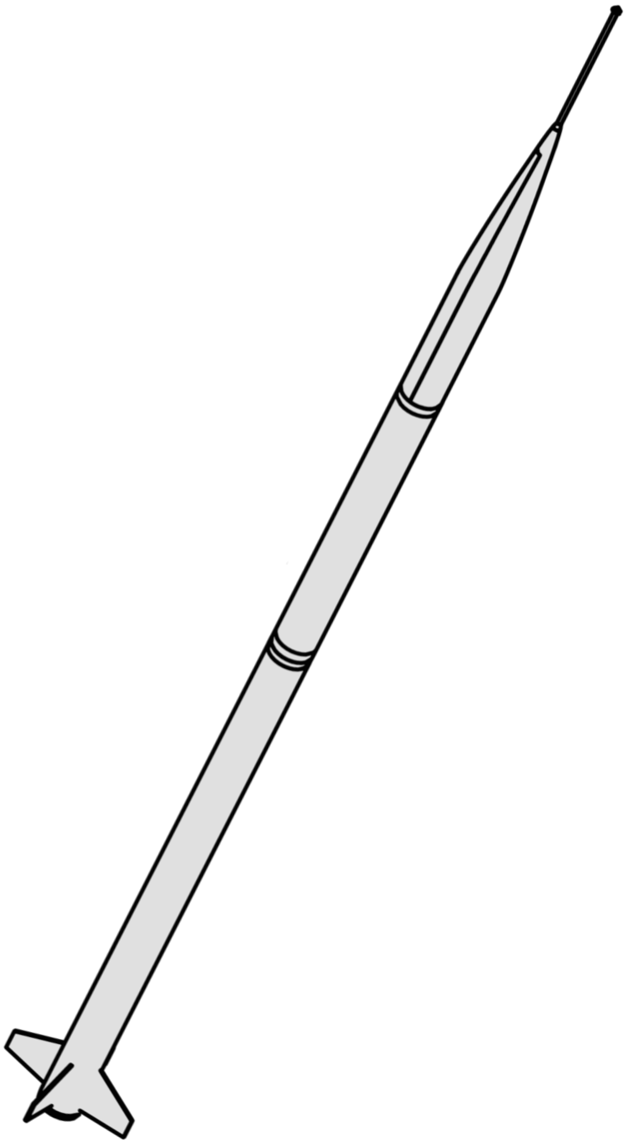
BIG RÖCKET



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Chapter 1: Introduction

Since its conception, it has been central to the principles that form Aurora to pursue ambitious goals that will provide the greatest opportunities to learn and develop innovative approaches to the field of rocketry. As part of our first year as a student society at Queen Mary University of London, it is our stated goal to compete at the European Rocketry Challenge (EuRoC) held in Portugal in October 2023 under the 9km apogee category. And while definitely not an easy goal, it is only by aiming high that real progress can be made, and with our capable team of students and extensive support from the university and sponsors, the way is paved for us to do our best.

In order to achieve this goal, the so called 'big rocket' (an incredibly original placeholder name) is being designed by the engineering team at Aurora. As a parallel project, a smaller rocket named Lil' Mary is being constructed for use as a testbed for different components, it's simple and economic design will allow for multiple test launches throughout the year which will provide invaluable knowledge and experience for the entire team.

This technical report will focus on explaining the design and functionality of the big rocket, but before this can be done it is important to know what this vehicle is meant to achieve and what are the main requirements that will make it work and that guide its design philosophy. As part of the EuRoC regulations and as internal goals specified by Aurora, five such requirements have been identified that dictate the overall design of the big rocket:

- **9km apogee**: As already mentioned this is the altitude our rocket must reach. Wining EuRoC requires getting as close to the specified apogee as possible, meaning that the performance of the rocket must be carefully studied to ensure the highest precision possible.
- **COTS Engine**: We currently do not possess the time nor the experience to design and construct our own engines, therefore it is safer to use a commercial off the shelf (COTS) solid rocket engine. The engine selection will have a great impact on the performance and design of the vehicle.
- **Minimum diameter structure**: In order to simplify the internal structure of the rocket, it is decided to use the diameter of the COTS engine as the base diameter of the big rocket, and while this will restrict the overall size of the launch vehicle, it will greatly reduce the complexity of the design.
- **All mechanical systems**: Using pyrotechnics involves great risks and complications, it is therefore chosen to pursue mechanical alternatives for certain flight components such as the parachute release system.
- **Deployable payload**: Our rocket must have some purpose beyond the arbitrary goal of reaching 9km, allowing the payload inside the rocket to be deployed at apogee and exposed to the atmosphere for several minutes will considerably increase the scientific potential of the big rocket.

By taking these goals as our priority, it is our hope to build a simple yet extremely effective launch vehicle capable of flying multiple times and extending its capabilities with every launch.

Chapter 2: Engine Selection

Rockets are in general defined by their engines, and the big rocket is no exception. Using a COTS engine carries many implications, as commercially built solid rocket engines performance figures are standardised, which means that one cannot build a rocket and choose a suitable engine but must rather choose an engine and build the rocket around it. If the final vehicle does not provide the desired performance, then a different engine must be used. Having this in mind, it is critical to choose an engine capable enough and in fact slightly overpowered that might be able to compensate for any extra weight the rocket might carry.

After various prototype simulations and consulting the engine choice of other EuRoC teams, the Cesaroni Technologies Pro98 N1560 engine stood out as the most viable choice, not only does it provide the necessary thrust to launch the rocket, but its burn time of 11 seconds is also uniquely long, which allows the vehicle to fly gently without experiencing extremely high accelerations. The engine assembly of Cesaroni motors comes in two main components: the reload and the hardware.

While commonly referred as the engine, the Pro 98 N1560 is actually the propellant of the solid rocket motor, it is composed of 6 cylindrical grains of Ammonium Perchlorate Composite Propellant (APCP). At 16803 Ns of total impulse, it classifies as a high power 'N' category motor that requires certain certifications to be acquired and flown. It is obviously not advisable to allow some inexperienced students to handle high grade explosives, therefore the reloads will be provided to the team by EuRoC at the competition site.

These reloads on their own are of little value, as they must be carefully cased to ensure a safe and reliable combustion, this is where the hardware comes into play. Given that each reload comes in different diameters and requires a certain number of grains, a specific casing must be chosen to accommodate the desired reload. As a high-power motor, the N1560 is composed of 6 reloads each being 98mm in diameter, the only hardware set suitable is therefore the Pro98 6G XL, were the Pro98 indicates diameter and 6G XL means 6 grains in the XL configuration. Using such a large hardware set comes with many benefits, it can accommodate the even more powerful 'O' class O3400 reload, or with the use of spacers it can also be used for engines that require fewer grains, thus giving the big rocket a wide range of possible flight configurations in case the launch requirements change. An adequate engine choice not only satisfies the COTS engine main design requirement, the chosen diameter of 98mm also fixes the minimum diameter requirement as this must be the internal diameter of the rocket itself. The following figure illustrates the two main components of the COTS solid rocket engine:

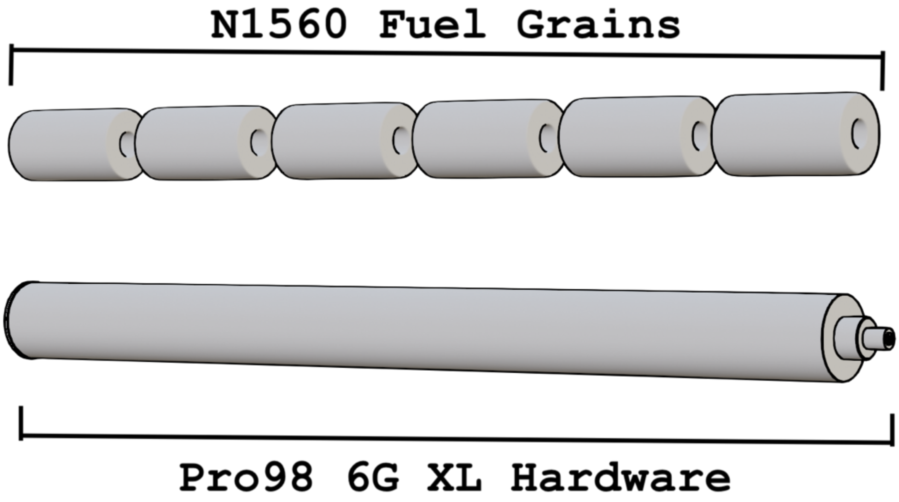


Figure 1: Engine components

The main performance figures and dimensions of the engine are shown below (note how the thrust of the engine gradually decreases throughout its 11 second burn):

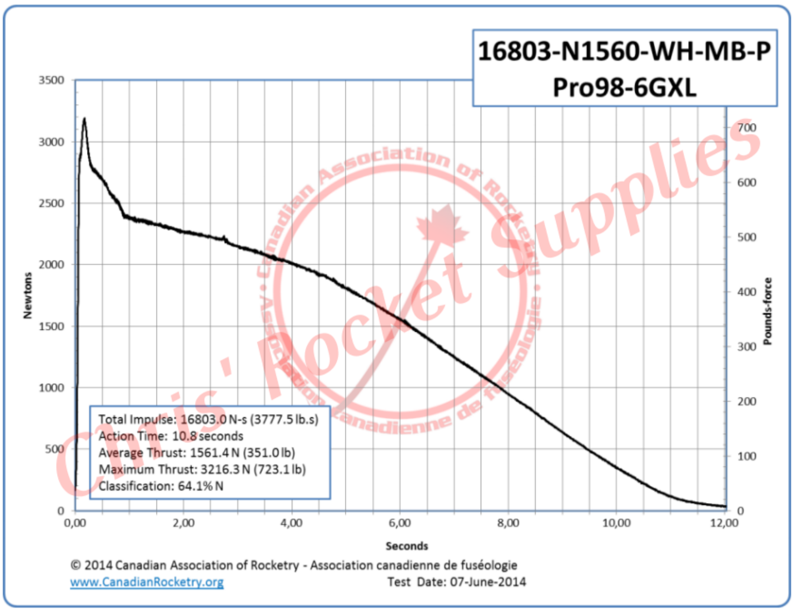


Figure 2 Engine performance

Table 1 Engine characteristics

MOTOR	16803-N1560-P
Diameter	98mm
Burn Time	10.76 seconds
Average Thrust	1561.4 Ns (351.02 lb-s)
Max Thrust	3216.3 N (723.05 lbs)
Total Impulse	16803 Ns (3777.46 lb-s)
Motor Type	Reload

Chapter 3: Aerodynamics

Rocketry and aerodynamics go hand in hand, the performance of a rocket can be substantially increased if the shape of its main aerodynamic components is chosen and optimised in accordance with the flight path of the vehicle. Of these components, the nosecone, the fins, and the overall structure of the airframe are the most important in aerodynamic terms. At Aurora, the aerodynamic design of the big rocket is being done as a collaboration between three 3rd year dissertation projects, with each focusing on the aerospike, nosecone, and the fin design of the vehicle.

Aerospike (Amalia Esperanza Llorca Salvador):

Drag-reducing aerospikes are devices meant to reduce the aerodynamic drag of bodies travelling at supersonic speeds, this is achieved by creating a detached shock ahead of the body which can reduce drug by up to 50% when travelling above Mach 1.

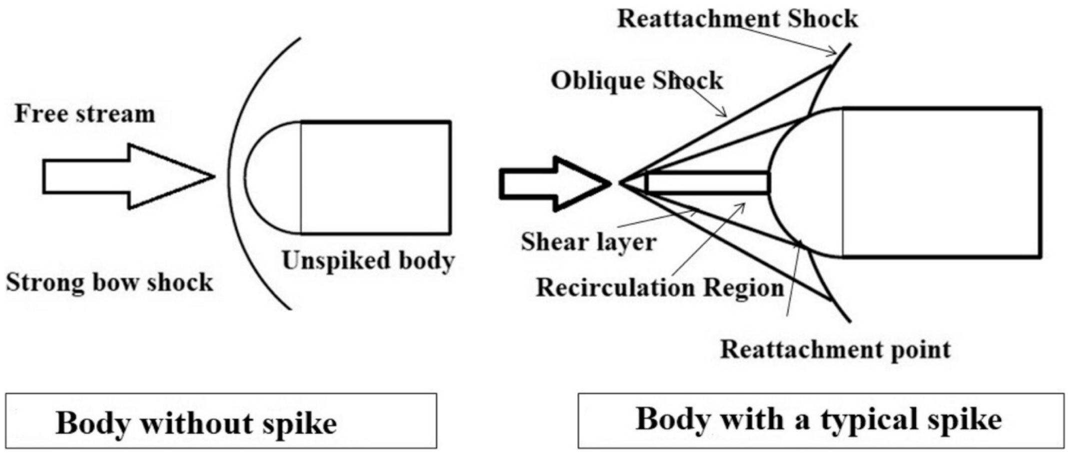


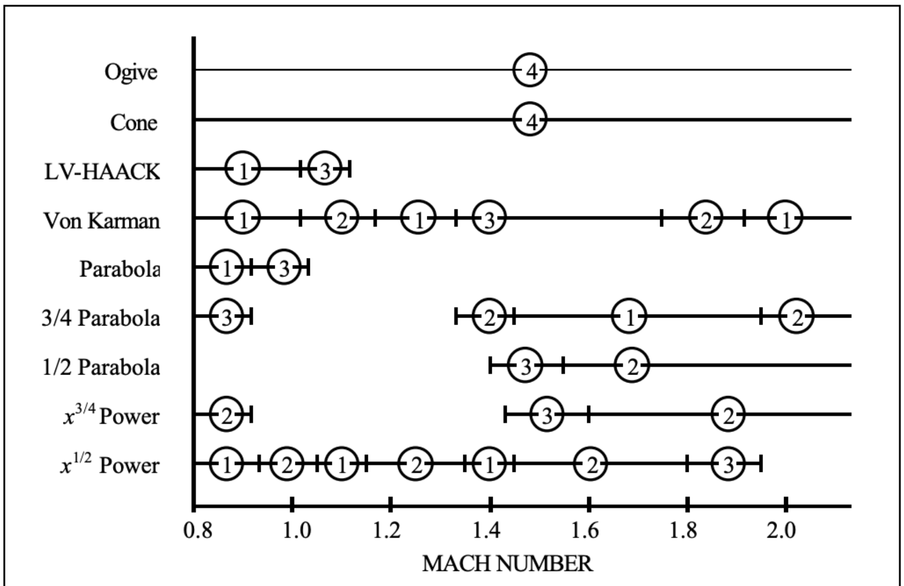
Figure 3 Aerospike effects

This sort of device is commonly used in missiles and launch vehicles that must travel at supersonic speeds for extended periods of time. Given that the big rocket is expected to spend a large portion of its flight in the subsonic regime, it must be studied whether the possible negative side effects of having an aerospike at subsonic speeds outweigh the clear advantages it provides when travelling above the speed of sound. This investigation will be conducted by 3rd year aerospace engineering student Amalia Esperanza Llorca Salvador as her dissertation project and depending on the outcome of her research it will be decided whether this component will be included on the big rocket or not.

