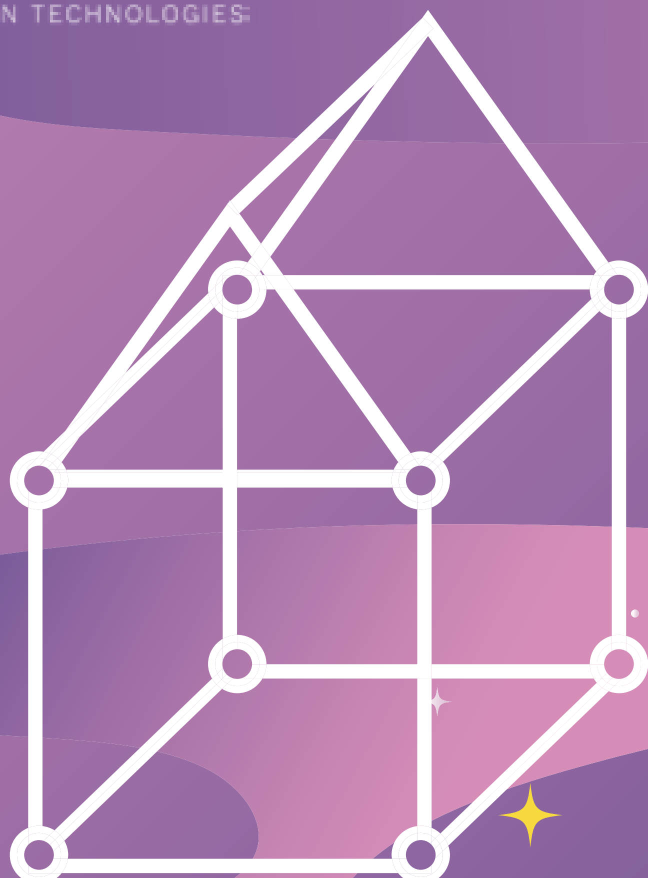
TEAM TARDIGRADE

AURORA
PROPULSION TECHNOLOGIES



Aalto University

Pontificia Universidad
JAVERIANA
Cali

Acknowledgments

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We make a special mention to Cali Design Factory.

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HELLO HUMANS

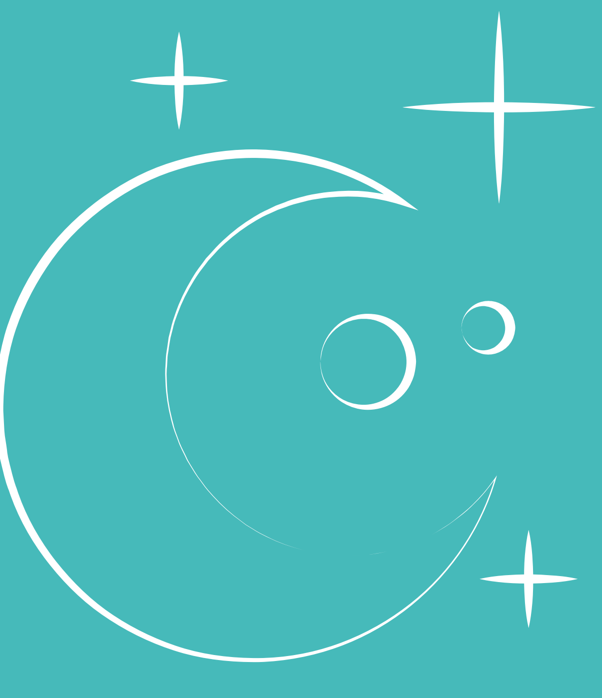
Executive Summary

PdP or Product Development Project is a course offered by Aalto University where students from different countries and universities are confronted with real industry challenges, applying Problem-Based Learning (PBL) methodologies. This document contains the work done by Team Tardigrade, a group consisting of five students from Aalto University (Espoo) and five students from Pontificia Universidad Javeriana in Cali. The project was sponsored by Aurora Propulsion Technologies, a Finnish startup dedicated to developing and manufacturing accessory technologies for nanosatellites or Cubesats.

When Cubesats are in orbit, they face air drag and different environmental factors which deteriorate them and make them fall back into the atmosphere in a short period of time. The challenge was designing an accessory to reduce the impact of the space conditions that cause this damage, increasing the lifespan of the product.

Team's name honors the capability of Tardigrades to live in extreme conditions in outer space. The goal of the team is for cubesats to endure harsh conditions and "live" longer, just like Tardigrades. Two prototypes were developed, each one of them comprising an opening mechanism triggered electrically and a selection of proposed materials. This document contains the methodology to develop the new product and details of the final prototypes.

THE ADVENTURE WE FELL IN LOVE WITH



01

Introduction

Years ago, research on and access to outer space was in government and military hands; besides being a restricted field, it required immense amounts of money. This dynamic is known as the oldspace. Today we live the newspace phenomenon, where there are a lot of opportunities for business, ideas, and innovation in the private sector, transforming into a commercial environment (Airbus, n.d). This is because many technological needs of organizations can be solved through the work of nanosatellites in a cheaper and faster way. CubeSats are a type of nanosatellites that has played a leading role in the technological and commercial revolution of space for its applications in telecommunications, photographic monitoring, collection of meteorological of data, technological development from university projects, among other possibilities (Alen Space, n.d).

Aurora Propulsion Technologies is a startup devoted to the manufacture of propulsion systems for small satellites. Their mission is to "ensure clean and debris free space, whilst prolonging the useful lifespan of satellites reducing the need to renew satellites as often as before " (Aurora, n.d). CubeSats work in low orbits where they face extreme environmental conditions, so its life lasts for about two years (Matney, et al. , 2017). Based on this problem, Aurora challenged Team Tardigrade to propose a new product for their portfolio that would help their clients increasing the durability of their investment on CubeSats.

Team Tardigrade's goal is to develop an accessory for CubeSats with a deployable mechanism that allows an initial folded or stored position and a final open or deployed position with a shape that reduces the impact of orbital conditions. Since the size and weight of CubeSats cannot be disproportionately altered because of the conditions the satellite must meet for launch **(Section 2)**, the accessory should be flat during launch and deployed when it is already in orbit.

1.1 Sponsor

Aurora Propulsion Technologies is a Finnish company founded in 2018 that currently has 17 employees. Aurora belongs to the space industry and creates components and modules for nanosatellites. These devices allow the control of three fundamental aspects of the nano satellite's path, which are altitude, speed, and attitude (i.e. orientation in space). By controlling the above factors, it is possible to make a satellite changing its orbit; aiming its cameras or other scientific devices towards its target.

Aurora designs every product in its portfolio to be mass-produced. This gives them a competitive advantage over other companies in the industry. Both in price, quality, and delivery time.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Analysis of the company's environment

The following pestel analysis allows to analyze the macroeconomic environment of the company Aurora Propultion. To identify opportunities and threats to Aurora. It will be possible to recognize external factors of the company on which one does not have control, but having information of them can diminish the effects of the threats and increase the effects of the opportunities.

Table 1. Pestel Analysis of Finland. Source: Euromonitor International. (2019) and Euromonitor International. (2020).

Pestel Analysis		
Political *Finland is among the least corrupt countries in the world. *Finland is one of the most politically stable countries, and is expected to remain so in the long term.	**Economical** *The Finnish economy will slow down slightly in 2020. Compared to the 1.0% growth in 2019, only 0.5% gains are expected in 2020. *By the end of 2019 the real value of private final consumption had increased by 1.0%. Due to the measures adopted to contain the crisis caused by the COVID-19, private consumption is expected to decrease by up to 1.8%. *This crisis will also be affecting unemployment. The current rate of 2.4% (which is lower than other Nordic countries)is expected to grow significantly in the next few years due to the aging population and skills mismatch *Real GDP growth should be slow to recover. About 1.3% between 2021 and 2027. Constraints such as declining external demand or shortage of skilled labour will prevent growth from being higher. *Due to Finland does not have an operational credit bureau, this can affect access to credit.	**Social** *Finland's total population was 5.5 million in 2019, an increase of 351,000 since 2000 *It has one of the most accelerated rates of aging in Europe. The average age is around 43 years and the group of people over 65 years was 21.8% in 2018 *Income growth could slow down due to ageing, and the working age population is expected to decline *Skill shortages are still a major concern * In 2018, Finland's higher education rate was the sixth highest in Western Europe *Youth unemployment is a big social problem *By 2019 the Finnish Gini coefficient was 26.2. Which makes it one of the most equal countries in the world in terms of income
Technological *The development of ITC and R&D are among finland's priorities *By 2020, investment in R&D will be 3% of GDP *In 2018 93.0% of households had an access to broadband internet *In 2018 the Prime Ministers of Denmark, Sweden, Norway and Iceland agreed to create a cooperation pact for the development of the fifth generation of the wireless system (5g) in	**Environmental** *The Finnish government is investing heavily in solving pollution problems *As a result many water sources have been cleaned up. In addition, the environment around the industrial centers has improved *The forests are treated with great care and sustainable forms of production are sought. The growth rate of forests tends to exceed that of crops	**Legal** *In 2006, Helsinki dropped its restrictions on migrant workers *In Finland the tax contribution to be paid by companies is relatively high, compared to other OECD countries

Table 2. SWOT Analysis: Finland. Adapted From (Euromonitor International, 2019)

Strengths	* Highly favourable rankings positively affect foreign investor perception towards Finland *Relatively lo taxes compared with regional peers may encourage more active investment in the long term
Weaknesses	*Skills shortages might impede development of some industries *The absence of public registry coverage and weak private bureau coverage could complicate the process of getting credit
Opportunities	*High R&D spending is expected to increase innovation *New major infrastructure projects will create business opportunities in long run
Threats	*A lack of anti-corruption reforms might prompt corruption in the future *A skills mismatch in anticipated to negatively affect youth unemployment

Finland has one of the best infrastructures in the world and is one of the easiest places to do business according to Doing Business. One of the greatest opportunities a company like Aurora Propulsions can have is the great interest the government has in continuing to invest in research and development and innovation. However, the country will be facing different remains. These include addressing the crisis caused by COVID-19, which is causing economic slowdown. This makes startups like Aurora eligible for government subsidies and financial assistance. They also draw up new work plans that allow them to adapt to current circumstances.

Table 3. Aurora business model

<table>
<tr><th colspan="12">Aurora Business Model (Cubesat accesory)</th></tr>
<tr>
<td colspan="3">Key Partners
*Users
*Aalto University
*European Space Agengy Business Incubator Centre Programme (ESA BIC Finland)</td>
<td colspan="3">Key Activities
*Build a final model based on the prototype
*Performing validation simulations
*Test the product
*Continued investment in research and development</td>
<td colspan="3">Value Propositions
To offer consumers an accessory that extends the life cycle of their cubesats. Which will keep them in orbit longer while contributing to reduce space debris</td>
<td colspan="3">Customer Relationship
*Customer Support
*Professional Consulting</td>
</tr>
<tr>
<td colspan="4">Customer Segments
Cubsat users interested in extending the life of their product:
*Government and military
*Universities
*Commercial enterprises</td>
<td colspan="4">Key Resources
*Financial resources
*Human resources (Such a s researchers, scientists and engineers)
*Laboratory and primary production facility</td>
<td colspan="4">Channels
*Official website
*Physical facilities
*Email
*Social media</td>
</tr>
<tr>
<td colspan="6">Cost Structures
*Logistics
*R&D
*Human resources
*Logistics
*Marketing and sales</td>
<td colspan="6">Revenue Streams
*Direct selling</td>
</tr>
</table>

1.2 Objectives and project scope

General Objective:

• Designing a deployable accessory that reduces the impact of orbital conditions on a CubeSat.

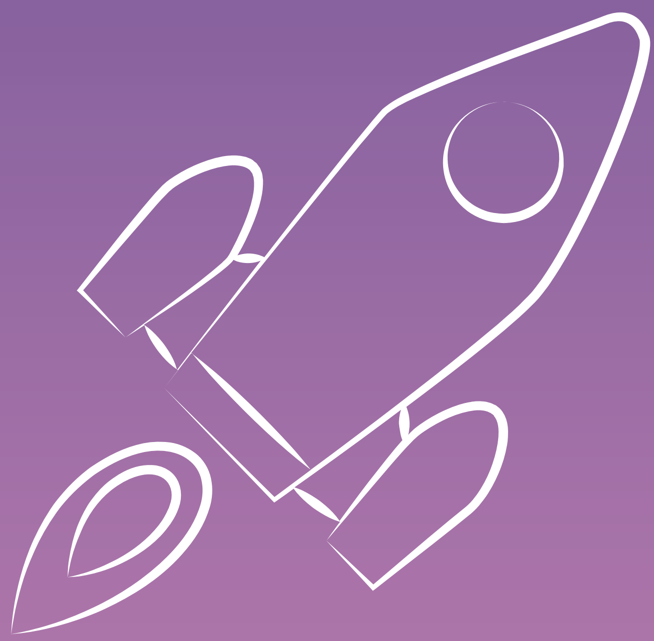
Specific objectives:

• Proposing an opening mechanism which allows the two required positions (folded and deployed).
• Proposing an electric deploying mechanism for the accessory.
• Identifying possible materials for the accessory.

Project Scope:

This project is specifically for CubeSat satellites and should not modify their structure or dimensions significantly. High-end specific simulation tests are not required, therefore the prototype does not need to be market ready. Also, it is not required for the project to determine how the satellite would technically receive an external signal for the accessory to initiate opening. The signal and its parameters come from the customer, so no programming is required. The priority is that the electrical solution inside the accessory works as intended and initiates the opening impulse. In addition, the actual opening process itself does not have to be quick, as the satellite is not in immediate danger of falling back down to earth. Finally, a business case, business-related planning, product strategies, operations-related planning considering manufacturing, production ramp-up, and distribution are not expected from this project.

PREPARING FOR LAUNCH



02

Literature Review

2.1 Nanosatellite properties

CubeSats are nanosatellites initially designed by the California Polytechnic State University (CalPoly) and Stanford University. The use of these satellites confers several advantages like low-cost and massive production, and are mainly used for scientific research, telecommunications, agriculture, exploration of new technologies, among others (Toorian et al. , 2005).

These nanosatellites are shaped like a cube and have standardized dimensions, known as 1U: 10x10x10 cm. Its weight varies between 1 and 1.33 kg (Chin et al., 2017). Standardization has allowed companies to commercialize individual and large quantities at an affordable price and its small size has reduced costs of transportation and space launching. CubeSats are usually launched on CubeSats deployers, which are small compartments that can be stored in a rocket without taking up much space, allowing the launch of nanosatellites to be less expensive. It is important to point out that these nanosatellites fit precisely in nanoracks which can store from one CubeSat (1U) to six CubeSats(6U) **(see figure 1)** (NanoRacks,2018) . These factors have allowed different organizations like educational institutions or companies from the private sector to participate in the development and commercialization of CubeSats.

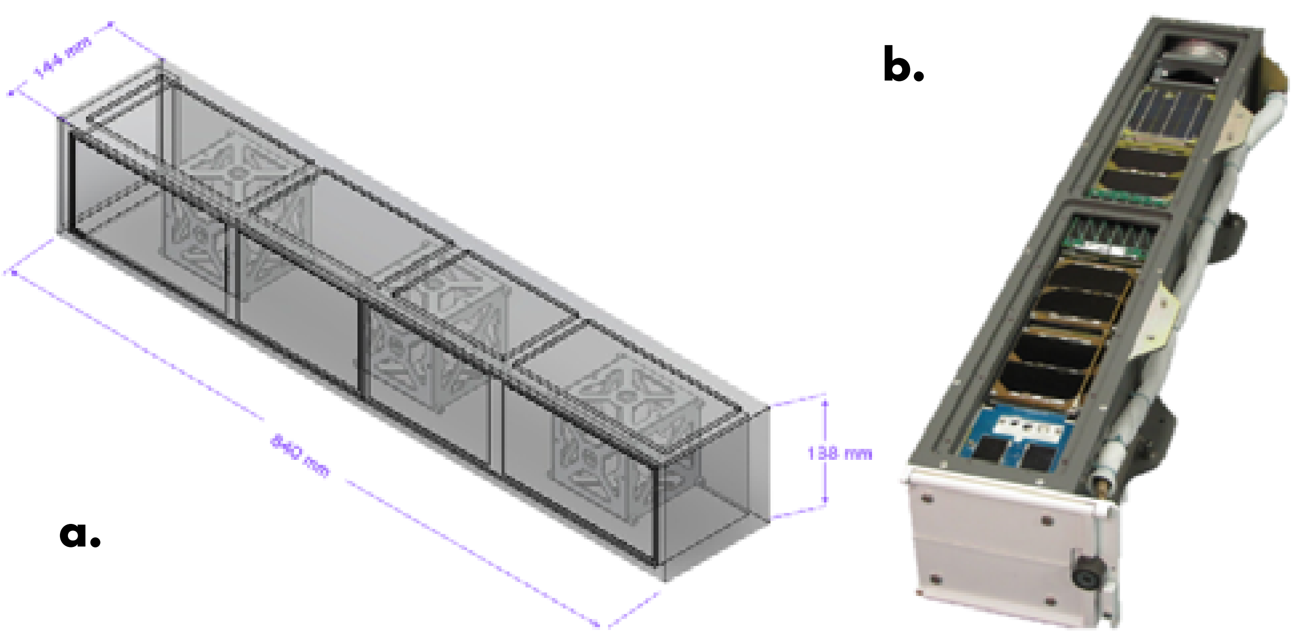


Figure 1. Nanoracks. (a) Model 3D of the nanoracks where the CubeSat are launched (b) 6U cubesat deployer photo. Adapted from: NanoRacks, 2018.

The Canadian Space Agency (2018) highlights the applications of CubeSats in technology, science, education, and industries. In the technological field, CubeSats can help with testing and validating new instruments or materials and their use in more complex missions. In the scientific field, these nanosatellites can execute experiments and collect data about orbit behavior. In the educational field, the experience of projects concerning CubeSats designs allow students to deepen their learning in space technology. Lastly, in the commercial field, telecommunications are the main application of the product, which allows for different companies to have high definition satellite pictures of earth. This last field enables many opportunities for exploring the different uses of the product, which include monitoring airplanes, fleets, traffic, meteorological activity, crop behavior. They also develop IoT technologies, allowing connection and communication through space infrastructure with remote areas (Alen, n.d).

In 2019 there were 188 CubeSat's launches; and for the years 2020 to 2023 there are 451 announced launches **(see figure 2)**. According to Camp (2009), between 2014 and 2018 **(see figure 3-a)** CubeSats' main uses were earth observation, followed by technological applications, science, communications and, finally, novel applications like test new materials for nanosatellites or measure the flux of antiparticles in space. Between 2019 and 2023 **(see figure 3-b)**, CubeSats' main use will be earth observation, followed by communication, science, technological applications and, lastly, novel applications. Until 2017, the main CubeSat's applicant were enterprises, followed by academic institutions, natural persons, and government organizations **(see figure 4)**.

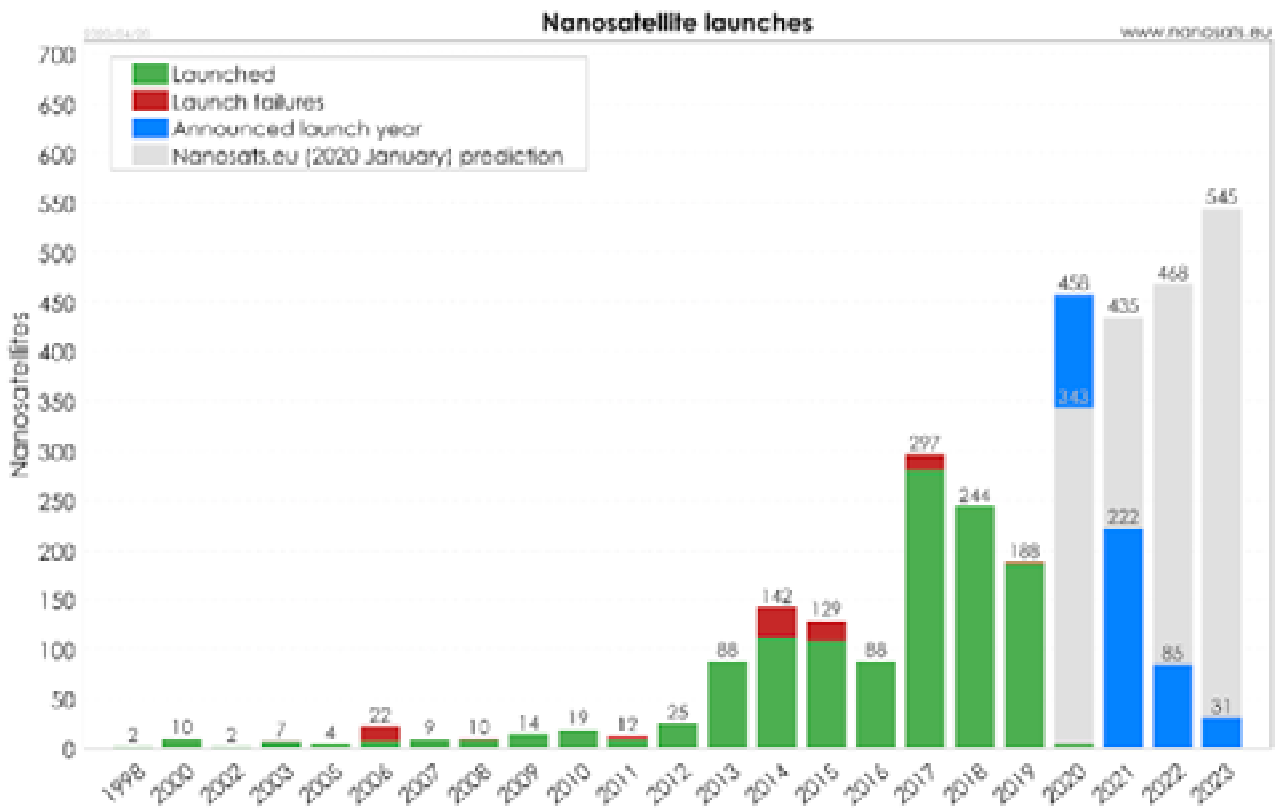


Figure 2. Nanosatellites launches. From: Nanosats Database, 2020. from: NanoRacks, 2018.

