ESCUELA SUPERIOR DE INGENIERÍA Y TECNOLOGÍA

Final Bachelor Thesis

DESIGN OF THE MECHANICAL STRUCTURE FOR THE TEIDESAT CUBESAT

Studies:

Mechanical Engineering Bachelor

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APPENDIX A: FEM ANALYSIS

Abbreviated terms

1U	1 unit CubeSat
2U	2 unit CubeSat
3U	3 unit CubeSat
AL	Acceptance test Load
AOCS	Attitude Orbit Control System
ATV	Automated Transfer Vehicle
CAC	CubeSat Acceptance Checklist
Cal Poly	California Polytechnic State University
CNC	Computer Numerical Control
CoG	Center of Gravity
CS	CubeSat
CVCM	Collected Volatile Condensable Material
DLL	Design Limit Load
DUL	Design Ultimate Load
DYL	Design Yield Load
ECSS	European Cooperation for Space Standarization
ESA	European Space Agency
FEM	Finite Elements Method
FOS, FS, SF	Factor Of Safety
FOSY	Yield Design Factor of Safety
FYS	Fly Your Satellite
GTO	Geostationary Transfer Orbit (35786 km)
HTV	H-II B Transfer Vehicle
IAC	Instituto de Astrofísica de Canarias
IOD	In-Orbit Demonstration
ISS	International Space Station
JAXA	Japanese Aerospace Exploration Agency
JEM	Japanese Experiment Module
JEMRMS	JEM Remote Manipulator System
J-SSOD	JEM Small Satellite Orbital Deployer
KA	Acceptance test Factor
K_{LD}	Local Design Factor
K_M	Model Factor
K_P	Project Factor
KQ	Qualification test Factor
LEO	Low Earth Orbit (160 – 2000 km)
LL	Limit Load
MRR	Most Restrictive Requirements
NRCSD	NanoRacks CubeSat Deployer

PLA	Polylactic Acid
P-POD	Poly-Picosatellite Orbital Deployer
QL	Qualification test Load
RBF	Remove Before Flight
RoD	Review of Design
SRS	Shock Response Spectrum
TML	Total Mass Loss
VCM	Volatile Condensable Material
VP	Verification Plan

Terms and definitions

CubeSat

CubeSat is a standardized nanosatellite (1-10 kg mass). The most common form factor is a 1U, which is a 10 cm cube approximately. There are multiple CubeSat configurations based on the 1U form factor such as a 2U (22cm x 10cm x 10cm), 3U (34cm x 10cm x 10cm), 6U (34cm x 20cm x 10cm) etc.

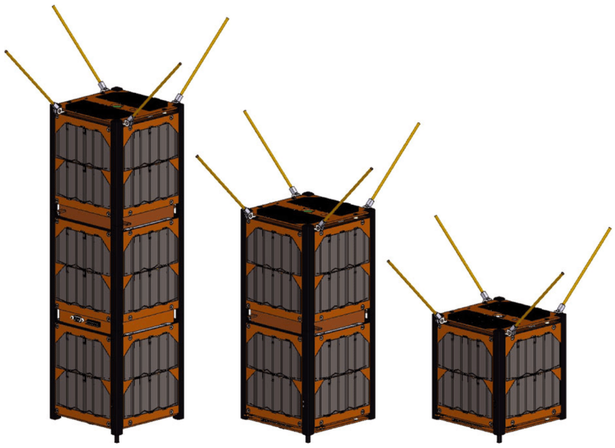

Figure 1: 3U, 2U, 1U CubeSats [1]

Dispenser

The dispenser is the physical container of the CubeSat which provides a standard interface between nanosatellites and launch vehicle. It also serves as a deployment system for CubeSats. It reduces cost and development time by using the standardized sizes for CubeSats. The most common dispenser is called a 3U dispenser, where different combinations of CubeSats fit: 3x1U, 1x1U + 1x2U or 1x3U. Furthermore, there are other dispensers using the CubeSat form factor of 6U. The dispensers are versatile, with a small profile and the ability to mount to different launch vehicles in a variety of configurations.

By the time launch vehicle reaches established altitude, launch vehicle sends a signal to open the spring-loaded door of dispenser, then the satellites are deployed from the dispenser by means of a spring and glide along smooth flat rails as they exit the deployer. It is remarkable the existence of deployment switches and separation springs in CubeSats top and bottom faces. They are inserted inside the corner guides as seen in Figure 3.

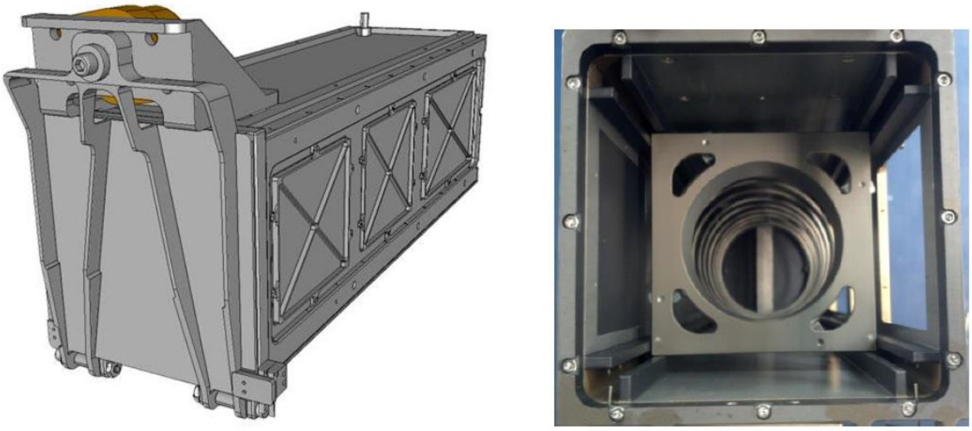

Figure 2: CubeSat deployer [2]

Figure 3: Deployment switch [3]

Payload

A spacecraft payload is a set of instruments or equipment which performs the user mission, the scientific objective.[4]

Platform

A satellite platform is a set of equipment which supports the payload (mechanical structure, On Board Data Handling, electrical power system, communications, Attitude Control and Orbit System (AOCS)…)

Space Segment

Set of elements or combination of systems placed in space that fulfils space mission objectives.[4]

System

Set of interrelated or interacting functions constituted to achieve a specified objective. [4]

Subsystem

Part of a system fulfilling one or more of its functions. [4]

Equipment

Integrated set of parts and components that accomplishes a specific function. The term "unit" is synonymous with the term "equipment".[4]

Component

Set of materials, assembled according to defined and controlled processes, which cannot be disassembled without destroying its capability and which performs a simple function that can be evaluated against expected performance requirements. The term "part" is synonymous. [4]

TeideSat

Is a group of interdisciplinary students from Universidad de La Laguna whose objective is to build a CubeSat 1U, tutored by IACTEC, and participate in Fly Your Satellite (FYS) competition organised by European Space Agency (ESA). This programme enhances engineering and science students to design and build low-cost and non-complex satellites to provide them with knowledge and experience in aerospace industry. Teams entering the programme have ESA tutoring, facilities and launch opportunity.