Nosecone (Alex Pinel Neparidze):

Nose cones are the forward-facing component of a rocket, their cone-like shape is meant to reduce aerodynamic drag by redirecting the incoming airflow. In the field of high-power rocketry, they are also commonly used to house a payload and necessary equipment to recover the launch vehicle. Therefore, the shape of the nose cone must be defined in such a way that payload is maximized while reducing aerodynamic drag to a minimum. The rocket will quickly transition between the subsonic, transonic, and supersonic regimes, this will subject the airframe to intense and rapidly evolving shocks and forces. Given its position at the top of the rocket, the aerodynamics of the nosecone are the most critical of the entire rocket, and its design will greatly affect the overall flight performance of the big rocket.

Research suggests that the Von Karman Haack series or the Power series n=0.5 geometries are the optimal for vehicles such as the big rocket. The comparison between these two geometries (both of a fineness ratio of 5, that is the relation between the diameter and length of the nosecone) will be done as part of Alex Pinel Neparidze's dissertation (the guy writing this document).



Comparison of drag characteristics of various nose shapes in the transonic-to-low Mach regions. Rankings are: superior (1), good (2), fair (3), inferior (4).

Figure 4 Nosecone geometries at different Mach numbers

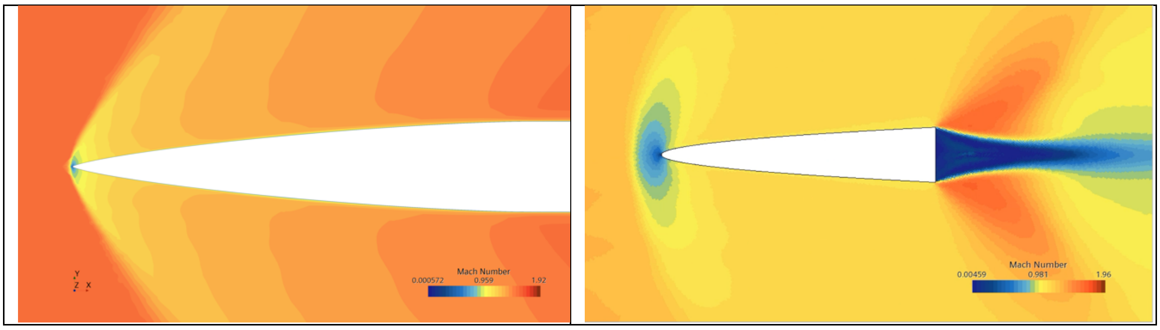


Figure 5 Von Karman and Power Series CFD simulations

Fins & Stability (Garance Cruchet-Passos):

The fins of a rocket are aerodynamic surfaces located on the exterior of the rocket that provide stability during flight. They are typically located near the base of the rocket and are used to control the rocket's direction and rotation during flight. They work by creating lift, similar to the wings of an airplane, which helps to guide the rocket along its desired flight path.

It is essential to design the fins in such a manner that rocket retains its stability while also decreasing drag in order to ensure no performance losses, thus, the difference between elliptical, trapezoidal, and clipped delta fins will be investigated by Garance Cruchet-Passos as part of her dissertation.

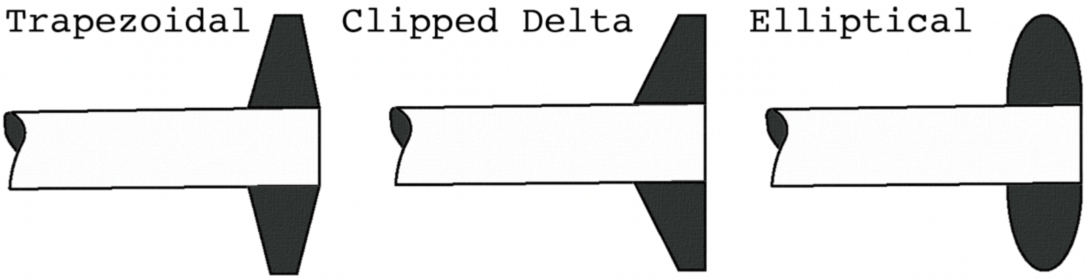


Figure 6 Fin shapes

The lift generated by these fins, together with the overall aerodynamic characteristics of the rocket can be concentrated in a single point, the centre of pressure. The position of that point relative to the centre of mass of the vehicle is crucial when determining the stability of the rocket and is measured using the following equation:

$$\boldsymbol{Stability\ Margin = \frac{XCoP - XCoM}{Diameter}}$$

Where XCoM and XCoP are the location of the centres of mass and pressure along the fuselage of the rocket. The resulting stability margin is therefore presented as a ratio between these two locations and the outside diameter of the vehicle, using the Aurora lil' Mary rocket as an example:

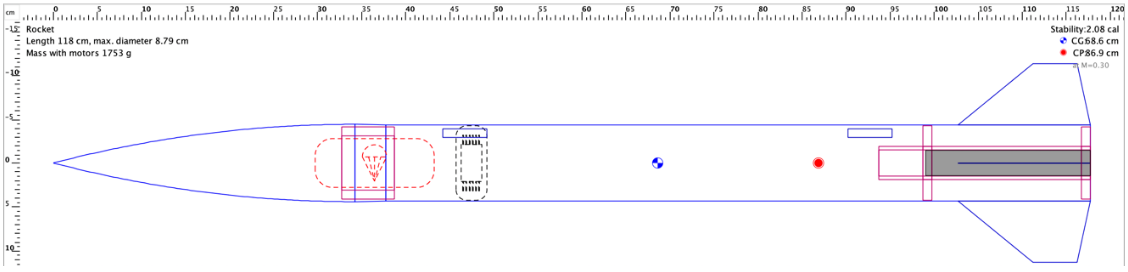


Figure 7 Lil' Mary rocket

XCoM (blue circle) is located at 68.5 cm from the tip of the rocket and XCoP is 87cm, using the previous equation and knowing that the diameter of this rocket is 8.79 cm the stability margin can be found:

$$\boldsymbol{Stability\ Margin} = \frac{\mathbf{87 - 68.5}}{\mathbf{8.79}} = \mathbf{2.1}$$

The common experience of rocketeers all over the world dictates that ideal stability is achieved when the stability margin is between 1.5 and 2, any value below that means the vehicle is unstable, and any value above 2 (as presented in this example) indicates over-stability which creates a risk of the vehicle changing its direction to align itself with any present wind. It is therefore crucial that the big rocket is designed to be stable, this can only be achieved by ensuring each team respects their respective mass budgets (which will be presented later on) so that the centre of mass remains at a specified position, and that the fins are shaped and sized in such a manner that the resulting centre of pressure yields a desirable centre of pressure.

Before proceeding with the structural design of the rocket it must be noted that any illustrations and designs will assume the use of a Von Karman nosecone with an aerospike and trapezoidal fins, all of these components are likely to change depending on the results and findings of the already mentioned 3rd year dissertation projects.

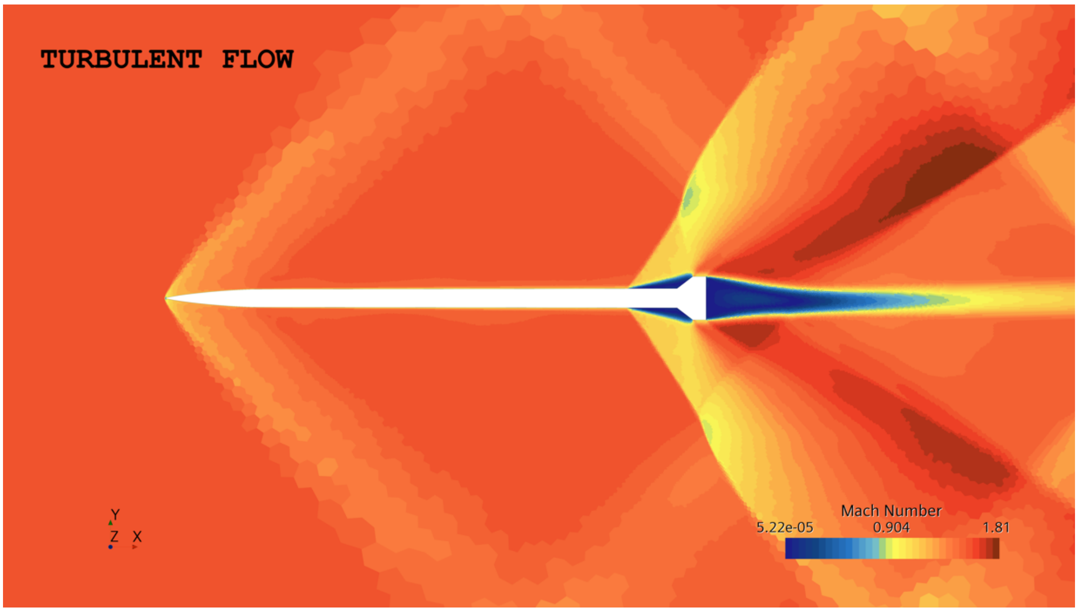


Figure 8 CFD simulation of the big rocket

Chapter 4: Structural Design

This chapter will focus on the main structural components of the big rocket, these components are designed to sustain all the aerodynamic, thermal, and structural loads that the rocket must sustain throughout its flight and operations. A proper selection of materials is crucial for the safe performance of the launch vehicle, and all components must be constructed with a safety margin of at least 2 (some exceptions might have to be made in specific cases). For most composite manufactured components, a thickness of 2mm has been chosen, this is well above the safety margin and will ease the manufacturing and integration of different parts.

The structure of the big rocket is composed of the following main elements: the nose cone, the centre tube, the coupler, the aft tube, and the fin structure. All these components are illustrated in the following page and will be carefully described in this section. The general dimensions of the rocket with all its subcomponents and the N1560 engine installed is presented in the following figure:

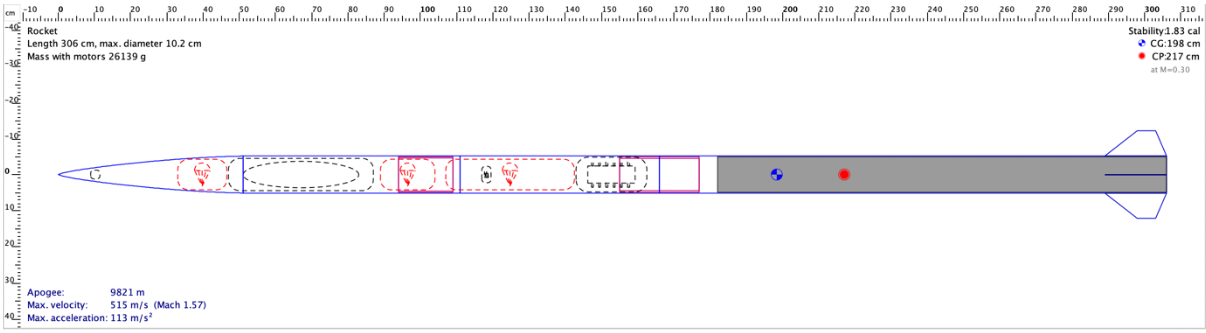
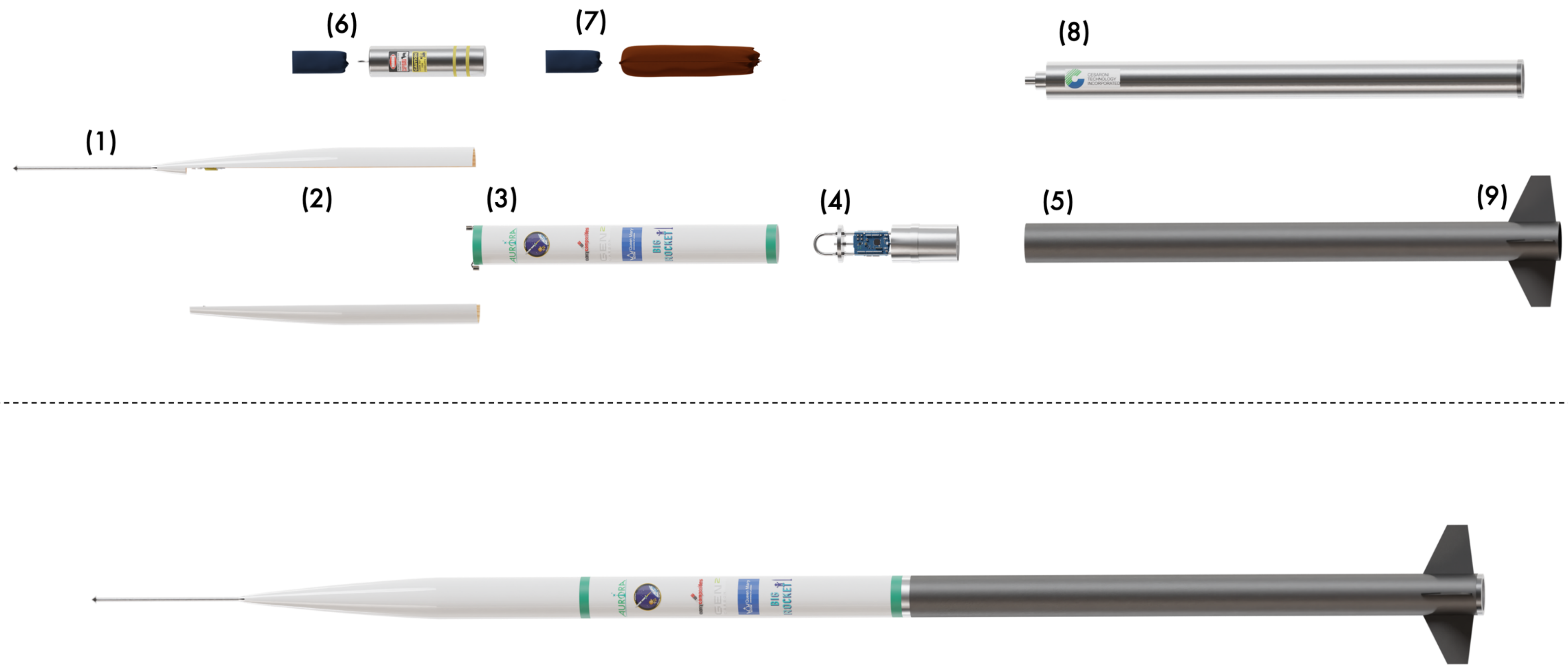


