Project Technical Reports for CU L8R

Team 108 Project Technical Report for the 2017 IREC

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Carleton University InSpace or CU InSpace, is a new team to the international stage. They will be competing at the Spaceport America Cup in the 10,000 ft AGL with commercial-off-the-shelf (COTS) solid rocket engine. Their design includes a student researched and design body structure and fins. The body tubes utilize aircraft grade plywood and phenolic tubing to achieve a lightweight design while remaining extremely strong. The fins also use 1/16" aircraft grade plywood with alternating layers of carbon fiber to also reduce weight while maximizing strength.

Nomenclature

AR	=	aspect ratio
c	=	root chord
G	=	shear modulus
P	=	air pressure
t	=	thickness
V_f	=	fin flutter velocity
λ	=	taper ratio (tip chord divided by root chord)
COTS	=	commercial-off-the-shelf
TN	=	tubular nylon
SRAD	=	student researched and designed
w.r.t.	=	with respect to

I. Introduction

Carleton University has a long standing relationship with aerospace engineering, opening its first aerospace program in 1988, making it the first university in Canada to offer such a program It now offers four different aerospace specializations; Aerodynamics, Lightweight Structures, Avionics and Space Systems Design.

Carleton has always had a proud history of hands-on learning experiences as well, being the first Canadian university to develop a capstone project in the student's final year of study to showcase all they have learned in their time at Carleton. Additionally Carleton has always strode to exceed in its extracurricular clubs from FSAE cars to UAV Blackbird, Carleton has always provided lots of support and financial assistance to students looking to further their education with hands-on experience. CU InSpace is now one of those teams.

CU InSpace is Carleton University's rocket engineering team. The team was created in 2015 and has since that date built three rockets of increasing size to better understand application of certain aeronautical theories on physical rockets. Since the team has never competed internationally before therefore the team deemed it best to compete at the 10,000 ft. AGL COTS solid engine level this year with hopes of competing at the SRAD hybrid engine level next year.

II. Rocket Design and Analysis

This section will outline the different aspects of each of the subsystems, the reason the team believed each decision made was correct and the process of integrating those pieces together to create its rocket. Since this is the team's first year at competition and due to the team being relative beginners in high-powered rocketry, the team sometimes elected to pick a simpler design that would perform the task effectively then picking the design that would work best in order to render the integration of the rocket easier.

A. Propulsion

As the majority team is comprised of members who have little to no experience working with rockets, the propulsion selection and therefore competition selection was aimed to be straightforward. The team opted to compete in the most introductory level the competition had to offer; the 10,000 ft. COTS competition. After developing a mass budget the team found 40 lbs to be an approximate weight for the purpose of the competition.

From this point, an engine was selected with a diameter for a body tube. After performing a first analysis of the items, an iteration of the engine chose the M-520 engine from Cesaroni. Unfortunately, due to the Cesaroni warehouse explosion, the selected engine was not available. Thus, the Aerotech M-1419, which produces comparable thrust and forces simulated in the team's tests, was chosen as an alternative to replace the original engine.

B. Body Structure

The body structure was originally designed to use sections of fiberglass tubing due to its proven strength and lightweight attributes - two very important items when designing any aircraft. However, members from the team were able to come up with an alternative design. This new design uses two concentric phenolic tubes with an inner skeleton composed of ribs and stringers to fill out the section between the two concentric tubes, forming a semi-monocoque structure like that of aircraft. The new design is more cost efficient, has a reduced weight, and provides sufficient strength for the forces the rocket is expected to face when compared to the previous structural design. The team also believed that even though the SRAD structure would be more restrictive in terms of space, it would also provide team members with an abundance of experience in the design and manufacturing domain. It was therefore selected as the chosen body structure design.

The diameter of the inner tube (4") was restricted by the diameter of the engine, which had already been selected. The outer tube (5.5") was selected as it was the next smallest size available in phenolic tubing at the required lengths of the first iteration of the rocket design. The original material selected for the ribs and stringers section of the rocket's structure was wood. However, after conducting some research, aircraft grade plywood was selected as the final material. This material was readily available in the team's home city of Ottawa, ON, Canada.

The plywood sections were designed by team members using Solidworks, which were then developed into vector files to be read by a CNC router table for cutting the sections. These pieces were then sanded and pieced together, and finally secured together with epoxy.

C. Nose Cone

The nosecone was the next item selected after the preliminary design review of the team's rocket. As the outer tube of the rocket was fixed at 5.5" in diameter, this meant that the nosecone would have to use the same diameter. Although the team believed it could be possible to manufacture their own nosecone using fiberglass, lack of experience with rockets and with fiberglass constructions resulted in the team choosing to purchase a COTS nosecone.

