UVic Rocketry Hyak-1 Technical Report

Team 117 Project Technical Report for the 2018 IREC

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The following document contains a technical summary of the operations and functions of Hyak-1, the experimental sounding rocket designed and manufactured by the UVic Rocketry Team. This rocket will compete at the 2018 Spaceport America Cup and launch to 30,000 ft. using a COTS motor as the propulsive power. Hyak-1 is the first of its design to be created by UVic Rocketry and is an extension of a previous rocket launched by the team. It is an 11.5 ft. rocket with a 4.6 in diameter, designed to reach supersonic flight. In the past year, the team has focused on rigorous testing to ensure the rocket remains stable at supersonic speeds. If successful, Hyak-1 will be the highest launched rocket for the UVic Rocketry team.

Nomenclature

A	=	surface area
AGL	=	Above Ground Level
APRS	=	Automatic Packet Reporting System
AR	=	Aspect Ratio
A_{ref}	=	reference area
ASTOS	=	Aerospace Trajectory Optimization Software
c	=	chord
CNC	=	Computer Numerical Control
HR	=	Homologous Recombination
N	=	number of moles
NACA	=	National Advisory Committee for Aeronautics
p	=	atmospheric pressure
PCB	=	Printed Circuit Board
PLA	=	Polylactic Acid
p_o	=	sea level pressure
R	=	universal gas constant
RF	=	radio frequency
SRAD	=	Student Researched And Developed
T	=	average fin thickness
UVR	=	UVic Rocketry Team
v	=	velocity of rocket
w	=	weight
λ	=	taper ratio
ρ	=	density

I. Introduction

UVic Rocketry (UVR) is made up of forty undergraduate students dedicated to furthering the aeronautics and aerospace fields. The team has previously launched three rockets at IREC 2016 and IREC 2017, all in the 10,000 ft. COTS category. In 2016, the team placed third, and in 2017 the team won the SDL payload competition. Through the success achieved at past competitions, the team has expanded and is now seeking to go higher and faster. Along with building the competition rocket, the team works on parallel projects to design and build supporting mechanisms to assist the rocket in further years. These projects include manufacturing a filament winding machine and developing a hybrid rocket engine. Amongst all the projects, UVic Rocketry places emphasis on engaging the community with aeronautics and spaces sciences; recently the club developed and implemented an outreach program for elementary schools.

II. System Architecture Overview

UVR is comprised of six technical teams that allow students to specialize in certain aspects of rocket development. The subdivisions include the following: aerostructure, in charge of the structure and airframe of the rocket; recovery, which focuses on the safe and controlled retrieval of the rocket by way of parachutes; payload, which designs and develops onboard science experiments; propulsion, responsible for sizing the motors and simulating launches; and finally avionics and telemetry. With this organizational structure, the team has been able to accomplish simultaneous projects while always working to the final objective: building a rocket capable of crossing the Karman line.

Hyak-1 is the most recent rocket designed and built by UVR. The internal layout can be seen in Fig 1. This rocket is designed to reach 30,000 ft. and fly at Mach 1.88. Each subsystem is critical in the successful launch and recovery of the rocket.

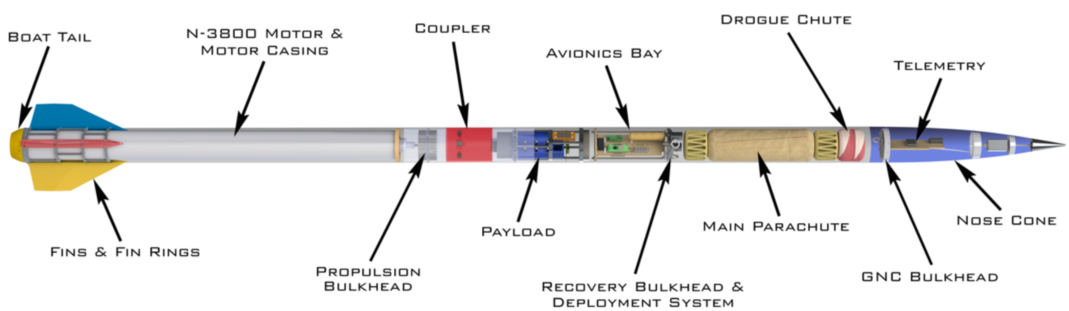


Fig 1. Overview of the rocket.

A. Aerostructure

Structurally, Hyak-1 consists of two carbon fibre fuselage segments joined by a fiberglass coupler with a foam core, a fiberglass nose cone, 3D printed fins laminated with carbon fibre, 3D printed boat tail, and various internal components. The rocket weighs 58.75 lbs (26.649 kg) at liftoff and stands 138.5 in (352 cm) tall. The rocket is structurally compliant with the following conditions as required by the Spaceport America Cup Rules and Requirements Document [1] and the UVic Rocketry Team.

1. Maintain structural integrity under all expected loadings and stresses during flight (powered flight, max Q, recovery deployment).
2. Possess an RF transparent window of at least 6" length and 360º overage at the top of the motor mount and position of greatest payload mass (both are at the same location on the rocket).
3. Contain no structural components made of low-temperature polymers, Public Missiles Ltd., Quantum Tube, or stainless steel.
4. Incorporate only load bearing eyebolts or U-bolts of the closed-eye, forged steel type.
5. Have launch lugs located at reinforced areas of the airframe and capable of supporting the vehicles weight.
6. Use coupling tubes that extend a minimum of one caliber in either side of the joint and prevent bending.
7. Include adequate venting to prevent pressure build-ups within the vehicle.

Exact expected loading conditions were used to determine the vehicle's structural integrity wherever possible, but in cases where uncertainty of the loading conditions was encountered, conservative worst-case scenarios and large factors of safety were employed. The following sections will describe each of the major structural components in detail, as well as key tests, simulations, and processes that were necessary to validate the design.

1. Nose Cone

The nose cone is primarily made of four layers of fibreglass with an aluminum tip. It has a full parabolic profile with a fineness ratio of 5 and a bluntness ratio of 5%. Fibreglass was chosen as the material as it provides a high strength-to-weight ratio while still maintaining the RF-transparency necessary for the avionics located in the nose cone to communicate with the ground station, while the aluminum cap adds strength to the tip of the nose cone, where aerodynamic heating and loading is most extreme. The parabolic profile was selected following several rounds of flight path simulation using ASTOS and RASAero software with varying nose cone profiles.

The nose cone was manufactured using a fibreglass strengthened gelcoat split mold, which is manufactured from an aluminum mold of the nosecone, turned down on a CNC lathe, (see Fig 2.)

Fig 2. Picture of nosecone skeleton.

Nose Cone Manufacturing Process

The outside profile of the nose cone was manufactured from two pieces of aluminum rod turned down on a CNC lathe. These two pieces are fastened together to form the complete nose cone male mold. A female split mold was then made using the solid aluminum nose cone mold and a combination of gel coat, epoxy, fibreglass, and carbon fiber. This split mold then served as the surface to perform the female layup of our fibreglass nose cone.

The nose cone layup process follows other layup procedures, with the main difference being the application method of fibres to the mold. Appropriate sizes of fibreglass were cut carefully and placed in the mold to start the epoxying process. Once epoxying was done, a layer of peel ply was put on the top of the fibre glass. Followed by breather cloth and vacuum bag which was sealed by the use of gum tape placed around the perimeter of the mold. Once the faces were sealed, the vacuum was started and the layup participants looked for leaks to ensure at least 80% vacuum relative to atmospheric pressure (see Fig 3).

Fig 3. Test layup of nosecone halves, shown under vacuum.

The two nose cone halves were then checked for any imperfections on the surface and cleaned using a pneumatic die grinder. Once approved, six rings of plywood were laser cut and friction fit to the halves to ensure concentricity (see Fig 4). And finally, a simple 2 strip layup process was done to bind the two halves of the nose cone which runs from the top to the bottom.

Fig 4. Picture of nose cone with laser cut rings.

2. Fins

The rocket's three fins were manufactured using carbon fibre-epoxy composite, laid up around a 3D printed male mold. They have a trapezoidal design and incorporate a diamond airfoil. Three fins were chosen to improve the efficiency of the rocket while ensuring stability. The fins utilize an eight-hole bolt pattern which allows them to be rigidly fastened to an aluminum structure inside the rocket fuselage using #6-32 machine socket head screws. This modular design allows for simple, convenient, and repeatable assembly of the fins to the rocket body. A fin is pictured below (see Fig 5) and full fin geometrical details are given in

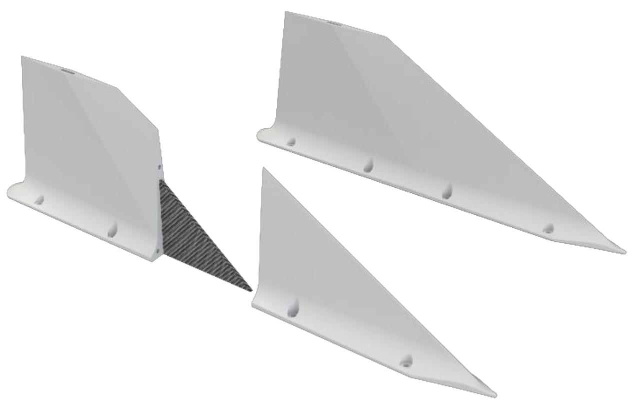


Fig 5. Two -piece PLA fin with 8-layers carbon fibre insert (2-layer carbon fibre wrap not shown).

Table 1. Fin design geometry.

Parameter	***Value***	***Unit***
Root Chord	13	in
Tip Chord	4.56	in
Sweepback Angle	60	deg
Semi-span	4.4	in
Root Thickness	0.5	in
Tip Thickness	0.3	in
Fairing Radius	0.8	in
Leading Edge Radius	0.0125	in

The fin mold is 3D printed in order to quickly and inexpensively iterate design parameters such as airfoil, fin shape and fin size. Due to limits imposed by 3D printer size, the fins are printed in two pieces separated halfway through the base chord. To increase the stiffness, 8-layer carbon fibre plates are cut into triangles and inserted inside a slot in the fin, as seen in Fig 5. To further strengthen the fin, two layers of carbon fibre are wrapped around the 3D printed mold. After curing, excess carbon on the fin is cut off using a pneumatic die grinder, holes are drilled, and any surface irregularities are sanded down in order to ensure the fin conforms to the required shape of the final product. This method of manufacturing takes approximately four days from start to end and can accommodate a wide variety of fin geometries without changing the manufacturing method. Because of the simplicity and ease of this method, it was possible to manufacture and test approximately 25 different fins in order to fully characterize the fins and gather the data needed to validate the final fin design. In addition to varying fin geometry, these iterations include different combinations of carbon fibre layering, heat-treatment, and carbon fibre plate inserts. Various fin iterations with nub attachments for testing purposes are depicted below in Fig 6.

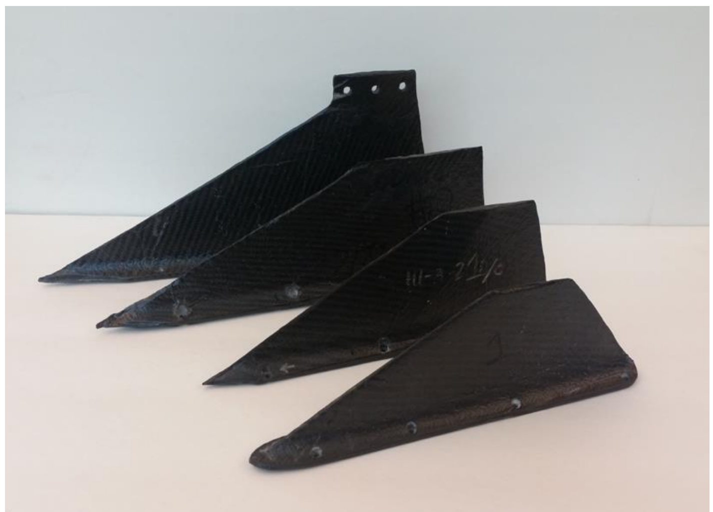


Fig 6. Test fins with stiffness test nubs. Left to right: H1-5, H1-4, H1-3, H1-2. The noticeable size difference between H1-5 and H1-4 versus H1-3 and H1-2 is iterating from one-piece to two-piece fins.

Due to the atypical method of manufacturing, the fin design has undergone extensive testing this year in order to ensure the fins do not fail under the extreme loading conditions the rocket will undergo on its supersonic trajectory to 30,000 ft. Specifically, two modes of failure were examined: failure due to aerodynamic loading on the fin, and failure due to aeroelastic flutter.

Aerodynamic Loading Analysis

Failure due to aerodynamic loading on the fin was approximated by considering the effect of a sudden, 10 m/s crosswind on the fin surface. Under these conditions, the critical failure mode will be bending due to lift, as the drag force is much smaller than the lift force, and the fin is structurally weaker in the axis that the lift force acts along. Aerolab is an aerodynamic simulation program that was used to extract the coefficient of lift of the fin as a function of the angle of attack and Mach number. The wind speed was used in conjunction with the rocket's speed to calculate the maximum expected angle of attack for a given rocket velocity. The lift equation was then used to evaluate lift force on the fins at varying rocket velocities. The lift force was calculated to increase with increasing velocity and was the largest at 568 N when the rocket was traveling at a speed of Mach 2, which is slightly above the expected highest velocity. A test was developed to find the maximum failure force the rocket fins are able to support when loaded in the direction of lift. This was done by suspending weights from the side of the fin in order to simulate a lift force, as shown below in Fig 7. Full fin strength test reports of several fin design iterations are included in Appendix II. The final fin design was tested three times and the weakest fin was able to support a transverse load of 687 N, giving it a safety factor against aerodynamic loading of 1.2 and ensuring that the fins will not fail due to bending even with the conservative assumptions used in the calculation approach.

Fig 7. H1-5-21 in the static-bending strength test apparatus. Weights are suspended in a tote bag at the tip of the fin.

Aeroelastic Flutter Analysis

Failure due to aeroelastic flutter was analyzed according to the method laid out in NACA TN 4197 [2]. This paper develops a simplified flutter criterion for lifting surfaces on missiles based on empirical data and compares a combination of geometrical parameters known as the "flutter factor" to the effective shear modulus of the fin's material to predict whether flutter will occur for a given fin design. The paper employs many simplifying assumptions, but offers an accessible and relatively accurate way of predicting the onset of flutter, especially since thorough vibrations/aeroelastic analysis in combination with flight testing is beyond our current team's knowledge and resources. As the fin is low aspect ratio, highly tapered, and supersonic, it lies within the scope of the NACA TN 4197 method, but a generous safety factor should be applied to account for the simplified nature of this approach. The flutter factor is described in Eq. (1) below, where all values are given in imperial units:

$$F_f = \frac{p}{p_o}\left(\frac{\lambda+1}{2}\right)\left(\frac{39.3(AR)^3}{\left(\frac{t}{c}\right)^3(AR+2)}\right) \quad (1)$$

Because the shear modulus for carbon over-wrapped 3D printed material is not readily available, the effective shear modulus was determined experimentally by measuring the torsional stiffness of the fin design and then calculating the corresponding effective shear modulus for an equivalent solid section. An image of the experimental stiffness test setup is shown in Fig 8 below. Full fin stiffness test reports of several design iterations are included in Appendix II. The final fin design was found to have a flutter factor value of 14.1 kpsi, and an effective shear modulus of 332 kpsi, which yields a safety factor of 5.88, according to the composite chart from NACA TN 4197 [2].

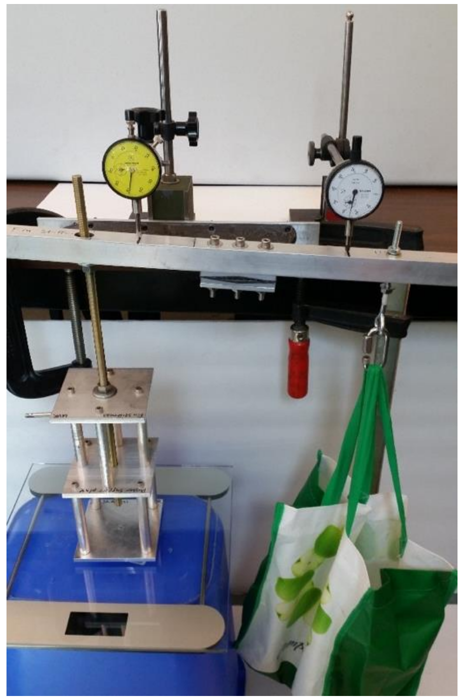


Fig 8. Apparatus of the torsional test. Weights are suspended from a tote bag 6 in from the center on a square tube mounted to the tip of the fin. A scale measures an equal and opposite force 12 in away provided by a threaded rod and nut system.

Additionally, the aerodynamic and flight simulation program RASAero was used to find the center of pressure of the rocket in order to guide the determination of the fin geometry and ensure stability. Additionally, RASAero was used to simulate aerodynamics and flight.

3. Coupler

Hyak-1's coupler consists of a Divinycell foam core, reinforced with eight layers of fibre glass, four on each side. Similar to the nose cone, fibreglass was selected for its RF transparency, allowing the rocket to meet the competition requirement for a beacon located at the greatest concentration of payload mass and at the top of the propulsion system. The number of layers is based on fastener tear-out data and the expected maximum tensile or compressive loading during powered flight and recovery of around 20 G. The coupler is manufactured by hand, using the wet layup technique, with a spare fuselage section used as the female mold. This ensures that the outside surface is smooth, and the coupler has a tight fit inside the carbon fiber fuselage to reduce bending and radial movement. To minimize this effect, the final coupler measures 18 in long, allowing 5.5 in of engagement in each fuselage section and a 7 in window of exposed section for beacon communication purposes.

Initial calculations regarding the forces acting on the coupler during flight showed a maximum force of 185 N in bending, and approximately 4650 N in compression. While the bending force is a result from only the aerodynamic drag, the compression force comes from the drag and the inertial forces produced during powered flight (See Fig 9.). Flight data from the previous year indicates that the rocket flew with an angle of attack of 3.6° at a velocity of Mach 0.9. Using this data as a starting point, while taking conservative estimations, and adding multiple factors of safety, one can derive the above forces. During the actual flight, a bending force of 178 N and a compression force of 4800 N is estimated to act on the coupler.

Before selecting the current composition, tests were run on the rigidity and resistance to fastener tear-out of the fibreglass-foam coupler, a pure fibreglass coupler, and an ABS coupler reinforced with fibreglass. ANSYS Workbench FEA simulations of a coupler from previous years, which was manufactured from Aluminum Alloy 6061 T6, were used as benchmarks for the tests. The results found in Appendix II demonstrate that the fibreglass-foam was the superior choice, as the pure fibreglass coupler was not rigid enough, while ABS-fibreglass coupler has a very low strength-to-weight ratio.

The drag forces on the coupler depend highly on the velocity and angle of attack as seen in Table 2. A higher angle of attack is expected at launch and lower velocities while at high velocities an angle of attack of around 2-3° is expected. Based on the recorded flight data of the rocket launched at the previous competition, an angle of attack of 3.6° at Mach 0.9 was calculated. Similar values are expected this year.

Table 2: Drag Force Data Table (Velocity and Angle of Attack).

Drag force (N) on the coupler at different velocities (Ma) and angles of attack (°)

Angle of attack (°) ***Velocity (Ma)***	***1***	***2***	***3***	***4***	***5***	***6***	***8***	***10***
0.25	14	28	42	56	70	84	112	140
0.5	56	113	169	225	281	338	449	561
0.75	127	254	380	507	633	759	1011	1262
1	225	451	676	901	1126	1350	1798	2243
1.25	352	704	1056	1408	1759	2110	2809	3504
1.5	507	1014	1521	2027	2533	3038	4045	5046
1.75	690	1380	2070	2759	3447	4135	5505	6869
2	902	1803	2704	3604	4503	5400	7190	8971

Using Hyak-1's rocket geometry, the mass, expected velocity, and thrust curves, which have been simulated using ASTOS, an aerodynamic drag coefficient of 0.8, atmospheric conditions at sea level, and a constant angle of attack of 3.4° throughout the flight, the acting forces on the coupler can be calculated. As seen in Fig 9, maximum forces are experienced at approximately 3.5 s. After the initial peak, overall forces decrease.

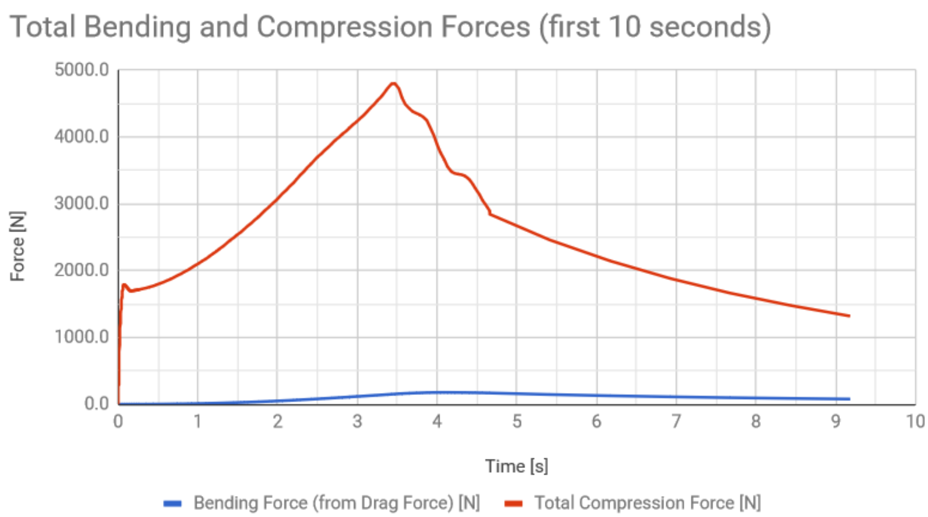


Fig 9. Bending and compression forces for first 10 s of flight.

Fig 10 below shows the composition of the compression forces. While the inertial forces are a result of the motor's thrust and the rocket's acceleration, which only occur during the firing time in the first 4.66 s, the compression forces due to aerodynamic drag occur until the rocket reaches apogee. The combined force reaches a maximum of 4800 N at 3.47 s after motor ignition.

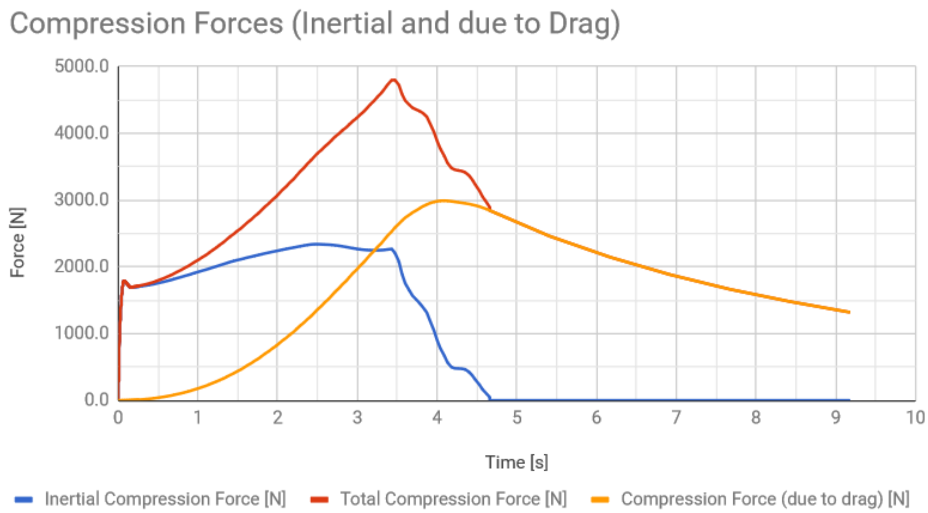


Fig 10. Compression forces for first 10 s of flight.

Since the layered structure of the coupler has anisotropic material properties, the coupler needs to be experimentally tested to determine factors of safety. Two tests were designed, one for pure bending and one for pure compression, but due to inaccessibility of the compression testing machine, only the bending test has been performed. At first, the bending test was designed to allow for deflection measurements, which can then be used to calculate a Young's Modulus, but the results showed that the compliance and error accumulation of the setup does not allow this. The fixture is not rigid enough and due to the coupler being relatively stiff, most of the measured deflection comes from the mounting structures deflections, see Appendix II. However, loading the unsupported end of the coupler with up to 80 kg with no sign of coupler failure and only expecting a load equivalent to 20 kg results in a safety factor of over 4 for pure bending. To put a safety factor onto the compression loading an extensive research was performed including comparisons between composites with and without foam to aluminum, steel and plastics. Then an analysis in ANSYS was performed using the isotropic materials and then compared to the results of the researched papers. The result is a safety factor in compression ranging from 1.8 to 4.3 which is sufficient due to the conservative assumptions initially made. Finite element analysis was used to confirm that the coupler's geometry and design could withstand buckling. Even though the exact material properties are unknown, the coupler will need to experience a force above 60 kN to buckle in the first mode between the bulkheads which gives a safety factor greater than 12.

B. Recovery

Hyak-1 is equipped with a two-event recovery system consisting of a drogue parachute and main parachute. The purpose of this system is to prevent injury or property damage, retrieve the rocket’s payload, and allow the rocket and its components to be reused. The rocket is compliant with the following conditions as required by the Spaceport America Cup [1] and UVic Rocketry Team:

1. Have a dual-event recovery system, including an initial drogue parachute deployment, followed by a main parachute deployment
2. Execute a drogue parachute deployment near apogee, and reduce the rocket's descent rate to between 75-150 ft./s [23-46 m/s]
3. Execute a main parachute deployment no higher than 1500 ft. AGL, reducing the vehicle's velocity to less than 30 ft./s [9 m/s]
4. Implement adequate protection to prevent hot gases from damaging recovery components
5. Include swivel links to all parachutes to alleviate torsion on components
6. Sufficiently differentiate each recovery event by means of parachute colouring and/or markings
7. Include redundant recovery system electronics
8. Sufficiently pass all ground test demonstrations before launch

The first event, the drogue parachute deployment, occurs at the apogee of the rocket's flight. At apogee, rapid CO_2 expansion will pressurize the upper fuselage, leading to the ejection of the nose cone and drogue parachute. Small pressure equilibration holes are drilled into the fuselage to prevent premature nose cone-ejection due to the decreasing atmospheric pressure as the rockets gains altitude. The drogue parachute will reduce the descent rate of Hyak-1 to approximately 120 ft./s [36 m/s]. This prevents significant drifting and eliminates tumbling as the rocket falls, as well as reduces the impulse experienced by the rocket during main parachute deployment. Finally, at 1,500 ft. AGL, the pyrotechnic release link will decouple causing the drogue parachute to pull the main parachute out of the nose-end of the fuselage, causing main parachute deployment. Under the main parachute, terminal velocity of Hyak-1 will be approximately 11.5 ft./s [3.5 m/s].

1. Drogue Parachute

The drogue parachute is a black and blue, SRAD parabolic cup parachute manufactured by UVR. It is comprised of durable 1.9 oz nylon ripstop, with four shroud lines, and a swivel link. The drogue parachute itself is 0.5 m in diameter with a total surface area of 0.2 m^2. The drogue parachute's coefficient of drag was tested and measured to be approximately 1.1, giving the rocket a terminal velocity of approximately 120 ft./s under drogue.

Using a 0.518 kg weight, the drogue parachute was measured to have a descent velocity of 6.1 m/s. Calculations for drogue parachute coefficient of drag are as follows using Equation 2.

$$Coefficient\ of\ Drag\ (c_{Drag}) = \frac{2*w}{\rho_{air}*v^2*A_{ref}} \quad (1)$$

$$CD = \frac{2(0.518\ \text{kg}*9.81\ \text{m/s}^2)}{1.2\ \text{kg/m}^3*(6.1\ \text{m/s})^2*0.2\ \text{m}^2}$$

$$CD = 1.1$$

Next, the terminal velocity of Hyak-1 can be approximated using the coefficient of drag calculated above and Equation 3.

$$Velocity\ (v) = sqrt\left(\frac{2*w}{\rho_{air}*c_{Drag}*A_{ref}}\right) \quad (3)$$

$$v = \sqrt{\frac{2*17\ \text{kg}*9.81\ \text{m/s}^2}{1.2\ \text{kg/m}^3*1.1*0.2\ \text{m}^2}}$$

$$v = 36\ \text{m/s} = 120\ \text{ft./s}$$

A terminal velocity of 120 ft./s [36 m/s] is within the range of 75-150 ft./s [23-46 m/s] recommended by the Spaceport America Cup: Intercollegiate Rocket Engineering Competition Design, Test, & Evaluation Guide. [1]

2. Main Parachute

The main parachute is orange and grey, SRAD toroidal parachute manufactured by UVR. It is made of 1.0 oz nylon ripstop sewed using techniques pertaining to strength (see Appendix II). It has a diameter of 3.65 m and a reference surface area of 10.5 m^2. At 1500 ft., the main parachute will deploy via the pyrelease (*See section 7. Pyrotechnic Release Link*) and fall at a velocity of 13ft./s [4.1 m/s]. The main parachute is packed into a custom 2-piece bag made of flame resistant Nomex, shown in Fig 11. This material will shield the heat sensitive nylon ripstop from the pyrotechnics and prevent damage to the main parachute. At main parachute deployment, the upper bag will pull away via the drogue parachute, and the lower half of the bag will stay attached to the rocket, leading to a tangle-free main deployment.

Fig 11. Custom 2-piece parachute bag enabling halves to split during main parachute deployment.

The terminal velocity of Hyak-1 under the main parachute can be estimated using Equation 3.

$$v = \sqrt{\frac{2 * 17\ \mathrm{kg} * 9.81\ \mathrm{m/s^2}}{1.2\ \mathrm{kg/m^3}\ * 2.2 * 10.5\ \mathrm{m^2}}}$$

$$v = 3.5\ \mathrm{m/s} =\ 11.5\ \mathrm{ft/s}$$

A terminal velocity of 11.5 ft./s [3.5 m/s] will reduce Hyak-1's descent rate sufficiently to prevent damage upon ground impact. It is below the required 30 ft./s [9 m/s] recommended by the Spaceport America Cup: Intercollegiate Rocket Engineering Competition Design, Test, & Evaluation Guide [1].

3. CO_2 Deployment Mechanism

The CO_2 deployment mechanism, shown in Fig 12, uses a small amount of black powder to force a puncture pin to release the compressed gas from a COTS CO_2 cylinder. The black powder is loaded onto a Delrin cup to which the steel puncture pin is attached. This is then loaded into an aluminum enclosure and attached to an aluminum bulkhead.

Fig 12. CO_2 ejection system. CO_2 cylinders threaded into puncture mechanism from below the bulkhead.

When attached, a spring holds the pin up in the enclosure above an opening for a 45 g CO_2 cylinder where, upon black powder detonation controlled by e-matches, the pin is forced down to puncture the seal on the tank. The pressure released from the CO_2 cylinder forces the nosecone and drogue parachute to be ejected by breaking 3 nylon shear pins and overcoming the frictional force. The aluminum enclosure includes eight gas ejection ports which will allow the gas from CO_2 cylinder and the black powder detonation to safely escape without damaging any internal components.

This ejection system is designed with two major redundancies. While the force from one CO_2 tank is sufficient to cause deployment, two identical but separately detonated tanks are attached to the bulkhead to provide a mechanical redundancy. The detonation of the main CO_2 tanks is triggered by an e-match that is connected to two separate control boards, allowing for electrical redundancy, while the secondary tank is attached to one control board, as depicted in Fig 13 below.

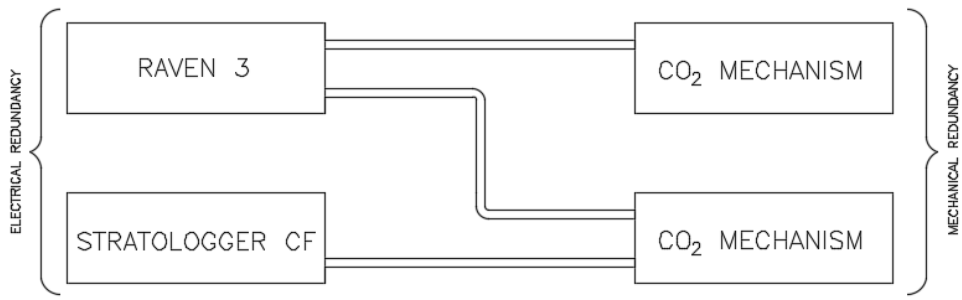


Fig 13. Recovery main and redundancy control path.

This ejection system has undergone multiple tests to ensure it functions properly. A variety of incremental tests were conducted to ensure the force from the CO_2 ejection would be sufficient to both break the three shearing pins holding the nosecone in place and to fully eject the nose cone and drogue parachute. The black powder puncturing mechanism for the CO_2 tanks was tested in a vacuum tube to ensure the detonation would occur even at the lower pressures and high altitudes expected during recovery deployment. In addition, the wiring and electrical controls were tested to ensure the system would function properly and that the redundancy deployment would work in case of an error in the primary system. Refer to Appendix II for all test reports.

Total pressure in recovery fuselage after CO_2 puncture using Equation 4.

$$Pressure\ (P) = \frac{nRT}{V} \quad (4)$$

$$P = \frac{45\text{ g } CO_2 * 8.5\text{x}10^{-5}\text{ m}^3\text{ atm K}^{-1}\text{mol}^{-1} * 300\text{ K}}{44\text{ g } CO_2/\text{mol} * \pi\left(\frac{0.1143\text{ m}}{2}\right)^2 * 0.66\text{ m}}$$

$$P = 3.85\text{ atm} = 56.6\text{ psi}$$

Force acting to eject the nose cone is calculated using Equation 5.

$$Force = PA \quad (5)$$

$$F = 56.6\text{ psi} * \pi\left(\frac{4.5}{2}\right)^2\text{ in}^2$$

$$F = 830\text{ lbf}$$

The force acting on the nose cone is in excess than required due to the fact that all the CO_2 will not deploy instantaneously.

4. Pyrotechnic Release Link

The main parachute deployment is triggered by detonating a small amount of black powder to uncouple a pyrotechnic release link, also known as the pyrelease. The pyrelease was designed and manufactured in-house by UVic Rocketry and has been validated by extensive testing in ground tests and in previous launches.

The pyrelease consists of two main components (see Fig 14): the main aluminum housing with a removable back plate, and the plunger piece, which slides into the housing. The plunger piece is made entirely of hardened steel to resist warping, except for the Delrin plunger, which was chosen for its low coefficient of friction. The notches in the sides fit quick links which are secured in position by the pins on the plunger piece. With the two pieces together and the quick links in place, the back plate can be removed to fill the main chamber with 0.5 g of black powder and insert the electronic igniters (e-matches). The back plate is secured to the main housing with four #4-40 fasteners. Two small holes in the ends of the plunger pins are threaded and tied with fishing line to prevent the pyrelease from separating early, which would cause the main parachute to deploy prematurely. The two pieces are connected by a short piece of Kevlar rope (not pictured) sewn tightly around the loop in the back plate and the front plate of the plunger piece. This section of rope is threaded through one of the quick links so that it does not fall from the rocket upon detonation.

Fig 14. Pyrelease link components: main housing with attached back plate (left) and plunger piece (right).

The pyrelease mechanism is activated at 1500 ft. AGL. The detonation is triggered by one or both of two e-matches that are connected to separate control boards, allowing for electrical redundancy. The Raven 3 board activates when the barometrically-determined altitude is less than 1500 ft., altitude is decreasing, and upward velocity is less than 400 mph (which enables Mach immunity). The StratologgerCF board is activated by barometric altitude less than 1500 ft. AGL and decreasing. Since the two boards are made by different manufacturers and have separate sensors, this is sufficient for electrical redundancy (see Fig 15).

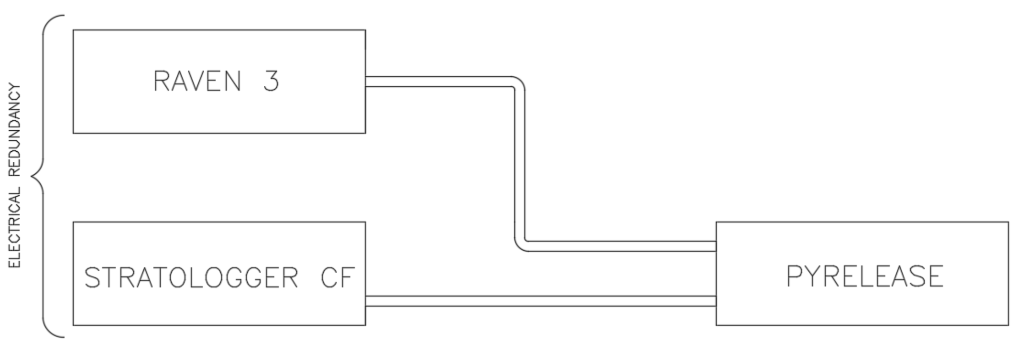


Fig 15. Pyrelease electrical redundancy control path.

C. Payload

The Hyak-1 payload carries a data acquisition module and a proof of concept ultraviolet sterilization unit on a custom-machined aluminum sled. The payload unit follows Space Dynamics Laboratory Payload Challenge and Experimental Sounding Rocket Association regulations, weighing approximately 9.86 lbs, and is entirely replaceable by non-functional mass. Space Dynamics Laboratory and Spaceport America Cup requirements are as followed [3]:

1. Weight (8.8 lbs or 4.0 kg minimum)
2. Removable from the rocket
3. Not affect the flight of the rocket if removed and replaced with ballast
4. Totally recoverable
5. Not contain any live, vertebrate animals
6. Not contain significant quantities of lead or other hazardous materials
7. CubeSat form factor (BONUS)

Compliance with requirements 1 – 6 was completed. Requirement 7 (CubeSat form factor) was not completed as restricting the shape of our payload to a square footprint would hinder the experiment greatly, due to the minimum commercially available size of sterile petri dishes, and the requirement for adequate surface area for colony growth to obtain statistically significant results.

The following sections will detail the purpose and experimental design of the payload, the testing procedures followed in laboratory and in field, the mechanical components of the system, and the electronic control system.

1. Experimental design and purpose

RecA-mediated homologous recombination (HR) is a ubiquitous DNA repair mechanism among prokaryotes. Orthologous proteins such as Rad51 direct HR in eukaryotes. In *Saccharomyces cerevisiae*, *rad51* knockout strains are sensitive to DNA damaging agents. This sensitivity is complemented by transformation with an expression plasmid of the *Escherichia coli recA* gene [4,5]. This study is investigating the degree to which dual-stress spacecraft sterilization affects these conserved DNA repair mechanisms. Our pilot study determined that exposing *Bacillus* species to deep UV radiation during the high acceleration loading of sounding rocket launch decreased viability more than either stress alone, suggesting that the combined stresses of launch acceleration and UV-induced DNA damage reduced the ability of our specimens to adequately respond to either insult. The Hyak-1 launch in June of 2018 will build on these data by exposing *S. cerevisiae* strains with disrupted Rad51 function, and strains rescued with *E. coli* RecA, to a modular low-output UV sterilization system through accelerations of up to 18.4g and characteristic vibrational loading. Preliminary ground tests showed an average 2% increase in survival in control BY4741 relative to the *rad51* knockout strain when exposed to the UV system at 275 nm. Furthermore, a 24% percent increase in survival in Δ*rad51* yeast expressing the *E. coli* RecA protein was observed when exposed to 275 nm UV light. This supports the assumption that defective HR is the cause of the reduced viability of Δ*rad51* yeast and demonstrates that the *E. coli* RecA protein can partially function in the yeast homologous recombination pathway. The results of the flight tests, available in June 2018, will determine if the Rad51-mediated homologous repair pathway is significantly affected by the acceleration stress inherent to a spacecraft launch, while allowing characterization of the mechanism of the RecA-rescued pathway. Similar responses to the dual stresses of launch and UV-directed DNA damage between BY4741 and the RecA-rescued Δ*rad51* yeast mutant may suggest that the mechanism of interaction of Rad51 with other components in its pathway is conserved between domains of life – this provides a potential target against which to develop effective broad-spectrum sterilization techniques.

2. Laboratory and field testing procedure

The following section will briefly summarize the testing procedures followed for laboratory and field experiments.

<u>In-laboratory control testing</u>

Cultures of four *Saccharomyces cerevisiae* strains (BY4741 Δrad51 carrying PVT103-L*recA*, BY4741 Δrad51 carrying PRS425, BY4741 carrying PVT103-L*recA*, BY4741 carrying PRS425) are each plated onto three 35 mm petri dishes with simple defined media lacking leucine. Plates are placed into a 3D-printed UV module with a disc of sterile fused quartz in place of a polystyrene lid to allow transmittance of UV light. Each UV-module contains two

UV LEDs, rated at 20 mA of current and 24 V, which are controlled by a NUCLEO board flashed with custom software and an Arduino IDE. Each test culture is exposed to 245 nm UV light or 275 nm UV light for 20 minutes, mimicking the approximate time of flight. The system will operate on a 50% duty cycle. A control culture not exposed to any UV light is also included. Cultures are incubated at 30°C until a lawn of growth is visible on control plates.

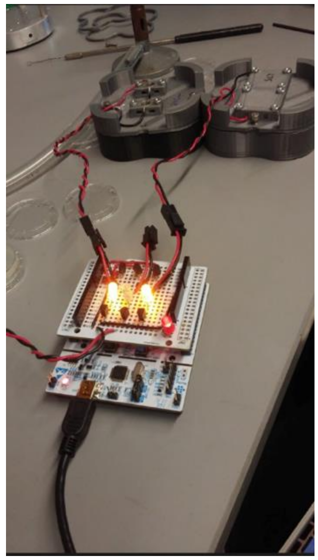


Fig 16. Lab testing setup on the prototype board, demonstrating safety LEDs.

<u>In-field launch test</u>

The 3D-printed UV modules carrying the sample cultures will be loaded onto the machined aluminum sled and fastened into the rocket. The UV system will be initiated by detection of launch acceleration and remain on for 20 minutes. Upon recovery of the rocket, each sample will be incubated overnight at 30°C.

3. Sterilization module data

Components used in the sterilization module were rigorously characterized to ensure well-constrained results. 1/8 in thick quartz discs were used to contain the samples, as the polystyrene lids of the petri dishes are opaque to UV light. The spectrum of commercial grade fused quartz can be seen below.

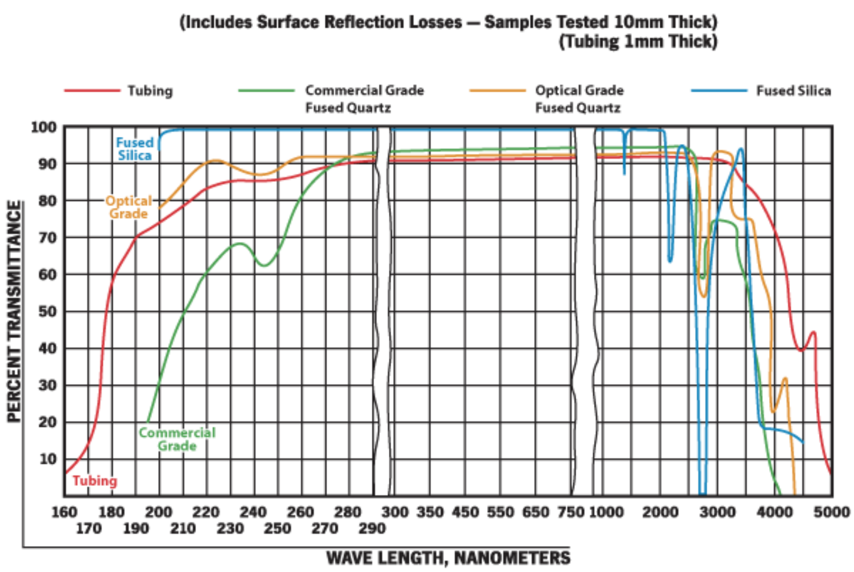
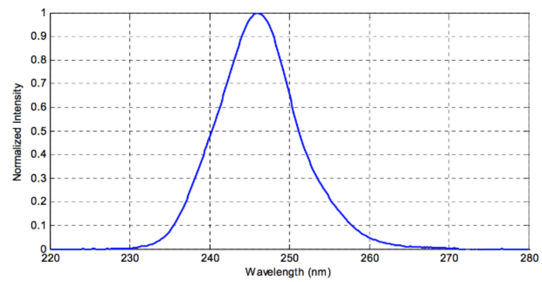
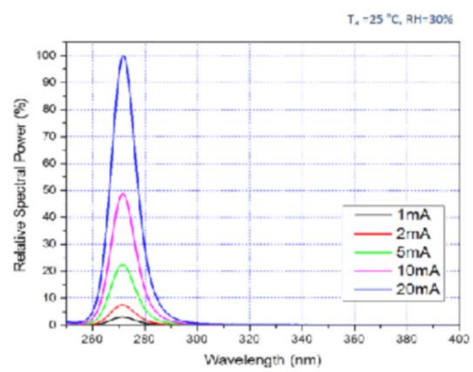


Fig 17. Percent transmittance of various grades of fused quartz products [6].

The ultraviolet LEDs used to induce DNA damage were commercially bought and controlled by a PCB board populated in-house. Details of the control system can be found in section C.10. The wavelength, manufacturing information, part number, and spectral distribution of the UV LEDs can be found below.

Table 3. Specifications for UV LEDs, including spectral distribution. Spectral distribution for UVTOP245 provided by Sandhouse Design [7]. Spectral distribution for MTSM275UV-F1120 provided by Marktech Optoelectronics [8].

Wavelength	*Manufacturer*	*Part Number*	*Spectral Distribution*
245 nm	Gamble Technologies	UVTOP 245	
275 nm	Marktech Optoelectronics	MTSM275UV-F1120	

4. Payload housing and sled design

The aforementioned PLA UV modules are designed to carry four petri dishes inside the rocket. They are manufactured using 3D printing to produce their precise geometry at a low cost and compact form factor. The modules are not designed to bear load greater than the weight of the petri dishes. The specific modular design was chosen to make preparing the microbiological samples for flight convenient. The lids of the UV modules screw on tight to minimize any exposure to outside elements. Mounting features on the lids for the UV LEDS were individually designed to create a snug fit for the LED and a uniform light distribution.

A rigidity test was conducted on the 3D printed PLA UV modules to ensure that they would remain structurally sound under various environmental conditions. As the glass transition temperature of PLA filament is listed as 50˚C, this was of some concern, as temperatures at the launch location often approach 47°C. These are not load-bearing components, so the only risk of deformation is compromising light distribution to the petri dishes containing our experimental specimens.

One entire module was placed in an EMD Millipore field incubator and held at 45°C for 4 hours. A thin insert was also placed in the incubator for the same duration. Neither insert nor module exhibited any significant deformation when removed from the incubator (see Appendix II).

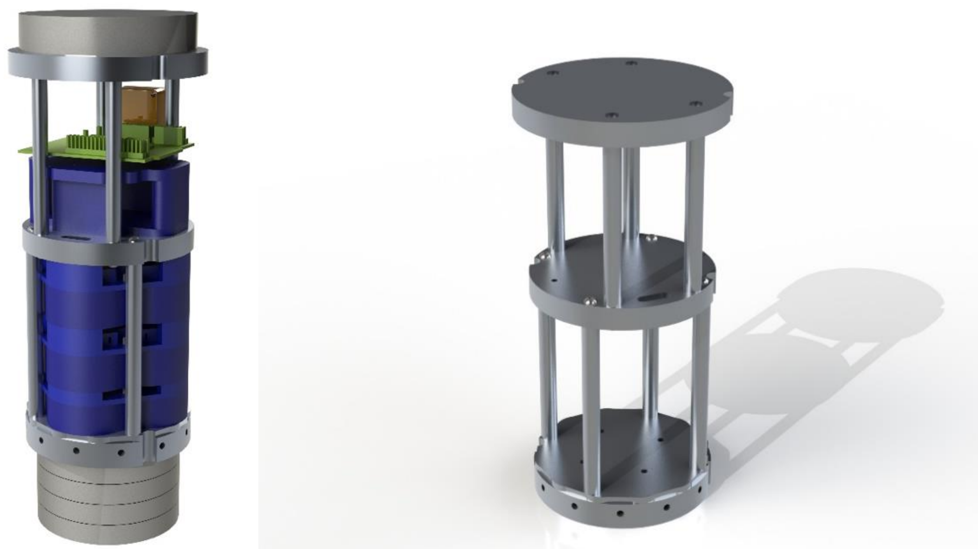


Fig 18. Render of machined aluminum sled (top left) and sled carrying PLA UV boxes, battery, PCB, and ballast.

The structural component of the payload sled design is made entirely out of machined aluminum. It is comprised of two sections. The lower section, called the box module, houses the PLA UV modules and the upper electronic module contains all the components used to run the experiment and perform data acquisition. The structural sled is comprised of three plates that were CNC milled, separated by two different sets of posts which were machined on a manual lathe.

The payload structure slides into the top of the coupler and sits between the coupler and recovery fuselage. The lower payload plate acts as the payload bulkhead connecting the coupler to the recovery fuselage. It applies the same standard of twelve radial holes with set screws that create the necessary engagement to hold the fuselage in place. With the lower four posts attached to the bulkhead, the PLA UV modules slide down and stack on top of each other. The circular cut-outs on the lids create a snug fit and the middle plate, once screwed on, fully constrains the UV modules. The concept behind this system was to provide a simple way to load and unload yeast samples. Since there are no fasteners between the UV modules and the payload structure, it is very quick to set-up and retrieve.

Attached to the middle plate are 3D printed parts to house the electrical systems. Directly screwed on to the plate is the battery housing. On top of that, the Nucleo PCB is held on by three screws to minimize the vibrations acting of the sensors. To measure the rocket flight forces there is an independent data acquisition device called a Slam Stick X (MIDÉ) which is an industrial vibrations sensor and accelerometer that can precisely log flight forces. The Slam Stick X incorporates a 3-axis piezoelectric accelerometer, temperature sensor, and pressure sensor. It can operate at a high sample rate, up to 20 kHz, allowing us to accurately monitor the entire flight duration. The top plate seals the structure from the recovery section as well as centers the electronic section with the larger diameter recovery fuselage.

The remaining weight requirements were met by screwing steel ballast to the bottom plate which simultaneously creates a weight beacon near the bottom of the payload sled. The steel ballast was machined in house on a CNC Lathe from round stock to be both volume and cost effective

To model the structural capabilities of the payload sled, the aluminum components as well as ballast were modelled in SolidWorks and simulated in ANSYS using a downward acceleration of 20 g and Von Mises failure criterion. The results can be seen in Fig 19.

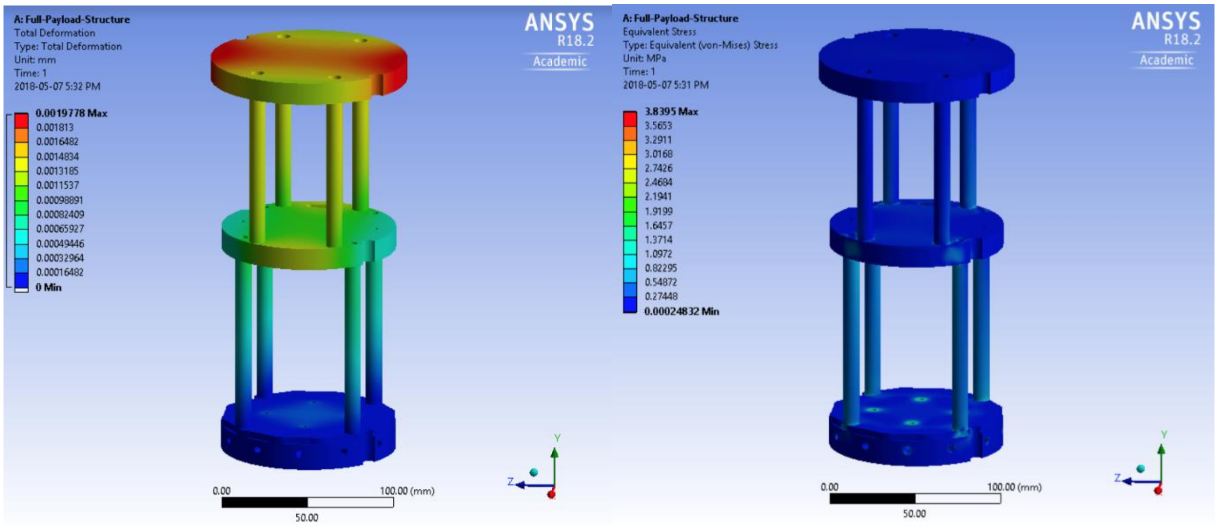


Fig 19. Finite element analysis demonstrating total deformation (top left) and equivalent stress (top right) courtesy of ANSYS R18.2

The modelled structure can be seen to have a very generous factor of safety through all possible failure modes. The first failure mode would be the yielding of the thread holding the steel ballast onto the bottom plate. This would cause the ballast to detach from the structure. Since this does not affect the function of the payload sled, it is not deemed to be a critical failure point. The next failure mode would be the buckling of the lower posts which would occur near 85 kN of loading, providing a factor of safety of 850. Through these results it was concluded that the payload sled will not critically fail during launch conditions.

5. Electronic control system Electronic control system

The in-flight experiment uses a STM32 Nucleo with a student designed daughter board to control the experiment.

UVR Flight Firmware

STM32 based system for rocket flight data recording and payload UV-sterilization experiment. Used in UVic Rocketry's custom flight hardware at IREC 2017/18.

Overview

This software is written for the STM32 Nucleo-L053R8. The flight board is powered on a 7.4 V lithium polymer battery, which is then regulated to a constant 24 V to power the UV LEDs.

Peripheral hardware

The Nucleo interfaces with a custom PCB containing sensor, data-logging, voltage regulation and control hardware.

- BMP280 temperature + pressure sensor
- BNO055 low-G accelerometer + orientation fusion sensor
- ADXL377 high-G accelerometer
- W25Q128FV flash memory module

Firmware

The hardware control follows a basic state machine model:

1. [STARTUP] reads the debug jumper pin on power-up, and transitions to [DEBUG] or [IDLE] depending on the reading of the jumper pin [1=DEBUG, 0=IDLE].
2. [DEBUG] is a special power-up mode used to test the external hardware and download the contents of the flash memory to PC via the GUI client (see below). It is not used for flight.

3. [IDLE] polls the external hall effect sensor for a magnetic activation signal. Transitions to [INIT_FLIGHT] on detection of the activation signal.
4. [INIT_FLIGHT] activates the external sensors and clears the data-log memory. Automatically transitions to [PAD].
5. [PAD] polls the sensors for a z-acceleration or altitude change corresponding to launch. Upon detection of launch, activates the UV-sterilization experiment and transitions to [FLIGHT].
6. [FLIGHT] continuously writes sensor readings to the flash memory. Upon detection of landing, transitions to [LANDED]
7. [LANDED] terminates data-logging and UV-sterilization experiment.

Utility program

The custom flight software includes a Windows GUI utility program to (1) view the flight sensor readings in real-time and (2) download the contents of the flash memory to the PC. The flight hardware must be powered up in [DEBUG] mode.

D. Propulsion

Hyak-1 uses an N-Class commercial-off-the-shelf (COTS) solid motor mounted into the lower fuselage section. In accordance with the IREC Rules and Requirements and the IREC Design, Test, and Evaluation Guide documents [1], Hyak-1 must:

1. Not exceed an installed total impulse of 40,960 Ns
2. Have a launch rail departure velocity exceeding 100 ft./s
3. Maintain a static margin of at least 1.5 to 2 body calibers
4. Avoid a static margin of greater than 6 body calibers

Hyak-1 will launch from the 17 ft. ESRA provided launch rail and launch control system, and therefore will comply with all launch rail requirements.

Fig 20. Hyak-1 propulsion cross-section.

The selected motor is the CTI N3800 motor, providing a total impulse of 17631.7 Ns, a burn time of 4.65 s, and a peak thrust of 1145.9 lbs, shown in Fig 21 [9]. Since only one motor will be loaded in Hyak-1, the installed total impulse is less than 40,960 Ns. The motor is held in place by the propulsion bulkhead and fin mount. The motor mount consists of two components, the propulsion bulkhead, and the fin mount. Based on the 17 ft. launch rail and locations of the launch lugs, Hyak-1 achieves a launch rail departure velocity of 111.5 ft./s, with a minimum static margin of 2.4 body calibers at takeoff, and a maximum of 5.1 calibers. Fig 22. shows changes to the static margin during flight.

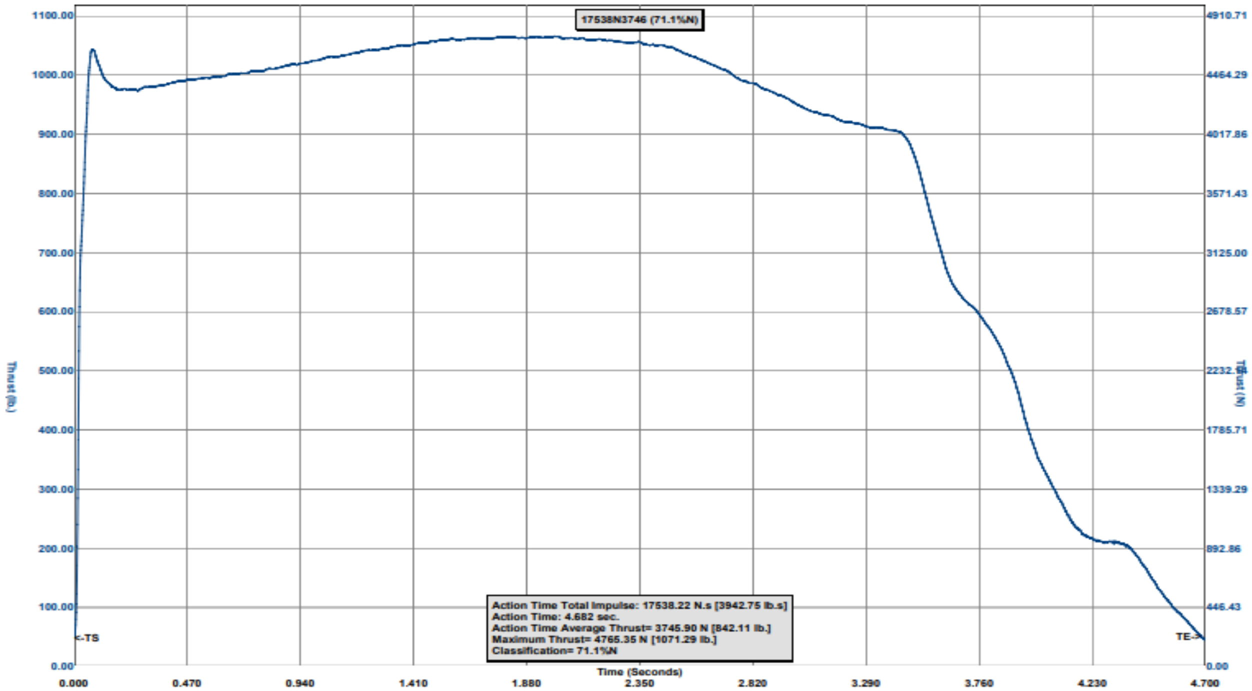


Fig 21. N3800 Thrust Curve [9].

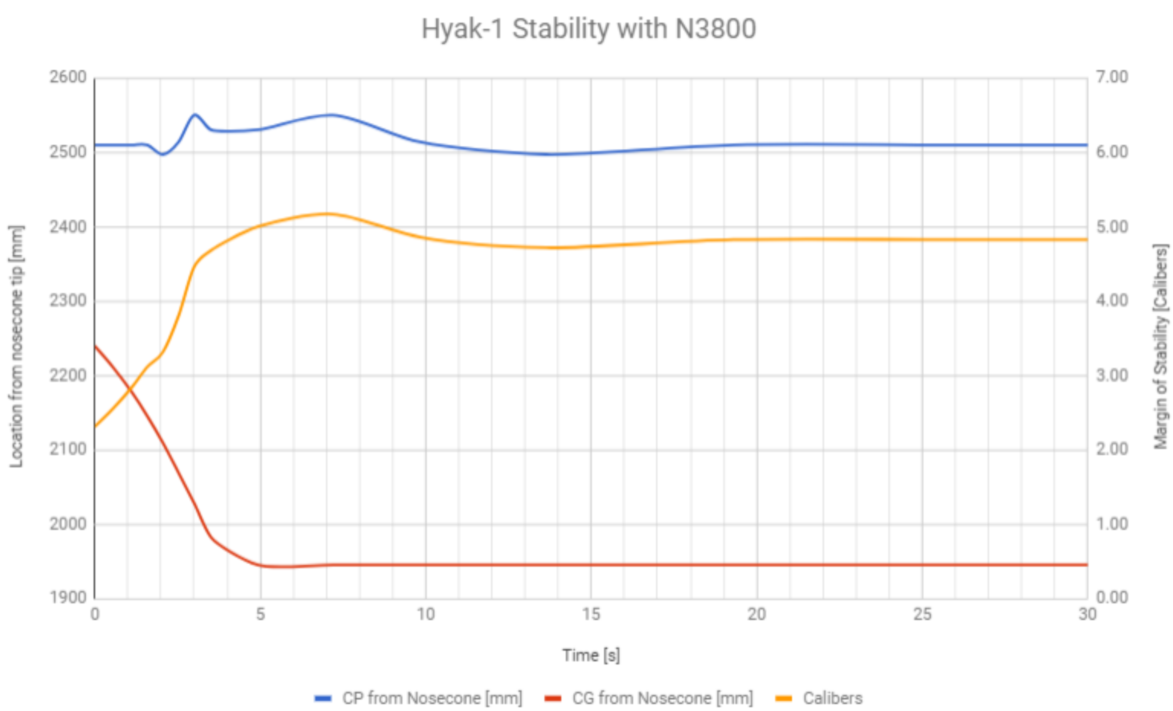


Fig 22. Plot showing the margin of stability during flight.

6. Propulsion Bulkhead

The propulsion bulkhead is a simple bulkhead located in the lower section of the coupler. The purpose of the bulkhead is to prevent the motor from becoming dislodged from the fuselage. The forward enclosure of the motor will be attached to the bulkhead using a threaded rod. Two failure methods exist for this bulkhead, the first is the yielding of the aluminum, and the second is the lower fuselage tear-out. Fig 23 shows the FEA results of the propulsion bulkhead during the main parachute deployment, which is when the bulkhead experiences the highest load. With the bulkhead manufactured from 6061-T6 aluminum, the safety factor is found to exceed 20. A safety factor of 17 was found for the carbon fibre tear-out, assuming 50% radial engagement.

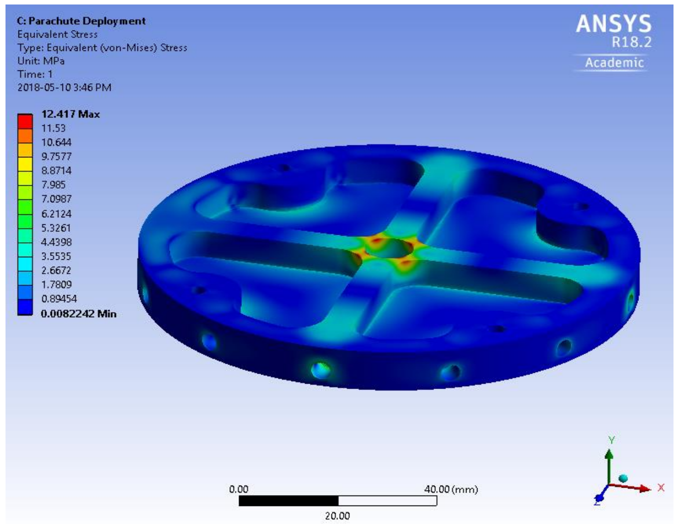


Fig 23. Propulsion Bulkhead Von-Mises Stress determined using ANSYS.

7. Fin Mount

The fin mount consists of three fin mounting rings and a thrust ring as shown in Fig 24. The thrust ring is designed to transfer the thrust of the motor from the aft retaining ring to the bottom of the lower fuselage. The fin mounting rings are connected to the thrust ring by simple posts of varying lengths between each ring. This is done to ensure correct fin orientation. Unlike previous rocket iterations (MVP-1, MVP-2, and Skookum-1), fin rails were not used due to space restrictions. Since the lower fuselage is only slightly larger than the motor casing, a different solution was required.

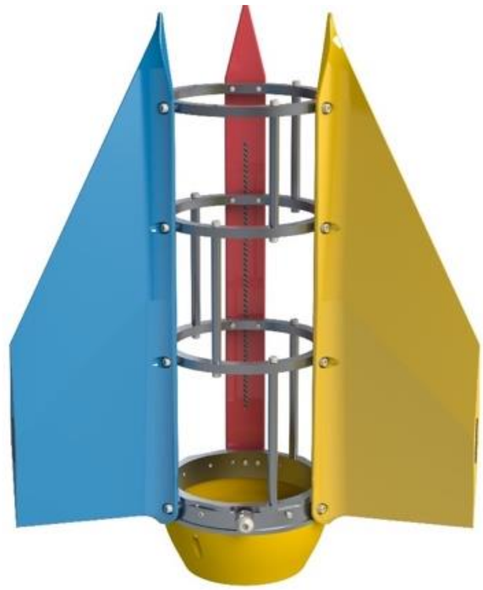


Fig 24. Fin mount with attached fins.

No explicit testing was performed on the fin mount, as the failure modes existed in the lower fuselage or the fins themselves, both of which underwent extensive testing.

8. Launch Lugs

The launch lugs are used to guide the rocket off the rail in the very beginning of the flight. This allows the rocket to build up enough speed for the fins to provide stabilization. The launch lugs are small delrin cylinders fastened to the thrust ring and propulsion bulkhead with ¼-20 fasteners. It is important that these launch lugs are strong enough to support the rocket on the launch rail, as a failure will prevent initial stabilization of the rocket. The launch lugs have a safety factor of 8.8, assuming one lug holds the entire rocket weight.

9. Performance Analysis

ASTOS, RASAero II, and OpenRocket were used for trajectory calculations. RASAero was used to determine the margin of stability and the aerodynamic coefficients of Hyak-1 to optimize the fin and nose cone shape. These aerodynamic coefficients were then used in ASTOS to perform a trajectory analysis. Because ASTOS is a very detailed and complex program, OpenRocket was only used to confirm the results. Simulations were done using a launch angle of 84° at an altitude of 4,595 ft. above sea level. The resulting simulations from each software can be seen in the following figures.

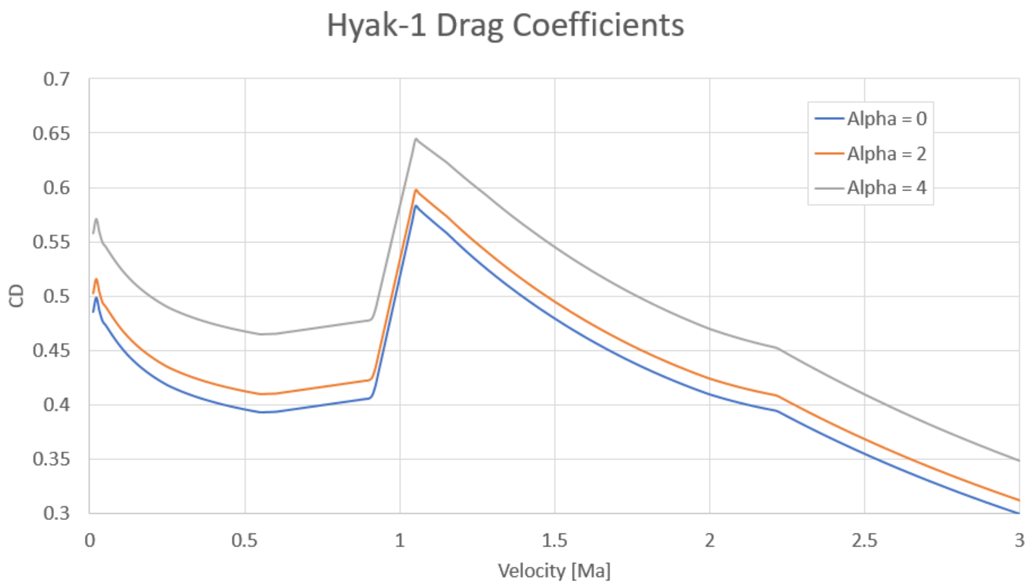


Fig 25. Coefficient of Drag at Different Mach Numbers and Angles of Attack Generated from RASAero II.