IACTEC

IACTEC is a technological and business collaboration space set up by the Instituto de Astrofísica de Canarias (IAC) to promote cooperation between the public and private sectors by boosting the creation of quality employment and the generation of high added-value technological products with a high commercialization potential, both nationally and internationally [5]. One of the lines of action of IACTEC is the Microsatellite Programme, which is directly related to this project.

European Cooperation for Space Standardization (ECSS) definitions

For the purpose of this document, the terms and definitions from ECSS-ST-00-01[4] apply. Furthermore, there is a clause with definitions in all ECSS standards applied in this document.

space segment	space segment system	space segment element	space segment subsystem	space segment equipment (=unit)	component (=part)	material
product or **item**						
examples						
	Data Relay Satellite System	spacecraft (physical view)	power	electronic unit (e.g. DHU, PCSU, PDU, ICU)	ASIC	Alumiunium
	Navigation Satellite System	satellite (physical view)	propulsion	thruster	hybrid	to be taken from Q60 & Q70
	spacecraft (functional view)	payload	data handling	valve	integrated circuit	
	satellite (functional view)					
		platform	thermal	battery	heat-pipe	
		instrument	structure	reflector	MLI	
		orbiter	AOCS	mechanism (when fully assembled)	structural panel	
		lander	Tm&Tc	vessel/tank	optical array	
		bay	optical	mirror/lenses/filters (assembly)	pyro components	
		module	RF	solar array (assembly)	PCB	
			communication	antenna (assembly)	mirror	
				focal plane assembly	solar cell	
				telescope (assembly)	insert	
				solar panel (equipped)	resistor	
				pressure vessels	diode	
				optical bench	transistor	
				RF filters	capacitor	
				LNA	thermistor	
				IMUX/OMUX	heater	
				OMT	propulsion fluidic	
				feeds		

Figure 4: Space segment structure [4]

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0. Identification page

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Date:	04/07/2018

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1. Purpose

The aim of this project is to produce a first version of the 1U CubeSat structural design, that is part of the satellite TeideSat.

The Microsatellite project team from IACTEC is also petitionary of this bachelor thesis because they are interested in gathering requirements a CubeSat must meet to be launched and verification procedures, so that they can develop their own nanosatellites. Furthermore, they want to check whether it is possible to manufacture a CubeSat that meets specifications with IAC resources.

2. Scope

This project will be focused on the space segment, more concisely, one CubeSat subsystem: the mechanical structure. A 1U CubeSat model will be developed. All requirements referred to the mechanical structure are applicable. However, the specifications for propulsion system and CubeSat re-entry will not be taken into account, as it will not be needed for the mission of TeideSat.

There are some parts of the physical CubeSat interface that will not be taken into account for this project because of its limited extension of it: bolts that connect the different parts, deployment switches and separation springs.

The verification process will include tests, analysis, inspections and reviews of design. Nevertheless, some tests needed for verification process will not be performed because the necessary equipment is not operationally available in IAC and because of the limited extension of the project. Those tests are related to: shocks, random vibrations, sinusoidal vibrations and static and quasi-static loads.

3. Abstract

The aim of this project is to produce a first version of the 1U CubeSat structural design, that is part of the satellite TeideSat. For this purpose, an exhaustive research was made in order to define requirements to be met by CubeSat mechanical structure. However, launching means have not been defined yet hence; the most restrictive combination of specifications is chosen to limit his design. This way, whichever launcher is selected at the end, the CubeSat structural design will fulfil all requirements.

After design, the CubeSat structure is manufactured using aluminium 6061 T6 as material in IAC's mechanical workshop. Finally, the verification process of the design is carried out. It is necessary to check dimensions and stiffness of the mechanical structure. That being so, metrology equipment and Finite Elements Method (FEM) analysis are used. As a result, not all requirements are compliant. Therefore, this structure's design is not valid to be launched to space. However, some solutions are exposed to be applied for the following versions of the structure as the mission progresses.

The main sections of this document develop the different stages of the project. In the State of the art section, it is explained which requirements for the CubeSat structure must be fulfilled and how they were found. In the Requirements conventions section, the notation

and the nomenclature used to define requirements are explained. This is due to the major importance of standardization in aerospace field. The Study of solutions section is divided in the 3 main stages of the designing process of a CubeSat mechanical structure: Design, Manufacturing and Verification. The Design part includes dimensional requirements and criteria taken into account to develop the design. The Manufacturing part explains the process involved to manufacture a product in IAC and departments involved. The Verification part includes the comparison of each requirement to be meet with the manufactured CubeSat characteristics. Finally, in the Conclusions, results of the whole process are exposed and solutions to the non-compliant requirements are given.

4. References

The following documents and webpages are referenced to develop this document. All the documents are free access or are written by the author. For dated references, subsequent amendments to, or revision of any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

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5. State of the art

The CubeSat Project was developed by CalPoly and Stanford University's Space Systems Development Lab. The Project is an international collaboration of universities, high schools, and private firms developing nanosatellites containing scientific, private, and governmental payloads. The aim of the CubeSat program is to provide access to space for small payloads. [2]

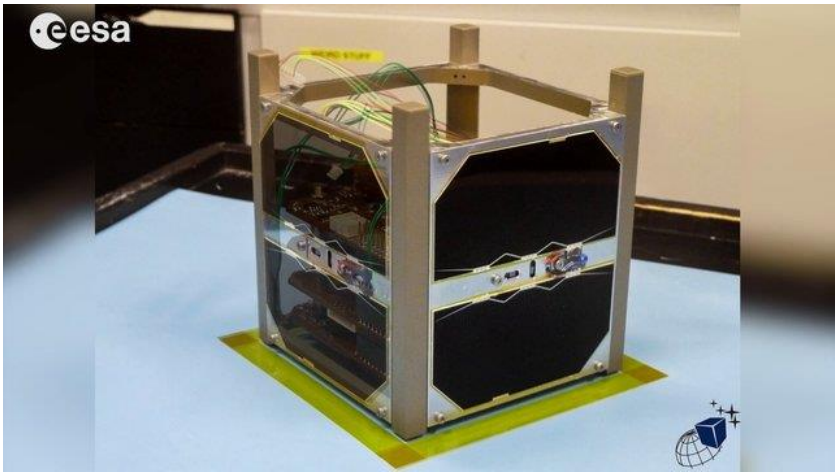


Figure 5: CubeSat example [6]

CubeSat projects for In-Orbit Demonstration (IOD) purposes in Low Earth Orbit (LEO) are generally characterized by the following attributes:

- Complete stand-alone systems including platform, payload, ground segment & operations
- Higher risk acceptance profile
- Low level of complexity
- Low cost and short schedule (typically <1 M Euro and <2 years to flight readiness)
- Short operational lifetime (typically <1 year in low altitude LEO)
- Limited redundancy
- Extensive use of commercial off-the-shelf elements (modules that have previous flight heritage and are supplied by small industrial suppliers at a fixed price)
- Extensive testing focussed on system level. [7]

As it is a standardized nanosatellite there are many specifications CubeSat design must meet. For a CubeSat mission, there are 3 entities that will provide requirements that the nanosatellite must fulfil:

- Mission Integrator
- Launch Vehicle
- CubeSat dispenser or deployer

The mission integrator is the organization that conducts the mission. It may be a space agency, like ESA, National Aeronautics and Space Administration (NASA), Japanese Aerospace Exploration Agency (JAXA), or the CubeSat designer itself.

