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Feasibility Study: Small and Low-Cost Electro–Mechanical Release Mechanisms for Space

FINAL REPORT

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EUROPEAN PROJECT SEMESTER | Glasgow Caledonian University I RESPONSIVE ACCESS

Dedicated to Andrew Quinn (EPS Manager), Dr. Mark Jenkins (Tutor), María Insa Iglesias (Tutor), Professor Gordon Morison (Tutor) and Andrew Paliwoda (CEO – RESPONSIVE ACCESS)

Special thanks to Glasgow Caledonian University and European Project Semester Program.

Executive summary

Space research is slowly but steadily becoming more accessible attracting more companies to work in space. However, some space solutions are not as accessible and expensive. This project is a study about low-cost opening mechanisms that are usable in space. The aim of this project is to come up with a mechanism design that could be manufactured and utilised in space projects by Responsive Access, the industrial collaboration company of this project. The ideal ending point for this project is to create and test a prototype, which can then be sent onwards to further development. This project also includes a study of current solutions, materials and tests implemented to consider when designing a device to be utilised in a space environment.

This report goes through every part of the project in sensible order, so that the reader has an idea what has been done in the project and what kind of things have been achieved. First it is introduced some basic information of the project such as background information and terms required to understand the project, information about the client of the project, the scope of the project or the management of the project.

Secondly, it is exposed the activities performed by the team before starting to design. These previous studies include a study of the release mechanism in the market, the conditions document presented to the client with all the characteristics of the device to develop and the materials study performed by the team.

After, the design study section goes through the different design stages. Starting from the brainstorming and ideation stage, every potential solution found is presented. Later mechanical and electronic decisions with respect the final candidates are described. Motion simulations of the devices might be found in this section as well. After the design study, everything related to the testing of the devices is explained.

Finally, final conclusions of this project are presented as well as possible future work and development of the project.

Acknowledgement

This project has been a massive learning experience for the whole team in many different aspects, such as learning about space development, teamwork and project management.

We would like to thank Glasgow Caledonian University for having us for the project. We would especially like to thank Andrew Quinn, Mark Jenkins and Maria Insa Iglesias for providing us with lots of help and support during the project.

We would also like to extend our thanks to the company Responsive Access, and especially to the CEO Andrew Paliwoda for trusting us with a project and always being willing to help.

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1. List of acronyms

AFSPCMAN	Air Force Space Command Manual
CAC	CubeSat Acceptance Checklist
Cal Poly	California Polytechnic State University, San Luis Obispo
CDS	CubeSat Design Specification
cm	Centimeters
CVCM	Collected Volatile Condensable Mass
DAR	Deviation Wavier Approval Request
ELaNa	Education Launch of Nanosatellites
EPS	European Project Semester
ESA	European Space Agency
FCC	Federal Communication Commission
GSFC	Goddard Space Flight Center
IARU	International Amateur Radio Union
LSP	Lunch Services Program
LV	Launch Vehicle
MIL	Military
mm	Millimetres
NASA	National Aeronautics and Space Administration
NPR	NASA Procedural Requirements
P-POD	Poly Picosatellite Orbital Deployer
RBF	Remove Before Flight
Rev.	Revision
RF	Radio Frequency
SLO	San Luis Obispo
SSDL	Space Systems Development Lab
STD	Standard
TML	Total Mass Loss
UG	User Guide
WBS	Work Breakdown Structure
µm	Micrometer

2. Responsive Access

This project was provided to us by the company Responsive Access.

Responsive Access is a company focused on offering its clients as easy access to space as possible through the use of advanced software. They are determined to be responsible users of space.

They also offer their clients optional services, such as environmental testing of satellite components, insurance service, legal guidance, export control advice and more.

3. Background knowledge

3.1 What is a CubeSat?

As the field of this project is unusual, some concepts are going to be used that might be unknown by some readers. This section pretends give some basic insight to make the understanding of this document easier.

A CubeSat is a standardized small satellite employed in space research or new technologies testing. They are made of modules or units, having each unit the following dimensions: 10x10x10 cm, which concludes in a cube shaped structure. This element is very fragile, sophisticated and useful in terms of space research.

Figure 1 Main specifications of the CubeSat

As we have said previously, the CubeSat is supposed to be a miniaturized satellite, so, the device must be assembled to a launch vehicle. The launch vehicle is a key component in the process of deployment of CubeSats. The launch vehicle will the pods o containers where the CubeSats will remain until deployment.

CubeSats are deployed in different launch pods. The pod is usually a metal box that contains the CubeSats. When the time comes to shoot the CubeSat from the launch pod into space, the door in the pod opens using an inbuilt release mechanism.

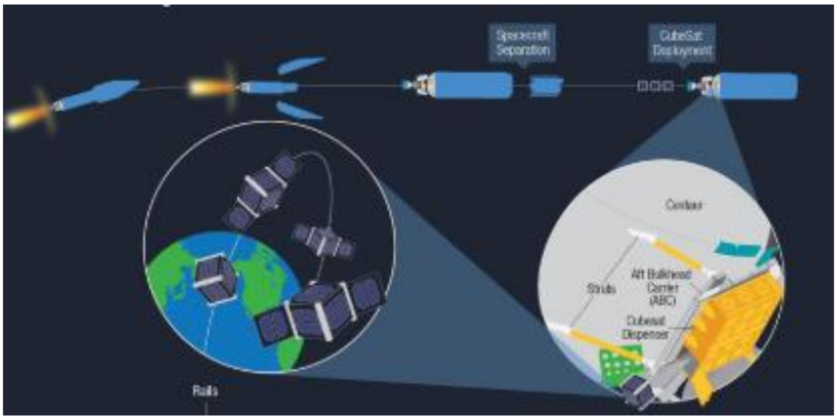


Figure 2 Steps of the CubeSat deployment

Our project was very related to the process of deploying the CubeSats. Our project is basically the development of a release mechanism that will keep the CubeSats into the pod until the moment of deployment.

4. Introduction to the project – what, why and how

This research project presents a feasibility study of a low-cost electro-mechanical release mechanism for space. This is a collaborative project with Responsive Access, a company focused on developing solutions for simpler access to space.

4.1 What is this project about?

The objective of this project is to study the current release mechanism used on CubeSat deployers and design a low-cost door mechanism considering the space limitations.

The main goal is to create an alternative design for this release mechanism that our client, Responsive Access, could use in their own CubeSat launchers. The end goal of the project is to produce a design proposal that Responsive Access could use as a base for their own produced mechanism.

4.2 Why is this project being done?

While there are different types of CubeSat deployers and launch mechanisms that already exist, most of them are patented. That means that they cannot be manufactured by Responsive Access. While it is possible to buy them from other companies that manufacture their own launchers, it is not very cheap. According to the CEO of the Responsive Access, Andrew Paliwoda, the costs can easily be as high as 7000 pounds for one launching pod. The cost mostly come from the development, testing and quality assurance. In addition, he explained that manufacturing their own launching pods would be beneficial to be less dependent on other companies.

It is also important to consider, that the CubeSat deployers cannot be recovered after they have been launched up into the space. This is a reason why the release mechanism should be as cheap as possible and as reliable as possible. Cheap because the pod will be gone forever after they reach the space and reliable because if the release mechanism refuses to work, all the money invested into the launch is essentially wasted.

To summarise, the main reason why Responsive Access requires the development of their own release mechanism is due to they have long supply lead-times, inflexible suppliers and they would reduce manufacturing costs.

Thus, having their own design would allow them to have more control on the production, reducing lead times, allowing more flexibility to the design and manufacturing while saving money during the process.

4.3 How are the results going to be achieved?

The project plan was the following. First step was to research as much information about the subject as can possibly be found, such as the used materials, already used methods, including their positives and negatives, the specifics they must adhere and the methods used to test them. The second stage started with the creation of a conditions document which specifies what kind of standards the final design must adhere to.

The last stage was the actual design process. At the beginning a set of concepts was created by getting inspiration of already used devices inside and outside the space industry. These concepts were discussed and the candidates with the higher potential developed further implementing the feedback from the client.

4.4 Limitations and restrictions of the project

The project had certain limitations that had to be followed.

First, the aim of the project was to only create the opening mechanism, which means that all the other aspects of the CubeSat launch-pod and everything about the CubeSat itself were outside of the scope of this project.

Second, the use of copyrighted designs had to be avoided. While studying the existing mechanism and thinking of different ways of applying something similar to the final design was completely acceptable and even recommendable, using the designs already used by other companies was not.

Third, there can not be any extra space debris produced. This means that the door cannot be separated completely from the pod for example. While the pod itself may be considered space debris, it can still be safely tracked from earth and thus it will be known when it falls back to the atmosphere of earth.

Fourth, use of explosions is forbidden. While there are some methods that use explosions to open the door, this method is way too risky to use. Therefore, the mechanism was designed such a way that explosions were not necessary.

5. Project management

5.1 The European Project Semester

The European Project Semester (EPS), is a 15 weeks exchange program, whose objective is the development of students from the development of an industrial project for a company. This project pretends to be a real contact with the industry and make the students improve relevant skills such as teamwork or project management.

The team is integrated by multidisciplinary students. The participation of a teacher, tutors and an industry responsible is needed in order to correctly perform this project.

5.1.1 Who are we?

The team is assembled by 3 students from multidisciplinary aspects in the world of engineering studies; supervised by Mark Jenkins, Gordon Morison and María Insa Iglesias, tutors from the Caledonian Glasgow University.

The project is developed in collaboration with Responsive Access, a company dedicated to offer a simple access to space for anyone interested.

Figure 3 Team members

Joona Hovi	Óscar Serrano	Rodrigo Vicente
Industrial Management	Mechanical Engineer	Electronical Engineer
Metropolia University of Applied Sciences (Finland)	Universidad Politécnica de Cataluña (Spain)	Universitat Politècnica de València (Spain)

5.2 Project planning

Due to the project complexity, the work required to be organised using project management skills gathered during the course.

Following deliverables and milestones were identified in the project:

1. Tested prototype -> Develop a first prototype of the release mechanism and perform some tests to make it usable. This was the main deliverable and the final objective of the project. However, a process had to be followed and a set of secondary deliverables were given to the client too.
    a. Previous studies -> First of all, a preliminary research was performed. In this document, the market and already implemented mechanisms were analysed.

       A specifications document had also to be delivered as this document will include all the conditions the final deliverable must achieve.

       These documents were delivered during a meeting with the client on Wednesday 26th of February, marking the first milestone.

    b. Design mechanism -> Once the specifications document was approved by the client, the exploration of ideas for mechanism began. Initially, a final design had to be delivered to the client as part of the second milestone during the last week of March.
    c. Build the prototype -> With the design finished, building of the prototype would begin. The major part of the physical built of the prototype would be performed by outsourced entities.

       The prototype was supposed to be presented during the second week of April, being this the third milestone and the end of the prototype development part.

    d. Test result -> Once the final design and the physical prototype were done, they could be tested, both virtually and physically.

       The result of these tests would be delivered by the end of April, being the last step of the project.

Once the deliverables were identified a Work Breakdown Structure (WBS) of the project was developed. There, the workload was organised and split into small tasks easier to handle.

The WBS of this specific project may be seen in figure 4.

NOTE: *In the project management of the document, only the industrial aspect was considered. Thus, midterm and final reports as well as presentations don´t appear. Also, the project management plan has been performed following space industry standards provided by the client.*

Due to the special situation caused by the global outbreak of COVID-19, the dimensions of this project were restricted. The last two steps in the project management plan, prototyping and testing, had to be rejected as the lockdown situation made them impossible to do.

The lockdown had another huge consequence on the development of the project. When it started, the team was on the critical task of presenting the designs to the client to choose the final solution (A.4 in the logic network, figure 5). This meeting had to be delayed 3 weeks, and due to its critical condition, it supposed a 3-week delay to the whole project.

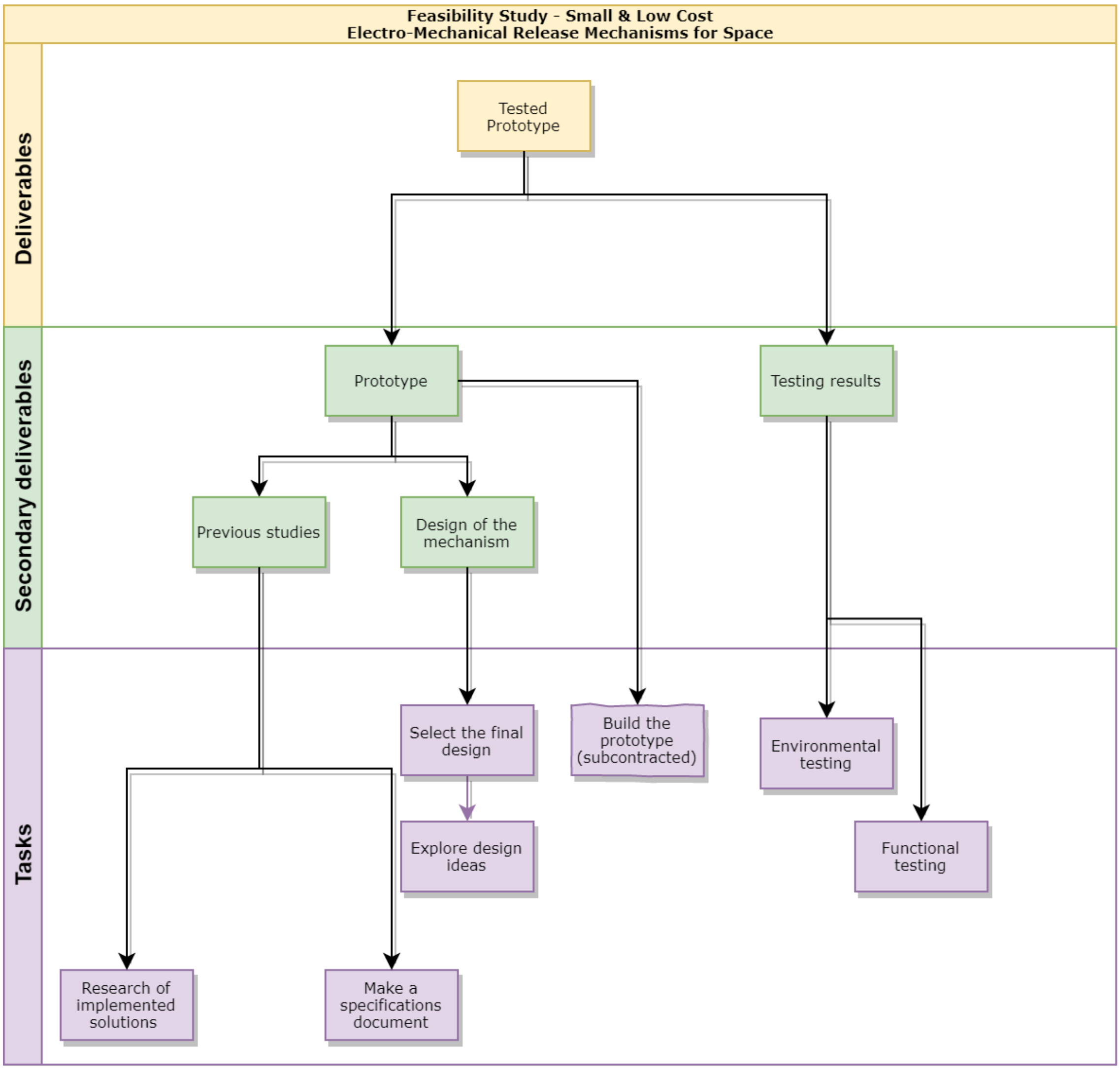


Figure 4 Initial Work Breakdown Structure (WBS) of the project

After their definition, the task were organised by making a logic network, figure 5, and a network diagram, figure 6.

The Gantt chart presented in figures 7 and 8 describe our initial working plan. However, after around mid-march the project group separated because of the corona crisis, which made the parts planned after that much more disorganised. The team also had to omit the creation of the prototype and testing from the plan, as previously explained.

Note that the gantt chart doesn't have reports and presentations and gives them only as milestones. That is because all of the writing work was done alongside the other work, meaning it did not have any set periods.

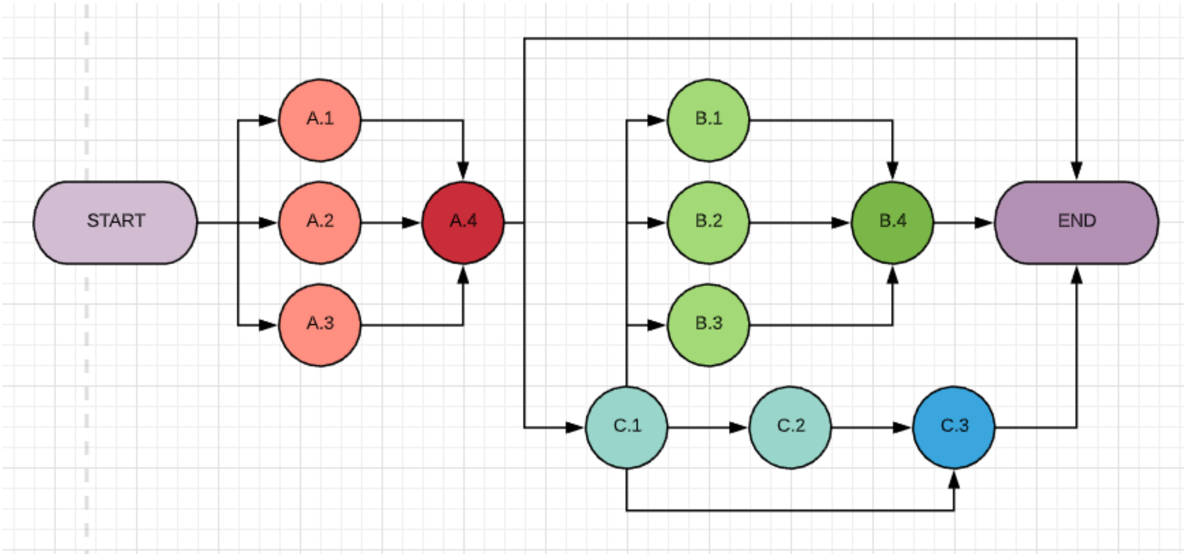


Figure 5 Project logic network

PROJECT'S TASK	TYPE	ID	DEPENDENCY Finish to Start	FIXED DURATION	FIXED WORK	RESOURCES	CAPACITY
RESEARCH	**Phase**	**A**					
Specifications Document	General task	A.1			22 hours	Rodrigo Vicente	100%
Design Document	General task	A.2			22 hours	Oscar Serrano	100%
Previous Studies Document	General task	A.3			22 hours	Joona Hovi	100%
Research Doc	Milestone	A.4	A.1,A.2,A.3	15 days		The 3 students	100%
TESTING	**Phase**	**B**					
Mechanical Tests	General Task	B.1	**C.1**		150 hours	Oscar Serrano	50%
Electronic Tests	General Task	B.2	**C.1**		150 hours	Rodrigo Vicente	100%
Envir. and Mat. Tests	General Task	B.3	**C.1**		150 hours	Oscar Serrano	50%
Testing Documentation	Milestone	B.4	B.1,B.2,B.3	3 days		2 students	100%
MANAGMENT	**Phase**	**C**					
Prototyping Organization	General Task	C.1	**A.4**	9 days		Subcontracted	100%
Project Management	General Task	C.2	**C.1**		100 hours	Joona Hovi	100%
Management Documentation	Milestone	C.3	C.1,C.2	10 days		Joona Hovi	100%

Figure 6 Network diagram of the project

Display Week: 1

TASK	ASSIGNED TO	START	END
Research			
Material reasearch	Joona	1.27.20	2.5.20
Old solution research	Oscar	1.27.20	2.5.20
Test and marketing research	Rodrigo	1.27.20	2.5.20
Planning			
Spacifications document	Oscar & Rodrigo	2.6.20	2.26.20
Mechanism design	Everyone	2.27.20	3.28.20
Building and testing			
Create prototype	Everyone	3.29.20	4.5.20
Test prototype	Everyone	4.6.20	4.7.20
Milestones			
Deliver specifications document	Everyone	2.26.20	2.26.20
Midterm presentation	Everyone	3.11.20	3.11.20
Present designs	Everyone	4.7.20	4.7.20
Final presentation	Everyone	5.8.20	5.8.20

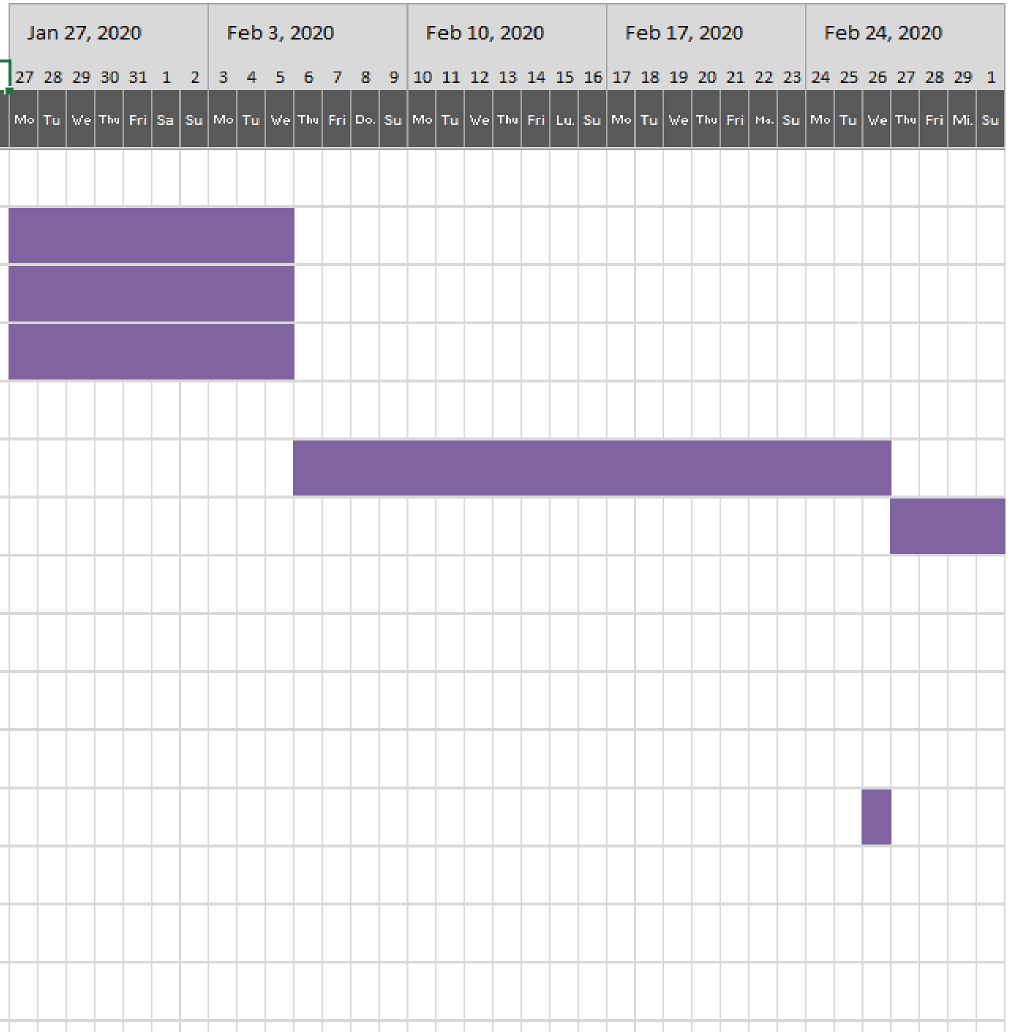


Figure 7 Gantt chart of the project (I)

Display Week: 5

TASK	ASSIGNED TO	START	END
Research			
Material reasearch	Joona	1.27.20	2.5.20
Old solution research	Oscar	1.27.20	2.5.20
Test and marketing research	Rodrigo	1.27.20	2.5.20
Planning			
Spacifications document	Oscar & Rodrigo	2.6.20	2.26.20
Mechanism design	Everyone	2.27.20	3.28.20
Building and testing			
Create prototype	Everyone	3.29.20	4.5.20
Test prototype	Everyone	4.6.20	4.7.20
Milestones			
Deliver specifications document	Everyone	2.26.20	2.26.20
Midterm presentation	Everyone	3.11.20	3.11.20
Present designs	Everyone	4.7.20	4.7.20
Final presentation	Everyone	5.8.20	5.8.20

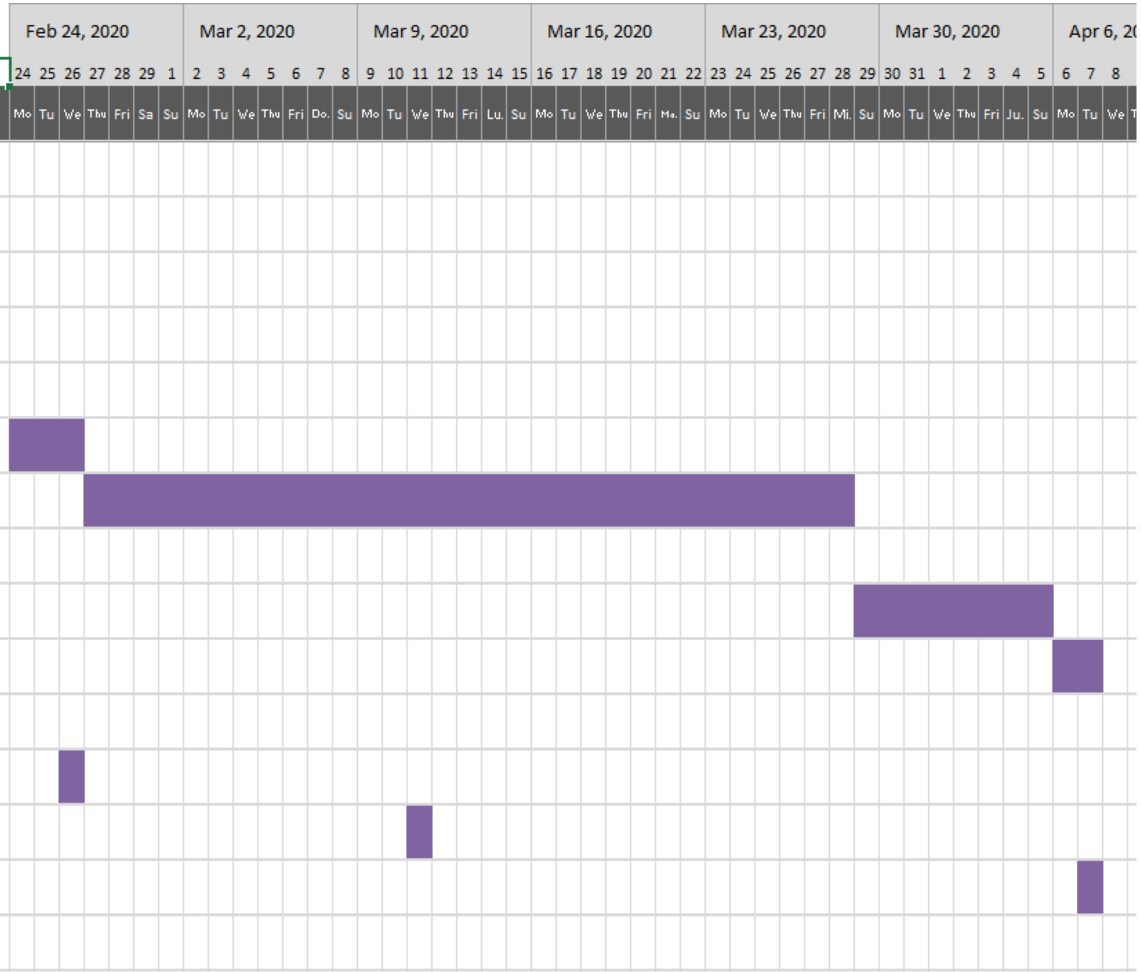


Figure 8 Gantt chart of the project (II)

6. Previous studies

The previous studies were divided in three sections: Designs Implemented, Specifications of the Product, and lastly, a Material Research.