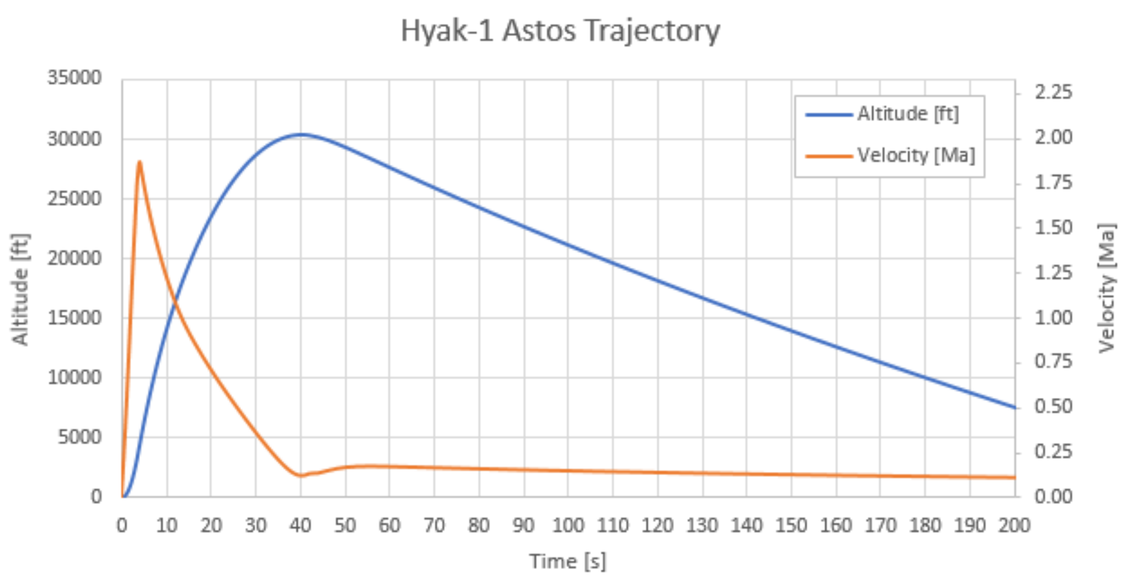


Fig 26. ASTOS simulation results.

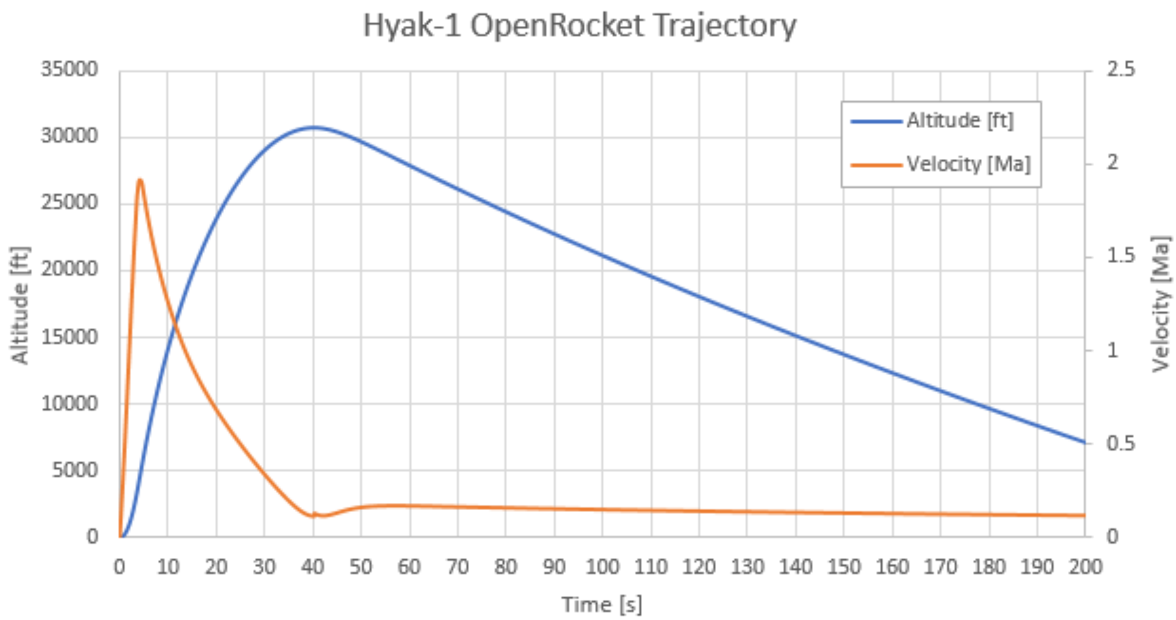


Fig 27. OpenRocket simulation results.

F. Avionics and Telemetry

To ensure a reliable deployment, Hyak-1 makes use of a redundant commercial altimeter system for activation of the recovery deployment charges. The rocket is also equipped with an APRS transmitter, allowing for flight telemetry and tracking of the rocket. For competition the requirements that the avionics must satisfy are as follows [1]:

1. Official competition apogee submission. This value must come from a commercial off the shelf product with a barometric sensor.
2. Redundant recovery electronics must be implemented, each with its own battery and wired in isolation from each other.
3. At least one of the redundant altimeters must be a commercial off the shelf product. Safety critical wiring must be braided, managed, and terminated with secure connections.
4. The avionics must be safe until the rocket is on the pad in the launch position, only then can the electronics be armed. The arming switches must be externally accessible.

This section will cover the electrical components of the recovery system avionics, the APRS transmitter, the ground station, as well as the tests for validation of these components.

10. Avionics

For deployment avionics, two commercial altimeters have been chosen for flight: The Featherweight Raven3 as the primary deployment board, and the PerfectFlite StratologgerCF as the secondary Fig 28. Previous rockets have flown with the Raven3 and the PerfectFlite HiAlt45k. While this combination has proven to work successfully at past competitions, this year the HiAlt45K has been replaced with its modern counterpart, the StratologgerCF. This setup combines a more feature and sensor-rich system in the Raven3 with the more basic and dependable StratologgerCF, allowing for a more diverse overall system. The decision to use two commercial flight computers was due to both boards being proven to be highly dependable in the field, while also fulfilling the competition requirements as specified in the Design, Test, and Evaluation Guide. The Raven3 will also be used for the official competition apogee submission.

Activation of the boards is done on the launch rail, while the rocket is vertical, minimizing the chance of accidental discharge. This is done via two screwdriver switches on the rocket body, allowing for each board to be activated independently to confirm operation. The boards are powered via separate 9V PP3 batteries that are mounted using Bulgin BX0033 battery holders as recommended in the IREC Design, Test, and Evaluation Guide [1]. All wiring to the charges is done with stranded 22 AWG wire braided together and held with p-clamps, until connected to the appropriate barrier block using crimped ring terminals. A colour guideline for wiring has been established to allow for easier identification of wires, enabling faster troubleshooting. Both boards also have beeper patterns which state their programmed altitudes, continuity on their charges, as well as alert team members to any errors that may occur on them. This allows for confirmation of both boards' settings on the pad, and to ensure that no wiring has become dislodged during final setup. Both boards are located in the avionics bay, which is found in the lower half of the upper fuselage. The avionics bay is mounted to an aluminum recovery bulkhead which fastens it to the fuselage while also protecting the electronics from the deployment of the recovery system.

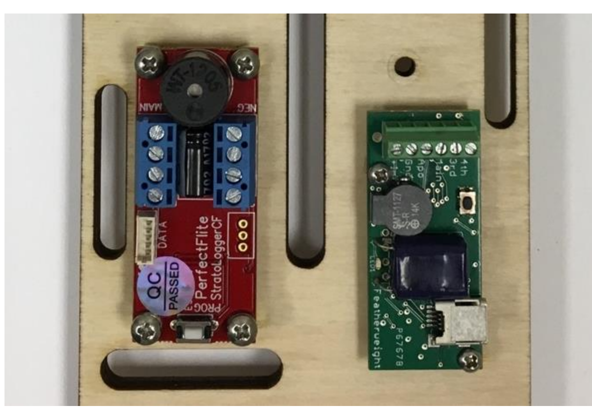


Fig 28. StratologgerCF (left) and Raven3 (right) mounted on the avionics sled.

Primary Board (Raven3)

The Raven has been selected as the primary board for reasons that have set it apart from other boards considered in previous years. These reasons include built in test capabilities and computer connectivity, multiple sensors, multiple ignitor connections, flight data storage, and a large capacitor to protect against wiring or battery failure. These features allow for faster integration testing with recovery system and increased ease of use, as well as faster programming of the board for flight configs. The Raven3 also has extra sensors in addition to the required barometric sensor to provide more reliable readings. The extra ignitor connections create greater redundancy for deployment charge activation, as it allows for the 3rd charge in addition to the apogee and main deployments.

Outside of these reasons for selection, the Raven has also proven to be dependable, as it was used last year during successful deployment. In flight operations, the Raven's simpler method of setup also allows confirmation of altimeter settings with the recovery subsystem and Team Lead (see Fig 29).

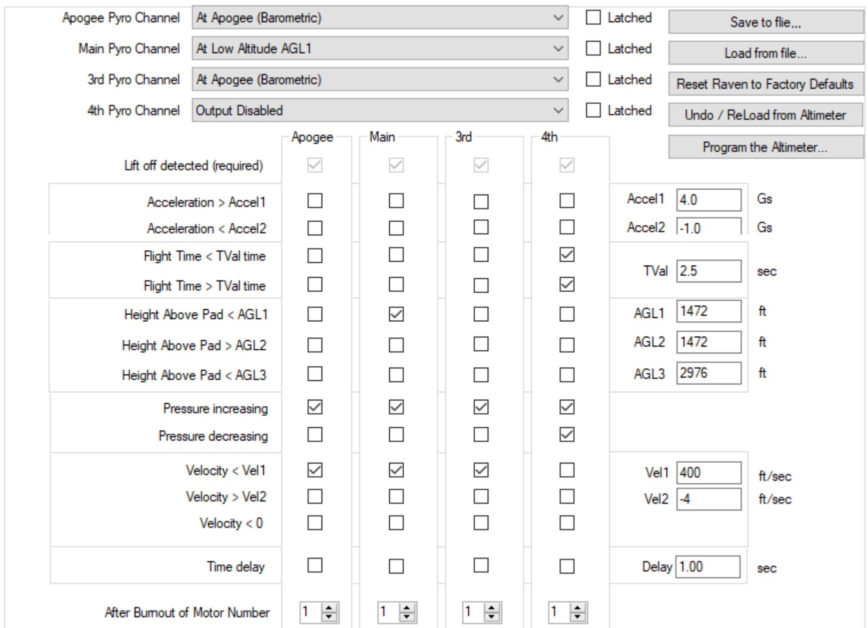


Fig 29. Raven3 setup program.

Testing of the Raven3 has been performed successfully, both by itself and integrated with the recovery subsystem. By itself, the board ran a full simulated flight in the same setup as the final rocket and tested to ensure it activated e-matches at apogee and the correct altitude for main deployment. This also allowed for testing of the switches and barrier block setup, which worked correctly and confirmed that the system can be safely locked out for on-rail work. A full integration test was also performed with this flight simulation, helping the recovery and avionics subsystems practice integration and wiring for the final product while also ensuring that the entire system works well. For full test details, please refer to Appendix II.

Secondary Board (StratologgerCF)

As the secondary board, the Stratologger serves to deploy the main and apogee charges in the recovery system, should there be a failure in the Raven3 system, either on the board itself or outside it (e.g. a wiring malfunction). In previous years, an older version of this board, the HiAlt45K, was used; the decision to upgrade this year was due to the Stratologger being more suited for trans-sonic flight. For example, while the HiAlt45K uses a basic mach-delay to account for the transition from sub to supersonic flight, the Stratologger uses a more modern "MachLock" feature. By analyzing the rocket's velocity in addition to changes in pressure, the Stratologger is able to accurately detect apogee and ensures that pressure spikes created by transonic flight do not cause premature deployment. This is also means that deployment at apogee can occur more accurately, reducing the possibility of damage such as fuselage zippering or stripped chutes. The Stratologger also replaces the jumper system from the HiAlt45K with a single button to cycle through preset deployment altitudes, and since the target main deployment altitude (6,095 ft. AGL, 1,500 ft. above launch pad) is one of the board's presets, only a button press is required for setup.

Fig 30. Set up for vacuum testing of Stratologger CF (inside container) with drogue and main parachute e-matches.

Testing of the Stratologger was done with a vacuum chamber, shown in Fig 30, which was brought down to the calculated pressure that would be seen during apogee, and slowly re-pressurized to simulate descent. Both the main and apogee deployments were tested, and both deployed successfully.

11. Telemetry System

The telemetry system consists of two components: the commercial BigRedBee BeeLine transmitter for data collection, encoding and transmission, and a custom-built Ground Station for receiving and displaying data. The Automatic Packet Reporting System (APRS) is the telemetry standard used.

<u>Transmitter Board (BigRedBee Beeline GPS)</u>

For transmission, the BigRedBee BeeLine GPS will be used for its main function of APRS telemetry transmission over the 70 cm band for over 40 mi of distance. This allows for live reception of latitude, longitude, and altitude data, from which the rocket's velocity can be approximated. The use of the 70 cm band requires the operator to have an amateur radio licence; for this reason, the team member responsible for the ground station has obtained an Amateur Radio Operator's Certificate from Industry Canada, allowing for operation in the United States due to a reciprocal operating agreement between the two countries. The call sign VA7AVE/W5 will be used, in accordance with regulations. Set up of the Beeline is done by connecting it to a laptop using the provided software prior to assembly.

The BeeLine comes with a pre-attached LiPo battery which provides enough life for 8 hours of transmissions, allowing for easy recovery even in the event of an early main deployment. As the system is self-contained, and not safety-critical, no additional wiring is needed. The BeeLine is mounted on a plywood sled which is located in the nose cone. This is necessary due to the nose cone being one of two RF transparent zones in the rocket, with the other zone being reserved for the competition required beacon.

Ground Station

The ground station is a system used to receive and display live telemetry transmitted as APRS packets from the BeeLine GPS board. The physical ground station consists of a Wandboard computer and uses an RTL-SDR USB device and a whip antenna to receive radio signals. The received data is demodulated and decoded using open-source software and is recorded and displayed in a user-friendly interface using a Python server and JavaScript client developed by the UVic Rocketry team, seen in Fig 31. This creates an interface that is easy to understand and read without specialized technical knowledge, allowing for faster identification of the rocket's location after landing and making it possible to identify anomalies during flight. The ground station uses a 15.5 in LCD display and is powered off a 22.2 V LiPo battery which is regulated to 12 V for the display, and 5 V for the Wandboard. The system is housed inside of a Pelican Case that increases the system's robustness for use in desert conditions. The antenna used is a commercial whip antenna, which can also be replaced with a custom backup whip antenna if needed.

The system was used to successfully recover two rockets at IREC 2017 and has been tested at a distance of 10.4km in the past. More recently, tests of signal demodulation and decoding were performed at short range, and long-range under conditions similar to real operating conditions. This long-range test was done at a distance of 2.57 mi [4.13 km] between two hills, to better simulate the predominantly flat, unobstructed landscape seen at Spaceport America. At this distance, the ground station received 90% of packets transmitted by the BeeLine GPS board.

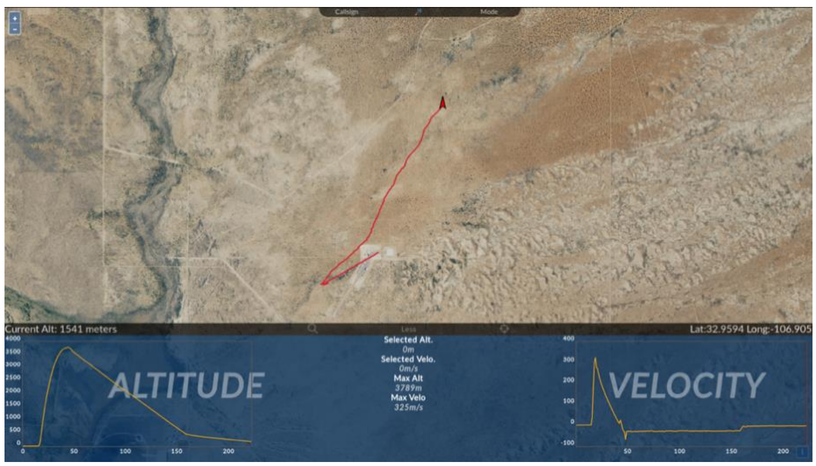


Fig 31. Ground station user interface.

III. Mission Concept of Operations Overview

Mission Concept of Operations is made up of nine stages, ranging from initial assembly to retrieval after launch. Each section broad overview of stages can be seen in Fig 32. For further detail a flow chart illustrates the chain of events (see Fig 33) and each mission phase is described in depth.

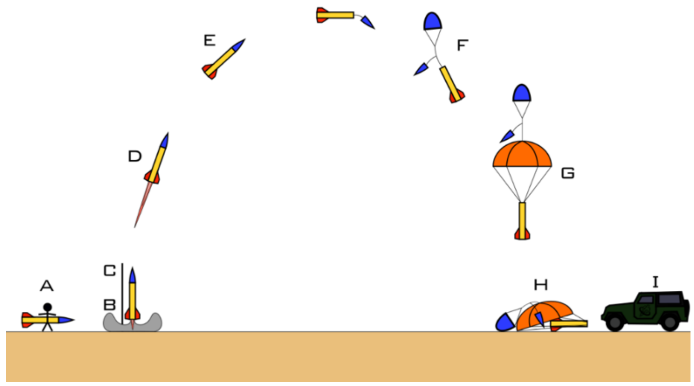


Fig 32. A visual showing the Mission Concept of Operations.

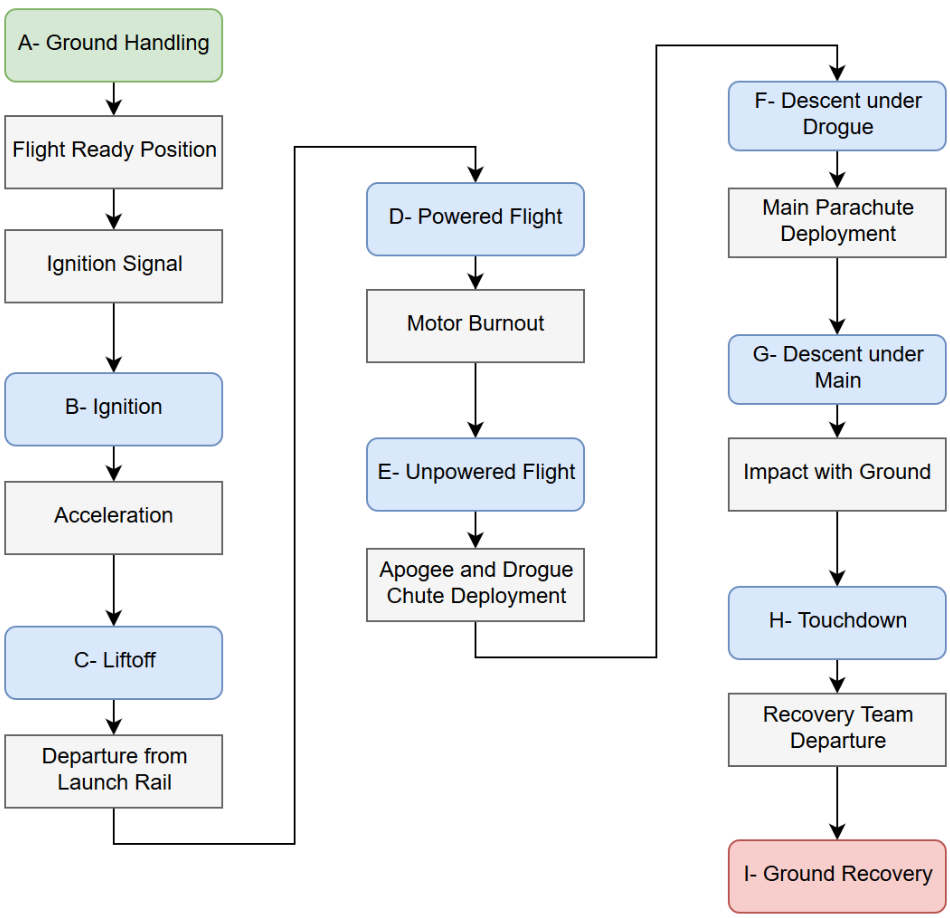


Fig 33. A flowchart showing the Mission Concept of Operations.

A. Ground Handling

Start: The rocket has left the main assembly area and is in transit to the launchpad.
End: The launch rail has been raised and secured and the rocket is ready for launch.

After all components have been assembled and the rocket has been transported to the launchpad, the rocket will be carefully loaded onto the horizontal launch rail which will then be raised and secured. Once the rocket has been erected, the avionics board and backup avionics board will be armed, and the payload experiment will be activated. The final step is the installation of the motor ignitor. All personnel will then vacate the premise and return to the Assembly Area. All subsystems will be on standby.

B. Ignition

Start: The ignition signal has been sent to the rocket and the propellant has been successfully ignited.
End: The rocket begins to accelerate.

Within the propulsion subsystem, the propellant will be successfully ignited. The combustion chamber will pressurize to the nominal chamber pressure. The rocket will then begin to accelerate up the launch rail. The recovery, payload, and avionics subsystems will remain on standby.

C. Liftoff

Start: The rocket has begun to accelerate.
End: The first launch lug has cleared the launch rail.

As the rocket begins to accelerate, the largest amount of impulse will be induced on the thrust ring and the internal structures. This phase is especially crucial to mission success since a shift of mass would destabilize the rocket. The propulsion subsystem will continue to be accelerating the rocket. Upon detecting 3 g's of acceleration, the avionics boards and the payload experiment will begin to acquire data. The recovery subsystem will remain on standby.

D. Powered flight

Start: The first launch lug has cleared the launch rail.
End: The motor burns out and the rocket begins to decelerate.

When the first launch lug has passed the top of the launch rail, the rocket will be ascending at a speed of 111.5 ft./s which will provide sufficient stability with a static margin of 2.31 calibers. Once the rocket has cleared the launch rail, it will accelerate to a maximum velocity of Mach 1.88, which will occur at an altitude of 9,149 ft AGL (4556 ft. above launch pad). The propulsion subsystem will continue to be accelerating the rocket. The avionics boards and payload experiment will continue to be acquiring data. The recovery subsystem will remain on standby. Avionics detect powered flight and disable ignitors.

E. Unpowered flight (Coast)

Start: The motor burns out and the rocket begins to decelerate.
End: The rocket has reached apogee and the drogue chute has been deployed.

After the motors burns out, the rocket will coast for 40.5s to an apogee of 30,367 ft. The propulsion subsystem will no longer be active. The avionics boards and payload experiment will continue to be acquiring data. The recovery subsystem will remain on standby. Avionics start looking for apogee for deployment.

F. Drogue descent

Start: The rocket has reached apogee and the drogue chute has been deployed.
End: The rocket has descended to an altitude of 1,500 ft. AGL and the main parachute has been deployed.

After the rocket has reached apogee, both the avionics board and the backup avionics board will immediately detect the decrease in altitude and activate the CO_2 parachute deployment system. Subsequently, the drogue chute will be deployed, slowing the rocket to a constant descent speed of 120 ft./s. The propulsion system will continue to be inactive. The avionics boards and payload experiment will continue to acquire data.

G. Main descent

Start: The rocket has descended to an altitude of 6,095 ft. AGL and the main parachute has been deployed.
End: The rocket has made initial contact with the ground.

Upon reaching an altitude of 6,095 ft. AGL (1500 ft. above launch pad), the pyrelease will be activated which will release the main parachute, slowing the rocket down to a constant descent speed of 11.5 ft./s. The propulsion system will continue to be inactive. The avionics boards and payload experiment will continue to be acquiring data.

H. Touchdown

Start: The rocket has made initial contact with the ground.
End: The rocket, main parachute, and drogue chute are at rest on the ground.

After the rocket gently impacts the ground, the rocket, main parachute, and drogue chute will come to rest. The ground station will display the touchdown location, from which a recovery route will be planned. The avionics boards and payload experiment will then be deactivated and will no longer acquire data. All subsystems will then be inactive.

I. Ground recovery

Start: The recovery team has been permitted to depart from the Assembly Area to retrieve the rocket body.
End: The recovery team has returned to the Mission Control Center with the rocket body for post-flight evaluation

After receiving permission from the Mission Control Officer, the recovery team will depart from the Assembly Area following the planned recovery route. The rocket will then be inspected for any damage to the rocket and unignited charges. All personnel will be wearing appropriate protective equipment. The rocket will then be returned to the Mission Control Center for post-flight evaluation.

IV. Conclusion and Lessons Learned

The Hyak-1 rocket represents a challenging step towards higher accelerations, speeds, and altitudes than the UVic Rocketry Team has dealt with in the past. Numerous components, the fins in particular, required significant modifications from the designs of the 2017 rocket in order to accommodate the challenges of supersonic airflow. The information and experience gained in the creation of Hyak-1 and the flight data that will be gathered from the launch will be crucial for future, more powerful rocket designs.

Naturally, as the part count and complexity of a project increases, so do the methods of failure. Therefore, proving the reliability of the system requires more effort. When performing any calculations and simulations, the input values should be triple checked. The simulations should always be checked against hand calculations to confirm no input mistake was made. A small error in input could lead to a large inaccuracy of the result. Additionally, when exploring new methods of manufacturing, it is important to plan for time-costly failures and provide adequate time to test the products. A crucial element of testing that may be overlooked is verifying the reliability and accuracy of testing equipment and environments. Unless this is ensured, testing results may not be valid due to the discrepancies caused by the testing equipment. Finally, communication is crucial to the success of the team. It is imperative that there is clear communication with the science and engineering subsystems to make sure the design meets all the objectives.

Appendix I: System Weights, Measures, and Performance Data

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: 117

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

Country: Canada

State or Province: BC

State or Province is for US and Canada

Team Information

Rocket/Project Name:	Hyak -1
Student Organization Name	UVic Rocketry
College or University Name:	University of Victoria
Preferred Informal Name:	Optional
Organization Type:	Club/Group
Project Start Date	9/25/2017
Category:	30k – COTS – All Propulsion Types

Projects are not limited on how many years they take

Member	Name	Email	Phone
Student Lead	Malaki Vandas	uvicrocketry@gmail.com	778-257-6721
Alt. Student Lead			
Faculty Advisor	Afzal Suleman	suleman@uvic.ca	1-250-721-6039
Alt. Faculty Adviser			

For Mailing Awards:

Payable To:	Uvic Rocketry
Address Line 1:	University of Victoria
Address Line 2:	Engineering Dean's Office - EOW 248
Address Line 3:	3800 Finnerty Rd., Victoria, BC V8P5C2
Address Line 4:	
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	33
Undergrad	42	Female	9
Masters	0	Veterans	0
PhD	0	NAR or Tripoli	0

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

This year, UVIC Rocketry has worked with classes to explain the Engineering Design Principle and the Scientific Method in a rocketry context, as well as curriculum development for further elementary and high school outreach events in the upcoming year. Working with a Grade 10 class this year , both in the Fall and Spring semesters, to build alkaseltzer rockets was very successful, with engagement from students in both the experiment and the field of rocketry as a whole. As the year progresses and the development of workshops continues, we hope to have more successful outreach events for youth. Other outreach events have been done around the University to encourage involvement of other students, such as clubs day events. We have also had the opportunity to attend events such as Tectoria, and other tech related events where we displayed our current and previous projects.

Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Airframe Length (inches):	138.5"	23" Nose cone, 114.5" Fuselage, 2" Boat tail
Airframe Diameter (inches):	4.6"	
Fin-span (inches):	13.2"	
Vehicle weight (pounds):	30.3	
Propellent weight (pounds):	18.6	
Payload weight (pounds):	9.8	
Liftoff weight (pounds):	58.7	
Number of stages:	1	
Strap-on Booster Cluster:	No	
Propulsion Type:	Solid	
Propulsion Manufacturer:	Commercial	
Kinetic Energy Dart:	No	

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

```
1st Stage: Cesaroni Pro 98, 17631N3800-P, N Class, 17631 Ns
```

Total Impulse of all Motors: 17631 (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:	ESRA Provide Rail	
Rail Length (feet):	17"	
Liftoff Thrust-Weight Ratio:	16.7	
Launch Rail Departure Velocity (feet/second):	118.5	
Minimum Static Margin During Boost:	2.14	*Between rail departure and burnout
Maximum Acceleration (G):	21.52	
Maximum Velocity (feet/second):	2028	
Target Apogee (feet AGL):	30K	
Predicted Apogee (feet AGL):	30367	

Payload Information

Payload Description:

organisms, and to ensure no false-positive results in the analysis of returned samples for life, probes sent to these planets must be entirely sterile. We propose that a landing unit be contained within a sterilization module, deployed to the surface of such a planet, then re-encapsulated in this module after sample retrieval to ensure complete multi-directional sterilization. We will be building on our 2017 research by investigating the conserved DNA repair pathways

in prokaryotes and eukaryotes, namely, the role of bacterial recA and eukaryotic recA homologs in DNA repair. The effects of launch conditions on this particular protein will be investigated using Saccharomyces cerevisiae recA homolog knockouts (rad51, rad52) transformed with recA in the lab.
UV Sterilization: A modular unit will expose a known volume of test specimens to 245 nm and 275 nm UV light in a sealed system from rocket assembly to recovery. A representative sample will be plated onto a supportive media and incubated to determine the proportion of surviving colony forming units per mL (cfu/mL).
Test protocol: The experiment will be performed repeatedly in a laboratory environment, exposing varying concentrations of organisms to UV light.
Wild-type S. cerevisiae, recA transformed rad51 knockout S. cerevisiae, untransformed rad51 knockout S. cerevisiae and transformed wildtype S. cerevisiae, unincubated on SD -Leu media, will be the flight samples. The UV system will only be armed once inside the sealed rocket, using rare earth magnets and a Hall effect sensor. The system will be activated completely on the detection of launch. The structure will also undergo physical testing. At present, FAE has been performed on the structure to ensure a high factor of safety, and 3D-printed UV modules have undergone incubation at 45˚C and subsequent stress testing to ensure they will withstand desert conditions.
Post-flight analysis will consist of incubating the test specimens and comparing the survival of the UV-exposed samples to the unexposed sample, and to previously lab-tested UV and non-UV samples. Incubation takes 18-24 hours and will occur using a mobile incubator.
This payload remains static in the rocket, so does not require a separate recovery system. The payload will be made up to the required 8.8 lbs mass using steel ballast.
Current status: Successful transformation of rad51 knockout strains with PRS425 empty plasmid vector and with

Recovery Information

Payload Recovery Method: Attached to main stage

Single Stage Recovery System

Event #1
Recovery Device: 20” SRAD drogue parachute (black and blue)
Deployment Method: SRAD CO2 ejection system – deploys from nose
Altitude: Apogee (~30 000ft AGL)
Sensor: COTS Altimeter, Barometer
Redundancy: 2 deployment devices (Raven 3, High Alt 45k), 2 triggering methods each (4x redundancy)

Event #2
Recovery Device: 144” SRAD main parachute (orange and grey)
Deployment Method: SRAD black powder mechanism – deploys from nose
Altitude: 1500ft AGL
Sensor: COTS Altimeter, Barometer
Redundancy: 1 deployment device (Raven 3), 2 triggering methods (2x redundancy)

Planned Tests

* Please keep brief

Date	Type	Description	Status	Comments
5/8/18	Ground	Raven 3 Testing	Successful	Test of the Raven 3 Main deployment board, both apogee and main e-matches ignited successfully at expected times.

5/19/18	Ground	Groundstation range test	Successful	Groundstation tested at range of 4.3km. ARPS packets successfully recived and decoded.
4/20/18	Other	Payload PCB test	TBD	Test of Payload Board activation and data acquisition in fuselage
11/3/17	Other	Fin Static Loading Test	Successful	Failure of 1-layer carbon fiber fins occured at higher than expected values. 2-layer fins surpassed strength target. Failure due to CF separation from PLA mold
1/26/18	Other	Fin Static Loading Test	Successful	Supersonic air foil weaker than subsonic airfoil. Inconsistent results for 2-layer fins. Fins did not meet supersonic flight strength target.
3/9/18	Other	Fin Static Loading Test	Successful	Tested three 2-layer fin, one control, one w/ heat treatment, one w/ carbon fiber plate inserted. All fins surpassed target strength. insert was stronger than control and heat treatment was weaker.
2/15/18	Other	Carbon Fiber-PLA Adhesion Testing	Successful	Tested effects of heat treatment and glue on carbon fiber-PLA adhesion with epoxy. Heat treatment drastically increases adhesion between the materials.
2/4/18	Other	Fin Torsional Stiffness Test	Minor Issues	Tested two 1-layer fins. Neither met stiffness targets. Testing procedure and issues encountered and addressed during testing
3/6/18	Other	Fin Torsional Stiffness Test	Successful	Tested three 2-layer fins. two heat-treated and one control. Heat treated were significantly less stiff and did not meet stiffness target. Control fin hit stiffness target with safety factor of 1.7
3/23/18	Other	Fin Torsional Stiffness Test	TBD	Testing four 2-layer fins. Fins are oversized to simulate worst case scenario. two fins contain 8-layer carbon fiber insert, two fins are controls
1/28/18	Other	Fiberglass and ABS fasterner tear-out testing	Successful	Testing fiberglass-epoxy tear-out strength with various fasteners and number of layers.
3/25/18	Other	Coupler Bending Test	TBD	Test of bending failure of fiberglass/ABS and fiberglass/foam couplers
4/6/18	Other	Composite Nose Cone Strength Test	TBD	Test of compressive strength of nose cone with exposure to elevated temperatures
1/20/18	Ground	CO2 deployment - puncture mechanism test	Successful	Black powder successfully drove pin through CO2 cannister stand-in
2/6/18	Ground	CO2 deployment - proof of concept	Successful	Puncture pin mechanism was able to succesfully pierce the CO2 cannister.
3/3/18	Ground	CO2 deployment - drogue parachute ejection	Successful	CO2 deployment mechanism has necessary force to break nose cone shear pins, eject nose cone, and eject drogue parachute from fuselage.

3/14/18	Ground	Payload lab circuit test	Successful	Lab PCB and flight circuit nominal
3/14/18	Ground	xperiment lab control trial - weekly until com	Minor Issues	Reduce exposure time for countable results
4/14/18	Ground	Recovery - Full system test	Successful	Test of full recovery system - Event 1 and Event 2
5/16/18	Ground	Recovery - black power ignition at apogee	Successful	Validation that 0.4g black powder will ignite at ~0.3atm
4/30/18	Other	Camera system test	TBD	Testing of external activation and operation of cameras in rocket
5/5/18	Ground	CO2 cartridge thermal test	Successful	CO2 cartirdges were determined to be resistant to the heat expected in the New Mexico desert
5/19/18	Ground	StratoLoggerCF Ignition Test	Minor Issues	StratoLogger successfully ignited both charges as expected. Issues with pressure chamber not reaching max altitude, or leaking causing incorrect flight simulation.
5/6/18	Ground	Ground Station Packet Decode Test	Successful	Simple test ensured that ground station could still decode packets from BeeLine GPS

Any other pertinent information:

The fins on the Hyak-1 rocket are fastened through the fuselage onto fin rings that are located around the motor casing.
This provides another degree of reusability to our rocket. UVic Rocketry has flown rockets with these types of detachable
fins in the past, however never to an altitude of 30,000 ft. For this reason, the team is working hard to test the fins for both torsional and bending stiffness to avoid failure caused by fin flutter.

Our payload experiment requires incubation after the flight has occurred. We plan to fly on either the first or second launch day to ensure that the experiment can be completed before the end of the event.

Appendix II: Project Test Reports

IREC Prescribed Tests

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Date: 16 May, 2018
Test Lead: Benjamin Stadnik

UVic Rocketry Test Report

Recovery – Full System Deployment Test

16 May, 2018

Test Lead: Benjamin Stadnik (Recovery Lead)

Associates: Shannon Dawson (Pyrotechnician), Alex Schell (GNC Lead), Garrett Krest (Safety Captain), Sebastian Panchyrz (Manufacture Lead)

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Date: 16 May, 2018
Test Lead: Benjamin Stadnik

Introduction

The Hyak-1 rocket has a target altitude of 30 000 ft AGL. At this altitude, the atmosphere is too thin to rely on large black powder charges to eject the drogue chute from the nose of the rocket. Instead, a canister of compressed CO_2 is evacuated into the upper half of the rocket to eject the drogue chute. To puncture the CO_2 canister, the recovery team has designed a mechanism that uses a much smaller black powder charge that will release the CO_2. A second device, known as the pyrelease, releases the main parachute when the rocket descends to 1500 ft AGL. This report assumes that the reader has seen or is familiar with the both mechanisms, but does not require a full understanding of the device.

Scope

This full system deployment test is to determine if the mechanical components of the recovery system will be correctly triggered by the GNC avionics at the appropriate times.

This test will simulate the 2 recovery events outlined in previous tests. The main GNC avionics board, the Raven3, will handle a full simulation of flight. It includes powered flight, unpowered flight, apogee, descent, main parachute deployment, and landing. The 2 events that will be used to activate recovery components will be the apogee event, and main parachute event. At apogee, the Raven3 will trigger the CO_2 ejection charge, which will decouple the nose cone, and deploy the drogue parachute. Next, the rocket will simulate descent. Finally, at 1500ft, the main parachute event will trigger the pyrelease to decouple, allowing for the main parachute to deploy.

Terminology

e-match	A single-use electronic match that ignites when a current is applied
Pyrelease	A pyrotechnic decoupling link developed by UVic Rocketry
GNC	Guidance, Navigation, and Control: Uvic Rocketry’s avionics subsystem
Raven3	Commercial off the shelf avionics board including accelerometer and barometer
AGL	Above ground level

Summary of Test Method

The recovery system is fully loaded with all flight essential components and energetic devices. Next, the avionics boards are fully wired to the e-matches, as per flight condition standards. Finally, the batteries are added, and a computer is connected to the Raven3 board.

The computer then uses the Raven3’s include software to run a full simulation of recovery events. At the event occur via software, the board will trigger the energetic devices in the recovery system. At simulated apogee, the Raven3 will detonate the CO_2 cylinders, ejecting the nose cone and deploying the parachute. Next, the software will simulate descent to 1500ft where the Raven3 will trigger the pyrelease, deploying the main parachute.

Date: 16 May, 2018
Test Lead: Benjamin Stadnik

Materials

- 2x 0.75g black powder
- 1x 0.5g black powder
- 2x CO_2 deployment mechanism with fasteners
- 5 e-matches
- Recovery bulkhead
- Recovery fuselage
- 45g CO_2 cartridge
- Pyrelease
- 8 quick links
- Fishing line
- Main parachute, bagged
- Drogue parachute with swivel link
- Free standing ladder
- Duct tape
- Main parachute shock cords
- Drogue parachute shock cords
- Masking tape
- Recovery fuselage
- Nose cone
- 3x 4-40 nylon shear screws
- GNC avionics boards, sled, and 3D printed guide
- Assorted wires
- 2x 9V batteries

Hazards

This test involves using black power to set off small-scale detonations in a contained environment. Safety glasses should be worn by all test personnel and anyone observing the detonation. A designated "Pyrotechnician" should be responsible for handling the black powder, connecting the apparatus to the detonator, and triggering the detonation. There should also be a designated "Safety Captain" to ensure the safety of the Pyrotechnician and any bystanders, as well as having some other responsibilities outlined in the procedure.

Procedure

Part 1: Load CO_2 mechanisms

1. The CO_2 mechanisms are set up as per standard test procedures (this test uses 0.75g of black powder each):

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Test Lead: Benjamin Stadnik

   a. Two e-matches are set in one mechanism, and one e-match is placed in the other mechanism. Hole should be blocked with masking tape
   b. All e-match ends are separated and then the exposed wires are twisted together to short the circuit (preventing any accidental detonation).
   c. 0.75g of black powder is measured and placed in each black powder chamber in the piston. Safety Note: the pyrotechnician should be wearing a full face shield when handling black powder and the loaded mechanism. Anyone else helping with the test should wear safety glasses while the mechanism is loaded.
   d. The piston is loaded into the mechanism chamber, followed by the spring.
2. Fasten both loaded mechanisms securely to the bulkhead
3. Thread two 45g CO_2 cartridges into the bulkhead so that their tips are flush with the surface of the bulkhead

Part 2: Load pyrotechnic release mechanism

4. The pyrelease is set up as per standard test procedures (this test uses 0.3g of black powder):
   a. The plunger is slid into the main housing of the pyrelease, with a quick link looped around each of the pins.
   b. The black powder is measured and placed in the chamber. Safety Note: the pyrotechnician should be wearing a full face shield when handling black powder and the loaded mechanism. Anyone else helping with the test should wear safety glasses while the mechanism is loaded.
   c. Two e-matches are set into the mechanism. The back panel of the pyrelease is screwed on using 4x 4-40 steel screws, securing the e-matches in place.
   d. All e-match ends are separated and then the exposed wires are twisted together to short the circuit (preventing any accidental detonation).
   e. A piece of fishing line is looped twice through the ends of the pins and tied to secure the [piece] until detonation.

Part 3: Load recovery system

5. The pyrelease is attached to an eyebolt on the bulkhead with either of the quick links that were attached in the previous step. Loop the tether line that holds together the two pieces of the pyrelease through the same quick link to prevent the pyrelease from becoming a projectile after detonation. Leave the pyrelease loosely inside the tube.
6. Connect pyrelease e-matches to corresponding avionics wires
7. Connect CO_2 mechanism e-matches to corresponding avionics wires
8. Plug wiring through-hole with putty
9. Attach main shock cord to bulkhead
10. Attach upper parachute bag to second pyrelease quicklink
11. Attach drogue shock cord to second pyrelease quicklink

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12. Insert and fasten bulkhead into upper fuselage (#10-32 set screw, 3/32 allen key)
13. Attach drogue to drogue shock cords
14. Attach drogue to nose cone via nose cone extension cable
15. Fasten nosecone to fuselage (4-40 shear pins, flathead)

Part 4: Recovery Simulation and Deployment

16. In a safe, outdoor location place the stand the testing ladder and duct tape loaded recovery fuselage perpendicular to ground
17. Connect batteries to avionics board. THE SYSTEM IS NOW CONSIDERED ARMED. All personnel should don safety glasses and stay clear of the nose cone ejection path.
18. Connect computer to Raven3 avionics board
19. Open Raven3 simulation and check presets: Apogee = increasing barometric pressure. Main = 1500ft AGL.
20. Begin simulation. Wait for all energetics to deploy.
21. After the simulation has concluded, check that the pyrelease has decoupled by dragging the drogue parachute. This pulls the main out of the fuselage, separating the bags, and deploying the main parachute.
22. Remove batteries, disconnect computer.
23. Disassemble and clean components.

Test Results

The first iteration of this test failed. The simulation reached apogee, and the CO2 deployed, but did not have sufficient force to eject nose cone and drogue parachute. The pyrelease decoupled successfully at simulated 1500ft AGL.

In the next test was successful. The simulation reached apogee, resulting in the CO2 ejecting the nose cone and drogue parachute as designed. Next the pyrelease successfully decoupled, allowing the main parachute to release from the fuselage and deploy.

Discussion

The first iteration of the test, the system did not deploy correctly. The CO2 had been validated a number of times before this integration, and a failure at this stage was unacceptable. An investigation determined that the CO2 puncture mechanism did not have sufficient force to puncture the CO2 cartridge. This lead to the compressed CO2 releasing too slowly, not sufficient for nose cone ejection. Another puncture mechanism test determined that 0.5g of black powder does indeed have enough energy to puncture correctly. Therefore, we concluded that black powder must have escaped the combustion chamber during moving and handling - which is unacceptable.

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For the next test, the CO2 mechanism was modified. Masking tape was applied to every hole in the chamber; enough to keep the black powder from escaping through the holes, but light enough as not to interfere with the rapid release of CO2 during ejection. The rocket was handled more or less the same, but no black powder was able to escape. This led to a clean CO2 cartridge puncture, and a violent release of gases enough to eject the nose cone and drogue parachute.

In both tests, the pyrelease functioned to specification. The explosive force of 0.4g of black powder is more than adequate to separate the two halves of the decoupling link and successfully deploy the main parachute.

Conclusion

The first test was a failure, but it was determined that small amount of black powder had been escaping through the holes in the combustion chamber meant for the e-match pass thru The problem was fixed by simply adding a thin layer of masking tape to the outer perimeter of the combustion chamber to keep the black powder from falling out. The layer of tape does not affect the explosive pressure of the CO2 system because the masking tape is fragile and will rip under drogue deployment. The integration with the GNC avionics board was a successful. Hyak-1 is now equipped with a fully tested, flight ready recovery system.

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Date: 3 February, 2018
Test Lead: Benjamin Stadnik

UVic Rocketry Test Report

CO_2 Deployment Mechanism – Black Powder Lower Limit Test

3 February, 2018

Test Lead: Benjamin Stadnik (Safety Captain)

Associates: Shannon Dawson (Pyrotechnician)

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Date: 3 February, 2018
Test Lead: Benjamin Stadnik

Introduction

The Hyak-1 rocket has a target altitude of 30 000 ft AGL. At this altitude, the atmosphere is too thin to rely on large black powder charges to eject the drogue chute from the nose of the rocket. Instead, a canister of compressed CO_2 is evacuated into the upper half of the rocket to eject the drogue chute. To puncture the CO_2 canister, the recovery team has designed a mechanism that used a much smaller black powder charge that will release the CO_2. This test is to determine an appropriate quantity of black powder to use puncture the CO_2 canister for future tests. This report assumes that the reader has seen or is familiar with the mechanism parts, but does not require a full understanding of the device.

Scope

The purpose of this test is to determine an appropriate quantity of black powder to use for the CO_2 ejection tests by finding the puncturing limit of various charges of black powder.

Due to the high cost of CO_2 canisters, it is necessary to determine an approximate quantity of black powder for the first canister test using other materials to simulate puncturing a CO_2 canister. Each iteration of this will give a yes/no result regarding whether or not the material being tested was punctured. This test is semi-quantitative in nature, since it relies on qualitative observations and results for different quantities of black powder. The ultimate goal is to puncture two thin sheets of stainless steel, which are assumed to require approximately the same force as puncturing the CO_2 canister. The reason for this system of incremental testing is to limit the amount of guesswork involved in choosing black powder quantities, therefore avoiding unnecessary risk with hazardous materials, and to reduce the amount of stainless steel needed for the tests.

Terminology

e-match	A single-use electronic match that ignites when a current is applied.
Detonation chamber	The space between the piston and housing that is filled with black powder.
Detonator device	An electronic device that sends a current through the e-match when activated.
Recovery test tube	A spare section of fuselage with holes for mounting the recovery bulkhead.

Summary of Test Method

This experiment starts by using 5 layers of masking tape, then moves on to a 0.005 inch sheet of stainless steel held down by a layer of tape, then two sheets of stainless steel, also held down by a layer of tape. The procedure involves incrementally increasing black powder charges until it can puncture the desired material, then the material is replaced with with something stronger, and the black powder is tested incrementally again, starting with the amount needed for the previous material. The process is repeated until the desired strength of material can be punctured; in this case, two sheets of stainless steel + one layer of tape are expected to approximate the force required to puncture the CO_2 canister.

Materials

- Black powder (various quantities)
- CO_2 deployment mechanism with fasteners
- Detonator device
- 1 live e-match and 1 dead e-match for each iteration
- Masking tape
- Recovery bulkhead
- Recovery test tube
- 0.005 in Stainless steel sheets (approx. 0.5 in x 0.5 in squares)

Hazards

This test involves using black power to set off small-scale detonations in a contained environment. Safety glasses should be worn by all test personnel and anyone observing the detonation. A designated "Pyrotechnician" should be responsible for handling the black powder, connecting the apparatus to the detonator, and triggering the detonation. There should also be a designated "Safety Captain" to ensure the safety of the pyrotechnician and any bystanders, as well as having some other responsibilities outlined in the procedure.

Procedure

1. The CO_2 mechanism is set up as per standard test procedures (starting with 0.1 g and increasing by 0.05 g for each iteration until the material is punctured):
    a. One e-match is set in the mechanism, and the second (redundant) e-match hole is blocked with a previously used "dummy" e-match.
    b. The dummy e-match is trimmed so it does not interfere with the rest of the apparatus. The live e-match ends are separated and then the exposed wires are twisted together to short the circuit (preventing any accidental detonation).
    c. Black powder is measured and placed in the black powder chamber in the piston. Safety Note: the pyrotechnician should be wearing a full face shield when handling black powder and the loaded mechanism. Anyone else helping with the test should wear safety glasses while the mechanism is loaded.
    d. The piston is loaded into the mechanism chamber, followed by the spring.
2. Five layers of masking tape are placed over the hole where the CO_2 mechanism would be loaded. Be sure not to block the holes where the mechanism is attached.

3. Fasten the loaded mechanism securely to the bulkhead and place inside the recovery testing tube. For this test, the bulkhead does not need to be fastened in.
4. In a safe, outdoor location place the testing apparatus on the ground, and fully extend the detonator cables so the detonator device is as far from the test apparatus as possible. Have the designated safety captain place the detonator on the ground and stand guard to ensure no one touches it and no water is allowed to fall on the detonator (which could close the circuit and trigger an early detonation).
5. When the safety captain has confirmed the detonator disconnected and on the ground, the pyrotechnician will untwist the ends of the e-match, touch the ends of the detonator cables together (to dispel any static charge) and attach them to the e-match.
6. The pyrotechnician will now take the detonator, and after ensuring that the area is clear and all test personnel are at a safe distance, countdown the detonation and push in the detonator pin. If the detonation was successful, the apparatus is now safe to handle without a face shield.
7. In case of a misfire:
    a. With the pin pushed in, press the button on the detonator, which will send a larger current through the e-match.
    b. If the charge still does not go off, place the detonator on the ground and have the safety captain watch over it while the pyrotechnician checks the connections between the detonator and the e-matches.
    c. Attempt detonation again, following the same procedures.
    d. If, after multiple attempts, the charge does not go off, the pyrotechnician should bring the apparatus inside and carefully disassemble it.
8. After the test is complete, bring the apparatus inside and disassemble it. The old dummy match can be discarded, and the other should be kept to use as a dummy for future tests.
9. Repeat steps 1-8, while increasing the black powder charge by 0.05 g with each test, until the mechanism punctures completely (a hole must be clearly visible).
10. Switch the puncture material to one sheet of stainless steel + one piece of masking tape to hold it in place, and repeat the tests, this time starting with the same black powder charge as the successful tape puncture test. Once this is successfully punctured, switch to two sheets of stainless steel + one piece of tape, starting with the same black powder charge as the successful single sheet puncture test.
11. When the amount of black powder required to puncture two sheets of stainless steel has been determined, the test is considered complete.

Test Results

After several test iterations, it was determined that 0.35 g of black powder was needed to puncture two sheets of stainless steel. This amount will be used for the initial CO_2 ejection tests.

Date: 3 February, 2018
Test Lead: Benjamin Stadnik

Data and Analysis

The results for each iteration of the test are given in table 1. The test results are binary: "yes" if the material was punctured successfully or "no" if the material was not punctured.

Table 1: Test results for various materials and black powder charges

Material	**Mass of black powder [g]**					
	0.1	0.15	0.2	0.25	0.3	0.35
5 layers masking tape	y/**n**	**y**/n	–	–	–	–
1 sheet of stainless steel + one piece of masking tape	–	y/**n**	**y**/n	–	–	–
2 sheets of stainless steel + one piece of masking tape	–	–	y/**n**	y/**n**	y/**n**	**y**/n

Discussion

Using the iterative technique, it was determined that a minimum of 0.15 g of black powder is needed to puncture 5 layers of masking tape, 0.2 g of black powder to puncture one sheet of stainless steel (plus tape), and 0.35 g of black powder to puncture two sheets of stainless steel (plus tape). Note that the actual minimum amount of black powder needed for each material is within the range of the successful test, and the unsuccessful test immediately prior. For example, the minimum amount of black powder needed to puncture five layers of tape must be greater than 0.1 g, and less than or equal to 0.15 g. Since finding the exact minimum would require significantly more testing, and since the interval between each iteration is sufficiently small, the successful puncture value can be used as an acceptable approximation to the actual minimum.

The iterative technique was an effective method to determine an approximate amount of black powder to deploy the CO_2 mechanism, while also ensuring the safety of the test personnel by increasing the amount of black powder in small amounts so that the detonation behaviour remained predictable.

Conclusion

To determine the approximate amount of black powder needed to puncture the CO_2 canisters, two sheets of 0.005in stainless steel were used to simulate the thickness of the CO_2 canister. The amount of black powder require to puncture the two sheets, plus the tape holding them in place, was 0.35 g. Since the force required to puncture the canisters is unknown, this result is still only an educated guess, however it allowed the behaviour of the CO_2 mechanism to be observed with different quantities of black powder in a relatively safe and inexpensive manner. A future test using an actual CO_2 canister must be conducted to ensure that 0.35 g of black powder is sufficient to engage the mechanism.

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Date: 4 February, 2018
Test Lead: Benjamin Stadnik

UVic Rocketry Test Report

CO_2 Deployment Mechanism – CO_2 Cartridge Puncture Test

4 February, 2018

Test Lead: Benjamin Stadnik (Safety Captain)

Associates: Shannon Dawson (Pyrotechnician)

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Date: 4 February, 2018
Test Lead: Benjamin Stadnik

Introduction

The Hyak-1 rocket has a target altitude of 30 000 ft AGL. At this altitude, the atmosphere is too thin to rely on large black powder charges to eject the drogue chute from the nose of the rocket. Instead, a canister of compressed CO_2 is evacuated into the upper half of the rocket to eject the drogue chute. To puncture the CO_2 canister, the recovery team has designed a mechanism that uses a much smaller black powder charge that will release the CO_2. This report assumes that the reader has seen or is familiar with the mechanism parts, but does not require a full understanding of the device.

Scope

The test is to determine whether CO_2 puncture mechanism loaded with 0.35g of black powder has sufficient force to puncture the a CO_2 cartridge.

Terminology

e-match	A single-use electronic match that ignites when a current is applied.
Detonation chamber	The space between the piston and housing that is filled with black powder.
Detonator device	An electronic device that sends a current through the e-match when activated.
Recovery test tube	A spare section of fuselage with holes for mounting the recovery bulkhead.

Summary of Test Method

The CO_2 deployment mechanism is loaded with 0.35 g of black powder. Only one e-match is used for testing, and the second e-match hole is blocked with a dummy e-match. The 30g cartridge will be threaded into the bulk head so that the tip of the cartridge will be flush with the surface of the bulkhead. The test is setup so that the CO_2 gases are exhausted in the upwards direction to mitigate the creation of a projectile.

Materials

- 0.35 g black powder
- CO_2 deployment mechanism with fasteners
- Detonator device
- 1 live e-match and 1 dead e-match
- Recovery bulkhead
- Recovery test tube
- 30 g CO_2 cartridge

Date: 4 February, 2018
Test Lead: Benjamin Stadnik

Hazards

This test involves using black power to set off small-scale detonations in a contained environment. Safety glasses should be worn by all test personnel and anyone observing the detonation. A designated "Pyrotechnician" should be responsible for handling the black powder, connecting the apparatus to the detonator, and triggering the detonation. There should also be a designated "Safety Captain" to ensure the safety of the Pyrotechnician and any bystanders, as well as having some other responsibilities outlined in the procedure.

Procedure

1. The CO_2 mechanism is set up as per standard test procedures (this test uses 0.35g of black powder):
    a. One e-match is set in the mechanism, and the second (redundant) e-match hole is blocked with a previously used "dummy" e-match.
    b. The dummy e-match is trimmed so it does not interfere with the rest of the apparatus. The live e-match ends are separated and then the exposed wires are twisted together to short the circuit (preventing any accidental detonation).
    c. Black powder is measured and placed in the black powder chamber in the piston. Safety Note: the pyrotechnician should be wearing a full face shield when handling black powder and the loaded mechanism. Anyone else helping with the test should wear safety glasses while the mechanism is loaded.
    d. The piston is loaded into the mechanism chamber, followed by the spring.
2. Fasten the loaded mechanism securely to the bulkhead.
3. Thread the 30g CO_2 cartridge into the bulkhead so that the tip is flush with the surface of the bulkhead.
4. Place bulkhead assembly inside the recovery testing tube. Fasten the bulkhead set screws into the recovery test tube.
5. In a safe, outdoor location place the testing apparatus on the ground in a position where the exhaust gasses will be released in the upwards direction. Fully extend the detonator cables so the detonator device is as far from the test apparatus as possible. Have the designated safety captain place the detonator on the ground and stand guard to ensure no one touches it and no water is allowed to fall on the detonator (which could close the circuit and trigger an early detonation).
6. When the safety captain has confirmed the detonator disconnected and on the ground, the pyrotechnician will untwist the ends of the e-match, touch the ends of the detonator cables together (to dispel any static charge) and attach them to the e-match.
7. The pyrotechnician will now take the detonator, and after ensuring that the area is clear and all test personnel are at a safe distance, countdown the detonation and push in the detonator pin. If the detonation was successful, the apparatus is now safe to handle without a face shield.
8. In case of a misfire:

   a. With the pin pushed in, press the button on the detonator, which will send a larger current through the e-match.
   b. If the charge still does not go off, place the detonator on the ground and have the safety captain watch over it while the pyrotechnician checks the connections between the detonator and the e-matches.
   c. Attempt detonation again, following the same procedures.
   d. If, after multiple attempts, the charge does not go off, the pyrotechnician should bring the apparatus inside and carefully disassemble it.
9. After the test is complete, bring the apparatus inside and disassemble it. The old dummy match can be discarded, and the other should be kept to use as a dummy for future tests.

Test Results and Analysis

The mechanism deployed successfully and punctured the CO_2 cartridge.

Discussion

The test successfully proved that the mechanism works as intended, and will successfully puncture either the 30g or 45g CO_2 cartridge; whichever we decide to choose. However, the puncture was not as large or clean as anticipated. The pin did not fully puncture the cartridge, but rather created a hole with a diameter smaller than the diameter of the pin. Also, the puncture wound create a “can opener” effect where the material was not removed but rather pushed to the side. More black powder may be required to obtain a cleaner hole.

In later tests, the puncture mechanism was raised to 0.5g of black powder, which significantly increased the diameter of the puncture hole and increased the reliability of the system overall. (See **Figure 1**)

Conclusions

This test was to determine if 0.35g of black powder loaded into the CO_2 puncture mechanism has sufficient force to puncture the CO_2 cartridge. The test was successful; the puncture mechanism punctured the cartridge and the CO_2 was released violently. Later tests determined that 0.5g of black powder is necessary to optimally puncture the canister and release the gases violently for a clean ejection of the nose cone.

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Date: 4 February, 2018
Test Lead: Benjamin Stadnik

Reference Figures

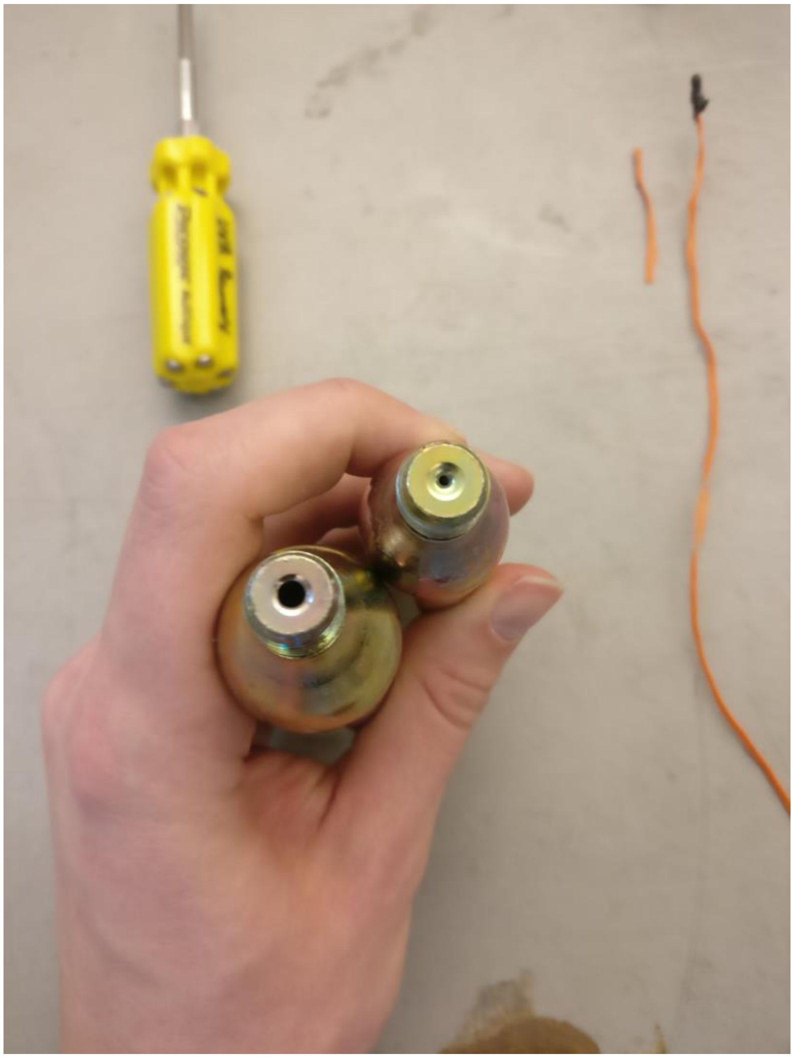

Figure 1: Optimal puncture (left) vs suboptimal puncture (right).

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Date: 24 February, 2018
Test Lead: Benjamin Stadnik

UVic Rocketry Test Report

CO_2 Deployment Mechanism – Drogue Deployment Test

24 February, 2018

Test Lead: Benjamin Stadnik (Safety Captain)

Associates: Shannon Dawson (Pyrotechnician)

Date: 24 February, 2018
Test Lead: Benjamin Stadnik

Introduction

The Hyak-1 rocket has a target altitude of 30 000 ft AGL. At this altitude, the atmosphere is too thin to rely on large black powder charges to eject the drogue chute from the nose of the rocket. Instead, a canister of compressed CO_2 is evacuated into the upper half of the rocket to eject the drogue chute. To puncture the CO_2 canister, the recovery team has designed a mechanism that uses a much smaller black powder charge that will release the CO_2. This report assumes that the reader has seen or is familiar with the mechanism parts, but does not require a full understanding of the device.

Scope

The test is to determine which CO_2 canister will have sufficient energy to shear the nylon pins, eject the nose cone, and deploy the drogue parachute.

Terminology

e-match	A single-use electronic match that ignites when a current is applied.
Detonation chamber	The space between the piston and housing that is filled with black powder.
Detonator device	An electronic device that sends a current through the e-match when activated.
Recovery fuselage	The upper portion of the rocket fuselage where the recovery components are housed during flight

Summary of Test Method

The CO_2 deployment mechanism is loaded with 0.35 g of black powder. Only one e-match is used for testing, and the second e-match hole is blocked with a dummy e-match. The CO_2 cartridges will be threaded into the bulkhead with tip of the cartridge flush with the surface of the bulkhead. Two tests will be conducted: 1 30g CO_2 cartridge followed by 1 45g CO_2 cartridge.

Materials

- 0.35 g black powder
- CO_2 deployment mechanism with fasteners
- Detonator device
- 1 live e-match and 1 dead e-match
- Recovery bulkhead
- Recovery test tube
- 1x30g, 1x45g CO_2 cartridges

Date: 24 February, 2018
Test Lead: Benjamin Stadnik

- Duct tape
- Ladder
- Nose cone
- Drogue parachute and quicklinks
- Main parachute and quicklinks
- 3x nylon shear pins
- e-match extension cables

Hazards

This test involves using black power to set off small-scale detonations in a contained environment. Safety glasses should be worn by all test personnel and anyone observing the detonation. A designated "Pyrotechnician" should be responsible for handling the black powder, connecting the apparatus to the detonator, and triggering the detonation. There should also be a designated "Safety Captain" to ensure the safety of the Pyrotechnician and any bystanders, as well as having some other responsibilities outlined in the procedure.

Procedure

1. The CO_2 mechanism is set up as per standard test procedures (this test uses 0.35g of black powder):
    a. One e-match is set in the mechanism, and the second (redundant) e-match hole is blocked with a previously used "dummy" e-match.
    b. The dummy e-match is trimmed so it does not interfere with the rest of the apparatus. The live e-match ends are separated and then the exposed wires are twisted together to short the circuit (preventing any accidental detonation).
    c. Black powder is measured and placed in the black powder chamber in the piston. Safety Note: the pyrotechnician should be wearing a full face shield when handling black powder and the loaded mechanism. Anyone else helping with the test should wear safety glasses while the mechanism is loaded.
    d. The piston is loaded into the mechanism chamber, followed by the spring.
2. Fasten the loaded mechanism securely to the bulkhead
3. Thread the chosen CO_2 cartridge into the bulkhead so that the tip is flush with the surface of the bulkhead
4. Fold and bag main parachute and main parachute lines. Attach main parachute assembly and drogue lines to bulkhead.
5. Attach e-match extension cables to e-match wires. Make sure to twist together the ends
6. Push assembly in to the recovery fuselage from the rear. Fasten the bulkhead set screws into the fuselage
7. Attach drogue parachute and nose cone. Fasten nose cone to fuselage with 3 nylon shear pins
8. In a safe outdoor location, duct tape recovery test setup to the ladder so that the fuselage is perpendicular to the ground. Fully extend the detonator cables so the detonator device is as far from the test apparatus as possible. Have the designated safety captain place the detonator on

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Test Lead: Benjamin Stadnik

the ground and stand guard to ensure no one touches it and no water is allowed to fall on the detonator (which could close the circuit and trigger an early detonation).

9. When the safety captain has confirmed the detonator disconnected and on the ground, the pyrotechnician will untwist the ends of the e-match, touch the ends of the detonator cables together (to dispel any static charge) and attach them to the e-match.
10. The pyrotechnician will now take the detonator, and after ensuring that the area is clear and all test personnel are at a safe distance, countdown the detonation and push in the detonator pin. If the detonation was successful, the apparatus is now safe to handle without a face shield.
11. In case of a misfire:
    a. With the pin pushed in, press the button on the detonator, which will send a larger current through the e-match.
    b. If the charge still does not go off, place the detonator on the ground and have the safety captain watch over it while the pyrotechnician checks the connections between the detonator and the e-matches.
    c. Attempt detonation again, following the same procedures.
    d. If, after multiple attempts, the charge does not go off, the pyrotechnician should bring the apparatus inside and carefully disassemble it.
12. After the test is complete, bring the apparatus inside and disassemble it. The old dummy match can be discarded, and the other should be kept to use as a dummy for future tests.

Test Results and Analysis

The 30g CO_2 cartridge misfired. The puncture pin mechanism did not rupture the cartridge, and instead the cartridge slowly leaked its contents. As this was the last 30g CO_2 in stock, another test could not be performed.

The black powder was increased to 0.4g for the next test. The 45g CO_2 detonated successfully, ejecting the nose cone and drogue parachute. (**Figure 1**)

Discussion

According to calculations, the 30g CO_2 cartridge should have enough compressed CO_2 to eject the nose cone and drogue parachute. It was unfortunate that the puncture mechanism misfired and that we did not have a substitute cartridge. The reason for failure was not the amount of black powder, but rather the condition of the puncture mechanism. AS many tests had run in this mechanism before, the cylinder had been clogged with black powder residue. The residue was compressed between the piston and the cylinder wall create much more friction than in previous tests. This test has taught us to always keep the puncture mechanism cylinder clean, and to replace the piston when it becomes warped.

However, the 45g CO_2 cartridge worked perfectly. 0.4g of black powder create a hole in the cartridge with the same diameter as the puncture pin. The release of gas had enough force to eject the nose cone approximately 2 meters from the fuselage. As a result, the drogue parachute was ejected successfully .

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Test Lead: Benjamin Stadnik

Conclusion

The 45g cartridge had sufficient energy to eject the nose cone a drogue parachute. The CO_2 puncture mechanism must be carefully maintained with the piston replaced after repeated use. Finally, 0.4g of black powder should be used for best puncture results.

Reference Figures:

Figure 1: Nose cone deployment test jig, left. Nose cone successfully deployed, right

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Date: 20 January, 2018
Test Lead: Benjamin Stadnik

UVic Rocketry Test Report

CO_2 Deployment Mechanism – Proof of Concept Test

20 January, 2018

Test Lead: Benjamin Stadnik (Safety Captain)

Associates: Shannon Dawson (Pyrotechnician)

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Date: 20 January, 2018
Test Lead: Benjamin Stadnik

Introduction

The Hyak-1 rocket has a target altitude of 30 000 ft AGL. At this altitude, the atmosphere is too thin to rely on large black powder charges to eject the drogue chute from the nose of the rocket. Instead, a canister of compressed CO_2 is evacuated into the upper half of the rocket to eject the drogue chute. To puncture the CO_2 canister, the recovery team has designed a mechanism that uses a much smaller black powder charge that will release the CO_2. This report assumes that the reader has seen or is familiar with the mechanism parts, but does not require a full understanding of the device.

Scope

This is a qualitative test to determine if the mechanism works as intended.