Figure 9 OpenRocket design of the big rocket

As can be seen, the rocket has a length of 306cm and an outside diameter of 10.2cm (the 9.8cm internal diameter plus the 2mm wall thickness of the composites). A table containing the dimensions and materials of each structural component is shown below:

Table 2 Structural components

COMPONENT	DIMENSIONS (mm)	MATERIAL
Nosecone tip/Aerospike	To be specified	Aluminium 6061
Nosecone	R51x1110	Fibreglass
Centre tube	R51x550	Fibreglass
Coupler	R49x220	Aluminium 6061
Aft tube	R51x1400	Unwoven recycled carbon fibre (URCF)
Fins	To be specified	URCF + Fibreglass reinforcement



(1) Aerospike, (2) Nosecone fairings, (3) Centre tube, (4) Coupler + AV Bay, (5) Aft tube, (6) Deployable payload, (7) Parachutes, (8) CTI Pro98 Engine, (9) Fin structure

Nosecone:

The nosecone, regardless of its shape, has a fineness ratio of 5, knowing that its base diameter is 10.2cm, the length is determined to be of 51cm. Fibreglass provides great material properties at a very low price and is therefore the ideal material for such a component. The very tip of the nosecone however (with or without an aerospike) will be made of aluminium, as it is subjected to higher temperatures and the geometry at the tip is hard to manufacture out of fibreglass.

The main differentiating factor between the big rocket and other rockets participating at EuRoC is its fairing actuated release system which will be explained in further detail later. This is significant because the nosecone will be made as two different pieces instead of one, this might simplify the manufacturing process as only a half mould will be necessary, but it will also require incredibly high precision to ensure each fairing is as meticulously accurate as possible to the desired dimensions.

As for the metallic tip of the nosecone, it will be machined separately and screwed into one of the fairings which is to be a bit larger and cover the entire top part of the nosecone:

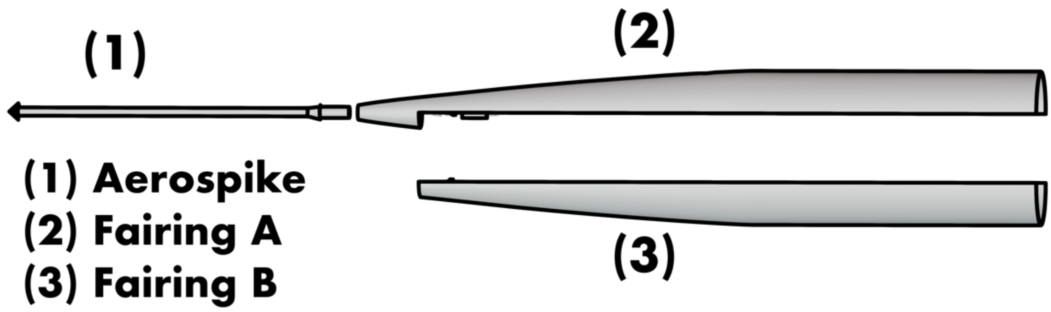


Figure 10 Nosecone design

The fairings will be manufactured inhouse using a fibreglass laminating process with epoxy, this method is already well known to the best co-presidents out there who undertook the task of manufacturing the nosecone of the lil' Mary rocket:

Figure 11 Best UK composite manufacturers

Centre tube:

Very easy and simple, the centre tube is the cylinder in which the parachutes and avionics are contained. It is also made of fibreglass due to its radio transparency which will allow telemetry to be sent back to ground as the rocket flies. Some components will be attached to it, which will require some screws and blablablabla, there is honestly not that much to say about it.

Figure 12 Centre tube render

Aft tube:

The crown jewel of composite components used by Aurora, the aft tube is designed to house the engine and the fins, and while fibreglass would perform the task just as well, the generous donation of 10kg of unwoven recycled carbon fibre (URCF) (affectionately known as Caroline fibre) from our kind sponsor GEN 2 CARBON allows us to use a stronger, lighter material which is at the same time more environmentally friendly. Nonetheless, it remains to be seen how exactly the tube will be made out of URCF as the manufacturing method is far more complex.

The fins would then be attached to the tube with epoxy and reinforced using the tip-to-tip method which involves the addition of several layers of fibreglass fabric covering the fins. The Airframe & Propulsion team will have to evaluate whether it is practical to attach the fins directly on the aft tube or whether it is more feasible to make a separate fin can, and in that case how that fin can must be attached to the aft tube.

Figure 13 Aft tube render

Aurora Bay Basic Attachment (ABBA):

Before describing this component, it is important to first indicate the normal arrangement of components between the centre and aft bay of most high-power rockets:

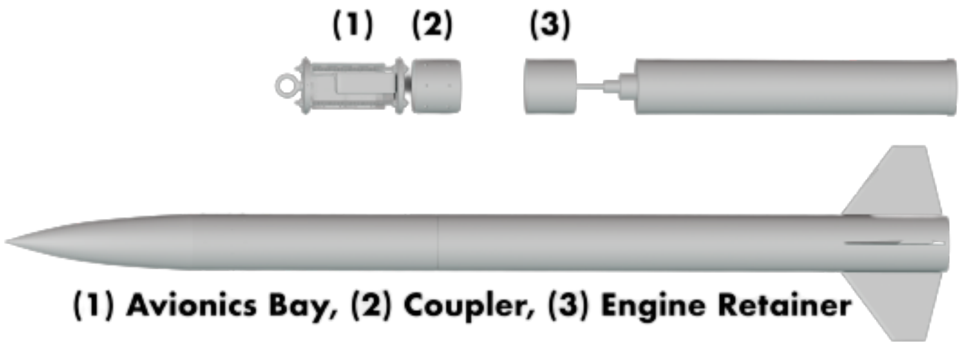


Figure 14 Common rocket configuration

As can be seen, the common arrangement involves a coupler that connects the two tubes, a retainer that keeps the engine in place, and the avionics bay in which the flight computers are stored. This results in what can only be called a waste of space, components which are only designed to perform a single task are too bulky and not at all optimised for assembly or ease of use, it is therefore imperative to reduce complexity by combining separate individual components into single pieces capable of performing a multitude of tasks at the same time. The Aurora Bay Basic Attachment (ABBA) is a combination of the avionics bay, coupler, and retainer into a single metallic element which will free up a lot of space as well as simplify the integration and assembly of the entire vehicle.

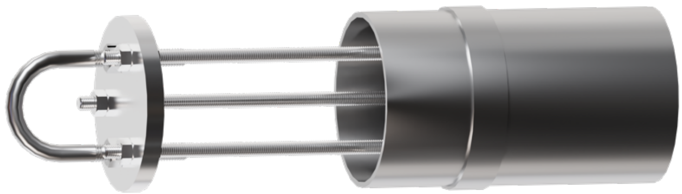


Figure 15 ABBA render

ABBA is composed of two main elements: the coupler-retainer section and the parachute mounting lid, both of which must be custom machined and are connected by three steel rods. These rods will serve as mounting support for the flight computers and will also help transfer the forces experienced during parachute deployment to the rest of the fuselage. At the bottom of the coupler-retainer section a threaded hole will be placed from which the engine can be securely fastened. In order to maintain stiffness throughout the entire airframe, the coupler section extends one body diameter length in its lower section and half that length in its upper section.

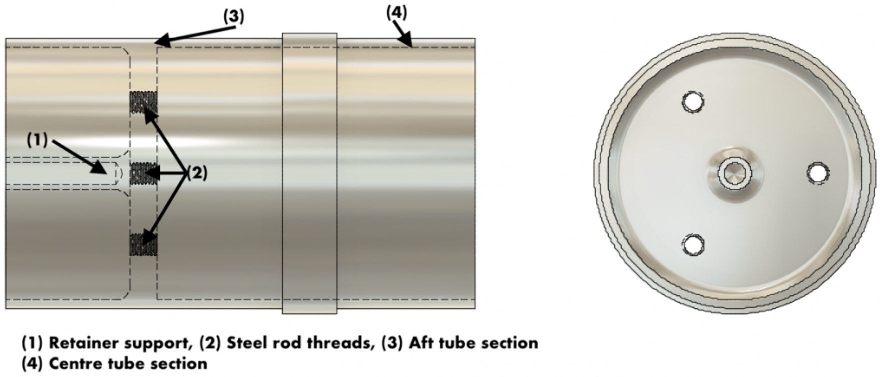
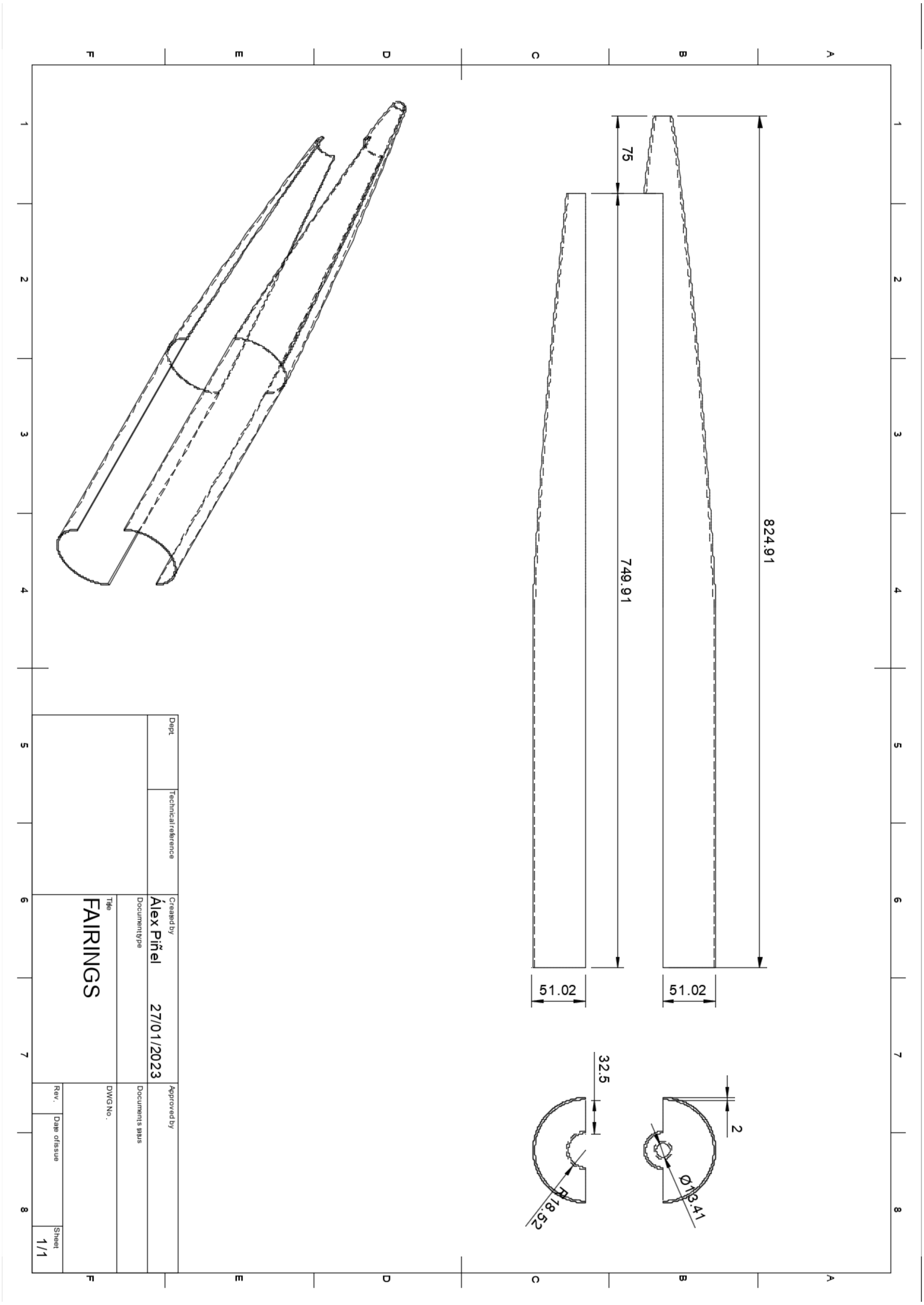


Figure 16 ABBA coupler-retainer

Here it can be seen how the structure of ABBA is divided into two different sections, the lower one contains the retainer support for the engine while the upper one will contain the avionics components. Between these two components is a wall on which steel rods are mounted, these rods must be as strong (and light) as possible, as they will be subjected to some of the highest loads experienced by the vehicle.

It must be clarified that this design is not final and is merely a representation of the idea and basic dimensions the actual coupler must satisfy. During the actual design process FAE simulations must be conducted from which the wall thickness and quantity of steel rods will be determined, it will also be necessary to analyse the positions of screw holes through which the airframe tubes will be attached on the coupler.

