

# ITA Rocket Design's eighth student built rocket, codenamed RD-08

## Team 73 Project Technical Report to the 2018 Spaceport America Cup,

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**This report describes the ITA Rocket Design team's project for the 10,000 ft above ground level (AGL) apogee with commercial-off-the-shelf (COTS) solid or hybrid rocket propulsion system category of the 2018 SACup IREC. Carrying a 8.8 lb payload and being reflyable are also among the rocket's primary missions. A dual deployment of parachutes and redundancy in avionics were used as a recovery system to ensure reflyability. Additionally, the payload's missions is to test part of a non-pyrotechnical gas ejection system, in order to be futrely implemented on the recovery subsystem. Several simulations were run with softwares such as CAD and MATLAB to ensure structural and aerodynamic reliability, as well as to provide important parameters to the project with precision. Safety was also an important priority, which resulted in many different manufacturing processes that in turn generated the final product. The project furthered the team's knowledge of the field, creating confidence that significant improvements will happen in future projects.**

### I. Introduction

THE ITA Rocket Design team is a group of undergraduate students at the Aeronautics Institute of Technology (ITA), a college that is managed by the Air Force's command and forms military as well as civilian engineers. Naturally, since the school is located in the southern hemisphere, the school year begins in February and ends in November. As such, Summer vacation happens between the months of December and February. This way, the Spaceport America Cup (SAC) always happens during the Fall Semester's exam period, which proves a great challenge to the team. The vast majority of the team's members are majors in Aerospace Engineering and, like all the other engineering programs in this school, provide a Bachelor's degree in a 5 year program which includes an internship and a thesis at the end.

The group was created in the year of 2011 and was one of the first international teams to ever participate in the IREC, and has accumulated knowledge as well as stakeholders since that time. Currently, the team has a major sponsorship from the Federation of Industries of the State of São Paulo (FIESP), assistance with machining and manufacturing from a partner Brazilian Enterprise and with chemicals from the school's chemistry laboratory. The team is also supported by ITAEx, an association of former students which sponsors undergraduation projects. There are further investments made in the team for the purpose of participating at the IREC that have a smaller scale but are not any less important than the last ones mentioned, e.g. donations of extremely high quality Printed Circuit Boards (PCBs) from NewTechnik.

As for organization and structure, the team has always focused on the systems engineering approach, dividing the team's departments according to the project's subsystems. There are two kinds of subsystems within the team: technical and administrative. The group's administrative departments are finances, logistics and marketing, whereas its technical departments are payload, electronics, propulsion, recovery, structures, integration, flight mechanics, and

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aerodynamics. Communication is not usually an issue because practically all of the team's members live in the same housing, as well as facilitation from social media. Organization and planning happen in general meetings that occur at least once a week, and there usually are subsystem meetings to organize, plan and complete specific tasks. In addition, to be able to accumulate knowledge and experience over time, the team certifies that all relevant details are thoroughly documented in an accessible manner, so that new members can continue the work of senior members with greater ease.

## II. System Architecture Overview

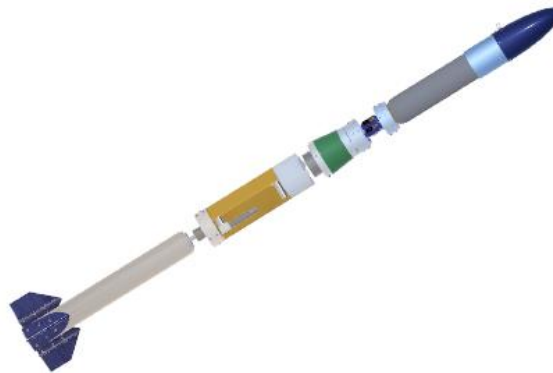
The Rocket consists of a solid propulsion system with parameters determined through flight simulations in order to optimize the proximity between the predicted apogee and the target apogee of 10,000 feet above ground level (AGL). The solid COTS motor is inside a carbon fiber airframe, in which three trapezoidal fins are fixed, in order to optimize aerodynamic stability. Directly above the propulsion system, the rocket carries a 8.8 lb payload that follows the 3U CubeSAT standard for geometry. The mission of the payload contained within the CubeSAT is to test a CO<sub>2</sub> ejection system's resistance to the flight's conditions and determine whether it is feasible to develop a recovery system using this CO<sub>2</sub> system in future projects. In the same tube, there is an electronic bay with inertial sensors, which will record data from the rocket trajectory for post-analysis. Following the payload section is the recovery system, consisting of a drogue and a main parachute to be deployed in two different and independent events, each with its own redundancy, in order to assure the rocket's reflability. Finally, just inside the elliptical nosecone there is a GPS tracking system for the rocket that will allow the reconstruction of the rocket's trajectory during flight and, more important, to locate it once it has landed in order to recover it. A full view of the rocket's assembly as described is shown in Fig. 1. Several aspects of the chosen architecture are very similar to the ones used on RD-07, the team's rocket of IREC 2017, which had a nominal flight.

All structures were analyzed through simulations where it was shown that they can withstand stress and forces that are significantly larger than the maximum expected forces during operation. The joints were projected and tested to support the stress when the rocket is maintained in horizontal position, being lifted by the propulsion system carbon fiber airframe.

### A. Propulsion Subsystem

Since its creation in 2011, projects from ITA Rocket Design were based on a SRAD solid "candy" rocket motors. Several proplelant with different sugars and oxidizers were made, with help of ITA's Chemistry laboratory. Unfortunately, in the middle of March 2017, there was an accident in the laboratory, when a solid propellant grain ignited with static electricity and four members of the propulsion team were burnt with first and second degrees. This event obligated the propulsion team to stop working for a while, and consequently ITA Rocket Design decided to buy and fly a COTS motor in IREC 2017 and is doing the same for the SAC 2018. Since that event, the team decided to keep focus on safety, and stop manufacturing it's own motor in USA because the level of safety the team needs to be comfortable to do so could not be met (e.g. access to a safe and appropriate facility).

The COTS motor to be used by the team was tested, with several simulations, which will be described in the Flight Dynamics section.. The chosen motor for RD-08 was, Pro98 9955M1450-P, manufactured by Cesaroni Technology. The specifications and thrust curve are shown in Fig. 2.



**Figure 1. Fully integrated launch vehicle.** *Assembly of all of the rocket's subsystems configured for the mission being flown in the competition.*

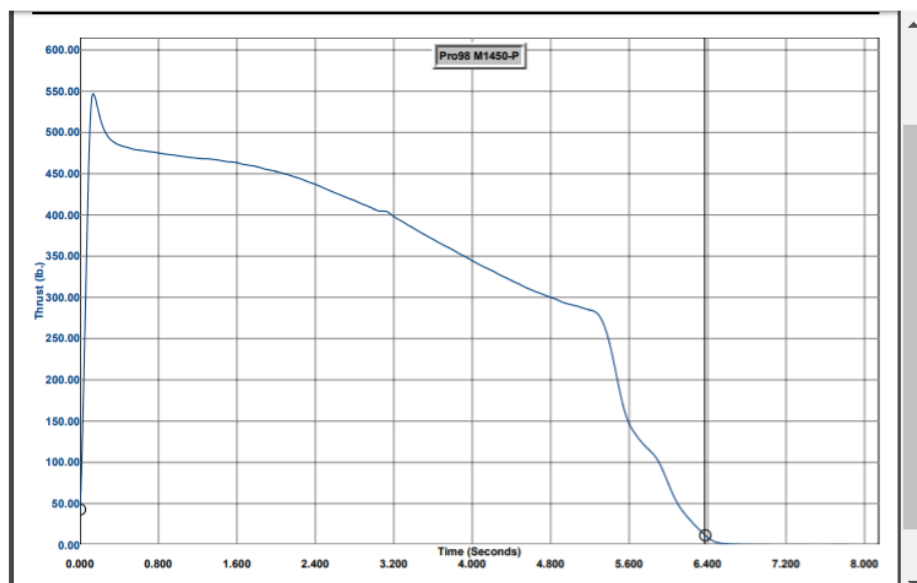
## Pro98 9955M1450-P

### Motor Data

Brandname	Pro98 9955M1450-P	Manufacturer	Cesaroni Technology
Man. Designation	9955M1450-P	CAR Designation	9955 M1450-P
Test Date	10/29/2004		
Single-Use/Reload/Hybrid	Reloadable	Motor Dimensions mm	98.00 x 702.00 mm (3.86 x 27.64 in)
Loaded Weight	8578.00 g (300.23 oz)	Total Impulse	9955.00 Ns (2239.88 lb/s)
Propellant Weight	4830.00 g (169.05 oz)	Maximum Thrust	2416.35 N (543.68 lb)
Burnout Weight	3610.00 g (126.35 oz)	Avg Thrust	1456.00 N (327.60 lb)
Delays Tested	Plugged	ISP	209.70 s
Samples per second	1000	Burntime	6.87 s
Notes	Also certified using the RMS 98 x 732 mm case. Refer to Certification Letter for details.		

### Representative CMT Thrust Curve

[Click Here for Larger View of Graph](#)



**Figure 2. Commercial motor's Specifications and Thrust curve.** Available in: <http://www.pro38.com/products/pro98/motor/MotorData.php?prodid=9955M1450-P>

## B. Flight Mechanics Subsystem

The flight mechanics subsystem is the one responsible for making flight simulations of the rocket during its different design phases, always trying to ensure the primary system mission of achieving 10.000 ft of apogee is being accomplished and making sure the safety is maintained during the whole flight. In order to perform such tasks, this subsystem has developed two different simulators with different levels of accuracy and system modelling.

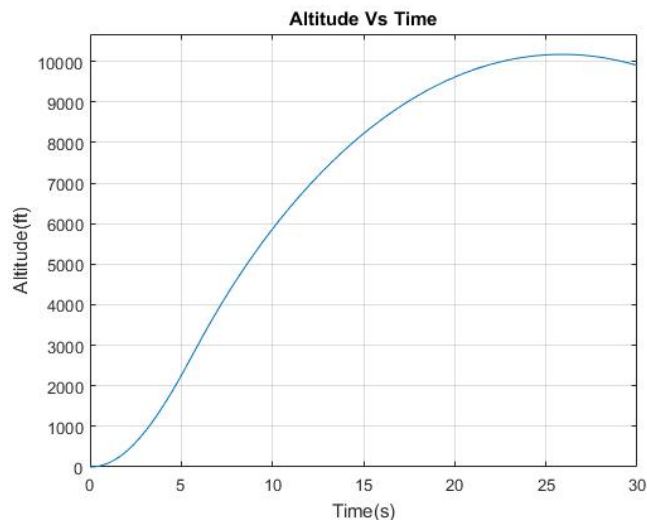
The first student-built flight simulator considered is a MATLAB<sup>1</sup> 2 degrees of freedom (DOF) longitudinal flight simulator, in which the rocket is basically a point-mass with zero angle of attack during all flight. Only drag, gravity and thrust are taken into account. This simulator is used during the preliminary phase of design, when there is very little information about the aerodynamics of the rocket and for monte carlo studies due to its execution speed. For preliminary studies this simulator was used to estimate which motor fits better with the requirements of the mission. To make this task a sheet were made with various motors from the company cesaroni technology and a preliminaire design of the rocket with different “boiler-plate” masses was simulated with all those motors. The motor chosen was the one which presented the smallest apogee variation with a change of the “boiler-plate” mass. Some of the parameters observed for the choice of the motor are presented in Fig. 3.

Burntime (s)	Diameter (mm)	Propellant	Altitude (ft)	Launch rail exit Velocity (ft/s)
4.44	75	Imax	6141.08	66.65
6.87	98	Classic	10052.09	60.67
12.76	98	Classic Longburn	7766.35	38.95
5.49	98	Blue Streak	10430.53	70.05
5.25	98	Red Lightning	10290.70	71.17
4.53	98	Skidmark	7532.82	69.80
2.92	98	White Thunder	11413.87	102.70
5.89	98	White	10962.84	67.94
1.36	98	Vmax	9289.85	143.57
7.23	98	Classic	6098.95	50.06
13.81	98	Classic Longburn	1403.24	27.61
4.97	98	Blue Streak	7013.32	65.39
3.00	98	White Thunder	7405.38	88.36
5.94	98	White	6685.06	57.68
1.53	98	Vmax	7429.01	126.54
4.74	75	Classic	7317.60	68.14
4.17	75	Imax	8746.99	77.25
3.61	75	Blue Streak	7332.41	79.46
3.47	75	Red Lightning	7405.29	81.38
3.34	75	Skidmark	4942.93	73.04
3.03	75	Smoky Sam	5424.86	79.01
1.83	75	White Thunder	6713.61	112.03
9.00	75	White Longburn	5599.33	42.50
4.29	75	Imax	11132.47	82.20
3.28	75	Skidmark	6105.33	78.60
5.29	75	Green3	7680.45	64.28

**Figure 3. Results for the motors choice.** The 2DOF student-developed flight simulator was used to simulate each motor.

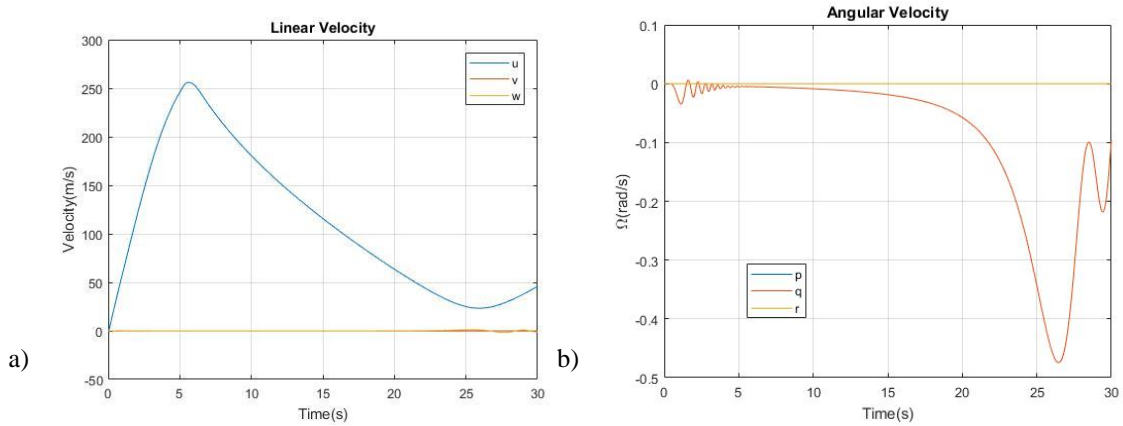
One of the most importante parameters observed (besides the apogee) was the launch rail exit velocity because it facilitates the stability of the beginning of the flight. To make those calculations the impulse curve of the motors were analized to check which one had the greatest initial thrust. The motors were, then, separated in 5 colours. The grey represents motors that didn't have enough thrust for the flight. The red represents the motor used on RD-07, for means of comparison. The yellow represents ones with extremes burn times, resulting either in a dangerous high acceleration or too low exil launch rail velocity. The green represent the ones available and the blue the chosen one.

With later information about the rocket project – Wind tunnel test, precise mass distribution, aerodynamics coefficients – It was possible to make simulations more precise. To do so we used our second simulator that considerates 6 DOF – X, Y and Z positions and rotations on those three axis. The main difference between those two codes is that with the 6 DOF we can check the system stability during the whole flight due to its more precise aerodynamic and propulsion modelation<sup>6</sup>. Using the RD-08 modelation It was possible to generate the graphs presented at Fig. 4 and Fig. 5. The Fig. 4 gives us a predicted apogee of 10189 ft (3105 m). From the Fig. 5a it is



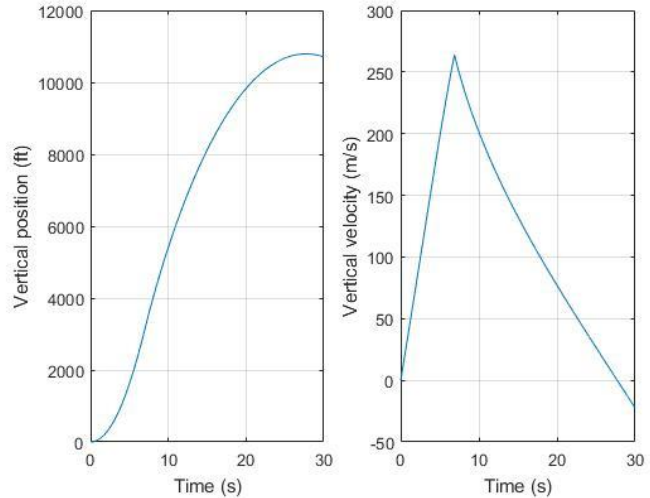
**Figure 4. Rocket altitude.** Result using the 6DOF flight simulator.

possible to obtain a launch rail exit velocity of 25.65 m/s (84.15 ft/s) which is higher than our last project for SAC (2017) that presented a nominal flight, which is a good parameter to indicate this project flight will also be stable. This launch rail exit velocity exceeds our expectations mainly because the shape of thrust curve reaches its maximum at the beginning of the burn giving us a maximum acceleration of 7G right at the beginning of the flight and for a short period of time. In addition, the Fig. 5a presents the maximum velocity of the rocket in flight, which is 840 ft/s (256 m/s). That means the rocket has a similar Mach velocity from last year (0.77 Mach). At Fig. 5b, there is another evidence of the flight's stability, it is the presence of the stabilization of pitch angle in the beginning of flight.