The launch vehicle is in charge of bringing the satellite to the proper altitude. CubeSat launch opportunity normally comes from a rocket with a primary mission, different from the CubeSat one, with available space, in which the dispenser will be located. It is essential that the secondary missions, like the nanosatellite ones, do not interfere with the primary one.

The dispenser is the physical container of the CubeSat which provides a standard interface between nanosatellites and launch vehicle. It also serves as a deployment system for CubeSats.

In the aerospace field, satellite missions have some uncertainty at the design stage of the project related to launch. As the design of the satellite is far away in time from the launch, it is not frequent to know the deployment system and launch vehicle from the beginning. For this reason, not all the requirements are clear from the start. In consequence, the requirement list that will be used to design the CubeSat must take into account as many launch options as possible.

Help from IACTEC [5] team and FYS programme [8] gave necessary information to start searching for requirement sources for CubeSats. Some useful documents were related to Q-B50 project [9], [10]. QB50 is an international network of CubeSats developed by university students for multi-point, in-situ measurements in the lower thermosphere and re-entry research [11]. Q-Bito satellite, from Universidad Politécnica de Madrid, is one of them. A related bachelor thesis was a key document to help in the development of this project [12].

This investigation task results in a list that gathers the maximum amount of technical requirements that may affect the mechanics of a CubeSat of 1U, 2U or 3U. This list is contained in the document "Mechanical requirements collection for CubeSats"[13]. Using this collection, it is easy to choose the most restrictive specifications, so that the CubeSat can be launched by any launcher taken into account in the writing of the document. The extract of the first list is contained in the document "Most restrictive mechanical requirements for CubeSats"[14]. These two documents were written as part of this bachelor thesis in order to support the development of the mechanical design of TeideSat. However, both of them will also be used for the mechanical design of nanosatellites developed by IACTEC. That is the reason why requirements for 1U, 2U and 3U CubeSats are included, even though TeideSat is a 1U CubeSat, so that they are useful for IACTEC current and upcoming projects.

Finally, a third list is written. In this case, only requirements applicable to the engineering model are included. This cut off is applied to conform the definitive collection of specifications that must be verified in the manufactured CubeSat as part of this bachelor thesis. Only structural requirements will be included. Therefore, there will not be requirements related to mechanisms, fracture control, AOCS, optic, pressurized hardware, Electric Power System, Electronic System, Thermal Control System, magnetic fields… This document is "Requirements for CubeSats to meet in bachelor thesis"[15] attached in appendix B. In Figure 6 there is a graphical explanation of relationships between these 3 requirements documents and filtration stages.

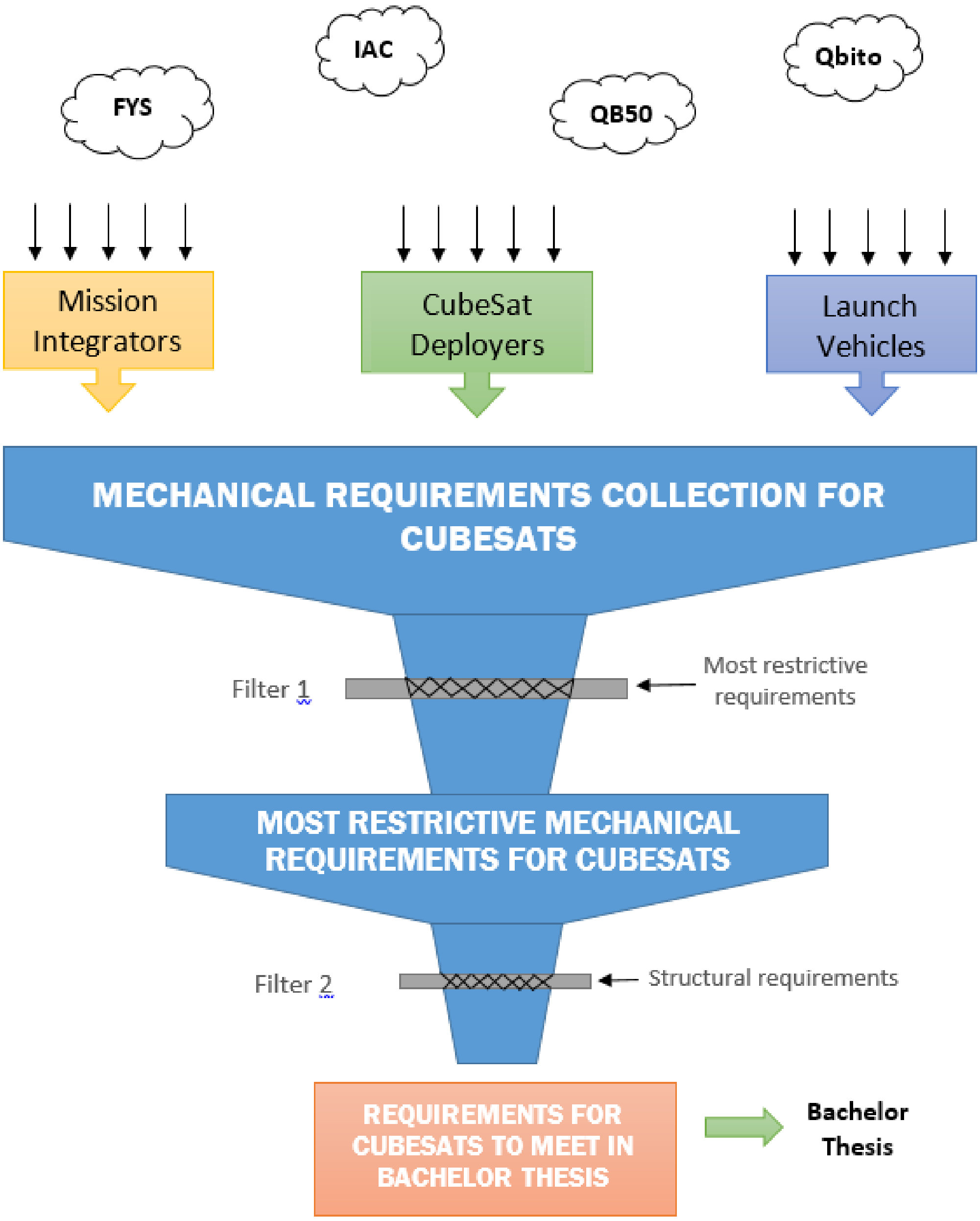


Figure 6: Requirements documents filtration

5.1. Requirements sources

The following requirement sources were taken into account for the writing of the different lists of requirements.