For the nosecone profiles, two separate designs were considered; the conical nosecone profile, and the Von Karman profile. With the selected engine, the maximum velocity would be approximately 0.86 Mach. Since both profiles provide admirable drag coefficients for speeds of less than Mach 1, they would be compatible with the current rocket design. In the end, due to its performance at the expected rocket speeds, the conical nosecone profile was selected.

The nosecone the rocket will utilize has a 5:1 ratio, meaning the nosecone is five times longer than its base diameter. It is also comprised of an aluminium tip to dissipate heat from stagnation heating.

D. Fins

When it came to the fins, the team began considering their design during the research and design of the rocket body. The team had been considering three or four fins, but increasing fin size had the same effect as does increasing the number of fins on the center of pressure (which moves it towards the bottom of the rocket). Therefore, the team decided to make three larger fins, instead of four smaller ones.

The fins were manufactured using the same aircraft grade plywood used for the body structure. Due to a concern of fin flutter, the team performed calculations to determine the fin flutter velocity. Using the design parameters of the rocket, five sheets of 1.5 mm aircraft grade plywood, epoxied together in an edge shape, these calculations resulted in a fin flutter velocity of approximately 550 ft/s. The final fin design also includes fiberglass sheets between each layer of plywood, which further strengthens the fins.

The fins were secured to the structure of the rocket using the same rings and stringers concept of the body. The bottom section of the rocket has six evenly spaced stringers running along the ribs, three are full-length, while the remaining being of a half-length. The three fins run the remainder of the length of the section, while being paired with each of the three half-length stringers. Integrating the fins into the structure in this fashion allows the fins to be perfectly aligned with the rocket body and be installed at exactly 120 degree increments.

$$V_f = \sqrt{\frac{\frac{G}{1.337AR^3P(\lambda+1)}}{2(AR+2)(\frac{t}{c})^3}}$$

E. Avionics Bay

The structure of the avionics bay follows a similar semi-monocoque design to the rest of the airframe, incorporating long stringers stiffened by annular ribs. In the middle of the avionics bay is a thick plywood ring which serves as the separation point of the two body tube sections. It has three metal tabs integrated into its structure which provide a shearing plane for the nylon retaining bolts and the shear tabs attached to the body tubes. On the inside of the electronics bay is a plywood sled that acts as the mounting surface for all flight electronics, from the pyrotechnic boards to the locators. It slides in and out along a series of notches in the ribs. The outside tube of the bay is made of a stiff phenolic tube capped by two plywood bulkheads with a metal reinforcing plate. Any tensile force applied to the bay is taken up by two steel all-thread rods that are connected to the reinforcing plates and run the length of the bay. The ejection charge caps are bonded to the outside of the bulkheads.

F. Recovery Systems

The recovery components that were selected for the rocket were all commercial-off-the-shelf. The system is composed of one main parachute, one drogue chute, quicklinks, barrel swivels, and shock cords. The size of the main parachute was able to be calculated based on the weight of the rocket after engine burn, as well as the target competition speeds for the safest recovery. The team's initial estimates utilized a total weight of 40 lbs, which was also used to select a commercial-off-the-shelf parachute, by calculating the amount of drag produced by the available parachutes, in order to slow the rocket's descent enough to safely recover the rocket and meet the outlined speed requirements.

In order to find the best possible size of parachutes, a series of calculations were conducted in a program that could handle large amounts of inputs in order to output values of descent speeds, landing speed, descent time, and any other information needed to ensure the safest recovery possible for our design. With these calculations, a 36” drogue chute was selected, with a 96” main chute.

The goal of the drogue chute is to minimize the descent rate of the rocket in order to minimize the drift range of the final landing site, yet slow down the initial descent enough with some extra stability for the main parachute to safely deploy at the desired altitude at lower than 1500 ft. The speed of the descent changes with the altitude as a function of the corresponding air density, and ranges from 137.6 ft/s to 88.2 ft/s for the initial descent by the drogue chute.

The goal of the main parachute is to greatly reduce the speed of the rocket for a safe landing at a speed desirable for the rocket to be able to be in a reusable state after flight. The speed of the final descent of the rocket due to the addition of the main parachute ranges from 30.83 ft/s to 28.88 ft/s based on the air density.