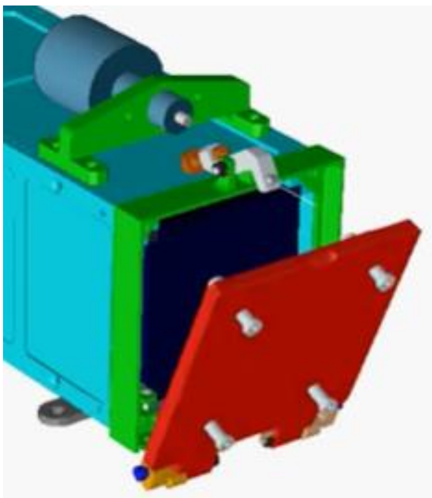
In order to develop a new mechanism, it was essential to first research what has already been done to properly understand the CubeSat industry.

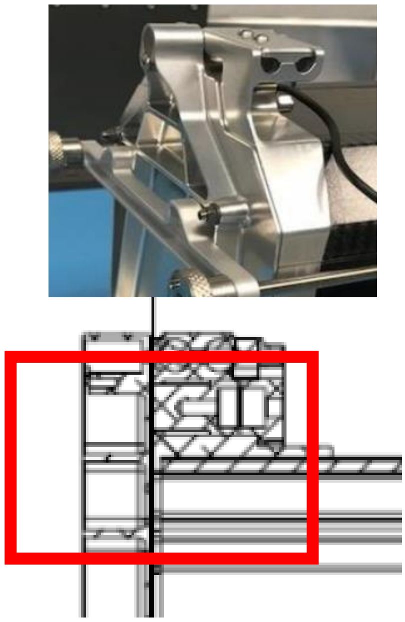
6.1 Release mechanism study

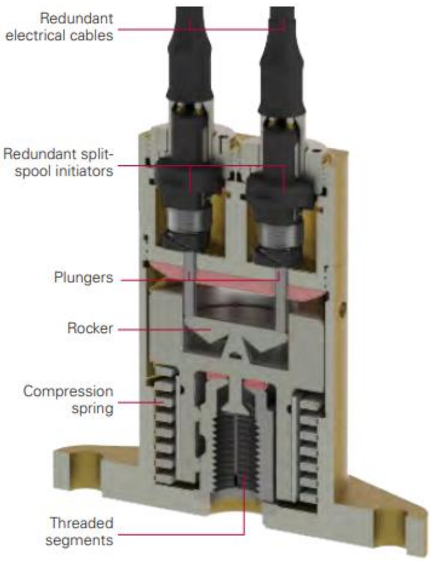
First of all, the team performed an extensive research of the models in the market, their performance and characteristics. The objective was to understand the trends in CubeSat deployers design and to look for margins of improvement.

The following table introduces a comparison of the most popular designs currently in use and some prototypes or ideas in development. It is impotant to remember that the cost of the mechanism is an important variable in the following study:

Table 1 Release mechanism comparison

	**Name: Magnetic Hook** **Description of the Mechanism:** A magnetic device assembled with a simple release mechanism with the shape of a hook that is used to close the door. **Price not stipulated**. **Advantages:** Once the magnetic field is removed, the device is automatically opened, and the actuation of explosives is no needed. It is a simple mechanism that works like the spit spool mechanism. **Disadvantages:** The door opens because of the presence of the inertia of the component, but as space is the working area, the mass of the component it is no considered, as a result, the device could fail.

	**Name: Magnetic Field Mechanism** **Description of the Mechanism:** Magnetic switch device controlled via the launch vehicle. Once the order of release is sent, the magnetic field is removed, and the door starts to open. **Price of the product 1 single unit, 15.000 usd.** **Advantages:** Once the magnetic field is removed, the device is automatically opened, and the actuation of explosives is no needed. Product already tested and used (**High reliability**). **Disadvantages:** The capacity to generate a magnetic field requires a lot of energy, so the compartment must be connected to the launch vehicle always.

	**Name: Split Spool Mechanism.** **Description of the Mechanism:** A small electronic device that uses the force of the magnetism to compact a cap that contain the main bolt that connects the hole device. **Price not stipulated**. **Advantages:** Small device, compact and resistant of high loads, such as 20 to 42,2 kN. Low power consumption and no presence of explosive devices. The theory of operation is explained in the catalogue of the company. **Disadvantages:** The necessity to be connected at the Launch vehicle, in order to receive the order in time. The mechanism could have a complex operation dude to the use of the magnetic fields, despite being explained in the catalogue.

Name: Torsion spring.

Description of the Mechanism: Mechanical mechanism composed by a single torsion spring. Simple and effective. **Price not stipulated**.

Advantages: Easy to be manufactured and high reliable.

Disadvantages: Despite being simple and illustrated as a release mechanism, is not a release mechanism. It could be used as a supplementary device to complete the opening of the gate.

Name: Pumpkin Panel Release Mechanism. PRM.

Description of the Mechanism: Aluminium housing that traps the burn wire against resistors that are connected in parallel. Used to release small panels.
Price not stipulated.

Advantages: Simple mechanism and easy to be manufactured and implemented. Could be perfectly extrapolated to accomplish with the release mechanism.

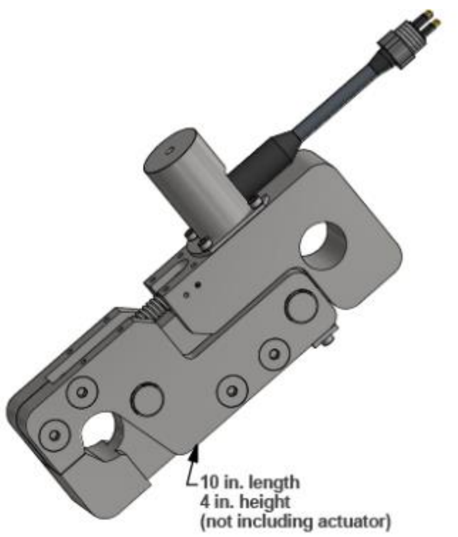
Disadvantages: It could be said that consist in a “explosive mechanism” because wire is burnt in order to start the release. Can´t be reusable (the wire must be changed after each use).

Name: U.S. Naval Research Laboratory Device.

Description of the Mechanism: A small device that uses a wire of nichrome. When the electricity flows through the wire, the temperature rises around the 900 K. Then the force of the compression springs opens the device. The price of production is around the 160 USD each one.

Advantages: Is simple and cheap.

Disadvantages: It could be said that consist in a “explosive mechanism” because wire is burnt in order to start the release. Can´t be reusable (the wire must be changed after each use).

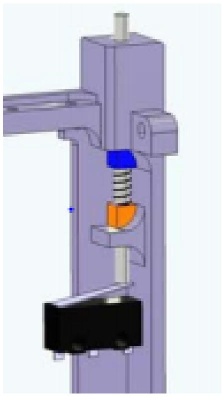


Name: CLAMP DEVICE.

Description of the Mechanism: Just like the clamp of a crab, this device is opened and closed the same way. **Price not stipulated**.

Advantages: Controlled via electronic device that must be connected to the Launch vehicle. The device can be installed vertical or horizontal. Is a simple mechanism with a capacity of 200 kN. Capacity of reusability.

Disadvantages: The device must be connected all the time with the launch vehicle in order to ensure that the order of opening is commanded. The rank of temperatures is between -4 and 60 ºC. The reusability must be done manually.

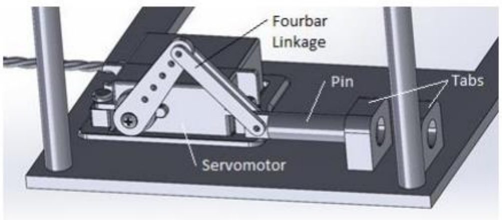


Name: Column Actuator.

Description of the Mechanism: A simple column Actuator. The presence of an electronic device controls the movement of the column that opens and closes as it is ordered. **Price not stipulated**.

Advantages: Controlled via electronic device that must be connected to the Launch vehicle. The device can be installed vertical or horizontal.

Disadvantages: The device must be connected all the time with the launch vehicle in order to ensure that the order of opening is commanded.

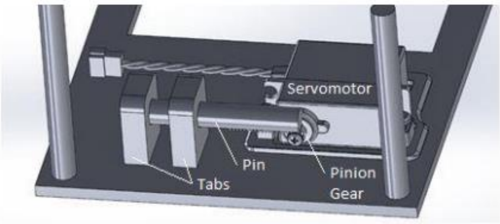


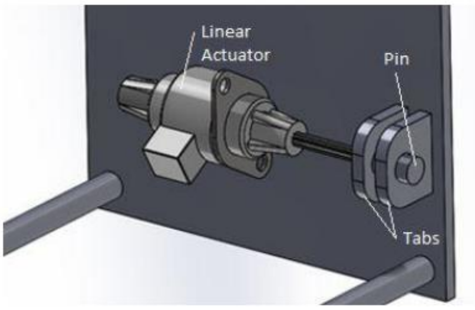
Name: Servomotor driven four bar pin-puller.

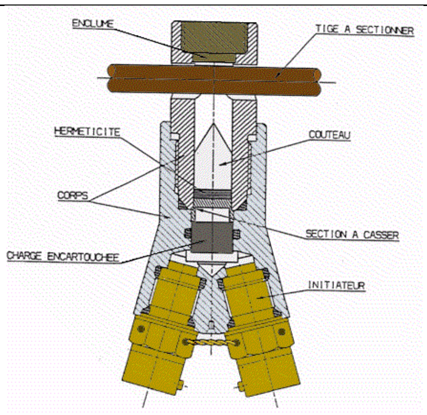
Description of the Mechanism: A servomotor that drives a pin in order to release the mechanism. **Price not stipulated**.

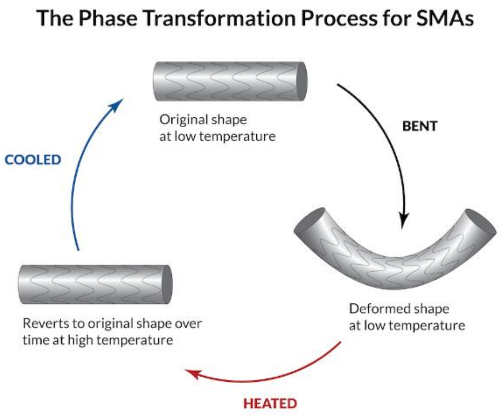
Advantages: Simple mechanism, could be tested perfectly and prototyped. The capacity to lock the door depends of the dimension of the pin.

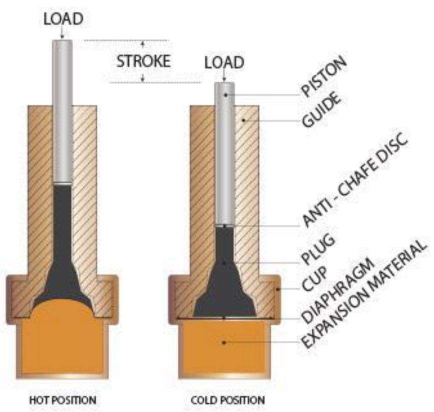
Disadvantages: The device must be connected all the time with the launch vehicle in order to ensure that the order of opening is commanded.

 	**Name: Servomotor pin – puller by a pinion gear actuator.** **Description of the Mechanism:** A servomotor that drives a pin in order to release the mechanism via a rack and pinion actuator. **Price not stipulated**. **Advantages:** Simple mechanism and more compact that the previous, could be tested perfectly and prototyped. The capacity to lock the door depends of the dimension of the pin. **Disadvantages:** The device must be connected all the time with the launch vehicle in order to ensure that the order of opening is commanded.

 	**Name: Linear actuator pin - puller.** **Description of the Mechanism:** A servomotor that drives a pin in order to release the mechanism via a linear actuator. **Price not stipulated**. **Advantages:** Simple mechanism and compact, could be tested perfectly and prototyped. The capacity to lock the door depends of the dimension of the pin. **Disadvantages:** The device must be connected all the time with the launch vehicle in order to ensure that the order of opening is commanded.

 	**Name: Pyrotechnic Cables and Bolt Cutters** **Description of the Mechanism:** A bolt is propelled towards a cable placed on an anvil. Once the bolt strikes, it will cut the cable. Releasing the deployable that the cable was securing. **Advantages:** They are quick, small and easy to use. **Disadvantages:** The explosion may generate internal forces that might create hazards for the payload. **Pyrotechnics are forbidden in this specific project**

 	**Name: Shape memory alloy (SMA)** **Description of the Mechanism:** A SMA is an alloy that "remembers" its original shape when it was formed and returns to it from its deformed state when heated. There are multiple actuators under development that exploit use of SMAs for release of the deployable. Some SMA mechanism ideas are: **Linear Actuators:** A hollow cylinder filled with a deformed SMA (usually in shape of a spring) is used, when heated the SMA expands and pushes a pin initiating the deployment. **Frangibolt:** The deployable is hold by a bolt inserted through an annular cylinder made of a SMA. Heating causes the SMA to expand and break the bolt, thus releasing the deployable. **Advantages:** These are small and usually have a quick release time. **Disadvantages:** They are still in development and lack testing. Also, some parts are difficult to manufacture, making them currently expensive. Finally, they might be susceptible to external rises of temperature causing unwanted deployments.

 	**Name: Paraffin release mechanism.** **Description of the Mechanism:** Paraffin wax has the property of expanding a lot with the increasing of heat. This mechanism uses that property to compress a cylindrical casing holding a pin. As the casing is compressed, it will eventually release the pin, triggering the deployment. **Advantages:** Release with reduced recoil. **Disadvantages:** Slow deployment. It might perform a spontaneous trigger if the temperature is too high.

6.2 Conclusion

Every mechanism must be connected to the Launch Vehicle in order to be operative. The team should take into account possible extra requirements derived from this condition.

Also, they often include torsion springs to get a higher reliability when opening the door. Inside the pod there is a spring pushing the CubeSats against the door too. Using a device to only keep the door closed and letting the operation of opening to the springs seems like the simplest way to get the job done. The team will try to follow this approach.

Finding a compatible design could be beneficial to get high reliability at a low cost.

Electromechanical and magnetic mechanisms are the most common ones. Magnetic ones, however, require more power to work.

Some small and efficient mechanisms are obtained by explosion or burn means. However, those ideas must be rejected, as they are not suitable for many clients.

7. Conditions document

This section introduces the list of specifications that the mechanism must achieve and are approved by the client.

This will allow a clear vision of what the mechanism must achieve and might be of help in finding some missing requirements or desires from the client.

CubeSats of only one module (1U) will be considered to explain each requirement. In case the device is used for CubeSats of other dimensions, some specifications might vary.

The final list of requirements after implementing client's feedback is the following:

7.1 General requirements

Table 2 Table of requirements: General requirements

CSGR 1.0.	The use of pyrotechnics is not permitted during the operation effectuated by the launcher.
CSGR 2.0.	During the Launch, Ejection and Operation, all parts shall remain attached to CubeSat. The launcher cannot harm the CubeSat.
CSGR 3.0.	Outgassing requirements. 1. Total mass loss TMS <1,0%. 2. Collected volatile condensable material CVCM <0,1%.
CSGR 4.0.	The exterior surfaces and internal mating surfaces of the launcher are alodined as per MIL-DTL-5541F Class 3 to provide corrosion resistance and grounding capability
CSGR 5.0.	The interior of the launcher is hard anodized as per MIL-A-63576 Rev. A with a Teflon coating, creating resiliency to cold welding and providing a smooth, slick surface on which the CubeSats ride during deployment.
CSGR 6.0.	The launcher door should be designed to open a minimum of 110 degrees and a maximum of 220 degrees, measured from its closed position. The door opening angle can be restricted to the desired position with an optional door stopper.
CSGR 7.0.	The release mechanism shall not generate debris.
CSGR 8.0.	The release mechanism may not exceed its allocated mass of 700 grams. Ideal proportion around the 100 and 200 g.
CSGR 9.0.	No material shall be used that can undergo a phase change in the launch or on-orbit environment.
CSGR 10.0.	Factors of safety to be used are 2.0 for mechanical tests.
CSGR 11.0.	The mechanism shall have a fundamental frequency above 100 Hz.
CSGR 12.0.	Composite materials shall not be used for the primary structure if the condition of outgassing is not accomplished.
CSGR 13.0.	Epoxies, adhesives, or tape shall not be used to join structural components if the outgassing condition is not accomplished.

7.2 Mechanical requirements

Specific requirements for the CubeSat release mechanism have not been found, but the CubeSat has some specifications of mechanical design that must be completed.

In addition, information about the performance of the test will be explained after, if in some point appears the need for doing them.

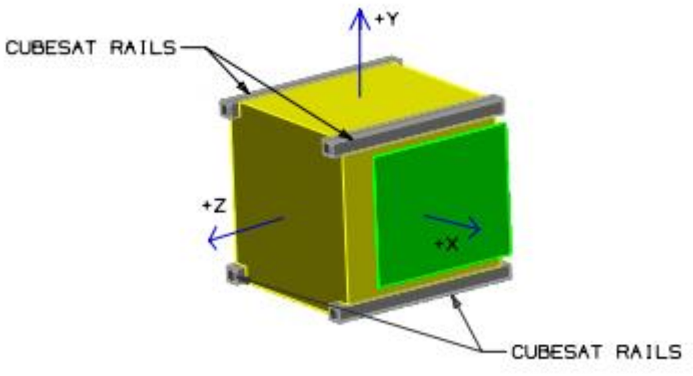


Figure 9 CubeSat placement in the launcher

Table 3 Table of requirements: Mechanical requirements

CSMR 1.0.	The –Z face of the CubeSat will be inserted first into the launch vehicle.
CSMR 2.0.	Deployables shall be constrained by the CubeSat, not the launch vehicle.
CSMR 3.0.	The actuators must survive a thermal range of $-25°C \leq T \leq 110°C$ and operate at a range of $0°C \leq T \leq 110°C$.
CSMR 4.0.	The 1U, 1.5U, and 2U CubeSats shall use separation springs to ensure adequate separation.

7.3 Test requirements

All devices must survive qualification testing as outlined in the **Mission Test Plan (MTP)** for their specific launch, so testing must be performed to meet all launch provider requirements as well as any additional testing requirements deemed necessary to ensure the safety of the CubeSats and the launcher.

All flight hardware will undergo a qualification and acceptance testing. The launchers will be tested in a similar fashion to ensure the safety and workmanship before integration with CubeSats. At the very minimum, all CubeSats and their deployers will undergo the tests presented in figure 10.

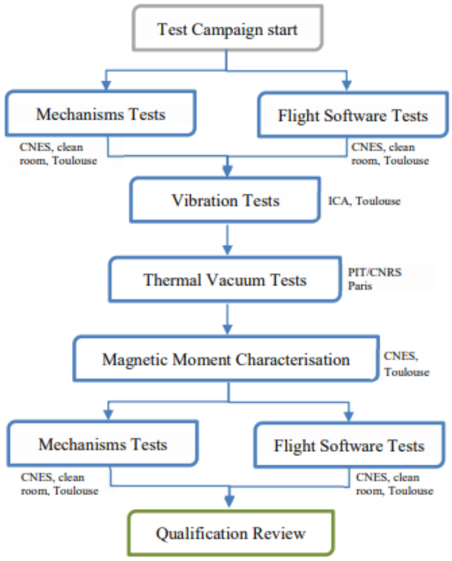


Figure 10 Testing Structure diagram

NOTE: *All the specifications as well as the acceptance levels must be provided by the Mission Test Plan, a document designed in order to sum up all the information from the environment and the situation the device will be working on. However, a more detailed description of the tests will be found in the section 11 of this document.*

The Random vibration test will be performed following indications on table 4:

Table 4 Table of random vibration test specifications

Frequency (Hz)	Acceleration Spectral Density (ASD) Level (G^2/Hz)
20	0.026
20-50	+6 dB/oct
50-800	0.16
800-2000	-6 dB/oct
2000	0.026
Overall	14.1 G_{rms}
Note: Random Vibration test duration is two minutes in each of the three orthogonal axes.	

7.4 Electronical requirements

Apart from the mechanical and structural requirements. The release mechanism shall present the following electrical requirements.

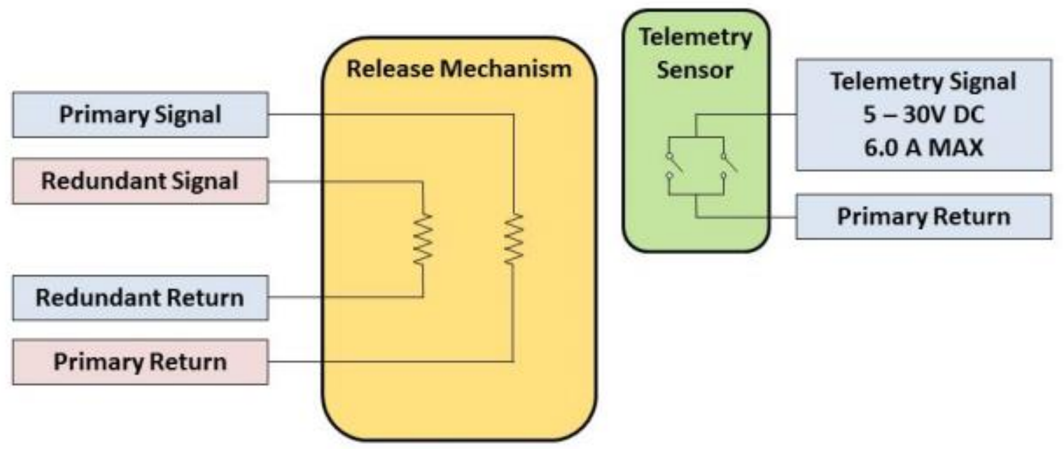


Figure 11 Electronical Structure of the mechanism

Table 5 Table of requirements: Electronical requirements

CSER 1.0.	The mechanism shall include a status sensor
CSER 2.0.	The mechanism shall present a redundancy launching signal.
CSER 3.0.	The Mechanism shall use 6 electrical pins. 4 of them will be used in the launching signal and 2 in the sensor.
CSER 4.0.	The mechanism shall be grounded to the Launch Vehicle
CSER 5.0.	The activation signal shall come from the Launch Vehicle with nominal current of 4A and a minimum duration of 100ms
CSER 6.0.	The internal resistance of the mechanism shall be in the interval between 0.8Ω and 1.9Ω
CSER 7.0.	Non.fire current maximum shall be 200 mA for 5 minutes
CSER 8.0.	The status sensor shall be shortcircuited in steady state. Opening the circuit at the same time the door is opened.
CSER 9.0.	The status sensor shallwork with a voltage range between 5VDC and 30VDC
CSER 10.0.	The satus sensor shall work with a maximum current of 6A
CSER 11.0.	All the components shall be tested and work properly in high radiation conditions. **This condition can be ignored because of the redundant electronical structure.**

8. Materials study

This study is based on the investigation of the materials implemented in the spacecraft industry.

This research makes it easier to identify what materials should be considered in building a release mechanism for a CubeSat, and what materials should be completely ignored.

Some graphs will be annexed in order to understand the importance of every requirement that has been selected from this point. For more details, consult annex 2.

8.1 Primordial properties of the materials

Table 6 Selection requirements for materials

General Requirements	Cost, Density
Mechanical Requirement	Elastic Module, Strength Module
Thermal Requirement	Thermal Shock and Thermal Conductivity
Corrosion Requirement	Corrosion rate

A lot of aspects must be considered in order to select a material.

These are some of the main aspects that must be considered for a project like this one:

1. **Low weight -** Each extra kilogram of mass supposes a huge increasement in launchment costs. Therefore, the weight of the device should be as low as possible.
2. **Cheap -** Since CubeSats and their launch equipment cannot be recovered from the space, the materials should be as cheap as possible without compromising the reliability of the release mechanism.
3. **Resistant to temperature changes -** The materials should be able to resist temperature changes at least to some degree, as the temperature at space near earth can alternate between as low as -100 celsius to as high as 120 celsius.
4. **Low outgassing -** Outgassing, which means release of gas trapped within (solid) material, happens to every material in the vacuum of the space and it results in material condensation and/or weight loss in the material, so high outgassing is not acceptable. Material that has TML (total mass loss) of under 1,0% and CVCM (Collected Volatile Condensable Material) could be considered having a low outgassing.
5. **Force resistance -** The materials have to be able to resist approximately 14 g of g-force.

8.2 The spacecraft industry materials

There is a huge variety of materials used in spacecraft construction and many of them fill different purposes in building a functioning spacecraft. However, we have to keep in mind that since we are designing a launch mechanism, we may not need materials that keep the underlying parts protected for extended time, because the mechanism fills its purpose as soon as it gets into the right position. After that it is completely discarded.

According to several sources, one of the most basic materials used in any kind of spacecraft is **aluminium**. That is because of aluminium is light weight and considerable durability. However, aluminium by itself is not durable enough to withstand needed forces most of the time and it has to be mixed with other metals into an alloy. Aluminium is most commonly mixed with lithium or titanium and NASA often produces several mechanical parts from it.

Aluminium-lithium alloy is good for parts that require damage and fatigue resistance, but it tends to be relatively expensive. On the other hand, it is lighter than normal aluminium.

Titanium, while more durable and heat resistant than aluminium is heavier and more expensive. Aluminium is also easier to work with. Titanium and its alloys are usually used more in structures that are under severe stress, where they exceptional characteristics are required.

