bipropellant, hybrid rocket system developed by members of the Texas A&M University Sounding Rocketry Team to power the Theseus vehicle to 24,000 feet; it will be scaled back to launch the rocket to 10,000 feet at the 2018 Spaceport America Cup in Las Cruces, NM.

Figure 7. MO-737 Nova-I

To facilitate consistent referencing across multiple engine designs, SRT has developed a naming convention similar to that of the Tripoli Rocketry Association (TRA). Figure 8 illustrates this convention.

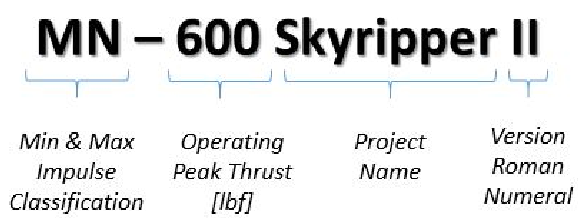

Figure 8. SRT Engine Naming Convention

For the remainder of this report, the engine will be referred to by its project name of Nova-I.

The engine uses liquid nitrous oxide (N_2O) as the oxidizer and solid hydroxyl-terminated polybutadiene (HTPB) as fuel. Table 2 summarizes the delivered performance values of the Nova-I engine at standard conditions.

The major engine systems are the oxidizer tank, oxidizer feed system, combustion chamber assembly, nozzle, igniter, and the flight control and instrumentation system. Each of these systems will be discussed along with the technical analyses used throughout the design process.

Table 2. **Nova-I Specifications**

Length	64 in.
Width	8 in.
Flight Configuration Weight	50.9 lbf.
Nozzle Throat Area	1.65 in.^{2}
Expansion Area Ratio	4.59
Combustion Temperature	5480°F
Chamber Pressure	290 psia
Thrust	650 lbf.
Specific Impulse	215 sec.
Burn Time	11 sec.
Flowrate (maximum)	3.1 lbm./sec.
Mixture Ratio (liquid burn, by mass)	5.1:1 (O:F)

Theoretical Model

A theoretical model of the entire engine process, designated as the `Hybrid Engine Model` or `HEM`, was developed to allow for rapid iteration through designs and to set certain propellant characteristics. The model splits the thrust profile into a liquid oxidizer flow phase and a gaseous oxidizer flow phase. The liquid phase is governed by a modified algorithm developed in a thesis completed at Rochester Institute of Technology.[32] This model utilizes the ideal gas law, Rasoult's Law (constant volume), and conservation of energy in the form of a forward difference to determine the phase composition, temperature (pressure from temperature derived by the Clausius-Clapeyron Equation), and mass flow rate of the oxidizer out of the tank. To model the gas phase, a modified algorithm from Aspire Space[33] iterates on a guessed value of vapor density to satisfy the ideal gas law with an estimated compressibility factor. The combustion portion of the model uses curve fitted data from algorithms based on constant pressure-constant temperature reactions minimizing Gibbs free energy (system energy). This combustion chemistry data is driven by the oxidizer to fuel ratio which is itself driven by the oxidizer mass flux through the injector. Potential energy is transferred to kinetic energy through the nozzle using isentropic expansion principles and the 'frozen flow' assumption. Real life effects such as heat transfer, combustion inefficiencies, hardware imperfections, etc. will add losses to the system not fully captured by this model, however adjustment of certain empirical constants based on empirical test data has given us confidence in its use. The team used the `HEM` in the design stages to set internal performance parameters (chamber pressure, flow rates, burn time, thrust) that translate to hardware specifications (injector area, chamber dimensions, nozzle throat, etc.) and continued to use it throughout the testing campaign for predictive purposes.

Propellant Choice

Oxidizer

Three oxidizer options were explored for this engine; hydrogen peroxide, liquid Oxygen, and nitrous oxide. Nitrous oxide was selected due to its relative inertness compared to other oxidizers, ease of storage, and its ability to self-pressurize following the Clausius-Clapeyron Equation.

$$P \propto \exp \frac{\Delta H}{RT} \tag{1}$$

Nitrous oxide is a non-cryogenic and non-toxic oxidizer with the ability to self-pressurize at expected operating conditions. Figure 9 shows nitrous oxide pressures as a function of its temperature. This is assumed to be the starting oxidizer tank pressure and consequently drives the performance (peak thrust, burn time) of the entire engine.

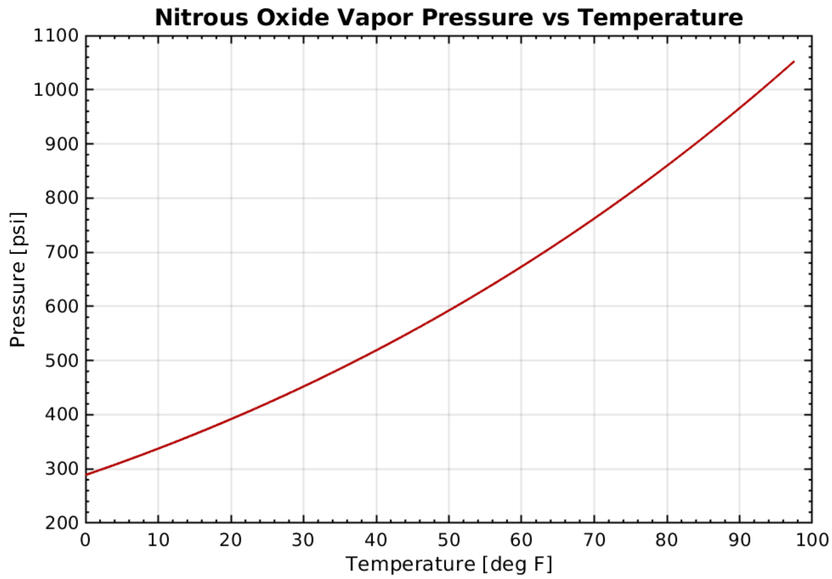

Figure 9. Nitrous Oxide Vapor Pressure

Nitrous Storage

Nitrous oxide becomes supercritical—a state at which distinct liquid and gas phases do not exist—at 97.5°F, and must be maintained below that temperature in order for the injector liquid flow design assumptions to be valid. Nitrous oxide is also susceptible to dramatic variations in pressure and in turn, performance. Since temperatures at the Spaceport America launch site are expected to rise above the critical threshold, the capability to set and maintain a desired oxidizer temperature is necessary to combat this variability. The thermal control system used is an insulated storage stand which accepts both an electric heating blanket and dry ice. A pressure gauge in line with the tank is used to monitor the tank's internal conditions. This storage system also enables the supply tank to be stored upside down which serves the purpose of facilitating the filling of liquid (and not gas) of the standard cylinder. Figure 2 depicts the finished system.

Figure 10. N_2O Temperature Control Box; Supply Tank Installed

Fuel

Hydroxyl-terminated polybutadiene (HTPB) was chosen as the solid fuel to be used in this engine over HDPE or paraffin wax. HDPE was eliminated due to its low regression rate and paraffin wax was removed due to its tendency to become structurally unstable (liquefy) which can potentially cause damage to the combustion chamber and nozzle. The HTPB polymer is a compromise with a relatively high chemical potential (measured using characteristic velocity, c*, and characteristic specific impulse, ISP*) and an acceptable regression rate when used with nitrous oxide. The HTPB is manufactured using a two-part mixture 83% HTPB R45-HTLO resin and 17% modified MDI isocyanate curative by weight.

HTPB's use as a hybrid fuel with nitrous oxide is well documented within the rocketry community and facilitates in accurate modeling of its combustion. Equation 2 represents the regression rate of hybrid fuels and the experimentally determined coefficients a and n are documented for HTPB-N_2O combustion in an AIAA paper from the 42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference.[34] These values were later verified in static engine testing by comparing fuel mass lost predictions with test results.

$$\dot{r} = aG_{ox}^{n} \tag{2}$$

The stoichiometric OF ratio for this system is between 6.25 and 6.5 and was set to be the target for the burn using the theoretical model described earlier. As shown in Figure 11, an output of the `HEM`, the OF ratio varies over time.

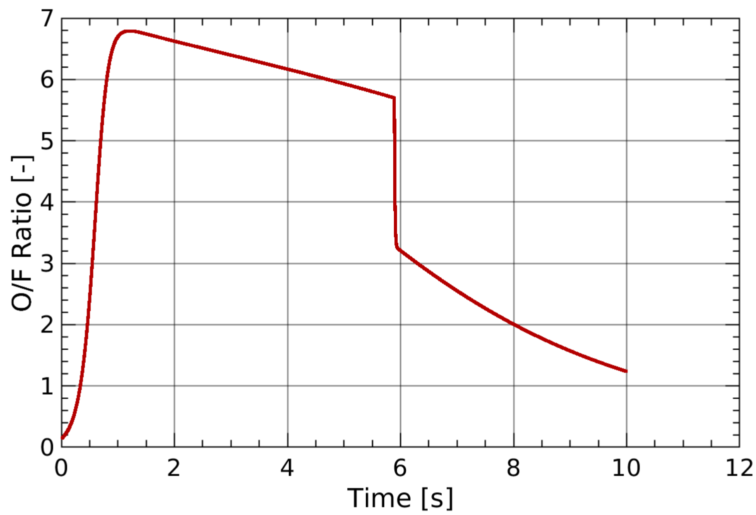

Figure 11. OF Ratio as a Function of Time

Oxidizer Tank

The flight oxidizer tank selected for Nova-I is a composite overwrapped pressure vessel (COPV) consisting of a carbon composite tank with an Aluminum liner. Manufactured by Luxfer Gas Cylinders, the T144A-003 has an operating pressure of 3600 psi which is over double the maximum allowed oxidizer tank pressure (as per the relief valve setting). This tank weighs 18.9 lbm, a nearly 50% reduction in some comparable Aluminum tanks.

Oxidizer Feed System

The plumbing system has the purpose of transporting sufficient oxidizer mass flow from the tank to the injection system. Due to the dependence of engine performance on oxidizer pressure, temperature and pressure monitoring throughout the operation of the engine is essential. A pressure relief valve is used to ensure that the system pressure is safely maintained below 1500 psi and the fill line incorporates a check valve for additional safety measure.

In order to drive the filling process, a vent line/dip tube extends from the plumbing cross to the top of the run tank. This feature is necessary to create a pressure differential by evacuating the air and oxidizer gas inside the tank and allow for an oxidizer fill. Unfortunately, the introduction of this vent line allows the liquid nitrous oxide to boil off inside the run tank as it attempts to maintain its vapor pressure as mass leaves the system. Phase changes and loss of mass through the vent line cause a drop in temperature which reduces the pressure in accordance with Equation 1. The team has minimized these thermodynamic effects through a reduced area vent line and by implementing a 'close and hold' procedure which prevent mass loss and allow the system to equalize its temperature with the environment through the plumbing; the vent line is kept open until the tank is full and subsequently closed off to maintain pressure.

Figure 12. Nova-I Plumbing System during Hydrostatic Test

The plumbing system is comprised of three subsystems; the plumbing cross, the ball valve actuator (BVA), and the quick disconnect system.

Plumbing Cross

To incorporate all of the necessary ports (fill line, vent line, 1500 psi pressure relief, pressure transducer, and thermocouple), a 'plumbing cross' was designed to minimize the number of fittings required to join them in a single line. All five of these ports connect to the main line joining the tank to the injector with a near constant area; minimizing the pressure loss in accordance to mass conservation and Bernoulli's principle. All fittings used are made of 316 stainless steel and sustain a service pressure of 5200 psi, significantly more than needed.

Temporary connections in the plumbing lines meant for easy disassembly and storage of the engine or for orienting hose and sensors are tube compression or JIC fittings.

Ball Valve Actuator

Oxidizer flow control was a major challenge during Nova-I's development. Previous teams experimented with using a chain and sprocket mechanism to actuate a ball valve and a design involving a piston plug released by an Estes motor, both without success. Using pneumatically or electrically actuated valves were going to be costly, heavy, and would require a larger diameter rocket. Nova-I solves this problem through use of a four-bar-linkage actuator and servo. Using trigonometry, the four-bar-linkage's output torque can be simulated from a given input torque. A stainless steel ball valve with the temperature, pressure, and size specifications needed was coupled with a HiTec HS-M7990TH servo motor to turn the servo's 611 oz-in input into 1100 oz-in output. These components—along with their mounting hardware—are collectively called the Ball Valve Actuator system (BVA) and initiate oxidizer flow prior to ignition.

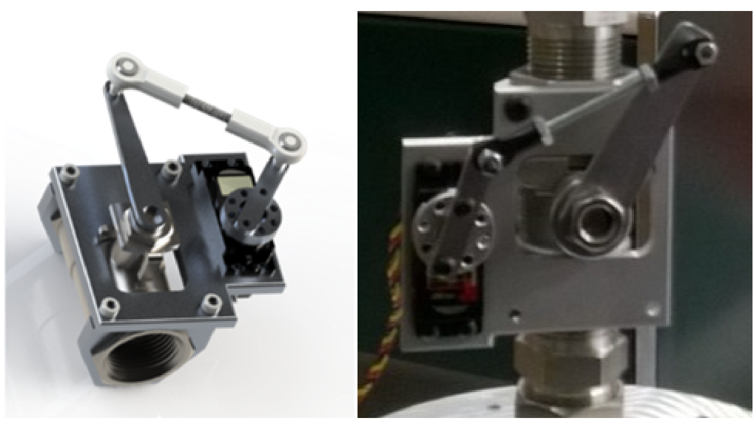

Figure 13. Ball Valve Actuator; CAD and manufactured

Powered separately from the main avionics, the servo receives a 7.4V Lithium Polymer (LiPO) battery capable of the high discharge rate required by the motor. Given the importance of safety when igniting the engine, there are 3 levels or redundancy when actuating the ball valve. First, a screw terminal must be manually set to the correct position allowing the battery to supply power to the servo. Second, a command must be sent from ground control to allow the servo to receive the required voltage. Lastly is the command that sends the Pulse Width Modulation (PWM) signal to the motor which finally turns the ball valve effectively allow the nitrous to flow into the combustion chamber.

Quick-Disconnect System

Quick disconnect fittings on the fill and vent lines allow for safe and remote disengagement of the exterior lines from the vehicle before launch. The internal tubing and female quick disconnect fitting is rigidly mounted to the vehicle bulkhead with a 3D printed collar. The disconnect sequence is actuated by an electric motor system.

Injection System

The injector assembly is made up of a Aluminum 6061-T6 injector housing, a 304 Stainless Steel NPT pipe fitting machined to accommodate a compression fitting, the injector coin, and top flange on the combustion chamber. Silicone and Buna-N orings provide sealing for the flange and coin respectively.

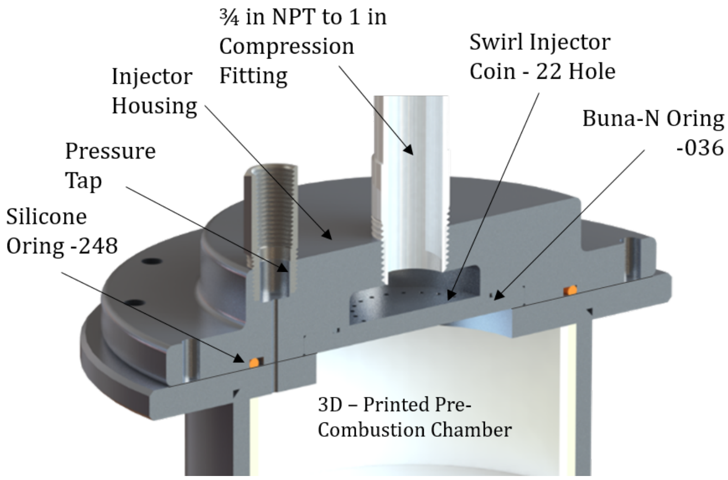

Figure 14. Injector Assembly

The injector must be able to atomize the liquid oxidizer and sustain an even burn with HTPB while maintaining a seal between the chamber and plumbing. Atomization is the process of creating tiny droplets in the injection stream, accomplished by limiting the diameter of each orifice to 1.5 mm. Small droplets are easier to ignite and mix with the fuel better as the reaction burns. The design goal was to find the total injector area that provided the mass flow rate needed for an OF ratio of 6.5 and to select the geometry which would provide the most even burn profile throughout the length of the fuel grain.

Oxidizer mass flow through the injector can be modeled as shown in equation 3. The discharge coefficient, C_d, is an empirically based parameter which represents the deviation of the flow from Bernoulli's equation.

$$\dot{m} = A_{inj} C_d \sqrt{2\rho_{ox} \Delta P} \tag{3}$$

In an attempt to better quantify C_d, a series of cold flow tests were completed using both water and nitrous oxide as the working fluid. Following the completion of the study, the best total injector area was found to be 0.092 in^2. To allow for atomization, this area was distributed among 30 orifices, each with a diameter of $\frac{1}{16}$ inches (0.0625 in.).

Nova-I utilizes swappable injector coins, enabling various injection geometries to be tested during the development phase of the engine testing campaign. The orifice arrangements considered for Nova-I consisted of variations of axial, vortex, and impinging geometries. Axial holes direct flow longitudinally into the combustion chamber while the vortex design introduces a radial component to the oxidizer flow as it enters the chamber which is meant to enhance mixing. Impinging injection also introduces an angular component to the flow, however the oxidizer converges at a central point just above the grain to deliver rapid atomization of the nitrous oxide. The previous SRT engine, Icarus-II, employed the use of vortex injection since the added radial component creates a swirl in the combustion chamber which has been shown to increase the regression rate by at least 36%[35] due to the centrifugal forces throwing the flame against the fuel grain walls in similarly sized engines. The orifices were arranged in a circle with a 15° angle from the axial direction which maximizes the mixing of propellant along the length of the chamber. This angle also reduces the chances of blowout and to date no blowout of combustion has been observed during tests. Unfortunately, implementation this geometry focused regression at the top of the fuel grain, as seen in Figure 4, so the Nova-I flight configuration coin implements a combination of vortex and impinging injection which has proven to yield a more even burn profile (Figure 4).

Figure 15. Icaurs-II: Fuel Grain from November 18, 2017 Static Engine Test

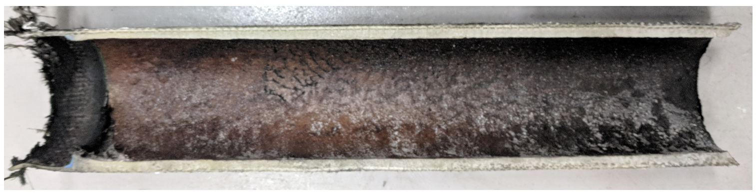

Figure 16. Nova-I: Fuel Grain from March 25, 2018 Static Engine Test

Combustion Chamber

The combustion chamber houses the HTPB-N_2O combustion reaction—with ideal internal conditions of 400 psi and 5500°F—and transmits thrust to the vehicle through its top flange. The combustion chamber contains the fuel grain throughout the fill and ignition sequence and receives oxidizer under pressure during engine operation.

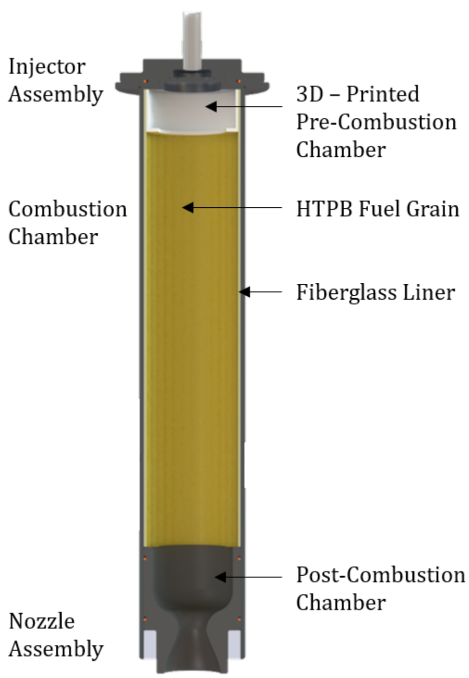

Figure 17. Nova-I Combustion Chamber Assembly

Combustion Chamber Body

The body of the combustion chamber is constructed from Aluminum 6061-T6; chosen for its high strength, low weight, and cost-effectiveness. The cylindrical chamber has a total length of 29.85 in. and a thickness of 0.25 in. Included in the combustion chamber length is a 2.2 in. PETG vaporization chamber for further atomization located aft of the injector and a 3.3 in. graphite mixing chamber to allow for additional stay time and a more complete combustion located aft of the fuel grain. The chamber's inner diameter was sized based on the amount of fuel required to reach a design altitude of 18,000 feet (2015-16 IREC); which was determined through a coupled propulsion (combustion/regression analysis) and trajectory analysis. The wall thickness was sculpted from a common pipe size through Finite Element Analysis (FEA) iterations to minimize weight while maintaining pressure ratings. Figure 1 shows the results of an FEA run in which a load equivalent to the uniform expected operating pressure on the inner surfaces of the tube and the top flange was applied. The design hold a factor of safety of 3. The length was chosen based on a desired OF ratio of HTPB/NOS propellant combination modeled the EPC and taking pre-combustion and post combustion chamber needs into account. Sealing to the injector housing is provided by a silicone o-ring. The assembly of these components is shown in Figure F.

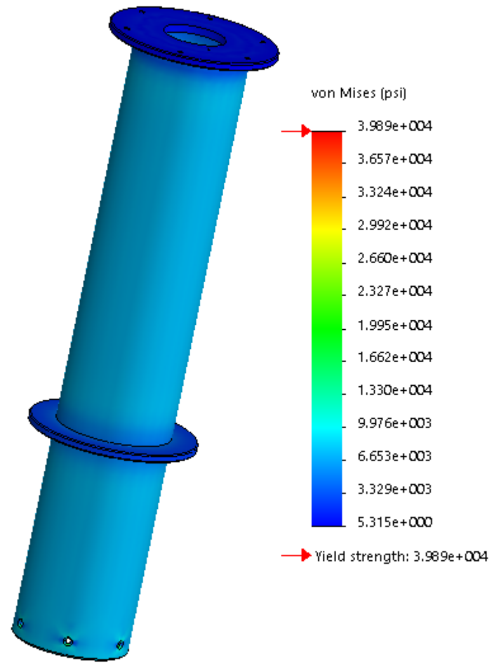

Figure 18. Finite Element Analysis of Nova-I Combustion Chamber Under Expected Operating Conditions

Fuel Grain

Nova-I's engine utilizes a 23 in. fuel grain with a single circular port (3 in. diameter). The team chose to use a circle port fuel grain for the explicit reason of more accurately comparing engine test results to the theoretical model. The mixture poured into a PVC mold with a fiberglass liner as insulation and cures for a minimum of three days before use.

Thermal Insulation

Fiberglass cloth—in addition to a thin layer of fuel which is expected to remain unburnt—is used as an insulative liner to protect the combustion chamber from the extreme temperature environment of combustion. The fiberglass is laid in the fuel grain casting rig and the HTPB-curative mixture is subsequently poured directly into this set-up.

Nozzle

The nozzle uses a converging-diverging geometry to accelerate combustion products to high velocities before ejecting them from the rocket to produce the desired thrust. Nova-I's nozzle was designed to operate at the worst flight conditions to ensure that its performance will not fall below the required performance. All values used during the design process assume isentropic flow within the nozzle and combustion product properties were determined using a stoichiometric oxidizer to fuel ratio and an ideal gas assumption.

The exit area must be such that the nozzle is slightly under-expanded at launch conditions, meaning that the exit pressure is slightly higher than ambient pressure conditions. This restraint ensures that no shocks form in the nozzle which could damage its structure and reduce performance. An exit pressure five percent higher than that of the ambient pressure at the competition launch site, Space Port America in New Mexico, was selected for this design.

The contour of the nozzle was chosen with expansion efficiency and weight minimization (in the form of length minimization) in mind. The cubic bell contour outperforms both conic and parabolic nozzles and was therefore selected for Nova-I despite it's difficulty to manufacture. The geometric specifications, outlined in figure 19, can be determined from known parameters.

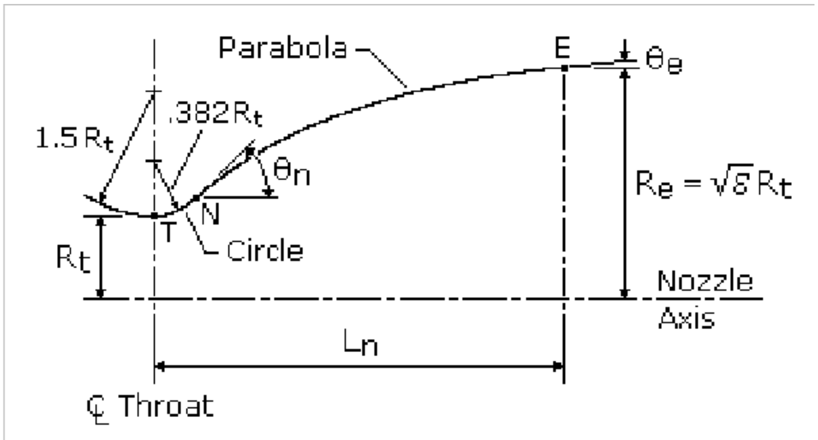

Figure 19. Definition of Nozzle Parameters

The throat entrance and exit radii inputs are factors of the throat radius; factors of 1.5 and 0.4 were used, respectively, as recommended by Sutton and Biblarz in Rocket Propulsion Elements.[36] The length of the expansion section of the nozzle is determined by taking 80% of the length of a cubic nozzle with departure angle of 14 degrees for the same throat and exit radii.

Table 3. Nozzle Design Specifications

Symbol	Value	Significance
P_0	375 psig	Chamber pressure
T_0	3300 K	Chamber temperature
k	1.25	Specific heat ratio of combustion products
MW	24.68 g/mol	Molecular weight of combustion products
A_t	1.628 in	Cross sectional area of the nozzle at the throat
A_e	6.859 in	Cross sectional area of the nozzle at the exit
ϵ	4.16	Expansion Ratio
θ_n	14°	Departure angle (bell nozzle)
θ_e	5°	Exit angle (bell nozzle)
$\dot{m}$	3.1 lbm/s	Mass flow rate
P_e	13.125 psia	Exit pressure
v_t	3538.9 ft/s	Velocity at the throat
v_e	7473.6 ft/s	Exit velocity
M_e	2.787	Mach Number at the exit

The nozzle structure consists of a graphite body which contains the cubic bell contour and an Aluminum collar. Graphite was chosen due to its high melting point and its relatively light weight compared to other materials with similar melting points.

The nozzle is retained by an Aluminum 6061-T6 collar secured radially to the combustion chamber body by six countersunk machine screws. This system is designed to be the weakest point of the combustion chamber assembly so as to be the first to fail in the event of a rapid over-pressurization event. Hydrostatic testing has confirmed calculations predicting this as the primary failure mode.

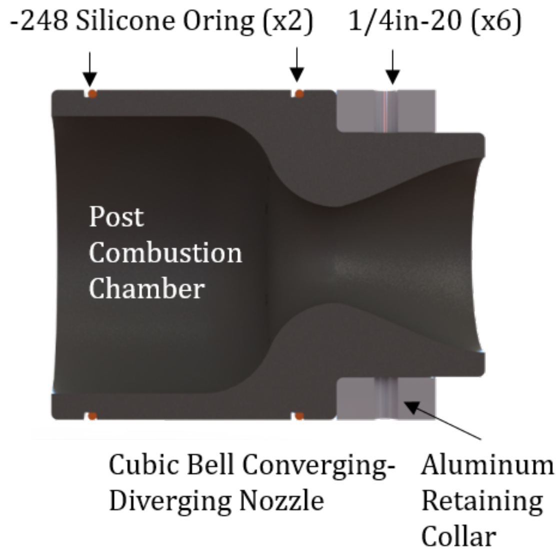

Figure 20. Nova-I Nozzle Assembly with Collar

Ignition

Nitrous oxide requires a temperature of around 1070°F to dissociate and begin the combustion reaction. To create this condition, an oxygen fire is burned in the chamber prior to the release of N_2O. Oxygen enters the chamber through vinyl tubing inserted through the nozzle and ignites a layer of lithium grease coating the fuel grain by means of a steel wool and black powder igniter.

Data Acquisition & Instrumentation

A BeagleBone Black will be the main computer in charge of the vehicle's data acquisition (DAQ) and ignition control. It, along with the rest of the avionics will be powered via a 12V Lithium-Iron-Phosphate battery. Operating at 5V, the voltage is shifted down from the battery to the computer using a DC-DC Buck Converter. All of the information read by the sensors are logged into the BeagleBone's internal memory storage and saved for post-processing. All communication to the rocket from ground control is done through 900 MHz Yagi-Uda antennas. Ground control transmits to our team's Launch Box, which communicates through a hardline serial connection to the vehicle's avionics. A Bi-Directional Logic Shifter enables a serial connection between the two systems. During this time the BeagleBone can transmit semi-instantaneous pressure or temperature through the hardline back to ground control, and once the final command is sent for ignition, all systems become internal and all information regarding data collection is saved onto the internal memory of the main DAQ computer.

In-Flight Sensor Suite

The vehicle's avionics are capable of logging the data received from 2 pressure transducers and a thermocouple. More specifically, we can measure the pressure observed inside the oxidizer tank and inside the combustion chamber. The data is stored inside of the main flight computers internal memory at a frequency of 100 Hz. Likewise, we can measure the temperature inside of the oxidizer tank and log it onto the computer's memory at a frequency of 10 Hz.

IV. Aerostructures

Nose Cone Design

Aerodynamics

Design

The nose cone design used in previous years was a Half-Power nose cone with a Fineness Ratio of 3.0. This design was chosen because the surface area was the smallest out of all the candidates being considered, thus minimizing surface friction. This is important because along with pressure-drag, surface friction would be the main source of drag at the low speed regimes for which the rocket was first designed. However, due to new optimizations for a higher altitude and thus a higher speed regime, the design had to be reconsidered.

The new nose cone design focused on improving flight performance at high-transonic speeds. At higher transonic speeds, wave drag becomes the more significant source of overall drag (as opposed to skin friction drag at low subsonic speeds). This lead to designs with smooth transitions that prevent the premature creation of shock waves. Thus, two new candidates were chosen that satisfied this transition criterion: Von Kármán and Spherically Blunted Von Kármán (abbreviated from here on as VK and SBVK, respectively). The former, in fact, was originally considered for the first nose cone design but was discarded as it was optimized for high transonic speeds.

The original design, along with other candidates being considered, was simulated using Computational Fluid Dynamics, or CFD, software (in this case STAR-CCM+) at Mach 0.8 with varying Fineness Ratio in order to determine which ratio would offer the lowest drag at transonic speeds. The results showed that a Fineness Ratio of 3.0 was optimum for high-transonic speeds - independent from the shape of the nose cone - and was thus selected to be used in the current nose cone. Since the new design would be flying at a similar speed to that of the simulations performed during the initial study, the results are applicable to the new nose cone regardless of the new geometry. The design candidates were then simulated using CFD at different Mach numbers in order to determine which shape would offer the lowest drag and optimal pressure distributions along the length of the nose cone.

Analysis

Using STAR-CCM+ and several educated simulation design decisions, CFD analysis was performed on each of the nose cone designs. The collective outcome of each of the simulations enabled the informed decision of a final nose cone design. With the transonic regime being of great concern, the performance of the previously used (and subsonic preferred) Half-Power nose cone was used as a baseline comparison for both the SBVK and VK configurations.

To begin the CFD analysis, the SBVK was first compared to the Half-Power due to their similar blunt-nosed configurations. The pressure distributions and pressure gradients along the length of each nose cone were of considerable concern because of the creation of pressure drag during flight. The results of the simulations are shown below in Figures 21 & 22. It is important to note that these figures represent gauge static pressure, and not absolute pressure (hence the negative values on the scale of the figures).

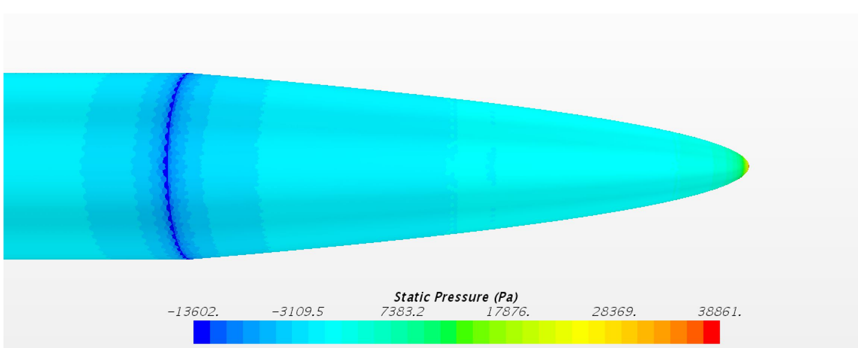

Figure 21. Pressure distribution over Half-power nose cone at Mach 0.7

As can be seen in Figure 21, the pressure distribution over the Half-Power nose cone exhibits a steep gradient at the transition between the nose cone and the body tube. This is due to the Half-power nose

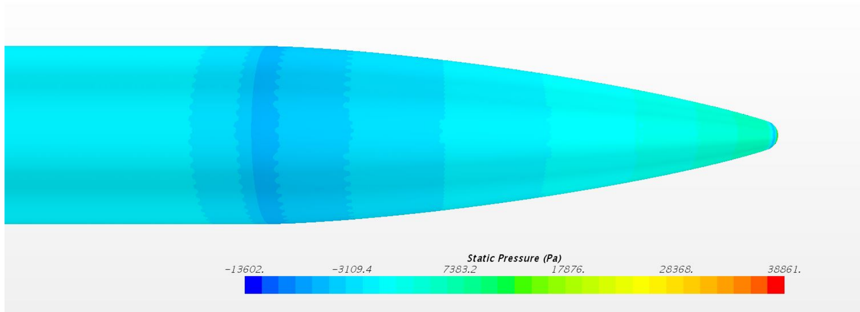

Figure 22. Pressure distribution over Spherically-Blunted Von Kármán nose cone at Mach 0.7

cone not having a tangential profile to the body tube at the connection point. As the flow is forced over the transition, the velocity increases rapidly to a maximum at the point of connection, then decreases significantly as it travels further down the body tube. According to isentropic relations between velocity and pressure, as shown in Equation 4, an increase in velocity will lead to a decrease in pressure. The rapid rate at which the velocity (or Mach number, M) increases over the surface leads to a rapid decrease in pressure, P. In the equation, γ is the specific heat ratio of air and P_0 is the stagnation pressure of the flow.

$$P = P_0\left(1 + \frac{\gamma - 1}{2}M^2\right)^{\frac{-\gamma}{\gamma-1}} \tag{4}$$

Steep pressure gradient regions in the targeted Mach regime have the potential to prematurely induce supersonic flow (a phenomena more often seen on fins). If the pressure gradient is steep enough, shock waves can potentially form, which drastically increases pressure drag and also induces wave drag. Therefore, the Half-Power nose cone configuration is a poor candidate for this rocket due to its high pressure gradient induced by its relatively abrupt change in angle from the nose cone to the body tube.

However, as shown in Figure 22, the pressure distribution over the SBVK nose cone has a more gradual pressure gradient and higher minimum static pressure value. This is a result of the fact that the Spherically-Blunted configuration connects to the body tube with a tangential surface profile. Because of this, the SBVK configuration will introduce a lower value of drag in the transonic Mach regime than would the Half-Power configuration. Furthermore, the VK nose cone has the same tangential connection with the body tube as the Spherically-Blunted configuration and would also exhibit a lower pressure gradient because of this. The gradual pressure gradient present in both Von Kármán configurations made them the final contenders for implementation.

In order to make an informed decision on the nose cone design between the two Von Kármán configurations, drag coefficients were calculated for both for a Mach range from 0.3 to 0.9. Using STAR-CCM+, simulations were run until the solutions converged and the Force Coefficient Report was extracted using several of the conditions used to define the physics and the flow in the simulation. Though the Mach number selection may seem sporadic, each simulation was run in order to quantify the drag at critical Mach numbers during the mission. Some of the lower Mach number values are used to detail the drag experienced by the vehicle in its cruise stages of the flight while a series of the higher Mach numbers (0.6 and 0.7) were used in order to characterize the drag induced by the nose cone as the rocket approaches its maximum velocity. Mach 0.9 was run in order to determine how quickly the drag coefficient increased in the transonic region and to serve as a baseline for future supersonic designs and considerations.

As seen in Figure 23, the SBVK seems to perform better than the regular VK configuration in subsonic speeds and is only outperformed during high transonic speeds. The results from this study were corroborated with the documentation used to obtain the geometry for both nose cones and the curves seem to follow the same trends and shapes as the original literature.[15]

Conclusion The Spherically-Blunted Von Kármán configuration was chosen as the final design. It offers better performance than the traditional Von Kármán configuration and is superior to the original Half-Powered nose cone in transonic speeds. SBVK also has the potential to perform better at supersonic speeds than the traditional configuration,[15] meaning that future teams now have a nose cone optimized for both the high transonic and supersonic flight regimes.

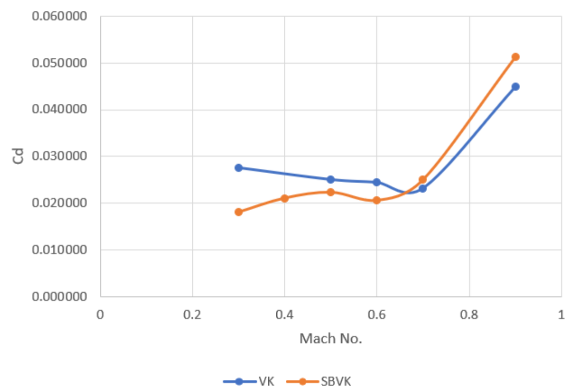

Figure 23. Drag coefficient per Mach number for two Von Kármán configurations

Manufacturing

The nose cone was constructed from fiberglass fabric wet-laid inside of a negative mold. The process began with a CAD model of the nose cone shape chosen by the dynamics team. The CAD model was used to create a negative mold that was cut from high density foam (HDF) on a 4-axis CNC. The negative mold was created in two halves to allow the team to prepare the inside surface of the mold and inspect its surface for defects. After light sanding to remove the ridges left from the CNC, the mold was prepared by painting on 5 layers of PVA release film. Special attention is required to not let the release film pool at the bottom of the mold.

The layup process begins with cutting 36 trapezoidal fiberglass pieces roughly 26 in. long x 4 in. wide. The two mold halves are fastened together using 18 in. long pieces of all-thread with necessary hardware, taking special care to ensure the interior seam of the molds are flush across their surface. The layup process consists of painting the fiberglass trapezoids to the interior surface of the negative mold, overlapping the fabric pieces by half an inch as one moves clockwise around the interior of the mold. For best results, quickly wet the entire piece of fiberglass to tack to the surface of the mold and then slide it into the proper overlapping position. To release the nose cone from the mold after the 24 hour cure period, remove the hardware connecting the two halves, insert a wedge on either side of the mold and slowly slide them toward the nose until the release film breaks its seal. Wash with soap and water to remove residual release film from the fiberglass surface. Prepare the nose cone for paint with 100, 220, 400 and 1000 grit sand paper in that order. Push lightly on the surface while making small circles with the sand paper to avoid gouging the material.

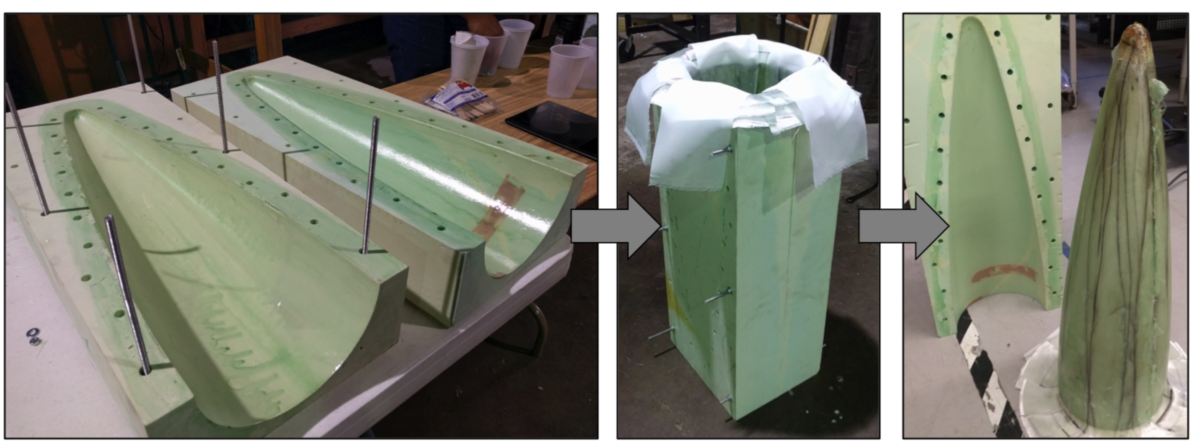

Figure 24. Nose cone manufacturing process, HDF mold - wet layup inside negative mold - mold release

Tail Cone Design

Aerodynamics

According to a document published by the Military Technical College in Cairo, Egypt, the inclusion of a boat-tail (fins attached to transitioning geometry) or tail cone has the capability of reducing the coefficient of drag of a projectile by nearly 60 % during the coast phase of the rocket's ascent.[17] The following is a verification of these claims. A conical design was chosen for manufacturing simplicity.

Computational Fluid Dynamic analysis was done to determine a trend rather than to identify actual Cd values. Two main parameters were varied - length of the tail cone and the taper angle. The results of the length simulations are shown in Table 4.

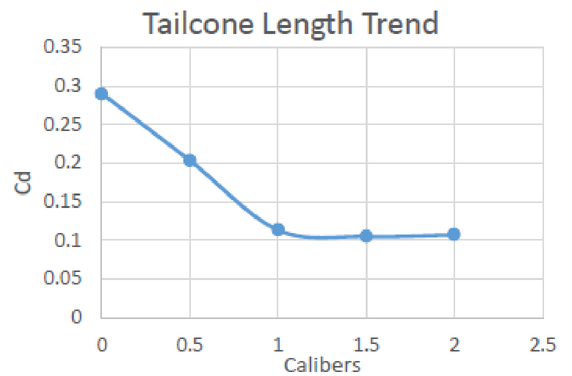

Figure 25. Tail Cone Length Trend

Table 4. Tail Cone Length Results

	Cd Reduction	Cd
No Tail	N/A	0.289770
0.5 Caliber	30%	0.202913
1.0 Caliber	61%	0.113309
1.5 Caliber	64%	0.105016
2.0 Caliber	63%	0.107139

The results of the taper angle simulations are shown in Figure 26. The taper angle trend discussed here is under the assumption that 1.25 caliber is the ideal length. Two additional tests were conducted at a taper angle of 16 degrees; one at 1 caliber in length and another at 1.5 caliber in length. This test confirmed the ideal length was indeed very close to 1.25 calibers.

From Figure 25, the drag reaches a minimum at around 1.25 calibers length where the combined pressure and skin friction drag are minimized. At smaller calibers, pressure drag dominates as the stagnation region behind the tail cone is larger. This effect can be seen in Figure 27.

At larger calibers, skin friction drag becomes more significant and the drag begins to increase again despite the reduction in pressure drag.

With respect to the tail cone taper angle, Figure 26 shows the determined trend. Drag is minimized at a taper angle of 14.5 degrees for the same reasons that the minimum was found in the length analysis.

Low speed wind tunnel testing was conducted to verify the CFD simulations already done. It should be noted that the tail cone tested was not at the ideal length determined by CFD simulations. Instead a length of approximately 0.8 calibers was used so as to fit on the wind tunnel sting assembly.

The results of the wind tunnel test with and without the tail cone are shown in Figure 28. Similar to CFD analysis, the coefficient of drag dropped with the addition of the tail cone. However, as displayed in Table 5, the percent reduction was not as great in the wind tunnel as it was in the CFD simulations. The first and most likely cause of the discrepancy is that the sting assembly interfered with the base drag.

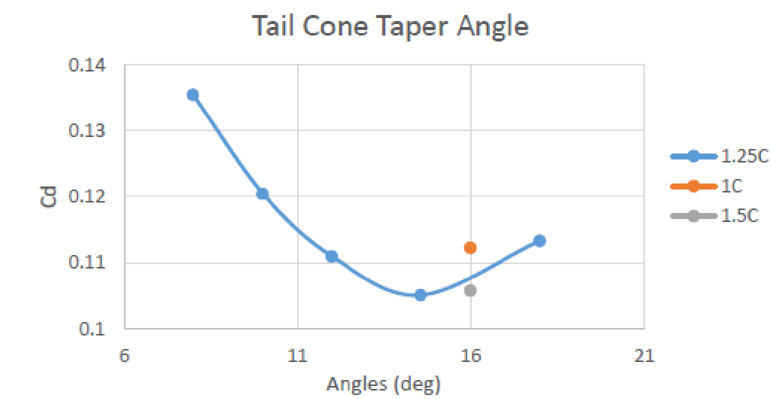

Figure 26. Tail Cone Taper Angle

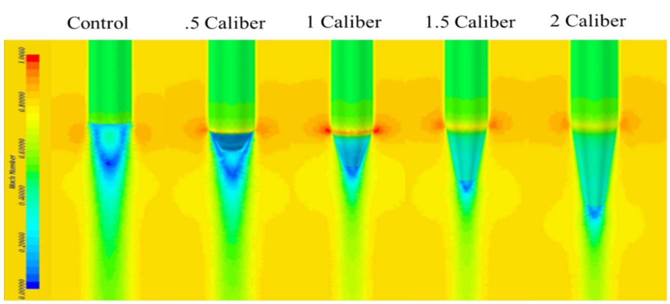

Figure 27. Direct Mach Scalar Scene Comparison

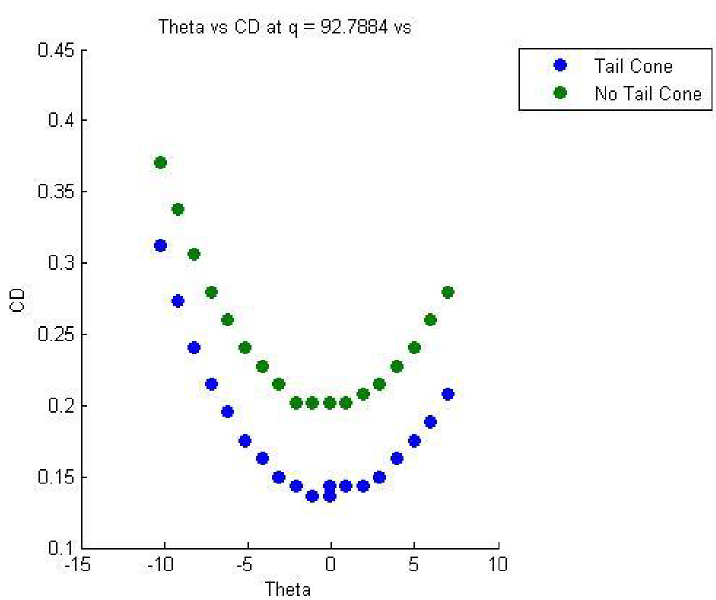

Figure 28. Tail Cone Cd Comparison

Another possible reason for the variation in results is that the Cd reduction varies differently as the flow velocity experienced by the rocket increases.

Table 5. Tail Cone Cd Reduction Comparison

	CFD (Full Scale)	Wind Tunnel (59% Scale)
Cd	0.1468	0.1399
Cd Reduction	49.34%	30.63%

For every test (CFD and Wind Tunnel), the tail cone decreased the overall Cd significantly. With a maximum Cd reduction of 63% determined by the CFD simulations for the ideal length, the rocket would gain an additional 20.7% in altitude. Due to design alterations in response to other parameters and non-ideal conditions experienced in the real world, it is not expected that the design will perform to its maximum potential. That being said, the Cd reduction is enough to warrant the incorporation of the tail cone into the final design. The ideal parameters are shown in Figure 6 and the final shape was determined by the structures team.

Table 6. Final Design Specifications

Tail cone (Y or N)	Y
Length (calibers)	1.25
Taper Angle (°)	8°-14.5°

Manufacturing

In a similar fashion to that of the nose cone, the tail cone was manufactured using a wet layup process on a positive mold. The manufacturing process began with making a positive mold onto which carbon fiber layers would be built up to the desired thickness and exterior diameter. The positive mold was cut out of low density foam on a 4-axis CNC in 4 separate layers due to the thickness of the final piece. The layers were glued together and the final mold wrapped in a layer of mylar film to create a barrier between the porous foam and resin.

The layup preparation begins with cutting 16 C-shaped carbon fiber pieces using a cardboard template. The C-shaped pieces are 1/4th of a transition template between the aft tail cone diameter and the forward tail cone diameter. The positive mold is coated in a thin layer of epoxy before the lay-up to assist in holding the carbon fiber pieces to the mold. The layup process consists of painting the carbon fiber pieces onto the mold, overlapping the next piece of fabric by half an inch and moving clockwise around the mold. For best results, throughly soak the carbon fiber fabric during each pass as excess resin will be allowed to exit the piece during curing. Once all 16 carbon fiber pieces have been applied to the mold, a peel ply cone is applied over the top of the positive mold to allow excess resin to be soaked up and provide for a consistent surface finish. Additionally, the layup is compressed into the positive mold via a mylar cone on-top of the peel ply. After 24 hours, the mylar and additional material is removed to expose the unfinished tail cone. Finishing consists of cutting both ends to the desired diameter via a hand-held rotary tool and finishing the surface per the same method as the body tubes.

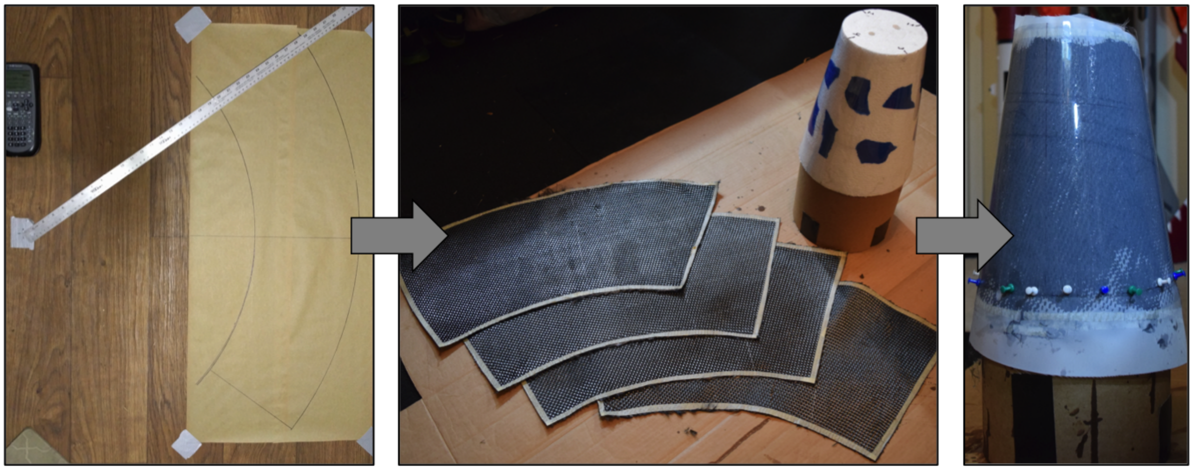

Figure 29. Tail cone manufacturing process, Transition template - wet layup on positive mold - mylar film compression

Fin Design

Aerodynamics

Airfoil Design

The vehicle will spend a significant portion of its flight in the transonic speed regime and as a result will be subject to aerodynamic phenomena that are characteristic of that regime, such as shock-induced flow separation. Therefore, one of the primary objectives in optimizing the cross-sectional profile of the fins is to decrease the effects of transonic flow phenomena in order to delay the onset of drag divergence at transonic speeds. While this is the primary goal, the fins must still possess suitable low speed lift characteristics so that they may serve their intended purpose, which is to stabilize the rocket just after it has left the launch tower. After consulting existing documentation, three airfoils were selected for further analysis: the NACA 65-010, the NASA SC(2)-0010, and the NACA/Langley Supercritical (also with a 10% thickness ratio). Flat plates were not considered for the cross-section since they produce a significantly lower lift force at low angles of attack compared to airfoil cross-sections, and therefore less stability.[18]

The three airfoils were then modeled two-dimensionally in XFLR-5 (a commercial airfoil and wing design program) using an inviscid assumption and a free-stream velocity of Mach 0.8. Pressure coefficient as a function of location along the chord is presented in Figure 30.