**Figure 5. Rocket angular and linear velocity results using the 6DOF flight simulator. a) Linear velocity; b) Angular velocity.**

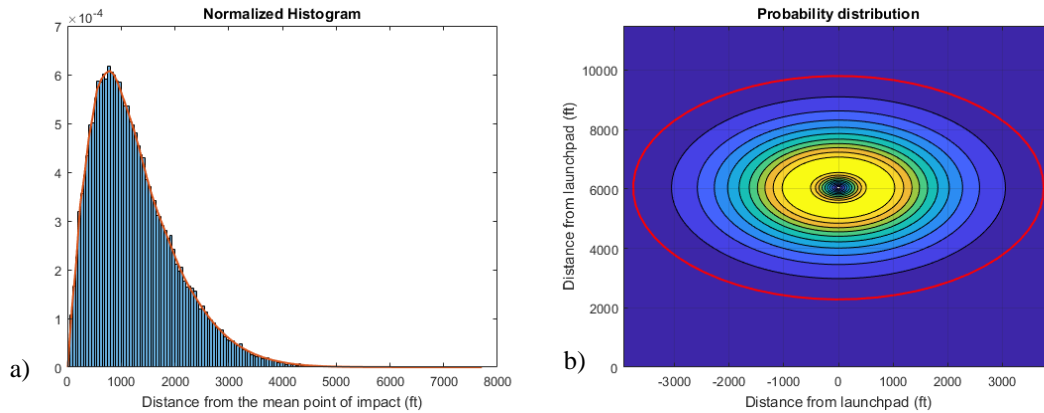
To compare both simulations, the rocket was simulated using the 2-DOF with a similar data used to simulate the graphs from the Fig. 4 and 5. Surprisingly, despite the simplicity of the 2-DOF simulator, it showed very similar results to the ones obtained above. The results are presented in the Fig. 6. With this simulation we obtained an apogee of 10787 ft (3288 m) and a maximum velocity of 866 ft/s (264 m/s). Since this simulation has a much lower computational cost we made a Monte Carlo simulation using it to model the dispersion area of the rocket landing zone considering an unaccomplished recovery. For this we simulated the flight of the RD-08 rocket 70000 times considering the empty mass, the thrust, the launching angle, the burntime and the azimuth as normally distributed random variables with mean values and standard deviation presented on Table 1. The data was processed and the probability distribution of the dispersion area was obtained, then, the results were organized in the two graphs shown on Fig. 7. From the Fig. 7a we can obtain the Fig. 7b where we present the circle of radius 3758 ft and center  $X = 0$  and  $Y = 6000$  ft – the launch rail was considered the origin - where there is 99% probability of the rocket to fall.



**Figure 6. Rocket altitude and vertical velocity. Both were results of 2DOF flight simulator.**

**Table 1. Mean values and standard deviation. Variables used in the Monte Carlo simulation**

	Empty mass	Thrust	Launching angle	Burntime	Azimuth
Mean	25.63 kg	1483.8 N	86°	6.86 s	0
Standard deviation	1	14.83	1	0.2	5



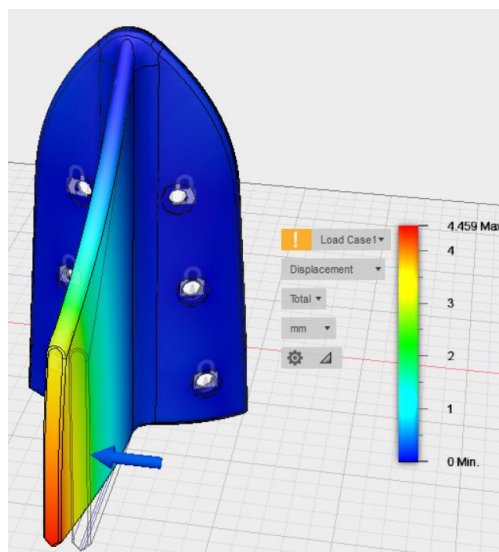
**Figure 7. Probability distributions for Monte Carlo simulation.** *a) Normalized histogram with the fitted probability distribution function; b) Area with 99% probability of the landing.*

### C. Aerodynamics Subsystem

The Aerodynamic subsystem is responsible for designing the control surfaces of the rocket, the nosecone and for deriving the dynamic and the flight coefficients in order to guarantee a stable and optimized trajectory. To achieve these goals, we conduct computational simulations and experimental tests.

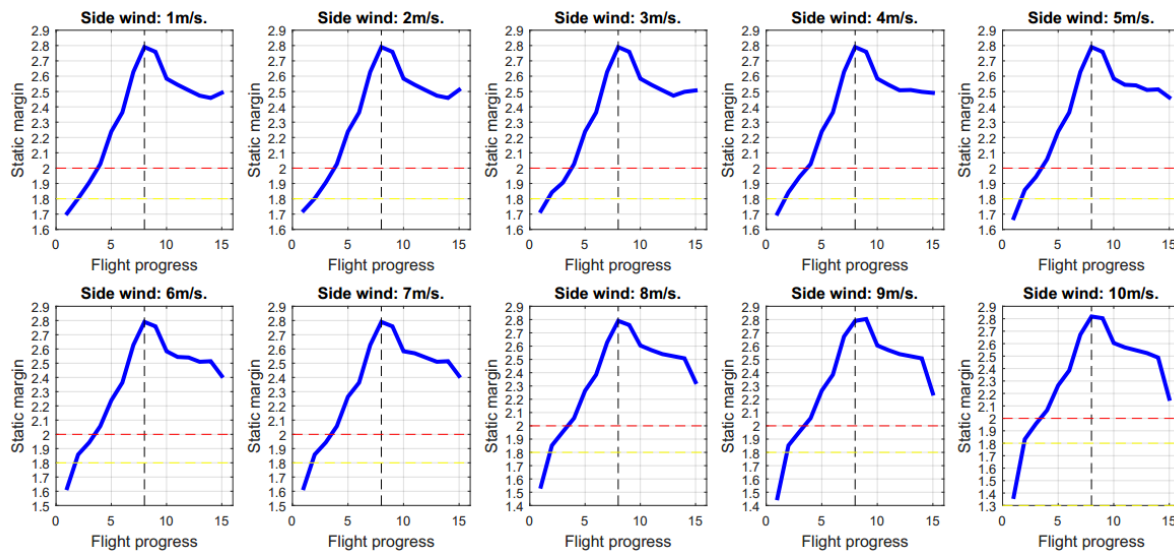
The material chosen to compose the fins was PLA so that it would be possible to manufacture the fins by 3D printing them. The basis for this choice was the good results that the team obtained in it's previous project for the IREC (RD-07), since no failure was observed in the fins' functionality. Consequently, the manufacturing process and coupling to the rocket were simple. Because of the fact that heat transfer between the motor and the main airframe is not significant due to the thin layer of air between the motor and the external fuselage in which the fins will be fixed, the team has still decided to chose PLA.

Furthermore, the material and shape of the fins were designed having the considerations and recommendations found in Richard Nakka's<sup>2</sup> site in mind. According to Richard Nakka, the best number of fins to be used is either 3 or 4. Since the use of 3 fins minimizes material use and mass carried by the rocket, as well as requiring an equal amount of effort to manufacture, this number was chosen, so that the rocket has 3 fins separated from each other by 120°. It is also shown by Richard Nakka that a good general shape for the fins is a trapezoid, with its specific dimensions being determined by the boundary conditions due to the position of the Center of Gravity (CG) in order to maintain stability during flight.



**Figure 8. Simulation of loads on fins.** *The trapezoidal section presented a small angular displacement.*

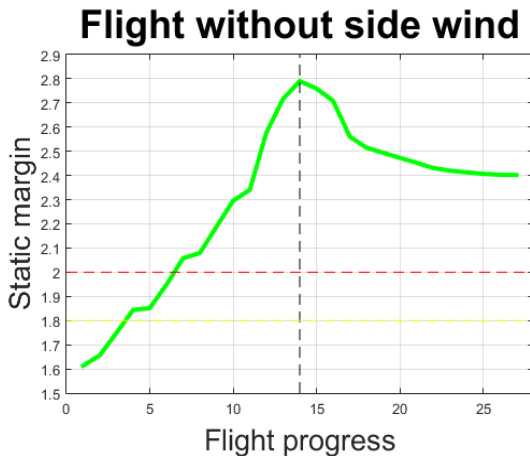




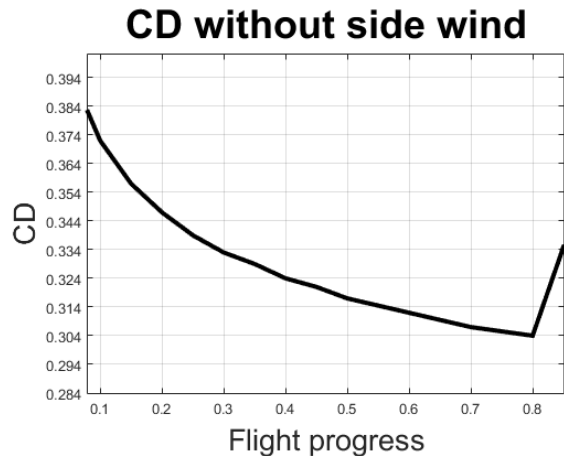
**Figure 9. Static Margin for flight progress.** Lateral wind velocities from 1m/s to 10m/s were considered.

Regarding the other main air-frame component that the subsystem is concerned with, the nosecone, the shape was established to be elliptical, since this design produces the least amount of drag for the subsonic regime, which is the regime that the rocket will achieve during flight (maximum Mach number of approximately 0.8). The fineness ratio chosen were 2, because of internal volume requirements as there is a telemetry antenna inside the nosecone.

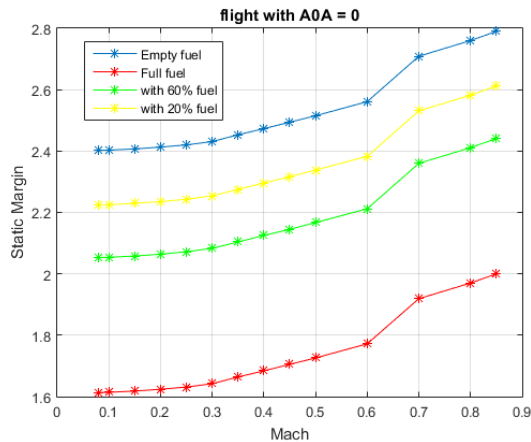
In addition, a few simulations were made to verify the reliability of the aerodynamic components and determine the dimensions of the fins. To simulate the forces applied on the fins' structure, the team used the software *Autodesk Fusion 360*<sup>3</sup>, and the results can be observed in Fig. 8. The applied vertical force was of 300 N, applied in the line that passes through the aerodynamic center of the fin, whereas the horizontal force is 600 N, applied directly at the aerodynamic center. The size of the fins was determined using a MATLAB routine (produced by the members) with the Missile Datcom software, having the goal to maintain the static margin of the rocket between 1.5 and 2.8 body calibers throughout the entire flight so as to maintain the rocket in a stable regime. The results of the latter simulations to determine the fins' dimensions and the effects in flight are shown in Figs. 9 and 10. The drag coefficient value during flight is shown at Fig. 11. As a result of the fins design, we obtained the static margin for different flight conditions and lift off elevation angle that are compiled in Figs. 12 and 13.



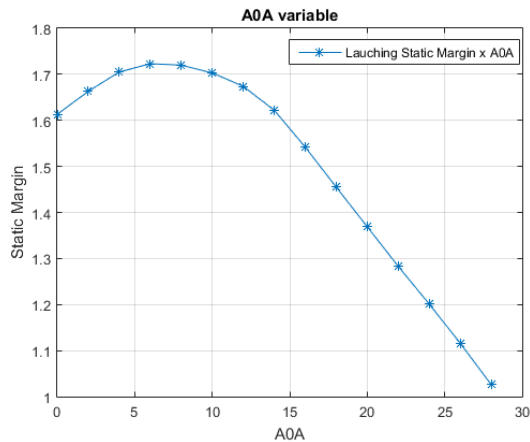
**Figure 10. Static Margin due as flight progresses.** Zero lateral wind velocities were considered.



**Figure 11. Drag coefficient due as flight progresses.** Zero lateral wind velocities were considered.

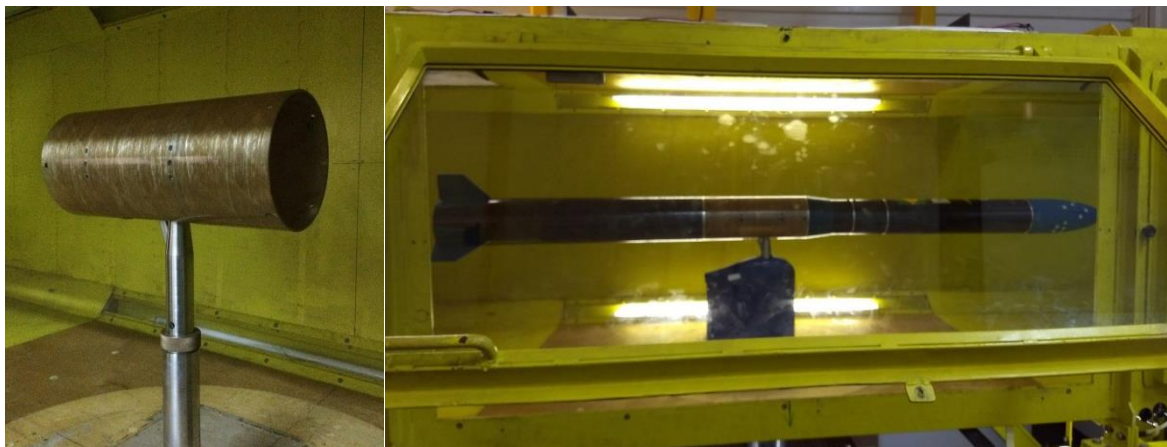


**Figure 12. Static margin due to Mach of flight, including loss of mass.** *Different mass configurations were taken into account.*



**Figure 13. Static margin at the launching x AOA (side wind).** *Various lift-off static margins due to initial elevation angle.*

In the past, the aerodynamic coefficients were calculated solely by the aid of the software Missile Datcom. With the purpose of improving flight performance, a better estimative of them showed necessary. The subsystem of aerodynamics used the Feng Laboratory at ITA to estimate experimentally the aerodynamic coefficients in a full size subsonic open circuit wind tunnel of 200 HP. We adapted RD-07 rocket - our previously developed rocket which has the same external geometry as RD-08 – on the wind tunnel's six degrees of freedom load cell. The test simulated, in the Reynolds number of flight, the entire flight packet by changing yaw and pitch angles of attack. As a result, we derived drag force coefficient, normal force coefficient and roll moment coefficient. Since the body reaches Mach number where compressible effects are relevant, we used the Prandtl-Glauert compressibility transformation to adapt experimental's data to flight condition. Hence, we could compare and check our Datcom's virtual model with our actual rocket's coefficients.