In conclusion, while the required dimensions and desired functionality of each structural component are known, further research, FAE simulations, and topology optimisation must be conducted to improve the design of the airframe and to ensure its sturdiness. Once this is achieved, procurement and manufacturing of the pieces can begin. Current CAD designs of each component are shown in the following pages: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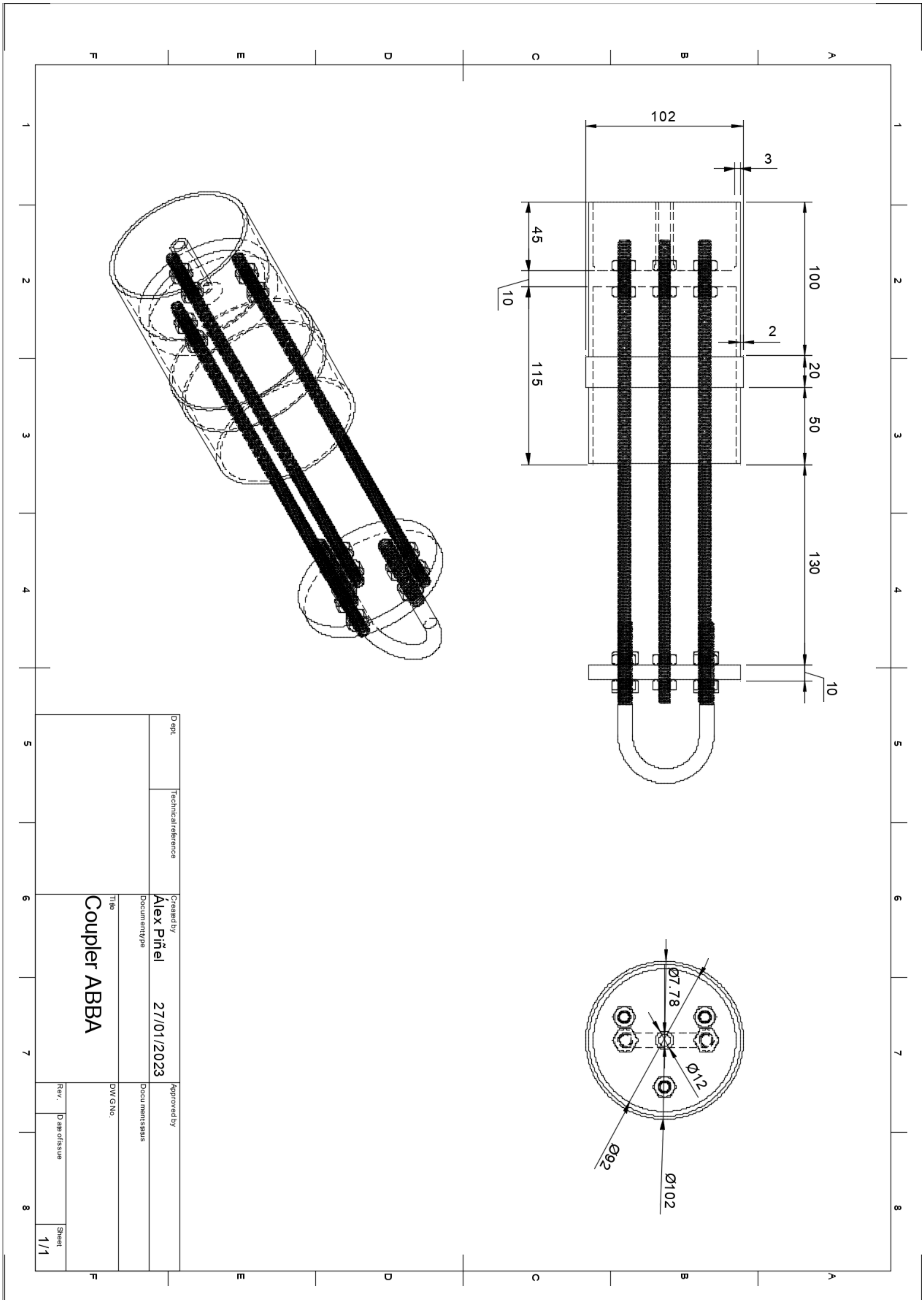
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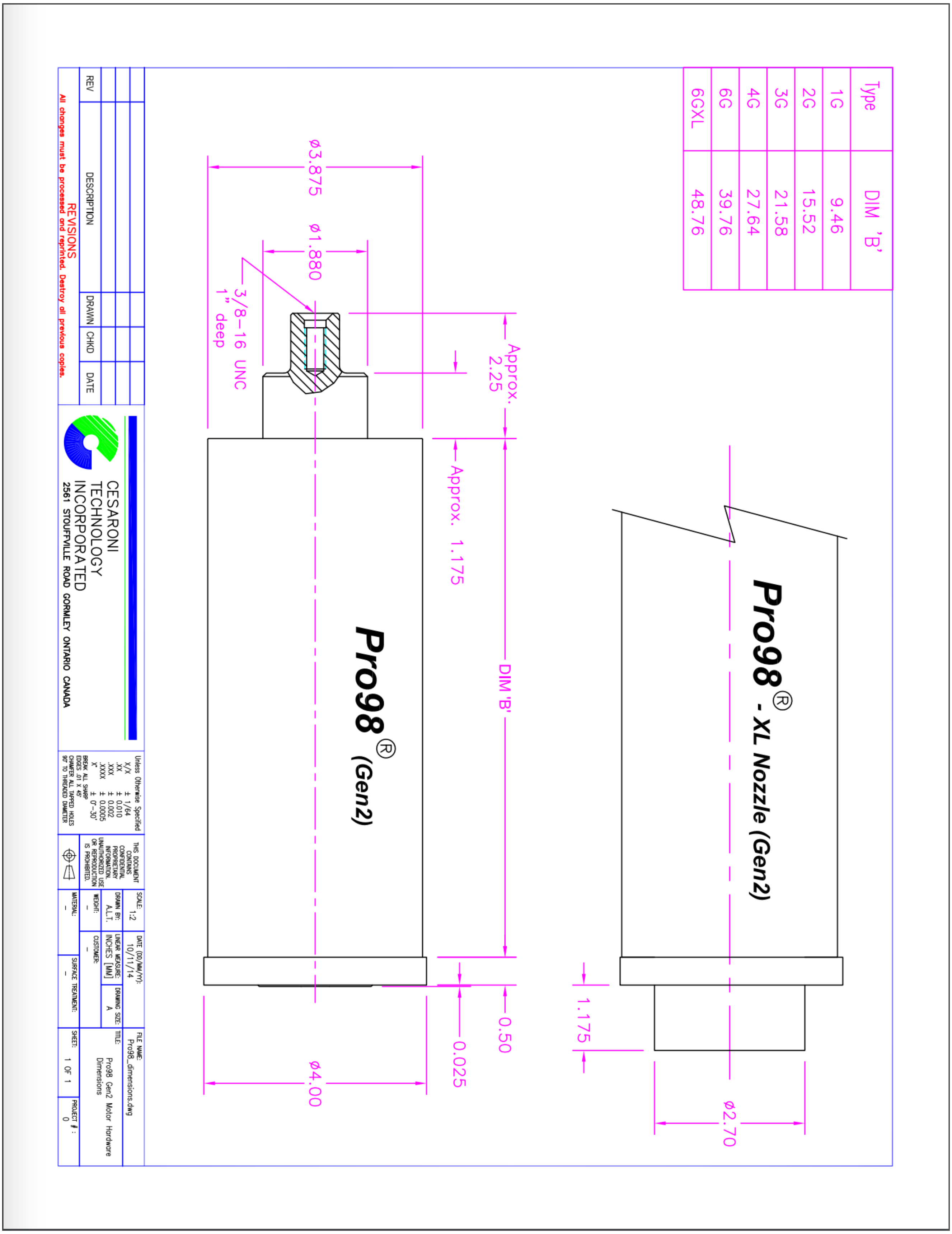
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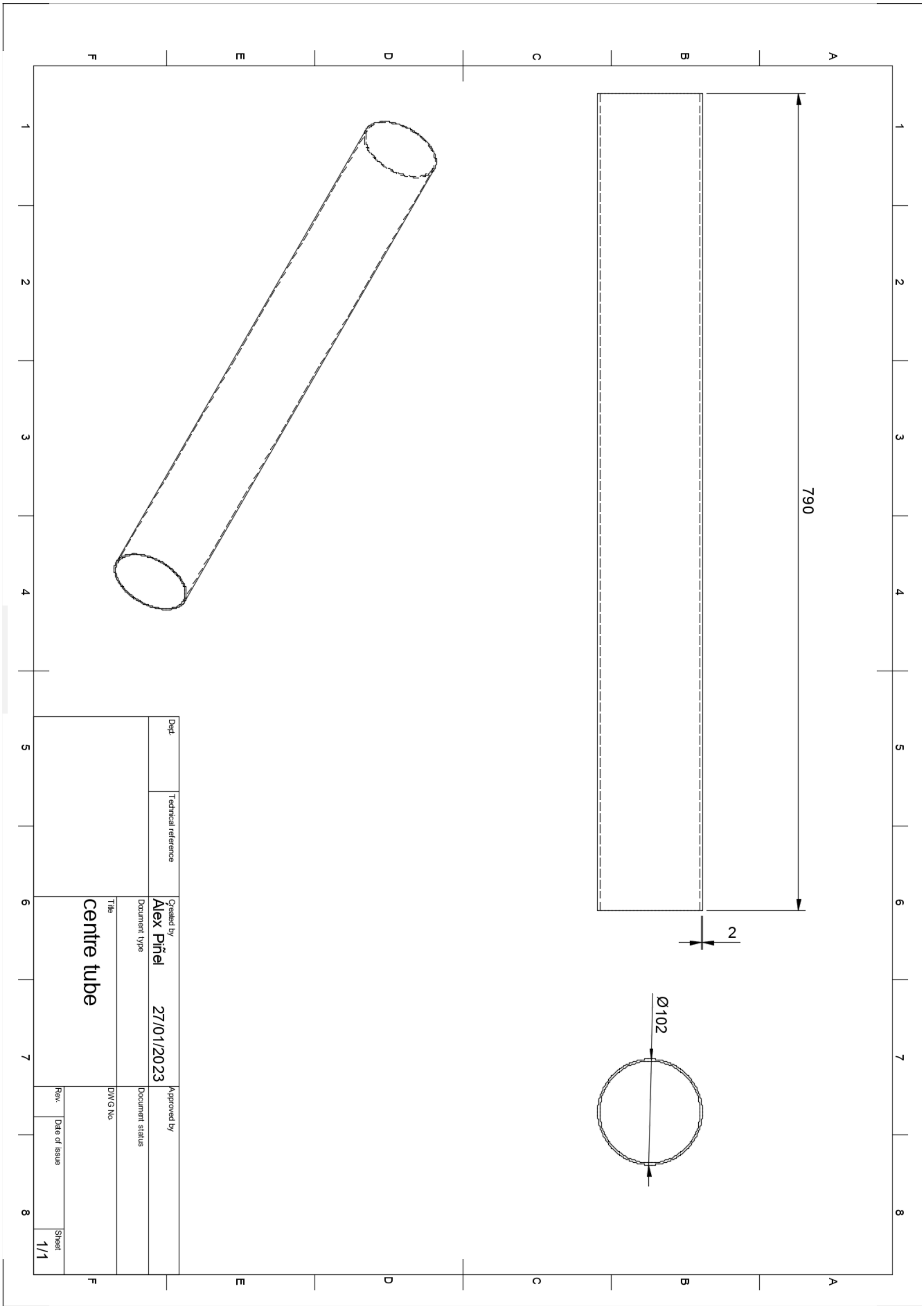
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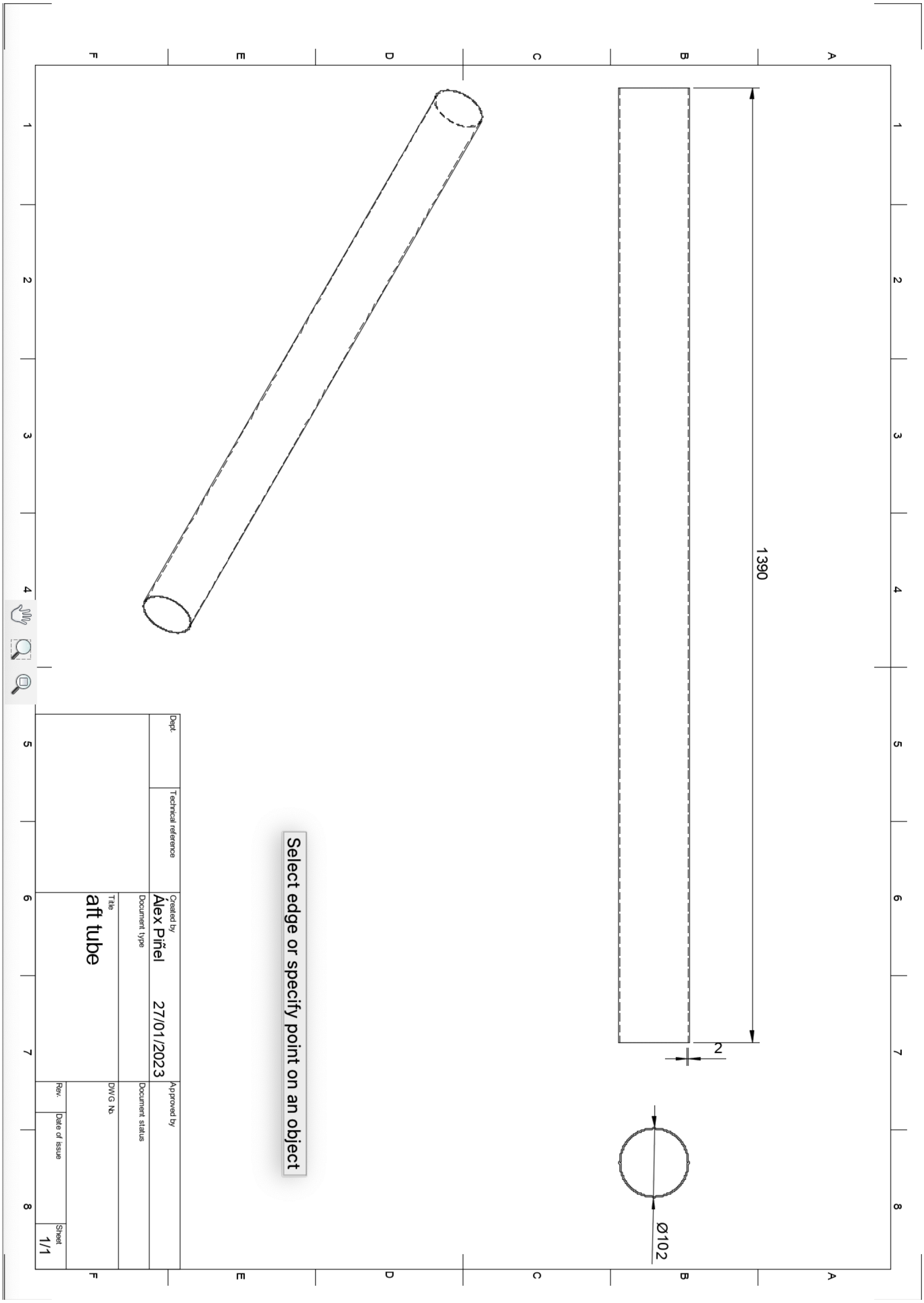
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Chapter 5: Deployment mechanism

The main distinguishing factor between the big rocket and other launch vehicles of similar characteristics is its parachute deployment mechanism, the innovative approach used is designed to satisfy both the mechanical systems and deployable payload main requirements providing a highly capable and easily reusable approach.