The horizontal dashed line indicates the critical pressure coefficient, i.e. the point at which the local flow velocity over the surface of the airfoil becomes sonic. It can be seen that the magnitude of the pressure gradient during the second sonic transition is relatively large for the NACA 65A-010. This is an undesirable characteristic when designing for the transonic regime, as a substantial pressure gradient across the sonic transition superimposed on the inevitable shock wave increases the magnitude of boundary layer separation, the main culprit of transonic drag divergence.[21] From this preliminary surface pressure analysis, it can be anticipated that full-scale CFD simulation will return lower drag values for the Supercritical airfoils than for the NACA 65A-010. On the other hand, the Supercritical airfoils have a relatively gentle pressure gradient across the transition, which can be attributed to the absence of any substantial curvature over the mid-chord region. This generally leads to a decrease in the extent of any flow separation that occurs, and is the reason Supercritical airfoils (both cambered and not cambered) are typically used for flight in the transonic regime.[22]

The airfoils were then applied to a full-scale model of the vehicle, and placed in CFD simulations; the simulations were run twice, the first with a free-stream of Mach 0.8, the second Mach 0.9, with both at a density altitude of 5000 ft. The results are summarized in Table 7 and Table 8 below:

At a free-stream of Mach 0.8, there was not enough variation between the three airfoils to come to any conclusions. However, at a free-stream of Mach 0.9, the vehicle models start to experience drag divergence,

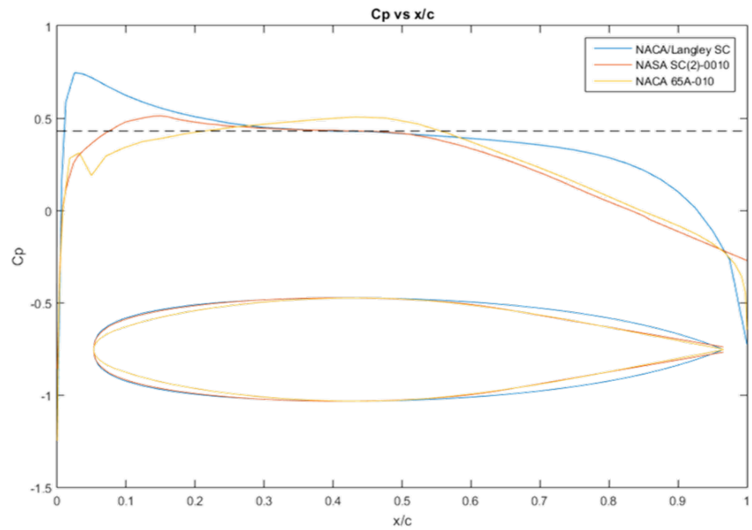

Figure 30. Surface pressure distribution

Table 7. Mach 0.8 - Drag Force Results

Airfoil	Peak Mach	Pressure [lb_f]	Shear [lb_f]	Total [lb_f]
NACA 65-010	0.975	25.6	30.2	55.8
NASA(2)-0010	0.955	25.2	30.4	55.6
NACA/Langley SC	0.943	24.7	30.4	55.1

Table 8. Mach 0.9 - Drag Force Results

Airfoil	Peak Mach	Pressure [lb_f]	Shear [lb_f]	Total [lb_f]
NACA 65-010	1.213	64.4	36.1	100.5
NASA(2)-0010	1.208	58.1	36.4	94.5
NACA/Langley SC	1.218	59.1	36.3	95.4

with the NACA 65A-010 causing the largest increase in drag. This is not surprising and logically follows from the results of the surface pressure analysis discussed earlier.

Drag polar plots were produced for both the NASA SC(2)-0010 and the NACA/Langley Supercritical using XFLR-5. This was done at a free-stream of Mach 0.1, and with a viscous flow model that used a Reynolds number of 1e5; these conditions best imitate those which the vehicle will experience just as it has left the launch rail, a point in time when it will be most vulnerable to wind and changes in its angle of attack, a point at which the low-speed lift characteristics of an airfoil come into play. The results are summarized below:

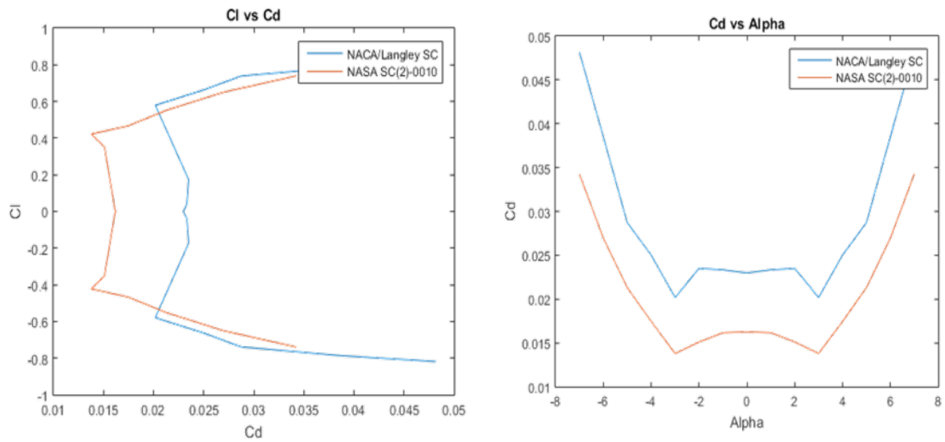

Figure 31. Drag Polar Plots

The NASA SC(2)-0010, indicated by the orange curve, has a significantly lower drag coefficient at low angles of attack. This metric alone is enough to come to the conlusion that that it has superior low-speed characteristics; for this reason, and for its favorable high-speed characteristics, the NASA SC(2)-0010 airfoil was chosen as the cross-sectional profile for the fins on this vehicle.

Planform Design

The shape of the fin planform is governed mainly by two factors: the drag coefficient and the stability margin of the rocket. The stability margin of the rocket is defined as the distance from the center of pressure (CP) and center of gravity (CG) of the rocket, non-dimensionalized by the rocket body diameter. The "unit" for stability margin is given in calibers, where one caliber is equal to one body diameter. For passive aerodynamically stabilized rockets, the CP must be aft of the CG. The generally accepted rule of thumb is that the stability margin should be between 1.0 and 2.0 for safety, even though mathematically any stability margin greater than 0 is still considered stable. The reason for the rule of thumb is due to the fact that when the rocket leaves the tower/rail, it experiences a non-zero angle of attack which in usually shifts the CP forward towards the CG. Under certain conditions this shift could cause the rocket to become unstable, where the CP moves in front of the CG.

To find an optimal stability margin for the rocket, a process involving linear stability analysis was performed but was far too lengthy to include in the scope of this report. Based on the results of that analysis, the optimal stability margin for Theseus is about 1.6 calibers.

The process for designing the planform itself involved performing trade studies in RASAero for the four main fin dimensions: root chord length, tip chord length, semi-span, and sweep distance. The layout of these dimensions is presented in Figure 32. Several planform designs were created that met the stability margin requirement of 1.6 calibers and the final design was chosen from among them based on the following criteria:

- Susceptibility to fin flutter
- Ease of manufacturing
- Minimization of drag coefficient across the flight regime

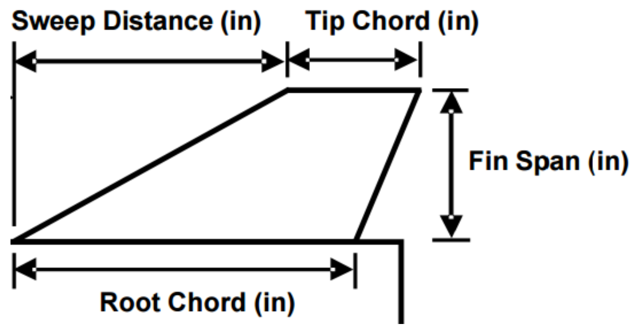

Figure 32. Diagram of basic fin with shape parameters labeled

The first criterion eliminated highly swept fin designs. In those cases the CG of the fin (generated from a CAD model in SolidWorks) lay well behind the CP of the fin (generated from XFLR-5); similar to the stability of the full rocket, the CP must lay behind the CG for fin stability. While flutter is a more complex phenomenon involving more than just the CP and CG of the fin, creating a fin which is inherently dynamically stable greatly decreases the likelihood of flutter. Although highly swept designs exhibit less drag in general, ensuring the rocket reaches apogee safely and smoothly is of greater importance. The second criterion eliminates designs with very small tip chords (less than 3 inches). This is purely based on past experience and is due to the method our team uses to manufacture fins (which will be elaborated upon further in the following sections). The third criterion served to choose the final planform candidate with the lowest drag. The final fin planform design is presented below:

Table 9. Theseus Fin Planform Dimensions

Root Chord [in]	Tip Chord [in]	Span [in]	Sweep Distance [in]
12.0	3.0	8.25	7.0

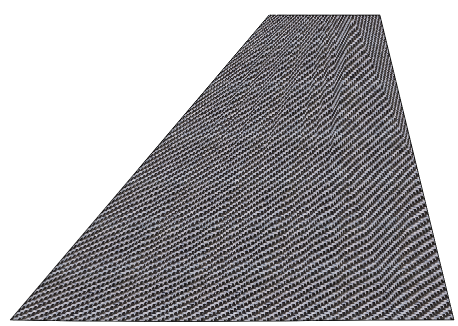

Figure 33. Final fin profile

Body Tubes

Design Discussion

The geometric constraints of the body tubes are determined from certain subsystems within the rocket. The body tube's inner diameter is determined from both the size of the oxidizer tank and the available sizes of cardboard tubes that are used as mandrels during tube construction. Cardboard tubes with outer diameters of 8.25 in. are used to create body tubes with an inner diameter of 8.25 in. This gives a radial clearance of 0.275 in. with the oxidizer tank. The length of a specific body tube is determined by the required length of that section of the rocket. For example, length of the combustion chamber dictates the length of the combustion chamber body tube. The wall thickness of the body tubes is determined by the required strength of the structure. Designed body tube wall thickness can vary depending on the maximum loads experienced by that section of the rocket.

The body tube thickness (i.e. number of fabric wraps) was determined through the use of composite tube buckling equations. If the body tubes do encounter failure, it's anticipated that they fail in a buckling mode due to the small aspect ratio of the tube directly above the thrust flange. Using this failure mode, the NASA/TP-2009-215778 report was used to construct a mathematical model for tube buckling in composite tubes. Although material characterization tests could not be conducted to find the exact modulus of elasticity, shear modulus, and Poisson's ratio, approximated values based on similar materials were used to find an optimal wall thickness of 0.105 in., which is sufficient to withstand the anticipated flight loads with a reasonable factor of saftey. This equates to approximately 3 carbon fiber layers.

Manufacturing

With a design that calls for wrapped body tube construction, it was decided to pursue a wet layup process in order to minimize expendable supplies and average resin content needed, and improve the finish of the final product. The need to construct the body tubes in a very short period of time led to the construction of a body tube rolling jig that can be operated by one person. This includes tube cutting capabilities and features adjustable tension on the dry fabric spool and mandrel. The tube rolling jig pictured below allowed construction of all 7 body tubes segments in two weeks.

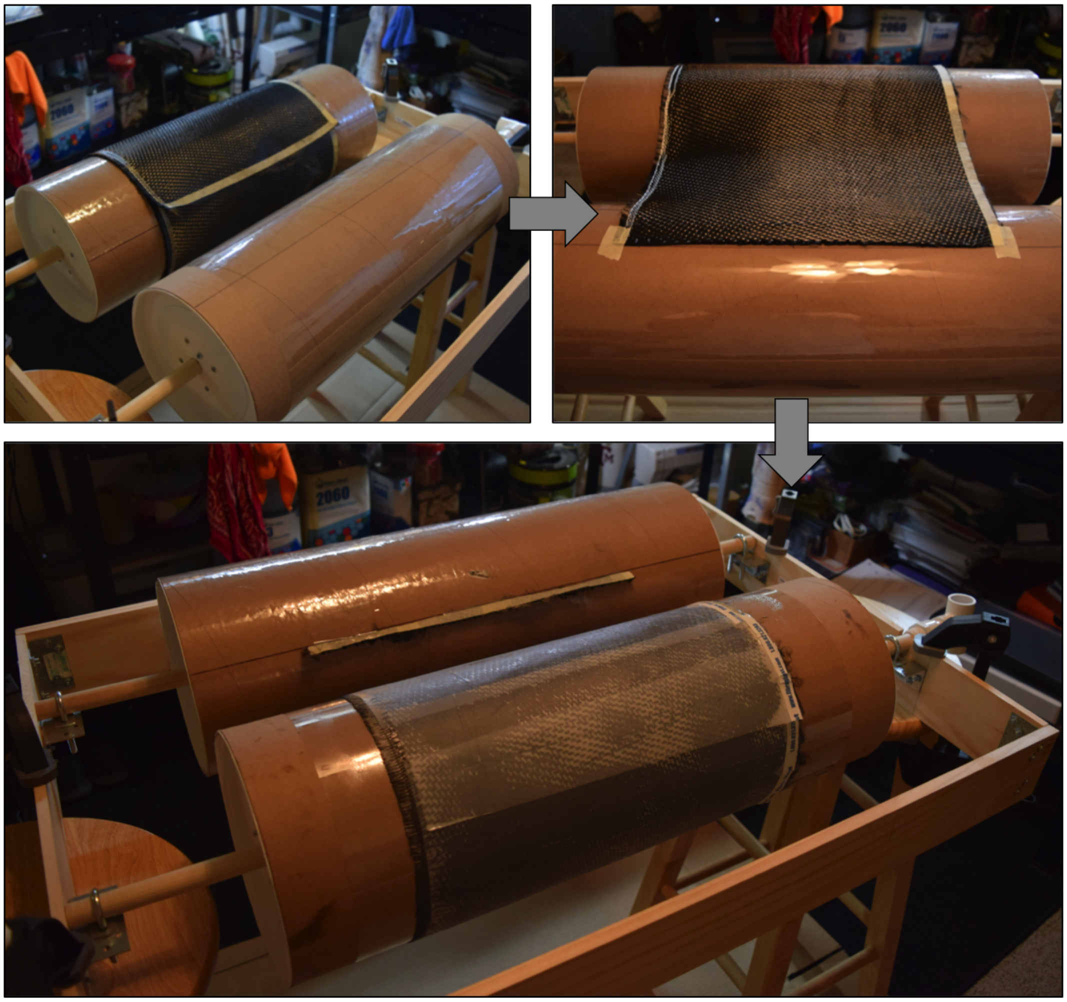

Figure 34. Body tube manufacturing process, dry fabric on spool - wrap/soak fabric on mandrel - peel ply application

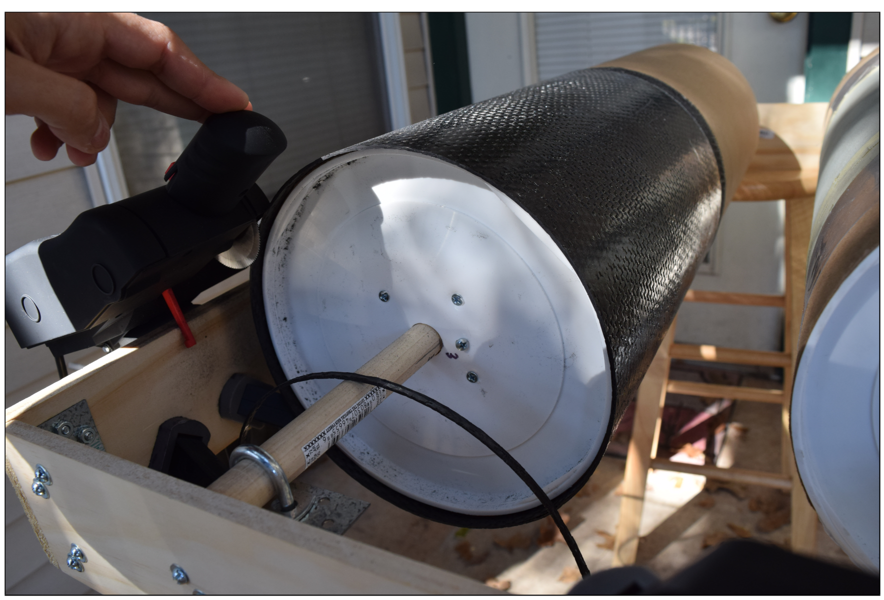

Figure 35. Body tube rolling jig with tube-cutter

Bulkheads & Couplers

Design Discussion

The function of bulkheads are to connect the carbon fiber body tube sections and to help transfer the major loads on the airframe, namely engine thrust and recovery deployment. The bulkheads should be lightweight to maximize the performance of the vehicle, must have high toughness, and must not be compromised by heat transfer from the engine components. The bulkhead's material must be of a reasonable cost and machinability. The desired properties are listed in the table below.

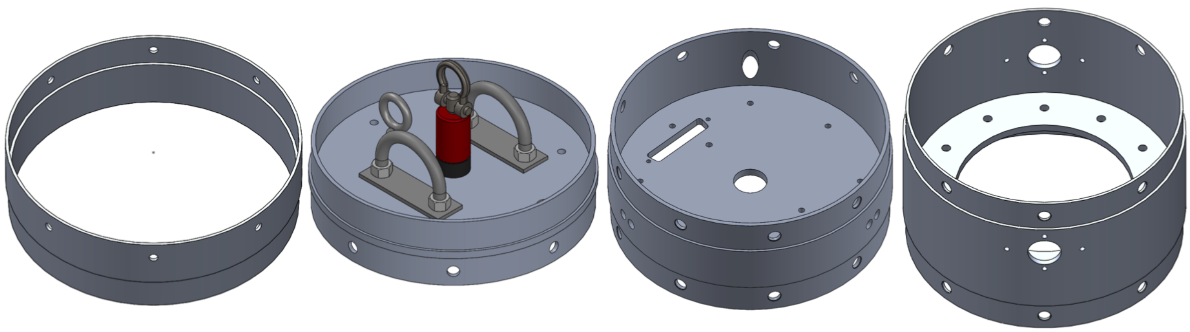

Figure 36. Standard Coupler - Recovery - E-Bay - Thrust

Table 10. Material Properties

Material Prop.	Desired Prop.	Description
Strength	High	High yield strength to withstand deformation
Density	Low	Low density to minimize weight
Toughness	Medium	Toughness allows for energy absorption without deformation
Cost	Low	Low cost allows for
Thermal Expansion Coe.	Low	Resist stress due contraction/expansion

To determine which material to select, the following Ashby charts were used:

The main material categories to consider are alloys, ceramics, and composites. While ceramics can withstand large stresses and heats, and composites have a high strength to weight ratio, neither can be easily formed into the shape that we need within our capabilities. Metal alloys are the best choice because they provide a good balance between the selected properties and because of their ease of machining. Aluminum 6061 was ultimately chosen due to its high strength to weight ratio seen in Figure 39, its favorable fracture toughness seen in Figure 37, its abundant availability, machinability and relatively low cost.

Preparation of any aluminum surface is required for components that will be permanently secured to a composite structure. Using LumaDyne LLC's patented coating process, the aluminum standard couplers were treated with a special chemical bath that grew a polymer layer on the aluminum surface. This polymer layer acts to provide a way for strong covalent bonds to be made with the epoxy that will be used to adhere the components. After surface preparation, all aluminum components are bonded to the carbon fiber body tubes via Fibre Glast 2000 series epoxy. The bond is rated up to 2000 psi shear strength per LumaDyne LLC.

Upon inspection of the possible points of failure in the vehicle, the thrust bulkhead and the standard bulkhead were analyzed under anticipated flight loads. FEA was done in SolidWorks to assess the designs. The maximum tensile load on the standard bulkheads will be the 400 lb. load expected from main parachute deployment. The maximum load on the thrust bulkhead will be 750 lbs. to simulate a hard start of the engine.

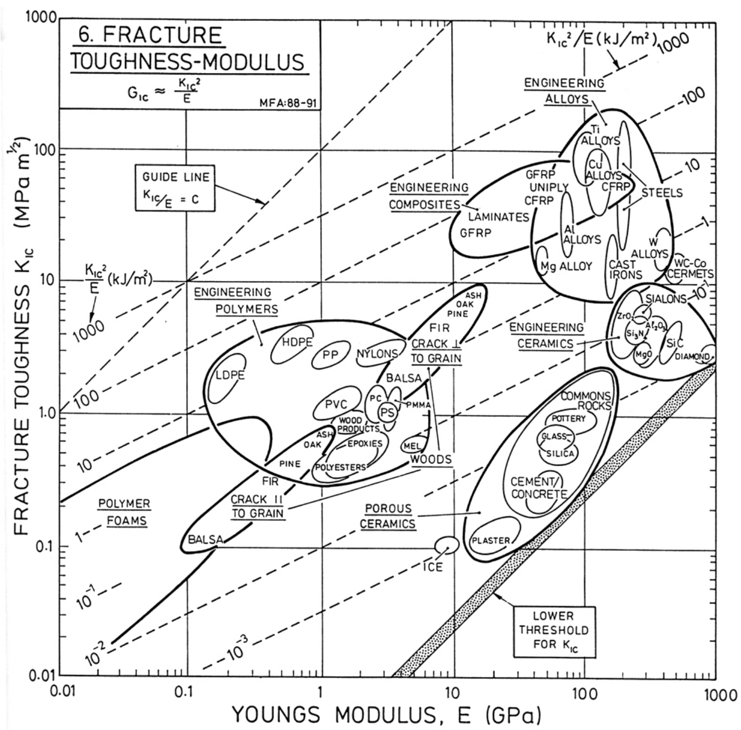

Figure 37. Ashby Chart 1 - Fracture Toughness vs. Young's Modulus

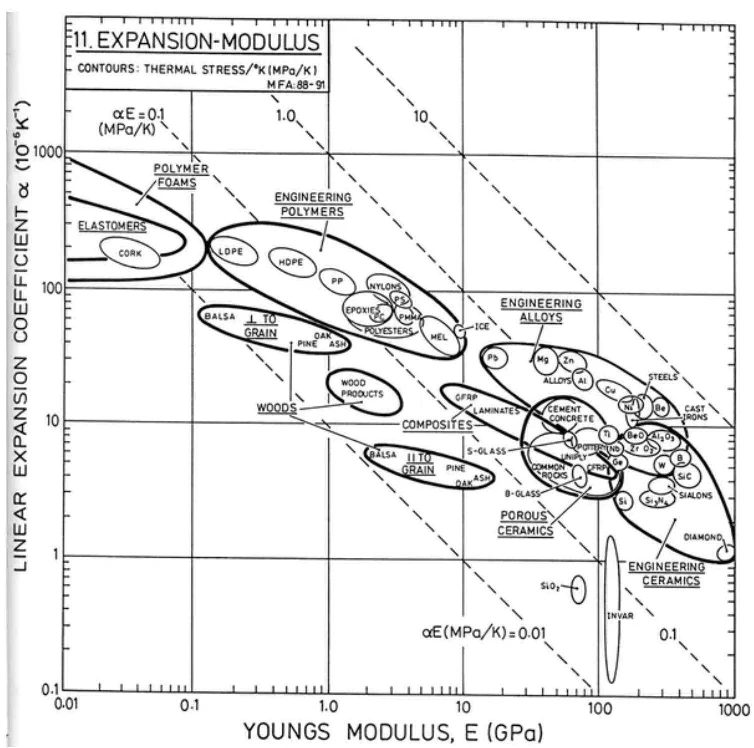

Figure 38. Ashby Chart 2 - Linear Thermal Expansion Coefficient vs. Young's Modulus

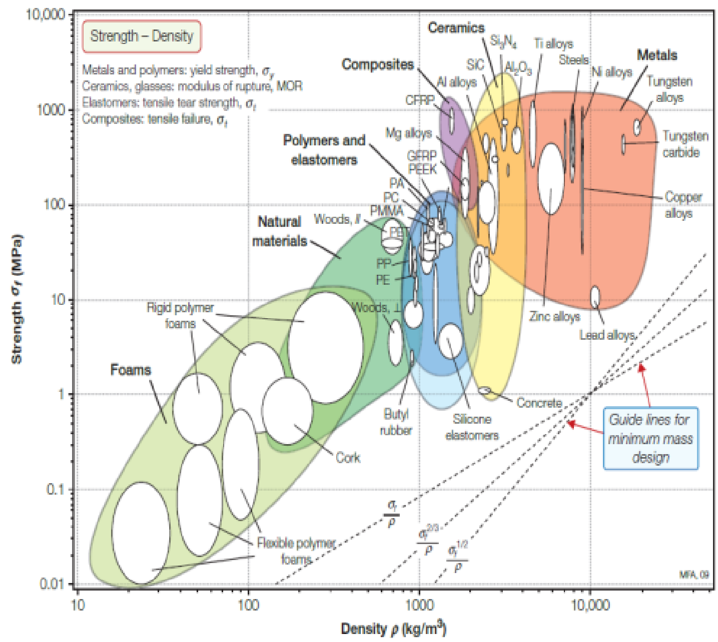

Figure 39. Ashby Chart 3 - Strength vs. Density

Table 11. Stress Analysis Results

Bulkhead	Force Applied (lbs)	Lowest Factor of Safety
Standard Bulkhead	400	12.51
Thrust Bulkhead	750	24.46

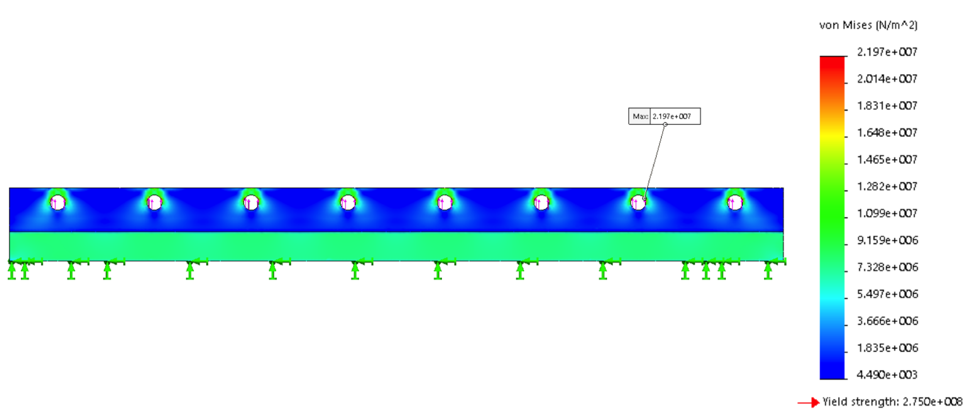

Figure 40. Stress Analysis: Standard Bulkhead

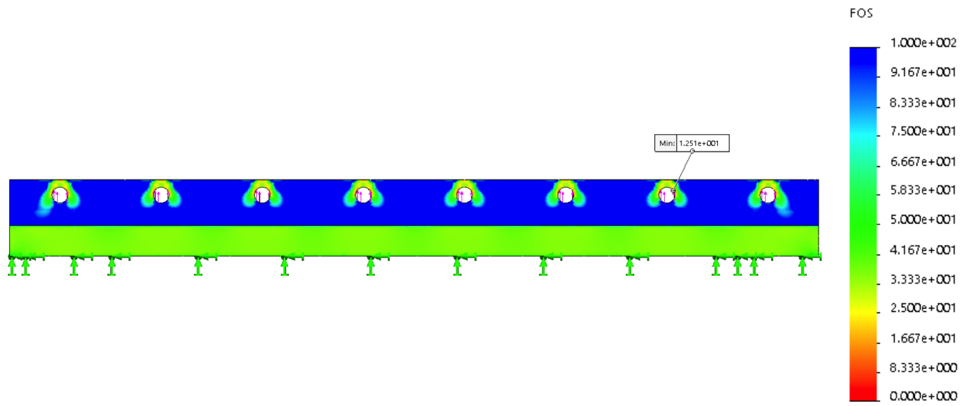

Figure 41. Factor of Safety: Standard Bulkhead

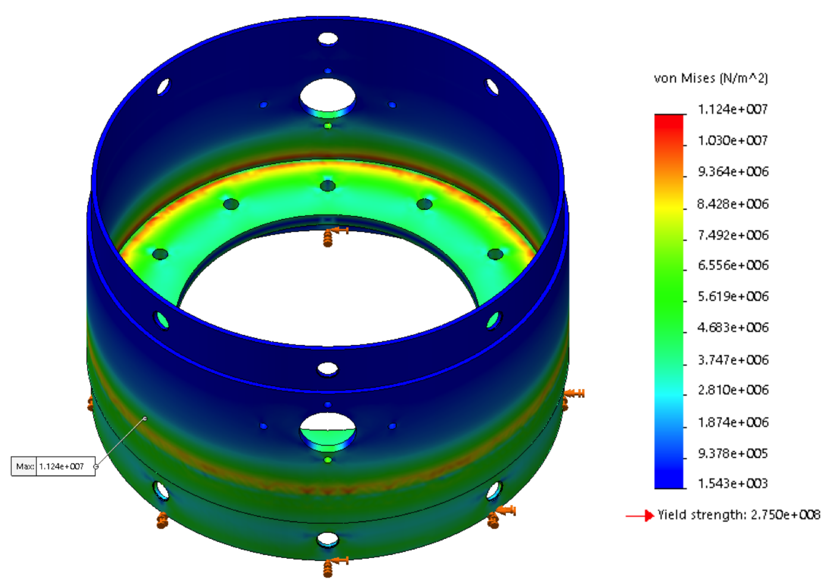

Figure 42. Stress Analysis: Thrust Bulkhead

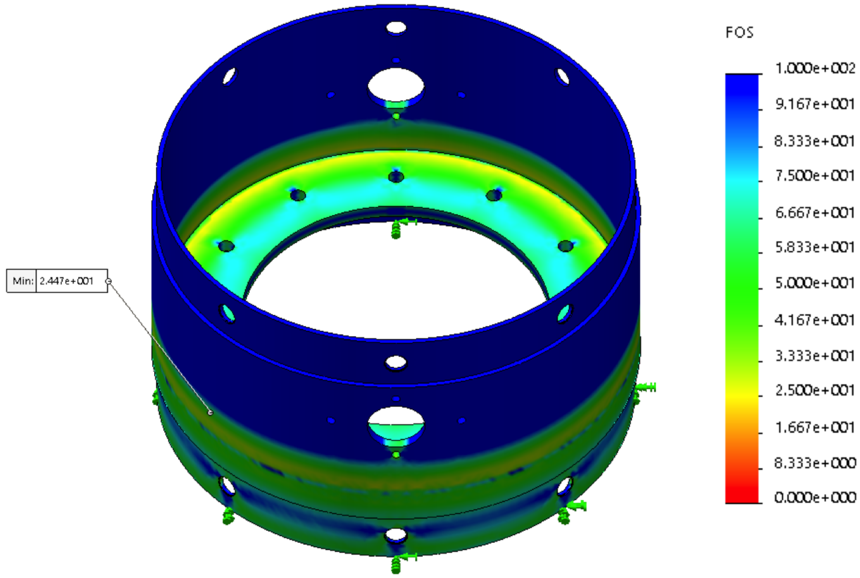

Figure 43. Factor of Safety: Thrust Bulkhead

Manufacturing

The standard bulkheads were machined from 6061-T6 aluminum pipe. The stock was turned down to the final shape on a lathe and the radial holes drilled using a mill with a super spacer attachment. The thrust bulkhead was machined from a solid round billet of 6061-T6 aluminum. Although the billet is substantially more expensive than using pipe and flat plate, the benefits of ensuring the thrust flange is perfectly perpendicular with the centerline of the rocket outweigh the additional costs. The billet was machined on a CNC-lathe to form the flange of the bulkhead and its other major dimensions. Similar to the standard couplers, the thrust bulkhead has its radial holes drilled on the mill.

Fin Can

Manufacturing

With the desire for a lightweight and rigid fin, the decision was made to use high density foam (HDF) as the fin core while carbon fiber would be used for the exterior shell. The process began with cutting the HDF fin cores on a 4-axis CNC. After the fin cores had been cleaned and shaped, a vaccum assisted resin transfer molding process (VARTM) was used to sandwich the fin cores between two layers of carbon fiber fabric. VARTM was chosen over a wet layup due to the active compression onto the foam surface during curing with the added benefit of a lower total resin content. After VARTM had been performed on all three fins, the excess carbon fiber was cut from the edges of the fin using a hand-held rotary tool and then shaped using a file and sanding block.

The three fins were then epoxied to the fin can body tube using Glenmarc G5000 high-strength epoxy. A 3D-printed jig was used to keep the fins normal to the body tube surface during curing. After epoxying each fin on individually, 0.5 in. radius epoxy fillets were applied two at a time across the entire joint. For best results, tape-off the fillet lines such that excess epoxy does not smear onto the fin surface during application. The last step in the process was to perform the tip-to-tip layup to increase the stiffness of the fin can such to avoid warping of the body tube and potential shearing of the fins. A wet layup was performed on each third of the fin can until complete. All carbon fiber edges were sealed with high-strength epoxy such that

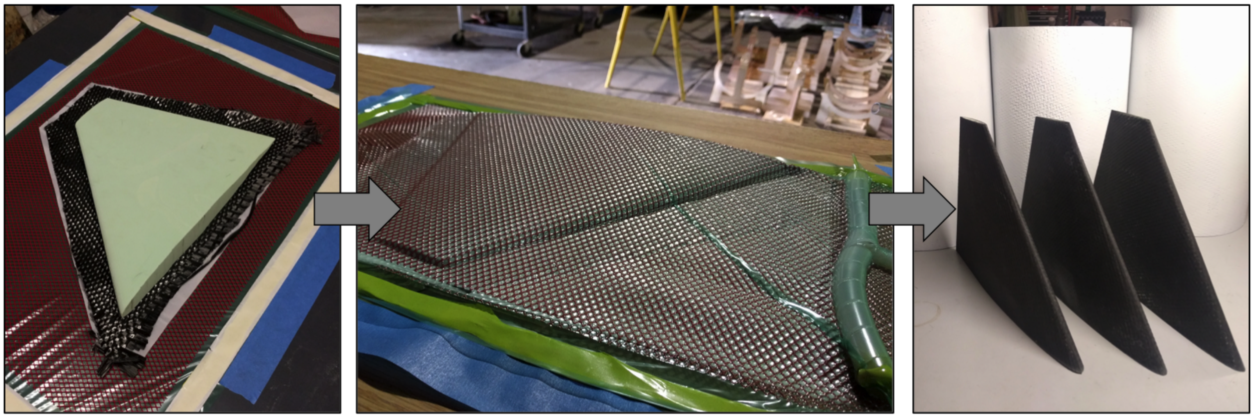

Figure 44. Fin VARTM process, Layup of dry fabrics - vacuum assisted resin transfer - trimmed and sanded fins

air could not act to delaminate the structure during flight.

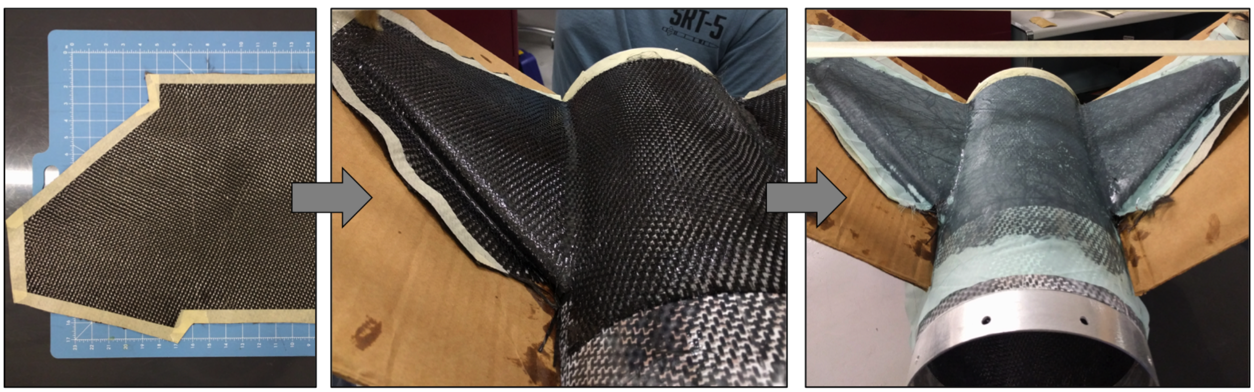

Figure 45. Fin can tip-to-tip layup, dry fabric - wet layup on fin can - peel ply application

V. Recovery

Table 12. Recovery Specifications

Component	Major Dimension	Weight	Max. Load
Recovery Bulkhead	8.42" OD x 2.25" L	1.21 lbs	5200 lbs
Main Parachute	120" diameter	2.43 lbs	3000 lbs (swivel)
Deployment Bag	3" x 9"	.05 lbs	-
Drogue Parachute	54" Cross	.24 lbs	2200 lbs (Shroud Lines)
Tubular Nylon Shock Cord	58' x 1" Tubular Nylon	2.32 lbs	4000 lbs
2 x Kevlar Y-harness	5/8" tubular kevlar x 6' L	.20 lbs ea.	6000 lbs
4 x Quick-links	3/8"-16 Thread	.12 lbs ea.	3600 lbs
RATTworks ARRD	2.37" L	.12 lbs	2000 lbs

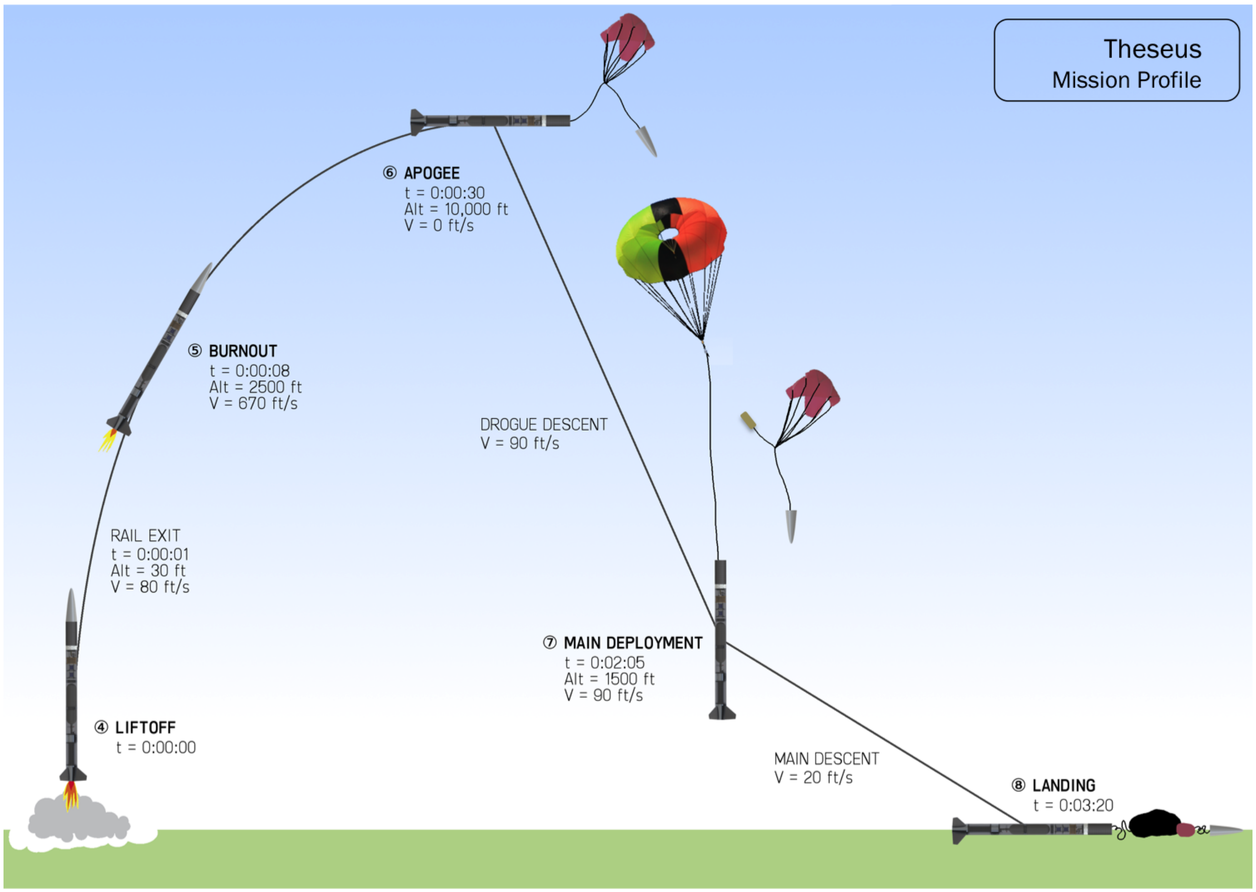

Figure 46. Theseus Mission Profile - Recovery Events

Design

System Requirements

The recovery system encompasses all of the components necessary to bring the vehicle from apogee back to the initial launch altitude in a safe manner that adheres to the NAR (National Association of Rocketry) and TRA (Tripoli Rocketry Association) safety guidelines.

The recovery system must perform all of the following functions to be considered successful:

- Ensure safety of the launch site and surrounding areas
- Minimize the distance of recovery from the initial launch site
- Prevent a harmful impact that may damage the vehicle's structure or internal subsystems by landing at a slow, controlled speed
- Retrieve the vehicle in a manner that ensures the process of the recovery does not cause damage to the airframe or internal sub-systems

Solution Identification

Due to the high altitude and necessity to minimize wind drift SRT's competition vehicle uses a dual deployment recovery system. The team's two-parachutes configuration allows independent deployment at two unique events. The smaller parachute of the two is called the drogue, and is deployed at apogee. The larger parachute, termed the main, is deployed at a pre-determined altitude above the ground later in the recovery process. When properly executed, this system minimizes the horizontal displacement of the rocket from the launch pad because of the faster vertical velocity under the drogue during the majority of the decent. The main parachute is deployed at an altitude of 1,000 vertical feet above the ground, slowing the rocket to a much slower and safer velocity before impact.

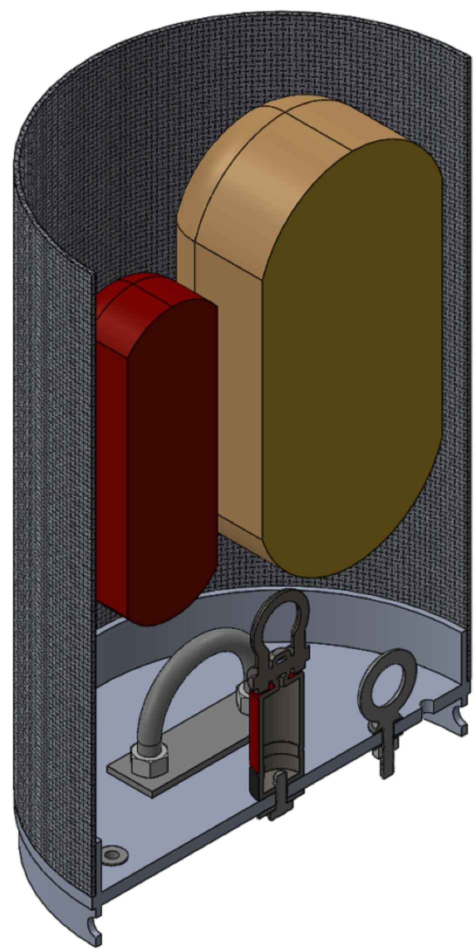

Figure 47. Pre-flight Recovery Bay Configuration (symmetric cross section of recovery bay showing packed drogue and main along with bulkhead hardware)

Deployment Sequence

The recovery events are detailed in the following paragraph. Before the vehicle is loaded onto the launch pad, the recovery bay is packed according to the configuration in figure 48. The ejection charges and pyrotechnic charge used in the ARRD are installed during the vehicle assembly before the vehicle is brought to the pad. The recovery system remains in this configuration from ignition to apogee. A pair of redundant barometric-pressure altimeters on the vehicle are used to sense apogee, and ignite the 7 gram main ejection charge. The expansion of gases from the charge ejects the nose cone, drogue parachute and shock cord as shown in figure 49. The ejected drogue parachute inflates to produce drag on the vehicle assembly as shown in figure 50. The equilibrium descent velocity of the system is approximately 90 ft/s.

Once the vehicle has descended to 1000 feet AGL, the redundant altimeters activate the ARRD via a pair of e-matches. The shackle, now released, allows the deployment bag to be pulled from the recovery bay until the shock cord lines are taut as shown in figure 51. The force of the drogue is now imparted on the deployment bag, effectively pulling it from the main parachute. The now exposed main parachute will inflate and impart a drag force on the vehicle bringing it to a final velocity of approximately 20 ft/s. The vehicle will fall in this configuration for the remaining 1000 feet as shown in figure 52.