The team then explored shock cord options between tubular nylon and kevlar. The advantage of Tubular Nylon (TN) is that it has a higher elasticity, which is better for the structure of the rocket in regards to impact forces from deployment. However, unlike the Kevlar shock cords, it is not fire-proof on it's own and must use an added fire-protecting sleeve of Nomex/Kevlar fabric. Other disadvantages of the TN cord, is that it is much thicker than the Kevlar cords, which means that it is heavier and requires more space in the parachute compartments. Thus, it was decided that the Kevlar would be used for the Main Parachute for it's space-saving advantage and fireproofing needs to maximize the space available in the Main Parachute compartment, as well as minimizing the weight needed for the extra length of cord required. The Main chute also uses a Parachute Bag or Deployment Bag to better contain and pack the parachute inside the main chute compartment. The bag allows for the shock cord to be neatly packed alongside the main chute, minimizing binding or tangling of the shock cord or shroud lines upon deployment. The bag uses a 36" pilot chute to assist in chute deployment from the bag, and allows for the main chute take a short amount of extra time in deployment, which reduces the loading impacts of low altitude deployment. For the drogue chute, it was decided that a 1" TN shock cord will be used, as the drogue chute will be carrying the loads of the entire rocket body itself, incurring larger impact forces on the rocket body; and thus will aid in softening this load force. In addition, the weight and space limitations were not a concern for the drogue chute, and thus allow for the extra space and fireproofing need for the TN cord to be incorporated. Both the drogue chute and main chute compartments incorporate recovery wadding for extra protection on the chutes, shock cords, and rocket body.

In order to keep all components of the rocket together and only have one item to locate, it was decided to attach each portion of the rocket through one shock cord for a total of two shock cords, as explained below:

1) Main chute, 1" TN main chute shock cord:

- Attaches to the payload bay U-bolt with a quick-link securely tied to the shock cord utilizing a Figure-8 knot as used in rock climbing,
- Then attaches to the pre-sewn harnessing loop in the main chute shroud lines through a quick-link attached to a barrel swivel that is incorporated in the Alpine Butterfly Loop, also used in rock climbing,
- And, finally attaches to the forged eye-bolt loop on the avionics bay through another Figure-8 knot.

2) Drogue chute, Kevlar shock cord:

- Attaches to the forged eye-bolt loop on the avionics bay through another Figure-8 knot,
- Then attaches to the pre-sewn harnessing loop in the drogue chute shroud lines through another quick-link attached to a barrel swivel incorporated in another Alpine Butterfly Loop,
- And, finally attaches to the aft rocket section on an eye-bolt incorporated in the engine section, through a Figure-8 knot tied to a quick-link.

Climbing knots were used in the shock cords, as multiple members have extensive experience with these type of knots, and they are easy to use, durable, and highly trusted.

The length of shock cord was determined through researched shock cord lengths w.r.t. the total rocket-body length. It was found that shock cords are often sized by a ratio of the rocket body length, with added shock cord length for the Main Parachute to decrease deployment impact loads at the low altitude, and keep the forward section form being the first to hit the ground. Allowing the aft section to reach the ground first removes extra descent forces from the main chute, and assists in a softer landing of the payload, avionics, and nosecone.

G. Electronics

Due to inexperience with rockets and electronics it was decided to use only off-the-shelf products in order to learn how certain components function, and to use this knowledge in manufacturing homebuilt electronics for next year.

The electronic systems used in the rocket comprise of a primary flight computer system, a secondary flight computer system, and a locator system comprising of a GPS module and beeper. Each system has an integral function in the recovery of the rocket, and follow strict safety measures.

The primary flight computer used in the recovery avionics of the rocket is the RRC2+ dual deployment COTS altimeter system. This board was selected after researching the available boards for purchase that meet both competition requirements for the 10,000 ft COTS category, and team goals for the present and future. As the primary system, this flight computer is the main pyrotechnique board to charge the E-matches used for parachute ejection. This system utilizes a barometric sensor to detect the change in pressure during the ascent of the rocket. Once the sensor detects relatively constant pressure, indicating apogee, the on-board computer will send current to the E-matches for the first event and Drogue Parachute ejection. After this event, the system continues to detect the changing pressure as the rocket descends until the corresponding pressure of the pre-programmed altitude of 1000 ft is detected. At this point, the computer sends current to the E-matches for the second ejection event and Main Parachute deployment.

As a redundancy and fail-safe measure, on the in case that the primary system is unable to ignite the ejection charge, a secondary flight computer system is used. This pyrotechnique flight system is the PET2+ dual deployment timer. This component was selected based on competition and team requirements and goals respectively, as well availability of boards that are able to time for a total duration longer than simulated and calculated rocket flight times. This system utilizes a 3-axis accelerometer to detect the change in acceleration during the ascent of the rocket, and is capable of using various flight events to initiate timing, including; Main Engine Ignition, Main Engine

Cut-Off, Second Engine Ignition, Second Engine Cut-off, or through a break-wire. The board includes the capability to set the inertial trigger event through selecting the magnitude of acceleration the rocket must surpass in order for the timer to initiate timing. For the uses of the CU L8R rocket, the timer is programmed to use main flight ignition as the inertial trigger event to initiate timing once the rocket surpasses 2 g's of acceleration. Once the timer reaches the first pre-programmed time, the on-board computer sends current to the E-match for the first event and Drogue Parachute ejection. The timer then continues until the second pre-programmed time for the second event when the on-board computer sends another charge to the E-matches for the second event and Main Parachute ejection.