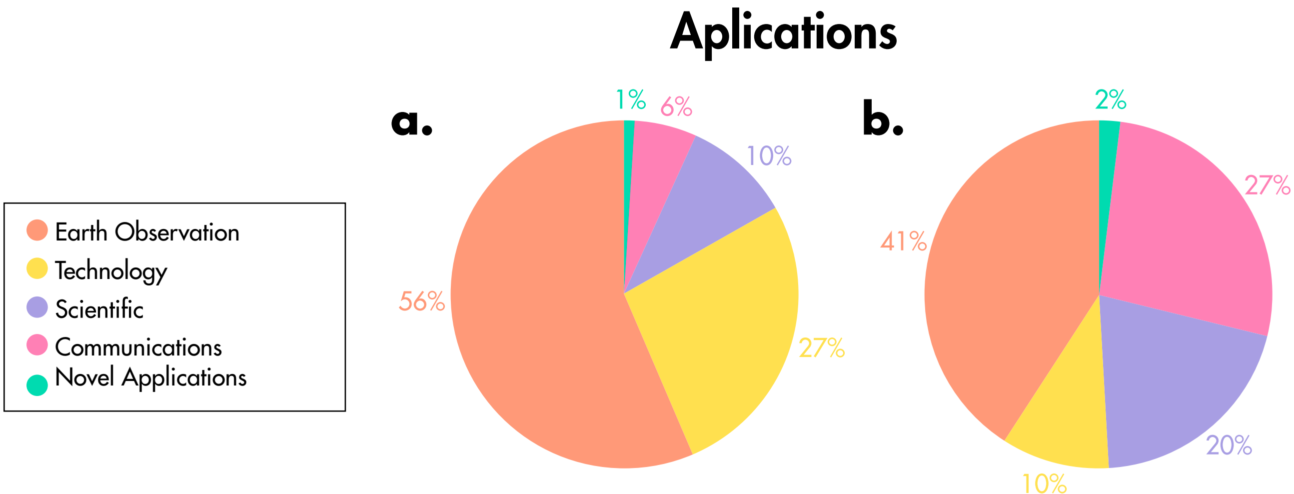


Figure 3. Main applications of Cubesats. (a) CubeSat Application between 2014-2018 (b) Cubesat application projection between 2019 and 2023. Adapted from: Camp, 2019.

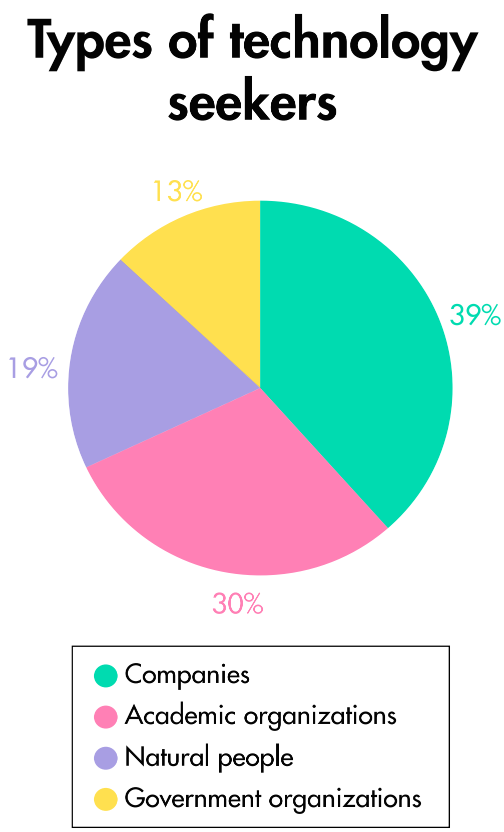


Figure 4. From Lead applicants. Adapted from: Superintendencia de Industria y Comercio, 2017.

2.2 Conditions and environmental factors in LEO

CubeSats are launched into the LEO (Low Earth Orbit) at an approximate height of 200-2000 Km. In this orbit a phenomenon known as airdrag occurs, which is caused by the force exerted by the air acting in the opposite direction of objects, in this case the CubeSats. This causes the satellites to be dragged towards the earth causing them to fall into the atmosphere and, as a consequence, burn **(see figure 5)** (SWPC,2020).

On the other hand, In this orbit several environmental factors that may cause material, mechanical and electrical component degradation can be found, a few of these are: thermal cycle, ultraviolet (UV) radiation, ionizing radiation micrometeoroids waste and atomic oxygen (AO). the latter is being one of the main factors to damage polymeric materials and found in big proportions in LEO (Fickenor & Groh, 2015).

Thermal cycle refers to the degree to which a material experiences extreme temperatures, which depends on the thermo-optic properties of the material (solar absorption and thermal emission) as much as it does on the time of sunlight and shadow exposure, this may provoke peeling, detachment and pore formation in the materials making them more susceptible to AO caused damage (Fickenor & Groh, 2015).

Plasma is a gas with large quantities of charged particles where electrons are found ion free, in LEO UV light ionizes atoms causing plasma formation, an atom detachment (known as sputtering) is caused when the electron cloud crashes into spaceships, at the same time, this may cause structural changes on the material and occasionally generate damage in the material and electric components (Fickenor & Groh, 2015).

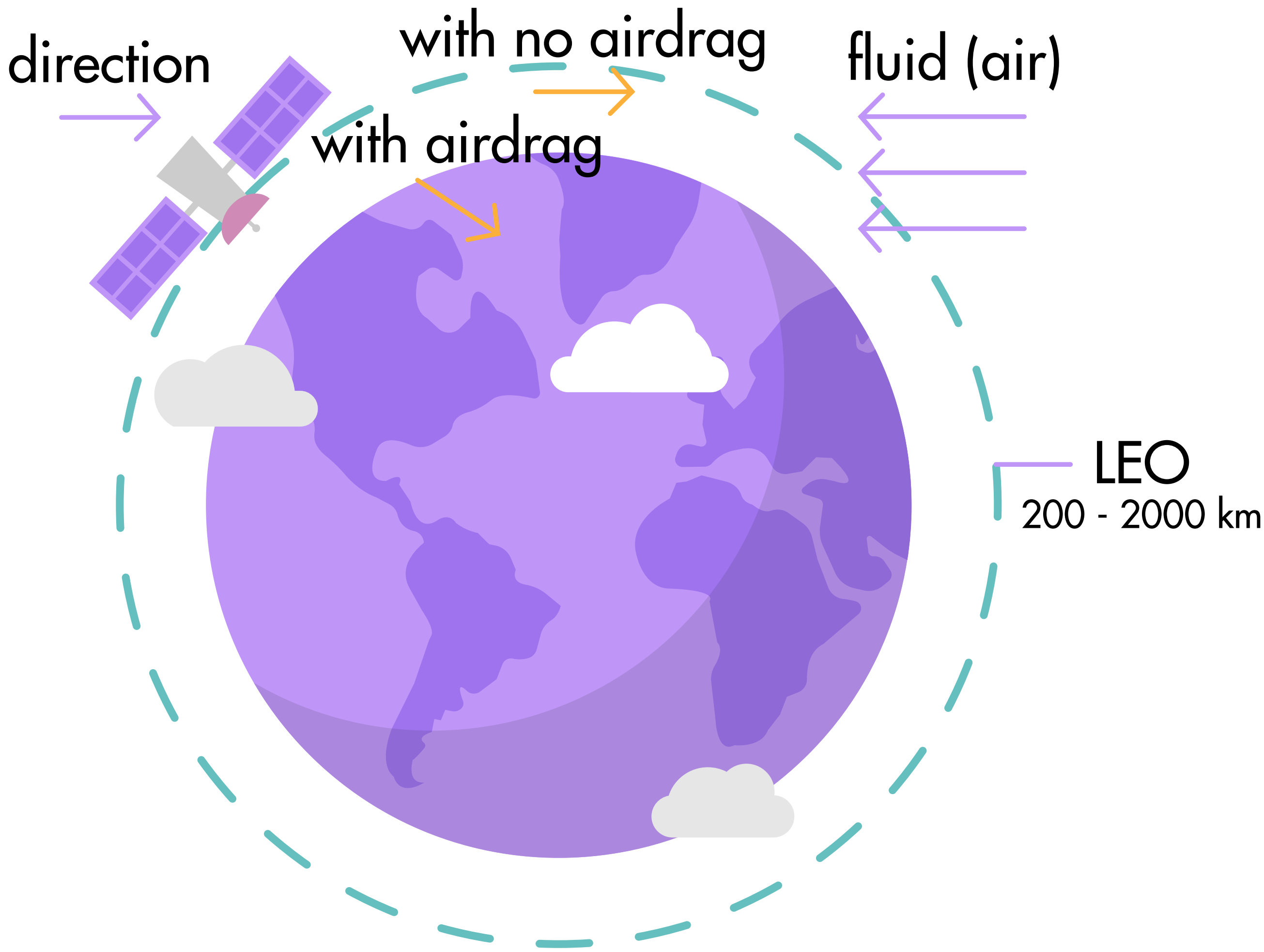


Figure 5. Airdrag phenomenon in LEO.
Adapted from: SWPC, 2020

UV radiation is the most common cause of material darkening, given that the atmosphere is the one filtering Sun's damaging rays and its presence is almost nonexistent in the space environment, which causes materials to be more affected by solar photons, additionally this factor may cause weakening (chain scission) or hardening (cross-linking) of polymers (Grossman & Gousman, 2013).

On the other hand, ionizing radiation, refers to the presence of large quantities of energy with the capacity to take electrons from an atom causing ionization of matter which can cause severe degradation damage (Grossman & Gouszman, 2013), in space there are 3 principal events known for causing this factor: galactic cosmic rays, solar proton events and trapped radiation belts. This kind of damage is similar to the ones caused by UV rays (Fickenor & Groh, 2015).

Likewise, atomic oxygen is a product of the contact between short waves' UV radiation and oxygen molecules over the atmosphere, which causes photodissociation of molecular oxygen in the superior atmosphere. It is one of the most abundant components in LEO. This is the main component causing metals like silver and copper to oxidize, besides reacting to materials composed by carbon, nitrogen, sulfur and hydrogen bonds, which can cause materials like polymers to erode, on the other hand it can produce changes in the chemical composition and morphology of some materials (Fickenor & Groh, 2015 ; Grossman & Gouzman,2013)

Lastly, orbiting satellites are also exposed to a certain flux of natural micrometeoroids and waste (like remains left by other space vehicles). These impacts occur at high speeds (an approximate speed of 19 km / s for meteors and 10 km / s for waste) the damage for impact with micrometeoroids/ waste may degrade the quality of the materials exposed to damage, and in some cases even destroy the satellite capacity, besides these impact damages may increase in consequence of UV ray exposure, ionizing radiation, AO, thermal cycles, etc., the effects depend on the size of the particle and its density (Grossman & Gouzman, 2013).

2.3 Materials

Although conditions like thermal cycle, atomic oxygen, radiation, etc. may present themselves in a smaller proportion in LEO they may have an impact in the degradation of materials (Grossman & Gouzman,2013). What follows is a literature review of possible materials that can be implemented in the product to meet orbital conditions. Some of the most important requirements are lightweight, strength, stiffness, resistance to the corrosion and good fatigue resistance (Lubin & Dastin, 1982).

The following materials could be implemented in a solution, they have been classified by composition and have a description of their main characteristics.

Metal Matrix Composite (MMC)

The metal matrix composites are made of 2 or more materials where the combination of these awards the composite new characteristics such as high resistance to elevated temperatures. The more often used metal matrices are low density metals like aluminum, magnesium, and titanium. Likewise, aluminum is the most often used metal since it is very light and more affordable than other metals like magnesium and titanium, additionally, it presents a slower oxidation compared to magnesium that despite being very light too, shows a higher susceptibility to corrosion for which it must be protected against it (Patrick, 1981).

Aluminum-lithium alloy (Al-Li)

During the last few decades a new generation of Al-Li alloys have been developed, the addition of the lithium to the aluminum reduces density and enhances the aluminum's alloy tenacity increasing corrosion resistance, besides its easy integration with standard manufacturing techniques, giving as a result lighter aluminum alloys and easier implementation. This alloy has been useful in the aerospace sector and is characterized by its low density (between 2.5 and 2.6 g/cm3). These materials also have great properties in relation to fatigue and toughness at low temperature. In space technology, this alloy conforms to basic rigid structures (Giummarra, 2007).

Nickel aluminide (NiAl)

Nickel aluminide is an intermetallic

alloy made of nickel and aluminum. Nickel aluminide is used as a strengthening component in high temperature nickel based super alloys, it has very high thermal conductivity (76 W / mK) combined with high resistance to high temperatures and a good resistance to oxidation. These properties, combined with its high temperature resistance and low density make it ideal for special uses like blade coating on gas turbines and jet engines, in the last few decades, intermetallic composites like NiAl have been considered like high temperature potential structural materials for the aerospace industry (Bochenek & Basista, 2015). Nevertheless, nickel aluminide's low tenacity to fracture and low temperature ductility are two of the main limitations for the alloy's implementation on the aerospace industry, studies concerning the issue of increasing this ductility resistance have grown making alloys like IC-221M, which, besides including nickel aluminide, combines other metals like boron, chrome and zirconium. The possibility of considering this material is open since it is important considering the possible implementation of other alloys and reinforcements that will probably enhance characteristics like low ductility (Bochenek & Basista, 2015).

Aluminum Graphene (Al/G)

As it has been mentioned before, the aluminum matrix composites have been widely studied and implemented in the industry given their high hardness and ductility, low density, good thermal conductivity among other properties, according to this, several new studies are being developed to look for possible new materials that will reinforce aluminum matrices. The aluminum graphene composites present approximately 2 to 3 times more resistance and ductility than the initial aluminum material (Zhang et al., 2018), likewise, they present a high corrosion resistance and, additionally, they (aluminum-graphene composites) can be rolled up into thin sheets or re-melted while conserving their mechanic properties (Yolshina et al., 2016). On the other hand, it is important to highlight that aluminum reinforcement with carbon materials is a relatively new area which means that the industrial processes can be complex given that the traditionally-method produced aluminum and carbon composite materials tend to have operative and technological deficient characteristics (Yolshina et al., 2016: Zhang et al., 2018).

Titanium alloys

Titanium alloys are light given they have a low density (4.5 g/cm3,) in comparison to other superalloys like nickel ones, they present properties like high resistance to traction and tenacity, high corrosion resistance and high capacity to resist high temperatures. However, their raw material and the high costs of obtaining raw materials and producing alloys are the main disadvantages to the industrial application of this material (Peters et al., 2003).

Magnesium alloys

Magnesium possesses the lowest density out of all metals, it's even lighter than aluminum, additionally, it possesses high rigidity, cushioning and a good molding capacity besides being recyclable at low costs and contamination-free (Furuya et al.,2000). However, one of its main disadvantages regarding aerospace applications is its low resistance to corrosion, this property may improve by covering it with paint, likewise, other known disadvantages are its low resistance to high temperatures and high thermal expansion coefficient, they reduce their potential for aerospace applications, consequently, carbon fiber reinforcing has been developed in order to increase its corrosion resistance and preserving its lightness (Mordike & Ebert,2001 ; Körner et al.,2000).

Carbon and carbon composites

Carbon materials have a wide field of application due to advantages like its high thermal stability without losing its properties, characteristics like resistance to deterioration, heat transfer capacity and ultralight weight. These are the factors that have made it the most wanted material in the aerospace industry. On the other hand, factors like technology used for the preparation of these composites just as the conditions these are put through (temperature, pressure, etc.) determine the type of material to be obtained, in consequence, several materials with very specific characteristics and behaviors have been developed. For example, carbon fiber or graphene which have been of great industrial interest in the last decades (Chowdhury et al., 2018).

Carbon fiber

Some of this material's characteristics are low density and hence low weight. Materials composed of carbon fiber are extremely dimensionally stable when put through temperature changes. Carbon fiber in aerospace composites may be long and continuous or short and fragmented, in general, short fibers involve lower costs including manufacturing, nevertheless, their properties end up being lower than the longer, more continuous fibers. On the other hand, this material can be used to cover other materials like aluminum alloys and therefore reinforce structures. One of its main limitations is the high production costs.

Graphene

Like carbon fiber, graphene possesses a low density and can be 5 times lighter than aluminum. Besides this, it has several properties that makes it one of the most ideal materials for the deployable accessory, among these: it's flexible, highly resistant, very light, auto-repairing capacities. However, this material has been implemented along the last few years, which may result in it being difficult to find and more likely high cost (Siochi,2014; Young et al.,2012).

Polymers

Polymers have been widely used as construction materials for specialized systems due to their high resistance and lightness, just as a variety of mechanical, thermal, electric and thermo optic properties. However, this material is more sensitive to LEO's environmental conditions, for example atomic oxygen. On the other hand, reinforcements composed of different materials have been developed to improve properties, some examples are carbon fiber reinforced plastics, glass fibers and plastic and metal mixed constructions (Grossman & Gouzman,2013).

Shape memory polymers (SMP) are a type of macromolecular intelligent material, which responds to external stimulus changing its properties like color and shape, while being able to return to their original form, additionally, they're light, low cost and are esasy to manufacture, they can be biodegradable and highly moldable. This kind of material has been implemented more for the construction of deployable structures like panels for the aerospace industry. Nonetheless, it has presented few limitations like the short variety of Shape Memory Polymers that withstand the temperatures of the space environment.

Kapton

Kapton Polyimide, shortly as Kapton is an efficient insulator and has excellent characteristics for many uses in many different industries. For example, electrical, medical, military, and aerospace. It has great radiation and chemical resistance while withstanding both high and low-temperature extremes. It maintains resplendent conditions of physical, electrical, and mechanical properties. It is a recyclable and unfilled polyimide thermoplastic material. Kapton has been used in space for example in; on the solar panels, the camera circuits, and keeping the weight of the landing probe as light as possible. (Dielectric Manufacturing,n.d). Because of its typical resistance of temperature rate and vibration, it is an ideal material solution for space conditions. Used in the outer layer as an insulator on spacecraft. In satellites, Kapton provides thermal and anti-static control. Being also flexible and lightweight, an organic polymer that is reliable for dielectric strength, great performance in high temperatures, and many chemicals, solvents, and oils. Overall, it is known for its possibilities to preserve its consistency and in different conditions. (Hendrick, 2014).

Beryllium copper

Beryllium-copper or copper-beryllium. Is a copper compound with tiny additions of beryllium. The beryllium-copper has two groups; beryllium included less than 1% and the other with more than 2%. Often used with other metal inclusions for presenting heat treatment purposes and tending to change inversely with beryllium. This offers better mechanical performance and electrical conductivity in springs, for great corrosion-resistant components. Moreover, for the project its non-ferromagnetic properties are more than ideal. Copper is also used in reinforced materials. Vacuum-presents are not a specific problem for beryllium copper. However, generally they are plated. To have more liability to cold weld, improved by mechanical rubbing or other reasons, which could erase surface oxide layers. Radiation in low orbit does not change the copper alloy. Atomic oxygen in low earth reacts with the copper (SPACEMATDB,n.d.).

Gold

Gold coating, a type of plating, is one of the expanding applications of the physical vapor deposition (PVD) in aerospace engineering. The PVD is a technology of depositing thin films on various types of surfaces through vaporization of the coating materials, where structure and density of the films are able to be adjusted due to the access to the atomic level of the materials. The main purpose of the PVD in aerospace application is: first of all, increasing the visibility of satellites by enhancing reflectivity of the surface; and increasing the durability of the satellites' surfaces against corrosion and scratch **(see figure 6)** (Hughes, n.d).

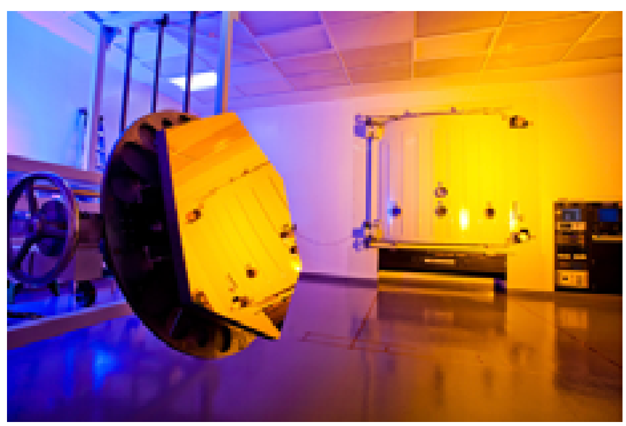


Figure 6. NASA's application of gold coating for increasing the reflectivity of the telescope from: NASA, n.d.

Other material findings

In addition to the described materials, the following materials are left for discussion for future research in the development of accessories for CubeSats. warp-knitted textiles made from gold-plated tungsten (Bettermann et al., 2018) Vitralit 7311 FO transparent acrylic adhesive, which cures under UV or visible light, offering high bond strength to many plastics (PC, PVC, PMMA, ABS) but also to glass and stainless steel. Vitralit was an interesting option that should also be environmentally friendly (Techsil, 2020).

GOING INTO ORBIT

03

Methodology

3.1 Design Thinking

Tardigrade Team decided to address this problem using an iterative methodology used for the user-centered design process for innovation called Design Thinking. It is based on the ability to empathize, discovering user needs, and building ideas that have a functional value based on interactive prototyping with the user. This methodology consists of the following 5 stages necessary for the innovation process **(see figure 7)** (Brown,2008).