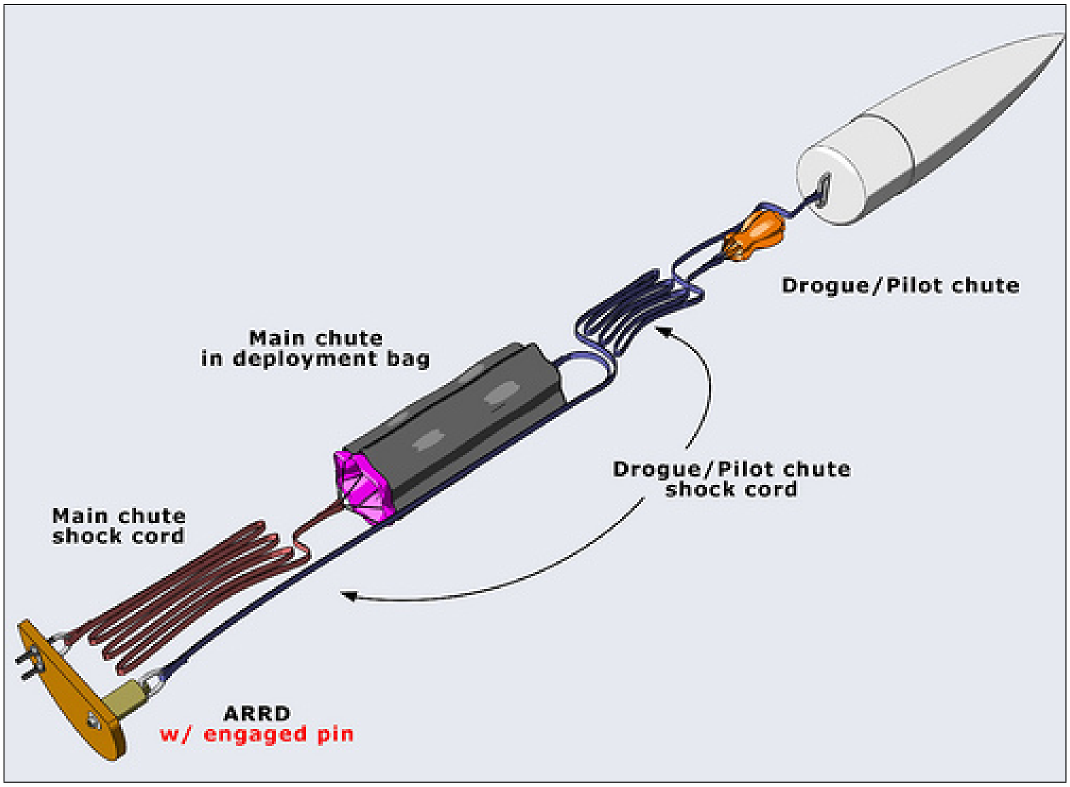

Figure 48. Pre-flight Recovery Bay Configuration

System deployment overview picture courtesy of Giacomo Bosso, TRA# 9986.[31]

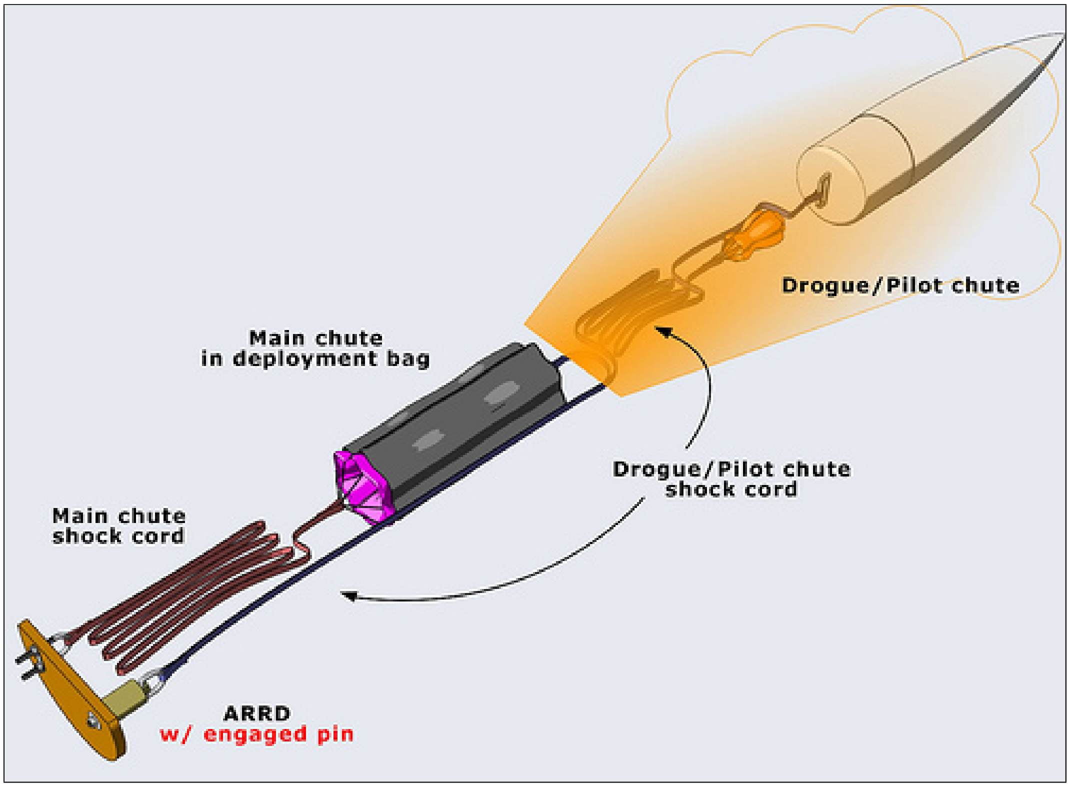

Figure 49. Ejection Charge Ignition at Apogee

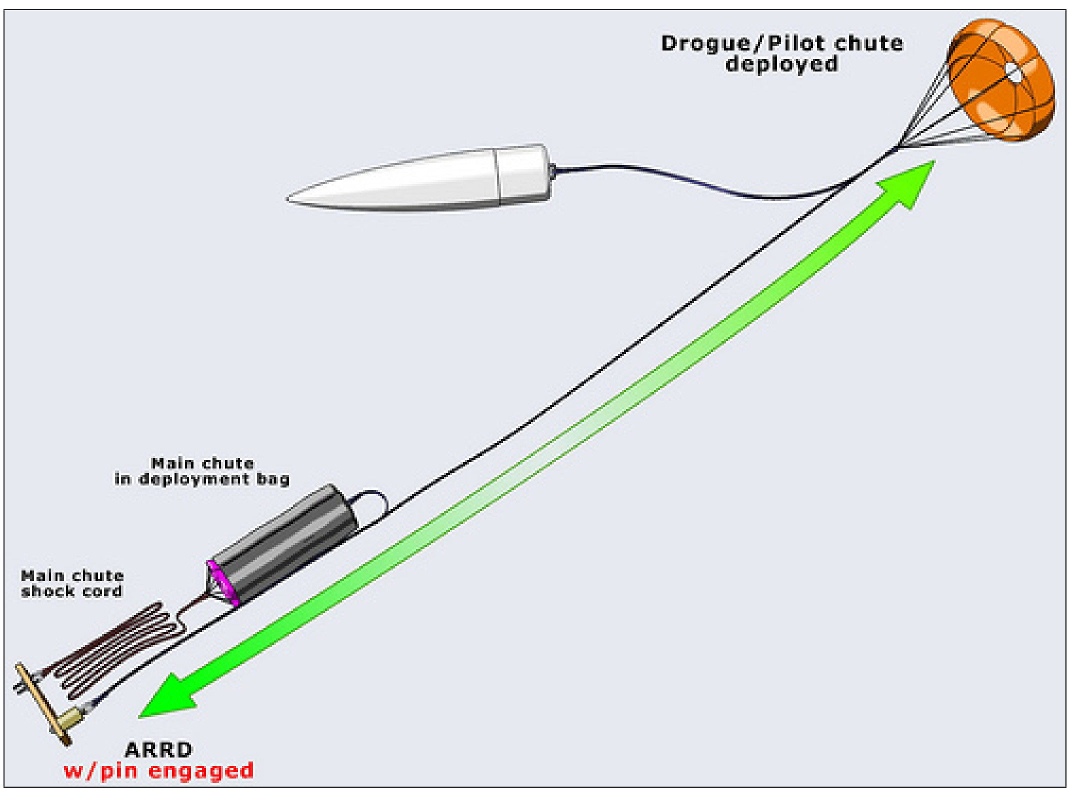

Figure 50. Drogue Deployment (descent configuration from apogee to 1000 feet AGL)

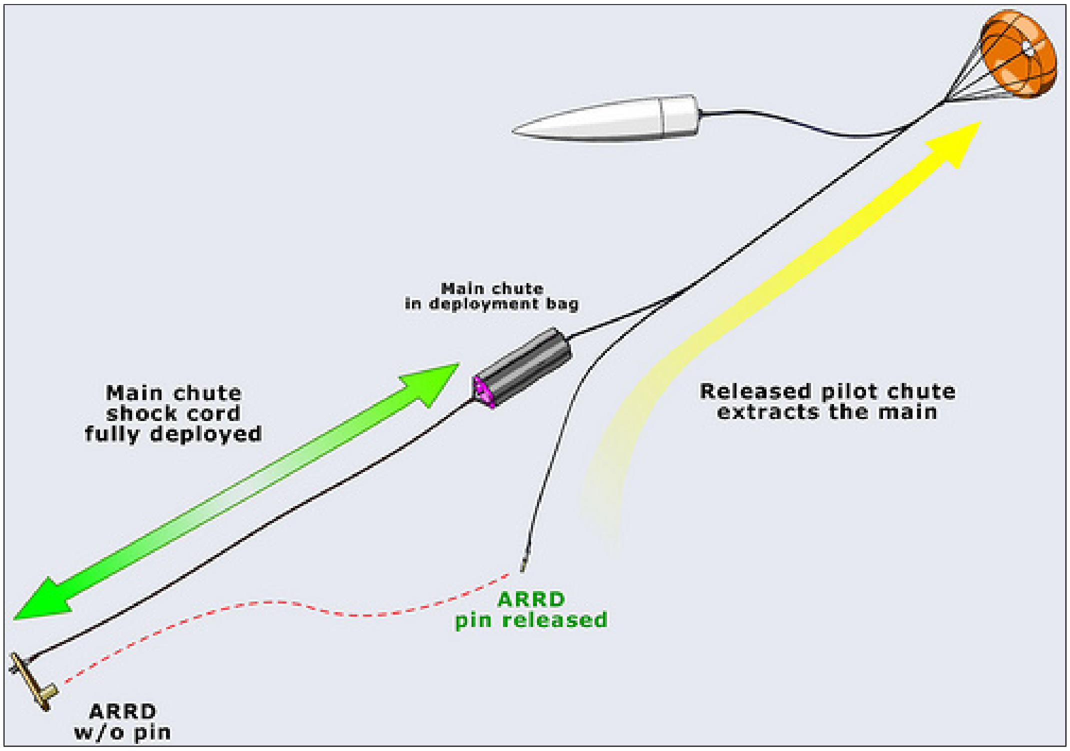

Figure 51. Main Parachute Deployment (activation of ARRD)

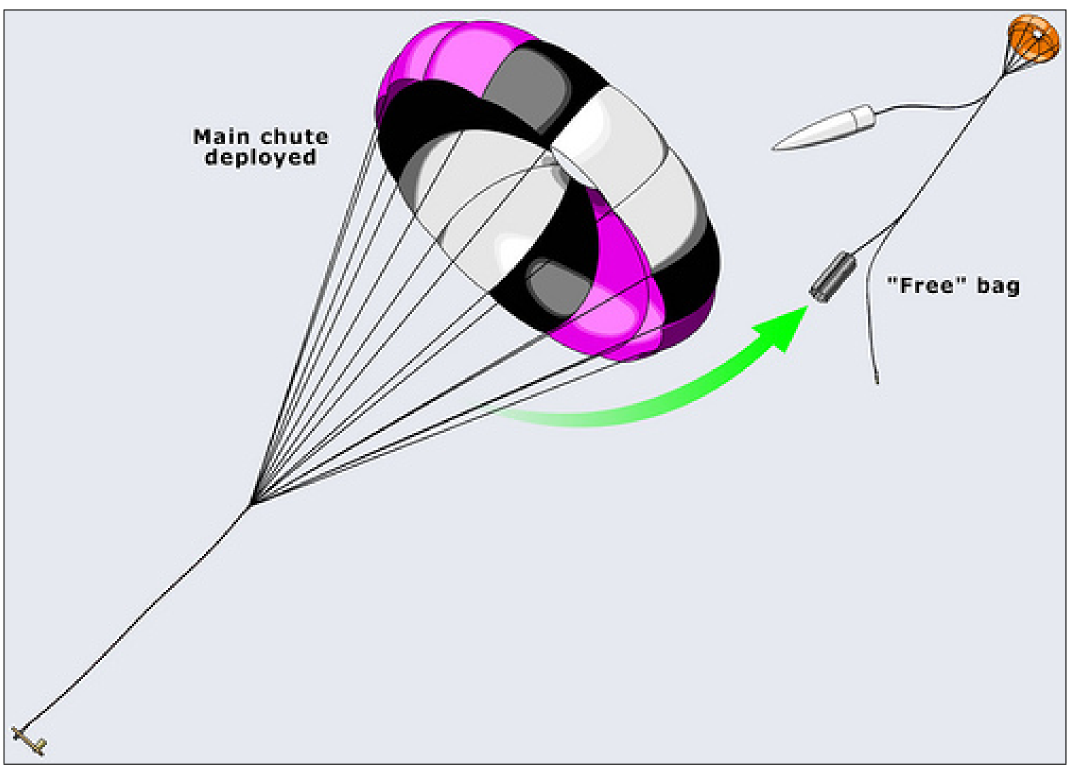

Figure 52. Main Parachute Deployment (main parachute inflation)

Recovery Bulkhead

The selection of components for the recovery system was based on the anticipated loads the system will encounter during its recovery events (the deployment of the drogue and the deployment of the main parachute). Based on the total change in momentum of the system during either recovery events, the deployment of the main parachute was calculated to be largest force. This force was quantified using the impulse-momentum theory[29] applied to the opening of the main parachute. An expression that relates the time rate of change of momentum to the inflation time of the parachute can be seen in equation 5. Using the dry mass of the vehicle and known parameters of the main parachute (i.e. Cd and inflated cross sectional area) the opening force was calculated. A reasonable inflation time for the main parachute was estimated to be between 1.5 - 2.25 seconds (based on timing parachute inflations of similarly weighted vehicles). To refine this approximation, wind-tunnel testing with high speed video of the deployment could be used to find a more precise inflation time window.

The second aspect of calculating the maximum opening force is the acceleration of the vehicle between the time the drogue connection is broken and the main parachute has yet to inflate. During this time the drogue no longer acts on the airframe allowing it to accelerate under gravity before the main parachute is inflated and imparts its drag force on the vehicle. Assuming the system is originally moving at 90 ft/s when the main parachute is released and that the main parachute remains stationary once ejected, a calculation yields an approximate acceleration time and final velocity to be 1.3 seconds and 131 ft/s, respectively. A final velocity of 150 ft/s is used in the calculation of the opening force to model an off-nominal deployment. In flight tests it has been noted that the opening time of the main parachute and the time in which the vehicle accelerates overlap, but to be conservative this calculation assumes them to be two separate events.

$$F_{Max} \approx \frac{2m_{dry}V_i}{t_f - t_i}\left[1 - \frac{V_f}{V_i} + \frac{g(t_f - t_i)}{V_i}\right] \tag{5}$$

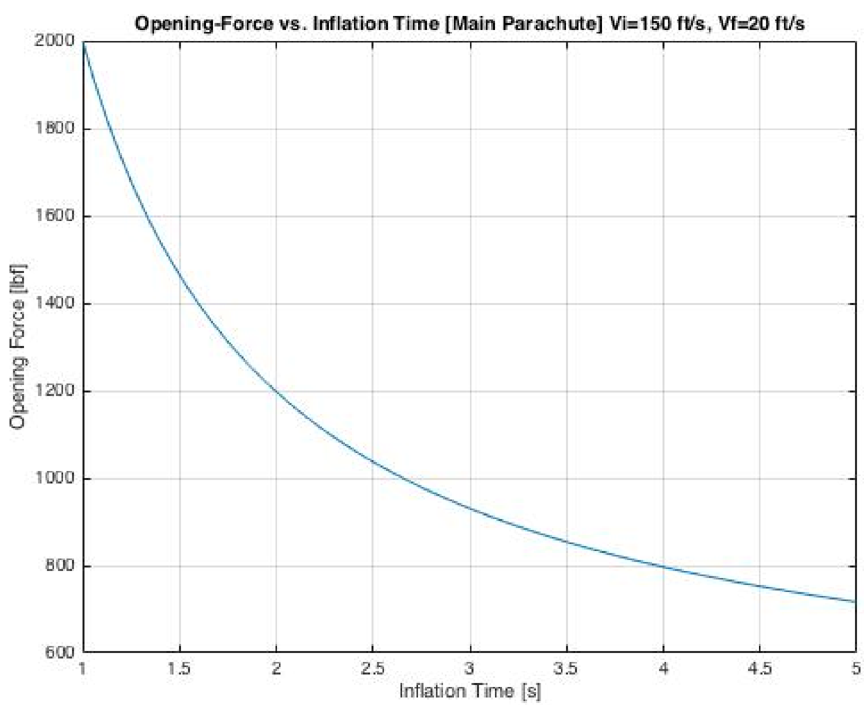

Figure 53. Opening-force as a Function of Parachute Inflation Time (via IM-Theory)

During the inflation of the main parachute the opening force is transferred to the airframe in the direction of the shock cord via the recovery bulkhead. Assuming an inflation time of 1.5 seconds and that the opening force is applied normal to the surface of the recovery bulkhead, impulse-momentum theory yields a maximum opening force of 1,464 lbf. An FEA simulation via SolidWorks 2016 yields a minimum factor of safety of 3.55 in the recovery bulkhead and validates the decision to manufacture the bulkhead 0.25 inches thick. The shear strength of the carbon fiber/aluminum connection (post LumaDyna LLC coating) is rated at 1800 psi. This equates to failure at 46,000 lbf, 31 times that of our nominal opening force.

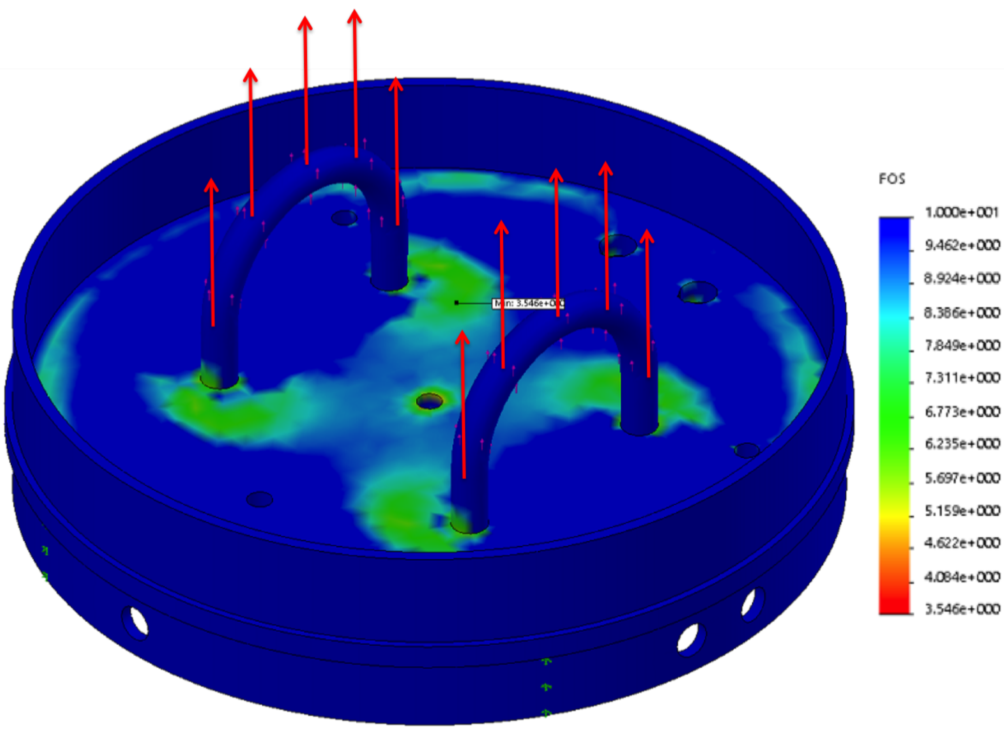

Figure 54. 1464 lbf Opening Force Applied to the Recovery Bulkhead (minimum FOS of 3.55)

Flight Computers

The vehicle's avionics contains two commercial off the shelf (COTS) flight computers. These flight computers main responsibility is to detect the rocket's apogee, and send an electrical signal to fire the appropriate charges at the correct times in the rocket's descent.

Figure 55. Telemega: Primary Flight Computer

The Telemega is the rocket's primary flight computer. Its armed through a screw terminal accessible from the exterior of the vehicle. The flight computer is powered by a 3.2V LiPo battery independent from the main avionics. This ensure the computer has adequate voltage to ignite the ejection charges for the apogee parachute and the pyrotechnic separation of the ARRD systems for the main parachute. Aside from the recovery system, the Telemega also acts as the main altimeter, accelerometer, and gyroscopic sensor for the rocket.

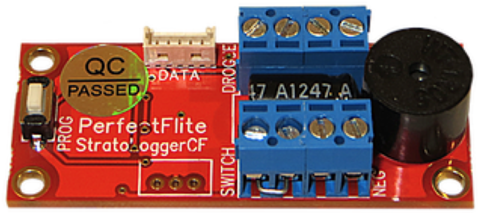

Figure 56. Stratalogger CF: Secondary Flight Computer

Operating independently on a 9V Alkaline battery, the Stratalogger CF is considered a redundant flight computer in the case that the Telemega does not fire the charges correctly. Much like the primary, the secondary is armed through an externally accessible screw terminal. It uses a barometric pressure difference to determine the rockets apogee and when to fire the ejection and pyrotechnic charges. Additionally, it acts as a secondary altimeter to verify the data recorded by the primary flight computer.

VI. Payload

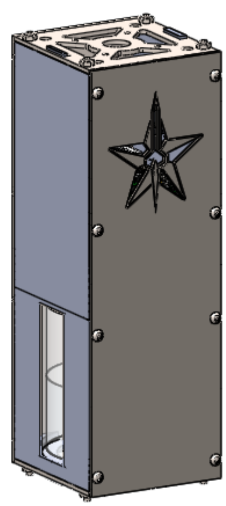

Figure 57. Fully Assembled Payload

Experimental Overview

The goal of the payload is to conduct an experiment that collects both inertial measurements of the rocket's motion and visual measurements of liquid slosh in a scaled-down mock fuel tank. The movement of liquid in the enclosed tank under multi-axial acceleration and gyroscopic motion will be specifically studied in order to calculate the lateral shift in the center of mass associated with the sloshing liquid as the rocket is ascending. The flight data will be analyzed using an in-house developed digital image correlation (DIC) program in MATLAB after the rocket is recovered. One of the main objectives of this experiment will be to produce a verification that the use of digital image correlation to model the 6 degree-of-freedom motion of liquid under rocket acceleration is a feasible method for our team to predict liquid slosh in the rocket's on-board oxidizer tank.

Experiment Methods

The experiment materials consist of a clear cylindrical tank, a floating device, and a camera for observing the activity inside of the tank. The cylindrical tank is needed for containing the liquid, which in our experiment is water. The floating device designed and fabricated by the team will float on the surface level of the water and will be representative of the liquid surface. And lastly, a single camera will face down from a position above the tank, where it will record the motion of the floating device.

The camera will record the planar surface level motion, and each image taken will be processed through an in-house Digital Image Correlation (DIC) program. The program will output the angle of the liquid in the tank relative to the camera based off of the changing geometry of the floating device. Once each frame has been processed, the program will output a video of the planar motion of the liquid surface based on results calculated from the flotation device.The process itself is outlined in the following paragraphs.

Components & Materials

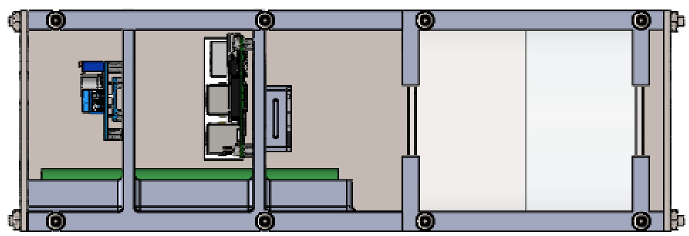

Figure 58. Fully Assembled Payload

Frame

The payload will be housed in a standard 3U cubesat frame, as per IREC's rules and regulations regarding payload specifications for 2018. The structure will be made from Aluminum Alloy 6061-T6 and all electronics will mount onto a 3D-printed wall designed to interface with the remaining structure. This will ensure easy assembly and a secure position of the electronics. The experiment housing will interface with the rocket's payload bay via the payload bulkhead, located underneath the rocket's main flight card and avionics. The payload will interface with the payload bulkhead via a steel mounting plate fastened to the bottom of the payload bay so that the payload itself is not a load bearing structure.

Tank

The tank will be made of an acrylic material purchased by the team. The fluid tank consists of a hollow cylindrical tube, which will be sealed off by chemically bonding two acrylic disks to the open ends of the tank with an acrylic cement. The inside of the tank will be coated with an anti-fogging agent that will prevent the build-up of humidity within the tank, which will maintain a clear image for the camera. The tank will be fixed to the bottom of the payload, with LED lights fixed below the tank to provide the contrast necessary for the DIC program. In the case of a leak, the payload section is sealed off from the rest of the rocket, putting only the experiment's electronics at risk.

Electronics

The Raspberry Pi 3 Model B+ will be used to log all sensor and camera data, and will also act as the main flight computer for the payload. The micro-controller will be responsible for triggering the camera and time-stamping the images to match with IMU data. Lastly, it will operate the tank lights to provide image contrast. Powered by a 7.4 volt 3 Amp-hour NiMH battery, the payload will have a pad life of approximately 5 hours once turned on. All inertial measurements will be obtained using a commercial 9-DOF inertial measurement unit (IMU). The data obtained from this unit will act as a control when post processing the data obtained from the camera images.

Fluid Imaging Device

The device used to determine the fluid sloshing angle via the mounted camera is a buoyant, triangular structure made of balsa wood, shown in Figure 59 and Figure 60. Though the design of this structure is fairly straightforward, every aspect is critical to providing the most accurate orientation measurement possible using the in-house Digital Image Correlation (DIC) code. By analyzing the video frame-by-frame in the DIC program, it is possible to use the geometries of this structure to output the actual orientation of the fuel with respect to the mounted camera, and therefore with respect to the rocket. The angle of the fluid can then be used to make calculations leading to the location of the center of gravity of the fluid itself.

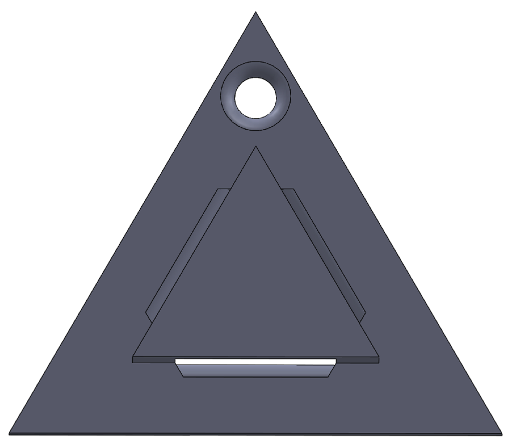

Figure 59. Fluid Imaging Device - Camera View

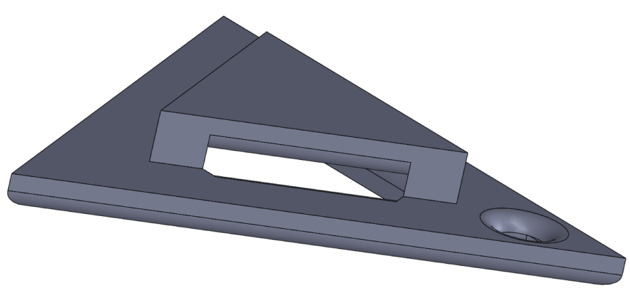

Figure 60. Fluid Imaging Device - Side View

The first level of interaction between the DIC code and the structure relies solely on the outermost triangle, or the base of the floating structure. Using the contrast in the image between the backlighting and the structure itself, the code determines where each of the three corners of the outermost triangle are located. Using these three points, each of the side lengths and angles of the outer triangle can be determined.

The second level of interaction utilizes the outer triangle corner locations to conduct a localized search for the single, circular hole located at only one of the corners. This hole serves to determine the rotation angle of the flotation device. At this stage, a second "dummy" triangle is created in the code in order to determine the devices orientation with respect to the camera. The "dummy" triangle, with same dimensions as that of the outer triangle, is rotated at the rotation angle determined by the circular hole (i.e. yaw), aligning the directions of the corners of the two triangles. A sweep is then conducted with the 'dummy' triangle for both the pitch and the roll rotations until the difference between the 'dummy' triangle and outer triangle angles is minimized. This step results in two potential orientations which are 180 degrees out of phase from each other.

The final step in the analysis focuses primarily on the innermost triangle, or the raised section of the floating device. The elevated center triangle provides a gap between the top of the base triangle and the bottom of the elevated triangle. Upon any change in the flotation device's angle from the horizontal, a slight gap will appear between the two triangles due to the backlighting. By locating these streaks of backlighting penetration, it is automatically understood that that side is located closest to the camera. Therefore, the fluid slosh can be narrowed down to a single orientation per frame, enabling the calculation of the liquid geometry, and hence the center of gravity of the fluid at every point in time during the flight.

VII. Mission Concept of Operations Overview

Description

There are four major subsystems that pertain to hybrid rocket launch operations. The Launch Control System (LCS) encompasses the custom built launch box, control and DAQ computers, and all RF communication infrastructure. The launch box is a system of relays and microprocessors that handle both command functions to the rocket and DAQ functions to and from the rocket and launch pad. The Oxidizer Loading System (OLS) is responsible for filling the flight tank and making sure the rocket is primed for lift off. OLS contains the oxidizer fill tank, the environmental control unit (temperature control box), fill and vent lines, and quick disconnects and it's supporting pneumatic and electrical systems. The OLS is supported by the LCS for command relay purposes. The Flight Propulsion System (FPS) contains the oxidizer flight tank, plumbing, ball valve actuation unit, injector, combustion chamber, and supporting sensor package. The FPS is controlled through breakaway line connection with the LCS. The Propulsion Ignition System (PIS) provides the energetics to begin the combustion reaction of the FPS. PIS encompasses the ignitor and the oxygen priming unit. The Vehicle Recovery System (VRS) is defined as the primary and secondary COTS flight computers, GPS module, and all parachute, shock cords, release mechanisms, and ejection charges.

Figure 61 outlines the operational process of the remote launch system and the ground control station.

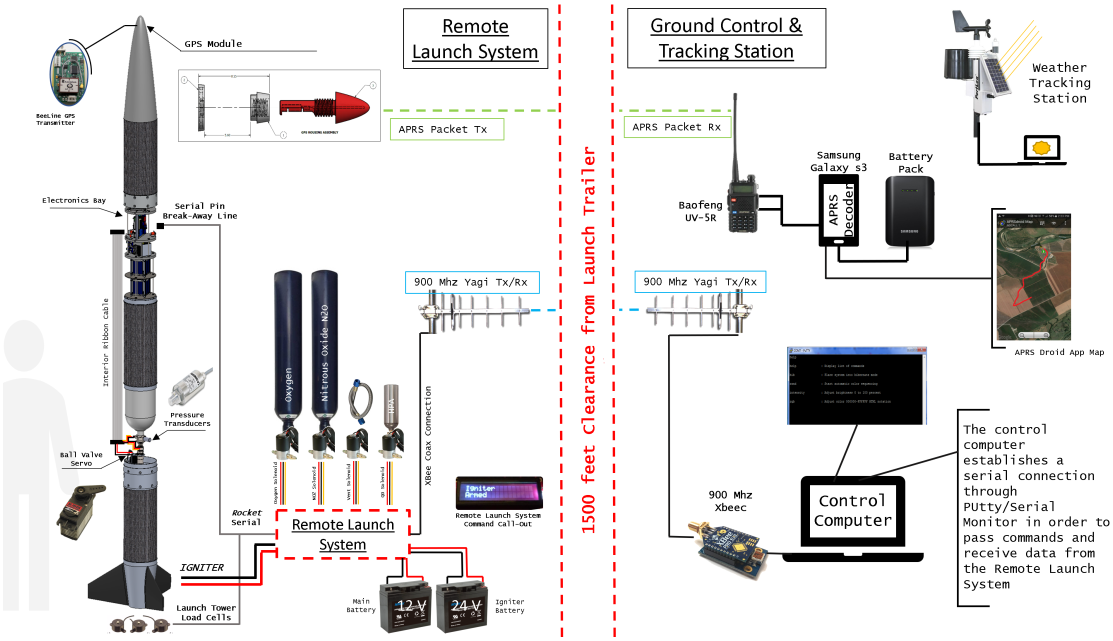

Figure 61. Overview of Electronic System Operations

Figure 62 graphically summarizes the mission phases.

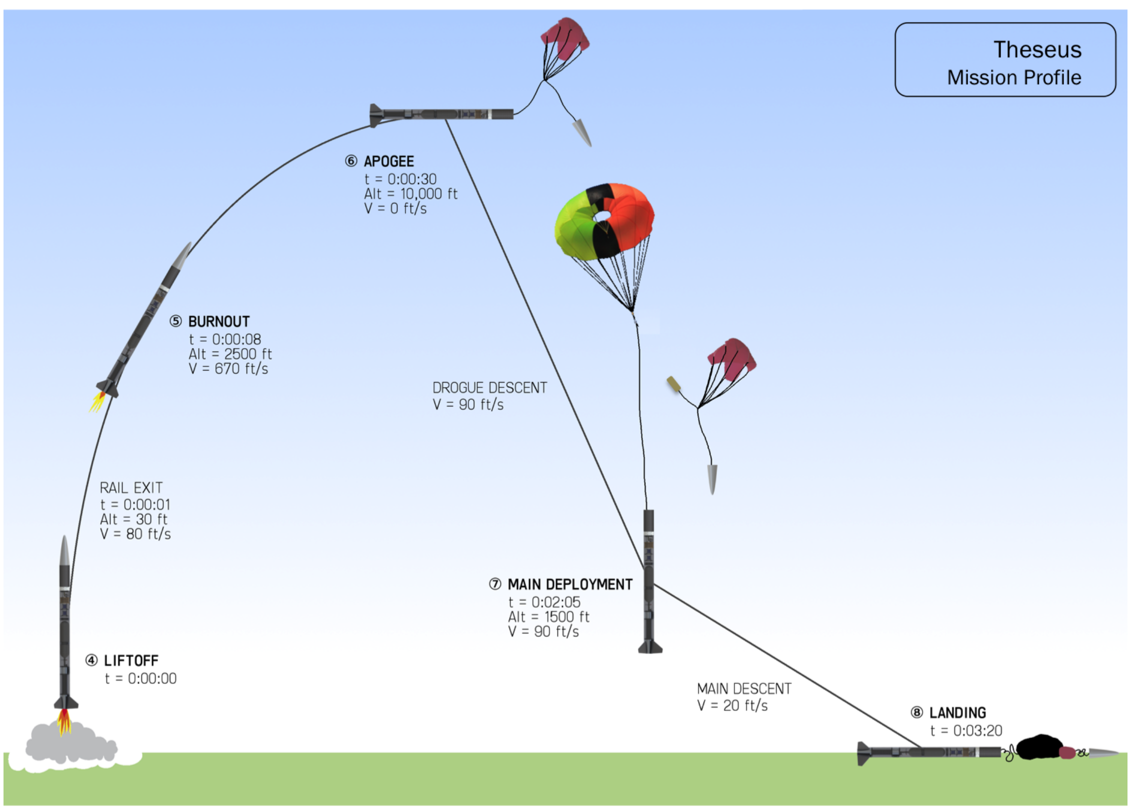

Figure 62. Daedalus Mission Profile, Phases 4-8

Definitions

Launch Control System, LCS – Launch box, computers
Oxidizer Loading System, OLS – Environmental control unit, fill tank, solenoids, QD
Flight Propulsion System, FPS – Oxidizer Tank, ball valve, combustion chamber
Propulsion Ignition System, PIS – Igniter, oxygen priming
Vehicle Recovery System, VRS – Flight computers, parachutes, GPS

Mechanical Safe, MS – Tank valves, tank regulators, turn keys/switches
Software Safe, SS – Digital command

Mission Phases

Assumptions: Rocket on pad, vertically installed

Energetic device safed and armed status are defined according to section 4 of the Spaceport America Cup *Intercollegiate Rocket Engineering Competition Design, Test, & Evaluation Guide*. Events listed in tables are the result of defining mission event.

SYSTEM PRIME
Defining mission event: Power provided to LCS/VRS

LCS	OLS	PIS	FPS	VRS
ARMED	SAFED	SAFED	NON-ENERGETIC	ARMED
Powered	2×MS, 2×SS	3×MS, 2×SS	Unpressurized	Powered
Check for RF Check igniter resistance	Fill Hose - *Connected* Vent Hose - *Connected* Oxidizer Fill Tank - *Closed* Solenoids - *Open*	Oxygen Tank - *Closed* Solenoids - *Closed* Igniter - *Installed/Shunted* Oxygen Sting - *Installed*	Ball Valve - *Closed* Oxidizer Tank - *Uncharged* Combustion Chamber - *Fuel loaded/greased*	Flight Computers - *Powered* Drogue Chute - *Internal* Main Chute - *Internal* Ejection Charges - *Installed*

personnel clear ——

FILL
Defining mission event: Command sent to open ”N_2O Fill” solenoid

LCS	OLS	PIS	FPS	VRS
ARMED	ARMED	SAFED	SAFED	ARMED
Powered	Active	1×MS, 2×SS	1×MS, 2×SS	Powered
Recording load cell Recording engine pressures Maintain RF connectivity	Fill Hose - *Connected* Vent Hose - *Connected* Oxidizer Fill Tank - *Open* Solenoids - *Open*	Oxygen Tank - *Open* Solenoids - *Closed* Igniter - *Installed* Oxygen Sting - *Installed*	Ball Valve - *Closed* Oxidizer Tank - *Pressurized* Combustion Chamber - *Fuel loaded/greased*	Flight Computers - *Powered* Drogue Chute - *Internal* Main Chute - *Internal* Ejection Charges - *Installed*

IGNITE

Defining mission event: Command sent to turn ball valve in rocket plumbing system which allows N_2O to flow into the combustion chamber from the internal oxidizer run tank

LCS	OLS	PIS	FPS	VRS
ARMED	SAFED	ARMED	ARMED	ARMED
Powered	1×MS, 2×SS	1×MS, 2×SS	Active	Powered
Maintain RF connectivity Record load cell Record engine pressures Send commands	Fill Hose - *Disconnected* Vent Hose - *Disconnected* Oxidizer Fill Tank - *Open* Solenoids - *Closed*	Oxygen Tank - *Open* Solenoids - *Open* Igniter - *Active* Oxygen Sting - *Active*	Ball Valve - *Open* Oxidizer Tank - *Pressurized* Combustion Chamber - *Ignited*	Flight Computers - *Powered* Drogue Chute - *Internal* Main Chute - *Internal* Ejection Charges - *Installed*

LIFTOFF

Defining mission event: Rocket clears launch tower and breakaway lines sever

LCS	OLS	PIS	FPS	VRS
ARMED	SAFED	SAFED	ARMED	ARMED
Powered	1×MS, 2×SS	1×MS, 2×SS	Active	Powered
Maintain RF connectivity Record load cell Record engine pressures Send commands	Fill Hose - *Disconnected* Vent Hose - *Disconnected* Oxidizer Fill Tank - *Open* Solenoids - *Closed*	Oxygen Tank - *Open* Solenoids - *Closed* Igniter - *non-energetic* Oxygen Sting - *non-energetic*	Ball Valve - *Open* Oxidizer Tank - *Pressurized* Combustion Chamber - *Pressurized*	Flight Computers - *Powered* Drogue Chute - *Internal* Main Chute - *Internal* Ejection Charges - *Installed*

BURNOUT

Defining mission event: Engine unchokes

LCS	OLS	PIS	FPS	VRS
SAFED	SAFED	SAFED	ARMED	ARMED
2×SS	1×MS, 2×SS	1×MS, 2×SS	Active	Powered
Maintain RF connectivity Send solenoid shut-off commands	Fill Hose - *Disconnected* Vent Hose - *Disconnected* Oxidizer Fill Tank - *Open* Solenoids - *Closed*	Oxygen Tank - *Open* Solenoids - *Closed* Igniter - *non-energetic* Oxygen Sting - *non-energetic*	Ball Valve - *Open* Oxidizer Tank - *Pressurized* Combustion Chamber - *Pressurized*	Flight Computers - *Powered* Drogue Chute - *Internal* Main Chute - *Internal* Ejection Charges - *Installed*

APOGEE
Defining mission event: Command send to fire ejection charges

LCS	OLS	PIS	FPS	VRS
SAFED	SAFED	SAFED	NON-ENERGETIC	ARMED
2×SS	1×MS, 2×SS	1×MS, 2×SS	Active	Active
Maintain RF connectivity Send solenoid shut-off commands	Fill Hose - *Disconnected* Vent Hose - *Disconnected* Oxidizer Fill Tank - *Open* Solenoids - *Closed*	Oxygen Tank - *Open* Solenoids - *Closed* Igniter - *non-energetic* Oxygen Sting - *non-energetic*	Ball Valve - *Open* Oxidizer Tank - *Unpressurized* Combustion Chamber - *Unpressurized*	Flight Computers - *Powered* Drogue Chute - *Active* Main Chute - *Internal* Ejection Charges - *Activated*

MAIN DEPLOYMENT
Defining mission event: Command send to fire Advance Retention Release Device charge

LCS	OLS	PIS	FPS	VRS
SAFED	SAFED	SAFED	NON-ENERGETIC	NON-ENERGETIC
2×SS	1×MS, 2×SS	1×MS, 2×SS	Active	Active
Maintain RF connectivity Send solenoid shut-off commands	Fill Hose - *Disconnected* Vent Hose - *Disconnected* Oxidizer Fill Tank - *Open* Solenoids - *Closed*	Oxygen Tank - *Open* Solenoids - *Closed* Igniter - *non-energetic* Oxygen Sting - *non-energetic*	Ball Valve - *Open* Oxidizer Tank - *Unpressurized* Combustion Chamber - *Unpressurized*	Flight Computers - *Powered* Drogue Chute - *Active* Main Chute - *Active* Ejection Charges - *non-energetic*

LANDING
Defining mission event: Rocket body impacts ground

LCS	OLS	PIS	FPS	VRS
NON-ENERGETIC	SAFED	SAFED	NON-ENERGETIC	NON-ENERGETIC
Unpowered	2×MS	3×MS	Unpressurized	Pyros depleted
Maintain RF connectivity Send solenoid shut-off commands	Fill Hose - *Disconnected* Vent Hose - *Disconnected* Oxidizer Fill Tank - *Closed* Solenoids - *Closed*	Oxygen Tank - *Closed* Solenoids - *Closed* Igniter - *non-energetic* Oxygen Sting - *non-energetic*	Ball Valve - *Open* Oxidizer Tank - *Unpressurized* Combustion Chamber - *Unpressurized*	Flight Computers - *Powered* Drogue Chute - *Inactive* Main Chute - *Inactive* Ejection Charges - *non-energetic*

VIII. Conclusion and Lessons Learned

This year marked SRT's fifth year of existence, and with it came a wealth of lessons. Over the past five years the team has honed and improved its ability to properly manage and grow its members both technically and professionally.

Team Management Lessons Learned

Every team lead must understand that their position actually encompasses two roles: that of a manager and of a leader. A leader must provide overarching goals, be personable, and inspire members. A manager must assign tasks, coordinate activities, and ensure that deadlines are met. Every sub-team manager on SRT must assign tasks and set a schedule for their team that respects their members and encourages them to excel. It is important for a manager to understand their members and know when it is appropriate to let them struggle and when to offer guidance. They must find the balance which pushes their members to grow without overwhelming them with excessive assignments. They must excite their members to enjoy their hard work and achieve their goals. The core objective of the Sounding Rocketry Team remains to develop its members technically, professionally, and personally.

It is imperative that the management team set a master schedule at the start of the project. Goals and milestones should be associated with this schedule and sub-teams should build their plans around it. The master schedule will aid the team by: gaging the amount of work necessary to achieve the primary goal of the team (participating at IREC), prioritizing tasks, and providing a realistic scope of the progress that can be made in the given time frame. Being a team of enthusiastic students, SRT members have a tendency to over commit their time. A team should not be so married to their schedule that they allow it to derail progress; SRT has learned to frequently audit its schedule to determine if the progress being made aligns with the overarching schedule. If a project is costing more than the predicted time and financial allowance then its criticality shall be evaluated. SRT does this continually, allowing the team to focus on the most pertinent assignments to the team competing this summer. Setting big-picture goals with associated dates holds the team accountable and allows the team to hone in on the critical path to competition.

A major lesson tackled this year was that of organization and version control. In light of previous team's experiences, this year's team decided to implement a cleaner and more user friendly file structure in its main file repository. This increased the use and effectiveness of the repository and proved that members will use systems that are easy to interact with and navigate. Version control was implemented in the team's CAD and software updates. A selected CAD reviewer acts as the gate keeper to master assemblies and ensures that all changes made to the CAD assemblies are properly documented and approved by the appropriate managers. GitHub and software change review meetings are now utilized by the team to track and approve all changes to software. Both of these systematic checks have allowed the team to make rapid developments without fear of retribution from unapproved changes.

Technical Lessons Learned

Communication is key when dealing with a highly technical team that works on complex systems. Each member is expected to present their progress on individual assignments and raise concerns every week during team-wide general meetings. It is crucial that each member on the team is aware of changes occurring on other sub-teams, especially when changes are being made to flight critical components.

Testing components is a critical phase of any engineering project. SRT has learned that testing in as close to flight configuration as possible offers the best filter for potential issues. The team uses its avionics to run hydrostatic tests, performs range testing of communication systems, and conducts mock launches all in attempt to catch issues which might arise during a launch. This also give the team an opportunity to reflect on the safety of their operations and improve procedures to ensure a smooth execution on launch day.

Strategies for Knowledge Transfer

Over the past five years SRT has learned the importance of proper documentation. Being that the team has generated an impressive amount of paperwork, a heavy emphasis was placed on file organization this year. The team's file repository (Google Drive) served a pivotal role in efficiently providing information to the team. How-to guides, operating procedures, reports, presentations, and media are all stored in an easy to access and navigate manner. The team also produces a design report which encompasses all managerial and design decisions made by the members. This report acts as an all-encompassing reference and contains enough information for future teams to operate independently of legacy members.

Younger member recruitment is another method of investment in knowledge retention. By attracting younger members, the team has the opportunity to instill the institutional and operational knowledge which the team has developed thus far. Young members grow with the team and can make great contributions to its development as a result of the experience they gain. Consequently, member retention is key to team success. The ideas and time of members are respected and their contributions are rewarded with technical expertise and personal skills they will use throughout their careers.

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- **Dr. Thomas Pollock** Senior Associate Professor for the Department of Aerospace Engineering and senior advisor of the Sounding Rocketry Team
- **Dr. Adonios Karpetis** Associate Professor for the Department of Aerospace Engineering and faculty advisor of the Sounding Rocketry Team
- **Mr. Evan Marcotte** Propulsion and Testing Engineer at Blue Origin and founder of the Sounding Rocketry Team
- Former team directors: **Mr. Evan Marcotte** (SRT-1), **Ms. Stephanie Recchia** (SRT-2), **Mr. Gabriel Aguilar** (SRT-3), and **Mr. Alexander Pages** (SRT-4)
- Members of previous teams (SRT-1, SRT-2, SRT-3, and SRT-4)

The support of all of these individuals has provided the Sounding Rocketry Team with critical guidance and leadership that has shaped the team and furthered its organizational efforts.

References

[1]Knacke, T.W.. Parachute Recovey Systems Design Manual. Naval Weapons Center, China Lake, 1992. Print.

[2]Sadeck, J., and Lee, C., 'Continuous Disreefing Method for Parachute Opening', Journal of Aircraft, vol. 46, 2009, pp. 1-4.

[3]Parachutes, H., 'How to make a Parachute — Fruity Chutes!', Fruitychutes.com. ¡https://www.fruitychutes.com/help_for_parachutes/how_to_make_a_parachute.htm.¿

[4]Nakka, R., 'Richard Nakka's Experimental Rocketry Site', Nakka-rocketry.net http://www.nakka-rocketry.net/paracon.html.

[5]Machine, Monterey. "RATTworks: Precision Hybrid & Tribrid Rocket Motors - Accessories." RATTworks: Precision Hybrid & Tribrid Rocket Motors - Accessories. Monterey Machine Products, 2006. Web. 19 Feb. 2017.

[6]Foster, Thomas. "Tubular Nylon Webbing 1"." Strapworks.com. Volusion, n.d. Web. 19 Feb. 2017.

[7]https://altusmetrum.org/TeleMega/

[8]Stoney,William., Transonic Drag Measurements of eight body-nose shapes, NACA RM l53K17, 5 February 1954

[9]Toft, Hans. "Nose Cone Drag Study for the SStS Rocket." (2005): 10. Sugar Shot to Space Program Documentation. Sugar Shot to Space. Web. 10 Oct. 2014. ¡http://sugarshot.org/downloads/nosecone_drag_study_ss2s_rocket.pdf¿.

[10]Owens, Robert. "Aerodynamic Characteristics of Spherically Blunted Cones at Mach Numbers from 0.5 to 5.0." NASA Technical Note D-3088 (1965). Print.

[11]Suliman, M. A., O. K. Mahmoud, M. A. Al-Sanabawy, and O. E. Abdel-Hamid. "Computational Investigation of Base Drag Reduction for a Projectile at Different Flight Regimes."ASAT-13-FM-05 (n.d.): n. pag. Military Technical College, Kobry Elkobbah, Cairo, Egypt, 2009. Web. ¡http://www.mtc.edu.eg/ASAT13/pdf/FM05.pdf¿.¿

[12]Hennin, Bart. "Why Should You Airfoil Your Rocket's Fins?" Peak of Flight Newsletter 305 (2012): n. pag. Apogee Rockets, 31 Jan. 2012. Web. 28 Oct. 2015.

[13]Harris, Charles D., NASA Supercritical Airfoils: A Matrix of Family-Related Airfoils, NASA Technical Paper 2969, Hampton, Virginia, January 1990.

[14]"Launching Safely in the 21st Century." National Association of Rocketry. 29 Oct. 2009. Web. 27 Oct. 2015.

[15]Wallskog, Harvey A., and Hart, Roger G., Investigation of the Drag of Blunt-nosed Bodies of Revolution in Free Flight at Mach Numbers from 0.6 to 2.3, Langley Aeronautical Laboratory, Langley Field, VA, June 11, 1953.

[16]Niskanen, S., "Development of an Open Source model rocket simulation software," M.Sc. thesis, Helsinki University of Technology, 2009.

[17]Mahmoud, Osama, Suliman, M.A., Al-Sanabawy, M.A., & Abdel-Hamid, Omar E., "Computational investigation of base drag reduction for a projectile at different flight regimes." 13th International Conference on AEROSPACE SCIENCES & AVIATION TECHNOLOGY, ASAT- 13. May 26-28, 2009.

[18]Hennin, Bart., "Why Should You Airfoil Your Rocket's Fins?" Peak of Flight Newsletter 305 (2012): n. pag. Apogee Rockets, 31 Jan. 2012. Web. 28 Oct. 2015.

[19]Scott, Jeff.,"NACA Airfoil Series," aerospaceweb.org, http://www.aerospaceweb.org/question/airfoils/q0041.shtml Web. 25 October 2015.

[20]Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S. Jr., "Summary of Airfoil Data," NACA Report No. 824, pp. 259-522.

[21]Harris, Charles D.,"NASA Supercritical Airfoils: A Matrix of Family-Related Airfoils," NASA Technical Paper 2969, Hampton, Virginia, January 1990.

[22]Anderson, John D., "Introduction to Flight," 7th ed. New York: McGraw-Hill, 2005. Print.

[23]"Launching Safely in the 21st Century," National Association of Rocketry,29 Oct. 2009. Web. 27 Oct. 2015.

[24]Chin, S.S., "Missile Configuration Design," McGraw-Hill, 1961.

[25]Munk, M.M., "The Aerodynamic Forces on Airship Hulls," NACA Report No. 184, Washington Government Printing Office, 1924.

[26]Military Handbook - 762. "Design of Aerodynamically Stabilized Free Rockets," Department of Defense, 1990.

[27]Meirovitch, Leonard. "Fundamentals of Vibrations," Print, Waveland Press, Inc., Long Grove, Illinois, 2010. Copyright 2001.

[28]Components, Inc Apogee. Intro to Dual Deployment in Rocketry. Model Rockets & How-To Rocketry Information, Apogee Rockets, www.apogeerockets.com/Intro-to-Dual-Deployment.

[29]Jean Potvin. "Momentum-Impulse Balance and Parachute Inflation: Disreefing", Journal of Aircraft, Vol. 44, No. 2 (2007), pp. 691-694.

[30]Feretich, Bob. Shear Pin, Screw Calculations. Feretich Rocketry, 12 Apr. 2006, www.feretich.com/Rocketry/Resources/shearPins.html.

[31]Bosso, Giacomo. Airframe Configuration for ARRD. EURocketry :: Thema Anzeigen - Airframe Configuration for ARRD, 28 May 2010, www.eurocketry.org/forum/german/viewtopic.php?t=1237.

[32]Fernandez, M. M., Propellant Tank Pressurization Modeling for a Hybrid Rocket, Thesis, Mechanical Engineering Dept., Rochester Institute of Technology, Rochester, NY, 2009.

[33]Newlends, R., Modeling the nitrous run tank emptying, Aspire Space

[34]Doran, E., Dyer, J., Lohner, K., Dunn, Z., Cantwell, B., Nitrous Oxide Hybrid Rocket Motor Fuel Regression Rate Characterization, 42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference, AIAA, Sacramento, CA, July 2006.

[35]Bellomo, Barato, Faenza, Lazzarin, Bettella, and Pavarin, Numerical and Experimental Investigation on Vortex Injection in Hybrid Rocket Motors, AIAA 2011-5675, 2011.

[36]Sutton, G. P., Biblarz, O., Rocket Propulsion Elements, 9th ed., Wiley, Hoboken, New Jersey, 2017, pp. 156-161, 593-619.

[37]Faure, J., Vergalla, M., Zhou, R., Chintalapati, S., Gutierrez, H., and Kirk, D., Experimental Platform for the Study of Liquid Slosh Dynamics Using Sounding Rockets, international Review of Aerospace Engineering, vol. 3, Feb. 2010, pp. 59 - 67.

[38]Ibrahim, R. A., Liquid sloshing dynamics: theory and applications, Cambridge: Cambridge University Press, 2006.

APPENDIX A
System Weights and Measures

Spaceport America Cup

Intercollegiate Rocket Engineering Competition

Entry Form & Progress Update

Color Key | SRAD = Student Researched and Designed | v18.1

Must be completed accurately at all time. These fields mostly pertain to team identifying information and the highest-level technical information.

Should always be completed "to the team's best knowledge" , but is expected to vary with increasing accuracy / fidelity throughout the project.

May not be known until later in the project but should be completed ASAP, and must be completed accurately in the final progress report.

Date Submitted: 5/25/2018

Team ID: 12

* You will receive your Team ID after you submit your 1st project entry form.

Country: United States of America

State or Province: TX

State or Province is for US and Canada

Team Information

Rocket/Project Name:	Theseus/TAMU-SRT5
Student Organization Name	Texas A&M Sounding Rocketry Team
College or University Name:	Texas A&M University
Preferred Informal Name:	TAMU-SRT
Organization Type:	Club/Group
Project Start Date	9/4/2017
Category:	10k – SRAD – Hybrid/Liquid & Other

Projects are not limited on how many years they take

Member	Name	Email	Phone
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Alt. Student Lead	Sarah Michaels	Smichaels737@tamu.edu	972-358-8955
Faculty Advisor	Dr. Adonios Karpetis	Karpetis@tamu.edu	979-458-4301
Alt. Faculty Adviser	Dr. Rodney Bowersox	Bowersox@tamu.edu	979-845-1602

For Mailing Awards:

Payable To:	Texas A&M Sounding Rocketry Team
Address Line 1:	235 John J Koldus Student Services Building
Address Line 2:	1236 TAMU
Address Line 3:	College Station, TX 77843-1236
Address Line 4:	ATTN: Mailbox 980
Address Line 5:	

Demographic Data

This is all members working with your project including those not attending the event. This will help ESRA and Spaceport America promote the event and get more sponsorships and grants to help the teams and improve the event.

Number of team members

High School	0	Male	25
Undergrad	27	Female	4
Masters	1	Veterans	0
PhD	1	NAR or Tripoli	4

Just a reminder the you are not required to have a NAR, Tripoli member on your team. If your country has an equivelant organization to NAR or Tripoli, you can cant them in the NAR or Tripoli box. CAR from Canada is an example.

STEM Outreach Events

The Texas A&M Sounding Rocketry Team promotes STEM, engineering curriculum, and rocketry by participating in events that allow the team to reach an extensive amout of the surrounding community. For example, SRT has developed a standing relationship with the local boyscout troop by volunteering at the annual Arrowmoon Day. This past October we assisted young boyscouts and cubscouts in building and launching over 100 small estes rockets. Another event where we have the opportunity to reach the youth of the community is the Moon Day hosted by the Frontiers of Flight Musuem. At this event, we volunteered to aid kids while they participated in Aerospace-themed ativities oriented towards education about space. Every year SRT partakes in Aggieland Saturday where we display our rockets and inform members of the community about the exciting possiblities a STEM based career can offer. In addition to these events, we work with high schools to develop payloads for lauches and provide guidance on their rocketry projects.

Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Airframe Length (inches):	136.4	
Airframe Diameter (inches):	8.42	
Fin-span (inches):	21.58	3 fin configuration, tip-to-tip distance (max width); single fin span 8.25in
Vehicle weight (pounds):	97.2	
Propellent weight (pounds):	22.5	Fuel grain + oxidizer
Payload weight (pounds):	8.8	
Liftoff weight (pounds):	128.5	
Number of stages:	1	
Strap-on Booster Cluster:	No	
Propulsion Type:	Hybrid	
Propulsion Manufacturer:	Student-built	
Kinetic Energy Dart:	No	

Propulsion Systems: (Stage: Manufacturer, Motor, Letter Class, Total Impulse)

```
1st Stage: SRAD Hybrid 7.0 pounds of HTPB and 15.5 pounds of Nitrous Oxide, N Class, 16103 Ns
```

Total Impulse of all Motors: 16103 (Ns)

Predicted Flight Data and Analysis

The following stats should be calculated using rocket trajectory software or by hand.

Pro Tip: Reference the Barrowman Equations, know what they are, and know how to use them.

	Measurement	Additional Comments (Optional)
Launch Rail:	Team-Provided	Launch tower with accompanying trailer
Rail Length (feet):	30	
Liftoff Thrust-Weight Ratio:	5.16	Std. Dev. : 5.2%
Launch Rail Departure Velocity (feet/second):	87.6	Std. Dev. : 3.4% (see 'other information' section)
Minimum Static Margin During Boost:	1.52	Nominal flight minimum stability (0 AoA)
Maximum Acceleration (G):	4.3	Std. Dev. :6.5%
Maximum Velocity (feet/second):	663.4	Std. Dev. : 1.3%
Target Apogee (feet AGL):	10K	
Predicted Apogee (feet AGL):	10095	Std. Dev. : 2.3%

Payload Information

Payload Description:

The payload will consist of an in-house designed, manufactured, and tested 3U CubeSat. Its primary objective is to quantify the shift in the center of gravity (CG) of sloshing fluids stored in the oxidizer tanks on aerodynamically stabilized hybrid rockets. A single camera will be used to capture the motion of fluid inside a cylindrical container. The captured images will be analyzed using a Digital Image Correlation (DIC) software developed by the team, which will take in the 2-dimensional image frames and output a 3-dimensional geometry of the fluid's surface in the tank. With this geometric information, the position of the center of gravity of the fluid in the tank will be determined. Since each frame of video data is time-stamped, the video – and hence the shift in CG – can be correlated with the data from a six degree of freedom accelerometer also on board the payload. This correlation between the rocket's dynamic motion and the motion of the fluid can be used to predict the motion of liquid nitrous sloshing in the rocket's oxidizer tank, and therefore the shift in the rocket's net CG. The working liquid of the payload will be water. There will be limited testing on the DIC program prior to flight, the payload's flight at competition will act as the experiments primary test. Results of the experiment will not be obtained immediately after flight, images must be post-processed and analyzed before a conclusion may be drawn. To the scientific community, the payload will aid in understanding the changes in stability and engine performance as a result of fuel sloshing during flight. The payload will not be ejected and does not require an independent recovery system. It will be fastened to the interior of the rockets aluminum bulkhead. The current payload is designed to weigh at least the required 8.8 pounds. There are some minor adjustments to be made that may alter the final weight of the payload.

Recovery Information

Theseus will utilize a dual-deployment recovery system to safely bring the vehicle to rest after its apogee. The vehicle and recovery system devices (airframe, engine, nose cone, main/drogue parachute and hardware) will stay connected via 1" tubular nylon shock cord such that a single system needs to be tracked from apogee to 1000' AGL. At 1000' AGL, the system will split into two individual systems that need to be recovered separately. The first system is the airframe, engine and main parachute. The second system is the nose cone, drogue and deployment bag of the main parachute. The recovery devices are deployed by one of two redundant commericial altimeters, those being the Altrus Metrum Telemega and PerfectFlite-StratologgerCF.

The components of the recovery system are as follows: 120 inch diameter Fruity Chutes annular parachute, 54 inch cross-type drogue parachute, 50 foot – 1 inch tubular nylon shock cord, RATTWorks ARRD (Main parachute release mechanism), 3 x 3/8 inch quick links, 2 x 1/4 inch quick links, 2 x kevlar y-harnesses, 1 x 7 gram ejection canister and 2 x 3/8 inch U-Bolts.

The events of the recovery system are as follows: At apogee, the onboard Telemega ignites a single 7-gram smoke-less powder charge to pressurize the recovery bay and eject the nose cone and drogue parachute. If the ignition of the ejection charge by the Telemega fails, the Stratologger will fire a second e-match at apogee plus 1 second. During the time of the vehicles descent from apogee to the next event, the main parachute is kept in the open recovery bay via a deployment bag secured to the Rattwork ARRD. The system will fall under the inflated drogue parachute at approximately 90 ft/s until the vehicle is 1000 foot above ground level (AGL) at which point the main parachute is to be deployed. The commercially available RATTworks ARRD is used as a link between the drogue and main parachute. The drogue parachute will be released by the ARRD and allow the drogue to pull the main parachute in its deployment bag from the recovery bay body tube. [Recovery continued in 'Other Pertinent Information' section]

Planned Tests

* Please keep brief

Date	Type	Description	Status	Comments
10/29/16	In-Flight	Daedalus flight & system verification	Successful	Flight to 8,800 ft on an N class solid motor
9/11/17	Ground	Engine hydrostatic test	Successful	Sensor verification
9/17/17	Ground	Cold flow test	Successful	Practice launch operations
10/4/17	Ground	Engine hydrostatic test	Minor Issues	1.5x operating pressure system & sensor test
10/6/17	Ground	Engine hydrostatic test	Minor Issues	1.5x operating pressure system & sensor test
10/7/17	Ground	Engine hydrostatic test	Successful	1.5x operating pressure system & sensor test
10/8/17	Ground	Cold flow test	Minor Issues	Practice launch operations
10/28/17	Ground	Static engine test	Minor Issues	Low ambient temp. caused ignition failure
11/11/17	Ground	Static engine test	Minor Issues	New ignition system failure
11/12/17	Ground	Static engine test	Minor Issues	New ignition system failure
11/15/17	Ground	Engine hydrostatic test	Successful	1.5x operating pressure system & sensor test
11/18/17	Ground	Static engine test	Successful	Engine characterizing hot fire
1/13/18	Ground	Cold flow test	Successful	Practice launch operations
2/7/18	Ground	Engine hydrostatic test	Successful	1.5x operating pressure system & sensor test
2/17/18	Ground	Static engine test	Minor Issues	Control system failure caused timing issues
2/18/18	Ground	Static engine test	Minor Issues	New ignition system failure
2/25/18	Ground	Static engine test	Successful	Engine characterizing hot fire
3/1/18	Ground	Engine hydrostatic test	Successful	1.5x operating pressure system & sensor test
3/3/18	In-Flight	Hybrid engine test flight	Minor Issues	Ignition system failure
3/6/18	Ground	Engine hydrostatic test	Successful	1.5x operating pressure system & sensor test
3/25/18	Ground	Static engine test	Successful	Engine characterizing hot fire
3/30/18	Ground	Engine hydrostatic test	Successful	1.5x operating pressure system & sensor test
3/30/18	Ground	Static engine test	Successful	Engine characterizing hot fire
4/5/18	Ground	Engine hydrostatic test	Successful	1.5x operating pressure system & sensor test
4/7/18	Ground	Static engine test	Successful	Engine characterizing hot fire
4/7/18	Ground	Recovery system test	Successful	Recovery system functionality verification
4/10/18	Ground	Engine hydrostatic test	Successful	1.5x operating pressure system & sensor test
4/18/18	Ground	Engine hydrostatic test	Successful	1.5x operating pressure system & sensor test
4/29/18	Ground	Mock launch	Successful	1.5x operating pressure system & sensor test
5/7/18	Ground	Engine hydrostatic test	Successful	1.5x operating pressure system & sensor test
5/9/18	Ground	Static engine test	Successful	Engine characterizing hot fire
5/15/18	Ground	Engine hydrostatic test	Successful	1.5x operating pressure system & sensor test
5/22/18	Ground	Recovery systems test	Successful	Integrated system deployment test
5/23/18	Ground	Recovery systems test	Successful	Integrated system deployment test

Any other pertinent information:

The Texas A&M Sounding Rocketry Team spent this school year verifying hybrid engine performance and developing an iteration of the team's previous launch vehicle, Daedalus. The Daedalus (rocket) and Icarus (hybrid engine) rocket system has been developed and tested over the past two years. Icarus has been statically tested successfully twice, but more reliable and repeatable data is necessary before flight verification. Daedalus has been flight verified to ~8,800 ft on an N class solid motor, but has yet to fly on Icarus. SRT recently completed an engine testing campaign to better understand the effect of changing different design parameters in Icarus. The team attempted hybrid engine launches of Daedalus the entire month of February up to mid-march. Due to weather most launch attempts had to be canceled. On the one weekend that offered flyable wheather the team had an igniter malfunction that caused the launch to be scrubbed. In order to properly prepare for the competition, the team stopped attempting to have a hybrid launch of Daedalus. In addition to engine characterization the team is worked on developing an iteration of Daedalus that optimized the performance and operational effeciency of the vehicle. This new vehicle is Theseus and can fly on its hybrid engine, Nova. Nova will be a variant of Icarus with minimal design changes. Nova and Theseus have both be tested in an engine test and mock launch. Should a catastrophic event occur between now and competition the Daedalus and Theseus systems are interchangable and the team will use components of both rockets to have a flight ready vehicle for competition.

[RECOVERY SECTION CONTINUED] When the shock cord is taut the drogue will pull the deployment bag off of the main parachute and the drogue, nose cone and deployment bag will separate from the main system and recovery as a separate system. The ARRD is activated at this altitude by one of two redundant e-matches, the first of which is ignited by the Telemega at 1000 ft and the second being ignited by the Stratologger at 1000 ft plus 1 second. When the ARRD is activated, a shackle connecting the main and drogue shock cord is released, allowing the drogue to act as a pilot chute for the main. The main parachute, once pulled from its deployment bag, will inflate and slow the vehicle down to 20 ft/s for its final ground landing.

[PREDICTED FLIGHT AND ANALYSIS EXPLANATION] In regards to the rail exit velocity being under 100 ft/s: For every flight, the team uses an in-house developed 6DOF flight simulation program. This program makes use of the Monte Carlo method, which takes statistical distributions of each input variable (in particular: all relevant weather conditions, rail elevation & heading, and engine performance parameters) and runs hundreds of simulated flights to produce statistical distributions for all output values (apogee, rail exit velocity, min stability, etc.) - hence the standard deviations given for each reported flight statistic above. The simulation outputs are then compared to results generated from well-known and trusted rocket simulation programs such as OpenRocket and RASAero as a form of validation. The predicted flight data statistics reported above were generated with several hundred Monte Carlo runs in the team's flight simulation program, and were verified with commercial software. None of the simulated flights (including those from commercial software) produced a flight that would be considered unsafe in regards to stability or any other flight statistic. In other words, there is no reason for the team to believe the rocket will exit the launch tower in an unsafe manner. A note about flight sim verification for our in-house program: Our team has gathered flight data from solid launches to validate our flight simulation program. All sizes of rocket and motor we possess have been tested: from small Estes kit rockets, to L1 and L2 rockets, to the Daedalus rocket from last year's SRT team (comparable to Theseus). We have been able to predict apogee values for at least 8 different flights with a mean average error of approximately 1.7%.

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APPENDIX B
Project Test Reports

SRTNOVA

STATIC ENGINE TESTING

OBJECTIVE

Characterize the performance of the MO-737 Nova-I hybrid engine and predict it's operation in flight configuration at the 2018 Spaceport America Cup.

TEST DESCRIPTION

The Nova-I engine is tested at the Texas A&M University RELLIS Campus in the Riverside Test Cell (RTC). The engine is tested vertically in flight configuration, utilizing the same control system used during a launch scenario. The RTC is equip with 14 independent sensor measurements, listed below, which are used to help characterize engine performance. The two primary sensors most critical to determining engine performance are the LPU-1K Transducer Techniques load cell (1) and the PX309-1K Omega pressure transducer (2).

RTC sensors: (1) engine system force, (2) combustion chamber total pressure, (3) run tank static pressure, (4) run tank temperature, (5) combustion chamber temperature: external, top, (6) combustion chamber temperature: external, bottom, (7) supply tank weight, (8) primary supply tank static pressure, (9) secondary supply tank static pressure, (10) oxygen tank static pressure, (11) primary ambient temperature, (12) secondary ambient temperature, (13) ambient pressure, (14) test stand visual.

Figure 1 shows Nova-I installed in the Riverside Test Cell with sensors and fluid lines attached.

The 1K load cell provides a direct measurement of thrust produced by the engine. The 1K pressure transducer located in the combustion chamber provides a secondary way to determine thrust and calculate mass flow rates seen in the system throughout engine operation.

Each of the three tests detailed in this testing report are full-duration burns. Although Nova-I is SRT's competition engine, this year's static test of sister engine Icarus-II is included in this report since the only functional difference between the two are their methods of oxidizer injection.

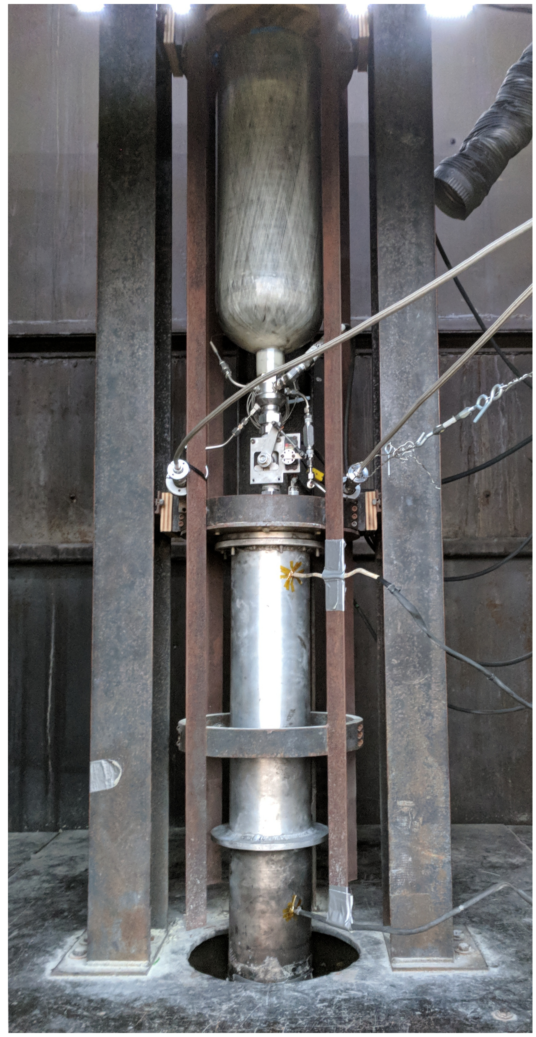


Figure 1: Nova-I in Testing Configuration

FLUID SYSTEM DIAGRAM

Figure 2 shows the Nova-I fluid system with the nominal operating pressures in each segment. The blue area represents volume to be occupied by nitrous oxide, the pink area represents the volume in which combustion occurs, and the green area represents volume occupied by gaseous Oxygen during our ignition sequence.

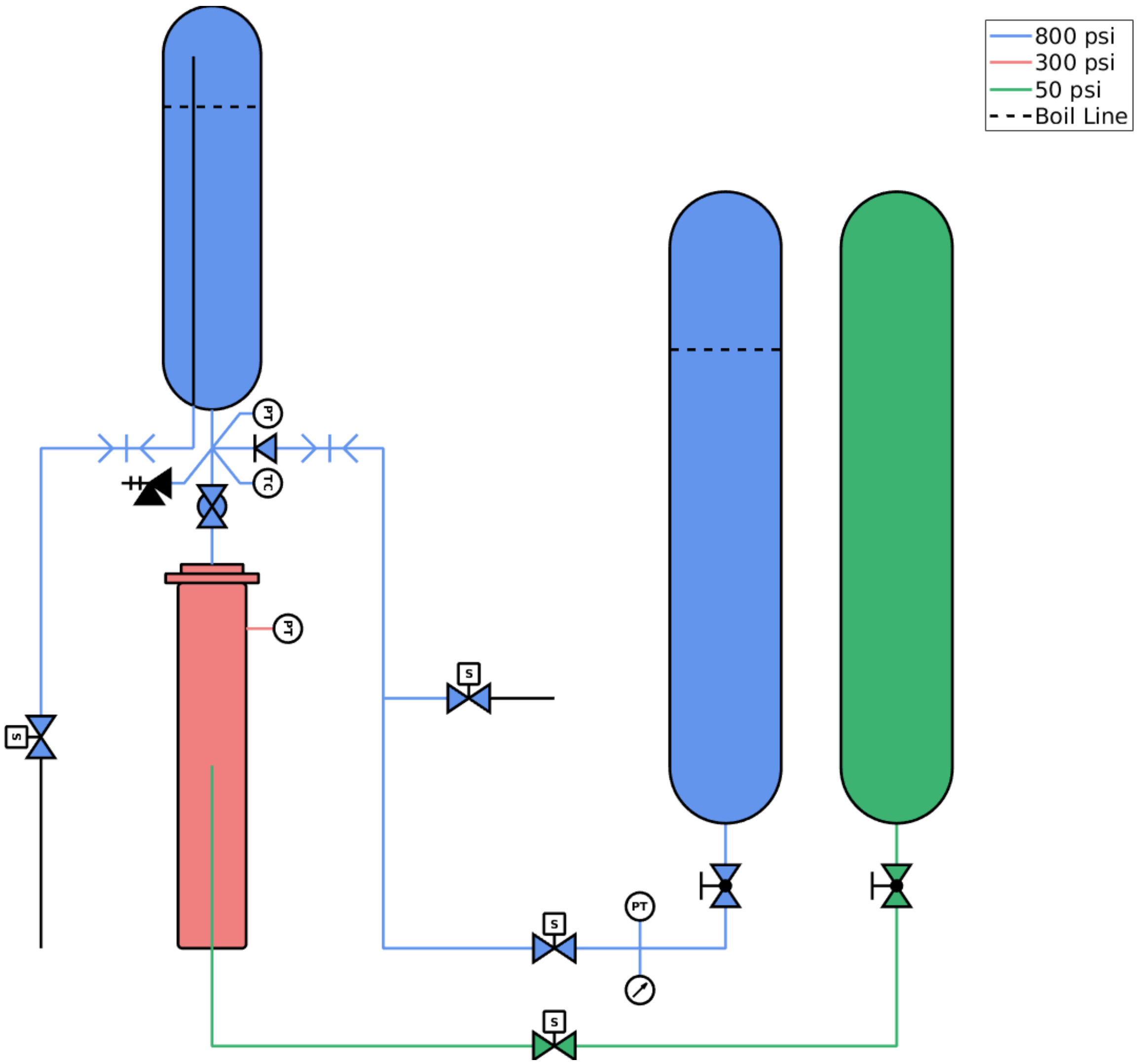


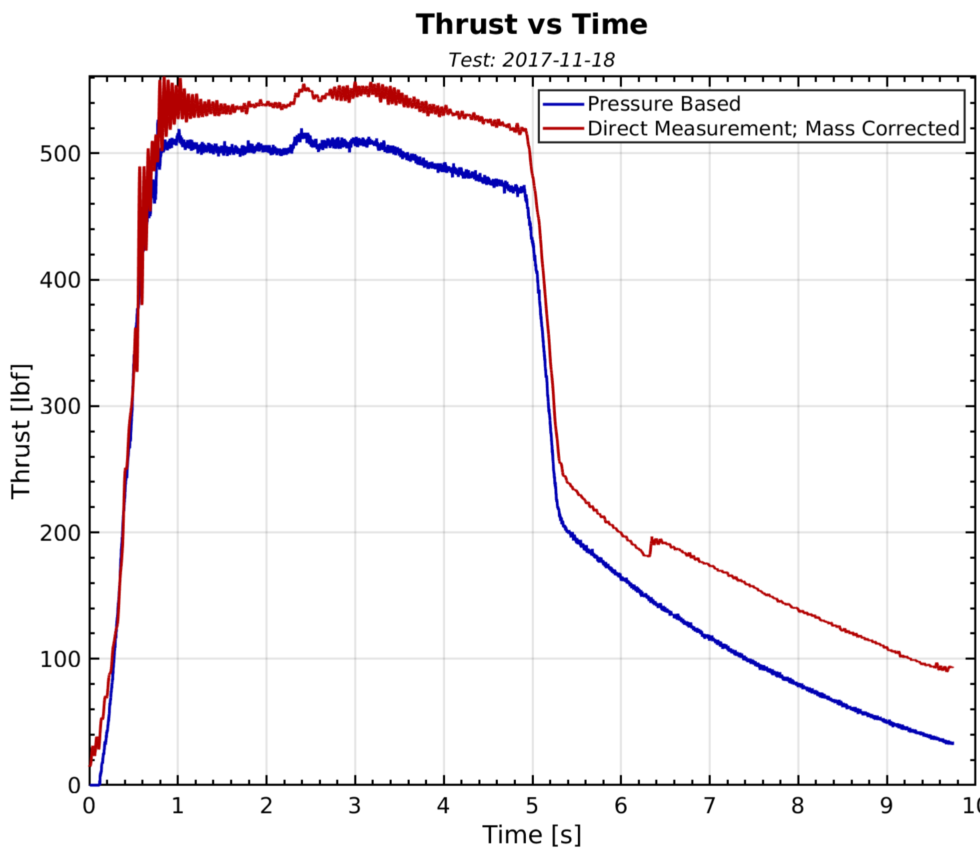
Figure 2: Nova-I Fluid System Diagram

SET-IV: November 18, 2017

TEST PARAMETERS

Engine:	`Icarus-II`	Propellant:	N_2O-HTPB	Oxidizer Fill:	`15.02 lbm`
Ambient Temp.:	65°F	Ambient Press.:	`30.09 inHg`	Run Tank Press.:	`730 psi`

ENGINE PERFORMANCE



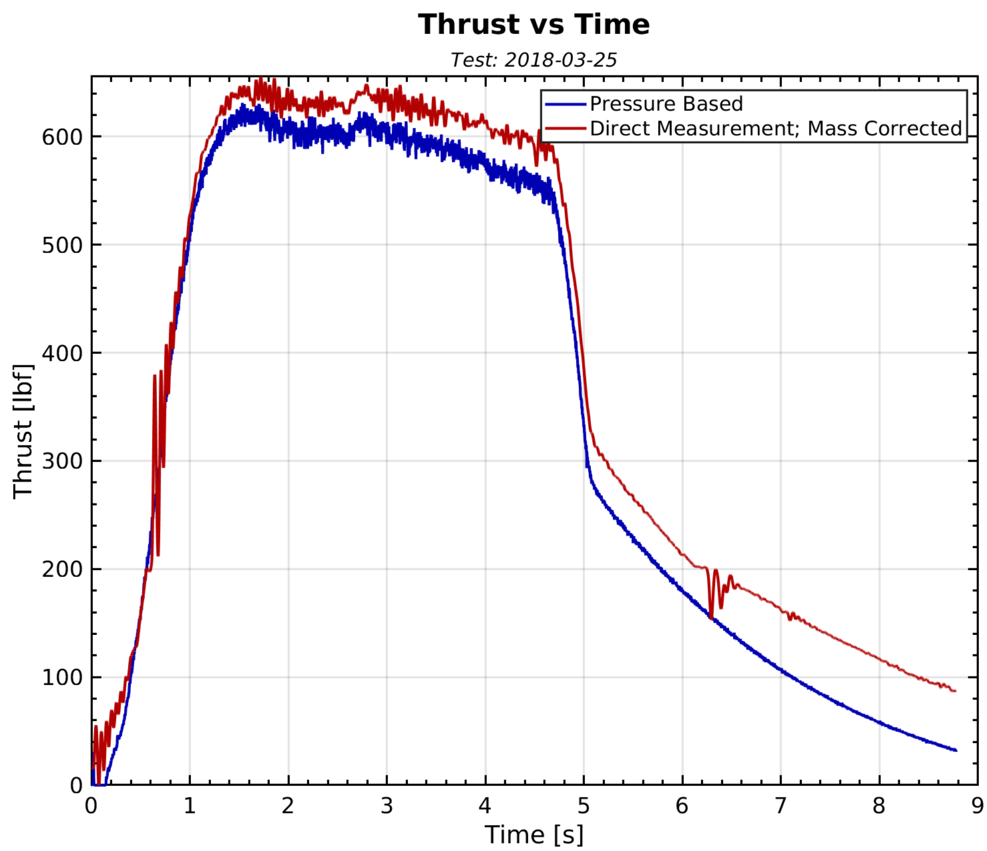
Peak Thrust:	`560 lbf`	Total Impulse:	`3430 lbf-sec`	Specific Impulse:	`212 sec`

SET-VIII: March 25, 2018

TEST PARAMETERS

Engine:	Nova-I	Propellant:	N_2O-HTPB	Oxidizer Fill:	16.92 lbm
Ambient Temp.:	80°F	Ambient Press.:	29.82 inHg	Run Tank Press.:	749 psi

ENGINE PERFORMANCE



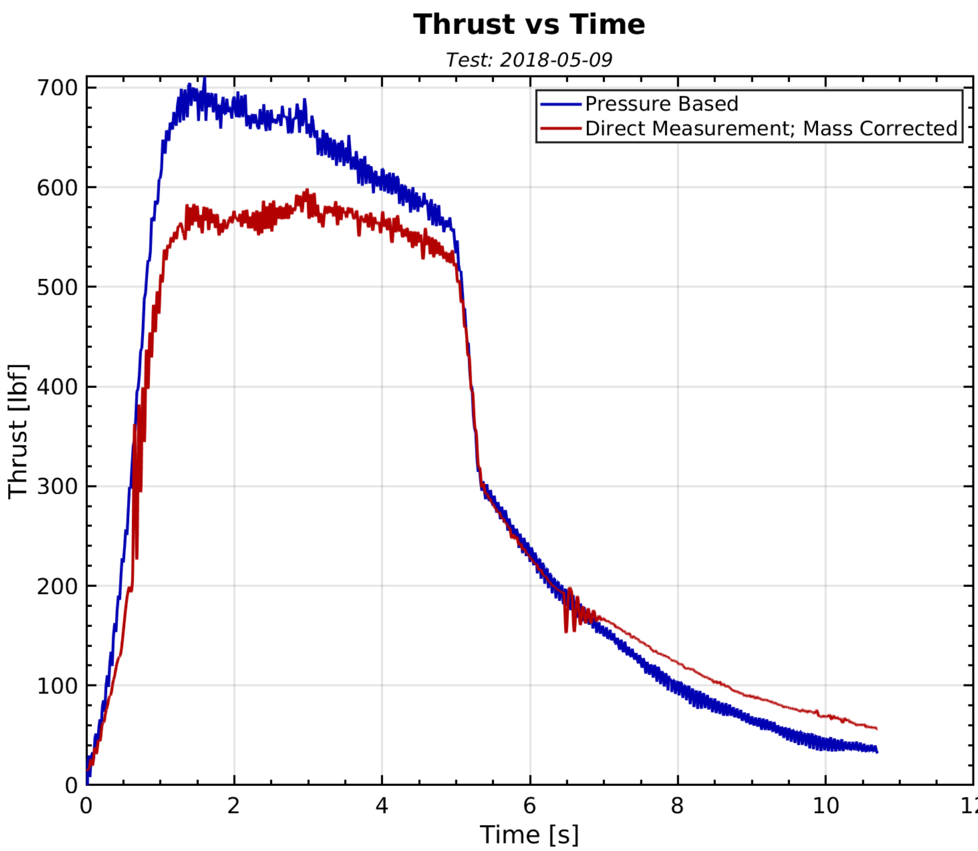
Peak Thrust:	655 lbf	Total Impulse:	3450 lbf-sec	Specific Impulse:	213 sec

SET-XII: May 9, 2018

TEST PARAMETERS

Engine:	Nova-I	Propellant:	N_2O-HTPB	Oxidizer Fill:	16.82 lbm
Ambient Temp.:	75°F	Ambient Press.:	29.98 inHg	Run Tank Press.:	745 psi

ENGINE PERFORMANCE



Peak Thrust:	600 lbf	Total Impulse:	3336 lbf-sec	Specific Impulse:	170 sec

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Icarus-II

DATE: September 11, 2017

TEST NUMBER: I

TEST RESULTS: Pass

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Assess functionality of pressure transducer in engine plumbing to diagnose IREC 2017 behavior.

NOTABLE SYSTEM CHANGES: N/A

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 750 psi   ☑ TESTED   ☑ PASS

PROOF PRESSURE: 1500 psi   ☐ UNTESTED   ☐ FAIL AT ____

Pressure transducer is reading roughly half of the pressure applied via the pump (as measured by gauge).

True Pressure	PT Readings
0 psi	4.4 psi
*	43 psi
200 psi	130 psi
300 psi	174 psi
400 psi	226 psi
450 psi	236 psi
500 psi	283 psi
600 psi	337 psi
700 psi	415 psi
800 psi	425 psi
900 psi	481 psi
1000 psi	538 psi

Note: '*' denotes the pressure of the water line.

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 750 psi ☐ TESTED ☐ PASS

PROOF PRESSURE: 1500 psi ☑ UNTESTED ☐ FAIL AT ________

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☐ TESTED ☐ PASS

PROOF PRESSURE: 500 psi ☑ UNTESTED ☐ FAIL AT ________

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Icarus-II   DATE: October 4, 2017

TEST NUMBER: II   TEST RESULTS: Minor Issues

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Assess functionality of pressure transducer in engine plumbing as a results of software changes. Plumbing system pressure check-out.

NOTABLE SYSTEM CHANGES: Implementation of internal hard lines: mil. spec. stainless steel tubing, 0.25" OD, 0.18" ID.

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 750 psi   ☑ TESTED   ☑ PASS

PROOF PRESSURE: 1500 psi   ☐ UNTESTED   ☐ FAIL AT ______

Bad pressure transducer readings.
Small leaks noted and repaired in fill line quick disconnect elbow, fill line to plumbing, and vent line quick disconnect. Small leak noted in yor-lok connection from tank to ball valve although pressure is still holding.

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 750 psi   ☐ TESTED   ☐ PASS

PROOF PRESSURE: 1500 psi   ☑ UNTESTED   ☐ FAIL AT ______

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☐ TESTED ☐ PASS

PROOF PRESSURE: 500 psi ☑ UNTESTED ☐ FAIL AT ________

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Icarus-II

DATE: October 6, 2017

TEST NUMBER: III

TEST RESULTS: Minor Issues

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Assess functionality of pressure transducers in engine plumbing and combustion chamber as a results of software changes. Engine system pressure check-out.

NOTABLE SYSTEM CHANGES: N/A

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 750 psi

PROOF PRESSURE: 1500 psi

☐ TESTED ☐ PASS

☑ UNTESTED ☐ FAIL AT

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 750 psi

PROOF PRESSURE: 1500 psi

☐ TESTED ☐ PASS

☑ UNTESTED ☐ FAIL AT

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☑ TESTED ☐ PASS

PROOF PRESSURE: 500 psi ☐ UNTESTED ☑ FAIL AT 400 psi

Pressure transducers are giving good readings.

True Pressure	Chamber PT	Plumbing PT
50 psi	86 psi	102 psi
100 psi	118 psi	133 psi
200 psi	218 psi	233 psi
300 psi	317 psi	331 psi
400 psi	414 psi	427 psi

Leak noted in yor-lok connection from tank to ball valve; tightened but leaking started again around 500 psi. Losing ~30 psi/min.

Nozzle collar bolts are yielded.

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Icarus-II

DATE: October 7, 2017

TEST NUMBER: IV

TEST RESULTS: Pass

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Plumbing system pressure check-out.

NOTABLE SYSTEM CHANGES: Replaced yor-lok fitting from tank to ball valve.

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 750 psi — ☑ TESTED — ☑ PASS

PROOF PRESSURE: 1500 psi — ☐ UNTESTED — ☐ FAIL AT ______

600 psi – Small leaks noted and repaired in compression fittings of fill and vent line elbows and top vent elbow on line.

1000 psi – Small leaks noted in fill line NPT fitting. leaks persisted through re-pressurization.

Oxidizer tank was dropped after test completion; retested to 1500 psi and maintained pressurization with no signs of compromise to integrity.

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 750 psi — ☐ TESTED — ☐ PASS

PROOF PRESSURE: 1500 psi — ☑ UNTESTED — ☐ FAIL AT ______

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☐ TESTED ☐ PASS

PROOF PRESSURE: 500 psi ☑ UNTESTED ☐ FAIL AT ________

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Icarus-II DATE: Novmember 15, 2017

TEST NUMBER: V TEST RESULTS: Pass

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Verify integrity of combustion chamber after November 12 burn.

NOTABLE SYSTEM CHANGES: N/A

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 750 psi ☐ TESTED ☐ PASS

PROOF PRESSURE: 1500 psi ☑ UNTESTED ☐ FAIL AT ______

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 750 psi ☐ TESTED ☐ PASS

PROOF PRESSURE: 1500 psi ☑ UNTESTED ☐ FAIL AT ______

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☑ TESTED ☑ PASS

PROOF PRESSURE: 500 psi ☐ UNTESTED ☐ FAIL AT ____________

300 psi - Leaking from nozzle cap o-ring seal. This is acceptable since the nozzle cap used in this location is a pressure testing component and is not present in engine assembly; combustion chamber can still be tested to desired pressure.

400 psi - Yielding of nozzle bolts observed.

Small leaks noted and repaired in NPT seal of pressure relief valve, compression seal of fill line elbow, and compression seal of vent line connection to plumbing cross.

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Icarus-II

DATE: February 7, 2018

TEST NUMBER: VI

TEST RESULTS: Pass

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Verify integrity of combustion chamber after November 18 burn. Assess functionality of pressure transducers in engine plumbing and combustion chamber.

NOTABLE SYSTEM CHANGES: Replaced one threaded insert in combustion chamber flange. Re-uploaded avionics code.

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 750 psi ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1500 psi ☐ PASS ☐ FAIL AT ______

SYSTEM WORKING TIME: 1 hour ☐ VERIFY 2X TIME - HOLD TIME ______

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 750 psi ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1500 psi ☐ PASS ☐ FAIL AT ______

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ______

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☑ TESTED ☐ UNTESTED

PROOF PRESSURE: 500 psi ☑ PASS ☐ FAIL AT ____

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ____

Pressure transducers are giving good readings.

True Pressure	Chamber PT	Plumbing PT
*	96 psi	84 psi
300 psi	311 psi	299 psi
400 psi	436 psi	427 psi

Note: '*' denotes the pressure of the water line.

300 psi - Leaking from nozzle cap o-ring seal. This is acceptable since the nozzle cap used in this location is a pressure testing component and is not present in engine assembly; combustion chamber can still be tested to desired pressure.

400 psi - Yielding of nozzle bolts observed.

SRT–5 HYDROSTATIC TESTING REPORT

ENGINE: Icarus-II

DATE: March 1, 2018

TEST NUMBER: VII

TEST RESULTS: Pass

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Verify integrity of combustion chamber after February 25 burn. Assess functionality of pressure transducers in engine plumbing and combustion chamber.

NOTABLE SYSTEM CHANGES: Three threaded inserts in nozzle collar were stripped → replaced two (one did not come out). Will test to 300 psi for pressure transducer verification and basic leak check.

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 750 psi

PROOF PRESSURE: 1500 psi

SYSTEM WORKING TIME: 1 hour

☐ TESTED ☑ UNTESTED

☐ PASS ☐ FAIL AT ______

☐ VERIFY 2X TIME - HOLD TIME ______

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 750 psi

PROOF PRESSURE: 1500 psi

SYSTEM WORKING TIME: 30 sec

☐ TESTED ☑ UNTESTED

☐ PASS ☐ FAIL AT ______

☐ VERIFY 2X TIME - HOLD TIME ______

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☑ TESTED ☐ UNTESTED

PROOF PRESSURE: 500 psi ☑ PASS ☐ FAIL AT ______

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ______

Pressure transducers are giving good readings.

True Pressure	Chamber PT	Plumbing PT
o	22 psi	7 psi
*	95 psi	81 psi
100 psi	128 psi	114 psi
200 psi	231 psi	217 psi
260 psi	291 psi	278 psi
300 psi	313 psi	300 psi

Note: 'o' denotes atmospheric pressure.
'*' denotes the pressure of the water line.

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Icarus-II

DATE: March 6, 2018

TEST NUMBER: VIII

TEST RESULTS: Pass

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Plumbing system pressure check-out after ball valve to plumbing cross compression fitting came off.

NOTABLE SYSTEM CHANGES: N/A

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 750 psi

PROOF PRESSURE: 1500 psi

SYSTEM WORKING TIME: 1 hour

☑ TESTED ☐ UNTESTED

☑ PASS ☐ FAIL AT ______

☐ VERIFY 2X TIME - HOLD TIME ______

500 psi - Nominal.

800 psi - Vent line (quick-disconnect tube fitting) has a small leak → tighten.

1000 psi - Nominal.

1300 psi - Nominal.

1500 psi - Compression fitting started leaking. Lost 100 psi in 16 seconds. Pressure relief valve is leaking a little.

Loosened the ball valve to plumbing cross compression fitting and the tank "dropped" into place; re-tightened.

500 psi - Nominal.

1000 psi - Small drop?

1300 psi - Nominal.

1500 psi - Very small leak forming from the top of the ball valve compression fitting at the plumbing cross; holding pressure. Leak at fill line.

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 750 psi ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1500 psi ☐ PASS ☐ FAIL AT ______

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ______

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 500 psi ☐ PASS ☐ FAIL AT ______

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ______

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Icarus-II

DATE: March 30, 2018

TEST NUMBER: IX

TEST RESULTS: Pass

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Verify integrity of combustion chamber after March 25 burn. Plumbing system pressure check-out due to integration of new pressure transducer.

NOTABLE SYSTEM CHANGES: New Kulite pressure transducer in engine plumbing. Fill line NPT fitting came loose during disassembly after last SET. Implementation of Grade 8 bolts to secure nozzle collar to combustion chamber. Different assembly procedures → remove lower compression fitting of ball valve (connection to housing) instead of upper fitting (connection to plumbing cross).

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 750 psi

PROOF PRESSURE: 1500 psi

SYSTEM WORKING TIME: 1 hour

☑ TESTED ☐ UNTESTED

☑ PASS ☐ FAIL AT ________

☐ VERIFY 2X TIME - HOLD TIME ________

Chased threads with tap on pressure transducer elbow (NPT male); re-taped fitting.

250 psi - Nominal.

500 psi - Small leak in ball valve to plumbing cross connection.

750 psi - Ball valve to plumbing cross yor-lok leaking. Small leak in fill line NPT connection to plumbing cross.

1000 psi - Pressure transducer NPT leaking; maybe? Yor-lok leak is getting worse; forming drops in more spots.

1200 psi - ''

Note: Not testing housing to ball valve compression fitting.

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 750 psi ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1500 psi ☐ PASS ☐ FAIL AT ________

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ________

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☑ TESTED ☐ UNTESTED

PROOF PRESSURE: 500 psi ☑ PASS ☐ FAIL AT ________

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ________

Before pressure - Housing to ball valve compression fitting leaking. Plumbing (new) pressure transducer leaking (NPT fitting). Small leak at combustion chamber plug.

100 psi - Nominal.

300 psi - Steady drip from pressure transducer NPT fitting → continue to test to pass chamber; will tighten before testing plumbing.

450 psi - ''

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Icarus-II DATE: April 5, 2018

TEST NUMBER: X TEST RESULTS: Pass

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Verify integrity of combustion chamber after March 30 burn.

NOTABLE SYSTEM CHANGES: N/A

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 750 psi ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1500 psi ☐ PASS ☐ FAIL AT ________

SYSTEM WORKING TIME: 1 hour ☐ VERIFY 2X TIME – HOLD TIME ________

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 750 psi ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1500 psi ☐ PASS ☐ FAIL AT ________

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME – HOLD TIME ________

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☑ TESTED ☐ UNTESTED

PROOF PRESSURE: 500 psi ☑ PASS ☐ FAIL AT ____________

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ________

100 psi - Nominal.

200 psi - Nominal.

300 psi - Nominal.

400 psi - Nominal.

500 psi - Minimal deformation in nozzle collar.

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Icarus-II DATE: April 10, 2018

TEST NUMBER: XI TEST RESULTS: Pass

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Verify integrity of combustion chamber after April 7 burn.

NOTABLE SYSTEM CHANGES: N/A

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 750 psi ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1500 psi ☐ PASS ☐ FAIL AT ______

SYSTEM WORKING TIME: 1 hour ☐ VERIFY 2X TIME - HOLD TIME ______

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 750 psi ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1500 psi ☐ PASS ☐ FAIL AT ______

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ______

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☑ TESTED ☐ UNTESTED

PROOF PRESSURE: 500 psi ☑ PASS ☐ FAIL AT ________

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ________

100 psi - Nominal.

200 psi - Nominal.

300 psi - Leak in vent line compression fitting → tighten.

400 psi - Nominal.

450 psi - Nominal.

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Nova-I DATE: April 18, 2018

TEST NUMBER: XII TEST RESULTS: Pass

TEST REPORTER: Ross Alexander

TEST OBJECTIVE: Verify plumbing system integrity after installation of new plumbing lines.

NOTABLE SYSTEM CHANGES: New fill and vent lines for the updated Theseus thrust bulkhead.

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 800 psi ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1600 psi ☐ PASS ☐ FAIL AT ______

SYSTEM WORKING TIME: 1 hour ☐ VERIFY 2X TIME - HOLD TIME ______

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 800 psi ☐ TESTED ☐ UNTESTED

PROOF PRESSURE: 1600 psi ☑ PASS ☐ FAIL AT ______

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ______

System pass at 1300 psi, overpressure of 500 psi - no leaking or venting observed.

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 600 psi ☐ PASS ☐ FAIL AT ______

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ______

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Nova-I

DATE: May 7, 2018

TEST NUMBER: XIII

TEST RESULTS: Pass

TEST REPORTER: Sarah Michaels

TEST OBJECTIVE: Verify integrity of Nova-I combustion chamber. Theseus avionics system verification.

NOTABLE SYSTEM CHANGES: Nova-I chamber has a slightly larger inner diameter than the Icarus-II chamber → nozzle plug is small; concerned about sealing.

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 800 psi — ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1600 psi — ☐ PASS ☐ FAIL AT ________

SYSTEM WORKING TIME: 1 hour — ☐ VERIFY 2X TIME - HOLD TIME ________

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 800 psi — ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1600 psi — ☐ PASS ☐ FAIL AT ________

SYSTEM WORKING TIME: 30 sec — ☐ VERIFY 2X TIME - HOLD TIME ________

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☑ TESTED ☐ UNTESTED

PROOF PRESSURE: 600 psi ☑ PASS ☐ FAIL AT ____________

SYSTEM WORKING TIME: 30 sec ☐ VERIFY 2X TIME - HOLD TIME ________

Dripping from nozzle collar plug before pressurized → stopped at 200 psi.

Could not complete avionics check-out: BeagleBone wasn't turning on; tried applying direct power. During troubleshooting, held pressure at 300 psi for over 30 minutes.

600 psi - Small leak in pressure relief → tightened. Weld is good.

SRT-5 HYDROSTATIC TESTING REPORT

ENGINE: Nova-I

DATE: May 15, 2018

TEST NUMBER: XIV

TEST RESULTS: Pass

TEST REPORTER: Silverio Canchola

TEST OBJECTIVE: Verify integrity of Nova-I combustion chamber after May 9 burn. Working time pressure check-out and IREC flight configuration plumbing seal.

NOTABLE SYSTEM CHANGES: N/A

OXIDIZER TANK → BALL VALVE

OPERATING PRESSURE: 800 psi — ☐ TESTED ☑ UNTESTED

PROOF PRESSURE: 1600 psi — ☐ PASS ☐ FAIL AT ____

SYSTEM WORKING TIME: 1 hour — ☐ VERIFY 2X TIME - HOLD TIME ____

OXIDIZER TANK → INJECTOR COIN (FULL PLUMBING)

OPERATING PRESSURE: 800 psi — ☑ TESTED ☐ UNTESTED

PROOF PRESSURE: 1600 psi — ☑ PASS ☐ FAIL AT ____

SYSTEM WORKING TIME: 30 sec — ☑ VERIFY 2X TIME - HOLD TIME 2 hours

No notable leaks.

OXIDIZER TANK → NOZZLE (COMBUSTION CHAMBER)

OPERATING PRESSURE: 300 psi ☑ TESTED ☐ UNTESTED

PROOF PRESSURE: 600 psi ☑ PASS ☐ FAIL AT ______

SYSTEM WORKING TIME: 30 sec ☑ VERIFY 2X TIME - HOLD TIME 10 min

Nozzle collar bolts started yielding a bit; likely because threaded inserts in the collar were pushed in too far.

SRT-5 RECOVERY TESTING REPORT

TEST SET-UP:

The Theseus recovery system utilizes two independent commercial flight computers for system redundancy.

SRT-5 RECOVERY TESTING REPORT

TEST: ARRD Validation Test DATE: 4-20-17
TEST NUMBER: 1 TEST RESULTS: Fail
TEST REPORTER: Tripp Illingworth

TEST OBJECTIVE: Assemble and activate the RATTWorks ARRD per the provided instructions to verify understanding of assembly procedures. Activation of the ARRD under 30 lbs of tension is used to simulate the drag of the drogue parachute.

NOTABLE SYSTEM CHANGES: N/A

TEST RESULTS: Upon activation of the ARRD via the installed e-match, the shackle did not release. A large quantity of gas was expelled from the side of the ARRD where the e-match is accepted into the device.

SRT-5 RECOVERY TESTING REPORT

TEST: ARRD Validation Test DATE: 4-20-17
TEST NUMBER: 2 TEST RESULTS: Pass
TEST REPORTER: Tripp Illingworth

TEST OBJECTIVE: Assemble and activate the RATTWorks ARRD per the provided instructions to verify understanding of assembly procedures. Activation of the ARRD under 30 lbs of tension is used to simulate the drag of the drogue parachute.

NOTABLE SYSTEM CHANGES: Used a second e-match wire lead to seal the hole in ARRD where the e-matches are accepted into the device.

TEST RESULTS: Upon activation of the ARRD via the installed e-match, the shackle and attached weigh were released. The previous issue regarding the escaping gases was corrected via a second e-match wire lead installed into the hole.

SRT-5 RECOVERY TESTING REPORT

TEST: ARRD Validation Test DATE: 4-20-17
TEST NUMBER: 3 TEST RESULTS: Pass
TEST REPORTER: Tripp Illingworth

TEST OBJECTIVE: Assemble and activate the RATTWorks ARRD per the provided instructions to verify understanding of assembly procedures. Activation of the ARRD under 30 lbs of tension is used to simulate the drag of the drogue parachute.

NOTABLE SYSTEM CHANGES: N/A

TEST RESULTS: Upon activation of the ARRD via the installed e-match, the shackle and attached weight were released.

SRT-5 RECOVERY TESTING REPORT

TEST: ARRD Validation Test DATE: 4-27-17
TEST NUMBER: 4 TEST RESULTS: Pass
TEST REPORTER: Tripp Illingworth

TEST OBJECTIVE: Assemble and activate the RATTWorks ARRD per the provided instructions to verify understanding of assembly procedures. Activation of the ARRD under 30 lbs of tension is used to simulate the drag of the drogue parachute.

NOTABLE SYSTEM CHANGES: N/A

TEST RESULTS: Upon activation of the ARRD via the installed e-match, the shackle and attached weight were released.

SRT-5 RECOVERY TESTING REPORT

TEST: ARRD Validation Test DATE: 4-27-17
TEST NUMBER: 5 TEST RESULTS: Pass
TEST REPORTER: Tripp Illingworth

TEST OBJECTIVE: Assemble and activate the RATTWorks ARRD per the provided instructions to verify understanding of assembly procedures. Activation of the ARRD under 30 lbs of tension is used to simulate the drag of the drogue parachute.

NOTABLE SYSTEM CHANGES: N/A

TEST RESULTS: Upon activation of the ARRD via the installed e-match, the shackle and attached weight were released.

SRT-5 RECOVERY TESTING REPORT

TEST: Ejection Charge Validation Test DATE: 4-7-18
TEST NUMBER: 1 TEST RESULTS: Pass
TEST REPORTER: Tripp Illingworth

TEST OBJECTIVE: Verify the theoretical ejection charge size and containment method via ignition in the sealed recovery bay chamber. During the test it is desired that all shear pins are cleanly cut, no structural damage is observed to the body tube, bulkhead or shear pins holes, and the nose cone is ejected with sufficient speed such that it ends at a distance greater than 15 feet away from the recovery bay.

NOTABLE SYSTEM CHANGES: N/A

TEST RESULTS: Upon activation of the ejection charge, the nose cone was ejected from the recovery bay with sufficient speed. Observing the recovery bay after the test, no observable damage was caused to the structure.

*Cleaning of the recovery bay bulkhead and interior body tube surface is needed before further testing due to smoke-less powder residue.

SRT-5 RECOVERY TESTING REPORT

TEST: Integrated System Deployment Test DATE: 4-18-18
TEST NUMBER: 1 TEST RESULTS: Pass
TEST REPORTER: Tripp Illingworth

TEST OBJECTIVE: Full-scale system deployment tests are used to validate the system packing method and assembly. A successful test is one in which the deployment devices (drogue, nose cone and shock cord) are ejected upon the ignition of the 7-gram pyrodex ejection charge in an orderly fashion such as to confirm organization in the recovery bay and proper ejection charge sizing.

The second aspect of the test of the activation of the RATTWorks ARRD. Exposing the ARRD to the conditions seen during flight will expose any weaknesses the device would encounter during integration into the recovery assembly.

NOTABLE SYSTEM CHANGES: First implementation of ARRD in full system deployment test.

TEST RESULTS: Nose cone ejected with sufficient velocity to pull drogue and shock cord from the recovery bay. All recovery devices laid-out cleanly and in an organized fashion as desired.

ARRD activated on command and released shackle without binding or complication. Upon pulling on the drogue, the remaining recovery devices (main parachute, deployment bag and shock cord) were easily pulled from the recovery bay and laid-out as desired.

Gas-leakage from between airframe and nose cone shoulder should be addressed before further testing is conducted.

SRT-5 RECOVERY TESTING REPORT

TEST: Integrated System Deployment Test DATE: 4-18-18
TEST NUMBER: 2 TEST RESULTS: Pass
TEST REPORTER: Tripp Illingworth

TEST OBJECTIVE: Full-system deployment tests are used to validate the system packing method and assembly. A successful test is one in which the deployment devices (drogue, nose cone and shock cord) are ejected upon the ignition of the 7-gram pyrodex ejection charge in an orderly fashion such as to confirm organization in the recovery bay and proper ejection charge sizing.

The second aspect of the test of the activation of the RATTWorks ARRD. Exposing the ARRD to the conditions seen during flight will expose any weaknesses the device would encounter during integration into the recovery assembly.

NOTABLE SYSTEM CHANGES: Revised packing procedure to better protect shroud lines of main parachute. During packing of main parachute, shroud lines are to be folded in a z-formation across the parachute and then rolled-up with the main parachute before being inserted into the deployment bag. High-quality painters tape used to build up nose cone shoulder O.D. to provide a better seal with the recovery bay body tube.

TEST RESULTS: Nose cone ejected with sufficient velocity to pull drogue and shock cord from the recovery bay. All recovery devices laid-out cleanly and in an organized fashion as desired.

ARRD activated on command and released shackle without binding or complication. Upon pulling on the drogue, the remaining recovery devices (main parachute, deployment bag and shock cord) were easily pulled from the recovery bay and laid-out as desired.

Gas-leakage from between the airframe and nose cone shoulder was corrected between tests using thin painters-tape to build up the shoulder's outer diameter. The additional sealing of the recovery bay resulted in less gas escaping, and a higher velocity of the nose cone at ejection.

APPENDIX C
Hazard Analysis

Appendix C: Hazard Analysis

Combustible Product Hazard: Pyrodex

Pyrodex is a black power substitute that is less sensitive as an explosive compared to traditional black powder but still is very dangerous if handled improperly. Pyrodex is a combustible product that converts chemical energy into thermal energy in a rapid combustion process. The pyrodex is the product that is used in the ejection charges to create an increase in pressure in the recovery bay to push the nosecone out of the airframe. This poses a hazard when packing the recovery bay and attaching the ejection charges to the e-bay electronics and arming the electronics before flight.