5.1.1. Mission integrator:

ESA was chosen as mission integrator because it represents European space activities and organises FYS programme. Besides, ESA and European national agencies work with European Cooperation for Space Standardization (ECSS). ECSS is an initiative established to develop coherent, single set of user-friendly standards for use in all European space activities. Thus, following ECSS standards means that some minimum requirements are fulfilled. Those requirements may be in terms of safety factors, verification processes, test accuracies, materials, redundancy, documentation and others. On this basis, ECSS standards are used to develop the design and verification stage of TeideSat mechanical structure. However, not all standards are applicable for CubeSat projects due to their lack of complexity compared to other ESA projects, specific tailoring is applied [7].

5.1.2. Launch Vehicles:

Many launch vehicles are used around the globe to put satellites into orbit. Nevertheless, only launchers that provide LEO deployment for small payloads or supply to ISS are considered. Apart from direct deployment of CubeSat from the launch vehicle into space, there is another common option: deployment from ISS using the Japanese Experiment Module Remote Manipulator System (JEMRMS), a robotic arm intended for supporting experiments out of the station. The CubeSats (contained in their dispenser) are installed by an astronaut on the sliding table of the Japanese Experimental Module (JEM). The table with the dispenser is moved outside of the station via the airlock. The dispenser is then grabbed by the robotic arm and moved into the correct position for deployment.

In consequence, these launch vehicles were taken into account to write the requirement lists:

- Delivery of small satellites at LEO
  - Vega: world's broadest range of commercial launch services (developed by ESA) [16]
  - Ariane 5 ES (developed by ESA) [17]
  - Ariane 5 ECA: reference for punctual delivery of satellites (developed by ESA) [17]
  - Soyuz: for orbit satellites that are not suited to Ariane 5 or Vega. (developed by ESA) [18]
  - Delta II (developed by NASA) [19]
- Resupply vehicle for ISS
  - HIIB Transfer Vehicle (HTV) [20]
  - Automated Transfer Vehicle (ATV) (developed by ESA) [20]
  - Ariane 5 ES (developed by ESA) [17]
  - Soyuz ISS Cargo (developed by ESA) [18]
  - Space X Dragon (developed by a private company) [20]
  - Orbital ATK's Cygnus (developed by NASA) [20]

Some other launch vehicles were studied, but they were not considered for the following reasons:

- Delta IV: used for heavy payloads (developed by NASA)
- Atlas V: used for heavy payloads (developed by NASA)
- LM-3A Series: used for Geostationary Transfer Orbits (GTO) (developed by China National Space Administration)
- Polar Satellite Launch Vehicle (PSLV): is a versatile vehicle for launching multiple satellites in LEO, polar orbits and GTO (developed by Indian Space Research Organization). The user manual of the vehicle was not free-access.

5.1.3. Dispensers or deployers:

- Poly-Picosatellite Orbital Deployer (P-POD). It was developed by California Polytechnic State University (Cal Poly). A collaboration between Cal Poly and Stanford University was responsible of creating the standard nanosatellite model known as CubeSat nowadays. In consequence, "CubeSat Design Specification"[2], the document where all its specifications are exposed, is the basis for all CubeSat developers. P-POD is the most used deployer for CubeSats.
- NanoRacks CubeSat Deployer (NRCSD). Based on P-POD. NanoRacks is the only commercial organization that can deploy CubeSats from the International Space Station (ISS) using the JEMRMS. Its specifications are exposed in "NanoRacks CubeSat Deployer Interface Control Document" [21].
- JEM Small Satellite Orbital Deployer (J-SSOD). Based on P-POD. It is used for CubeSat deployed from ISS using the JEMRMS. Its specifications are exposed in "JEM Payload Accommodation Handbook. Small Satellite Deployment Interface Control Document" [20].

As P-POD is the most common deployer for CubeSat missions, its specifications will be chosen to conform the satellite requirements for this project. However, as it is possible that TeideSat is deployed from ISS, it is necessary to take into account requirements from J-SSOD and NRCSD that are more restrictive than the former one.

In Figure 7 there is a graphical explanation about CubeSat options considered for deployment and launch.