**Figure 14. Adaptation body and full size rocket inside the test section of Feng Laboratory's wind tunnel.** *The integration process was quick due to the rocket's modular design.*

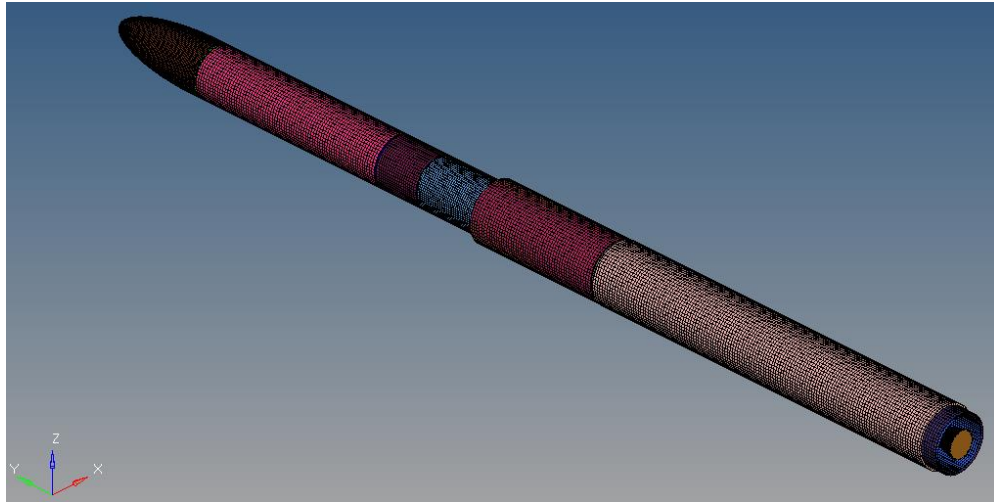
#### D. Structures Subsystem

The main goal of the structures subsystem is to design the parts that are used by other subsystems, as well as to study the behavior of the part subjected to the stresses involved in the rocket's operation. All calculations and simulations using the Finite Element Method analysis were made using CATIA® V5 R20, Abaqus®, Autodesk® Fusion 360™, Femap and HyperMesh softwares. A global model of the entire rocket structure was made to calculate the margin of safety of each individual part. In this section, it is assumed that the transition section does not carry



any load, and therefore it won't be analyzed. In order to verify the stresses that the structure was exposed to, a inertia relief analysis was performed.

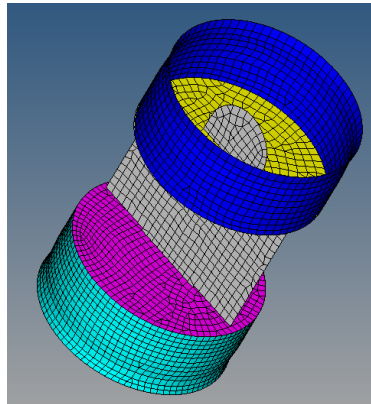
The idea was to check if the rocket was oversized for the expected load and to adjust its final weight in accordance with the motor capabilities in order to achieve the expected apogee.



**Figure 15. RD-08 Global model.** *Finite element model of the current sounding rocket for static analysis.*

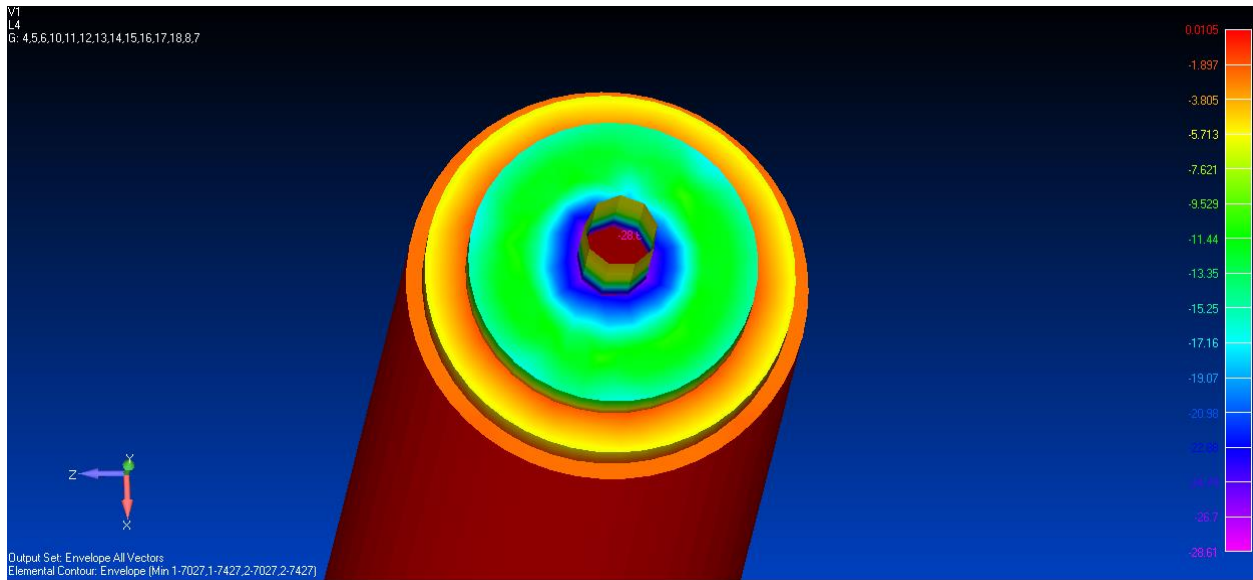
#### *1. Metal parts*

Most of the metal structure was modeled using 2D plate elements with isotropic material. For extension stress margin of safety, a top/bot envelope of Von Mises stress was implemented. As for compression stresses, a top/bot envelope of Minor Principal stress was verified.



**Figure 16. Metal structure modeling example.** *Plate element design of the electronics bay.*

The highest compressive stresses were found in the connection between the engine and the lowest metal section of the rocket. Despite being the location with the highest membrane force in a situation of maximum thrust, the margin of safety was still very high.

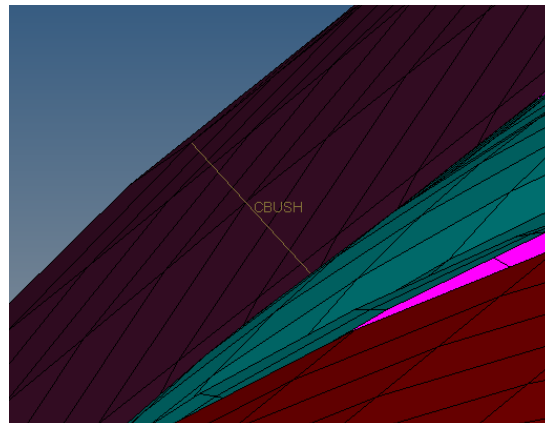


**Figure 17. Minimum Principal stress [N/mm<sup>2</sup>]. Maximum compressive stress near the motor.**

It is important to note that no contact was modeled between elements in the model, so all the loads are being transferred from one section to another through the fasteners. Thus, despite the conservative approach, it is also important to mention that two load cases are being implemented in the global model. One representing a maximum thrust concentrated force applied in the nozzle and a second one similar to the latter with a increment lateral gust of 7m/s.

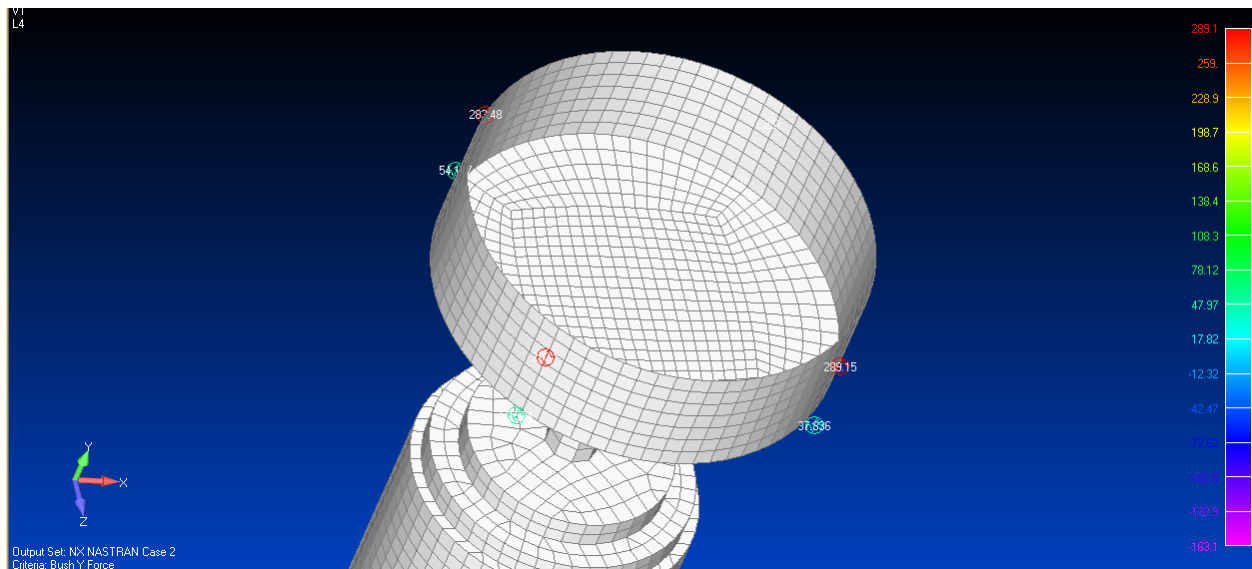
## 2. Fasteners

All bolts in the structure was modeled using spring elements. Stiffness was added in all 6 degrees of freedom through a PBUSH property entry card.



**Figure 18. Example of a spring element representing a fastener. Finite element model representation of a bolt.**

Having in mind that no bearing or pullout tests were performed, theoretical allowed values were adopted. Also, as mentioned before, no contact was established between non coincident nodes, therefore it was considered that the resulting bush forces was conservative.



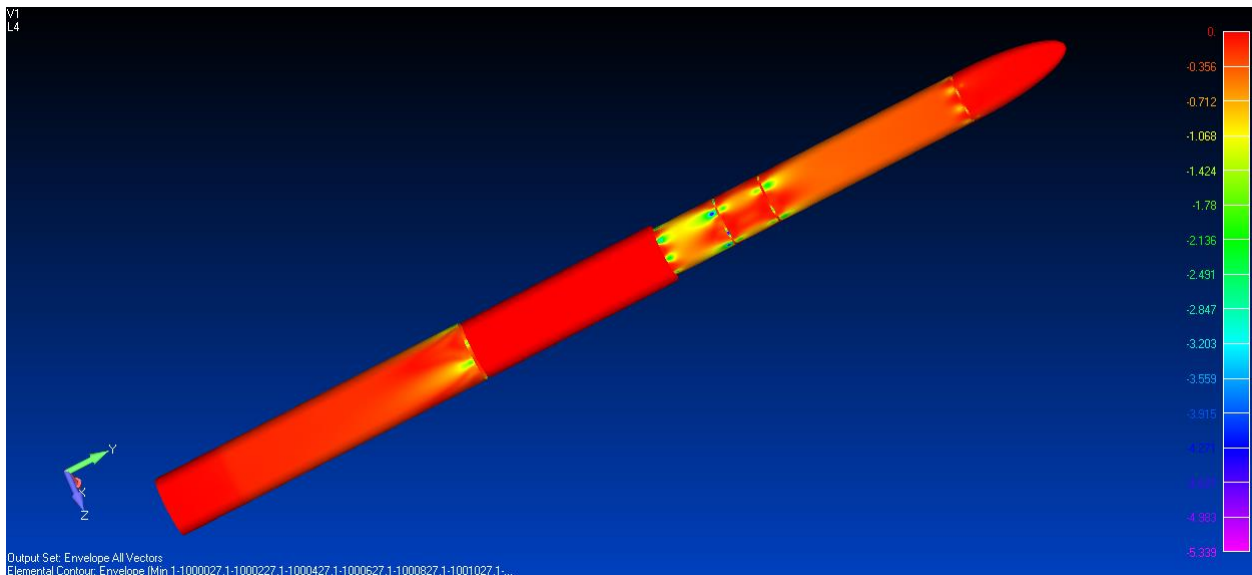
**Figure 19. Fasteners bearing load [N].** *Maximum shear load acting on the finite element model.*

Two types of bolts were used in the rocket structure (M8-1.25 X 10 BUTTON HEAD SOCKET CAP SCREW ISO 7380 CLASS 12.9). Both were made of alloy steel with a yield stress of 1080 N/mm<sup>2</sup>. Beyond that, the diameters of 8 and 6mm have been chosen to connect composite and metal structures within the rocket structure. Through bearing and shear calculations a high margin of safety was found for the most loaded bolts in the structure.

### 3. Composites

Most of the rocket's cylinders were manufactured using composites material in order to minimize the mass of the system and, at the same time, ensure the strength of the parts. The recovery system uses unidirectional carbon fiber and the payload system uses unidirectional fiberglass, both manufactured by a filament winding process.

All composite laminates holds a symmetric and balanced stacking sequence to avoid bending-extension coupling as well as shear-extension coupling stiffness terms. Taking into account the inaccuracy of the total amount of resin per ply, the percentage of each orientation was defined instead of defining a stacking sequence. Thus, it was possible to avoid variations on the total thickness of each part. The final proportion was defined as 40% of the plies defined at a  $\pm 45^\circ$  angle, 40% at a  $0^\circ$  angle and 20% at a  $90^\circ$  angle.



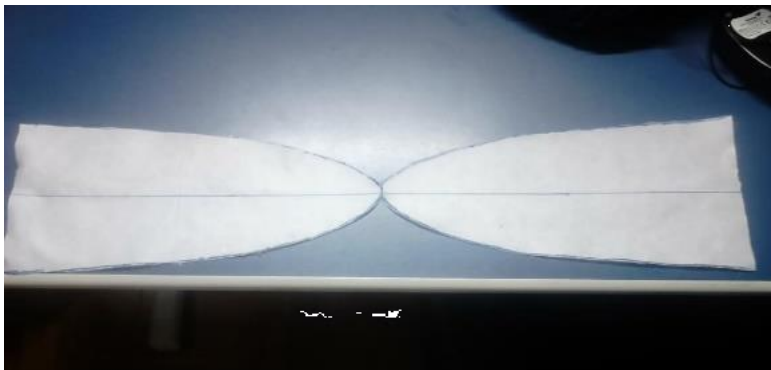
**Figure 20. Composites cylinder minor principal stress envelope [N/mm<sup>2</sup>].** *Maximum compressive stress acting on composite components of the rocket.*

The composite analysis also showed that the total thickness of the cylinder added more stiffness than the necessary for supporting the applied loads. However, the focus was not to find the lowest optimum weight. With a maximum thrust defined, associated with a specific apogee goal, the principal mission was to find the correct weight in order to achieve that goal. If the structure had been optimized to the lowest weight possible, eventually some boiler plate mass would have to be used.

#### 4. Detailing the nose cone manufacture process

The nosecone is manufactured with fiberglass by hand lay-up, and its mold was produced in nylon. This manufacturing process requires specific materials intended for its manufacture, surface smoothing and external finishing. Made from the fiberglass composite, the first step in its manufacture consists in calculating the number of fiber layers that will be superimposed to obtain the desired thickness. The outside diameter of the tube for the recovery module is 5 inches or 127 mm, while the outside diameter of the mold base (male) is 123.10 mm. The desired thickness, therefore, is worth  $(127.00 \text{ mm} - 123.10 \text{ mm})/2 = 1.95 \text{ mm}$ .

The thickness of one layer of the fiberglass blanket was estimated to be 0.294 mm by measurements with the pachymeter, and therefore  $(1.95 \text{ mm}) / (0.294 \text{ mm}) = 6.63 \approx 7$  layers of glass fiber cutouts in the appropriate format were required, which is outlined in Fig. 21.



**Figure 21. Model for cutting the layers of fiberglass.** *Paper model made by the team.*

The model mentioned above consists of a nylon mold manufactured specifically for the making of the nose cone. It is important to note that the length of the mold should be greater than the length of the nose cone, because the end portion of the fiber fabric curves near the table support plane, disabling this portion. Because of this, the mold has a groove to mark the position of the final cut for finalizing the part.

In order to extract the part from the mold without having to cut it (which compromises its final shape and mechanical properties), the mold has an extractor system. This system is composed of a threaded rod axially fixed there in which a ring is fitted, adjusted to the diameter of the base of the mold, which in turn is pushed by a disk drawn by a nut (using a wrench), as shown in Fig. 26. Note that, because of the threaded rod, a base (a metal cylinder, in this case) is required to support the mold on a table.