Transportation

The pyrodex is transported in its store purchased plastic container with twist-off top while also inside of a water-proof and non-conductive box that is to be brought to the launch site for prep to eliminate static discharge.

Storage

The pyrodex is stored in its plastic container with twist off top at room temperature in a flame-retardant cabinet away from other combustible products and sources of heat until it is used. During recovery preparation the pyrodex is measured from the plastic container until the required amount is acquired and then the plastic lid is secured back and the whole container relocated to its safe position.

Handling

During the assembly of the ejection charges the e-match wires are kept clipped to ensure that the ends of the wires are insulated and are not exposed to any static charge that is potentially near.

While installing the ejection charges, binding posted are used to connect the e-match leads to the e-bay. These insulate the wires from the airframe to ensure again no static charge is able to find the bare wires.

When connecting the ejection charges to the e-bay all power is disconnected and then the connections are made. The commercial altimeters used in the vehicle have built in safety's that do not allow them to arm until they are approximately 300 feet above their original location of power-on.

Only packaged the day of the test by a member experienced with handling Black Powder along with a faculty advisor.

Combustible Product Hazard: HTPB

Hydroxyl-terminated polybutadiene (HTPB) is a resin-based polyurethane elastomer and is the solid fuel of the Icarus II hybrid engine. There is a potential hazard for HTPB to ignite if in contact with an oxidizer and exposed to significant heat.

Transportation

The HTPB fuel grain will be cast before transport and the solid grain will be transported in a sealed and insulated container.

Storage

Fuel grain must be kept away from oxidizer and extreme heat.

Handling

Significant heat or flame exposure is required to cause a reaction since the fuel grain contains no oxidizing agent.

Pressure Vessel/Flammable Hazard: Nitrous Oxide Tank

A single nitrous oxide tank is used to provide the oxidizer for the hybrid engine. If exposed to heat or abuse the tank has the potential to rupture.

Transportation

Fill tanks will be purchased on site to reduce transport time to launch site. When transported, tanks will be secured to the vehicle via chains or straps. During local transportation, to avoid potential damage to the plumbing of the tank, a steel cap us screwed onto the top of cylinder not to be removed until the tank is in place and secure in its launch day location on the tower trailer.

Storage

On launch day the tank is moved from its transportation truck to the tower trailer into a steel box used to protect the tank from any potential shrapnel in the case of an emergency. Tanks will be stored upright and secured via chains or straps.

Handling

The tank valves will remain closed before the set-up begins. To achieve optimum performance from the engine the nitrous oxide tank is regulated to a specific temperature through the use of an insulated wooden box with a water piping system that delivers hot or cold water through the internal plumbing of the box. The conduction between the steel tank and the copper pipes in which the water flows regulate the temperature.

This insulated box with nitrous oxide tank is placed inside a steel box on the launch trailer and is not touched again until the launch site is cleared and the select technicians required for operation are instructed to open the tank.

The tank is operated remotely by a solenoid connected to the plumbing of the tank as to ensure all personnel are removed from the area incase of a leak.

Once the engine is filled to the proper weight the solenoid is closed to stop the flow of nitrous oxide. A positive feedback message of the solenoids opening and closing is displayed to the operator at the control station during these operations.

Always be careful when handling the pressurized tank as to ensure it is not dropped or damaged during motion.

Pressure Vessel/Flammable Hazard: Oxygen Tank

A single high-pressure oxygen tank is used to provide oxygen to the sting in the engine. The sting is a vinyl hose that supplies oxygen to the top of the combustion chamber to assist in the ignition of the engine. If exposed to heat or abuse the tank has the potential to rupture.

Transportation

The oxygen tank is transported in the bed of a truck to the competition, strapped in place with heavy-duty ratchet straps to prevent rolling during transport. During transportation to avoid potential damage to the plumbing of the tank a steel cap us screwed onto the top of cylinder not to be removed until the tank is in place and secure in its launch day location on the tower trailer.

Storage

On launch day the tank is moved from its transportation truck to the tower trailer into a steel box used to protect the tank from any potential shrapnel in the case of an emergency.

Handling

The tank is ensured closed before the set-up begins and is not touched again until the launch site is cleared and the select technicians required for operation are instructed to open the tank.

Due to oxygen's flammable nature the technicians are instructed to inspect the launch site prior to operations to ensure no exposed flames or electrical components could potentially start a fire pre-maturely once the sting is operational.

The tank is operated remotely by a solenoid connected to the plumbing of the tank as to ensure all personnel are removed from the area incase of a leak.

Once the engine is ignited the oxygen solenoid is closed to stop the flow of oxygen. A positive feedback message of the solenoids opening and closing is displayed to the operator at the control station during these operations.

Always be careful when handling the pressurized tank as to ensure it is not dropped or damaged during motion.

Electrical Shock Hazard: AC Power Systems

The launch tower and control trailer both utilize electrical power by means of gas generators that provide 120-volt AC for the launch systems and accompanying electrical hardware. This electrical power is transferred to the necessary locations via extension cords and power strips. This poses a hazard to the operators in the form of electrical shock via an expose wire or loose connection that has exposed a connection.

Transportation

The gas generators and power cables do not pose a hazard to the operators of the system until they are in place and the generator is powered on.

Storage

The gas generators will be stored in a location in which they are isolated from any potential sources of heat or flame. The launch trailer generator shall be located at the tongue of the trailer opposite from the direction in which the blast deflector of the tower will direct the exhaust flames to ensure no heat from the engine or shrapnel in the case of a launch failure can damage it.

Handling

Operators are advised during set-up of the electrical systems, inspect all extension cords for damage or exposed wires before making connections to power to ensure to shock hazards exist. All connections should be made before the generator is turned on.

Ensure that all power strips are rated for the load of the device before connecting the device to avoid overloading the power strip.

Technicians are asked during the pre-launch sequence to ensure all extension cords and wires are moved out of the blast deflector area to a safe location to ensure no wires are melted during operation potentially leading to a short during operation.

Flammable Hazard: Engine Ignition

There is a potential for a fire to be ignited over grass in an open field as a result of recovery system testing or wires burning out.

Handling

During testing, the recovery section is placed on top of a base that, in case of any fire, would protect the grass underneath. Members present should have passed fire safety training and must have an appropriate fire extinguisher during the test.

Only use batteries that output current that has the proper current handled by the wires and computer connected to the recovery bay. Batteries are tested for charge before being connected. Members present should have passed fire safety training and must have an appropriate fire extinguisher during the test.

Use of a fireproof blanket between drogue parachute and shock chords as well as a deployment bag around main parachute to protect elements from a potential fire caused by detonation. Members present should have passed fire safety training and must have an appropriate fire extinguisher during the test.

Hearing Hazard: Engine Ignition

There is a potential for hearing damage to occur as a result of a catastrophic failure of either the fill tank of the run rank during a static engine test. Additionally, unpredictable noise levels during a static engine test can cause hearing damage.

Handling

All personnel participating in and/or observing the test must wear both ear plugs and ear phone headset protection.

All personnel participating in and/or observing the test must wear both ear plugs and ear phone headset protection. During the test, sound recording instruments will be used by the technicians to collect noise data at several locations (specifically: inside the control room, inside the conference room, and at pertinent locations in the Riverside campus). Following the first engine test, noise data will be assessed, and plans will be made to further attenuate the noise to the best of our ability.

Flammable Hazard: Lithium Polymer (7.3 V) Battery

If Lithium Polymer battery is discharged past acceptable levels (6.0 V or Lower) a possible risk of fire may exist.

Storage

Battery cells cannot be pierced by sharp objects, exceed temperatures of 140 F, or exceed charging/discharging capacities.

Handling

Lithium Polymer batteries must also be charged to appropriate levels (7.5 V at maximum) with a balancer and be supervised throughout the charging process.

APPENDIX D
Risk Assessment

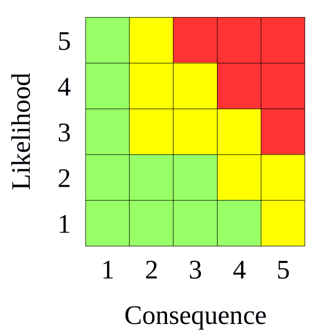
Risk Assessment Appendix

Likelihood Rating

5	Very Likely - expected to happen
4	Likely - could happen; controls have significant limitations or uncertainties
3	Possible - could happen; controls exist with some limitations or uncertainties
2	Unlikely - not expected to happen; controls have minor limitations or uncertainties
1	Highly Unlikely - extremely remote possibility that it will happen; strong controls in place

Consequence Rating

			1	2	3	4	5
Technical	Safety	Human Health	Minor or first aid injury	Moderate injury, illness, incapacitation, or impairment	Significant or long-term injury, illness, incapacitation, or impairment	Permanent or major injury, illness, incapacitation, or impairment	Death
		System Safety	Damage to non-flight critical assets	Loss of non-flight critical measures	Damage to major elements of flight vehicle or ground facility	Loss of major elements of flight vehicle or ground facility	Loss of program
		Regulation Compliance	Minor non-compliance	Moderate non-compliance	Significant non-compliance	Major non-compliance	None defined
	Mission Success	Operations & Objectives	Minor increase in flight operations timeliness or complexity	Significant increase in flight operations timeliness or complexity	Failure to achieve any planned mission objective	Failure to achieve all mission objectives or performance requirements; pad abort	Contingency abort; site evacuation
Programmatic	Schedule	Mission Schedule	Minor operational slips	Less than 5-hour milestone slip	Greater than 5-hour milestone slip	One day delay from launch schedule	Indeterminate delay from launch schedule
	Cost	Risk Recovery Cost	< $25	$25 - $75	$75 - $150	$150 - $500	> $500



Mission Phase	Risk	Possible causes	Mitigation approach	L	C
0	Insufficient number of fasteners and other hardware	Fasteners are stripped, sheared, or lost during assembly	Ensure spare fasteners and other hardware are on hand	2	2
0	Stripped threads on engine plumbing fittings	Applying torque when fittings are incorrectly oriented	Hand tighten fittings first to ensure resistance is normal, have spare fittings on hand, remove only designated “temporary” fittings when storing the engine	3	2
		Over torquing during assembly	Apply the proper amount of torque, have spare fittings on hand		
0	General composite fabrication failures	Part not drying due to improperly mixed epoxy resin and hardener	Always use digital scales capable of weighing mass up to a resolution of 0.1g	2	2
		Part is unusable due to fabrication tolerances	Employ the phrase “measure twice, cut once,” design with reasonable tolerances for available manufacturing resources		
0	Body tube fabrication failure	Filament winding failure due to improper manufacturing coding parameters	Ensure clear how-to guides are written and available to personnel operating filament winder	3	3
		Wind failure due to fiber breakage	Have personnel observe winder during entirety of body tube manufacturing		
		Wind failure due to machine malfunction	Know machine’s limit and abilities, pray before starting program		
0	Nose cone fabrication failure	Nose cone sticks to mold and cannot be separated without compromising the structural integrity of the part	Use proper releasing agents, use a negative mold, have robust manufacturing procedures developed before attempting construction	3	2
		Nose cone lacks rigidity necessary for flight	Use proper amount fabric and epoxy, consult team members with knowledge and experience		
		Nose cone lacks radio transparency	Use only paints and epoxies know to allow radio transmission		
0	Fin fabrication failure	Loss of vacuum during VARTM	Follow best practices developed by team to reduce leak points in vacuum bag, ensure seals around all fittings, perform process on clean surface to reduce hole puncturing	3	2
		Missing internal components	Follow step-by-step manufacturing guidelines developed by team		
0	Bulkhead fabrication failure	Part damaged by machining equipment	Ensure all parts are properly secured during	2	2

			machining operations, follow all shop practices and safety rules		
		Part not properly machined to tolerance	Ensure tolerances are clearly labeled on part drawings, have experienced members teach new members how to properly operate machinery		
0	Tail cone fabrication failure	Machinery not large enough to roll metal sheet	Properly spec the machinery to be used and appropriately size fabrication materials	2	3
0	Personnel exposure to epoxy and fumes	Performing work in a confined space without proper ventilation	Perform work outside or in a large well ventilated area, perform work quickly to limit time that personnel is exposed to fumes	3	2
		Personnel not wearing proper PPE	Enforce personnel to wear the proper PPE (ex. nitrile gloves) before working with epoxy		
0	Injury sustained during part fabrication	Sharp machined edges	Ensure all edges are deburred and chamfered	2	4
		Inexperienced machinery user	Have shop technician or experienced member teach new members		
1	Insufficient Nitrous Oxide, Oxygen, or air supply	Leaks in filling system connections	Verify weight/pressure before use	1	2
		Tanks were not filled properly or purchased on time	Purchase tanks ahead of launch and verify weight/pressure before use		
1	Launch-box malfunction (fails to turn on/arm)	Battery malfunction/low power	Use multimeter to measure voltage batteries before connecting to launch box	1	2
		Short circuit inside launch box	Handle launch box with care. Do not drop or place objects over it		
1	Launch-box malfunction (fails to detect igniter)	Faulty connection between launch box and igniter wires	Ensure proper connection to launch box by tugging on wires after connecting them. Should remain in place and connected	1	1
		Faulty connection inside launch box	Handle launch box with care. Do not drop or place objects over it		
1	Intermittent or lack of communication with Launch box	Battery malfunction/low power	Use multimeter to measure voltage batteries before connecting to launch box	1	3
		Short circuit inside launch box	Handle launch box with care. Do not drop or place objects over it		
		Misalignment or poor placement of antennae	Antennae should be placed on top of a non-conductive surface with its long side pointing towards the launch tower and the transverse rods oriented parallel to the ground.		

1	Flight computers fail to turn on	Battery malfunction/low power	Use multimeter to measure voltage batteries before connecting to flight computers	3	1
		Flight computers became damaged during transportation	Flight computers should be turned on and off before placing them into the rocket to ensure that they are working properly		
		Wires got disconnected during the assembly process	Ensure proper connections by tugging on wires after connecting them. Should remain in place and connected		
1	External fill tanks start to leak	Fill solenoid was left open after previous use	Perform closing procedures after each test or launch according to instructions	3	1
		Leak in plumbing connecting solenoid to the tank	Use of plumbing tape for connections, ensure fittings are rated for the pressures that are being handled, and apply the proper amount of torque for each connection		
1	Connection to GPS lost	Battery malfunction/low power	Use multimeter to measure voltage batteries before connecting to launch box	3	1
		Short circuit inside GPS transmitter	GPS transmitter should be turned on and off before placing them into the rocket to ensure that they are working properly		
1	Fire in Electronics Bay	Lithium Polymer Batteries being damaged	Lithium Polymer (7.4 V) battery is secured by multiple zip ties in all axes in similar fashion to previous batteries in other successful flight tests.	1	3
		Lithium Polymer Batteries at a low voltage	Motor controller was installed & tested in Electronics Bay which control computers use to stop current flow of battery after servo operation is complete. There is also a key switch that also keeps the battery from being drained while the rocket sits on the launch pad until nearing launch. Visual inspection of the batteries and charging them to appropriate voltage every time before use to a avoid expedited degradation.		
2	Connection to Launch box lost	Battery malfunction/low power	Use multimeter to measure voltage batteries before connecting to launch box	3	2
		Short circuit inside launch box	Handle launch box with care. Do not drop or place objects over it		

		Misalignment or poor placement of antennae	Antennae should be placed on top of a non-conductive surface with its long side pointing towards the launch tower and the transverse rods oriented parallel to the ground.		
2	After sending fill command, no weight change is reporter on rocket or fill tank	Solenoid malfunction on nitrous tank	Test solenoids prior to starting launch procedures to ensure that they are working properly and that they are set to default state.	3	1
2	Fill and (or) vent lines disconnect upon initiating filling sequence	Connection between Quick Disconnect fittings not properly secured	During placement, ensure that an audible “click” is heard once the line is connected to the rocket. Ensure this by slightly tugging the line and making sure the connection does not come undone.	1	2
		Quick disconnects used were not rated for the correct pressure	Ensure fittings are rated for the pressures that are being handled prior to assembly.		
2	Loss of gas on fill tanks is reported to be faster than weight gained by rocket	Leak in plumbing connecting solenoid to the rocket	Use of plumbing tape for connections, ensure fittings are rated for the pressures that are being handled, and apply the proper amount of torque for each connection	1	1
		Connection between Quick Disconnect fittings not properly secured	During placement, ensure that an audible “click” is heard once the line is connected to the rocket. Ensure this by slightly tugging the line and making sure the connection does not come undone.		
2	Loss of pressure on run-tank after is full and lines are closed	Leak in plumbing connecting the run-tank to the ball valve	Use of plumbing tape for connections, ensure fittings are rated for the pressures that are being handled, and apply the proper amount of torque for each	3	1
		Leak in plumbing connecting plumbing cross to fill, vent, or other sensor ports	Use of plumbing tape for connections, ensure fittings are rated for the pressures that are being handled, and apply the proper amount of torque for each		
2	Fill tank or fill lines rupture due to cavitation	Nitrous oxide becomes supercritical due to exceeding high temperature (97.5°F) and bubbles form in flow to the run tank	Constant monitoring of fill tank temperature and pressure, ensure fill tank is at a manageable temperature by using the insulated box, ensure all personnel are at a safe distance	2	3
		Servo closing by itself during burn time, causing the flow to go into the nitrous tank as opposed to out.	There are multiple steps required in order to change the position of the servo. Power must first supplied to servo by sending a command to the motor controller and then a command must be given to the flight. If both requirements are not meet then the servo will not change its position.		

		Accidentally sending the command after being told to close at an inappropriate time	The default state of the flight configuration is that the power to servo is not provided until a command is sent to provide power to servo. The protocol to operate the servo is to only provide power when the position needs to be changed, and power is off the rest of the time.		
2	Connection to GPS lost	Battery malfunction/low power	Use multimeter to measure voltage batteries before connecting to launch box	3	1
		Short circuit inside GPS transmitter	GPS transmitter should be turned on and off before placing them into the rocket to ensure that they are working properly		
3	Intermittent or lack of communication with Launch box	Misalignment or poor placement of antennae	Antennae should be placed on top of a non-conductive surface with its long side pointing towards the launch tower and the transverse rods oriented parallel to the ground.	1	3
3	After ending fill, fill tanks still report loss of pressure	Leak in plumbing connecting the solenoid to the tank	Use of plumbing tape for connections, ensure fittings are rated for the pressures that are being handled, and apply the proper amount of torque for each	1	1
3	Fill and vent lines disconnect not confirmed on camera feed	Lines did not fully disconnect	Have the proper placement of QD system's pistons be pointing towards the rocket and ensure metal lines have little to no slack.	3	1
3	After sending ignition command, no flame is confirmed on camera feed	Solenoid malfunction on oxygen line	Test solenoids prior to starting launch procedures to ensure that they are working properly and that they are set to default state.	3	1
		Leak present from oxygen line's solenoid to rocket	Use of plumbing tape for connections, ensure fittings are rated for the pressures that are being handled, and apply the proper amount of torque for each		
		Igniter fabrication problem	Build igniter according to instructions on SOP and test its continuity to ensure proper ignition		
3	After oxygen ignition and ball valve is opened, no ignition is confirmed on camera feed.	Oxygen fire melted tape securing flexible oxygen line to the combustion chamber; oxygen line falls out before ignition	Apply a generous amount of tape around the nozzle to ensure that the oxygen line will remain in place	3	3
3	After oxygen ignition and ball valve is intended to open, no oxidizer is released	Servo is unable to open ball valve	Ensure actuator system is secure and properly oriented, ensure proper voltage on battery	3	3
3	Run tank or plumbing rupture do to cavitation during ignition	Nitrous oxide become supercritical due to exceeding high temperature (97.5°F) and bubbles form in the	Constant monitoring of run tank temperature and pressure before ignition, keep vent line attached until	2	3

		flow to the injector	launch to release nitrous as needed, ensure all personnel are at a safe distance		
3	Run tank ruptures due to over-pressure	Nitrous oxide exceeds supercritical due to high temperature (above 97.5°F)	Implement a relief bleed off valve set to 1500 psi, use a tank with a high (3600 psi) pressure rating	1	3
3	Connection to GPS lost	Battery malfunction/low power	Use multimeter to measure voltage batteries before connecting to launch box	3	1
		Short circuit inside GPS transmitter	GPS transmitter should be turned on and off before placing them into the rocket to ensure that they are working properly		
4	Failure to leave launch rail	Insufficient thrust from engine	Multiple static engine tests providing data to support favorable rail exit velocity	1	5
		Obstruction such as lip in railing connections	3D printed ramps to cover joints in aluminum rail hardware		
		Launch rails too tight on airframe	Implementation of CNC rail adjustment guides to ensure clearance for rocket airframe		
4	Failure of launch tower during initial boost	Rocket slipping through guide rails	Implementation of CNC rail adjustment guides to ensure proper rail positions	1	5
		Tower failure to guide rocket in vertical direction	Appropriate number of guide rails to ensure rocket is fully restricted to movement in the proper direction		
		Failure of launch infrastructure to protect electronics/ sensitive launch critical hardware	Blast deflector to direct exhaust of engine away from tower and launch infrastructure		
4	Body tube failure due to delamination or buckling	Improper body tube layer thickness or epoxy transfer	Ensure structural integrity of body tube after construction	2	5
4	Fin failure due to fin flutter	Fin is not properly tightened to tail cone	Ensure all bolts inserted in fin are properly torqued against the tail cone	2	4
5	Premature separation of airframe recovery section	Hard stop of engine provides a sufficient impulse to airframe to separate nosecone	Shear pins between nosecone and airframe provide temporary structure to hold sections together	1	5
		Insufficient connection to hold nosecone to airframe during engine burnout	Shear pin number and size determined through numerous recovery tests and appropriate material property calculations		
6	Failure of the separation of nosecone and airframe	Flight computer malfunction	Utilization of a redundant commercial flight computers designed and tested for use in rocketry application	2	5
		Failure of ejection charges to ignite	Redundant ejection charges with separate e-matches		

			increased the chances of a successful ignition of single ejection charge		
		Insufficient ejection charge sizes	Heavy testing of ejection charge sizes along side calculations supporting proper pressure generated by charge for proper separation		
		Open circuit between electronics and ejection charges	Use of insulated binding posts in bulkhead and continuity checked before, during, and after installation		
		Insufficient seal between nosecone and airframe allowing ejection gases to leak	Heavy testing of ejection system in flight configuration ensures proper seal is maintained		
6	Drogue parachute fails to deploy after nosecone has separated	Tangle of shock cord and drogue parachute	Use of Nomex blanket to act as separator between drogue and shock cord works to minimize risk of entanglement	2	4
		Tangle of drogue and main parachute	Deployment bag houses main parachute and all shroud lines minimizing chances of entanglement with drogue parachute		
6	Pre-mature deployment of main parachute after nosecone has separated	Main parachute loose in recovery bay	Main parachute is housed in deployment bag ensuring that parachute is kept in its proper folded configuration	3	3
		Main parachute loose in deployment bag	Deployment bag sizing ensures a snug fit while proper folding ensures that it will fill the bag and maintain proper fit		
		Main parachute pulled out due to shock cord tangling with drogue shock cord	Heavy ground deployment testing and following packing procedures ensure the shock cord between main and drogue stay separated and untangled		
		Pre-mature release of ARRD shackle	Following procedures during assembly and procedural testing after assembly lessen the chances of a pre-mature release		
6	Nose cone loss due to recovery expansion release	Recovery connection to nose cone not properly secured to nose cone	Use structural epoxy to adhere connection piece to nose cone, use 3D printed shoulder to physically constrain connection piece in nose cone	2	3
7	Failure of ARRD to release connecting shackle	Improper charge sizes for activation	Following manufacturer charge recommendations and also heavy testing of system	2	4
		Failure of e-matches in ARRD	Redundant e-matches in ARRD wired to separate commercial altimeters		

		Improper seal in ARRD leading to loss of charge pressure	Following procedures during assembly ensure a proper seal of the ARRD		
7	Main parachute fails to deploy after ARRD has released shackle	Main parachute stuck in deployment bag	Deployment bag sizing ensures a snug fit but one that will still allow the main parachute to be pulled out	1	4
		Drogue parachute is insufficiently strong to pull main parachute out of recovery bay	Shock cord packing ensures that the drogue can pull the main parachute from the deployment bag once its shock cord is pulled		
7	Main parachute fails to inflate after deployment	Tangled with shroud lines/shock cord	Following procedures during assembly lessens chance of entanglement of shock cord because of strategic packing	1	4
		Improper folding	Following procedures during assembly ensures the main parachute is packed the same as in recovery testing		
8	Damage to vehicle upon landing	Improper sizing of recovery parachutes	Previous flight data supports favorable descent velocities during main parachute descent	2	3
		Reduced size of parachutes due to tangling during deployment/descent	Following procedures during packing of recovery system reduces chances of tangling due to strategic packing order		
		Landing on an unfavorable surface i.e. Concrete	Proper position of launch tower based on current weather and recovery map simulations increases chance of a favorable landing surface		
8	Damage to property/ persons upon landing	Unexpected drift due winds at altitude	Implementation of weather station at ground level to gauge winds at altitude. Launch day weather analysis to better characterize winds during modeling	1	2
		Improper launch tower position	Dynamics sub team launch day roles ensuring proper position of launch tower based on current weather and recovery map simulations		
		Pre-mature deployment of main parachute	See above under subsection (Pre-mature deployment of main parachute after nosecone has separated)		
8	Landing in a restricted location or one in which recovery would be difficult	Improper launch tower position	Dynamics sub team launch day roles ensuring proper position of launch tower based on current weather and recovery map simulations	1	4
		Unexpected restrictions to recovery zone	Available recovery zones verified before launch day by dynamics sub team		

APPENDIX E
Assembly, Pre-Flight, & Launch Checklists

Version 5.3 Released 05/25/18

SRT-5 Launch Operations

Texas A&M University® Sounding Rocketry Team

Academic Year 2017-2018

ENGINEERING
TEXAS A&M UNIVERSITY

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1 Launch Day Roles

Flight Director [FLIGHT]
Responsible for launch execution: timeline management, system readiness, and labor organization. Serves as the central point-of-contact for team members. Primary flight controller during test & launch sequence(s).

Mission Operations Director [MOD]
Senior representative, coordinates launch approval with site sponsors and management. Provides final launch decision to FLIGHT. Primary safety officer and point-of-contact for public.

Assembly and Checkout Officer [ACO]
Responsible for airframe assembly & integration with hybrid engine, avionics, and payload. Provides final approval for vehicle checkout and flight readiness.

Launch Infrastructure Officer [LIO]
Responsible for the assembly and setup of the launch tower and trailer. Provides final approval for launch pad readiness and coordinates vehicle-tower integration as well as tower erection.

Propulsion Officer [PROP]
Responsible for hybrid engine assembly and checkout. Will monitor engine conditions during fill process, and will provide final approval for engine ignition during launch sequence.

Avionics Officer [AVO]
Responsible for functionality of onboard avionics & payload. Provides final approval for readiness of all onboard electrical systems. Assists PROP with hybrid engine checkout.

Instrumentation and Communications Officer [INCO]
Responsible for functionality of camera system and data acquisition. Serves as primary data engineer during launch sequence.

Data Engineer [DATA] – Offboard instrumentation support.

Control Officer [CONTROL]
Will serve as ground controller during test & launch sequence(s).

Flight Dynamics Officer [FDO]
Responsible for the vehicle's flight plan; determines oxidizer fill weight, estimated apogee, and monitors atmospheric conditions. Provides launch decision to Flight Director from dynamic safety criteria.

Dynamics Engineer [DYN] – Trajectory support.

Launch Technician(s) [TECH 1 & TECH 2]
Responsible for launch pad operations; system arming, fluid control, and pad safety.

Telemetry & Recovery Officer [TELRE]
Responsible for packing, stowage, ejection charge construction and instillation, and all other necessary components for successful recovery of the rocket. Will lead rocket retrieval effort after landing.

Recovery Engineer 1 [RECO 1] – Recovery system specialist.

Recovery Engineer 2 [RECO 2] – Electronics & Payload specialist.

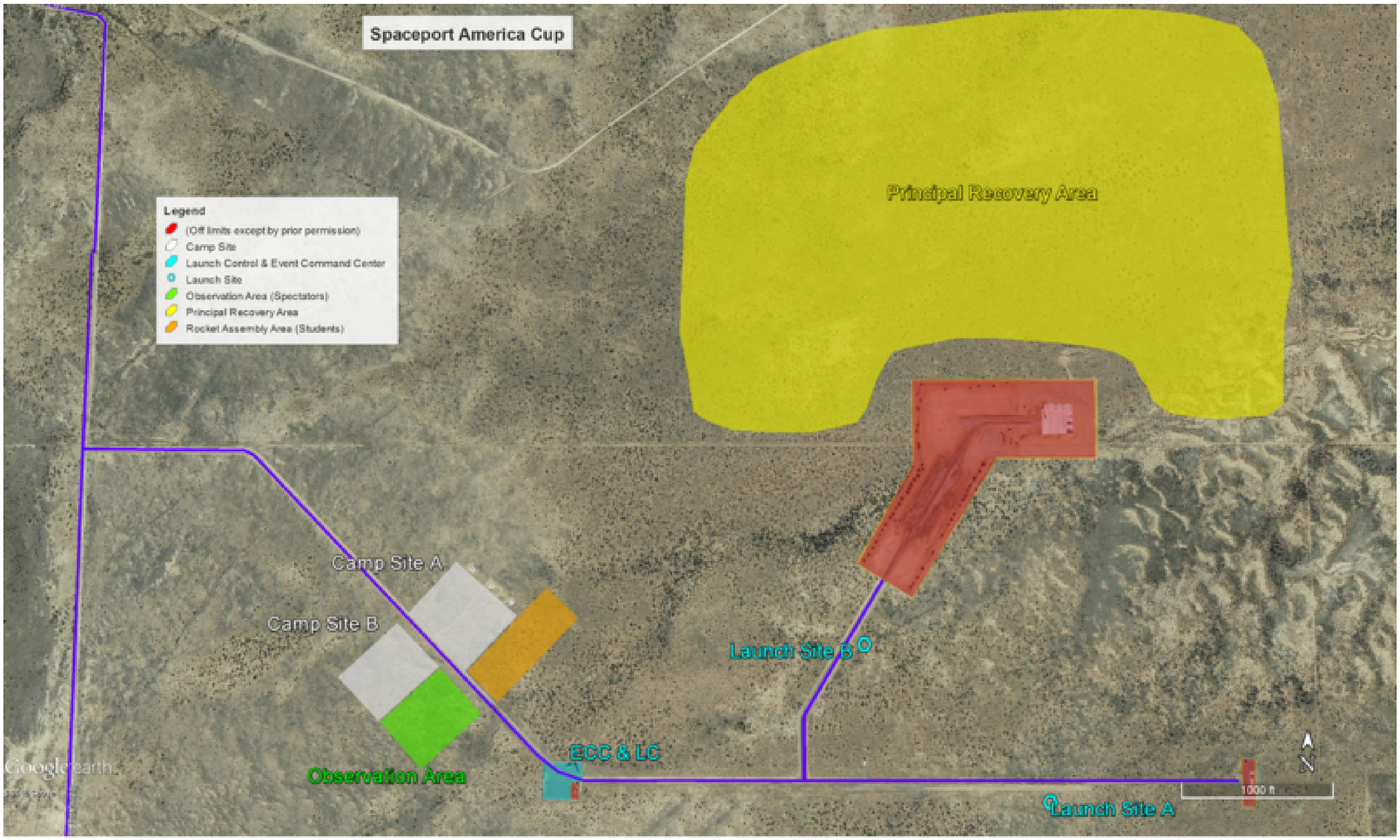
MOD	J. Pasket	**CONTROL**	V. Wright	**PAD**	M. Noble	**BOX**	M. Kriel
FLIGHT	R. Doddanavar	**FDO**	J. Doll		J. Robles		J. Villegas
ACO	T. Illingworth	**DYN**	J. Caesar		E. Swiny		R. Alexander
LIO	A. Maruffo	**TECH 1**	W. Young		C. Finke		J. Kizer
PROP	S. Michaels	**TECH 2**	A. Smith		D. Guo		S. Canchola
AVO	L. Martinez	**TELRE**	A. Gonzalez				A. Riha
INCO	M. Roberts	**RECO 1**	T. Illingworth				A. Aguilar
DATA	M. Silberberg	**RECO 2**	A. Castrellon				

2 Launch Timeline

				T-04:00	T-03:30	T-03:00	T-02:30	T-02:00	T-01:30	T-01:00	T-00:30
TOWER											
Tower Setup											
Tower Transport	*LIO*	*A. Maruffo*	:	6							
Trailer Unload	*LIO*	*A. Maruffo*	:		6						
Tower Construction										**Test Sequence**	
Assemble Members	*LIO*	*A. Maruffo*	:			4					
Integrate/Calibrate	*LIO*	*A. Maruffo*	:				4				
Fluid Control											
Tank Setup	*TECH 2*	*A. Smith*	:			3	3	3			
Line Setup	*TECH 2*	*A. Smith*	:			3	3	3			
Ignition Setup	*TECH 2*	*A. Smith*	:						2		
QD Setup	*TECH 2*	*A. Smith*	:						2		
VEHICLE											
Assembly											
Avionics Checkout	*AVO*	*L. Martinez*	:		1						
Recovery Checkout	*RECO 1*	*T. Illingworth*	:		1						
Plumbing Checkout	*PROP*	*S. Michaels*	:		1					**Test Sequence**	
Integration/Weight-In	*ACO*	*T. Illingworth*	:			3					
Tower Integration											
Transport/Integration	*ACO*	*T. Illingworth*	:				4				
Tower Erection	*LIO*	*A. Maruffo*	:					8			
GROUND CONTROL											
Trailer Comm											
Dynamics Setup	*FDO*	*J. Doll*	:		2	2					
Control Setup	*INCO*	*M. Roberts*	:		1	1					
Camera Setup	*INCO*	*M. Roberts*	:		2	2					
Pad Comm										**Test Sequence**	
RLS Setup	*RECO 2*	*A. Castrellon*	:			1					
RDS Setup	*RECO 2*	*A. Castrellon*	:			1					
Camera Setup	*RECO 2*	*A. Castrellon*	:			2	2	2			

3 Launch Site Layout

The following is a graphic showing an overview of the launch site setup with designated recovery zones marked.



<u>Principle Recovery Area</u>

1. TECH identifies location of last received GPS data packet
2. Walk to probable rocket location after approval of Range Safety Officer
3. Locate vehicle by normalizing recovery grid search method to location by applying distribution from impact map
4. Recover vehicle and transport back to command center
5. Disconnect all rocket power

4 Materials Required for Theseus Launch

Theseus Airframe

responsibility of ACO

- ☐ Body sections
  - ☐ Main Body Tube
  - ☐ Thrust Bulkhead w/ Aft Body Tube
  - ☐ E-bay and payload compartment
  - ☐ Recovery Bay
- ☐ Nose Cone
- ☐ Tail Cone w/ Fins (3)
- ☐ Airframe Tool Box

Nova Engine

responsibility of PROP

- ☐ Combustion Chamber with Pressure Transducer
- ☐ Nitrous Tank
- ☐ Injector Housing
- ☐ Injector Coin
- ☐ Plumbing Cross
- ☐ Nozzle
- ☐ Nozzle Collar
- ☐ Ball Valve
  - ☐ Connecting 1" Yor-Loks (2)
  - ☐ Ball Valve Servo
  - ☐ Ball Valve Servo Mounting Bracket w/ Bolts (4)
- ☐ Vent Line and Hoses
- ☐ Pressure Relief
- ☐ Pressure Transducer (2)
- ☐ Thermocouple
- ☐ O-rings
  - ☐ Injector Plate/Combustion Chamber (1)
  - ☐ Nozzle (2)
  - ☐ Injector Coin/Housing (1)
  - ☐ Nitrous Tank/Plumbing Cross (1)
- ☐ Hardware
  - ☐ 1/4"-28 x 1$\frac{1}{2}$" hexhead bolts for combustion chamber to injector housing (12)
  - ☐ 1/4"-20 x 3/4" countersunk screws for nozzle (6)
  - ☐ Washers
  - ☐ Nuts

Electronics

responsibility of INCO

- ☐ Payload (If Applicable)
- ☐ E-bay
  - ☐ Flight Card
  - ☐ E-Bay Arming Keys (3)
  - ☐ 7.4 Volt LiPo battery (2)
  - ☐ 9 Volt Energizer Batteries (4)
  - ☐ 12 Volt $LiFePo_4$ Main Power Batteries
- ☐ Battery charger
- ☐ DC motor controller
- ☐ Telemega
- ☐ Beeline
- ☐ Stratalogger
- ☐ LC power supply
- ☐ FTDI (2)
- ☐ Thermocouples (2)
- ☐ Teledongle
- ☐ Voltage regulators
- ☐ Insulation sleeve

Recovery

responsibility of TELRE

- ☐ Main parachute
- ☐ Drogue parachute
- ☐ Shockcord
- ☐ Kevlar Y-Harness
- ☐ Deployment Bag
- ☐ 3/8" Quicklinks (5)
- ☐ 1/4" Quicklink (1)
- ☐ E-matches
- ☐ 4-40 Shear Pins (4)
- ☐ ARRD
  - ☐ 5 Ball Bearing
  - ☐ Piston w/ Spring
  - ☐ Pyrodex Dish
  - ☐ Pyrodex Dish Cap Stickers (10+)
- ☐ Pyrodex P
  - ☐ Black Powder Measuring Tube

Launch Infrastructure

responsibility of LIO

- ☐ Launch Box w/ Keys
- ☐ Yagi Antennas (2)
- ☐ X-Bee w/ Antenna
- ☐ Computer w/ Putty Software
- ☐ Blast deflector
- ☐ Clear Vinyl Tubing (Disposable Oxygen Line)
- ☐ E-Match Wire, Testors Glue and Pyrodex
- ☐ Clear toolbox
  - ☐ Nuts and bolts
- ☐ Hitch
- ☐ 12 V batteries (2)
- ☐ Igniter
  - ☐ 12-gauge ignition wire
  - ☐ Steel wool
  - ☐ Razor
  - ☐ Cement for Metal & Wood
- ☐ Camera
- ☐ Camera transmitter and reviver
- ☐ Camera wires and adapters
- ☐ Computer monitor
- ☐ Clamp for quick disconnect
- ☐ Fill tank temperature box
- ☐ Electric scale
- ☐ Load cells (3)

Miscellaneous

responsibility of ACO

- ☐ Ratchet
  - ☐ 7/16"
  - ☐ 9/16"
- ☐ Torque Wrench
- ☐ Crescent wrench
  - ☐ Big ones
- ☐ Weather station and base
- ☐ Screw driver set
  - ☐ Tiny ones for Ball Valve Actuator
- ☐ Allen wrenches
  - ☐ Tiny ones
- ☐ Screws
  - ☐ 4-40
- ☐ Nuts
  - ☐ 4-40
- ☐ Duct-tape
- ☐ Lubricant
- ☐ Misc Wire Nuts, Wire Connectors
- ☐ Wire Strippers
- ☐ Needle Nose Pliers
- ☐ Electrical Tape
- ☐ Soldering Iron
- ☐ Pipe Thread Tape

- ☐ O-ring grease
- ☐ Tent
- ☐ Table (1-2)
- ☐ Charis (3-4)
- ☐ Ladder
- ☐ Level
- ☐ Extension cord
- ☐ Wire rack
- ☐ HVAC system
- ☐ White lithium grease
- ☐ Soldering iron
- ☐ Solder
- ☐ Zip-ties
- ☐ Drill with battery and charger
- ☐ Jumper wires
- ☐ Stand-offs
- ☐ Crimp connections
- ☐ Crimp tool
- ☐ Tape measure
- ☐ Dremel
- ☐ Multimeter (2)
- ☐ Binoculars
- ☐ Walkie-talkies with chargers (4)
- ☐ Sunscreen
- ☐ Bug spray
- ☐ First aid kit
- ☐ Generators (3)

5 Simulation Procedure

5.1 Pre-Flight

Led by FDO

- ☐ 1 Setup weather station and base. Place station in accordance with Launch Site Layout
  - ☐ 1.1 Weather 1: Begin recording relevant parameters. Identify following values & estimated MC bounds in dedicated spreadsheet every 15 minutes:

	mean ± std. dev	
Time (MDT)	________	
Wind Heading	________	deg
Wind Speed	________	mph
Temperature	________	°F
Pressure	________	psia
Rel. Humidity	________	%

  - ☐ 1.2 Monitor weather trends.
- ☐ 2 Record launch tower GPS coordinates: ____________ , ____________
- ☐ 3 Begin running 100 MC simulations every 30 minutes until beginning of launch sequence using recorded weather data
  - ☐ 3.1 Run `FIND IMPULSE` script and determine target nitrous fill.
  - ☐ 3.2 Run `FLIGHT SIM` script and verify FAA waiver is not violated.
  - ☐ 3.3 Use printed FPE's to assess estimated downrange distance and provide optimal launch tower azimuth and elevation.
  - ☐ 3.4 Record the following simulation results in dedicated spreadsheet:

Oxidizer Fill Recommendation	________	lbs
Est. Altitude	________	ft
Est. Rail Exit Velocity	________	ft/s
Downrange X	________	ft
Downrange Y	________	ft

- ☐ 4 One hour prior to launch, begin recording relevant parameters (wind heading and speed, temperature, pressure, and relative humidity) every 5 minutes

- ☐ 5 Verify empty rocket weight and C.G. position
- ☐ 6 Record loaded rocket weight: ______________________ lbs
- ☐ 7 30 minutes prior to launch sequence, record weather conditions, run final pre-flight simulation, and record results:

Time (MDT)	____________________	
Wind Heading	________ ± ________	deg
Wind Speed	________ ± ________	mph
Temperature	________ ± ________	°F
Pressure	________ ± ________	psia
Rel. Humidity	________ ± ________	%
Oxidizer Fill Recommendation	________ ± ________	lbs
Est. Altitude	________ ± ________	ft
Est. Rail Exit Velocity	________ ± ________	ft/s
Downrange X	________ ± ________	ft
Downrange Y	________ ± ________	ft

- ☐ 8 Review Go/No-Go criteria and give decision

5.2 Post-Flight

Led by FDO

- ☐ 1 Record GPS coordinates of landing location: ______________________ , ______________________
- ☐ 2 Record number of beeps from electronics bay for altitude at apogee estimate: ___________
  - ☐ 2.1 Weather: Record final relevant parameters. Identify mean values & estimated MC bounds; end spreadsheet
- ☐ 3 Begin final simulations with final weather conditions to verify launch statistics
  - ☐ 3.1 Run `FLIGHT SIM` script
- ☐ 4 Collect weather station and base

6 Recovery Assembly

6.1 Recovery

Led by TECH

- ☐ 1 Main/ Drogue Parachute Packing
  - ☐ 1.1 Pack main parachute into the deployment bag according to procedures outlined in Appendix A (Main Parachute Packing Procedures) and set aside
  - ☐ 1.2 Pack drogue parachute according to procedures outlined in Appendix B (Drogue Parachute Packing Procedures) and set aside
- ☐ 2 Advanced Retention Release Device (ARRD) Assembly
  - ☐ 2.1 Unscrew base and push piston up to remove shackle
  - ☐ 2.2 Push piston out from top side of red housing and remove 5 ball bearings, being careful not to dislodge spring
  - ☐ 2.3 Place 5 ball bearings in red anodized body
  - ☐ 2.4 Place shackle and piston assembly into red housing and push piston into body up to the end of the threads
  - ☐ 2.5 Insert two e-matches into ARRD base ensuring a proper seal is made in the Pyrodex chamber
  - ☐ 2.6 Insert e-match leads (2) through hole in black base, pull the leads through until the cartridge is seated in place flush with the top of the base
  - ☐ 2.7 Measure and pour .4 grams of Pyrodex P into cartridge well
  - ☐ 2.8 Place a 3/4" diameter adhesive disk over the end of the cartridge
  - ☐ 2.9 Screw the red housing and black anodized base assembly together by turning the red body until firmly seated
  - ☐ 2.10 Grasp body and base assembly and firmly pull the shackle while twisting and turning to confirm lock
  - ☐ 2.11 Cut e-match wires to 8" long in preparation for installation into recovery bay and set aside
- ☐ 3 Airframe/Shock Cord Assembly
  - ☐ 3.1 Check continuity of recovery e-matches using a multimeter. Resistance is expected to be $2 \pm 0.2\ \Omega$.
  - ☐ 3.2 Connect ejection pods (4) and ARRD (4) e-match leads to binding posts outside of recovery bay
  - ☐ 3.3 Install ARRD and ejection pods in the recovery bay
  - ☐ 3.4 Install binding posts through the recovery bulkhead with respect to the labels on the bottom side of the bulkhead, tighten with a pair of needle nose pliers
  - ☐ 3.5
  - ☐ 3.6 Check continuity of recovery e-Matches through the binding posts using a multimeter. Resistance is expected to be $2 \pm 0.2\ \Omega$.
- ☐ 4 Recovery Bay Packing Procedures
  - ☐ 4.1 Slide the deployment bag with main parachute installed into the recovery bay
  - ☐ 4.2 Slide the deployment bag U-bolt through the recovery bulkhead and fasten the corresponding washer and nut on the opposite side to secure it in the recovery bay
  - ☐ 4.3 Lay the recovery bay on its side such that the deployment bag will lay up against the side of the airframe and expose a void for the remaining components
  - ☐ 4.4 Connect shock cord to Kevlar y-harness using pre-installed 3/8 inch Quick-link

- ☐ 4.5 Connect both free ends of Kevlar y-harness to 3/8 inch U-bolts in recovery bay using 3/8 inch quick links
- ☐ 4.6 Fold the length of shock cord between the Kevlar y-harness and the main parachute attachment loop in an accordion fashion
- ☐ 4.7 Wrap the shock cord bundle in the Nomex blanket attached to the Kevlar y-harness
- ☐ 4.8 Connect the main parachute swivel and ARRD shackle to the corresponding shock cord loop using a single 3/8 inch quick link (At this point the main parachute swivel is connected to the recovery bulkhead through the ARRD)
- ☐ 4.9 Place the bundle of shock cord in between the deployment bag and the opposite side of the recovery bay ensuring a clear path for the ARRD shackle upon its release
- ☐ 4.10 Fold the length of shock cord between the ARRD and the Drogue parachute loop in an accordion fashion and place on top of the previous bundle already inside recovery bay
- ☐ 4.11 Connect the drogue parachute swivel and the shock cord loop using a single 3/8 inch quick link
- ☐ 4.12 Remove the rubber band on the packed drogue parachute and place it in the center of recovery bay on top of shock cord
- ☐ 4.13 Connect the nosecone via a 1/4" quick link to the last loop in the shock cord away from the recovery bay
- ☐ 4.14 Fold the length of shock cord between the nosecone and the drogue parachute in an accordion fashion and place it on top of the drogue parachute
- ☐ 4.15 Insert the nosecone into the recovery bay being careful to have all shock cord/ shroud lines inside the recovery bay
- ☐ 4.16 Insert the 4 (4-40) shear pins through the airframe and nosecone
- ☐ 4.17 Secure the shear pins in place with a single ring of Gorilla tape around the perimeter of the recovery bay

7 Launch Infrastructure Assembly Procedure

7.1 Launch Tower

Led by LIO

☐ 1 Move launch trailer to its launch location and orientation.

☐ 2 Remove both tower halves and other tower components (blast deflector, rails, hinge, cap, etc) from trailer. Place tower halves to the side of the trailer opposite the spare tire.

☐ 3 During this time, the tank integration team should begin integrating the tanks into the launch trailer. Ensure the rear trailer jacks are down before lifting the tank box onto the back of the trailer to prevent the trailer from tipping.

☐ 4 Assemble rails. Be sure rail markings line up to ensure proper assembly.

☐ 5 Orient tower halves such that the "Y" hole pattern in the plywood platforms are facing upwards.

☐ 6 Connect tower halves together with the steel couplers. Hand tighten.

☐ 7 Place 4x4s and 2x4s underneath tower to level it.

☐ 8 Fully tighten coupler joints.

☐ 9 Insert a rail into the tower.

- ☐ 9.1 Align the holes in the aluminum angle with the holes in the plywood such that the rail is centered. Secure it by hand tightening the bolts.
- ☐ 9.2 Ensure that the letter at the top rung of the rail corresponds with the letter marked on the top plywood platform. For example: Rail "A" goes with location "A".
- ☐ 9.3 Repeat this step until all rails are attached. For 3 fin rockets, use 3 rails spaced 120 degrees apart. For 4 fin rockets, use 4 rails spaced 90 degrees apart.

☐ 10 Insert rail alignment templates between the rails for the specific rocket being launched. Slide templates along the length of the rails and adjust them accordingly, while fully tightening the bolts at each respective plywood platform.

☐ 11 Bolt the hinge to the trailer (use the shorter 1/2" bolts).

☐ 12 Place the longer bolts through the upward facing flange of the hinge to receive the tower.

☐ 13 Level the trailer using the trailer jacks. Raise the trailer to a height such that the wheels are barely/almost touching the ground.

☐ 14 Lift the tower and bring it to trailer. Rest the tower on the side railing of the trailer to allow lifters to regroup.

☐ 15 Lift the tower and place it over the hinge. Use bolt template to align the bolts and put them through the bolt holes in the tower. IMPORTANT: Place two 2x4s flat between the bolts to prevent tower from crushing fingers. Once all bolts are through, remove 2x4s and template and tighten down the bolts.

☐ 16 Connect the ropes to the top platform of the tower using the quick links. The two "double" ropes each go on the top two eyebolts. The two "single" ropes go on the bottom two eyebolts.

☐ 17 Integrate load cells into the tower cap plate.

- ☐ 17.1 Attach load cells to their individual adjustment mounts using the 4-40 screws and hex nuts.

- ☐ 17.2 Bolt adjustment mounts through the holes in the cap plate.
- ☐ 17.3 Route wires through the holes immediately adjacent to the mounts.
- ☐ 17.4 Insert protection plate through large hole in cap plate and then secure with bolt on other side of cap plate to prevent it from falling back out.

☐ 18 Insert rocket into tower from the bottom. Ensure rocket is oriented in the correct way to attach quick disconnects ("58 TAMU SRT" facing outward away from the trailer).

☐ 19 Place cap plate onto bottom of tower and then secure it with the nuts that are on the extended bolts on the bottom of the tower. Orient the cap plate such that the load cells are directly beneath each of the rails (for a 3-fin rocket). The load cell protector plate should still have ample clearance and not be touching the bottom of the rails.

- ☐ 19.1 Secure the load cell wires to the underside of the cap plate.
- ☐ 19.2 Ensure the rocket is up against the load cell protection plate.

☐ 20 Place blast deflector on the ground directly behind the hinge and oriented such that the blast is directed straight back.

☐ 21 Lift tower to a vertical position

- ☐ 21.1 Station 4 people on ropes to the rear of the trailer, with 2 others on ropes to the front of the trailer.
- ☐ 21.2 At least 4 people begin lifting the tower while on the trailer deck, with others lifting from the ground at the front of the trailer if more people are available.
- ☐ 21.3 The 4 people on ropes as well as those on the trailer begin lifting the tower to a vertical position. The other 2 on ropes at the front of the trailer must keep their ropes without slack to prevent the tower from falling forward once it approaches vertical.

☐ 22 Once the tower is vertical, adjust the leveling feet as well as the jacks on the trailer to either level the tower or bring tower to launch angle of 5 degrees. Those on ropes are still holding them to steady the tower.

☐ 23 Once tower orientation is achieved, stake down the ropes to secure the tower.

☐ 24 Make all necessary connections to rocket and load cells.