The E-matches are another COTS component that are easy to use and connect to the system, requiring a 3 Amp charge for ignition. It was decided to be a COTS component after having attempted to create homebuilt igniters using nichrome wire. Upon testing, it was found that the homebuilt were not able to reliably or quickly ignite, which would create a larger time difference in overall deployment, incurring higher deployment loads on the rocket body and parachutes. Without 100% success in the homebuilt ignitors, it was decided that it would be better to utilize the COTS component for reliability, and continue on the homebuilt design for future competitions. For each of the ejection charges, 4 grams of 4FG black powder surrounds the ignition end of the E-matches in order to provide enough chamber pressure to separate the rocket and deploy the parachutes.

In order to locate the rocket, two COTS components will be used and incorporated into the avionics bay. The two components are: the TeleGPS system for real-time telemetry updates on location, altitude, speed, acceleration and more, and the Transolve BeepX Beeper for an audible locator of 105 dB. The TeleGPS system utilizes the COTS TeleDongle system to receive live telemetry data for the TeleGPS. This ground base station consists of the COTS TeleDongle system in conjunction with the COTS 440-3 Yagi antenna to increase the reception range over the radio frequency. An amplifier may be attached between the dongle device and antenna to increase the receiving power and ultimately the reception range as well, if necessary. Since both the TeleGPS and TeleDongle are Altus Metrum products, the ground base system also utilizes the Altus Metrum ground based telemetry receiving software, which shows a map with a trace of the GPS location and movement, updates on flight information, and the satellites in view being used for the GPS location. The beeper is capable of chirping for 11 hrs straight, and will beep once per minute for the first 25 min of activation.

Both the altimeter and timer boards utilize 9V alkaline battery power sources, 22 AWG wires, and screw terminals for wire connection and securing. The two boards have the ability to each send a 3~5 Amp charge current for E-match ignition. The E-matches are 24 AWG connect through ring terminals on a barrier block to the 22 AWG wires from the pyrotechnic boards also attached by ring terminals on the barrier block. The GPS uses its own 3.7 V, 900 mAh LiPo battery as provided by Altus Metrum. The Transolve BeepX Beeper uses an A23 size 12 V alkaline battery, as provided by the vendor as well. Each avionics component is secured to the sled of the avionics bay with 4-40 hardware (screws, nuts, standoffs, and split-ring washers), and cable ties. The wires are secured through staples to the sled.

H. Payload

The team originally approached the CanSat team from Carleton University to develop the payload on their behalf. The CanSat team tasks themselves with creating micro-satellites with unique objectives on a yearly basis, and thus, integrating their micro-satellite as a payload into the CU InSpace rocket seemed possible. Unfortunately, in early December 2016, CU InSpace was informed that CanSat was no longer able to help with the design of the payload. The task then fell on a small group of electronic enthusiasts within the CU InSpace team.

The original plan for the payload was two-part. The first would be to analyze weather data acquired by the rocket, in real time. The weather data included temperature, humidity, positioning, and pressure of the rocket-surroundings. The results would then be used to better understand the environmental situations subjected to the rocket, which would aid in future homebuilt altimeter designs for future competitions. The second part of the payload involved using a COTS Geiger counter to measure the radiation at various altitudes in New Mexico, and to compare that data to what would be acquired during a flight in Ottawa, ON, Canada.

Other explored ideas for the payload included utilizing a vibration sensor, and a CO_2 sensor. The vibration sensor would be used to analyze and understand the vibrations occurring during the entirety of the flight. The CO_2 sensor would be used to detect the amount of CO_2 present in the atmosphere at the time flight, and create a gradient map of how the amount CO_2 in the air changes with altitude over Las Cruces. This CO_2 map could then be created to current data of CO_2 data of Las Cruces at present. However, not enough research could be conducted in these areas, due to lack of experience, and it was decided to hold off on these design ideas, and it was decided to go ahead with the original plan.

Unfortunately, due to a shortened schedule, the team was unable to meet the deadlines since the original designs needed much learning, and it was determined that it would be best to use a boilerplate payload, while focusing on the previously mentioned payload for a future competition.

III. Testing and Results

Several of the components of the team's rocket and all its major components were tested; the components that were tested include the altimeters, the timers and the ejection systems for the systems team. The aerostructures team also performed their own tests from tensile tests for fin flutter simulations and structural tests while doing a compression test of the student designed body tube.