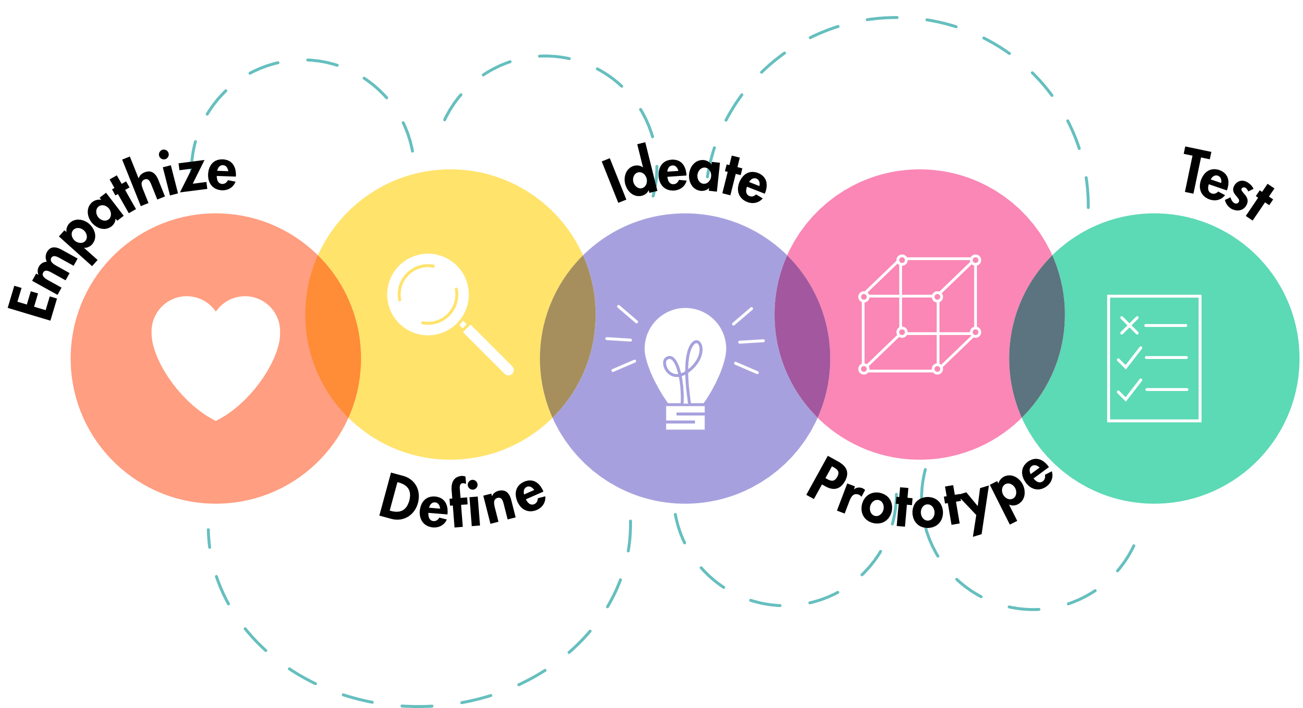


Figure 7. Process of Design thinking. Adapted from: Design Thinking, n.d.

EMPATHY is the phase for understanding the needs of the users and stakeholders involved in the solution being developed. Designers should be able to put themselves in the shoes of the user to generate solutions that are consistent with their realities.

DEFINITION is the phase where all the insights obtained in the empathy stage are collected and debugged, to approach new and interesting perspectives. During this stage, designers identify critical requirements and review existing solutions.

IDEATION is the phase where large numbers of options are generated in order not to pursue with the first idea generated. Here, even the most bizarre ideas are considered, as they are often the most visionary concepts.

PROTOTYPE is the phase where ideas are materialized. The construction of prototypes makes the ideas palpable, helping designers visualize possible solutions and detecting elements to improve or refine before arriving at the result.

TESTING is the phase where prototypes are assessed by users and under criteria built during the definition stage. Testing is crucial since it helps designers identifying significant improvements, failures to be solved and possible deficiencies. In this phase the idea presents an evolution until it becomes the solution that was being looked for.

Figure 8 shows in more detail the process that was followed (Based on the design thinking methodology).

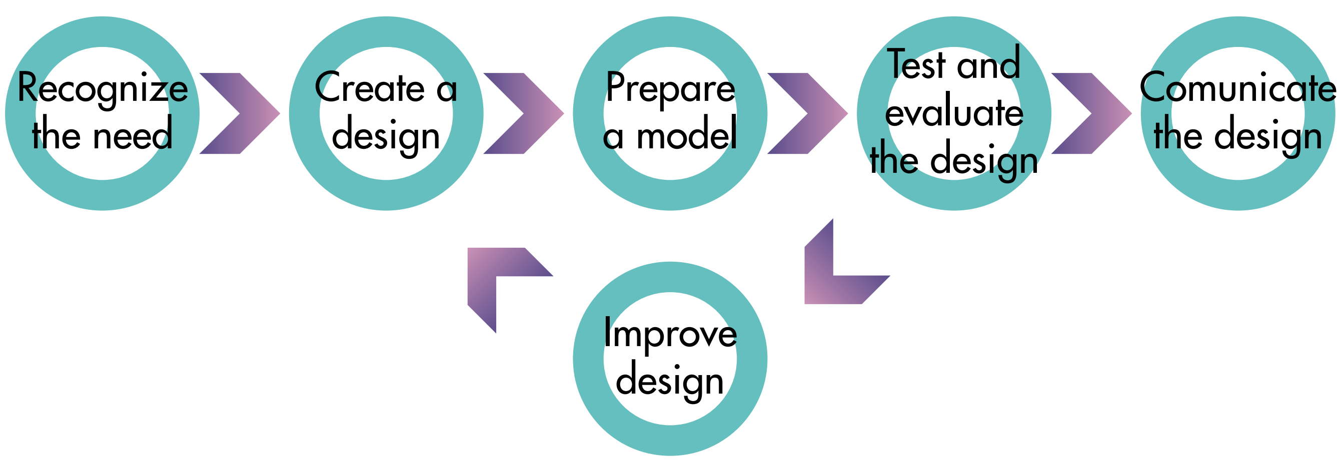


Figure 8. Design process Adapted from: Padilla, 2018

3.2 Empathy phase

All along this project, there were weekly meetings in which the sponsors and the local and global teams took a part of. The goal was not only to share the advances made, but to have a space for questions and feedback from the sponsors to have a deeper understanding of their needs as a company and discuss the best ways to go further. Empathy was a reiterative process reflected on the research made and the concepts and prototypes developed.

Aurora Propulsion Technologies is a startup dedicated to the development and manufacturing of accessories for CubeSats, having three products in its portfolio: Single orbital thruster, Plasma break and Satellite simulator environment. Their vision is "Standardizing production and scaling products to work on a vast range of satellites ensures similar mission possibilities for different bus designs for orbit and even beyond it" (Aurora Propulsion Technologies, 2020). Their mission is focused on promoting a space free of space junk and reducing the need for satellite renewal. For Aurora, the phenomenon of NewSpace, which has allowed greater access to outer space, is very valuable.

Based on Aurora's interests, the understanding of the problem that was established for the project and the research on the nanosatellite industry, it is possible to understand, through a journey map **(see figure 9)** why a user who faces the problem of this project, would go to Aurora to solve it. The user of the journey map is ÓMICAS: "the In-silico Multiscale Optimization of Sustainable Agricultural Crops (ÓMICAS) research program is the winner of the second call from Scientific Colombia in the Food focus where it seeks, through seven projects, to develop and implement scientific-technological strategies for improvement of agricultural varieties with the aim of contributing to food security and sustainable production worldwide." (ÓMICAS, n.d)

Known as : *The guardians of crops*

Dream: *That agricultural production becomes globally sustainable*

Experience: *2 years*

Superpowers: *environmental solidarity, interdisciplinary teams, techno-scientific innovation with social impact*

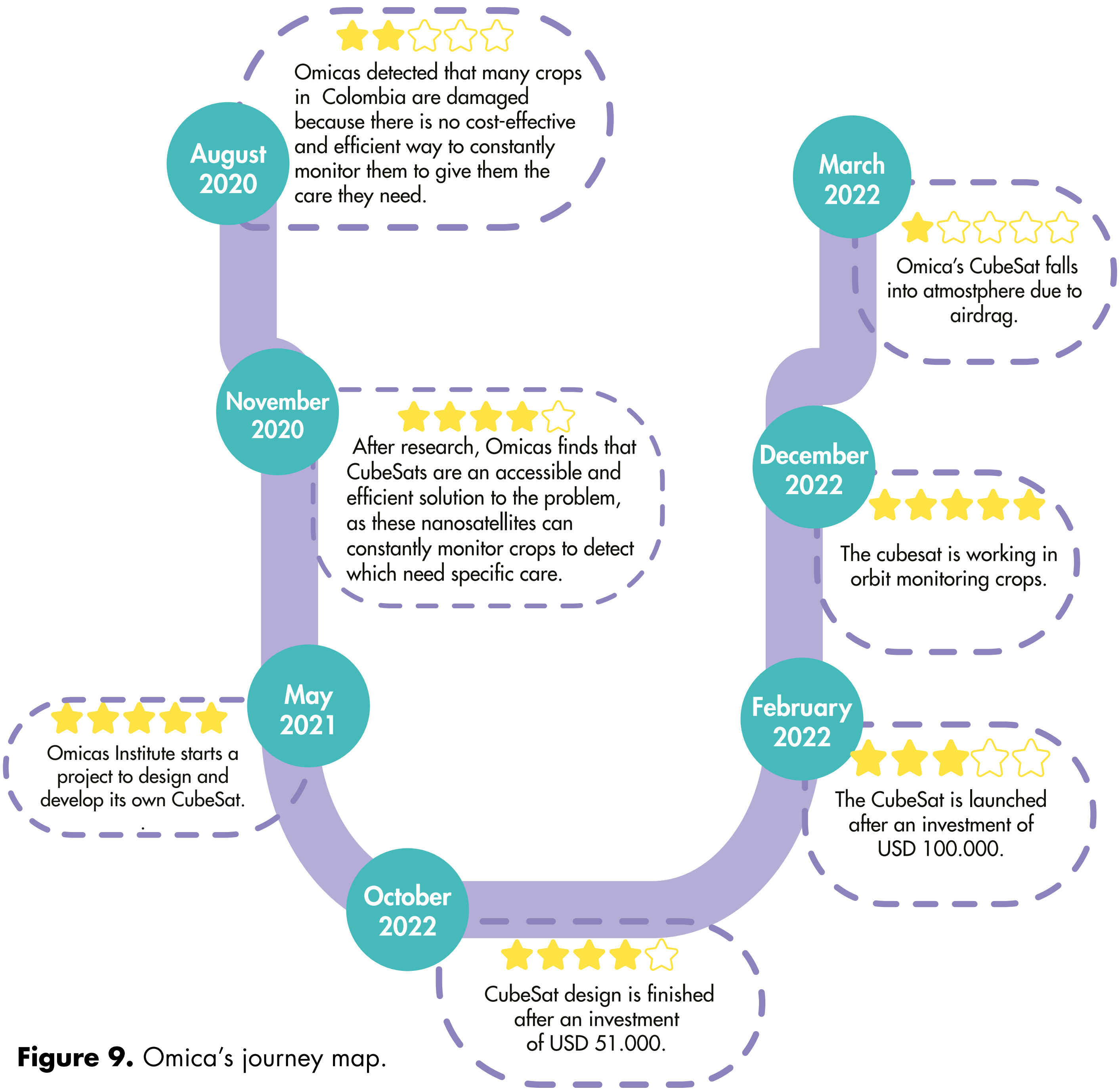


Figure 9. Omica's journey map.

As part of the empathy process, the local team participated in the Finnish Satellite Workshop (see figure 10), 20-22 January 2020, held in Helsinki, Finland. The Team joined Aurora in the biggest New Space meeting in Finland, Scandinavia, and the Baltic countries. It brings together space tech specialists, scientists, and students to discuss current topics in a rapidly developing space field. The scope was set on New Space, small satellite missions, small satellite platform development, space science missions and instruments, Earth Observation, and sustainable utilization of space, not forgetting about collaboration and politics.

Tardigrade Team presented a poster about PdP work: *Deployable Nose Cone for CubeSats to Extend Mission Lifetime in Low Earth Orbit.* In their stand, the team presented the problem, objectives, current ideas, and findings with simplified scientific evidence. There was very valuable feedback from different industry experts, professors, and students about how to approach the problem, the prototype possibilities and space conditions.

Figure 10. Picture of Aurora representatives attending the event.

3.3 Definition phase

Based on the empathy process, for this project team Tardigrade will attempt to answer the following question: ***How Might We*** reduce the impact of air drag on cubesats through an accessory that helps extending these nanosatellites' lives.

Based on the literature review, it was possible for the team to establish restrictions and requirements regarding weight, mechanisms, and materials. It is important that any accessory is lightweight and low density since CubeSat's dimensions and weight cannot vary significantly. We considered factors such as manufacturability and price.

Team Tardigrade set three main FUNCTIONAL AND NON-FUNCTIONAL requirements for the product: (a) it should be consistent with the factors that make CubeSats vehicles for easy access to space; (b) it should consider regulations on the use of materials, both to keep the space free of space garbage, and not to interfere with other missions and satellites; (c) it should reduce the constant need for renewal of nanosatellites and contribute to the reduction of space debris.

3.3.1. Product evaluation criteria

Functional requirements:

• Weight: It is important that any accessory is lightweight and low density since CubeSat's dimensions and weight cannot vary significantly. Range: (500-600)g

• Price and operating costs. (a) it should be consistent with the factors that make CubeSats vehicles for easy access to space. Range: (600 - 800) USD.

• Performance: degree to which the design effectively reflects particle collisions and reduces air drag. Range: 60%-70%

• Reliability: probability that the system opens safely. Range: (89-98)%

• Energy consumption Low. Range: (0.9 - 1) W

• Some of the most important requirements are lighthweight, strength, stiffness, resistance to the corrosion and good fatigue resistance (Lubin & Dastin, 1982).

Non-Functional requirements:

• Manufacturability: Use of relatively accessible materials and relatively simple mechanisms.

• Materials: it should consider regulations on the use of materials, both to keep the space free of space garbage, and not to interfere with other missions and satellites.

Restrictions:

• Reduced space: The accessory should occupy only one face of the CubeSat and must be no more than 1 cm high.

• Limited structure (There must be two free spaces on the sides of the nosecone after deployment to be able to put devices like cameras or antennas without obstructing them).

Overall budget for the project was 10 000€ and it was originally distributed without considering transatlantic travels for the international team. After further instructions, it had to be redistributed as shown on Table 4. Other costs included prototyping materials such as aluminum sheets of different thicknesses; different types of springs; electrical components and 3D printing filaments. Because of the COVID-19 pandemic, prototyping and testing had to be suspended, and final prototypes were not completed. Part of the budget was meant to be used for the Final Gala which was originally in May and was postponed until September. To the date of this document it is still undecided if the Gala will be held remotely or in person. cancelled or postponed to next fall. However, if the final gala will be held, we do have budget left to use for that.

Table 4. Budget for the project

Initial Budget	**Redistributed Budget**
Material costs 6000€	Material costs 1200€
Traveling costs 2500€	Traveling costs 8510€
Gala 500€	Gala 290€
Emergency fund 1000€	Emergency fund 0€
Total: 10.000€	**Total: 1000€**

3.4 Ideation phase

This section will explain the ideation process throughout the project which consisted of: brainstorming, concept development, concept selection from requirements, expert feedback and final concept selection **(see figure 11)**.

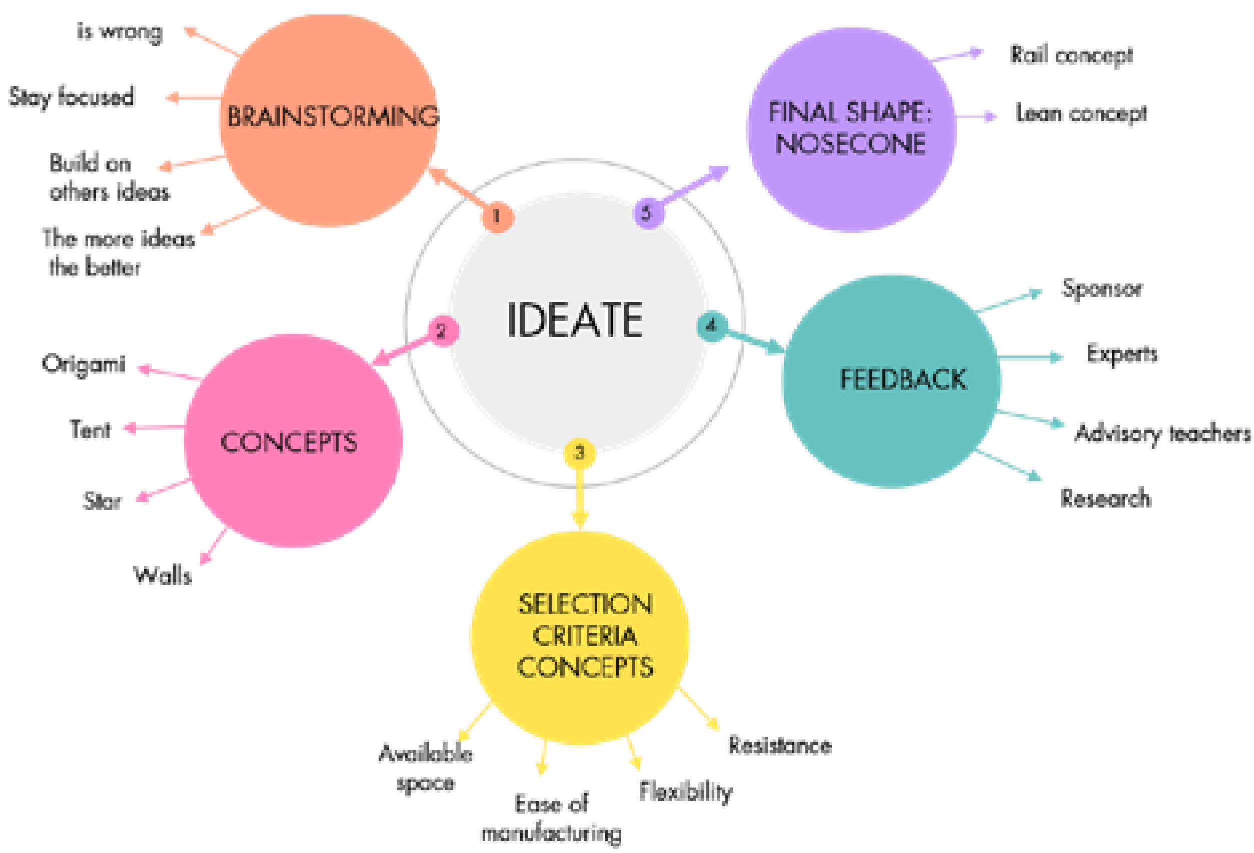


Figure 11. Process of the ideation stage.

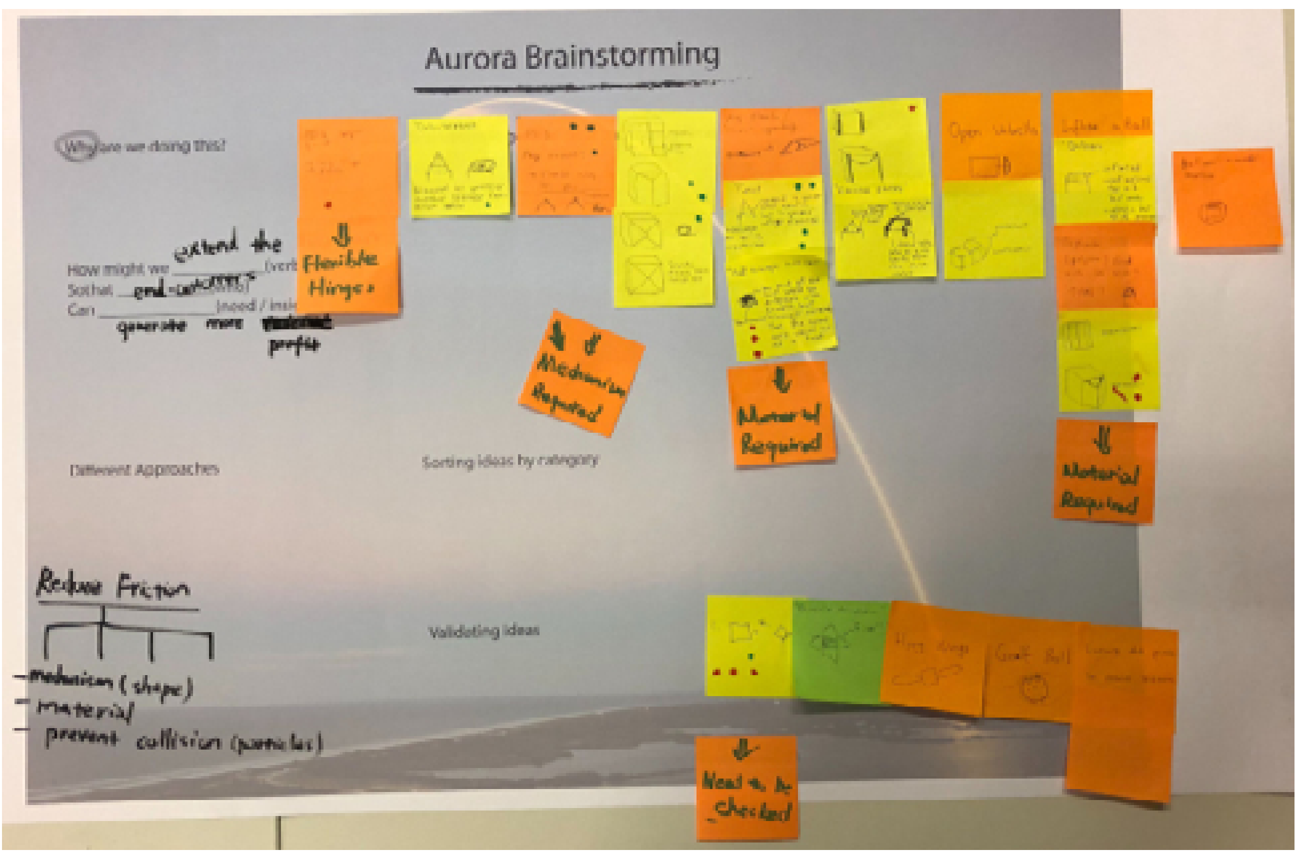
Brainstorming

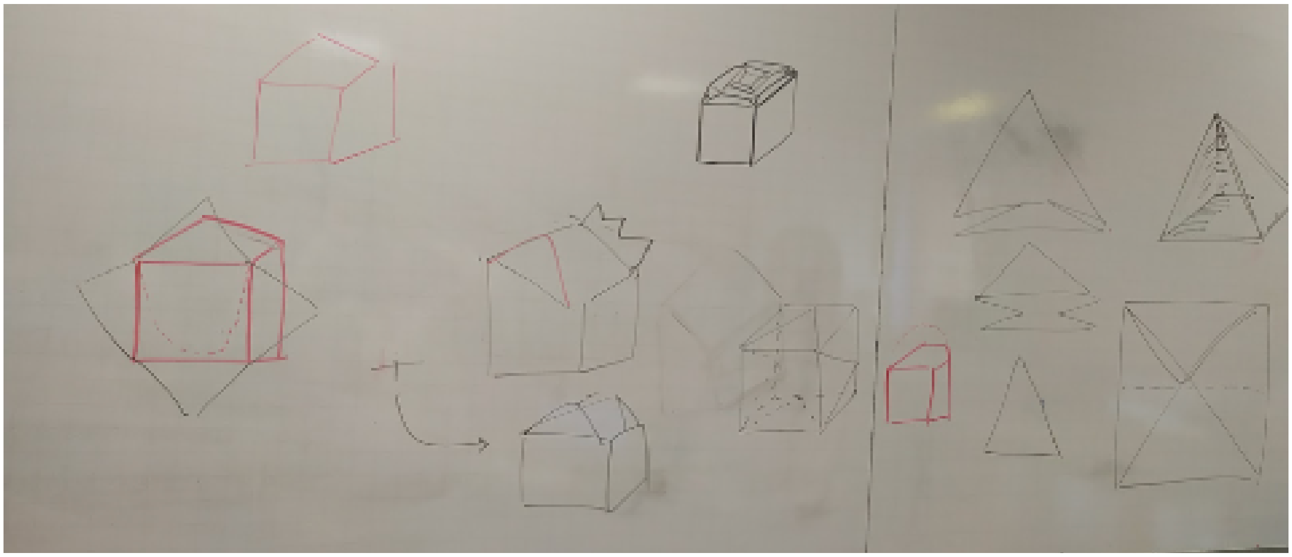
In PdP week, after a short process of empathy with Aurora Propulsion, the first brainstorming session **(see figure 12)** was held with the sponsor, the global and the local teams. Based on the ideas presented and the different feedback from the participants, the possibility of developing two types of concepts was established:

• Flexible materials that could adapt to certain shapes
• Rigid faces that formed figures with geometric principles

Figure 12. Sponsor-global-local brainstorming in PdP Week

In the brainstorming iteration **(see figure 13)**, several design questions were raised that allowed to build the product requirements according to the constraints of the problem. Guiding questions were considered for the development of this stage such as why are we doing this?, what is the problem that we are solving" and how might we...? These prompted constant research to understand the problem in depth and to establish relevant and contextualized requirements.