☐ 25 Inspect rocket to ensure it is sitting flat on the load cell protector plate

- ☐ 25.1 Ensure the load cell protector plate is centered in the thru hole in the cap and not rubbing against the side of the thru hole and creating friction.
- ☐ 25.2 Adjust height of load cells to ensure good contact with bottom of protector plate. Coordinate with the electronics team to ensure force data is coming from all 4 load cells.

☐ 26 Inspect rails to ensure rocket has a clear path to exit the tower. Make all other necessary checks to rocket.

8 Theseus Pre-Launch Day Assembly Procedure

8.1 Nova Engine Assembly

Led by PROP

- ☐ 1 Assemble Oxidizer Tank to Plumbing Cross and Assembly
  - ☐ 1.1 Tighten Plumbing to Oxidizer Tank to required torque setting
- ☐ 2 Assemble Plumbing Cross to Ball Valve
- ☐ 3 Combustion Chamber Assembly
  - ☐ 3.1 Flip Combustion Chamber upside down
  - ☐ 3.2 Assemble Fuel Grain into Combustion Chamber
    - ☐ 3.2.1 Insert Fuel Grain through the bottom of the Combustion Chamber
    - ☐ 3.2.2 Make sure to insert the Fuel Grain in its proper orientation, with the pre-combustion chamber entering first. Ensure that no gap exists at the top.
- ☐ 4 Integration with Rocket Thrust Bulkhead
  - ☐ 4.1 Install Injector Coin
    - ☐ 4.1.1 Place Injector Coin O-ring (coated with O-ring grease) in Injector Coin, making sure it is flat against the surface
    - ☐ 4.1.2 Insert injector coin into the injector coin housing in its proper orientation (greased O-ring facing tank). Be careful it is not upside down, this is extremely important for impinging injectors.
    - ☐ 4.1.3 Press down around the edges to ensure it is making complete contact with the face.
  - ☐ 4.2 Confirm that the 1K pressure transducer is installed in the injector housing.
    - ☐ 4.2.1 Transducer thread should be wrapped with 1 wrap of Teflon tape evenly covering all the thread surfaces
  - ☐ 4.3 Integrate Thrust Bulkhead with Injector and Combustion Chamber
    - ☐ 4.3.1 Place Injector on top of Combustion Chamber flange and ensure that the Pressure Transducer is aligned with the port in the Combustion Chamber and that greased O-ring is sitting in the injector
    - ☐ 4.3.2 Slide Thrust Bulkhead/ Lower body tube assembly over the Plumbing Assembly and align the holes
    - ☐ 4.3.3 The Thrust Bulkhead w/ Body Tube, Injector and Combustion Chamber should sit together going from top to bottom respectively with holes aligned
    - ☐ 4.3.4 Hand tighten all 1/4"-28 bolts
    - ☐ 4.3.5 Tighten all bolts to the required torque setting of 105 in-lbs in a star formation

8.2 Electronics

Led by INCO

- ☐ 1 Avionics
  - ☐ 1.1 Mount Hardware to E-Bay Frame

- ☐ 1.1.1 Mount the recovery U-Bolts to the E-Bay tower with the recovery bulkhead
- ☐ 1.1.2 Secure main battery to E-Bay with heavy duty zip-ties
- ☐ 1.1.3 Mount Flight Card in E-Bay

☐ 1.2 Ensure all batteries are charged

Battery		Nominal Voltage [V]	Measured Voltage [V]
Main	$LiFePo_4$	12	
Beeline GPS	LiPo	7.3	
TeleMega (CPU)	LiPo	7.3	

☐ 1.3 Ensure correct wiring

- ☐ 1.3.1 Note all wiring must pass the "tug-test", that is any wiring connection must not feel loose when tugged, else it shall be corrected. All pairs of wires should be twisted to reduce EMI through mode rejection. Refer to the ESRA wiring rules.

☐ 1.4 Non-critical Flight Components

- ☐ 1.4.1 With key switch off and disconnected from 12 V screw terminal block:
  - ☐ 1.4.1.1 S3 terminal 3 to main battery POS(+) terminal
  - ☐ 1.4.1.2 12V- screw block to 12V battery NEG(-) terminal
  - ☐ 1.4.1.3 Voltage regulator 12V inputs to 12V screw terminal block
  - ☐ 1.4.1.4 Voltage regulator 5 V output are wired to Main Circuit Board (MCB) 5V input
  - ☐ 1.4.1.5 Main circuit board 12 V input to 12V screw block

☐ 1.5 TeleMega - Primary Flight Computer

- ☐ 1.5.1 With key switch off and both LiPo and 9V batteries disconnected:
  - ☐ 1.5.1.1 S1 terminal 1 to TOP 2 (*Need to label switches, verify and update)
  - ☐ 1.5.1.2 S1 terminal 3 to TOP
  - ☐ 1.5.1.3 S1 terminal 8 to TOP 3
  - ☐ 1.5.1.4 Mega pyro battery clip NEG(-) lead to Bottom 1 and POS(+) lead to Bottom 2
  - ☐ 1.5.1.5 Main pyro to TOP 4 & 5 (polarity independent)
  - ☐ 1.5.1.6 Drogue pyro to TOP 6 & 7 (polarity independent)

☐ 1.6 StratoLoggerCF - Secondary Flight Computer

- ☐ 1.6.1 With key switch off and 9V battery unclipped:
  - ☐ 1.6.1.1 S2 terminal 1 to B1 (*Need to label switches, verify and update)
  - ☐ 1.6.1.2 S2 terminal 3 to B2
  - ☐ 1.6.1.3 SL battery clip NEG(-) lead to A1 and POS(+) lead to A2
  - ☐ 1.6.1.4 Main redundant pyro to C1 & C2 (polarity independent)
  - ☐ 1.6.1.5 Drogue redundant pyro to D1 & D2

☐ 1.7 Test everything

- ☐ 1.7.1 Temporary connections for verification
  - ☐ 1.7.1.1 Connect S3 terminal 1 to 12V+ screw block.
  - ☐ 1.7.1.2 Connect both flight computer 9V and LiPo batteries
  - ☐ 1.7.1.3 Connect ribbon cable to MCB
  - ☐ 1.7.1.4 Place EBay in rocket
  - ☐ 1.7.1.5 Connect serial line (TX, RX, GND pins) to the launch box.
  - ☐ 1.7.1.6 Turn S1 to ON and verify TeleMega's settings are reported as expected, turn off.
- ☐ 1.7.2 TeleMega audible output at startup
  - ☐ 1.7.2.1 Startup: Battery voltage in decivolts

- ☐ 1.7.2.2 Idle (Horizontal): dit dit
- ☐ 1.7.2.3 Pad (Vertical): dit dah dah dit
- ☐ 1.7.2.4 Turn S2 to ON and verify StratoLogger's settings are reported as expected, turn off.

☐ 1.7.3 Stratologger audible output at startup. Digits reported as:

- ☐ 1.7.3.1 0 beep-beep-beep-beep-beep-beep-beep-beep-beep (9 tones)
- ☐ 1.7.3.2 1 beep
- ☐ 1.7.3.3 2 beep-beep
- ☐ 1.7.3.4 3 beep-beep-beep
- ☐ 1.7.3.5 (and so on up to nine)

☐ 1.8 Power-up

☐ 1.8.1 *if siren sounds then refer to printed stratologger manual for possible errors*

- ☐ 1.8.1.1 Digit beep ranging from 1-9 according to program preset
- ☐ 1.8.1.2 A two second pause followed by a three or four digit number corresponding to main deploy altitude
- ☐ 1.8.1.3 If there is a five second continuous tone there is an apogee delay
- ☐ 1.8.1.4 A two second pause and then a two or three digit number representing apogee altitude
- ☐ 1.8.1.5 A two second pause and then a two or three digit number representing battery voltage

☐ 1.8.2 Turn Key 3 ON

☐ 1.8.3 Perform control system test as outlined in Controls Checklist

☐ 1.8.4 Disconnect TX,RX,GND, ribbon cable, batteries and S3 connection to screw block

☐ 2 Wireless Control System

☐ 2.1 Yagi Antenna Network

- ☐ 2.1.1 Visually inspect antennas for proper element placement and good solder connections.
- ☐ 2.1.2 Run a condensed connectivity test and disassemble

☐ 2.2 Launch Box

- ☐ 2.2.1 Tighten all screw terminals, visually inspect wiring. Use a multimeter to perform continuity checks to ensure good connections.
- ☐ 2.2.2 Power on Arduino and check for connection to computer

9 Theseus Launch Day Assembly Procedure

9.1 Nova Engine Assembly

Led by PROP

- ☐ 1 Grease fuel grain
- ☐ 2 Install the Nozzle to Combustion Chamber
  - ☐ 2.1 Apply liberal amount of O-ring grease to O-rings (2) and slide them into grooves (2) on Nozzle. DO NOT use silicone-based lubricant
  - ☐ 2.2 Slide Nozzle Collar over the bottom of Nozzle until it is seated on the Nozzle Shoulder
- ☐ 3 Slide the two into the Combustion Chamber, applying pressure onto the Collar instead of the Nozzle, until the Collar sits flush with the Combustion Chamber and the bolt holes are aligned
  - ☐ 3.1 Ensure the Nozzle is touching the fuel grain and that the Nozzle is pinched between the Fuel Grain and Collar. There should be no gap.
  - ☐ 3.2 Ensure the Nozzle is pointed away from the Fuel Grain
- ☐ 4 Secure the Nozzle Collar with bolts provided
  - ☐ 4.1 Tighten bolts until flush
- ☐ 5 Install tailcone to aft body tube section
  - ☐ 5.1 Slide tailcone into place
  - ☐ 5.2 Align all holes and rivet to secure
- ☐ 6 Assemble Ball Valve to Injector
  - ☐ 6.1 Coat Injector NPT side thread with pipe dope making sure to evenly cover all the thread surfaces
- ☐ 7 Attach Servo to Ball Valve
  - ☐ 7.1 Align ball valve mounts (2) with hexagonal heads of ball valve
  - ☐ 7.2 Align ball valve plate with ball valve mounts and hand tighten the 2 bolts evenly, securing the plate to the mounts
  - ☐ 7.3 Tighten to required torque setting
- ☐ 8 Ensure that all connections are in and route all hoses out of the rocket
  - ☐ 8.1 Assemble the vent hose to the vent line in the Plumbing Cross.
    - ☐ 8.1.1 Inspect for kinks and check alignment with vertical axis of rocket
    - ☐ 8.1.2 Do not over tighten (Possibility of kinking tube at base)

9.2 Electronics

Led by INCO

☐ 1 Avionics

☐ 1.1 Ensure all batteries are charged

Battery		Nominal Voltage [V]	Measured Voltage [V]
Main	$LiFePo_4$	12	
Beeline GPS	LiPo	7.3	
TeleMega (CPU)	LiPo	7.3	
TeleMega Pyro	9V Alkaline	9.0	
StratoLogger	9V Alkaline	9.0	

☐ 1.2 GPS

☐ 1.2.1 Power on BeeLine GPS

☐ 1.2.2 Power on Baofeng radio and set channel to 433.920 MHz. Connect radio to a computer or phone running APRS decoding software.

☐ 1.2.3 Ensure that packets are transmitting reliably and GPS has satellite connection.

☐ 1.2.4 Secure GPS in nosecone and perform another test.

☐ 1.3 Mounting

☐ 1.3.1 Tighten all screws, nuts, standoffs, etc.

☐ 1.4 Wiring

☐ 1.4.1 Tighten all screw terminal blocks and tug on wires

☐ 1.4.2 Place brand new Duracell 9V batteries in battery clips

☐ 1.4.3 Connect TeleMega LiPo to TeleMega

☐ 1.4.4 Connect S3 terminal 1 to 12V+ block

☐ 1.4.5 Ensure all wiring outlined in prelaunch checks are correct

☐ 1.5 Rocket Interface

☐ 1.5.1 With key switches all in OFF position, plug in ribbon cable from rocket to MCB

☐ 1.5.2 Place EBay in rocket, ensure key switches, GoPro and data out are aligned with corresponding ports

☐ 1.5.3 Place keys in switches with "remove before flight" hangers attached, maintain off position

☐ 1.6 Final Launch Procedures - Rocket Vertical

☐ 1.6.1 Ensure GPS is transmitting as expected (APRS - Android App GUI)

☐ 1.6.2 Plug in serial line from launch box to rocket (TX, RX, GND)

☐ 1.6.3 Turn S3 to ON position, remove key

☐ 1.6.4 Turn S2 to ON, remove key and listen for StratoLogger audible status report

☐ 1.7 Stratologger (according to plan)

☐ 1.7.1 Beep.Beep.Beep

☐ 1.7.2 Two second pause

☐ 1.7.3 Beep.Beep.Beep (700 feet deploy)

☐ 1.7.4 Two Second Pause

☐ 1.7.5 Beep corresponding to altitude of last flight

☐ 1.7.6 Two Second Pause

☐ 1.7.7 Beep corresponding to battery voltage

☐ 1.7.8 Turn S1 to ON, remove key and listen for TeleMega audible status report

☐ 1.8 TeleMega (according to plan)

☐ 1.8.1 Battery Voltage in Decivolts

- ☐ 1.8.2 Pause
- ☐ 1.8.3 Dit dah dah dit
- ☐ 1.8.4 Dit dit dit (continuity detected on both igniters)

☐ 2 Wireless Control System

☐ 2.1 Yagi Antenna Network

- ☐ 2.1.1 To maximize signal strength, choose antenna placement such that there are no large obstructions in the antenna line-of-sight. E.g. avoid having the launch tower or any vehicles between the antennas.
- ☐ 2.1.2 Screw the RPSMA connector of the Base antenna into the 900 MHz Master XBee radio module
- ☐ 2.1.3 Seat the XBee into the XBee Explorer USB Dongle
- ☐ 2.1.4 Connect the USB A-Female to A-Male cable to the XBee dongle and to the Control Station laptop
- ☐ 2.1.5 Fix the antenna in a horizontal orientation (elements parallel with the horizon) as high above ground as reasonable using a tripod or pole. Point towards launch site antenna
- ☐ 2.1.6 Screw the SMA connector of the launch site antenna into the SMA connector on the launch box panel. Ensure the panel connector is securely connected to the XBee inside the launch box
- ☐ 2.1.7 Ensure the 900 MHz Slave XBee module is seated properly on the Arduino shield inside the launch box
- ☐ 2.1.8 Fix the antenna in a horizontal orientation (elements parallel with the horizon) as high above ground as reasonable using a tripod or pole. Point towards base antenna

☐ 2.2 Launch Box

- ☐ 2.2.1 Plug in the N2O Fill solenoid to the launch box panel outlet by the same name
- ☐ 2.2.2 Plug in the N2O Vent solenoid
- ☐ 2.2.3 Plug in OX Flow solenoid
- ☐ 2.2.4 Plug in the Pneumatic QD solenoid
- ☐ 2.2.5 Screw one lead from the igniter to the screw on the "Igniter" block labeled "GND."
- ☐ 2.2.6 Screw the other igniter lead to the screw on the "Igniter" block labeled "+".
- ☐ 2.2.7 Connect the serial line from the rocket (telephone jack) to the "Rocket Data" jack on the launch box.
- ☐ 2.2.8 Make sure all switches on the launch box are turned OFF.
  - ☐ 2.2.8.1 Toggle switches in the position away from their indicator light.
  - ☐ 2.2.8.2 Key switch in the vertical position.
- ☐ 2.2.9 Remove the key from the "Arm" switch.
- ☐ 2.2.10 Put the "CPU PWR SELECT" switch inside the launch box on the "9V" position.
- ☐ 2.2.11 Place 2 fresh 9V batteries in the holders inside of the launch box. Make sure the polarity is correct.
- ☐ 2.2.12 Close the launch box lid and close the 2 clasps that hold it.
- ☐ 2.2.13 Connect the antenna to the "ANT." Connector and screw it down tightly.
- ☐ 2.2.14 Aim the antenna towards the base station.
- ☐ 2.2.15 Connect one end of the battery cable 1 clamps to the identically named "GND (-)" and "+12V (+)" lugs on the launch box. Do not connect the battery.
- ☐ 2.2.16 Connect one end of the battery cable 2 clamps to the identically named "+12V (-)" and "+24V (+)" lugs on the launch box. Do not connect the battery.
- ☐ 2.2.17 Connect the free "GND (-)" clamp on battery cable 1 to the negative terminal of battery 1.
- ☐ 2.2.18 Plug everything else in

☐ 2.3 Systems Test

- ☐ 2.3.1 At the base computer run a systems check and dry run the launch sequence

9.3 Theseus Airframe Assembly

Led by ACO & PROP

- ☐ 1 Lower Body/Engine Integration
  - ☐ 1.1 Quick Disconnect System Assembly
    - ☐ 1.1.1 Apply 3 wraps of teflon tape on the male threads of the oxidizer fill line from the plumbing cross
    - ☐ 1.1.2 Screw the male quick disconnect fitting onto the oxidizer fill line hand tight and then an additional full turn
    - ☐ 1.1.3 Insert quick disconnect bolts into thrust bulkhead
    - ☐ 1.1.4 Slide the quick disconnect springs over the bolts now pointing in toward the center of the rocket
    - ☐ 1.1.5 Slide the quick disconnect plate w/ male quick disconnect fitting over the end the bolts compressing the springs enough to expose the end of the bolts
    - ☐ 1.1.6 Screw on the corresponding washer and nut configuration to hold the plate,spring,bolt assembly together
    - ☐ 1.1.7 Ensure that the male fitting can be pulled out of the thrust bulkhead far enough to mate with the female quick disconnect fitting
  - ☐ 1.2 With the quick disconnect system installed in the thrust bulkhead proceed to slide the oxidizer tank body tube over the oxidizer tank until only the plumbing cross is exposed
  - ☐ 1.3 Using the ribbon cable from the bulkhead above the oxidizer tank proceed to connect the engine pressure transducer, thermocouples and servo signal wires
  - ☐ 1.4 Push all wires inside the body tube while sliding the upper body tube down to the thrust bulkhead ensuring the no wires get pinched in the process
  - ☐ 1.5 Attach the upper body tube with the thrust bulkhead with the appropriate bolts
- ☐ 2 E-Bay Installation
  - ☐ 2.1 Pull the ribbon cable from the bottom of the e-Bay bulkhead and connect it to the flight computer
  - ☐ 2.2 Pull the slack from the ribbon cable and tuck it into the e-bay
  - ☐ 2.3 Slide the e-bay in the body tube leaving the top 4 inches exposed for connection to recovery bulkhead
  - ☐ 2.4 With the recovery bay packed, connect the leads from the e-bay altimeters to the 4 pairs of binding posts in the recovery bulkhead
    - ☐ 2.4.1 Ensure that all binding post connections are tight and all leads are wired to the correct binding post as labeled
  - ☐ 2.5 Connect e-bay to the recovery bulkhead by inserting u-bolts of recovery bulkhead through the top bulkhead of the e-bay and tightening nuts on each u-bolt end
    - ☐ 2.5.1 Tighten nuts onto u-bolts in a star pattern such that the e-bay bulkhead isn't pinched
  - ☐ 2.6 Slide e-bay in the body tube until the recovery bulkhead is mated with the e-bay body tube
  - ☐ 2.7 Using appropriate bolts connect recovery bulkhead with e-bay body tube
- ☐ 3 Proceed to Launch Tower

9.4 Pad Integration

Led by ACO & PROP

☐ 1 Set-up tank box

☐ 2 Make igniter

- ☐ 2.1 Cut 12 gauge wire (twice desired length + 5 feet)
- ☐ 2.2 Strip 3 inches of wire off center from the middle
  - ☐ 2.2.1 Make "cut" in middle
  - ☐ 2.2.2 Make "cut" 3 inches to one side and another in the middle of this 3 inch segment
  - ☐ 2.2.3 Use razor to remove insulation
- ☐ 2.3 Strip 2 inches from each end of wire
  - ☐ 2.3.1 Make "cut" then use razor
- ☐ 2.4 Untwist middle section of wire
- ☐ 2.5 Slowly cut away wires from middle section until only 2 remain
- ☐ 2.6 Coat remaining 2 wires in "Cement for Metal & Wood"
- ☐ 2.7 Dip this middle section in gunpowder (all the way around)
- ☐ 2.8 Wrap a wisp of steel wool around the gunpowder of this two wire middle section

☐ 3 Fasten igniter to oxygen line and tape to nozzle

☐ 4 Connect fill and vent lines to rocket via quick disconnect system

- ☐ 4.1 Ensure that base of bracket is oriented away from direction of pull

10 Test Sequence

Test Team

FLIGHT	**Flight Director**	Overall supervision of launch and primary flight controller
CONTROL	**Ground Control**	Remotely controls arming, filling, & ignition via Launch Box
INCO	**Instr. & Comm. Officer**	Monitors sensor readouts & launch pad camera feed
TECH 1	**Pad Technician 1**	Responsible for system arming and launch pad safety
TECH 2	**Pad Technician 2**	Responsible for fluid control and launch pad safety

10.1 Solenoid Control Test

1	FLIGHT	"Test team, begin solenoid control test."
2		***TECH 1 move towards launch cart***
3		***TECH 2 move towards fill & oxygen tanks***
4		"TECH 1, connect launch system to battery 1."
5		"Confirm that all power swtiches are set to on and indicator lights for **COM** and **SOLENOID** power are on."
6	TECH 1	"Launch system is connected to power and indicator lights are confirmed on."
7	FLIGHT	"Arm the system and confirm that solenoid armed light is on."
8		***By turning arm key and looking for the "armed" light***
9	TECH 1	"System is armed and red armed light is confirmed on."
10	FLIGHT	"CONTROL, activate control program."
11	CONTROL	`SYS ARM` "Control program activated."
12	FLIGHT	"TECH 2, locate fill solenoid."
13	TECH 2	"Fill solenoid located."
14	FLIGHT	"Cycling valve." ***Cycle through 2 rounds of open/close commands***
15	CONTROL	`FILL OPEN` `FILL CLOSE` "Fill open, fill close." ***X 2***
16	TECH 2	"Fill solenoid [is/is not] nominal." ***Confirm functionality via audible valve click***
17	FLIGHT	"TECH 2, locate fill vent solenoid."
18	TECH 2	"Fill vent solenoid located."
19	FLIGHT	"Cycling valve." ***Cycle through 2 rounds of open/close commands***
20	CONTROL	`FILL VT OPEN` `FILL VT CLOSE` "Fill vent open, fill vent close." ***X 2***
21	TECH 2	"Fill vent solenoid [is/is not] nominal." ***Confirm functionality via audible valve click***
22	FLIGHT	"TECH 2, locate tank vent solenoid."
23	TECH 2	"Tank vent solenoid located."

24	FLIGHT	"Cycling valve."
25	CONTROL	`TANK VT OPEN` `TANK VT CLOSE` "Tank vent open, tank vent close." ***X 2***
26	TECH 2	"Tank vent solenoid [is/is not] nominal." ***Confirm functionality via audible valve click***
27	FLIGHT	"TECH 2, locate oxygen solenoid."
28	TECH 2	"Oxygen solenoid located." ***Cycle through 2 rounds of open/close commands***
29	FLIGHT	"Cycling valve."
30	CONTROL	`OX OPEN` `OX CLOSE` "Ox open, ox close." ***X 2***
31	TECH 2	"Oxygen solenoid [is/is not] nominal." ***Confirm functionality via audible valve click***
32	FLIGHT	"Confirm the fill and oxygen tanks are closed."
33	TECH 2	"Check, fill and oxygen tanks are closed."

If solenoids are not functioning properly, troubleshoot and repeat the test procedure. Common troubleshooting items include a poor communications connection with the Launch Box, failure to plug the solenoids into the Launch Box, valve sticking, or failure to fully arm the Launch Box. Proceed to next line when all solenoids are confirmed functioning.

10.2 Quick Disconnect Test

34	FLIGHT	"Test team, begin quick disconnect test."
35		"Techs, clear area and give a Go/NoGo for line disconnect."
36	TECH 1	"TECH 1 is in position."
37	TECH 2	"TECH 2 is in position. Go for test."
38	FLIGHT	"CONTROL, activate QD system."
39	CONTROL	`MOTOR ON` `MOTOR OFF` "QD system activated."
40	TECH 2	"Fill & vent line disconnect [is/is not] confirmed."
41	FLIGHT	"TECH 2, reattach fill & vent lines."
42	TECH 2	"Check. Fill & vent lines are secure."

If quick disconnect system fails, troubleshoot and repeat the test procedure. Common troubleshooting items include bulkhead misalignment, or a loose pulley cable. Proceed to next test if quick disconnect system is confirmed functional.

10.3 Vehicle Communication Test

43	FLIGHT	"Test team, begin vehicle comm test."
44		***TECH 2 move towards tower w/ ladder***
45		***TECH 1 move towards tower & hold ladder***
46		"TECH 2, verify that breakaway line is connected to vehicle."
47	TECH 2	"Breakaway line is connected."
48	FLIGHT	"TECH 2, turn screw switches to connect avionics systems to power.
49		Repeat back: **MAIN** → **PRIMARY**."
50	TECH 2	"**MAIN** → **PRIMARY**. Screw switches are activated."
51	FLIGHT	"Verify connection with onboard avionics by initializing data collection."
52	CONTROL	`DATA INIT` "Onboard connection confirmed."
53		***Verify nominal pressure transducer readings from plumbing and combustion chamber***
54		"Pressure readings [are/are not nominal]."
55	FLIGHT	"INCO, confirm APRS packets from vehicle."
56	INCO	"Packets [are/are not] confirmed."
57	FLIGHT	"Confirm that live telemetry is functional."
58	INCO	"Live telemetry [is/is not] functional."
59	FLIGHT	"TECH 2, disconnect systems from power by deactivating screw switches.
60		Repeat back: **PRIMARY** → **MAIN**."
61	TECH 2	"**PRIMARY** → **MAIN**. Screw switches are deactivated."

If data initialization is not functioning properly, troubleshoot and repeat the test procedure. If the failure persists, proceed to next test if remote connection is functioning. Common troubleshooting items include a poor remote connection with the Launch Box, or an improperly installed breakaway cable. Proceed to next test when remote connection to vehicle is confirmed functional.

10.4 Ignition System Check

62	FLIGHT	"Test team, begin ignition system check."
63		***TECH 1 move towards launch cart***
64		***TECH 2 move towards tower***
65		"TECH 2, confirm that oxygen sting and igniter are installed."
66	TECH 2	"Check, oxygen sting and igniter are installed."
67	FLIGHT	"TECH 1, check igniter resistance and read back value."
68		***Check that igniter resistance is negligible (***$\sim 10\ \Omega$***)***
69	TECH 1	"Igniter resistance is negligible and reads _______ Ω."
70	FLIGHT	"TECH 1, ARM the igniter by switching the **IGNITER** switch to **ENABLE**."
71		"Confirm visual signal."

72	TECH 1	"Switch has been switched on, visual signal confirmed."
73	FLIGHT	"Confirm igniter continuity by pressing button and viewing indicator light."
74	TECH 1	"Indicator light confirmed."
75	FLIGHT	"CONTROL, confirm remote connection by verifying igniter continuity."
76	CONTROL	`IGN CONT` "Igniter continuity [is/is not] confirmed."
77	FLIGHT	"CONTROL, deactivate control program."
78	CONTROL	`SYS DISARM` "Control program deactivated."
79	FLIGHT	"TECH 1, disarm launch system by turning key switch to off, **COM** & **SOLENOID** power switches to off, and **IGNITER** switch to **DISABLE**. Disconnect battery 1."
80	TECH 1	"Launch system is disarmed and disconnected from power."

If oxygen sting or igniter is not secure, reevaluate and improve installation. If igniter continuity is not confirmed, troubleshoot and repeat the test procedure. Common troubleshooting items include a poor connection to the control system, or a loose screw terminal head. Proceed to launch sequence when igniter system is confirmed functional.

11 Launch Sequence

Launch Team

FLIGHT	**Flight Director**	Overall supervision of launch and primary flight controller
PROP	**Propulsion Officer**	Monitors filling/ignition sequence and assesses engine performance
FDO	**Flight Dynamics Officer**	Determines flight profile and assesses range safety
CONTROL	**Ground Control**	Remotely controls arming, filling, & ignition via Launch Box
INCO	**Instr. & Comm. Officer**	Monitors sensor readouts & launch pad camera feed
TECH 1	**Pad Technician 1**	Responsible for system arming and launch pad safety
TECH 2	**Pad Technician 2**	Responsible for fluid control and launch pad safety

Hold Sequence *Initiated by any member of the launch team at any time*

< Operator >	"Launch team, **HOLD**. < reason for **HOLD** > ."
FLIGHT	"FLIGHT, check."
< Operator >	"Launch team, all clear."
FLIGHT	"CONTROL"
CONTROL	"CONTROL, Go."
FLIGHT	"Launch team, proceed at Line < # >."

11.1 Setup Sequence

81	FLIGHT	"SRT-5, we are go for Theseus [solid/hybrid] launch No. ________ ."
82		"INCO, ensure that we have a visual of the launch pad; confirm video recording and note the time."
83	INCO	"Time is ___________ on _______________ ________ , 2018 and video recording [is/is not] confirmed. Video time is noted as ___________ ."
		HOLD LINE *If video recording is not confirmed, HOLD*
84	FLIGHT	"Technicians, inspect the launch pad and surroundings for tools and debris, put on safety glasses, and give a Go/NoGo to begin the launch sequence."
85	TECH 1	"TECH 1, Go."
86		***TECH 1 move towards launch cart***
87	TECH 2	"TECH 2, Go."
88		***TECH 2 move towards fill & oxygen tanks***
89	FLIGHT	"TECH 1, connect launch system to battery 1."
90	TECH 1	"Check. Launch system is connected to battery 1."

91	FLIGHT.	"TECH 1, confirm that all power switches are set to on and indicator lights for **COM** and **SOLENOID** power are on."
		HOLD LINE *If red indicator light are not on, HOLD*
92	TECH 1	"Indicator lights are confirmed on."
93	FLIGHT	"CONTROL, confirm that remote link to launch system has been established."
94	CONTROL	"This is CONTROL, connection is secured and system is functioning properly."
95	FLIGHT	"INCO, confirm that remote link to DAQ system has been established."
96	INCO	"Connection is secured and DAQ system is functioning properly."
97	FLIGHT	"TECH 1, arm the launch system and confirm that the solenoid armed light is on."
		By turning arm key and looking for the "armed" light
98	TECH 1	"System is armed and red armed light is confirmed on."
99	FLIGHT	"TECH 2, open oxygen tank valve to full."
100	TECH 2	"Check. Oxygen tank valve is turned to full."
101	FLIGHT	"Turn oxygen regulator to read 50 psi."
102	TECH 2	"Check. Oxygen regulator reading 50 psi."
103	FLIGHT	"Turn Nitrous valve 4 turns."
104	TECH 2	"Check. Nitrous valve is turned 4 turns."
105	FLIGHT	"TECH 2, read fill tank gauge."
106	TECH 2	"Fill tank pressure is _______ psi."
107	FLIGHT	"INCO, read fill tank transducer."
108	TECH 2	"Fill tank pressure is _______ psi."
109	PROP	"Fill tank pressure is sufficient for safe launch. Continue to fill sequence."
		HOLD LINE *If fill tank pressure is insufficient for safe launch, HOLD*
110	FLIGHT	"TECH 1, connect launch system igniter circuit to battery 2."
111		***TECH 2 move towards tower w/ ladder***
112	TECH 1	"Check. Igniter circuit is connected to battery 2."
		HOLD LINE *If indicator lights are incorrect, HOLD*
113	FLIGHT	"CONTROL, confirm launch connection by verifying igniter continuity."
114	CONTROL	`IGN CONT` "Igniter continuity confirmed."
115	FLIGHT	"TECH 1, ARM the igniter by switching the **IGNITER** switch to **ENABLE**."
116		"Confirm visual signal."
117	TECH 1	"Switch has been switched on, visual signal confirmed."
		HOLD LINE *If visual signal is not present, HOLD*
118	FLIGHT	"Tech 2, confirm that breakaway line is connected to vehicle."
119		***TECH 1 move towards tower & hold ladder***
120	TECH 1	"Check, breakaway line is connected."

121	FLIGHT	"TECH 2, turn screw switches to connect all avionics systems to power."
122		"Repeat back: **MAIN** → **BVAS** → **PRIMARY** → **SECONDARY**."
123	TECH 2	"**MAIN** → **BVAS** → **PRIMARY** → **SECONDARY**. Screw switches are activated."
124	FLIGHT	"The launch pad is live. Technicians, proceed to 100 ft standoff radius and apply hearing protection. Report when present."
125	TECH 1	"TECH 1 is in position."
126	TECH 2	"TECH 2 is in position."

11.2 Filling & Ignition Sequence

127	FLIGHT	"Launch team, give me a Go/NoGo to proceed with the filling and ignition sequence."
128	FLIGHT	"TECH 1."
129	TECH	"TECH 1, Go."
130	FLIGHT	"TECH 2."
131	TECH	"TECH 2, Go."
132	FLIGHT	"INCO."
133	INCO	"INCO, Go."
134	FLIGHT	"CONTROL."
135	CONTROL	"CONTROL, Go.
136	FLIGHT.	"PROP."
137	PROP	"Oxidizer state [is/is not] favorable for launch. Predicted run tank pressure is _______ psi."
138		"PROP, [Go/NoGo]."
139	FLIGHT	"FDO."
140	FDO	"Ambient conditions [are/are not] favorable for launch. Estimated apogee is _______ and rail exit velocity is _______ ft/s. FDO recommends to fill with _______ lb of nitrous."
141		"FDO, [Go/NoGo]."
		HOLD LINE ***If conditions are not favorable for launch, HOLD***
142	FLIGHT	"Launch team, we are Go for beginning the filling and ignition sequence. Target fill is _______ lb."
143		"CONTROL, activate and arm control program."
144	CONTROL	`SYS ARM` `IGN ARM` "Control program activated and armed."
145		`TANK VT OPEN` "Run tank vent open."
146		`BV CLOSE` "Ball valve is confirmed to be closed."
147		"All controls in default state."
148	FLIGHT	"CONTROL, initiate DAQ recording."
149	CONTROL	`DATA INIT` `DATA START` "DAQ recording initialized."
150		**HOLD LINE** ***If DAQ initialization fails, HOLD***
151	FLIGHT	"INCO, note the fill tank and pad weight readings, and tare the system."
152	INCO	"Fill tank reads _______ lb, pad weight reads _______ lb. System tared."

153	FLIGHT	"Prepare to begin filling the run tank on 3-count. INCO, time the fill, and alert if nitrous venting is seen. Target fill weight is _______ lb."
154		"Beginning nitrous fill in 3...2...1."
155	CONTROL	`FILL OPEN` "Fill control initiated."
156	INCO	***Call out scale reading every pound***
157	CONTROL	***Call out run tank pressure (prompted)***
158	FLIGHT	"Close the vent."
159	CONTROL	`TANK VT CLOSE` "Closing vent."
		Continue filling until target weight is reached
160	FLIGHT	"Stop the fill."
161	CONTROL	`FILL CLOSE` "Stopping fill."
162	FLIGHT	"Launch team, hold for launch approval. Run tank pressurized at _______ psi."
163		***Hold until launch approval granted by MOD***
164	FLIGHT	"Launch approval granted. Purge nitrous fill line and activate QD system."
165	CONTROL	`FILL VT OPEN` `FILL VT CLOSE` "Fill line purged."
166		`MOTOR ON` "Motor on."
167	INCO	"Fill & vent line disconnect [is / is not] confirmed."
168	CONTROL	`MOTOR OFF` "Motor off"
		HOLD LINE ***If fill & vent lines did not disconnect, HOLD***
169		"SRT-5, we are Go for launch. INCO, note camera time."
170	INCO	"Camera time is noted as __________ ."
171	FLIGHT	"CONTROL, prime system."
172	CONTROL	`READY 1` `READY 2` "Firing system is live."
173		`PWR ON` "Servo powered."
174	FLIGHT	"3-count to Ox flood, 6-count to ignition."
175		"3...2...1, Flood."
176	CONTROL	`OX OPEN`
177	FLIGHT	"6...5...4...3...2...1, Ignite."
178	CONTROL	`IGN ON`
179	PROP	***Wait until sufficient oxygen flame*** "Flow."
180	CONTROL	`MDOT`
181	INCO	"Engine ignition [is/is not] confirmed."
		HOLD LINE ***If engine ignition is not confirmed, HOLD***
182	FLIGHT	"Disarm firing system."
183	CONTROL	`IGN OFF` "Igniter off." `OX CLOSE` "Oxygen line closed."
184		`IGN DISARM` `ABORT` "Firing system disarmed."

11.3 Closing Sequence

185	FDO	"Vehicle has left pad."
186		"Vehicle has entered coast phase."
187		"Vehicle is at apogee."
188		"Drogue deployed."
189		"Main deployed."
190	FLIGHT	"Recovery team prepare to retrieve vehicle. Standby for heading."
191	FLIGHT	"Launch pad is safe to approach."
192		"TECH 2, turn off Oxygen and Nitrous valves."
193	TECH 2	"Check. Valves closed."
194	FLIGHT	"TECH 2, clear the area and report when present."
195	TECH 2	"TECH 2 is in position."
196	FLIGHT	"CONTROL, purge all lines."
197	CONTROL	`BUZZ OFF`
198		`FILL VT OPEN` `FILL OPEN`
199		`FILL CLOSE` `FILL VT CLOSE` "Fill line purged."
200		`TANK VT OPEN` `TANK VT CLOSE` "Vent line purged."
201		`OX OPEN` `OX CLOSE` "Oxygen line purged."
202	FLIGHT	"TECH 2, confirm venting."
203	TECH 1	"Venting confirmed."
204	FLIGHT	"CONTROL, deactivate control program."
205	CONTROL	`SYS DISARM` "Control program deactivated."
206	FLIGHT	"TECH 1, disarm launch system."
207	TECH 1	"Check. launch system is disarmed."
208	FLIGHT	Technicians, evaluate situation and give an all-clear."
209	TECH 1	"TECH 1, all clear."
210	TECH 2	"TECH 2, all clear."
211	FLIGHT	The all-clear has been given. Do not touch the tower assembly for another 15 minutes.
212		"SRT-5, this concludes Theseus [solid/hybrid] launch No. _______ . INCO, note the time and cease video recording."
213	INCO	"Time is __________ . Video time is noted as __________ ."

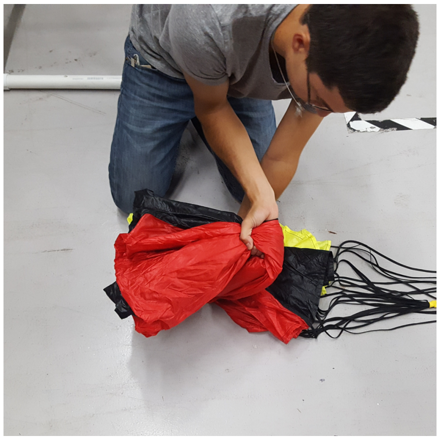
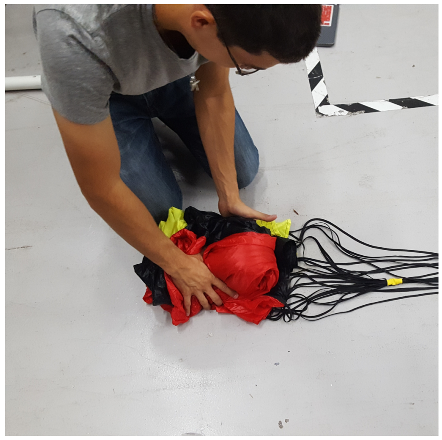
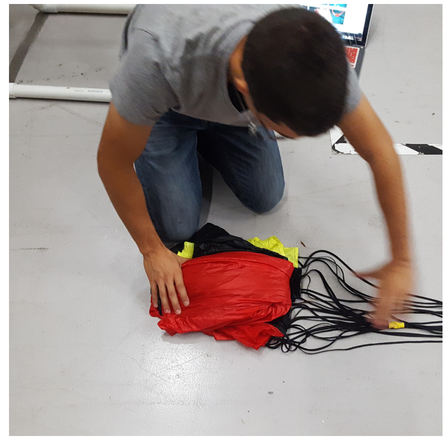
11.4 Abort Sequence

214	< Operator >	"Launch team, **ABORT**. < reason for **ABORT** > ."
215	FLIGHT	"FLIGHT, check."
216		"Control, send **ABORT** command."
217	CONTROL	`ABORT` "Firing system is disarmed."
218	CONTROL	`PWR ON` `MDOT` "Dumping nitrous."
219	FLIGHT	"Now entering the 3-minute waiting period before approaching the launch pad."
		Wait one minute
220	INCO	"2 minutes remaining in waiting period."
		Wait one minute
221		"1 minute remaining in waiting period."
		Wait one minute
222		"3 minute waiting period has elapsed."
223	FLIGHT	"Launch pad is now safe to approach." ***Pending approval from adviser***
224		"TECH 2, turn off Oxygen and Nitrous valves."
225	TECH 2	"Check."
226	FLIGHT	"TECH 2, clear the area and report when present."
227	TECH	"TECH 2 is in position."
228	FLIGHT	"CONTROL, purge all lines."
229	CONTROL	`BUZZ OFF`
230		`FILL VT OPEN` `FILL OPEN`
231		`FILL CLOSE` `FILL VT CLOSE` "Fill line purged."
232		`TANK VT OPEN` `TANK VT CLOSE` "Vent line purged."
233		`OX OPEN` `OX CLOSE` "Oxygen line purged."
234	FLIGHT	"TECH 2, confirm venting."
235	TECH 1	"Venting confirmed."
236	FLIGHT	CONTROL, deactivate control program and cease data acquisition."
237	CONTROL	`DATA STOP` `SYS DISARM` "Control program deactivated and data acquisition halted."
238	FLIGHT	"TECH 1, disarm launch system."
239	TECH 1	"Check. Launch system is disarmed."
240	FLIGHT	Technicians, evaluate situation and give an all-clear."
241	TECH 1	"TECH 1, all clear."
242	TECH 2	"TECH 2, all clear."
243		"SRT-5, this concludes [Daedalus/Theseus] [solid/hybrid] launch No. _______ . INCO, note the time and cease video recording."
244	INCO	"Time is __________ . Video time is noted as __________ ."

A Launch Contingencies

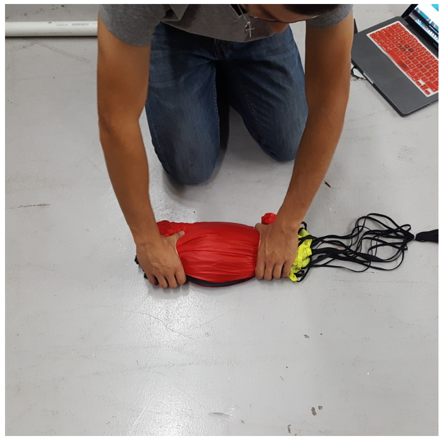
RISK EVENT	TRIGGER	RESPONSE
Quick-Disconnect Failure	Visual cue, *INCO*	Technicians use 100 ft. ropes to manually disconnect the fill and vent lines.
Insufficient Run Tank Pressure	Run tank pressure below cut-off criteria, *PROP*	IF fill tank pressure is lower than 750 psi, fill process will not proceed. ☐ Technicians assess functionality of temperature control system. IF run tank pressure is lower than 600 psi, launch sequence will not proceed.
Plumbing System Leak	Uncharacteristic run tank pressure behavior, *PROP*	IF run tank is not holding pressure, cease fill and allow technicians to approach after visual assessment of launch pad from INCO. ☐ IF leak is determined to be external to rocket, technicians will make an effort to repair the leak by tightening connections or sealing hose. ☐ IF leak is determined to be internal to rocket, rocket will be opened at the thrust bulkhead connection on the pad and connections will be tightened. There may be a second fill attempt following the success of these procedures.
Failed Ignition	Visual cue, *INCO*	Heat the grain using a mobile heater and attempt launch again with a new igniter after re-greasing the grain. ☐ Open rocket on pad at thrust bulkhead connection and manually close ball valve.
Camera Failure	Prolonged loss of signal, *INCO*	IF failure occurs prior to operation of quick disconnect system, utilize binoculars to confirm detachment of fill and vent lines and proceed with launch sequence. ☐ Send command to release nitrous $\sim$ 2 seconds after ignition command is sent. IF failure occurs post quick disconnect system operation, proceed with the launch sequence–sending command to release nitrous $\sim$ 2 seconds after ignition command.
Comm. System Failure	Consistently dropping packets, *CONTROL*	Perform full restart of remote launch system. ☐ IF failure occurs while the rocket is pressurized, allow technicians to approach launch system shielded by blast deflector.
Failed Vehicle Recovery	Visual cue, *TELRE*	Take cover.

B Main Parachute Packing Visualization

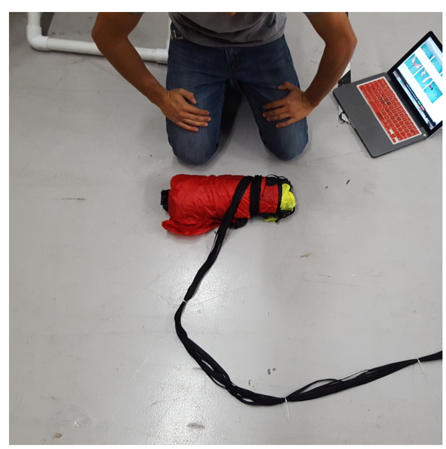




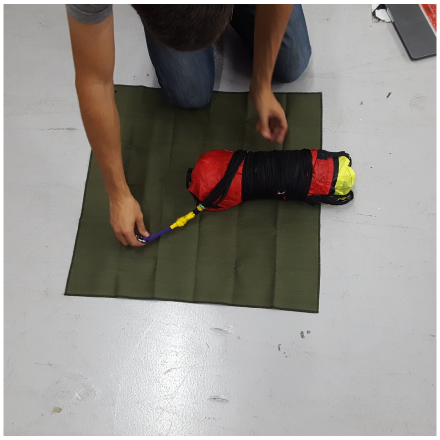







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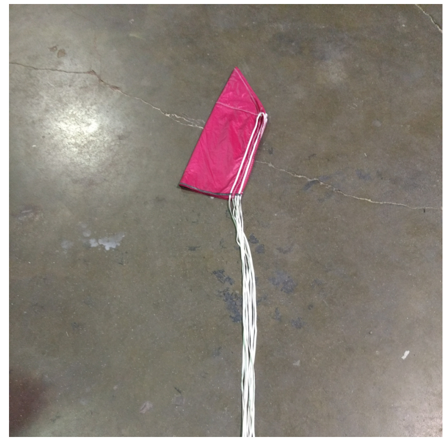



IX. Computer Aided Design (CAD) Appendix

APPENDIX F
Engineering Drawings

0.1 Computer-Aided Design (CAD) Appendix

The relevant CAD drawings for Theseus and its hybrid engine Nova are presented here.

Hybrid Engine

1. Nova Assembly
2. Combustion Chamber Assembly
3. Combustion Chamber
4. Graphite Nozzle
5. Ball-Valve Assembly
6. Injector Housing
7. Plumbing Assembly
8. Plumbing Cross

Avionics

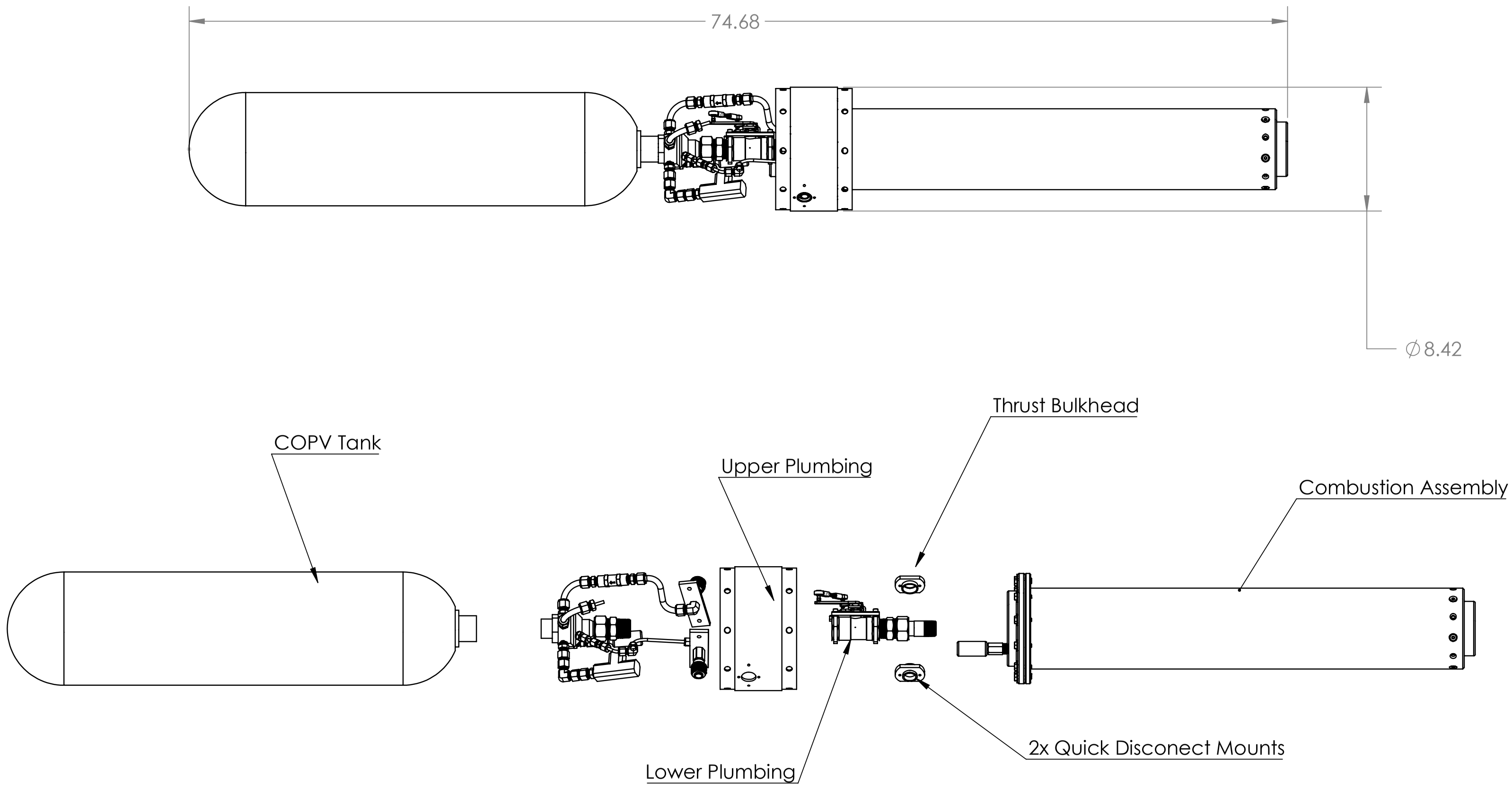
1. E-Bay Assembly
2. Flight Computer PCB
3. Acrylic E-bay Level

Airframe

1. Theseus Airframe
2. Nose Cone
3. Recovery Bay Body Tube
4. RATTWorks ARRD
5. Recovery U-Bolt
6. Low-profile Rivet Nut
7. Recovery Bulkhead
8. E-Bay Body Tube
9. E-Bay Bulkhead
10. Payload Body Tube
11. Payload Bulkhead
12. Oxidizer Tank Body Tube
13. Oxidizer Tank Body Tube Coupler
14. Thrust Bulkhead
15. Fin Can
16. Tail Cone Coupler
17. Tail Cone

Payload

1. Payload 3U CubeSat Structure



PROPRIETARY AND CONFIDENTIAL

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: CF, AL

FINISH: Polished

NEXT ASSY | USED ON — APPLICATION

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AS	5-24-2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

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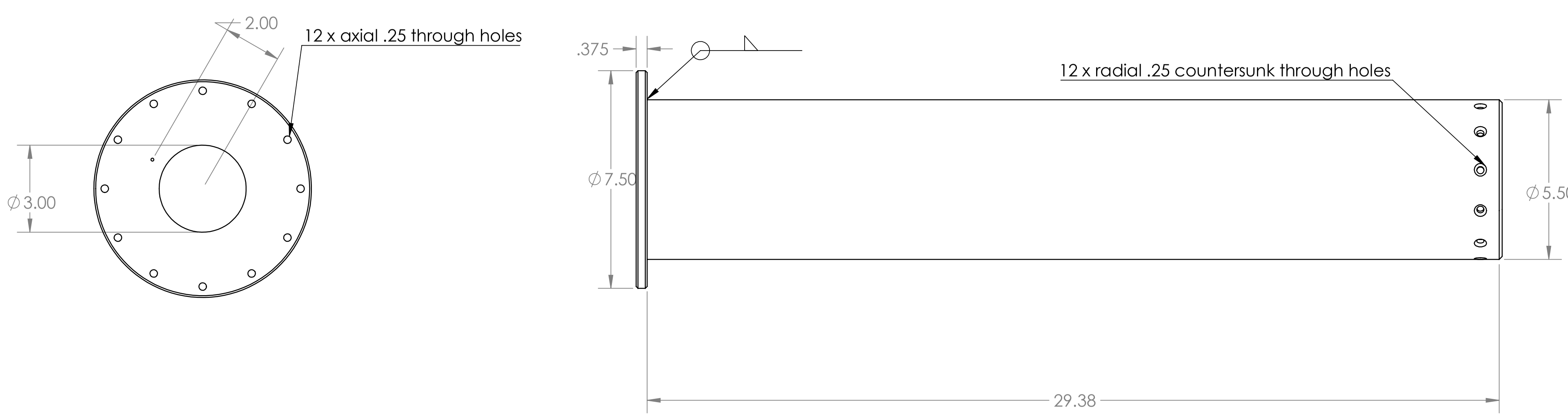

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	CHECKED		
	ENG APPR.		
	MFG APPR.		
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MATERIAL AL 6061-T6	COMMENTS:		
FINISH Polished			
DO NOT SCALE DRAWING			

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APPLICATION	

TITLE:

Combustion Chamber Assem.