As for the electronic materials, **oxygen-free copper** is the best solution for wiring for its reliability and high conductivity.

NASA has been testing the usage of 3D printed plastic parts in a rover with a plastic called **RXF1,** which is more durable than aluminium. However, this kind of new synthetic materials are out of our reach for this project, as we don´t have the resources and reducing costs is one of the main focuses for the project.

Ceramics are mainly used for protection and heat resistance, so they are not relevant for designing the mechanism itself.

Having considered every alternative, the materials used in the device will be metals. Here is a list of the most common metals used in spacecraft industry.

- **Aluminium:** Mainly used for structural applications, resistant to generate corrosion pitting intergranular corrosion and stress corrosion cracking. The 5000 series must not be used.
- **Steel:** Used in operations of drilling, machining of steels, low stress machining techniques with coolant. The martensitic structure is the most common, but the use of austenitic steels for corrosion applications is common (not usable under 371 º C).
- **Titanium:** The surface of titanium and alloys of titanium must be 100% machined and chemically milled in order to remove all contaminated zones and layers. Must not be used with GOX or LOX at any partial pressure above 35 MPa. **Titanium alloys must not be machined inside spacecraft modules.**
- **Magnesium:** Magnesium alloys shall not be used in primary structure or in other areas of spaceflight hardware. Magnesium alloys shall not be machined inside spacecraft modules.
- **Beryllium:** Exceptionally lightweight alloys, but not used because of extreme toxicity. The >4% mass beryllium shall not be used in primary structural applications. Unless suitably protected to prevent erosion or formation of salts or oxides.
- **Cadmium:** Hight toxicity, can sublime and cause outgassing contamination at elevated temperatures in vacuum. **Not usable in vacuum environments.**
- **Zinc:** Metallic zinc is less volatile than cadmium but should be used in vacuum environments. **Can cause contamination of optical surfaces or electrical devices.**

8.3 Material requirements

There are some requirements that must be followed in order to correctly select the materials.

The general requirements are a selection of norms that must be completed in order to start the manufacturing of the components.

- Each company is responsible of the design and fabrication of spaceflight hardware. The company shall provide Materials and Process selection, Control and Implementation Plan.
- Materials and Process selection, Control and Implementation Plan shall describe the methods as well used to control compliance with the subcontractors.
- Materials and Process selection, Control and Implementation Plan shall become the MP implementation document used for verification.

For the design values of the product, the information about the materials must accomplish the normative too.

- All the data related to the material properties must be statistical values offered by the hardware simulator.
- Other mechanical properties related to the design of the component, must be provided by the simulator to during the design process.

Finally, the outgassing requirements are related to these norms.

- Flammability test in materials used in sealed containers are exempt because of insufficient oxygen.
- Offgassing test in materials used in sealed containers shall meet requirements of TEST 7 NASA STD – 60001B. (<1,0% Collected Volatile Condensable Material).

9. Design study

This section introduces the designing of the solution proposed, which corresponds to the second phase of the project after the previous studies.

At the beginning the team came up with some ideas and started developing them. However, after the midterms, the team realised the amount of designs was not enough and it was decided to take a step back and start this phase from scratch.

The first phase of the design study consisted on a brainstorm, with the objective of gathering a reasonable number of concepts. Secondly, potential solutions were organised and analysed, so they could be discussed and selected. The third phase was the process of selection. There was a meeting gathering the team, their tutors and the client. During the meeting every potential solution was discussed, and the final candidates were chosen. The last phase was implementing feedback and redesign final solutions to get the best version of them.

9.1 Brainstorming study

Following our tutors' feedback and what was learned during Design Thinking lessons, the team followed a process of ideation performing a brainstorm. That was found to be the best way to come up with ideas and understand the necessities of the company.

The main objectives of this phase were:

- **Ideas expansion:** Find more ideas that might work as potential solutions and perform a wider approach to the design phase.
- **Design inspiration:** By sharing and comparing ideas, new and better concepts were born.

9.2 Potential solutions

After the brainstorm, the team had gathered a considerable amount of concepts. This subsection presents every potential solution developed by the team. Each one is presented with:

- A general description of the devices and its functioning.
- A 3D CAD model of the Mechanism and another 3D model of the mechanisms but attached to the CubeSat structure in order to understand the operation of the device.
- Advantages and potential weaknesses that the device might present.
- Margin of improvement of the design.
- Conclusions for each mechanism.

9.2.1 Electromechanic hook

1. **Name:** Electromechanic Hook.
2. **Description of the device:** This device is based on a L-shaped structure that locks the CubeSat door in order to keep the gates closed. When the order to open is fired, this mechanism rotates in the axis which frees the door and induce the opening.
   At the beginning of the concept, an alternative application was considered. The idea was to lift the whole door avoiding torsion springs. However, it requires more power and it might several problems if not fast enough, so it was discarded.
3. **3D Model and CubeSat structure:**

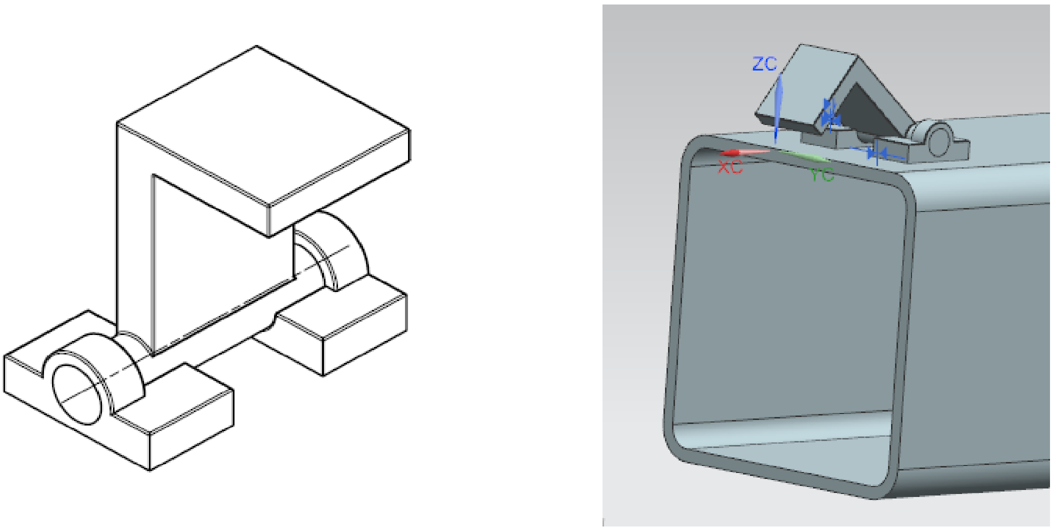


Figure 12 Electromechanical hook

4. **Advantages and disadvantages:** We must not work in lifting the door, because is the spring inside the pod already performs the release of the structure. The option of lifting the door is excluded.
   Despite this fact, the idea of the lock is interesting, but the use of a servomotor could be a disadvantage, because we would need a lot of power and the mass might be too high.
5. **Perspectives of improvement:** Our perspectives of improvement can be related in the use of a simpler way to release the mechanism. The lock is probably a good way to re-establish the design.
6. **Final conclusions:** Despite being a good choice, we are supposed to accomplish the total weight of the device, the servomotor could be heavy for the requirements of power; and in addition, the requirements of the servomotor could not be suitable in our situation of work, the space.

9.2.2 Clamp device

1. **Name:** Clamp Device.

2. **Description of the device:** This device is based on a rack and gear attached to a structure of a clamp. The operation of this device is easy because as it goes forwards it opens and if it goes backwards it closes.

3. **3D Model and CubeSat structure:** 2 versions of the device, first version and the updated version.

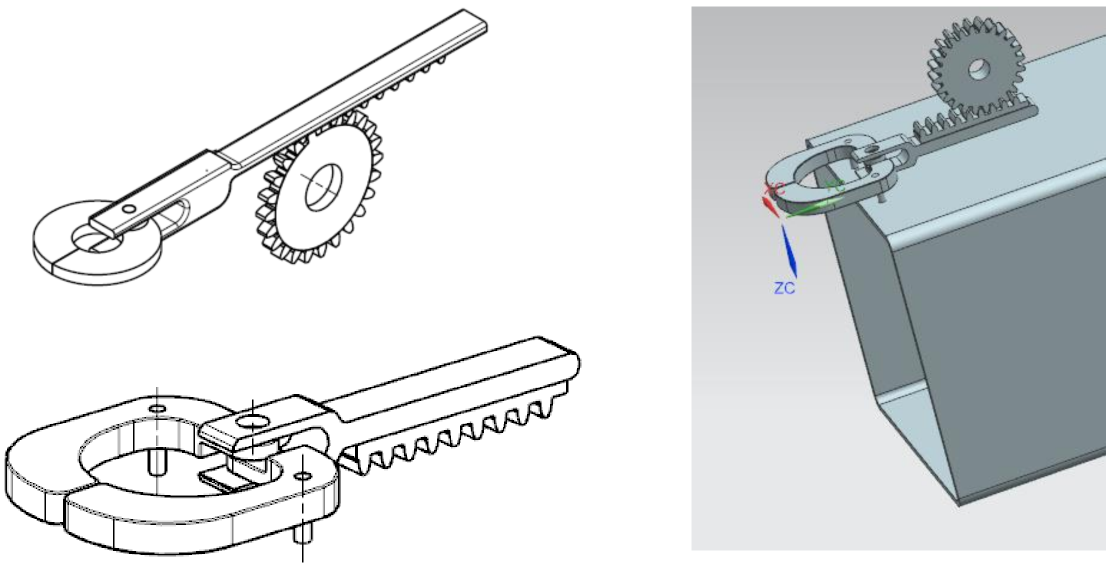


Figure 13 Clamp device

4. **Advantages and disadvantages:** The operation is simple, so the capacity to lock the door is reliable. But the use of a gear is needed to properly move the clamp. In addition, the use of a servomotor is needed, and could be seen it as a disadvantage. The mechanism might have too many parts resulting in overweight.

5. **Perspectives of improvement:** The device could need a higher improvement in the dimensions and maybe the design of the components, but everything referred to the reliability and performance of the device is good.

   A possible improvement of the device is changing the concept of the device, by making the gear and rack mechanism a lineal actuator, this could be good in order to simplify the structure and the operation of the mechanism.

6. **Final conclusions:** Despite being a good choice, the high complexity of the element, the combination of the rack and gear, makes the device less interesting to apply, the use of a lineal actuator in order to avoid the use of rack and gear could be seen as an improvement.

9.2.3 Magnetic hook

1. **Name:** Magnetic Hook.

2. **Description of the device:** The use of a quadrilateral cover, with 4 hooks in the middle of each side will keep the door closed until the moment we turn on 4 magnets that will pull the hooks. That will release the door, letting the spring launching it with the CubeSats.

3. **3D Model:**

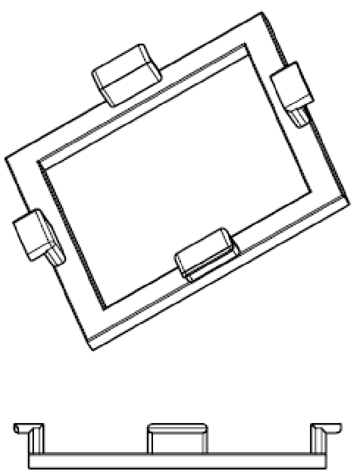


Figure 14 Magnetic hook

4. **Advantages and disadvantages:** This idea was based on the concept of releasing the whole door, therefore torsions springs would not be needed. The approach was cheap, simple and reliable.

   However, it was discovered that it is highly advised to avoid the increase of free objects in space. After that the idea was discarded.

   The use of magnets seems like a good idea.

5. **Perspectives of improvement:** This idea is not currently approved by the team as previously explained.

6. **Final conclusions:** The use of magnets and hooks must be seen as an opportunity to expand our designs, but this concept must be discarded.

9.2.4 Rolling wire

1. **Name:** Rolling Wire.
2. **Description of the device:** The rolling wire device is simply a wire rolled in an axis that will keep the gate close. This device will keep attached outside or inside the main structure and locked in order not to roll and open the gates of the mechanism.

   The point of this device is that will be the measure to keep the door closed, once we free the mechanism, the doors will open, and the wire will unroll.
3. **3D Model and CubeSat structure:**

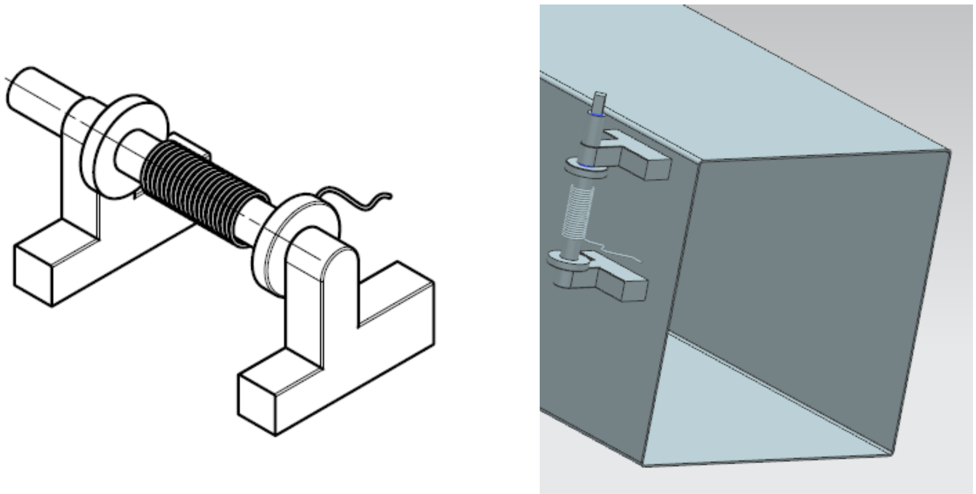


Figure 15 Rolling wire

4. **Advantages and disadvantages:** Despite being complex to explain, the mechanism is easy and can be applied perfectly. The structure will stay attached to the main structure, that will not interfere with the devices that will be inside the structure.
5. **Perspectives of improvement:** A change in the design of the element to a plainer structure will be good in order to earn space and do not unbalance the weight of the hole mechanism.
6. **Final conclusions:** The current situation of the device could be a bit complex to explain and implement, but if we manage to make changes in the design, this idea could be seen as a potential solution.

9.2.5 Magnetic lock

1. **Name:** Magnetic Hook.

2. **Description of the device:** The magnetic lock is based on a simple symmetric structure of 2 L shape pins and a block with the shape of a T that will remain together until we activate a magnetic field. Once this magnetic field is activated, the L pins will remove from the main T structure and the door will be free to be opened. Simple and effective.

3. **3D Model and CubeSat structure:**

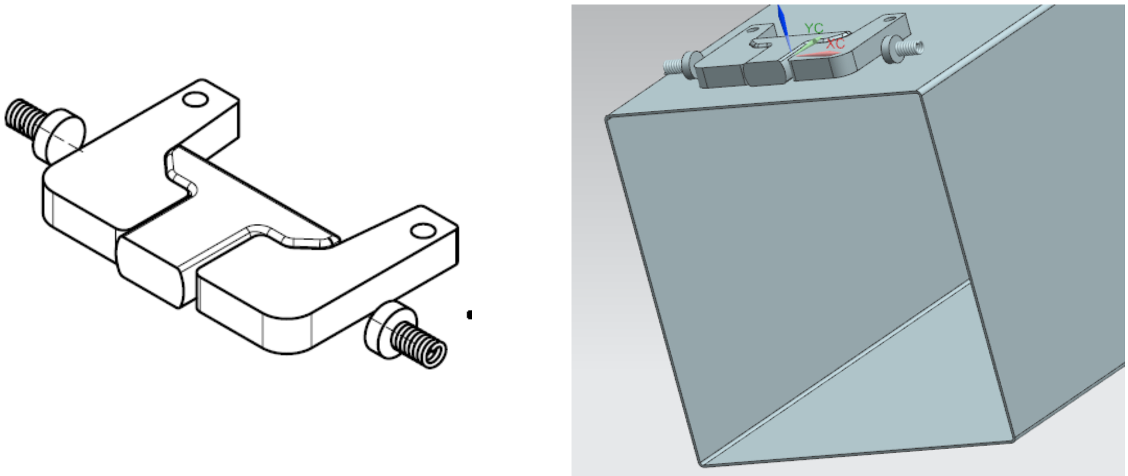


Figure 16 Magnetic lock

4. **Advantages and disadvantages:** The use of 2 magnets could be useful in order to open the mechanisms, and the pins will stay attached to the main structure with the use of springs. The simplicity of the mechanism is the best of this device.

5. **Perspectives of improvement:** The study of the magnetic field and the materials that could be used in the mechanisms in order to perform a better operation. Some materials are more suitable for magnetic applications than others.

   Also, looking for ways to increase the reliability are recommended. As with this design both electromagnets must work properly.

6. **Final conclusions:** This mechanism looks promising. As it is simple while using some of the strengths of the previous designs.

9.2.6 Quadrilateral

1. **Name:** Quadrilateral.

2. **Description of the device:** The quadrilateral is a version of the electromagnetic lock seen previously. The principal difference between this mechanism is that instead of holding the top of the door, this mechanism pretends to grab the whole door and lifted.

3. **3D Model and CubeSat structure:**

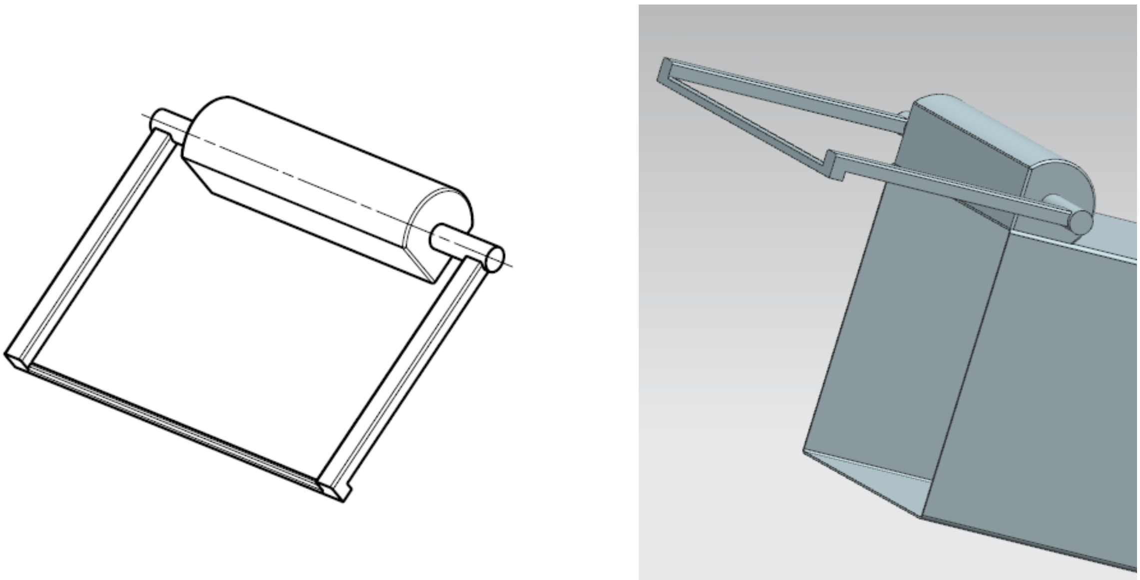


Figure 17 Quadrilateral

4. **Advantages and disadvantages:** Practically the same cons and pros of the electromagnetic lock. The use of a servomotor is complex due to the power necessary to hold the hole door, and the requirements of the servomotor could not be adequate for space applications. In addition, holding the hole door and lifted is more complex and the specifications of the client says that we must not lift the door.

5. **Perspectives of improvement:** Still found a way to implement an idea that does not require a servomotor or equivalent to make the device operative.

6. **Final conclusions:** Another approximation of the electromagnetic hook but holding the whole door and not lifting it in order to make a better performance.

9.2.7 Supplementary mechanism

1. **Name:** Supplementary Mechanism.

2. **Description of the device:** The supplementary mechanism is as its name says, some help for other mechanisms in order to open the door but can be used as an individual mechanism is enough force is applied. It could be used on its own with a similar functioning than the rolling wire.

   The device consists of two linear pieces attached to an axis. One of them is attached to the door while the other is operated through an electromotor.

3. **3D Model and CubeSat structure:**

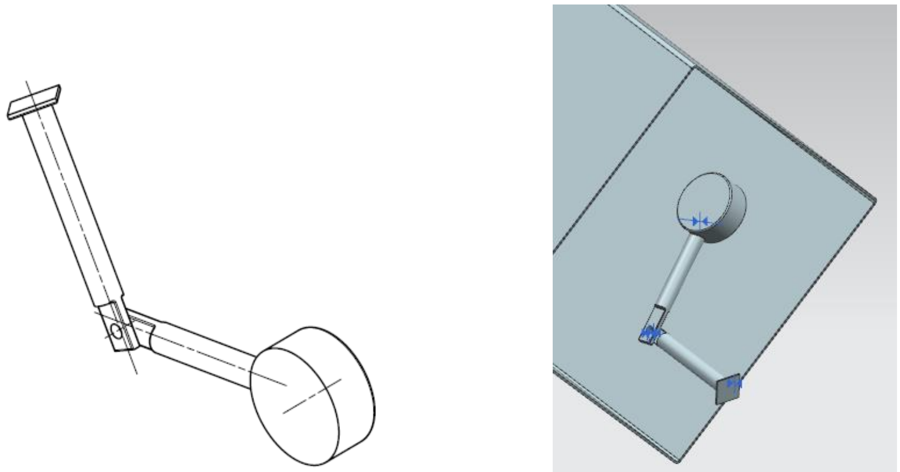


Figure 18 Supplementary mechanism

4. **Advantages and disadvantages:** The force necessary in order to open the door could be high, so this idea could be said as a non-applicable idea because of this disadvantage. This idea comes from the already implemented mechanisms used in shelves to open their doors.

   The use as an auxiliary device for opening is overperformed by torsion springs. On the other hand.

5. **Perspectives of improvement:** Non-applicable idea. This idea is not currently approved by the team because is highly complex to perform and the existence of other similar solutions with netter characteristics (such as the rolling wire).

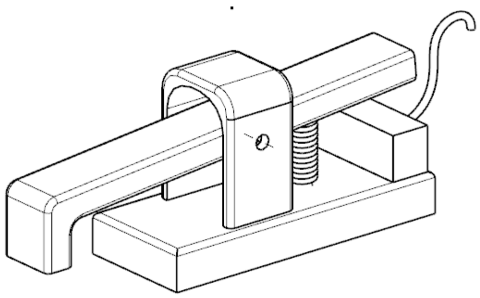
6. **Final conclusions:** The application of this device as a supplementary help is not useful in our situation, more designs and ideas must be developed.

9.2.8 Magnetic beam

1. **Name:** Magnetic Beam.
2. **Description of the device:** This mechanism was born taking the best characteristics of the magnetic and the magnetic hooks. It is based on a simple structure based on 3 elements. A magnet in the back side, a spring in the middle side and a L shape structure that is the responsible of keeping the gates closed.

   The spring will ensure that the hook is pushing the door with enough strength to keep it closed. Once the activation signal is received the electromagnet is turned on and attracts the hook, which opens the door.

3. **3D Model and CubeSat structure:**



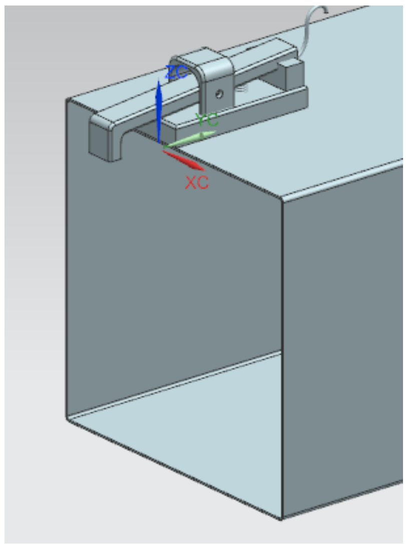


Figure 19 Magnetic beam

4. **Advantages and disadvantages:** The simplicity of the mechanism is the best point, and as the opening of the mechanism relies on the force of the magnet, the reliability of the mechanisms will rely on the power of the field. The only problems that could be related to the mechanisms could be the power of attraction of the magnet and the materials of use, as the materials react differently to the magnetic fields.
5. **Perspectives of improvement:** Possible modification of the spring position and the magnet format. Possible changes in the L shape structure of the device.

   With some of those changes the objective would be to achieve some sort of redundancy to improve reliability.

6. **Final conclusions:** The application of this device or similar is a possible adaptation of the electromagnetic hook seen previously, the reliability of the device is based on the power of the magnet and the behaviour of the spring and the interaction of the different materials with the magnetic fields.

9.2.9 Rotary latches

1. **Name:** Rotary Latches.

2. **Description of the device:** This mechanism is based on a simple structure based on a rotary latching.

   We have two types of rotary latches, single stage and doble stage. The functioning of both is similar and simple. The latch has two steady states: open and closed. Before launchment the latch would be closed manually retaining the door. When the deployment signal is fired, the latch will be opened by the linear actuator, opening the door.

   The mechanism will be attached in the top of the structure, with the help of a lineal actuator and the mechanism will be kept closed until new orders.

3. **2D representation and 3D MODEL:**

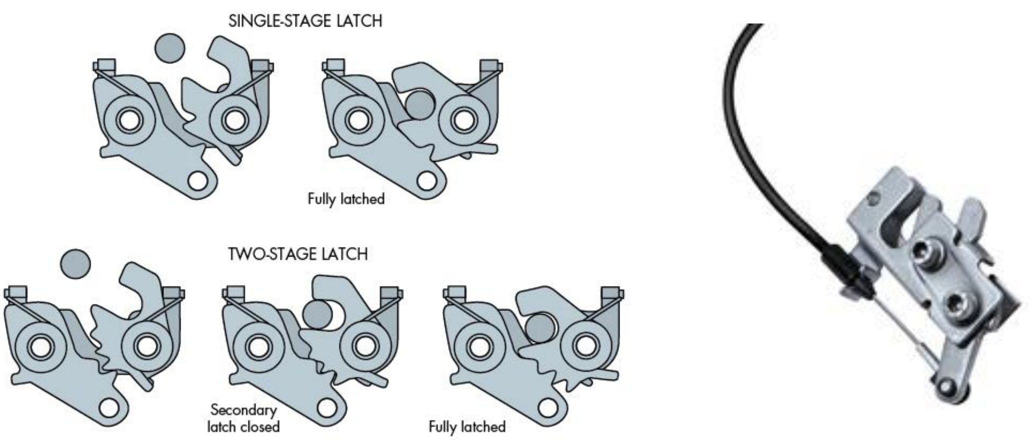


Figure 20 Rotary latches

4. **Advantages and disadvantages:** The simplicity of the mechanism is the best point, and as the opening of the mechanism relies on the use of a lineal actuator. The best point is that as far as is a normalized component, this can be bought by the company.