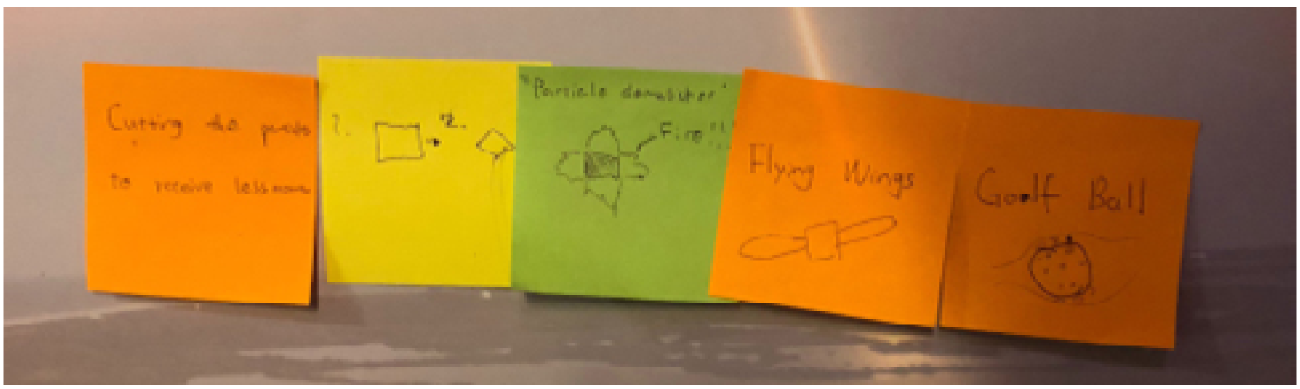
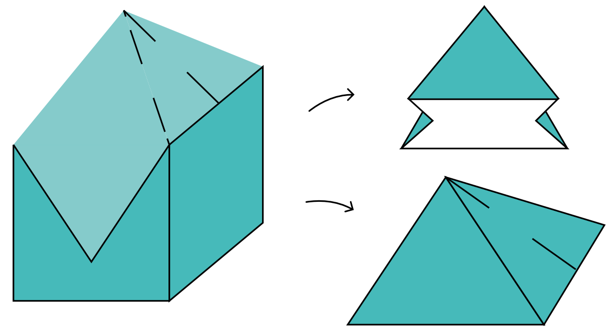


Figure 13. Brainstorming sessions.

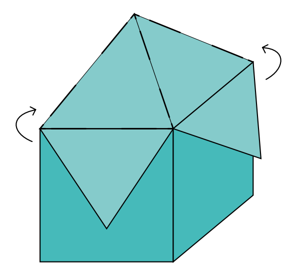
Concepts

Most part of the ideation process was dedicated to thinking about the shape of the folding roof of nosecone, the main concepts that arose in the ideation stage were:

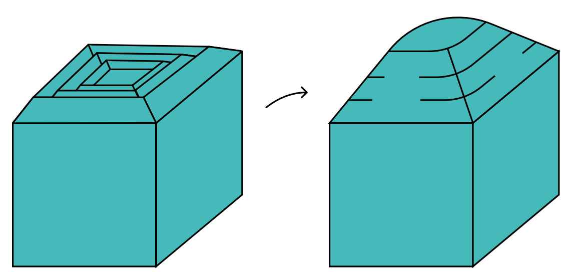
Origami concept: The structure is folded in the upper face of the CubeSat. Then this structure is lifted and then unfolded to form a pyramid.



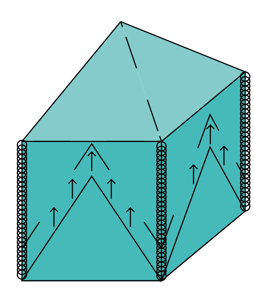
Star concept: On each side (4 sides) of the satellite there is a triangular plate (with the tip pointing downwards) that will unfold upwards to form a pyramid.



Umbrella concept: In the upper face of the CubeSat there's a structure in the shape of a tent/umbrella, it has a curved shape. We haven't figure out an open up mechanism for this concept.



Walls concept: On each side of the satellite there is a triangular plate (with the tip pointing upwards) that will ascend until the base of the triangle is at the edge. Then the triangular plates will be inclined to form a pyramid.



Selection criteria concepts

The above concepts were discarded because they did not meet different product requirements (see definition section). On the one hand the concepts walls and star use more than one side of the cubesat. On the other hand, the tent and origami concepts need several folds to close, so it would be difficult to manufacture.

Feedback

The concept selection process was iterative and there were weekly consultations with the sponsor. Their constant feedback was fundamental since the technical validation of the product requires a complex testing process that involves several investments and long periods of time. The sponsor also made it possible to have a feedback session on the progress with Hiraku Sakamoto, an expert in the field of nanosatellite technology. Thus, the ideation process was always advised by sponsor, professional experts and consulting teachers. During this phase, the team concluded it was important that the concept had no more that 2 visible sides to not take up much space of the nanosatellite and its manufacture was much easier.

Final concept: TRIANGULAR PRISM

This is how, from iterating research and ideation, the triangular prism concept was born, which would have two visible faces that would be folded only in one of the faces of the cubesat **(see figure 14)**.

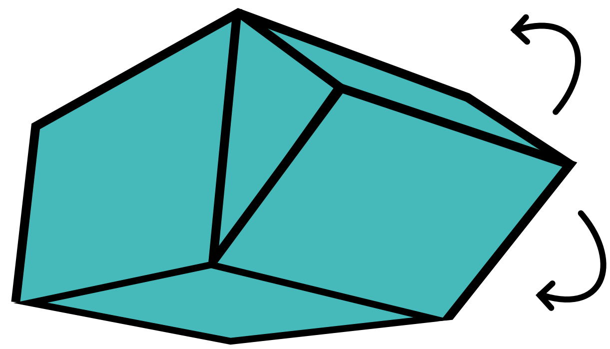


Figure 14. Nosecone shape

Once the final shape was decided, two concepts were proposed as a possible opening mechanism:

Rail concept: This concept consists of the three main faces that unfold for the construction of the triangular prism, at the base there is a rail that guides the other two to a final position x that allows the nosecone to be fully opened **(see figure 15)**.

Lean concept: This concept has two rigid sides and one flexible side as a membrane, additionally it has springs that allow the opening and deployment of the roof **(see figure 16)**.

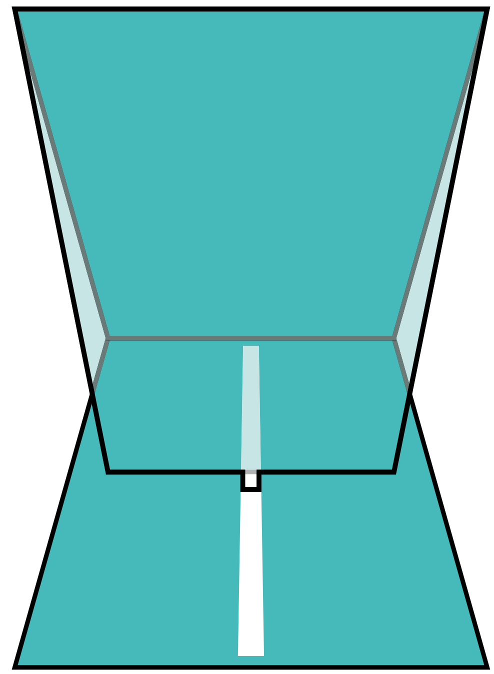


Figure 15. Rail concept

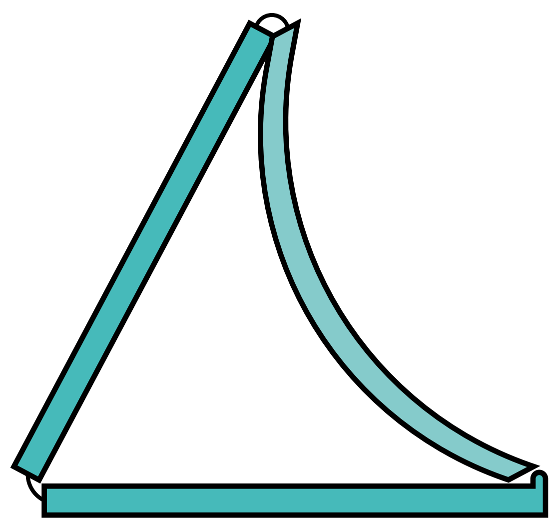


Figure 16. Lean concept

ACTIVATION MECHANISMS

Lock mechanism: This opening mechanism is based on a lock that keeps the faces folded at first, so that later with a signal, it retracts this lock and generates the expected opening **(see figure 17)**.

Fire mechanism: This concept has a rope of a material to be defined that fulfilled the function of tying the faces to keep the nosecone closed and that in some way, being burned by an external signal, it would open by going down the rail to reach the final position **(see figure 18)**.

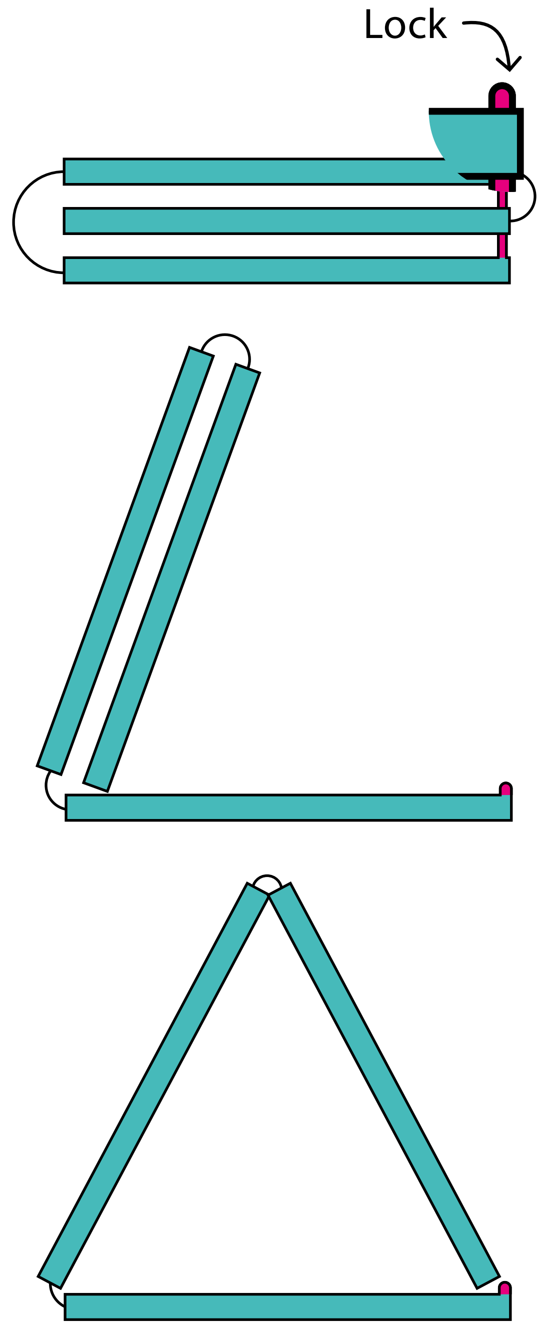


Figure 17. Lock mechanism

Figure 18. Fire mechanism

3.5 Prototyping phase

A CubeSat model was built on a CAD program based on CubeSat design specifications (CDS, 2004) **(see figure 19)**. This model was used for mounting the nose cone models on one side of the Cube to understand how they would work and communicating the concept with others. Additionally, it provided an efficient way of the nose cone designs, allowing the consideration of the physical requirements including the dimensions of the tolerated space for nose cone on the CubeSat and the physical conditions of the rail bars on the nano racks.

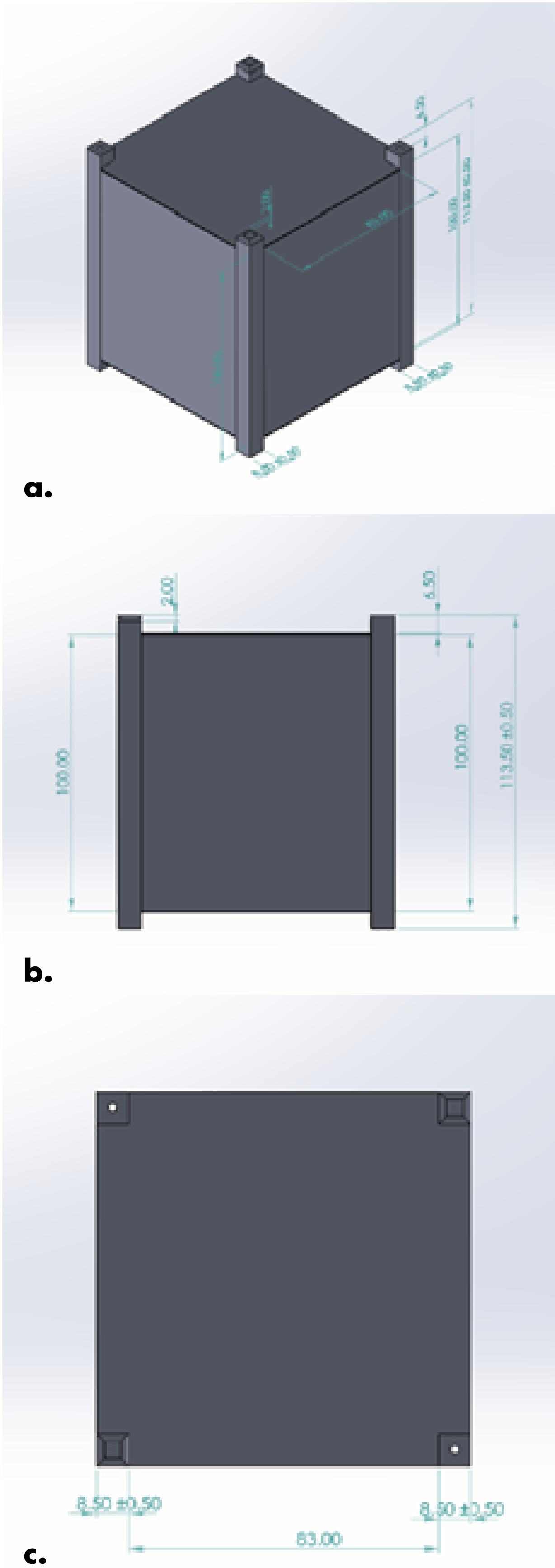


Figure 19. CubeSat 3D model (units in mm) . (a) Isometric view (b)Top view (c) Front view. Adapted from: CubeSat Design Specification (CDS), 2004.

A theoretical analysis was performed to calculate the expected performance of the nose cone in extending the lifespan of the satellites. CubeSats are working under the special environment of low earth orbit where the atmosphere is not a perfect vacuum. Certain levels of air density are causing drag forces on the CubeSats which is the main source of disturbing forces that results in satellites falling off from orbits. The drag force is induced from collision of micro-particles on the surfaces of the CubeSats and thus the magnitudes of drag forces cannot be obtained through conventional drag coefficient.

The deployed nose cone will form a sharp-shaped heading in order to reduce the drag forces as shown in the following **figure 20**, below.

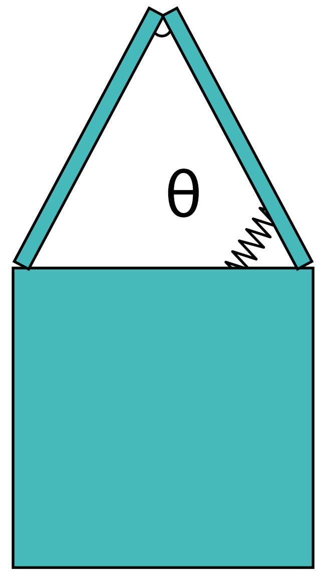


Figure 20. Shape of deployed nose cone

Several assumptions are established for the theoretical analysis. First, particles that collide with CubeSats are perfectly mirrored back after the collisions. Only the collisions occurring on the head surface of the CubeSat are used for calculating the drag effect. The particles hitting other sides of CubeSats are not considered, collisions on the sides are assumed to balance each other; the collisions on the tail surface are perceived to have zero contribution to the drag force due to the high velocity of CubeSats and thus ignored in the calculation process. In addition, attitude control is preventing the CubeSats from spinning during the entire orbiting journey. Finally, the magnitude of the drag force is proportional to the momentum reduction caused from the particle collisions.

Without a nose cone, the head or front of the CubeSats is a flat surface and thus bounces all the particles back in the exact opposite directions. This will cause the CubeSats to lose double the amount of the momentum of the collision particles. When the nose cone is deployed and forms the sharp heading surfaces, the particles hitting the surface with the same direction will bounce to the sides which reduces the amount of the momentum reduction received by the CubeSats as shown in **figure 21**.

The magnitude of the vertical vector of the particle's velocity after the collision can be calculated through the geometrical relationship which leads to the calculation of the amount of reduced momentum. Eventually, the expected collision impact after deploying the nose cone has functional relationship with the inclined angle **θ** of the nose cone **(see figure 22)**.

$$\text{Collision Impact} = [1 - \text{SIN}(2\boldsymbol{\theta} - 90)] / 2$$

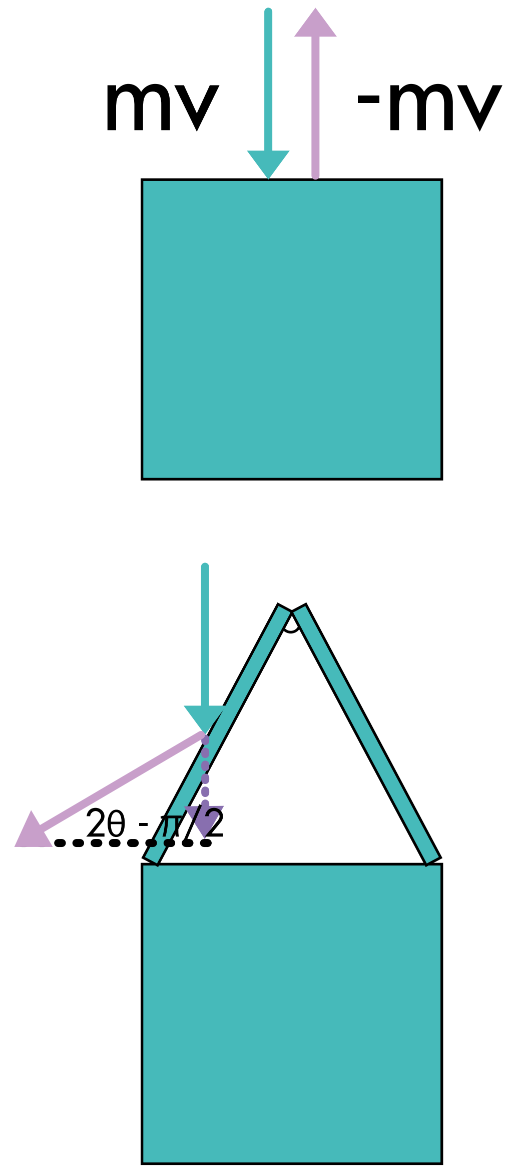


Figure 21. Particle collision before and after the mounting the nose cone

Where the collision impact value 1 indicating same collision impact as of the CubeSats without nose cone and 0 indicating zero drag force caused to the CubeSats. Life extension of the CubeSats has a non proportional relationship with the collision impact **(see figure 23)**

Life extension = 1 / Collision Impact Reduction

3.5.1.Product architecture

To consider every aspect of the product, the team identified its main components under a scheme of product architecture. The engine component represented by the **electrical activation mechanism** is understood as the one taking the energy and information from outside the system or in this case stored in the CubeSat through a photovoltaic or chemical process, to set the entire system in motion. Transmission is represented by **springs and wires** and the tool component which is the part acting on the object to fulfill a main function is represented by the **structural sheets** of the nose cone. Control is performed from earth through signals that are sent synchronically or stored in the system's intelligence **(see figure 24)**.