A. Partial Vacuum Pressure Chamber Tests

Although access to Carleton's partial vacuum pressure chamber was granted to CU InSpace, another experiment which had previously used the chamber caused it to produce certain problems rendering the team's use of this machine inadequate for its purposes. A team member had the idea of creating the team's very own "MacGyver-ed" chamber.

The assembly consisted of a cooking pot with a hole on the lid, to which was fixed via duct tape a hose from a household vacuum and duct tape the entire edge of the cooking pot thus when the vacuum was turned on the pressure inside the pot was reduced. This method allowed us to simulate a pressure state of about 3500 ft. at 0.9kg/cm^2. The test was simulated with an LED light which during competition will be substituted for an igniter and black powder to produce a large pressure difference which will break the shear pins and split the rocket. The reason the test was done at 3500 ft. was because using the team's "partial vacuum pressure chamber" there existed lots of sources of error which created a pressure limit which was found to be approximately 3500 ft.

Although the test was only performed at a pressure of 3500 ft., the test was a success as the system that was being tested performed as anticipated and produced the expected results, therefore testing it at a lower pressure and higher altitude should produce the same results.

B. Timer Tests

As stated previously the rocket's secondary recovery system ignition is with a timer. To ensure that this method works the team simulated the rocket's launch and trajectory and were able to isolate the time it should take to reach apogee, where the drogue chute will deploy, and the time it will take to reach 1200 ft., where the main parachute will deploy.

Using this data it was possible to program a dual deployment to ignite an ignitor at the drogue chute deployment time with a black powder charge to blow an unscrewed lid off a mason jar, simulating the contained explosion that would occur.

C. Ejection Tests

The ejection test occurred on two separate occasions, one for the upper portion of the rocket (which contains the main parachute) and one for the lower portion of the rocket (which contains the drogue chute). The ejection tests occurred on the ground and was triggered by the timer.

The portion of the rocket being tested contained the avionics bay, which houses the timer. A wire was lead from the timer to an ignitor, which was then placed in a container with 2 grams of 4 FG black powder. During both tests, once the programmed time was reached, a signal was sent from the timer to the ignitor, igniting the black powder. The ignition of the black powder sheared the shear pins and separated the two sections of the upper/lower portions of the rocket, as anticipated.

D. Tensile Failure Test

The aerostructure subteam of CU InSpace believed a large source of error with using 1/16" plywood for the structure of the rocket was with fin flutter. A small research team was formed to provide simulations, tests, and solutions to the behavior of the material the forces will occur during flight. The simulations did not provide sufficient evidence to satisfy the team therefore testing was required.

Fin flutter was determined to be a significant risk with using 1/16" plywood for the rocket structure. While simulations and calculations were carried out, these things did not provide sufficient evidence to suggest no fin flutter would occur. In addition, despite in-depth research into the aircraft grade plywood, material properties, such as shear modulus, were difficult to obtain. A tensile test using a 1" by 6" piece of the plywood was performed. The plywood underwent 3.04 kN of tensile force before failure and it was determined the shear modulus of the plywood is around 60,000 psi, well within the anticipated range from research (24,000 psi to 90,000 psi). The shear modulus was able to be calculated by using data obtained from two sets of strain gauges mounted at right angles to each other.

E. Compression Test

The SRAD body structure of the rocket was designed with a safety factor of 8, by considering simulation results run with available programs. These programs included ANSYS, OpenRocket and solidThinking. In order to confirm the design and simulations, a compression test of a portion of the body structure was carried out. The separation point between the two parts of the rocket body was deemed to be the weakest point of the structure and, therefore, it was this portion that was fabricated and used for the compression test.

The team manufactured two 10” sections of the body tube in the same manner as the final rocket would be made. Additionally, a mock couple tube electronics bay (8” length) was made. The three pieces were assembled and subjected to a steadily-increasing compression force.

The structure of the rocket is expected to face a maximum of 950 N of force during flight. Despite having designed the structure with a safety factor of 8, the team only believed the rocket would withstand 3 kN of compressive force. This belief was due to inexperience with the manufacturing materials and the construction process. Unexpectedly, the structure was able to withstand being subjected to 6.1 kN of force before any visible deformation occurred. The test results have shown the structure is capable of facing approximately six times the expected forces it will experience in flight.

Not only was the compression test a success, but it also provided the team with the skills required to manufacture the competition rocket.

IV. Conclusion and Lessons Learned

The team has found that it has learned tremendous amounts throughout the year and will use all this knowledge moving forward. The team also believes that being at competition and seeing how other teams compete and design their rockets will improve their future designs and the way they approach challenges. The lessons the team has learned throughout this experience have been to be better prepared, to have more testing, to not rely on other teams and to utilize our resources better.