5. **Perspectives of improvement:** We can work in our own design in order to stablish modifications in the design such as the incorporation of the lineal actuator.

   Another possible improvement would be a way of operating latches with more reliability.

6. **Final conclusions:** Simple and cheap to make component. The mechanism is based on a known structure and can be implemented easily in our current situation with few improvements.

9.3 Feedback

The team presented the potential solutions to the client and the tutors. In general, a magnetic approach was discussed to have more potential than an electromechanical one. Every potential solution was discussed.

In the following table the comments and decisions about the potential solutions will be presented:

Table 7 Table of mechanism developement discussion

NAME	COMMENTARY	FUTURE DEVELPOMENT
Electro mechanic hook	Although a good idea, a magnetic equivalent could perform better as the motor might have problems to hold the door.	**Not worth developing further**
Clamp device	The moving parts can be a disadvantage in order to release the structure and has no capacity for a redundant mechanism of release.	**Not worth developing further**
Quadrilateral	It might have problems to hold the whole door. A different approach could be interesting but there are lots of constraints that may appear from moving the door out of the way.	**Not worth developing further**
Rolling wire	It was discussed the maximum force it could support against the supplementary mechanism	**Not worth developing further**
Supplementary mechanism	It was discussed the maximum force it could support against the rolling wire.	**Not worth developing further**
Magnetic beam	Shock might be a problem with this design, could accidentally open during the launch. If we manage to isolate the mechanism from hits and other environmental shocks, the device could be a good idea.	**If modified, could be developed further.**
Magnetic lock	Looks like a good concept. Similar approximations have been implemented in several dispensers. A great improvement would be to make it work even if only one of the magnets works. Other redundant mechanisms, such as a linear actuator could be beneficious.	**Should be developed further.**
Rotary latches	The device looks promising as it may fix problems of the clamp device. However, it may have problems to introduce redundancy solutions.	**Could be developed further.**

Finally, 3 concepts were chosen to keep developing: the magnetic lock, the magnetic beam and the rotary latches.

For each design, there are some aspects that were pointed out as potential weaknesses and should be solved, or at least reduced.

In the case of the magnetic beam, the most important improvement is the capacity to isolate the components in order to avoid a possible release of the mechanism caused by the contact between the elements. Also, the shock produced by the activation of the device might harm some components or cause issues to the mission. A way to reduce the consequences of the shock is highly recommended.

For the magnetic lock, the modifications are related to the capacity to add a redundant mechanism that will act as a secondary release mechanism if the primal one fails. The capacity to make it work even if one of the magnets fails would be beneficious too.

Lastly, rotary latches lack a redundancy or alternative actuations. Finding a way to improve reliability and install some sort of redundancy should be the objective of improvement.

9.4 Final designs

This subsection introduces the modifications applied to every selected design in order to apply the feedback received and improved the devices.

For each device, it has been made a 3D plot in order to explain the improvements implemented.

9.4.1 Magnetic beam

In this case, the improvements are related to the capacity to isolate the components and reduce the shock from the activation of the device.

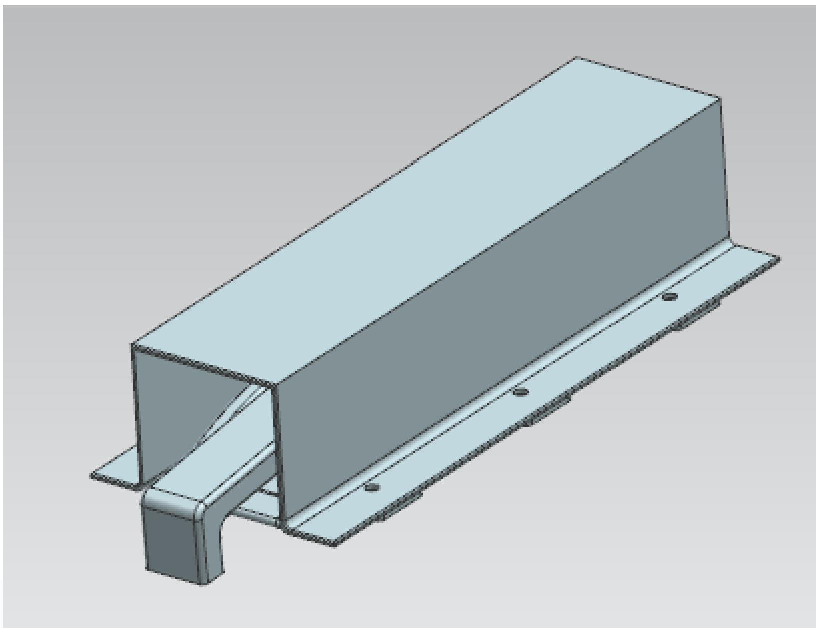


Figure 21 3D Model 1 - Magnetic beam design with cube shaped structure covering the mechanism

In order to avoid possible hits of the mechanism with other components of the deployer vehicle, we added a structure covering the mechanism. This structure is based on a cube shape that covers all the device.

The structure of the device has changed too:

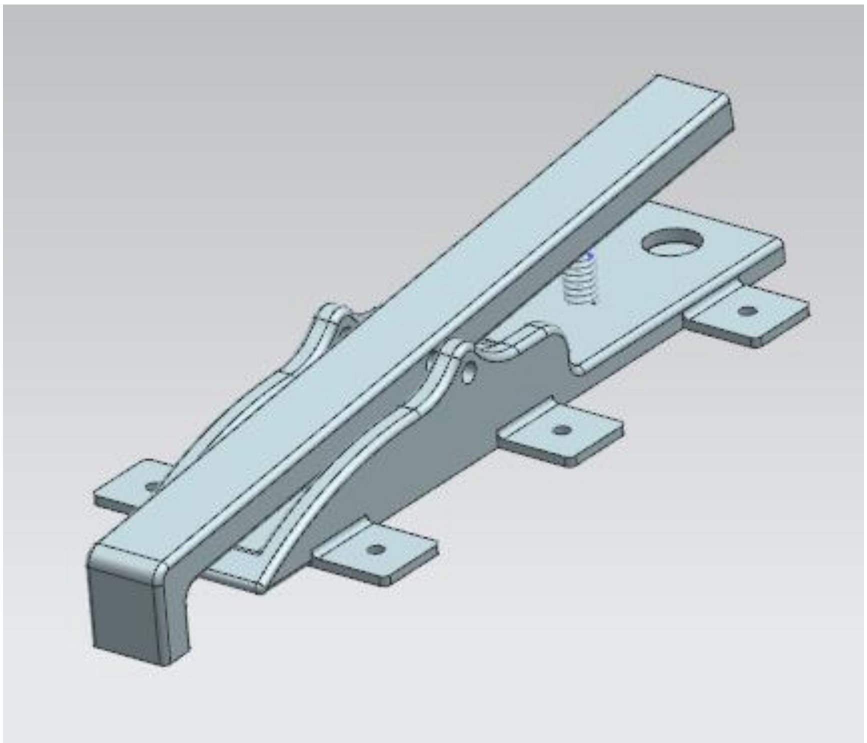


Figure 22 3D Model 2 - Magnetic beam design display of the underneath mechanism

In order to reduce the impact from the activation, the team found the solution of aplying a layer of foam in the zone impact. The task of this layer is to receive the impact and reduce the impulse eliminating risks produced by the shock.

For this solution, the team proposed viscoelastic foams as they are used by the NASA in similar situations. However, other solutions might be valid and could be tested.

Finally, in order to improve reliability and apply redundancy the team came up with the idea of using a couple of electromagnets. Both of them will be fired by the same signal, but they have their own isolated circuit. The device might work with the activaion of both elevtromagnets or even if only one of them works properly.

The addition of a new structure and the capacity to add at the end of the platform the pair of magnetic devices, makes the element more aestetic and easy to understand, also it facilitates the deployment of the layer of foam.

The device is made of several components:

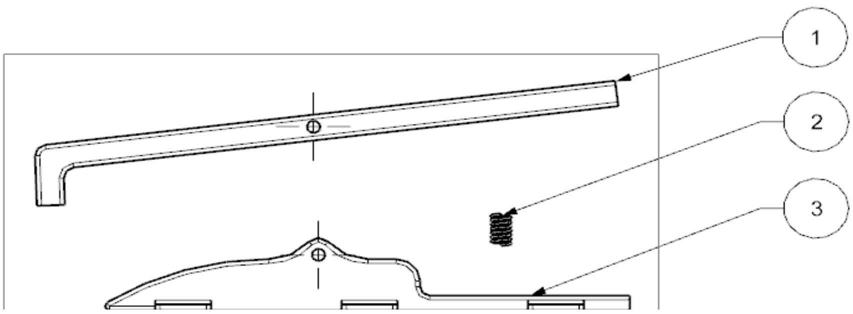


Figure 23 Magnetic beam: Exploded view

Table 8 Magnetic beam: Table of components

NAME	NUMBER OF REFERENCE	EXPLANATION
L shaped beam structure	**1**	This element will be the operator to keep the device closed. Once the magnet is activated the end part will come down releasing the mechanism,
Traction Spring	**2**	A spring of traction, this spring is made specificly in order to keep the structure in the normaly close position. Once the magnet is activated this spring will compress, permiting the release of the device.
Mechanism Base Structure	**3**	The base of the mechanism where all the components are fixed.
Structure – COVER	**NON DEFINED**	This element is not part of the mechanism but can be visualized in the images. This cover prevents the elements from any shock from external elements.
Magnet	**NON DEFINED**	If we analyse the structure of the element, we can see a hole in the back part of the structure. This compartment is dedicated to the placement of a electromagnet.
Viscoelastic foam	**NON DEFINED**	A layer of foam deployed on the zone of impact to reduce the shock caused by the activation of the device.

To ilustrate the magnet required we can show a image:

Figure 24 Illustration of an electromagnet for the magnetic beam

9.4.2 Magnetic lock

For the magnetic lock, several modifications have been made to the design. First of all, the structure has been changed in order to introduce a redundant mechanism, a rotative servomotor that will help in the releasing.

As in the previos design, a secondary redundant circuit and a new pair of magnets have been implemented in a symmetric arrange. Each circuit contains a pair of magnets (one for each hook) and a servomotor, everything in parallel.

As we will see in the following picture, the structure now is caged in a cover where the servomotor, the secondary release option, will be located. The magnet will be placed outside the box but connected to this in order to get the power.

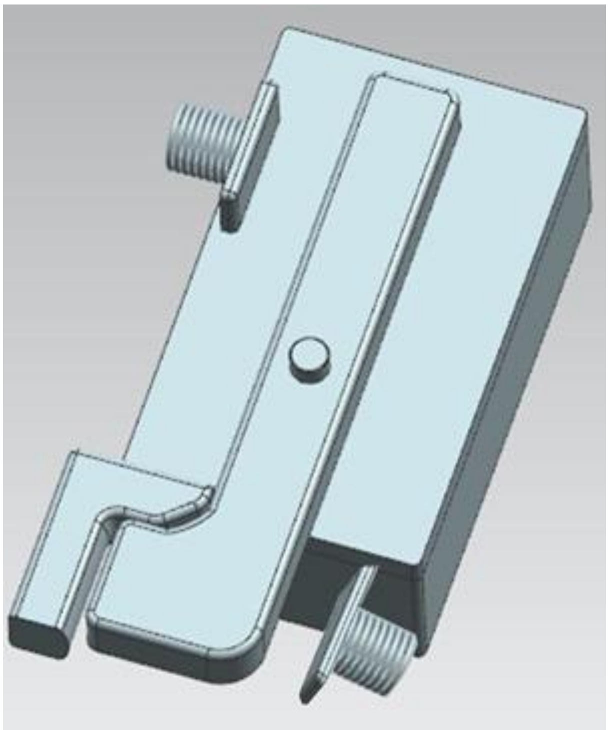


Figure 25 3D Model 1 - Magnetick lock arrangement

The improvement of this device is huge increasement on reliability as it has been implemented a redundant electromagnet and a electromotor to the device.

The magnets activations will be the main way of operating the mechanism. But the servomotor could work as an auxiliary device or even operate in case of both magnets failing.

Inside the box there is enough space to connect the device with the launch vehicle power station.

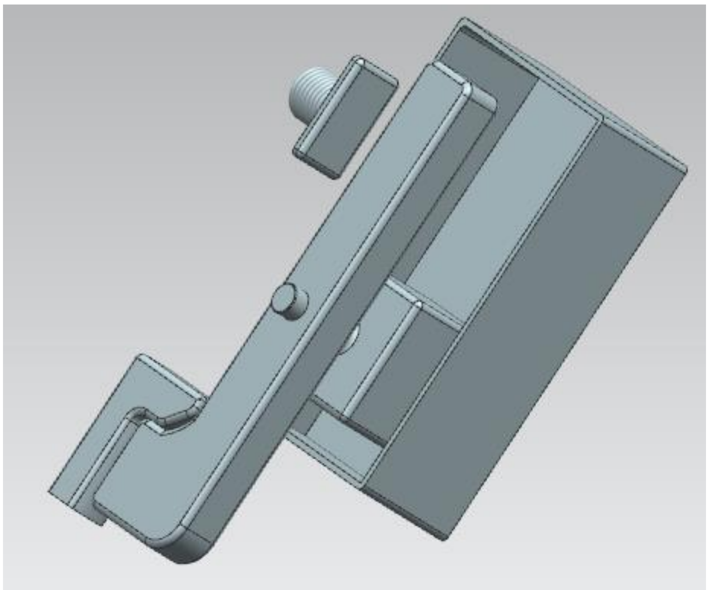


Figure 26 3D Model 2 - Magnetic lock perspective view

The device is made of several components:

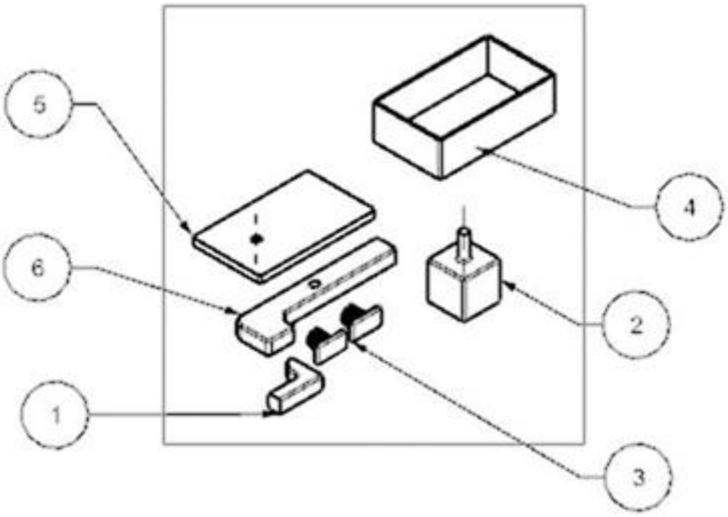


Figure 27 Magnetick lock: Exploded view

Table 9 Magnetic lock: Table of components

NAME	NUMBER OF REFERENCE	EXPLANATION
L shaped lock	**1**	This element is basically a L shaped structure that will be attached to the door. The operation of this element is related to the element 6.
Rotational Servomotor	**2**	The rotational servomotor is a simple element that will permit the rotation of the element 6 that interacts directly in the operation of release with the element 1.
Rectangular Magnets x2	**3**	Main mechanisms of release. Rectangular shape.
Structure	**4**	This element prevents the elements from any shock from external elements. In addition, is where all the electronic components will be placed.
Cover	**5**	Considered as the element that will protect all the electronic devices form external shocks and the enviroment.
L shape rotative structure	**6**	This element will interact with the elements 1 and 3 in order to perform the primary release. In case of any inconvenience the suplementary release mechanism will be activated and the elements 2 and 6 would interact.

The servomotor, as the rectangular magnet are elements that can be easily found in the industry.

Figure 28 Illustration of the components: Rectangular Lock + Rotative Servomotor

Finally, a design studio image has been designed in order to show the current state of the design:

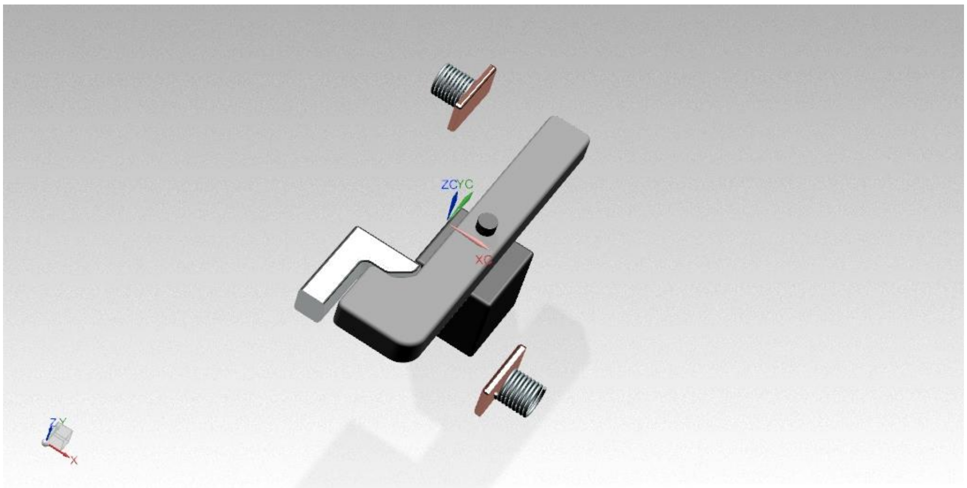


Figure 29 3D Model 3 - Magnetick lock

9.4.3 Rotary latch

The device rotary latch was presented as an alternative solution to the clamp device.

The modifications of the device have been focused in the application of redundant mechanisms of release. The implementation of a rotatory servomotor as primary release option is the proposed idea for the design team, in addition, as in the previous design, a secondary redundant circuit have been implemented with the incorporation of magnets.

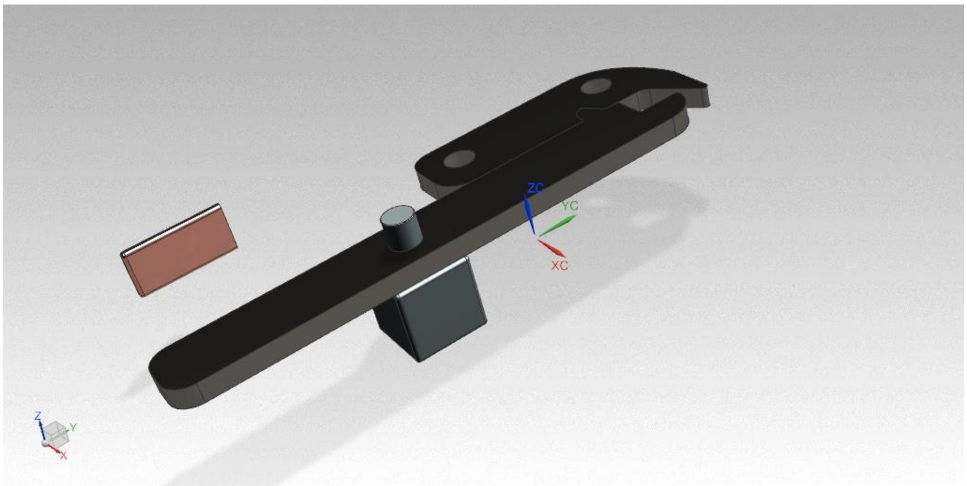


Figure 30 3D Model 1 - Rotary latch

If we analyse the mechanism, the device is made from several components:

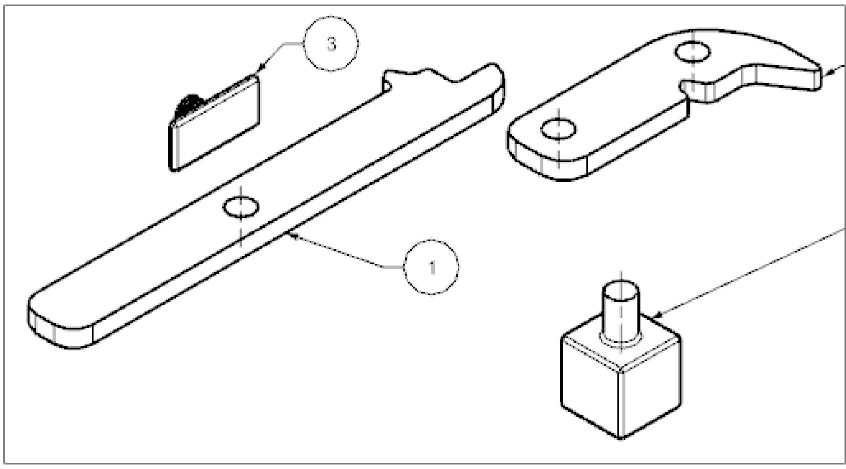


Figure 31 Rotary latch: Exploded view

Table 10 Rotary latch: Table of components

NAME	NUMBER OF REFERENCE	EXPLANATION
I shaped lock	**1**	This element is basically a I shaped structure that will be attached to the fixed structure in order to operate the release.
Fixed Strucutre	**2**	This structure will be fixed in order to perform a solid position for the release.
Rectangular Magnet	**3**	Main mechanisms of release. Rectangular shape.
Servomotor	**4**	The rotational servomotor is a simple element that will permit the rotation of the element 6 that interacts directly in the operation of release with the element 1.

9.5 Motion simulation

A 3D motion simulation has been performed to display the functioning and movement of every solution. In this subsection these simulations will be discussed.

The motion simulations may be seen in the annex 4 of the document.

9.5.1 Magnetic beam – Motion simulation

The illustration of the movement of the device as well as the interaction of the different components is necessary to correctly comprehend the operation of the device. The results of the simulations are related to these graphs:

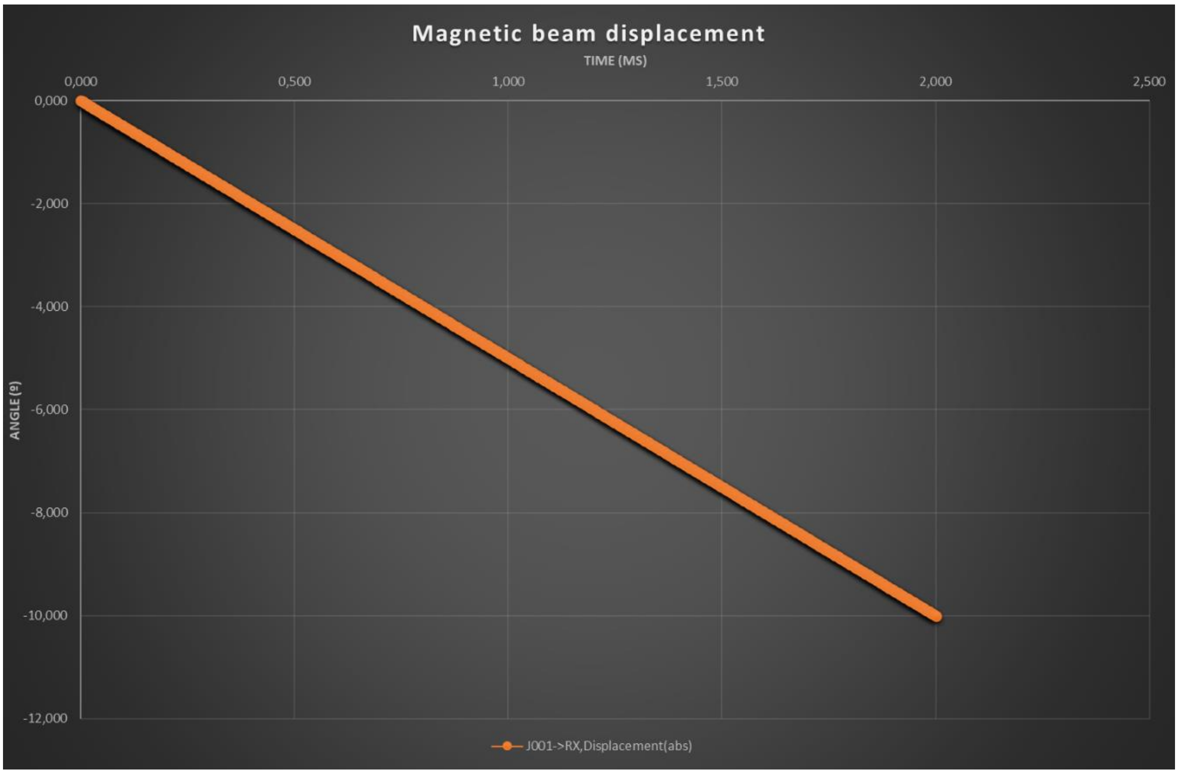


Figure 32 Magnetic beam: Illustration of the movement

The graph, as well as the 3D Movement Simulation, has the objective to inform about the operation of the device. In this case the movement is elaborated by the component nº 1 (L SHAPE BEAM).

The rotation is a continuous angular movement of 2 seconds with a rotation of 10 degrees.

To comprehend more clearly the situation, a 3D studio of movement has been effectuated.