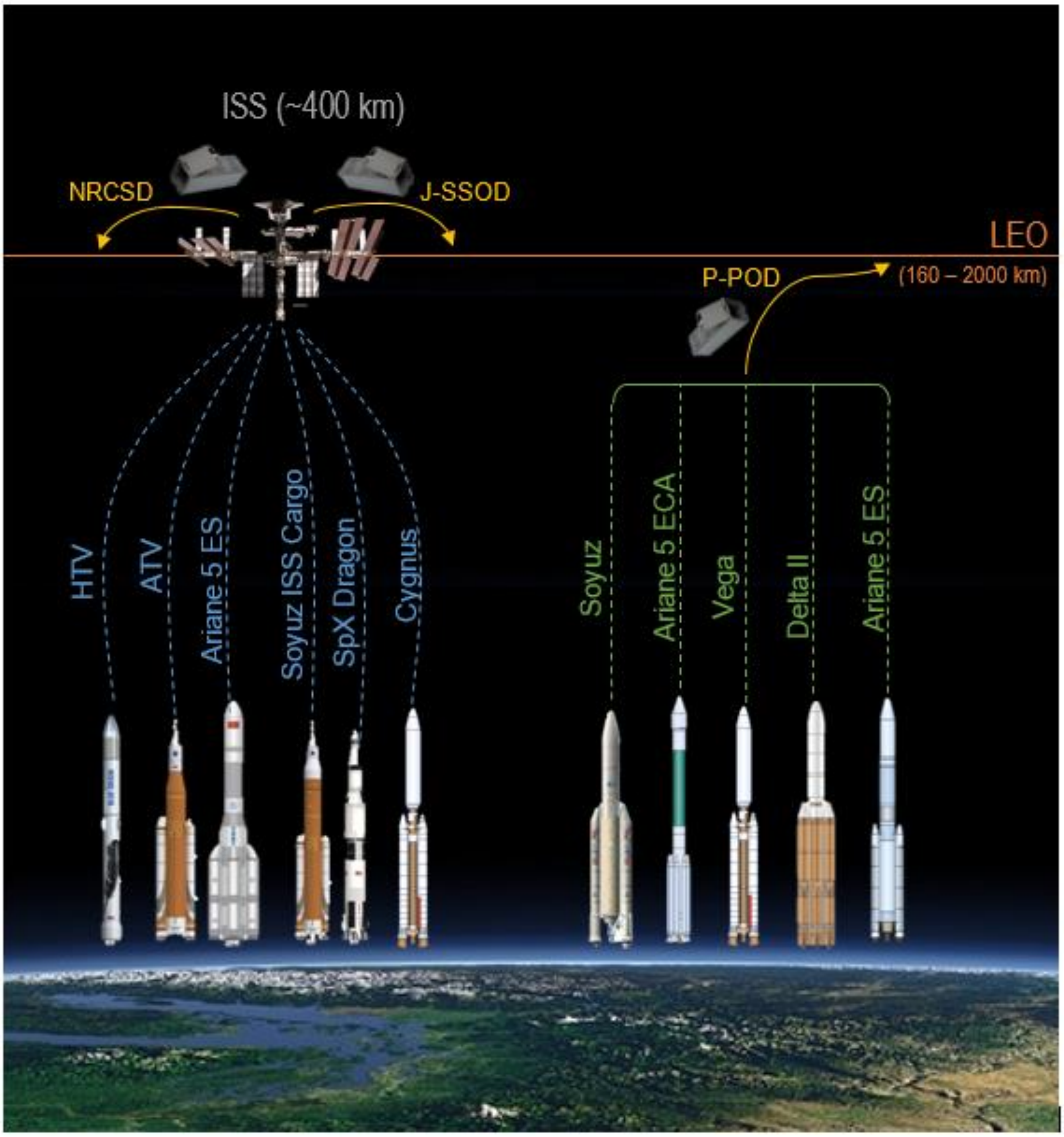


Figure 7: CubeSat launch and deployment options

6. Requirements conventions

6.1. Notation

All requirements in this document are denoted as

X. Reference-Source-N.N.N

Requirement text.

NOTE

Where:

- **X:** indicates number of requirement related to "Requirements for CubeSats to meet in bachelor thesis"[15] list.

- **Reference-Source-N.N.N:** indicates the requirement ID number according to chapter and section found in its document reference source. Possible reference sources are:
  - CDS: CubeSat Design Specification, California Polytechnic [2]
  - NRCSD-ICD: NanoRacks CubeSat Deployer Interface Control Document [21]
  - JX: JEM Payload Accommodation Handbook - Vol. 8 - Small Satellite Deployment Interface Control Document [20]
  - MRR: Most Restrictive Mechanical requirements for CubeSats [14]
  - SOYUZ-CSG: Soyuz User's Manual [18]
  - VEGA: Vega User's Manual [16]
- *Requirement text:* describes the requirement.
- *NOTE:* (optional) provides additional information regarding the requirement.

6.2. Nomenclature

The following nomenclature applies throughout requirements of this document:

a. The word "shall" is used to express requirements.
b. The word "should" is used to express recommendations.
c. The word "may" is used to express positive permission.
d. The words "need not" are used to express negative permission.
e. The word "can" is used to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.

NOTE: In ECSS "may" and "can" have completely different meanings: "may" is normative (permission), and "can" is descriptive.

f. The present and past tenses are used to express statements of fact, and therefore they imply descriptive text.

7. Study of solutions

7.1. Design

This project is the first iteration on the design of the mechanical structure as part of the mission TeideSat. Design criteria are two:

- **Stiffness**. A stiff structure is needed to survive launch and space environments, especially when the most demanding requirements of CubeSat industry are applied.
- **Lightness**. The lighter the structure, the better because then there is more mass margin for the payload, which is not defined yet. This is important in order to fulfil requirement 8 of "Requirements for CubeSats to meet in bachelor thesis"[15] outlined below.

8. CDS-3.2.10

The maximum mass of a 1U CubeSat shall be 1.33 kg.

Based on this criteria and some already existing CubeSat models, design process starts.

Figure 8: CubeSat structure examples [22]–[24]

However, a more conservative design than the ones shown in Figure 8 is chosen. As payload mass is still unknown, stiffness criteria gains importance and stiffer plates are designed with more material. In IAC there is a CubeSat model manufactured with additive procedures (3D printer) in polylactic acid (PLA). It was used as a preliminary design of the mechanical structure in order to define the definitive version. Furthermore, it was helpful to define analysis settings and understand the results of the FEM analysis (see appendix A) because it helps engineers to visualize effects of loads.

Once model is chosen, structure must be designed so that applicable requirements are fulfilled. These are requirements from "Requirements for CubeSats to meet in bachelor thesis"[15].

1. **CDS-3.2.1**

   The CubeSat shall use the coordinate system as defined in the figure below for the appropriate size. The origin of the CubeSat coordinate system is located at the geometric center of the CubeSat.

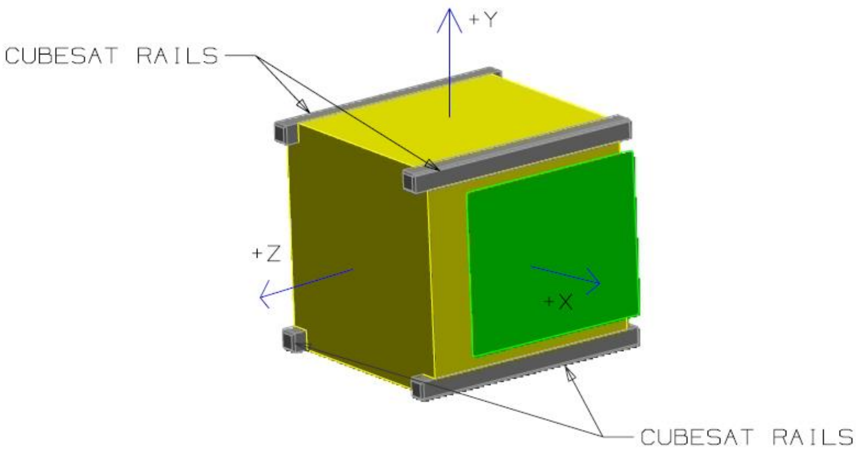


Figure 9: CubeSat configuration [2]

2. **JX-2.1.2.2**

   The dimensional requirements for a CubeSat are defined in Figure 10.