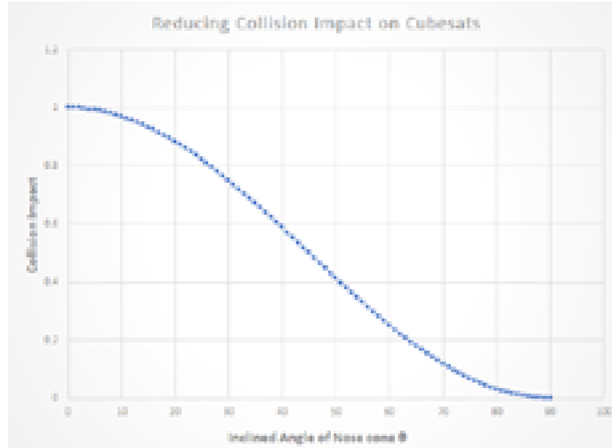


Figure 22. Relationship between nose cone angle and the collision impact

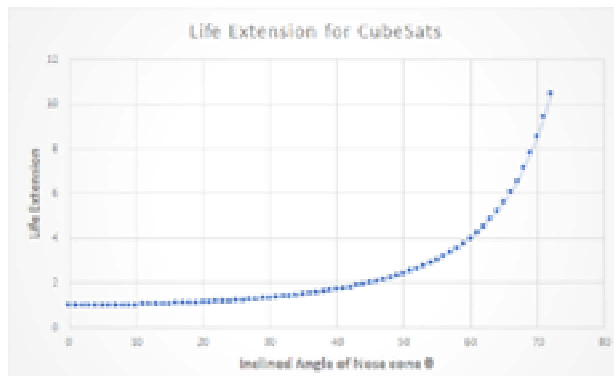


Figure 23. Relationship between nose cone angle and the life extension

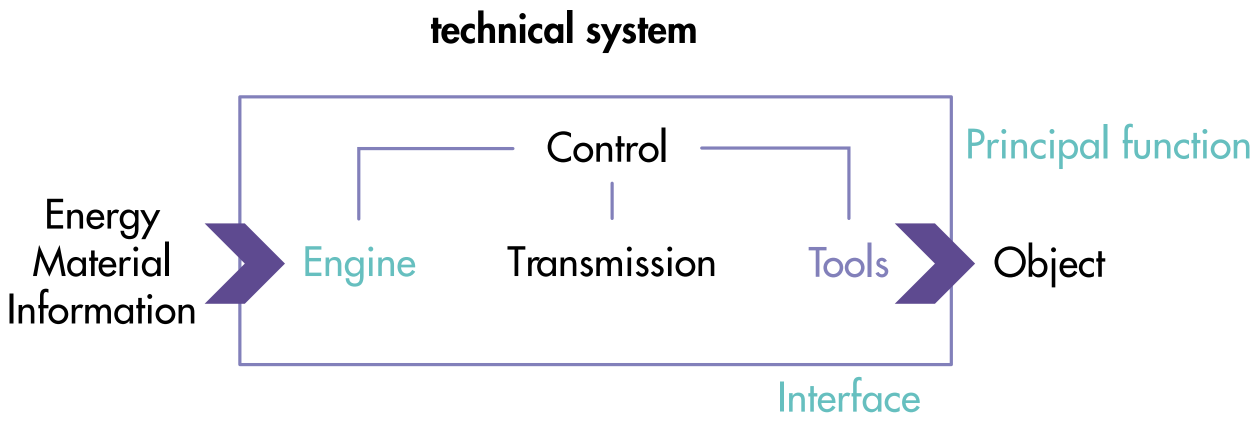


Figure 24. Architecture of a technical system flow diagram. Adapted from Aguilar-Zambrano et al., 2002

3.5.2. Structural sheets

Initially the prototyping began with 100 x 100 mm pieces, to keep it simple. However, as stated in the specifications, CubeSat have rail bars extending from its corners and penetrating the cone, as those rail bars cannot be covered at any point because of their use in deployment out of the rocket. The team realized that as the top sheets of the cone would also fold down during the rocket launch, 100 x 100 mm pieces would cover the CubeSats rail bars. Thus, as a first measure each sheet's corner pieces (8,5 x 8,5 mm) were cut out **(see figure 25)**.
However, as one could imagine this was not ideal from the prototype's performance perspective. This was corrected by making the top sheets roughly 8,5 mm shorter and not cutting the other side of the sheet's corners off. Thus, the top sheets of the cone would not extend over the CubeSat rail bars and would hold a uniform sharp edge on the top.

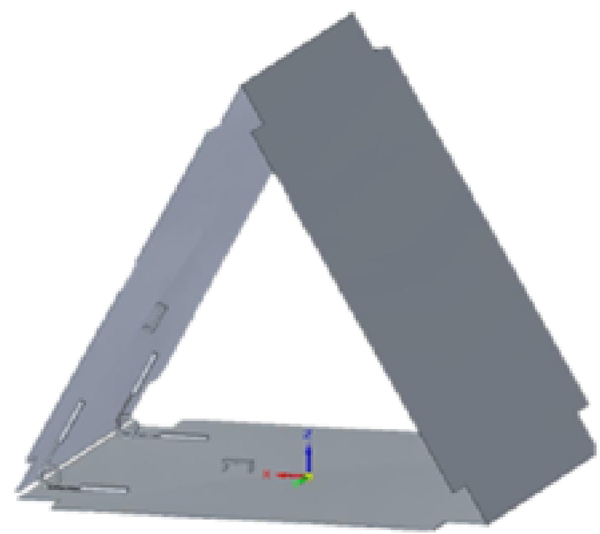


Figure 25. All the corners are cut from the sheets by 8,5 x 8,5 mm.

The downside in this solution is that the nose cone performs better the higher the cone is, due to its improved capability to reflect and mitigate collision impacts. However, this effect of reduced height is minor compared to the alternative of having the top corners cut off.

An alternative version did not use a membrane side and had more hinges. First, we had hinges both in the bottom, as well as in the middle of the folding side **(see figure 26)**. This was the case for the very initial prototype model, inspired by the PD6 model.

However, we soon realized that there is no need to use hinges in the bottom, as springs perform the same function beside their main purpose. That said, there were still bulky hinges between the top sheets, as well as between the two smaller sheets on the other side of the prototype (see picture above). These bulks created performance issues due to unfavorable capability to reflect collisions. Therefore, we later ideated if the traditional metal hinges could be replaced by flexible, membrane hinges. It occurred to us that there are space-grade membranes as well as space grade glues. Thus, the bulky metal hinges could be replaced with lighter, less voluminous, and gap-filling hinges. The open gap on top of the cone would be filled with a membrane, as well as similarly the

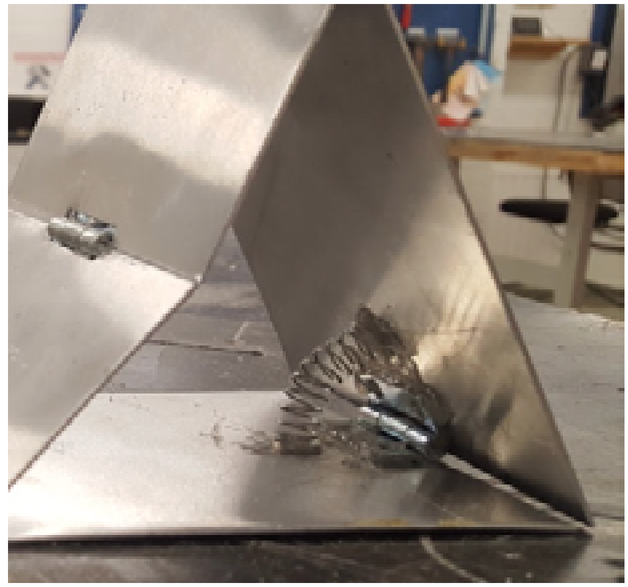


Figure 26. Early prototype using metal hinges to attach each sheet together. .

gap on the side part **(see figure 27)**.

Another challenge we faced was how to tie the sheets together, so that they keep folded down during the rocket launch **(see figure 28)**. We decided early on that the activation mechanism would be based on electrically heated resistor (nichrome) wire, and thus the cone should be kept down with something having a relatively low melting point. Thus, we conceptualized around tying the sheets together with nylon wire, which in turn would be in physical contact with the activation mechanism. After the nichrome wire receives a signal to heat, it would burn the nylon holding the cone's sheets down, and thus releasing the cone erect. However, attaching the nylon wire into 0,5 mm thick aluminum proposed a challenge. We could not use heat applications to weld wire holders, nor did tapes work.

Therefore, the mechanism holding the wire should be mechanical. Yet, it proposed a challenge how to create such a thing, without it affecting the nose cone's surface smoothness, as it could not be welded and other applications would require milling the sheet from a thick piece, removing 90% of the initial material. Such maneuvers would be highly costly, considering the difficult manufacturability **(see figure 29)**.

In the end, the easiest, yet not the most optimal decision, was to drill two small

Figure 27. Prototype with bulky hinges replaced with membrane "hinges" on top and on the side.

Figure 28. Failed attempt to glue the nylon wire to the sheets.

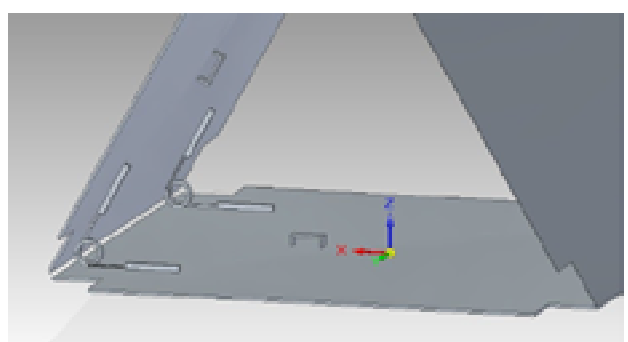


Figure 29. Illustration of two string holders between the left-top and bottom sheet.

holes to the top and bottom sheets, by which from the nylon wire would be tied and fastened from. Finally, to reduce the structure's weight further, the bottom sheet's excess surface area was reduced **(see figure 30)**.

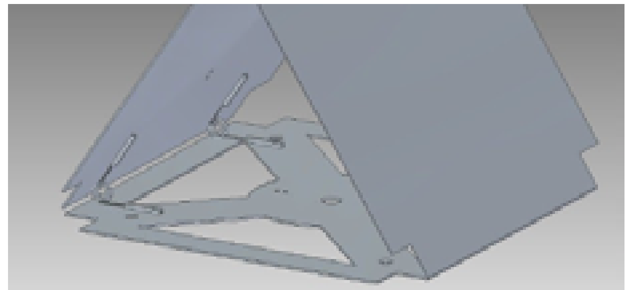


Figure 30. Prototype with wire holders replaced by two small holes, and excess bottom sheet material removed.

Another concept consisted initially of two opening mechanisms, one for each structural sheet, however this would imply higher complexity and it is the reason we decided to make a one-piece folding mechanism for greater ease and efficiency as you can see below.

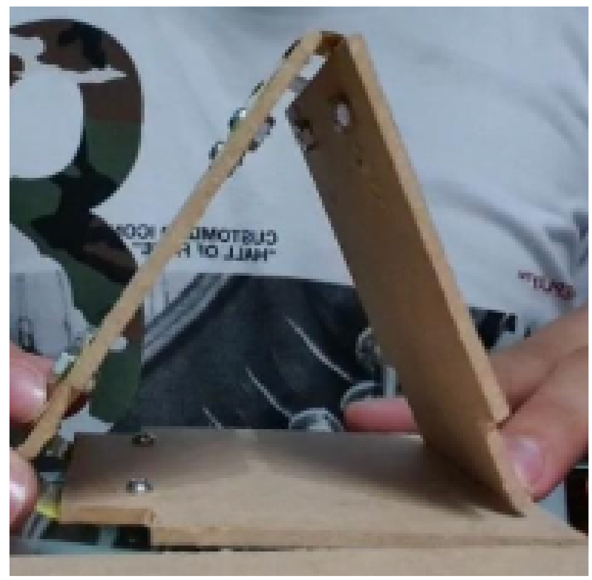


Figure 31. First concept prototype in wood

Considering that the first concept was made of wood and measuring tape **(see figure 31)**, we decided to design it in a more detailed way, into a concept fitting the CubeSat standards **(see figure 32)**.

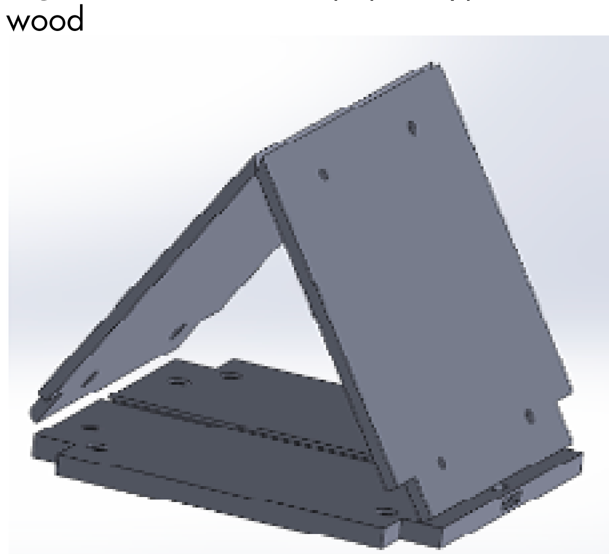


Figure 32. 3D model concept

For the implementation of this model, we 3D printed the pieces using PLA filament. Then they were assembled with screws and measuring tape as spring, which provided useful properties to deploy the mechanism **(see figure 33)**. This model was designed with a central rail going across the bottom sheet which provides the release mechanism with a more controlled opening.

We decided to focus on important details like closing gaps between the sheets **(see figure 34)**, as well as making sure that the nose cone folds lightly and unfolds reliably. For example, since initially using tape springs, it was impossible for the top and bottom sheet to join both faces when folded, because the measurement tape's physical attributes would not allow it and result in deformation and lost ability to spring. Another detail was the integration of the activation mechanism to the nose cone, to create a single piece single piece unit.

With the help of a 3D modeling tool, some improvements were made to the mechanical application of opening the nose cone and the activation mechanism was also integrated.

To integrate the activation mechanism into the nose cone, we decided to create a cavity for the actuation mechanism **(see figure 35)**.

3.5.3. Electrical activation mechanism

After determining the initial nose cone structure and opening mechanism, the team focused on searching solutions to activate remotely, either mechanically or electronically, the nose cone. During the research, various ideas were generated, of which we decided to test two of them, taking in count that the mechanism should be simple and compact.

This mechanism should be restricted so that it opens only once it has reached orbit. This aspect was not considered

Figure 33. First 3D model concept printed and assembled along with measuring tape springs.

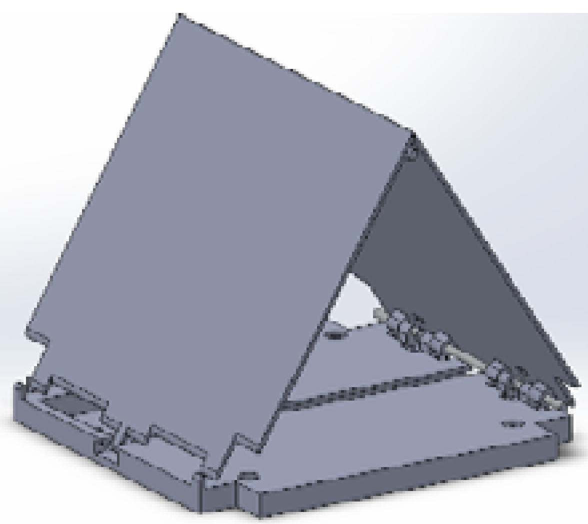


Figure 34. Correction error at the tip of the nose cone, by adding bevels to the sheets meeting at top, and thus allowing them to meet without a gap between.

too much in the early prototypes even though a burnable string was a likely choice. Burnable plastic wires are used in other CubeSat applications and were mentioned by the sponsor as well. This might have caused a small bias on our team, but nevertheless the mechanism is quite compact as it only requires a plastic wire to restrict the mechanism and a metal wire that is heated up. The mechanism was tested on our early prototypes by running a wire through the plates and releasing it from our hands rather than burning it. As the method worked fine more refined prototypes were made using nichrome wire that can burn the string **(see figure 36)**. The greatest downside is the setup time required to thread the wire to hold the mechanism in place.

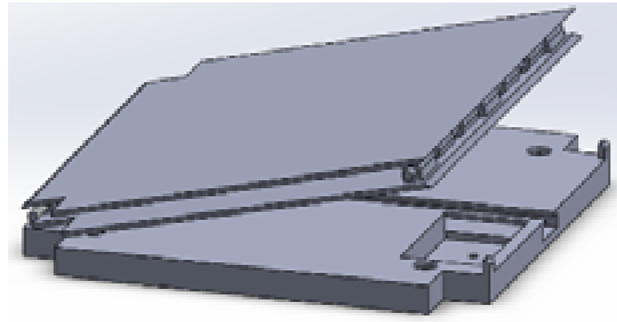


Figure 35. Cavity at the bottom right contains the activation mechanism.

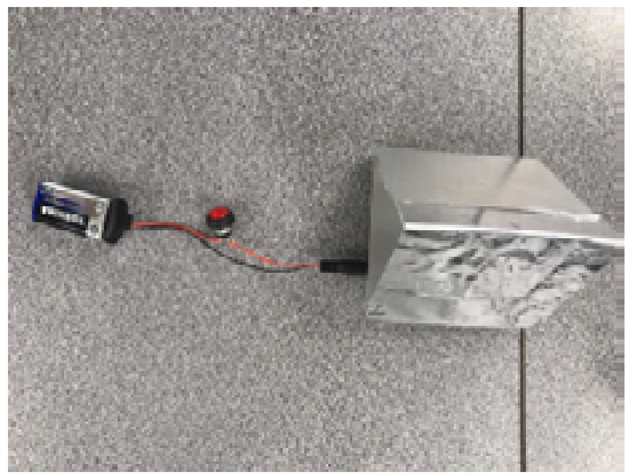


Figure 36. Illustration of early activation mechanism, kapton insulated nichrome wire, where an additional nylon wire would be tied into from the top sheet, locking the nose cone fold.

Figure 37 illustrates a mechanism inspired by a work conducted in university of Cincinnati, Northeastern University from Boston, as well as by researchers from the Naval Research laboratory, Washington DC. The proposed mechanism consists of heating a nichrome wire to cut a vectram string, it is relatively simple and easy to implement as it consists of low-cost and commercial materials **(see figure 38)**.

While the functional test was a major success, the application was too large to fit the product specifications given, as its height surpassed 10 millimeters. Nevertheless, the parts were convenient to reduce in size, providing a total height of 6 millimeters for the application alone. This modification did not affect the functional performance **(see figure 39)**.

3.5.4. Springs

The opening mechanism considered the use of springs for transmission from the start **(see figure 40)**. Other considered options included gases, motors, telescopes, and even explosives. A spring- operated mechanism is reliable and simple in its functionality. Springs in various forms, diameters and torque were used from the very first PD6 prototype to the final prototypes.

While springs did provide enough torque to open the cone, it was difficult to either fit the springs in, or alternatively the springs were too short to keep the moving parts in their final position. Thus, the springs were extremely difficult to fit and often ended up twisted or pressed during the testing. Moreover, often the cone did not reach a steady form, and one side was left without the required rigidness **(see figure 41)**.

Using measuring tape as a spring, the team prototyped with leaf springs **(see figure 42)**, however, none seemed to work. Either the springs lacked stiffness, or they were deformed by overextension. We realized at the time that thickness and weight of the moving sheets in the different prototypes

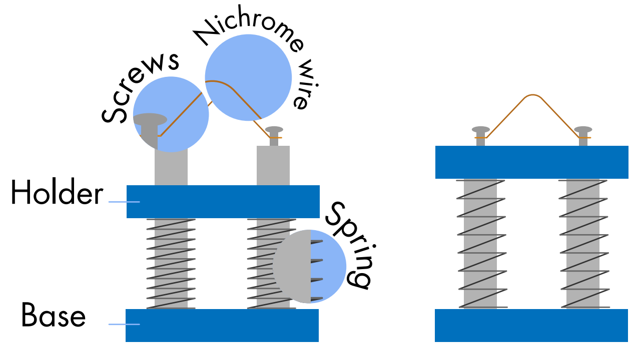


Figure 37. Nichrome Burn Wire Release Mechanism for CubeSats.

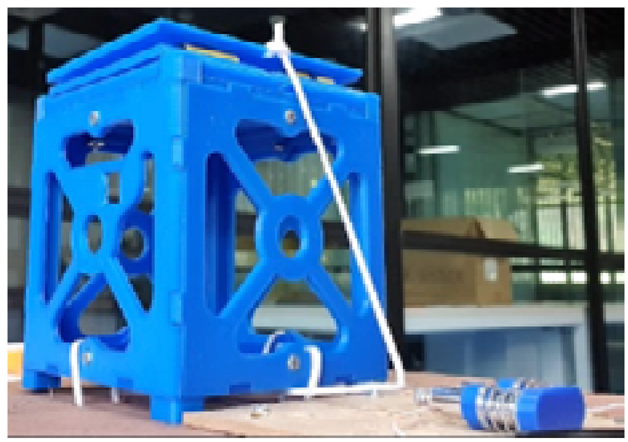


Figure 38. Activation mechanism in test.

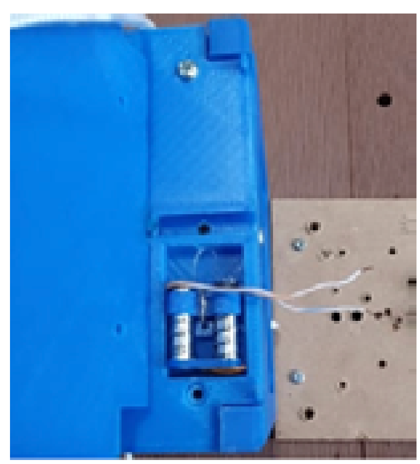


Figure 39. New, smaller iteration of the activation mechanism mounted on the product.

affected the result, one prototype was made of metallic sheets and the other was 3D printed PLC and thus the springs would also extend more in the first prototype.

Additional inspiration from the sponsor took us exploring the use of leaf springs in unconventional ways.