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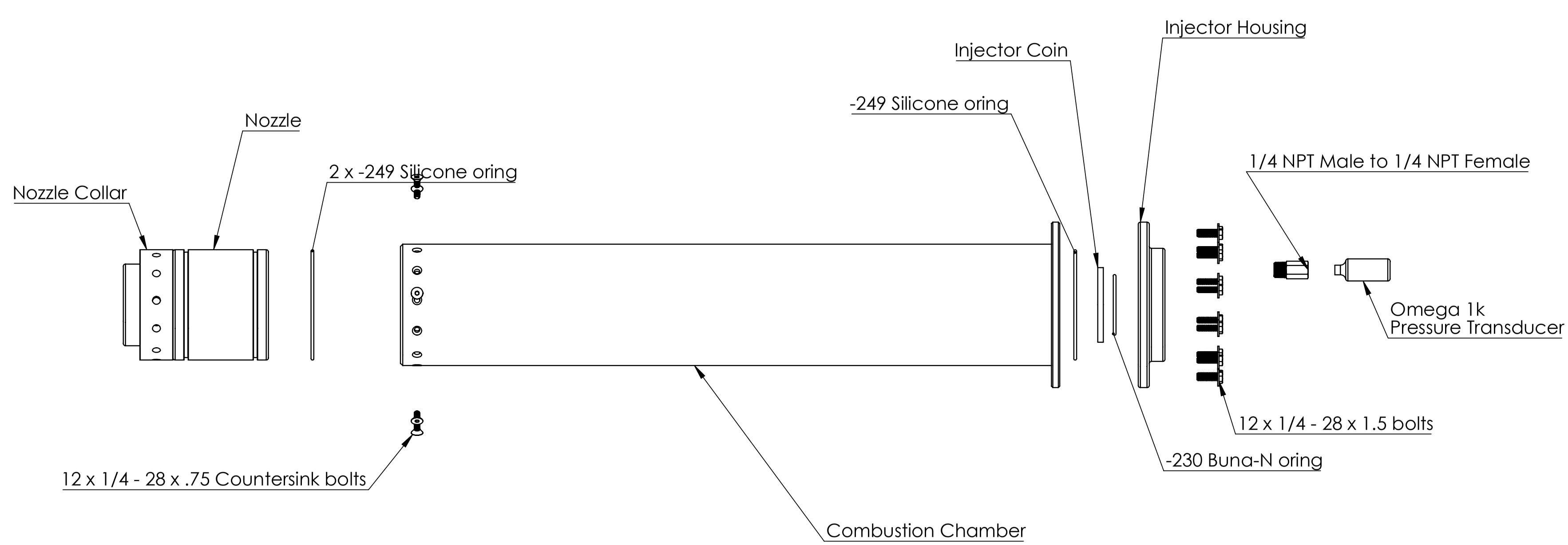

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NEXT ASSY	USED ON	
APPLICATION		

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL ± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ± 0.005
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: AL 6061-T6

FINISH: Polished

DO NOT SCALE DRAWING

	NAME	DATE
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CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Combustion Chamber

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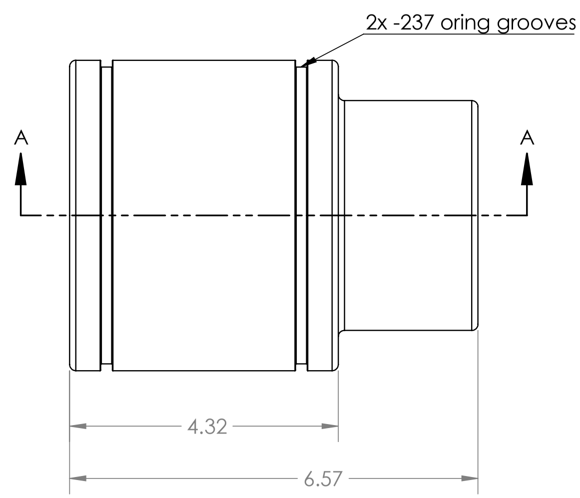

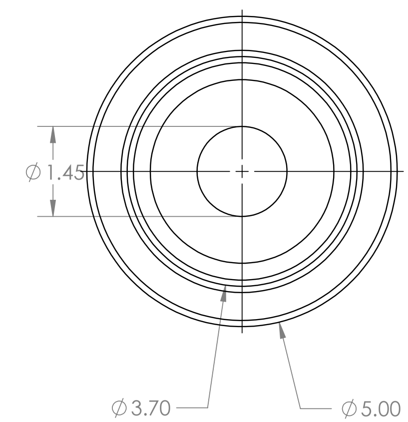

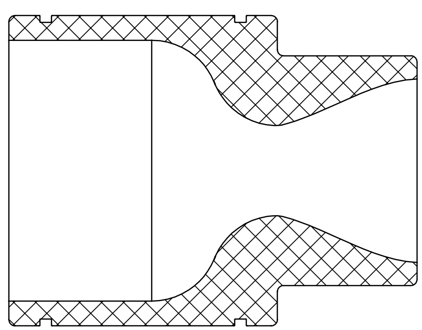

SECTION A-A
SCALE 1 : 2

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DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL ± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Graphite

FINISH: Polished

NEXT ASSY | USED ON
APPLICATION

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AS	5-24-2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

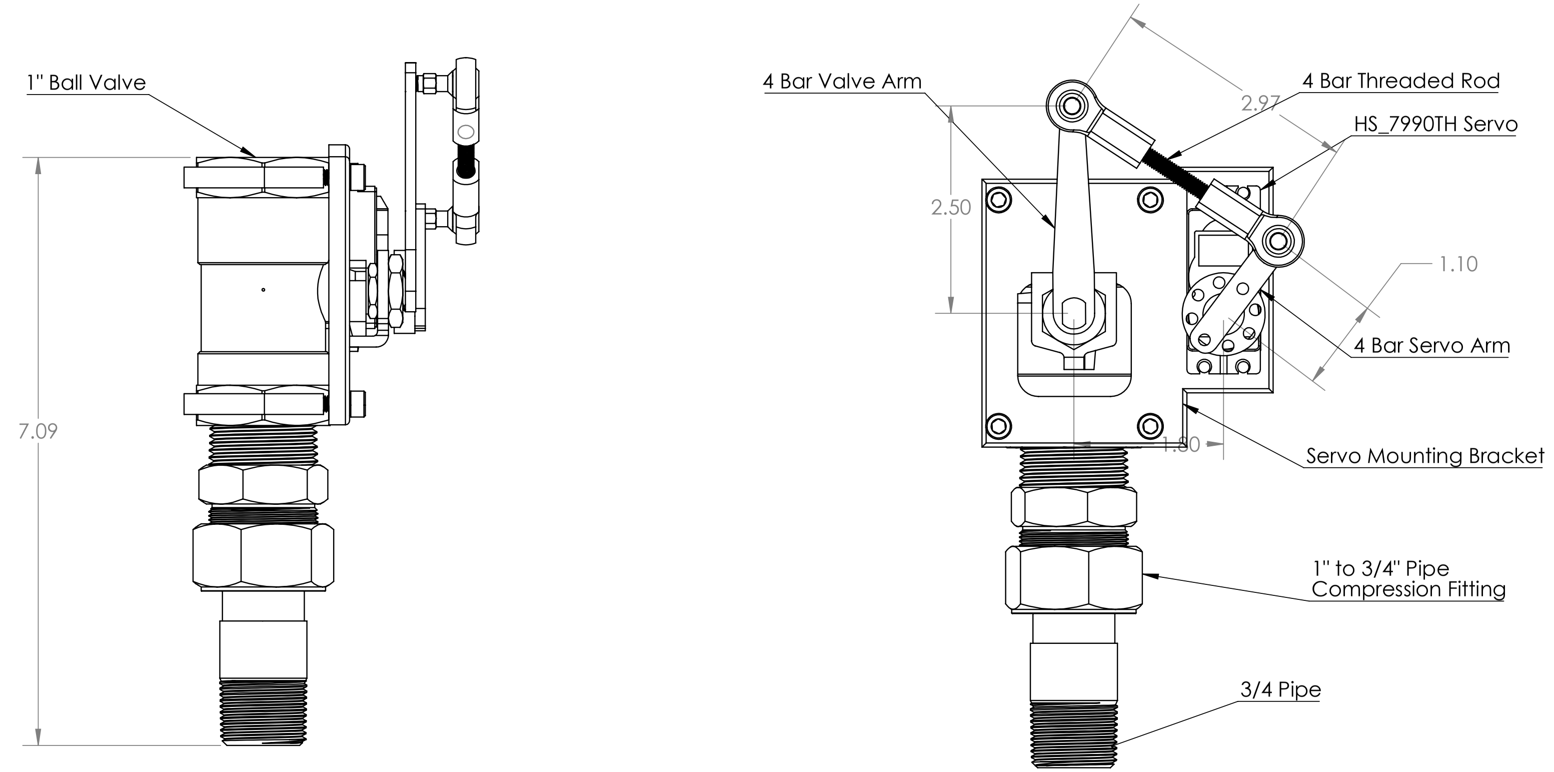
COMMENTS:

TITLE:

Cubic Nozzle

SIZE	DWG. NO.	REV
B	nozzle	

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

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FRACTIONAL ± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Steel

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	AS	4-24-2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

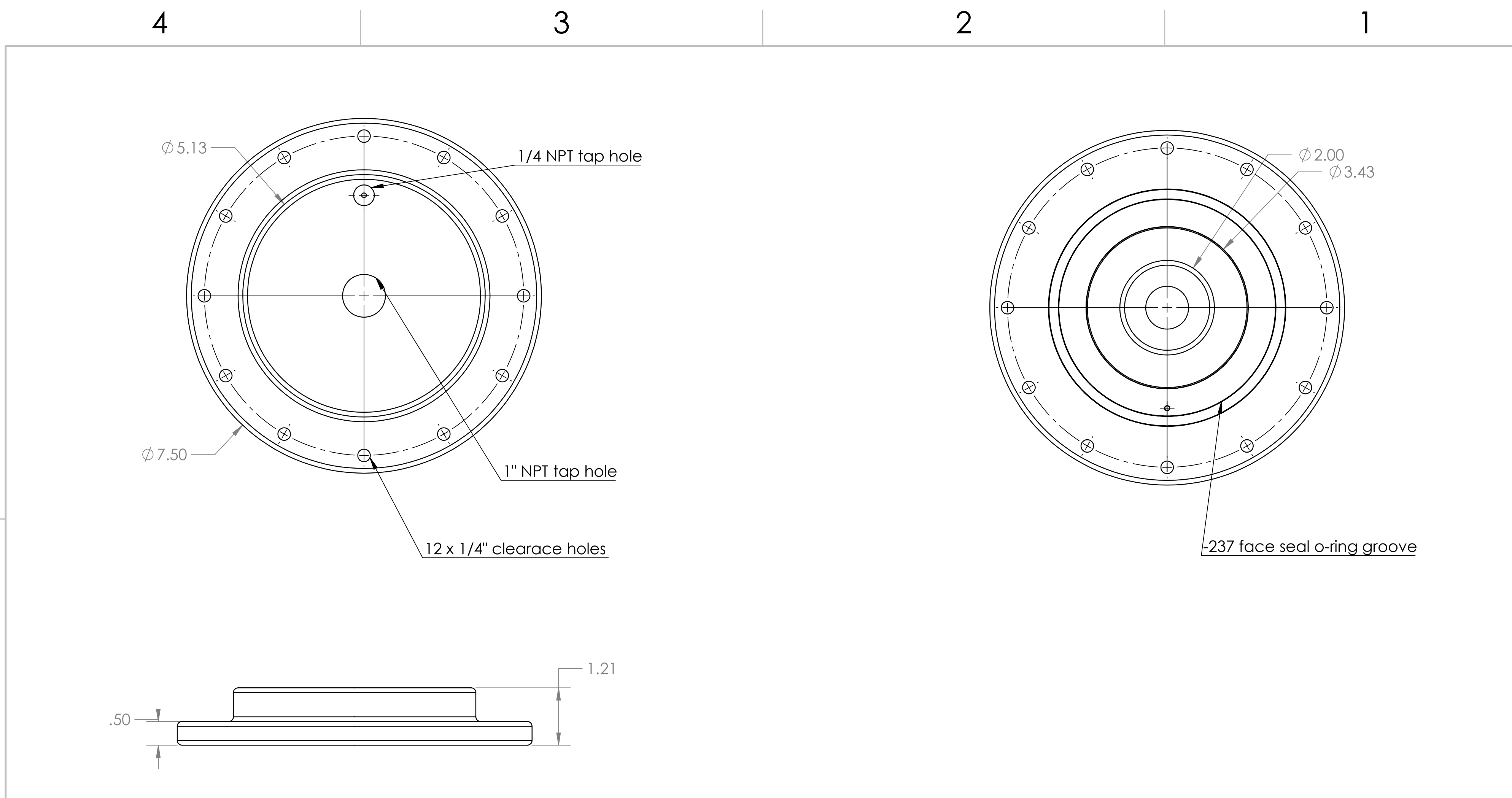
COMMENTS:

TITLE:

4-Bar Linkage Assembly

SIZE	DWG. NO.	REV
B	4barlinkage_assem	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

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TOLERANCES: 0.005
FRACTIONAL± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Aluminum 6061-T6

FINISH
Polished

DO NOT SCALE DRAWING

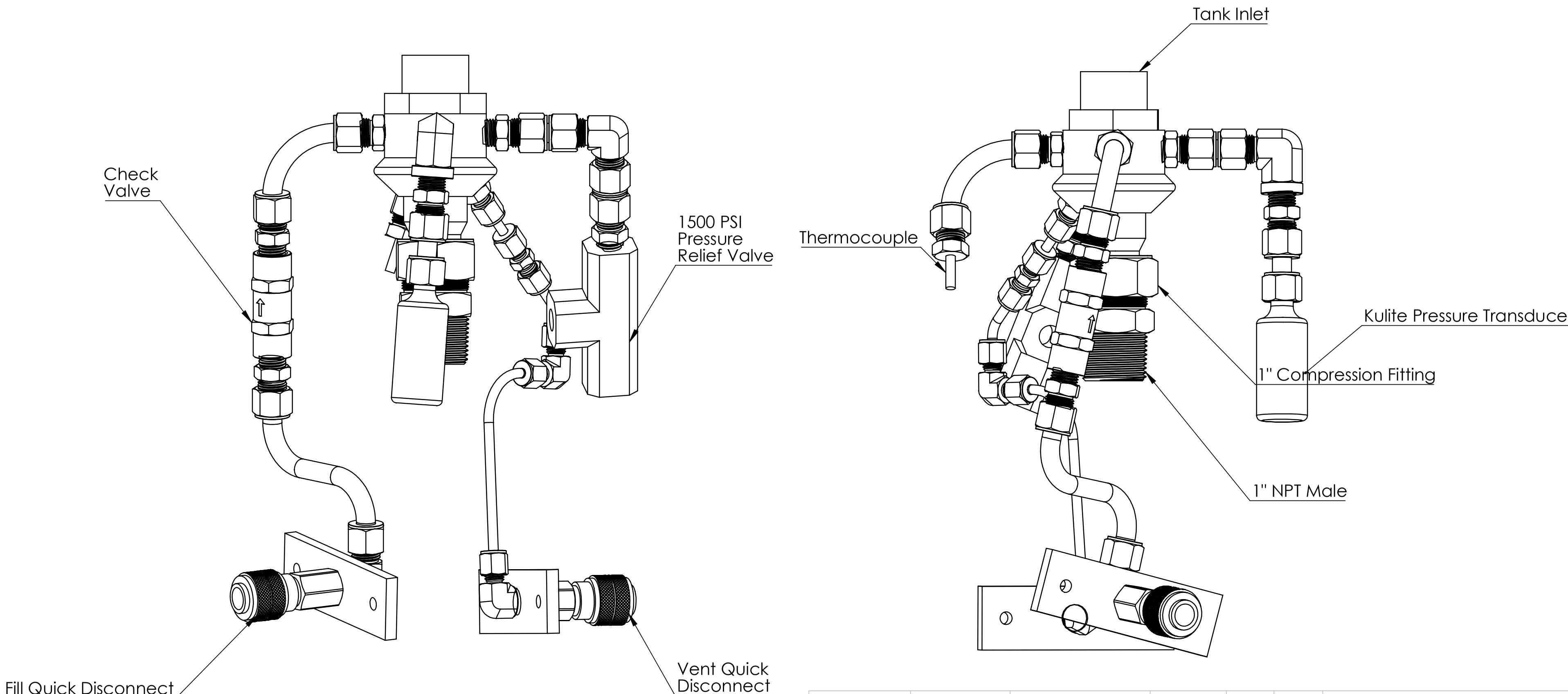
	NAME	DATE
DRAWN	AS	5-24-2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Injector Housing

SIZE	DWG. NO.	REV
B	injector_housing	

SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



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NEXT ASSY	USED ON	
APPLICATION		DO NOT SCALE DRAWING

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DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL ± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL: Steel
FINISH

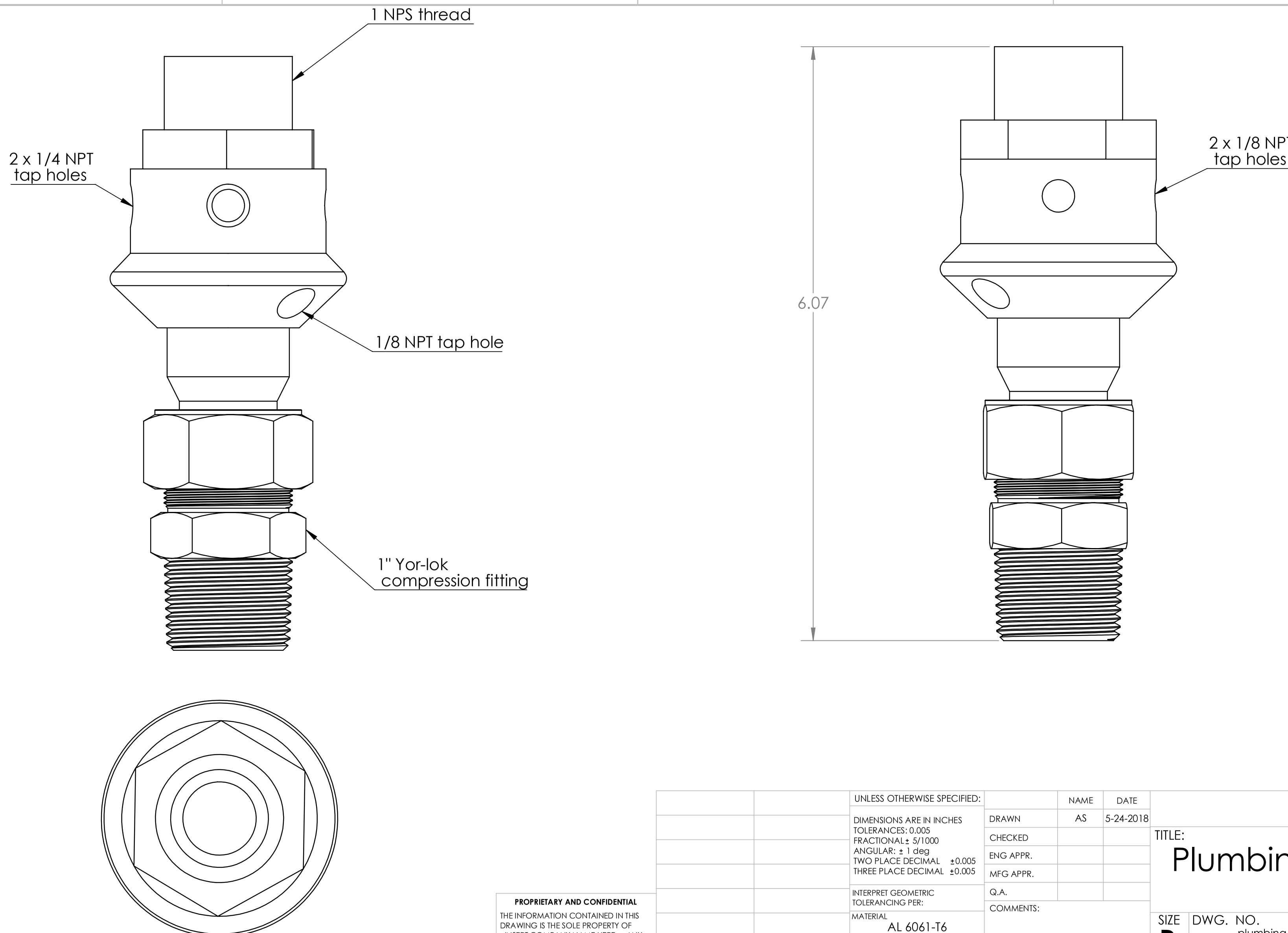
	NAME	DATE
DRAWN	AS	5-24-2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Plumbing Assembly

SIZE	DWG. NO.	REV
B	plumbing_assem	
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

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TOLERANCES: 0.005
FRACTIONAL± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: AL 6061-T6

FINISH: Polished

DO NOT SCALE DRAWING

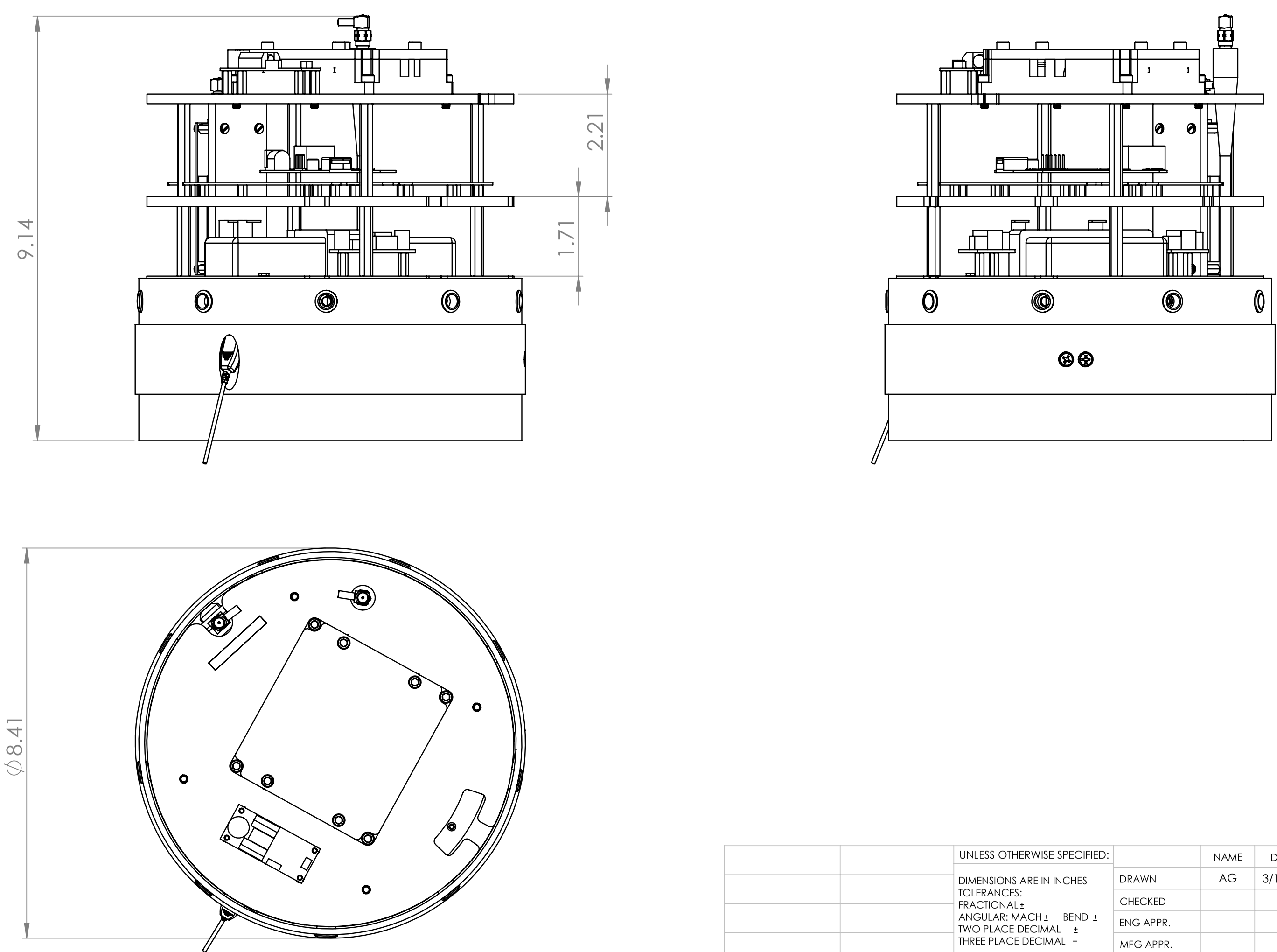
	NAME	DATE
DRAWN	AS	5-24-2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Plumbing Cross

SIZE	DWG. NO.	REV
B	plumbing_cross	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



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UNLESS OTHERWISE SPECIFIED:		
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		
INTERPRET GEOMETRIC TOLERANCING PER:		
MATERIAL		
NEXT ASSY	USED ON	FINISH
APPLICATION		DO NOT SCALE DRAWING

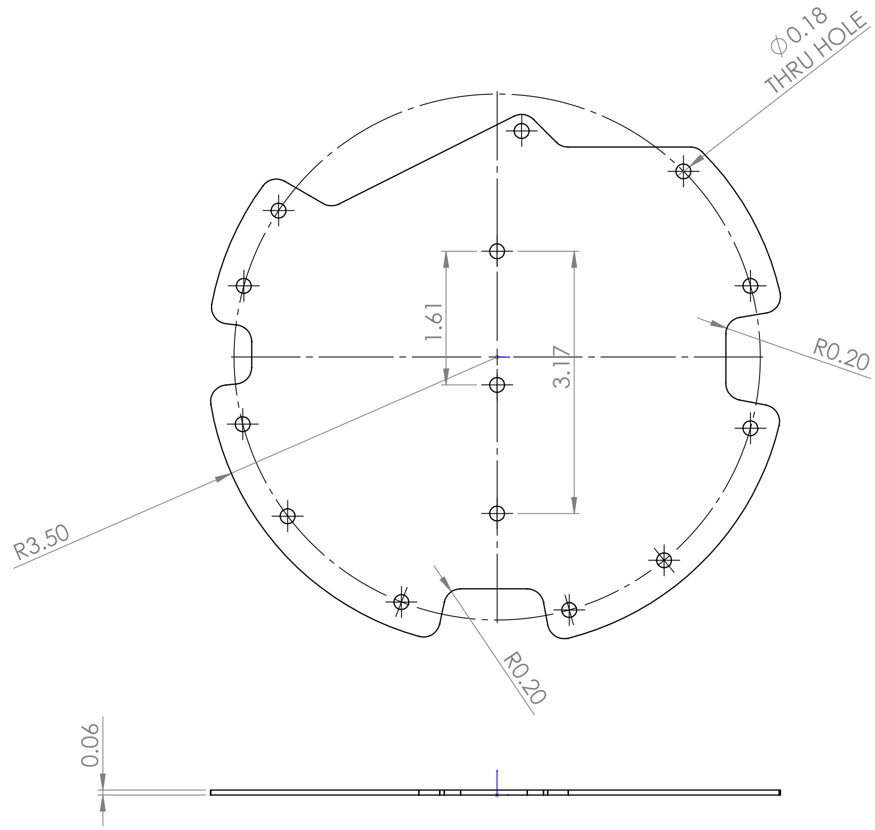
	NAME	DATE
DRAWN	AG	3/15/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

Electronics Bay

SIZE	DWG. NO.	REV
B	T_ElectronicsBay_S_A74_v4	
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	AG	5/20/18
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

Avionics PCB

SIZE	DWG. NO.	REV
B	T_AvionicsPCB_EP_P71_v2	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

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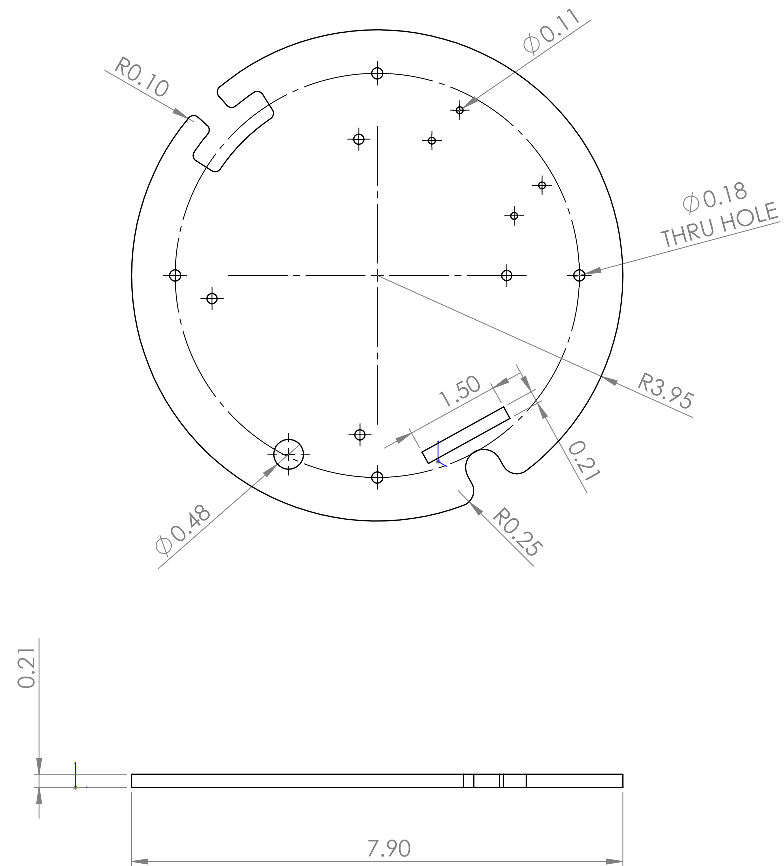

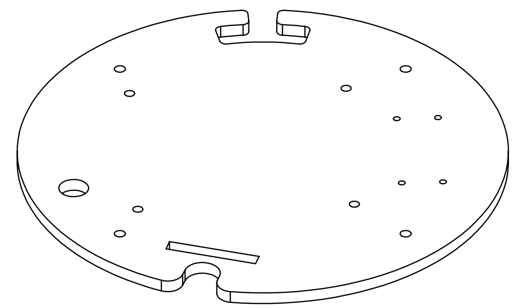

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Cast Acrylic

FINISH
Transparent

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

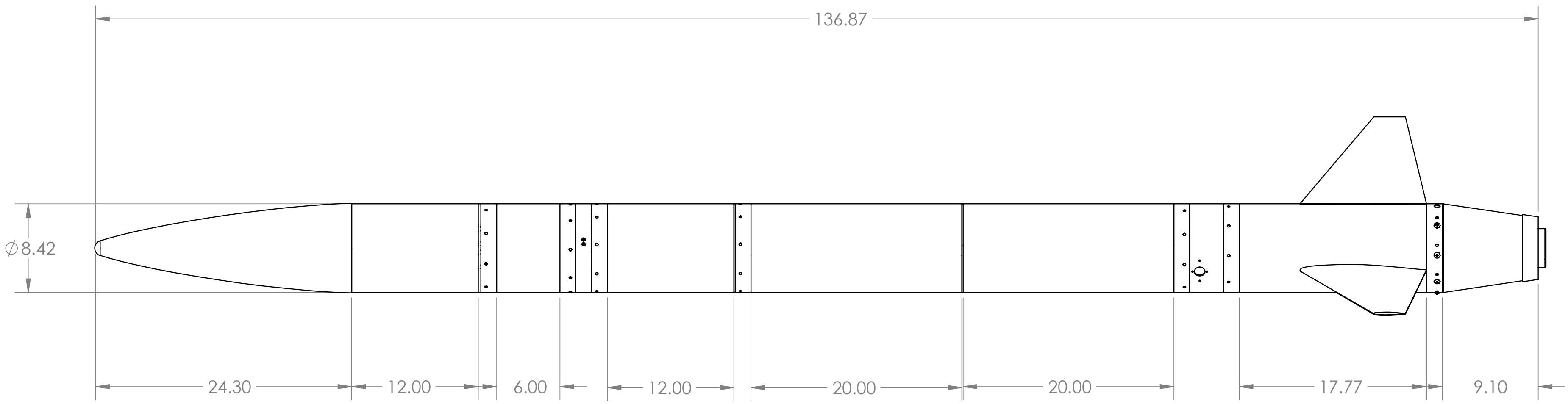
COMMENTS:

TITLE:

Avionics Level 1

SIZE	DWG. NO.	REV
B	T_DiskLevelPart(1)_EP_P74_v4	
SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
DIMENSIONS ARE IN INCHES TOLERANCES: 0.005 FRACTIONAL ± 5/1000 ANGULAR: ± 1 deg TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.005	DRAWN	TI	5-20-18	TITLE:	
	CHECKED			Theseus Airframe	
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL FG, CF, AL	COMMENTS:			SIZE B	DWG. NO. T_Theseus_Master_v1 · REV
FINISH Gloss/Polished					
DO NOT SCALE DRAWING				SCALE: 1:24 · WEIGHT: 128 lbs	SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

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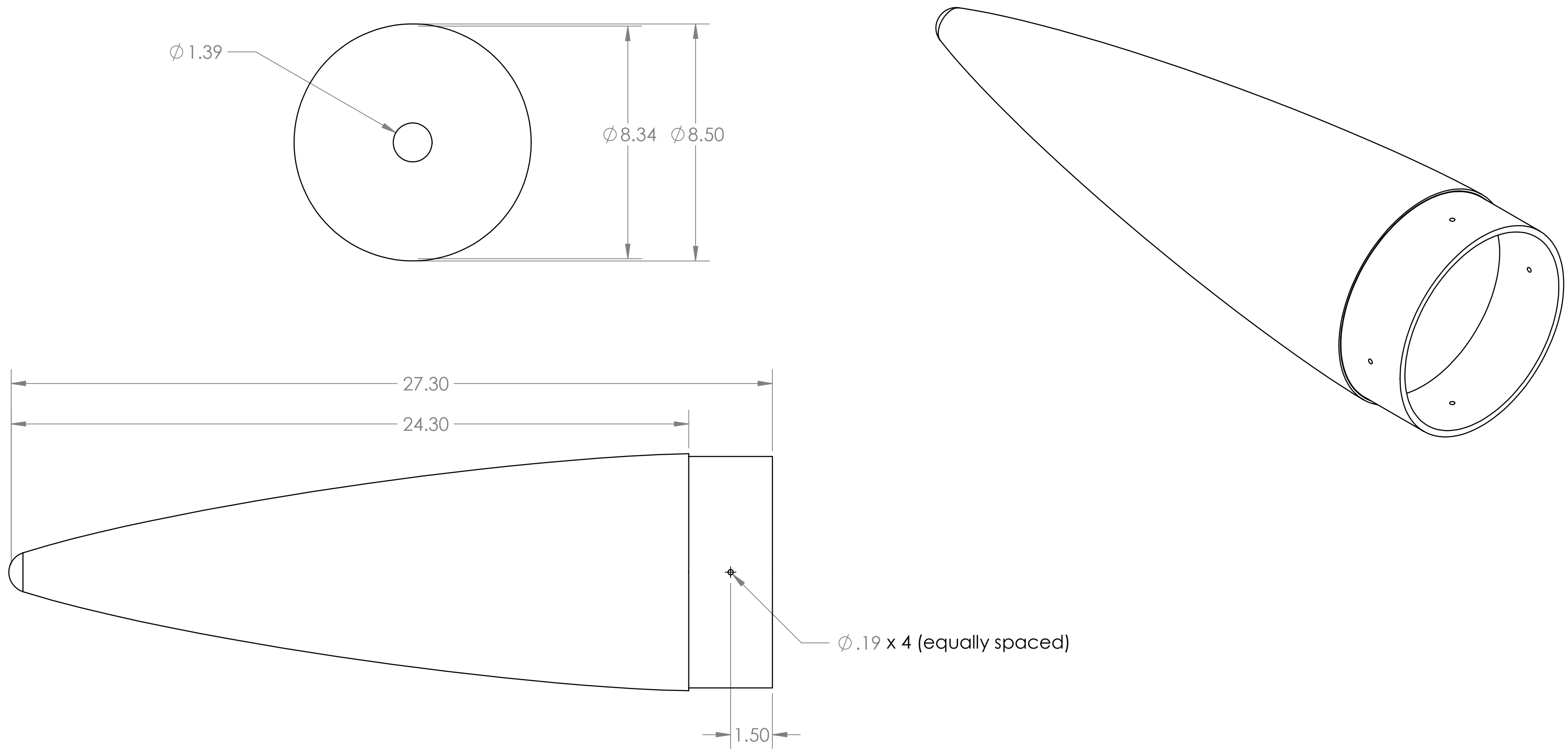

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NEXT ASSY	USED ON
APPLICATION	

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DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL ± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ± 0.005
THREE PLACE DECIMAL ± 0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Fiberglass

FINISH: Gloss

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TI	5/20/18
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

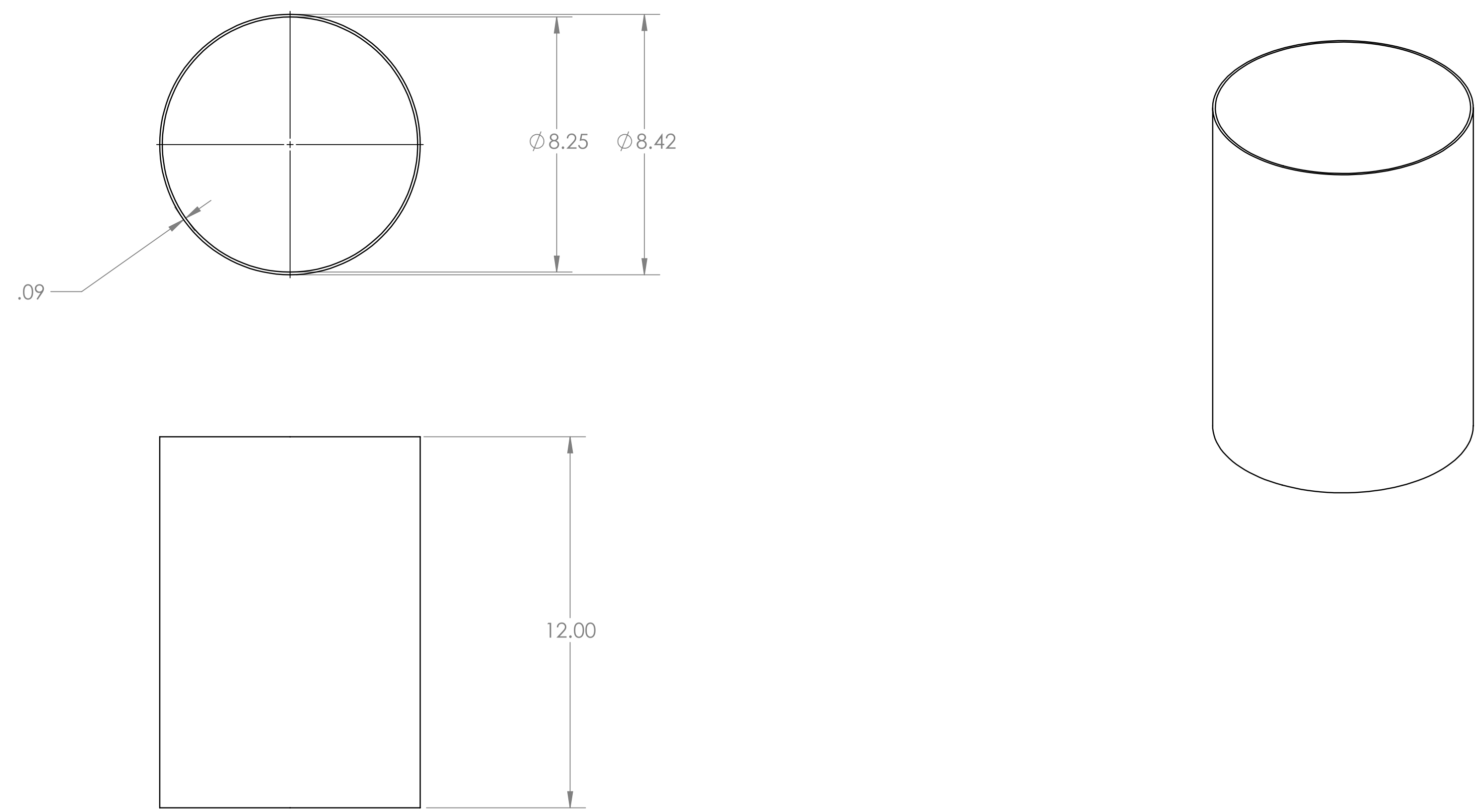
COMMENTS:

TITLE:

Nose Cone

SIZE: **B** | DWG. NO. T_VonKarman_NC_P45_V1 | REV

SCALE: 1:4 | WEIGHT: 2.42 lbs | SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

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TOLERANCES: 0.005
FRACTIONAL± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Carbon Fiber

FINISH
Gloss

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

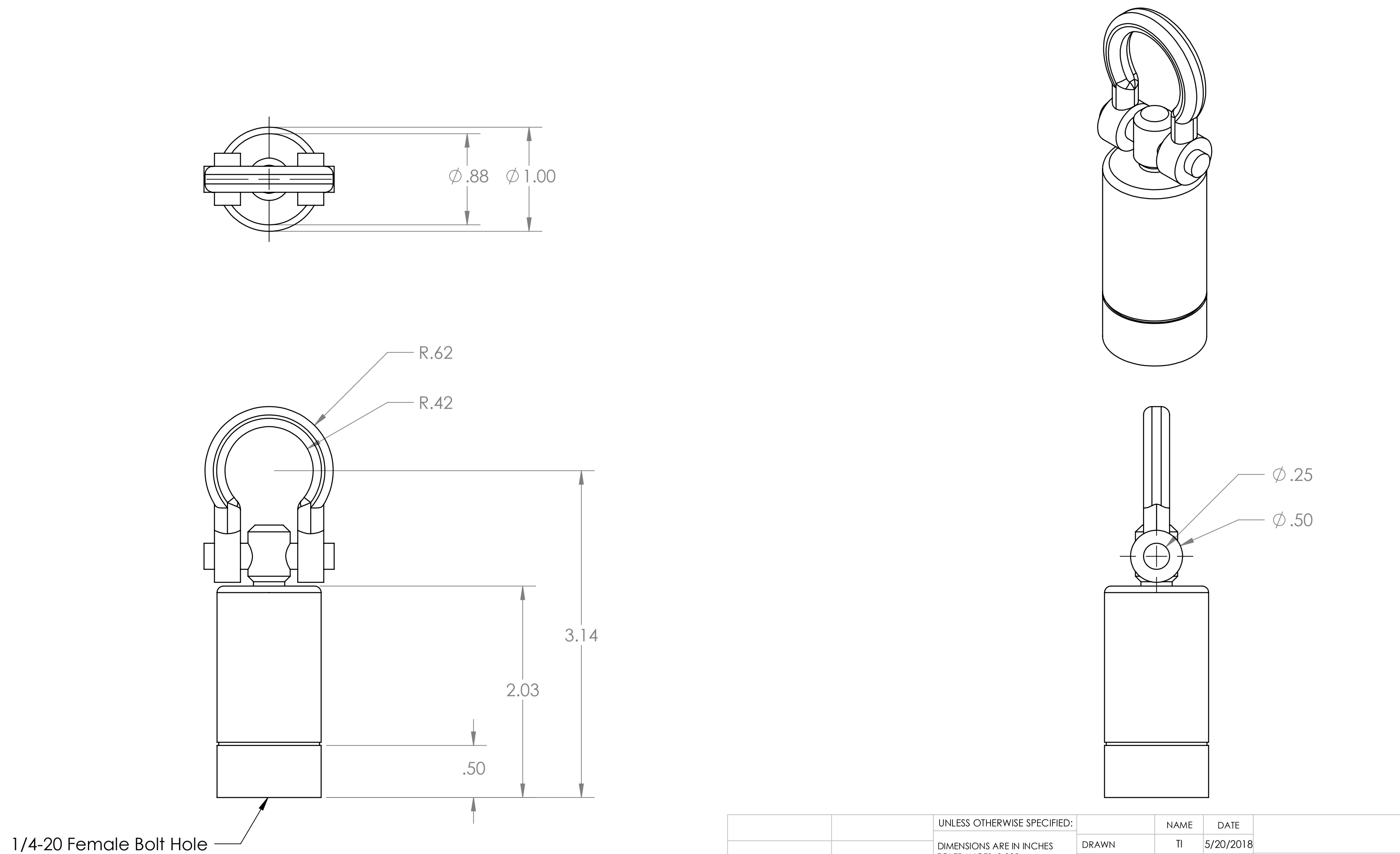
COMMENTS:

TITLE:

Recovery Bay BT

SIZE	DWG. NO.	REV
B	T_Recovery_BT_S_P54_v1	

SCALE: 1:4 WEIGHT: 1.06 lbs SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL ± 5/1000
ANGULAR: ±1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
AL 6061-T6

FINISH
Matte

DO NOT SCALE DRAWING

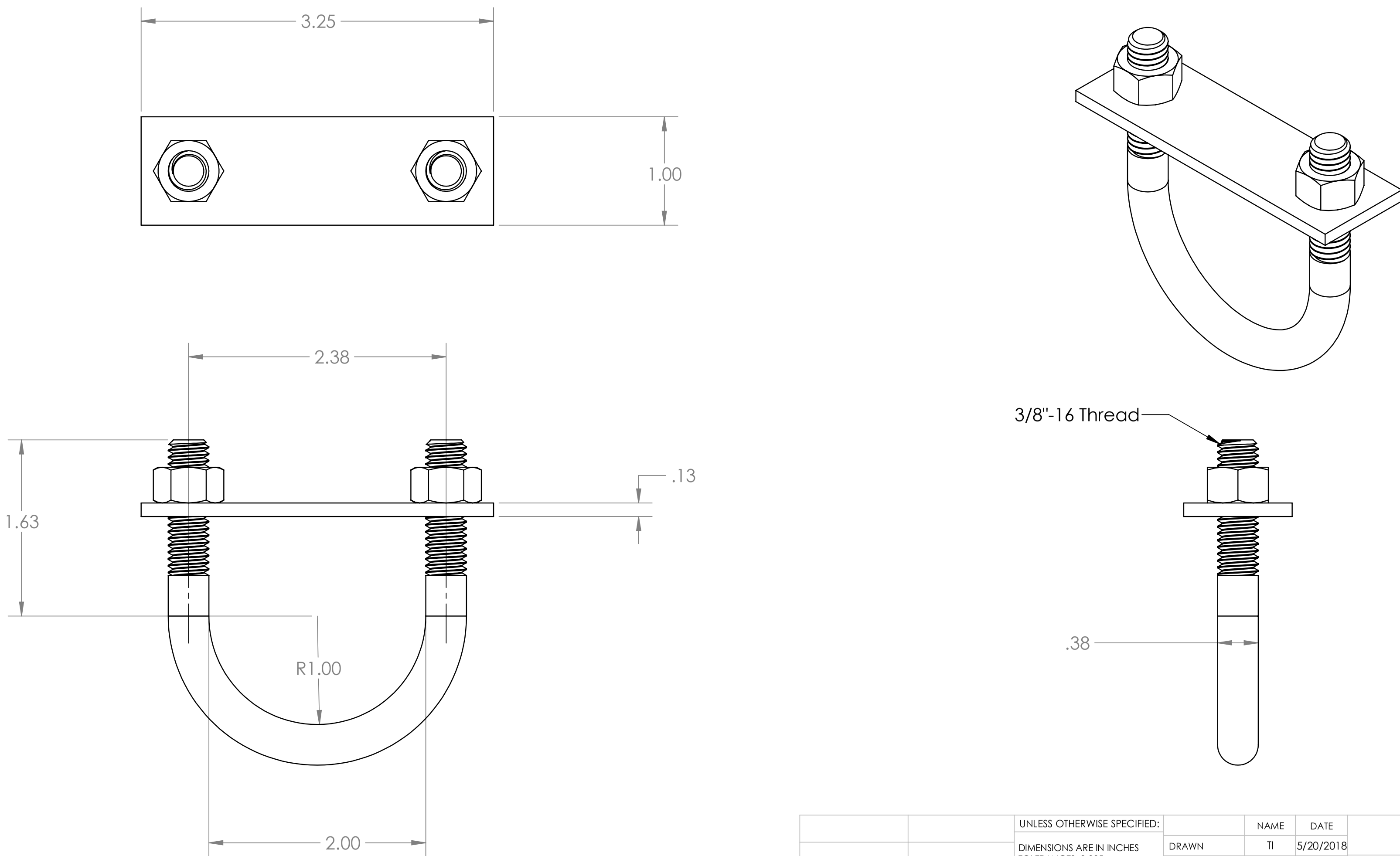
	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS: Commericially purchased component from RATTWorks.
ARRD - Advanced Retension Release Device

TITLE:
RATTWorks ARRD

SIZE	DWG. NO.	REV
B	T_ARRD_S_P64_v1	

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



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NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL ± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Black-Oxide Steel