Before delving into the technicalities of this method, it is important to understand the main challenges involved in parachute deployment and how these challenges are commonly handled in high power rockets. As per the requirements of EuRoC, the rocket must deploy a small drogue parachute at apogee, as the rocket descends below 500m the main parachute must be deployed for safe touchdown, this combined with the expected payload release means the big rocket will undergo a sequence of three deployments: drogue, payload, and main. Given that the parachutes and payload are stored inside the rocket, it is common practice to separate the rocket into two or more parts and expose the components that must be deployed, it is this separation that presents the biggest challenge, the rocket must be sturdy during flight but must also be capable of providing a reliable separation. In most rockets, this is achieved by generating high pressures inside the rocket (either by use of black powder or CO2 canisters) which separate the nosecone from the rest of the airframe, other vehicles rely on mechanical methods such as the clamp band system which are more reliable at the cost of higher complexity, in other cases multiple separations occur for each deployable component. An illustration of this systems is provided in the following figure:

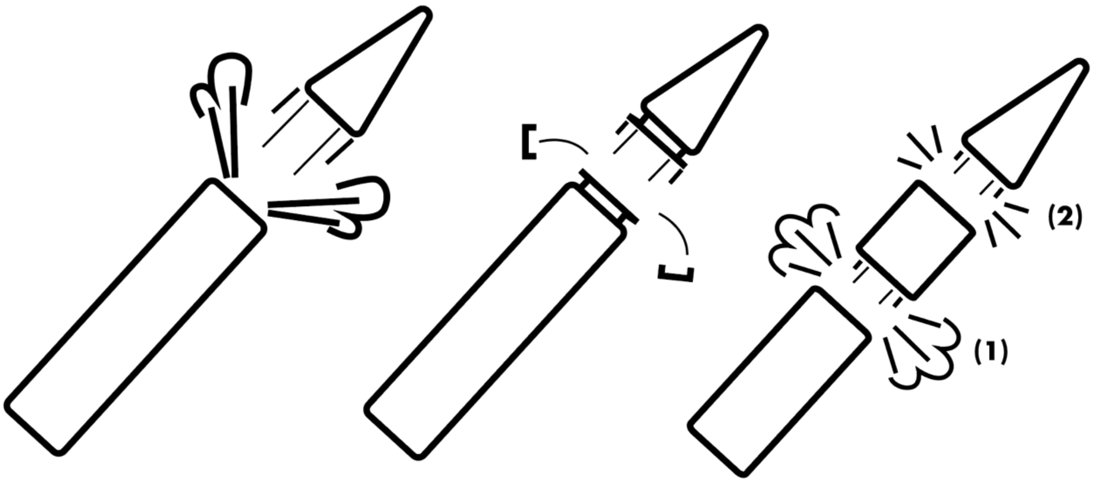


Figure 17 Common separation techniques

Using a clamp band system would satisfy the mechanical systems requirement, however, deploying the payload would be extremely complicated as either the parachutes or the payload itself are very likely to get stuck inside the rocket. This highlights the need for a system that exposes as much of the deployable components in a single action as possible, this can best be achieved through the use of fairings:

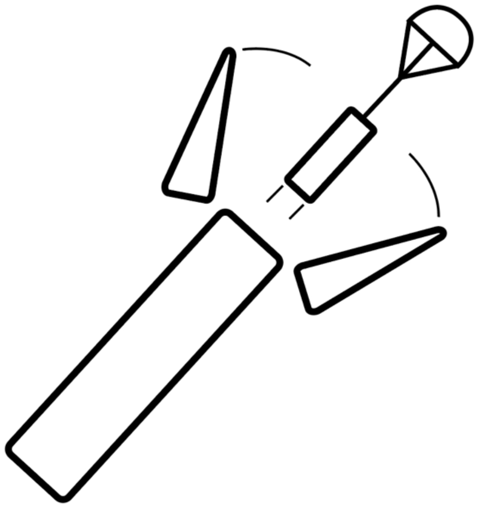


Figure 18 Fairing separation

While this system does offer a safe detachment of all components, two issues immediately stand out: how are the two fairings separated, and how are the fairings kept in place before separation. During flight the fairings must be kept tightly together and with no gaps between them as that can impair the aerodynamic performance of the vehicle, at separation, the fairings must separate with enough strength and speed so as to ensure the payload and drogue can be released. The big rocket uses a combination of springs and hinges to solve both issues:

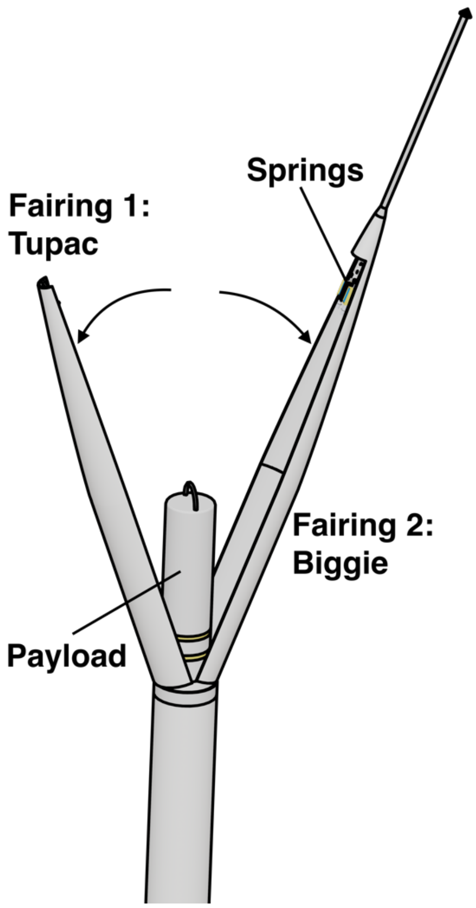


Figure 19 Big rocket deployment system

Spring actuated mechanism:

The Mechanic-Electric Spring-Solenoid (MESS for short) is the mechanism by which the fairings are both kept together during flight and separated at apogee. By using a single device located at the top of the structure, the entire system is vastly simplified, especially when compared with previous methods which would have involved at least 2 nichrome wires plus an independent spring release. The specific details on how the MESS will work are yet to be developed by the engineering teams at Aurora, but here is a proposed method which might provide some inspiration:

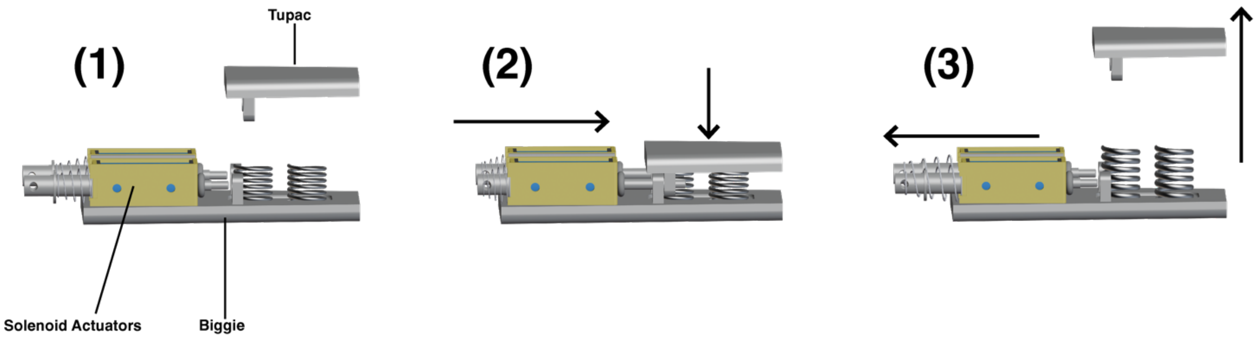


Figure 20 Mess

In this case, solenoid linear actuators are used to press keep together the two fairings by extending into a pair of rings. Once the actuators are detracted, a set of compressed springs releases its energy thus pushing the two fairings apart. There are two main aspects to develop regarding this method:

First, the characteristics of the springs must be researched, these must be strong enough to push the fairings apart with sufficient force while also being easy to compress.

Second, the best solenoid linear actuators must be found for this specific task. These come in three configurations: Push, Pull, and Push/Pull, of these the option that would consume less electricity must be used as ideally the actuators will be 'neutral' in their extended configuration. The strength of the actuators must also be considered as it would be rather embarrassing if the actuator of choice fails to withstand the loads of the springs. Lastly, form factor is also of great importance, as the actuators should ideally be as small as possible.

Other alternatives might use servos, nichrome wires, or even magnets, but then again this is all up to the engineering department to investigate.

Hinges:

Oh boy here we go, as far as I am aware hinges are usually not a very relevant topic when it comes to high power rockets, but the big rocket is special, and hinges have unexpectedly arisen as a source of great relief and of insufferable headaches. To whoever must work on the hinges I can only wish the best of luck and hope they find the topic more entertaining than I ever did.

So, why hinges? Why do we even need them? Originally, the fairings were planned to detach completely from the rocket as is usually done in larger orbital vehicles, but that presented a series of important issues: How do you keep the fairings in place before detaching them? How to prevent the fairings from being lost? And if the fairings are tied to the rocket, how can one stop them from smashing into the rest of the vehicle? Having to deal with these questions proved way beyond my capabilities and what I considered to be feasible, but inspired by a muse that can only be traced to the divine, the idea of using hinges was presented to me, not only could they keep the fairings firmly in place during launch, but they would also keep them with the rocket while not interfering with the deployment process, it really did seem like a perfect idea… this brings one final question: what is the problem with hinges?

There is no problem per se, but the requirements expected from these hinges are complicated to say the least. The hinges will have to work under three different flight conditions: flight, deployment, and main parachute deployment.

During the flight condition, the hinges must hold the two fairings firmly in place, ensuring that they do not move whatsoever and that they remain in their closed position. Throughout this period, thrust from the engines will travel through the hinges, therefore they must be strong enough to sustain this force.

At apogee, the MESS mechanism will engage, and the two fairings will separate. The movement of the hinges must be smooth and quick to allow the contents inside the rocket to be released. As the vehicle starts falling again under the drogue parachute, air will blow on fairings pushing them upwards again, this can be prevented by minimizing the drag on the deployed fairings by rotating them a full 180˚, and by making the hinges lock in place once they are fully deployed.

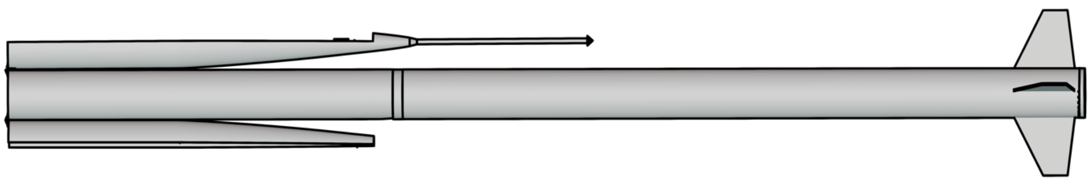


Figure 21 Fully deployed fairings

The main source of concern appears at the last stage of flight: the main parachute deployment. As the velocity of the falling rocket suddenly changes form 30m/s to 5m/s violent forces act on the entire rocket. According to the Project Birkeland technical report by Propulse NTNU the main parachute deployment generates loads of up to 4000N, substantially higher than the 3216N maximum thrust of the engine. It remains to be seen how that force would affect the hinges as this load does not travel through them. Regardless, it is very likely this force would yank the fairings upwards potentially tangling or cutting the parachute. SIMULATIONS MUST BE CONDUCTED TO STUDY THE FORCE THAT WILL TRAVEL THROUGH THE HINGES, THIS IS OF VERY HIGH IMPORTANCE!

Based on this information, it is very clear that the hinges must fit the following requirements: high strength, 180 ˚ rotation, and self-locking. It must also be as compact and easy to attach and assemble as possible. It is doubtful commercial options exist that can fit all these requirements, but rather than making a brand-new hinge it might be better to modify an existing commercial design. A lot of research must be conducted on this topic, but the Barrel-Shaped Mortise-Mount Concealed Cabinet Hinges from McMaster-Carr might provide some inspiration. These are small, easy to install, and can rotate 180 ˚, however they have no self-lock mechanism and might not be strong enough.

Figure 22 Barrel shaped hinge

In conclusion, an elite hinge team is required to research this topic. This team must understand how parachute deployment loads will affect the hinges and must design a self-lock mechanism to make the hinges stay in their fully rotated position. This mechanism might involve a spring that pushes a small metal rod that locks the hinge for example, but I am tired of this and would rather think about something else. In case it is not possible to use hinges, other possibilities will need to be put in place, this might involve hinges designed to break at main parachute deployment or in a worst-case scenario a redesign of the deployment mechanism.

Chapter 6: Recovery

Armed with a proper understanding of the deployment mechanism of the big rocket, it is now possible to discuss how the parachutes of the rocket will work. As per EuRoC regulations the vehicle must use a double deployment sequence, during descent it must fall at a speed of around 30m/s, and after passing an altitude of 450m it must be slowed down to 5m/s for safe impact with the ground. This is achieved by using two parachutes: a drogue for initial descent, and a main for touchdown.

Based on the findings of the "*Calculations and lots of stuff FROG*" document by Aurora, it can be found that the drogue parachute area must be of around 0.5m^2 and that of the main parachute must be of approximately 4.4m^2. These two will be placed inside the rocket, the main being right above ABBA and the drogue sandwiched between the payload and the main parachute.