Due to the high cost of CO_2 canisters, a piece of masking tape will be used in place of the canister to prove that the puncture pin will pierce the CO_2 canister. This test does not account for the force needed to puncture the canister, or the exact amount of black powder that will be used in flight. The only goal for this test is to prove that the mechanism functions for how it was designed.

Terminology

e-match	A single-use electronic match that ignites when a current is applied.
Detonation chamber	The space between the piston and housing that is filled with black powder.
Detonator device	An electronic device that sends a current through the e-match when activated.
Recovery test tube	A spare section of fuselage with holes for mounting the recovery bulkhead.

Summary of Test Method

The CO_2 deployment mechanism is loaded with 0.1 g of black powder. Only one e-match is used for testing, and the second e-match hole is blocked with a dummy e-match. One piece of masking tape is place over the hole in the bulkhead to simulate the CO2 cartridge. In a safe location, the black powder charge is ignited with the detonator, pushing the puncture pin through the tape.

Materials

- 0.1 g black powder
- CO_2 deployment mechanism with fasteners
- Detonator device
- 1 live e-match and 1 dead e-match

Date: 20 January, 2018
Test Lead: Benjamin Stadnik

- Masking tape
- Recovery bulkhead
- Recovery test tube

Hazards

This test involves using black power to set off small-scale detonations in a contained environment. Safety glasses should be worn by all test personnel and anyone observing the detonation. A designated "Pyrotechnician" should be responsible for handling the black powder, connecting the apparatus to the detonator, and triggering the detonation. There should also be a designated "Safety Captain" to ensure the safety of the pyrotechnician and any bystanders, as well as having some other responsibilities outlined in the procedure.

Procedure

1. The CO_2 mechanism is set up as per standard test procedures (this test uses 0.1 g black powder):
    a. One e-match is set in the mechanism, and the second (redundant) e-match hole is blocked with a previously used "dummy" e-match.
    b. The dummy e-match is trimmed so it does not interfere with the rest of the apparatus. The live e-match ends are separated and then the exposed wires are twisted together to short the circuit (preventing any accidental detonation).
    c. Black powder is measured and placed in the black powder chamber in the piston. Safety Note: the pyrotechnician should be wearing a full face shield when handling black powder and the loaded mechanism. Anyone else helping with the test should wear safety glasses while the mechanism is loaded.
    d. The piston is loaded into the mechanism chamber, followed by the spring.
2. A piece of masking tape is placed over the hole where the CO_2 mechanism would be loaded. Be sure not to block the holes where the mechanism is attached.
3. Fasten the loaded mechanism securely to the bulkhead and place inside the recovery testing tube. For this test, the bulkhead does not need to be fastened in.
4. In a safe, outdoor location place the testing apparatus on the ground, and fully extend the detonator cables so the detonator device is as far from the test apparatus as possible. Have the designated safety captain place the detonator on the ground and stand guard to ensure no one touches it and no water is allowed to fall on the detonator (which could close the circuit and trigger an early detonation).
5. When the safety captain has confirmed the detonator disconnected and on the ground, the pyrotechnician will untwist the ends of the e-match, touch the ends of the detonator cables together (to dispel any static charge) and attach them to the e-match.
6. The pyrotechnician will now take the detonator, and after ensuring that the area is clear and all test personnel are at a safe distance, countdown the detonation and push in the detonator pin. If the detonation was successful, the apparatus is now safe to handle without a face shield.

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Test Lead: Benjamin Stadnik

7. In case of a misfire:
    a. With the pin pushed in, press the button on the detonator, which will send a larger current through the e-match.
    b. If the charge still does not go off, place the detonator on the ground and have the safety captain watch over it while the pyrotechnician checks the connections between the detonator and the e-matches.
    c. Attempt detonation again, following the same procedures.
    d. If, after multiple attempts, the charge does not go off, the pyrotechnician should bring the apparatus inside and carefully disassemble it.
8. After the test is complete, bring the apparatus inside and disassemble it. The old dummy match can be discarded, and the other should be kept to use as a dummy for future tests.

Test Results and Analysis

The mechanism deployed successfully and punctured the tape on the bulkhead. There was no damage to the outer housing, although the delrin piston was damaged slightly by the detonation, but not enough to cause concern. The black powder residue coated the the detonation chamber and part of the sides of the piston, making the apparatus sticky and somewhat difficult to disassemble. It was determined that pliers would be needed to remove the piston, and the housing and piston must be cleaned and dried between tests. During the test setup, the e-matches were found to be too tall when inserted upright, causing the spring and piston to sit too far out of the housing. Instead, they should be folded down to sit flat against the bottom of the detonation chamber. In this orientation, the e-match left scorch marks on the piston, however the damage was minimal enough to not be a concern.

Discussion

The test successfully proved that the mechanism works as intended, and provided some ideas for what to expect in future tests. The test procedure was proved to be effective, and takes very little time to prepare and execute an individual detonation. The setup allows the testing team to easily determine whether or not the test was successful, since it is easy to see if the material was punctured or not. To execute multiple tests, the mechanism parts will need to be cleaned between each test, but this only takes a few minutes and will not cause significant delays.

Conclusions

This proof of concept test was successful, as it showed that the mechanism worked as intended. It also provided expectations for for future tests, and established a standard for testing procedures, including safety standards and practices. The only minor setback was learning that the parts would need to be cleaned after each test. The next test following this will be to determine which shape of pin is ideal for puncturing the canister.

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Date: 5 May, 2018
Test Lead: Benjamin Stadnik

UVic Rocketry Test Report

CO_2 Mechanism – CO_2 Cartridge Thermal Test

5 May, 2018

Test Lead: Benjamin Stadnik (Recovery Lead)

Date: 5 May, 2018
Test Lead: Benjamin Stadnik

Introduction

The Hyak-1 rocket has a target altitude of 30 000 ft AGL. At this altitude, the atmosphere is too thin to rely on large black powder charges to eject the drogue chute from the nose of the rocket. Instead, a canister of compressed CO_2 is evacuated into the upper half of the rocket to eject the drogue chute. To puncture the CO_2 canister, the recovery team has designed a mechanism that uses a much smaller black powder charge that will release the CO_2. This report assumes that the reader has seen or is familiar with the mechanism parts, but does not require a full understanding of the device.

Scope

This is a quantitative test to determine if the CO_2 canister will be able to withstand the temperatures experienced in the desert of New Mexico, USA.

According to the manufacturer, the CO_2 cartridges are able to withstand temperatures up to 50°C [122°F]. On a previous launch, the ambient temperature of the interior of the rocket had been measured to be 48°C [118°F]. If the temperature increases, or if the rocket has to sit on the launch pad for an extended duration, then the interior of the rocket may exceed 50°C. It is important to determine if exceeding the manufacturer’s recommendations by a small margin will result in failure.

Summary of Test Method

The CO_2 cartridge will be submerged in water with a temperature greater than 50°C for a duration of at least 1 hour. Since the thermal conductivity of water is greater than air, submerging in water will cause greater stress on the cartridge than what can be expected in the desert of New Mexico.

Materials

- Metal bucket, lid
- CO_2 cartridge
- Masking tape
- Electric heating element
- Water bottle
- Infrared thermometer

Hazards

This test involves highly compressed CO_2. Safety glasses should be worn by all test personnel and anyone observing.

Date: 5 May, 2018
Test Lead: Benjamin Stadnik

Procedure

1. Tape the CO_2 cartridge to the underside of the plastic water bottle. (see **Figure 1**)(This will keep the CO_2 cartridge afloat, and away from contacting sides or bottom of the metal bucket)
2. Fill metal bucket with sufficient amount of water (so the CO_2 cartridge will not contact the bottom)
3. Heat water using the heating element
4. Once temperature reaches 55°C, remove bucket from heating element
5. Move bucket to safe location
6. Place CO_2 cartridge gently on surface of water and place lid over system
7. Move away from test apparatus
8. Check apparatus using infrared thermometer in 10 minute increments. If the temperature reduces below 50°C, add more hot water to restore the temperature to 55°C
9. After 1 hour, remove cartridge from system. Check for damage.

Test Results

The CO_2 cartridge survived after 1 hour submerged in water greater than 50°C

Data and Analysis

Maximum temperature: 56°C

Minimum temperature: 48°C

Duration of test: 1 hour, 6 minutes

Discussion

Over the 1 hour duration of this test, the temperature varied little. The system reached a peak temperature of 56°C, and the lowest temperature being 48°C. The system only required replenishing once during the hour long test. Upon removal of the CO_2 cartridge, there were no visible signs of stress or bulging, and the temperature quickly returned to room temperature.

Conclusion

According to the manufacturer, a 45g CO_2 cartridges is only rated to 50°C. However, tests proved that the cartridges will be able to withstand temperatures over 50°C for at least an hour. Given that the stresses induced in this test is greater than what would be experience in competition, it is reasonable to

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assume the cartridges will survive the 48°C heat experienced in the deserts of New Mexico, USA. **It is required that these cartridges be stored in a closed container, under the shade of a tent. Direct sunlight may increase the temperature far beyond 50°C, which will result in failure.**

Reference Figures:

Figure 1: CO_2 cartridge attached to water bottle that acts as a floatation device

Figure 2: Heating up water and checking temperature with infrared thermometer

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Date: 14 April, 2018
Test Lead: Benjamin Stadnik

UVic Rocketry Test Report

CO_2 Deployment Mechanism – Vacuum Chamber Test

14 April, 2018

Test Lead: Benjamin Stadnik (Safety Captain)

Associates: Shannon Dawson (Pyrotechnician), Garret Krest, Kamal Fouda

Date: 14 April, 2018
Test Lead: Benjamin Stadnik

Introduction

The Hyak-1 rocket has a target altitude of 30 000 ft AGL. At this altitude, the atmosphere is too thin to rely on large black powder charges to eject the drogue chute from the nose of the rocket. Instead, a canister of compressed CO_2 is evacuated into the upper half of the rocket to eject the drogue chute. To puncture the CO_2 canister, the recovery team has designed a mechanism that uses a much smaller black powder charge that will release the CO_2. This report assumes that the reader has seen or is familiar with the mechanism parts, but does not require a full understanding of the device.

Scope

This is a qualitative test to determine if the mechanism works as intended at in a low pressure environment where oxygen is less abundant.

At apogee, the atmosphere is much thinner than at ground level. The worst-case-scenario is 0.3 atm, which corresponds to approximately -0.7 bar gauge pressure at sea level. To ensure that the CO_2 mechanism will deploy properly in flight, the mechanism is tested inside a vacuum chamber at -0.7 bar. This test is very similar to other CO_2 mechanism tests, only the recovery test tube has been modified to act as a vacuum chamber.

Terminology

E-match	A single-use electronic match that ignites when a current is applied.
Detonation chamber	The space between the piston and housing that is filled with black powder.
Detonator device	An electronic device that sends a current through the e-match when activated.
Recovery test tube	A spare section of fuselage with holes for mounting the recovery bulkhead.

Summary of Test Method

An description of the test procedure describing essential features and omitting details. Should only be included if full procedure is very long and complicated.

Materials

- 0.4g, 0.5g, and 0.75g of black powder
- CO_2 deployment mechanism with fasteners
- Detonator device
- 1 live e-match and 1 dead e-match

Date: 14 April, 2018
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- Recovery bulkhead
- Recovery test tube
- 45g CO_2 cartridge
- Vacuum chamber end plates (one flat, one with hose fitting)
- Non-porous putty
- Vacuum pump
- Hose with valve

Hazards

This test involves using black power to set off small-scale detonations in a contained environment. Safety glasses should be worn by all test personnel and anyone observing the detonation. A designated "Pyrotechnician" should be responsible for handling the black powder, connecting the apparatus to the detonator, and triggering the detonation. There should also be a designated "Safety Captain" to ensure the safety of the Pyrotechnician and any bystanders, as well as having some other responsibilities outlined in the procedure.

Procedure

1. The CO_2 mechanism is set up as per standard test procedures (this test uses 0.4g of black powder, then a second test with 0.5 g):
    a. One e-match is set in the mechanism, and the second (redundant) e-match hole is blocked with a previously used "dummy" e-match.
    b. The dummy e-match is trimmed so it does not interfere with the rest of the apparatus. The live e-match ends are separated and then the exposed wires are twisted together to short the circuit (preventing any accidental detonation).
    c. Black powder is measured and placed in the black powder chamber in the piston. Safety Note: the pyrotechnician should be wearing a full face shield when handling black powder and the loaded mechanism. Anyone else helping with the test should wear safety glasses while the mechanism is loaded.
    d. The piston is loaded into the mechanism chamber, followed by the spring.
2. Fasten the loaded mechanism securely to the bulkhead.
3. Thread the 30g CO_2 cartridge into the bulkhead so that the tip is flush with the surface of the bulkhead.
4. Place bulkhead assembly inside the recovery testing tube. Fasten the bulkhead set screws into the recovery test tube. Cover the set screws with duct tape to prevent leaks.
5. Use putty to attach the end plates to the test tube, making sure that there are no gaps for air to pass through. The plate with the hose fitting should be on the end of the tube marked "top." The e-match wires pass between the upper plate and the test tube, and should be surrounded on all sides by putty where they pass through the seal. Losely tape the top and bottom plate so that they can't fly off when the CO_2 is released.

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6. If the hose connected to vacuum pump is long enough to reach a safe outdoor location, the apparatus should be brought outside before the chamber is evacuated. Otherwise, the pyrotechnician should take extra caution when transporting the apparatus from the pump to the testing location.
7. Connect the vacuum pump to the hose fitting. The pyrotechnician should open the valve on the hose, then another person activates the vacuum pump. When the desired pressure (-0.7 barg) is reached, the person operating the pump alerts the pyrotechnician, who will then shut the valve. The pump can now be turned off.
8. Taking extreme precaution, the pyrotechnician should listen for any leaks, and seal them with putty. If there are any leaks, repeat step 7 & 8. Once the vacuum chamber has been sealed and set to the correct pressure, the person operating the pump can disconnect the hose so that the apparatus can be moved to the testing location.
9. In a safe, outdoor location place the testing apparatus upright on the ground. Place the hose so that if the apparatus tips, it will fall away from any bystanders or test personnel. Fully extend the detonator cables so the detonator device is as far from the test apparatus as possible. Have the designated safety captain place the detonator on the ground and stand guard to ensure no one touches it and no water is allowed to fall on the detonator (which could close the circuit and trigger an early detonation). (see **Figure 1**)
10. When the safety captain has confirmed the detonator disconnected and on the ground, the pyrotechnician will untwist the ends of the e-match, touch the ends of the detonator cables together (to dispel any static charge) and attach them to the e-match.
11. The pyrotechnician will now take the detonator, and after ensuring that the area is clear and all test personnel are at a safe distance, countdown the detonation and push in the detonator pin. If the detonation was successful, the apparatus is now safe to handle without a face shield.
12. In case of a misfire:
    a. With the pin pushed in, press the button on the detonator, which will send a larger current through the e-match.
    b. If the charge still does not go off, place the detonator on the ground and have the safety captain watch over it while the pyrotechnician checks the connections between the detonator and the e-matches.
    c. Attempt detonation again, following the same procedures.
    d. If, after multiple attempts, the charge does not go off, the pyrotechnician should bring the apparatus inside and carefully disassemble it.
13. After the test is complete, bring the apparatus inside and disassemble it. The old dummy match can be discarded, and the other should be kept to use as a dummy for future tests.

Test Results and Analysis

The first test, using 0.4 g of black powder, successfully punctured the mechanism while under vacuum. Upon inspection of the spent CO_2 canister, the surface around the puncture hole was deformed inward, and the hole itself was not very large. Although the detonation was successful, and the CO_2 release was relatively fast, it was not a clean puncture as desired. In effort to obtain a larger hole and improve the

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Test Lead: Benjamin Stadnik

performance of the CO_2 ejection system, a second test was performed with 0.5 g of black powder. This resulted in a much faster release of CO_2 and a clear hole in the canister that matched the full diameter of the puncture pin. Finally, a charge of 0.75g was tested successfully to increase the factor of safety to 1.5.

Discussion

This test proved that the CO_2 deployment mechanism can successfully puncture the CO_2 cartridge that will eject Hyak-1's drogue parachute. Although the first test was technically successful, the small size of the puncture hole made it uncertain whether the CO_2 ejection would be fast enough to push off the nose cone and deploy the drogue. For this reason, a second test was performed with 0.5 g black power, yielding much more promising results. Finally, a third test determined that a charge of 0.75g was able to cleanly puncture the CO_2 cylinder with the greatest amount of success, with the benefit of and added safety factor of 1.5. Since the reduced pressure at apogee is the main factor affecting the black powder combustion, this vacuum chamber test is sufficient to decide the amount that should be used in flight.

Conclusion

This test was to determine if the mechanism will work as intended at 30 000 ft AGL, where the low pressure makes oxygen less abundant. After three iterations of the tests, it was determined that the mechanism will function correctly, and the amount of black powder to be used in-flight is 0.75 g.

Reference Figures

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Date: 14 April, 2018
Test Lead: Benjamin Stadnik

Figure 1: Vacuum chamber test setup

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Date: March 17, 2018
Test Lead: Shannon Dawson

UVic Rocketry Test Report

CO_2 Mechanism/Pyrelease Interference Test

March 17, 2018

Test Lead: Shannon Dawson (Pyrotechnician)

Associates: Kamal Fouda (Safety Captain)

Date: March 17, 2018
Test Lead: Shannon Dawson

Introduction

The Hyak-1 rocket has a target altitude of 30 000 ft AGL. At this altitude, the atmosphere is too thin to rely on large black powder charges to eject the drogue chute from the nose of the rocket. Instead, a canister of compressed CO_2 is evacuated into the upper half of the rocket to eject the drogue chute. To puncture the CO_2 canister, the recovery team has designed a mechanism that uses a much smaller black powder charge that will release the CO_2. A second device, known as the pyrelease, releases the main parachute when the rocket descends to 1500 ft AGL. This report assumes that the reader has seen or is familiar with the both mechanisms, but does not require a full understanding of the device.

Scope

This is a qualitative test to determine if the CO_2 ejection will damage the pyrelease or interfere with its proper detonation.

This test will combine a simple CO_2 ejection test with a pyrelease test. The recovery test tube will be assembled with a CO_2 mechanism, CO_2 cartridge, pyrelease, and a short length of Novabraid cord that can be loaded with weights. With the loaded pyrelease in place, the CO_2 mechanism is activated. Following its successful deployment, the test apparatus is suspended by the pyrelease from a ladder, with a weighted bucket hung from the Novabraid to simulate the weight of the rocket. The pyrelease is then tested to determine if the CO_2 ejection caused any issues with its detonation. The success of this test will also be the final checkpoint towards a full recovery system deployment test.

Terminology

e-match	A single-use electronic match that ignites when a current is applied.
Detonation chamber	The space between the piston and housing that is filled with black powder.
Detonator device	An electronic device that sends a current through the e-match when activated.
Pyrelease	A pyrotechnic decoupling link developed by UVic Rocketry.
Recovery test tube	A spare section of fuselage with holes for mounting the recovery bulkhead.

Summary of Test Method

The CO_2 deployment mechanism is loaded with 0.45 g of black powder. Two e-matches are used for testing: one for the CO_2 mechanism and one for the pyrelease, and the second e-match hole in each device is blocked with a used e-match. The 45 g cartridge is threaded into the bulk head so that the tip of the cartridge will be flush with the opposite surface of the bulkhead. Quick links are attached to the two release pins on either side of the pyrelease, and one of the links is attached to an eyebolt on the

Date: March 17, 2018
Test Lead: Shannon Dawson

bulkhead. The test is setup for the first part (the CO_2 mechanism) has the test tube standing upright on the ground so that the CO_2 gases are exhausted upwards in case of unexpected projectiles. The CO_2 mechanism is triggered, and the test setup is quickly rearranged for the next part.

For the second part of the test (the pyrelease), the test tube is hung from a rope on a ladder by attaching the free quick link to the rope. A short piece of Novabraid (about 2 ft) is secured to another eyebolt and threaded through the unused meant to house the second CO_2 canister, and a weighted bucket equivalent to the total mass of Hyak-1 is suspended from the bulkhead via the Novabraid. The pyrelease is activated, and inspected for damage or other indications of improper deployment.

Materials

- 0.45g black powder
- CO_2 deployment mechanism with fasteners
- Detonator device
- 2 live e-matches and 2 dead e-matches
- Recovery bulkhead
- Recovery test tube
- 45g CO_2 cartridge
- pyrelease
- 3 quick links
- fishing line
- approx. 2 ft Novabraid cord
- free standing ladder with hanging ropes
- weighted bucket

Hazards

This test involves using black power to set off small-scale detonations in a contained environment. Safety glasses should be worn by all test personnel and anyone observing the detonation. A designated “Pyrotechnician” should be responsible for handling the black powder, connecting the apparatus to the detonator, and triggering the detonation. There should also be a designated “Safety Captain” to ensure the safety of the Pyrotechnician and any bystanders, as well as having some other responsibilities outlined in the procedure.

Procedure

1. The CO_2 mechanism is set up as per standard test procedures (this test uses 0.45g of black powder):
    a. One e-match is set in the mechanism, and the second (redundant) e-match hole is blocked with a previously used “dummy” e-match.

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   b. The dummy e-match is trimmed so it does not interfere with the rest of the apparatus. The live e-match ends are separated and then the exposed wires are twisted together to short the circuit (preventing any accidental detonation).
   c. Black powder is measured and placed in the black powder chamber in the piston. Safety Note: the pyrotechnician should be wearing a full face shield when handling black powder and the loaded mechanism. Anyone else helping with the test should wear safety glasses while the mechanism is loaded.
   d. The piston is loaded into the mechanism chamber, followed by the spring.
2. Fasten the loaded mechanism securely to the bulkhead
3. Thread the 30g CO_2 cartridge into the bulkhead so that the tip is flush with the surface of the bulkhead
4. Place bulkhead assembly inside the recovery testing tube. Fasten the bulkhead set screws into the recovery test tube
5. The pyrelease is set up as per standard test procedures (this test uses 0.45g of black powder):
   a. The plunger is slid into the main housing of the pyrelease, with a quick link looped around each of the pins.
   b. The black powder is measured and placed in the chamber. Safety Note: the pyrotechnician should be wearing a full face shield when handling black powder and the loaded mechanism. Anyone else helping with the test should wear safety glasses while the mechanism is loaded.
   c. One e-match is set in the mechanism, and the second (redundant) e-match channel is blocked with a previously used “dummy” e-match. The back panel of the pyrelease is screwed on, securing the e-matches in place.
   d. The dummy e-match is trimmed so it does not interfere with the rest of the apparatus. The live e-match ends are separated and then the exposed wires are twisted together to short the circuit (preventing any accidental detonation).
   e. A piece of fishing line is looped twice through the ends of the pins and tied to secure the [piece] until detonation.
6. The pyrelease is attached to an eyebolt on the bulkhead with either of the quick links that were attached in the previous step. Loop the tether line that holds together the two pieces of the pyrelease through the same quick link to prevent the pyrelease from becoming a projectile after detonation. Leave the pyrelease loosely inside the tube.

Part 1:

7. In a safe, outdoor location place the testing apparatus on the ground in a position where the exhaust gasses will be released in the upwards direction. Stand the testing ladder nearby for later use. Fully extend the detonator cables so the detonator device is as far from the test apparatus as possible. Have the designated safety captain place the detonator on the ground and stand guard to ensure no one touches it and no water is allowed to fall on the detonator (which could close the circuit and trigger an early detonation).
8. When the safety captain has confirmed the detonator is disconnected and on the ground, the pyrotechnician untwists the ends of the e-match connected to the CO_2 mechanism, touches the

ends of the detonator cables together (to dispel any static charge), and attaches them to the e-match.

9. The pyrotechnician will now take the detonator, and after ensuring that the area is clear and all test personnel are at a safe distance, countdown the detonation and push in the detonator pin.
10. In case of a misfire:
    a. With the pin pushed in, press the button on the detonator, which will send a larger current through the e-match.
    b. If the charge still does not go off, place the detonator on the ground and have the safety captain watch over it while the pyrotechnician checks the connections between the detonator and the e-matches.
    c. Attempt detonation again, following the same procedures.
    d. If, after multiple attempts, the charge does not go off, the pyrotechnician should bring the apparatus inside and carefully disassemble it.

Part 2:

11. Once the CO_2 canister appears to have depressurized, the pyrotechnician should disconnect the detonator cables and quickly but cautiously move the test apparatus over to the ladder. Have the designated safety captain place the detonator on the ground and stand guard to ensure no one touches it and no water is allowed to fall on the detonator (which could close the circuit and trigger an early detonation).
12. Hang the pyrelease and test tube from a rope on the ladder by attaching the free quick link to a loop in the rope. Tie a loop in the Novabraid cord attached to the bulkhead and attach the weighted bucket to the loop with a quick link. If necessary, adjust the loop so that the bucket is close to, but not touching the ground.
13. When the safety captain has confirmed the detonator is disconnected and on the ground, the pyrotechnician untwists the ends of the e-match connected to the pyrelease, touches the ends of the detonator cables together (to dispel any static charge), and attaches them to the e-match.
14. The pyrotechnician will now take the detonator, and after ensuring that the area is clear and all test personnel are at a safe distance, countdown the detonation and push in the detonator pin.
15. In case of misfire, follow the same procedure as in part 1.
16. After the test is complete, bring the apparatus inside and disassemble it. The old dummy matches can be discarded, and the others should be kept to use as a dummies for future tests.

Test Results and Analysis

Both mechanisms deployed successfully; the CO_2 ejection did not interfere with the pyrelease. Additionally, the pyrelease sustained no visible damage.

Discussion

Date: March 17, 2018
Test Lead: Shannon Dawson

The test successfully proved that the CO_2 ejection would not damage the pyrelease or interfere with its proper deployment. The transition between part 1 and part 2 was done in less time than the expected descent time from apogee to 1500 ft, meaning that any potential temporary effects (such as cooling from the CO_2 release) would still be present. Due to the apparatus being adjusted between tests, it is possible that the test results could be affected, however this would most likely result in a false negative result than a false positive, meaning that a successful test should be a reliable one. If the test results were negative (i.e. the pyrelease was damaged or did not deploy successfully), then another test would be performed to confirm the results.

Conclusion

This test was to ensure that the CO_2 mechanism deployment and the resulting CO_2 ejection would not interfere with the proper deployment of the pyrelease or cause any damage to its components. If future testing is necessary, the procedure should be revised to reduce handling between the two detonations. Since this test was successful, it is now safe to go ahead with a full system deployment test.

Pyrelease Under Tension

Date: 20-May-2016 **Location:** Pathway outside of ELW near Aero room

Members Present:

Benjamin Stadnik, Shannon Dawson, Sachi Premathilaka, Kyler Gray, Philipp Sharikov, Josiah Stefani, Jack Shudian

Report By: Benjamin Stadnik

Flight Condition Tested:

Main parachute deployment via pyrelease (pyrotechnic release system). The pyrelease will be under tension from the drogue for the duration of the descent of the rocket. At 1500 ft AGL, the pyrelease will separate drogue from the rocket, pulling the main parachute out from rocket.

Test Objective:

To test if the pyrelease can cleanly separate under drogue tension.

Materials:

- Pyrelease
- Bucket of sand weighing 16kg
- 0.3 grams black powder
- Ladder
- Rope
- Detonator and wire
- Fishing line
- 2 quick links
- 2 e-matches

Test Procedure:

1. Fill pyrelease with black powder
   - **a.** Insert quick links on both ends and close pyrelease
   - **b.** Unscrew 4 bolts on rear of blast chamber
   - **c.** Fill chamber with 0.3 grams of black powder; insert 2 e-matches
   - **d.** Close chamber; screw in bolts
   - **e.** Thread fishing line through the pins so pyrelease doesn't fall apart during handling
2. Take ladder, rope, bucket, pyrelease, detonator, and wire to remote location
3. Tie rope onto ladder
4. Hang bucket from ladder, with pyrelease holding the bucket to the rope (**Figure 1** and **Figure 2**)
5. Attach leads of detonator to pyrelease
6. Detonate

Test Results:

The resulting explosion cleanly separated pyrelease halves. (**Figure 3**) The bucket was separated from the ladder.

Observations:

Although under tension, the charge had enough force to cleanly separate the two halves of the pyrelease with ease. It was found that the pyrelease must be connected to the quick links upon separation or else it wont be attached to the rocket.

Conclusion:

Flight condition successful. Pyrelease is capable of separation under tension.

Reference Figures:

Figure 1: The 16kg bucket hanging from the ladder

Figure 2: The pyrelease holding the bucket against gravity.

Figure 3: Clean separation of pyrelease, dropping the bucket.

Seam Tensile Test

Date: 06-Mar-2017 **Location:** Tensile Machine Room

Members Present: Josiah Stefani, Kali Salmas, Erin Wikenheiser, Benjamin Stadnik, Jack Shudian

Report by: Benjamin Stadnik

Flight Condition Tested:

Tensile test of 1.9 oz ripstop seam strength

Test Objective:

To determine the relative strength of 2 different seam styles. To compare the old-seam (**Figure 1**) strength to the new-seam (**Figure 2**) strength and compare both of those to the absolute strength of the fabric.

Materials:

- Access to tensile test machine room
- Custom tensile strength test jig (**Figure 3**)
- 3 sheets of 5"x20" 1.9oz 5mm grid ripstop nylon. (**Figure 4**)
- Sewing machine and 100% polyester thread
- Safety glasses

Test Procedure:

1. Cut 3 ripstop nylon 5"x20" sheets (ideally 2 sheets from one colour and one sheet of another colour)
2. Cut 2 out of 3 sheets in half; leave the third as a control
3. Sew old-style seam into one sheet
4. Sew new-style seam into the second
5. Obtain access to tensile strength room, don safety glasses
6. Fasten sewed sheet to jig, making sure to tighten well
7. Fasten rig to machine (**Figure 5**)
8. Use machine to test fabric strength and record sheer force
9. Do steps 6-8 for each test subject
10. Compare results to the control fabric to obtain a percent strength of each seam style

Test Results:

Using 5 inches cross-sectional ripstop nylon, we obtained the following results:

	Control (no) seam	**Old-style seam**	**New-style seam**
Shear strength (lbs):	340	175	284
Shear strength per unit length (lbs/inch):	68	35	56.8

% strength of old-style seam = 35/68*100 = 51.5%

% strength of new-style seam = 58.6/68*100 = 86.2%

There is a 35% increase in seam strength with the new-style seam.

Observations:

The control fabric seam failed at 340 lbs. This is the absolute strength of the fabric without stitches. The old-style seam failed due to the fabric. There was not enough surface area for the stitches to hold on to and the fabric simply sheared away. The new-style seam compensated for this weakness by interlocking fabric pieces together. Therefore, the fabric could hold on much longer until the threads themselves sheared. Interestingly, after the new-style seam failed, the intermediate stitch used in the sewing process continued to hold the fabric together.

Conclusion:

The old-style seam is 51.5% the strength of the unsewn fabric. The new-style seam can withstand 86.2% of the load the unsewn fabric can. Therefore, the new-style seam gave us a 35% strength increase over the old-style seam.

In conclusion, it is recommended to use this new-style of seam as it is far superior in strength.

Reference Figures:

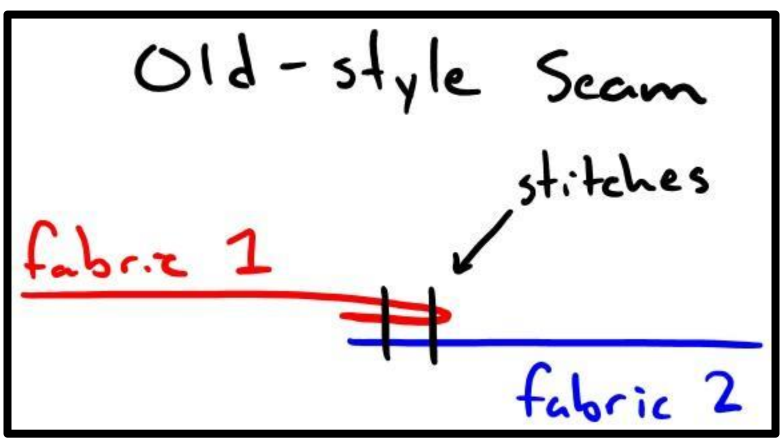

Figure 1: Old-style seam used on previous drogue parachute

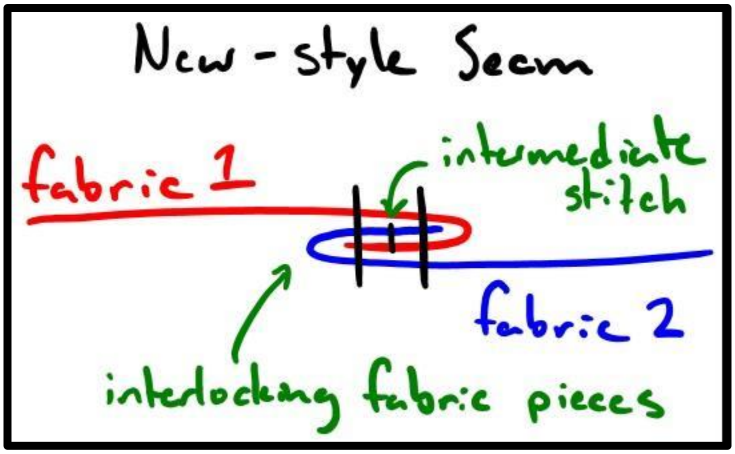

Figure 2: New-style seam


Figure 3: Custom test jig designed by Josiah Stefani. Fabric is squeezed between cylinder and block.

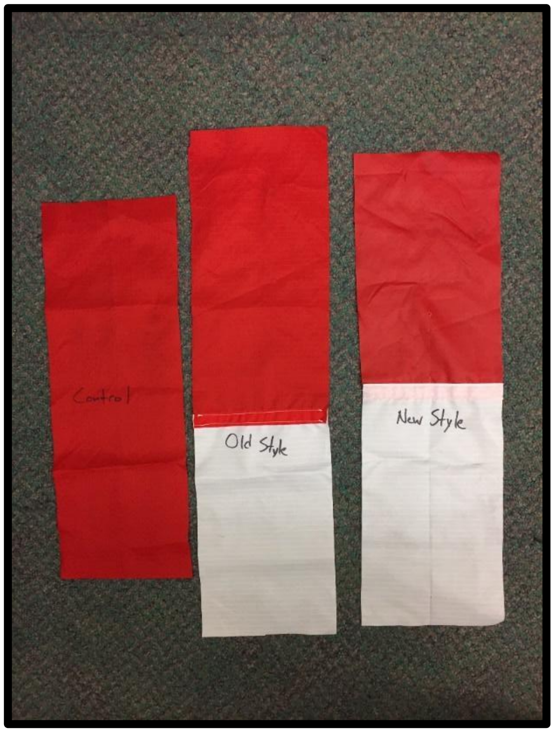

Figure 4: 5”x20” Test templates with the different seam styles

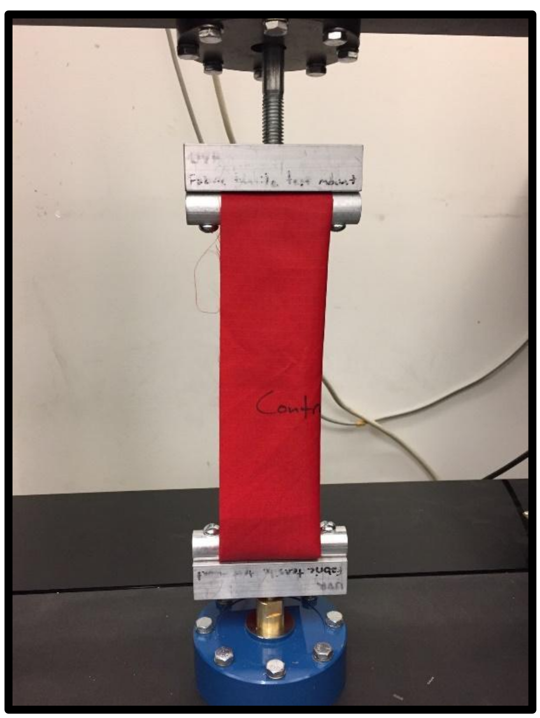

Figure 5: Jig setup on tensile test machine

UVic Rocketry Test Report

GNC– Raven3 E-Match Activation Test

8 May, 2018

Test Lead: Alex Schell (GNC Lead)

Introduction

The Hyak-1 rocket uses two boards to ensure proper deployment of the parachutes at apogee and a precise altitude for the main. The Featherweight Altimeters Raven3 is used as the main one of these boards, due to its feature-richness and ease of use. Deployment is done via black powder charges activated by e-matches, which are activated by applying current to them. For safety, tests for GNC only are run with e-matches.

Scope

This test is done as prerequisite for the main integrated payload test, and is used to ensure that the board will successfully ignite the charges to pierce the CO2 canisters. The Raven3 has a built in testing function which simulates a flight on each of it’s sensors, and therefore activates charges based on the settings programmed onto the board through the featherweight software. The test also allows GNC members to become familiar with the beep patterns that the board uses to signal its status.

Terminology

e-match	A single-use electronic match that ignites when a current is applied.
GNC	Guidance, Navigation, and Control: Uvic Rocketry’s avionics subsystem.

Summary of Test Method

The Raven3 is hooked up the battery and charges as it would be in the rocket, using a 9v battery and terminal block, the raven is then connected to via USB to a laptop with Featherweight's programming software installed. This software is used to then set the board using the settings that would be used in the actual flight, and the live data from the board is monitored on the laptop to ensure that the sensors are working properly. After this, the board is run through it’s test function through the laptop, and checked to ensure that the e-matches ignite at the correct altitude and at apogee.

Materials

- 2x e-matches
- Raven3
- Avionics mounting board
- Assorted wires
- 2x 9V batteries
- USB cable
- Laptop with Featherweight software

Hazards

Due to not using black powder, the risks of the test are minimized. However, the e-matches are still considered a fire hazard, and steps are taken to ensure that they are attached to the circuitry for as little amount of time as possible. During the test itself, the e-matches are pointed out a 3rd-story window to ensure the materials around them to possibly ignite are minimized.

Procedure

1. Mount Raven3 and other components to avionics board
2. Connect Raven3 main and apogee control wires to terminal block
3. Connect switch to terminal block and Raven3
4. Attach battery, turn on switch
5. Connect USB to Raven3 and laptop
    a. Check all settings with Recovery to ensure proper settings.
    b. Write these settings to the Raven3
6. Turn off switch
7. Connect e-matches to power terminal and corresponding signal terminals
8. Place board such that the e-matches are away from any flammable materials
9. Turn on switch
10. Run Raven3 simulation
    a. Activate flight mode, listen to beeps to ensure correct setup, note for pre-flight checks
    b. Hit Launch button to simulate 9 g burn
    c. After a few seconds to ensure we hit correct apogee, hit coast to simulate coast
    d. Watch apogee e-match to ensure ignition at apogee
    e. After apogee, watch to ensure main ignition at correct altitude
    f. After main, abort simulation
11. Turn off switch, disconnect e-matches and dispose of

Test Results

All tests were successful, with apogee deploy and main deploy occuring as required on both boards. Both boards set to same deploy settings, and first board was calibrated. Beep mode for pre-flight checked and noted below. Apogee deployed as required, and main deployed at 1500ft AGL as required. Furthermore, readings from the board sensors were within expectations.

Data and Analysis

Beep pattern:

For dual deployment HIGH BEEP HIGH BEEP LOW BEEP LOW BEEP.

Discussion

Test confirms that system will deploy correctly for the integration test, and therefore for the actual launch. Beep pattern conforms to that seen in the manual, so for 3 e-matches we will have a beep pattern of HIGH BEEP HIGH BEEP HIGH BEEP LOW BEEP LOW BEEP LOW BEEP.

Conclusion

As a test to check if the Raven3 is ready for integration, this test passed all goals we have set for. If time permits, possible future tests could include the vacuum chamber to ensure the entire system works without relying on the on-board simulation. However, due to the successful activation of the e-matches and proper readings off the sensor live readings, the Raven3 can be considered ready for flight.

*** This test procedure template is largely based on “Form and Style for ASTM Standards” from ASTM International, which can be accessed at:
https://www.astm.org/bluebook_FormStyle111017.pdf ***

UVic Rocketry Test Report

StratoLoggerCF E-Match Activation Test

19 May, 2018

Test Lead: Alex Schell (GNC Lead)

Introduction

The Hyak-1 rocket uses two boards to ensure proper deployment of the parachutes at apogee and a precise altitude for the main. The StratoLoggerCF by PerfectFlite is used as our backup board in case of wiring or sensor failure on our main board (the Raven3), so that main and apogee charges can be deployed regardless. The main factors for choosing the StratoLoggerCF were its simplicity, cost and the fact we have used its predecessor, - the HiAlt45k - before successfully.

Scope

Due to the simplicity of the StratoLoggerCF, tests had to be performed by using a pressure simulation for the flight. The StratoLoggerCF has a recommended method to test main and apogee activation, which is used to check the operation of the board and the wiring. The test also helps us become familiar with beep pattern used to confirm settings on the pad.

Terminology

e-match	A single-use electronic match that ignites when a current is applied.
GNC	Guidance, Navigation, and Control: Uvic Rocketry's avionics subsystem.
SL	StratoLoggerCF

Summary of Test Method

The SL is hooked up to a barrier block and e-matches as it would be before launch, and the SL is then placed within the pressure chamber, which is sealed around the wires. After powering on the board via a switch and the beep pattern confirmed, the test proceeds. For both tests, vacuum is applied to the chamber via venturi effect, which brings up the board to a simulated altitude based on pressure. First, the main e match is disconnected, as to test the apogee. The board is then brought up to altitude, and then allowed to return to normal, which should make the charge activate. The same process is repeated with the main charge connected.

Materials

- 2x e-matches
- StratoLoggerCF
- Assorted wires
- 9V battery
- Barrier block terminal
- Switch
- Pressure chamber container
- Venturi effect attachment

Hazards

Due to not using black powder, the risks of the test are minimized. However, the e-matches are still considered a fire hazard, and steps are taken to ensure that they are attached to the circuitry for as little amount of time as possible. The test also takes place outside on concrete to avoid fire hazards. This also protects against the chance of the pressure chamber imploding, as it removes the enclosed space and risk to others. To further protect test participants, the test is performed while wearing safety glasses.

Procedure

1. Check SL for defects
2. Wire up power and charge ports on board to barrier block
3. Wire up switch to board
4. Attach battery with connector to appropriate terminal blocks for power
5. Turn on switch, ensure board powers on
6. Power off
7. Attach apogee e-match only to apogee barrier block terminals
8. Move outside
9. Attach venturi pump to top part of vacuum chamber
10. Place board inside chamber, seal chamber
11. Bring chamber to target pressure by turning on air hose
12. After max, turn off air and allow to return to normal, checking for ignition
13. Get board out, power off, and switch e-matches for main deployment
14. Repeat step 9-12 for main charge

Test Results

Both tests were successful, with main and apogee both deploying as expected during their relevant tests. However, the chamber had difficulty reaching max altitude, and seal would sometimes fail, causing a . Also noted that a expected slight delay is incurred with deployment during testing, due to board having a machlock feature.

Data and Analysis

Beep Pattern:

For dual deployment we will get 3 quick beeps to signal all wires connected properly.

Delay In Charges:

Cause by feature on board, expected during test [1], safe to classify as normal deployment.

Discussion

Test confirms that board will work in flight. Beep pattern noted and used for checklists. Improvements needed for vacuum chamber for future flights, especially at higher altitudes.

Conclusion

We feel that the StratoLoggerCF is good to use in flight, as both deployments were successful. Moving forward however, improvements should be made to the test equipment itself to allow for easier tests, as time was wasted on false starts due to leakage in the seal for the chamber. A more powerful vacuum pump should also be acquired, to prepare for higher altitudes in future tests.

References

[1] *StratoLoggerCF* users manual, PerfecFlite
http://www.perfectflite.com/Downloads/StratoLoggerCF%20manual.pdf

*** This test procedure template is largely based on “Form and Style for ASTM Standards” from ASTM International, which can be accessed at: https://www.astm.org/bluebook_FormStyle111017.pdf ***

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UVic Rocketry Prescribed Tests

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Date: March 9, 2018
Test Lead: Benjamin Klammer

UVic Rocketry Test Report

Hyak-1 Fin Static Bending Loading Test

January 26, 2018

Test Lead: Benjamin Klammer

Associates: Noah Mar, Aaron Latorre, Meet Dobariya, Keagan Shedden, Sebastian Panchyrz

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Date: March 9, 2018
Test Lead: Benjamin Klammer

Introduction

The MVP/Skookum style rocket fins are being redesigned to ensure they do not fail under the new supersonic flight conditions that Hyak-1 is expected to undergo. This test aims to determine whether rocket fin prototypes will fail under static loads similar to those predicted for the flight. This test is being conducted for the Propulsion and Aerostructure subsystems for the Hyak-1 rocket.

Scope

The objective of this test is to determine under what conditions the fins will fail when subject to a transverse load causing bending.

This test simulates lifting forces as a result from corrections to deviations from the flight path due to a launch rail angle of 84°, cross winds, and slight asymmetries in the rocket's structure. The gained data will be used as a benchmark to determine if the fins are strong enough to survive the flight. This is done by loading the top edge of the fin with increasing weights until the fin fails. Calculations were performed using aerodynamic data including the lift coefficient from Aerolab and different angles of attack and wind speeds. The maximal occurring force during the flight is 568 N, encountered when the rocket flies at Mach 2 with a gust of 10 m/s. This calculation considers the worst case scenario, hence the greatest expected force is 341 N acting if the rocket is flying at Mach 2 with a wind speed of 6 m/s. Since this rocket is only expected to reach a velocity of Mach 1.86, both calculations already have some conservative estimations built in. For the fins to withstand the forces a strength target of 588 N or 60 kg was set. These result in safety factors of 1.03 for the conservative worst case scenario and 1.71 for the expected flight performance. Therefore, if a fin design consistently supports more than 60 kg of weight on the top edge, it is considered strong enough for flight. This test assumes that a line load near the top edge of the fin is a conservative estimate of the aerodynamic force, which will act over the entire area of the fin during flight.

This test is also used for validating the geometrical design of the fin, optimizing number of carbon fiber layers and layup sequence, determining if manufacturing methods are consistent, and determining if low cycle fatigue plays a role in failure. This is done by noting the weight at failure for a variety of fin designs and observing the failure mechanisms. Carbon fiber failure modes are inconsistent regardless of how consistent composite manufacturing is, so care must be taken to gather sufficient data points for a given fin design before drawing conclusions about that fin's performance.

Referenced Documents

Fin Strength Testing.xlsx
Fin Tracking.xlsx
MVP wit S-Fin.xlsx
Fin Naming Convention.docx

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Date: March 9, 2018
Test Lead: Benjamin Klammer

Terminology

PLA	Polylactic Acid, the thermoplastic polymer that is used as the 3D print material
Fairing	The part of the fin connecting the airfoil surface to the body of the rocket
Semi-span	Distance from base of fin to tip of fin (also known as panel span)

Summary of Test Method

Weights are suspended from horizontally fixed fins to simulate side loading. The suspended weight is increased until failure. The weight at failure is recorded for each fin, and the failure mechanism is noted.

Materials

- Various weights (90 kg total, ideally in steps of 2-3 kg)
- Tote bags for holding weights
- 4 C-clamps (2 for clamping fins, 2 for clamping jig)
- Fin test jig
- Various fins to be tested
- Table to mount jig to
- Several large pieces of plywood (to protect floor from falling weights)
- Small pieces of wood (to protect fin from clamps)
- 3D printed fin spacers
- Bolts for attaching fin to jig (4-40 for old fins, 6-32 for new fins)

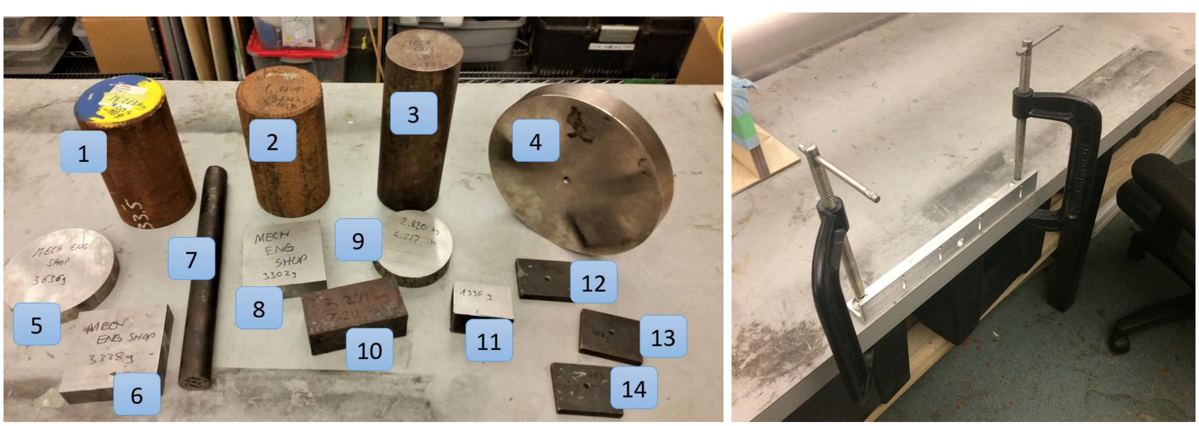

Figure 1: Various test Apparatus Materials

Date: March 9, 2018
Test Lead: Benjamin Klammer

Hazards

This test involves falling weights of up to 90kg. Area underneath weights should be avoided, and precautions should be taken to ensure that the weights fall safely to the ground in a controlled manner.

This test involves catastrophic failure of composite structures. Eye protection should be worn while completing the test to avoid injuries from projectiles.

Procedure

1. Fasten fin and 3D printed spacer to angle test jig (Use 6-32 screws for Hyak-1 or later, and 4-40 screws for MVP-3 or earlier)
2. Clamp angle test jig to table, ensuring sufficient overhang of fins off the table
3. Attach clamps to end of fin with pieces of wood protecting fin from clamp
4. Place plywood on floor directly under end of fin
5. Place weights in tote bag and hang on end of fin, ensuring bag does not slide off clamp
    a. See weight increments in Appendix
    b. DO NOT put more than 20kg in a tote bag, as they break easily
6. Leave weights hanging on fin for at least 30 seconds
    a. Wait for longer if fin makes any noises such as cracking
7. Unload fin completely
8. If fin does not fail, increase the weight in the tote bags and repeat steps 5-8 until fin breaks
    a. Fin is considered failed if it loses its shape significantly, even if it is still in one piece
9. Record the suspended weight after each loading and note any irregularities (sounds, sights, etc.)
10. Take video (slow motion preferred) of every fin failure, take pictures of fin after failure

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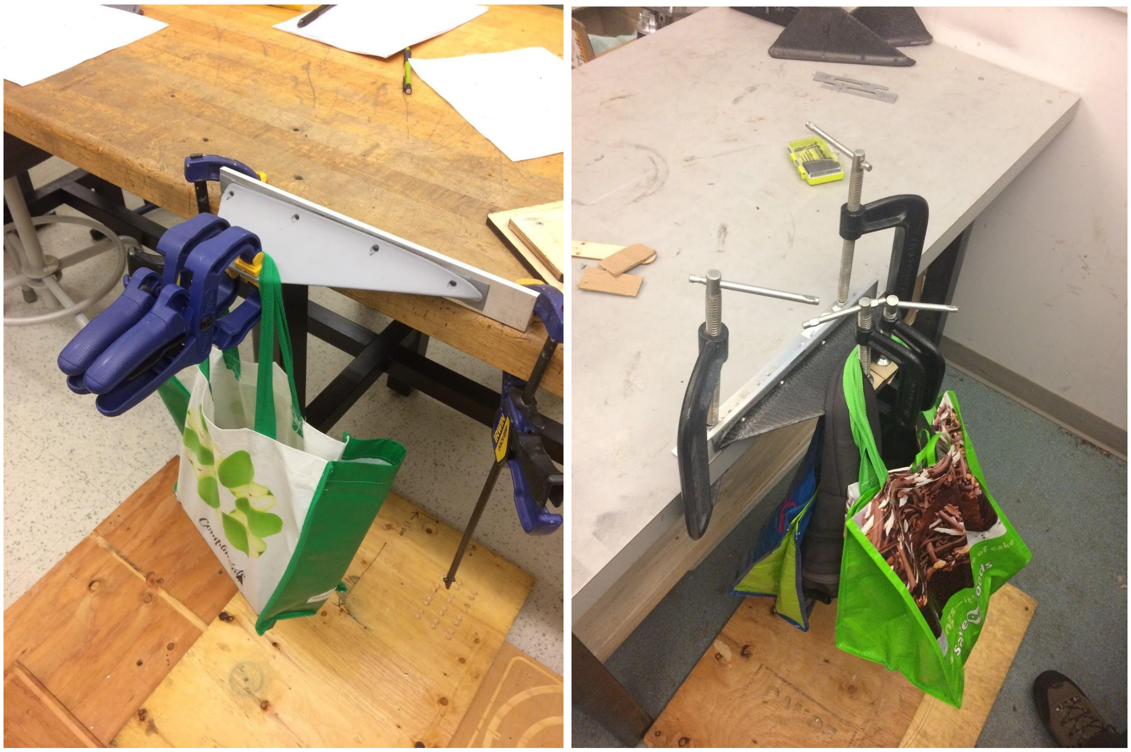

Figure 2: Test Apparatus During Testing

Test Results

After four design iterations, two-layer carbon fins with carbon-fiber inserts (H1-5-2X/C) were found to have the highest passing failure weights at 70 kg, 83 kg, and 88 kg. Two out of three H1-3 fins also surpassed the strength target at 66 kg and 76 kg. H1-1 and H1-2 fins had average failure weights of 56 kg and 45 kg, both under the strength target.

MVP-3 fins failed catastrophically by the carbon fiber ripping along the bottom edge. The majority of the first iteration Hyak-1 fins displayed separation where the carbon fiber detached from the 3D mold but did not rip, resulting in large deformation but no catastrophic failure. H1-5 fins experienced carbon fiber separation near the base and fasteners and then experienced complete fastener tearout after additional force. Cracking was heard before failure on most fins. This is likely the sound of carbon fiber peeling off of the 3D print, as the carbon fiber was observed to rip only at high impact.

Data and Analysis

Date: March 9, 2018
Test Lead: Benjamin Klammer

Five different design iterations were tested between October 18, 2017 and April 23, 2018. Most of the data of this test comes from close examination of failure modes. Table 1 below indicates the fin number, failure weight, and failure mechanism:

Table 1: Fin Failure Weight and Mechanism

Fin Name	Test No.	Date Tested	Failure Weight	Failure Mechanism
M3-1-11	1	18 Oct 2017	461 N	Carbon ripped along bottom side edge of fin and top of fin completely detached from 3D print and base.
M3-1-12	1	3 Nov 2017	510 N	Carbon ripped along bottom side edge of fin but did not completely detach. 3D print was broken.
H1-1-11	1	3 Nov 2017	451 N	Carbon detached from 3D print but did not rip. 3D print broken inside of fin. Little noticeable change in fin shape upon unloading.
H1-1-12	1	3 Nov 2017	559 N	Carbon detached from 3D print, causing the end of the fin to move down and then stop abruptly when the carbon straightened out. Upon this impact, the carbon ripped along the bottom side edge of fin.
H1-1-23	1	3 Nov 2017	618 N	Fin was initially tested to 65 kg without failure (Nov 3). Upon further testing (Nov 8), it failed at 63 kg by separation of carbon from 3D print.
H1-1-24	1	8 Nov 2017	549 N	Carbon separated from 3D print, fin otherwise intact.
H1-2-11	2	26 Jan 2018	362 N	Carbon separated from 3D print.
H1-2-12	2	26 Jan 2018	362 N	Carbon separated from 3D print.
H1-2-23	2	26 Jan 2018	618 N	No carbon separation. Bottom rear bolt ripped the bottom of the fin from the rest of the fin. PLA visibly crushed under second rear left bolt.

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H1-2-24	2	26 Jan 2018	422 N	Bottom rear bolt ripped the bottom of the fin from the rest of the fin.
H1-3-21/C	3	9 Mar 2018	N/A	No failure with max weight and additional force with wiggling.
H1-3-22/SH	3	9 Mar 2018	559 N	Violent failure. Carbon did not peel off of PLA, PLA tore off at base instead of 1/2" from base previously.
H1-3-24/S	3	9 Mar 2018	647 N	PLA tore off at base.
H1-3-print/C	3	9 Mar 2018	128 N	Failure at base 20s after loading.
H1-5-21	4	23 Apr 2018	687 N	Violent failure. Fastener tearout of top the top screws while the fin was hinged by the bottom screws. Bottom part of fin not covered by carbon fiber ripped off from fin, still attached to the mount (about 0.25in).
H1-5-22	4	23 Apr 2018	863 N	Fastener tearout of the top screws while the fin was still attached by the bottom screws.
H1-5-23	4	23 Apr 2018	814 N	Fastener tearout of the top screws while the fin was still attached by the bottom screws.

Figure 3 compares the average failure weight of MVP-3, first iteration Hyak-1 one-layer carbon fiber, first iteration Hyak two-layer carbon fiber, and third iteration Hyak two-layer carbon fiber with carbon insert fins. There is little difference between the first three types while H1-5 fins are noticeably stronger.

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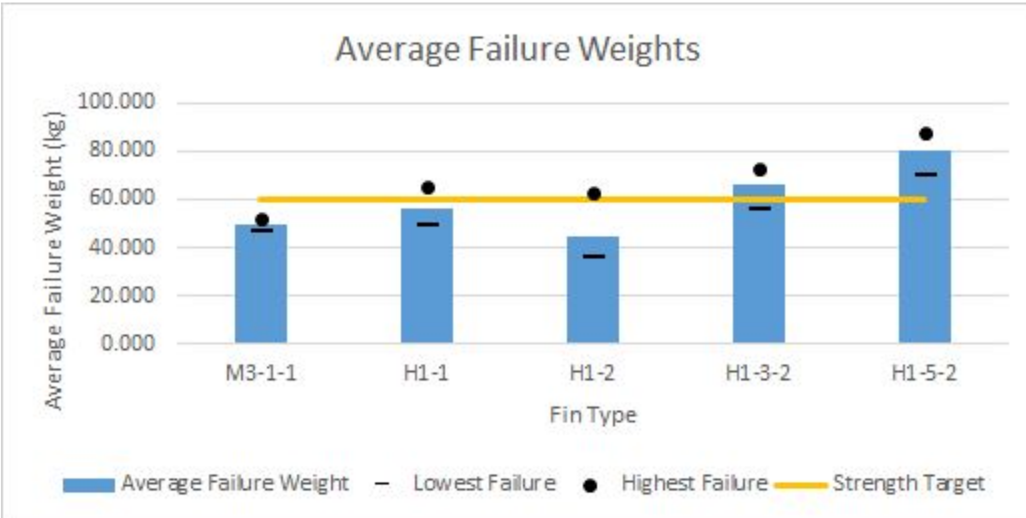

Figure 3: Average Failure Weights vs. Fin Type

A more detailed overview of the test results can be found in the “Fin Strength Testing” spreadsheet, and images and videos of the test can be found in the “Fin Strength Test” folder on the +UVR google drive.

Discussion

Test 1: October 18, 2017 and November 8, 2017 - M3-1 and H1-1

Changes to the design of the first iteration Hyak fins (H1-1-XX) are described in the “Fin Naming Convention” document and included a new bolt hole pattern, a significantly wider bolt stance, and a smaller radius between the fin airfoil and the base. Additionally, the bottom edge of the fins was rounded off to get rid of the sharp corner that was the location of failure for both MVP-3 fins. Otherwise, the same airfoil (NACA 0006) and geometry was used between the MVP-3 and first iteration Hyak-1 fins.

There was no appreciable difference between the performance of the first iteration Hyak-1 fins when compared to the MVP-3 fins. There is a slight gain in strength between the one layer carbon fiber MVP-3 and two layer carbon fiber Hyak-1 fins. However, the variance in the data is very high, and there is a small sample size with only two identical fins of each kind. As such, any conclusions drawn from these test results should be made very cautiously.

Although the failure mode of carbon separating from the 3D print may be the root cause of failure for all fins, the first iteration Hyak-1 fins displayed a less catastrophic failure than the MVP-3 fins. This could possibly be because the sharp edge on the bottom of the MVP-3 fins was redesigned to be a rounded corner in the first iteration Hyak-1 fins.

This first test succeeded in establishing a baseline for understanding the various factors that influence the strength of the fins. It also showed that only small improvements must be made to make the new fin design meet its strength target. The test is very simple and easy to perform, but is prone to errors due both to the test method (which is discussed below), but also due to the inconsistent nature of composites manufacturing and failure. In order to attain more consistent test values, a more consistent manufacturing process should be applied.

Sources of error include:

- Due to method of attachment, the distance of the load from the base of the fin varied depending on the fin. An attempt was made to place clamps in same place every time, but complete accuracy is difficult to ensure. This is also of concern when analyzing fin geometries with larger semi-spans, since this will increase the moment arm and thus the torque that a given loading on the end of the fin will create. This means that the test results may not be comparable between different fin geometries. This line loading on the tip of the fin is also inconsistent with the actual loading condition of the fin, where air creates a force on the entire fin area and not only at the fin tip. This contrived loading is a conservative estimate of the actual in-flight loading.
- Discrete loads were used in steps of around 3 kg, so the actual failure weight of the fin could be up to 3kg smaller than the tested weight of failure. This could be improved by using smaller weights but would require an increase in weight resources and would significantly lengthen the time taken to test the fins.
- Load history seems to have an effect on the strength of the fins, as fin H3-1-23 did not fail at 63.5 kg or 65.2 kg when tested on November 3, but failed at 62.7 kg when tested again on November 8. This indicates that the test is not very repeatable, and that care must be taken to ensure each fin has a similar load history for results to be comparable
- Weight of clamps and bags is not included in the failure weight. This renders the test results conservative, as the true weight on the end of the fin is up to 1 kg heavier than stated.
- There is no standard for the amount of weight loaded on fin each time. As such, each fin is subjected to slightly different loading before failure. This may contribute to the high variance in test results as load history may have an effect on fin strength. This is mitigated by preparing an excel spreadsheet with the various weights and the prescribed order of use, which is reproduced in Table 3 in the Appendix.
- For this test, each fin was loaded for different amount of time at each weight. This could contribute to the high variance in test results as load history may have a significant effect on fin strength. This is mitigated in future tests by implementing a 30 second load time, which is described in the procedure but was not followed in this test.

From this test it is clear that the failure mode of carbon fiber separating from the 3D printed PLA should be targeted in order to improve the strength of the fins. Thus, more detailed research and testing effort was put in place to investigate ways to improve adhesion between the 3D printed PLA and the carbon fiber. Additionally, geometrical alterations to the fin are also recommended, such as placing the bolt holes closer to the fin centre line and increasing the fairing radius to make the carbon fiber less prone to peeling off of the fairing radius.

One way to mitigate some of the errors and improve testing consistency is to use a tensile testing machine to break the fins instead of simply hanging weights. Although this may add some complexity to the testing jig, it has the possibility to make testing easier, quicker, and more reliable. As such, this avenue should be explored further.

Test 2: January 26, 2018 - H1-2

One-layer versus two-layer carbon fiber fins were tested with updated geometry. Three out of four fins failed and the passing fin (two-layer) passed at 618 N. Furthermore, a new failure mode was identified where the bottom rear bolt ripped the bottom of fin out of rest of fin.

Carbon fiber weave direction was also tested, where H1-2-23 had the weave in the same direction as the leading edge and H1-2-24 had the weave in cross direction. Although H1-2-24 was considerably weaker than H1-2-23, one cannot deduce that the cross-directional weave has any added benefit to strength. The sample sizes are only one and H1-2-23 was a poorly manufactured fin in general, so differences in strength can not be conclusively attributed to weave direction.

Test 3: March 9, 2018 - H1-3

For H1-3 fins, one PLA-only fin and three two-layer fins (all with an updated span of 4”) were strength tested. This iteration was the first to implement nubs for stiffness testing, heat treatment, and carbon fiber stiffness inserts. H1-3-21/C was the only fin to pass the strength target while the PLA-only fin failed at a mere 13kg.

As noted previously, the loading distance varies as there’s no convenient way to accurately and consistently apply the weights at a set distance from the base of the fin. The stiffness nub and updated wingspan both increase the torque applied to the fin with a given weight, implying that this iteration takes on a larger moment at the base for an equivalent applied force when compared to previous iterations. Because these updates yield more conservative results, no further actions are required concerning these changes.

The single heat-treated fin (Preheat oven to 100 °C, insert fins and simultaneously turn off oven, allow fins to cool down to room temperature in closed oven) was the weakest fin of test 3. Heat treatment after this iteration was no longer pursued as it added no significant strength to the fin.

Six H1-3 fins were made, although only three were tested because the other three (one-layer) fins physically failed during stiffness testing. This is because the stiffness testing method was not yet optimized and the fins were a weaker one-layer type. Furthermore, poor stiffness testing results from H1-3-22/SH gave no reason to test the other heat treated fin. The other H1-3-2X fins, on the other hand, were stiffness tested but did not physically fail. This is a source of error as it is not known whether or not stiffness testing a fin prior to strength testing weakens a fin, and if so, to what extent. Due to time and resource limitations, further study of this effect has been omitted. H1-4 fins were also not strength tested as they failed stiffness testing and are thus not valid designs, making it not worth the time and resource commitment required to conduct strength testing on them.

Test 4: April 23, 2018 - H1-5

Two-piece fins with updated geometry (13” root chord, 4.3” span, 4” tip chord, 8.5” sweep edge, and 0.4” average thickness), carbon stiffness inserts, and two-layer carbon fiber was explored for H1-5 fins.

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Test Lead: Benjamin Klammer

All three fins surpassed the strength target by an average of 43%. H1-4 and H1-5 fins are noticeably bigger than previous iterations as it was found that fins could be printed in two separate pieces, separated halfway along the base chord. Two-layers of carbon fiber and carbon fiber inserts were at this point the best method of fin manufacture, as it results in the most strength and stiffness given the difficulty, time, and effort required. Fin geometry was therefore the last parameter needed to be optimized to yield strong fins.

All fins had the same failure mode of carbon fiber-PLA separation at the base of the fin by each fastener, followed by fastener tearout of the top fasteners. The point of carbon fiber-PLA separation is considered failure, however every fin was still attached to the mount at these points. Extra force was added by pushing down on the fins, causing the fins to tear and separate from the mount and fasteners.

Fast progressing weight jumps were used once it was found that the fins could handle more weight to decrease test duration. Although this may indicate that the fins undergo less cumulative load and would appear stronger than a similar fin under slower progression, the fins are strong enough that it is unlikely the weight jump would be the difference between passing or failing the test.

Conclusion / Lessons Learned

The test successfully examined the conditions under which the fins will fail when subject to a transverse load causing bending. After 4 design iterations, the H1-5-2X/C fins were found to be the strongest and safest fin design, with the three fins failing at 70 kg, 80 kg, and 88 kg, which is roughly 1/3rd more than the strength target of 60 kg. The weakest of these fins has a safety factor of 1.4 in the worst case scenario and a safety factor of 2.01 for the expected flight performance. Initially, the most common failure mode was the separation of carbon fiber from the 3D print along the fairing radius. After updating fin geometry and targeting the adhesion between carbon fiber and PLA, the main failure mode of H1-5 fins was fastener tearout. In these cases the fin was still rigidly attached, and with additional forces (5 - 10 kg), the fins tore away from both the mount and fasteners.

The test has several sources of error, but succeeds in providing a metric to measure the strength of the fins. Due to the small sample size and large variance, any conclusions drawn from this test data should be approached with caution. It is recommended that further fin designs are tested using this test and research to prevent the common failure modes of the adhesion between carbon fiber and PLA as well as the fin mounting-fastener connection.