**Figure 22. Extractor system.** *Extractor made of nylon.*

The manufacturing process begins with the preparation of the worktable, which is lined with a non-stick plastic. The preparation of the mold consists of passing a release agent with the aid of a tow on its surface in order to

facilitate decoupling of the nose cone after the curing process. The materials needed for subsequent steps are two paintbrushes, a pair of disposable gloves, a plastic cup and a digital scale. At this time, 100 g of Araldite LY-5052 epoxy resin is placed in the beaker, thereafter adding 37 g of ARADUR HY-5052 catalyst. The mixture is homogenized for a few minutes until the formation of rising bubbles, which characterizes the desired viscosity, is observed. The first cut of fiberglass (one of the seven layers) is then placed on the surface, and thereafter the operator will brush the resin / catalyst blend onto the fiberglass mat until the fabric is translucent and adheres to the mold surface (for this, strong brush strokes are recommended in order to ensure impregnation of the fiber by the resin). This process is repeated until the seven layers are brushed and adhered to the mold. At this point, we can make an important caveat: the layer to be brushed over the previous layer of fiberglass should be placed with a certain angle of lag, so that possible spans can be evenly distributed. At the end of the process described, the piece is left to cure for 24 hours or more.



**Figure 23. Fiber lamination process.** *Nose cone after impregnation of the fiber by the resin. It is important to notice the lag between the layers illustrated in the red lines.*

After the newly manufactured part is cured, the decoupling process begins. Due to mechanical difficulties in removing the nose cone from the mold, after numerous unsuccessful attempts to push it upwards to separate it, we made use of some thermal properties of the parts constituting the system. The coefficient of linear expansion of the nylon that composes its part is almost nine times greater than that of fiberglass. Upon cooling the system, the mold was expected to contract much more than fiber and assist in the decoupling process.

After 4 hours in the refrigerator, the ring and the metal disk that compose the extraction system were coupled to the base of the nose cone. The threading of the nut was then performed to generate a force that moved the fiber out of the mold. Lacking much force in relation to the decoupling process of the nose cone without refrigeration, the nose cone was easily extracted from the mold.

With the decoupled nose cone, the process of smoothing its surface begins with the use of Primer, a compound used in the aeronautics industry with high chemical and mechanical resistance and anticorrosive properties. In this context, 100 g of Primer and 1 g of the respective catalyst are placed in a beaker (now made of glass). After homogenizing the system, the nose cone is covered with this blend by brush strokes. The total healing time is 4 to 5 days. After this time, its surface was sanded with a hard sandpaper until it became approximately smooth and without irregularities, then applying the spray with the desired tonality as can be seen in Fig. 24.



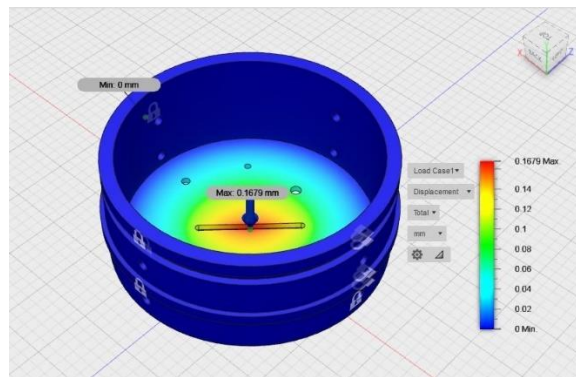


**Figure 24. Finished nose cone.** After the sanding process, surface smoothing and painting.

### 5. Bulkhead

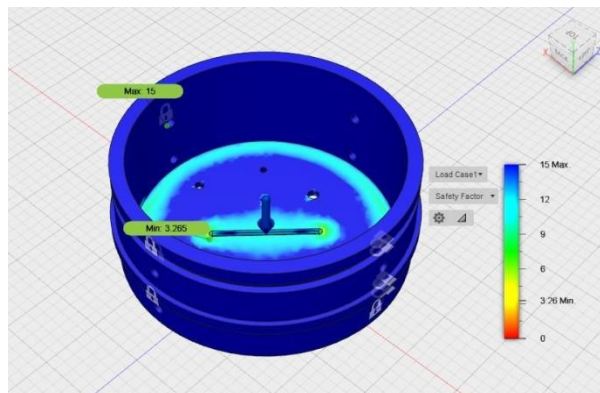
Simulations were carried out in order to determine the effects of the deflagration of the gunpowder on the activation of the recovery system. The expansion of gases generates an estimated force of 130 kgf on the indicated face of the bulkhead in Figs. 25 and 26. The complete configuration is:

- structure made of 6351-T6 aluminium
- 3 mm thickness of the analyzed surface



**Figure 25. Deformation of bulkhead.** Distribution of the deformation in the component after suffering the action of the forces generated by the explosion of the gunpowder.

Figure 25 shows the deformations found by static stress simulation in Autodesk® Fusion 360™. As can be seen, the maximum deformation during the process is estimated to be 0.1679 mm.



**Figure 26. Safety factor of bulkhead.** Distribution of the bulkhead's safety factor after suffering the action of the forces generated by the explosion of the gunpowder.



Another important step of the analysis is to ensure that the component will not undergo permanent deformations or disruption when subjected to the deflagration of gunpowder. For this, the safety factor was analyzed. The safety factor guarantees that for values greater than 1, no structural disruption or permanent deformations will occur<sup>4</sup>. The safety factor calculated by the software was 3.265, which ensures that structural failures will not occur due to the activation of the recovery system.

#### 6. Payload section

The tube for the payload module was previously wound with carbon fiber, which inhibits the passage of electromagnetic waves through its surface and therefore makes it difficult to ground contact with the embedded rocket electronics. Aiming to reconcile structural strength to electromagnetic transparency, ensuring communication telemetry with the rocket in this project, the payload tube will be also coiled in composite material, but in fiberglass.

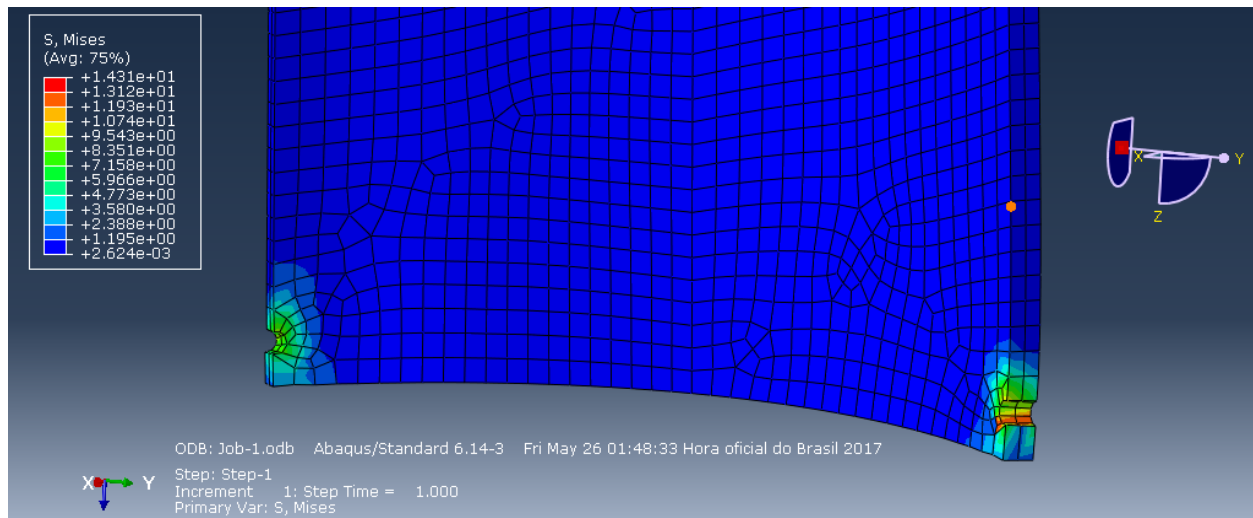
Having a lower tensile structural strength than carbon fiber, a structural simulation of the fiberglass tube has been required to ensure that it withstands the stresses to which the rocket will be subjected during flight, especially during the opening of the parachute. The purpose is to calculate the required thickness of the tube to ensure that the bolts do not break the tube during the opening stride.

The structural simulation was performed using the Rayleigh-Ritz finite element method in Abaqus® software. The mechanical properties used in the simulation for the fiberglass composite were taken from literature<sup>5</sup>, considering the winding angle of their manufacture ( $\pm 45^\circ$ ), and are outlined in Table 2.

**Table 2. Mechanical properties of the fiberglass. Data used for structural simulation.**

Winding angle	$\pm 45^\circ$
Ultimate tensile strength (MPa)	62.0
Modulus of elasticity (GPa)	15.2
Poisson Ratio	0.19
Density (g/cm <sup>3</sup> )	1.54

The simulation results showed that the maximum stress observed in the holes according to the Von Mises yield criterion is 14.3 MPa and therefore the tube will withstand the stresses that it will be subjected to during the flight. The loads and stresses in the holes resulting from the simulation are shown in Fig. 27.



**Figure 27. Simulation of electronics module tube. Scale of stresses observed in the holes when the tube is subjected to traction forces. The estimated maximum is 14,3 MPa according to the Von Mises yield criterion.**

#### 7. Reinforcement of the fins

In order to ensure greater stiffness to the fins, a primer epoxy resin was applied on them with a brush. This resin, in addition to offering greater structural strength, fills the pores in the fin, which makes painting them easier.

## **E. Recovery Subsystem**

The recovery system was built as follows: Two StratoLoggers (COTS), used in this quantity for redundancy in their functionality, constantly monitor the rocket's altitude through the measurement of air pressure. When either of them detects apogee, they trigger the detonation of a charge cup, which pressurizes the drogue parachute chamber, breaks the shear screws that keep it locked, divides the rocket in two, and releases the drogue parachute in sequence. The estimated terminal velocity at this phase of flight is 25 m/s. The rationale behind a low terminal velocity for the drogue was to minimize the impact on the rocket structure when the main parachute is released.

When the StratoLoggers detect 700 ft AGL after apogee, they release the Main parachute from its independent chamber in the same way as the drogue parachute in the previous deployment event. The main parachute should slow the rocket down to a speed of 5 m/s for touchdown.

This system was flight-tested on 2017 IREC with the nominal flight of RD-07. Minimum changes were made, none of them affecting the system functionality: coupling interfaces shown on Appendix F, Fig. F.1 and F.2, had a mass reduction, and electronics supports were redesigned in order to optimize integration and tests processes.

## **F. Payload Subsystem**

The payload will be a functional, 8.8 lb technology demonstrator on CubeSat format. It will test the viability of using a CO<sub>2</sub> canisters ejection system for future recovery applications. As the recovery subsystem is extremely important for the success of the mission, the team considers it is safer to partially test different methods in flight before applying them. Our intention is to test whether the gas ejection of CO<sub>2</sub> canisters will happen during flight at the intended time of parachute deployment. The CO<sub>2</sub> canisters system will not be connected to the recovery system, being independent from the other parts of the rocket. It will have its own altimeters system to detect the time to act. It will not separate parts of the rocket. We will use pressure and temperature sensors, connected to a microcontroller, to detect if the CO<sub>2</sub> canisters gases were ejected at the correct time. This way, we will check if the system can support the acceleration and vibration of the rocket during flight and provide pressure to deploy chutes.

## **G. Electronics Subsystem**

The main objective of the electronical project is to acquire and transmit critical data, it means, acquire GPS and sensors data (accelerometer, magnetometer, barometer and gyrometer) and transmit latitude, longitude and altitude. By doing so, we will be able to track and locate it during the flight and reconstruct its trajectory.

The GPS assembly in the nose cone consists of a three-layered electronic board. The first board is an Arduino MEGA for data processing. Right above it, there is a board (designed by the team) consisting of a PAM-7Q u-blox module (GPS module), one 3V battery and one logic level converter. Finally, there is an XBee shield for communication with an XBee PRO900 for communication with one Yagi antenna at the ground station. Attaching all these boards, we have a location system to obtain the rocket's location in real time.

The sensors are right above the payload and acquire data of pressure, acceleration, magnetic field and orientation using an IMU GY-80. As a matter of redundancy, there are two different boards. One of them only acquire sensors data, while the other acquire both sensors and GPS data. It is important to highlight that every data acquired in-flight are written into SD cards in order to increase its reliability.

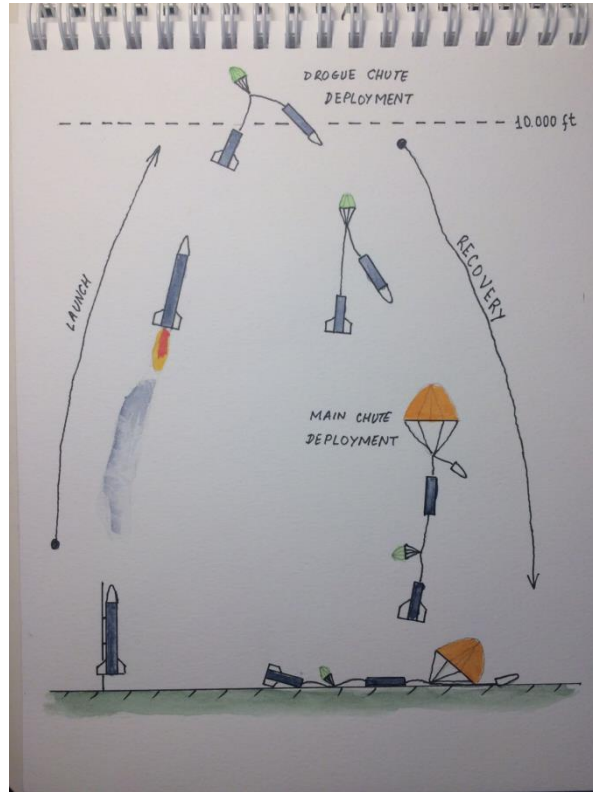
As a post-flight analysis, we developed a quaternion-based Kalman Filter for position, attitude and linear velocity estimation using the data acquired in flight. This filter enables us to reconstruct the trajectory. By doing so, we will significantly improve the modeling of the rocket and, therefore, increase its reliability.

Another safety system implemented by the team is an umbilical power system. The main function of this external battery is to supply power while the rocket is at the ground station to keep the electronics working avoiding draining its internal battery. The implementation used a simple diode OR logic switching between the internal and the external battery. The internal battery chosen was a 9.9V LIFE battery due to its thermal resistance (doesn't explode and reasonably keeps its voltage), high energy density and high current capability to endure inrush current. The external battery is a high electrical charge 12V stationary battery. It is important to highlight that we used Schottky diodes due to its low forward voltage, which means low power dissipation.

The GPS data transmission were calculated to send data at a rate of 10kbps at a maximum distance of 10km, in case we face strong winds and the main opens in the apogee. Using high power XBee (250mW) with a rubber duck 3dBi antenna and receiving with an 14dBi Yagi antenna with an XBee with -110 dBm @ 10kbps sensitivity, applying the Friis Transmission Equation, we will receive a signal 10000x stronger than our sensitivity. Therefore, even considering the nose cone and environment losses, we will have a smooth data transmission.

### III. Mission Concept of Operations Overview

The mission concept of operations is of a launch with a two event recovery. The first recovery event is the deployment of the drogue chute at apogee. From apogee the rocket falls under the drogue chute until a preset height at which the onboard avionics deploys the main chute. From the second event, the rocket falls under the main chute until touchdown. Fig. 28 shows it in detail.



**Figure 28. Detailed CONOPS.** *Flight scheme from launch to landing.*

### IV. Side Projects

Along with the main project mission for the 2018 Spaceport America Cup, the team handled several side projects that were considered important for the development of the aerospace engineering and rocketry areas in Brazil. These side projects are listed in their entirety in the following subsections.

#### A. COBRUF

COBRUF is the "Brazilian University Rocket Competition". It was created in 2015 and is specifically inspired by IREC. It takes place in the city of Natal (RN), and its objective is to spread Aerospace culture across the country, stimulating the creation of other rocket design teams. Our team was one of the pioneers, joining the competition in its first edition and winning the 1st Place Prize among the 13 participating teams. Last year, the competition had its second edition, in which the number of participating teams was 24. In 2017 edition, the ITA Rocket design team participated only in the scientific-computational project category and won the first place again. In addition, the member Arthur Durigan Bahdur won the award for best oral presentation and the team made an extra presentation as an award due to a social network video about the scientific-computational project. The publication of the video was a requirement of the competition.