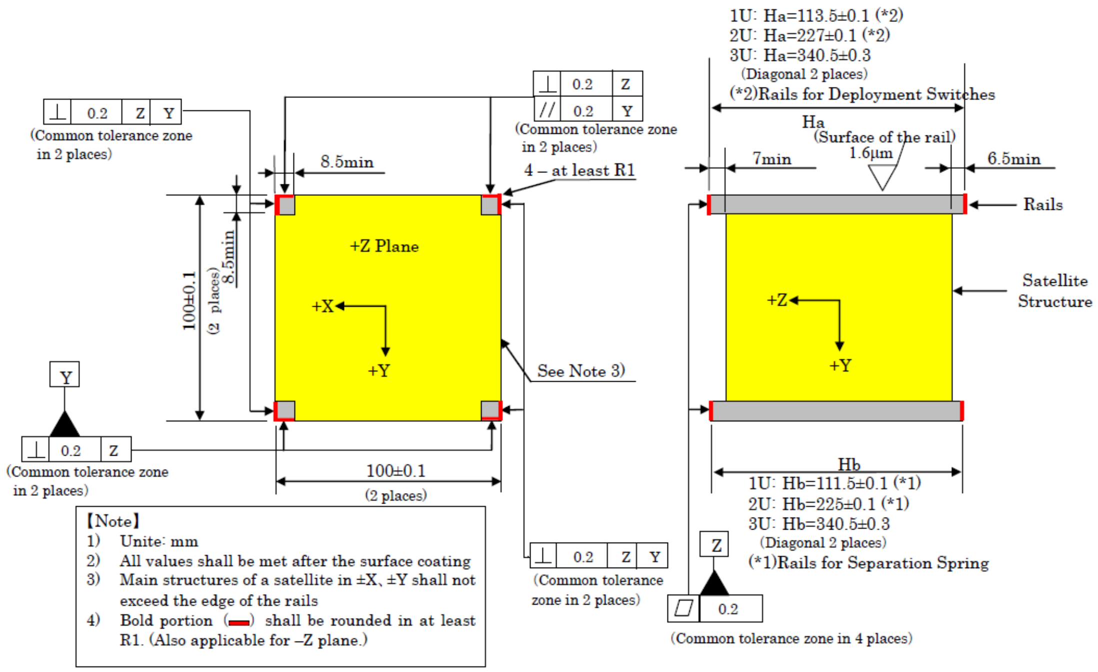


Figure 10: Dimensional requirements for CubeSats

3. JX-2.1.4.2

The main structure of a satellite in +Z shall be recessed more than 7.0mm from the edge of the rails. All components in +Z shall be recessed more than 0.5mm from the edges of the rails.

4. JX-2.1.4.3

The main structure of a satellite in -Z shall be recessed more than 6.5mm from the edge of the rails. All components in -Z shall be recessed from the edges of the rails.

7. JX-4.2.2.1.1

In order to protect crewmembers from sharp edges and protrusions during all crew operations, they need to be rounded or planed greater than 0.7mm to the utmost. If a satellite has any potential sharp edges which cannot be rounded or planed (ex. An edge of a solar cell), a satellite provider shall identify the sharp edge positions with an acceptance rationale for JAXA approval.

Holes (round, slotted) without covers need to be 25 mm or longer, or be 10 mm or shorter in diameter.

10. NRCSD-ICD-4.4

The CubeSat center of gravity shall be within 2cm of its geometric center.

14. NRCSD-ICD-4.6.1

A CubeSat shall have four (4) rails, one per corner, along the Z axis.

15. CDS-3.2.5

Rails shall have a minimum width of 8.5mm.

18. CDS-3.2.7

The edges of the rails will be rounded to a radius of at least 1 mm

20. CDS-3.2.8

The ends of the rails on the +/- Z face shall have a minimum surface area of 6.5 mm x 6.5 mm contact area for neighbouring CubeSat rails.

Using the Academic Version of CREO Parametric, the different parts and the final assembly are created. Furthermore, PTC Windchill software was used to save and manage version control and collaborative work.

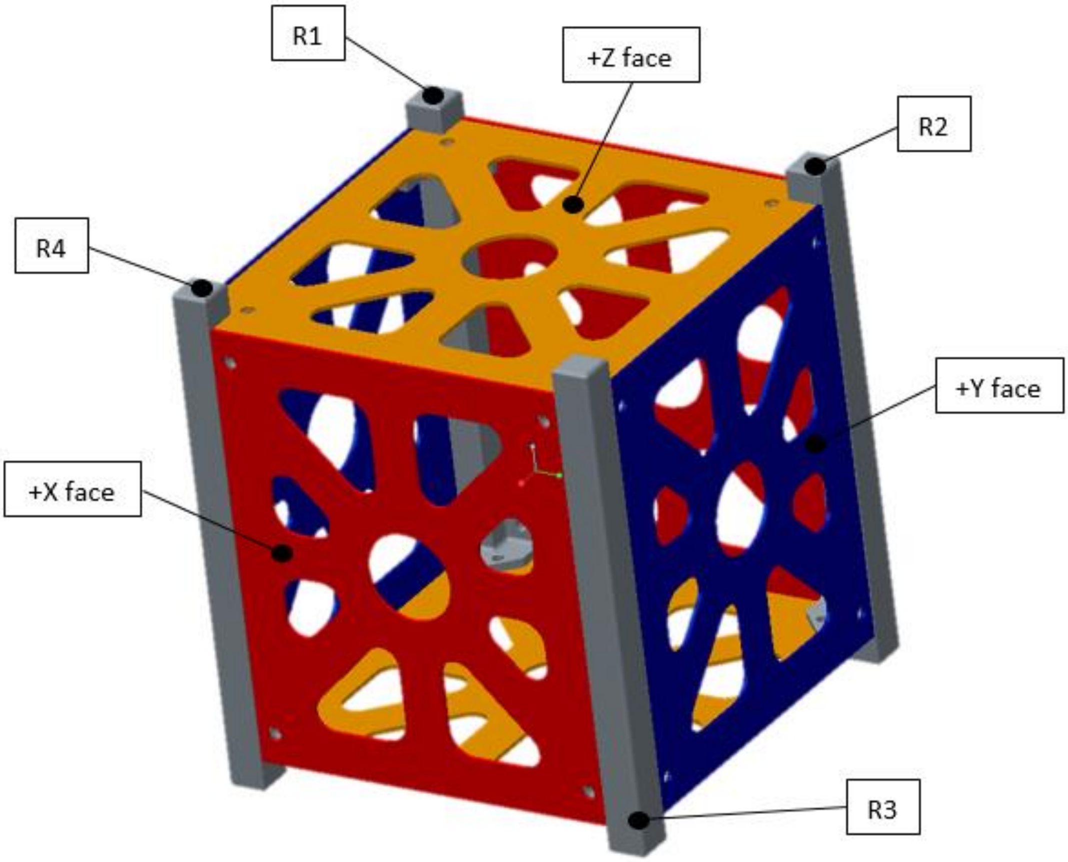


Figure 11: 3D CubeSat model

It is formed by 10 parts:

- 2 top/bottom plates perpendicular to Z direction (orange plate)
- 4 lateral panels perpendicular to X and Y direction (red and blue plates)
- 2 spring rails in Z direction (R1 and R3)
- 2 switch rails in Z direction (R2 and R4)

These parts have an identification code following IACTEC product tree, which helps organizing and differentiate products from different projects and field.

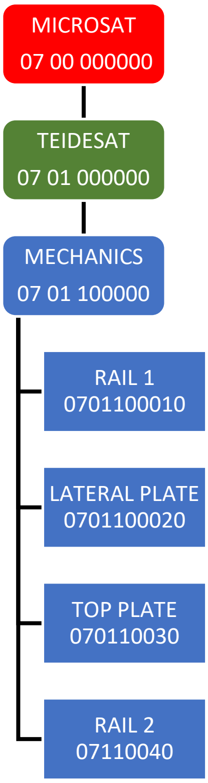


Figure 12: Product tree

Apart from lightness and stiffness criteria, manufacturing was taken into account for design phase. Plate thickness was modified because preliminary design value was not available in mechanical workshop stock. Each plate is connected to rails with 4 M3 bolts.