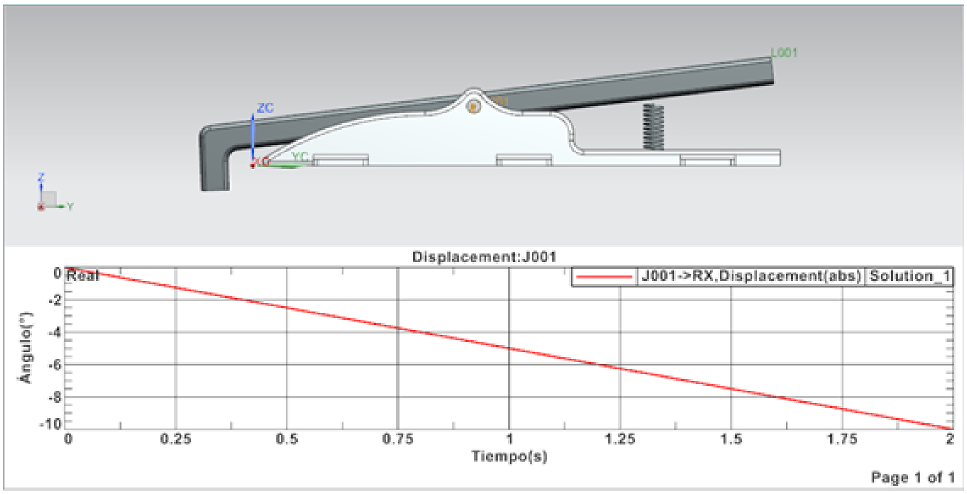


Figure 33 Magnetic beam: Illustration of the simulation

9.5.2 Magnetic lock – Motion simulation

The illustration of the movement of the device as well as the interaction of the different components is necessary to correctly understand the operation of the device. The results of the simulations are related to this graph:

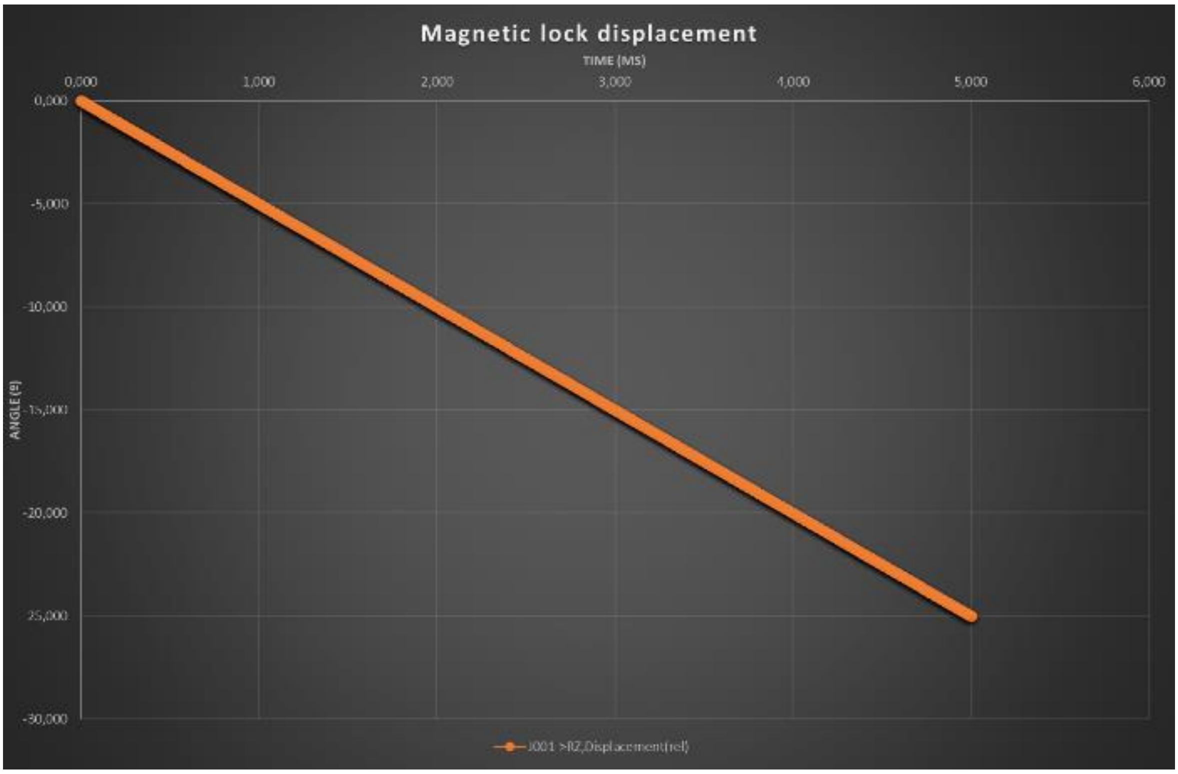


Figure 34 Magnetic lock: Illustration of the movement

To understand more clearly the situation, a 3D studio of movement has been effectuated.

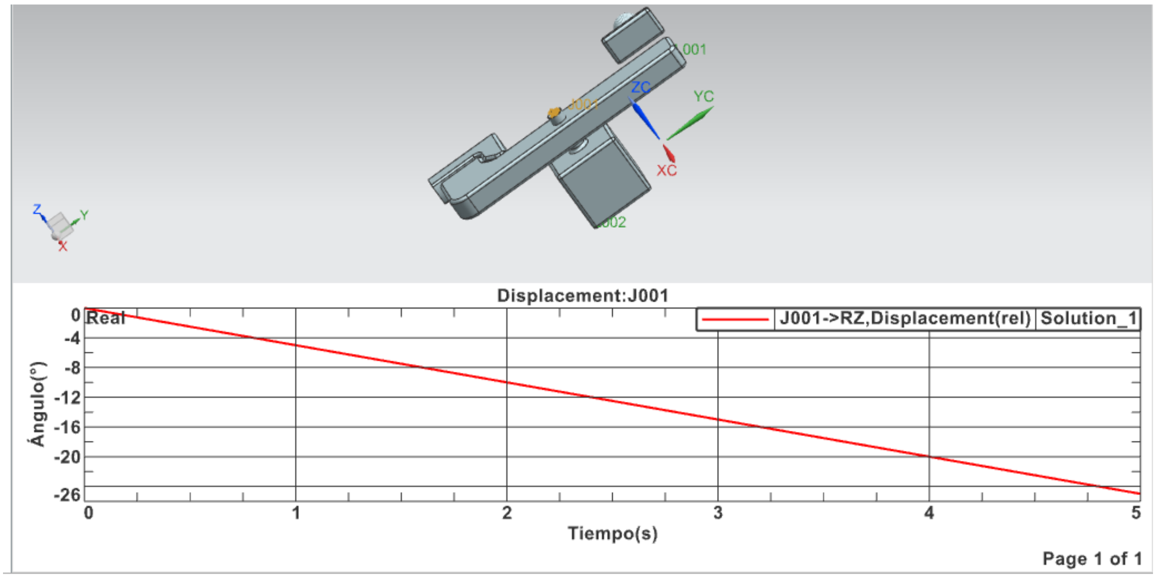


Figure 35 Magnetic lock: Illustration of the simulation

The graph, as well as the 3D Movement Simulation, has the objective to inform about the operation of the device. In this case the movement is elaborated by the component nº 2 (Servomotor) that rotates the element nº 6.

The rotation is a continuous angular movement of 5 seconds with a rotation of 25 degrees.

9.5.3 Rotary latch - Motion simulation

The illustration of the movement of the device as well as the interaction of the different components is necessary to correctly comprehend the operation of the device. The results of the simulations are related to these graphs:

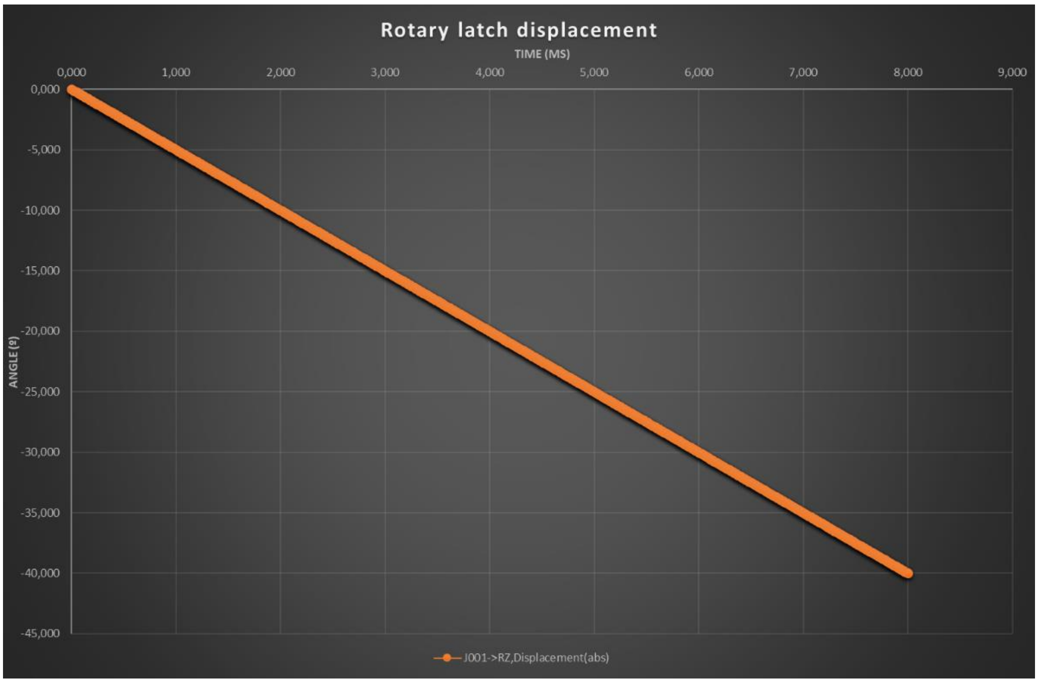


Figure 36 Rotary latch: Illustration of the movement

The graph, as well as the 3D Movement Simulation, has the objective to inform about the operation of the device. In this case the movement is elaborated by the component I SHAPE BEAM.

The rotation is a continuous angular movement of 8 seconds with a rotation of 40 degrees.

To comprehend more clearly the situation, a 3D studio of movement has been effectuated.

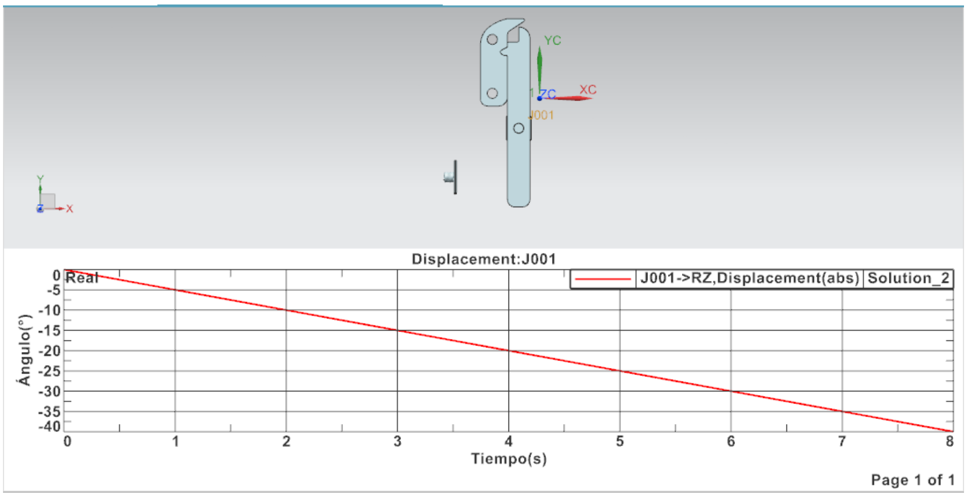


Figure 37 Rotary latch: Illustration of the simulation

9.6 Electronic study

In this subsection, the decisions made regarding electronics of the devices will be presented. At the beginning of the design face, the team was facing the problem of improving the reliability of a device while nor raising much the cost.

Special coatings, used in the spacecraft industry to protect the electronics from solar radiation, are expensive and not extremely required in the circumstances the device would work (around 700km of height, which is relatively low and there is still some protection from the atmosphere).

Thus, the team came up with an action that would put a solution to both problems: redundancy.

In the industry, the most common connector is MIL-DTL-38999 (see figure 38) and the decided to safe 4 pins for the release mechanism. 2 of them would be use for the main circuit and the remaining two would be used for a secondary redundant circuit.

Both circuits are isolated and independient and the deployment signal activates both circuits at the same time. The system would work if both circuits succes and even if one of them fails.

Figure 38 MIL-DTL-38999 connector

Also, the trigger signal to activate the deployment has an established minimum duration of 100ms and a minimum current required of 200mA.

With these measures, the device is protected from fake activations and the redundancy improves reliability while also covering the system from a fail activation caused by radiation (as this happening to one circuit is unlikely, happening to both circuits at the same time is close to impossible).

The team also suggest the installation of a telemetry sensor that will activate when the door of the pod is opened. An example of limit switch used as telemetry sensor may be seen in figure 38.

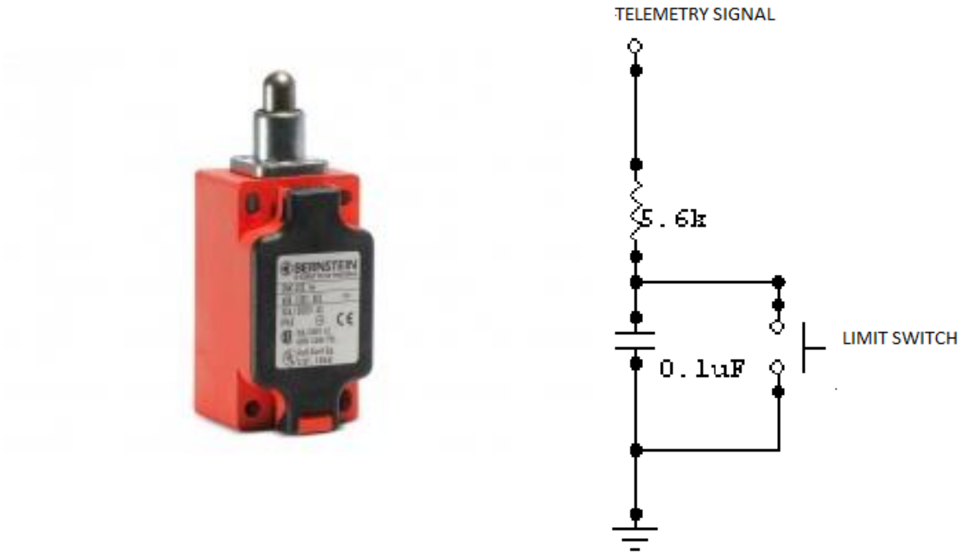


Figure 39 Limit switch and electronic diagram of the telemetry signal

On every device, the team has installed electromagnets as they were considered the most efficient solution. On the following subsections the electronic diagram off each concept will be presented. However, the electromagnet will be simplified for clarification purposes in those diagrams. The detailed diagram of the electromagnet may be seen in the figure 39.

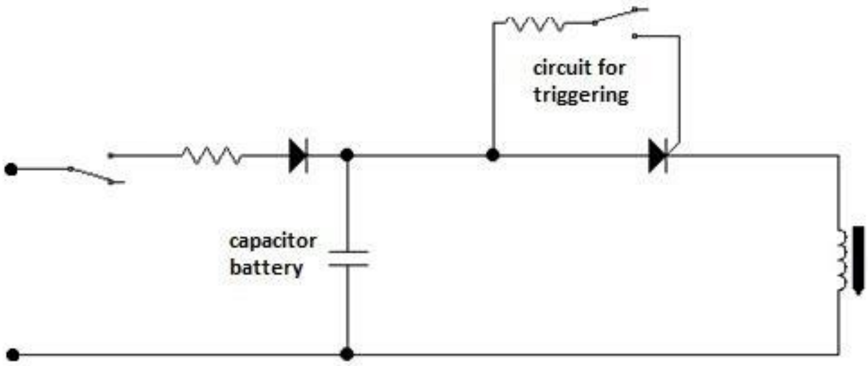


Figure 40 Electronic diagram of an electromagnet

9.6.1 Magnetic beam – Electronic study

The magnetic beam uses an electromagnet as the main actuator for pulling the beam. There are 2 identical circuits with the same task.

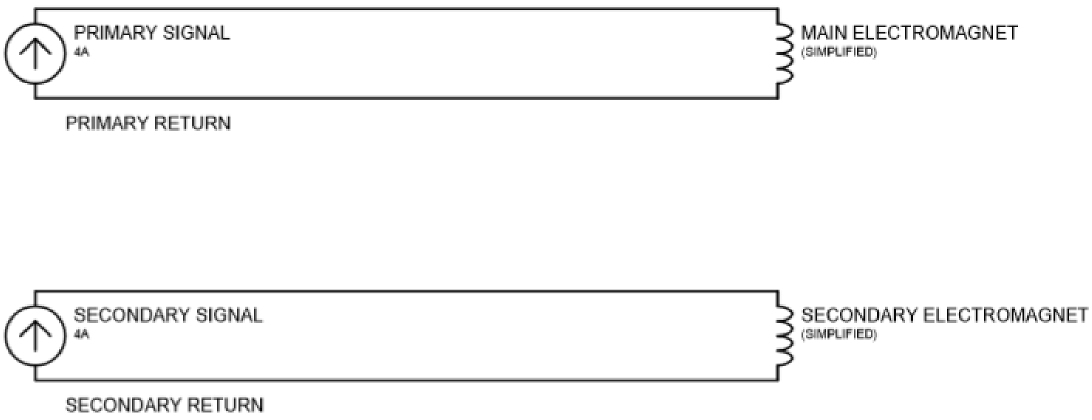


Figure 41 Magnetic beam: Electronic diagram

9.6.2 Magnetic lock – Electronic study

The magnetic lock is the most complex solution regarding electronics. A total of 6 different actuators are used to maximize reliability. Each circuit contains:

- A couple of magnets one for each L-shaped rotary part.
- A DC motor as a secondary device to move the structure. The main motor will be placed at the right structure while the secondary at the left.

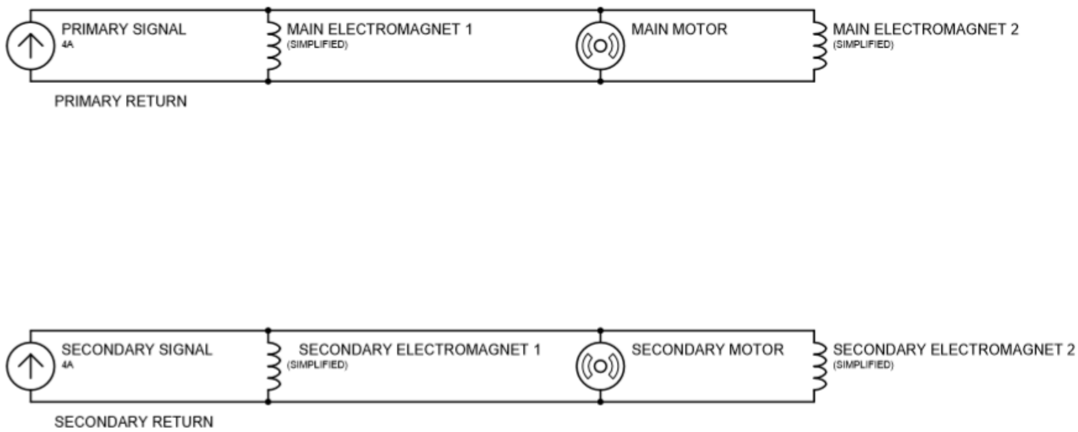


Figure 42 Magnetic lock: Electronic diagram

9.6.3 Rotary latch – Electronic study

The rotary latch uses both an electromagnet and a DC motor to operate. As the motor is considered the main activator it is placed on the main circuit.

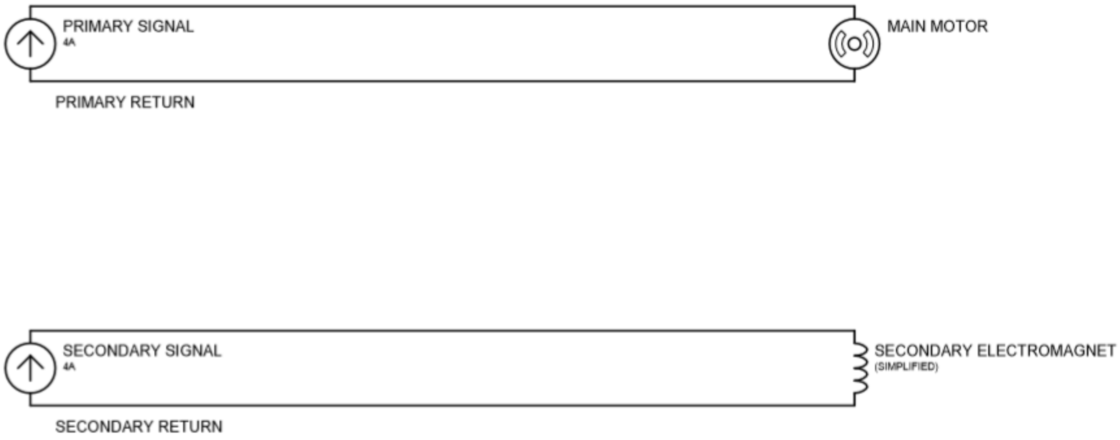


Figure 43 Rotary latch: Electronic diagram

10. Testing study

Several tests have to be performed before any object is sent to space, as the payload sent to space has to withstand several different forces during the launch and the journey. An inadequate element would risk the whole mission.

During our previous research, we had been studing the test that must be done in order to operate correctly the mechanisms that must be tested. This tests can be divided in functional testing and enviromental testing. Functional testing means testing the functions and if the mechanical and electronical parts work as supposed, while enviromental testing means seeing that the product is able to withstand the environment where it is supposed to work at.

In this section, every test that must be performed will be explained with more details.

10.1 Functional testing

The concept of functional testing describes the development of every test required to assure the correct operation of the mechanism during the mission. Principally these tests are based on the physical behaviour.

The presence of external and internal forces, the vibrations caused during the operation, external shock forces and random forces of vibration are elements that must be controlled by the performance of this tests.

10.1.1 Random vibration testing

Random vibrations are vibrations of different frequencies that cannot be precisely predicted. The payload has to be able to endure these vibrations, typically during the launch of the delivery vehicle. If the payload is unable to endure these vibrations, it may end up shattering in the worst case scenario. Since the objective of this research is to provide a door opening mechanism, one of the encountered problems might be the mechanism not being able to resist the random vibrations and triggering during the launch, which would end up ruining the whole mission in the launching space, since the CubeSat would never get to space.

The testing itself is usually not overly complicated. The part or material being tested is attached to the testing equipment. Shaker tables are commonly used for this. After this, random vibrations in the specified frequency range are applied to the component being tested through the testing equipment. The specifics for the tests are usually a bit different depending on the part being tested and the clients needs. The frequency of random vibrations during the testing usually changes between 5Hz and 2000Hz.

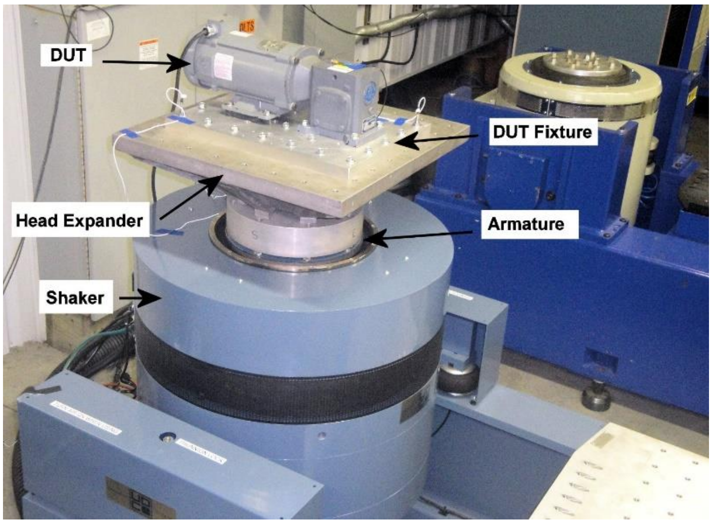


Figure 44 Illustration of the random vibration testing

10.1.2 Sinusoidal vibration testing

Sinusoidal vibrations are vibrations that are not random, but fixed in a certain frequency (for example, everty vibration comes at 20Hz). Sinusoidal vibrations do not usually occur in real world but they are still worth testing. That is, because finding resonances of the component can still be useful,it is such a simple test to do and it produces constant frequency vs acceleration.

Sinusoidal vibration testing is done pretty much in the same way as the random vibration testing, the only difference being that the frequency is the same all the time.

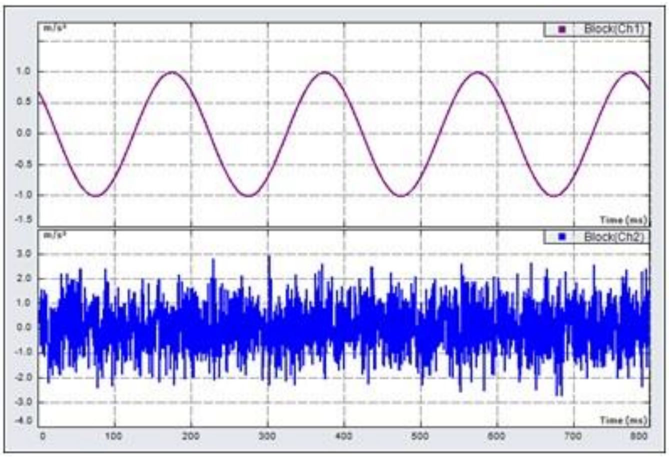


Figure 45 Illustration of random vibration testing results

10.1.3 Shock testing

During space flights there are instances where the product may be exposed to sudden and relatively infrequent force impulses, which it has to withstand. Shock testing is done to see how well the product can endure these kinds of sudden impulses and how durable the product is.

There are several different methods of shock testing. Drop testing includes dropping the product from a certain height. This is usually tested for any kind of handling or transportation mishaps. Drop towers are also used to test mechanical shock resistance. Then there is temperature shock testing, which tests the products durability towards sudden temperature changes.

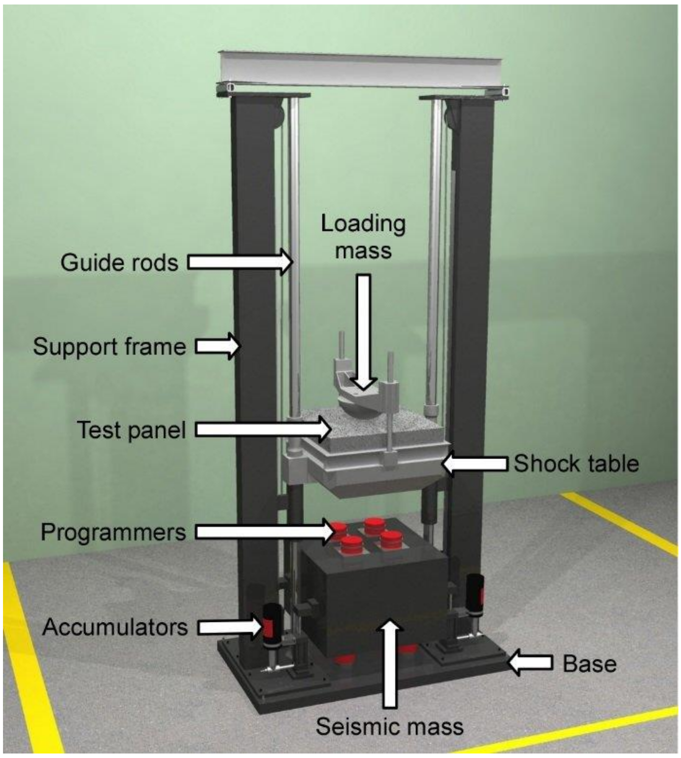


Figure 46 Illustration of the Shock testing

10.2 Environmental testing

During the operation of the mechanism, the space is the field of actuation, and the conditions are completely different from the conditions of the Earth. For this reason, trying to simulate the conditions of work in the space, the environmental tests are performed.