#### B. STEM<sup>2</sup>D Project

The project STEM<sup>2</sup>D aims to encourage girls of all ages to get interested in the fields of STEM, which are science, technology, engineering, manufacturing, math and design. At ITA, the single headquarter of STEM<sup>2</sup>D in Brazil, the project is composed of female teachers and female students of the Institute in a partnership with Johnson&Johnson Company.

The current project acts on many fronts and has six subgroups that are:

- Workshops: this subgroup works with hands-on projects in public schools, in parks and in events in ITA, in order to show the STEM areas to girls of all social classes, democratizing their access to this knowledge. Workshops events lasts one day.
- Mentoring: this subgroup supports 24 girls of around 13 years old to help them in their personal and social development. There are weekly meetings where topics such as “How I imagine myself in the future?”, “Empathy with other women”, “Do I know all the careers?”, etc are discussed.
- Engineering project: this subgroup is responsible for recruiting 15 girls of around 15 years old to do an engineering project during the year. In 2018 the project is an amateur radio. There are also classes to teach them all the concepts about this technology.
- Universities: the main idea of this subgroup is to democratize the material that we use at the Institute to other universities in order to increase the number of women interested in spreading knowledge about STEM all over the country.
- Marketing: this subgroup is responsible for posting on Facebook and on Instagram all the activities we have and all the events we organize.
- Events: this subgroup is responsible for organizing events and seminars for the ITA female students and other big events, such as “Liderança Feminina” (Female Leadership), which, this year, had the participation of Donna Hrinak, the Latin America Boeing’s president. Also, we organized “Dia da Engenharia” (Engineering Day), that gathered students of many public schools to work on one day projects.

### **C. Model Rocket Project**

Every year, the team receives new members and trains them, so they can effectively participate in the challenging projects. This year, our model rocket project played a big role in the process of learning and practicing rocketry for our new members.

After a cycle of basic training in each subsystem, the newcomers were divided in two teams of six, and each was responsible for developing a model rocket on their own. Working on such a project for the first time allowed the new members to learn simple, but important principles in rocketry. Also, the project was an important opportunity of practicing important safety protocols, paramount to every rocketry operation.

After simulating and planning the behavior of the rocket, it was then modeled, and 3D printed in PLA plastic. Then, they performed static fire tests and flight tests, each followed by performance analysis, and design corrections. All these steps allowed both teams to successfully design, build, and fly a model rocket for the first time.

### **D. Development of a new propellant**

In view of an accident in the production of propellant known as KNSB, the team decided to go in search of a new formulation for its propellant. In partnership with the Chemistry Department of the Aeronautics Institute of Technology, a propellant was developed using epoxy and potassium nitrate. It has the advantage over the sugar propellant of not heating the energy material at any moment of its manufacturing. In order for the new formulation to provide sufficient energetic conditions to replace the old formulation, some components such as aluminum were added to the polymer matrix of the epoxy. In addition, studies such as static tests and DSC's were performed to obtain data of each manufactured formulation. For the use of any of the manufactured formulations to be viable, more tests are needed. In conclusion of the research project it has been that the use of aluminum and some other compounds to improve the performance of the epoxy propellant make it a viable alternative to KNSB.

### **E. Development of a kinetic model of combustion of propellant based on potassium nitrate and sorbitol**

To characterize better the propellant used in the manufacture of the team's own motors (KNSB), and in order to obtain information about the design of the igniter used and energy information that keeps the operation of our motor safer, a project research with the Chemistry Department of the Aeronautics Institute of Technology to develop a kinetic combustion model of the KNSB is in development. For this, energy tests such as DSC and TGA were performed to serve as experimental data to compare the data from the theoretical model. Currently, the project is in the development phase of computational models based on kinematic chemistry theory.

## **V. Conclusions and Lessons Learned**

Several conclusions could be drawn from the experiences of the project development. In a technical sense, it was perceived through flight experience during the competition noticeable difference between the designed and real

apogee height of last year's project. To better understand the reasons of the said difference we chose to perform a wind tunnel test of our rocket using one of our university's subsonic wind tunnels. We have learned a lot about how to integrate the rocket structure to the wind tunnel's measurement apparatus and that computer fluid dynamics is only an approach to estimating values and not an absolute truth. With the results of the wind tunnel test, we believe our designed apogee height will be much closer to the target.

One specifically insightful lesson learned was about the design approach regarding mass. We have noticed that optimizing excessively a rocket's weight might not be ideal if in the end we might need to add weight to calibrate our system to reach the target altitude.

The final technical aspects of the rocket that were learned pertain to the flight mechanics. With the end of last year's project cycle, a great deal of experienced members of our team that worked on flight simulation graduated and were no longer part of the team. To circumvent this problem, we took a great effort to document previous year's design processes that used flight mechanics simulations. Now our methods for simulation of apogee height are thoroughly documented and a new member of the team can improve on previous experiences and does not need to waste time and effort on "reinventing the wheel" every year.

Furthermore, from a management perspective, it was found that the development would have been more efficient if it had the tasks been better divided among members of the team, given that many times an individual member would be overloaded with tasks and would therefore become inefficient in completing them. Another conclusion regarding management was to have the progress of the team's knowledge in mind when planning the project's activities, i.e. develop the project so that future projects can build up from it instead of having to start from scratch.

Finally, to optimize the transmission of knowledge from the senior students to the new members of the team, the best observed method was to organize all lessons achieved during development in an organized manner through thorough documentation of processes.

## Appendix A. System Weights, Measures and Performance Data

<span style="font-size: 24px; font-weight: bold; margin: 0 10px;">Spaceport America Cup</span>																					
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<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <b>Demographic Data</b> <p><small>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.</small></p> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> <div> <b>Number of team members</b> </div> </div> <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <tbody> <tr> <td style="width: 30%;">High School</td> <td style="width: 10%; text-align: center;">0</td> <td style="width: 30%;">Male</td> <td style="width: 10%; text-align: center;">17</td> </tr> <tr> <td>Undergrad</td> <td style="text-align: center;">18</td> <td>Female</td> <td style="text-align: center;">3</td> </tr> <tr> <td>Masters</td> <td style="text-align: center;">2</td> <td>Veterans</td> <td style="text-align: center;">0</td> </tr> <tr> <td>PhD</td> <td style="text-align: center;">0</td> <td>NAR or Tripoli</td> <td style="text-align: center;">0</td> </tr> </tbody> </table> <p><small>Just a reminder the you are not required to have a NAR, Tripoli member on your team. If your country has an equivalent organization to NAR or Tripoli, you can cant them in the NAR or Tripoli box. CAR from Canada is an example.</small></p> </div> <div style="width: 45%;"> <b>STEM Outreach Events</b> <div style="background-color: #f8d7da; padding: 10px; margin-top: 10px;"> <p>Our team took part in an event organized jointly by our university (ITA) and the company Johnson&amp;Johnson called "Mulheres em STEM" (women in STEM) to encourage women to pursue careers in Science, Technology, Engineering and Mathematics. This is more discribed more detailed in the 73_Project report</p> </div> </div> </div>		High School	0	Male	17	Undergrad	18	Female	3	Masters	2	Veterans	0	PhD	0	NAR or Tripoli	0				
High School	0	Male	17																		
Undergrad	18	Female	3																		
Masters	2	Veterans	0																		
PhD	0	NAR or Tripoli	0																		



## Rocket Information

Overall rocket parameters:

	Measurement	Additional Comments (Optional)
Airframe Length (inches):	96	
Airframe Diameter (inches):	6	
Fin-span (inches):	7.5	radial fin size (semi-span): 3.75 inches
Vehicle weight (pounds):	48.09	
Propellant weight (pounds):	10.57	
Payload weight (pounds):	8.8	
Liftoff weight (pounds):	67.46	
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 Technology , Pro98 9955M1450-P , M Class, 9955 Ns

Total Impulse of all Motors:	9955	(Ns)
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### 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:	8	
Launch Rail Departure Velocity (feet/second):	84.15	See 'more information' box
Minimum Static Margin During Boost:	1.5	*Between rail departure and burnout
Maximum Acceleration (G):	8	
Maximum Velocity (feet/second):	840	
Target Apogee (feet AGL):	10K	
Predicted Apogee (feet AGL):	10189	

## Payload Information

### Payload Description:

The payload will be a functional, 9 lb technology demonstrator on CubeSat format. It will test the viability of using a CO2 canisters ejection system for future recovery applications. As the recovery subsystem is extremely important for the success of the mission, the team considers it is safer to partially test different methods in flight before applying them. Our intention is to test whether the gas ejection of CO2 canisters will happen during flight at the intended time of parachute deployment. The CO2 canisters system will not be connected to the recovery system. It will have its own altimeters system to detect the time to act. It will not separate parts of the rocket. We will use pressure and temperature sensors, connected to a microcontroller, to detect if the CO2 canisters gases were ejected at the correct time. This way, we will check if the system can support the acceleration and vibration of the rocket during flight and provide pressure to deploy chutes.

## Recovery Information

The recovery system will be built as follows: Two StratoLoggers (COTS), used in this quantity for redundancy in their functionality, constantly monitor the rocket's altitude through the measurement of air pressure (barometric trigger). When either of them detects apogee, they trigger the detonation of a charge cup (black powder deployment energy source), which pressurizes the drogue parachute chamber, breaks the nylon shear screws that keep it locked, divides the rocket in two, and releases the drogue parachute in sequence. The estimated terminal velocity at this phase of flight is 25 m/s. The rationale behind a low terminal velocity for the drogue was to minimize the impact on the rocket structure when the main parachute is released. When the StratoLoggers detect 700 ft AGL after apogee, they release the Main parachute from its independent chamber in the same way as the drogue parachute in the previous deployment event. The main parachute should slow the rocket down to a speed of 5 m/s for touchdown. This system was used on 2017 IREC/SA CUP on RD-07 project and it worked perfectly (150/150 recovery points, nominal flight)

[illegible][illegible]

**Any other pertinent information:**

Launch Rail Departure Velocity: Our rail departure velocity is expected to be of 90 ft/s based on computer simulation of our rocket's configuration. The design and rail departure velocities were approximately kept the same regarding the design of last year's rocket (Team id 25 for 2017) and the flight and exit from the ramp was nominal. A 6 Degrees of Freedom (6 DoF) flight mechanic analysis and aerodynamic analysis are described on the Project Technical Report (73\_Project Report.docx - 2018) and validate the flight stability.

End of File

## Appendix B. Project Test Reports

The following tests were performed in order to ensure the successful operation of the recovery system:

### **Test 1 – Parachute “table-top” simulated ejection**

This test’s objective is to verify if the components in the recovery system are appropriately accommodated inside the tubes and if, when the command for deployment is sent, the parachutes and lines will perform their functions without tangling or colliding. In other words, it is a manual simulation of the recovery’s sequence of operations/CONOPS. The test was successful and a video of the test was sent to the judges’ appreciation (a copy is also available on our facebook page).

### **Test 2 – Parachute ejection test with pyrotechnic charges (black powder)**

This test’s objective is to verify if the black powder used is enough to shear the nylon screws that hold the parachute compartment closed and verify the sealing between parachutes compartments and Stratologgers bay. With all the recovery components integrated, the squibs terminals are connected to wires over 10m long. At the end of the wire, a regular 6V, 9V or 12V battery is connected at the proper time in order to detonate the black powder and eject the parachutes.

### **Test 3 – Parachute visual verification, inspection and inflation test**

Used to verify the integrity of both main and drogue parachutes. A person holds a parachute and runs with it, inflating it. This test helps us identifying possible tears, holes and other deformities, which affect the parachutes efficiency.



**Figure B.1. Recovery avionics bay.** *The redundancy implemented can be observed by the two parallel and equal circuits of Stratologgers.*

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## **Appendix C. Hazard Analysis**

Since the ITA Rocket Design team has a propulsion system and uses pyrotechnics for its recovery system, the hazard analysis is of high importance to us. These systems must have a hazard analysis on the systems loading with the active materials, the integration of the system on the rocket, and on the system tests. The following subsections present a complete description of all the safety procedures adopted by team in detail. At the end of the Appendix, Table C.1 compiles all of the information presented in a hazard analysis matrix.

### **A. Propulsion hazard analysis**

In the propulsion subsystem, the major factor of risk is the assembly and loading of the COTS motor. In these steps, there is a risk of fire in the grains, and after loading and closing the nozzle, a risk of explosion, so there are some rules of security that must be followed:

- 1) It is prohibited to work alone, but the number of operators working simultaneously must be kept at a minimum to accomplish the activity;
- 2) All operators and the motor must be grounded;
- 3) The use of PPE is mandatory;
- 4) The motor can only be closed at the site of the flight, for more security on the transport.
- 5) After the motor is loaded and closed, and the rocket has been mounted and placed in the base, a single operator proceed to insert the igniter.

### **B. Recovery system hazard analysis**

Since the recovery system uses pyrotechnics to eject the parachutes, there must be a hazard analysis for its pertaining procedures.

#### *1. Integration of the system*

- 1) It is prohibited to work alone, but the number of operators working simultaneously must be kept at a minimum to accomplish the task;
- 2) The use of PPE is mandatory during the whole integration of the system;
- 3) There must be a clear area of at least 5 meters, where only authorized personal is allowed inside;
- 4) All operators must be grounded during the entire process.

#### *2. Testing*

- 1) The testing procedure follows items 1) through 3) listed in sub-subsection B.1;
- 2) In case of hang fire of the system, the wires are disconnected and there must be a minimum wait of 3 minutes before anyone is allowed in the clear area.

### **C. Fiberglass handling**

Since the team works with a considerable amount of fiberglass to manufacture the nosecone, there are some risks to this activity, here are listed some procedures to mitigate the risks:

- 1) Use latex gloves and masks with filters for handling the fiberglass fabric;
- 2) Since the resin curing process is exothermic, it can go out of control and, if so, the operators must change from the latex gloves to thermal ones and dispose safely of the mixture.

**Table C.1. Hazard Analysis Matrix.** *A compilation of all potential hazards to operating personell in the project.*

<b>Team: ITA Rocket Design (ID 73)</b>	<b>Rocket/Project Name: RD-08</b>	<b>Date: 05/25/2018</b>		
<b>Hazard</b>	<b>Possible Causes</b>	<b>Risk of Mishap and Rationale</b>	<b>Mitigation Approach</b>	<b>Risk of Injury after Mitigation</b>
Rocket deviates from nominal flight path, comes in contact with personnel at high speed	Incorrect fin design	High; unknown weather conditions at the launch site or incorrect launch procedures	Check empirically the position of the CG and the CP and the weather conditions at the time of flight	Medium
	Launch pad pointed at wrong angle		Check the structure of the launch pad and its launching angle	Low
Recovery system fails to deploy, rocket or payload comes in contact with personnel	Stratologger fails to detect apogee	High; student built recovery system with limited testing	Design system with redundancy and do ground tests	Medium
	Stratologger fails to provide current to ignite squib		Design system with redundancy and do ground tests	Medium
	Parachutes fail to come out of the rocket		Do ground tests	Medium
	Personnel at prohibited area during launch		Make area check for clear area before launch	Medium
Recovery system partially deploys, rocket or payload comes in contact with personnel	Stratologger fails to detect apogee	Medium; student built recovery system with limited testing	Design system with redundancy and do ground tests	Low
	Stratologger fails to provide current to ignite skib		Design system with redundancy and do ground tests	Low
	Parachutes fail to come out of the rocket		Do ground tests	Low
	Personal at prohibited area during launch		Make area check for clear area before launch	Low
Recovery system deploys during assembly or prelaunch, causing injury	Short circuit	High; electronics systems plugged with pyrotechnics	Check connections before turning the system on	Medium
	Static charge		Ground system and operators	Low
	Stratologger misreading		Turning the stratologger with the pyrotechnics on only when vehicle is assembled and on the launch pad	Medium

			Making sure all operators are using PPE	Low
Fiberglass resin coming into contact with the skin, causing injury	Lack of PPE	Low; Manufacturer might be uninformed of the resin's toxic characteristics	Instruct manufacturer to wear the appropriate PPE at all times	Minimum
Main parachute deploys at or near apogee, rocket or payload drifts to highway(s)	Stratologger misreading	Medium; student built and untested on-flight recovery system	Ground tests	Low
	Failure of the recovery system structure		Ground structural testing of the system	Low
	Incorrect clear area zone		Correct zoning of the clear area with dispersion simulations	Low
Rocket does not ignite when command is given ("hang fire"), but does ignite when team approaches to troubleshoot	Stratologger wires for main and drogue charge cups switched	High; operators within the danger zone of a fully assembled motor or rocket	Use different colours of wires and label them. Do ground tests	Minimum
	Static charge from the operator		Making sure all operators are grounded as well as the motor	Medium

## Appendix D. Risk Assessment

The risk assessment matrix is a compilation of all failure modes considered by the team to be relevant to the system's reliability and that can possibly affect the missions's success, their possible causes, risk of happening, following mitigation approach, and risk of failure after mitigation. It is represented by Table D.1.