There are two types of rails, the ones that have inserted springs or inserted switches for deployment. They are almost the same, except for total length as specified in Figure 10. Rails for separation springs are 2 mm shorter than rails for deployment switches. Apart from that, 4 of them have rounded edges in the visible edges when assembled as required by 18.CDS-3.2.7. Besides some inner edges had to be rounded in order to simulate machining, because by the time of manufacture, machine cannot make a perfect inner corner. It must have some radius that simulates machine tool. On each rail bracket there are 3 threaded holes for M3 bolts.

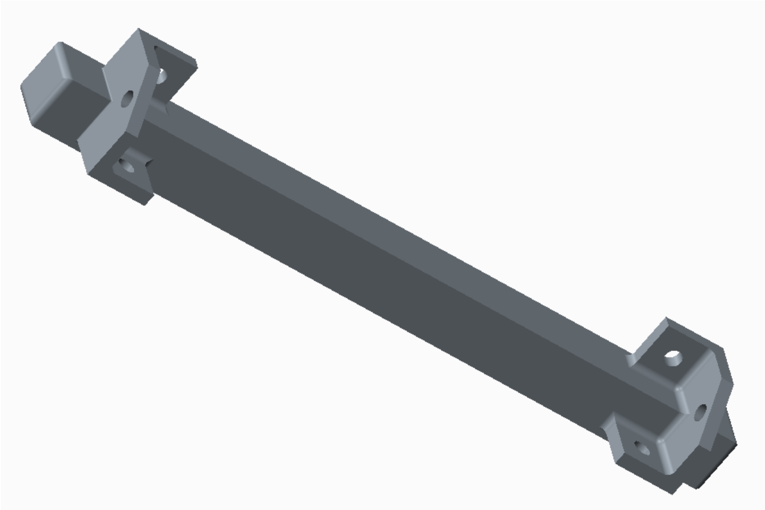


Figure 13: Rail for separation spring

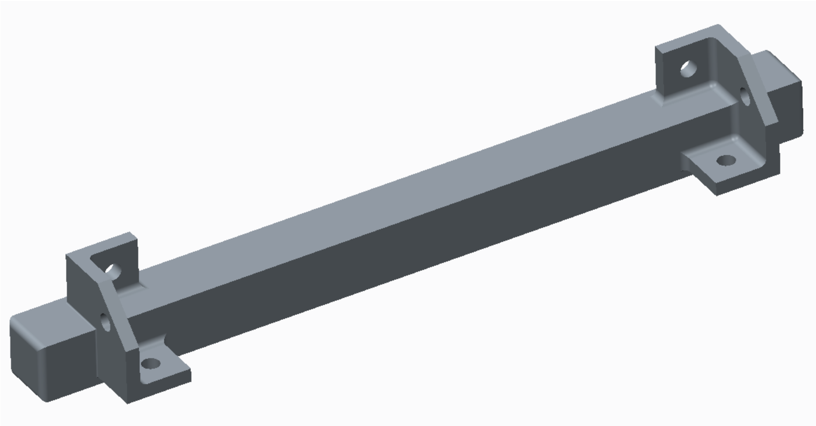


Figure 14: Rails for deployment switch

Each plate has 4 drills for M3 bolts.

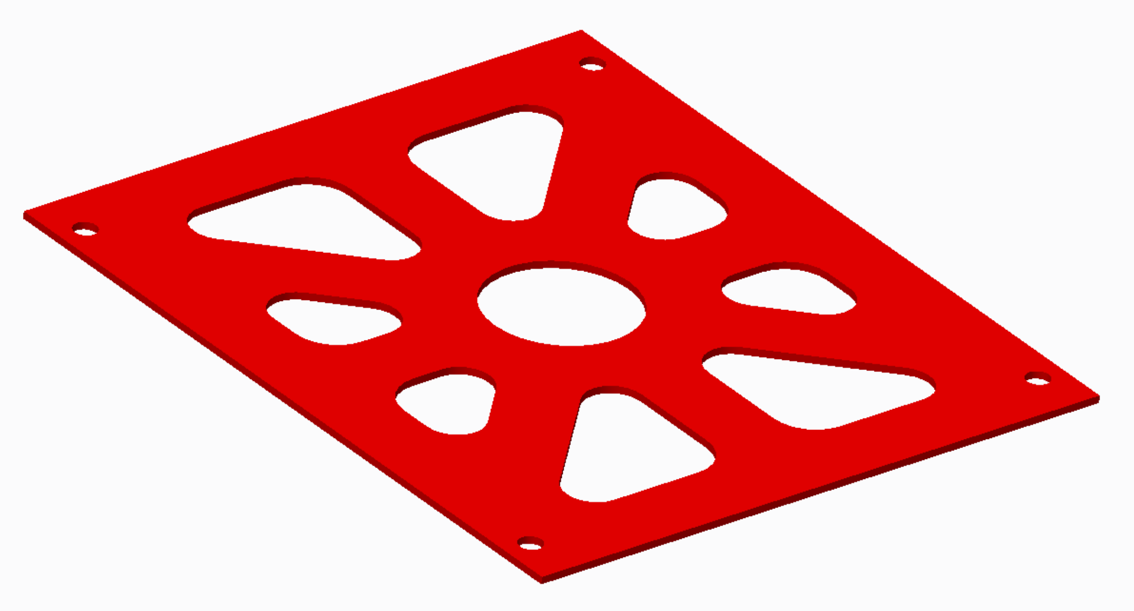


Figure 15: Lateral plate

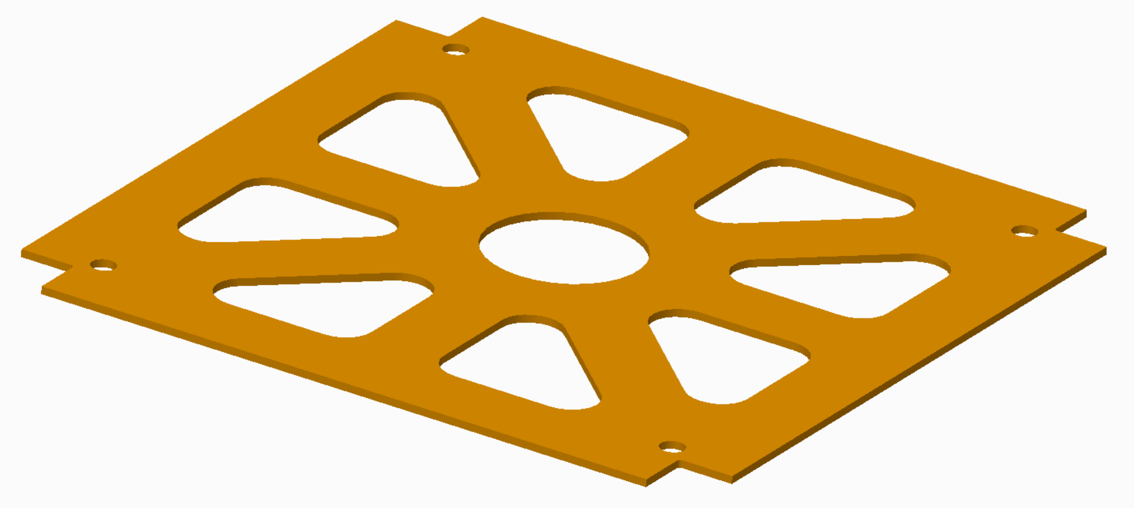


Figure 16: Top/bottom plate

There is also a requirement about material used for CubeSat structure mentioned below.