Further exploration took us to torsion springs **(see figure 43)** with excellent initial results, albeit we did not get the sizes right on the first time. The diameters were quite large and some of the springs did not raise the cone in the required manner. Some of the early torsion springs provided too much torque, resulting in excessive launch strength in the initiation **(see figure 44)**. This could result in malfunctions or breaking of other components in the product. However, eventually we returned to torsion springs, as we found even further applicable sizes, and in general torsion springs were reliable and easy to handle.

In addition, not only did torsion springs provide great reliability and performance, also extreme foldability of the whole system (the nose cone) was achieved with small-diameter torsion springs.

After determining to use torsion springs, we faced a problem in how to attach them to the product. At this moment, the material in use was alu-

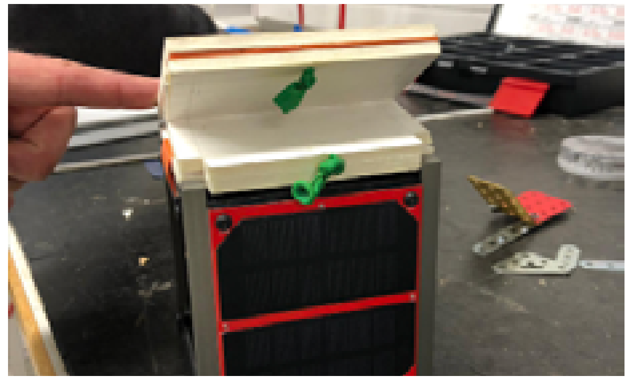


Figure 40. PD6 Iteration mounted on top of a CubeSat.

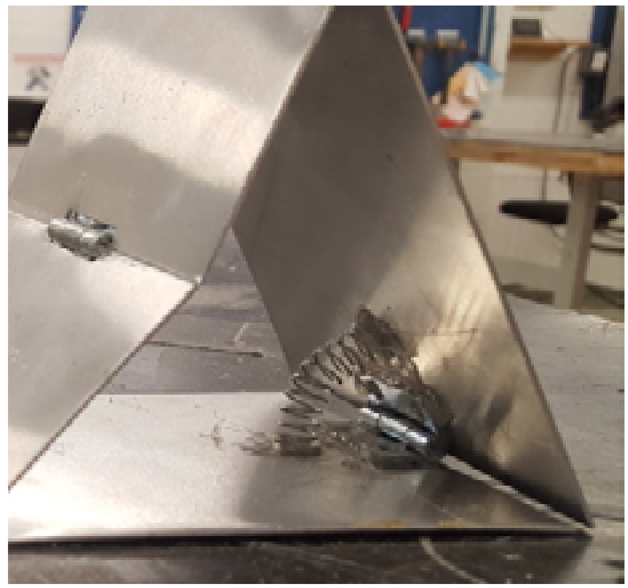


Figure 41. Inapplicable spring, glued to the prototype

Figure 42. Illustration of overextended leaf spring, a measurement tape in this case.

minum, which would be difficult to weld. Furthermore, the sheet thickness was as low as 0,5 mm, complicating any heat-using application as a method of attachment. Thus far, screws and hot glue were primarily used in prototyping, for fast paced prototyping progress. However, this became quite the obstacle for the time being. The sponsor inspired us to think of other mechanical ways in "locking in" the springs, whether by pressing or manufacturing some sort of structures to hold the springs in place. We punched holes to the sheet to "thread" the springs in, and the press shut **(see figure 45)**.

The downside in this method is that it would create small surface anomalies on one of the top sheets, where the springs are threaded from. The effect is minor, as the nose cone performance is measured only from the surface area where single particles hit. Therefore, if a particle does not happen to hit the unpolished spring area, the nose cone performs as if the surface anomalies are not there in the first place. Moreover, the total area of the exposed springs is extremely low in percentage of the total, directional surface area.

Finally, metals in proximity are subject to cold welding in the atmospheric environment. Cold welding is a solid-state welding process in which joining takes place without fusion or heating at the interface of the two surfaces. This is something we had to consider, after

Figure 43. Illustrative of unconventional use of a leaf spring.

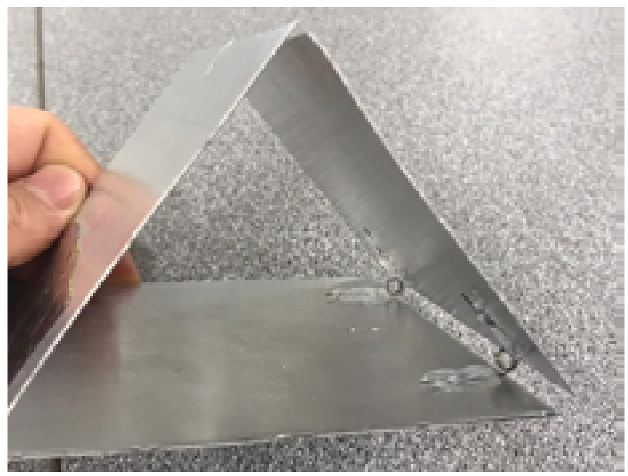


Figure 44. Illustration of torsion springs used.

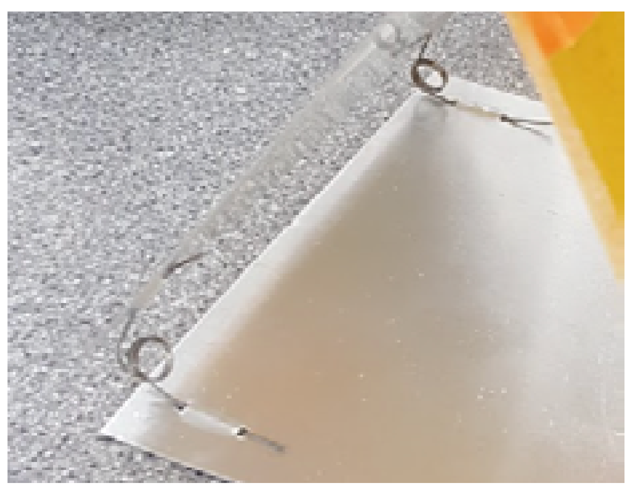


Figure 45. Testing how torsion springs could be "threaded" in a sheet. No supplementary pressing utilized at this point.

deciding on the use of springs using coils. The approach to tackle this was to opt for coating the springs with outgassing compatible, non-metallic material. However, cold welding should not be a critical issue if the cone is activated soon after the deployment.

A new concept explored replacing the measurement tapes with torsion springs and steel rods that connect sheets of the nose cone to the base from the ends **(see figure 46)**. Torsion springs gave us more torque when deploying the nose cone, but more importantly, torsion springs are more reliable due to their ability to withstand excessive amounts of pressure during the folded state **(see figure 47)**, compared to the previous findings of leaf springs malfunctions under high overextension.

Lastly, the torsion springs were provided with supportive structure, for better "lock-in". In addition, this concept removed excess material from the base sheet, to reduce the overall weight.

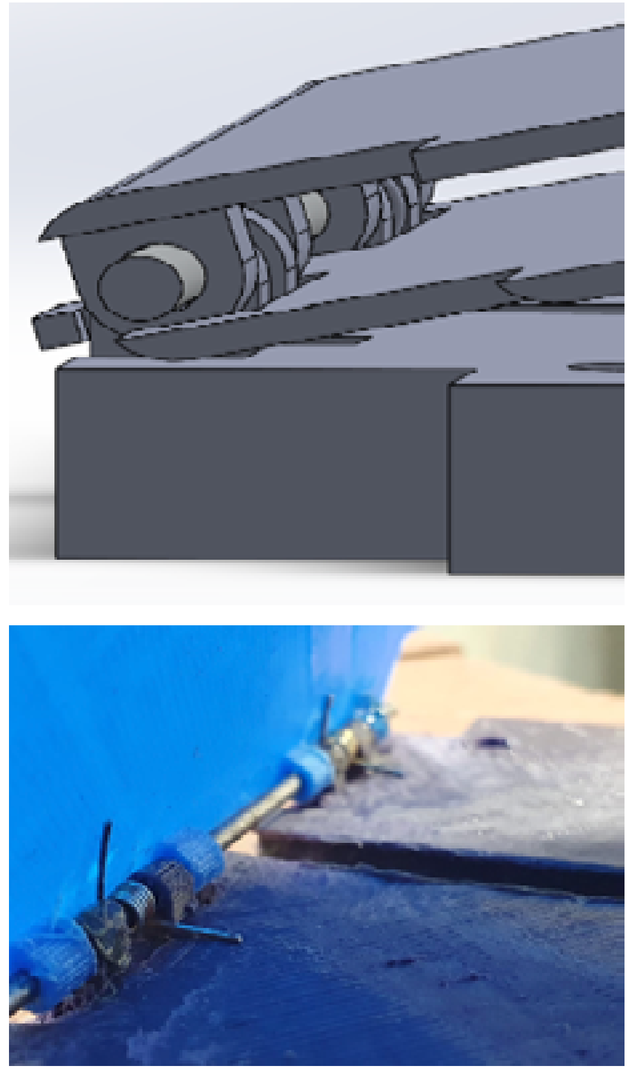


Figure 46. Union of ends with steel rods cuct.

3.5.5. Prototyping materials

When starting the prototyping phase, we used a white Kapa sheet, in the first prototypes, we used: Kapa sheets, paper, space blankets, and finally Kapton foil. Space blankets, that were recommended by the sponsors, were easy to use and the price was convenient in prototyping.

The Kapton sheet worked the best, compared to the others. The ordered aluminum sheets were in three different thicknesses: 1mm, 0,7 mm, and finally 0,5mm. The aluminum as a material worked fine.

Springs were stainless steel, various shapes, and sizes. We used normal springs, leaf springs, torsion springs, and push springs. We had some problems with the springs, as some of them were too strong, too big, or too thick. Because less force is needed in space, we could use weaker springs. The material worked in prototyping, although beryllium copper or bronze would be less magnetic. In that way, we tried metal hinges and then we had a trial with sticky kapton and space blankets. Kapton worked well from the material perspective, metal hinges were too much trouble to set up.

We consider the possibility that one side of the nose cone could be a membrane, because of its flexibility and smooth surface. Also, the materials must have low outgassing properties, like in Kapton. The sheet material chosen has similar requirements as above for the membrane, except the flexibility. The springs, on the other hand, must be non-magnetic, for example, a leaf spring with beryllium copper.

a.

b.

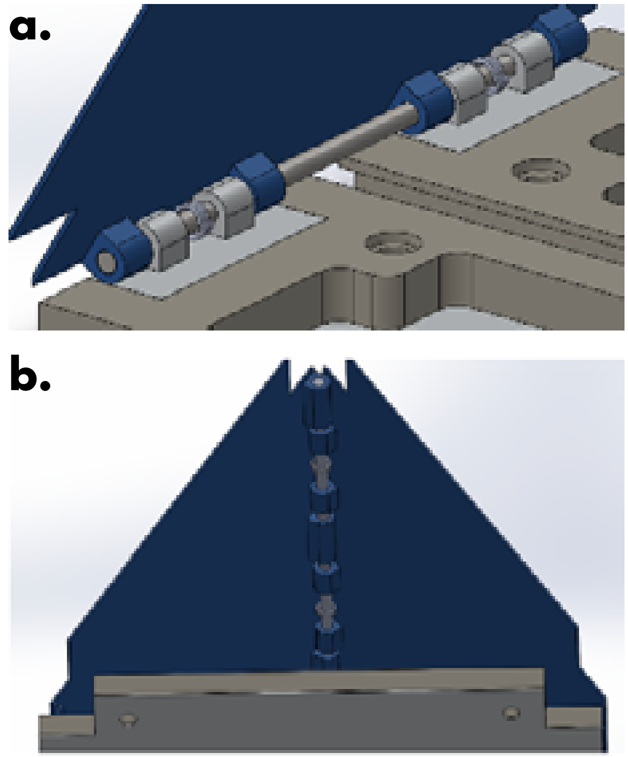


Figure 47. Illustration of the torsion springs.

3.6 Testing phase

The product testing consists of validating the functionality and reliability of the product, under different environmental influences. The product is exposed to varying challenging environments throughout its lifecycle, especially during and after the launch. These environments can be simulated with vibration, vacuum, and thermal tests. For example, during the launch the satellite is exposed to high vibration and temperatures, whereas in orbit the temperature change can be dramatic. Material outgassing is an additional critical factor.

Prototype testing can be divided into four sub-areas: electrical and mechanical integration, functional testing, mass properties, and environmental testing **(see figure 48)**. The integration test simply ensures that electrical and mechanical integrations are safe and secure. The functional testing will mainly focus on electrical and magnetics, EMC/EMI, as well as mechanical activation. Mass properties will focus on the product's weight balance and alignment. Lastly, the environmental aspect should include vibration and thermal tests, as well as vacuum outgassing tests.

Testing

Integration	Functional	Mass properties	Enviromental
• Mechanical & Electrical	• EMC/EMI • Electrical & Mechanical deployment	• Weight balance • Alignment	• Termal • Vibration • Vacuum outgassing

Figure 48. Structure of required tests

Materials can also be tested by vacuum chambers, vibration tests, heat tests, electricity tests and shock box tests. (Predicting the Lifespan of Materials in Space by Kelly Heidman from Nasa, 2018) (Source), unfortunately, the initial budget does not allow the facilitation of space-grade tests. However, the sponsor has access to a vacuum chamber to perform vacuum outgassing tests. The integration and functional tests for the most part can be tested in normal conditions. Moreover, the vibration and thermal tests could be simulated through do-it-yourself methods, albeit with only rough and directional results, by building alternative homemade testing methods for vibration and thermal tests (e.g. simulating vibration by shaking the boxed product on a table, and thermal by cyclical heating and freezing with cold water).

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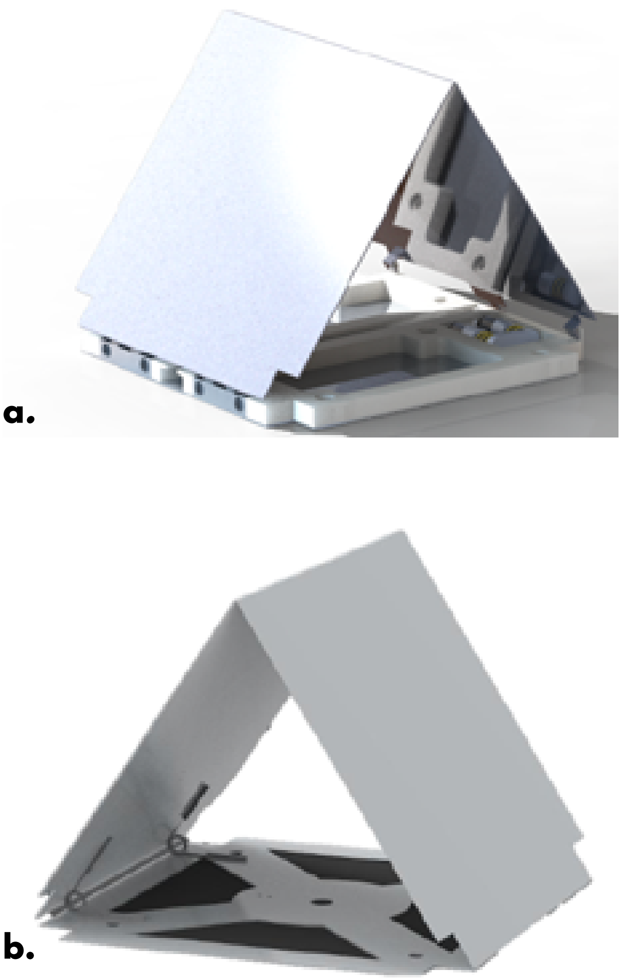
04

4.1 Final concepts

In this chapter we present final iterations of the two nose cone prototypes: a) Rail Concept, b) Lean Concept **(see figure 49)**. The prototypes were developed concurrently, locally, and globally. Moreover, both are similar in the sense that they are two-sided nose cones, yet with different mechanisms, layout, as well as materials to minor extent.



a.

b.

Figure 49. Illustration of the alternative concept prototypes. (a) rail concept (b) lean concept

Rail concept

Based on the mechanical system flow diagram **(rewind figure 24)** we can describe the final operation of the first concept in the following way: The first element refers to the energy stored in the CubeSat from a photovoltaic or chemical process. This **energy** supplies all the internal and external electronic systems of the nanosatellite.

The first component of the system is the Nichrome Wire release Mechanism which initiates the movement of the system by cutting the vectran cable (made from fiberglass that keeps the mechanism closed) as a result of heating the nichrome wire.

Nichrome wire is a resistive material with very favorable physical characteristics such as resistance to high temperatures and low impedance **(see figure 50)**. The minimum current required to heat the wire in the worst cases is 1.4 amps and the maximum is 1.9 amps. It is not recommended to use the maximum value because it can generate system failures, so an average value of 1.6 amps is established for which the system is stable and performs correctly.

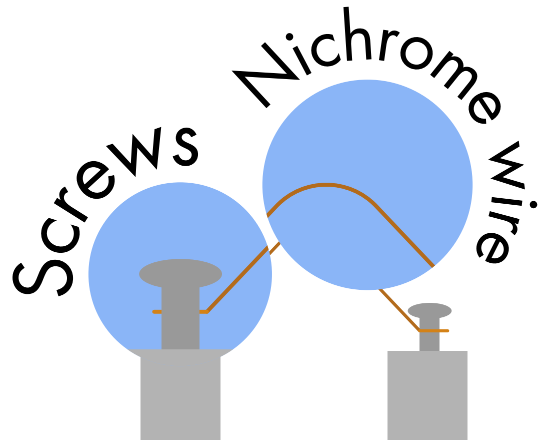


Figure 50. Nichrome wire zoom

The compression spring, applies an attractive force on the nichrome cable **(see figure 51)** which cuts the *vectran* cable.

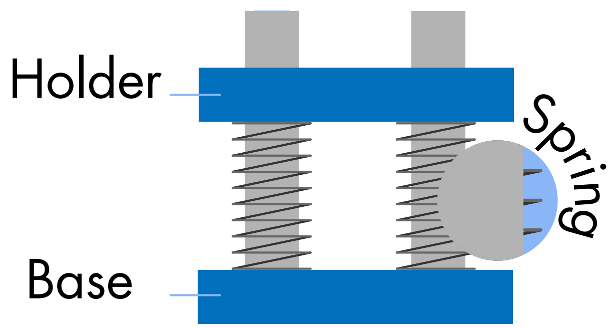


Figure 51. Compression springs in the activation mechanism

The force applied by the spring can be calculated by knowing the spring outer diameter, wire diameter, wire material, number of active coils, and type of spring end. In this case, a spring with the following parameters was used, Which gives us the following properties **(Table 5 and 6)(see figure 52)**.

Table 5. Compression spring parameters.

Wire Diameter,	**1.5 mm**
Outer diameter, *OD*	**5 mm**
Free lenght	**10.5 mm**
Number of active coils, n_a	**4 mm**
Material	**Stainless 302 ASTM A313**

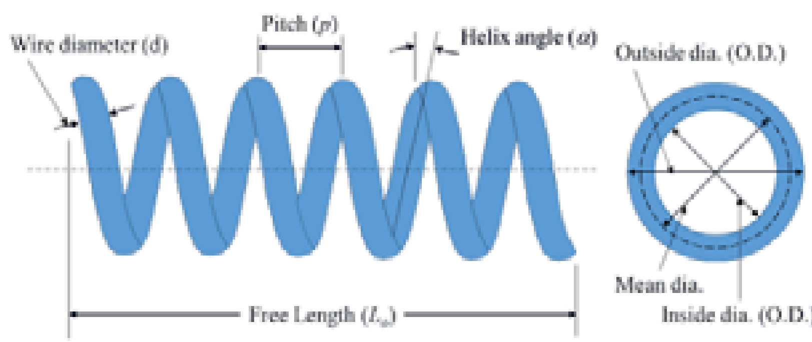


Figure 52. Parameters location of the compression spring. Adapted from: (Sinitski, 2009)

Table 6. Supply force of the compression spring.

Spring Rate (or Spring constant), *k*	***253.122 N/mm***
True Maximum Load	**175.390 N**

This spring together with the nichrome wire can make a cut in a vectran cable in an average time of 2.5 seconds according to the tests carried out in the laboratory.

The second component of the interface allows the **"Engine"** to be activated through a signal sent by a human agent or a pre-programmed signal to be activated when the CubeSat enters in to the orbit

The third component refers to the torsion springs that allow the stored energy to be released to move the **sheets** once the vectran cable is cut **(see figure 53)**.

Like the compression spring, we can know the torque applied by the torsion springs on the nose cone faces, knowing its parameters **(table 7) (see figure 54).**

a.

b.

Figure 53. Torque spring location. (a) Nosecone folded (b) Nosecone open

Table 7. Torque spring parameters

Wire Diameter, *wd*	**1 mm**
Outer diameter, *OD*	**5 mm**
Inner diameter, *ID*	**3 mm**
Number of active coils, n_a	**5 mm**
Lenght of leg 1	**10 mm**
Lenght of leg 2	**10 mm**

With the above parameters we can calculate the torque generated on both sides of the nose cone by the four torsion springs **(Table 8).**

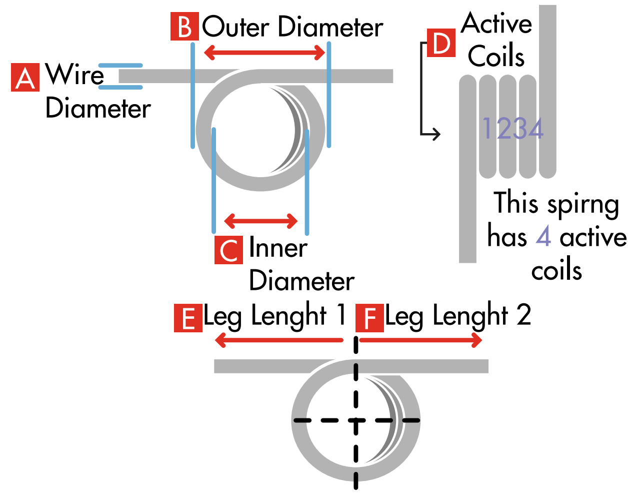


Figure 54. Parameters location of the torque spring. Adapted from: Betlejemski, 2009

Table 8. Supply force of the torque spring

Maximum torque possible, $Torque_{max}$	**935 Nm**
Spring Rate (or Spring constant) per 360 degrees, k_{360}	**14,648.14 Nm/360 Degrees**

With 939 Nm per torsion spring we obtain a total of 1,878 Nm for each face of the nose cone, this presented an opening time between 1 and 2 seconds in laboratory tests.