Ensuring safe parachute deployment is a very complicated task that will require a lot of careful considerations, it must be noted that the details regarding lines, chords and other components involved in the recovery system are very likely to change as further studies are carried out. The fairing mechanism previously detailed greatly simplifies the parachute deployment and chord structure. As the fairings open the payload and its independent parachute will instantly fly away, the drogue being exposed right after would also very likely immediately open on its own. If this is found not to be the case an easily breakable cable can be placed connecting the payload to the drogue, this would allow the payload to push the drogue out before the cable breaks allowing the payload to fly away.

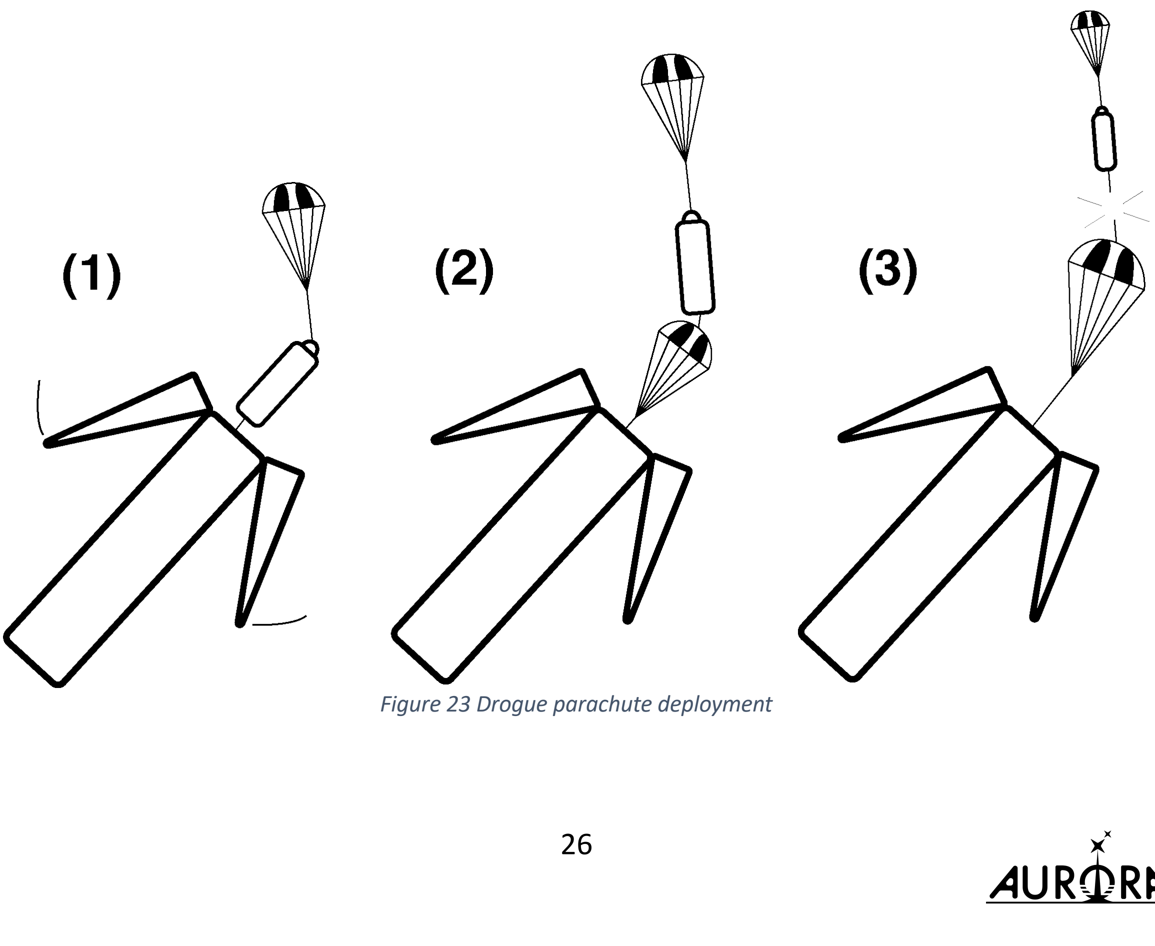


Figure 23 Drogue parachute deployment

Once the drogue parachute is deployed, the rocket will fall down at a moderate velocity of 30m/s. As the rocket descends from a height of 9000m, air density will start increasing, thus reducing the velocity of the rocket further, taking into account this descent in velocity the descent time from apogee to a height of 450m can be estimated to be of around 6 minutes. Deploying the main parachute is the real challenge when it comes to the recovery system, as it must be kept safely in place inside the rocket throughout the aforementioned 6 minutes and must be safely deployed once the order is given. To this end, a 3-ring release system is used:

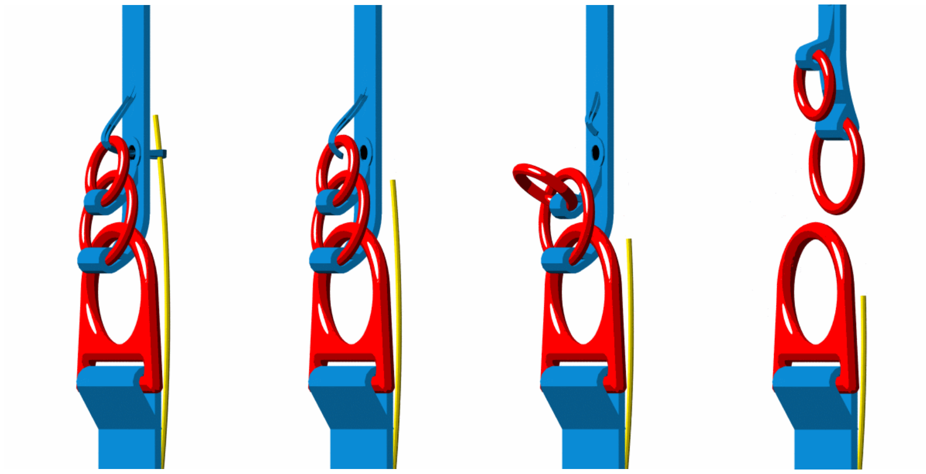


Figure 24 3-ring system

The three rings provide a very strong link when connected which prevents the main parachute from being pulled away out of the rocket. To separate the rings, a nichrome wire is burned which cuts the cord connecting the rings (yellow string in the previous figure), this allows the chord to be pulled out by the drogue parachute which in turn deploys the main parachute. To ensure the main parachute does not tangle and to minimize the amount of space it takes inside the rocket, it is placed inside a bag from which it is also pulled out by the drogue:

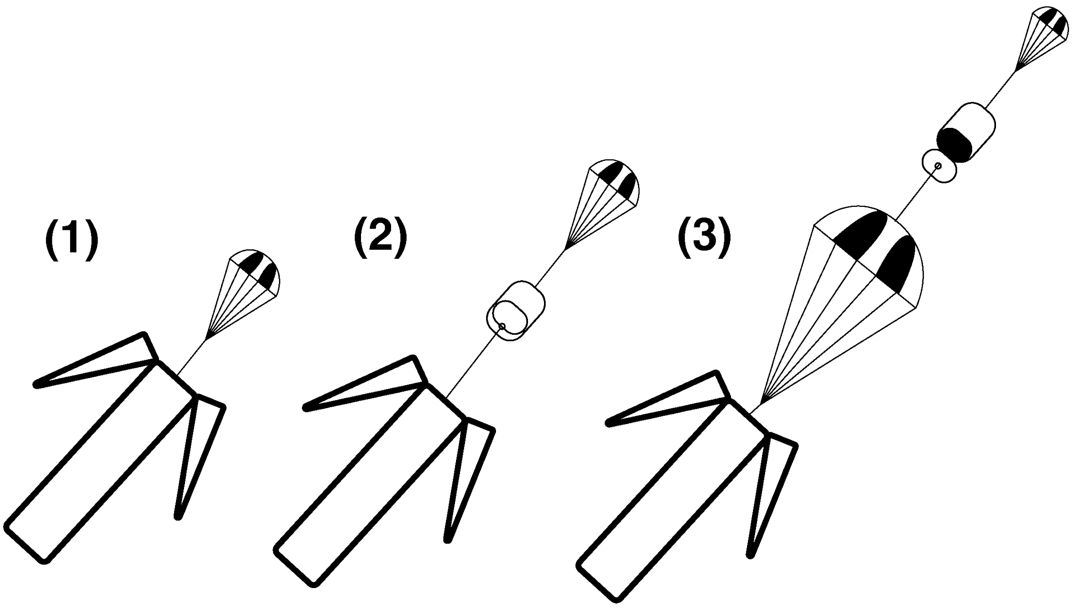


Figure 25 Main parachute deployment

Having a clear picture on the way every recovery component is connected is crucial to its development. In essence, both parachutes and the three-ring system connect in different ways to a shock chord which is in turn connected to the U bolt of ABBA. As the drogue is released the first half of the shock chord is extended up to the 3 rings which are kept in place by the nichrome wire at the U bolt, once the nichrome wire is burned the rest of the shock chord is allowed to release which then pulls the main parachute bag and the parachute itself out of it. The following diagram illustrates two possible arrangements of the recovery system components inside the rocket:

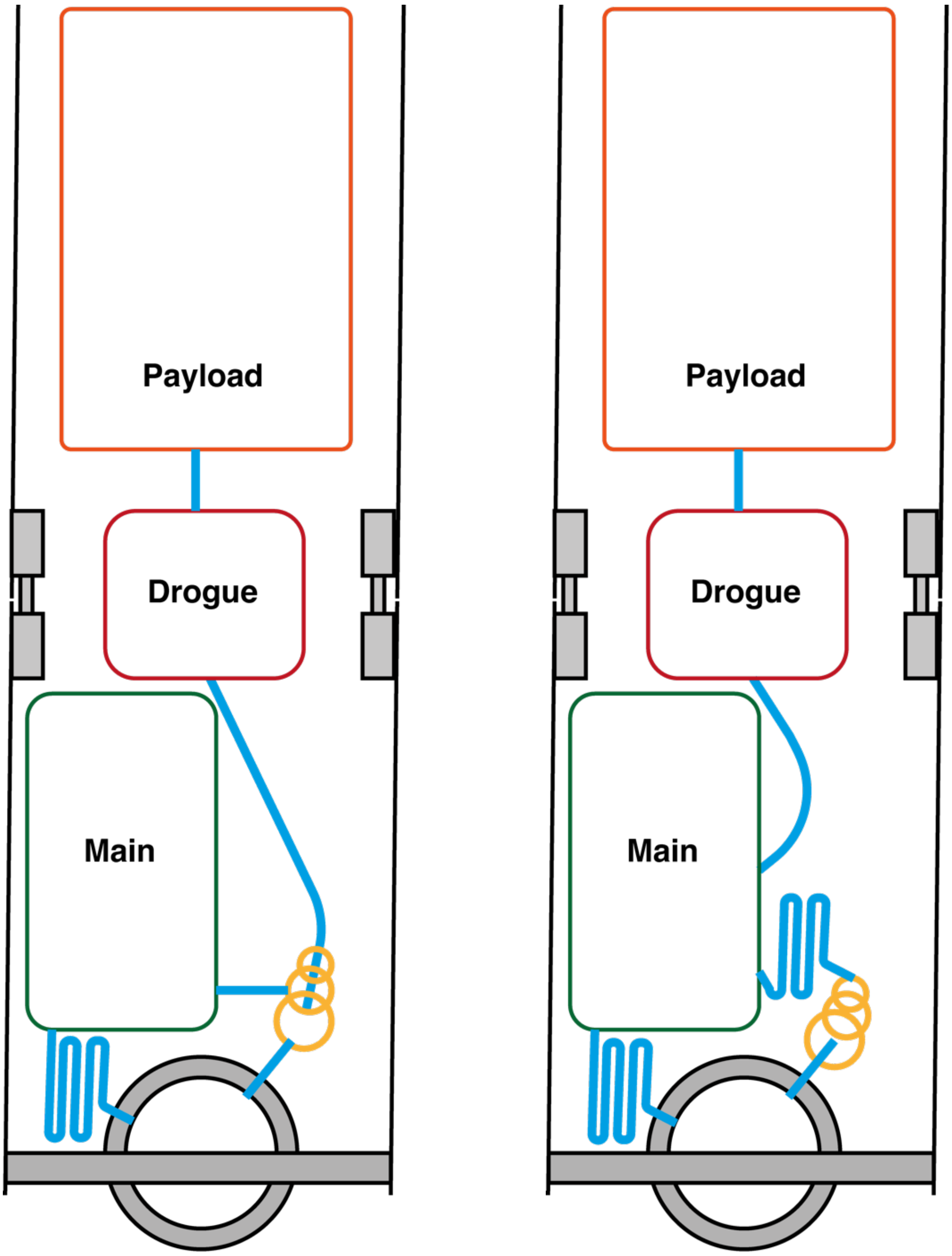


Figure 26 Component arrangement

Once again it must be clarified that this arrangement is very likely to change, and it is up to the recovery team, its team head and assistant team head to develop the best recovery system ever presented at EuRoC. Here is a render of the big rocket as it descends with its fully deployed parachutes:

Chapter 7: Avionics

A rocket without a brain is a stupid rocket, and stupid rockets do not fly very well. As smart and brave as the hamster some in the team want to sneakily place inside the rocket is, it is not fully qualified to control the multitude of things going on as the rocket flies. It is therefore the job of the avionics team to build a brain for the rocket and give it all the necessary sensors that will make it aware of its environments and experience existential angst.

Before proceeding with the description of the avionics system, it must be disclaimed that this is a very simplified attempt at explaining the electronics inside the rocket based entirely on my limited knowledge. Those who desire to learn more about it are better off asking team heads Hamza and Vishisht or any other member of the amazing avionics team.

Throughout its flight path, the rocket must perform a multitude of tasks, some more critical than others. The only flight critical task (and main priority) is the actuation of the recovery system at the required altitudes, other important tasks include telemetry, data recording, camera operation, and EggTimer usage.

Recovery:

How does the rocket know when to deploy its parachutes? Apogee detection algorithms will be discussed in the following chapter, but the important thing here is that the rocket must know its position and velocity at all times, this is achieved by the use of three different redundant sensors: barometer, IMU, and GPS tracker.