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Date: March 9, 2018
Test Lead: Benjamin Klammer

Appendix:

Table 2: Machine Shop Weights Used in Test

Weights		
Number	Description	Weight [kg]
1	Yellow Cylinder	18.263
2	Short Cylinder	18.232
3	Long Cylinder	16.503
4	Big Disk	13.462
5	Small Disk	3.636
6	Square Block	3.338
7	Long round Bar	3.334
8	Square Block	3.302
9	Rectangular Block	3.271
10	Short Cylinder	2.820
11	Small rectangular Block	1.396
12	Rectangular Flat	0.468
13	Rectangular Flat	0.468
14	Rectangular Flat	0.463

Figure 4: Weights Used in Test

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Date: March 9, 2018
Test Lead: Benjamin Klammer

Table 3: Standard Weight Combinations for Test

Fast Progressing Combinations															
Numbers														Weight [kg]	Delta [kg]
1	2													36.495	
1	2			5										40.131	3.636
1	2			5	6									43.469	3.338
1	2			5	6	7								46.803	3.334
1	2		4											49.957	3.154
1	2	3												52.998	3.041
1	2	3		5										56.634	3.636
1	2	3		5	6									59.972	3.338
1	2	3		5	6	7								63.306	3.334
1	2	3	4											66.460	3.154
1	2	3	4	5										70.096	3.636
1	2	3	4	5	6									73.434	3.338
1	2	3	4	5	6	7								76.768	3.334
1	2	3	4	5	6	7	8							80.070	3.302
1	2	3	4	5	6	7	8	9						83.341	3.271
1	2	3	4	5	6	7	8	9	10	11				87.557	4.216
1	2	3	4	5	6	7	8	9	10	11	12	13	14	88.956	1.399

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UVic Rocketry Test Report

Hyak-1 Fin Torsional Stiffness Test

March 20, 2018

Test Lead: Benjamin Klammer

Associates: Sebastian Panchyrz, Aaron Latorre

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Test Lead: Benjamin Klammer

Introduction

The MVP/Skookum style rocket fins are being redesigned to ensure they do not fail under the new supersonic flight conditions that Hyak-1 is expected to undergo. This test aims to determine whether rocket fin prototypes meet the torsional stiffness target set in order to avoid the flutter mode of failure. This test is being conducted for the Propulsion and Aerostructure subsystems for the Hyak-1 rocket.

Scope

The objective of this test is to non-destructively determine the effective shear modulus and associated parameters of the Hyak-1 fins.

This test aims to extract the relevant information needed to analyze the fins for the flutter failure mode using the semi-empirical equation and approach outlined in NACA TN 4197 [1]. The deflection and torque on a fin are measured and simplified beam equations are used to find the effective shear modulus of the fin. The effective shear modulus necessary to avoid flutter depends on the geometry of the fin, and can be found using the “Flutter Stiffness Target” spreadsheet located in the +UVR drive. This method contains many simplifying assumptions and the results must be approached with the proper discretion.

Each test iteration is considered a success if the test consistently and accurately meets the effective shear modulus. The test is qualitative, as the data rely on numerical results.

Referenced Documents

“NACA TN 4197,” Dennis J. Martin

Flutter Stiffness Target.xlsx

Fin Torsion Test.xlsx

Hyak-1 Fin Static-Bending Loading Test.docx

Fin Naming Convention.docx

Terminology

Airfoil - The cross-sectional shape of the fin normal to the body of the rocket

Bending-Torsion Flutter - Most common type of flutter for rocket fins, occurs when the first two natural frequencies of the fin (bending and torsion) line up.

Chord - The length of the airfoil from the leading edge to the trailing edge

Effective Shear Modulus - The shear modulus of the solid material that would give the same stiffness testing results as the actual fin if it were the same shape and made out of an equivalent solid material

Flutter - Aeroelastic phenomenon where the aerodynamic and elastic forces on an object cause it to oscillate uncontrollably. Once started, flutter almost always results in failure.

Semi-span - The height of the fin measured normal to the chord from the root to the tip

Sweepback Angle - The angle between the leading edge and a line normal to the chord

Summary of Test Method

A pure torque is applied to the end of the fin using a force couple. Vertical deflection of the fin tip is measured using dial gages for various applied torques. The torque and angular deflection are calculated and used (along with fin geometry) to determine the effective shear modulus of the fin.

Theory

In order to extract a meaningful effective shear modulus from the test data, several simplifying assumptions were employed. The fin is modeled as a beam of uniform cross section in order to employ the following equation:

$$JG = TL/\theta$$

Where J is the cross section torsional modulus, G is the shear modulus (modulus of rigidity), T is the applied torque, L is the length of the beam (equivalent to the fin's semi-span), and θ is the angle of twist in radians. Imperial units are used throughout the analysis in order to easily use the relations found in NACA TN 4197. Furthermore, the effective shear modulus was computed as suggested in NACA TN 4297 using the approximate cross section torsional modulus for a solid thin airfoil:

$$G_e = 6(JG)/ct^3$$

Where c is the average chord and t is the average thickness of the fin. These two assumptions allow for the experimental obtention of the shear modulus, which is needed to compare against the flutter factor to determine the safety factor for flutter of the fins.

In order to apply a pure torque to the fins, a specified amount of weight was applied downwards by hanging metal blocks from one end of the stiffness bar, and was matched with the stiffness pusher applying the same amount of force upwards. This force was applied by increasing the distance between the stiffness bar and the ground using a screw and then measuring this force using a scale. The torque applied to the fin is the weight of the metal blocks multiplied by the distance between the hanging weights and the stiffness pusher.

Test Lead: Benjamin Klammer

In order to measure the angular deflection of the fins, the deflection of the stiffness bar was measured using two dial gages and these readings were combined with the distance between the two dial gages and trigonometric relations to find the angular deflection according to:

$$\theta = tan^{-1}((\delta_1 + \delta_2)/d)$$

Where θ is the angular deflection, δ_1 is the measured vertical deflection at point 1, δ_2 is the measured vertical deflection at point 2, δ_1 and δ_2 are in opposite directions, and d is the horizontal distance between point 1 and point 2.

Materials

- Various weights (10kg total, ideally in steps around 0.75kg)
- Two dial gages
- Various fins to be tested (must have stiffness nub)
- Fin test jig
- 3D printed fin spacers
- Bolts for attaching fin to jig (4-40 for old fins, 6-32 for new fins)
- Table to mount jig to
- 2 C-clamps clamping jig to table
- Tote bag for holding weights
- Stiffness bar assembly
- Stiffness pusher jig
- Scale (to register stiffness pusher force)
- Stool (to support stiffness pusher on top of scale)
- One medium sized piece of plywood (to place on scale in order for scale to register stool)
- Computer to enter data into “Fin Torsion Test.xlsx” spreadsheet
- Various allen wrenches and crescent wrenches for assembly
- Calculator (optional)
- Camera (optional)

Hazards

This test involves the use of delicate instruments. Care should be taken when handling the dial gages. The area directly under the weights should be avoided. No personal safety protection is required for this test.

Test Lead: Benjamin Klammer

Procedure

Setup Procedure

1. Fasten fin and 3D printed spacer to angle test jig with the appropriate fasteners
2. Fasten stiffness bar assembly to stiffness testing nub on fin. Ensure the stiffness bar is parallel to the face of the angle test jig by using a level.
3. Set up stiffness pusher jig, stool, and scale an appropriate distance from table (use blue shop microscope stool or some other spacer). Ensure stool is properly sitting on scale by placing a piece of plywood between the stool and scale.
4. Place a weight (approx. 15 kg) on top of plywood on scale beneath stool
5. Clamp angle test jig to table, ensuring sufficient overhang of fins off the table. Ensure the pusher hole on the stiffness bar is inserted into the threaded rod on the stiffness pusher.
6. Attach tote bag to quick link on stiffness bar assembly
7. Set up dial gages on table so that they are touching the black sharpie lines on the stiffness bar
    a. Use the magnet base and some payload weights to add stability
    b. Ensure the expected deflections are within the range of the dial gages
    c. Ensure the dial gage closest to the weights is arranged so that as the bar lowers, it reads values throughout the expected deflection range

Testing Procedure

8. Open the “Fin Torsion Test.xlsx” spreadsheet for data entry
9. Place a weight in the tote bag, and record it in the “weight” column of the spreadsheet
10. Measure weight of pusher assembly on scale, and record it in the “Start pusher weight” column of the spreadsheet
11. Tighten the nut on the pusher assembly until the scale reads within 0.2 lbs of the value in the “Desired pusher weight” column of the spreadsheet (start pusher weight plus the weight in tote bag). Record the final scale reading in the “End Pusher Weight” column of the spreadsheet
12. Record the deflections of the dial gages. The dial gages must be moving in opposite directions for the spreadsheet to correctly calculate shear modulus
13. Loosen the nut on the pusher assembly until the assembly is unloaded
14. Remove all weights from tote bag
15. Record the deflections of the unloaded fin. Reset the dial gages to zero if plastic deformation occurs
16. Repeat steps 9-15 while incrementing the weight in the tote bag until the fin being tested experiences significant plastic deformation of approximately 0.3mm after unloading

Test Lead: Benjamin Klammer

Test Results

After 3 design iterations, two-layer carbon fins with carbon-fiber inserts (H1-5-2X/C) were found to have passing effective shear moduli of 361 ksi, 359 ksi, and 332 ksi. H1-3 fins were the first fins to be stiffness tested and the one-layer fins had an average shear moduli of 98.3 ksi while the two-layer fins had an average shear moduli of 209 ksi. H1-4-2X fins had an average shear moduli of 229 ksi. Errors in the testing method and setup were found and mitigated.

Data and Analysis

Three different design iterations were tested between February 4, 2018 and April 23, 2018. The dimensions of each iteration is shown in Table 1 below.

Table 1: Fin Design Iterations

Fin Iteration	**Root Chord (in)**	**Tip Chord (in)**	**Semi-span (in)**	**Sweepback-angle (degrees)**	**Root Thickness (in)**	**Tip Thickness (in)**
H1-3	11	3	4	60	0.5	0.3
H1-4	14	3	5.5	60	0.5	0.3
H1-5	13	4	4.3	60	0.5	0.3

Full data including all deflections and weights can be found in the “Fin Torsion Test.xlsx” spreadsheet in the +UVR google drive.

Metric units were used throughout the testing data acquisition (mass in kg, deflections in mm), with the exception of the bathroom scale reading, which is in lbf. The analysis was performed using imperial units (lbf, in, ksi, etc.) in order to follow the analysis laid out in NACA TN 4197 and to facilitate comparisons with external testing data.

Deflections at various applied torques were measured, the effective shear modulus for each value was calculated, and the average of the effective shear moduli was taken to determine a representative shear modulus for the given fin. The overall results are shown in Table 2 below.

Test Lead: Benjamin Klammer

Table 2: Fin Stiffness Test Results

Test Date	Fin Number	Test Number	Effective Shear Modulus (ksi)
2/4/2018	H1-3-11/S	1	118
2/4/2018	H1-3-11/S	1	75.8
2/4/2018	H1-3-12/S	1	101
2/22/2018	H1-3-23/SH	1	185
3/6/2018	H1-3-24/S	1	260
3/6/2018	H1-3-22/SH	1	181
3/20/2018	H1-4-21/S	2	238
3/20/2018	H1-4-22/SC	2	236
3/22/2018	H1-4-23/S	2	248
3/22/2018	H1-4-24/SC	2	194
4/23/2018	H1-5-21	3	361
4/23/2018	H1-5-22	3	359
4/23/2018	H1-5-23	3	332

Additionally, the applied torque was plotted against the resulting displacement for the 3 tests, as shown in Figures 1, 2, and 3 below. This is done to better show the torsional rigidity (JG) of the various fins, since the torsional rigidity is the slope of the torque-displacement graph. Since the effective shear modulus is proportional to the torsional rigidity, this gives an image of how the shear modulus varies with increasing torque and across the various individual fins.

Test Lead: Benjamin Klammer

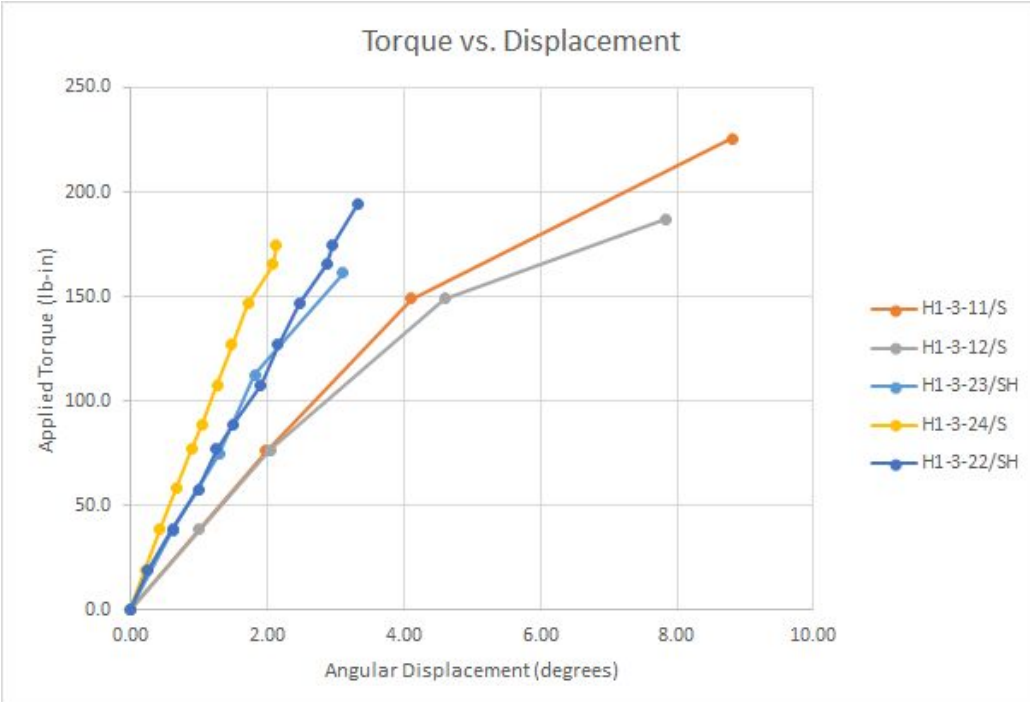

Figure 1: H1-3 Applied Torque versus Angular Displacement for Various Fin Designs

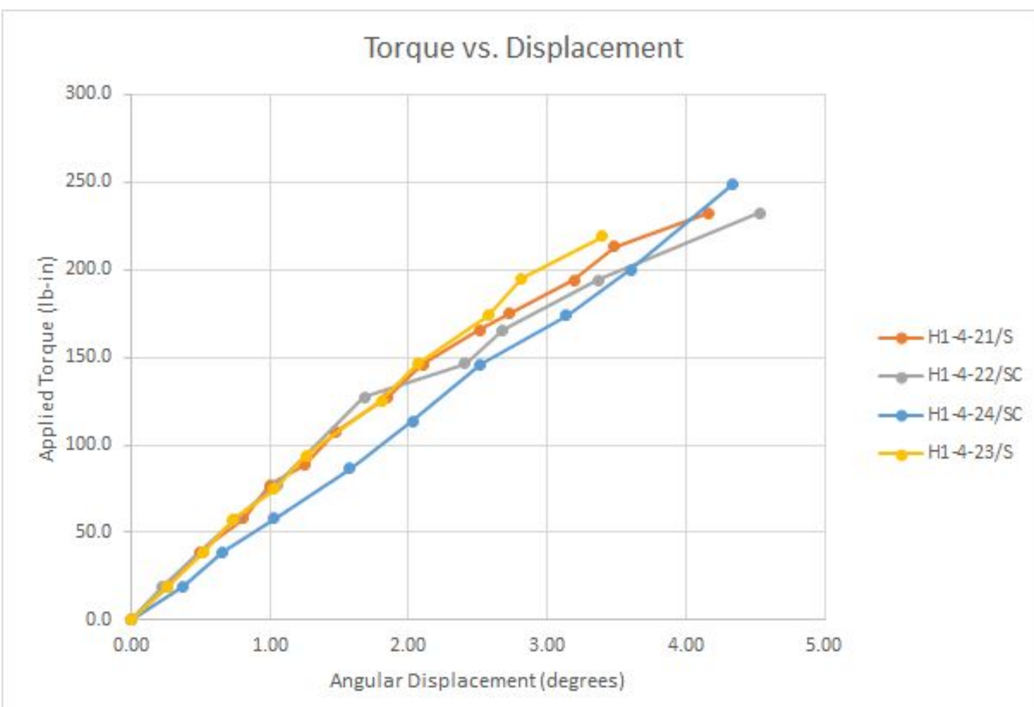

Figure 2: H1-4 Applied Torque versus Angular Displacement for Various Fin Designs

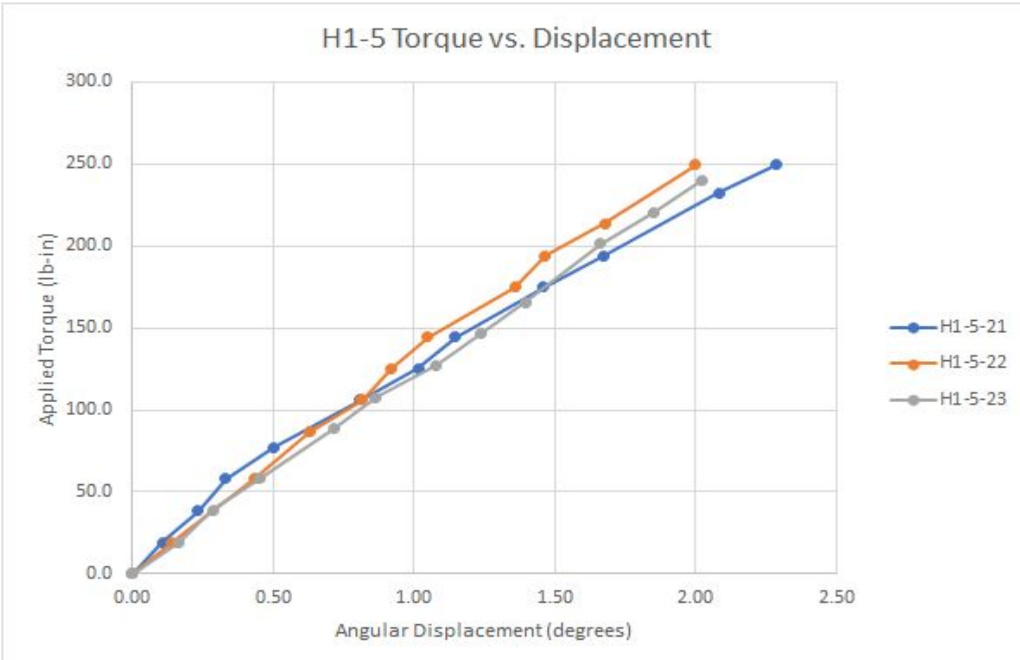

Figure 3: H1-5 Applied Torque versus Angular Displacement for One Fin Design

Discussion

Test 1: February 4 to March 6, 2018 - Iteration H1-3

The first stiffness test tested 5 fins and 2 parameters - carbon fiber layering and heat treating. The 2 one-layer fins failed at a much earlier weight than expected, due to both a large moment arm of the applied force (24” between forces) and the fact that the fins were significantly weaker than expected based on cursory estimations of the shear modulus of carbon fibre-PLA composite materials. These fins experienced unwanted plastic deformation (nonlinear torque-deflection plot).

The two layer fins performed better due to a reduction in the moment arm (12” between forces). The test was terminated when plastic deformation occurred - when the unloaded deflection of a dial gage is greater than 0.3mm - reflected in the linear torque-deflection plot (constant effective shear modulus).

Surprisingly, the heat treated fins demonstrated a significant reduction in torsional stiffness compared to the non-heat treated fins. Although the sample size is small, the consistency in the shear modulus between identical fins indicates that the 42% difference in shear modulus cannot be fully be accounted for by experimental error. It is still unknown why the heat treatment (Preheat oven to 100 °C, insert fins and simultaneously turn off oven, allow fins to cool down to room temperature inside oven with door closed), has such a large impact on torsional stiffness. A temperature of 100 °C is well below the glass transition temperature of the epoxy used in the carbon composite, has no effect on the carbon fibers themselves, and is predicted to have a strengthening effect on the PLA 3D print. Due to this adverse effect, the heat treatment of the fins has been discontinued.

From the data, it is clear that adding additional layers of carbon fibre results in a stiffer fin, with the two layer carbon fibre fin displaying a 127% improvement as compared to the average of the one layer carbon fin. However, adding more than two layers of carbon to the outside of the fin is not feasible to increase fin stiffness, as it significantly increases carbon layup difficulty and decreases the fidelity of the 3D printed shape.

The testing method heavily relies on the rigidity of the stiffness nub and the connection between the fin and the test jig. Additionally, the nub extends the span by around 0.75 in (conservatively not accounted for) and assumes perfect torsion about the fin as a link between the fin and stiffness jig. Because the test assumes that this connection is a rigid attachment to the fin, it is a major source of error and may be a testing flaw in the case that the connection is not rigid. Any loss in rigidity would therefore mean the test measures stiffness of the nub instead of the fin.

In addition to finding the effective shear modulus of the fins, the goal of the first stiffness test was to discover and mitigate any major sources of error in the testing method. Initially, there were many sources of error, including:

- The bathroom scale is only accurate to ± 0.4 lbs. This has not been mitigated, but could be improved by finding a more accurate scale.
- The weight of the stiffness pusher does not place the bathroom scale in its proper range (approx. 15 lbs). To mitigate this, a weight was added to move the overall weight of the pusher apparatus into a more accurate human-sized range (approx. 45 lbs).
- The fins experienced slight plastic deformation after each loading, so if that is not accounted for, the test is not measuring the elastic deformation of the fin necessary to obtain the shear modulus. To mitigate this, the dial gages were reset to zero after every unloading, and the test was stopped once plastic deformation greater than 0.3mm is observed.
- Under high angular deflections, contact between the stiffness pusher's threaded rod and the stiffness bar pushes the stiffness pusher into an angled position. This makes the pusher force unreliable, as it is no longer completely vertical and can slip more easily. To mitigate this, a larger slot is cut in the stiffness bar so threaded rod does not interfere with the aluminum.
- The deflection of the stiffness bar is larger than the gages' ability to measure. To avoid this, the dial gages were moved closer to center of rotation, resulting in a smaller deflection.
- Compliance of system (fin twisting in bolts, jig twisting on table, bar twisting on edge of fin) may contribute to inaccuracies in the measured torsional stiffness of the fin. To mitigate this, the deflection at the base of the fin was measured and found to be insignificant when compared to the deflections of the fin. Furthermore, any effect of compliance on the results is conservative, as it makes the fin appear weaker than it actually is. As such, any compliance of the system can be safely neglected.
- Weight of pusher might change depending on angle. To mitigate this, the stiffness pusher weight) is recorded before each loading.

- The lever arm is too large, resulting in weights are very small for a given applied torque. This results in increased relative error from the bathroom scale, and decreased resolution because it is difficult to find smaller weights to test with. To mitigate this, new holes were drilled in the stiffness bar to move the center to center distance of the weights and stiffness pusher from 24" to 12", thus increasing the applied force for a given torque by a factor of two. Despite these errors, the stiffness testing data for the various fins is remarkably consistent, with identical fins having very similar effective shear moduli. This indicates that the test is repeatable and somewhat robust. However, it does not indicate that the results are accurate, as there may be a common factor to the testing method that results in a consistent under or over-estimation of the fin shear modulus.

Despite these errors, the stiffness testing data for the various fins is remarkably consistent, with identical fins having very similar effective shear moduli. This indicates that the test is repeatable and somewhat robust. However, it does not indicate that the results are accurate, as there may be a common factor to the testing method that results in a consistent under or over-estimation of the fin shear modulus.

Test 2: March 20 and 22, 2018 - Iteration H1-4

The fourth design iteration fins (H1-4) comprise of four 2-layer fins, two fins with carbon fiber stiffness inserts and two without. Fin H1-4-24/SC was the weakest of the four fins, as the effective shear modulus was 195 ksi compared to the other 3 fins with values around a consistent 240 ksi. This weakness is likely because the stiffness numb at the tip chord was printed separately from the rest of the fin, while the two fins without the carbon fiber stiffness inserts had the test nub extruded onto the tip directly. The separation and resulting decrease in stiffness between connection of the test nub to the fin would cause a greater deflection in the nub connection and thus an under-estimation of the fin stiffness. Inspection verified this effect as the fin appeared to be under little to no stress under heavy load or by twisting the stiffness test jig. The fin was printed this way due to an oversight and tested because this weakness was not expected.

These fins were also printed in two separate pieces, limited by the size of our 3D printers. Two-piece printing has no noticeable disadvantage regarding the strength or stiffness of the fins, as testing of H1-4 fins result in a passing average safety factor of 2.44. This also implies that the test is consistent and that the results are indicative of the weakness of the nub rather than no effect from the carbon inserts.

In this second round of fin stiffness testing, the testing method improved, although some errors remain. These improvements and errors include:

- The scale is only accurate to ± 0.4 lbs. This has not been mitigated, but could be improved by finding a more accurate scale.
- The weight of the stiffness pusher does not place the bathroom scale in its proper range (approx. 15 lbs). To mitigate this, a weight was added to move the overall into a more accurate human-sized range (approx. 45 lbs).
- Compliance of system (fin twisting in bolts, jig twisting on table, bar twisting on edge of fin) may contribute to inaccuracies in the measured torsional stiffness of the fin. To mitigate this, the

deflection at the base of the fin was measured and found to be insignificant when compared to the deflections of the fin. Furthermore, any effect of compliance on the results is conservative, as it makes the fin appear weaker than it actually is.

- Weight of pusher might change depending on angle. To mitigate this, the stiffness pusher weight) is recorded before each loading.

The stiffness data are still consistent given the errors as all fins tested have similar effective shear moduli. The testing procedure is more efficient as compared to the first stiffness test. However, similarly to the first test, this does not show that the tests results are accurate, so the actual effective shear moduli could be consistently under or over the results due to some common test or production factor. A major test error was the separated H1-4-24/SC stiffness nub. Further iterations should have the nubs printed as part of the fin, ensuring the connection between the stiffness nub and body is rigid.

Test 3: April 23, 2018 - Iteration H1-5

New fin geometry and two-layer carbon fiber fins with carbon inserts and stiffness nubs were tested and were found to have consistent effective shear moduli of 361 ksi, 359 ksi, and 332 ksi. The shear moduli of these 3 fins are around 40% higher than the previous iteration and are in general much higher than all previously tested fins - looking at the torque vs. angular displacement graph, one can see that under similar forces of torque, the angular displacement is almost half that of the H1-4 fins. As expected from the graph, the three fins have a similar torsional rigidity.

The testing method is solidified, although the errors and discretions from the previous iteration remain - all fins were printed directly with stiffness nubs to mitigate the previous test's error. The stiffness data is consistent but accuracy is not confirmed.

Conclusion/Lessons Learned:

This test non-destructively determined the effective shear modulus and associated parameters of the Hyak-1 fins. The third and final test yielded 3 fins with similar effective shear moduli of 361 ksi, 359 ksi, and 332 ksi. H1-3 fins had an average shear moduli of 153 ksi and H1-4 fins had an average shear moduli of 229 ksi. Two-piece 3D printed fin with two layers of carbon fiber and a carbon fiber insert (for strength, not stiffness) were found to have the highest effective shear moduli compared to combinations of varying fin geometry, heat treatment, amount of carbon fiber layers, and carbon fiber inserts. Errors in the testing method were found and mitigated. The fin stiffness data is consistent.

It is recommended that an error propagation analysis is conducted to find the effect of uncertainty in measurements on final stiffness results in order to better understand the theoretical error involved with the calculations. It is important to make sure that the fin stiffness nub is rigid and one piece with the fin, not separately attached. The elastic axis could also be analyzed for use in other analytical flutter predictions by measuring the distance of the deflections from the leading edge of the fin in order to find out the location of rotation of the fin in response to a torque. A more accurate scale that can display weight changes in real time will greatly increase the speed of the test.

Test Lead: Benjamin Klammer

References:

[1] D. J. Martin, “Summary of Flutter Experiences as a Guide to the Preliminary Design of Lifting Surfaces on Missiles,” National Advisory Committee for Aeronautics, Langley Aeronautical Laboratory, February 1958.

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Date: May 20, 2018
Test Lead: Noah Mar

UVic Rocketry Test Report

Hyak-1 Coupler Static Bending Test

May 2, 2018

Test Lead: Noah Mar

Associates: Alex Canan, Sebastian Panchyrz

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Date: May 20, 2018
Test Lead: Noah Mar

Introduction

The MVP/Skookum style rocket coupler is being redesigned to ensure it does not fail under the new supersonic flight conditions that Hyak-1 is expected to undergo. This test aims to determine whether rocket coupler prototypes will fail under static loads similar to those predicted for the flight. This test is being conducted for the Aerostructure subsystem for the Hyak-1 rocket.

Scope

The objective of this test is to determine whether the coupler prototypes will fail when subject to a transverse load causing bending.

This test simulates a estimated bending force of 177.7 N due to drag force on the coupler. This estimated bending force is based on a highly conservative angle of attack of 3.4 degrees, in addition to a 0.8 coefficient of aerodynamic drag. As the coupler prototypes are of mixed material, consistent and accurate data and properties are not readily available, thus, this test will provide critical data for the Hyak-1 rocket and future rockets.

This test is also used for validating the design of the couplers. This is done by noting the weight at failure for both coupler designs and observing the failure mechanism. If failure does not occur past the simulated expected force, it can be deemed validated.

Referenced Documents

Coupler Bending Test Data.xlsx

Coupler Bending Test Information.docx

Terminology

ABS	Acrylonitrile Butadiene Styrene, the thermoplastic polymer that is used as the main material of one of the two coupler designs.
Divinycell	A closed cell medium to high density foam which has high compression strength, durability, and excellent fire resistance.
Weighted-End	A component of the custom built bending jig. This half suspends the weights and is attached to the free end of the coupler during testing.
Fixed-Base	A component of the custom built bending jig. This half is fixed to a table and is acts as the static end of the coupler during testing.

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Date: May 20, 2018
Test Lead: Noah Mar

Summary of Test Method

Weights are suspended from a horizontally fixed coupler to simulate bending between the two halves of the rocket, assuming one end is static. The suspended weight is increased until failure, or until the expected force is surpassed. The weight at failure is recorded for each coupler prototype, and the failure mechanism is recorded.

Materials

- Coupler bend test jig
- Various weights (90 kg total, ideally in steps of 4-6 kg)
- Tote bags for holding weights
- 4 C-clamps (2 for clamping fixed-end to table, 2 for clamping fixed-end layers)
- 3 Quick release clamps (2 for reinforcing and closing weighted-end, 1 for additional clamping force of coupler to fixed-end)
- Timer/Stopwatch
- Table to mount jig to
- Folded tarp (to protect floor from falling weights)
- Coupler prototypes
- Ladder

Figure 1: Foam-fibreglass coupler (left), ABS-fibreglass coupler (right)

Date: May 20, 2018
Test Lead: Noah Mar

Hazards

This test potentially involves falling weights of up to 90kg. Area underneath weights should be avoided, and precaution should be taken to ensure that weights fall safely to the ground in a controlled manner.

This test potentially involves catastrophic failure of couplers. Eye protection should be worn while completing the test to avoid injuries from projectiles.

Procedure

1. Place laser-cut fixed-base layers on the coupler.
2. Clamp fixed-base to tabletop using 2 c-clamps
3. Add two C-clamps to the top corners of the fixed-base.
4. Add one quick-clamp to the top of the fixed-base and the inside of the coupler.
5. Take the weighted end block and carefully slide it onto the opposing end of the coupler.
6. Using a quick-clamp, clamp the non-slotted side of the weighted-end, such that the clamping force is in line with the center of the thinnest part of the non-slotted side.
7. Using a quick-clamp, clamp the slotted side of the weighted-end, again, such that the clamping force is in line with the center of the thinnest part of the slotted side.
8. Open the ladder and position over the coupler and jig.
9. Place weights in tote bag and hang on end of weighted-end
    a. See weight increments in Appendix
    b. Do not put more than 20kg in a tote bag, as they break easily.
10. Wait 30 seconds, record dial-gauges (jig component), and unload the weighted-end completely.
11. Wait 30 seconds, and record the dial-gauges again.
12. Repeat steps 9-11, until maximum weight is achieved or failure occurs.

Figure 2: Test apparatus during testing (unloaded), only one of two dial indicators shown

Date: May 20, 2018
Test Lead: Noah Mar

Test Results

After testing, both couplers, ABS-fibreglass and foam-fibreglass, were both verified to be able to withstand supersonic flight. During testing, neither coupler prototype failed catastrophically.

Data and Analysis

Two different coupler designs were tested on May 2, 2018. Most of the data of this test comes from dial indicators measuring the change in displacement, which is then used to calculate the angle at which the coupler makes with the horizontal axis of a coupler's initial position. Figure 3 below compares the relative angle made by both coupler prototypes when the simulated forces are applied.

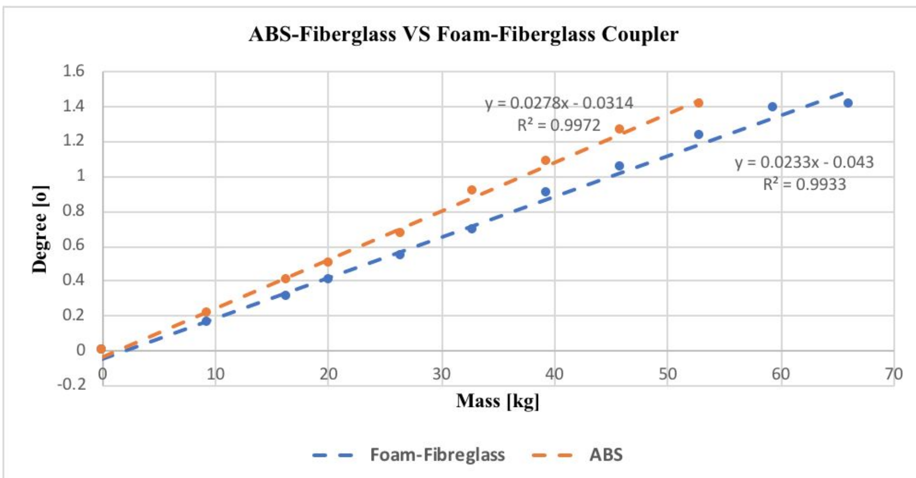

Figure 3: Plot of the angle formed during loading of both coupler prototypes.

Discussion

This test allowed for the verification of both coupler prototypes. This allowed for the foam-fibreglass coupler to be deemed the design of choice, as it can be manufactured in-house, has a reduced weight, and as shown in fig. 3, is more rigid than the ABS-fibreglass coupler. However, this test became one of qualitative data, as opposed to quantitative. When the data gathered from this test was used to calculate Young's modulus of either coupler, both values failed sanity checks, providing a value similar to rubber. Nonetheless, the ABS-fibreglass coupler underwent finite element analysis (FEA) using ANSYS, and was deemed a valid design to withstand the supersonic flight of the Hyak-1 rocket. Thus, as the foam-fibreglass coupler was deemed to be more rigid than the ABS-fibreglass, it can be concluded that the foam-fibreglass coupler is the design of choice. Foam-fiberglass couplers will be used on the Hyak-1 rocket and rockets to come in the foreseeable future, as it's properties are optimized. The foam-fiberglass material choice of the coupler may possibly be applied to other components of future rockets.

In order to attain more viable and plausible data, a more consistent jig should be used. The jig's design was limited by cost and materials.

Sources of error include:

- Due to the material used for the jig, wood, said material's ability to flex and deform, the jig itself likely skewed the data recorded. This could be improved by using a more rigid material that is less likely to deform or flex, perhaps a machined block of metal, funds allowing.
- Due to the location and setup of the jig, the fixed-end of the jig was likely not fully fixed, but allowed to lift from the table slightly. This could be fixed by fixing the fixed-end of the jig to a heavier table with bolts and nuts, tightened sufficiently.
- Loading of weights may have been inconsistent, due to the increasing difficulty to place the weights on the jig gently and with as little force as possible. This can be mitigated by additional people assisting in loading the weights on the jig, or by a different loading method.

Conclusion/Lessons Learned

This test successfully examined the conditions under which the coupler would fail testing when subject to a transverse load causing bending. Comparing two design prototypes, one of ABS-fibreglass and the other of foam-fibreglass, the foam-fibreglass coupler was determined to be the most rigid and safest coupler design, due to its superior rigidity as opposed to the ABS-fibreglass coupler.

This test has several sources of error, but succeeds in providing a qualitative metric to measure the strength of the coupler designs. Due to the errors, small sample size, and large variance, any conclusions drawn from this test data should be approached with caution. It is recommended that the testing jig be improved such that accurate data and research can be collected using this test.

Appendix

Table 1: Machine Shop Weights Used in Test

NAME	*Small Rusty Disk w/Lines*	*Steel Ingot*	*Square Ingot*	*Skinny Rusty Rod*	*Medium Shiny Disk*	*Large Shiny Disk*	*Medium Rusty Rod*	*Large Plain Rusty Rod*	*Large Yellow-Blue Rusty Rod*	TOTAL MASS
MASS	2.82 kg	3.271 kg	3.302 kg	3.335 kg	3.636 kg	13.46 kg	16.503 kg	18.232 kg	18.263 kg	82.822 kg

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Date: May 20, 2018
Test Lead: Noah Mar

Table 2: Standard Weight Combinations for Test

Trial	Small Rusty Disk w/Lines	Steel Ingot	Square Ingot	Skinny Rusty Rod	Medium Shiny Disk	Large Shiny Disk	Medium Rusty Rod	Large Plain Rusty Rod	Large Yellow-Blue Rod	TOTAL MASS [kg]
1	X	X	X							9.39
2	X					X				16.28
3		X	X			X				20.03
4	X	X	X		X	X				26.49
5	X					X	X			32.78
6	X							X	X	39.32
7	X	X	X					X	X	45.89
8	X	X	X	X	X			X	X	52.86
9	X				X		X	X	X	59.45
10	X	X	X		X		X	X	X	66.03
11	X	X				X	X	X	X	72.55
12		X	X	X		X	X	X	X	76.37
13	X	X	X	X	X	X	X	X	X	82.82

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Date: 2017-03-19
Test Lead: Annaliese Meyer

UVic Rocketry Test Report

PLA UV Box Rigidity Test

2017-03-19

Test Lead: Annaliese Meyer

Associates: Sachi Premathilaka, Tessa Charlton, Sean Farley

Date: 2017-03-19
Test Lead: Annaliese Meyer

Introduction

The housing for the ultraviolet LEDs and petri dishes that form the basis of our payload experiment are 3D-printed from polylactic acid filament. This test will act to ensure no deformation of the payload modules will occur in warm environmental conditions as experienced during launch.

Scope

This test aims to determine if any deformation of the 3D-printed PLA modules will occur at the approximate temperatures experienced at the launch location.

This is a semi-quantitative test, involving the qualitatively light application of stress on the payload module followed by numerical measurement to assess any deformation. Given the limitations of our incubator, this test does not allow testing of temperatures exceeding 45 ˚C. Given previous conditions, temperatures approaching 47 ˚C may be experienced.

Referenced Documents

"Poly(lactic acid): plasticization and properties of biodegradable multiphase systems," Martin, O., Averous, L.

Terminology

PLA: polylactic acid, a filament type used for 3D printing

LED: light-emitting diode

Materials

- EMD Millipore Field Incubator
- 3D-printed PLA box and insert
- Infrared gun
- Calipers

Hazards

No significant hazards to personnel or equipment.

Procedure

1. Plug in incubator and preheat to maximum allowed temperature (45˚C).

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2. Check horizontal dimensions of each piece with calipers.
3. Once heated, place box and insert into incubator. Leave for 3 hours, periodically testing temperature with infrared gun.
4. Remove box and insert and apply pressure, then immediately measure horizontal dimensions with calipers to check deformation.

Test Results

No significant deformation was measured when pressure was applied after heating.

Data and Analysis

Axis	Initial dimension (inches)	Dimension after heating (inches)
X	3.175	3.171
Y	3.175	3.167

Conclusion

No noticeable deformation occurred. PLA is a suitable material for this purpose.

References

Martin, O., Avérous, L. :Poly(lactic acid): plasticization and properties of biodegradable multiphase systems," *Polymer*, vol. 42, no. 14, 2001. [ISSN 0032-3861]. Available http://www.sciencedirect.com/science/article/pii/S0032386101000866. [Accessed March 1, 2018].

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Date: May 6th 2018
Test Lead: Avery Hiebert

UVic Rocketry Test Report

Ground Station Short-Distance Basic Tracking Test

May 6th 2018

Test Lead: Avery Hiebert

Associates: Alex Schell

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Date: May 6th 2018
Test Lead: Avery Hiebert

Introduction

The “ground station” is a system used by Uvic Rocketry to track and display telemetry information transmitted live by a BeeLine GPS board placed inside the rocket. The hardware component of the ground station consists of a Wandboard computer, a monitor, a battery, and other electrical components housed inside a Pelican case, as well as an RTL-SDR USB dongle and a whip antenna that can be used to receive radio signals on the 70cm band. The software component of the ground station consists of a server written in Python which uses the “rtl-sdr” and “direwolf” open-source software packages to receive and decode radio data, alongside a JavaScript client that displays information obtained by the server by marking the location and path of the rocket on a map, and plotting the rocket’s altitude over time. The ground station is developed and maintained as part of the GNC subsystem, although its purpose relates to recovery of the rocket rather than to guidance or control of the rocket.

The system was successfully used to recover two rockets at the IREC 2017 competition, but it has not been operated since the competition, and could conceivably have sustained some damage during transportation. Additionally, small cosmetic changes have been made to the software, which could have unintended consequences. Thus, some testing is required in order to ensure that the system still works as intended.

Scope

The purpose of this test is to qualitatively confirm that the entire ground station system (including both hardware and software components) is still capable of receiving, decoding, and displaying information transmitted by the BeeLine GPS board in real time.

Since no changes to the ground station hardware, and only minor changes to the software, have been made since the IREC 2017 competition, the purpose of this test is simply to re-test basic functionality, and not to investigate the limits of the system’s performance when the transmitter is far from the receiver; we have tested the system in the past at a distance of 10.4 km, and plan to conduct similar tests within the next three weeks, once some logistical obstacles are resolved.

We will consider the test successful if, while the BeeLine GPS board is actively transmitting, the Ground Station is able to display both the board’s location and its altitude in a visual interface that is consistently updated once for every packet of data emitted by the board, without any noticeable packet loss.

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Date: May 6th 2018
Test Lead: Avery Hiebert

Terminology

Ground station computer	The physical computer – including the Pelican case housing and all internal electronics – on which we run the ground station software.
Ground station software	The software run on the ground station computer for the purpose of receiving, decoding, and displaying location information received from the transmitter on the rocket.
Server	The Python program “wsserver.py” found in the “server” directory of the ground station software project repository.
Client	The web page “index.html” and associated JavaScript scripts, found in the “client” directory of the ground station software repository.
Configuration file	The file “config.json” found in the “server” directory of the ground station software repository.
BeeLine GPS	A board which transmits its location and altitude (obtained via GPS) at a frequency in the 70 cm band (430MHz to 450MHz) using the APRS protocol.
Coaxial cable	A type of cable used to transmit an analog signal from an antenna to a receiver.
Programming software	A program with a graphical user interface used to configure the behaviour of the BeeLine GPS.

Summary of Test Method

The computer is connected to an antenna via a coaxial cable. The server is configured to receive a digital radio signal on a fixed frequency. The server and the client are started. The BeeLine GPS is configured to transmit its location on the same frequency, and is turned on. The ground station is observed visually to ensure that the signals transmitted by the BeeLine GPS are displayed as expected by the ground station.

Materials

Date: May 6th 2018
Test Lead: Avery Hiebert

- The ground station computer, with the ground station software installed and with its battery fully charged
- The BeeLine GPS unit (including the antenna, battery, and USB connector that it is sold with), with battery fully charged
- A computer with the BeeLine GPS programming software installed
- An antenna appropriate for receiving on the 70cm band
- A coaxial cable, and appropriate connectors to attach the antenna to the cable, and to attach the cable to the port on the ground station
- A team member with a valid Amateur Radio Operator's Certificate or an equivalent certification legally allowing transmission on the amateur radio 70cm band in Canada
- A wireless internet connection

Hazards

This test involves electronic equipment. Care should be taken when connecting and disconnecting batteries, especially since the only way to turn off the BeeLine GPS device is to disconnect the battery.

Although the BeeLine GPS transmitter operates at a low power output of 100mw, for added safety the antenna should not be held close to the head and eyes of human operators while transmitting.

Procedure

1. The BeeLine GPS board is configured to transmit the desired data on an appropriate frequency:
   a. The BeeLine GPS board is connected to the computer containing the programming software, via the USB connector sold with the BeeLine device.
   b. Using the programming software, the "ID String" parameter is set equal to the call sign of the licensed radio operator performing the test. (In this particular test, the call sign VA7AVE was used.)
   c. Using the programming software, the "Frequency" parameter is set to 433.0 MHz, or to another frequency on which the licensed radio operator is authorized to transmit digital packets.
      i. Ideally, the chosen frequency should not interact with the local APRS network; in North America, this means that the frequency 144.39 MHz should not be used, but this frequency does not lie within the 70cm band anyways.
   d. Using the programming software, the "Tx Rate" is set to 10 seconds, and the "Transmit Course/Speed" option is turned off.
   e. When programming is finished, the BeeLine GPS is disconnected from

the computer.

2. The ground station computer is connected to its battery and then turned on.
3. The configuration file is edited to include the following settings:
    a. “doTestFromFile”: true
    b. “haveSDR”: true
    c. “doWebSocket”: true
    d. “frequency”: “433.00M” (unless a different frequency is chosen in step 1c.)
    e. “filterCallsign”: false
4. The receiving antenna is attached to the antenna port on the ground station computer via a coaxial cable.
5. The server is run in a terminal window, by executing the command “python wsserver.py” from within the “server” directory of the ground station software project.
6. The client is opened in the Firefox web browser.
7. The BeeLine GPS is placed in an indoor location where it will *not* easily achieve GPS lock, and then turned on by connecting the battery. This is done in order to test for a ground station error that has occurred in the past when the BeeLine GPS fails to achieve GPS lock.
8. The terminal output of the server is observed for at least five minutes.
    a. If an unhandled exception occurs, the test has failed.
    b. All observations are recorded in writing.
9. The battery of the BeeLine GPS is disconnected.
10. The BeeLine GPS is placed outdoors (or in a windowsill), at a distance of at least multiple meters from the ground station antenna, with a clear line of sight to the ground station antenna. The battery is reconnected
11. The terminal output of the server is observed for a period of at least two minutes.
    a. Once the red LED on the BeeLine GPS begins to flash at a rate of once per second, a json-formatted packet should appear in the terminal output once every ten seconds, until such a time as the server is stopped or the battery of the BeeLine GPS is disconnected.
    b. All observations are recorded in writing.
12. The behaviour of the client is observed for a period of at least two minutes.
    a. Once every ten seconds, the “altitude” and “vertical velocity” charts in the client interface should appear to be updated with a new data point.
    b. A red triangular icon should appear on the map portion of the client interface, at a location in the map corresponding to the real-world location of the BeeLine GPS board.
    c. All observations are recorded in writing.
13. Once all observations are completed, the battery is disconnected from the BeeLine GPS board.
14. The browser, server, and any other programs running on the ground station computer are exited.
15. The ground station computer is turned off, and the battery and antenna are disconnected.

16. All equipment is put away in its usual location.

Test Results and Analysis

A test was performed on May 6th, 2018. Initially, at step 8a an unhandled exception occurred while running the server, causing the server to cease receiving data entirely. After inspection of the stack trace and the server code, it was determined that a bug which had previously been fixed in 2017 was inadvertently re-introduced during a minor software change, when a statement erroneously believed to be redundant was removed.

After modifying the server code to correctly handle the exception, the test was restarted from step 5 and carried out to completion. No further errors were observed, and the client did appear to receive a packet of data once every 10 seconds while the BeeLine GPS was transmitting, with no packets dropped during the period of observation.

These results support the hypothesis that, aside from the error that was fixed during testing, the ground station still functions as it did in 2017 and has not sustained major damage to its hardware or software.

Discussion

The test did not surface any errors other than the reversion that was fixed during the test. However, this does not preclude the possibility that system could be flawed in a less severe way which would nonetheless render it useless under real launch conditions. In particular, it is possible that some flaw in the receiver or antenna could reduce its ability to handle weaker signals, causing the ground station to fail when far from the transmitter, despite appearing to work perfectly when the transmitter is close to the receiver. We intend to test for such defects in a long-distance test as soon as possible, once multiple difficulties involved in performing such a test are resolved.

The fact that a previously fixed error was reintroduced during what was intended to be a cosmetic modification to the software suggests that testing should always be conducted prior to competition, regardless of whether major changes to the system were knowingly introduced, since unknown errors may also have been introduced.

Conclusion

The purpose of this test was to verify that the ground station system is still capable of successfully receiving, decoding, and displaying data packets transmitted by the BeeLine GPS transmitter. During the test, a known software error was encountered.

Date: May 6th 2018
Test Lead: Avery Hiebert

After the error was corrected, the ground station performed as expected and no further errors surfaced. However, further testing at a long distance is still desirable in order to verify that the ground station will function as expected under conditions more similar to those of an actual launch.

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Date: May 19th 2018
Test Lead: Avery Hiebert

UVic Rocketry Test Report

Ground Station Long-Distance Test Under Realistic Conditions

May 19th 2018

Test Lead: Avery Hiebert

Associates: Alex Schell, Jennifer Bonham, Eric Fraser

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Date: May 19th 2018
Test Lead: Avery Hiebert

Introduction

The “ground station” is a system used by Uvic Rocketry to track and display telemetry information transmitted live by a BeeLine GPS board placed inside the rocket. It uses a software defined radio to receive and decode APRS-encoded data transmitted on the 70cm band, and displays the location and altitude of the rocket in a graphical user interface. This system is developed and maintained as part of the GNC subsystem, although its purpose relates to recovery of the rocket rather than to guidance or control of the rocket.

The system was successfully used to recover two rockets at the IREC 2017 competition, and has recently been tested for basic functionality at a short distance. However, there are multiple respects in which the previous test did not resemble real launch conditions. In particular, the antenna used during testing was not the antenna that we plan to use for competition, the transmitter was not inside the rocket nose cone (which differs from the nosecone used in 2018) when transmitting, and the test was conducted with the transmitter and receiver less than ten metres apart. Thus, some testing is required to confirm that the intended antenna receives well at a long distance, and that the new nosecone (which is made of fibreglass but includes an aluminum cap) does not obstruct signals from the transmitter.

Scope

The purpose of this test is to qualitatively confirm that the entire ground station system (including both hardware and software components) is capable of receiving, decoding, and displaying information transmitted by the BeeLine GPS board in real time, under conditions similar to those of a real launch. The system’s performance will also be measured quantitatively, by observing the ratio of packets that are not successfully decoded by the system.

This is primarily a test of hardware, since the only differences between this test and the previous “basic tracking” test are related to the hardware and the physical distance between the transmitter and the receiver. Thus, known software bugs will not be tested for. The only known critical bug in the software was fixed during the “basic tracking” test.

We will consider the test successful if, while the BeeLine GPS board is actively transmitting, the Ground Station is able to display both the board’s location and its altitude in a visual interface that is consistently updated once for every packet of data received from the BeeLine board, while missing no more than 1 packet in 10.

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Date: May 19th 2018
Test Lead: Avery Hiebert

Terminology

Ground station computer	The physical computer – including the Pelican case housing and all internal electronics – on which we run the ground station software.
Ground station software	The software run on the ground station computer for the purpose of receiving, decoding, and displaying location information received from the transmitter on the rocket.
Server	The Python program “wsserver.py” found in the “server” directory of the ground station software project repository.
Client	The web page “index.html” and associated JavaScript scripts, found in the “client” directory of the ground station software repository.
Configuration file	The file “config.json” found in the “server” directory of the ground station software repository.
BeeLine GPS	A board which transmits its location and altitude (obtained via GPS) at a frequency in the 70 cm band (430MHz to 450MHz) using the APRS protocol.
Coaxial cable	A type of cable used to transmit a radio signal from an antenna to the receiving hardware.
Programming software	A program with a graphical user interface used to configure the behaviour of the BeeLine GPS.
Nose cone	The hollow, approximately conical aluminum-tipped fibreglass shell designed to fit on top of the rocket, in which the BeeLine GPS will be placed during flight.
Packet	A single unit of digitally-encoded information emitted by the BeeLine GPS transmitter.

Summary of Test Method

The ground station computer and the BeeLine GPS are placed in locations multiple kilometres apart, with a direct line of sight between the two devices. The computer is connected to the receiving antenna via a coaxial cable. The server is configured to receive a digital radio signal on a fixed frequency. The server and the client are started. The BeeLine GPS, previously configured to transmit its location on the same frequency, is turned on and placed inside the nosecone. The ground station is observed visually to ensure that the signals transmitted by the BeeLine GPS are displayed as expected by the ground station, and the packets received are recorded for later analysis.

Materials

- The ground station computer, with the ground station software installed and with its battery fully charged
- The antenna intended for use with the ground station
- The BeeLine GPS unit (including the antenna, battery, and USB connector that it is sold with), with battery fully charged
- A computer with the BeeLine GPS programming software installed
- A coaxial cable, and appropriate connectors to attach the antenna to the cable, and to attach the cable to the port on the ground station
- A team member with a valid Amateur Radio Operator's Certificate or an equivalent certification legally allowing transmission on the amateur radio 70cm band in Canada
- A means of communication between two parties in different locations (e.g. cell phones or hand held radios).
- A wireless internet connection (optional)

Hazards

This test involves electronic equipment. Care should be taken when connecting and disconnecting batteries, especially since the only way to turn off the BeeLine GPS device is to disconnect the battery.

Although the BeeLine GPS transmitter operates at a low power output of 100mw, for added safety the transmitting antenna should not be held close to the head and eyes of human operators while transmitting.

Procedure

1. The BeeLine GPS board is configured to transmit the desired data on an appropriate frequency:
    a. The BeeLine GPS board is connected to the computer containing the programming software, via the USB connector sold with the BeeLine device.
    b. Using the programming software, the "ID String" parameter is set equal to the call sign of the licensed radio operator performing the

test. (In this particular test, the call sign VA7AVE was used.)

c. Using the programming software, the "Frequency" parameter is set to a frequency on which the licensed radio operator is authorized to transmit digital radio.
    i. Ideally, the chosen frequency should not interact with the local APRS network; in North America, this means that the frequency 144.39 MHz should not be used, but this frequency does not lie within the 70cm band supported by the BeeLine GPS anyways.
    ii. An RF spectrum analyzer or equivalent device should be used to confirm that transmitting on a given frequency will not interfere with other radio signals.
d. Using the programming software, the "Tx Rate" is set to 10 seconds, and the "Transmit Course/Speed" option is turned off.
e. When programming is finished, the BeeLine GPS is disconnected from the computer.

2. The ground station computer (including antenna, battery, and other associated equipment) is brought to the top of a large hill, mountain, or similarly unobstructed location. Simultaneously, the BeeLine GPS transmitter (along with the nosecone) is brought to a distant location with a direct line of site to the location of the ground station.
    a. For this test, locations on Mt. Tolmie and Mt. Douglas in Victoria, BC were used. The two locations are approximately 4.3 km apart.
3. The ground station computer is connected to its battery and then turned on.
4. The configuration file is edited to include the following settings:
    a. "doTestFromFile": true
    b. "haveSDR": true
    c. "doWebSocket": true
    d. "frequency": "433.00M" (unless a different frequency is chosen in step 1c.)
    e. "filterCallsign": false
    f. "doLogData": true
5. The receiving antenna is attached to the antenna port on the ground station computer via a coaxial cable.
6. The server is run in a terminal window, by executing the command "python wsserver.py" from within the "server" directory of the ground station software project.
7. The client is opened in the Firefox web browser.
8. The BeeLine GPS is turned on by connecting the battery.
9. When the red LED on the BeeLine GPS begins to blink once per second, indicating that GPS lock has been achieved, the BeeLine GPS is placed inside the nosecone and held vertically.
10. The behaviour of the client is observed for a period of at least five minutes.
    a. Once every ten seconds, the "altitude" and "vertical velocity" charts in the client interface should appear to be updated with a new data point.
    b. If a wireless internet connection is available, a red triangular icon should appear on the map portion of the client interface, at a location

on the map corresponding to the real-world location of the BeeLine GPS board. If no internet connection is available, the red icon should still appear, although the map itself will be empty.
    c. All observations are recorded in writing.
11. The server is stopped. The existing log file is saved, and a new log file is created.
12. The server is restarted, and run for a period of at least 5 minutes for the purpose of quantitative evaluation.
    a. All packets received are automatically logged.
13. Once all observations are completed, the battery is disconnected from the BeeLine GPS board.
14. The browser, server, and any other programs running on the ground station computer are exited.
15. The ground station computer is turned off, and the battery and antenna are disconnected.
16. All equipment is returned to its usual location.
    a. Prior to putting away the ground station, the log file produced in step 12 is obtained from the ground station and analyzed to determine the rate of packet loss.

Test Results and Analysis

The test was performed on May 19th, 2018. The locations chosen for the transmitter and receiver were approximately 4.3 km apart. While the BeeLine GPS was transmitting, the ground station client did display and update the location and altitude of the transmitter in real time. Over the 5 minute period designated for determining the rate of packet loss, 30 packets were transmitted by the BeeLine GPS, of which 27 were successfully decoded by the ground station server, giving a 10% rate of packet loss.

These results suggest that the antenna intended for use at competition is capable of effectively decoding packets at a distance, and that the nose cone does not obstruct communication from the transmitter to the receiver.

Discussion

The measured rate of packet loss falls within our specified success criteria of “no more than 1 in 10 packets lost”, but only barely. However, this threshold is somewhat arbitrary, and we intend to transmit packets more frequently at competition (although a rate of 1 packet every 10 seconds was used during testing to further reduce the risk of inconveniencing users of nearby radio frequencies), reducing the importance of receiving any individual packet.

The packet loss measurement was made using only 5 minutes of data (30 packets).

A larger sample would be more meaningful, but since the qualitative component was the primary purpose of this test, we considered it acceptable to reduce the length of the qualitative portion of the test due to external time pressure.

This test was performed at a distance of approximately 4.3 km. Since we will be launching a rocket to 30,000 feet (about 9.14 km), the ground station will need to operate at even longer distances; however, it is not necessary that we be able to track the rocket during the entire duration of its flight (in particular, we do not expect to track it perfectly at apogee), so long as the final landing location of the rocket is within range. Furthermore, we have tested the ground station successfully at a distance of 10.4 km in the past, albeit with a different antenna, and we have no reason to expect noticeably different performance with the current antenna.

Conclusion

The purpose of this test was to verify that the ground station system is capable of successfully receiving, decoding, and displaying data packets transmitted by the BeeLine GPS transmitter under conditions similar to real operating conditions. The qualitative results of the test show that our antenna is capable of receiving signals at a distance of 4.3 km, and that the nose cone does not obstruct the BeeLine GPS transmitter. The rate of packet loss under these conditions was 10%, which we consider acceptable.

Appendix III: Hazard Analysis and Risk Assessment

University of Victoria Rocketry Hazard and Risk Assessment

Hazard	CONOPS Phase	Possible Causes	Risk of Mishap / Rationale	Consequence	Mitigation Approach	Risk After Mitigation
Explosion of solid motor on the launch pad or low in the air	A,B,C,D	Cracks in propellant grain	Low: COTS motor from CTI	Severe: Irreparable damage to casing and remainder of rocket; Possible injury or death	Proper handling of propellant grains before and during installation	Low
	A,B,C,D	Clogged nozzle throat			Proper handling of propellant grains before and during installation	
	A,B,C,D	Gaps in fuel grain sections	Medium: Installation of propellant grains is a multi-step process where mistakes can be made		Follow all installation steps provided by CTI exactly. Ensure a member with installation experience is helping	
	A,B,C,D	Incorrect installation of propellant grains			Follow all installation steps provided by CTI exactly. Ensure a member with installation experience is helping	
	A,B,C,D	Incorrect casing installation	Low: Designed for easy, "foolproof" assembly		Inspect casing installation	
	A,B,C,D	Damage to motor casing	Medium: Small likelihood of damage during transportation or handling		Do NOT use CTI-provided casing case (end caps easily fall off); Inspect casing for damage before installation	
Unplanned motor ignition	A	Incorrect electrical wiring	Low: Most electrical system components controlled by ESRA	Severe: Uncontrolled "flight" without stabilizing launch rail; possible damage to person or property	Follow all directions of ESRA and printed procedures checklist	Low
	A	Static discharge	Low: Unlikely to occur		Keep motor cap on until ready for launch	
	A	Contact with open flame	Low: Unlikely to occur		Keep away from any open flames	
Rapid unplanned disassembly ***Continued***	B,C,D	Fins detach from rocket	Medium: Possibility of manufacturing errors due to unavailability of non-destructive testing	Severe: Falling fins could collide with personnel causing injury. Unstabilized flight could lead to haywire rocket motion, leading to high speed contact with personnel causing serious injury or death	Perform extensive testing of fins	Low
	B,C,D	Motor shifts upwards	Low: Designed with a high factor of safety	Severe: Possibly unstable flight	Tearout tests performed on propulsion bulkhead fasteners.	

				due to vertical axis of motor not aligning with vertical axis of vehicle	Redundant system, for failure to occur bulkhead fasteners, thrust ring fasteners, and thrust ring must fail.	
	G	Motor shifts downwards / detaches from rocket	Low: Designed with a high factor of safety	Severe: Falling components could collide with personnel causing injury.	Tearout tests performed on propulsion bulkhead fasteners. Motor attached using standard methods.	
	B,C,D,E	Premature nose cone ejection	Low: Fuselage has equilibration holes to relieve slow pressure changes	Severe: Falling components could collide with personnel causing injury.	Include equilibration holes in fuselage	
	F,G	Pyrelease falls out from rocket	Medium: Pyrelease is not permanently fixed to the recovery bulkhead, small size makes it difficult to identify if it falls from the rocket	Severe: Falling object could collide with personnel causing injury	Pyrelease components are tethered together and to bulkhead with Kevlar rope, follow checklist	
Drogue parachute does not deploy	F	Nose cone shear pins do not shear	Low: Designed and tested for separation	Severe: High speed impact with the ground resulting in complete destruction of the rocket, possible damage to property or injury to spectators.	Test ejection with varying charges and packing schema to ensure function in all cases	Low
	F	Insufficient CO2 ejection	Low: Tested at ground level where internal gauge pressure is lower			
	F	Release of CO2 is too slow or does not occur	Low: CO2 ejection mechanisms tested under vacuum to simulate apogee conditions			
	F	Electrical Failure	Low: Wiring standard specified by ESRA			
	F	Main board and backup board do not detect apogee, sensor or board failure	Low: Commercially designed boards, multiple backup sensors. Holes in fuselage ensure proper reading. Mach compensation built in.		Simulate flight conditions cycling between all flight states, verify sensor stability Simulate flight in pressure chamber, verify sensor stability Calibrate board accelerometer pre-assembly	
Continued	F	Primary ignitor and redundant ignitor become disconnected	Low: All connectors and wiring adhere to competition standards		Follow pre-flight checklist	

	F	Entanglement of chute/lines	Medium: Lines can tangle due to vehicle rotating about vertical axis		Minimize complexity of drogue chute/lines, ensure properly stuffed in rocket (lines on top of chute)Only fly in low-wind conditions	
	F	One board has software failure and the other becomes disconnected from ignitor	Low: All connectors and wiring adhere to competition standards		Follow pre-flight checklist	
	F	Complete separation of upper fuselage section via fastener tearout	Low: Nylon shear screws have significantly lower strength than screws holding coupler	Medium: Main recovery system may still deploy correctly	Full system tested	
Main parachute does not deploy	G	Main board and backup board do not detect 1500 ft. AGL, sensor or board failure	Low: High exposure to outside atmosphere ensures correct reading	Severe: High speed impact with the ground resulting in complete destruction of the rocket, possible damage to property or injury to spectators	Simulate flight conditions cycling between all flight states, verify sensor stability, calibrate accelerometer pre-assembly	Low
	A,B,C,D,E,F, G	Primary ignitor and redundant ignitor become disconnected	Low: All connectors and wiring adhere to competition standards, board communicates how many charges connected		Complete pre-flight checklist, continuity checks pre-flight	
	A,B,C,D,E,F, G	One board has software failure and the other becomes disconnected from ignitor	Low: All connectors and wiring adhere to competition standards, board communicates how many charges connected		Complete pre-flight checklist, continuity checks pre-flight	
Main parachute failure	G,H	Parachute burnt during pyro release	Low: CO2 mechanism uses small quantities of black powder	Medium: Medium speed impact with the ground resulting in complete destruction of the rocket, possible damage to property or injury to spectators	Fire resistant parachute bag and heat shield between parachute and pyrotechnics	Low
	G,H	Parachute rips or tears	Low: Drogue chute slows descent prior to main deployment and shock cords to reduce impulse acting on main		Parachute is made from ripstop so tears will not propagate	
Continued	G,H	Shroud lines tangle	Medium: Many thin, flexible lines can become tangled easily		Proper chute packing procedure and checks. Only fly in low-wind conditions	
Main parachute deploys at or near apogee, causing drift to populated areas	F	Failure of pyrelease	Low: Standard manufacturing techniques used to make pyrelease	Medium: Rocket will drift slowly toward people or property, but may cause damage to structures or vehicles	Pyrelease tested in simulated flight conditions, tested in previous launches	Low
	A	Main parachute is poorly packed	Medium: Main parachute lines are sufficiently long for main parachute to unfold outside of the fuselage before deployment		Use manufacturer's instructions for packing	

	B,C,D,E,F	Premature ejection of pyrelease due to electrical failure	Low: All connectors and wiring adhere to competition standards		Proper sealing of pyrelease compartment; extensive testing of complete system	
On-Pad recovery deployment charge ignition during flight-ready state	A	Drogue ignitor activation due to apogee misdetection	Low: Boards locked out until ready, require launch detection	Low: Flight delay requiring disarming of rocket	Simulate flight conditions cycling between all flight states, verify sensor stability Simulate flight in pressure chamber, verify sensor stability Calibrate board accelerometer pre-assembly	Low
	A	Main ignitor activation due to altitude misdetection	Low: Boards locked out until ready, require launch detection		Simulate flight conditions cycling between all flight states, verify sensor stability Simulate flight in pressure chamber, and verify sensor stability. Calibrate board accelerometer pre-assembly	
Recovery system separates from vehicle	F,G	Shock cord failure, via sewing failure	Low: Sufficient sewing techniques	Severe: High speed impact with the ground resulting in complete destruction of the rocket, possible damage to property or injury to spectators	Qualify shock cord loading experimentally, high-strength thread used for sewing	Low
	F,G	Eye bolts separate from bulkhead	Low: Bulkhead made using standard manufacturing practices		Use welded steel or forged eye bolts, use Loctite on threads	
	F,G	Bulkhead fails/separates from coupler	Medium: Impulse acting on fuselage from bulkhead set screws could tear fuselage		Carbon fibre testing to qualify a safety factor for the fuselage, and FEA analysis of metal components	
	F,G	Coupler tears out from lower fuselage	Medium: Impulse acting on fuselage from bulkhead set screws could tear fuselage		Carbon fibre testing to qualify a safety factor for the fuselage	
Weather hazard	A,B,C,D,E,F, G,H,I	Poor weather predictions	Low: Advances in weather prediction capabilities in the 21st century	Low: Fly or no fly call	Monitor weather conditions	Low
	A,B,C,D,E,F, G,H,I	Rapid changing weather patterns	Low: Advances in weather prediction capabilities in the 21st century		Monitor weather conditions	
	A,B,C,D,E,F, G,H,I	Intense heat and UV exposure	High: Multiple occurrences at previous competition	Medium: Risk of heat stroke and sunburns	Designate one medic person, drink lots of water, stay in shade, electrolytes, wear long sleeve clothing, wear a hat, use sunscreen	Medium

Motor falls out	F,G	Failure of propulsion bulkhead due to high speed parachute deployment	Low: Designed with high safety factor	Medium: High speed impact of the motor casing with the ground, possible damage to property or injury to spectators	Perform FEA on bulkhead and consult tear out data for bulkhead from coupler	Low
Off nominal trajectory	B,C,D	Fin failure	Medium: Possibility of manufacturing errors due to unavailability of non-destructive testing	Severe: Falling fins could collide with personnel causing injury. Unstabilized flight could lead to haywire rocket motion, leading to high speed contact with personnel causing serious injury or death	Perform extensive testing of fins	Low
	D	Slow speed off of launch rail	Low: Trajectory calculations confirm speed off launch rail	Severe: Rocket will point in a possibly dangerous direction, damage to persons or property	Model and cross check model using detailed masses; ensure rail is undamaged and rocket slides smoothly	
	A,B,C,D,E,F	Misaligned rocket motor	Low: Radial locating rings in assembly ensure motor alignment		Careful construction and inspection of radial locating rings. Inspection prior to launch	
	A,B,C,D,E,F, G,H,I	Strong wind gusts	Low: Regulations prevent flight in strong winds		Monitor weather conditions	
Continued	A	Improper motor reload/nozzle installation	Medium: Installation of propellant grains is a multi-step process where mistakes can be made		Follow manufacturer's instructions and recommendations of supplier	
Non-ignition (hang fire)	B	Failure of ignitor	Low: Commercial igniter	Medium: Potential late ignition of motor causing unplanned motor ignition	Use high quality squibs/ignitor provided by COTS motor supplier. Follow ESRA procedures. If non-ignition occurs, disarm ignition system and wait at least 5 minutes before approaching.	Low
	B	Ignition battery failure	Medium: Can't test battery during ground handling	Low: No ignition of motor	Disarm ignition system and wait at least 5 minutes before approaching. Follow ESRA procedures.	