FINISH
Polished

DO NOT SCALE DRAWING

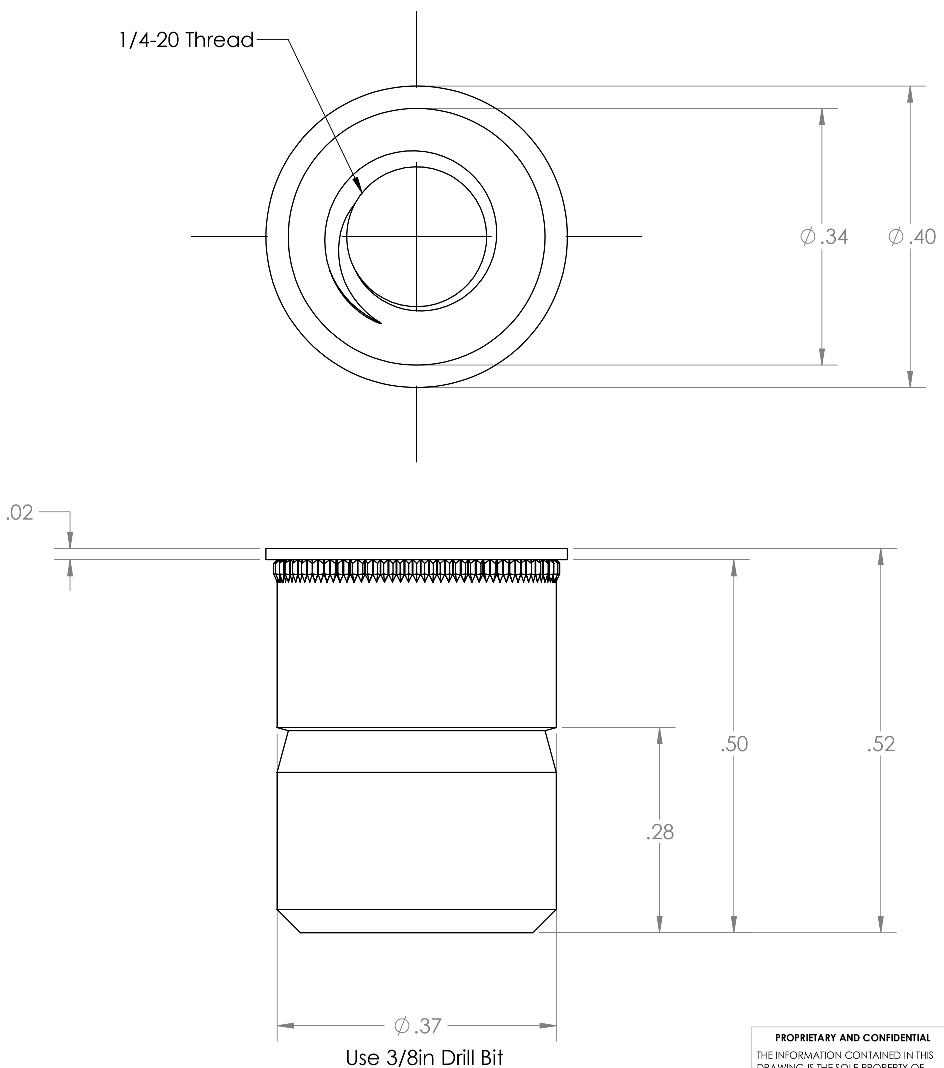
	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

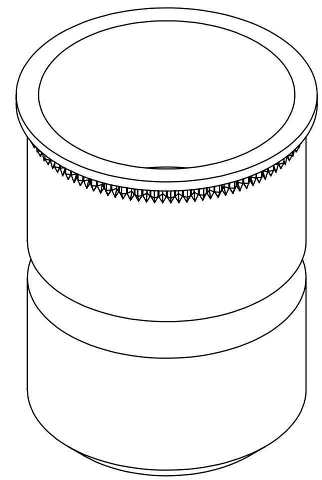
COMMENTS: Commercially purchased component from McMaster-Carr Item #:3201T67

TITLE:
Recovery U-Bolt

SIZE **B** | DWG. NO. T_Recovery_3_8_Ubolt_S_P64_v1 | REV

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1





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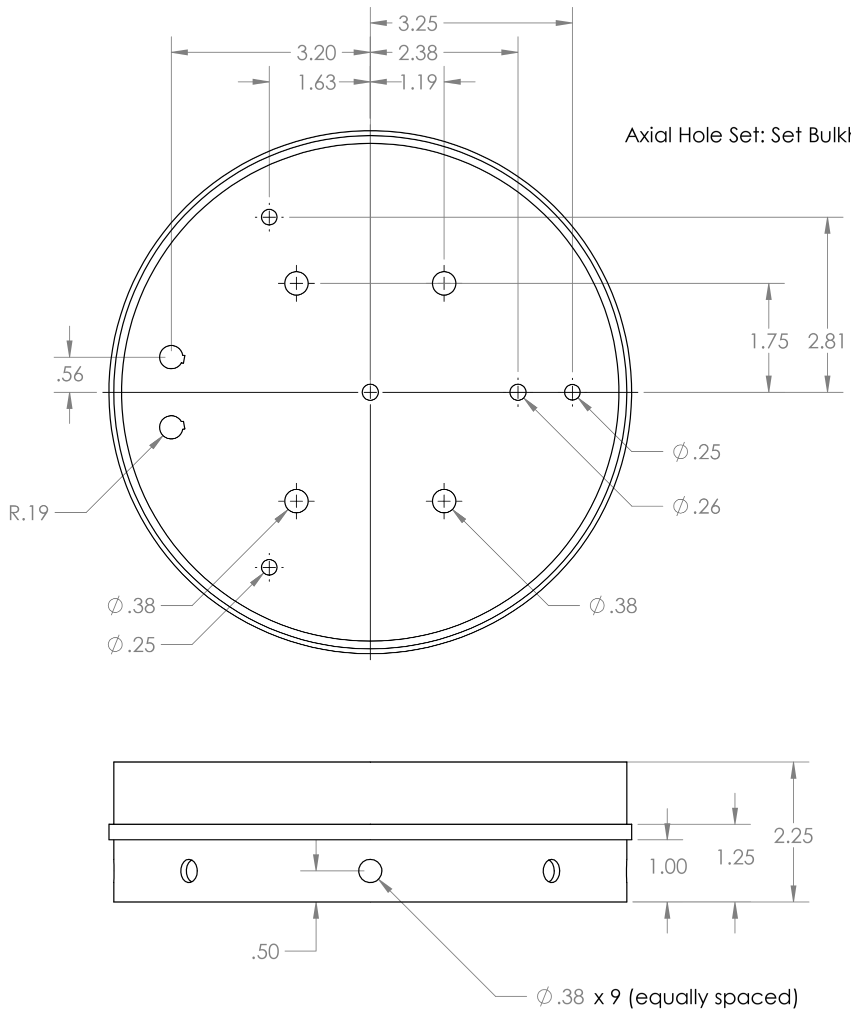
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: 0.005 FRACTIONAL± 5/1000 ANGULAR: ±1 deg TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.005	DRAWN	TI	5/20/2018
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL Steel	COMMENTS: Commercially purchased component - McMaster-Carr Item# 98560A571		
FINISH Cadmium-Plated			
DO NOT SCALE DRAWING			

NEXT ASSY	USED ON
APPLICATION	

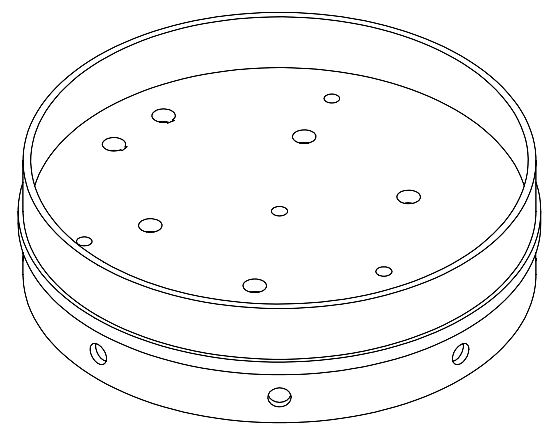
TITLE:

Low-Profile Rivet Nut

SIZE	DWG. NO.	REV
B	LOW-PROFILE RIVET NUT	
SCALE: 4:1	WEIGHT:	SHEET 1 OF 1



Axial Hole Set: Set Bulkhead center as zero on mill



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NEXT ASSY	USED ON		
APPLICATION			

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TOLERANCES: 0.005
FRACTIONAL± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
AL 6061-T6

FINISH
Polished

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

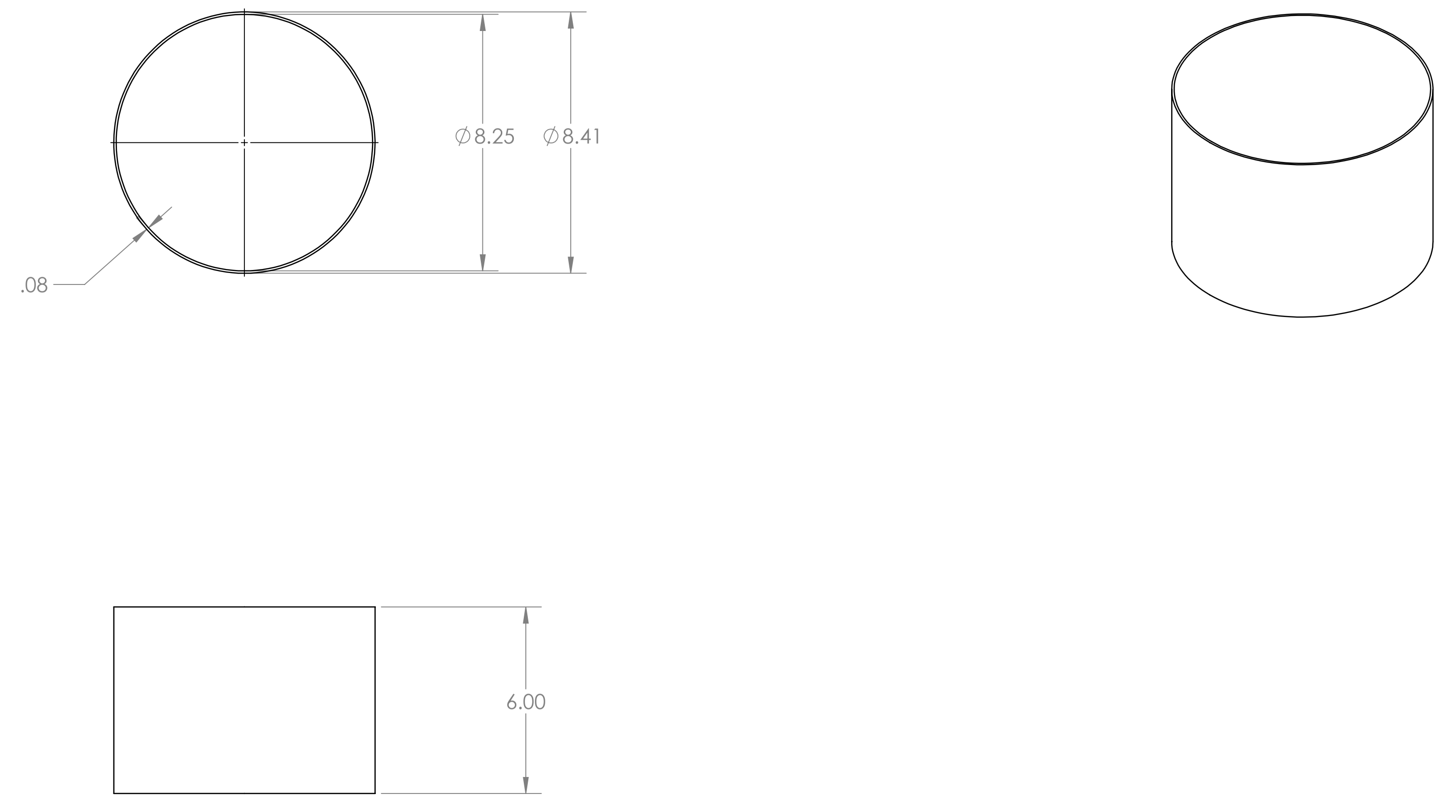
COMMENTS:

TITLE:

Recovery Bulkhead

SIZE	DWG. NO.	REV
B	T_Upper_Ebay_Bulkhead_S_P54_v1	

SCALE: 1:2 | WEIGHT:1.92 | SHEET 1 OF 1



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NEXT ASSY	USED ON	
APPLICATION		

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DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Fiberglass

FINISH: Gloss

DO NOT SCALE DRAWING

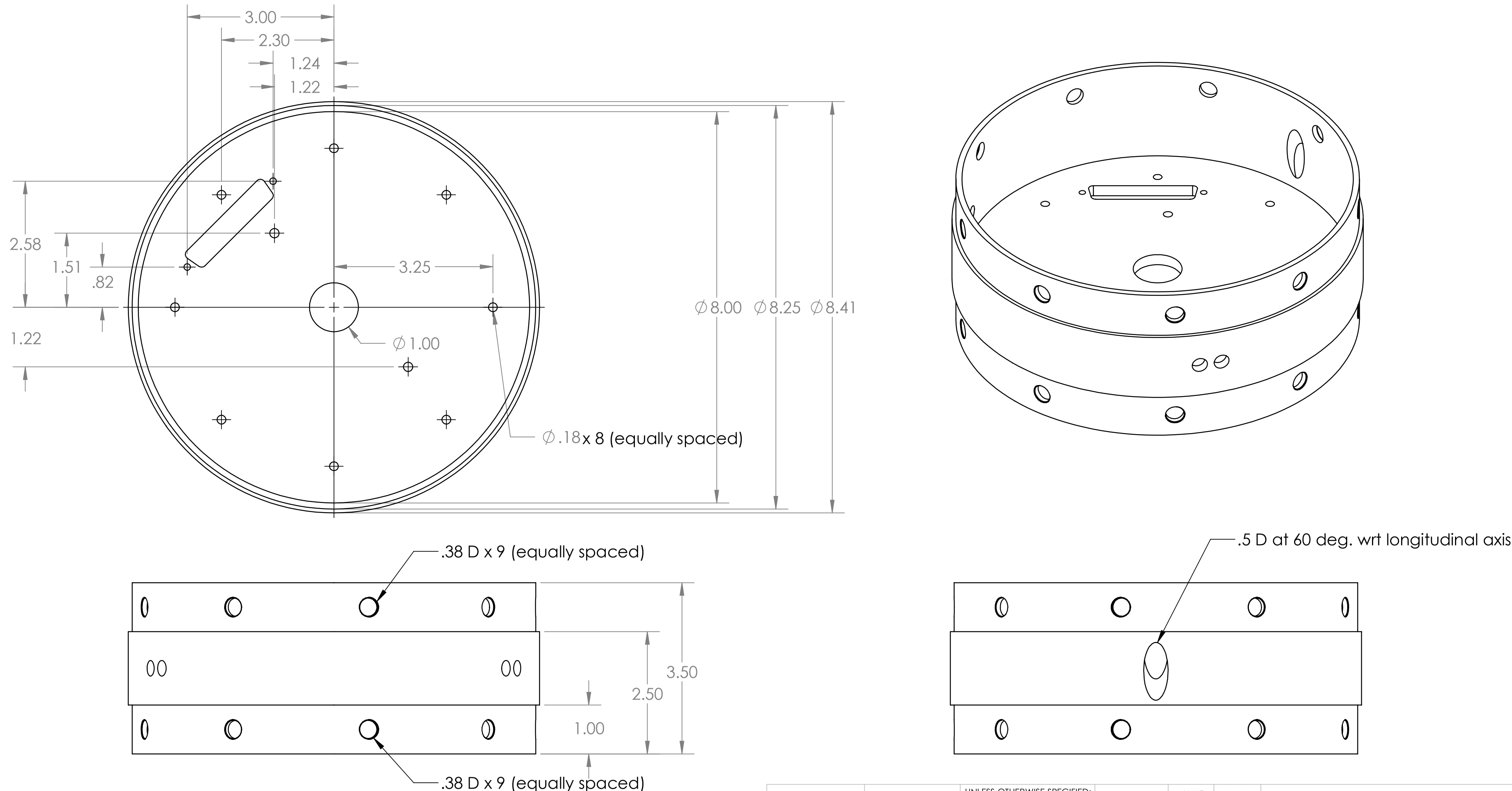
	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

E-Bay BT

SIZE	DWG. NO.	REV
B	T_E-Bay_BT_S_P74_v2	
SCALE: 1:4	WEIGHT: 1.23	SHEET 1 OF 1



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TOLERANCES: 0.005
FRACTIONAL± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
AL 6061-T6

FINISH
Polished

DO NOT SCALE DRAWING

NEXT ASSY	USED ON
APPLICATION	

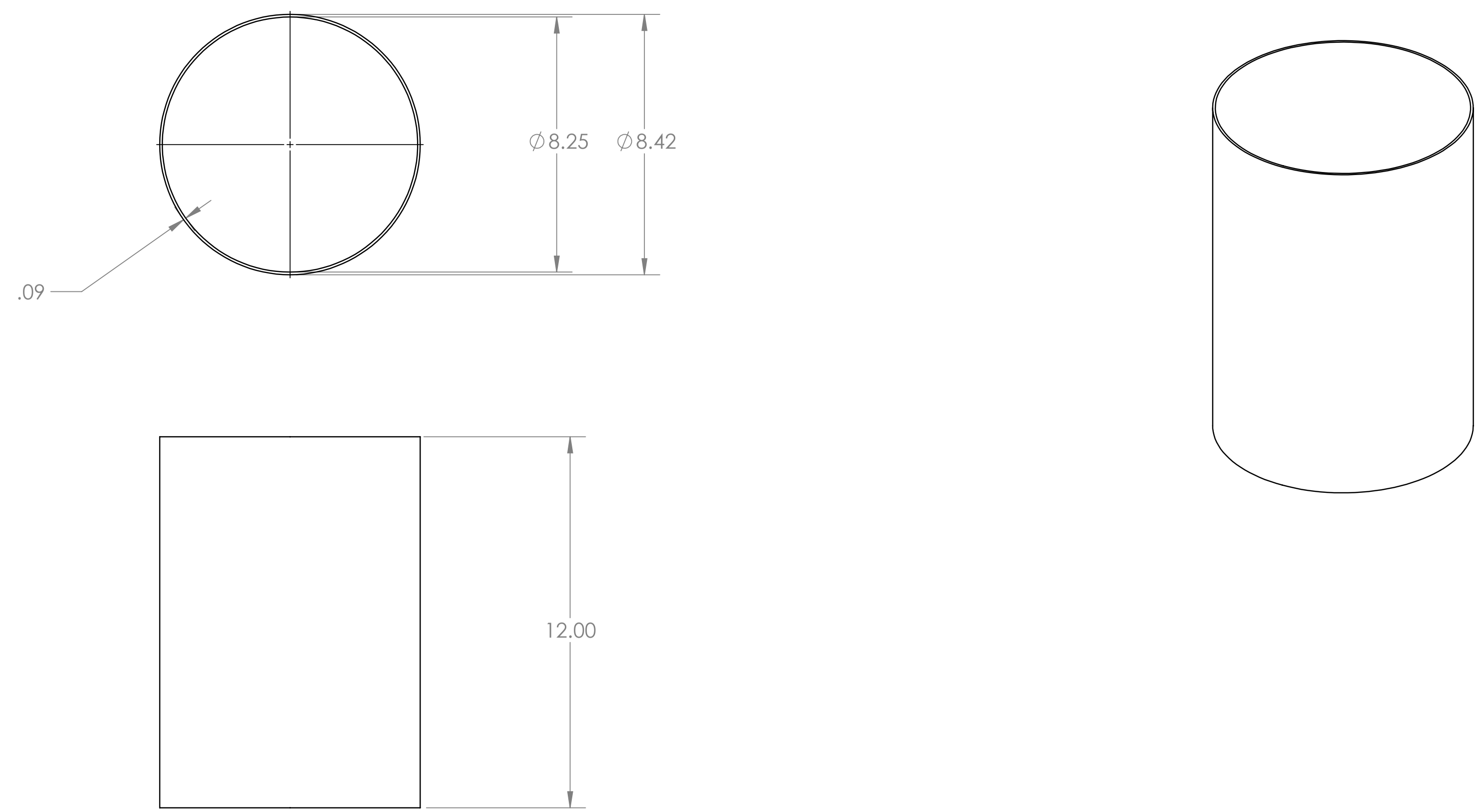
	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
E-bay BH

SIZE	DWG. NO.	REV
B	T_LowerE-bayBulkhead_S_P74_v4	

SCALE: 1:2 WEIGHT: 2.53 lbs SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL ± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Carbon Fiber

FINISH: Gloss

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

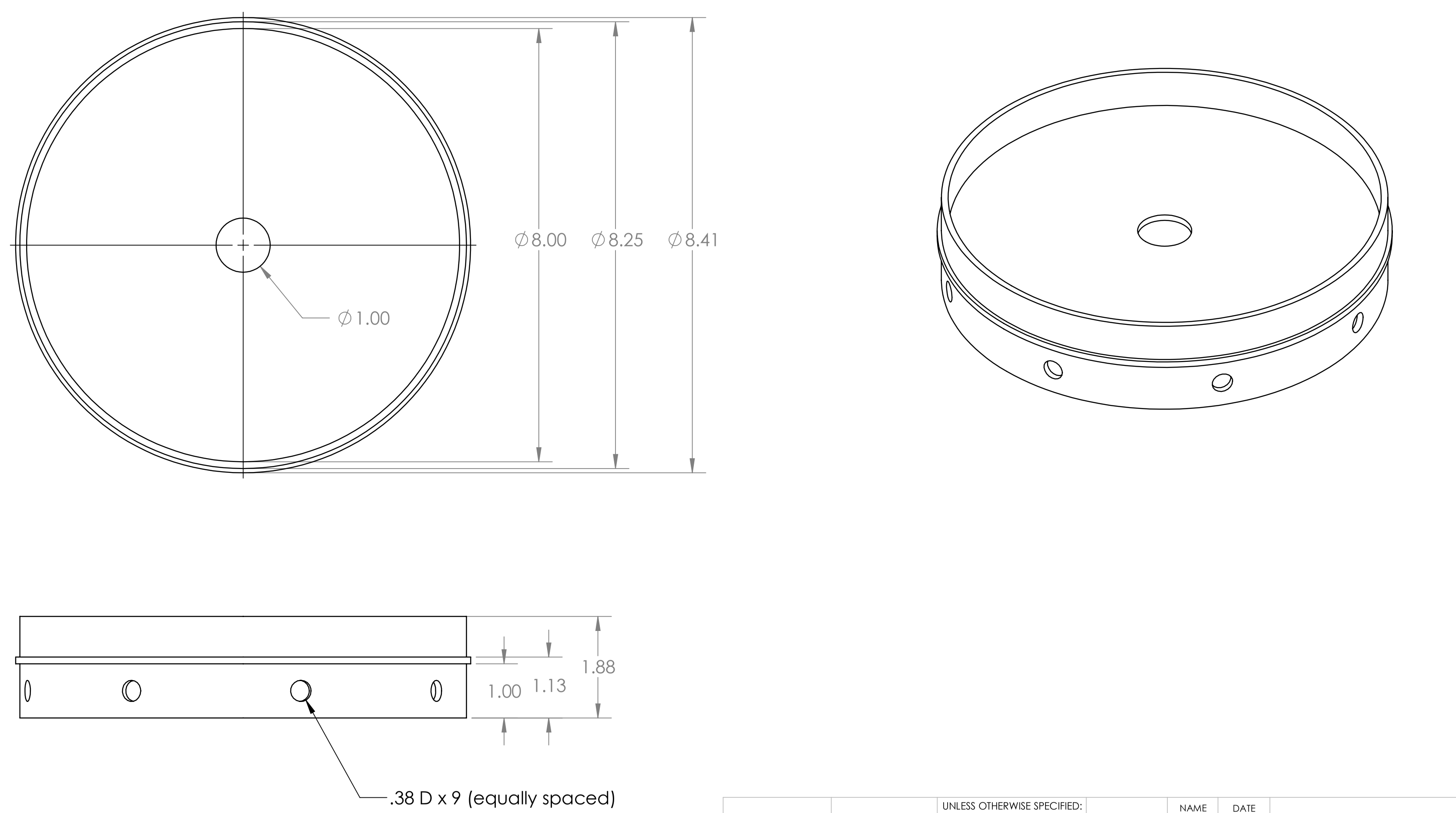
COMMENTS:

TITLE:

Payload Bay BT

SIZE	DWG. NO.	REV
B	T_Payload_BT_S_P54_v1	

SCALE: 1:4 WEIGHT: 1.06 lbs SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL ± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: AL 6061-T6

FINISH: Polished

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

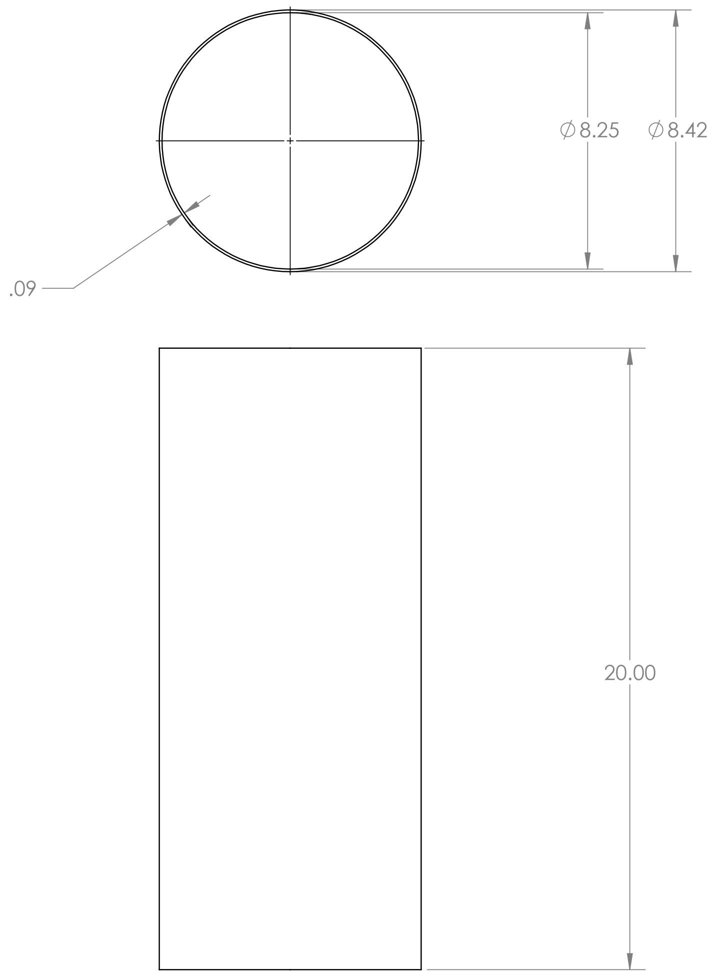
COMMENTS:

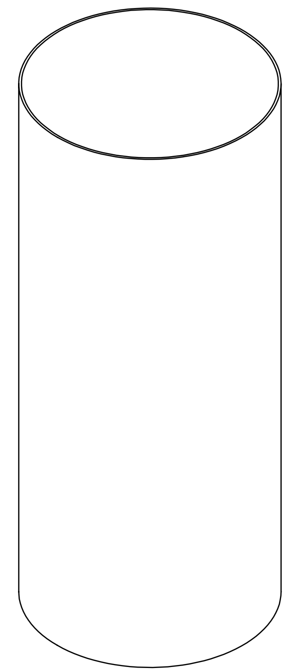
TITLE:

Payload BH

SIZE	DWG. NO.	REV
B	T_Payload_Bulkhead_S_P54_v1	

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1





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NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL ± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Carbon Fiber

FINISH
Gloss

DO NOT SCALE DRAWING

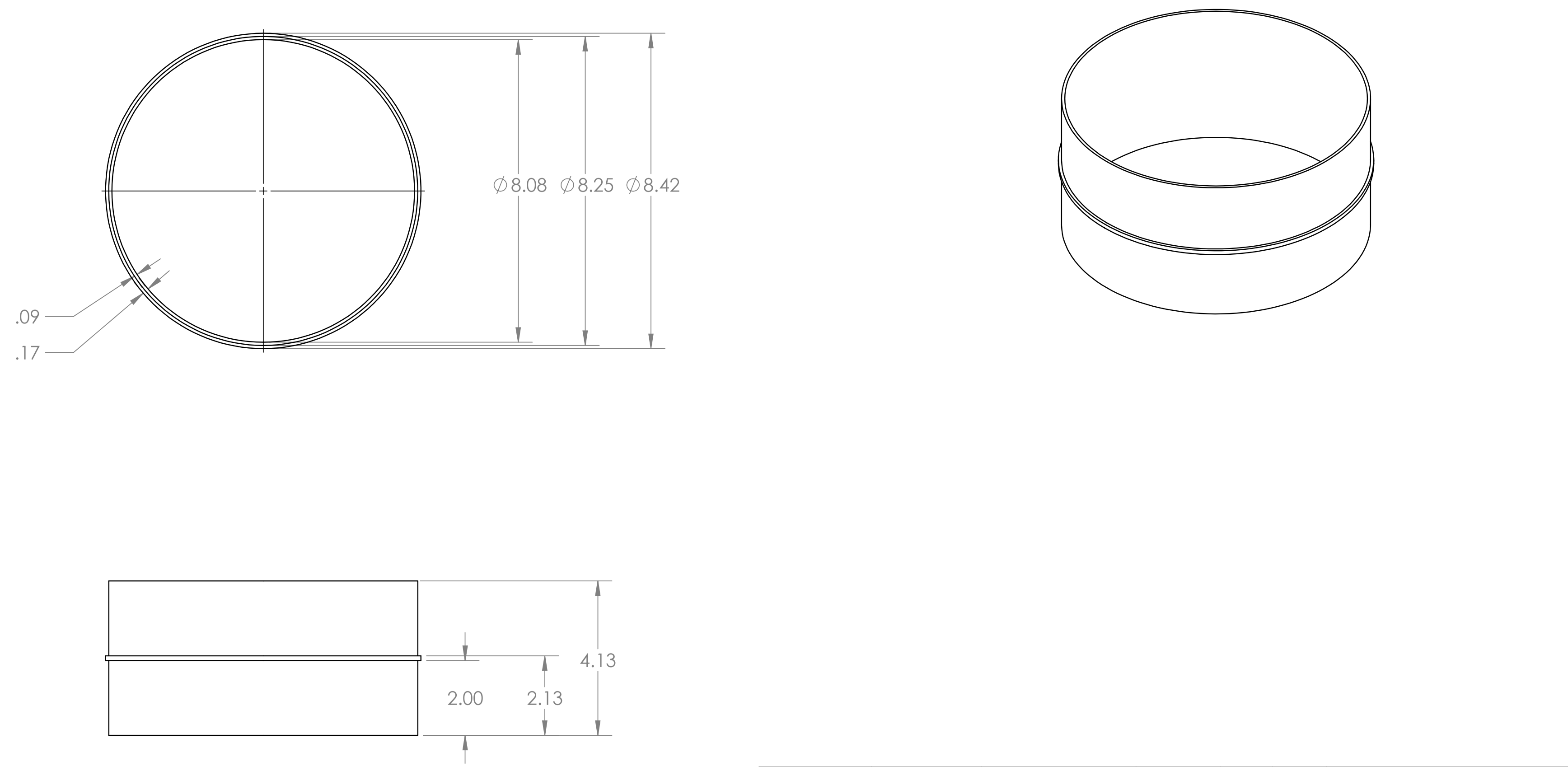
	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Oxidizer Tank BT

SIZE **B** | DWG. NO. T_Oxidizer_Tank_BT_S_P54_v1 | REV

SCALE: 1:8 | WEIGHT:1.85 lbs | SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: AL 6061-T6

FINISH: Polished

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

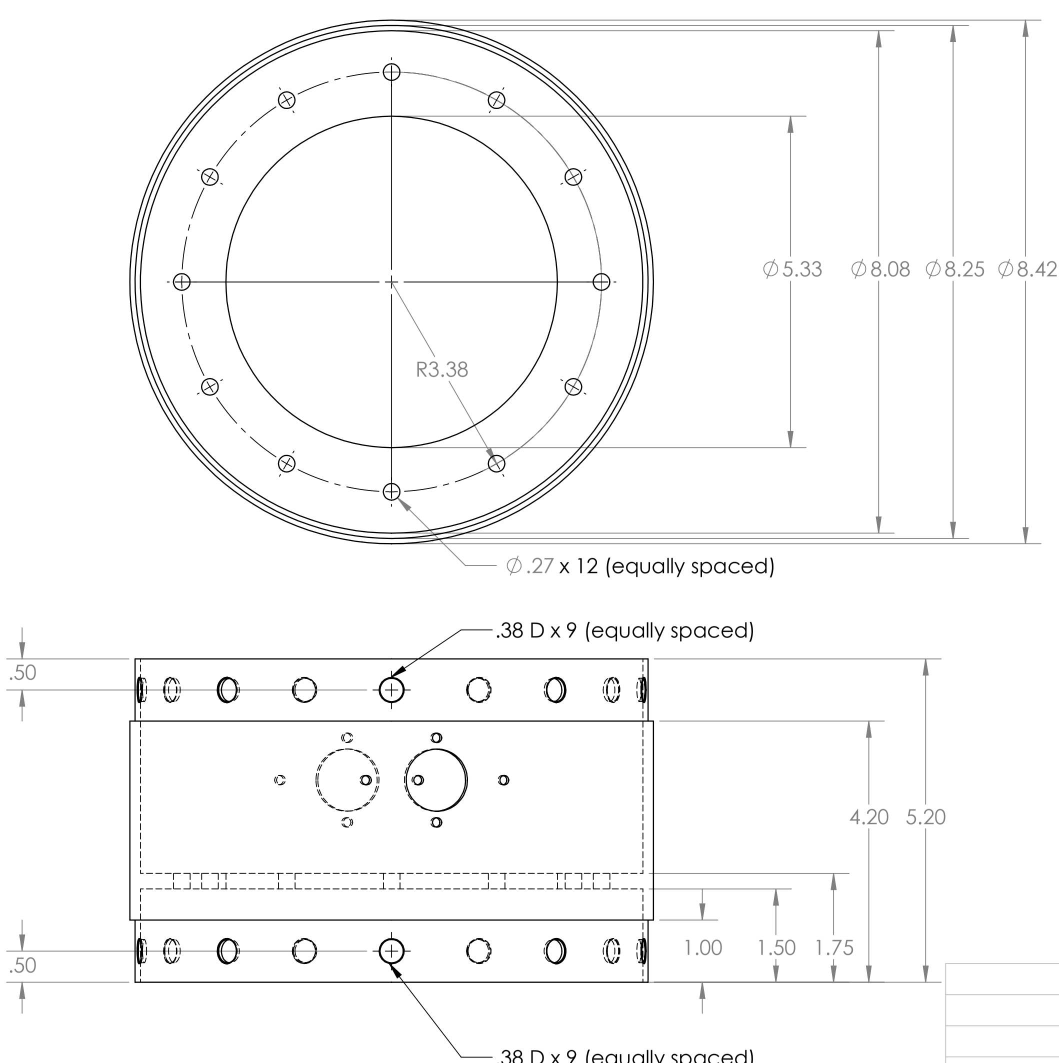
COMMENTS:

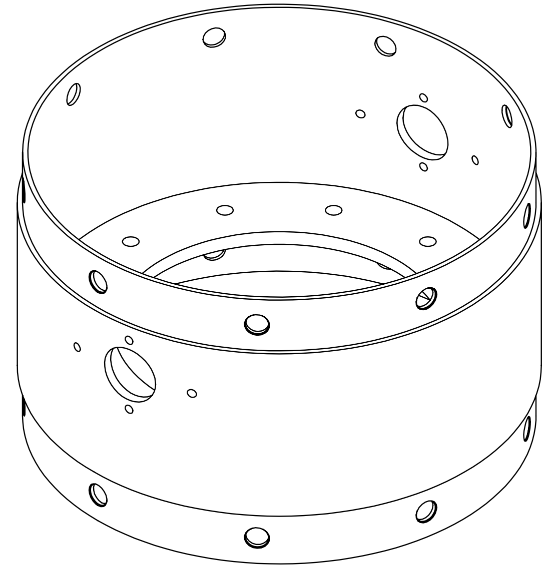
TITLE:

Ox. Tank BT Coupler

SIZE	DWG. NO.	REV
B	T_Oxidizer_BT_Coupler_S_P54_v1	

SCALE: 1:4 | WEIGHT:0.93 lbs | SHEET 1 OF 1





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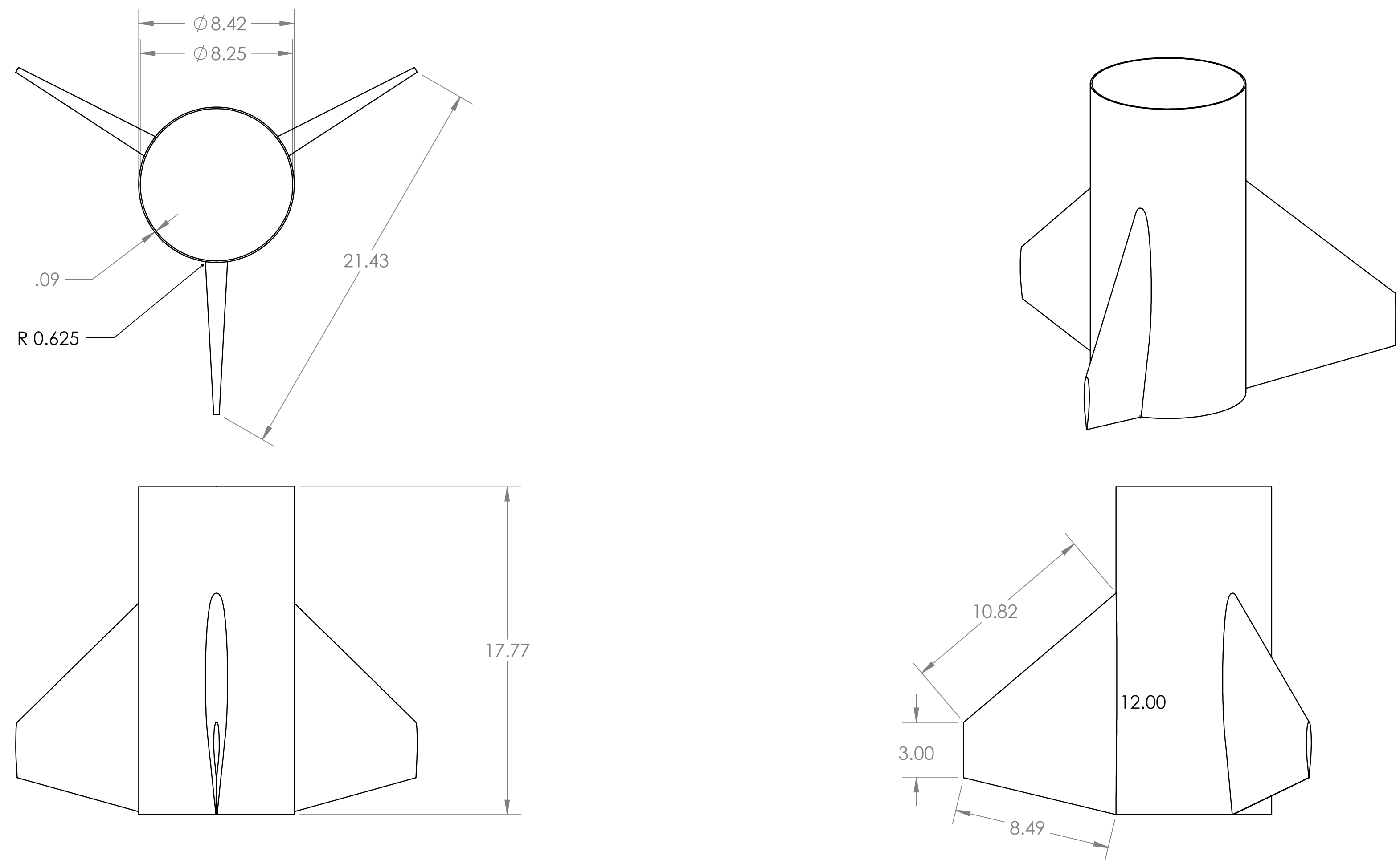
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: 0.005 FRACTIONAL± 5/1000 ANGULAR: ± 1 deg TWO PLACE DECIMAL ±0.005 THREE PLACE DECIMAL ±0.005	DRAWN	TI	5/20/2018
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL AL 6061-T6	COMMENTS:		
FINISH Polished			
DO NOT SCALE DRAWING			

NEXT ASSY	USED ON
APPLICATION	

TITLE:

Thrust BH

SIZE	DWG. NO.	REV
B	T_ThrustBulkhead_S_P54_v1	
SCALE: 1:4	WEIGHT: 2.46 lbs	SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL± 5/1000
ANGULAR: ±1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: Carbon Fiber

FINISH: Gloss

DO NOT SCALE DRAWING

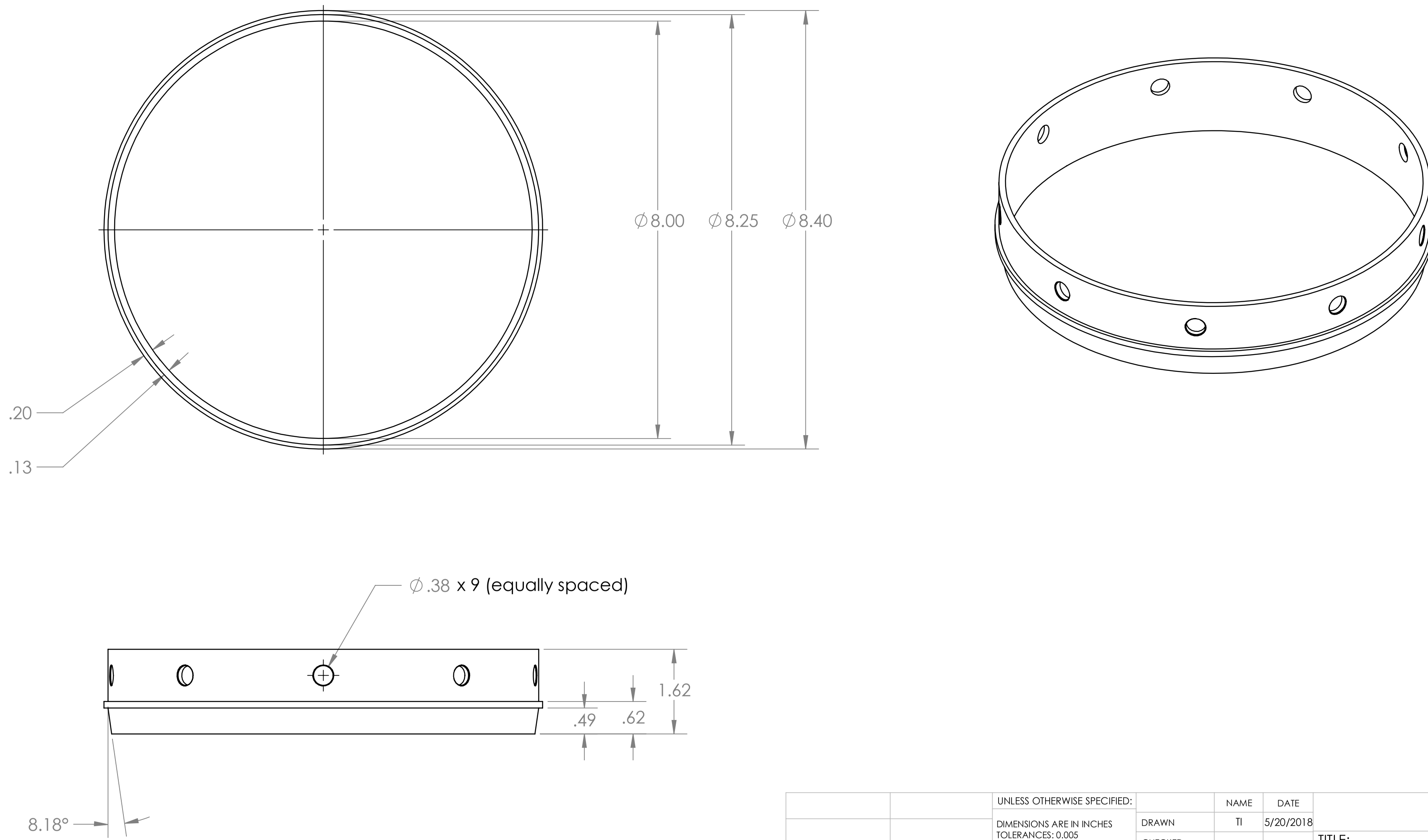
	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: Fin Can

SIZE	DWG. NO.	REV
B	T_Fin_Can_S_A54_v1	

SCALE: 1:8	WEIGHT:	SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL ± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL: AL 6061-T6

FINISH: Polished

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

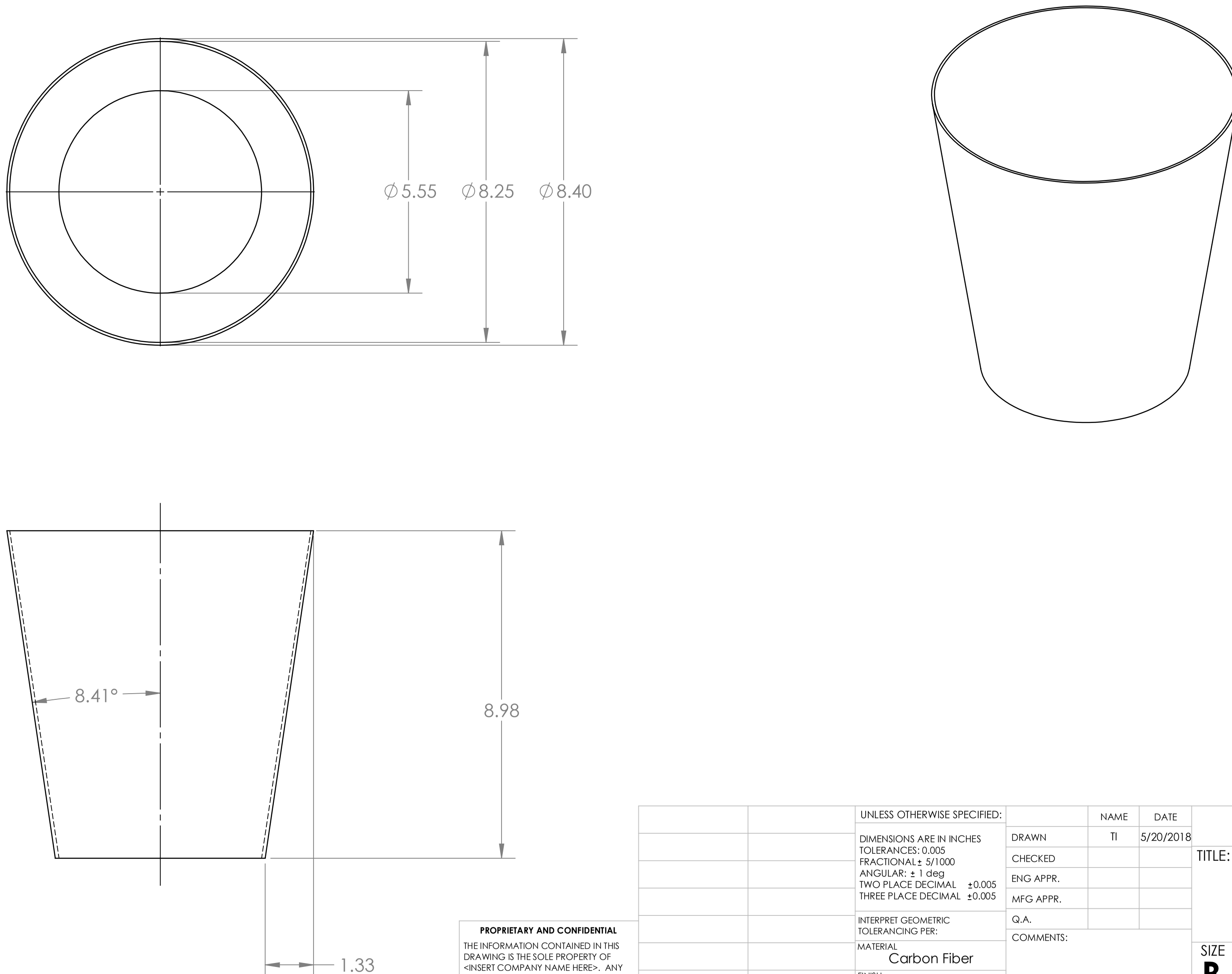
COMMENTS:

TITLE:

Tail Cone Coupler

SIZE	DWG. NO.	REV
B	T_Tail_Cone_Coupler_S_P54_v1	

SCALE: 1:2 WEIGHT: 0.54 lbs SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES: 0.005
FRACTIONAL ± 5/1000
ANGULAR: ± 1 deg
TWO PLACE DECIMAL ±0.005
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Carbon Fiber

FINISH
Gloss

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	TI	5/20/2018
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

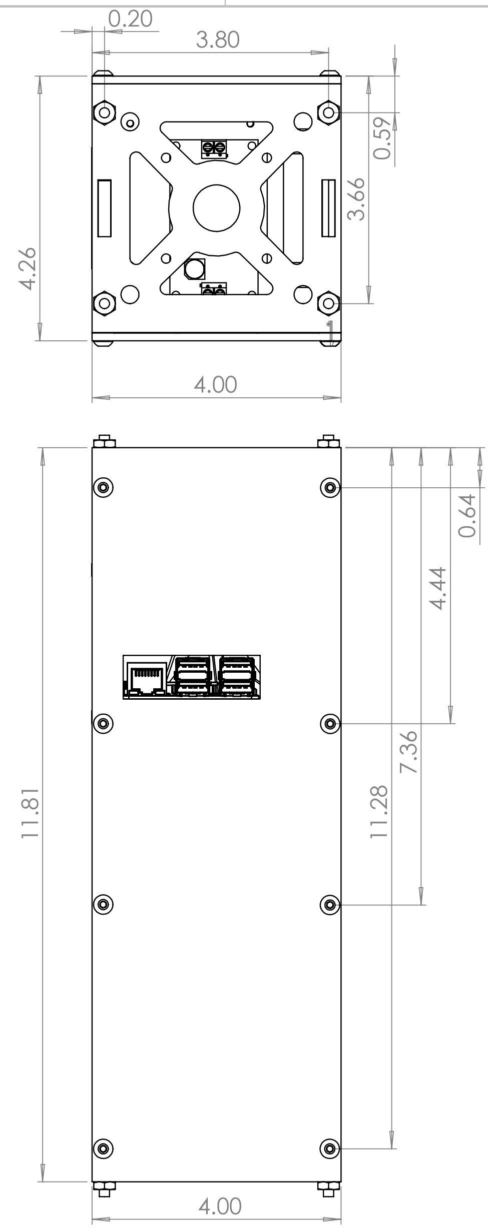
COMMENTS:

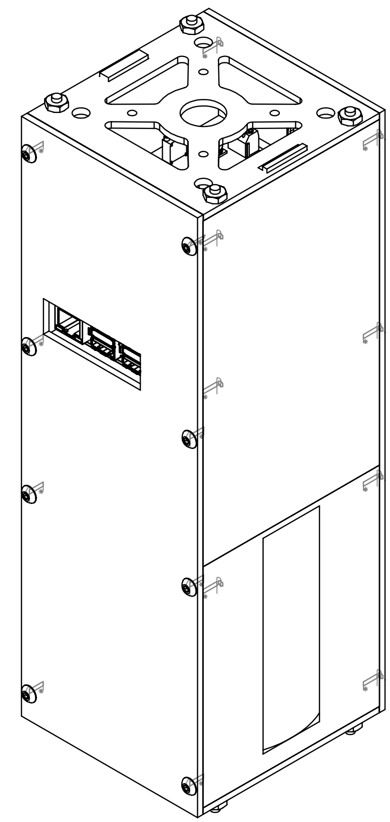
TITLE:

Tail Cone

SIZE **B** | DWG. NO. T_Tail_Cone_Composite_S_P54_v1 | REV

SCALE: 1:4 | WEIGHT:0.83 lbs | SHEET 1 OF 1





		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	McKenna Roberts	05/25/2018
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

Payload

SIZE	DWG. NO.	REV
B	T_payload_EP_A72_v5	
SCALE: 1:2	WEIGHT: 8.8 lb	SHEET 1 OF 1

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