Barometers are pretty simple devices; they measure atmospheric pressure. Knowing that air pressure changes with altitude it is possible to compute the altitude of the rocket based on the measurements of the barometer, and as soon as pressure reaches a minimum and starts increasing again one can assume that apogee has been reached. The work rate of the avionics team is faster than my brain frequency allows me to perceive so things might have changed since I checked last time, but as far as I am aware the current plan is to use the Bosch BMP280 barometer which has an accuracy of ± 1 hPa, this translates to around 12 meters of error.

Inertial Measurement Units (IMU) are as rocket sounding as it gets, they provide angular velocity and linear acceleration data on three axes, this allows for the acceleration, velocity, and position of the rocket to be computed in 3-dimensional space to be computed at any moment. This not only allows for apogee detection, but also provides very valuable telemetry data on the trajectory of the vehicle.

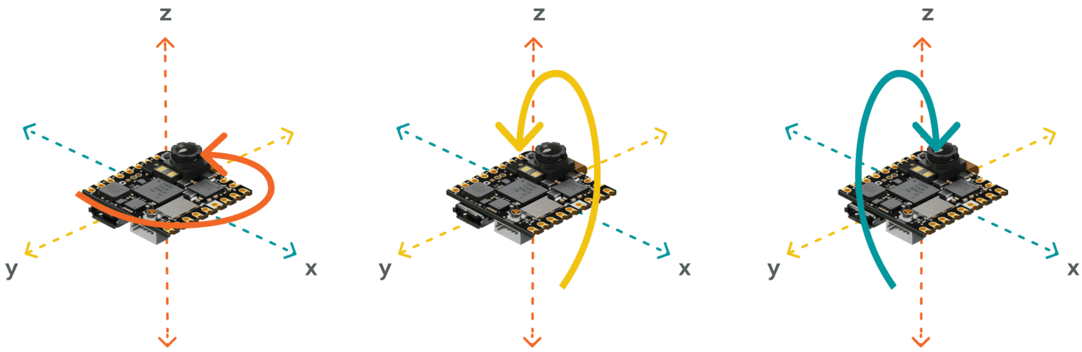


Figure 27 Inertial Measurment Unit

The IMU for lil' Mary (and probably the big rocket) is the Adafruit BNO055 Stemma. It must be noted that this device runs at a frequency of 100Hz or produces a reading evert 0.001 seconds. While this might seem extremely fast, the rocket might experience large acceleration changes in similar timeframes which might produce inaccuracies in the IMU readings.

GPS tracking is quite self-explanatory, a GPS receiver (Adafruit 746 Ultimate) is installed inside the rocket and positioning data is obtained from satellites orbiting around the earth. Out of the three sensors this might be the most inaccurate, especially considering it does not operate at speeds above Mach 1. Nevertheless, this device will be extremely important when the rocket must be found after landing.

<u>Telemetry:</u>

As the rocket lifts off and flies away, it would be nice to know if it is doing well. Telemetry data is therefore to be relayed from the rocket providing information on position, velocity, and flight status. The big rocket will use a LoRa radio module operating at 433Hz to transmit this information, this will be received by a yagi antenna in the ground and translated into visual data from the ground computer. Again, the avionic team knows far more about how telemetry systems will work, but an important factor to consider will be the positioning of the antennae as some of the airframe components are not radio transparent.

The aft tube and ABBA are made of non-RF transparent materials meaning that all transmitters must be located somewhere along the centre tube. The ideal place would be the avionics bay inside ABBA, however its close proximity to the aft tube and the reflectiveness of the aluminium might severely impair its transmitting range. Another possibility would be to place it above ABBA although that might cause problems with the recovery system, otherwise the antennae can be placed inside the fairings or outside the airframe of the rocket although that would bring all the complications related with having an antenna exposed to the elements.

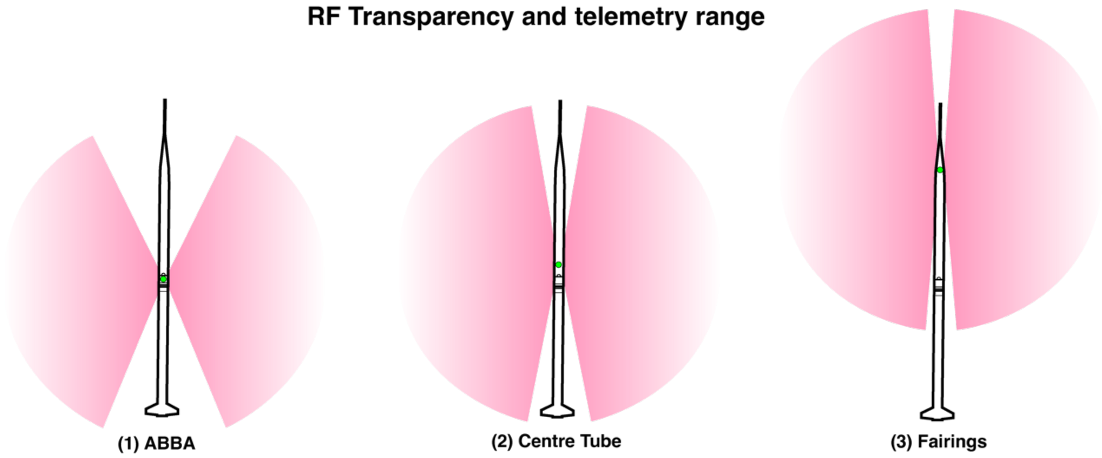


Figure 28 RF transparency for different antenna positions

It seems quite clear that the higher the transmitters are placed the more range they provide. The final choice regarding antennae location must be made by the avionics team based on EuRoC documentation and the requirements of the recovery and airprop teams.

Data recording:

I know nothing about data recording and will therefore not talk much about it. But in case something was to go wrong with the rocket it would be handy to keep all the flight data safe. I know some teams include small "black boxes" with SD cards as part of their avionics systems, maybe it would be good to include something similar inside the big rocket. Just in case…

Cameras:

One cannot launch a rocket without placing any cameras on it, not only do they provide amazing views but are also essential for post-flight analysis of the performance of our rocket.

Being a non-flight critical component, the placement of the cameras is essentially an artistic choice made in search of the "wow" factor. For the big rocket it is suggested to use 3 cameras placed in the following positions:

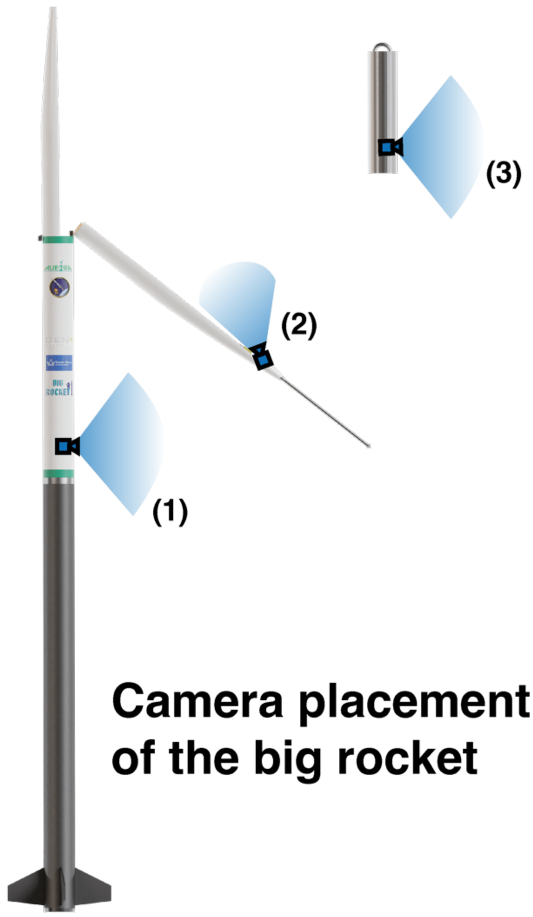


Figure 29 Camera placement

Camera 1 would be placed inside ABBA pointing through a hole in the airframe, camera 2 would be placed somewhere next to the MESS system and would provide excellent views of the payload and parachute deployments, as well as the fairing system as a whole, camera 3 would be placed inside the payload to provide amazing views of its descent as it travels through the atmosphere.

<u>EggTimer:</u>

Sometimes having just one brain is simply not enough, EuRoC beliefs it is never enough and therefore requiring each rocket to fly with a redundant COTS flight computer. The flight computer of choice for the last few years was the EggTimer classic (apparently a huge pain in the ass according to other teams) but that might be subject to change this year. The EggTimer is there mainly to ensure parachute deployment, and includes many of the same sensors that the SRAD flight computer will use, most of the information about this flight computer is in the EuRoC documentation, but perhaps the most important piece of information is showcased in the following picture:

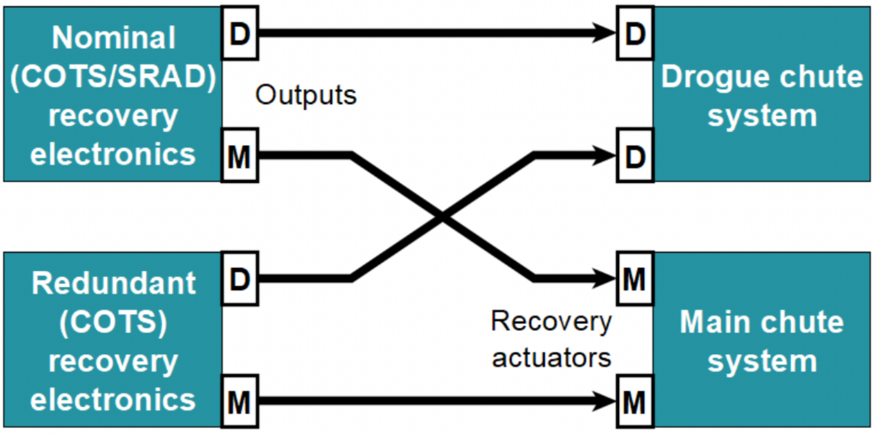


Figure 30 Flight computer redundancy

Essentially, both flight computers must be capable of deploying both parachutes, in the case of the big rocket that means deploying the fairings and burning the 3-ring system nichrome wire.

The location of the EggTimer inside the rocket is up to the avionics team, it can be placed inside ABBA with the other avionics components, or it can be placed somewhere else (if it fits) for extra redundancy or for the RF transparency issues previously discussed.

Chapter 8: Software

Software is not easy; in fact, it is quite painful. Everything in the rocket can go wrong if the code is not written right. Hopefully these reassuring words produce some warm, encouraging excitement for the reader, who is now about to read about how to make the rocket not crash.

If the flight computer is the brain of the rocket, the software is everything it learned at school, and Aurora's big rocket deserves only the best education. The software team's work can be divided into two sections: RocketOS, and ground control, the first controls everything that happens inside the rocket, and the latter handles all the telemetry and ground operations of the vehicle.

RocketOS:

The rocket operating system will operate from inside the rocket as it flies. It will allow for sensor data from the IMU, barometer, and GPS tracker to be processed and understood by the flight computer (the methods by which this data can be understood will be explained in the following chapter). If this data is read correctly, then all launch events will happen as expected and the rocket will deploy its drogue parachute at apogee and the main at 450m.

Apart from apogee detection, the RocketOS will handle the transmission of telemetry and the storage of data inside the rocket. It remains to be seen what data exactly will be transmitted back to the ground, data from the main three sensors is enough to understand how the rocket is performing at any moment, but if opportunities arise it might also be possible to transmit video footage in real time from the three cameras installed in the rocket.

All the RocketOS code must be written in C++ programming language, as that is the operating language of the Teensy 4.1 microprocessor chosen by the avionics team for the flight computer.

Ground Control:

This is the code that will run from the ground during launch preparation and actual flight. Through it, the team will be able to check the status and flight-readiness of each component, it will control every part of the rocket as it sits on the launch pad and will execute a launch abort if deemed necessary. It will also receive the telemetry of the rocket and convert it into easy to interpret visual data.

In this case, the software team's code of preference can be used (probably python as it already includes many libraries and is relatively easy to use). As for the data visualisation, the free OpenMCT programme by NASA is specifically designed for tasks of this sort and might result particularly useful.

Chapter 9: Apogee detection

The main challenge of the RocketOS team and perhaps of the entire department, how does one measure exactly when something stops going up and starts going down? The attentive reader (aha! Spinoza reference) might understand that this is as simple as checking whatever the sensors say and go along with it. But we live in an imperfect world, and as beautiful as sensors can be (not really) they all process data in different ways, and moreover they all fall victim to noise and other inaccuracies in their readings. Before dealing with the noise and errors, the way data is processed by each of the main three sensors can be explained:

IMU:

As previously mentioned, an inertial measurement unit provides linear and angular acceleration data along 3 different axis (X, Y, Z) and does so once every 0.001 seconds for the big rocket. Therefore, working in timesteps of 0.001s it is possible to track the position of the vehicle at any time by integrating the acceleration data relative to time:

$$\boldsymbol{v}_{(x,y,z)t} = \int_{0}^{t} \boldsymbol{a}_{(x,y,z)}\, \boldsymbol{dt}$$

$$\boldsymbol{p}_{(x,y,z)t} = \iint_{0}^{t} \boldsymbol{a}_{(x,y,z)} \boldsymbol{dt}$$

Where $\boldsymbol{v}$ represents velocity, $\boldsymbol{p}$ is position, and $\boldsymbol{a}$ is acceleration. If the altitude (that is $\boldsymbol{p}_y$) at timestep $\boldsymbol{t-1}$ is subtracted from that of the present $\boldsymbol{t}$ a deviation can be measured:

$$\Delta \boldsymbol{p}_{\boldsymbol{y}} = \boldsymbol{p}_{\boldsymbol{y}(\boldsymbol{t})} - \boldsymbol{p}_{\boldsymbol{y}(\boldsymbol{t}-\mathbf{1})}$$

The value of this deviation during ascent will always be positive, as each present altitude must naturally be higher than any previous value. On the other hand, $\Delta \boldsymbol{p}_{\boldsymbol{y}}$ will become negative as the rocket starts to fall. Therefore, it can be understood that apogee is reached the moment this deviation switches from positive to negative values. This is perhaps a rather simplified explanation of the principles behind the IMU, but it should hopefully get the point across.