V. Appendix

A. Design Summary

Below, in Table 1, the components of the rocket are listed and categorized as either COTS (Commercial-Off-The-Shelf) or SRAD (Student Researched And Designed). For the items that were researched, designed and built by the team's students a brief description is available

Table 1: Summary of Rocket Components

Component	**Source**	**Description (if SRAD)**
Body Structure	SRAD	Comprised of wooden rings and stringers running between the space between the two phenolic tubes
E-Bay	SRAD	Comprised of a phenolic tube that acts as a couple tube with wooden centering rings
Electrical Components	COTS	N/A
Fins	SRAD	Comprised of alternating layers of plywood and fiberglass
Nosecone	COTS	N/A
Recovery Systems	COTS	N/A

B. Hazard Analysis Appendix

Hazard: Black powder
Mitigation: the powder can be stored in the original container away from sources of heat. Additionally, safety goggles and safety gloves must be worn during handling.

C. RISK ASSESSMENT MATRIX

Table 2: Risk Assessment Matrix

TEAM: Carleton University, CU InSpace	**PROJECT NAME:** CU L8R	**DATE** June 15th, 2017		
HAZARD	**POSSIBLE CAUSE(S)**	**RISK OF MISHAP AND RATIONAL**	**MITIGATION METHOD**	**RISK AFTER MITIGATION**
Explosion of rocket motor creating debris and/or large blast	Cracks in Propellant Grain	Low-Medium. Motor uses COTS components tested rigorously by manufacturers. Risk is increased slightly due to cross-brand compatibility of fuel reload and motor case.	Ensure fuel grains are not dropped or mishandled	Low. Fuel and motor case from different companies are known to be compatible.
	Gap Between fuel and liner		Visually inspect for gaps and/or cracks	
	Chunk of propellant dislodges from grain		Ensure cross-compatibility is researched and the motor is assembled properly	
	End closures fail to hold		Inspect components for flaws or defects	
	Case fails at lower than normal operating pressure		Launch crew 200 ft+ away from site at ignition	

Rocket deviates from nominal flight path, comes in contact with personnel at high speed	Failure of fin causes instability due to CP shift	Low-Medium. Student built and designed structure with limited testing.	Ensure all aerodynamic surfaces are rigid and properly assembled/bonded	Low.
	Mass shift inside rocket causes CG change leading to instability		Ensure payload is stowed properly and parachutes are packed properly	
	Structural failure leads to instability		Take care not to damage structure prior to launch	
Recovery system fails to deploy, rocket or payload comes in contact with personnel	Nylon retaining bolts fail to shear during ejection	Low-Medium. Student designed ejection system with limited testing	Ensure shear bolts are properly installed	Low
	Parachutes fail to open		Ensure parachutes are packed properly	
	Ejection charge is not ignited		Check all wiring and flight electronics for shorts or breaks	
Recovery system partially deploys, rocket or payload comes in contact with personnel	Parachute Lines are Tangled	Low	Check that all chute lines can be pulled freely from body tube	Low
	Parachute is not pulled from chute bag		Ensure there is only a small amount of force needed to remove chute	
	Only the drogue chute opens		Check all wiring connections	
Main parachute deploys at or near apogee, rocket or payload drifts to highway(s) or near personnel	Ejection charge is ignited early	Low-Medium. Student built design with limited testing of ejection system.	Check ejection circuit is wired correctly	Low-Medium.
	Nylon retaining bolts fail to hold during drogue ejection		Ensure shear bolts are not damaged or installed incorrectly	
Rocket does not ignite when command is given (“hang fire”), but does ignite when team approaches to troubleshoot	Igniter not installed properly	Low	Make sure igniter is inserted into motor all the way	Low
	No current is sent to igniter upon launch command		Check electrical continuity of launch circuit before launch. Disarm if “hang fire”.	
Rocket falls from launch rail during prelaunch preparations, causing injury	Rail guides are not properly inserted into rail groove	Low	Visually inspect guides to ensure correct attachment to rail before rail is lifted to position	Low
	Rail guides detach from rocket body		Test strength of guides before inserting onto the rail	

Ejection charges detonate early or during prelaunch causing injury to personnel	Timers are set incorrectly before launch	Low	Ensure the G-switch of timers is properly set and correct time is entered	Low
	Ejection charge is exposed to high heat		Ensure open flames or heat sources away from set-up	