**Table D.1. Risk Assessment Matrix.** *A compilation of all failure modes that are relevant to the system's reliability and can potentially affect the mission's success.*

<b>Team: ITA Rocket Design (ID 73)</b>	<b>Rocket/Project Name: RD-08</b>	<b>Date: 05/25/2018</b>		
<b>Risks</b>	<b>Possible causes</b>	<b>Risk of mishap and rationale</b>	<b>Mitigation approach</b>	<b>Risk of failure after mitigation</b>
Explosion of the COTS motor	Cracks on the grain;  Errors in the design of the nozzle or the case;  Pressure generated by combusting the propellant having greater magnitude than projected.	Low; it is s a motor that has been made in a production line and tested extensively and completely.	Choose a reliable seller.	Minimum.
Assembly of the COTS motor with the rocket not being possible	Misunderstanding of the technical drawing;  Errors on the dimensions of the pieces of the motor.	Medium; The team does not have the motor available for testing before arrival in the USA, but is experienced in the interpretation of technical drawings.	Study the motor and simulate assembly of entire rocket with a 3D-printed motor repeatedly.	Low.
Instability of the CG because of the COTS motor	There is no knowlegde of the exact position of the motor's CG.	High; it is necessary to know the position of the motor's CG to project the fins.	Estimate the grain's CG, the motor's CG and the CG of the loaded motor, to allow for a better approximation for the entire rocket's CG.	Low.
GPS not operating during propulsive phase	Acceleration GPS suffers is above its capacity, which is 4g.	High; The GPS module is not designed to operate during these stages of flight.	Designing part with sturdiness so it can operate normally after propulsive phase.	Low.
Losing GPS signal	Rocket landing far from base camp;  Apogee point far from base camp.	High; Signal strength in the desert is not reliable.	Use of Yagi directional antenna to increase power gain and therefore transmission range.	Low.

Components running out of power	Long period of time between rail fixation phase and ignition phase.	Medium; There can be a long wait until conditions are favorable enough for ignition phase.	Applying more durable batteries in a greater amount.	Minimum.
Components subduing to structural strains.	Massive acceleration of up to 10g during propulsive phase.	Medium; The safety factor required for the accelerations expected during the propulsive phase is large.	Producing components with increased thickness;  Apply more resistance when soldering components, making the filler metal thicker	Low.
Interference of the signals being transmitted.	Excessive use of Radio Transmissions around line of transmission between GPS and base of operations.	High; The GPS Works with weak signals, and thus any other radio frequency transmission can generate noise.	Placement of ground plane under the GPS's antenna;  Furthering distance between antenna and the circuit's noise generating elements, such as the microcontroller and the Xbee.	Medium.
Static margin falling out of the range between 1.5 and 2	Significant difference between the CG used for calculation and real CG	Low; The CG was calculated in software simulations by <i>Autodesk Fusion 360</i> and measured in the real rocket after the assembly test without the motor, but there was no integration test of the rocket with the engine.	Thorough computational analysis so that the rocket could remain stable in a wider position interval for the CG, as well as obtain a more precise value of the motor's mass.	Minimum
Recovery system failing to deploy	Failure in Stratologgers-squibs circuit due to rupture in a wire, Stratologger disconnecting, and/or batteries running out of power;  Shear screws not breaking after black powder detonates due to being overdimensioned.	Medium; Student-built components with limited testing	Dual redundancy Stratologger-squibs circuit;  Recovery deployment ground tested	Low



Recovery system deploying during assembly or prelaunch	Electrostatic discharge (detonating black powder) due to contact with charged bodies during assembly;  Stratollogger detecting high pressure variations during assembly or transportation to launchrail due to strong air currents.	Low; It would take unusual conditions to trigger these events, but there is still a likelihood worth considering.	Use of antistatic mat during assembly;  Use of Remove Before Flight (RBF) system, closing the Stratollogger circuit only when the rocket is mounted on the launchrail.	Minimum
Main parachute deploying at or near apogee	The main chamber's shear screws breaking with drogue deployment, during liftoff, assembly or transport to launchrail due to acceleration after drogue deployment;  Stratollogger detecting a drop of altitude due to gas escape from drogue chamber due to the possibility of its pressure being very high.	Medium; Student built parts with limited ground testing and no flight test.	Use of 8 M3 nylon screws on Main compartment, designed to withstand over 130kgf of force;  Use of a slider to reef Drogue;  Verifying screws at launchrail;  Ground testing the sealing between Drogue compartment and Stratologgers bay.	Low
Main or Drogue Parachute not inflating after ejection	Humid environment;  Parachutes lines, slider, shock cord or canopy getting tangled	Medium; Student developed mechanism with limited testing.	Use of baby powder while packing parachutes;  Appropriate folding techniques and ground tests	Low
Accelerated epoxy reaction between resin and catalyst during fiberglass manufacturing process	Non-uniform mixing of the blend;  Excess in the addition of catalyst, exceeding the desired ratio.	Low; the mixture is gently stirred until the formation of the first bubbles and the mass of the catalyst is carefully measured.	Precisely measure the mass of resin and catalyst;  Stir the mixture gently; Use glass cups for the mixture and PPE's.	Minimum.
Fiberglass tube of payload section breaking during flight.	Strong stride on parachute opening.	Low; a finite element simulation was performed to measure the tensile stress of the bolts in the tubes, which were designed to withstand these forces.	Perform computational simulations to measure tensile stresses and establish a conservative safety factor.	Low.

## Appendix E. Assembly, Pre-Flight and Launch Checklists

REC MATERIALS CHECKLIST	Check?
<b><u>Manufactured Aluminum joints</u></b>	
2 Aluminum Joints (REC Electronics bay)	
1 Aluminum Coupling Joint (Payload-REC)	
1 Aluminum Coupling Joint (Nose Cone-REC)	
1 Aluminum Board	
<b><u>Carbon Fiber Tubes</u></b>	
1 Carbon Fiber tube (Main)	
1 Carbon Fiber tube (Drogue)	
2 Carbon Fiber half-tubes (Electronics bay)	
<b><u>Screws/fixation</u></b>	
2 M8 Eyebolts (with screw)	
2 M8 washers	
2 M8 nuts	
26 M6 screws	
2 M6 nuts	
8 M3 screws	
8 M3 nuts	
8 M3 washers	
8 M2,5 female spacer screws	
16 M2,5 screws	
16 M2,5 nuts	
16 M2,5 washers	
16 Nylon M3 screws	
<b><u>Electronics/supports</u></b>	
2 Stratologgers	
2 9V batteries	
2 battery clips type 1- Horizontal	
2 PLA 9V battery supports	
4 Zipties	
2,20m 22AWG wire (4x20cm + 4x20cm + 4x15cm)	
2 NO/NC switches (RBF)	
2 PLA RBF supports	
2 RBF rods with RBF red stripe	
Heat shrinkable tube	
4 terminal block connectors	
<b><u>Pyrotechnicals/Supports</u></b>	
GunPowder	
4 E-mathces	
2 cut syringes	

1 tow bag	
Tape	
2 plastic cups	
<b>Sealing</b>	
4 O-rings	
Silicon Tube	
<b>Parachutes, cords and links</b>	
1 Drogue Parachute	
1 Main Parachute	
2 Wire rope clips	
2 Swivels	
1 Main Parachute bag	
2 Nomex Blankets	
10m shock cord	
4m shock cord	
2m shock cord	
1m shock cord	
6 Quick links	
Baby Powder	
Parachute folding GSE	

REC TOOLS CHECKLIST	Check?
<b>Tools</b>	
M6 Allen wrenches	
Precision wrenches kit	
Lighter	
Scissor	
Multimeter	
Precision scale	
<b>PPE</b>	
1 Anti-static mat	
1 Anti-static wrist strap	
2 Anti-static gloves	
3 safety glasses	
2 safety coats	

REC ELE-BAY ASSEMBLY CHECKLIST TASKS	Check?
<b>Preliminar</b>	
Separate materials listed on <u>REC Materials Checklist</u> and <u>REC Tools Checklist</u>	

Crimp 22AWG wires (12 wires, 3 colors, 4 wires per color) and battery clips wires		
<b><u>Aluminum Board</u></b>		
Place both 2 PLA 9V battery supports on the aluminum board		
Fix the supports with 8 M2,5 female spacer screws, 8 M2,5 nuts, 8 M2,5 washers, 8 M3 screws, 8 M3 nuts, 8 M3 washers		
Fix both 2 Stratologgers over the 8 M2,5 female spacer screws with 8 M2,5 screws		
Connect 2 battery clips on 2 9V batteries		
Place both 2 9V battery on the PLA battery supports		
Fix battery on PLA battery supports with zipties		
Connect the battery clips wires on the stratologgers		
Fix 4 AWG wires, color 1 (____), on drogue terminals of both stratologgers		
Fix 4 AWG wires, color 2 (____), on main terminals of both stratologgers		
Identify wires with tape for each stratologger (S1 and S2)		
<b><u>2 Aluminum Joints (REC Electronics bay) (drogue and main sides)</u></b>	<b><u>drogue</u></b>	<b><u>main</u></b>
Identfy aluminum joint with tape (Drogue or Main)	-	-
Place O-ring on Aluminum joint		
Weld 2 AWG wires, color 3 (____), on terminals Normally Closed and Commom of NO/NC switch		
Place heat shrinkable tube over the welds and heat it with lighter		
Place PLA RBF support over the switch		
Fix RBF switch on Aluminum joint with 2 M2,5 screws, washers and nuts		
Fix 2 terminal block connectors on aluminum joints with 2 M2,5 screws, washers and nuts		
Fix cut syringe on aluminum joint with 1 M6 screw, washer and nut		
<b><u>REC Electronics bay Assembly</u></b>		
Place Aluminum board between both Aluminum Joints		
Connect AWG wires from RBF switches (color 3) on Stratologgers switch terminals		
Connect AWG wires from Stratologgers drogue terminals (color 1) on terminal blocks of drogue aluminum Joint		
Connect AWG wires from Stratologgers main terminals (color 2) on terminal blocks of main aluminum joint		

seal holes of aluminum joints with silicone	
Close REC Electronics bay with 2 Carbon Fiber half-tubes (Electronics bay) and 8 M6 screws	

PARACHUTE ASSEMBLY CHECKLIST TASKS	Check?
<b><u>Shock Cords assembly</u></b>	
Mount parachute folding GSE	
Fold 10m shock cord and hold with tape	
Fold 4m shock cord and hold with tape	
Identify quicklinks from 1 to 6 with tape	
Place 1 nomex blanket on 4m shock cord	
Place 1 nomex blanket on 1m shock cord	
Place quicklinks 1 and 2 on 2m shock cord	
Place quicklinks 2 and 3 on 4m shock cord	
Place quicklinks 4 and 5 on 1m shock cord	
Place quicklinks 5 and 6 on 10m shock cord	
<b><u>Drogue parachute assembly</u></b>	
Pass baby powder on drogue parachute	
Fold drogue parachute	
Pass drogue's rigging on 1 swivel	
Fix drogue's rigging with 1 wire rope clip	
<b><u>Main parachute assembly</u></b>	
Pass baby powder on drogue parachute	
Fold main parachute	
Put main parachute on its bag	
Pass main's rigging through bag elastics	
Pass main's rigging on 1 swivel	
Fix main's rigging with 1 wire rope clip	

CHARGE CUPS ASSEMBLY CHECKLIST	Check?
<b><u>Selection of assembly participants</u></b>	<u>Name</u>
Operator (OP): will handle pyrotechnic materials	
Assistant (A): will help operator	
Reader (R): will read and mark the checklist	
<b><u>Safety pre-assembly procedures</u></b>	
OP, A and R: put safety glasses	
OP and A: dress safety coat	
OP and A: put antistatic gloves	
OP: put antistatic mat on a table	
A: put Materials (Pyrotechnical/Support) on mat	
OP: ground mat	
A: put REC ELE-Bay on mat	
OP: put antistatic wrist strap	

A: place plastic cup with water near mat	
Everyone but OP and A shall be at least 2m away from mat	
<b><u>Connecting e-matches</u></b>	
A: Cut 4 e-matches wires (10cm)	
OP: Connect the 4 e-matches on terminal block connectors	
OP: remove one RBF rod and check if e-mathces are connected to Stratologgers	
OP: if not, verify continuity with multimeter, reconect squibs, try again	
OP: replace RBF rod	
OP: remove other RBF rod and check if e-mathces are connected to Stratologgers	
OP: if not, verify continuity with multimeter, reconect squibs, try again	
OP: put the 4 e-matches heads inside syringes	
<b><u>Putting powder</u></b>	
OP: Turn on precision scale	
OP: Place gunpowder weighing container on scale	
OP: Tare scale	
OP: open gunpowder storage container	
OP: weigh amount of powder to be put in the drogue syringe (2.50 g)	
OP: Close gunpowder storage container	
OP: turn off scale	
A: Hold paper funnel inside drogue syringe	
OP: put gunpowder on funnel	
OP: Fill syringe volume with tow	
A: cut tape stripes to close syringe	
OP: close syringe with tape	
OP: turn REC ELE-Bay upside down, check for leak	
OP: if there is a leak, discard powder on water and repeat <b><u>Putting Powder</u></b>	
OP: turn on scale	
OP: Place gunpowder weighing container on scale	
OP: Tare scale	
OP: open gunpowder storage container	
OP: weigh amount of powder to be put in the main syringe (4.50 g)	
OP: Close gunpowder storage container	
OP: turn off scale	
A: Hold paper funnel inside main syringe	
OP: put gunpowder on funnel	
OP: Fill syringe volume with tow	
A: cut tape stripes to close syringe	
OP: close syringe with tape	
OP: turn REC ELE-Bay upside down, check for leak	
OP: if there is a leak, discard powder on water and repeat <b><u>Putting Powder</u></b>	
OP: Keep REC ELE-Bay over mat	
A: store materials	

OP, A and R: remove PPE	
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REC FULL ASSEMBLY CHECKLIST	Check?
<b><u>Drogue tube assembly</u></b>	
Fix M8 eyebolt with nut and washer on Aluminum joint (REC-Payload)	
Attach Quicklink 1 on Aluminum joint (REC-Payload) eyebolt	
Put baby powder on drogue parachute	
Attach drogue's swivel on quicklink 2	
Envelope shock cords and drogue with nomex blanket	
Place nomex blanket inside Aluminum joint (REC-Payload)	
Place Aluminum joint (REC-Payload) inside drogue carbon fiber tube	
Fix with 8 M3 nylon screws	
Place 5"-6" PLA transition around drogue tube	
Attach Quicklink 3 on REC ELE-Bay - drogue side (operator shall use gloves)	
Fix drogue tube on REC ELE-BAY with 4 M6 screws	
<b><u>Main tube assembly</u></b>	
Pass 1m shock cord through main carbon fiber tube	
Put baby powder on main parachute bag and main tube inner walls	
Attach main's swivel on Quicklink 5	
Envelope main bag base with nomex blanket	
Put main bag inside main tube	
Attach Quicklink 6 on Aluminum joint (REC-Nosecone) and main bag chord	
Place shock cord inside Aluminum joint (REC-Nosecone)	
Place Aluminum joint (REC-Nosecone) inside main tube	
Fix with 8 M3 nylon screws	
Attach Quicklink 4 on REC ELE-BAY - main side (operator shall use gloves)	
Fix main tube on REC ELE-BAY with 4 M6 screws	