	A,B	Wire or terminal disconnects/breaks	Medium: Frequency handling of terminals could lead to disconnection or breaks		Ensure proper wiring procedures are followed. Use high quality squibs/electronics and visually inspect the connections	
Internal load shift (ballast or payload)	B,C,D,E,F,G,H	Failure of screws holding payload bulkhead into fuselage	Low: Designed with high safety factor	Medium: Stability of rocket is affected, but the payload can only shift approximately one caliber	Tearout testing on sample fuselage to ensure high safety factor	Low
	B,C,D,E,F,G,H	Improper fixturing of payload or ballast	Low: Difficult to assemble incorrectly	Medium: Stability of rocket is affected	Ensure assembly procedures have been followed and checklist completed and personnel involved have practice assembling the payload	
LiPo failure	A	Manufacturer defect	Low: High quality batteries are used	Medium: LiPo fire, damage to rocket and/or ground personnel, payload experiment malfunctions	Testing of battery to ensure high quality	Low
	A,B,C,D,E,F,G,H,I	Mechanical damage from LiPo holder failure	Low: Designed with enough clearance and high factor of safety		Static testing of LiPo holder design to quantify failure conditions, redesign of LiPo holder to acceptable safety standards, completing pre-flight checklist.	
	A,B,C,D,E,F,G,H,I	Batteries overheat	Low: Temperature unlikely to get to dangerous levels		Ensure that the current draw is minimal	
	A,B,C,D,E,F,G,H,I	Battery life fatigue	Low: Battery fatigue can be monitored		Usage of new battery	
Recovery system deploys during assembly or prelaunch	A	Electronics failure	Low: Commercial product, switches lock out power to entire system pre-vertical	Severe: Hazard to ground crew, personal injury	Appropriate PPE will be worn when arming, all personnel will stay out of firing line when arming. Will be armed in the vertical upright position.	Low
	A	Continuity testing	Medium: E-match ignition current low, can be tripped by multimeter	Severe: Hazard to ground crew, personal injury	Only perform tests on closed circuit outside of assembly area	
Rocket falls from launch rail during pre-launch install	A	Launch lug failure, due to poor machining or non-spec manufacture.	Medium: Rocket is bottom heavy.	Medium: Rocket could fall and hit personnel	Exercise caution installing the rocket, remain out of the probable path	Low
Animal hazard	A	Animal enters rocket, interrupts function	Low: Animal unlikely to approach due to people around rocket	Medium: Damaging electrical components. Failure could lead to damage to	Inspect rocket during operations	Low

				personnel or property. Potential animal death		
	A,I	Contact with dangerous animal	Low: Animal unlikely to approach people	Severe: Dangerous animals such as snakes and scorpions could lead to serious injury or death	Be aware of warning signs of dangerous animals such as a rattlesnake. Always wear long pants and closed toe shoes when entering desert	
UV payload exposure	A	Premature activation of payload system	Low: Payload system is sealed	Medium: Vision damage with extended exposure	Inline visible LEDs to indicate activation; use UV protective goggles during assembly; do not initialize payload until mounted in rocket	Low
Failure of control LEDs	A	Incorrect wiring, incorrect initialization	Low: System is checked independently by multiple individuals	Medium: Will not know if UV lights are on, more likely to be exposed to UV	Wear UV protective goggles at all times	Low
Contamination from test specimens ***Continued***	A,I	Improper specimen handling, failure of payload structure	Low: Using risk group 1 specimens, work with specimens done in a lab with proper biosafety equipment	Low: Risk Group 1 specimens commonly found in environment, cannot cause human infection or environmental damage	Always follow proper handling procedures, set up experiment before arrival at launch site	Low
Payload electronics failure	A	Incorrect wiring, incorrect initialization	Medium: Complex payload wiring and initialization steps	Low: No data collection	Follow predefined procedures for payload initialization	Low
Agar melting	A,B,C,D,E,F, G,H,I	Temperature exceeds melting point of agar (85 degrees Celsius)	Low: Agar melting point is high, 85 degrees Celsius	Medium: Agar leaks into and damages electrical systems, data loss	Ensure proper sealing of payload	Low

Appendix IV: Assembly, Pre-flight, and Launch Checklists

Master Checklist

A - Aerostructure
G - GNC
P - Propulsion
PE - Payload Engineering
PS - Payload Science
R – Recovery

Section A

A.1		Verify that the **1-P Motor Mount Assembly and Installation** checklist is complete
A.2		Verify that the **2-P Motor Assembly** checklist is complete
A.3	*Proceed with **11-P Motor Insertion** checklist*	
A.4		Verify that the **11-P Motor Insertion** checklist is complete

Section B

B.1		Verify that the **3-PE Payload Engineering Pre-Assembly** checklist is complete
B.2		Verify that the **4-PS Payload Science Pre-Assembly** checklist is complete
B.3	*Proceed with **12-PE Payload Engineering Assembly** checklist*	
B.4		Verify that the **12-PE Payload Engineering Assembly** checklist is complete

Section C

C.1		Verify that the **6-R Recovery Bulkhead Assembly** checklist is complete
C.2		Verify that the **7-G Avionics Pre-Assembly** checklist is complete
C.3		Verify that the **13-G Avionics Assembly** checklist is complete
C.4	*Proceed with **15-R Recovery Bulkhead Wiring** checklist*	
C.5		Verify that the **15-R Recovery Bulkhead Wiring** checklist is complete

D.3		Verify that the **9-A Nose Cone Pre-Assembly** checklist is complete
D.4	*Proceed with **18-A GNC Bulkhead Assembly** checklist*	
D.5		Verify that the **18-A GNC Bulkhead Assembly** checklist is complete

Section E

E.1		Verify that **Section A** is complete
E.2		Verify that **Section B** is complete
E.3		Verify that the **5-A Coupler Pre-Assembly** checklist is complete
E.4		Verify that the **16-R Parachute Attachment** checklist is complete
E.5		Verify that the **17-R Recovery Insertion** checklist is complete
E.6	*Proceed with **20-A Coupler Assembly** checklist*	
E.7		Verify that the **19-A Nose Cone Assembly** checklist is complete
E.8	*Proceed with **21-R Nose Cone Installation** checklist*	
E.9		Verify that the **21-R Nose Cone Installation** checklist is complete
E.10		Verify that the **20-A Coupler Assembly** checklist is complete
E.11	*Proceed with **24-P Fin Attachment** checklist*	
E-12		Verify that the **24-P Fin Attachment** checklist is complete

Section F

F.1		Verify that the **10-G Ground Station Pre-Assembly**
F.2	*Proceed with **22-G Ground Station Configuration** checklist*	
F.3		Verify that the **22-G Ground Station Configuration** checklist is complete

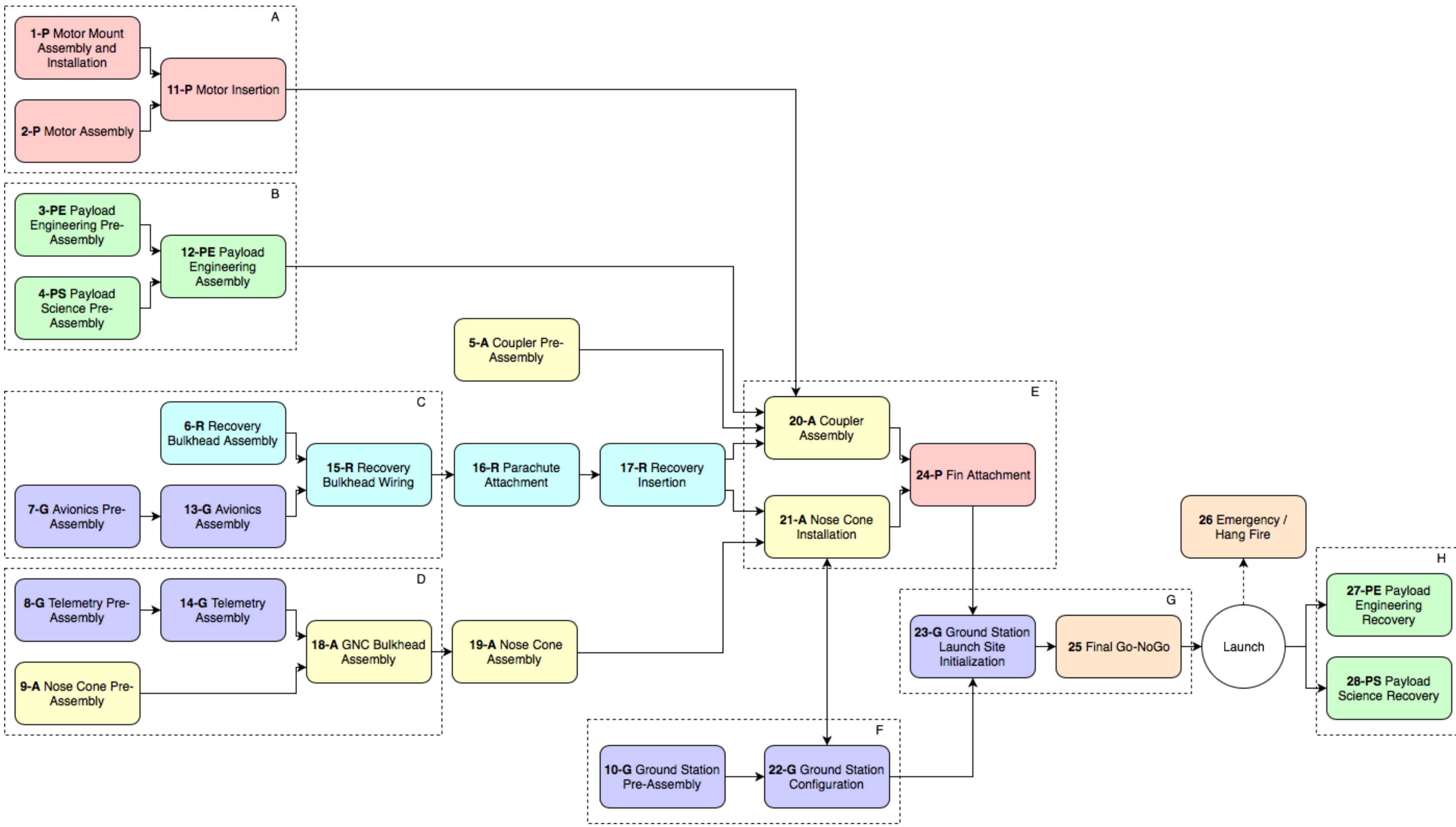
Section G

G.1		Verify that **Section E** is complete
G.2		Verify that **Section F** is complete
G.3		Verify that the **23-G Ground Station Launch Site Initialization** checklist is complete
G.4	*Proceed with **25 Final Go-NoGo** checklist*	
G.5		Verify that the **25 Final Go-NoGo** checklist is complete

Section H

H.1		Verify that the rocket has touched down
F.1		Verify that the **27-PE Payload Engineering Recovery** checklist is complete
F.3		Verify that the **28-PS Payload Science Recovery** checklist is complete

Checklist Flow Diagram



Propulsion Checklists

1-P Motor Mount Assembly and Installation

Complete partially at the hotel, partially at assembly tent.

1.1		Ensure all components and tools are present and undamaged O All components of the H1-51 and Z5 series O Propulsion Bulkhead (H1-31-03) O Coupler (H1-31-01)
1.2		Inspect the pre-assembled fin mount
1.3		Verify that no components obstruct the motor locating holes
1.4		Verify fin ring orientation is correct
1.5		Verify all threads are clean and undamaged
1.6		Confirm all fasteners are tightened with loctite
1.7		Ensure lower fuselage is undamaged
1.8		Ensure there are no obstructions in the lower fuselage
1.9		Slide the fin mount into the fuselage, ensuring launch lug holes are aligned
1.10		Ensure the thrust ring sits flush with the bottom edge of the fuselage
1.11		Apply loctite to 12 6-32 set screws
1.12		Tighten set screws into thrust ring until flush with fuselage
1.13		Fasten launch lug, being careful not to over tighten
1.14		Verify launch lug has not been squished

2-P Motor Assembly

Complete at assembly tent

2.1		Ensure motor casing and components are present and undamaged
2.2		Verify no cracks or damage to propellant grain
2.3		Verify o-rings are undamaged
2.4		Following reload instructions provided by Cesaroni, assemble the motor

2.5		Ensure forward and aft retaining rings are tightened and secure
2.6		Place assembled motor into plastic casing

11-P Motor Insertion

Complete at assembly tent

11.1		Ensure assembled motor is not damaged
11.2		Thread threaded rod completely into forward enclosure using loctite
11.3		Slide rocket motor into lower fuselage
11.4		Notify team that the motor has been loaded into the rocket
11.5		Place upper centering ring from the top and ensure it sits flush
11.6		Verify propulsion bulkhead is undamaged and radial hole threads are clear
11.7		Verify coupler is undamaged and radial holes are clear
11.8		Align the bulkhead with the launch lug hole on the lower end of the coupler
11.9		Unthread 3 10-32 set screws until flush with outer edge of coupler
11.10		Verify the top of the lower fuselage is undamaged and radial holes are clear
11.11		Slid the coupler into the lower fuselage, ensuring the launch lug hole is aligned
11.12		Verify the threaded rod has passed through the center hole of the bulkhead
11.13		Unthread 3 10-32 set screws until flush with outer edge of the fuselage
11.14		Insert remaining 8 set screws into bulkhead through the fuselage holes
11.15		Verify all set screws are flush with the fuselage
11.16		Fasten launch lug, being careful not to over tighten
11.17		Verify launch lug has not been squished
11.18		Ensure the aft retaining ring is sitting flush against the thrust ring
11.19		Thread nut onto threaded rod and tighten against bulkhead
11.20		Thread second nut onto threaded rod and tighten to lock in place

11.21		Notify Aerostructure team that propulsion no longer needs access to the coupler
11.22		Verify that the boat tail has not been damaged and the holes are clear
11.23		Place boat tail over the aft retaining ring
11.24		Apply loctite to 3 6-32 fasteners
11.25		Fasten boat tail to thrust ring using 3 6-32 fasteners

24-P Fin Attachment

Complete at assembly tent

24.1		Ensure Fins are present
24.2		Verify no cracks or damage on fins
24.3		Verify fin holes are not obstructed
24.4		Verify fin base is not damaged
24.5		Confirm that the nose cone and fuselage are all attached
24.6		Apply loctite to 8 6-32 fasteners
24.7		Align fin with fin holes and fasten to fuselage
24.8		Ensure fin sits flush with fuselage
24.9		Repeat steps 6 to 8 for the second fin
24.10		Repeat steps 6 to 8 for the third fin
24.11		Notify Aerostructure that the fins have been attached

Payload Engineering Checklists

3-PE Payload Engineering Pre-Assembly

Complete at hotel

3.1		Ensure all components and tools are present and undamaged O All components of the H1-41 and Z4 series
3.2		Begin charging Z-LiPo Battery until fully charged DO NOT LEAVE OVERNIGHT. Disconnect when charging is complete.
3.3		Begin charging Z-Slam Stick X until fully charged DO NOT LEAVE OVERNIGHT. Disconnect when charging is complete.
3.4		Test and Verify that Data transfer on Z-Slam Stick is working as intended.
3.5		Test and Verify that Data transfer on Z-Nucleo board is working as intended.
3.6		Test and Verify that 245nm box, and 275nm box UV LEDs are working as intended.
3.7		Test and Verify that Z-Mobius Camera is working as intended.
3.8		Verify, using a multimeter, that Z-LiPo Battery is fully charged.
3.9		Verify, using a multimeter, that Z-SlamStick is fully charged.
3.10		Return all Components to their respective Packing Locations.
3.11		Final Check to ensure all components are returned and undamaged for transport. Refer to attached BOM.

12-PE Payload Engineering Assembly

Complete at assembly tent
Refer to assembly drawings when told to "assemble"

12.1		Ensure all components and tools are present and undamaged O All components of the H1-41 and Z4 series
12.2		Ensure all assembly Drawings are present

12.3		Assemble Control box, 245nm box, and 275nm box
12.4		Hand Control box, 245nm box, and 275nm box to Science
12.5		Assemble Box Module Once Science has returned Control box, 245nm box, and 275nm box
12.6		Hand Box Module to Science
12.7		Assemble Electrical Module
12.8		Once Science has returned Box Module, Assemble Payload Assembly
12.9		Attach MOLEX Connectors from Box Module to Electrical Module
12.10		Connect Z-LiPo Battery to Z-Nucleo board
12.11		Perform Final Inspection of Payload Structure. Verify that all bolts have been properly torqued
12.12		Activate Payload PCB by pressing switch (To be done by GNC member)

27-PE Payload Engineering Recovery

Perform at assembly tent, after launch

27.1		Listen for appropriate beep sequence to indicate payload is disarmed and lights are off
27.2		Sink all twelve radial set screws on the bottom plate of payload
27.3		Slide off the recovery fuselage to reveal the payload structure
27.4		Pull, holding by the top plate, the payload out of the coupler. Careful not to interfere with the electrical systems (primarily mobius camera)
27.5		Inspect for any damages or discrepancies. Immediately report findings to Payload Science
27.5		Disconnect all MOLEX connectors on the flight board
27.6		Unscrew the four 6-32 screws connecting the Electrical Module to the Box Module
27.7		Carefully hand the Box Module to Payload Science
27.8		Keep electrical module secure until data can be extracted

Payload Science Checklists

4-PS Payload Science Pre-Assembly

Complete In NMSU Laboratory Space

4.1		Ensure all components and tools are present and undamaged O All components of the H1-41 and Z4 series
4.2		Allow 24 SD-leu agar plates to come to room temperature
4.3		Prepare suspension of each culture → one colony per 2 mL sdH2O
4.4		Flame sterilize a 16 mm spreading rod with ethanol
4.5		Using aseptic technique, plate each culture onto a labelled plate in duplicate; Retain 12 as ground control samples
4.6		Allow all plates to dry under flame
4.7		Sterilize quartz covers with ethanol
4.8		Using parafilm, attach each quartz plate to the petri dish
4.9		Place plates securely in respective UV box, clicking into corner
4.10		Attach lid for 245 nm box, 275 nm box, and control box
4.11		Secure lid with fasteners
4.12		Slide boxes over threaded rods
4.13		Place entire lower payload assembly in 4˚C environment until launch
4.14		Retain sterile petri dish lids for post flight treatment
4.15		Hand Science Module (Box Module) to Engineering to attach to rest of payload on site.

28-PS Payload Science Recovery

Complete at assembly tent, after launch

28.1		Listen for appropriate beep sequence to indicate payload is disarmed and lights are off
28.2		Remove fasteners from coupler and fuselage to remove payload assembly (details of disassembly)
28.3		Replace all quartz discs with sterile petri dish lids, under flame
28.4		Parafilm all dish stacks to retain moisture

28.5		Incubate flight dishes and control dishes in EMD Millipore incubator for 24 hours
28.6		Measure zone of inhibition after incubation; record
28.7		Dispose of biohazardous waste at NMSU

Aerostructure - Coupler Checklists

5-A Coupler Pre-Assembly

Complete at assembly tent

5.1		Ensure all components and tools are present and undamaged ❑ Coupler (H1-31-01) ❑ Mobius Camera (Body, Lens, Mount, and Cable) (Z4-05, Z3-06, and Z4-06) ❑ Mobius Lens Mount (H1-31-04) ❑ Superglue ❑ 2x Switches (Z3-05) ❑ Coupler Band (H1-31-02) ❑ Upper Fuselage (H1-21-01) ❑ Lower Fuselage (H1-51-04) ❑ Propulsion Bulkhead (H1-31-03) ❑ Ballast (H1-31-10) ❑ Payload Bulkhead (H1-41-01) ❑ 12x 10-32x0.5” set screws (Z3-04)
5.2		Pass Coupler off to Propulsion for insertion
5.3		Ensure Propulsion is finished with Coupler
5.4		Ensure Mobius camera is sufficiently charged
5.5		Slide Coupler Band over Coupler and ensure all holes line up
5.6		Insert and attach 2 Switches
5.7		Check cable connections for Mobius Camera Body and Lens
5.8		Insert Mobius Lens and Mobius Lens Mount and secure with glue
5.9		Insert Beacon

20-A Coupler Assembly

Complete at assembly tent

20.1		Ensure Payload is ready
20.2		Double check that Mobius Camera is ready to be inserted
20.3		Turn on Mobius Camera and Place in Mobius Camera Mount on bottom of Payload

20.4		Insert Payload and ensure bulkhead holes line up
20.5		Fasten set screws to sit flush with the Coupler
20.6		Insert Payload end of Coupler into Upper Fuselage and raise set screws to sit flush with fuselage
20.7		Double check that all fasteners are secure

Recovery Checklists

6-R Recovery Bulkhead Assembly

Complete at assembly tent

6.1		Ensure all components and tools are present and undamaged O All components of the H1-21 and Z2 series
6.2		Attach main shock cord to recovery bulkhead
6.3		Attach main parachute to upper parachute bag
6.4		Fold main parachute and put in upper parachute bag
6.5		Fold and tape shock cords for main parachute
6.6		Fold and tape shock cords for drogue chute
6.7		Attach main parachute to shock cords
6.8		Cover main chute and shock cords with bottom parachute bag and secure with tape
6.9		Load 2 live e-matches into one CO_2 housing
6.10		Load one live e-match and one dummy e-match into other CO_2 Housing
6.11		Tape over CO_2 housing holes
6.12		Load CO_2 plunger and pin with 0.5 g black powder
6.13		Insert plunger and spring into CO_2 housing
6.14		Fasten CO_2 mechanism to bulkhead using #10-32 socket head cap screws and 5/32 allen key
6.15		Mount CO_2 cartridge to bulkhead with stop collar
6.16		Set 2 quicklinks into pyrelease
6.17		Load pyrelease with 0.5 g black powder
6.18		Load 2 live e-matches into pyrelease
6.19		Fasten backplate onto pyrelease (#4-40 button head cap screws, robertson)
6.20		Tie pyrelease with fishing wire

6.21		Thread pyrelease cable through the quicklink attached to the left side of the pyrelease
6.22		Attach pyrelease to bulkhead with the left quicklink

15-R Recovery Bulkhead Wiring

Complete at assembly tent

15.1		Connect pyrelease e-matches to corresponding avionics wires
15.2		Connect CO_2 mechanism e-matches to corresponding avionics wires
15.3		Plug wiring through-hole with putty

16-R Parachute Attachment

Complete at assembly tent

16.1		Attach upper parachute bag to second pyrelease quicklink
16.2		Attach drogue shock cord to second pyrelease quicklink

17-R Recovery Insertion

Complete at assembly tent

17.1		Insert and fasten recovery bulkhead into upper fuselage using #10-32 set screws and 3/32 allen key

GNC - Avionics and Telemetry Checklists

7-G Avionics Pre-Assembly

Complete at hotel

7.1		Ensure all components and tools are present and undamaged ❑ Ring terminals (x6) ❑ Ring terminal crimper ❑ Switch Wiring (Pre-Soldered) (x2) ❑ Terminal blocks (Z2-04) (x2) and mounting screws ❑ Terminal block screws (Z2-15) (x16) ❑ Wires,22 gauge, pair braided ❑ Zip ties ❑ P clamps ❑ Driver tool set ❑ Raven 3 (Z2-08) mounting hardware (bagged) ❑ Stratologger (Z2-07) mounting hardware (bagged) ❑ Wire strippers ❑ Wired battery holders (x2) ❑ Multimeter ❑ Tape ❑ Clear shrink wrap
7.2		Ensure board intact, no cracks or damage
7.3		Attach standoffs and barrier blocks
7.4		Mount Stratologger to standoffs
7.5		Mount Raven3 to standoffs
7.6		Connect Raven3 to laptop via USB and calibrate using software interface
7.7		Ensure Stratologger and Raven3 are secure to board
7.8		Wire battery holders to Raven3 and terminal block and stratologger directly
7.9		Wire in switch connector to Raven3 In+ and raven terminal block terminal 1
7.10		Wire in _______ wire to terminal _______ for apogee charge signal port from raven using

Aerostructure - Nose Cone Checklists

9-A Nose Cone Pre-Assembly

Complete at hotel

9.1		Ensure all components and tools are present and undamaged O All components of the H1-11 and Z1 series O ¼-20 nut driver O 4x #8-32 screws O Allen key for #8 socket heads
9.2		Attach ¼-20 nylon lock nut at base of lead screw
9.6		Insert lead screw into fiberglass nose cone and thread into PLA tip mount until nylon lock nut sits flush against it
9.7		Attach nose cone tip over fiberglass nose cone and thread onto lead screw
9.8		Grip aluminum tip and use nut driver to tighten together
9.9		Verify aluminum tip is butted against fiberglass shoulder

18-A GNC Bulkhead Assembly

Complete at hotel

18.1		Use 4x #8-32 screws to fasten GNC bulkhead assembly to Shear Pin Insert
18.2		Signal aerostructure lead to confirm checklist
18.3		Pack away partial nose cone assembly, GNC bulkhead assembly, and tools

19-A Nose Cone Assembly

Complete at assembly tent

19.1		Ensure all components and tools are present and undamaged O All components of the H1-11 and Z1 series ❑ Partially-assembled nose cone ❑ GNC bulkhead assembly ❑ Allen key for #10 set screws ❑ Flathead screwdriver
19.2		Inspect partially-assembled nose cone: ❑ Aluminum tip is tight against fiberglass shoulder

		❏ Fasteners are secure and have loctite
19.3		Inspect GNC bulkhead assembly: ❏ Antenna is intact and securely connected ❏ Altimeter has full battery
19.4		Get go-ahead from propulsion to couple nose cone to fuselage (after fins are mounted)
19.5		Get go-ahead from GNC to: ❏ Connect battery of altimeter ❏ Push orange button once to turn on altimeter ❏ Press and hold orange button and release once "LAUNCH" is displayed ❏ Report battery level to GNC Battery Power: __________ % Time: __________ AM / PM
19.6		Use 8x 10-32 ⅜ set screws to fasten GNC bulkhead assembly into nose cone
19.7		Attach locking carabiner to eye screw at base of GNC bulkhead

21-A Nose Cone Installation

Complete at assembly tent

21.1		Recovery team member complete the following steps ❏ Attach drogue (H1-21-12) to drogue shock cords (H1-21-13) ❏ Attach drogue to nose cone via nose cone extension cable
21.2		Insert nose cone assembly into fuselage (H1-21-01)
21.3		Use 3x shear pins to fasten nose cone assembly to fuselage
21.4		Signal teammate to confirm checklist
21.5		Signal nose cone assembly is complete
21.6		Pack away tools

		ring terminals
7.11		Wire in ______ wire to terminal ______ for secondary apogee charge signal from raven using ring terminals
7.12		Attach ______ wire for main strip and leave for recovery
7.13		Check raven connections with multimeter
7.14		Plug in battery to raven holder and attach usb cable to laptop, connect and turn on switch for testing
7.15		Run featherweight software, confirm settings with recovery, and program board
7.16		Remove battery from Raven holder and ensure voltage is nominal
7.17		Connect switch connector directly to Stratologger board
7.18		Wire in _______ and _______ braided wires to terminals ________ and ________ for backup main charge signal and ground using ring terminals
7.19		Wire in _______ and_______ braided wires, strip ends and leave out for recovery to attach
7.20		Check connections with multimeter
7.21		Insert battery to Stratologger holder, connect switch ensure board powers on and correct preset (7 beeps) is selected.
7.22		**If beeps incorrect** turn off, hold down button as repowering, and press button 7 times to select 1500 ft main deployment
7.23		Remove battery from Stratologger holder and ensure voltage is nominal
7.24		Use P-clamps to secure all wires, check slack
7.25		Store avionics sled in Pelican case for transport

8-G Telemetry Pre-Assembly

Complete at hotel

8.1		Ensure all components and tools are present and undamaged ❑ APRS Beeline Board (Z1-05) ❑ APRS mounting equipment (bagged) (Z1-08, Z1-15) ❑ Driver Set

		❏ USB cable ❏ Whip antenna (Z1-07) ❏ Beeline charging/programming board ❏ Laptop with BeeLine software ❏ Spare LiPo battery (Z1-06)
8.2		Ensure that Beeline battery is fully charged for 8 hours beforehand, check to ensure no damage or bulges
8.3		Attach antenna to Beeline
8.4		Mount board using standoffs in bag, ensure secure
8.5		Connect charging/programming board to side of Beeline, power on by connecting battery to main board
8.6		Run interface program, ensure callsign and other settings correct
8.7		After getting frequency to transmit on from officials, add to program ensure ground station software is set to frequency ________________________
8.8		Power down board and disconnect battery
8.9		Store telemetry sled in Pelican case for transport

13-G Avionics Assembly

Complete at assembly tent

13.1		Ensure switches are securely mounted to the coupler and that the wires have been fed through Payload
13.2		Mount the avionics sled to the avionics bulkhead
13.3		Handoff to recovery for final wiring
13.4		Check all wires to ensure no shifting/disconnection occurred in transport
13.5		Ensure switches are open
13.6		Connect switches to switch connectors on board
13.7		Insert new batteries into battery holders for both boards and secure with velcro straps

IF SWITCHES TURNED ON AT THIS POINT CHARGES WILL BE LIVE		
13.8		Tape over switches to protect from accidental activation
13.9		Attach avionics sled to the recovery bulkhead by fastening the ready rods to the avionics bulkhead
At this stage the avionics bay has been integrated into the recovery system. The recovery system is NOT ARMED at this stage.		

14-G Telemetry Assembly

Complete at assembly tent

14.1		Ensure all components and tools are present and undamaged ❑ Screwdriver for switch activation
14.2		Mount the telemetry sled to the nose cone bulkhead
14.3		Ensure Groundstation ready to receive APRS signal
14.4		Activate BeeLine GPS by attaching battery to plug
14.5		Wait till BeeLine has GPS lock, indicated by 1hz LED
14.6		Hold Beeline upright and aloft, check to see if ground station gets signal
14.7		Activate Altimeter Two, 2 hours max. Activation time: ________________
14.8		Insert and attach APRS sled into nose cone, hand off to recovery

GNC - Ground Station Checklists

10-G Ground Station Pre-Assembly

Complete at assembly tent

10.1		Check that all components are present and ready:
		❏ Ground station (G series)
		❏ Fully charged LiPo batteries (ZG-14)
		    ❏ Primary
		    ❏ Backup
		    ❏ LiPo battery buzzer (ZG-20)
		❏ Mouse (ZG-10) and keyboard (ZG-09)
		    ❏ AA Batteries (ZG-19)
		❏ Receiving antenna (ZG-21)
		❏ Coaxial cable (ZG-22)

10.2		Obtain frequency to be used with BeeLine GPS transmitter:________________
10.3		Connect the antenna to the ground station coaxial port with coaxial cable
10.4		Ensure that the LiPo battery screamer is attached to the primary battery
10.5		Connect the ground station battery to the ground station
10.6		Turn on the ground station computer and log in
10.7		Start the GeoServer instance by running the script “startgeoserver.sh” in a terminal window
10.8		Open the configuration file “groundstation/server/config.json” in a text editor and ensure that the configuration includes the following settings: ❏ “doTestFromFile”: true ❏ “haveSDR”: true ❏ “doLogData”: true ❏ “doWebSocket”: true ❏ “Frequency”: “433.00M” (replace with the frequency being used by the BeeLine GPS transmitter) ❏ “filterCallsign”: false
10.9		GNC lead confirmation:______________________

22-G Ground Station Configuration

Complete at assembly tent

22.1		Run the server program "server/wsserver.py" ❏ Confirm that decoded data from the BeeLine GPS is being received at the expected transmission rate
22.2		Start the GeoServer instance by running the script "startgeoserver.sh" in a terminal window
22.3		Open the client webapp "client/index.html" in the Firefox web browser ❏ Confirm that the decoded data from the BeeLine GPS unit is appearing in the client interface ❏ Confirm that satellite and aerial imagery is appearing on the map as expected
22.4		Close Firefox, stop the server, and stop GeoServer
22.5		Delete, remove, or rename the existing log file in the server directory
22.6		Close all programs running on the ground station computer
22.7		Log out of the ground station computer and power it off

23-G Ground Station Launch-Site Initialization

Complete at launch site

23.1		Power on the ground station and log in
23.2		Start the GeoServer instance by running the script "startgeoserver.sh" in a terminal window
23.3		Run the server program "server/wsserver.py"
23.4		Open the client webapp "client/index.html" in the Firefox web browser ❏ Confirm that data is being received from the BeeLine GPS. Note that, depending on the distance and nearby obstructions, this may not be possible until the rocket is vertical on the pad
23.5		GNC lead confirmation:____________________

Final Go-NoGo

Record total weight: ____________________ kg
Record center of mass location: ____________________ in

25.1		Verify all necessary personnel are wearing face shields and safety glasses
25.2		Verify all accessible fasteners are tight and undamaged
25.3		Verify launch lugs (H1-51-07) have not been damaged
25.4		Slide rocket onto 17 foot launch rail
25.5		Move rocket to upright position
25.6		Setup ladder next to rocket, ensuring two members present
25.7		Check with ground station that APRS signal is still broadcasting
25.8		**Wait for approval by pad attendendents and team before next steps**
25.9		Remove tape from switches (Z3-05), ensure switches secure
25.10		**Announce "Arming Raven3"**
25.11		Use screwdriver to turn on Raven3 board (Z2-08) switch
25.12		Confirm beep pattern with second GNC member with beep pattern sheet
25.13		Check for **9 beeps** for 9V battery source (Z2-06)
25.14		Check for **3 high beeps repeating**, ensuring both main charges and apogee charge are connected
25.15		**Announce "Arming StratologgerCF"**
25.16		Use screwdriver to turn on StratologgerCF (Z2-07) switch
25.17		Confirm beep pattern with second GNC member with beep pattern sheet
25.18		Confirm no warning beeps, **7 beeps** to confirm deployment preset 7
25.19		Confirm **1 beep then 5** to confirm deployment altitude of 1500ft
25.20		Wait, confirm **3 beep pattern repeating** to confirm all charges connected
25.21		Record time of arming boards ___________________
25.22		Hold strong magnet over payload arming location, record time of activation _________________
25.23		Announce "**GNC GO**"

25.24		Record altitude: ____________________ ft (~4596.5 ft expected)
25.25		Verify the igniter is not damaged
25.26		Confirm that igniter is shunted
22.27		**Receive permission from Range Manager to install igniters**
22.28		Attach igniter to dowel rod
22.29		Insert igniter into motor and secure with provided cap
22.30		Announce that the igniter has been inserted
22.31		Confirm that the firing line is not hot by touching the leads together
22.32		Connect igniter to circuit
22.33		Announce igniter has been connected
22.34		Check leads for continuity
22.35		Remove shunt from igniter
22.36		Ensure all personnel move to safe location
22.37		Announce "**Propulsion GO**"

Emergency / Hang Fire

In the event of a hang fire the guidance and directions from ESRA personnel shall be followed; this checklist shall remain secondary to their directions. In the event of a hang fire confirm all actions with ESRA personnel before proceeding.

26.1		Wait for ESRA to declare a hang fire
26.2		Start a timer
26.3		Wait 2 minutes before proceeding
26.4		Put on safety glasses and face shield
26.5		Bring a new igniter and a digital multimeter
26.6		Confirm with ESRA personnel the igniter circuit is disconnected
26.7		Only allow a single person to approach the launch pad
26.8		Shunt igniter
26.9		Inspect the igniter connection for incorrect wiring or any signs of damage
26.10		Note: ______________________________
26.11		Disconnect the igniter and announce disconnection
26.12		Remove the igniter and visually inspect for damages
26.13		If necessary, replace igniter
26.14		Note: ______________________________
26.15		Connect igniter to dowel rod
26.16		Insert igniter into motor and secure with provided cap
26.17		Announce that the igniter has been inserted
26.18		Confirm that the firing line is not hot by touching the leads together
26.19		Connect igniter to circuit

26.20		Announce igniter has been connected
26.21		Check leads for continuity
26.22		Remove shunt from igniter
26.23		Ensure all personnel move to safe location
26.24		Announce “**Propulsion is GO**”

Appendix V: Engineering Drawings

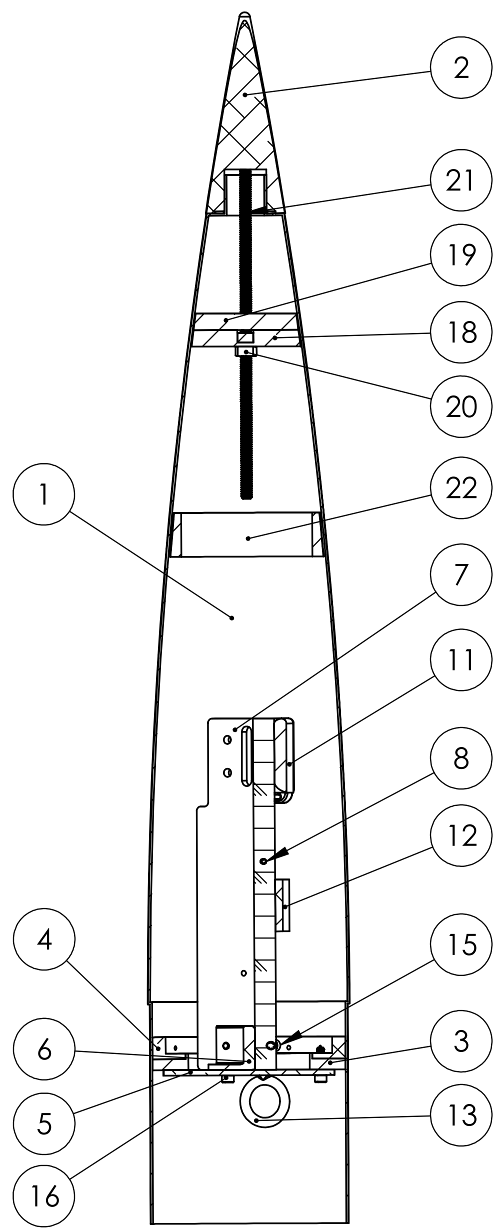
Hyak-1 Parts List			
Number	**Name**	**Amount**	**Material**
Nose Cone Assembly			
H1-11-01	Fiberglass Nose Cone	1	Fiber Glass
H1-11-02	Nose Cone Tip	1	Al 6061-T6
H1-11-03	Tip Mount Lower Plate	1	3D printed PLA
H1-11-04	Tip Mount Upper Plate	1	3D printed PLA
H1-11-05	Reinforcement Band	1	3D printed PLA
H1-11-06	GNC Flange Insert	1	3D printed PLA
H1-11-07	Shear Pin Insert	1	3D printed PLA
H1-11-10	Nose Cone Bulkhead	1	Al 6061-T6
H1-11-11	Angle Bracket	1	Al 6061-T6
H1-11-12	GNC Nose Cone Sled	1	Birch Plywood
H1-11-50	Adjustable Ballast	0-21	Al 6061-T6
Z1-01	1/4-20 Threaded Rod	1	
Z1-02	1/4-20 Nut	5	
Z1-03	1/4-20 Nylon Nut	1	
Z1-04	Altimeter	1	
Z1-05	APRS Beeline Board	1	
Z1-06	Nose Cone Battery	1	
Z1-07	Whip Antenna	1	
Z1-08	4-40 Standoff	2	
Z1-09	1/4-20 Eye Bolt	1	
Z1-10	8-32 Nut	4	
Z1-11	8-32 5/8" Fastener	4	
Z1-12	8-32 3/8" Fastener	4	
Z1-13	4-40 3/8" Nylon Shear Pin	3	
Z1-14	10-32 3/8" set screw	8	
Z1-15	4-40 button head cap screws	2	

Number	Name	Amount	Material
Recovery Assembly			
H1-21-01	Upper Fuselage	1	Carbon Fiber
H1-21-02	Recovery Bulkhead	1	Al 6061-T6
H1-21-03	CO2 Housing	2	Al 6061-T6
H1-21-04	CO2 Plunger	2	Al 6061-T6
H1-21-05	CO2 Pin	2	Cold Rolled Steel
H1-21-06	GNC Sled Guide	1	3D printed PLA
H1-21-10	Main Parachute	1	1.1 oz Nylon ripstop
H1-21-11	Main Chute Shock Chord	1	20 ft 3/4" Tubular Kevlar
H1-21-12	Drogue Parachute	1	1.9 oz Nylon ripstop
H1-21-13	Drogue Chute Shock Chord	1	20 ft 3/4" Tubular Kevlar
H1-21-20	GNC Bulkhead	1	Birch Plywood
H1-21-21	GNC Recovery Board	1	Birch Plywood
H1-21-22	Angle Bracket	1	Al 6061-T6
H1-21-23	Pyrelease housing	1	Al 6061-T6
H1-21-24	Pyrelease plunger	1	Al 6061-T6
Z2-01	1/4-20 Eye Bolt	3	
Z2-02	1/4-20 Nut	7	
Z2-03	1/4-20 Threaded Rod	2	
Z2-04	Terminal Block 4x2	4	
Z2-05	CO2 Cartridge	2	
Z2-06	9V Battery	2	
Z2-07	StratoLogger CF	1	
Z2-08	Raven 3 Board	1	
Z2-09	Standoff	8	
Z2-10	Spring	2	
Z2-11	10-32 1/2" Fastener	8	
Z2-12	8-32 3/8" Set Screw	8	
Z2-13	4-40 nylon shear screw	3	
Z2-14	E-match	5	
Z2-15	4-40 button head cap screws	4	

Number	Name	Amount	Material
Coupler Assembly			
H1-31-01	Coupler	1	Fiber Glass + Foam
H1-31-02	Coupler Band	1	Fiber Glass
H1-31-03	Propulsion Bulkhead	1	Al 6061-T6
H1-31-04	Mobius Lens Mount	1	3D printed PLA
H1-31-10	Ballast	1	C 1020
Z3-01	3/8-16 Threaded Rod	1	
Z3-02	3/8-16 Nut	2	
Z3-03	1/4-20 1" Fastener	1	
Z3-04	10-32 1/2" Set Screw	23	
Z3-05	Switch	2	
Z3-06	Mobius Camera Lens	1	
Payload Assembly			
H1-41-01	Payload Bulkhead	1	Al 6061-T6
H1-41-02	Mid Plate	1	Al 6061-T6
H1-41-03	Top Plate	1	Al 6061-T6
H1-41-04	Lower Post	4	Al 6061-T6
H1-41-05	Upper Post	4	Al 6061-T6
H1-41-10	Dish Tray Control	1	3D printed PLA
H1-41-11	Lid Control	1	3D printed PLA
H1-41-12	Dish Tray	2	3D printed PLA
H1-41-13	245nm Lid	1	3D printed PLA
H1-41-14	245nm Holder Top	2	3D printed PLA
H1-41-15	245nm Holder Bottom	2	3D printed PLA
H1-41-16	275nm Lid	1	3D printed PLA
H1-41-17	275nm Holder Top	2	3D printed PLA
H1-41-18	275nm Holder Bottom	2	3D printed PLA
H1-41-20	Battery Mount	1	3D printed PLA
H1-41-21	Nucleo Board Mount	1	Acrylic
H1-41-30	Round Ballast	3	C 1020
H1-41-31	Round Ballast Counterbore	1	C 1020
Z4-01	Slam Stick	1	
Z4-02	Slam Stick Fastener	2	
Z4-03	6-32 1/2" Fastener	16	
Z4-04	10-32 2-1/4" Fastener	4	
Z4-05	Mobius Camera	1	
Z4-06	Mobius Camera Mount	1	
Z4-07	Camera Fastener	2	
Z4-08	6-32 1/2" Fastener	8	
Z4-09	4-40 1/2" Fastener	12	
Z4-10	LiPo Battery	1	

Number	Name	Amount	Material
Propulsion Assembly			
H1-51-01	Fin	3	3D printed PLA + Carbon Fiber
H1-51-02-1	Fin Mount Posts long	3	Al 6061-T6
H1-51-02-2	Fin Mount Posts medium	3	Al 6061-T6
H1-51-02-3	Fin Mount Posts short	3	Al 6061-T6
H1-51-03	Fin Rings	3	Al 6061-T6
H1-51-04	Lower Fuselage	1	Carbon Fiber
H1-51-05	Thrust Ring	1	Al 6061-T6
H1-51-06	Boat Tail	1	3D printed PLA
H1-51-07	Launch Lug	2	Delrin
H1-51-08	Upper Centering Ring 1	1	Birch Plywood
H1-51-09	Upper Centering Ring 2	1	Birch Plywood
Z5-01	Motor Casing CTI Pro 98mm Casing	1	
Z5-02	Forward Retaining Ring	1	
Z5-03	Aft Retaining Ring	1	
Z5-04	Forward Closure	1	
Z5-05	Nozzle Holder	1	
Z5-06	6-32 5/8" Fastener	36	
Z5-07	6-32 3/8" Fastener	3	
Z5-08	1/4-20 3/4" Fastener	1	
Z5-09	6-32 3/8" Set Screw	11	
Z5-10	3/8-16 Threaded Rod	1	

Number	Name	Amount	Material
	Ground Station		
G2-01-01	Acrylic Screen Housing	1	Acrylic
G2-01-02	Acrylic Main	1	Acrylic
G2-01-03	Post	4	Al 6061-T6
G2-01-04	Bottom Plate	1	Birch Plywood
G2-01-05	Keyboard Mount 1	2	Birch Plywood
G2-01-06	Keyboard Mount 2	1	Birch Plywood
G2-01-07	Switch Spacer	3	Birch Plywood
G2-01-08	Delrin Post	2	Delrin
G2-01-09	Acrylic Side Compartement	1	Acrylic
G2-01-10	Compartement Wall 1	2	Birch Plywood
G2-01-11	Compartement Wall 2	1	Birch Plywood
G2-01-12	Compartement Wall 3	1	Birch Plywood
G2-01-13	Compartement Wall 4	1	Birch Plywood
G2-01-14	Compartement Wall 5	1	Birch Plywood
ZG-01	Pelican Case 1525	1	
ZG-02	Screen	1	
ZG-03	Terminal Block 2x4	1	
ZG-04	Terminal Block 2x8	1	
ZG-05	Battery Voltage Regulator	2	
ZG-06	Computer	1	
ZG-07	Graphics Card	1	
ZG-08	USB Hub	1	
ZG-09	Keyboard	1	
ZG-10	Mouse	1	
ZG-11	Mousepad	1	
ZG-12	Key Switch	3	
ZG-13	Toggle Switch	3	
ZG-14	LiPo Battery	1	
ZG-15	AC Power Socket	1	
ZG-16	XT 60 Connector	1	
ZG-17	Nylon Coupling Nut 0.75"	4	
ZG-18	Nylon Coupling Nut 0.375"	8	
ZG-19	AA Batter	4	
ZG-20	LiPo Battery Buzzer	1	
ZG-21	Receiving Antenna	1	
ZG-22	Coax Cable	1	



ITEM NO.	PART NUMBER	QTY.
1	H1-11-01 Fiberglass Nose Cone	1
2	H1-11-02 Nose Cone Tip	1
3	H1-11-06 GNC Flange Insert	1
4	H1-11-07 Shear Pin Insert	1
5	H1-11-10 GNC Nose Cone Bulkhead	1
6	H1-11-11 Angle Bracket	1
7	H1-11-12 GNC Nose Cone Sled	1
8	4-40 x 0.25" Standoff	2
9	Antenna Board	1
10	Antenna	1
11	Altimeter	1
12	Nose Cone Battery	1
13	1/4-20 Eyebolt	1
14	1/4-20 Hex Nut	1
15	8-32 x 3/8"	4
16	8-32 x 5/8"	4
17	8-32 Hex Nut	4
18	H1-11-03 Tip Mount Lower Plate	1
19	H1-11-04 Tip Mount Upper Plate	1
20	1/4-20 Hex Nut	2
21	1/4-20 Threaded Rod	1
22	H1-11-05 Reinforcement Band	1

	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Malaki	24.05.18
APPROVED BY	Cheyenne	24.05.18

TITLE:

H1-10-00 Nose Cone Assembly

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

SIZE A | DWG. NO. 1 | REV 1

SCALE: 1:4 | SHEET 1 OF 1

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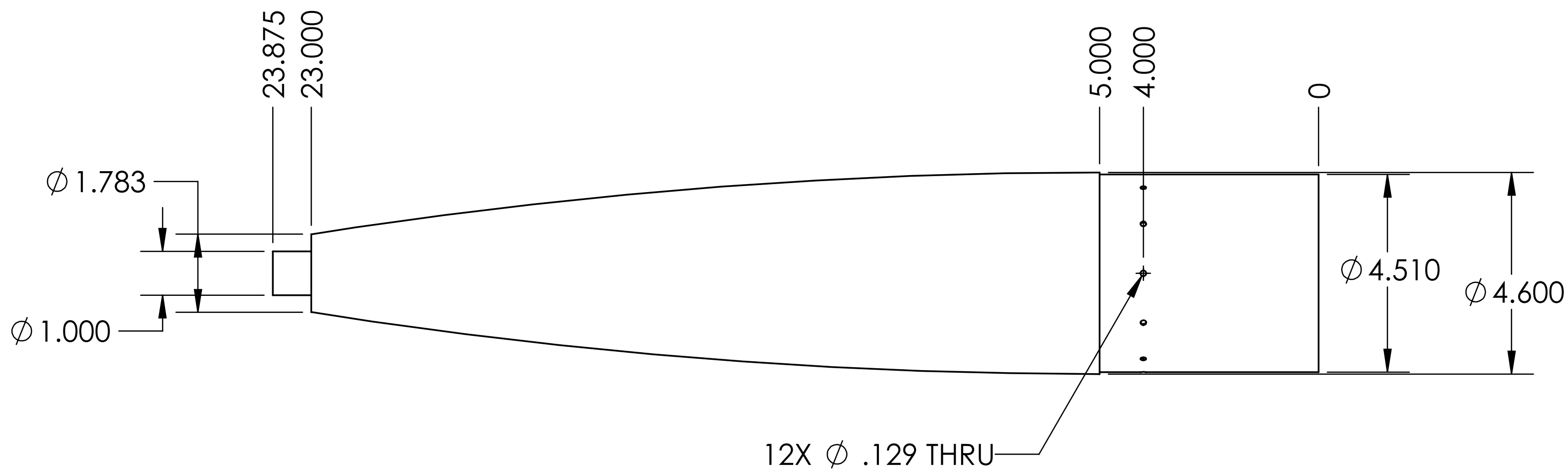


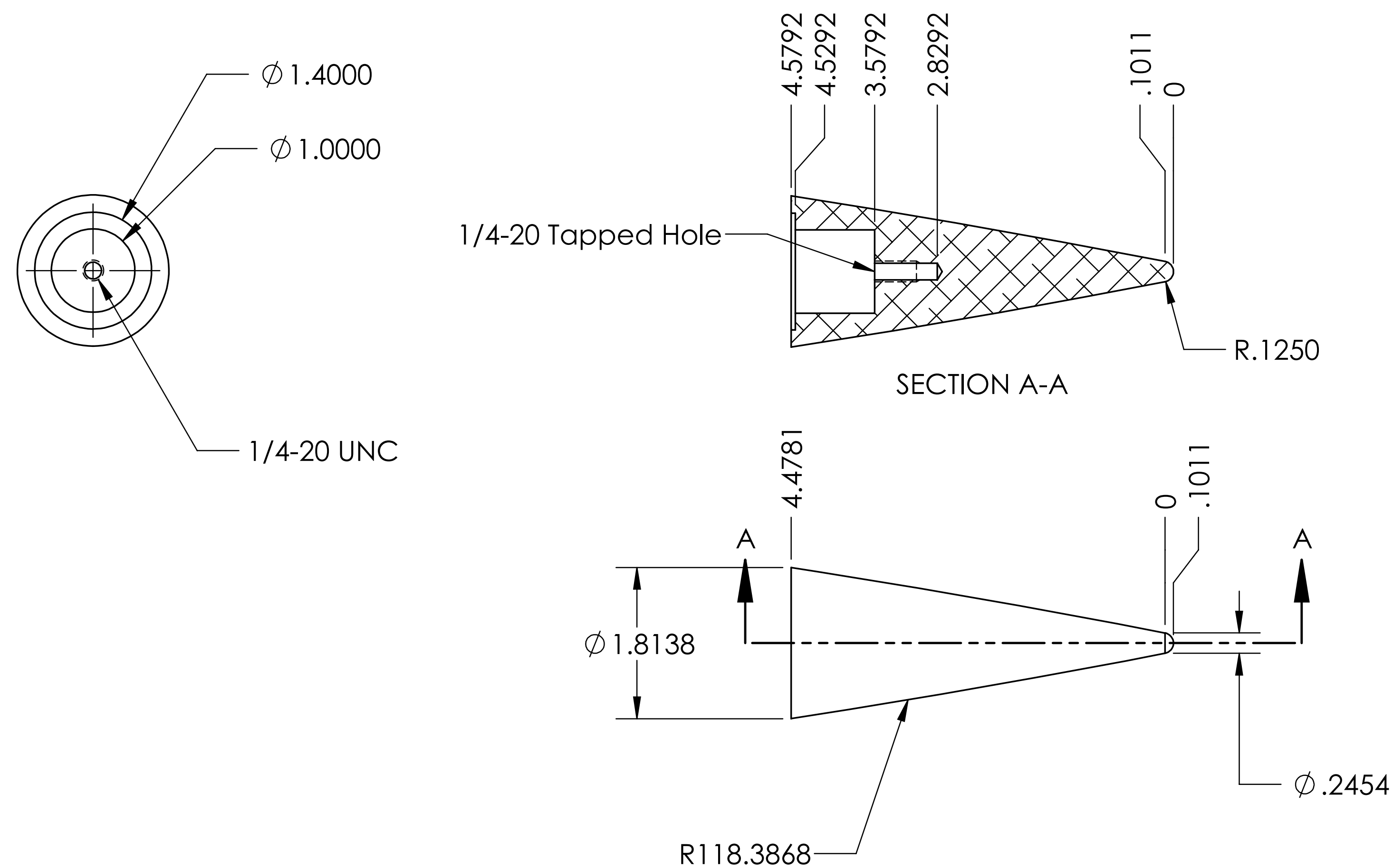
This nosecone is a fiberglass layup.
The drawing is just a reference.

		NAME	DATE
	DRAWN BY	Graham	24.05.18
	CHECKED BY	Sebastian	24.05.18
	APPROVED BY	Cheyenne	24.05.18
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: Fiberglass		
	QUANTITY: 1		

TITLE:
H1-11-01 Fiberglass Nose Cone

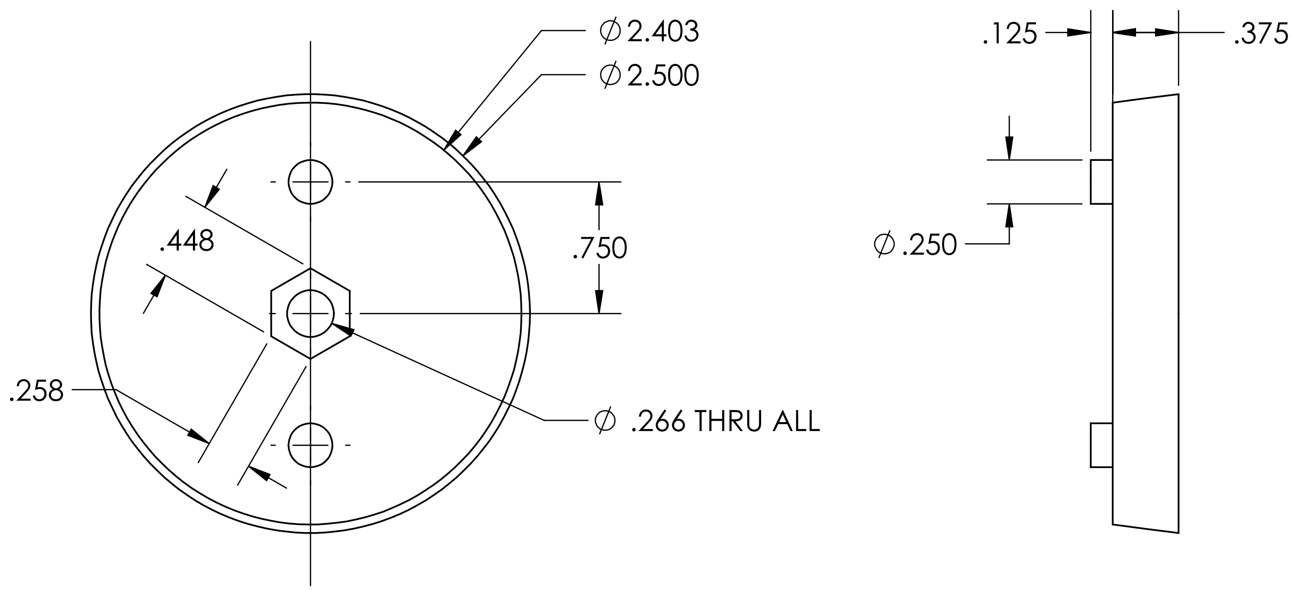
SIZE	DWG. NO.	REV
A	1	1
SCALE: 1:4		SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



		NAME	DATE	TITLE: H1-11-02 Nosecone Tip
	DRAWN BY	Meet.D	24.05.18	
	CHECKED BY	Cheyenne	24.05.18	
	APPROVED BY	Sebastian	24.05.18	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.003	MATERIAL: Aluminium			SIZE A · DWG. NO. 1 · REV 1
	QUANTITY: 1			SCALE: 1:2 · SHEET 1 OF 1

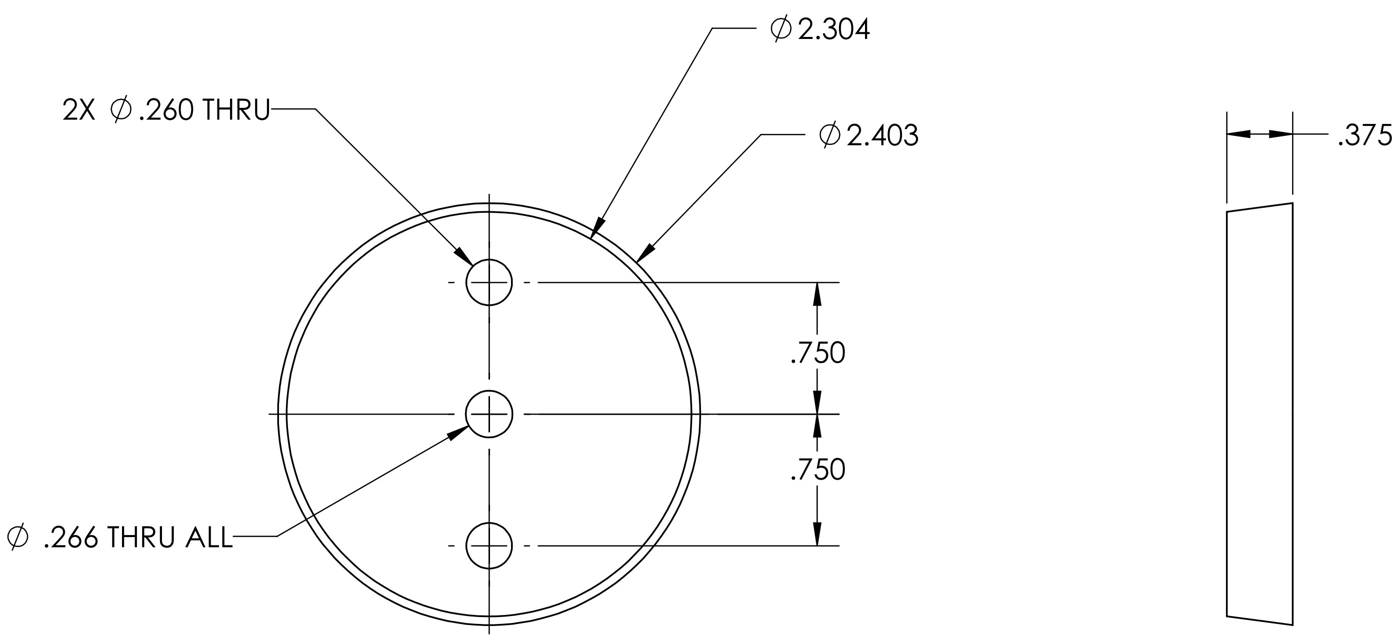
SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using a STL file

		NAME	DATE	TITLE: H1-11-03 Tip Mount Plate		
	DRAWN BY	Graham	24.05.18			
	CHECKED BY	Cheyenne	24.05.18			
	APPROVED BY	Sebastian	24.05.18			
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: PLA			SIZE A	DWG. NO. 1	REV 1
	QUANTITY: 1			SCALE: 1:1		SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using a SFL file

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Sebastian	24.05.18

TITLE:

H1-11-04 Tip Mount Upper Plate

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

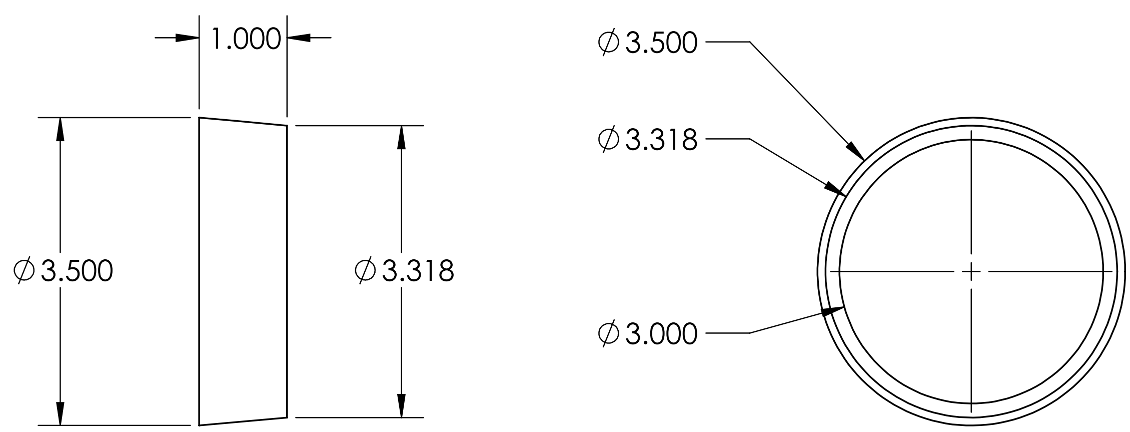
MATERIAL: PLA

QUANTITY: 1

SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:1 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using a SFL file

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Malaki	24.05.18
APPROVED BY	Sebastian	24.05.18

TITLE: H1-11-05 Reinforcement Band

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

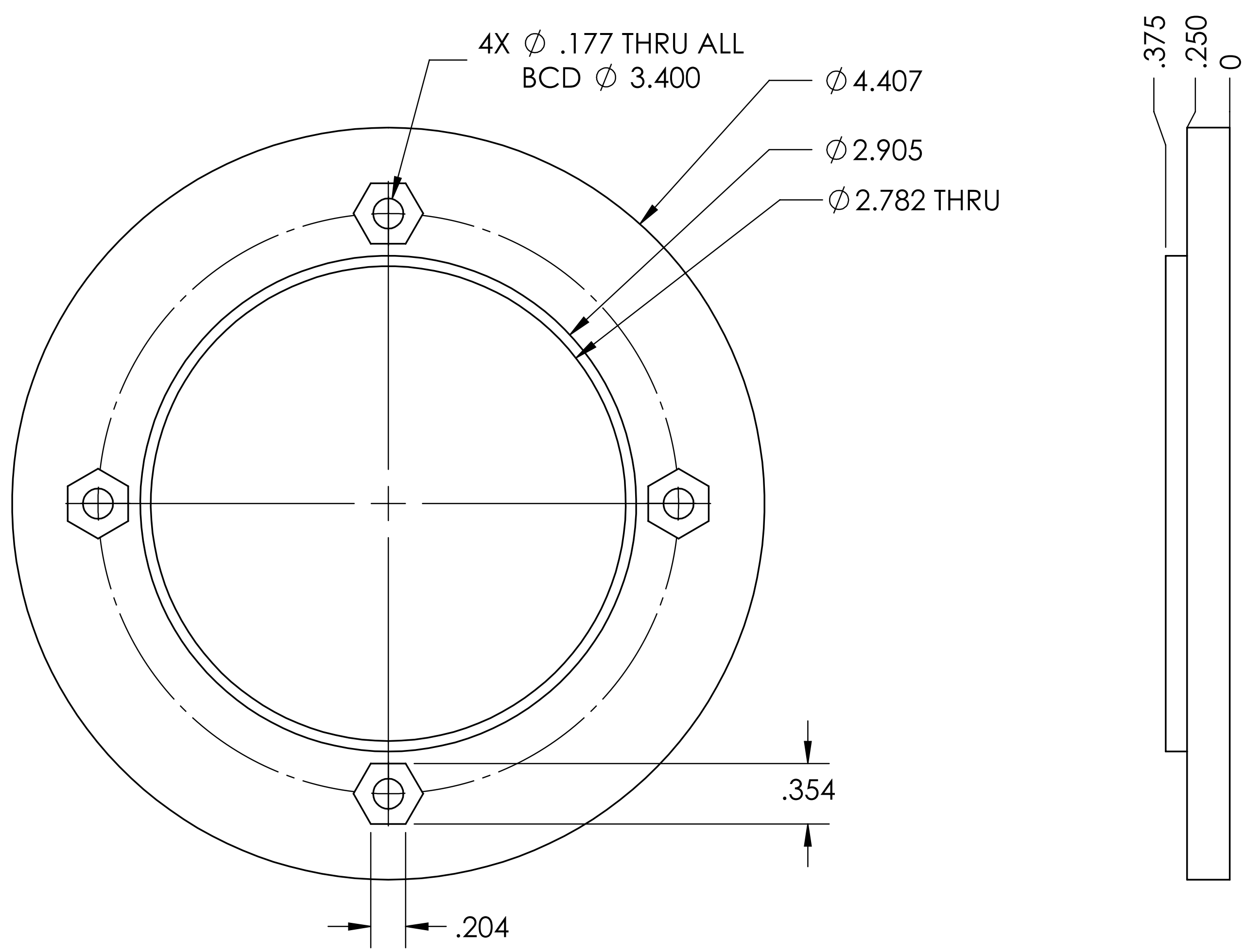
MATERIAL: PLA

QUANTITY: 1

SIZE: A | DWG. NO. 1 | REV 1

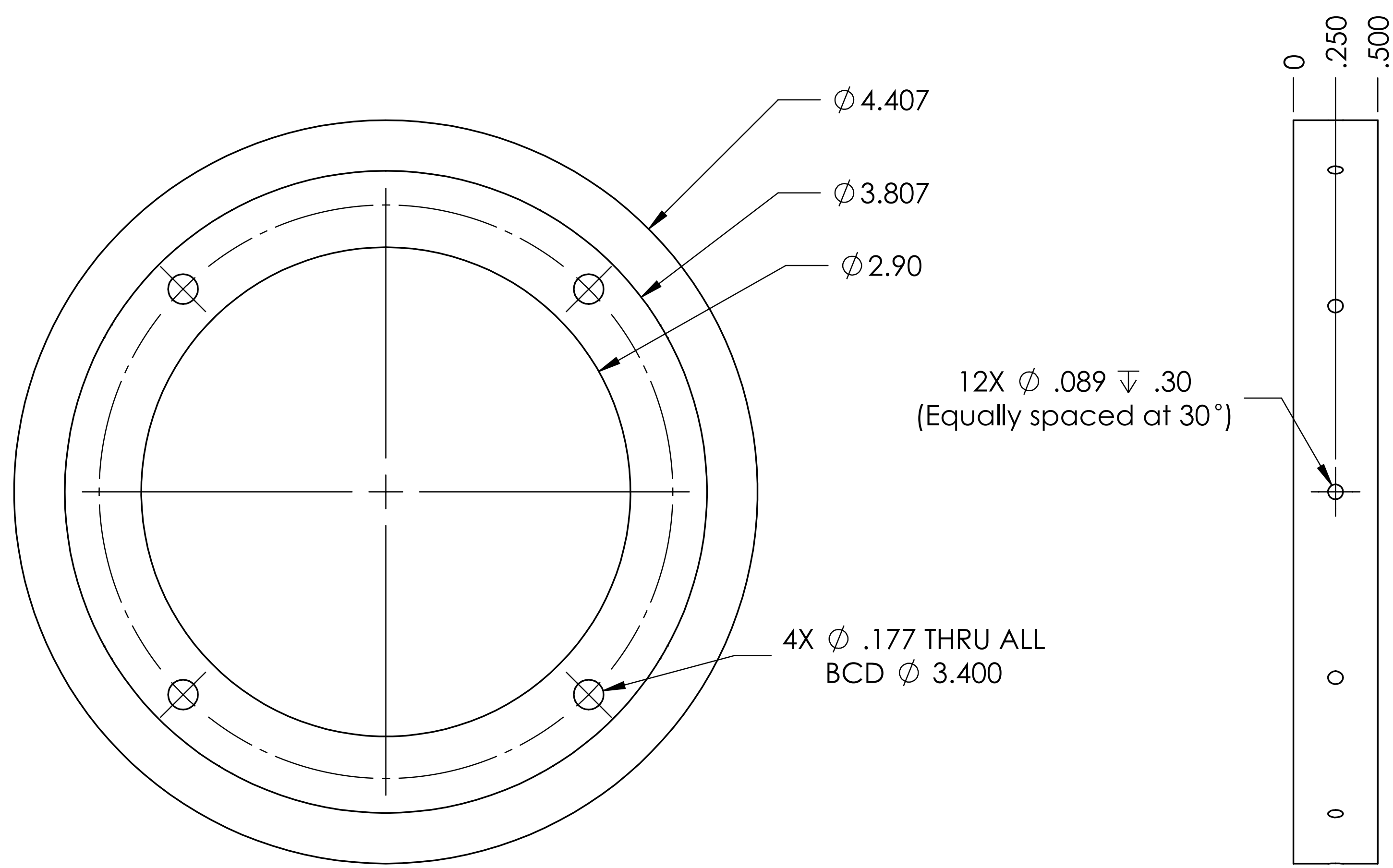
SCALE: 1:2 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