These tests have the objective to comprehend the behaviour of the devices working in the conditions of the thermal space vacuum and predict the outgassing properties of materials.

10.2.1 Thermal vacuum testing

Thermal vacuum testing is a type of test done to equipment to simulate space conditions, pressure and temperature in particular. The testing is done with help of thermal vacuum chamber. While the workings of such a machine are complicated, the idea of the test itself is quite simple. The equipment being tested is simply insterted into the chamber and the exposed to the amount of pressure and temperature desired. It is important to note however, that the release mechanism has to survive and be operational in space for relatively short time (usually around 2 hours), so the tests are not as extreme as they would be for satellite parts, for example.

Figure 47 llustration of thermal Vacuum testing

11.2.2 Outgassing testing

Outgassing means release of the gas trapped within material. Since every material has airpockets in it, it means every material also has outgassing effects. However, some materials get way less air trapped inside them than others, and since space is vacuum where all of the air tends to leave the material, we need materials with as little outgassing as possible. To put it in simple terms, outgassing is basically the mass loss of material due to change of conditions

Outgassing testing is done in quite the same way as the thermal and vacuum testings. First, the material being tested is submittd to pre-conditioning so that they uptake moisture. After that, they are weighted. The material being tested is then put inside a test chamber, where the conditions of the situation are simulated. After that, the material is weighted again. This process allows us to see the amount of gas that gets outgassed from the material.

11. Conclusions

While the team did not manage to create and test the prototype because of the COVID-19 situation, the team finished at a steady stated and achieved some of the objectives and valuable documents for the client.

The team got a good understanding of the industry and developed a comparison of fourteen different release mechanisms. This document implies a huge value for the company for present and future projects.

Also, a condition document approved by the client was redacted. That document might be used as a base for the construction of the final release mechanism. While some of the designs were completely scrapped as ideas, they still offered inspiration to a wide branch of potential solutions that might be used for similar problems. In fact, three of the designs were considered good enough to further develop. Those three designs were magnetic beam, magnetic lock and the rotary latch. These designs have the potential to be the final solution of the problem and they are really advanced in the design stage. In these designs, the team came up with a valuable solution to increase reliability while avoiding expensive materials: electronic redundancy.

Additionally, the team gathered a lot of new knowledge as they have to face new situations every day. Not only technical knowledge about the spacecraft industry was learned. Many skills were developed, such as creative thinking, project management, improvisation skill and teamwork.

12. Future work

Due to the COVID-19, the team couldn´t follow the project as it was planned, and therefore the project is unfinished. In this section, the remaining work for the project will be presented.

It would be advisable to pick single design out of the presented three final designs and keep developing it. The design has been made from a theoretical point of view. So, the device should be prototyped as soon as possible. Prototyping and following a more practical approach may result in new unknow issues that should be solved by modifying the design (even moving to another of the ideas might be possible).

After that, the prototype must me testes before the design can be actually used. Both, environmental and functional test must be passed to ensure the device is eligible. In this stage, the final changes of the device will appear to pass every test in the most optimal way. A change of material, changes in the dimensions or in the actuators are some of the changes that may appear during this stage.

Aside from that, there is not lot of future work left that directly relates to the opening mechanism. However, all the other parts of the launch pod still have to be designed and created before the opening mechanism can be put to use.

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ANNEXES

Annex 1: Mechanism sketches

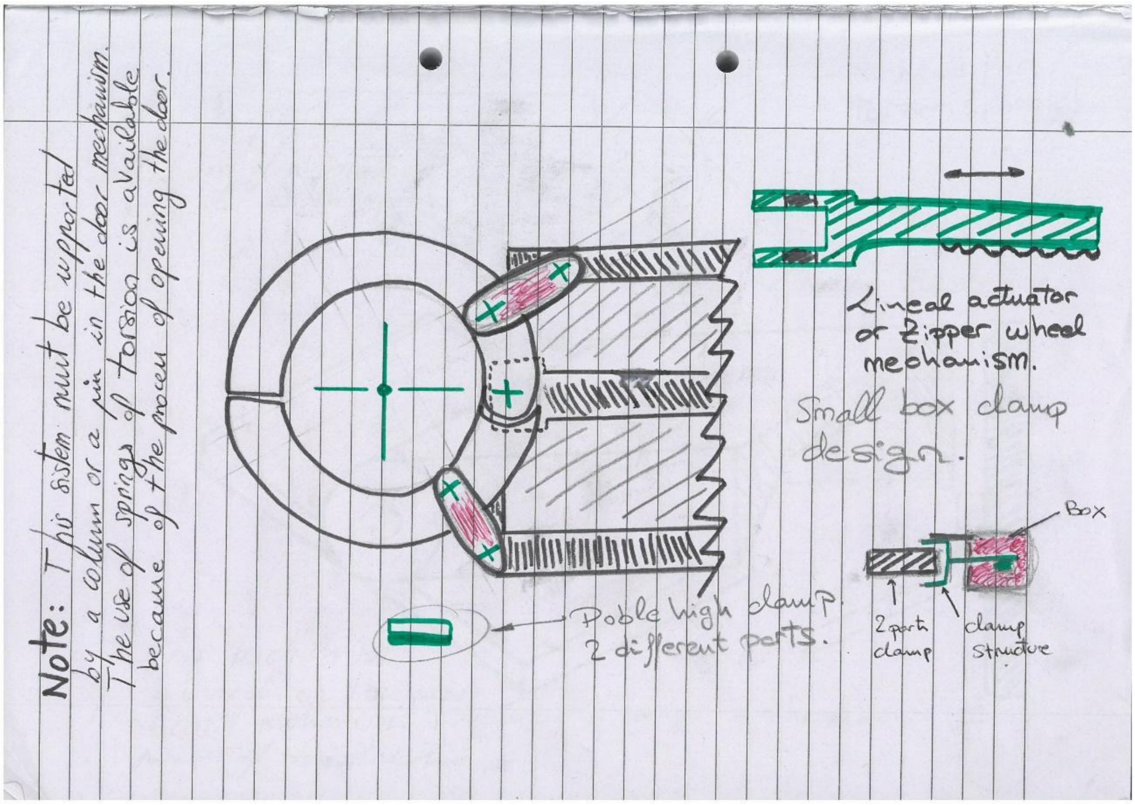

Figure 48 Magnetic clamp: Initial sketch

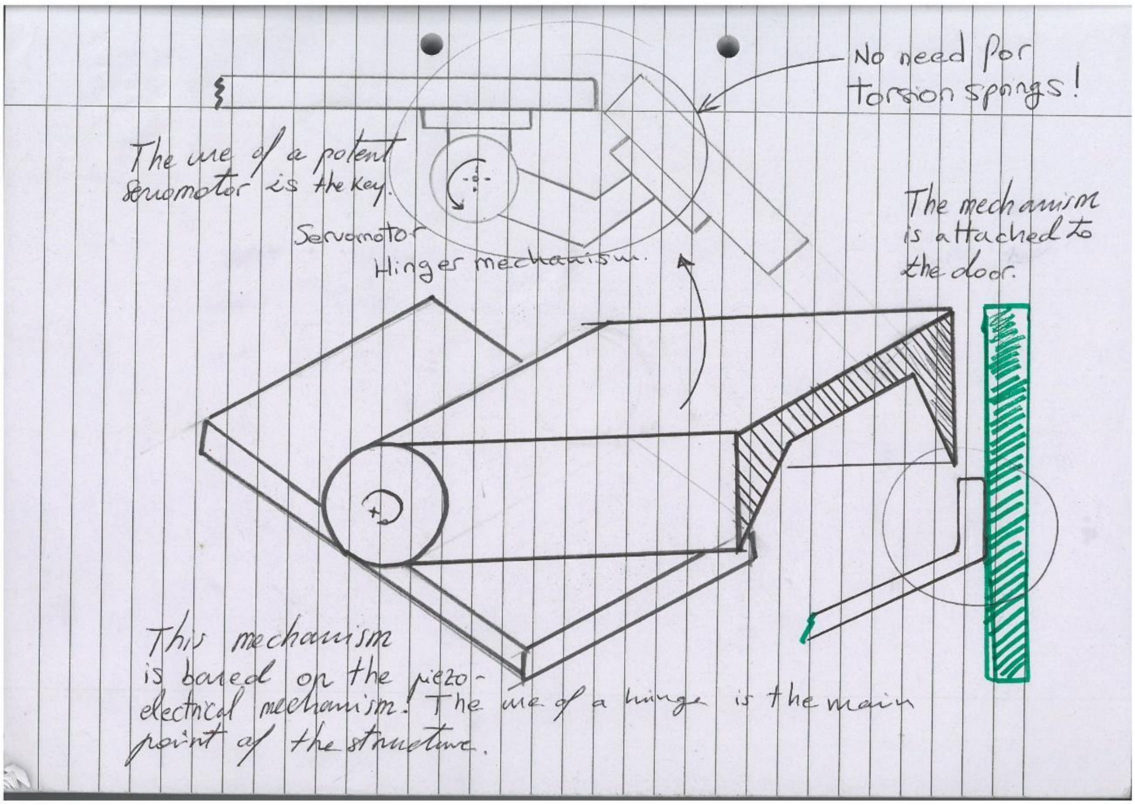

Figure 49 Electromechanic hook: Initial sketch

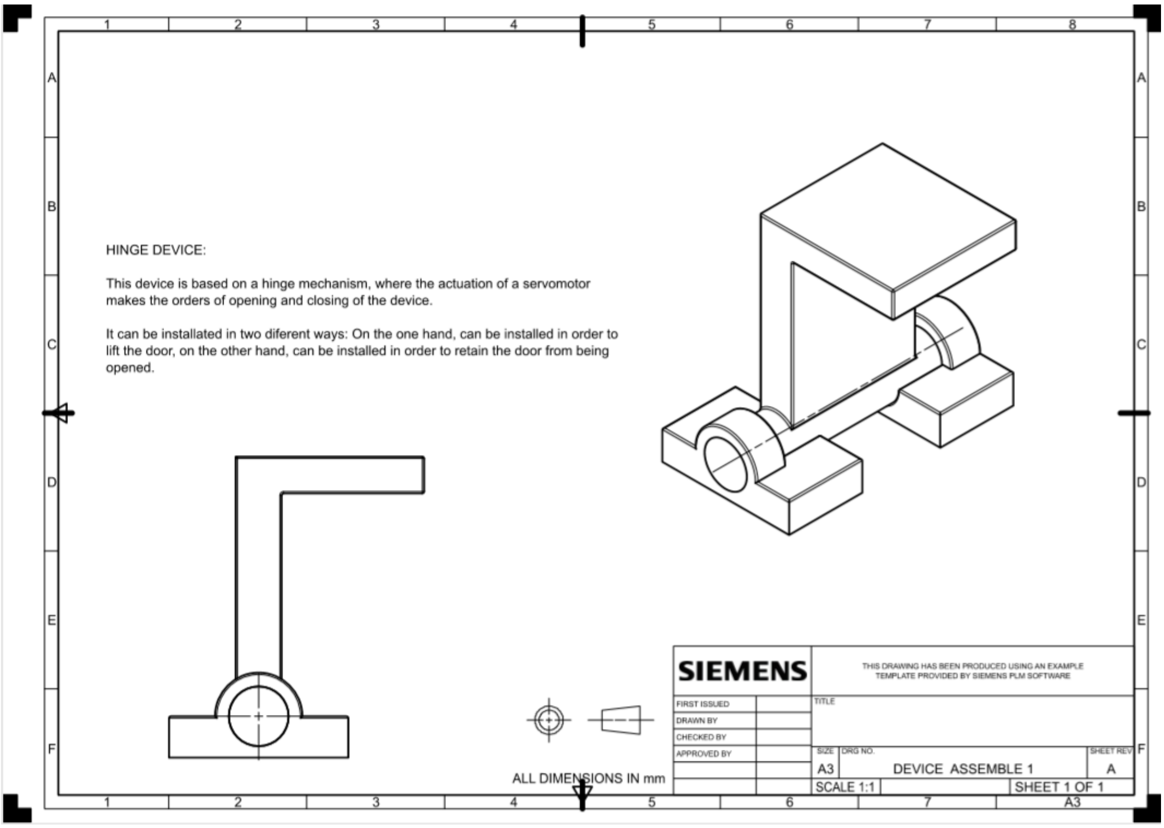

Figure 50 Hinge mechanism (later renamed as Electromechanic hook)