The IMU also allows for the actual flight path of the rocket to be found, this might be useful for post-flight trajectory analysis and might provide some insightful data on the stability and overall performance of the rocket:

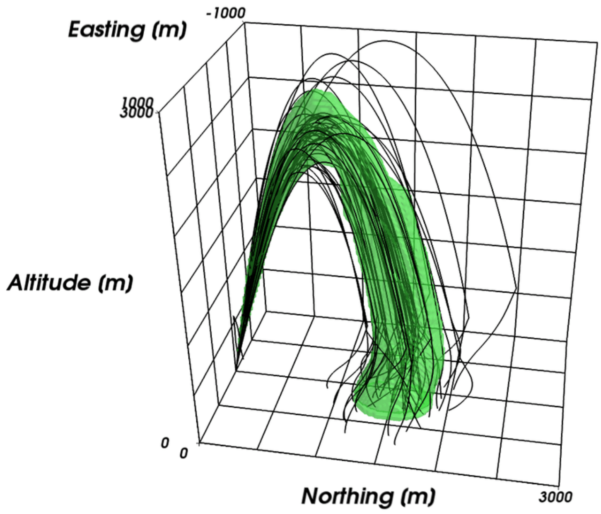


Figure 31 Rocket trajectory

Barometer:

Pretty much the same principle, a deviation can be found for each time-step of flight and apogee can be understood to happen after the sign of the deviation changes. In this case however, $\Delta \boldsymbol{Pressure}$ is negative during ascent and positive during descent given that air pressure decreases the higher you go.

GPS:

The GPS locator allows for the rocket to be tracked by up to 22 satellites orbiting around earth. The data provides position data with an error of less than 3 metres and velocity information with an accuracy of 0.1m/s. It is important to know however, that most GPS locators do not work properly at high altitudes and velocities due to legal concerns, and therefore might not provide accurate apogee detection data.

GPS will have its time in the spotlight as the rocket (and payload) touchdown and must then be located. The use of GPS for apogee detection is therefore left as an exercise to the reader.

So, easy peasy right? Rocket goes up and then it goes down! Well, it is not that simple… Each of these sensors have inaccuracies and their readings are always affected by noise and other unexpected factors. If for whatever reason pressure readings were to increase for a few timesteps, the change of sign in the pressure deviation would suggest apogee has been reached which could lead to catastrophic consequences. How then can one determine which readings are accurate and which are not? The answer lies in certain algorithms designed for this purpose such as the Kalman filter.

For statistics and control theory, Kalman filtering, also known as linear quadratic estimation (LQE), is an algorithm that uses a series of measurements observed over time, including statistical noise and other inaccuracies, and produces estimates of unknown variables that tend to be more accurate than those based on a single measurement alone, by estimating a joint probability distribution over the variables for each timeframe (Literally copy-pasted from Wikipedia).

Kalman filtering works by using a mathematical model of the system being estimated and a process model that describes how the state of the system evolves over time. The algorithm uses a combination of predictions based on the process model and measurements from sensors to update the estimated state of the system. This is done iteratively at each time step, considering the estimated error covariance and the measurement noise.

The algorithm consists of two main steps: prediction and correction. In the prediction step, the estimated state of the system is propagated forward in time using the process model and the estimated error covariance is updated to reflect the uncertainty in the prediction. In the correction step, the estimated state is updated based on the measurement information, considering the measurement noise.

The key to the effectiveness of the Kalman filter is the choice of the mathematical models and the estimation of the parameters that describe the process and measurement noise. The accuracy of the estimated state depends on the accuracy of these models and parameters, and the Kalman filter provides an iterative method for refining these estimates based on the available data (All of this was written by ChatGPT).

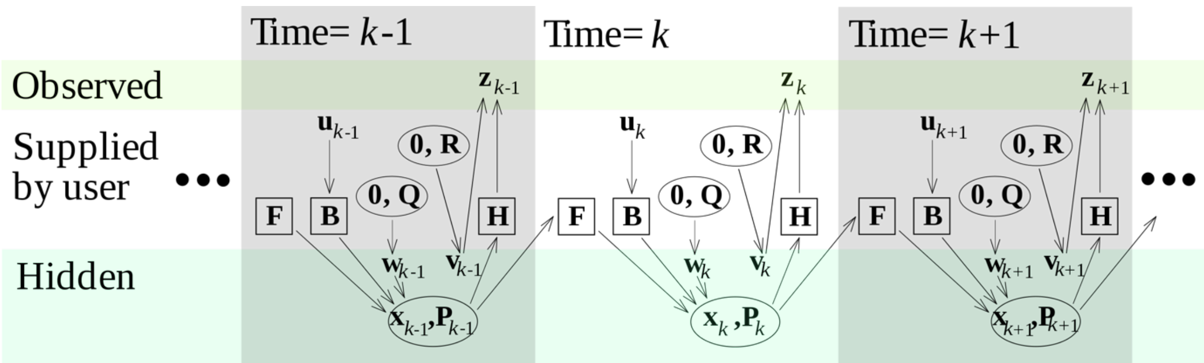


Figure 32 Kalman filter

Model underlying the Kalman filter. Squares represent matrices. Ellipses represent multivariate normal distributions (with the mean and covariance matrix enclosed). Unenclosed values are vectors. For the simple case, the various matrices are constant with time, and thus the subscripts are not used, but Kalman filtering allows any of them to change each time step.

Chapter 10: Payload

EuRoC regulates that each rocket must carry at least 1kg of payload, at Aurora we are rather extra and have decided to make the payload an integral component of the big rocket. As stated in the main requirements for the rocket, our payload must be deployable, meaning that it must be ejected from the rocket and land under its own parachute. It has also been decided to allow the payload to be 3kg in mass, vastly increasing its scientific potential.

As for the deployment system, it has already been covered in detail in previous chapters. Once the fairing is open the entire payload and its parachute will be exposed, forcing the parachute to open and separating it from the rest of the rocket.

The dimensions and form factor of the payload are limited by the design of the rocket. In order to fit inside the fairings, the payload cannot exceed 30cm in length and 8cm in diameter (this is a conservative estimate and might change in the future). The shape, configuration, and choice of material for the payload is left entirely to the payload team, but here are some illustrations on how it could potentially look:

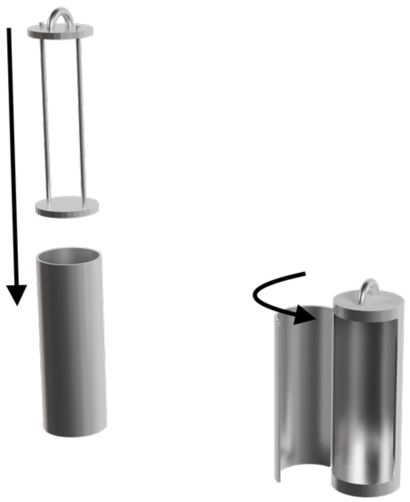


Figure 33 Possible payload designs

Ideally, the payload should be made out of fibreglass as it is lightweight, relatively easy to manufacture, and is RF transparent. Being a deployable payload means that must carry its own electronics, a special compartment must be built to house a gps locator, batteries, camera, and potentially an additional EggTimer flight computer.

The "*Calculations and lots of stuff FROG"* document suggests that the parachute area for the recovery should be of around $1m^2$ (very similar to that of the Lil' Mary rocket), this means the payload will take around 20 minutes to descend from apogee at velocities in the range of 9-6m/s.

Chapter 11: Conclusion

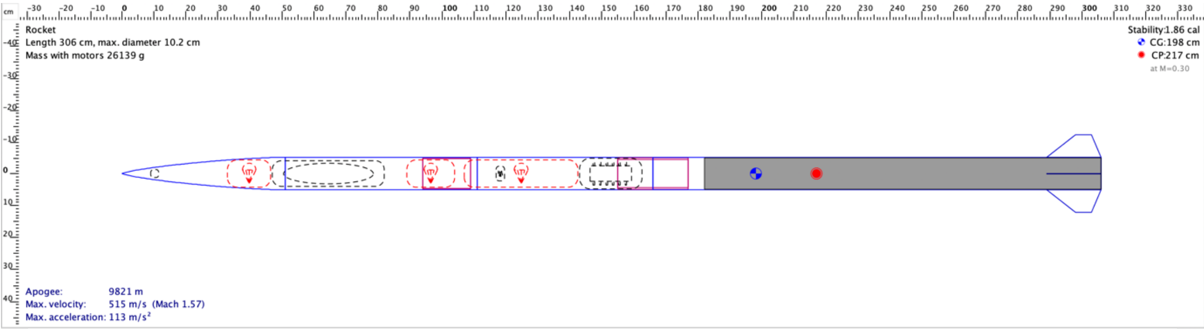
The document ends here. I am tired. Many of the things I mention are likely to change as work on the big rocket moves on, but hopefully this report offers a clear idea on the systems and ideas that make the big rocket work.

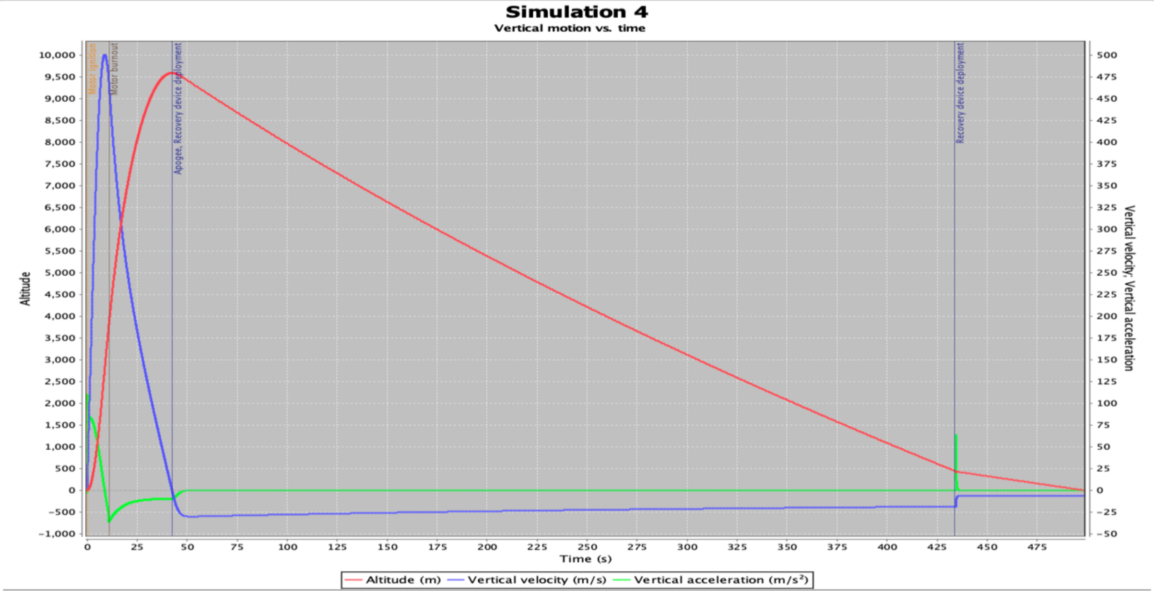
I can only ask the reader to be as critical as possible, if something does not seem right think about it, figure out if there is a flaw and if there is communicate it with the rest of the team and try to solve it. This is a team project, and only by working together and working well can we expect to make the big rocket a reality and watch it soar into the skies as the best rocket ever sent to EuRoC.

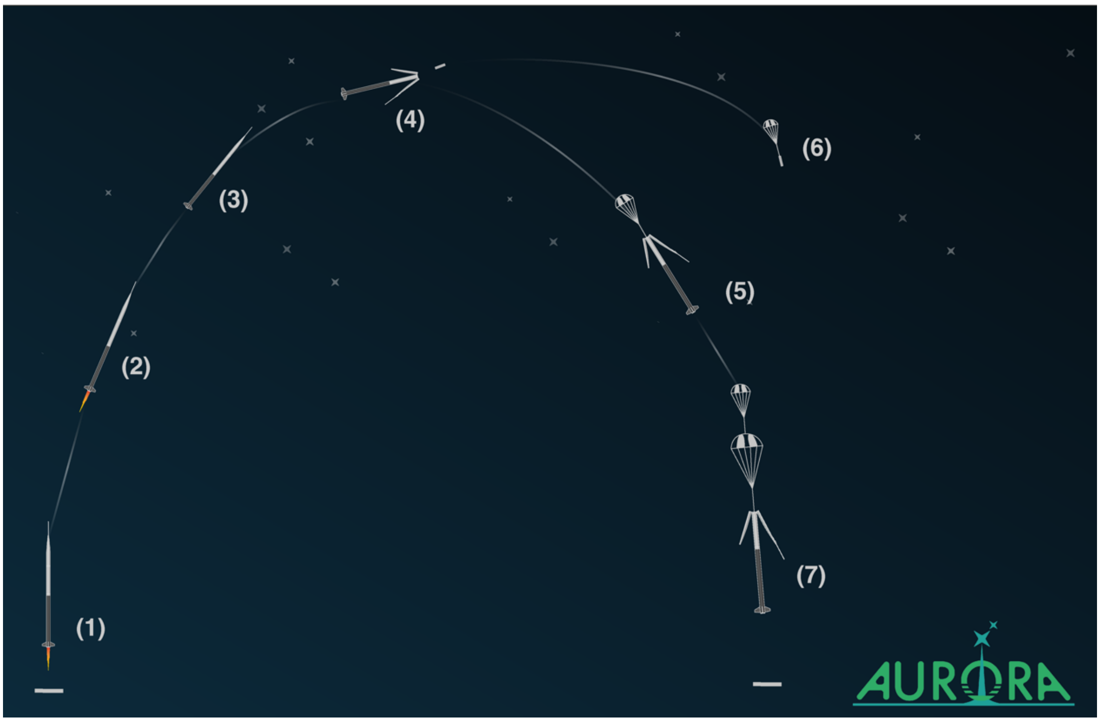
References:

- Trust me bro
- Wikipedia
- ChatGPT
- EuRoC documentation
- EPFL, Endeavour, TU Wien Concept reports
- NTNU Project Birkeland & Project Stetind technical reports
- BPS Space
- Some American technical reports
- Some documents kindly given by Dr. Fariborz Motallebi
- Idk, I'll write this properly some day

Some general information:







GAR NCE fouded aurora

Alex Piñel Neparidze