		NAME	DATE	TITLE:	
	DRAWN BY	Graham	24.05.18	H1-11-06 GNC Flange Insert	
	CHECKED BY	Sebastian	24.05.18		
	APPROVED BY	Malaki	24.05.18		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: Al 6061-T6			SIZE A	DWG. NO. 1 / REV 1
	QUANTITY: 1			SCALE: 1:1	SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using SFL file

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Malaki	24.05.18
APPROVED BY	Sebastian	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

MATERIAL: PLA

QUANTITY: 1

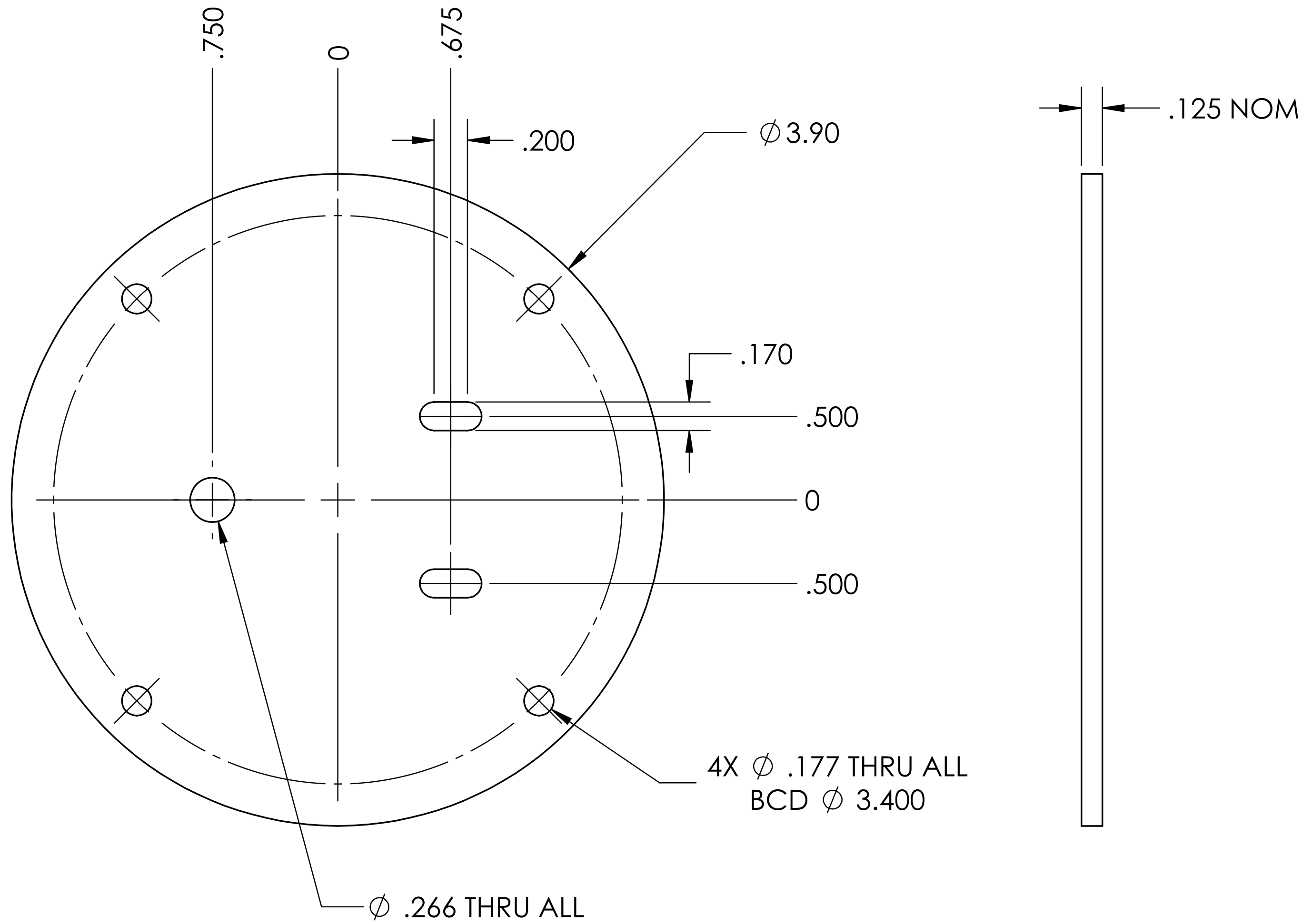
TITLE:

H1-11-07 Shear Pin Insert

SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:1 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Cheyenne	24.05.18

TITLE:
H1-11-10 GNC Nose Cone Bulkhead

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

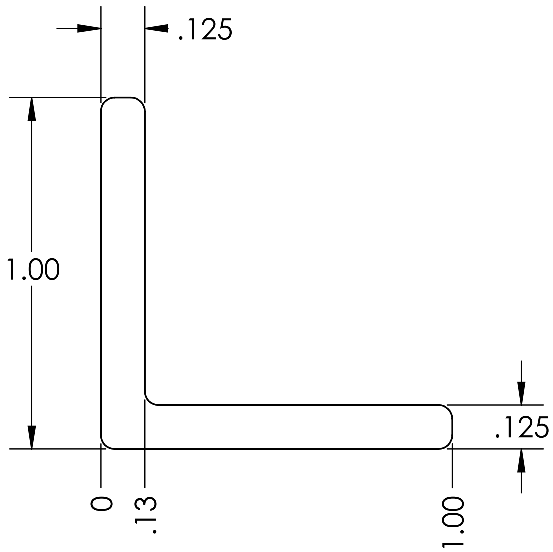
MATERIAL: Al 6061-T6

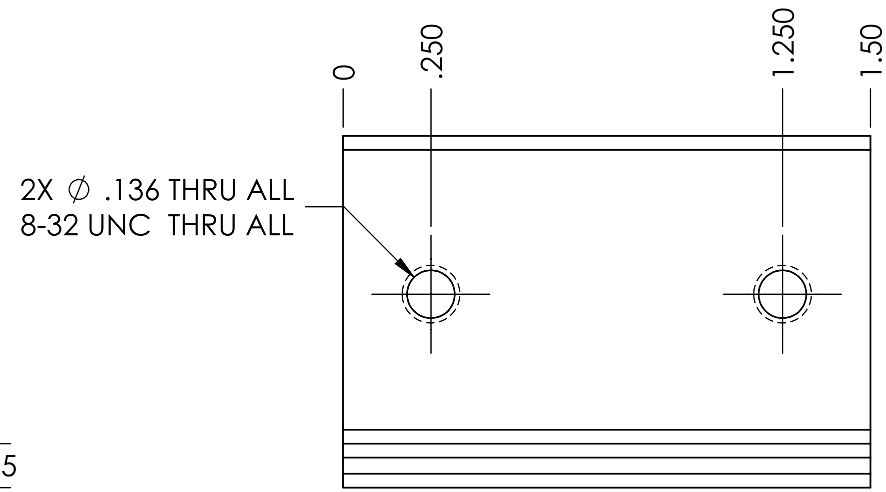
QUANTITY: 1

SIZE: A | DWG. NO. 1 | REV 1

SCALE: 1:1 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

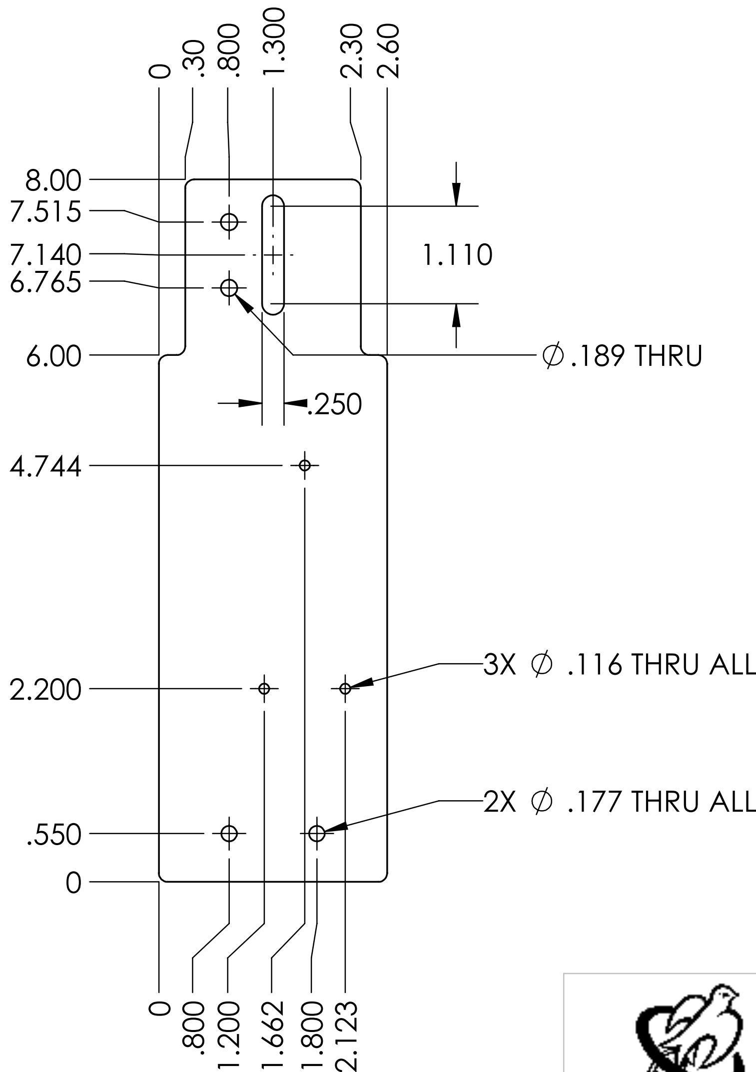


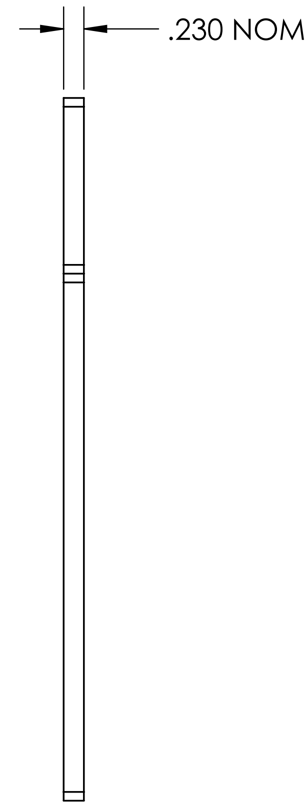


Use commercial angle extrude.

		NAME	DATE	TITLE:
	DRAWN BY	Graham	24.05.18	H1-11-11 Angle Bracket
	CHECKED BY	Sebastian	24.05.18	
	APPROVED BY	Cheyenne	24.05.18	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: Al 6061-T6			SIZE A / DWG. NO. 1 / REV 1
	QUANTITY: 1			SCALE: 2:1 / SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

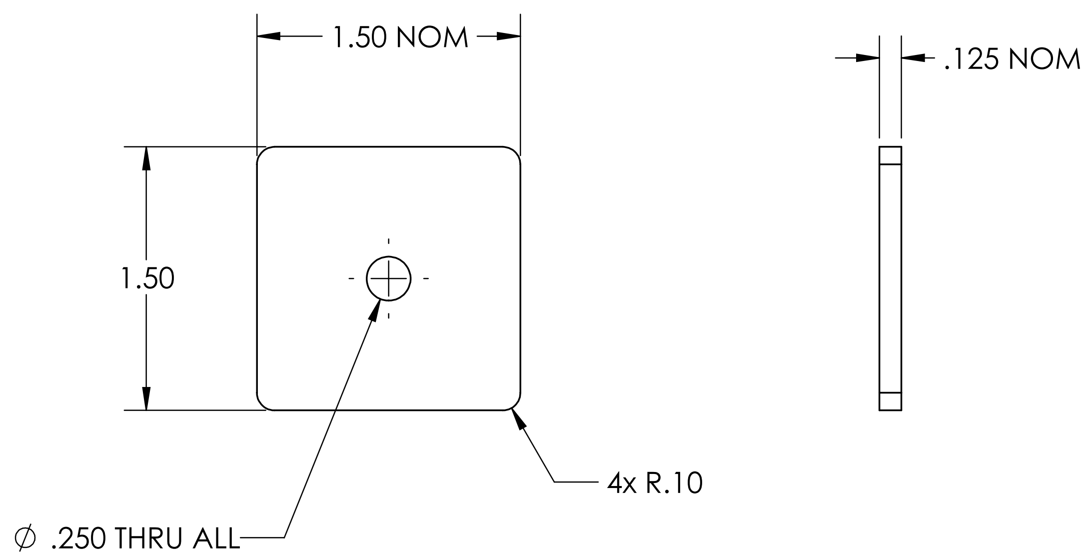




This part is lasercut using a DXF file

		NAME	DATE	TITLE:
	DRAWN BY	Graham	24.05.18	H1-11-12 GNC Nose Cone Sled
	CHECKED BY	Cheyenne	24.05.18	
	APPROVED BY	Sebastian	24.05.18	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: Birch Plywood			SIZE A · DWG. NO. 1 · REV 1
	QUANTITY: 1			SCALE: 1:2 · SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



	NAME	DATE
DRAWN BY	Sebastian	30.04.18
CHECKED BY	Sebastian	30.04.18
APPROVED BY	Cheyenne	01.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL: 6061-T6

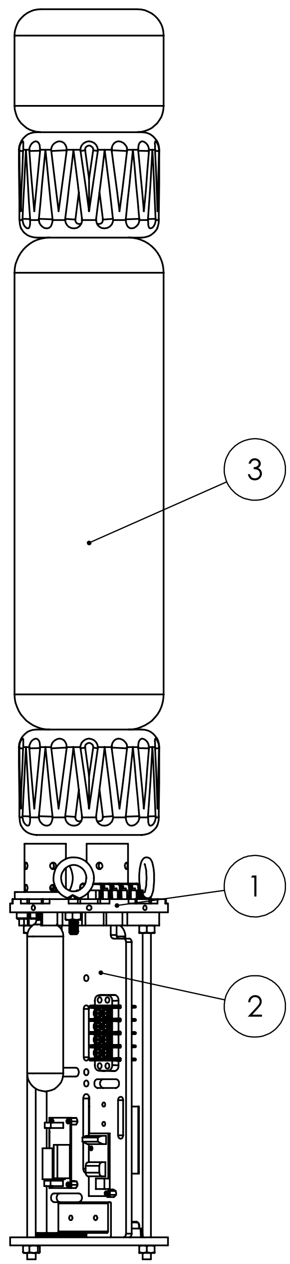
QUANTITY: 20

TITLE:
H1-11-50 Adjustable Nosecone Ballast

SIZE A | DWG. NO. 1 | REV 1

SCALE: 1:1 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



ITEM NO.	PART NUMBER	QTY.
1	H1-20-01 Recovery Bulkhead Assembly	1
2	H1-20-10 Main Avionics Assembly	1
3	H1-20-03 Parachute Assembly	1

	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Malaki	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

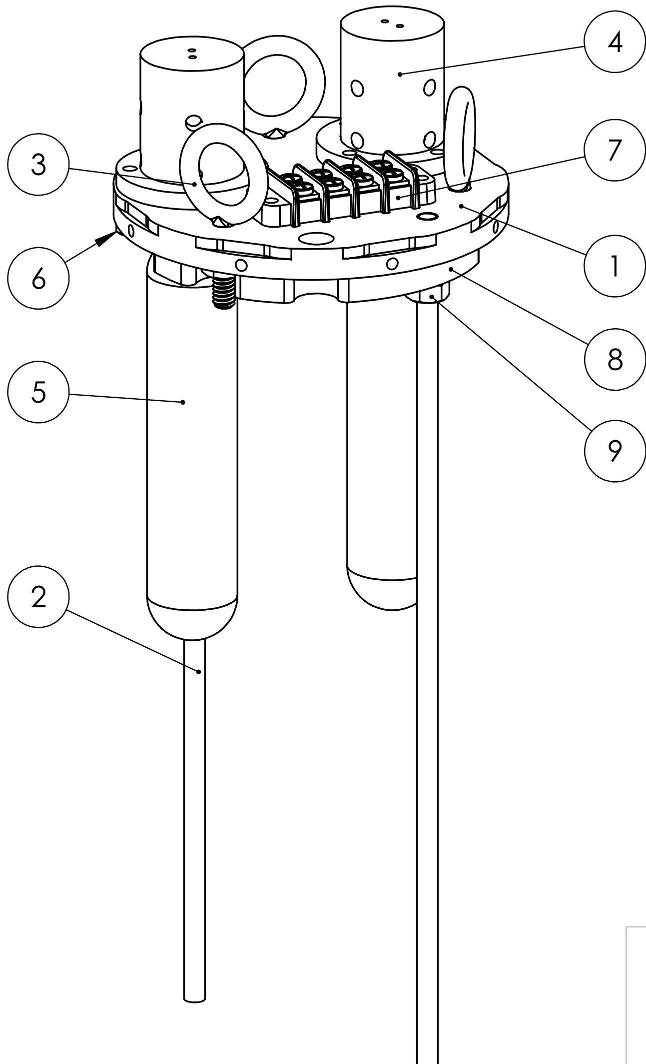
TITLE:

H1-20-00 Recovery Assembly

SIZE A | DWG. NO. 1 | REV 1

SCALE: 1:5 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



ITEM NO.	PART NUMBER	QTY.
1	H1-21-02 Recovery Bulkhead	1
2	1/4-20 Threaded Rod	2
3	1/4-20 Eyebolt	3
4	H1-20-02 CO2 Deployment System Assembly	2
5	Z CO2 Cartridge	2
6	10-32 x 0.75"	8
7	4x2 Terminal Block	1
8	H1-21-06 GNC Sled Guide	1
9	1/4-20 Hex Nut	5

	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Malaki	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

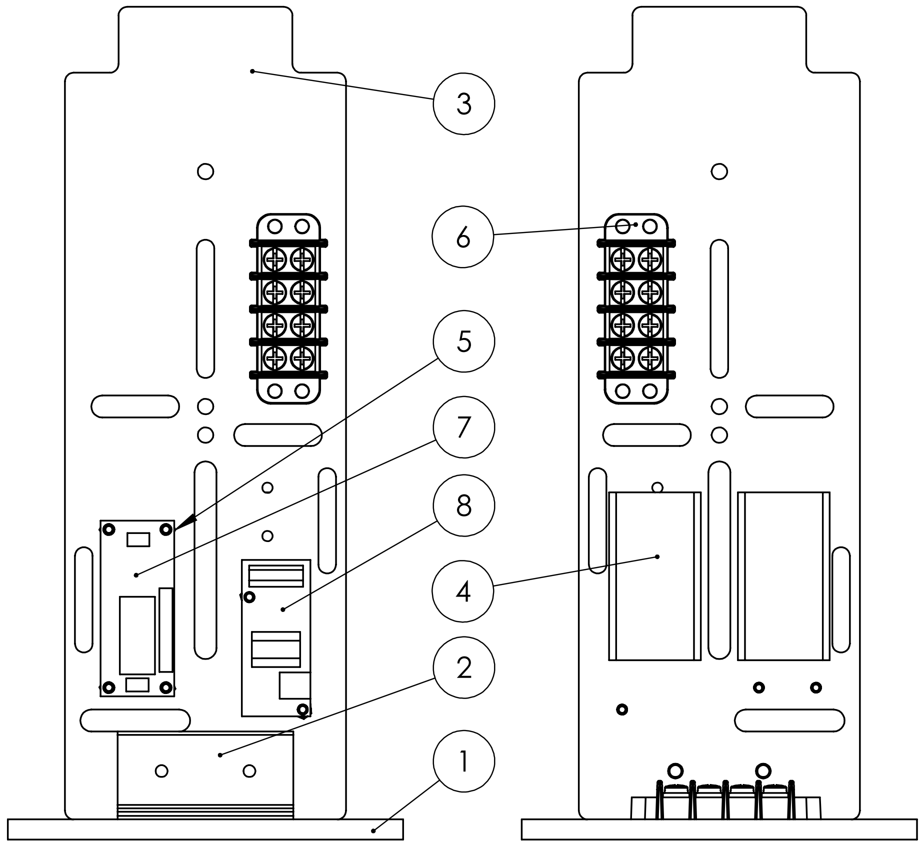
TITLE:

H1-20-01 Recovery Bulkhead Assembly

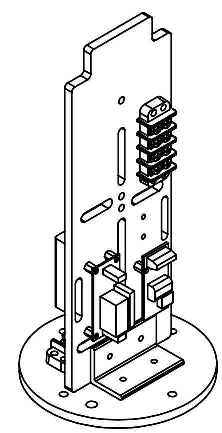
SIZE **A** DWG. NO. 1 REV 1

SCALE: 1:2 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



ITEM NO.	PART NUMBER	QTY.
1	H1-21-20 GNC Bulkhead	1
2	H1-21-22 Angle Bracket	1
3	H1-21-21 GNC Recovery Board	1
4	9V Battery	2
5	3-16 x 0.25" Standoff	6
6	4x2 Terminal Block	3
7	PerfectFlite-StratoLoggerCF	1
8	Featherweight Raven 3	1



	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Malaki	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

TITLE:

H1-20-10 Main Avionics Assembly

SIZE A | DWG. NO. 1 | REV 1

SCALE: 1:2 | SHEET 1 OF 1

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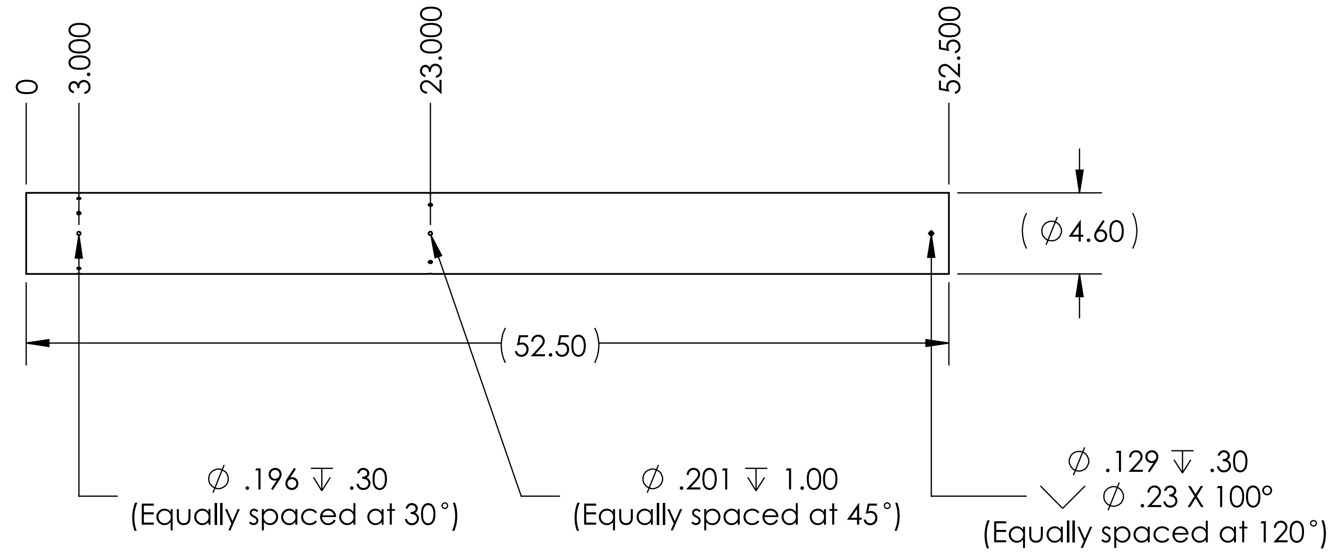


This drawing is only needed to drill the holes.

	NAME	DATE
DRAWN BY	Sebastian	30.04.18
CHECKED BY	Malaki	30.04.18
APPROVED BY	Cheyenne	01.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL: Carbon Fiber

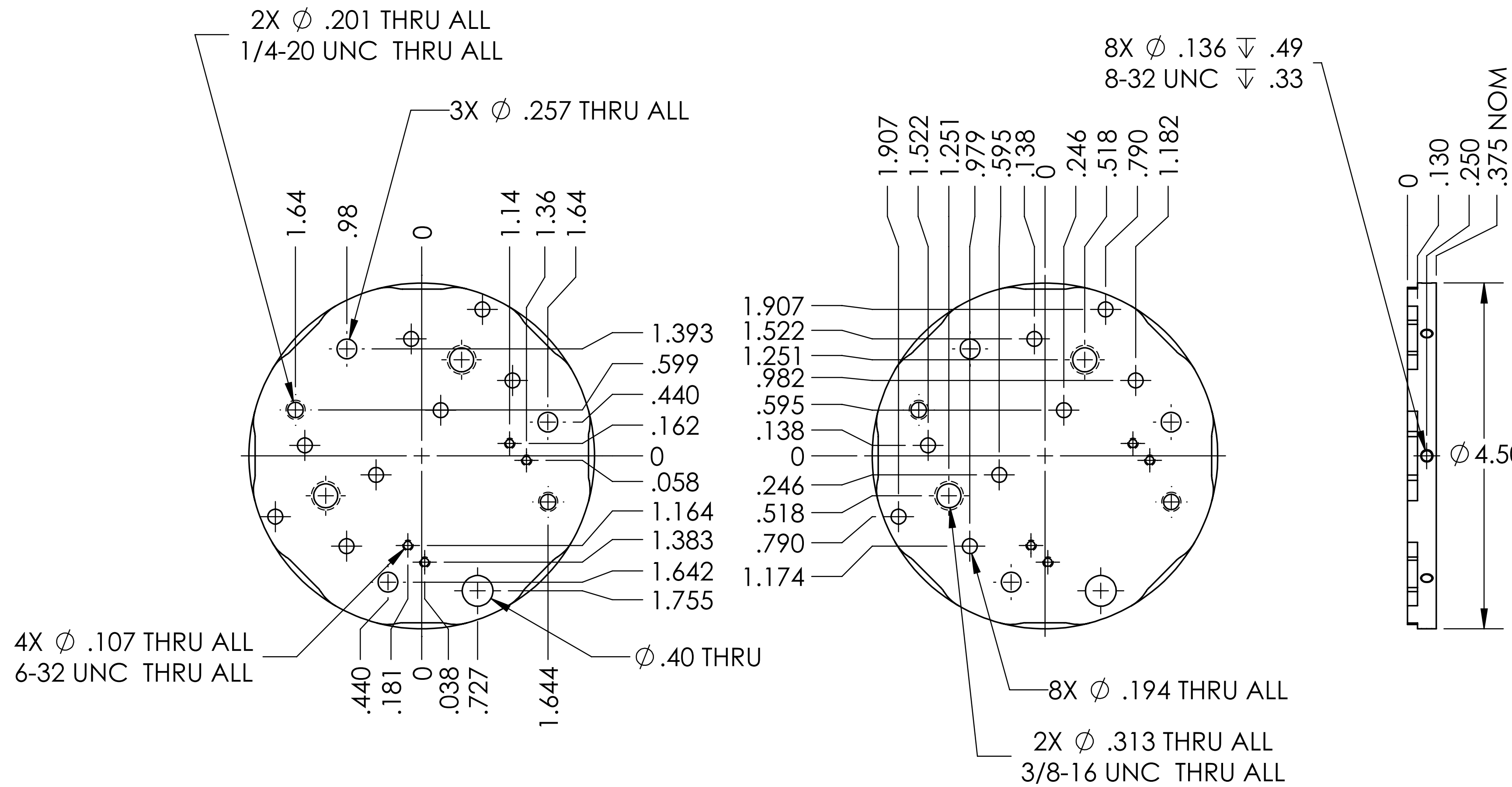
QUANTITY: 1

TITLE: H1-21-09 Upper Fuselage

SIZE: A | DWG. NO.: 1 | REV: 1

SCALE: 1:10 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



Location features (on side) are done on the CNC.

	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Malaki	24.05.18
APPROVED BY	Cheyenne	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL: 6061-T6

QUANTITY: 1

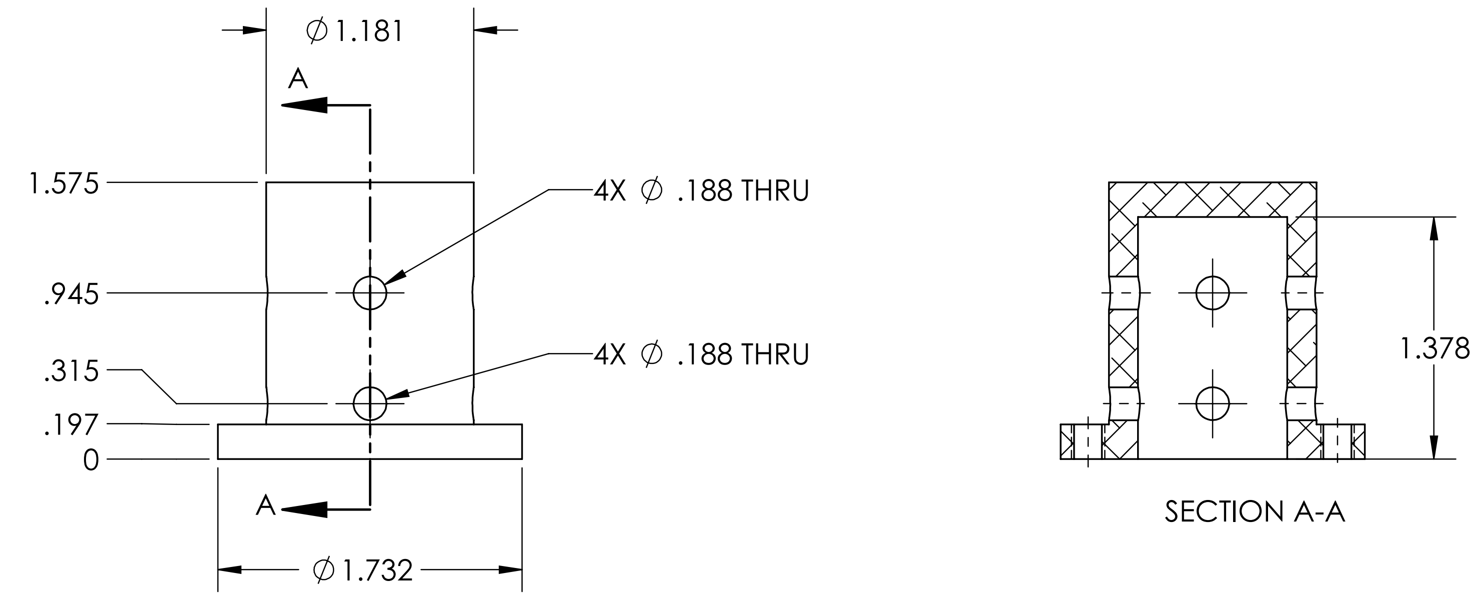
TITLE:

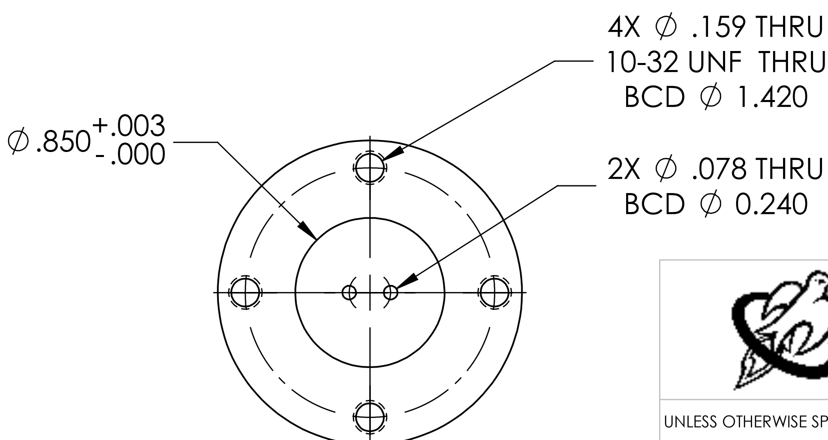
H1-21-02 Recovery Bulkhead

SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:2 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.





		NAME	DATE
	DRAWN BY	Graham	24.05.18
	CHECKED BY	Cheyenne	24.05.18
	APPROVED BY	Sebastian	24.05.18
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: Al 6061-T6 QUANTITY: 2		

TITLE:

H1-21-03 CO2 Housing

SIZE	DWG. NO.	REV
A	1	1
SCALE: 1:1		SHEET 1 OF 1

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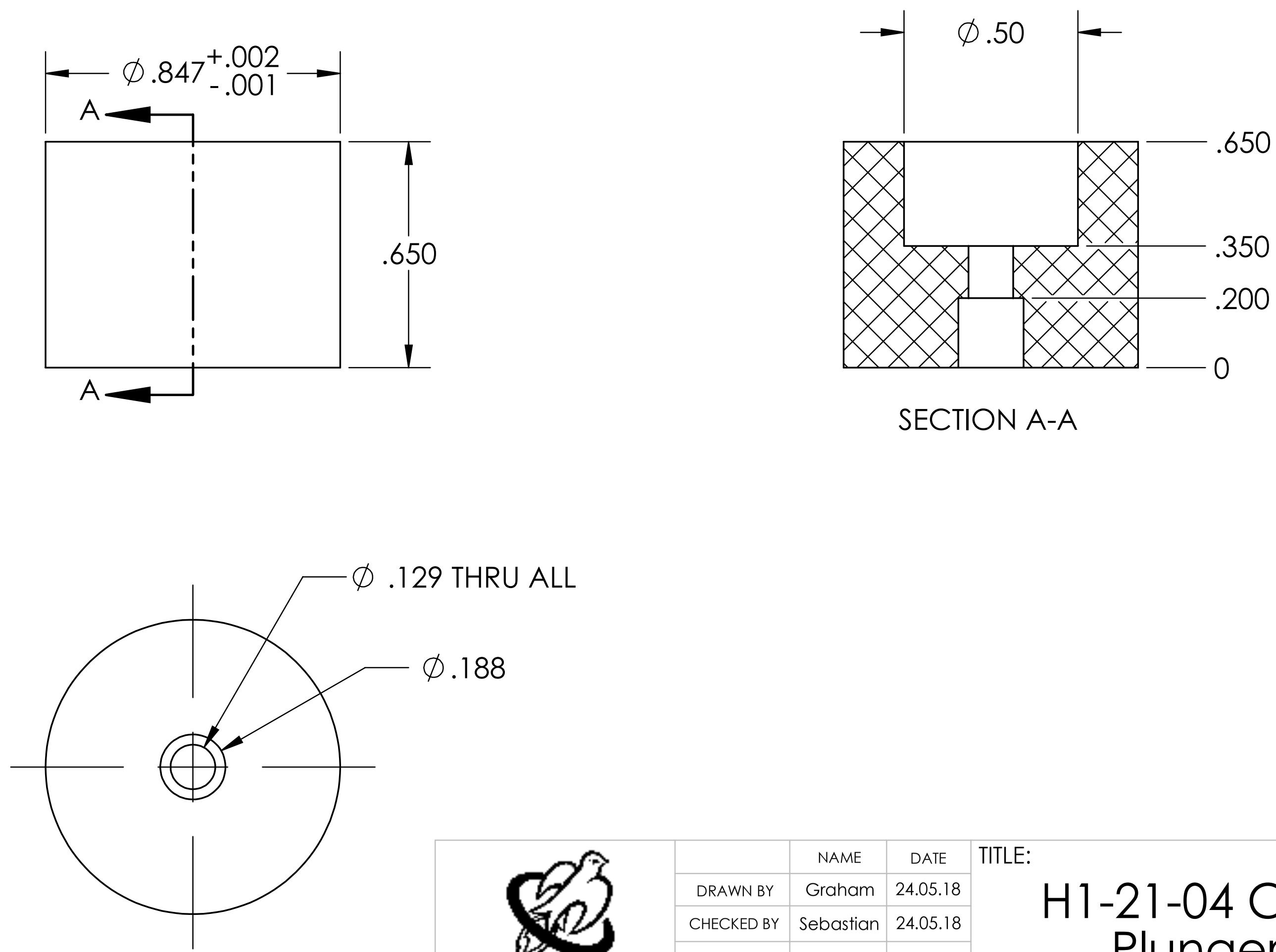


	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Cheyenne	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

MATERIAL: Al 6061-T6

QUANTITY: 2

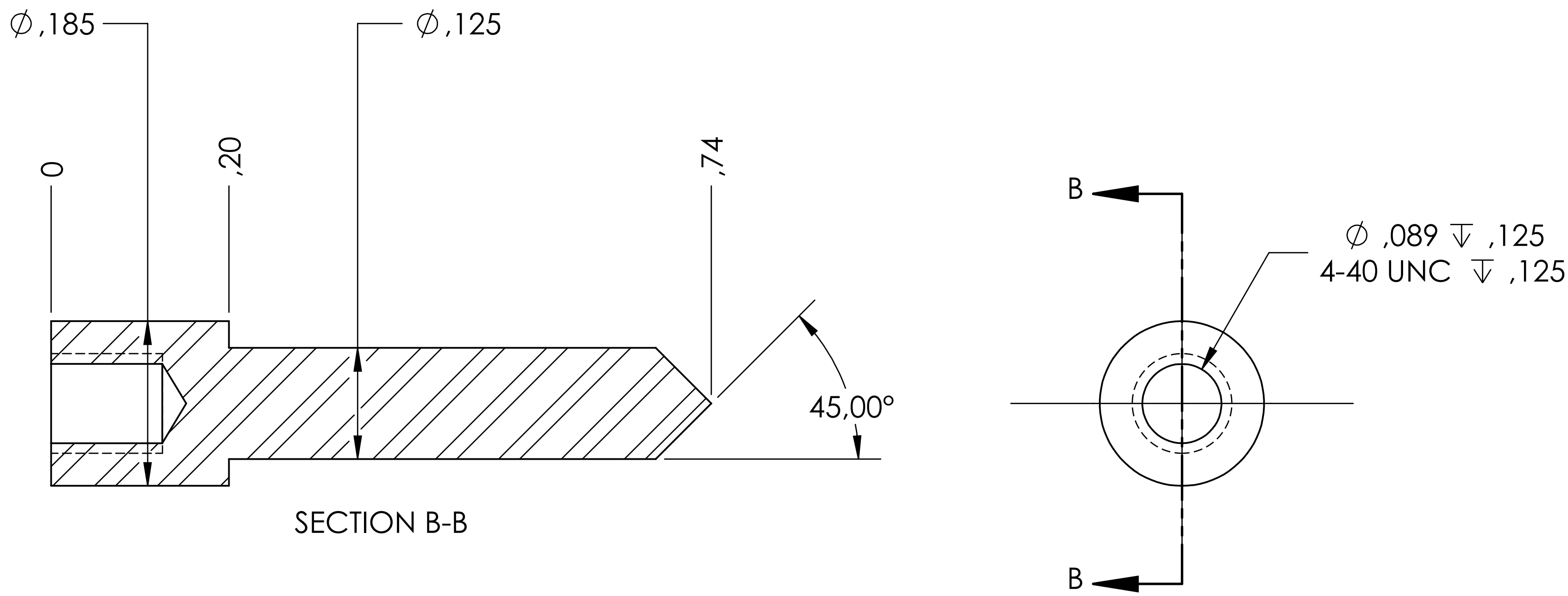
TITLE:

H1-21-04 CO2 Plunger

SIZE A | DWG. NO. 1 | REV 1

SCALE: 2:1 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Malaki	24.05.18

TITLE:

H1-21-05 CO2 Pin

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

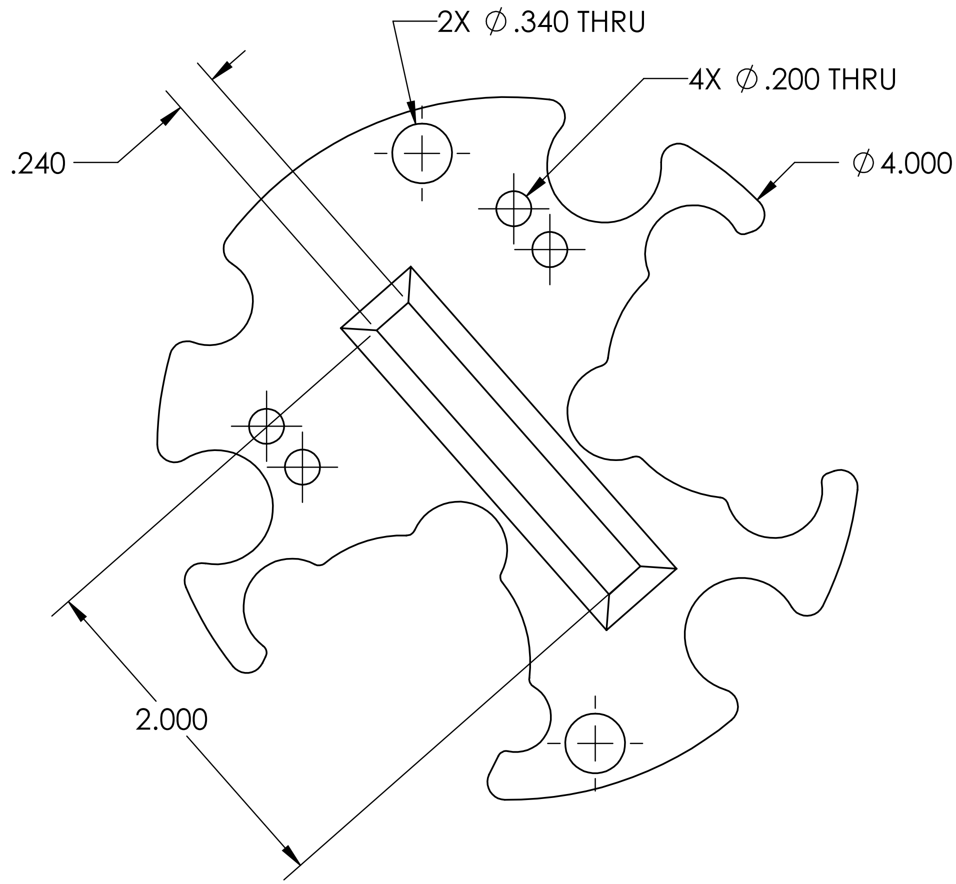
MATERIAL: Al 6061-T6

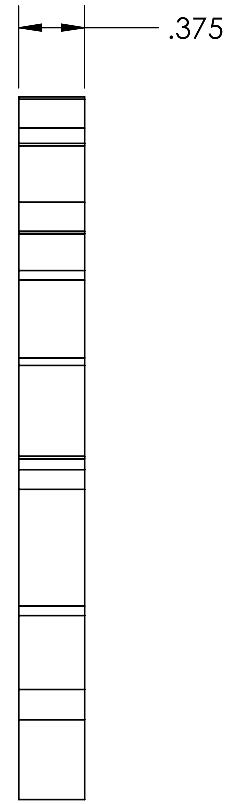
QUANTITY: 2

SIZE	DWG. NO.	REV
A	1	1

SCALE: 5:1 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.





This part is 3D printed using a STL file

		NAME	DATE
	DRAWN BY	Graham	24.05.18
	CHECKED BY	Sebastian	24.05.18
	APPROVED BY	Cheyenne	24.05.18
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: PLA QUANTITY: 1		

TITLE:

H1-21-06 GNC Sled Guide

SIZE	DWG. NO.	REV
A	1	1
SCALE: 1:1		SHEET 1 OF 1

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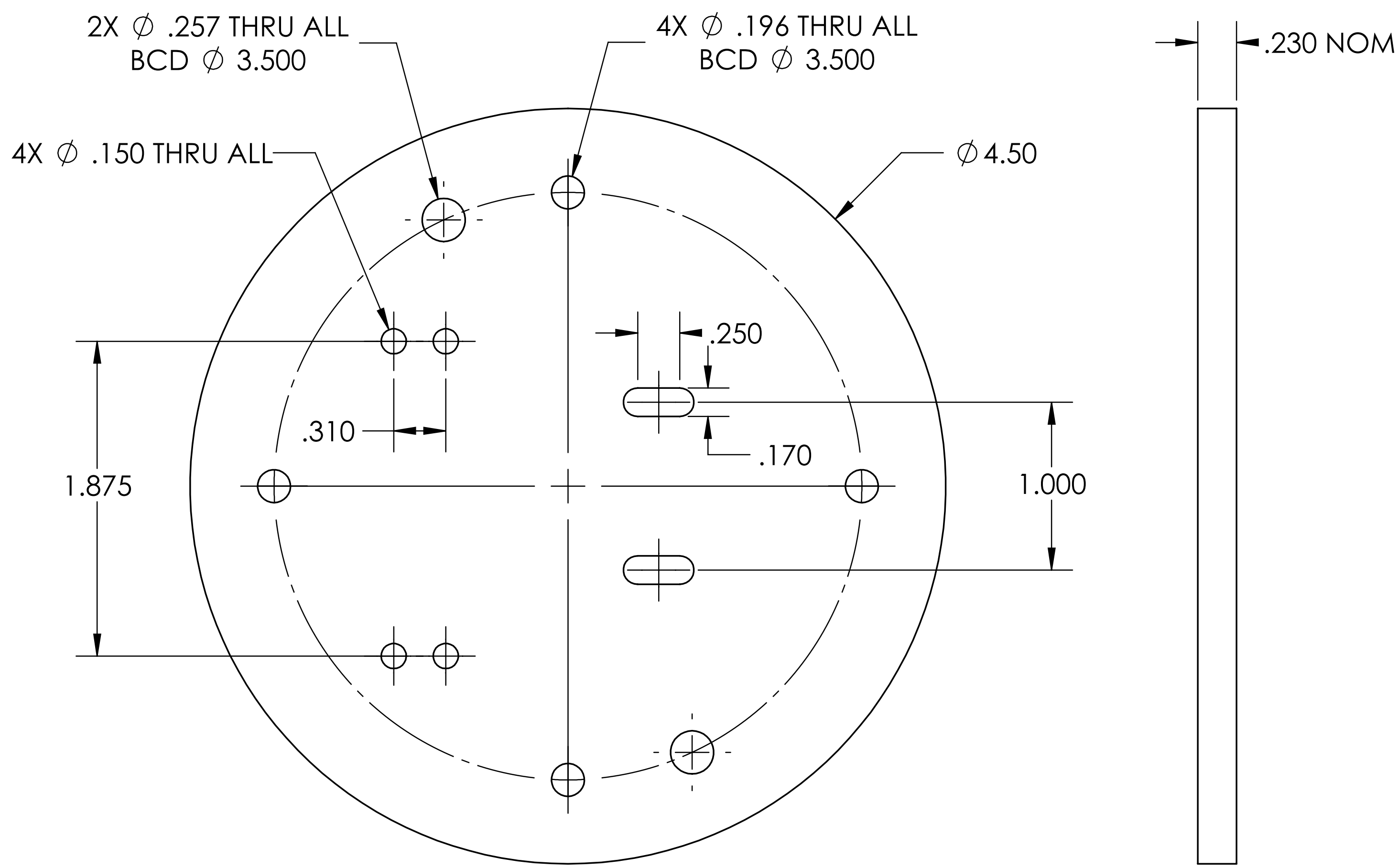


This is lasercut using a DXF file

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Cheyenne	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

MATERIAL: Birch Plywood

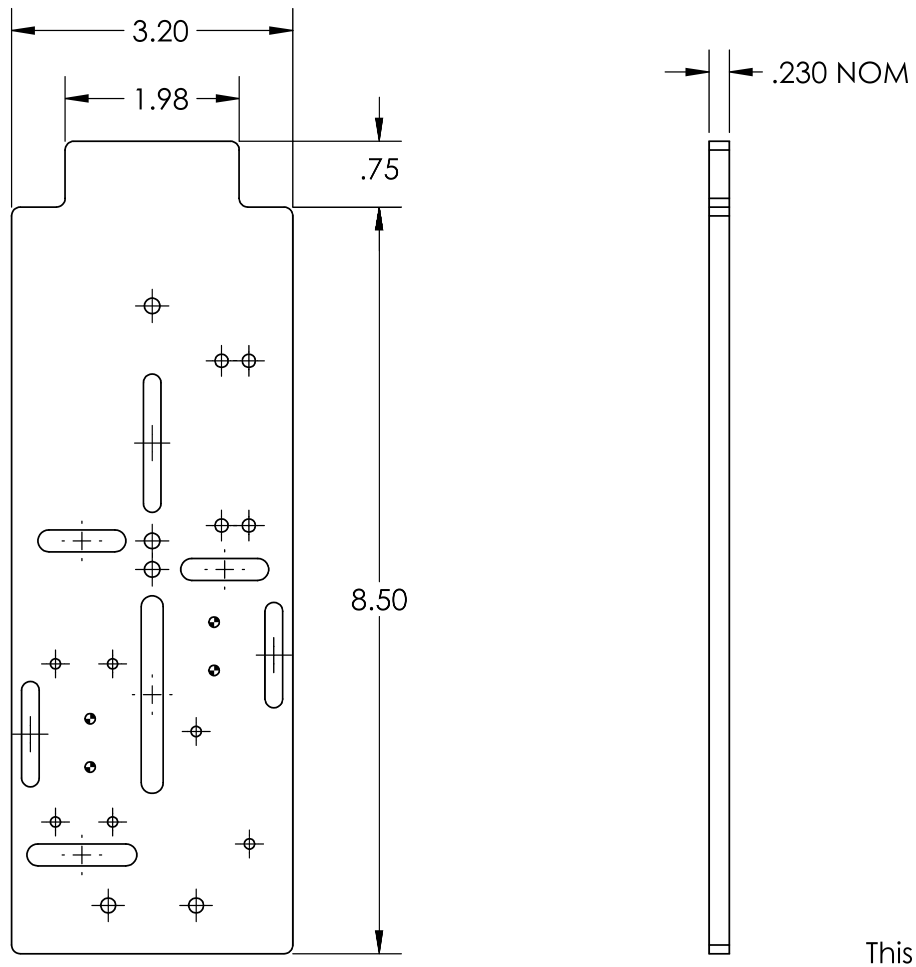
QUANTITY: 1

TITLE: H1-21-20 GNC Bulkhead

SIZE: A | DWG. NO. 1 | REV 1

SCALE: 1:1 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This part is being lasercut using a DXF file.

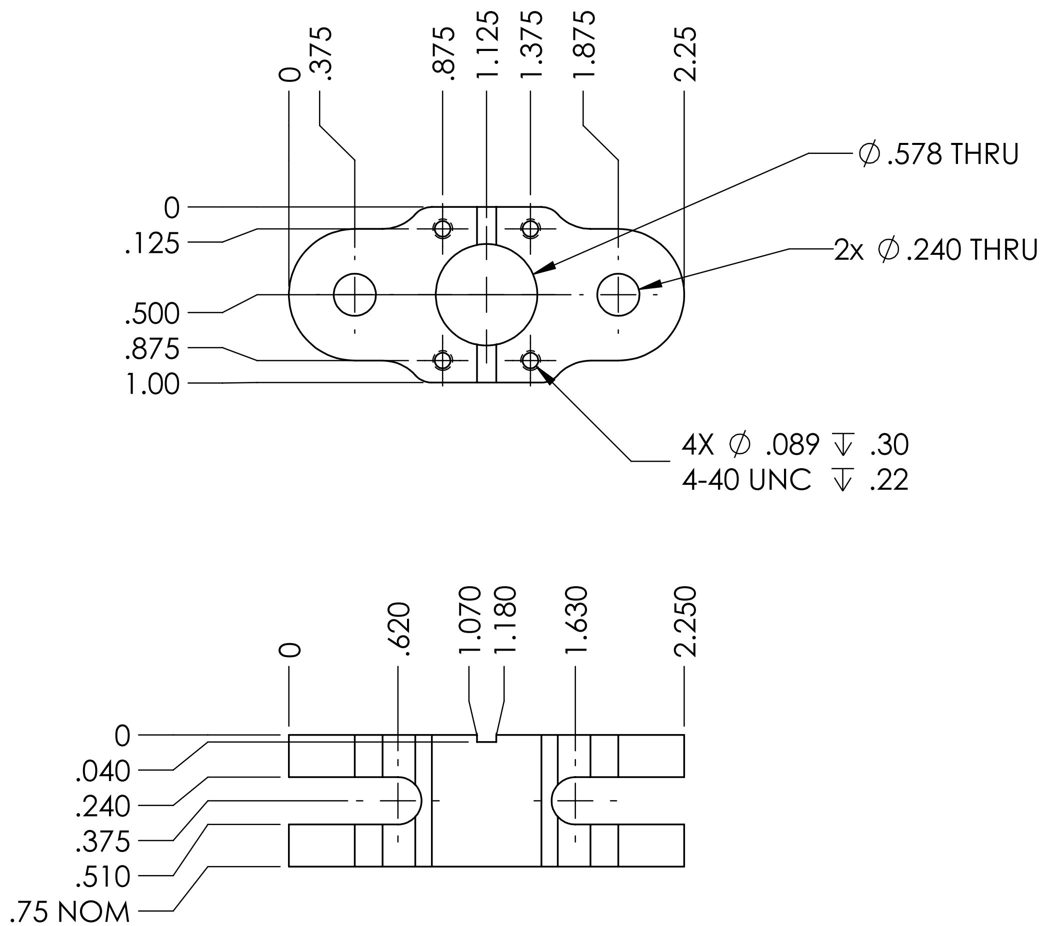
		NAME	DATE
	DRAWN BY	Graham	24.05.18
	CHECKED BY	Sebastian	24.05.18
	APPROVED BY	Cheyenne	24.05.18
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.003	MATERIAL: Birch Plywood; QUANTITY: 1		

TITLE:

H1-21-21 GNC Recovery Board

SIZE	DWG. NO.	REV
A	1	1
SCALE: 1:2		SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



		NAME	DATE	TITLE:
	DRAWN BY	Sebastian	24.05.18	H1-21-23 Pyrelease housing
	CHECKED BY	Malaki	24.05.18	
	APPROVED BY	Cheyenne	24.05.18	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.003	MATERIAL: 6061-T6			SIZE A — DWG. NO. 1 — REV 1
	QUANTITY: 1			SCALE: 1:1 — SHEET 1 OF 1

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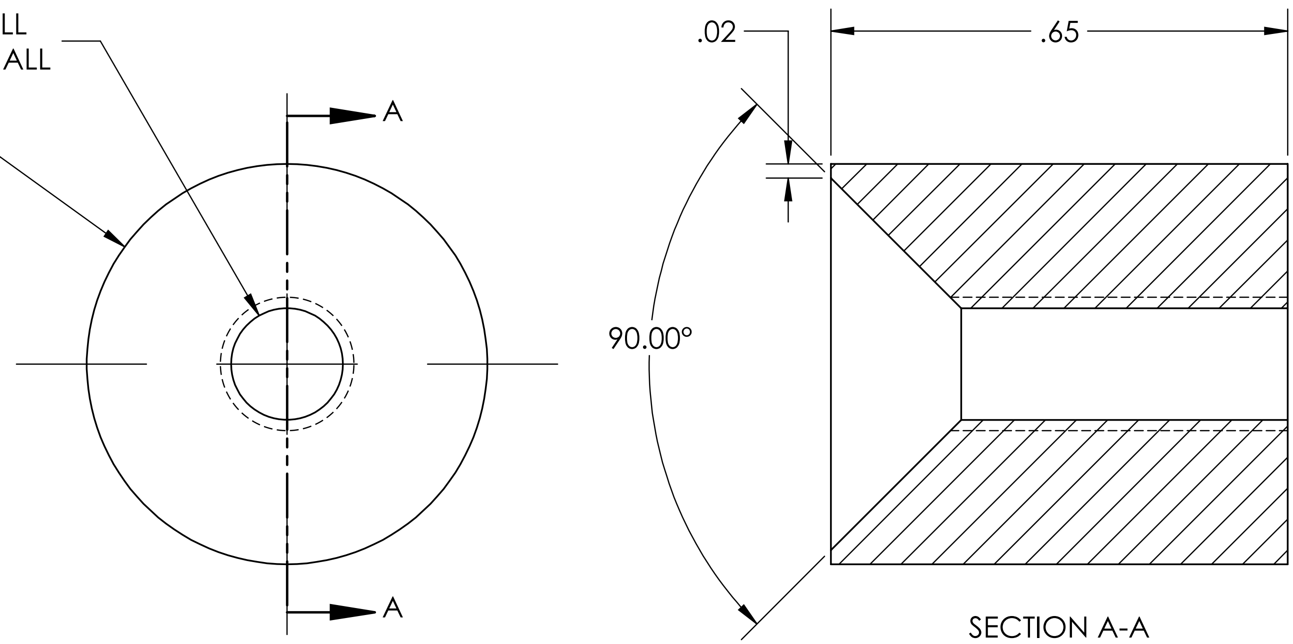

		NAME	DATE	TITLE: H1-21-24 Pyrelease Plunger
	DRAWN BY	Sebsatian	24.05.18	
	CHECKED BY	Malaki	24.05.18	
	APPROVED BY	Cheyenne	24.05.18	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.003	MATERIAL: Delrin			SIZE A · DWG. NO. 1 · REV 1
	QUANTITY: 1			SCALE: 4:1 · SHEET 1 OF 1

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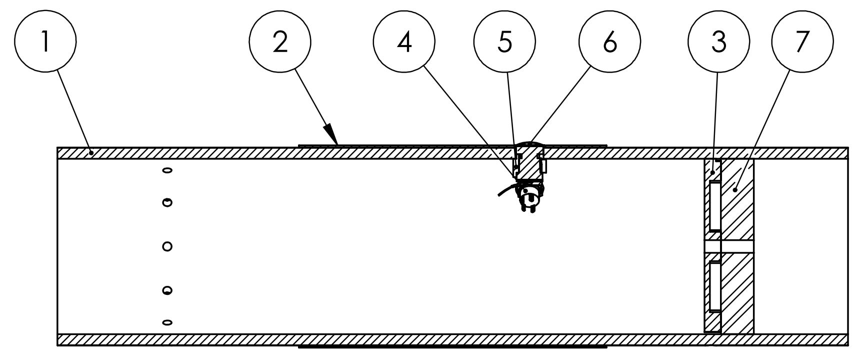
ITEM NO.	PART NUMBER	QTY.
1	H1-31-01 Coupler	1
2	H1-31-02 Coupler Band	1
3	H1-31-03 Propulsion Bulkhead	1
4	Switch	2
5	H1-31-04 Mobius Lens Mount	1
6	Z Mobius Camera Lens	1
7	H1-31-10 Ballast	1



	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Malaki	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

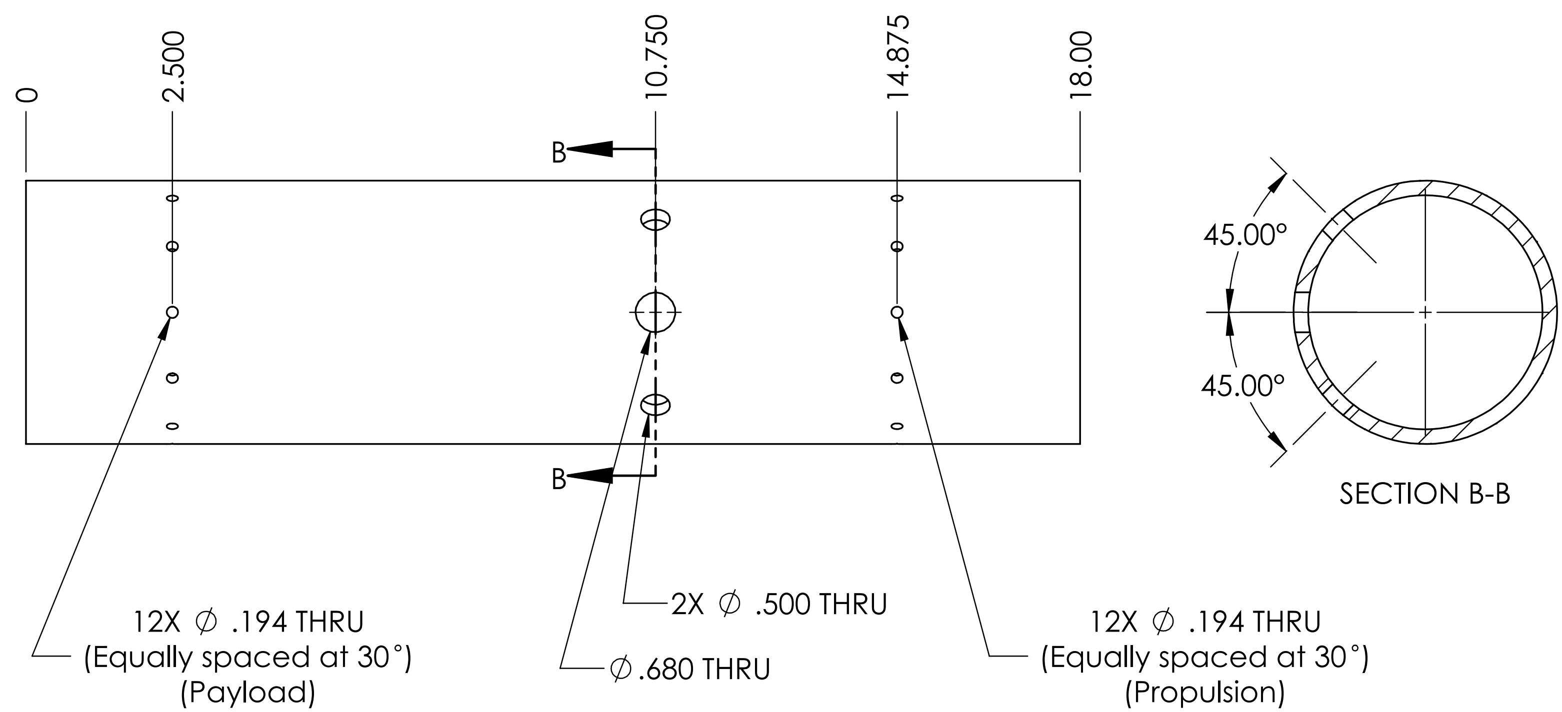
TITLE:

H1-30-00 Coupler Assembly

SIZE A | DWG. NO. 1 | REV 1

SCALE: 1:4 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



The coupler is a figer glass and foam layup.
This drawing is only used for machining the holes.

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Sebastian	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

MATERIAL: Fiber Glass, Foam

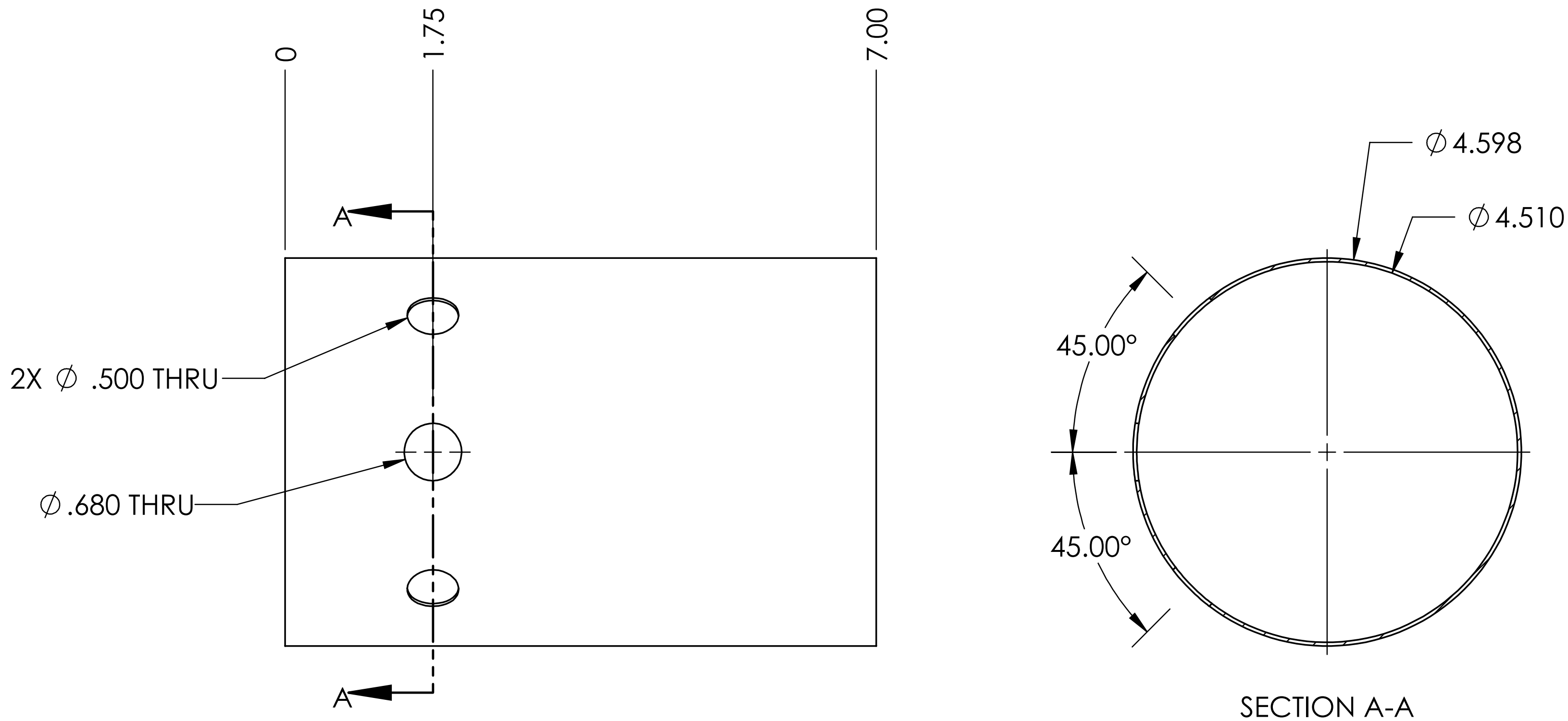
QUANTITY: 1

TITLE: H1-31-01 Coupler

SIZE: A | DWG. NO. 1 | REV 1

SCALE: 1:3 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This is a figer glass layup.
The drawing is just for reference.