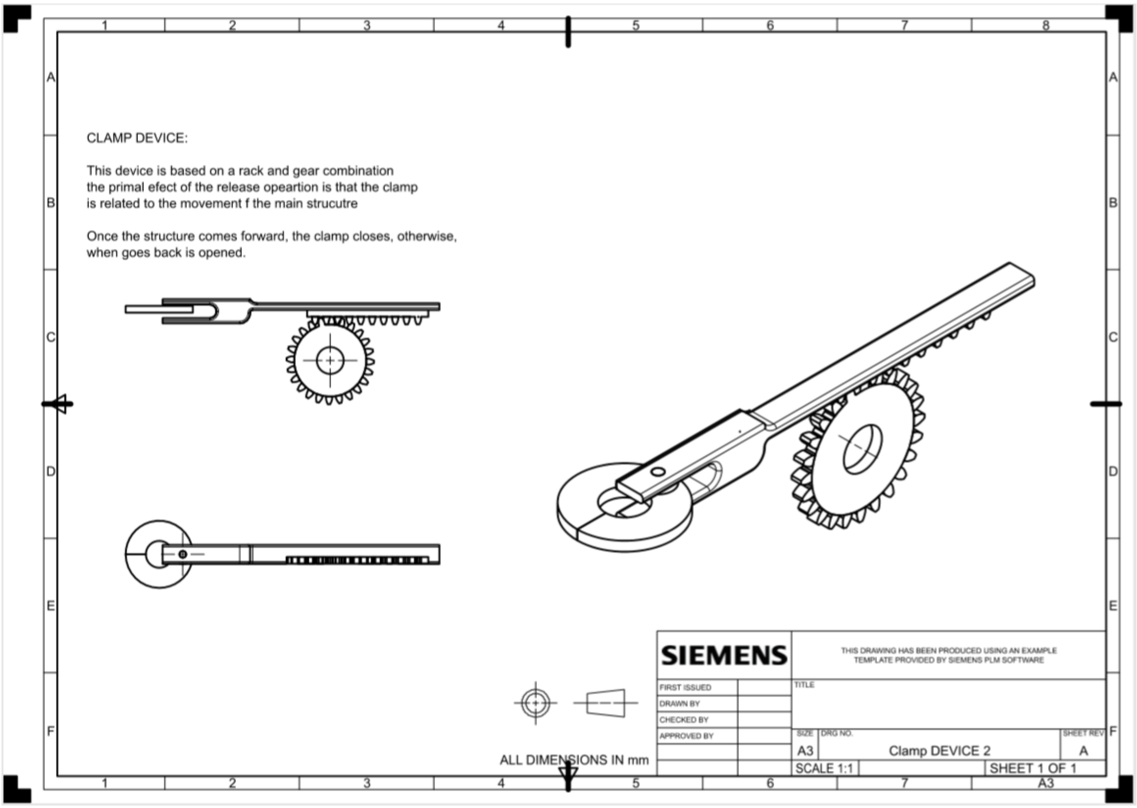

Figure 51 Clamp device: First version

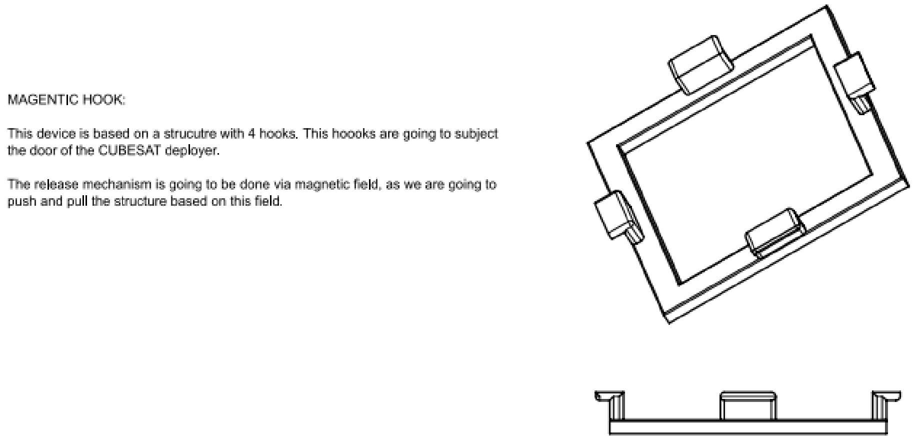

Figure 52 Hook device

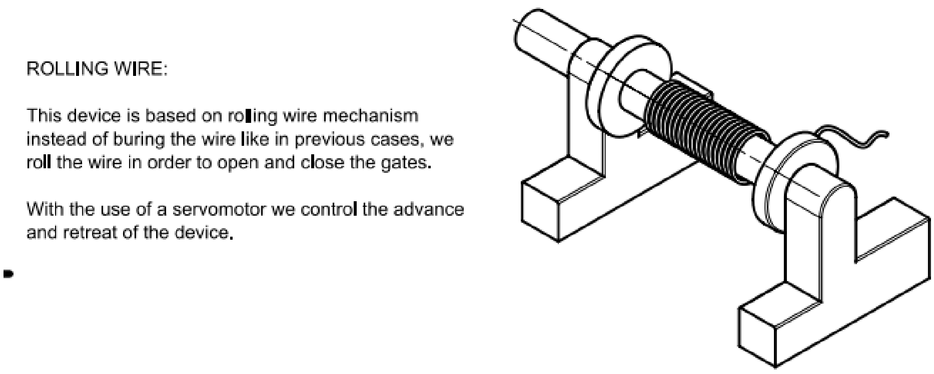

Figure 53 Rolling Wire device

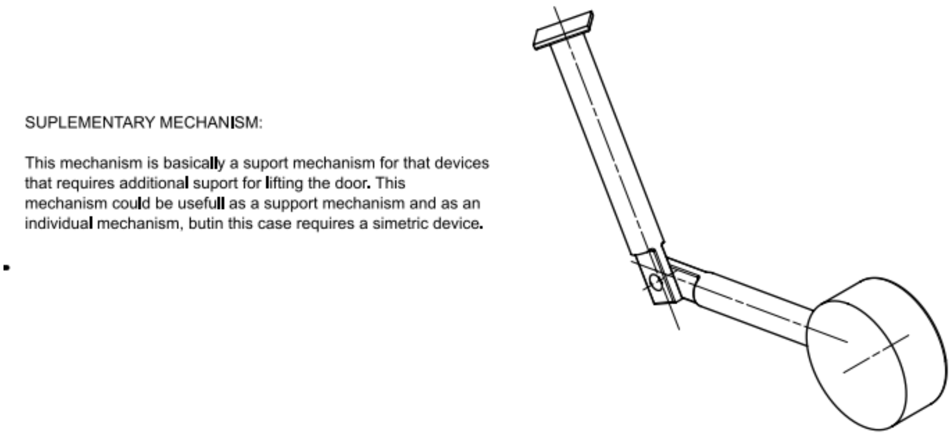

Figure 54 Supplementary mechanism device

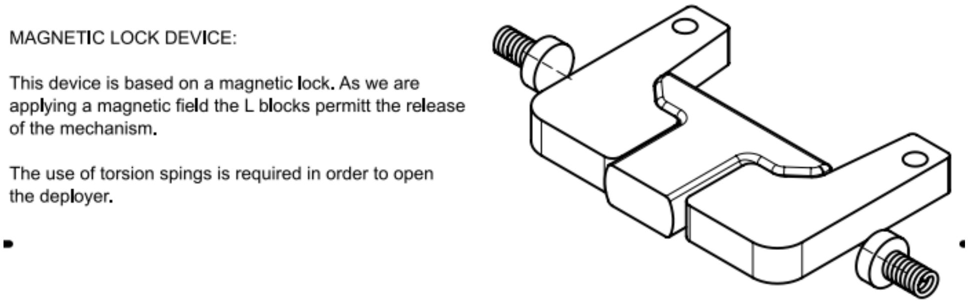

Figure 55 Magnetic lock: First versión

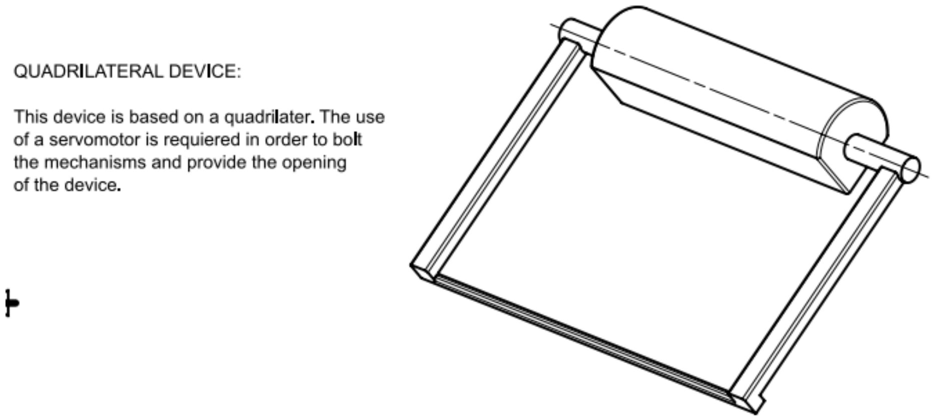

Figure 56 Quadrilateral device

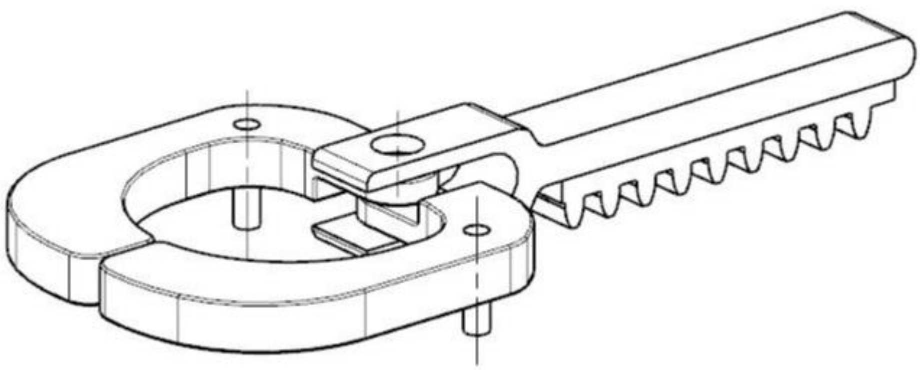

Figure 57 Clamp device: Final version

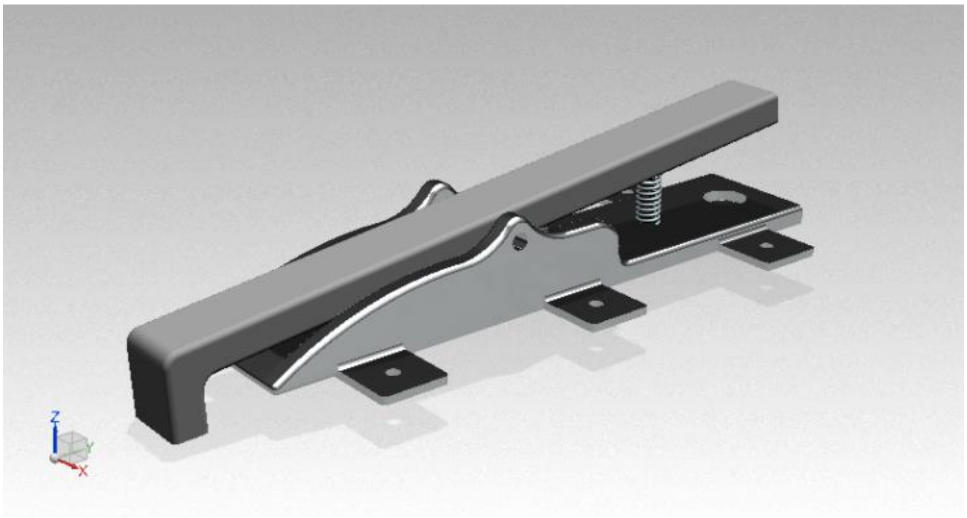

Figure 58 Magnetic beam: Studio image

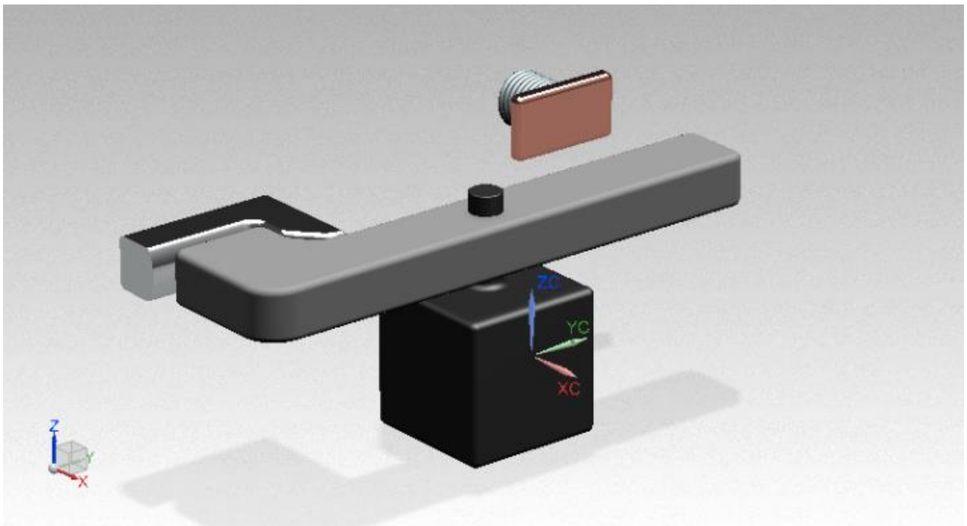

Figure 59 Rotary latch: Studio image

Annex 2: Material study diagrams

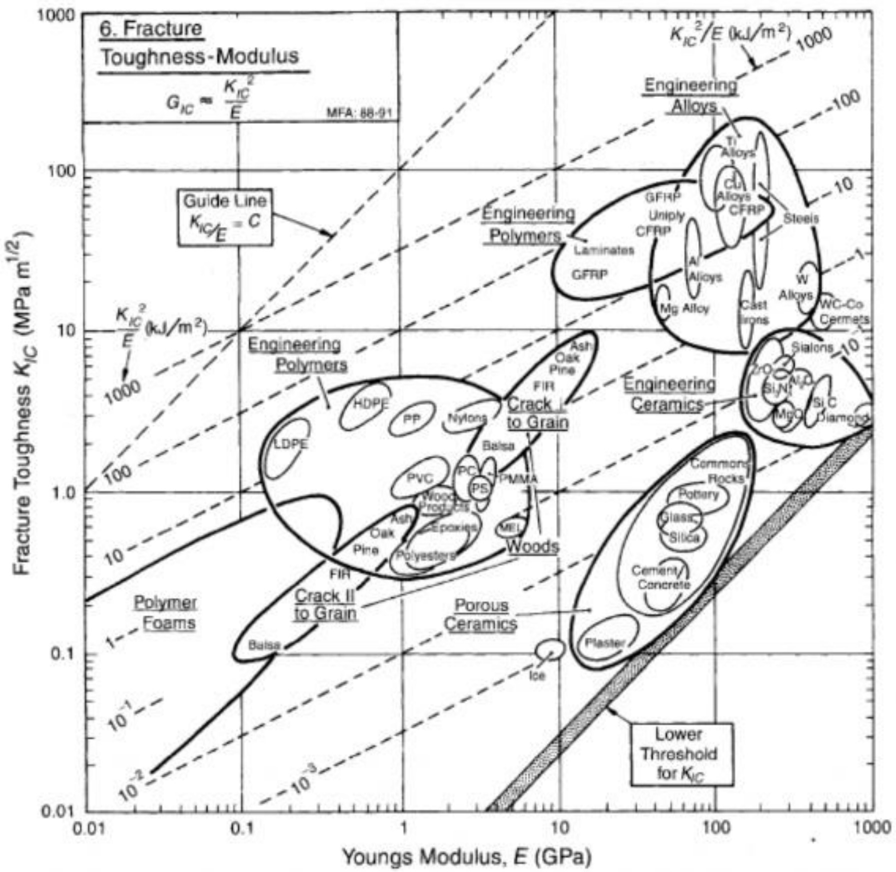

Figure 60 Material diagram: Frature toughness vs Young modulus

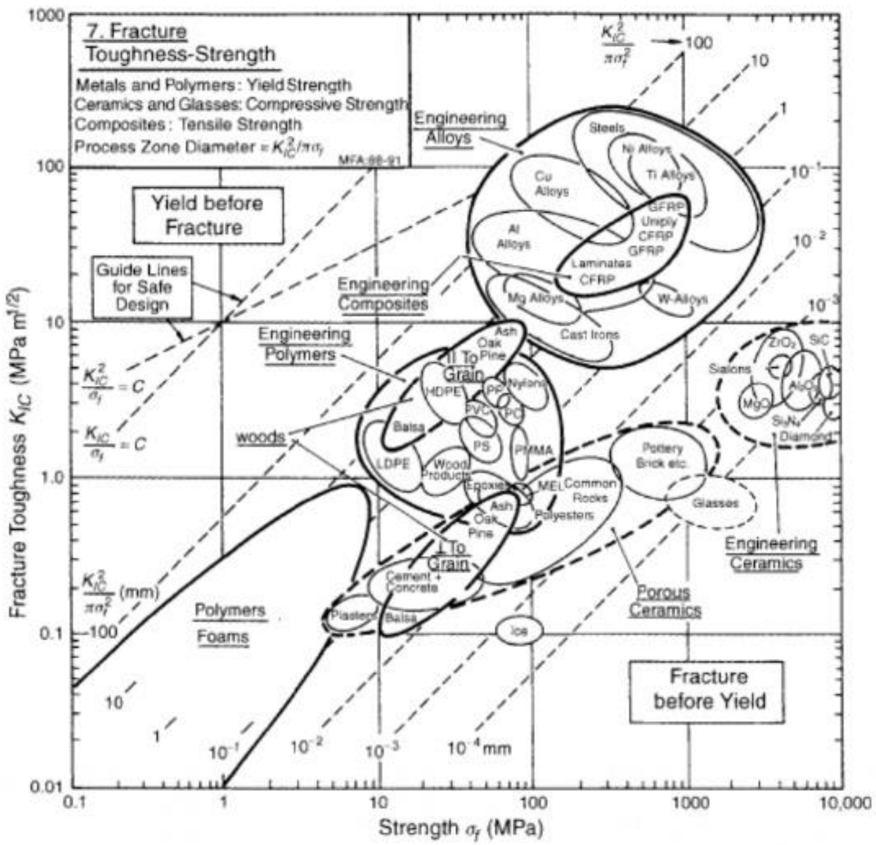

Figure 61 Material diagram: Fracture toughness vs Strength

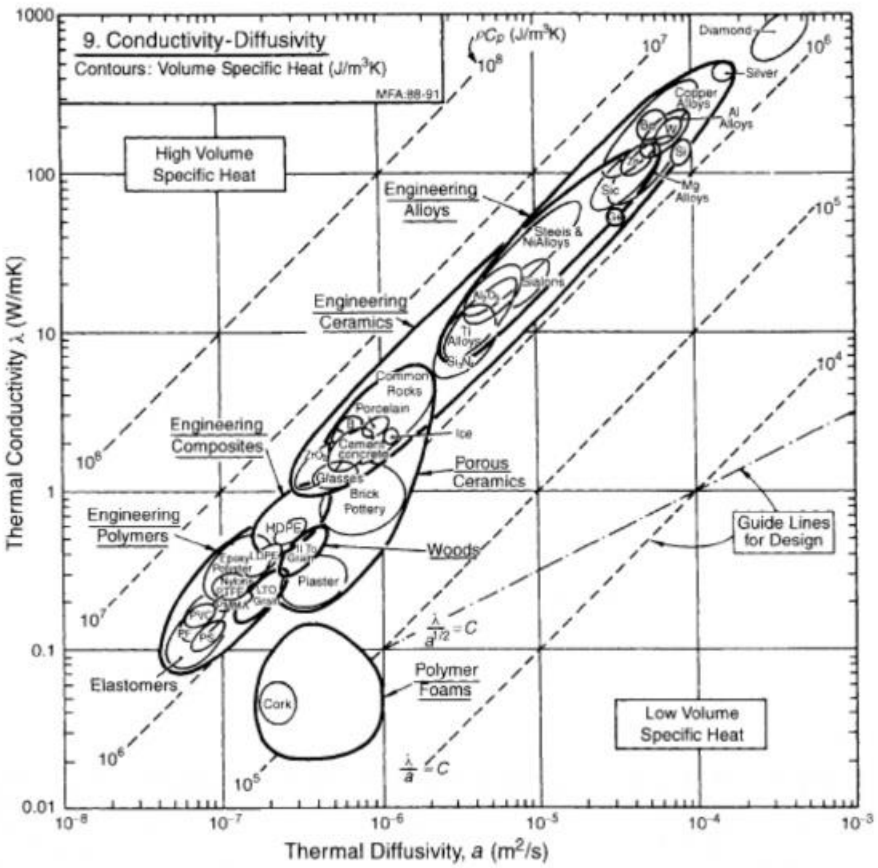

Figure 62 Material diagram: Thermal conductivity vs Thermal diffusivity

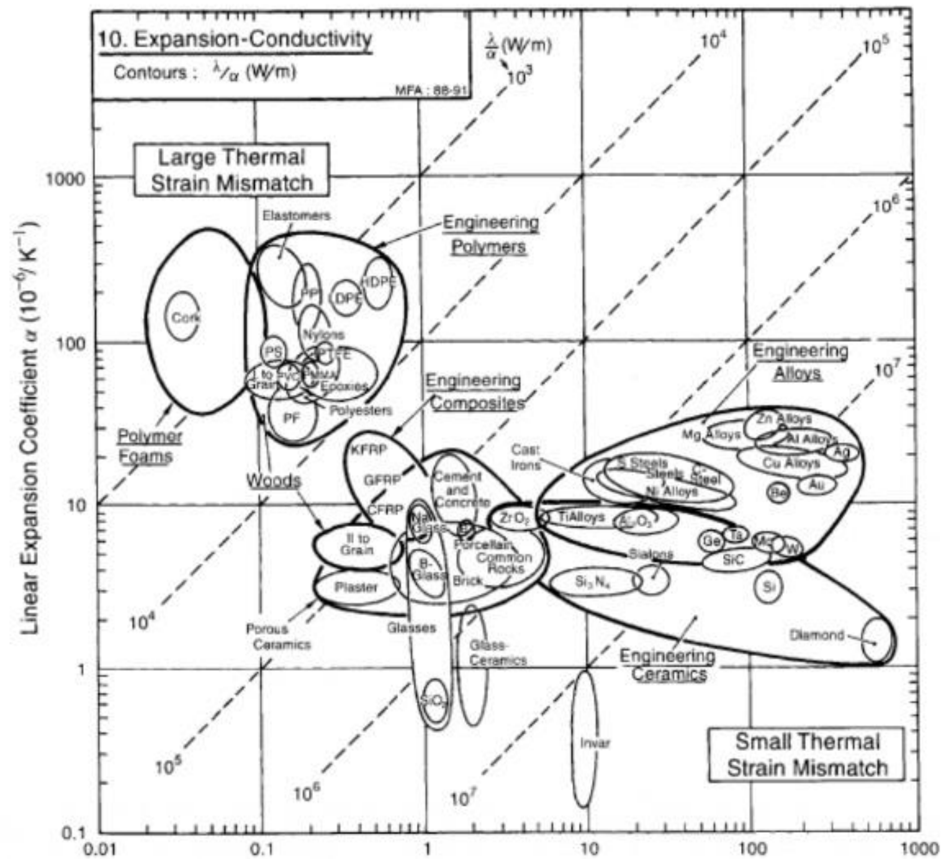

Figure 63 Material diagram: Linear expansion coefficient vs Thermal conductivity

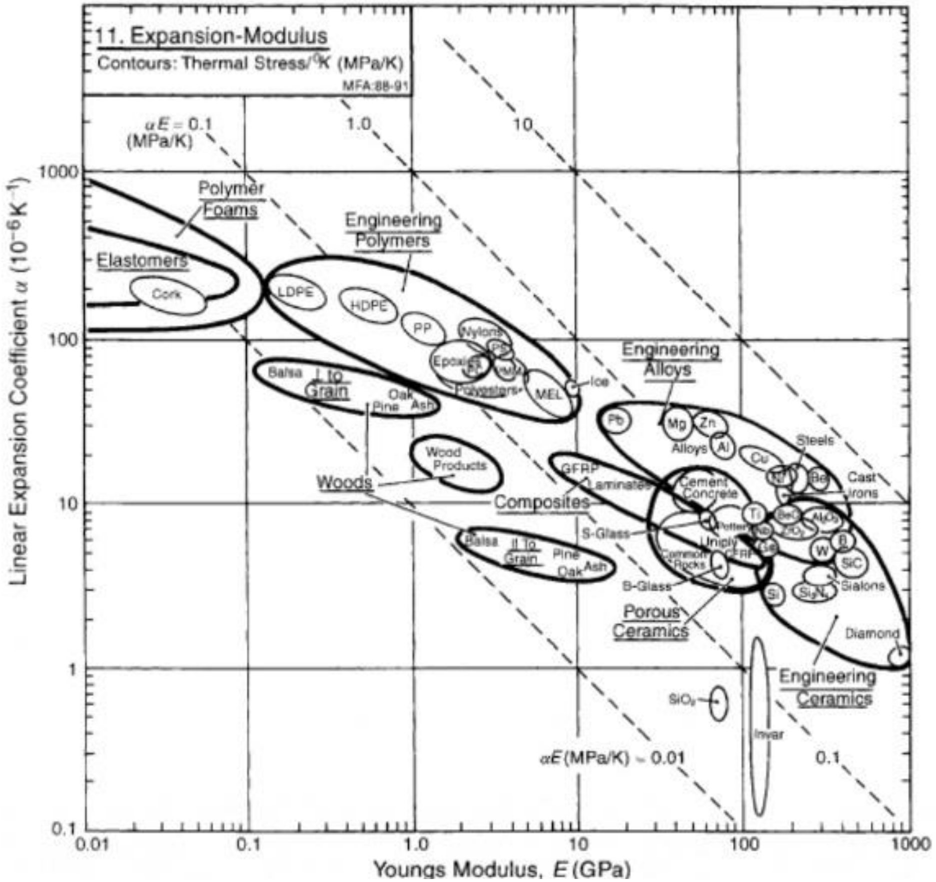

Figure 64 Material diagram: Linear expansion coefficient vs Young modulus

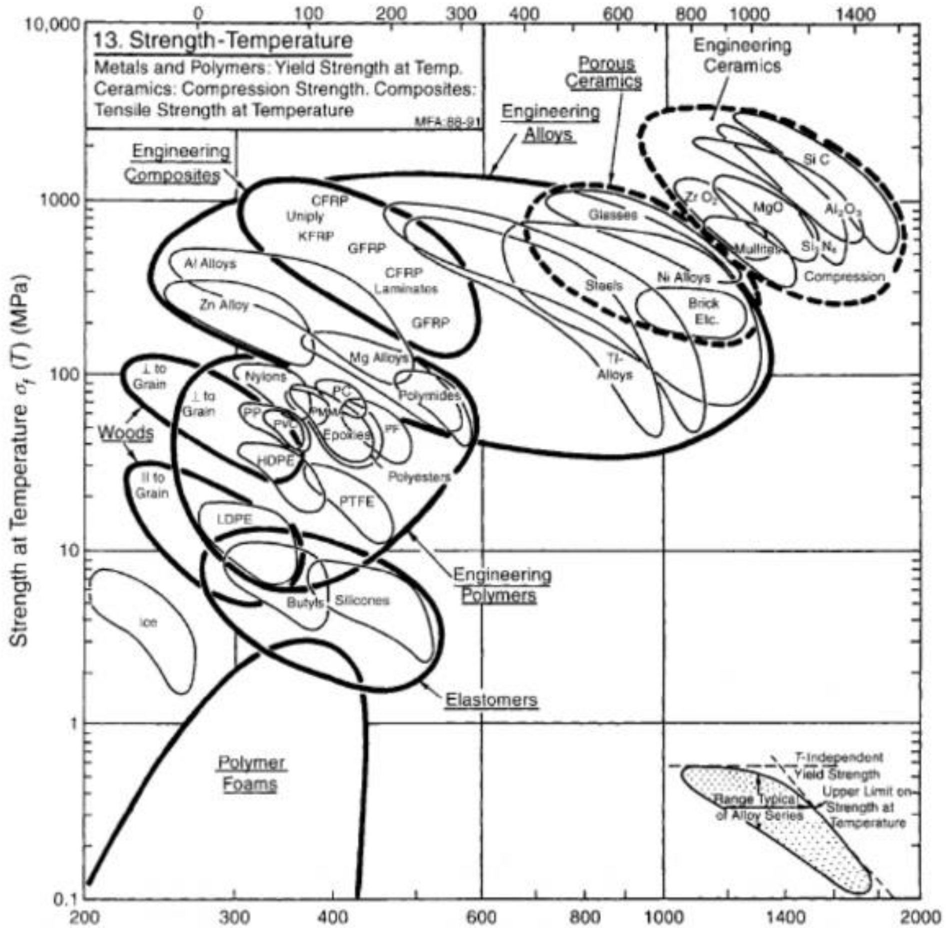

Figure 65 Material diagram: Strength vs Temperature

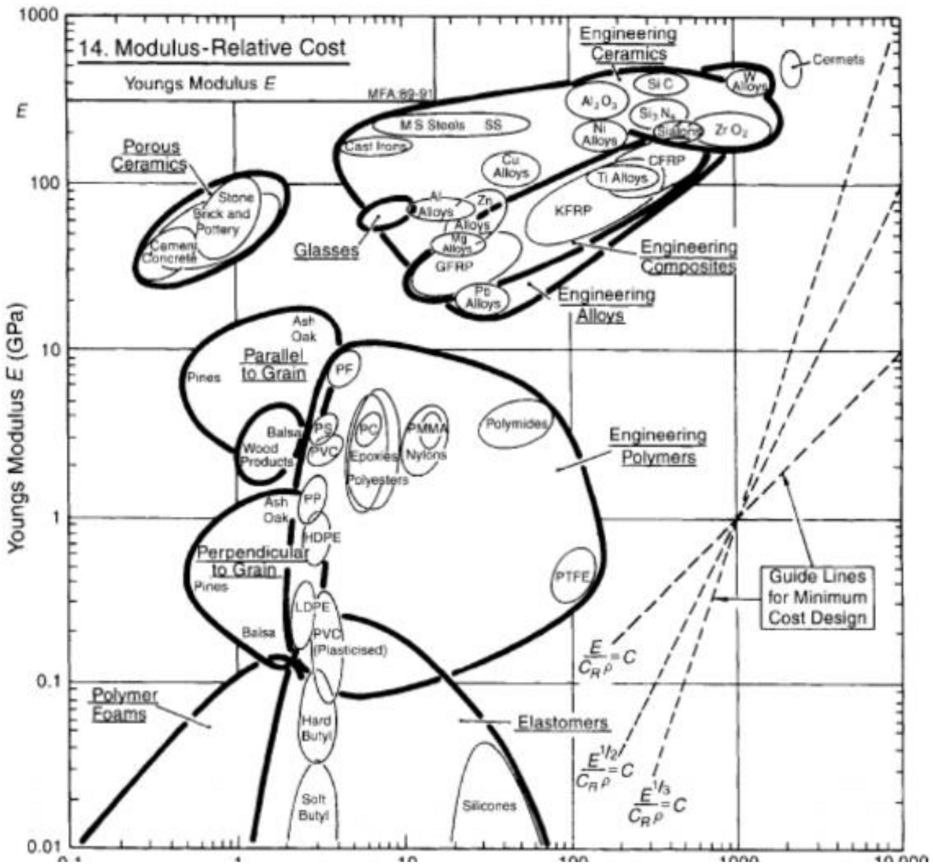