REC DISASSEMBLY CHECKLIST	Check?
<b><u>Disarming pyrotechnicals (1 Operator)</u></b>	
Dress up safety coat	
put safety glasses	
put anti-static gloves	
put anti-static mat on table (if on basecamp)	
ground anti-static mat (if on basecamp)	
put recovery system on mat (if on basecamp)	
put anti static wrist strap (if on basecamp)	
open REC ELE-Bay half carbon fiber tube (Stratologgers side)	
disconnect Vcc battery wire from 2 Stratologgers	
disconnect drogue wires from 2 Stratologgers, short circuit them	
disconnect main wires from 2 Stratologgers, short circuit them	
<b><u>Main tube disassembly</u></b>	
Remove M6 screws from main carbon fiber tube	



Separate main tube from REC ELE-Bay joint	
Separate Quicklink 4 from REC ELE-Bay joint	
Remove tape from serynge	
Discard gunpowder on water	
<b>Drogue tube disassembly</b>	
Remove M6 screws from drogue carbon fiber tube	
Separate drogue tube from REC ELE-Bay joint	
Separate Quicklink 3 from REC ELE-Bay joint	
Remove tape from serynge	
Discard gunpowder on water	

REC PRE-LAUNCH CHECKLIST	Check?
Remove RBF rod 1	
Wait for initial Stratologgers beeps	
If 3 beeps repeatition begins, nominal	
If not, place RBF rod 1 back, return to assembly	
Place RBF rod 1 back	
Remove RBF rod 2	
Wait for initial Stratologgers beeps	
If 3 beeps repeatition begins, nominal	
If not, Place RBF rod 2 back, return to assembly	
Remove RBF rod 1	

ROCKET INTEGRATION MATERIALS CHECKLIST	Check?
<b>Materials</b>	
3 fins	
1 propulsion system carbon fiber aiiframe ("saia")	
1 Aluminum Motor-joint spacer	
1 Motor-Payload aluminum joint	
1 M8 rod bar	
2 M8 nut	
2 M8 washer	
2 M6X20mm screws	
2 Rail buttons	
1 Payload section fiberglass tube	
1 Assembled Electronics Sensors bay	
1 Assembled 3U CubeSat Payload	
1 Assembled Recovery System	
1 Assembled GPS-telemetry system	
21 M6x16mm screws	
4 M6x10mm screws	
4 M6X8mm screws	

<b>Tools</b>	
M6 allen wrench	
Fins mounting GSE	
Recovery system PPE	
<b>PPE</b>	
1 Anti-static mat	
1 Anti-static wrist strap	
2 Anti-static gloves	
3 safety glasses	
2 safety coats	

ROCKET INTEGRATION ASSEMBLY CHECKLIST	Check?
<b><u>REC + Nose Cone</u></b>	
Place Assembled GPS-telemetry system over REC	
Place Nose Cone over Assembled GPS-telemetry system	
Fix Nose Cone with 4 M6x8mm screws	
<b><u>"Saia" integration without motor</u></b>	
Place 3 fins around saia using mounting fins GSE	
Fix fins with 18 M6x16mm screws	
Fix rod bar with 2 nuts and 2 washers on aluminum joint	
Place aluminum motor-joint spacer on rod bar	
Fix aluminum joint on "saia" with 3 M6x16mm screws	
Fix 2 rail buttons on "saia" with M6x20mm screws	
<b><u>Payload and sensors bay integration</u></b>	
Place payload over aluminum joint	
Place fix sensors bay over Payload	
Fix Payload fiberglass tube on aluminum joint with 4 M6x10mm screws	
Fix Rec+Nose Cone on Payload tube with 4 M6x8mm screws	
<b><u>Motor integration</u></b>	
Check motor assembly and security checklists	
Fix motor on rod bar inside "saia"	

**Transporting (unloaded motor) and Grounding Checklist.** *This shows how to transport the grains.*

Make the grounding system near the car	
Insert the copper bar in the ground	
Connect a conductor cable on the bar	
Throw Gatorade on the ground	
Test if the grounding is ok with the batteries	

Ground the car	
Three operators must wear Lab clothes, trousers, shoes, safety glasses, face mask, and safety gloves	
Make the grounding in the room with the tap.	
Ground the operators	
Ground the grains	
Select an operator to carry the grains	
Connect this operator to the grains with a conductor cable	
Take the grains to the place of the car	
Ground the grains with the anti static mats	
Insert them in the car	
Undo the grounding and guard it in the car	
Remove gloves, glasses and face mask	
Go to the spaceport	
Leave the car	
Do the grounding again	
Wear the safety equipment again	
Ground the car	
Ground all operators using wrist band	
Ground the grains using the mats	
Do another grounding on the place where the motor will be assembled and shut. The place must be under shadow.	
Select an operator to transport the grains	
Ground the operators	
Ground the grains	
Remove the wrist band	
Connect the operator selected with the grains	
Carry the grains to the other grounding	
Ground the operator and the grains altogether	
Disconnect the operator from the grains	
Keep throwing Gatorade in the ground every time it is dry	

**Grains – Motor Assembly Checklist.** *This shows how to assembly the grains in the motor.*

This time the grains should be already grounded	
Undo the assembly of the motor until item 2.4 using the manual	
Select two operators to work on the assembly and one for further help (as keep throwing Gatorade in the grounding)	
Three operators must wear safety equipment, including: safety gloves, Lab clothes, trouser, shoes, anti static wrist band, safety glasses and face mask	

Clear the area	
Ground all three operators with the wrist band connected with the mat	
Put the biggest anti static mat in a table for working. The mat must be grounded.	
Put the grains above the mat.	
Remove slowly all five grains from the boxes and put them above the mat.	
Ground the motor with the anti static mat.	
Follow the instructions in the manual to assembly the motor	
After the motor is closed select an area under shadow to keep it.	
Ground that area	
Connect the motor in the ground with the grounding mat as redundancy	
Keep people far from the motor	
Keep throwing Gatorade in the ground until the motor must be assembled	

**Motor – Rocket Assembly Checklist.** *This shows how to be safe on the Motor – Rocket assembly.*

Ground the Rocket with the motor	
The Assembler must wear safety equipment as much as possible. The minimum required are: Trousers, shoes, Electrician clothes, safety glasses, face mask, anti static wrist band and one safety glove on the hand that will be lesser used.	
Clear the area	
Ground the motor, the Rocket and the assembler altogether.	
Start the assembly	
End the assembly	
Disconnect the operator from the ground	
Keep the Rocket Grounded until second command	
Keep throwing Gatorade on the ground	

**Rocket transportation Checklist.** *This shows how to transport the loaded Rocket to the launch pad safely.*

Put the car near the grounded Rocket	
Ground the car and keep grounded	
Select two operators to take the rocket to the car	
These operators must wear safety gloves, safety glasses, trousers, shoes, face mask, anti static wrist band and Electrician clothes	
Ground the operators	
Connect the rocket to the operators through the wrist band	

Clear the area	
Take the PVC tubes to the car (other operator)	
Ground an anti static mat and put it above the PVC tubes while connect to the ground of the car.	
Take the rocket to the car	
Put it on the mat on the PVC tubes	
The nozzle must be turned to outside of the car	
The rocket must be in the middle of the car	
Connect the rocket to the anti static mat with another one above the rocket and grounded too.	
Ground the rocket, the mats and the car altogether	
Undo the grounding	
Connect the two mats	
Transport the rocket to the launch pad (using all safety equipment) slowly while one operator holds the rocket using all the safety equipment too. Take grounding equipment, including Gatorade.	
Reach the place	
Ground the car	
Ground the operators	
Ground the rocket	
Ground the launch pad	
Take the rocket out from the car and take it to the launch pad	
Keep all grounded	
Connect the Rocket on the launch pad using the slugs	
Keep the rocket and the launch pad grounded until second command	
Keep throwing Gatorade on the ground	

**Grains – Motor Disassembly Checklist.** *This shows how to disassembly the loaded motor.*

Ground the Rocket with the motor	
The disassembler must wear safety equipment as much as possible. The minimum required are: Trousers, shoes, Electrician clothes, safety glasses, face mask, anti static wrist band and one safety glove on the hand that will be lesser used.	
Clear the area	
Ground the motor, the Rocket and the assembler altogether.	
Ground the operator with the wrist band connected with the mat	
Put the biggest anti static mat in a table for working. The mat must be grounded.	
Remove the motor from rocket	
Remove the nozzle	
Remove slowly all five grains from the boxes and put them above the mat.	
Ground the grains box	
One by one, put the grains in the box	
Close the box	
Disassembly the motor	

Appendix F. Engineering Drawings

The present appendix contains a series of technical drawings that are necessary to define significant subsystems or components. In these drawings, all unspecified tolerances are of  $\pm 0.1$  mm.

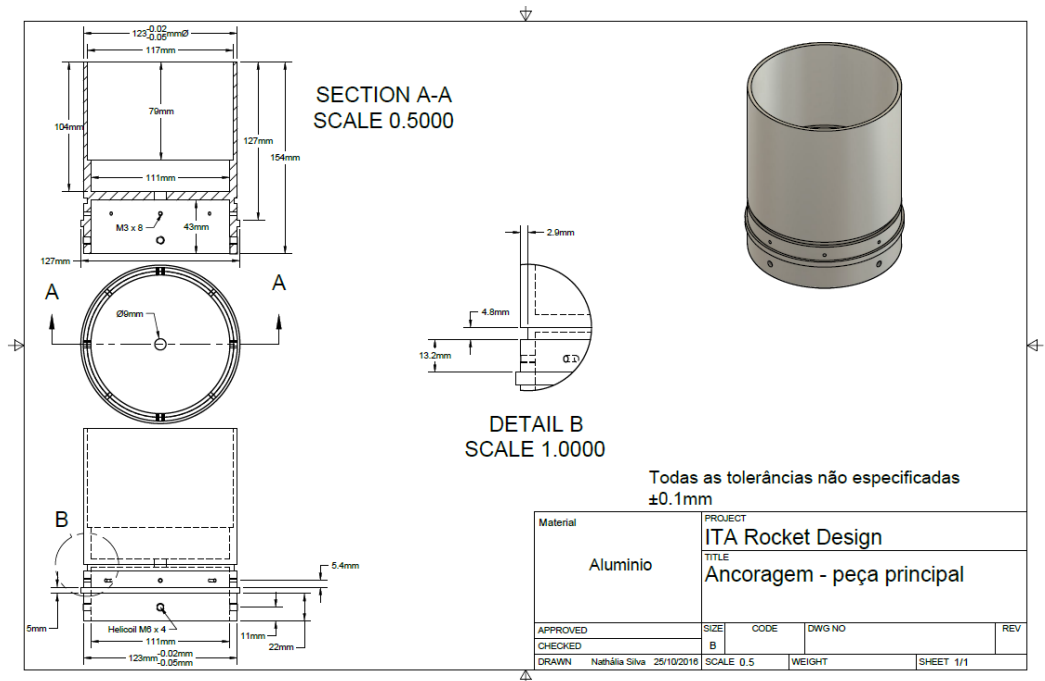


Figure F.1. REC-Nose Cone section interface technical drawing.

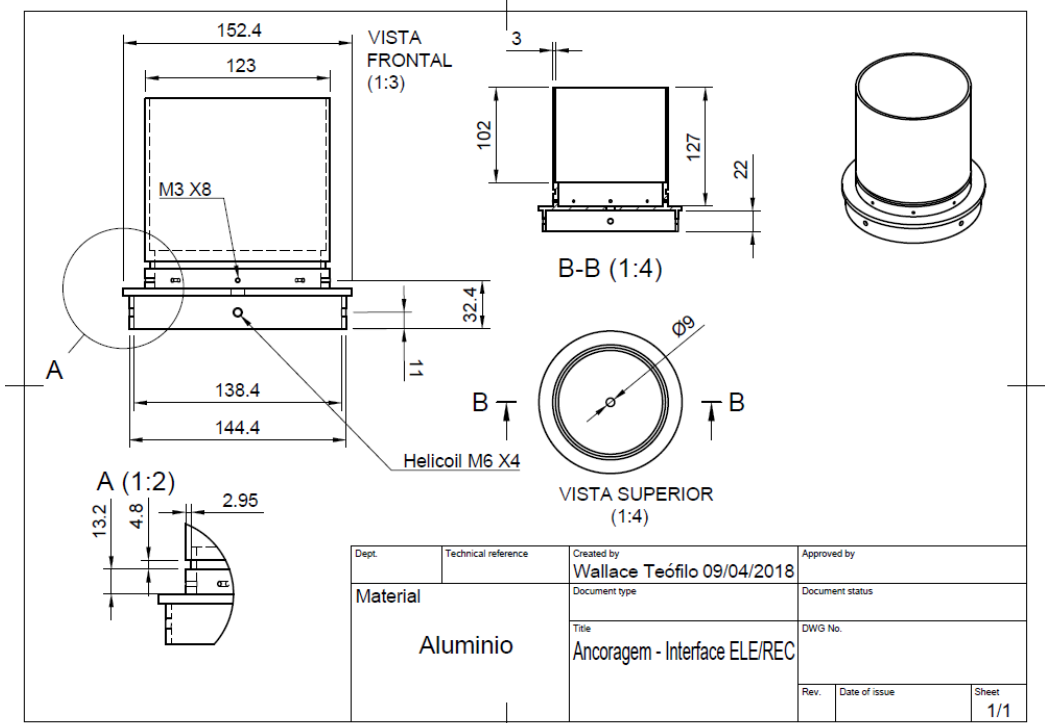
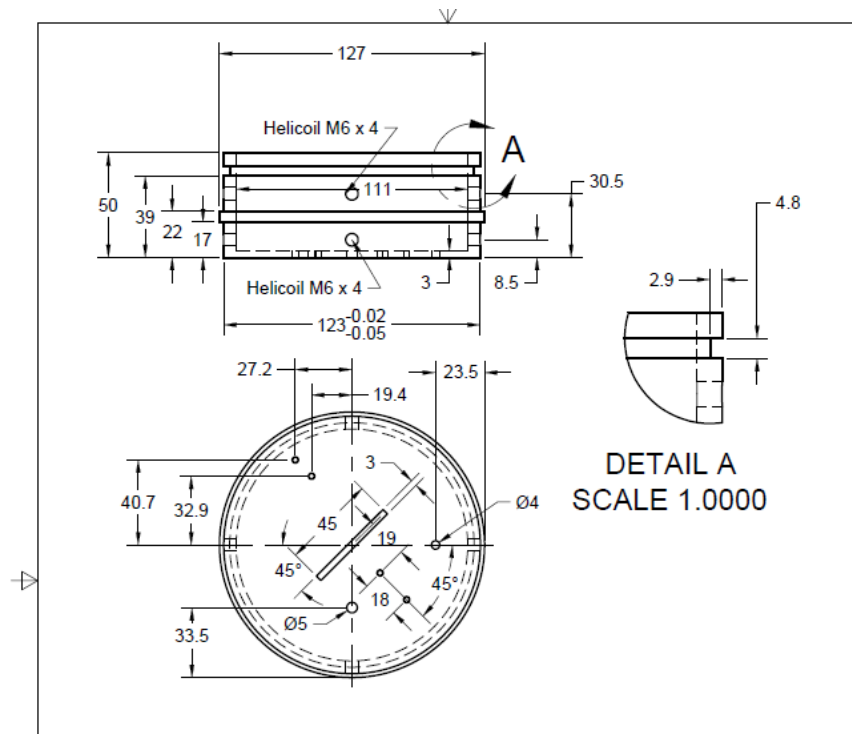
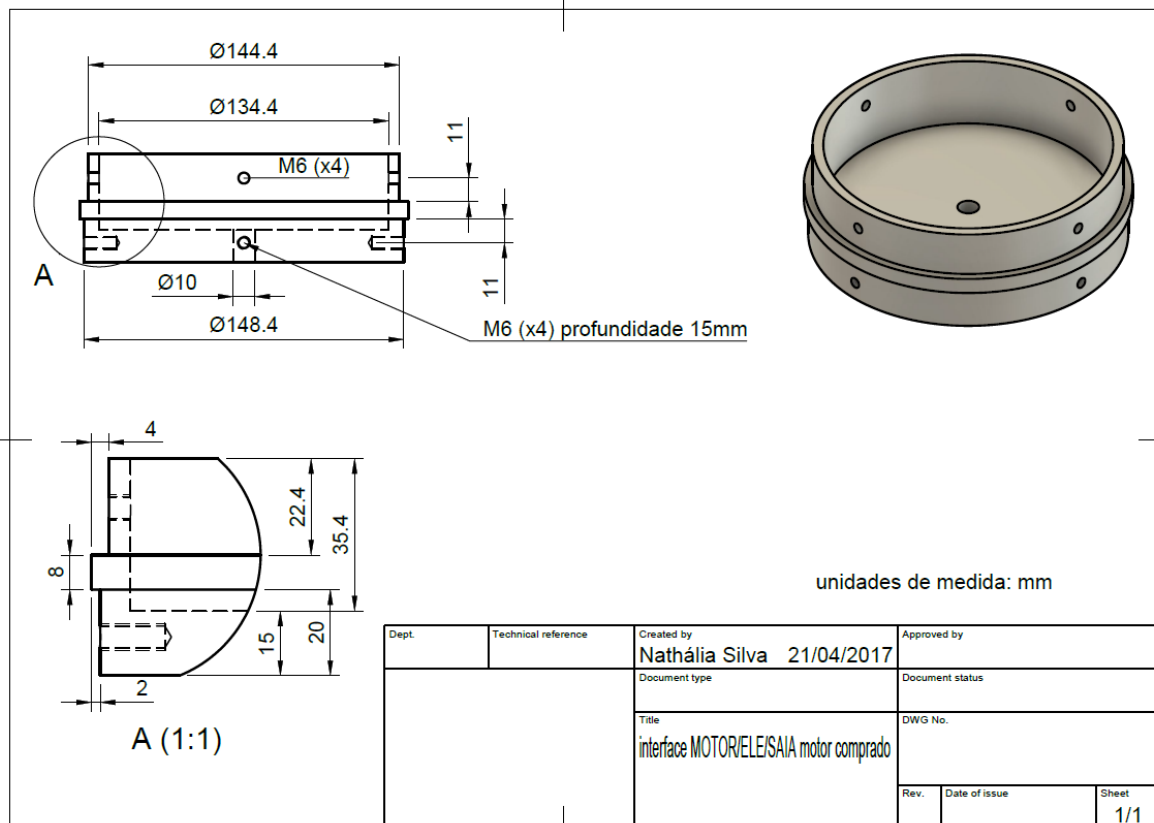