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Sebastian	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

MATERIAL: Fiber Glass

QUANTITY: 1

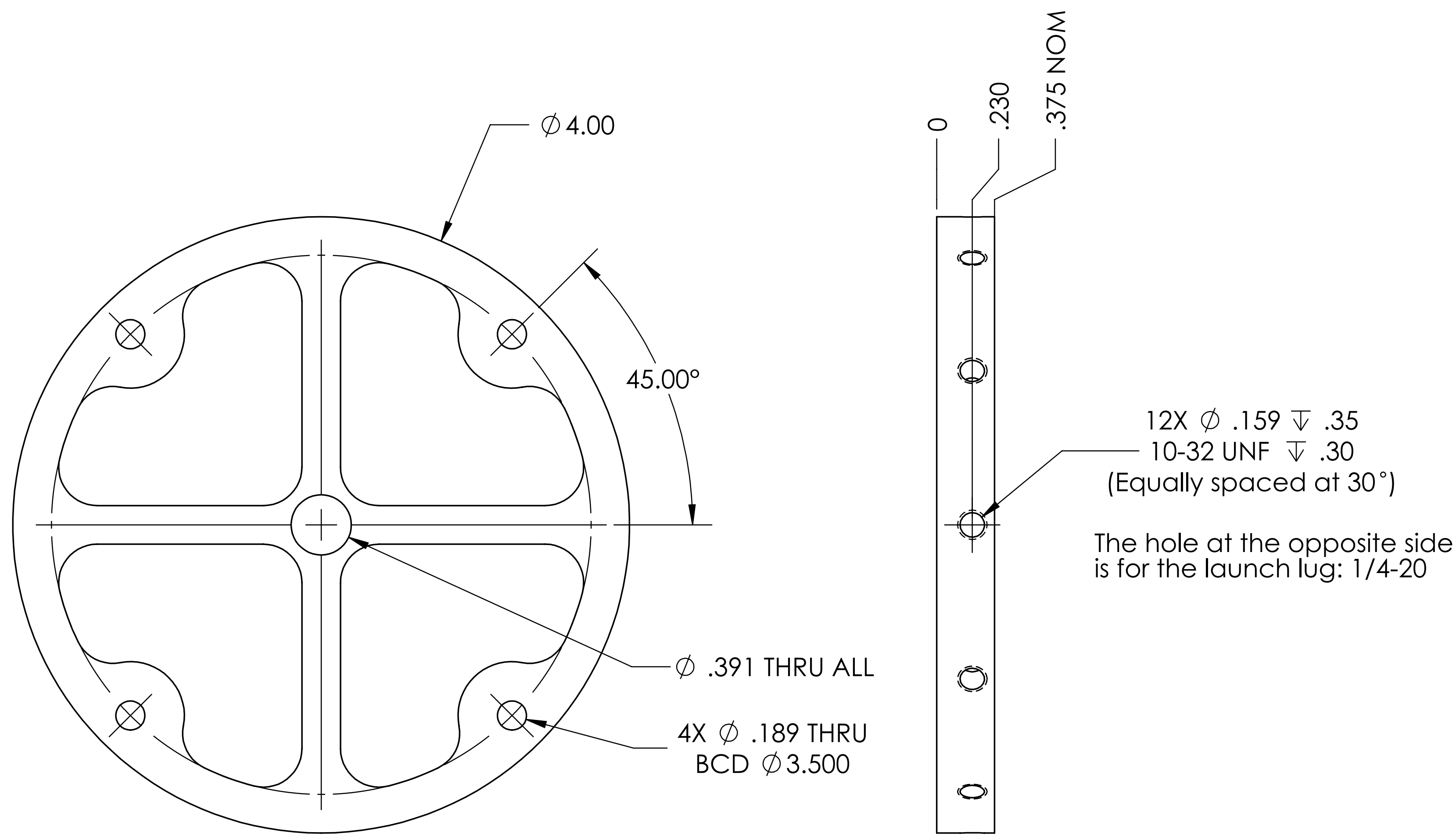
TITLE:

H1-31-02 Coupler Band

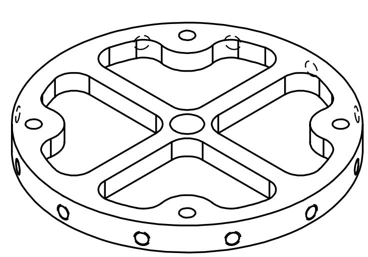
SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:2 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

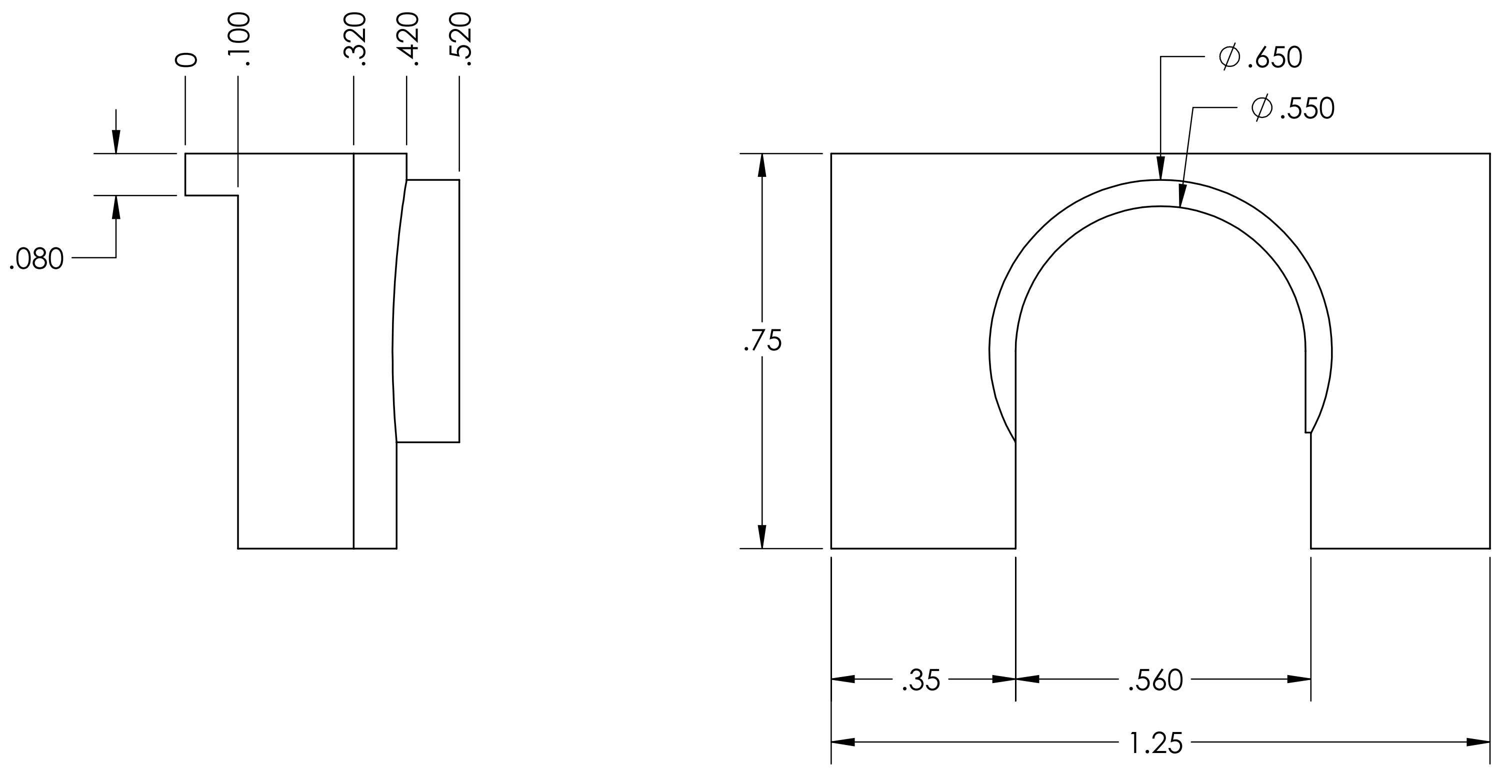


The weight saving cutouts are done on the CNC.



		NAME	DATE	TITLE: H1-31-03 Propulsion Bulkhead
	DRAWN BY	Sebastian	24.05.18	
	CHECKED BY	Malaki	24.05.18	
	APPROVED BY	Cheyenne	24.05.18	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.003	MATERIAL: 6061-T6			SIZE A · DWG. NO. 1 · REV 1
	QUANTITY: 1			SCALE: 1:1 · SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using a STL file

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Sebastian	24.05.18

TITLE:

H1-31-04 Mobius Lens Mount

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

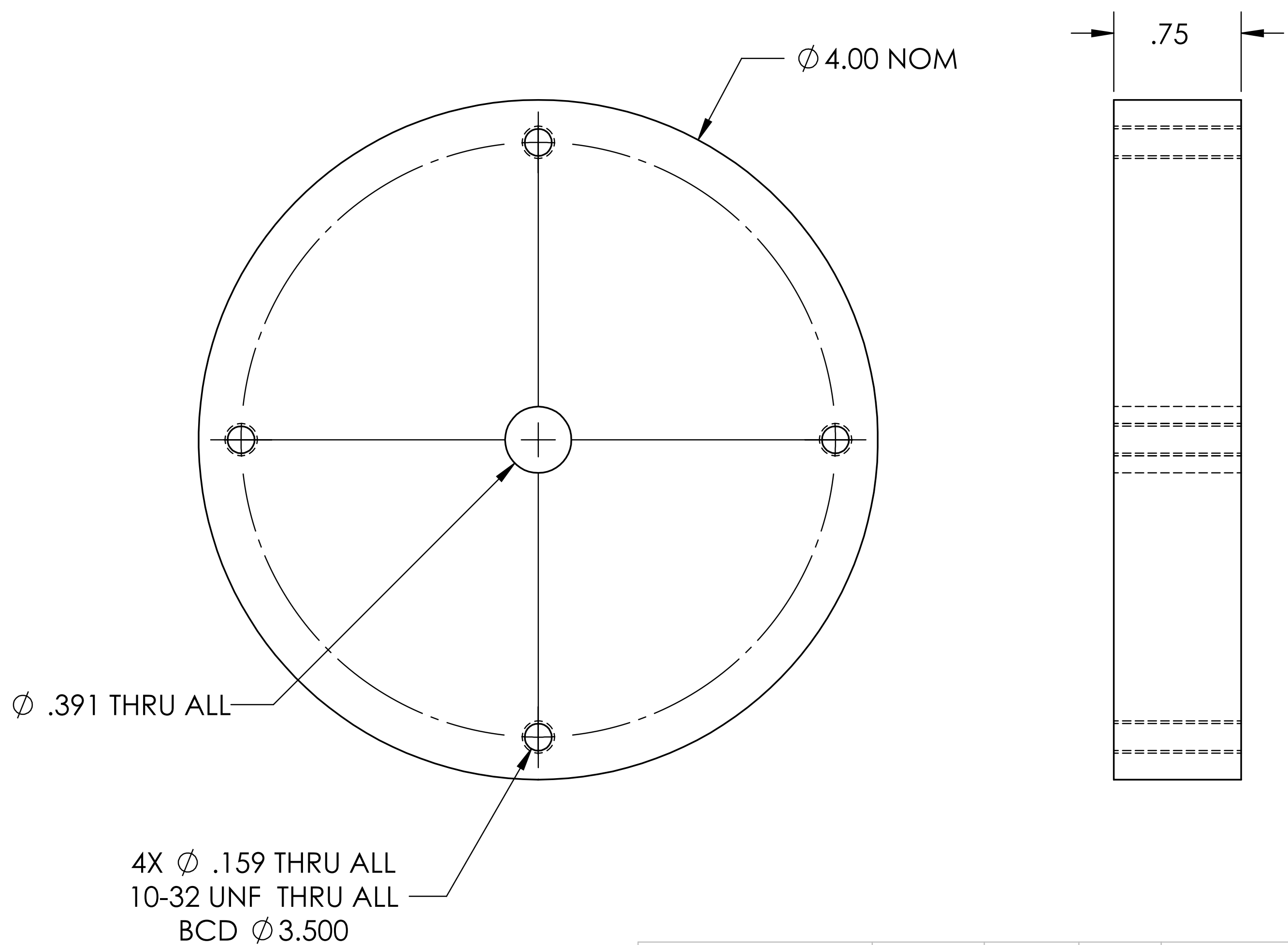
MATERIAL: PLA

QUANTITY: 1

SIZE: A | DWG. NO. 1 | REV 1

SCALE: 3:1 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



		NAME	DATE
	DRAWN BY	Sebastian	24.05.18
	CHECKED BY	Cheyenne	24.05.18
	APPROVED BY	Malaki	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL: C 1020

QUANTITY: 1

TITLE:

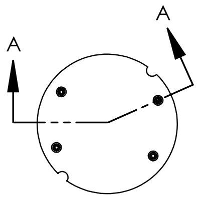
H1-31-10 Ballast

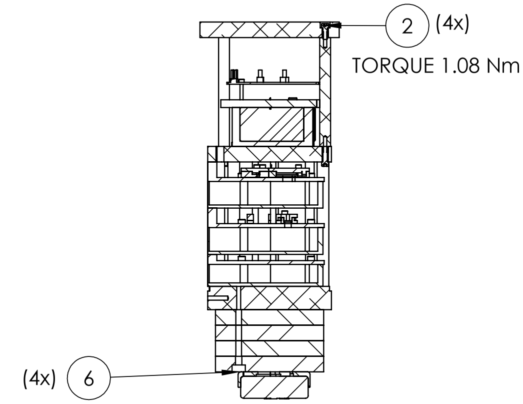
SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:1 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

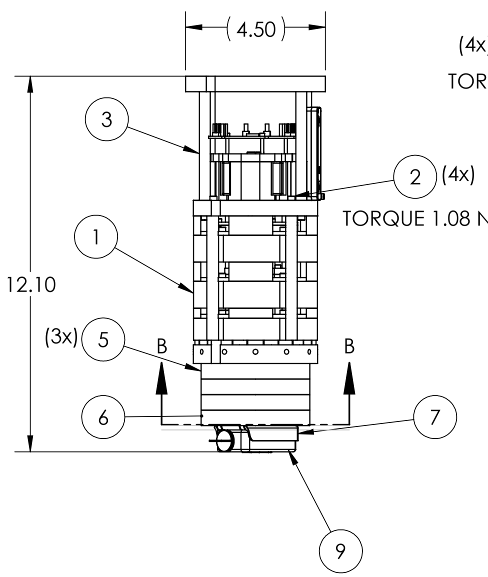
TOTAL QTY	NEXT ASSY REF
1	MASTER

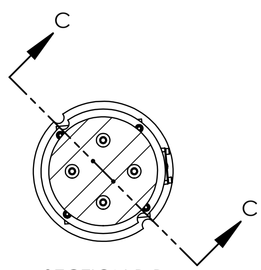




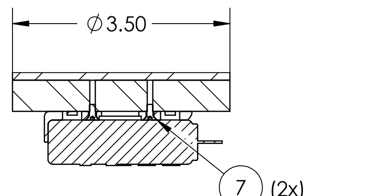
SECTIONA-A

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	H1-40-05	Box Module	1
2	HX-SHCS 0.138-32x0.375x0.375-N	6-32 1/2" Socket Cap Screw	8
3	H1-40-06	Electrical Module	1
4	H1-41-03	Top Plate	1
5	H1-41-30	Round Ballast	3
6	H1-41-31	Round Ballast Counterbore	1
7	Z 4-06	Mobius Body Mount	1
8	SCHCSCREW 0.099-48x0.25x0.25-HX-N	3-56 1/2" Countersunk Socket Screw	2
9	Z 4-05	Mobius Camera Body	1

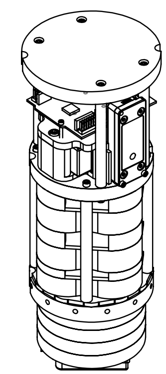




SECTION B-B



SECTION C-C
SCALE 1 : 2



ISOMETRIC VIEW

NOTES:

1. FASTEN AND INSEPCT 1 AND 3 FIRST
2. FASTEN AND INSPECT 5 AND 6 PRIOR TO FASTENING 7
3. ASSEMBLE 9 LAST
4. FULLY TIGHEN ALL BOLTS TO CORRECT TORQUE VALUES

	NAME	DATE
DRAWN BY	Sachi	17.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Cheyenne	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

TITLE: PAYLOAD ASSEMBLY

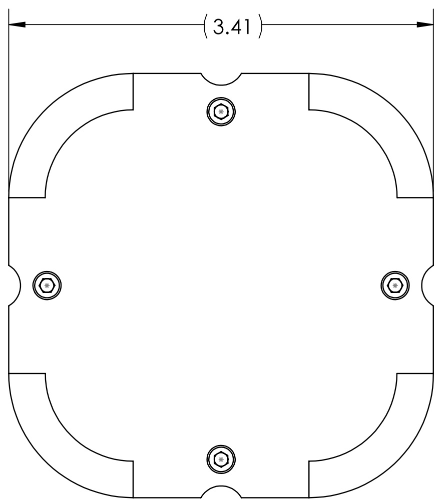
SIZE B | DWG. NO. H1-40-00 | REV 1

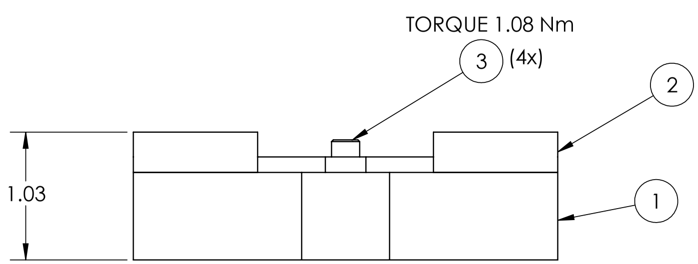
SCALE: 1:4 | SHEET 1 OF 1

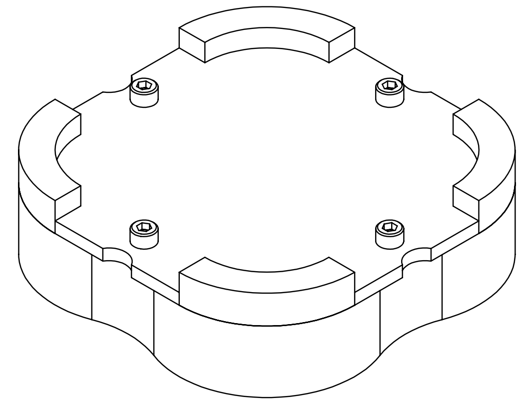
SOLIDWORKS Educational Product. For Instructional Use Only.

TOTAL QTY	NEXT ASSY REF
1	H1-40-05

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	H1-41-10	Dish Tray Control	1
2	H1-41-11	Lid Control	1
3	HX-SHCS 0.138-32x0.5x0.5-C	6-32 3/4" Socket Cap Screw	4







ISOMETRIC VIEW

NOTES:

1. ASSEMBLY TO OCCUR AT SITE BY MICROBIOLOGIST
2. FULLY TIGHTEN ALL BOLTS TO CORRECT TORQUE VALUE

	NAME	DATE
DRAWN BY	Sachi	17.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Malaki	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

TITLE: CONTROL BOX

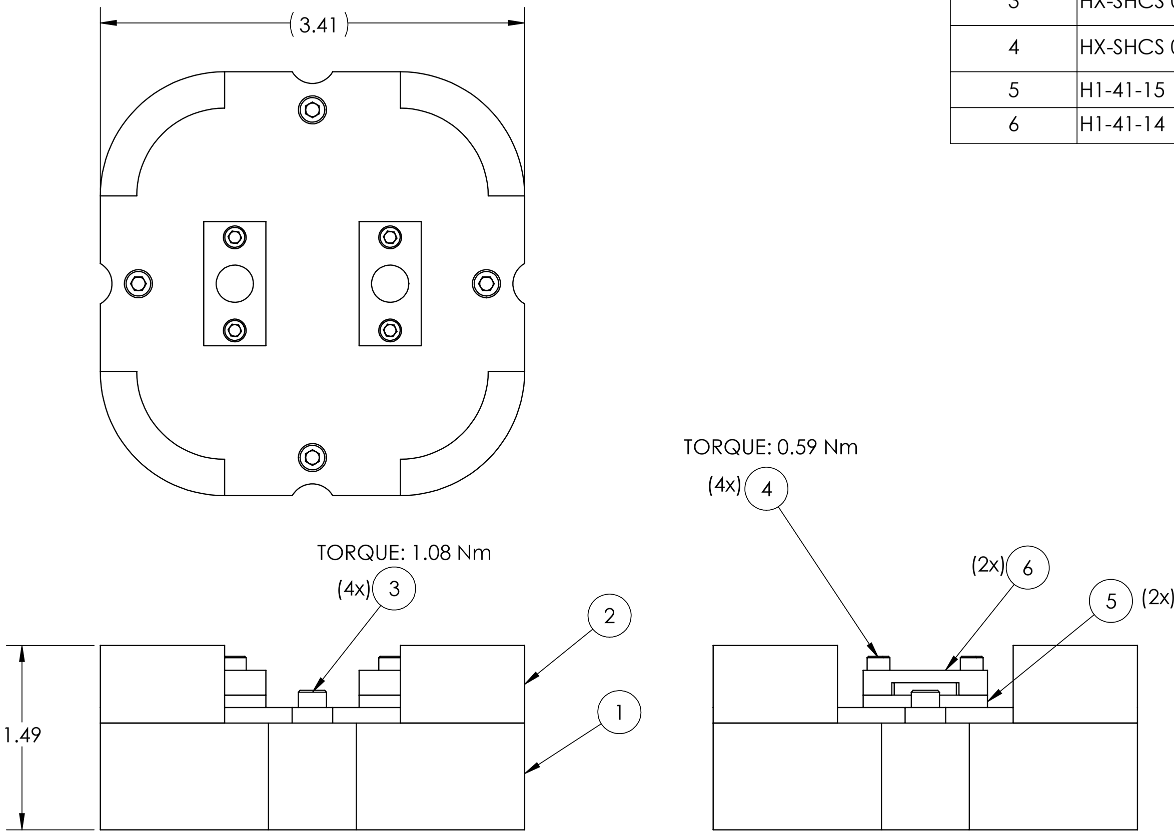
SIZE B DWG. NO. H1-40-02 REV 1

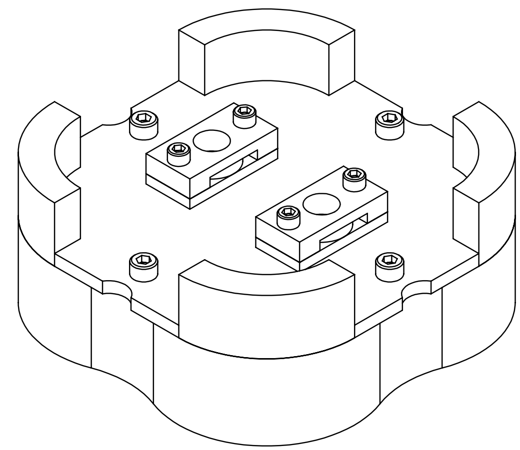
SCALE: 1:1 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

TOTAL QTY	NEXT ASSY REF
1	H1-40-00

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	H1-41-12	Dish Tray	1
2	H1-41-13	Lid 245nm	1
3	HX-SHCS 0.138-32x0.25x0.25-N	6-32 3/4" Socket Cap Screw	4
4	HX-SHCS 0.112-40x0.375x0.375-N	4-40 1/2" Socket Cap Screw	4
5	H1-41-15	245nm Holder Bottom	2
6	H1-41-14	245nm Holder Top	2





ISOMETRIC VIEW

NOTES:

1. FASTEN AND INSPECT PARTS 5 AND 6 FIRST
2. FINAL ASSEMBLY AT SITE BY MICROBIOLOGIST
3. FULLY TIGHTEN ALL BOLTS TO CORRECT TORQUE VALUE

	NAME	DATE
DRAWN BY	Sachi	17.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Cheyenne	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

TITLE: 245nm BOX

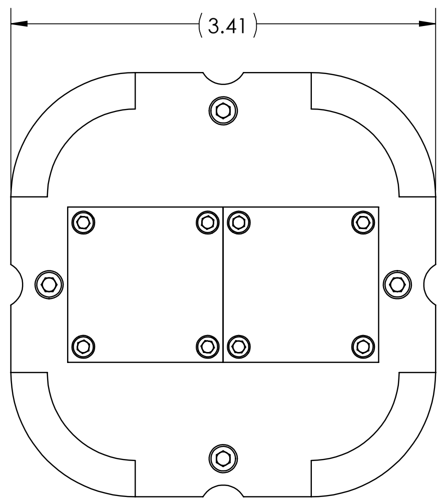
SIZE B | DWG. NO. H1-40-03 | REV 1

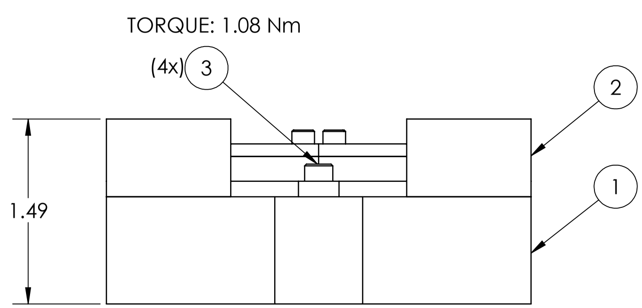
SCALE: 1:1 | SHEET 1 OF 1

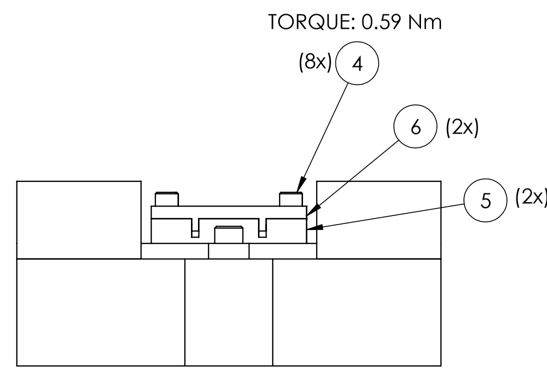
SOLIDWORKS Educational Product. For Instructional Use Only.

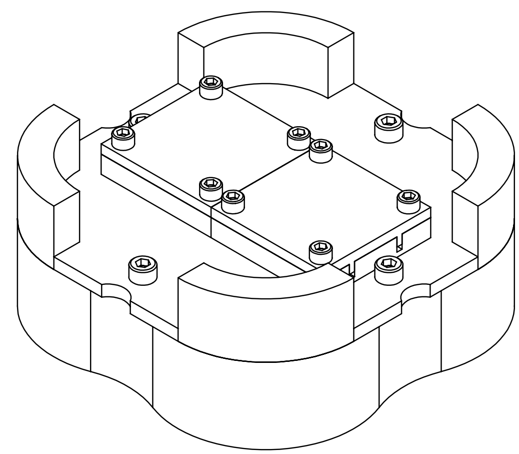
TOTAL QTY	NEXT ASSY REF
1	H1-40-00

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	H1-41-12	Dish Tray	1
2	H1-41-16	Lid 275nm	1
3	HX-SHCS 0.138-32x0.375x0.375-N	6-32 3/4" Socket Cap Screw	4
4	HX-SHCS 0.112-40x0.375x0.375-N	4-40 1/2" Socket Cap Screw	8
5	H1-41-18	275nm Holder Bottom	2
6	H1-41-17	275nm Holder Top	2









ISOMETRIC VIEW

NOTES:

1. FASTEN AND INSPECT 5 AND 6 FIRST
2. FINAL ASSEMBLY AT SITE BY MICROBIOLOGIST
3. FULLY TIGHTEN BOLTS TO CORRECT TORQUE VALUE

	NAME	DATE
DRAWN BY	Sachi	17.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Sebastian	24.05.18

TITLE: 275nm BOX

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

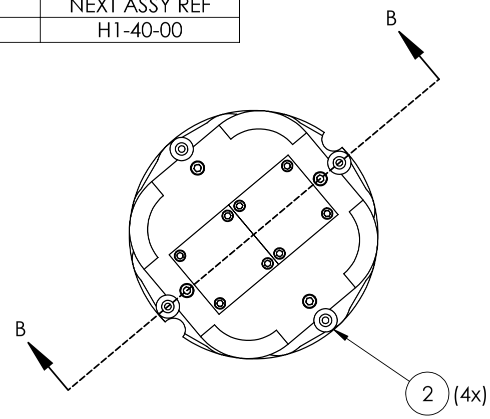
SIZE B DWG. NO. H1-40-04 REV 1

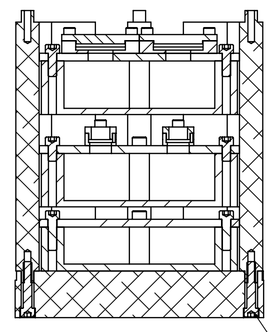
SCALE: 1:1 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

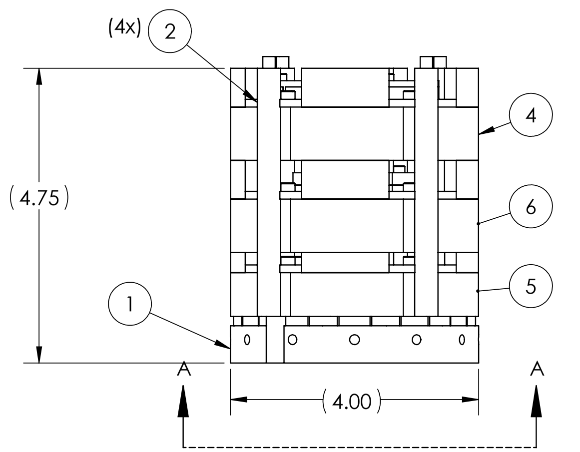
TOTAL QTY	NEXT ASSY REF
1	H1-40-00

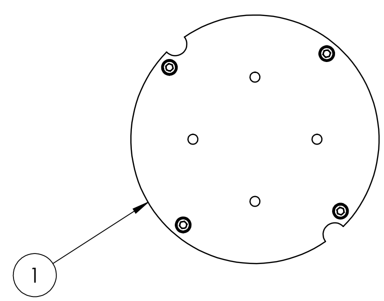
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	H1-41-01	Bottom Plate	1
2	H1-41-04	Lower Post	4
3	HX-SHCS 0.138-32x0.75x0.75-C	6-32 3/4' Socket Cap Screw	4
4	H1-40-08	275nm Box	1
5	H1-40-09	Control Box	1
6	H1-40-07	245nm Box	1



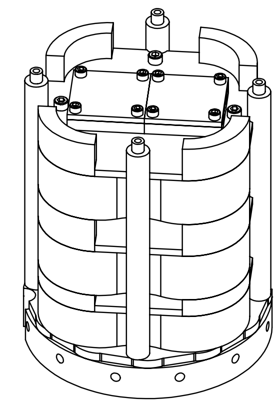


SECTION B-B





VIEW A-A



ISOMETRIC VIEW

NOTES:

1. FASTEN AND INSPECT 1 AND 2 FIRST
2. FULLY TIGHTEN ALL BOLTS TO CORRECT TORQUE VALUES

	NAME	DATE
DRAWN BY	Sachi	17.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Sebastian	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

TITLE: BOX MODULE

SIZE: B | DWG. NO. H1-40-05 | REV 1

SCALE: 1:2 | SHEET 1 OF 1

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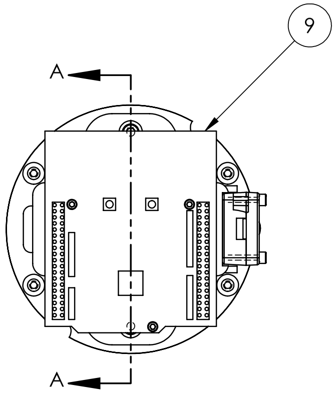
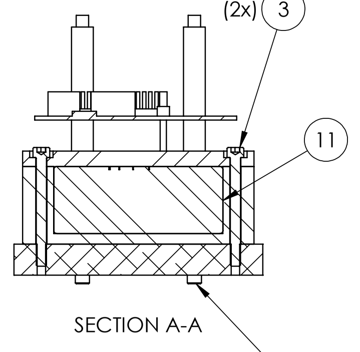
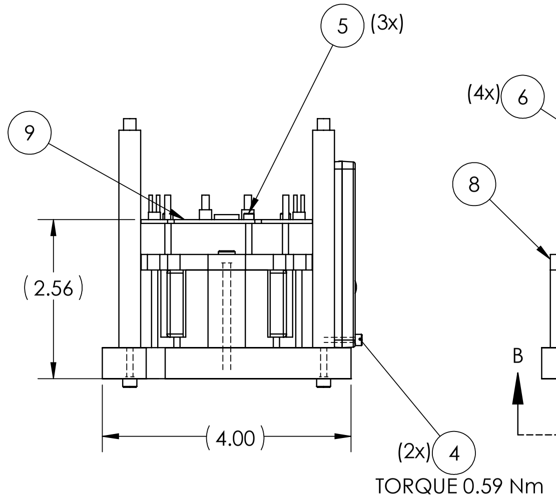
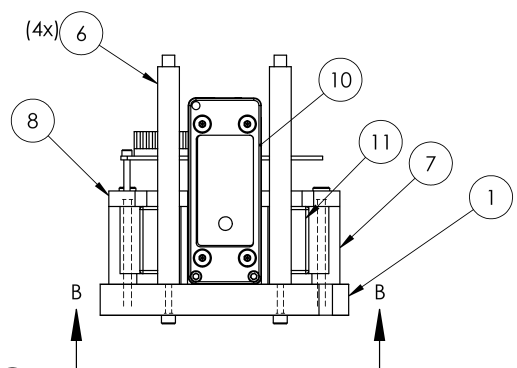
TOTAL QTY	NEXT ASSY REF
1	H1-40-00

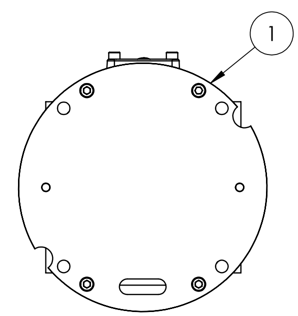


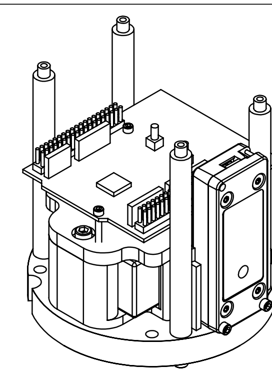


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	H1-41-02	Mid Plate	1
2	HX-SHCS 0.138-32x0.5x0.5-C	6-32 1/2" Socket Cap Screw	4
3	HX-SHCS 0.164-32x1.75x1.75-C	8-32 1.75" Socket Cap Screw	2
4	HX-SHCS 0.112-40x0.5x0.5-C	4-40 1/2" Socket Cap Screw	2
5	HX-SHCS 0.099-56x0.75x0.75-N	3-56 3/4" Socket Cap Screw	3
6	H1-41-05	Upper Post	4
7	H1-41-20	Battery Mount	1
8	H1-41-21	Nucleo Board Mount	1
9	Z1	NUCLEO PCB	1
10	Z2	Slam Stick X	1
11	Z5	LiPo Battery	1








ISOMETRIC VIEW

NOTES:

1. FASTEN AND INSPECT 1 AND 6 FIRST
2. ASSEMBLE 11 AND 7 PRIOR TO FASTENING TO 8
3. FASTEN AND INSPECT 7 AND 8 PRIOR TO FASTENING TO 1
4. FULLY TIGHTEN ALL BOLTS TO CORRECT TORQUE VALUE

	NAME	DATE
DRAWN BY	Sachi	17.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Malaki	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

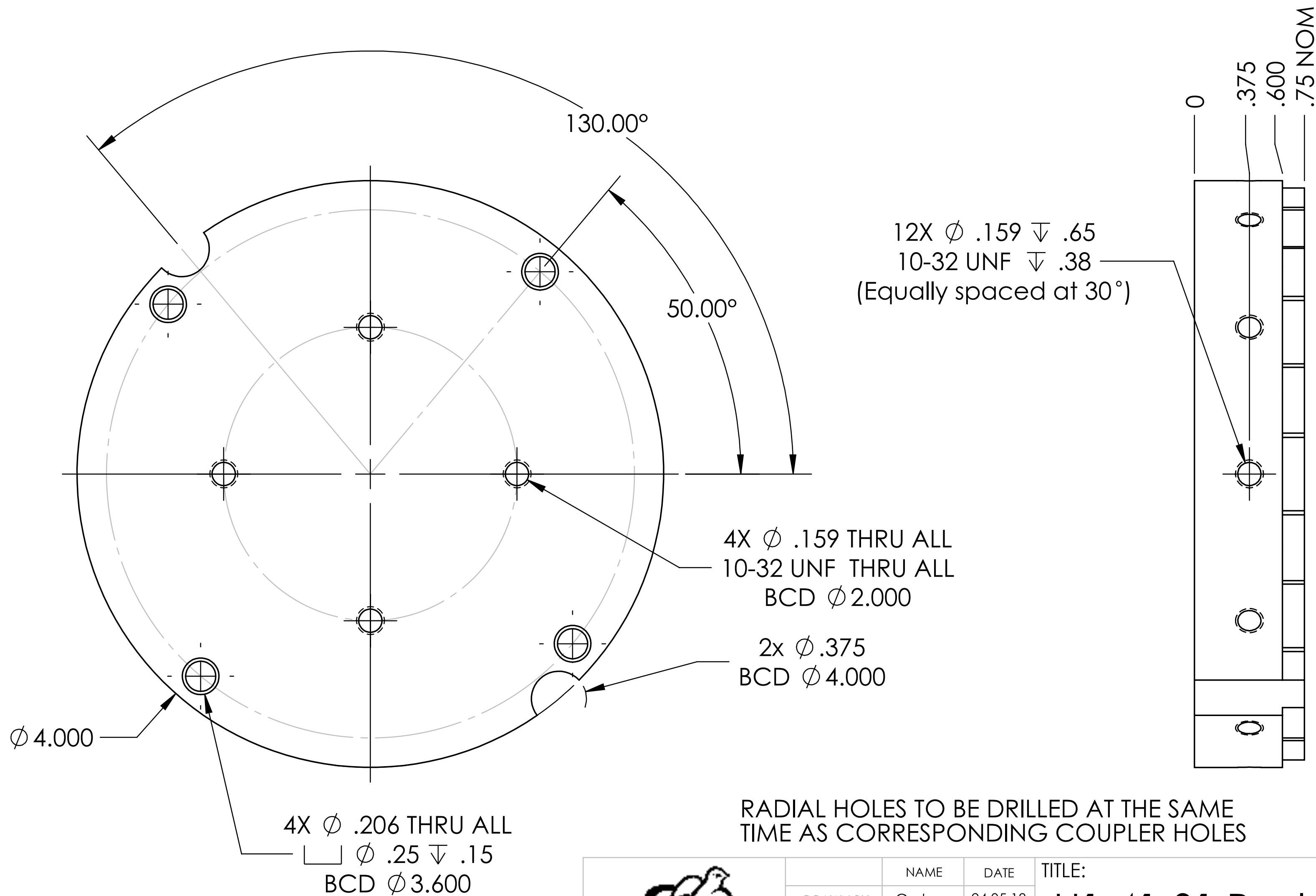
MATERIAL: -
QUANTITY: 1

TITLE: ELECTRICAL MODULE

SIZE B | DWG. NO. H1-40-06 | REV 1

SCALE: 1:2 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



RADIAL HOLES TO BE DRILLED AT THE SAME TIME AS CORRESPONDING COUPLER HOLES

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Sebastian	24.05.18

TITLE:

H1-41-01 Payload Bulkhead

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

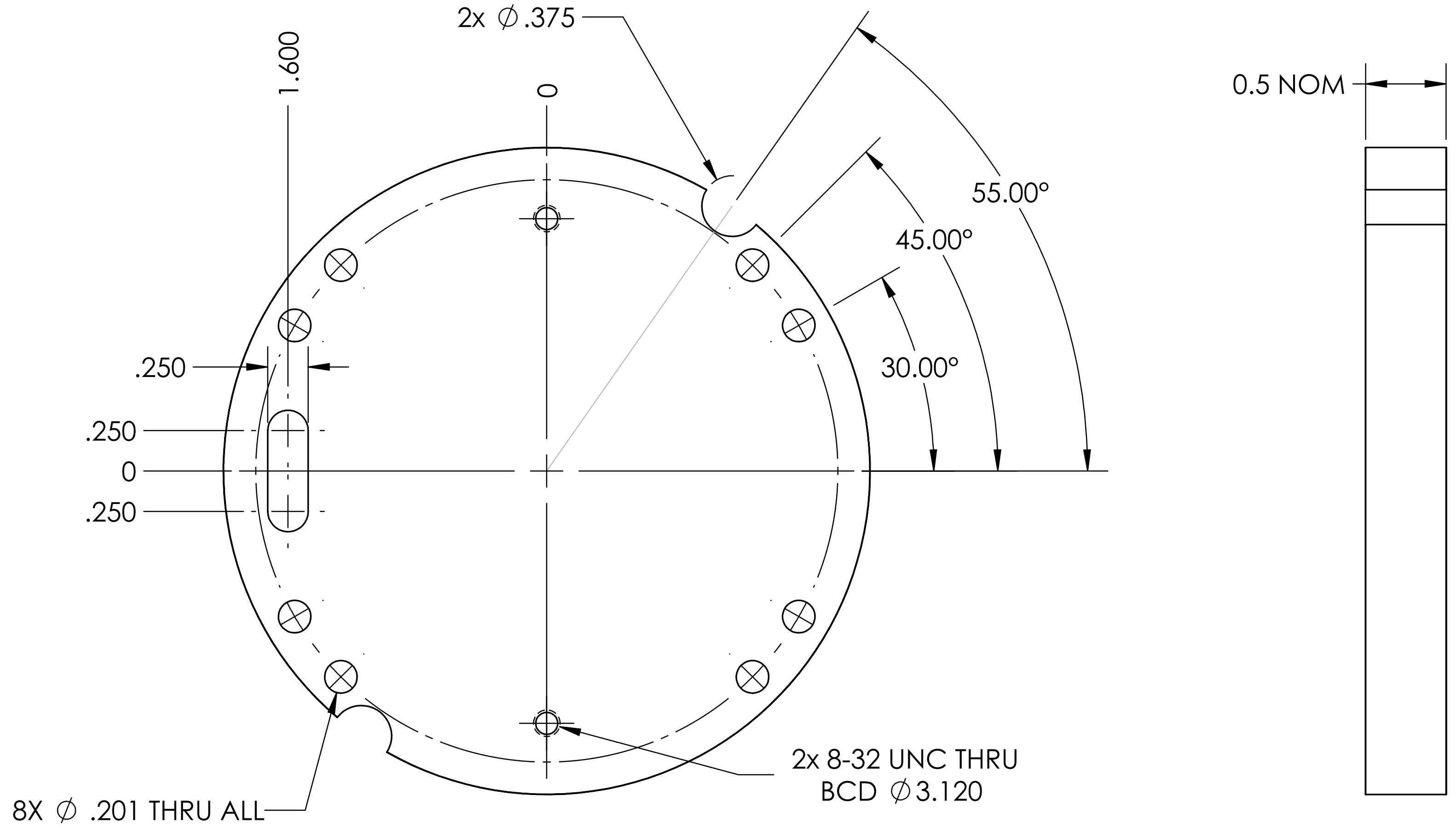
MATERIAL: Al 6061-T6

QUANTITY: 1

SIZE	DWG. NO.	REV
A	1	1

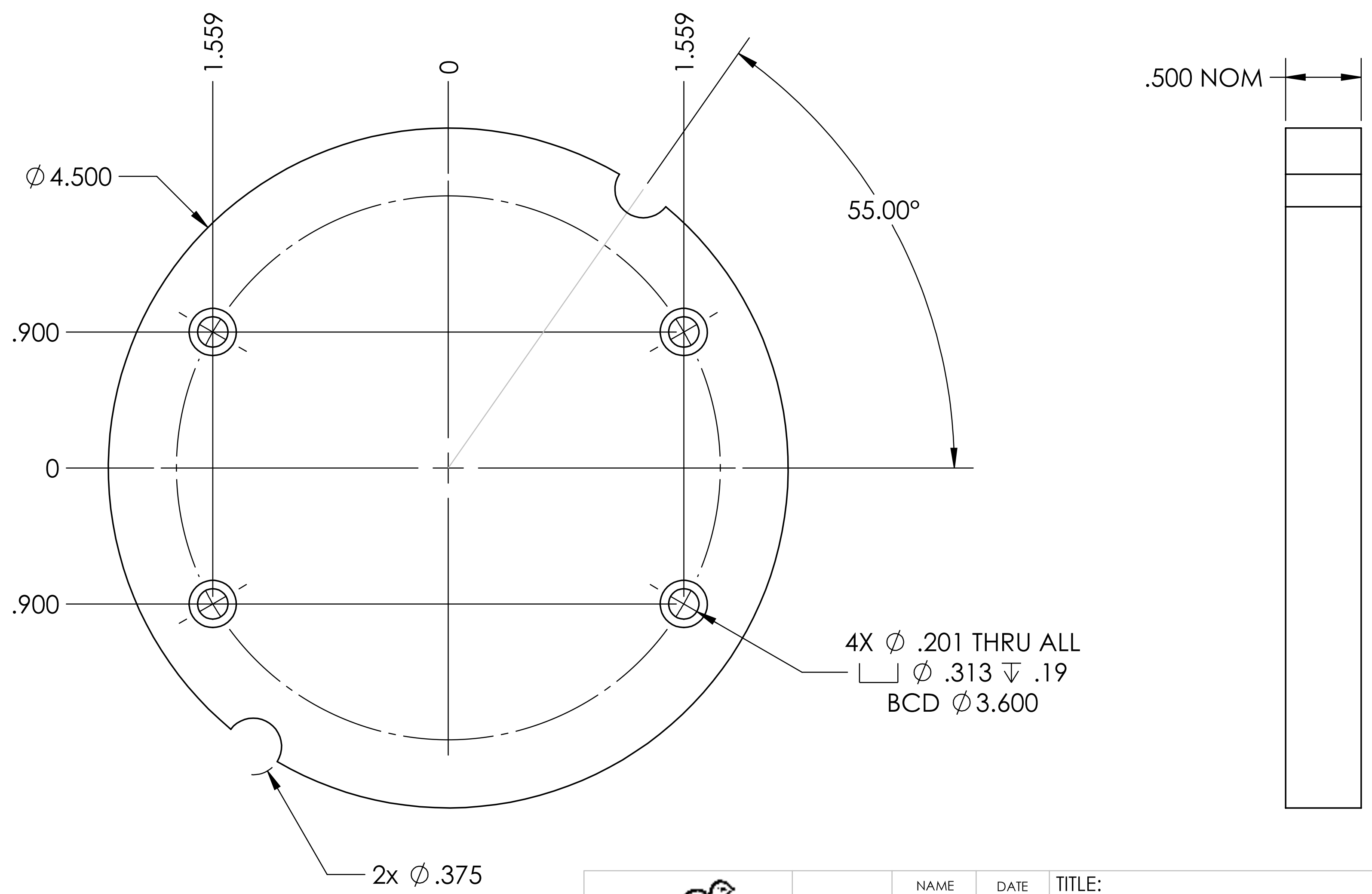
SCALE: 1:1 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



		NAME	DATE	TITLE:	
	DRAWN BY	Graham	24.05.18	H1-41-02 Mid Plate	
	CHECKED BY	Cheyenne	24.05.18		
	APPROVED BY	Sebastian	24.05.18		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: Al 6061-T6			SIZE **A**	DWG. NO. 1 — REV 1
	QUANTITY: 1			SCALE: 1:1	SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

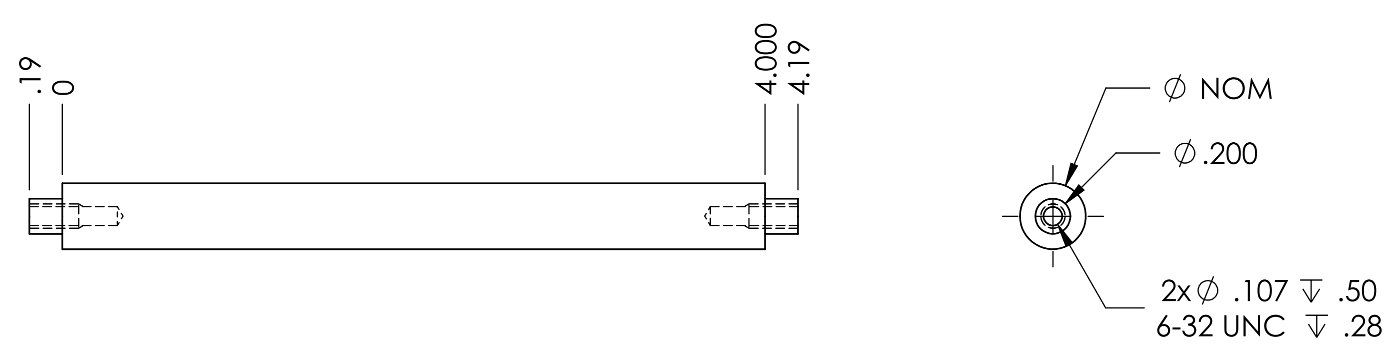


		NAME	DATE
	DRAWN BY	Graham	24.05.18
	CHECKED BY	Malaki	24.05.18
	APPROVED BY	Sebastian	24.05.18
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: Al 6061-T6		
	QUANTITY: 1		

TITLE: H1-41-03 Top Plate

SIZE	DWG. NO.	REV
A	1	1
SCALE: 1:1		SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Cheyenne	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

MATERIAL: Al 6061-T6

QUANTITY: 4

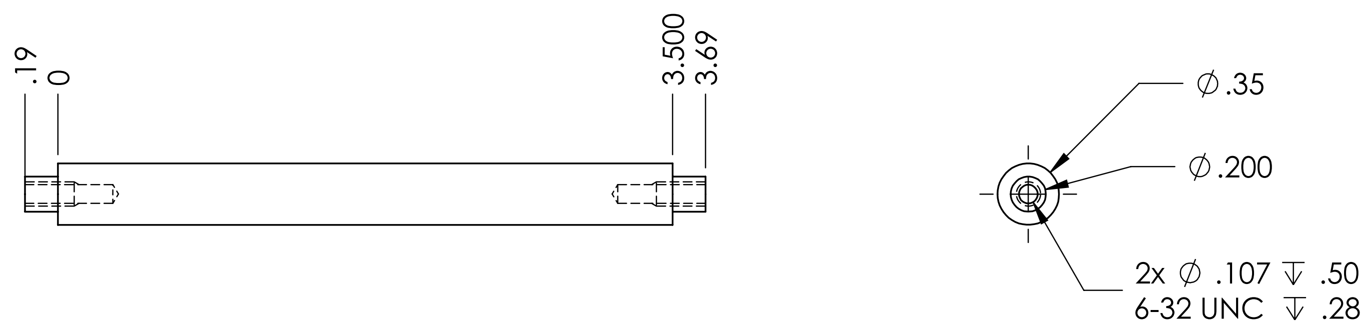
TITLE:

H1-41-04 Lower Post

SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:1 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



		NAME	DATE	TITLE:
	DRAWN BY	Graham	24.05.18	H1-51-05 Upper Post
	CHECKED BY	Sebastian	24.05.18	
	APPROVED BY	Malaki	24.05.18	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.003	MATERIAL: 6061-T6			SIZE A / DWG. NO. 1 / REV 1
	QUANTITY: 4			SCALE: 1:1 / SHEET 1 OF 1

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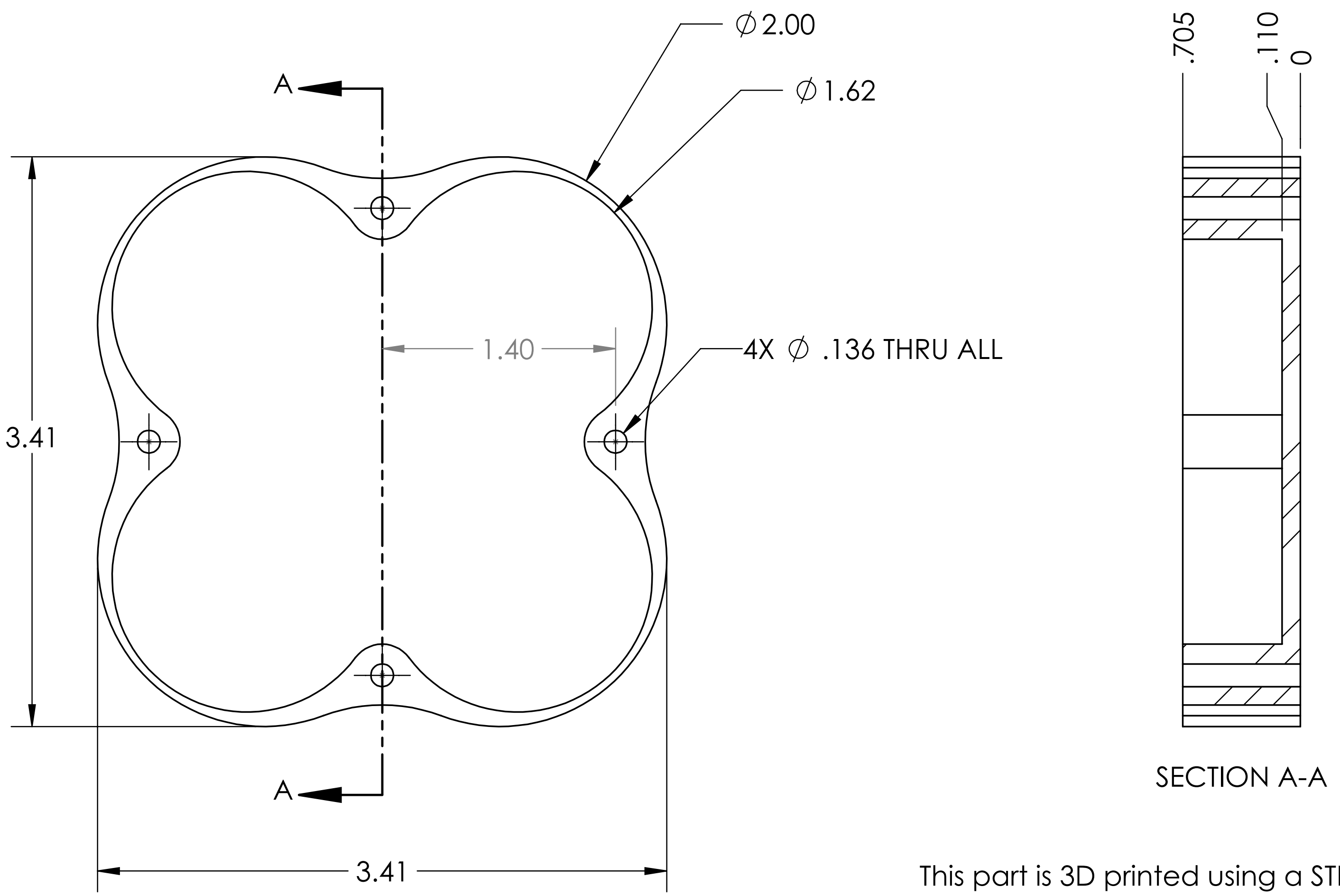

This part is 3D printed using a STL file.

		NAME	DATE
	DRAWN BY	Graham	24.05.18
	CHECKED BY	Cheyenne	24.05.18
	APPROVED BY	Sebastian	24.05.18
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: PLA		
	QUANTITY: 1		

TITLE:
H1-41-10 Dish Tray Control

SIZE	DWG. NO.	REV
A	1	1
SCALE: 1:1	SHEET 1 OF 1	

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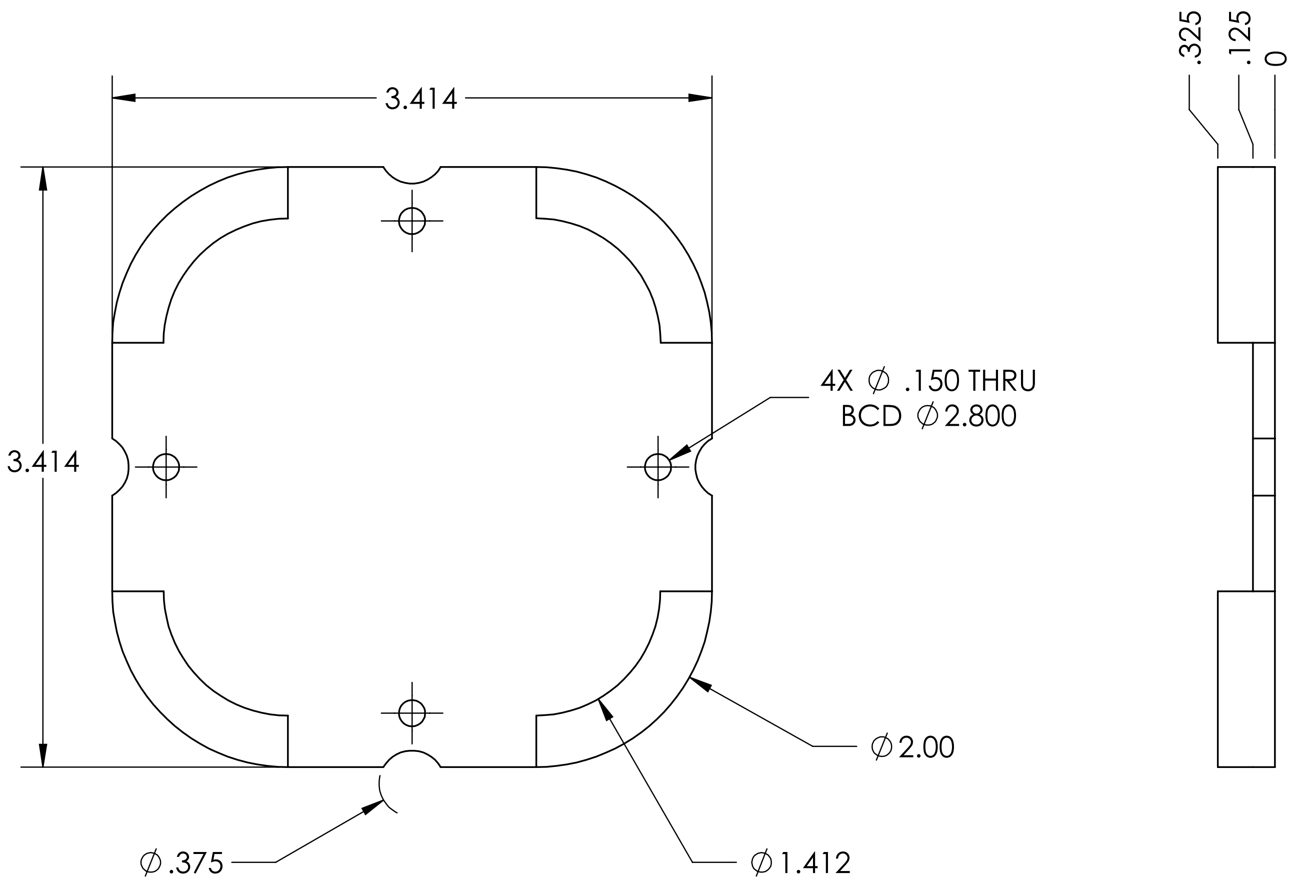


This part is 3D printed using a STL file

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Sebasitan	24.05.18

TITLE:

H1-41-11 Lid Control

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

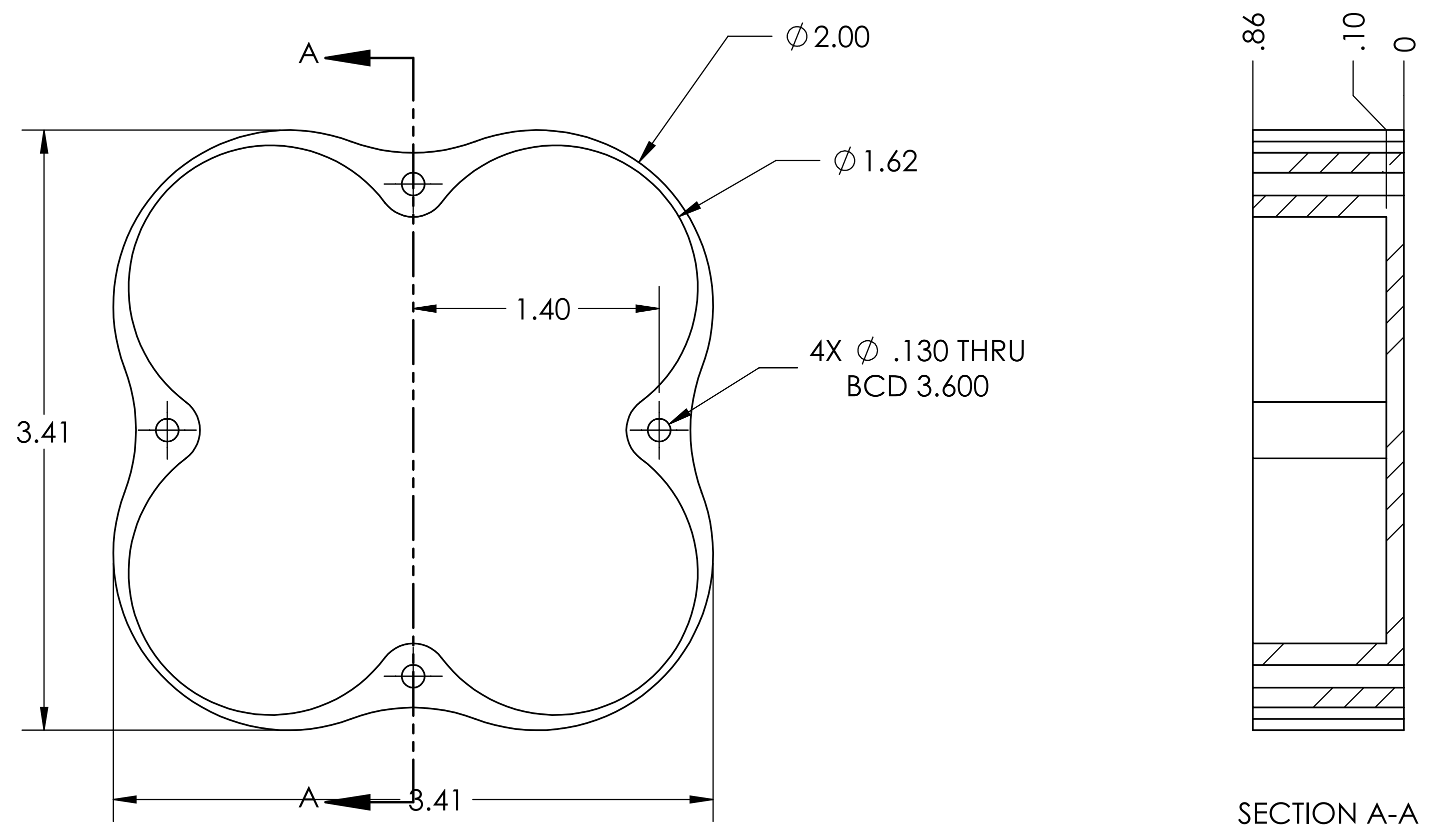
MATERIAL: PLA

QUANTITY: 1

SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:1 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using a STL file

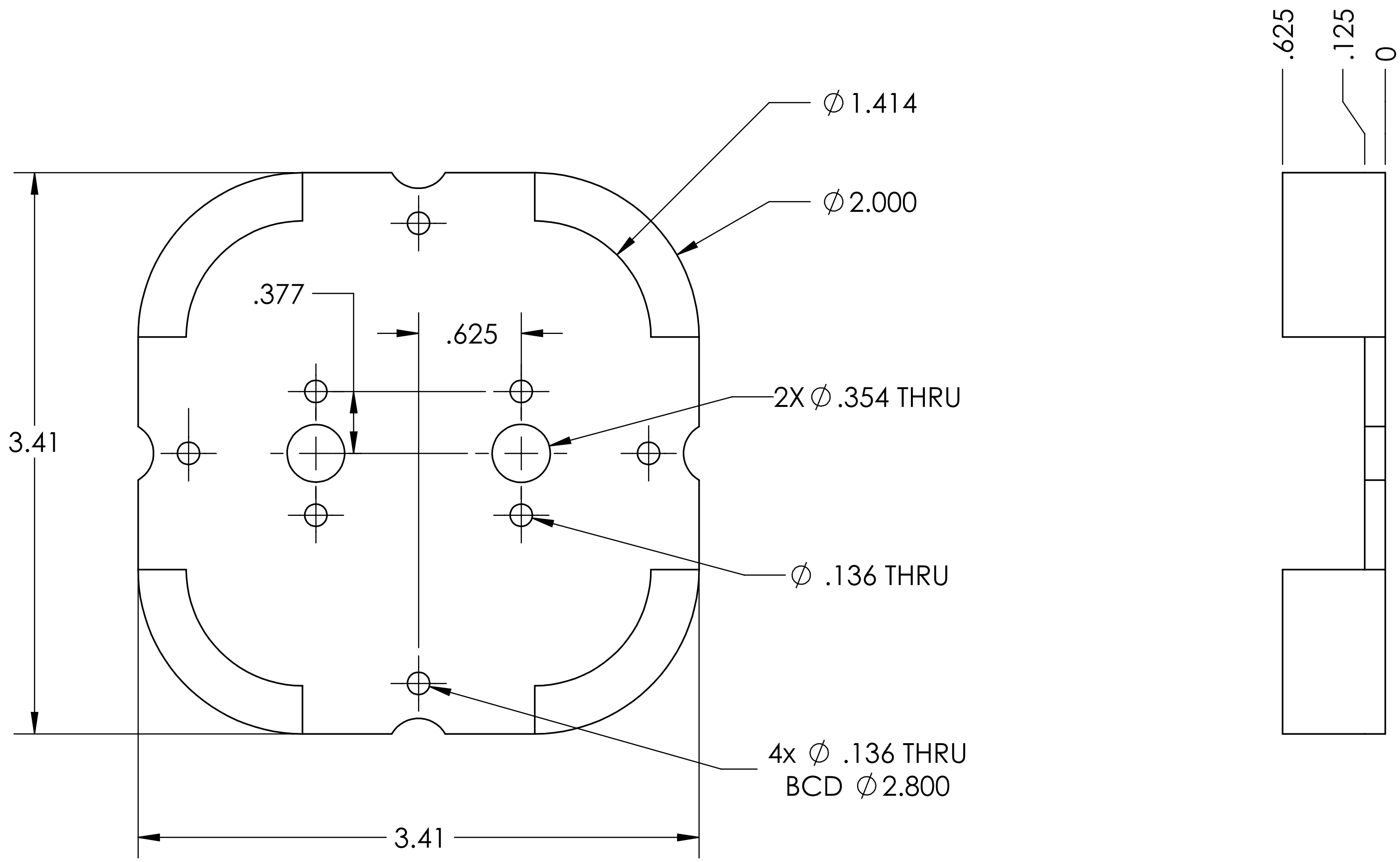
		NAME	DATE
	DRAWN BY	Graham	24.05.18
	CHECKED BY	Cheyenne	24.05.18
	APPROVED BY	Sebastian	24.05.18
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: PLA		
	QUANTITY: 1		

TITLE:

H1-41-12 Dish Tray

SIZE	DWG. NO.	REV
A	1	1
SCALE: 1:1		SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using a STL file