Figure 66 Material diagram: Young modulus vs Relative cost

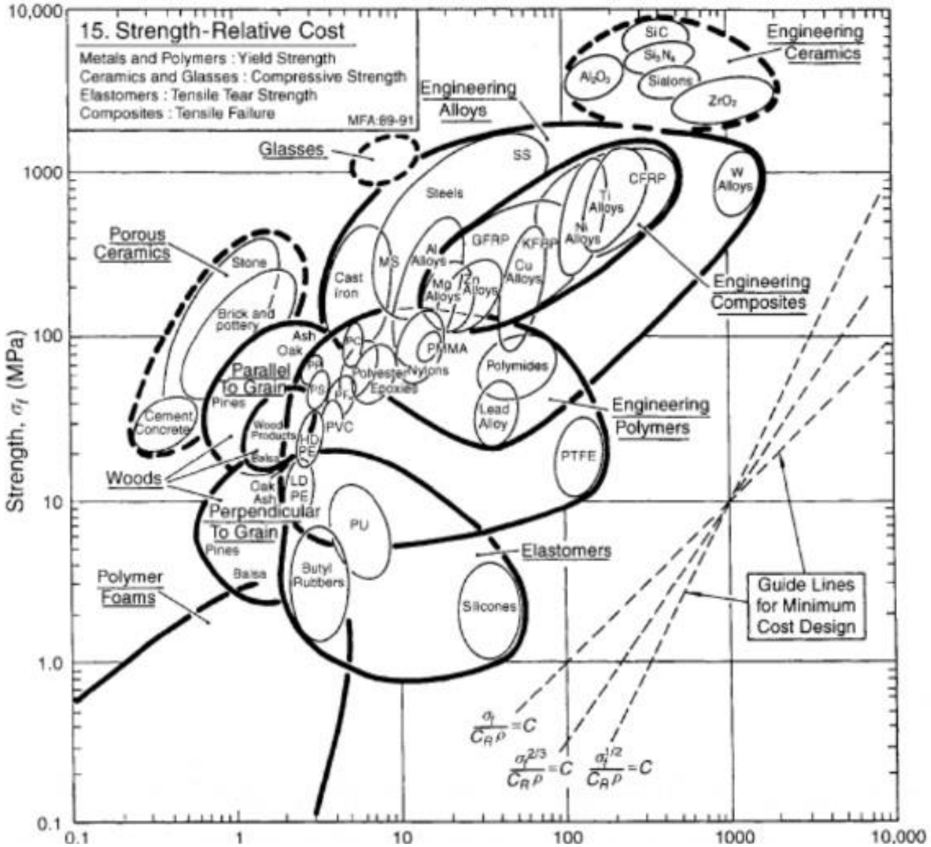

Figure 67 Material diagram: Strength vs Relative cost

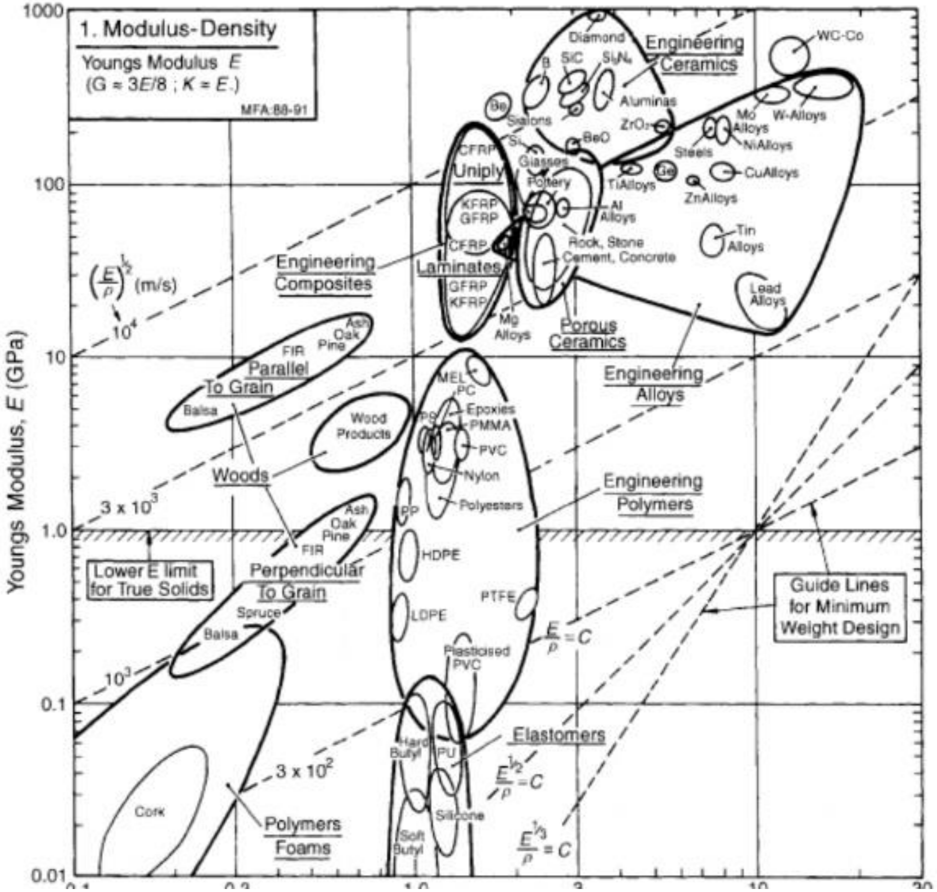

Figure 68 Material diagram: Young modulus vs Density

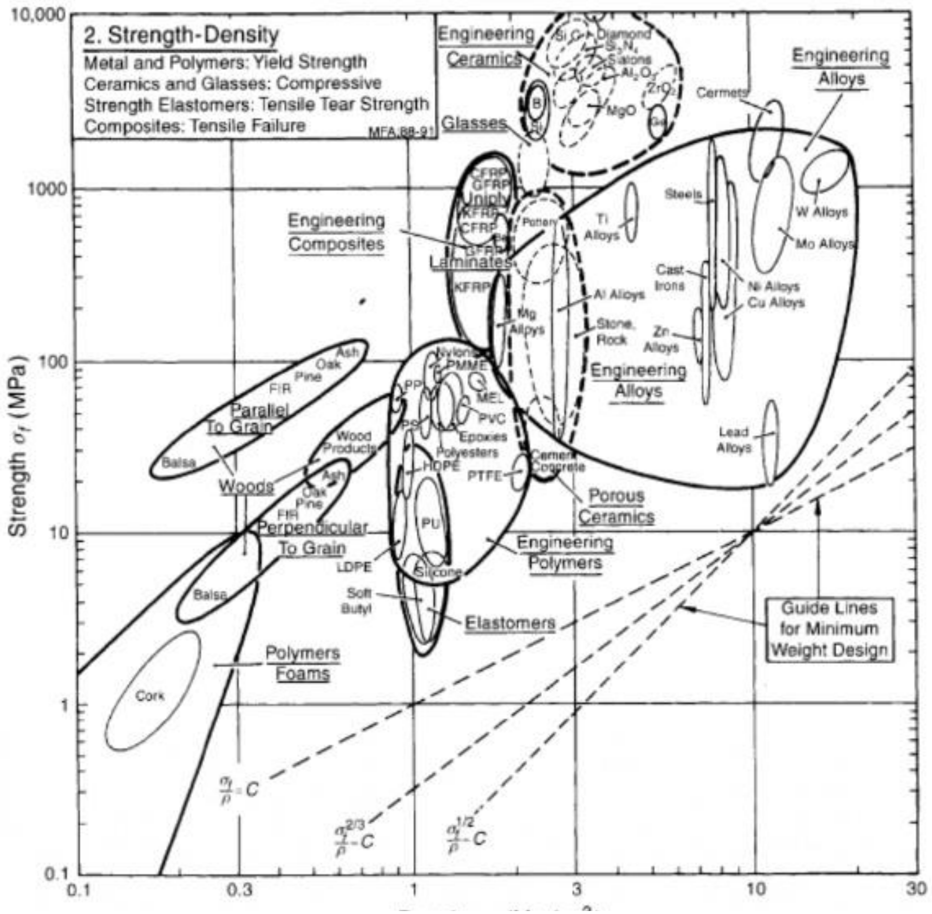

Figure 69 Material diagram: Strength vs Density

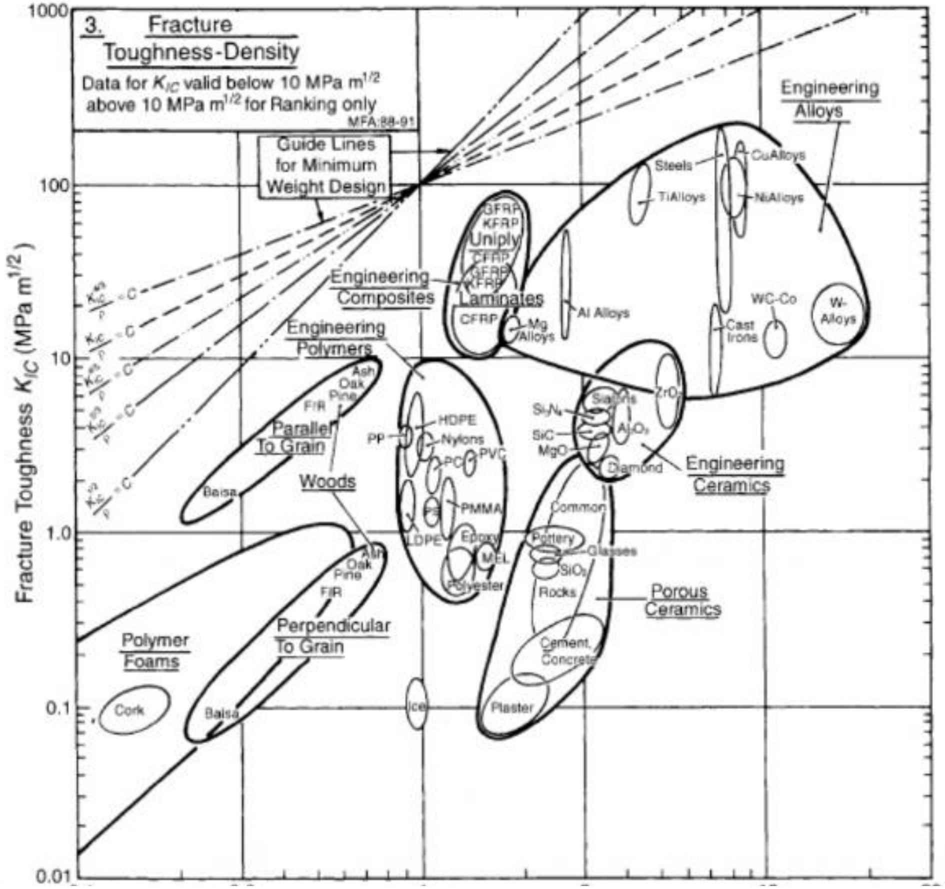

Figure 70 Material diagram: Fracture toughness vs Density

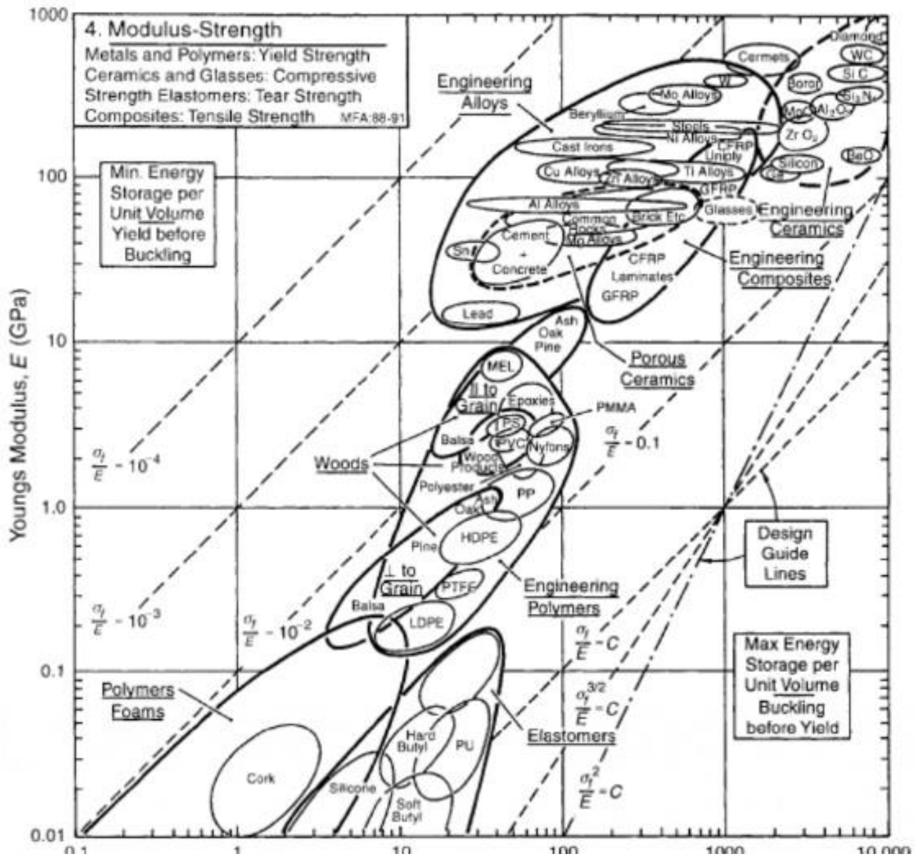

Figure 71 Material diagram: Young modulus vs Strength

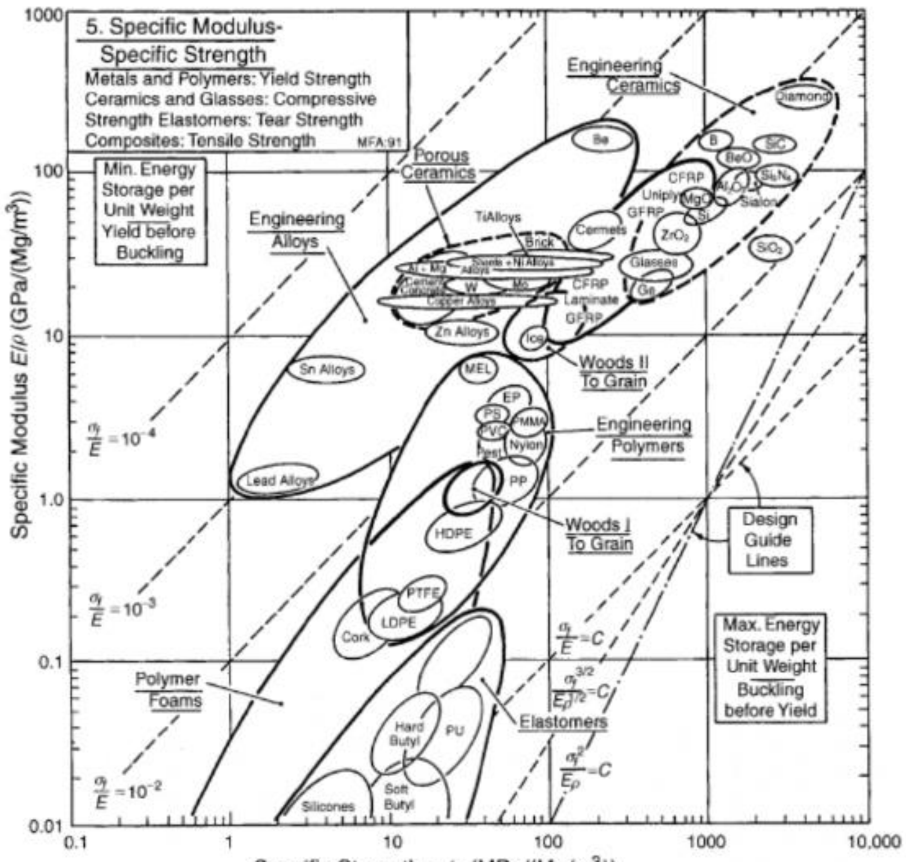

Figure 72 Material diagram: Specific modulus vs Specific strength

Annex 3: CubeSat specification drawings

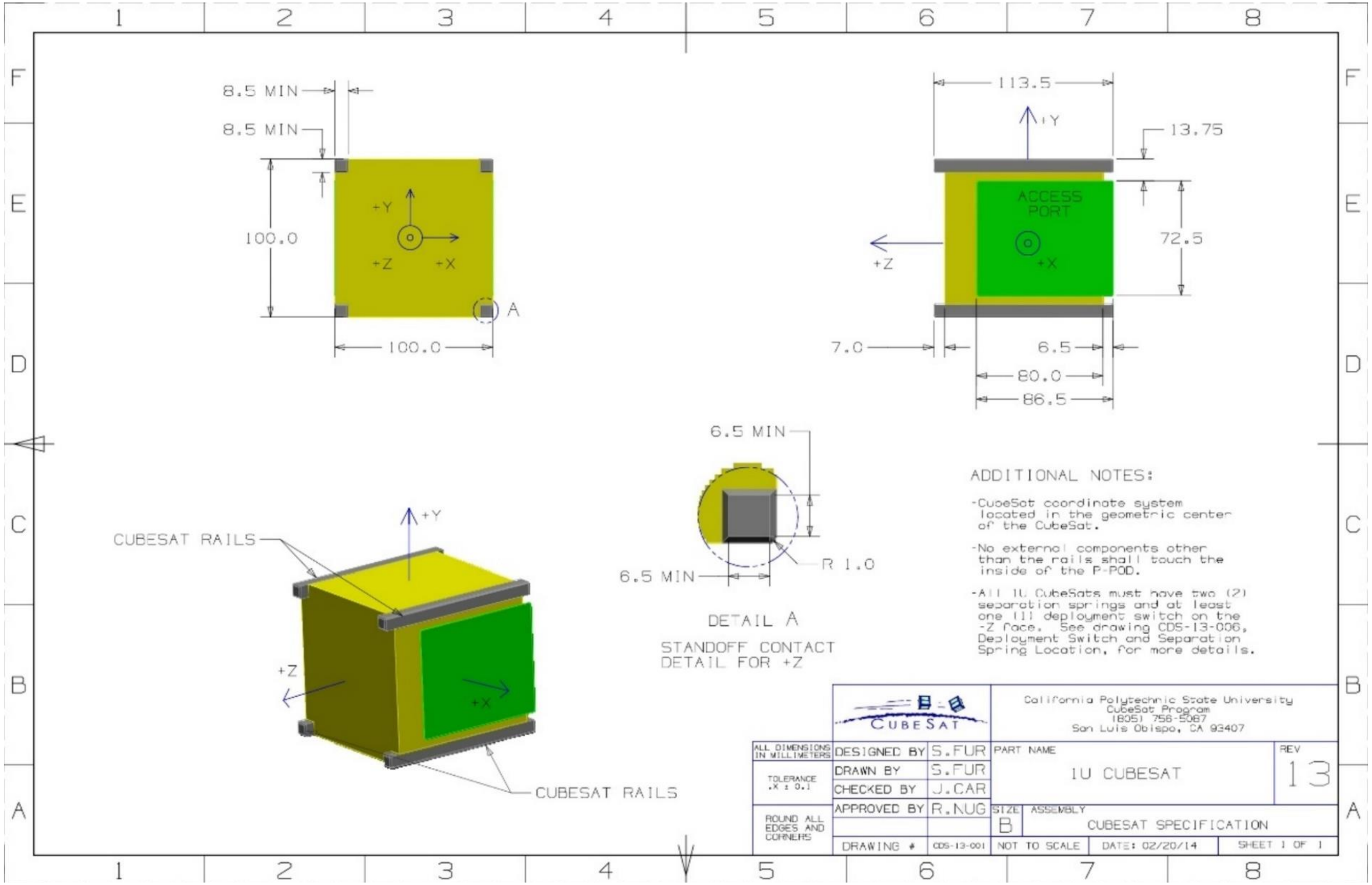

Figure 73 1U CubeSat design specification drawing

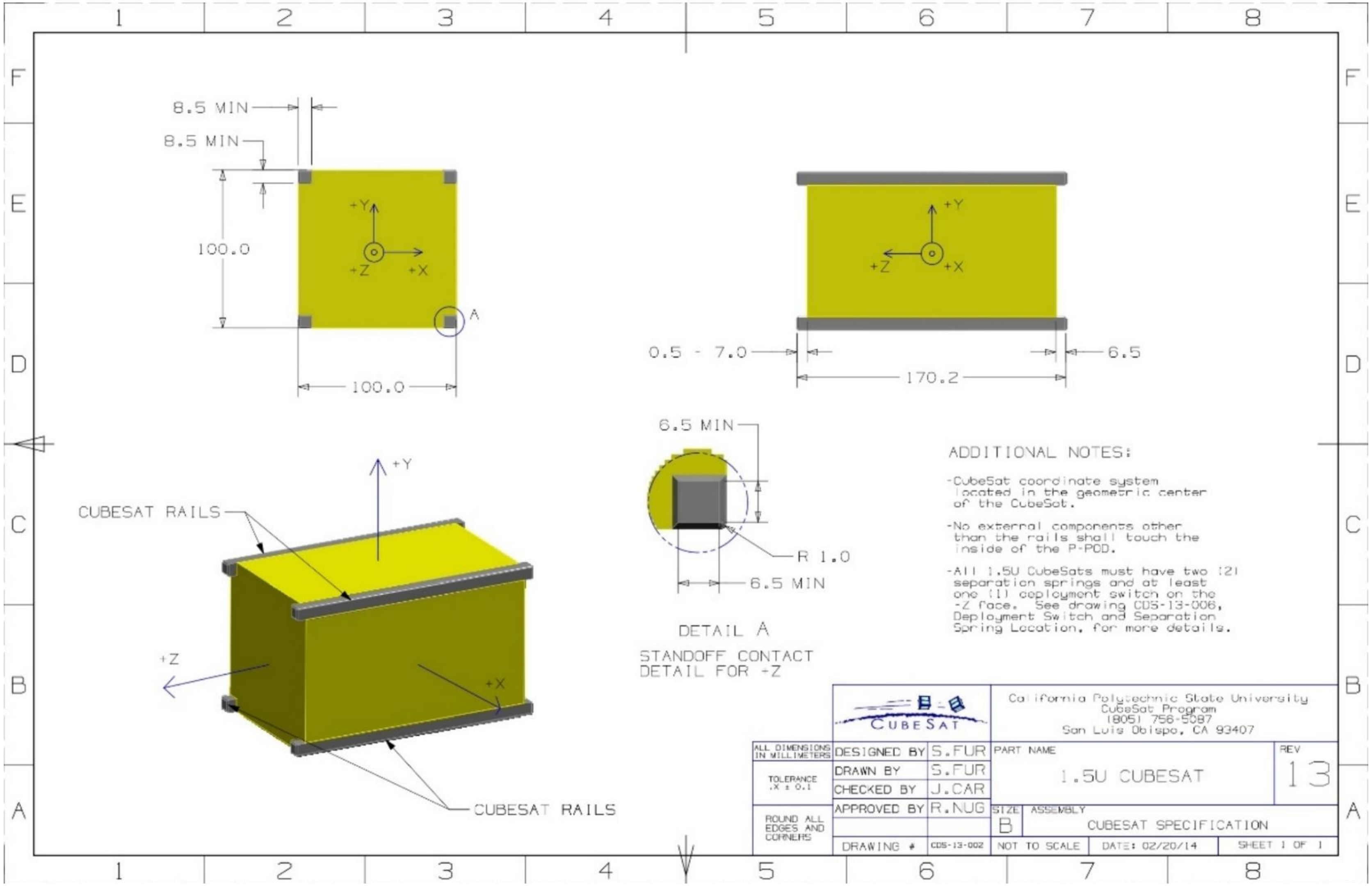

Figure 74 1.5U CubeSat design specification drawing

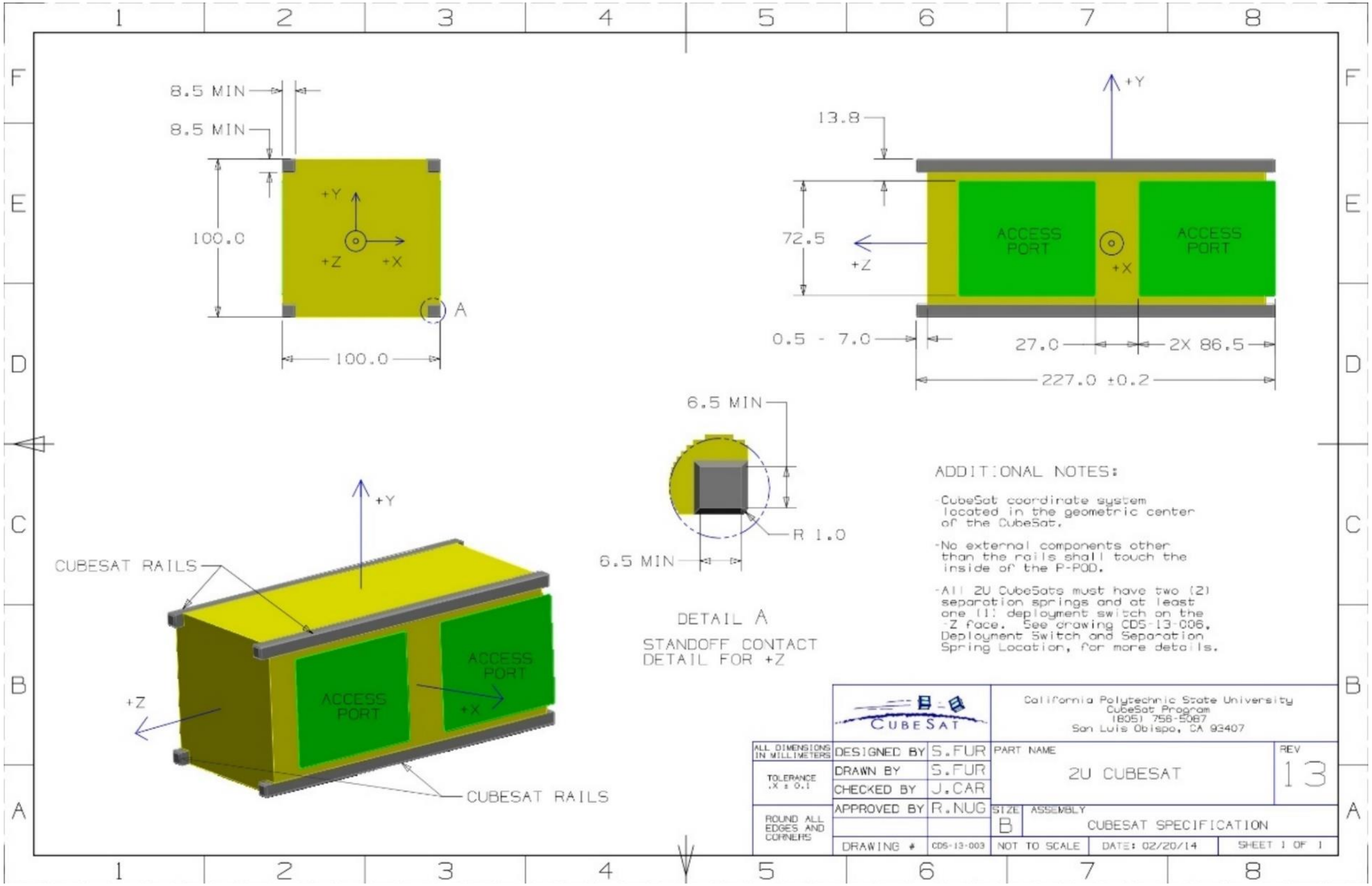

Figure 75 2U CubeSat design specification drawing

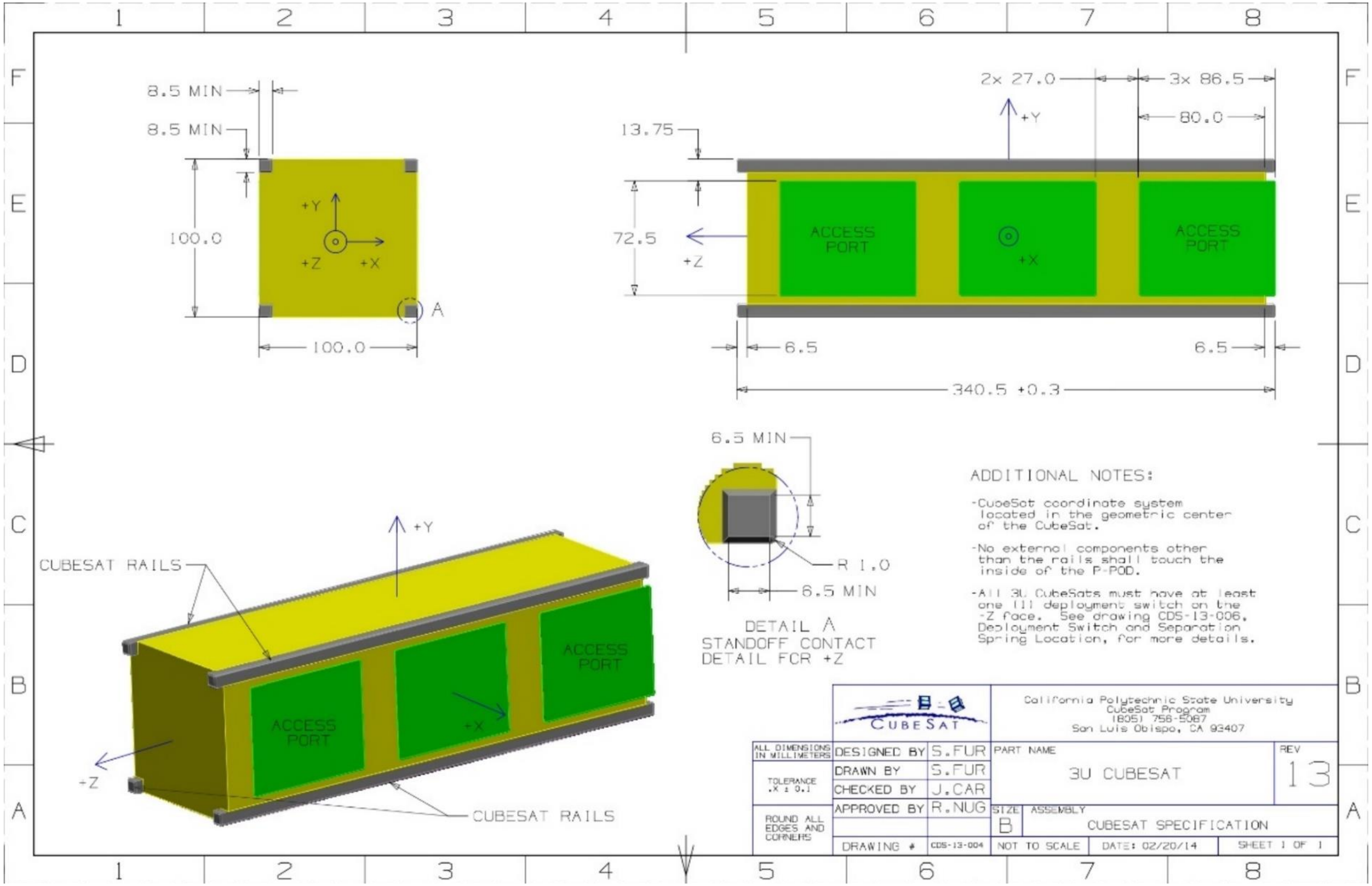

Figure 76 3U CubeSat design specification drawing

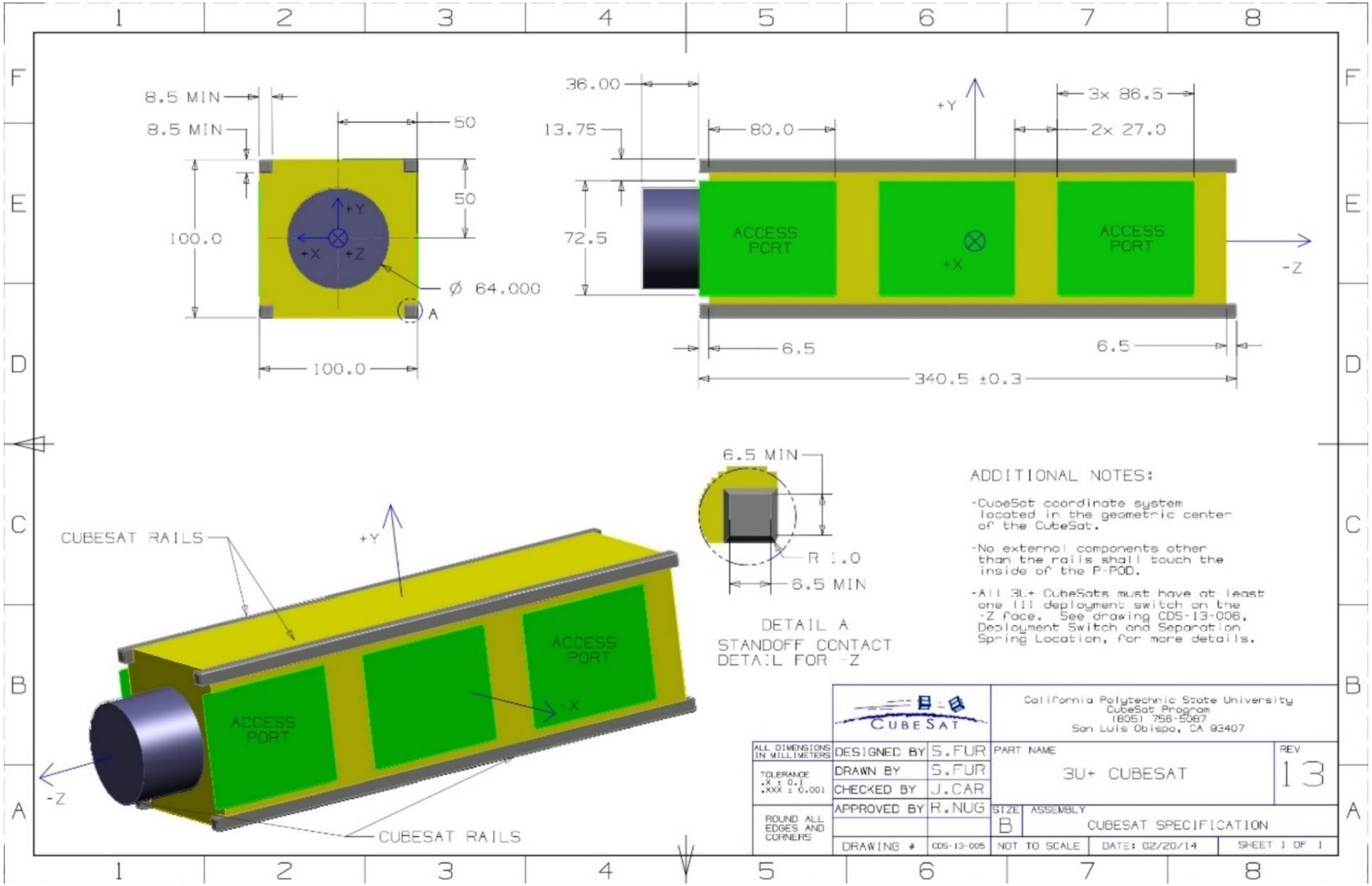

Figure 77 +3U CubeSat design specification drawing

Annex 4: Device motion simulation

In this annex a simple movement simulation of each design may be found.

Magnetic beam

Magnetic beam - Simulation.mp4

Magnetic lock

Magnetic lock - Simulation.mp4

Rotary latch

Rotary latch - Simulation.mp4