D. Motor Assembly Checklist

INSTRUCTIONS FOR LOADING THE MOTOR

[] 1. INSERT PROPELLLANT GRAINS INTO LINER ENSURING SPACER O-RING BEWTWEEN EACH

[] 2. USE NOZZLE TO PUSH GRAINS INTO LINER

[] 3. GREASE REMAINING O-RINGS

[] 4. PLACE SEAL DISK O-RING ONTO FORWARD SEAL DISK

[] 5. APPLY GREASE TO THE END OF THE SMOKE CHARGE

[] 6. INSERT CHARGE INTO INSULATOR

[] 7. INSERT CHARGE ASSEMBLY INTO FORWARD CLOSURE, GREASED END FIRST

[] 8. INSERT FORWARD CLOSURE O-RING (-237) INTO FORWARD CLOSURE GROOVE

[] 9. INSERT FORWAD SEAL DISK INTO THE END OF THE LINER SO IT IS FLUSH

[] 10. INSERT FORWARD END OF LINER INTO MOTOR CASING, AND PUSH LINER ASSEMBLY ALMOST TO THE THREADS

[] 11. APPLY GREASE TO THE INSIDE OF THE FORWARD END OF THE MOTOR CASE

[] 12. PUSH IN LINER ASSEMBLY ALL THE WAY UNTIL THE START OF THE THREADS, THEN BACK OUT SLIGHTLY

[] 13. INSERT FORWARD CLOSURE

[] 14. THREAD FORWARD RETAINING RING INTO CASE ABOUT HALFWAY

[] 15. INSERT NOZZLE INTO LINER

[] 16. PLACE NOZZLE O-RING ONTO NOZZLE SHOULDER

[] 17. PLACE NOZZLE HOLDER ONTO NOZZLE, NOTCHED END FIRST

[] 18. INSERT NOZZLE ASSEMBLY INTO CASE

[] 19. THREAD ON AFT RETAINING RING ABOUT HALFWAY

[] 20. TIGHTEN FORWARD RETAINING RING UNTIL FLUSH WITH CASE

[] 21. TIGHTEN AFT CLOSURE SO IT IS FLUSH WITH CASE, SHOULD FEEL O-RINGS COMPRESSING

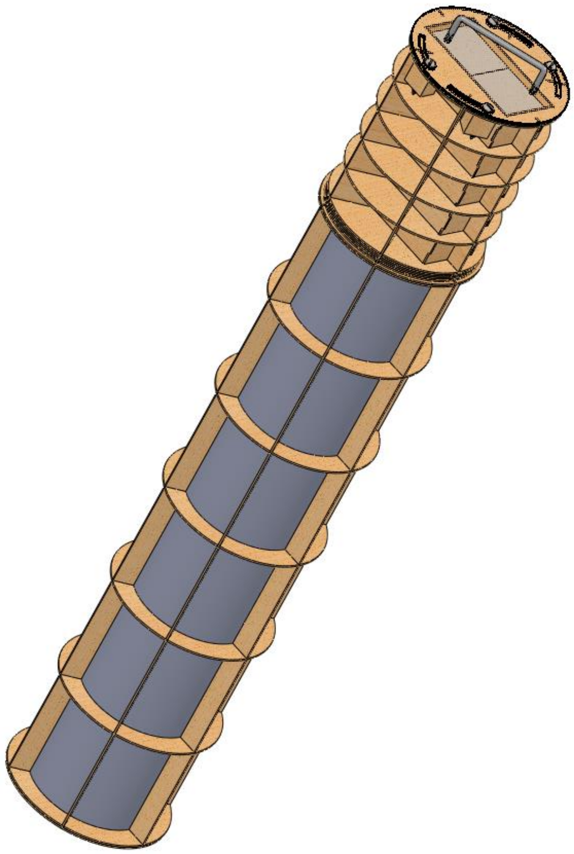
NOTES:

AEROTECH ENGINES ALWAYS COMPRESS THE NOZZLE ORING WITH THE NOZZLE ITSELF, IT HAS NO "GROOVE" IN THE FWRD CLOSURE

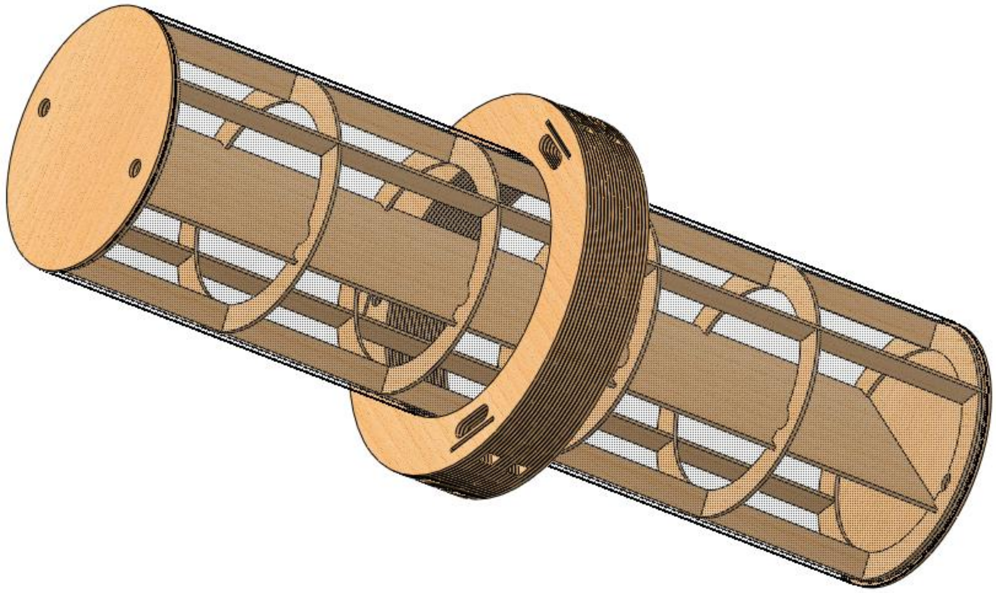
THE NOZZLES FROM BOTH COMPANIES APPEAR TO HAVE VERY SIMILAR DESIGNS

E. Engineering Drawings

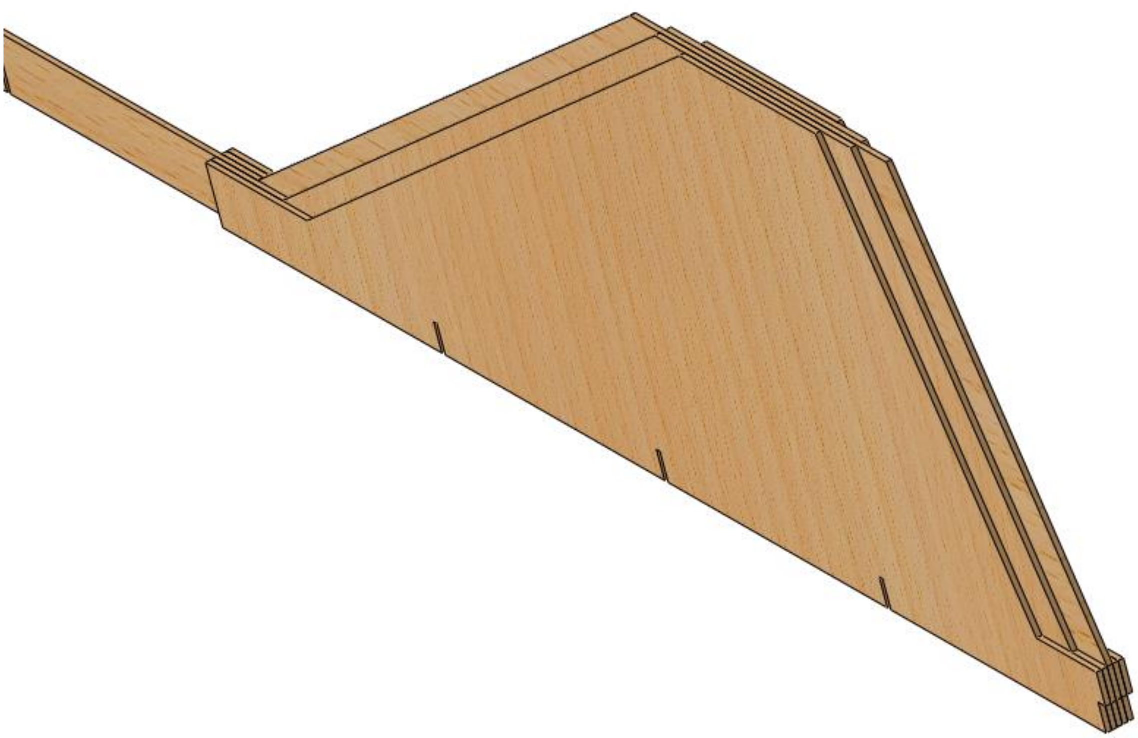
Body Skeleton



Avionics Bay



Fins



Payload

VI. Acknowledgments

The authors would like to thank our faculty advisors for being able to meet outside of class hours to go over certain problems we were having whenever we would get stuck; Dr. Jason Etele and Dr. Steve Ulrich. We would like to thank members of Carleton University's staff; Alex Proctor, Steve Truttmann, Ian Lloy, Kevin Sangster and Bruce Burlton. We would also like to thank our graduate students advisors; Tyler Hewitson, Stefano Sandri, Brent Cameron. A special thanks to all our team member over the years who have given up hours of their time researching; designing, iterating, building and testing. We would also like to thank our wonderful sponsors, without their financial support our team would be just designing and only understanding a portion of the creation process; Carleton University Faculty of Engineering and Design, the Carleton Undergraduate Engineering Students' Equipment Fund (CUESEF), Lockheed-Martin Canada, ColdEx, Carleton Undergraduate Student Association (CUSA), LOC Precision Tubing, SolidWorks and Carleton Student Engineering Society (CSES).