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Cheyenne	24.05.18

TITLE: H1-41-13 Lid 245nm

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

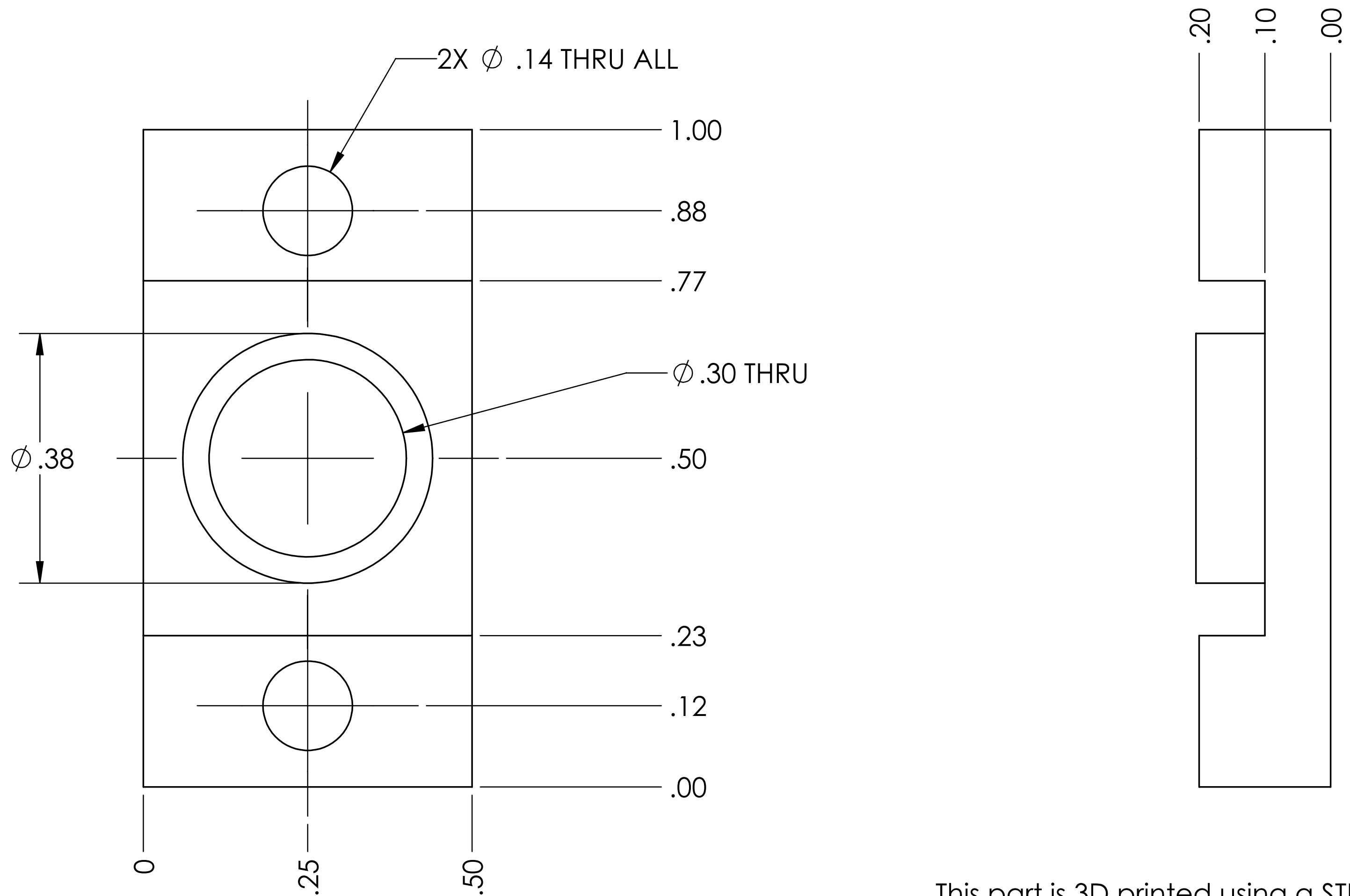
MATERIAL: PLA

QUANTITY: 1

SIZE: A | DWG. NO. 1 | REV 1

SCALE: 1:1 | SHEET 1 OF 1

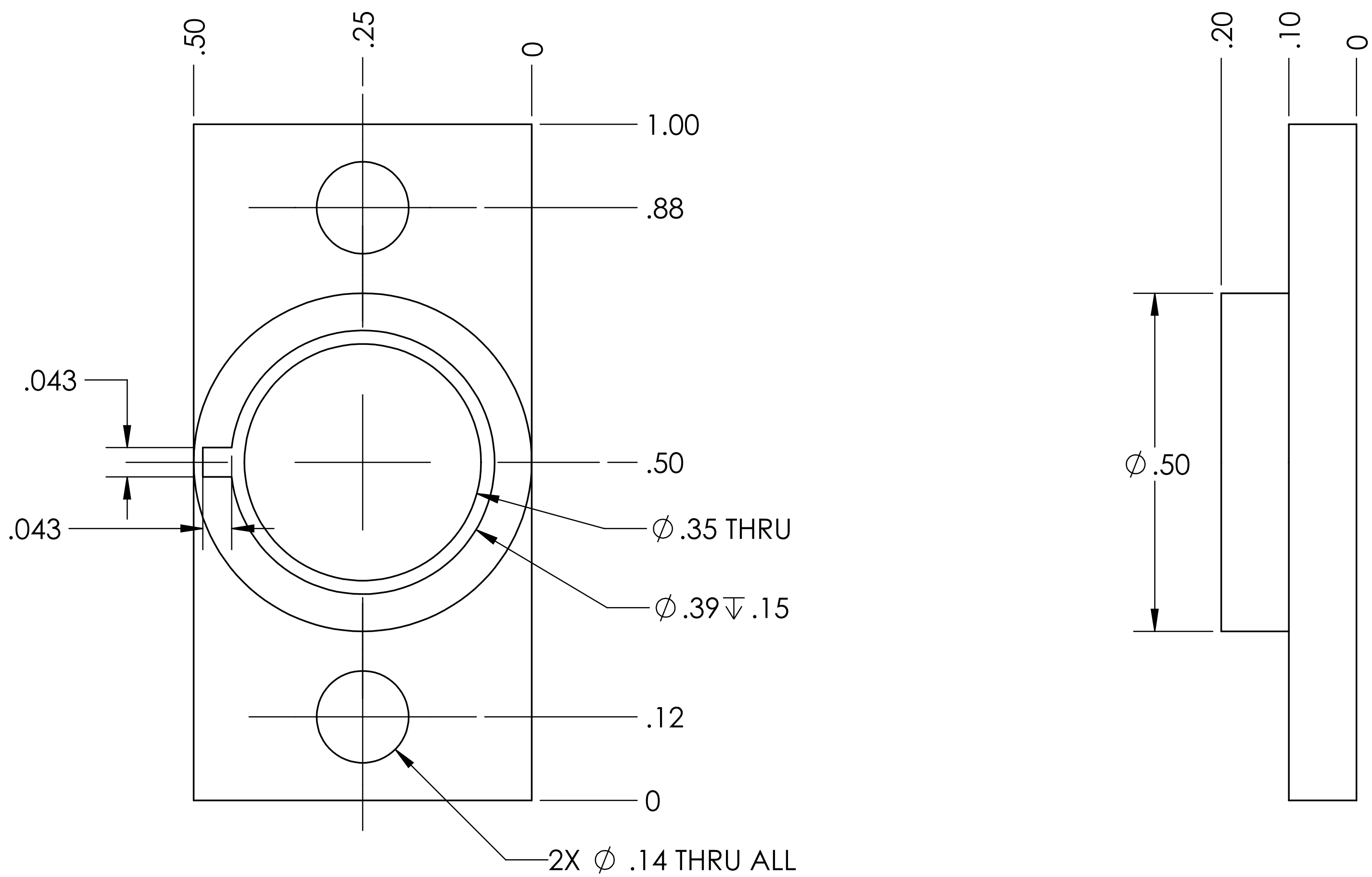
SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using a STL file

		NAME	DATE	TITLE: H1-41-14 245nm Holder Top
	DRAWN BY	Graham	24.05.18	
	CHECKED BY	Sebastian	24.05.18	
	APPROVED BY	Cheyenne	24.05.18	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: PLA			SIZE A / DWG. NO. 1 / REV 1
	QUANTITY: 2			SCALE: 4:1 / SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using a STL file

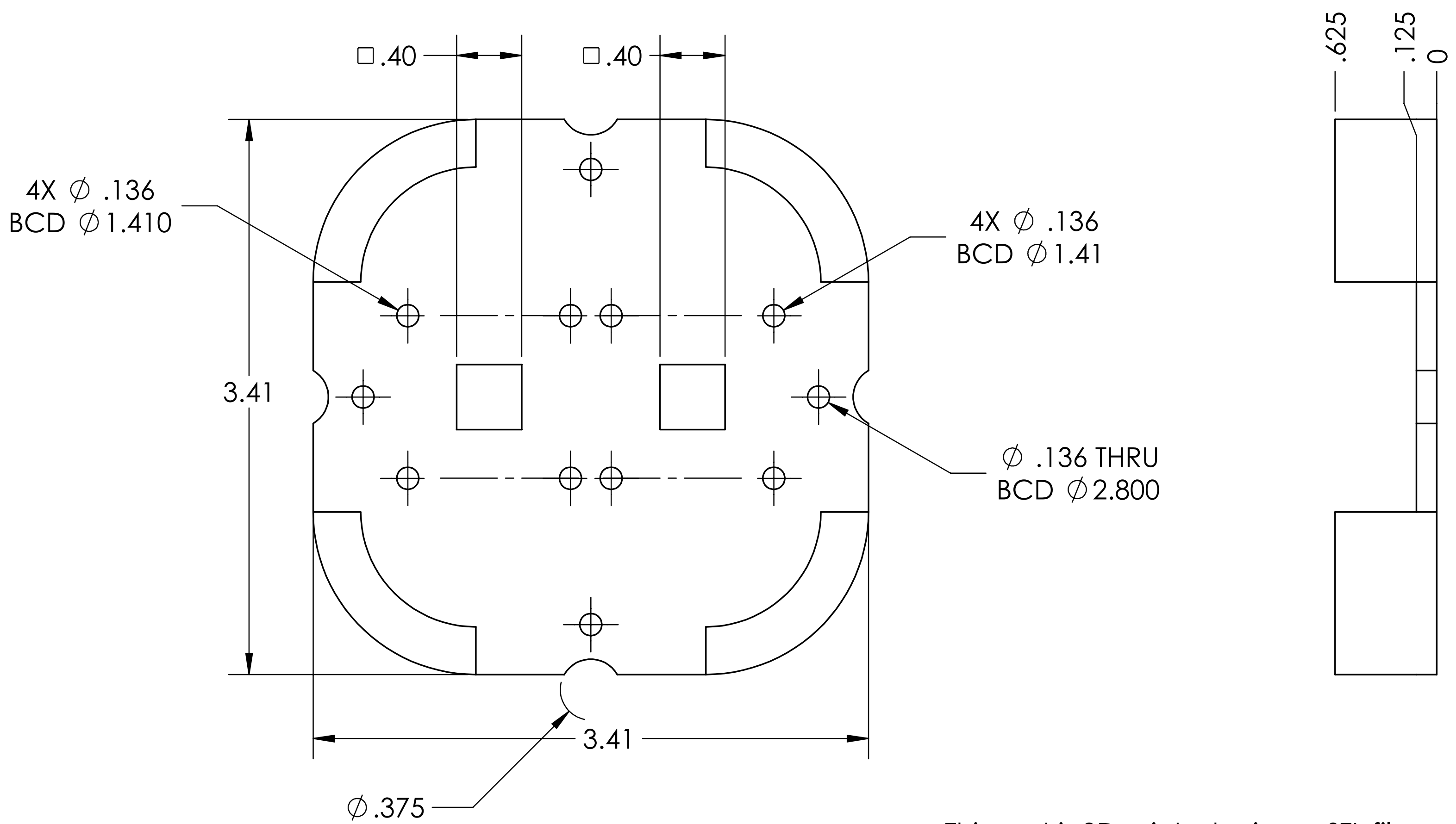
		NAME	DATE
	DRAWN BY	Graham	24.05.18
	CHECKED BY	Sebastian	24.05.18
	APPROVED BY	Cheyenne	24.05.18
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: PLA		
	QUANTITY: 2		

TITLE:

H1-41-15 245nm Holder Bottom

SIZE	DWG. NO.	REV
A	1	1
SCALE: 4:1		SHEET 1 OF 1

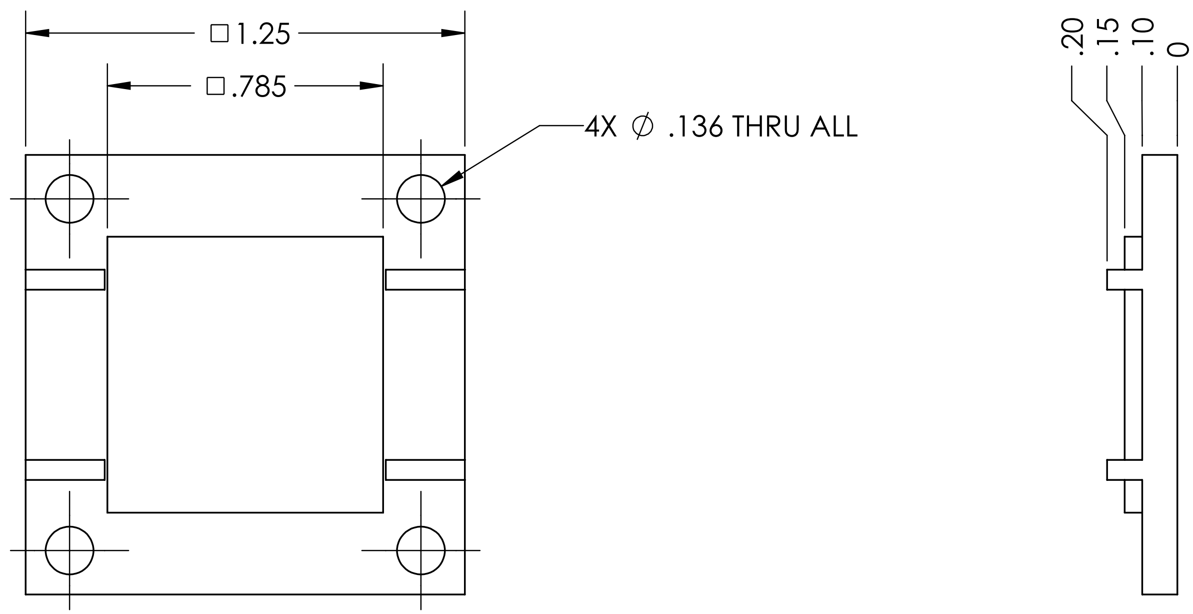
SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using a STL file.

		NAME	DATE	TITLE:	
	DRAWN BY	Graham	24.05.18	H1-41-16 Lid 275nm	
	CHECKED BY	Sebastian	24.05.18		
	APPROVED BY	Malaki	24.05.18		
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: PLA			SIZE A	DWG. NO. 1 — REV 1
	QUANTITY: 1			SCALE: 1:1	SHEET 1 OF 1

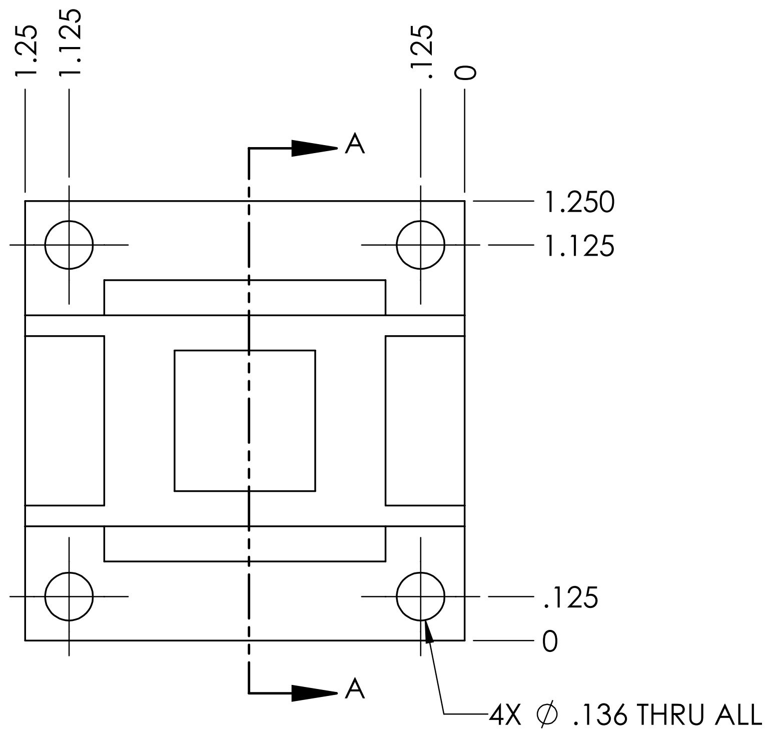
SOLIDWORKS Educational Product. For Instructional Use Only.

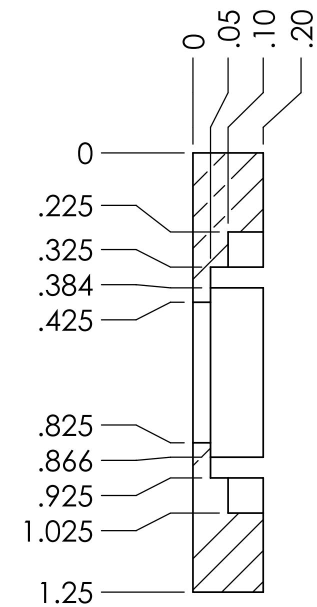


This part is 3D printed using a STL file

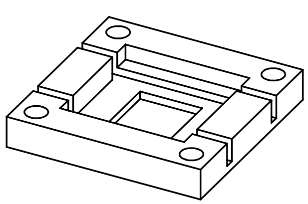
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003		NAME	DATE	TITLE: H1-41-17 275nm Holder Top
	DRAWN BY	Graham	24.05.18	
	CHECKED BY	Cheyenne	24.05.18	
	APPROVED BY	Sebastian	24.05.18	
	MATERIAL: PLA			SIZE A — DWG. NO. 1 — REV 1
	QUANTITY: 2			SCALE: 2:1 — SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.





SECTION A-A



This part is 3D printer using a STL file

		NAME	DATE	TITLE: H1-41-18 275nm Holder Bottom
	DRAWN BY	Graham	24.05.18	
	CHECKED BY	Cheyenne	24.05.18	
	APPROVED BY	Sebastian	24.05.18	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.020 THREE PLACE DECIMAL ±0.003	MATERIAL: PLA			SIZE A — DWG. NO. 1 — REV 1
	QUANTITY: 2			SCALE: 2:1 — SHEET 1 OF 1

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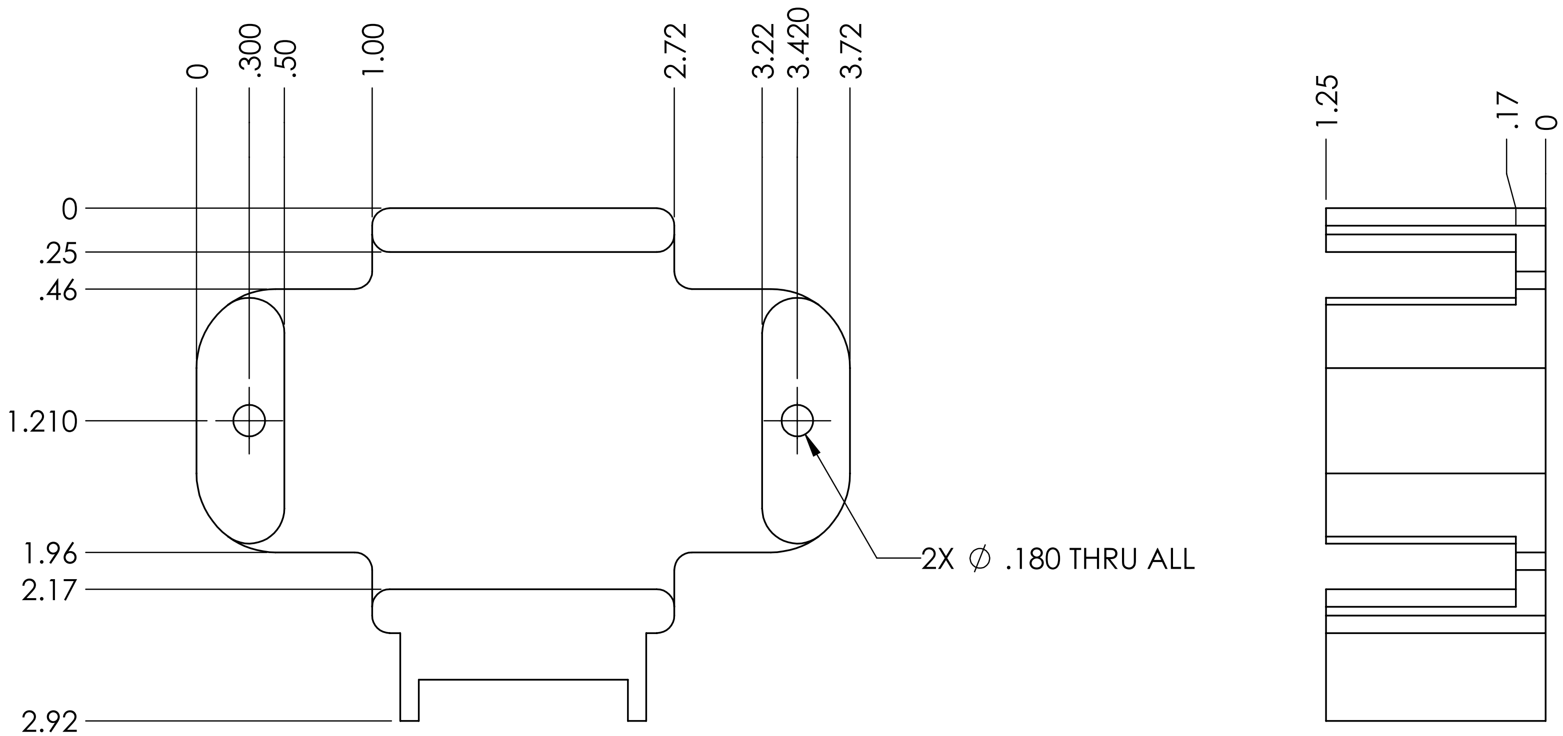


This part is 3D printed using a STL file

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Sebastian	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

MATERIAL: PLA

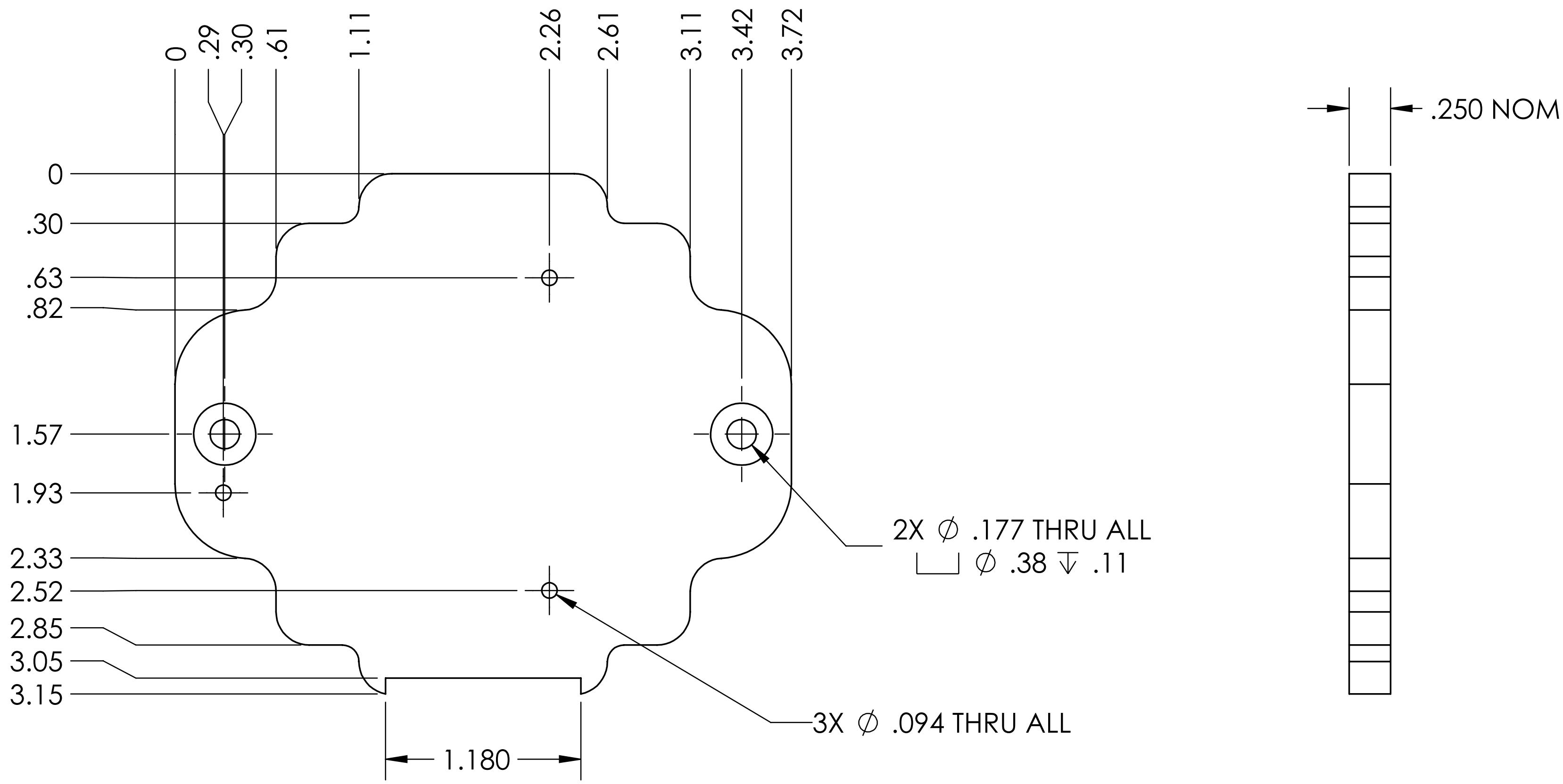
QUANTITY: 1

TITLE:
H1-41-20 Battery Mount

SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:1 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using a STL file

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Malaki	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

MATERIAL: ACRYLIC

QUANTITY: 1

TITLE:

H1-41-21 Nucleo Board Mount

SIZE	DWG. NO.	REV
A	1	1
SCALE: 1:1		SHEET 1 OF 1

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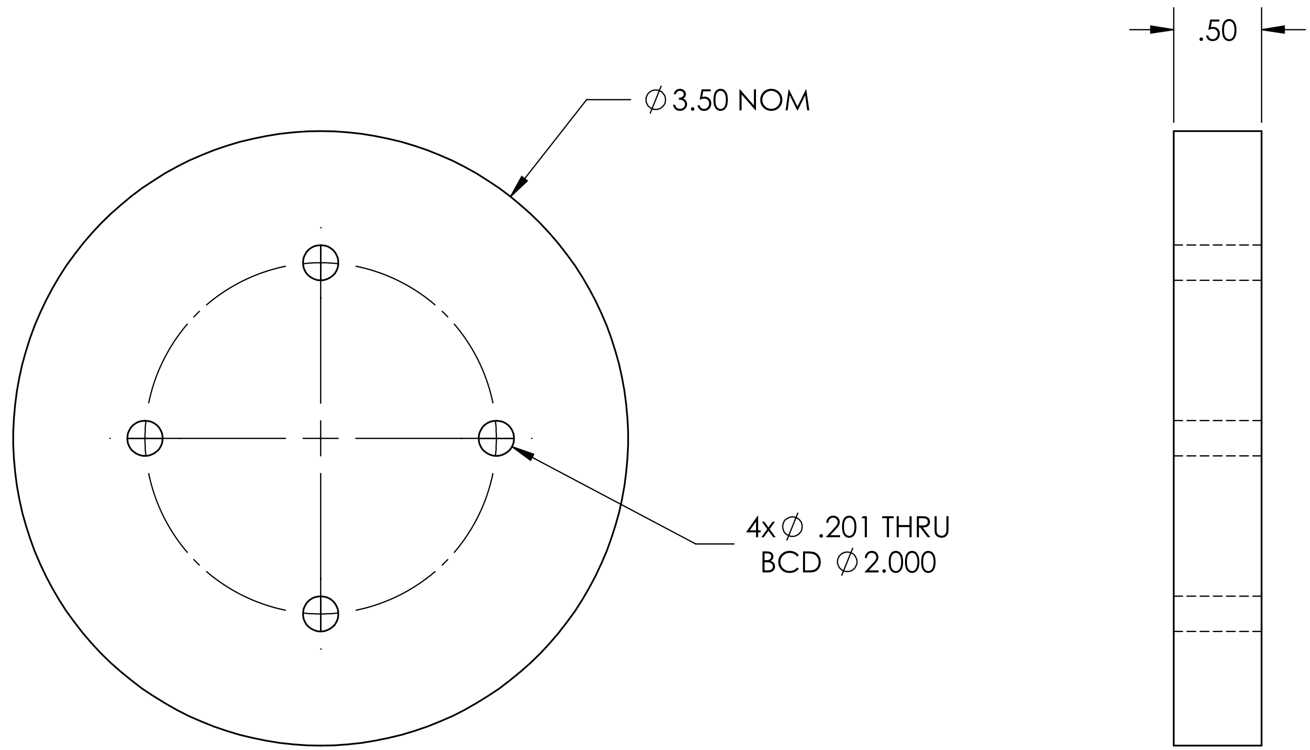


	NAME	DATE
DRAWN BY	Graham	30.04.18
CHECKED BY	Sebastian	30.04.18
APPROVED BY	Cheyenne	30.04.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL: C 1020

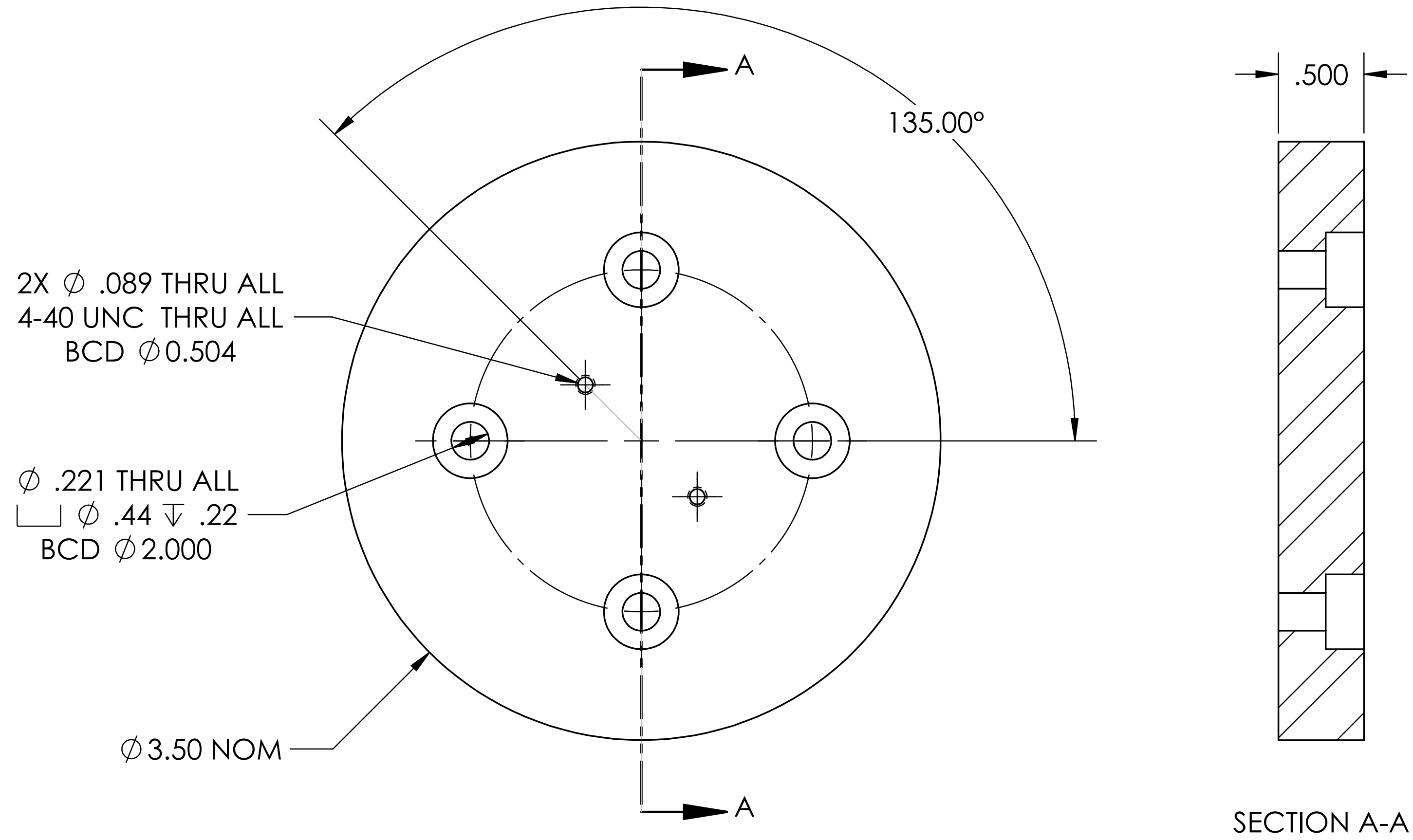
QUANTITY: 3

TITLE: H1-41-30 Round Ballast

SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:1 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



	NAME	DATE	TITLE:
DRAWN BY	Graham	24.05.18	H1-41-31 Round Ballast Counterbore
CHECKED BY	Sebastian	24.05.18	
APPROVED BY	Cheyenne	24.05.18	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.003	MATERIAL: C 1020		SIZE A / DWG. NO. 1 / REV 1
	QUANTITY: 1		SCALE: 1:1 / SHEET 1 OF 1

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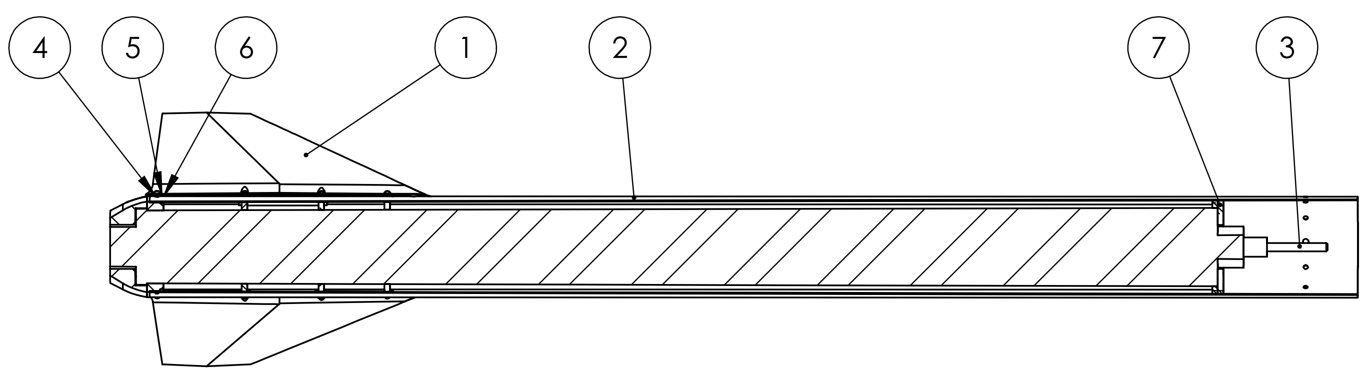
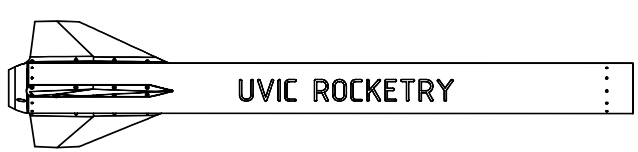
ITEM NO.	PART NUMBER	QTY.
1	H1-50-01 Fin Mount	1
2	H1-51-04 Lower Fuselage	1
3	3/8-16 Threaded Rod	1
4	6-32 x 3/8"	8
5	H1-51-07 Launch Lug	1
6	1/4-20 x 0.75"	1
7	H1-50-04_Upper-Centering-Ring	1





	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Malaki	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

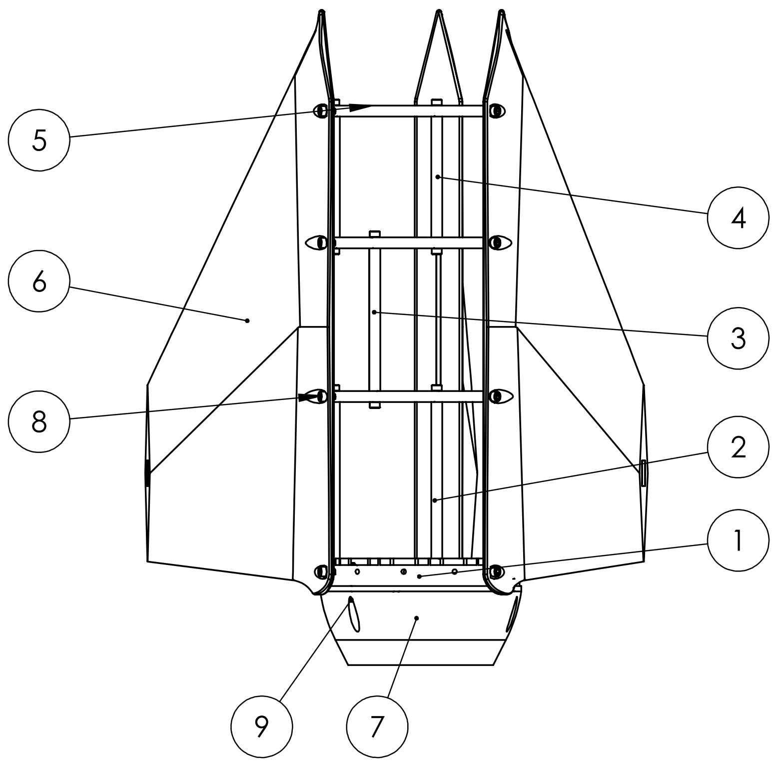
TITLE:

H1-50-00 Propulsion Assembly

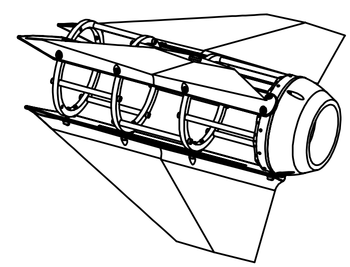
SIZE: A | DWG. NO. 1 | REV 1

SCALE: 1:8 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



ITEM NO.	PART NUMBER	QTY.
1	H1-51-05 Thrust Ring	1
2	H1-51-02 Post	3
3	H1-51-02 Post	3
4	H1-51-02 Post	3
5	H1-51-03 Ring	3
6	H1-51-01 Fin	3
7	H1-51-06 Boat Tail	1
8	6-32 x 5/8"	42
9	6-32 x 1/4"	3



	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Malaki	24.05.18
APPROVED BY	Cheyenne	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL:

QUANTITY: 1

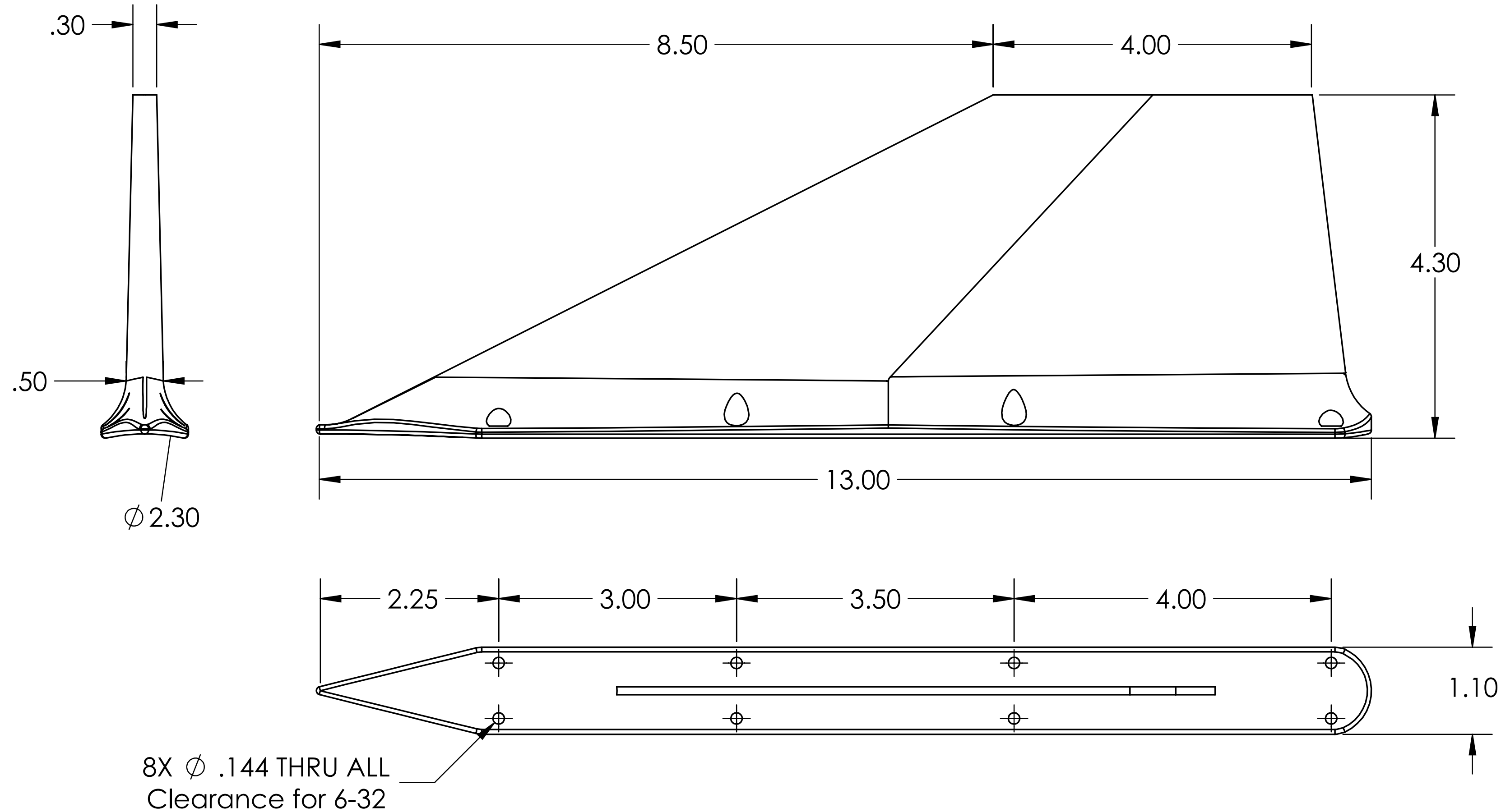
TITLE:

H1-50-01 Fin Mount

SIZE **A** | DWG. NO. 1 | REV 1

SCALE: 1:4 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This drawing is not for machining.
The fins are 3D printed.

	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Cheyenne	24.05.28
APPROVED BY	Malaki	24.05.18

TITLE: H1-51-01 Fin

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL: PLA

QUANTITY: 3

SIZE A | DWG. NO. 1 | REV 1

SCALE: 1:2 | SHEET 1 OF 1

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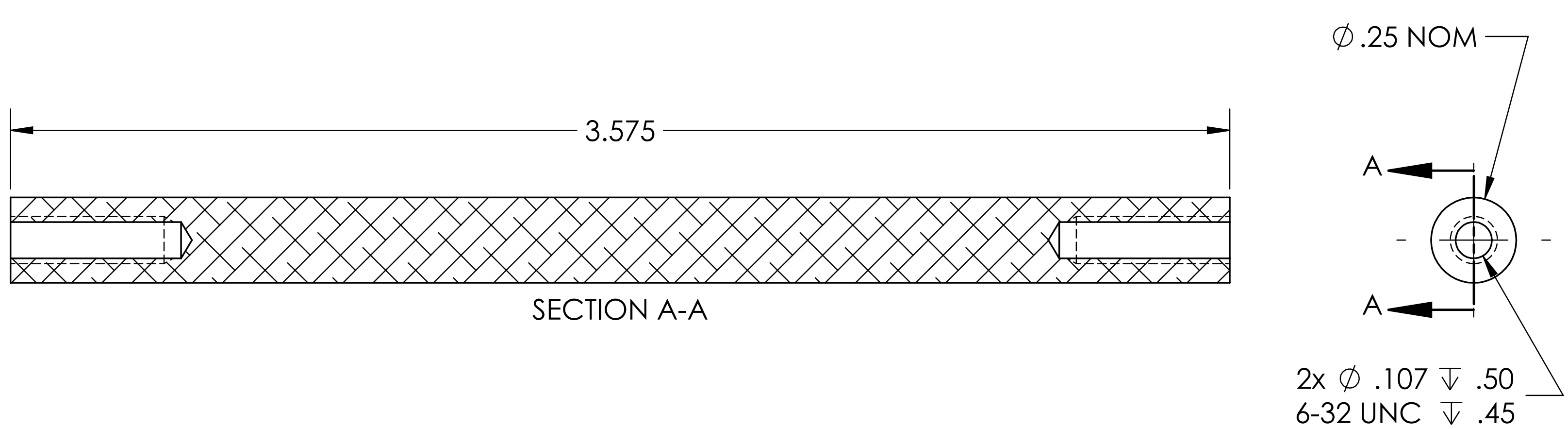


	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Cheyenen	24.05.18
APPROVED BY	Malaki	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL: 6061-T6

QUANTITY: 3

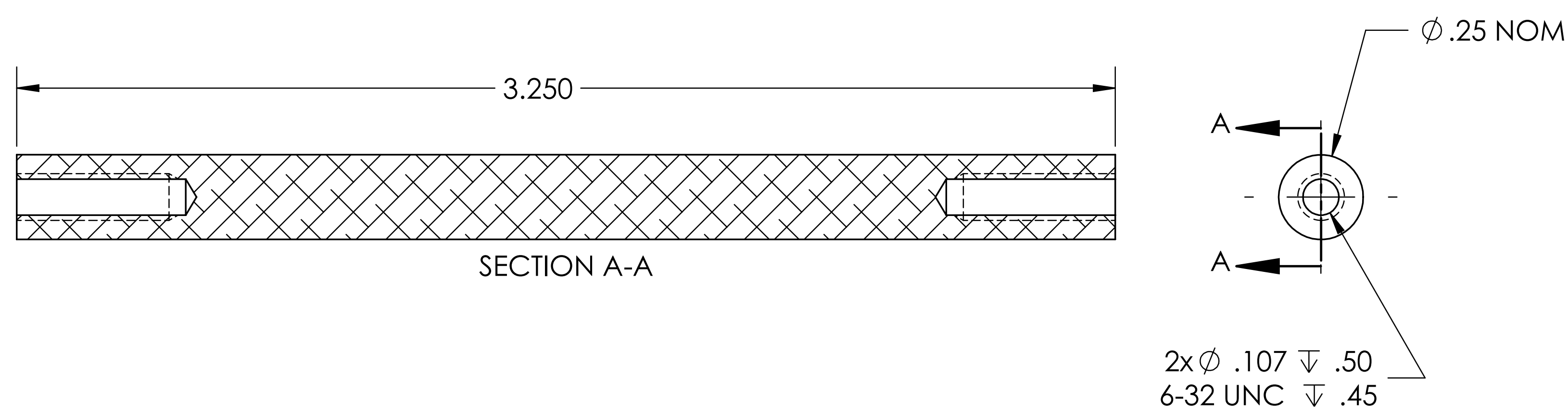
TITLE:

H1-51-02-1 Fin Mount Post long

SIZE: A | DWG. NO. 1 | REV 1

SCALE: 2:1 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Cheyenne	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL: 6061-T6

QUANTITY: 3

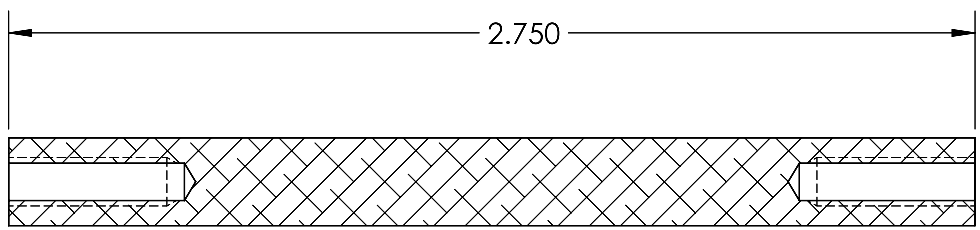
TITLE:

H1-51-02-2 Fin Mount Post medium

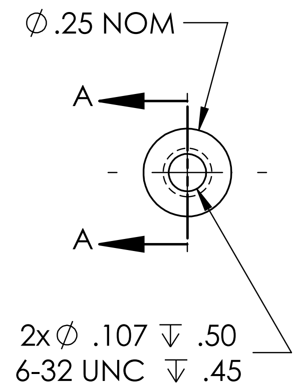
SIZE	DWG. NO.	REV
A	1	1

SCALE: 2:1 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



SECTION A-A



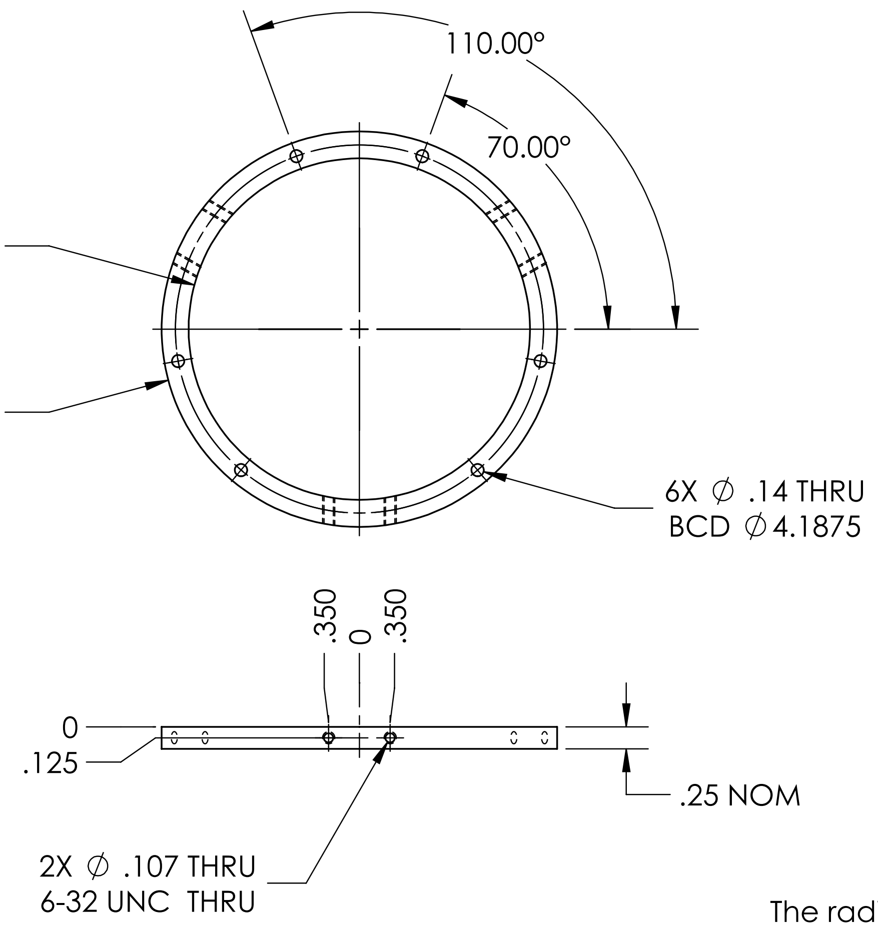
		NAME	DATE
	DRAWN BY	Graham	24.05.18
	CHECKED BY	Sebastian	24.05.18
	APPROVED BY	Malaki	24.05.18
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.003	MATERIAL: 6061-T6 QUANTITY: 3		

TITLE:

H1-51-02-3 Fin Mount Post short

SIZE	DWG. NO.	REV
A	1	1
SCALE: 2:1		SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



The radial holes will be done separately when the fin mount is inside the fuselage.

	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Malaki	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL: 6061-T6

QUANTITY: 3

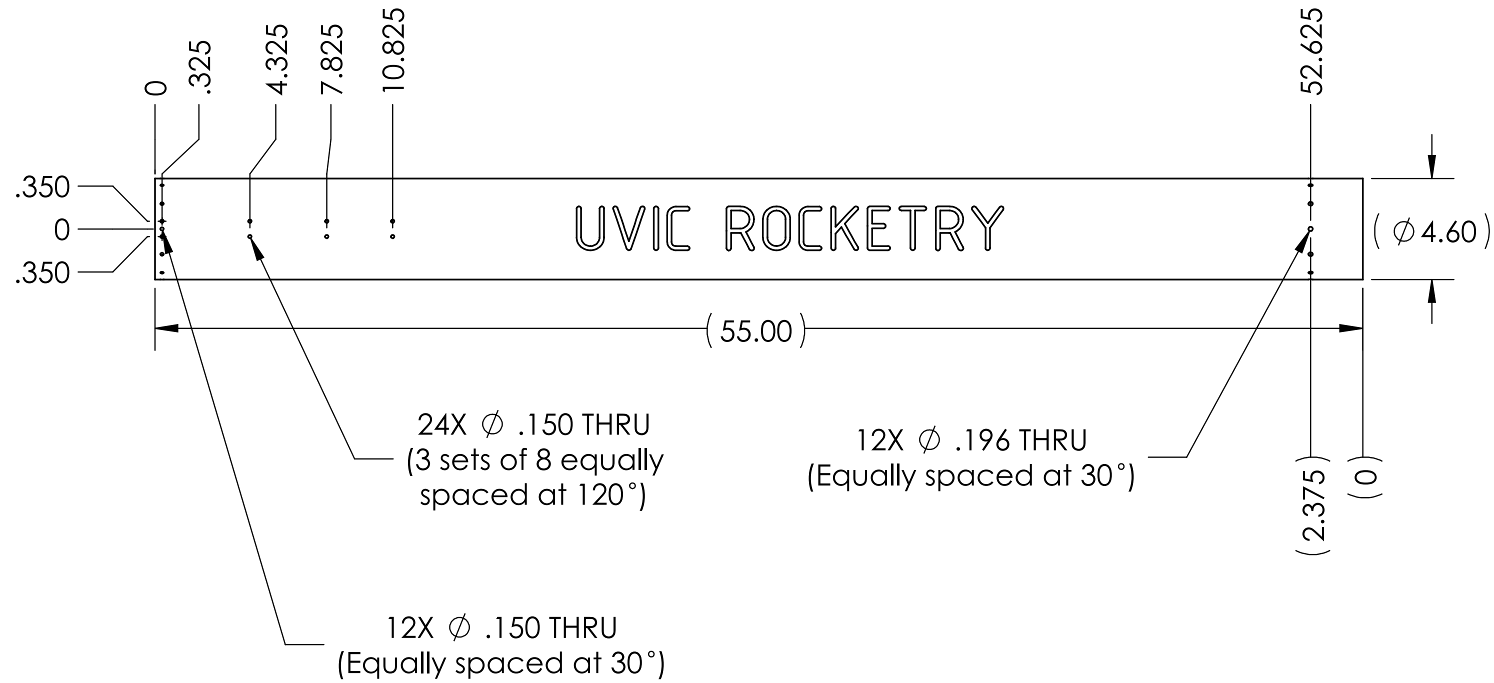
TITLE:

H1-51-03 Fin Rings

SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:2 SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



The hole on the opposite side of the bulkhead
and thrust ring is for the launch lugs.
Medium clearance for 1/4-20.
Make sure that they align.

This drawing is only needed to drill the holes.

	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Malaki	24.05.18
APPROVED BY	Cheyenne	24.05.18

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

MATERIAL: Carbon Fiber

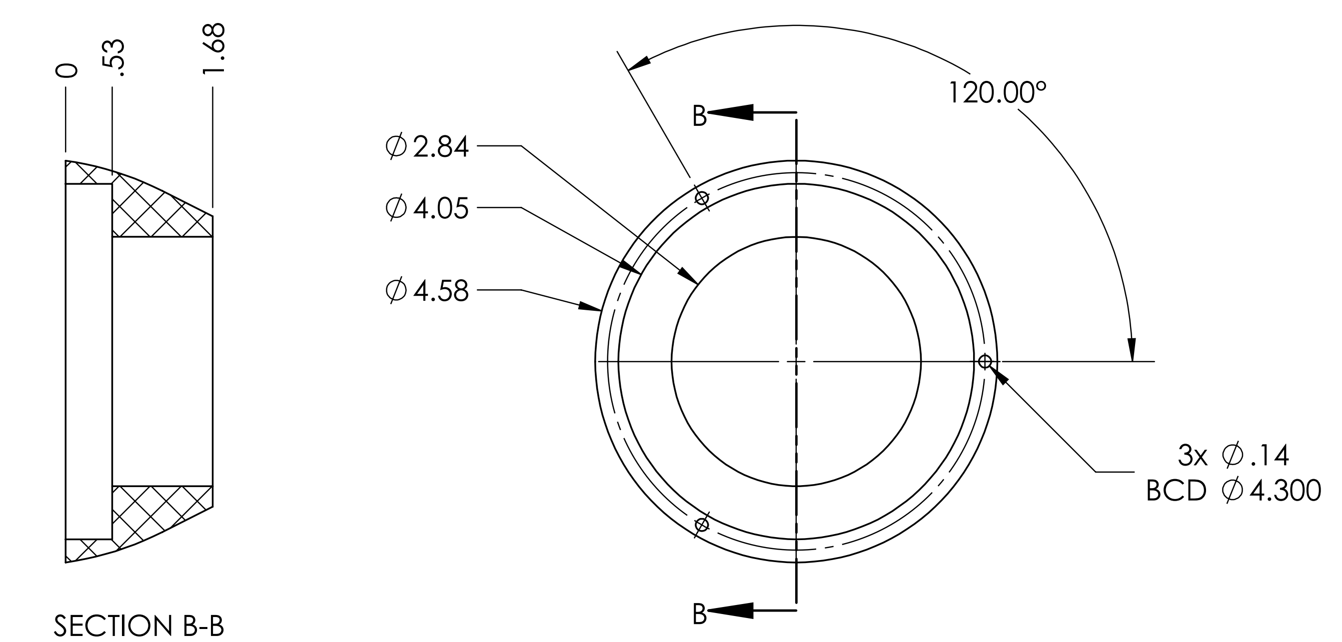
QUANTITY: 1

TITLE: H1-51-04 Lower Fuselage

SIZE: A | DWG. NO.: 1 | REV: 1

SCALE: 1:8 | SHEET 1 OF 1

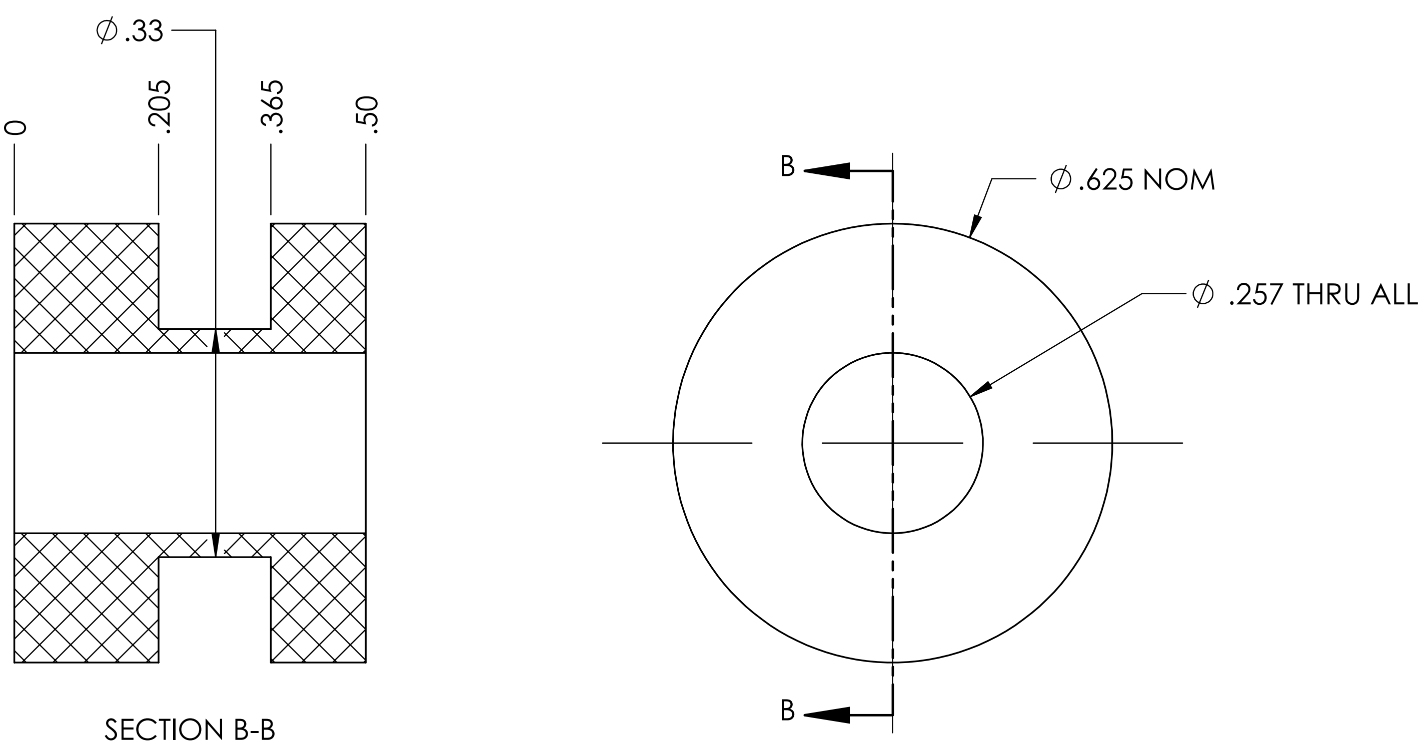
SOLIDWORKS Educational Product. For Instructional Use Only.



This part is 3D printed using a STL file.

		NAME	DATE	TITLE:
	DRAWN BY	Graham	24.05.18	H1-51-06 Boat Tail
	CHECKED BY	Sebastian	24.05.18	
	APPROVED BY	Cheyenne	24.05.18	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.003	MATERIAL: PLA			SIZE A · DWG. NO. 1 · REV 1
	QUANTITY: 1			SCALE: 1:2 · SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



	NAME	DATE
DRAWN BY	Sebastian	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Malaki	24.05.18

TITLE:

H1-51-07 Launch Lug

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.003

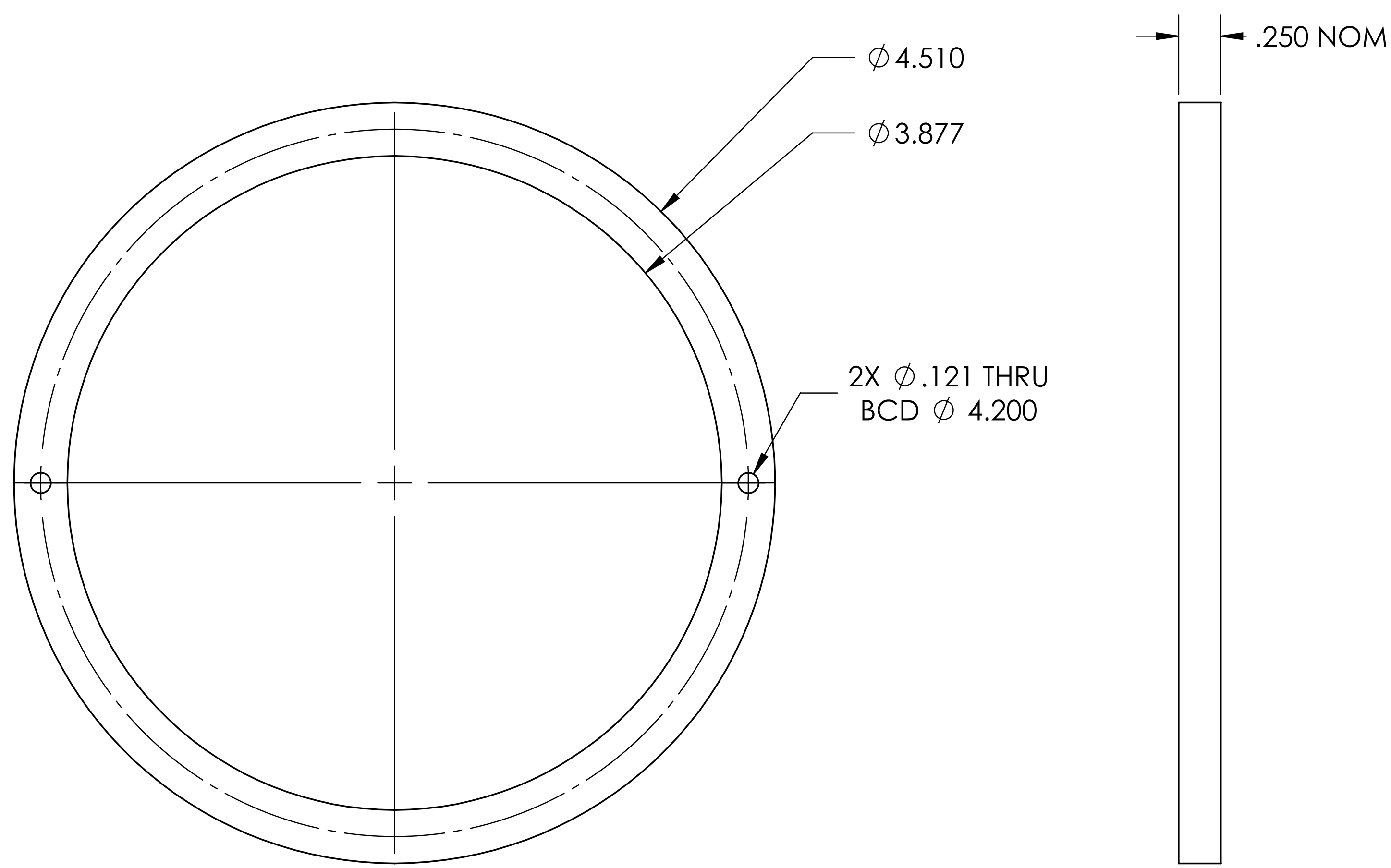
MATERIAL: Delrin

QUANTITY: 2

SIZE: A | DWG. NO.: 1 | REV: 1

SCALE: 4:1 | SHEET 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



This part is lasercut using a DXF file

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Sebastian	24.05.18
APPROVED BY	Cheyenne	24.05.18

TITLE:

H1-51-08 Upper Centering Ring 1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

MATERIAL: Birch Plywood

QUANTITY: 1

SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:1 SHEET 1 OF 1

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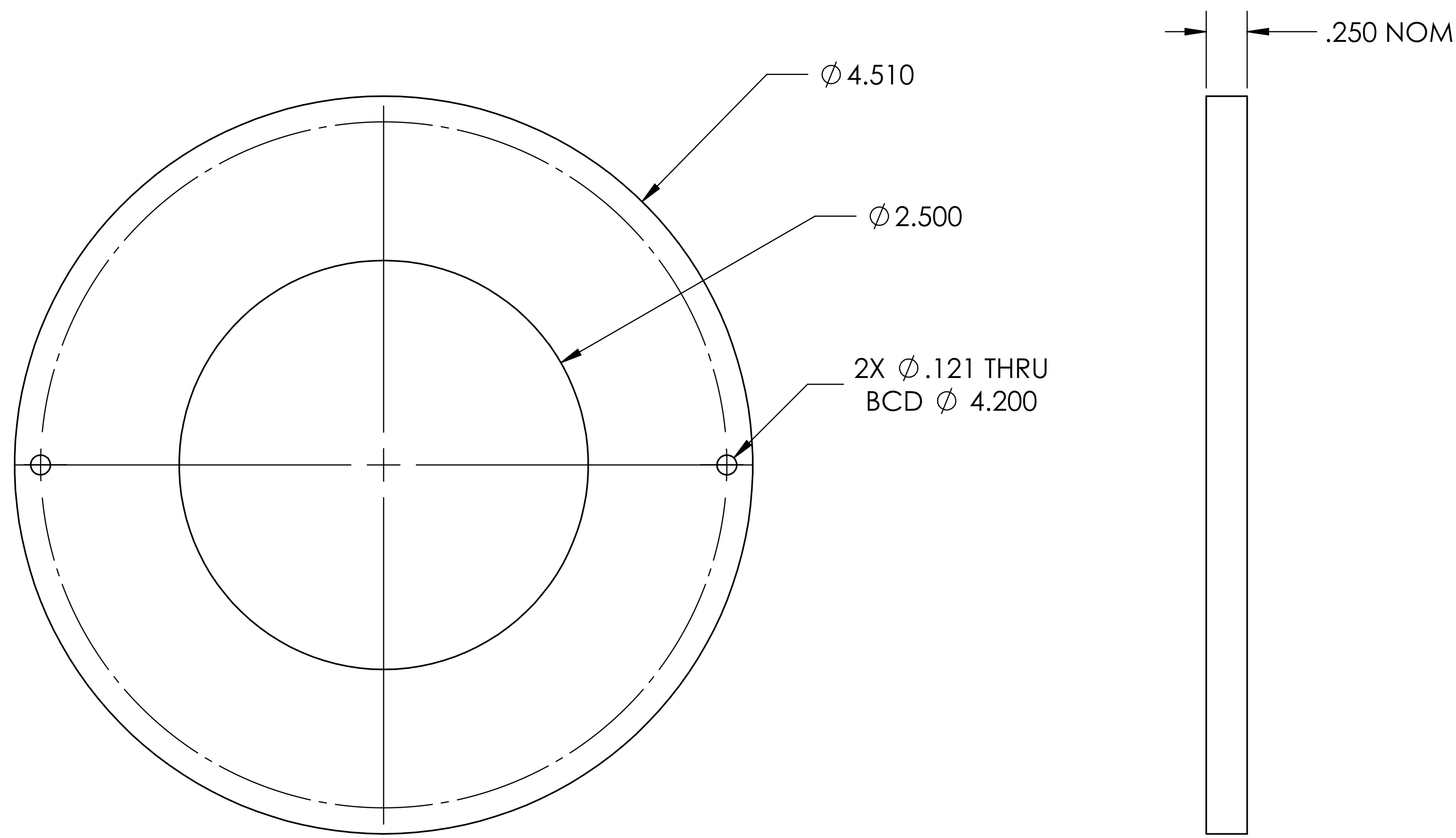

This part is lasercut using a DXF file

	NAME	DATE
DRAWN BY	Graham	24.05.18
CHECKED BY	Cheyenne	24.05.18
APPROVED BY	Sebastian	24.05.18

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.020
THREE PLACE DECIMAL ±0.003

MATERIAL: Birch Plywood

QUANTITY: 1

TITLE: H1-51-09 Upper Centering Ring 2

SIZE	DWG. NO.	REV
A	1	1

SCALE: 1:1 SHEET 1 OF 1

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