The fourth component refers to the faces of the nosecone that receive the energy released by the torsion springs to execute a movement **(see figure 55).**
All these elements interact to fulfill the

system's main function, which is to extend the lifespan of the CubeSat, protecting it from atomic oxygen, UV radiation, and other factors **(see figure 56).**

Finally, unnecessary material was removed, and the model was fragmented into several pieces to avoid complex shapes to manufacture. each of the pieces that make up the nose cone and its dimensions are presented below **(see figure 57).**

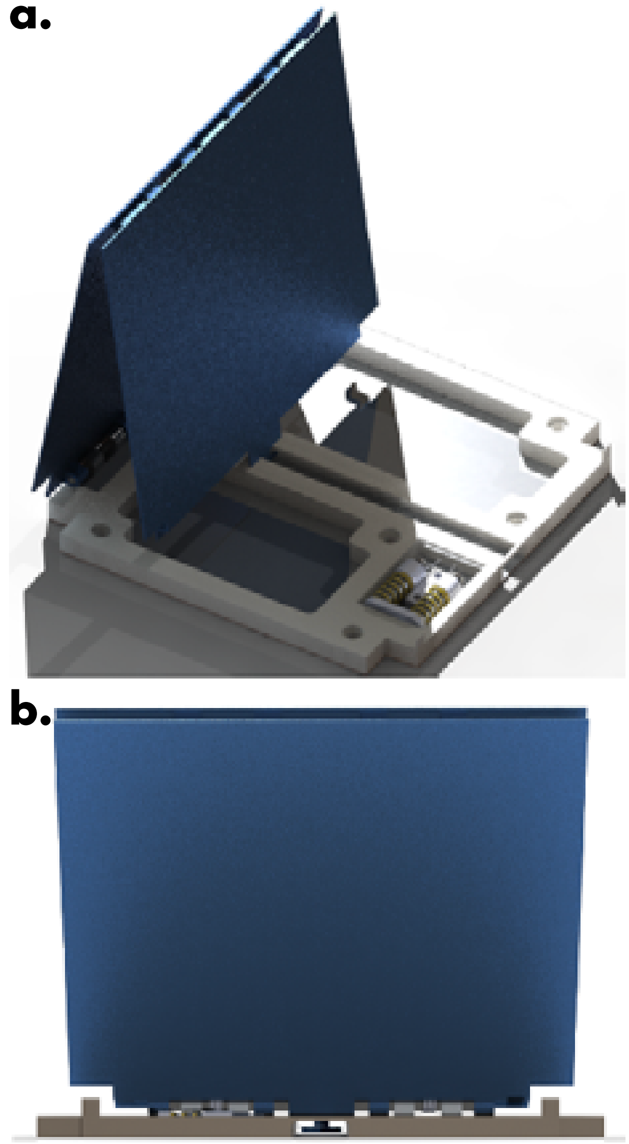
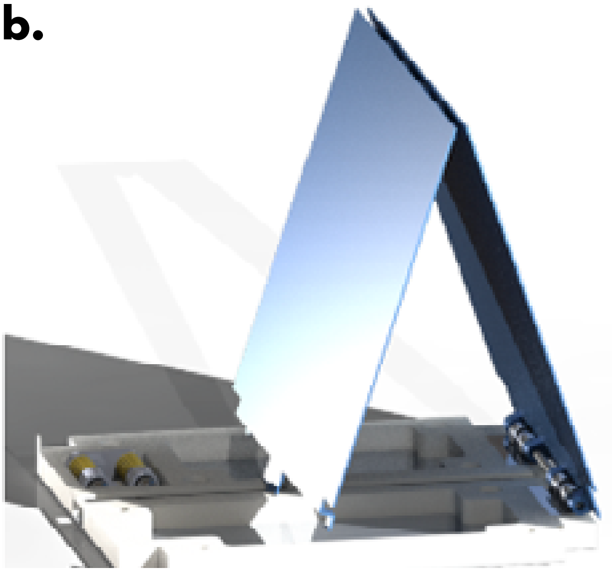


Figure 55. Motion steering rail

a.

b.



c.

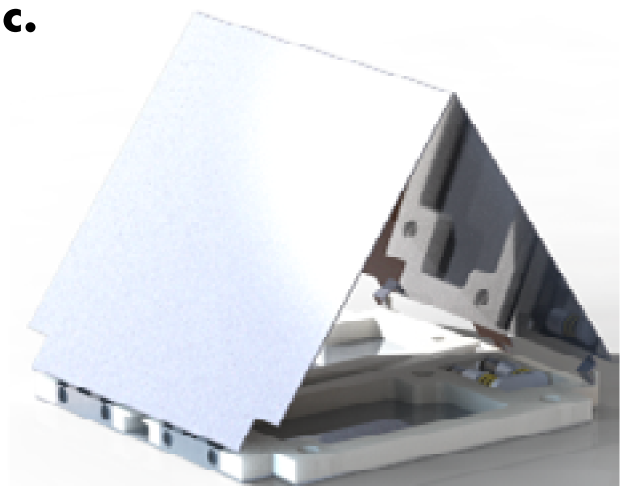


Figure 56. Final concept, closed, semi-open and totally open

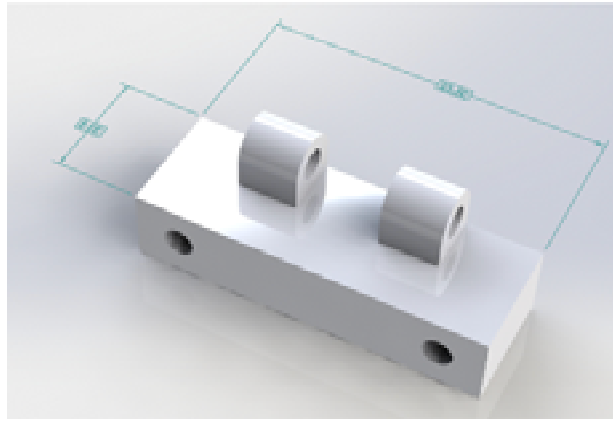


Figure 57. Aluminum bar holder (units in mm)

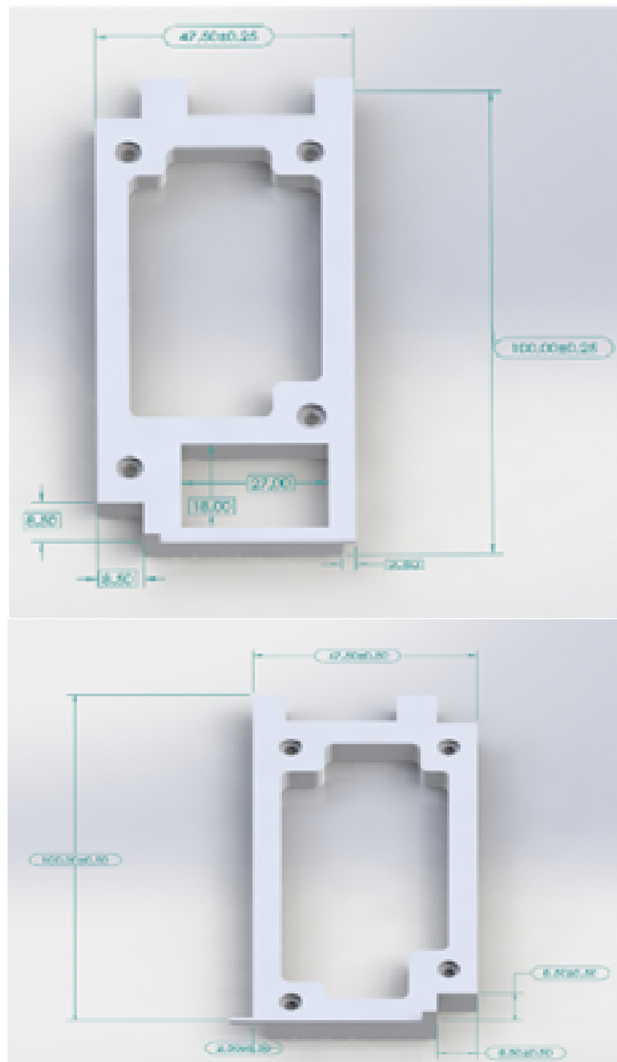


Figure 58. left side and Right side (when assembled they create the rail) (units in mm)

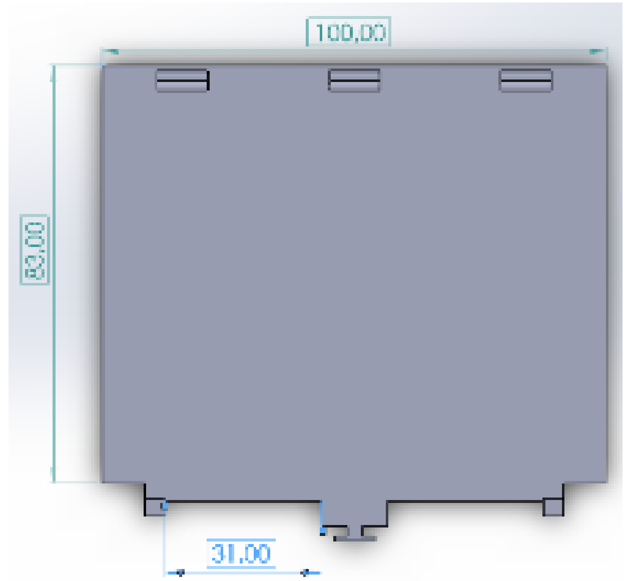
Lean concept

The second prototype uses the same torsion springs and electrical release mechanism as the rail concept.

Second prototype has another side of the cone's top-surfaces made fully from flexible, yet durable membrane. Alternatively, the membrane could be replaced by two sheets that are connected with the top and bottom parts via "membrane hinges" and epoxy glue. By this design choice, the overall product structure was maintained as simple and as light as possible. Not only does the light structure improve the overall quality and satellite performance, it makes the product considerably easier and cheaper to manufacture.

Figure 60 below shows the prototype in both folded and unfolded states. The side with springs attached is a solid aluminum sheet and the other side is a thin kapton membrane that can fold between the sheets. The membrane is smooth, durable, and lightweight, providing overall better performance to the product, in the light of the product specifications given.

The membrane is folded between the aluminum plates which are connected by two torsion springs. The torsion springs are acting as a hinge for the plates while also providing force to



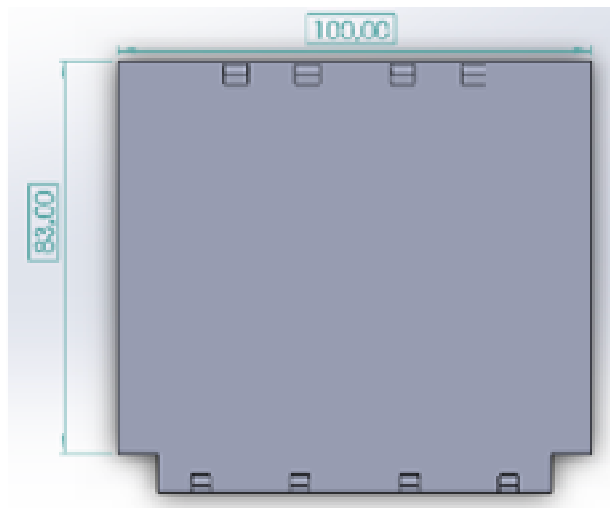


Figure 59. top and bottom cap (units in mm).

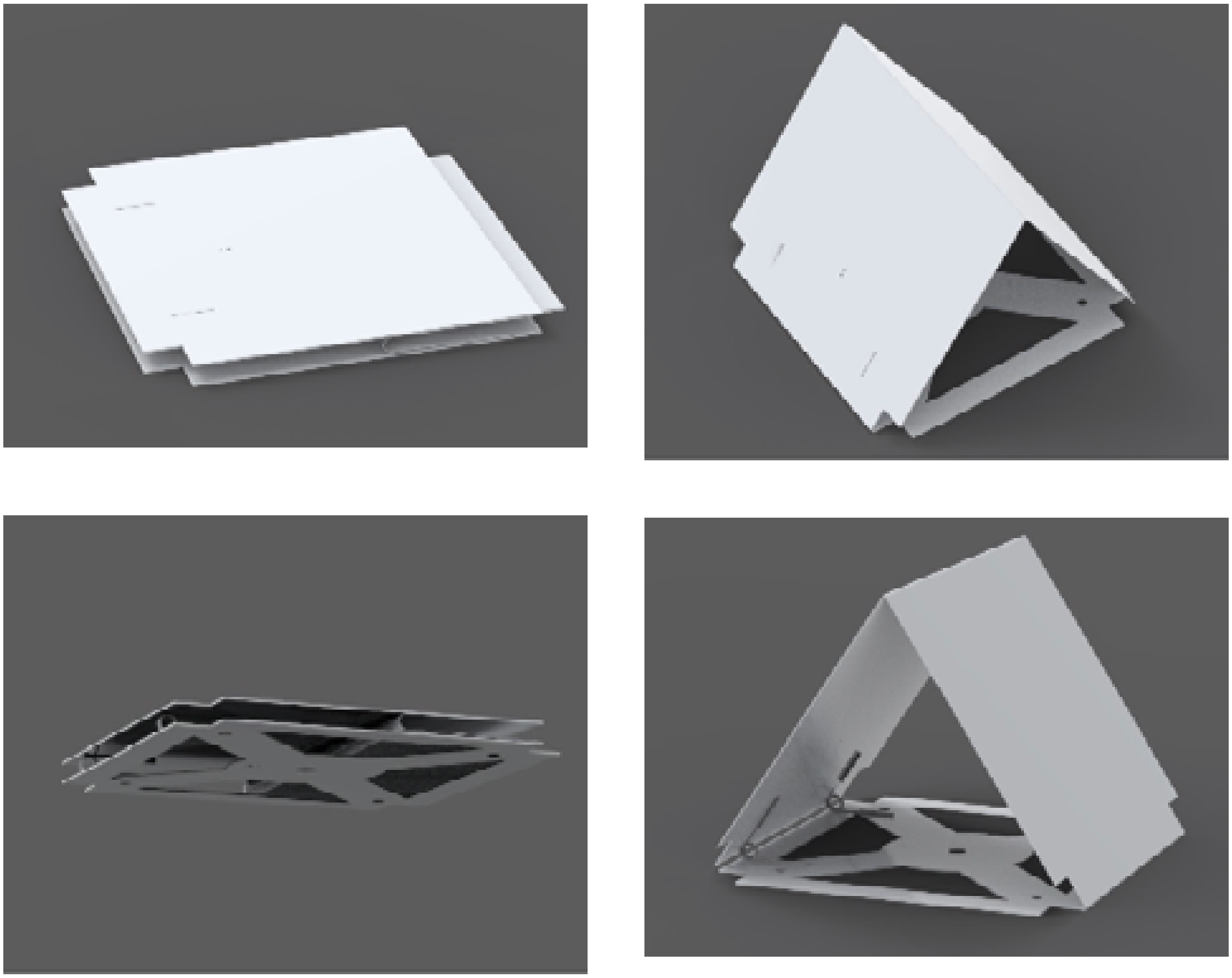


Figure 60. The CAD model of the prototype, where the right-side sheet is a membrane. The electrical application is not mounted here.

open the mechanism. The last physical prototype made, before the pandemic hit, can be seen in **figure 61**. The springs are attached by punching slots for the tails, and later realizing that slots could be pinched shut.

The prototype is very lightweight as almost all the mass comes from the two 0.5mm thick aluminum sheets. The final prototype is 8 mm thick folded, thus leaving some extra room for possible changes. 8.5 x 8.5mm cuts are made to the corners so it can be installed onto the CubeSat. The aluminum sheet is left at 91 mm so that it does not collide with the CubeSat rail bars. Further developments involve making the base plate lighter by milling out excess material and refining dimensions.

Once the CubeSat is delivered onto orbit, the internal computer of the CubeSat starts the opening mechanism of the nose cone. The mechanism consists of a nichrome wire that is heated up using the CubeSat power supply. The current is activated by the computer and lasts for long enough to burn the plastic wire holding the nose cone mechanism shut. The spring-loaded mechanism then opens as it is no longer restricted by the wire. This opening mechanism does not have to be fast, but our prototypes, being spring loaded, open within a second. The mechanism must be reliable, considering the operational environment, and this is best achieved through electrical mechanism. The mechanical and electrical mechanisms form together the nose cone for the CubeSat and the geometry stays constant due to the tension from the mechanism springs. Further development ideas include mechanical locks that hold the cone in place in addition to the tension from the springs.

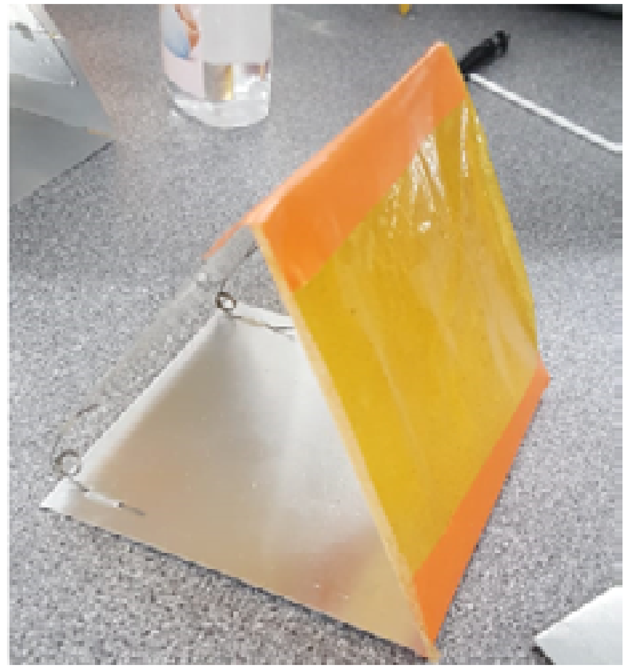


Figure 61. Late February prototype with kapton membrane, before the pandemic restrictions hit.

4.2 Final proposal of materials

Due to their low densities and capacity to alloy with other materials that provide the possibility to improve their properties, such as resistance to corrosion (as seen in the AL-Li alloy), aluminum alloys are one of the most feasible match for the manufacturing of the CubeSat's deployable roof. Additionally, aluminum alloys have significantly lower costs than the other materials like the ones previously shown. Nevertheless, the possibility of considering these materials for the construction of the nose cone are still open, given their flexibility, resistance, and useful lifetime properties.

On the other hand, plating or veiling the nose cone with a material would help reducing the damages caused by the space conditions. Traditionally gold coating is applied to protect delicate equipment in the satellite. However, for this project, gold coating is preferred for the smoothness and density it provides, to improve mitigation of overall particle collision impacts in the orbit.

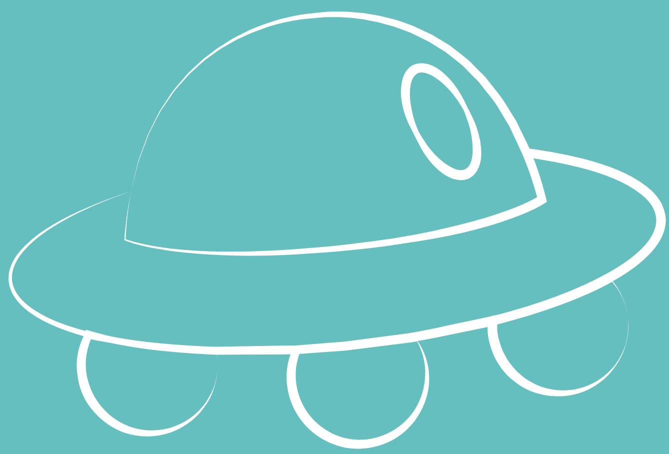
If used, a membrane of Kapton foil (FN type) could be applied. The decision is based on the Kaptons low weight and other physical properties, for example, it is strong, dense, and additionally resistant to heat and radiation. Springs would ideally be from beryllium copper since it is not a ferromagnetic material. The wires used could be nylon for tying the sheets together, and nichrome in the electrical application. Finally, the nose cone's surface pieces will be coated to make them smoother and denser, which helps the space particles to bounce off reducing the collision impact and providing improved overall performance for the product and thus to the satellite. These materials may change depending on the needs of the prototype and the available budget.

4.3 Instructions of use

The product goes through two phases: preparation phase before the rocket launch and deployment phase after the product has deployed into orbit. Practically, the post-deployment activation is the only form of use. During the preparation phase the product must be installed on top of a CubeSat. The prototypes have screw placement holes placed in the bottom sheet. The mounting happens by placing the product, in an open state, on top of the CubeSat, and screwing the product from the pre-existing holes (see the drilled bottom sheets in **Figure 38**). The CubeSat has excess surface space in its sides, and thus can be easily screwed together with the nose cone. After mounting the nose cone, it must be folded for the rocket launch. It must stay down, so the springs create static counter force. Thus, the lock-in of the folding happens by attaching nylon wire between the sheets, from the specific holes made to the top and bottom sheet, and fastening the nylon wire until the sheets meet each other, with total product height not exceeding 10 millimeters, which is the additional limit that CubeSat standard allows for the product.

In the deployment phase, the use of the product is straightforward. After the CubeSat (and the mounted nose cone on top of it) has deployed from the rocket into orbit, the nose cone can be opened remotely. This happens from the customer side, by a command sent from a specific controller to the CubeSat's system unit, which then proceeds to give signal to the nose cone's activation mechanism, to initiate the opening. Therefore, during the orbiting, there are no other user actions required beside giving the opening signal.

FUTURE SPACE MISSIONS



05

Conclusions

It is common to think about complex solutions to solve a space project. Throughout the design process, Team Tardigrade realized that the simplest solutions are often the most feasible to implement in space applications. The development of a mechanical system allows practicality when implementing it since it does not require control systems that can intervene negatively in the price of the CubeSat or directly in its internal circuits.

It was possible to develop two simple devices that respect the restrictions given by the sponsor. The devices do not make use of DC motors controlled by a PWM, neither do they use magnets of any kind that can alter the electromagnetic field of the CubeSat's internal electronic circuits. They also respect dimensional restrictions, avoiding exceeding 1 cm in height and 10 cm in width.