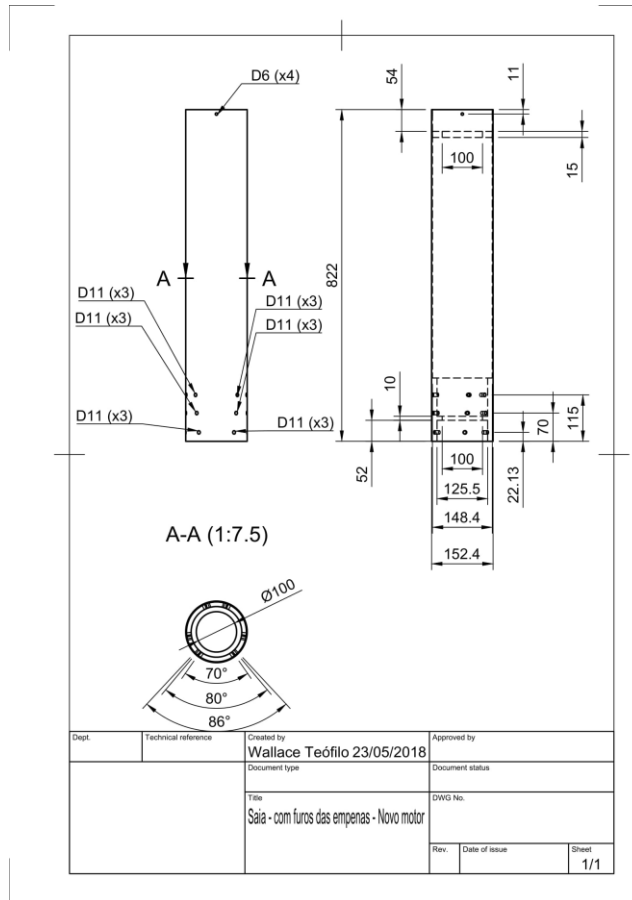
Figure F.2. REC-Payload section interface technical drawing.



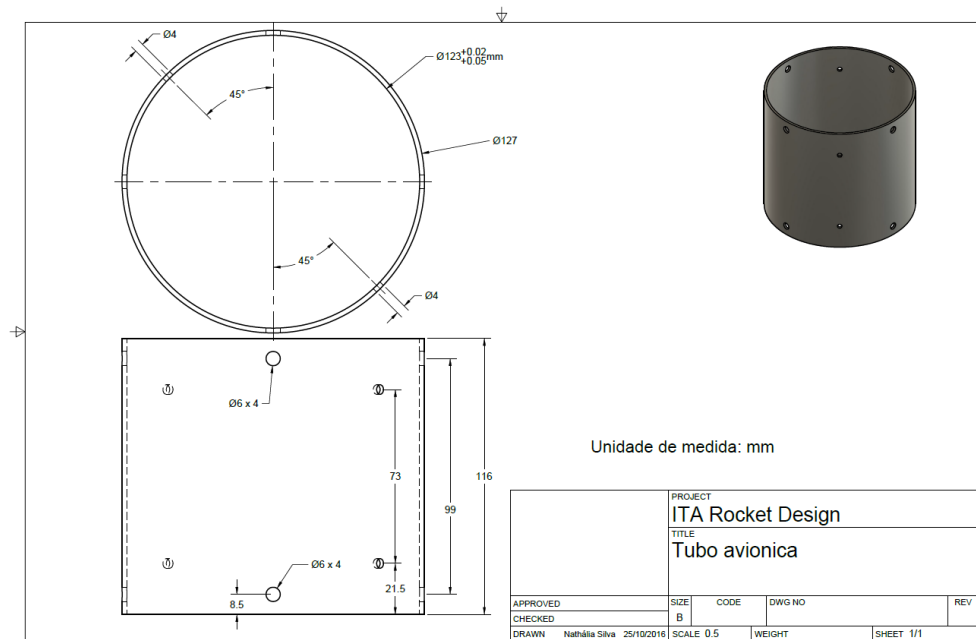
**Figure F.3. Recovery electronics joint technical drawing.** All unspecified diameters are 3 mm and the unit of measure is mm



**Figure F.4. Joint between the payload and propulsion sections technical drawing.**

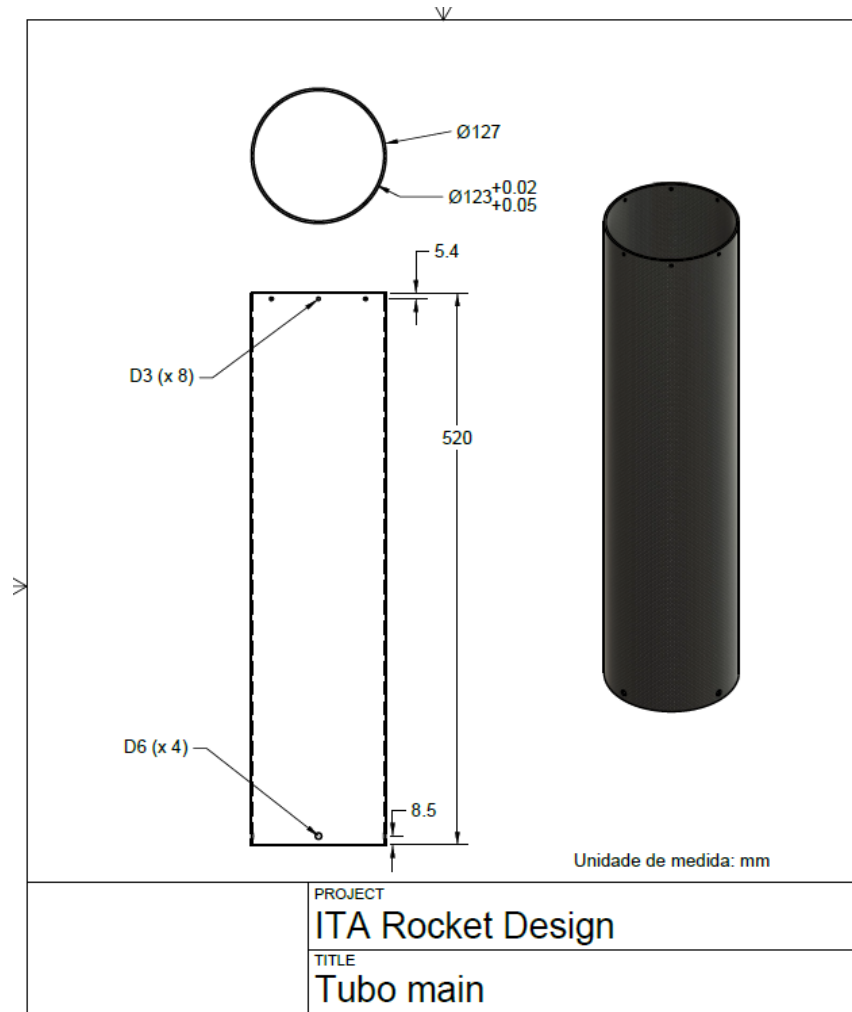


**Figure F.5. Carbon Fiber Propulsion System airframe body tube**

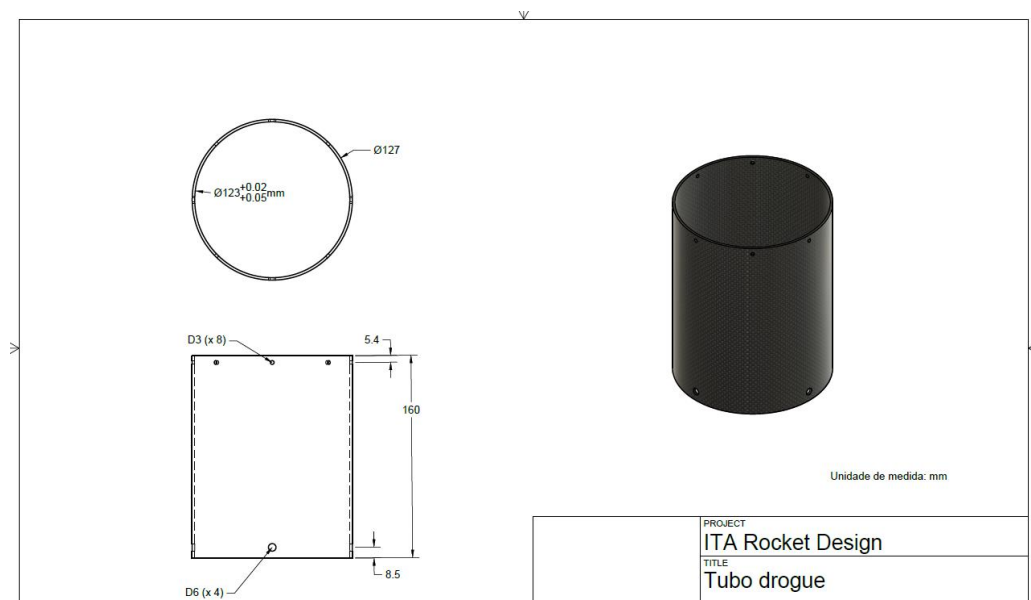


**Figure F.6. Recovery Electronics body tube technical drawing**

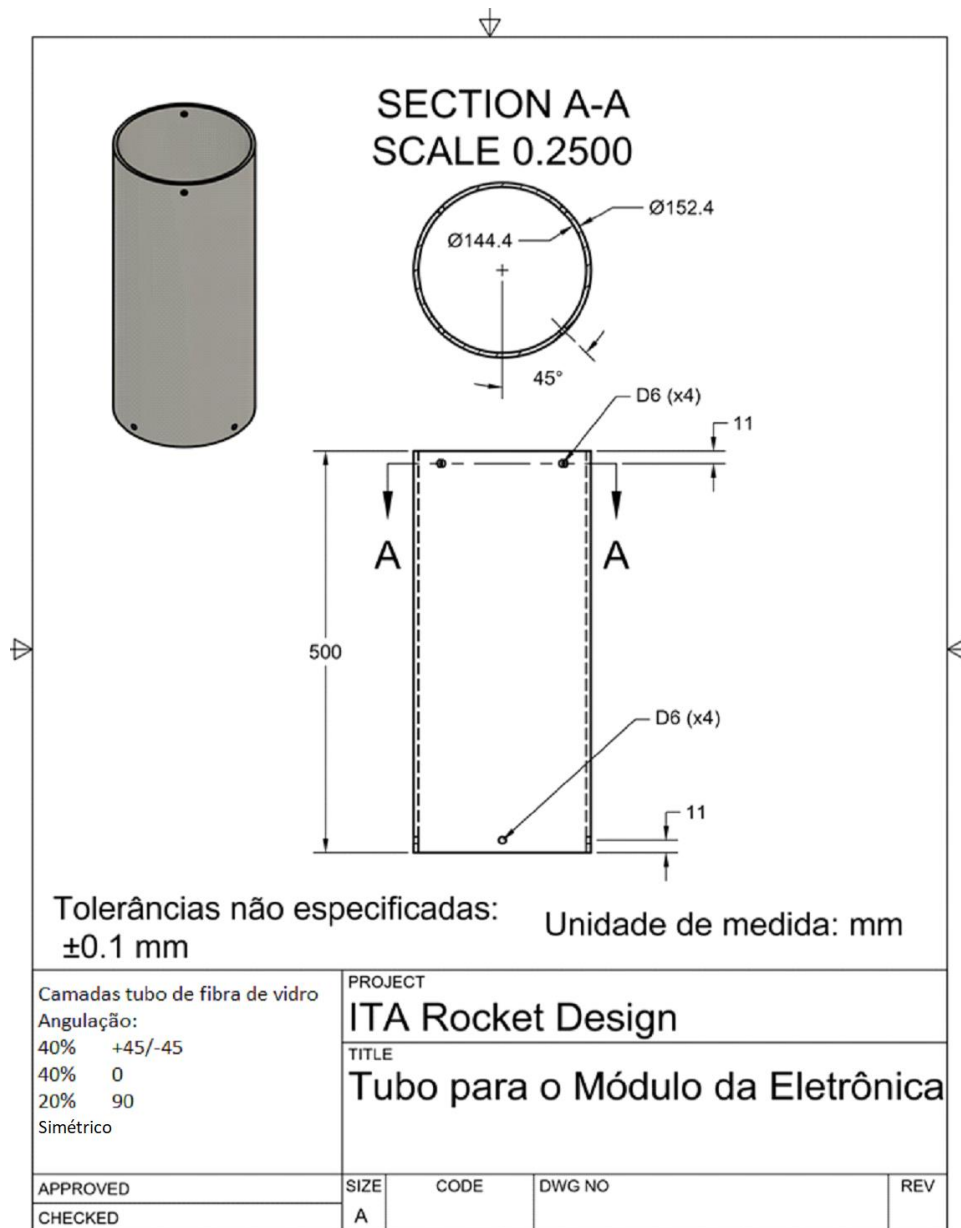




**Figure F.7. Main parachutes body tube technical drawing.**



**Figure F.8. Drogue parachute body tube technical drawing.**



**Figure F.9. Payload section body tube technical drawing**

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## References

- [1] MATLAB (2017). Ver. R2017a Natick, Massachusetts. The MathWorks Inc.
- [2] Nakka, R., "*Richard Nakka's Experimental Rocketry Web Site*". <http://www.nakka-rocketry.net/> [retrieved 25 May 2018]
- [3] Fusion 360, Autodesk, San Rafael, California. Autodesk, Inc.
- [4] Timoshenko, S.P. *Mechanics of Materials*. 3<sup>th</sup> edition, 1991.
- [5] Leitão, E.S. *Mechanical characterization of polymeric composites winding in diverse reinforced orientation of the reinforcement*. Instituto de Pesquisas Energéticas e Nucleares. São Paulo, SP, 2007.
- [6] da Silveira, G., "Desenvolvimento de uma Ferramenta Computacional para Simulação de Voo de Veículos Lançadores", Master Thesis, Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 2014.