When a 3D model is made it is important to consider standard and commercial dimensions of components such as screws, rods, springs, sheet thickness, etc. This can help reducing the production costs by 50-70% while increasing product accessibility. Therefore the devices are considered low cost.

Finally, the prototypes are within the predetermined scope. The product structures have good performance, the shape provides favorable reflections, are lightweight, non-magnetic, and affordable.

5.1 How to develop this solution further

There are several aspects to make improvements for the product. The first one is modification of the mechanical design, which would reduce or fully remove the holes and surface anomalies. This could be executed by developing a mechanical structure for the springs to lock into, without the need of drilling holes to the sheets. Of course, the problem here is that the manufacturability suffers. Hence the product's performance improvement compared to the increased manufacturing costs should be evaluated.

Secondly, the surface smoothness should be looked more into. As of now, gold-plating is our proposal for robust mirror finish. However, there are other chemicals, likely more affordable, procedures to improve surface quality. For example, electropolishing. It is an electrochemical process that removes material from a metallic workpiece, reducing the surface roughness by levelling micro-peaks and valleys.

The product itself could be further developed in a manner which would also cover the rail bars sticking up from the four corners of the CubeSat, also penetrating the nose cone's corners. The rail bars cover a flat surface area of four times 8,5 x 8,5 mm, which accounts for 289 mm2, and thus 2,89 % of the total surface area which is not covered by the nose cone. However, this is quite the difficult task, as initially there cannot be anything attached on top of the rail bars.

Thus, to increase the corner coverage, the solution could be additional "wings" flaring out from the side of the top sheets. In result, the "wings" would remove, at least to an extent, the direct flat surfaces. That said, the larger angle from such an application would not be fully optional from the reflective performance perspective, and it also vastly increases the complexity of the product. Therefore, the benefits and costs must be evaluated, where the solution should be quite convenient considering the amount of surface area there is left to cover.

Another thing to consider is if the prototypes, especially the rail bar prototype, could be printed from plastic, but then plated with thick enough aluminum coating. There are several suppliers for such services, yet the durability of the coating must be researched more into. The coating must last in vacuum at least as much as the satellite's mission. This method would make especially the rail bar concept's manufacturing more streamlined and reduce its overall weight drastically.

Moreover, for the lean concept, electrolysis or electroless plating, or addition of thin sheet or other covering materials could be considered, in order to fill the two small surface errors caused by the torsion springs which are "threaded" through one of the top sheets. However, this requires more research and cost-benefit evaluation.

Currently the sponsor has limited milling and cutting capabilities. Thus, the manufacturing process should be streamlined as much as possible, without critically affecting the product's performance or functionality. This can be improved by reducing different gaps and holes in the product, without critical purpose. This would decrease the man hours required for pure manufacturing.

Lastly, those design choices that are required, should be examined if they can be modified so that they are manufactured altogether with the same machine or at least with the same size of the drill, as an example. Thus, the configuration and changeover times would be reduced.

5.2 Other opportunities for exploration

Shape-memory materials and other materials shaped or formed chemically are something potential to put more research into. Traditionally, shape-memory metals work in a manner where they are manipulated with temperatures. However, this is counterintuitive for this project, as the metals are deformed by cold temperatures and formed through application of heat. Whereas, the satellite's environmental temperature changes from hot to cold (from launch to orbiting). Thus, a deformation would initiate after the cone's deployment. Therefore, additional preventive or lock-in methods would require additional research. In addition are the shape memory polymers, which are a type of macromolecular intelligent material, which respond to external stimuli changing their properties like color and shape, while being able to return to their original form.

In addition to experimenting with new materials, the possibility of experimenting with new forms for the deployable roof is open, such as those presented in the ideation section which were inspired by the origami technique, a technique that has been implemented in recent years in the construction of large scale satellites since this technique can be very useful to save space, facilitate the deployment of the accessory and minimize costs.

LEARNING JOURNEY

06

The PDP course has taught us extensively about product development, its processes, and methodologies, as well as about use of different technologies. However, we have additionally acquired invaluable experience from interpersonal and -disciplinary work, within a global setting.

6.1 Product development dimension

It has become apparent that while there are different ways and procedures in innovating and developing products, the most efficient results follow well planned and thought out processes. That said, it was eye-opening to realize how many different methodologies and approaches can be had in one certain phase of a product development project. For example, in concept generation, it can be either visual, structural, collaborative, individual, accidental, and even happen outside the working environment. Yet, it is best conducted by predetermined structure, or as in our case, by organized chaos and by utilization of colleagues from diverse backgrounds.

The product development course along supporting materials have provided a distinct, but not limiting overview on product development processes. First, it is fundamental to understand the background, including problems and the underlying customer needs and values. After understanding those, can ideation be initiated. It is followed by research, which can then continue in micro-levels during later phases. Nevertheless, speaking of ideation and preliminary research, a well conducted plan has proven to be of good worth. Potential concepts are then generated, further researched, developed, and designed, with appropriate product architecture and schematics, which provide the foundation for further development.

Moreover, the course taught us that early prototyping can be highly beneficial in finding unseen obstacles or ideas within a product concept, those that did not occur during the design phase. Thus, we realized that designs or schematics do not need to be considered perfect, before transitioning into prototyping. Moreover, we found prototyping also as an extremely good method to practice hands-on ideation.

The amount of detail that can go into a seemingly simple product was also surprising to us. There is much to consider beside the physical attributes of a product. For example, the materials and their relation to the environment, how the product operates and fits into a system, its robustness, how different materials work or alternatively do not work together, tolerances and surface treatments. Speaking of those, one vivid and educational moment was the realization of manufacturability and the importance of its consideration during the design phase. This was something we did not put much thought into, later realizing that manufacturing an intricate solution from metal would require several special machines and man hours of expertise - resources of which the team did not have access to. Therefore, design changes had to be made later in the process, to maintain manufacturing costs on a tolerable level.

The prototyping sessions deepened our knowledge of creating models that are used to express ideas. It is good to start with very basic and easy to work with materials that can be used to prove that the concept works. After the initial idea is complete a more thorough prototype can be created using materials that are closer to the final product. The course also introduced prototyping and hands-on way of working to some who had little experience of it much before.

6.2 Some personal reflections

Janna

"Understanding is the key", they say. That phrase is suitable in this course in multiple different ways. In our project, working with people from different scientific study backgrounds has its own challenges. Whilst having both; Master's and Bachelor's degree level students with various expertise and skills. Some of us have more previous experience working in this type of project and some of us had nearly zero.

Understanding starts with the language; Finnish, English, and Spanish mixed together. It continues with more professional and sector-wise expressions, which might be hardly understandable for the rest. However, we are lucky to have Google and dictionaries to help with that.

To add up, working with a remote team both globally and locally, can be challenging. We are all different kinds of people with different interests, which makes it intriguing to find out the way to build up an excellent team. Although, we managed to do it well! We built a team of people who will all have an educational and pleasant experience of this kind of project.

Working in a multilingual team with diverse degrees highlights the importance of well presented and built information. Telling the information in a simple and clear way as possible eases more effortless co-operation. The documentation part needed to be done in a way that everyone can understand the problem, meaning, and finally, the decisions made.

Also, helping and being genuine to each other, assisted the project to flow. For example, visiting the sponsor's headquarters brought us closer together, which helped the team to grow and, in that way, made the bond stronger.

Sometimes studying and projects can be stressful which is why listening to each other's worries and feelings is vitally important. Caring is underrated and laughing while and then is recommendable!

Isabella

The interdisciplinary nature of the PdP has made me question my profession as a philosopher. I always had a dream of working on an interdisciplinary project, so knowing that I would participate in the PdP made me feel very happy. When we were told that in our challenge we should work with nanosatellites I was very worried, because what could I contribute? I had no knowledge of engineering or outer space. At first, I thought that the right way to go was to leave the philosophy aside and try to contribute to the technical part of the project. However, remembering the slogan "Fall in love with the problem, not the solution" made me think that philosophical thinking is dedicated to proposing, analysing, delimiting and reflecting about human life problems. Why not apply its tools to this product design challenge?

I think I was able to contribute valuable questions and insights to understand the problem in depth and thus think of a relevant solution. Sometimes it was a bit tedious to ask so many questions, but these are the ones that allow us to rethink and reinterpret our work to approach it in the best way possible. Working with people from other disciplines and getting to know their perspectives was very valuable to me because it inspired me to be more creative and not be afraid to experiment, something that philosophers have a hard time doing, and I learned about the space industry, something I never thought I would know. I am very grateful for this opportunity and I hope to be able to participate in other innovation projects from an interdisciplinary perspective. Thanks to my team, our Responsible Professor, the sponsors, the Course Staff for their support.

Juliana

This project has given me one of the most enriching experiences in my professional training, it allows me to work with different disciplines that at first were unknown to me, and it also allowed me to expand my capacity for creativity and innovation. On the other hand, facing such a demanding project in technical terms allowed me to reinforce the research skills that I have been training throughout my career. The interdisciplinary team made me work in my soft skills as abstract thinking and concept illustration and in this way know and learn about modeling programs like Solidworks. Finally, I consider that one of the most important experiences I had with this interdisciplinary team is learning and understanding different visions of the same subject, as well as being more tolerant and respectful of the ideas of all my colleagues.

Sebastian

As an international business student, participating in this project allowed me to deepen, through experience, different areas of knowledge acquired during my career. I mainly had the opportunity to work in a group of diverse backgrounds. Since the team members belonged to different programs. In addition, a multicultural context, since part of the group members are Finns. Another main challenge was that the project had to be carried out in English, which allowed me to practice that language both orally and in writing. I also appreciate the experience of having been able to travel to Finland. This helps me to know first-hand the cultural context of that country, to which my colleagues belong. With the knowledge that I acquired in subjects like negotiation and culture I could have tools to have a better dynamic of work with people from such a different cultural context.

Valentina

Working at PdP has been one of the most enriching experiences I have had both professionally and personally. From my profession I can say that on multiple occasions I have worked with interdisciplinary teams, but the challenges always revolved directly around design. Finding myself with a challenge as alien to my profession, as nanosatellites are, generated some discomfort that in turn was charged with much interest in learning about new topics.
As I got to know more about the project and my colleagues, I became more excited about topics that I never thought I was interested in, in turn, this generated that I was able to take risks and take the first step to see subjects outside of my university of different subjects of my degree such as industrial design, I also learned the importance of having a more global thought about each project and this was taught to me by each of my colleagues from different degrees, a great teaching that I will always keep in mind in my life

Juan Camilo

During my degree, I had never had the opportunity to apply my knowledge in a project related with the space, much less in the company of other disciplines. At first, it was challenging to communicate technical issues with the rest of the team, fortunately I was able to develop the ability to communicate my ideas thanks to the project and the process that was carried out, but that was not the only skill that this project helped me improve, I was also able to acquire skills in the use of 3D modeling tools, knowledge of energy storage elements among others.

Emma

The yearlong PdP-course has been much different from the other courses I have had in university. The teaching methods have made the learning unnoticeable and fun. Since the course structure is relatively free, the team had to plan the schedule mainly by themselves. This requires good teamwork skills. During the course my teamwork skills have been growing enormously. Our team had members from various study fields and the global team was located on the other side of the Earth. This fact posed some challenges but also opportunities and we also got a great chance to learn from other cultures. Acting as the economy officer in the project taught me a little bit of project budgeting which will definitely be a good thing to master in the future.

Ilkka

Orchestrating a team of ten members, with half of the group consisting of international and remote members have been quite the challenge. First, any managerial role is surely challenging, but without formal managerial experience, and with exposure to such project setting, made it that much more challenging.

A technical project surely added more complexity to the managerial role. Thus, it was required to learn to listen to those with better command of certain domain expertise, and in decision-making to participate even further. Through active dialogue and with psychological safety within the team, everyone felt good to voice their opinions and hence contributing to the best solution available. Therefore, creating a relaxed culture and open communication have perhaps been one of the most important managerial achievements for the project's success.

Moreover, leading by own example, in bad and good, showed to have a real impact. For example, at times of high pressure from the other studies, one was clearly more absent. The absence showed both, as a lack of support, as well as a lack of psychological absence - even if physically present. It could be argued that this absence reflected on the team's motivation and especially the overall progress. It was realized how important, but also how hard, being present and listening actually are. This is something to consider later in our careers, as stress and a sense of hurry will surely be something also later accompanying us.

Lastly, even though the global members had less technical background in numbers, and initially grasping the project background and scope might have been more difficult to most of them, those of us with more technical background want to acknowledge they are highly valuable assets and that everything is possible with the right motivation.

From a project management perspective, the establishment of objectives and structuring of work was not entirely new, albeit this experience was derived from non-technical projects. Nevertheless, the most important learnings have been regarding explicitly illustrating where we are going both, in short and mid-term. Even though the project plan was thought out and shared, with appropriate phases, we did not return to it often enough, especially to review the mid-term objectives. Thus, the larger picture or a phase transition may have been more ambiguous at times. Generally, this may affect motivation, but even more so the proactivity. By understanding the broader process flow better, individuals may require less guiding and can take proactive ownership over the next steps. The timeline review aspect could have been more emphasized in this project, especially now that the technology and the development processes were new to the large majority of the team.

REFERENCES

Alen Space. (n.d.). A Basic Guide to Nanosatellites. Retrieved May 14, 2020. Available from https://bit.ly/2LsQL9T

Alen Space. (n.d). How to Do Business in Space?. Retrieved May 14, 2020. Available from https://bit.ly/2zI9rj0

Aurora Propulsion Technologies. (n.d.). Retrieved May 14, 2020. Available from https://bit.ly/2Z6Egc4

Aguilar-Zambrano, J., González, M. C., Valencia, M., Valencia, A., Leyton, A., Casanova, F., & Riveros, D. I. (2009). Analysis of mobility support products under the evolution laws of technical systems for detecting opportunities of innovation. In Proceedings of the 1st Int. Conf. on Integration of Design, Engineering and Management for innovation IDEMI09 (pp. 14-15).

Airbus .(n.d). New Space Europe: should shape the future of space. Retrieved May 14, 2020. Available from https://bit.ly/2Z87Lu6

Betlejemski, C. (2009). Spring Training (Trakar - supplier of stock springs in Ayr, Ontario, Canada). Available from https://bit.ly/2TaKeVr

Bettermann I., Raina A., Gries T. (2018). Warp knitted textiles for space satellites. techtex trends. Retrieved May 14, 2020. Available from https://bit.ly/2WxgxzX

Bochenek, K., & Basista, M. (2015). Advances in processing of NiAl intermetallic alloys and composites for high temperature aerospace applications. Progress in Aerospace Sciences, 79, 136-146.

Brown, T. (2008). Design thinking. Harvard business review, 86(6), 84

Camps, A (2019). Nanosatellites and Applications to Commercial and Scientific Missions [Online First], IntechOpen, DOI: 10.5772/intechopen.90039. Available from https://www.intechopen.com/online-first/nanosatellites-and-applications-to-commercial-and-scientific-missions

Canadian Space Agency. (2018). What is a CubeSat. Retrieved June 5, 2020. Available from https://www.asc-csa.gc.ca/eng/satellites/cubesat/what-is-a-cubesat.asp

Cavataio, P., & Rus, G. (2019).Industria Espacial 2019. Buenos Aires: OiNK.

Chand, S. (2000). Review carbon fibers for composites. Journal of materials science, 35(6), 1303-1313.

Chin, I., Coelho, R., Foley, J., Johnstone, A., Nugent, R., Pignatelli, S....Robinson, A. (2017). Cubesat 101: Basic concepts and Processes for First-Time Cubesat Developers. California Polytechnic State University, San Luis Obispo (Cal Poly) CubeSat Systems Engineer Lab. Retrieved May 14, 2020. Available from https://go.nasa.gov/2Lyvuf0

Chowdhury, P., Sehitoglu, H., & Rateick, R. (2018). Damage tolerance of carbon-carbon composites in aerospace application. Carbon, 126, 382-393.

CubeSat Design Specification (CDS). (2004). Revision 9. Retrieved May 14, 2020. Available from http://cubesat.calpoly.edu

Design thinking. (n.d). Retrieved May 14, 2020. Available from http://www.designthinking.es/inicio/

Dielectric Manufacturing. (n.d). Kapton® (Unfilled Polyimide). Retrieved May 14, 2020. Available from https://bit.ly/3bA9lHx

Euromonitor International. (2019).Business Dynamics: Finland . pp. 1-6

Euromonitor International. (2020).Finland: Country Profile. pp. 1-5

Finckenor, M.M & Groh, K.K (2015). Space environmental effects. National Aeronautics and Space Administration (NASA).

Furuya, H., Kogiso, N., Matunaga, S., & Senda, K. (2000). Applications of magnesium alloys for aerospace structure systems. In Materials science forum (Vol. 350, pp. 341-348). Trans Tech Publications Ltd.

Giummarra, C., Thomas, B., & Rioja, R. J. (2007). New aluminum lithium alloys for aerospace applications. In Proceedings of the light metals technology confer-

ence (Vol. 2007).
Grossman, E., & Gouzman, I. (2003). Space environment effects on polymers in low earth orbit. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 208, 48-57.

Hendrick. M.(2014) ,Kapton Film and the Aerospace Industry, Retrieved May 14, 2020. Available from https://bit.ly/2LxsXS4

Hughes, M (n.d.). What Is PVD Coating? Physical Vapor Deposition Coatings. SEMICORE. Retrieved May 14, 2020. Available from https://bit.ly/369Z4AY

Hurst, Nath. (2018). Why Satellite Internet Is the New Space Race [illustration]. From https://www.pcmag.com/news/why-satellite-internet-is-the-new-space-race

Körner, C., Schäff, W., Ottmüller, M., & Singer, R. F. (2000). Carbon long fiber reinforced magnesium alloys. Advanced engineering materials, 2(6), 327-337.

Liu, Y., Du, H., Liu, L., & Leng, J. (2014). Shape memory polymers and their composites in aerospace applications: a review. Smart Materials and Structures, 23(2), 023001.

Lubin, G., & Dastin, S. J. (1982). Aerospace applications of composites. In Handbook of Composites (pp. 722-743). Springer, Boston, MA.

Matney, M., Varvin, A., & Manis , A. (2017). Effects of CubeSat Deployments in Low-Earth Orbit (T. Flohrer & F. Schmitz, Eds.). https://conference.sdo.esoc.esa.int/proceedings/sdc7/paper/509/SDC7-paper509.pdf

Mellor, B. G. (2006). Surface coatings for protection against wear. Taylor & Francis US.

Mordike, B. L., & Ebert, T. (2001). Magnesium: properties—applications—potential. Materials Science and Engineering: A, 302(1), 37-45.

NanoRacks LLC. (2018). NanoRacks CubeSat Deployer (NRCSD) Interface Definition Document (IDD). Available from:

Nanosats Database (2020) Nanosatellites Launches. Available from: https://www.nanosats.eu/

NASA. (n.d.). Mirrors Webb/NASA. Retrieved May 14, 2020. Available from https://go.nasa.gov/2Z6FaW0

ÓMICAS. (n.d). What is ÓMICAS? Retrieved July 14, 2020, from: https://www.omicas.co/que-es-omicas

Padilla, D. (2018) Diseño y manufactura de la estructura de un CubeSat 2U. Universidad Nacional Autonoma de Mexico, 27
Patrick, T. J. (1981). Space environment and vacuum properties of spacecraft materials. Vacuum, 31(8-9), 351-357.

Peters, M., Kumpfert, J., Ward, C. H., & Leyens, C. (2003). Titanium alloys for aerospace applications. Advanced engineering materials, 5(6), 419-427.

Sinitsky, J. (2009) Spring Design - How to Design and Choose the Right Coil Compression. Bright Hub Engineering. Retrieved May 15, 2020. Available from https://bit.ly/3fQNH5l

Siochi, E. J. (2014). Graphene in the sky and beyond. Nature nanotechnology, 9(10), 745.

Space Materials DataBase . Copper and its Alloys. Retrieved May 15, 2020. Available from https://bit.ly/2WSlTog

Superintendencia de Industria y Comercio, Centro de Información Tecnológica y Apoyo a la Gestión de la Propiedad Industrial - CIGEPI, Silva, L. A., & A, B. (2017). Boletín tecnológico Nanosatélites. Available from https://bit.ly/3g0K-GyI

Surface Treatment Experts (STC). (n.d.). Different Types of Coatings for Metal Plating. Retrieved May 14, 2020. Available from https://bit.ly/2WDI1nP

SWPC, (2020). Satellite Drag . Space Weather Prediction Center. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION. Retrieved June 5,2020. Available from https://www.swpc.noaa.gov/impacts/satellite-drag

Techsil, (2020). The Future is Orange - Techsil Launch New Biocompatible Plastics Adhesive Which Fluoresces Orange, Retrieved May 15, 2020. Available from https://bit.ly/36115zn

Toorian, A., Blundell, E., Puig-Suari, J., & Twiggs, R. (2005). CubeSats as responsive satellites. In Space 2005 (p. 6828).

Urlich, K. & Eppinger, S. (2015). Product Design and Development. McGraw-Hill Professional.

Work Bank Group. (2020).Economy Profile of Finland (p. 4)

Yang, J. M., Kao, W. H., & Liu, C. T. (1989). Development of nickel aluminide matrix composites. Materials Science and Engineering: A, 107, 81-91.

Yolshina, L. A., Muradymov, R. V., Korsun, I. V., Yakovlev, G. A., & Smirnov, S. V. (2016). Novel aluminum-graphene and aluminum-graphite metallic composite materials: Synthesis and properties. Journal of alloys and compounds, 663, 449-459.

Young, R. J., Kinloch, I. A., Gong, L., & Novoselov, K. S. (2012). The mechanics of graphene nanocomposites: a review. Composites Science and Technology, 72(12), 1459-1476.

Zhang, L., Hou, G., Zhai, W., Ai, Q., Feng, J., Zhang, L., ... & Ci, L. (2018). Aluminum/graphene composites with enhanced heat-dissipation properties by in-situ reduction of graphene oxide on aluminum particles. Journal of Alloys and Compounds, 748, 854-860

ANNEX 1

Poster for the Finnish Satellite Workshop, 20-22 January 2020. Helsinki, Finland.