11. CDS-3.2.15

Aluminum 7075, 6061, 5005, and/or 5052 will be used for both the main CubeSat structure and the rails.

Therefore, material chosen was Al 6061 T6. Aluminium 6061 is a precipitation-hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. It has good mechanical properties, combines relatively high strength, good workability, and high resistance to corrosion; exhibits good weldability, and is widely available. However, the most important factor is that it has already been tested in space. T6 is a type of tempered grade available in Instituto de Astrofísica de Canarias.

Requirements also include tolerances and surface roughness. In appendix C there are drawings of each part. Applied tolerances are those established in the following rules, unless a more restrictive parameter is specified on the drawing;

- UNE-EN 22768:1994. General tolerances. [25]
- UNE-EN ISO 1302:2002. Surface quality. [26]
- UNE-EN ISO 1101:2017. Geometrical Tolerancing - Tolerances of Form, Orientation, Location And Run-Out. [27]

Nevertheless, in general all UNE rules applicable are applied.

7.2. Manufacturing

In Instituto de Astrofísica de Canarias there is an established manufacturing process engineers must follow when they want to manufacture some parts. When design is made by the engineer, engineering drawings are made by the draftsmen of IAC. Next, the engineer must revise the drawings so that all measurements are specified, tolerances are correct, required rules are applied… After the corresponding errors are solved, engineering drawings are sent to the mechanical workshop to machine the parts. Once manufacturing is finished, parts are sent to the metrology laboratory in order to check whether design indications were followed, because machining equipment may be imbalanced or tool precision may not be good enough. In case that pieces do not fulfil engineer’s design requirements and are not useful for operation, then they are modified or remanufactured in the mechanical workshop. Last but not least, new engineering drawings with real measurements are made by the drafsmen.

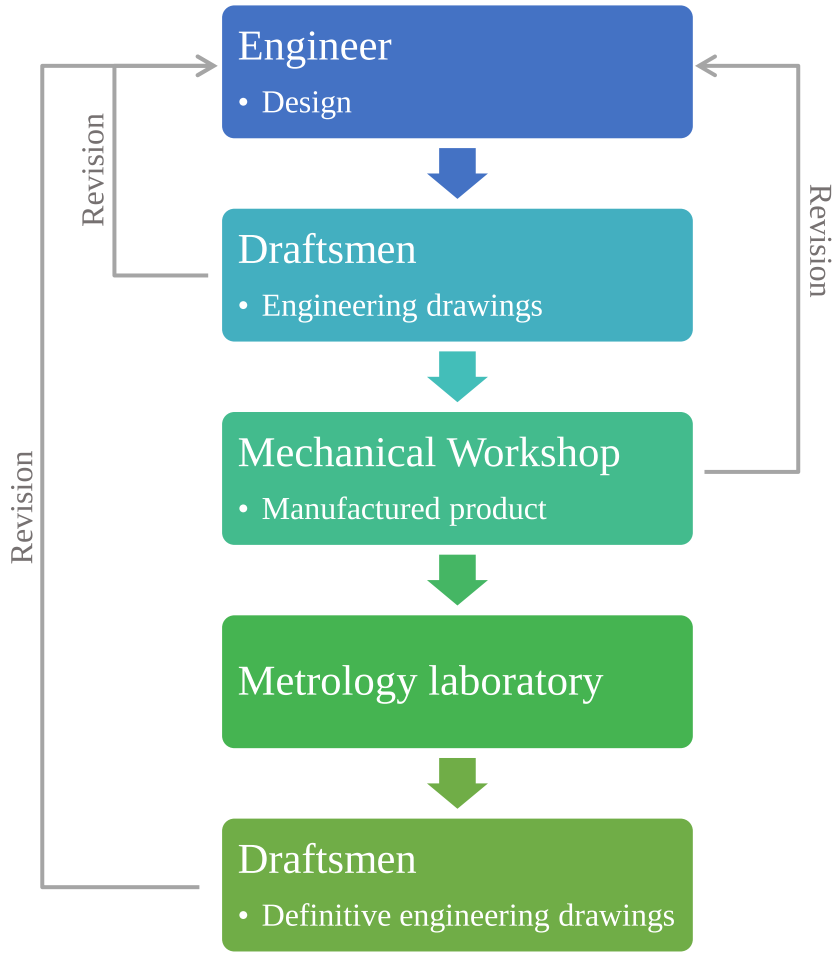


Figure 17: Manufacturing process

For the purpose of verifying dimensional requirements, the CubeSat was manufactured. The process mentioned was followed. First, engineering drawings were made and revised (see attached documents in appendix C). Then, machining process was developed using two different machines for the different parts.

- Rails were manufactured in a lathe-milling machine with 5 axis of movement make MAZAK. It is a Computer Numerical Control (CNC) machine. Rails were machined from a single block of aluminium as it can be seen in Figure 18.

Figure 18: Lathe-milling machine

- Plates were machined in a milling machine with 3 axis of movement from MAZAK brand. It is a CNC machine. These pieces were cut from a bigger plate of aluminium with the proper thickness and machined with the mill in order to make the holes.

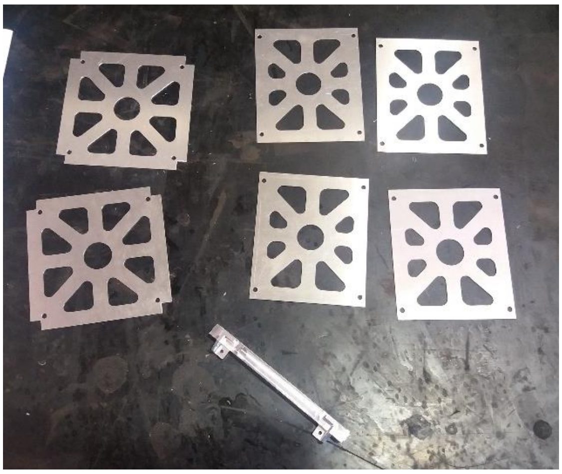


Figure 19: Manufactured pieces

Finally, parts were sent to metrology laboratory, where necessary measurements to verify requirements were made (see Metrology report in appendix F). First, individual pieces were measured. Thereupon, all CubeSat elements were integrated with M3 bolts, so that assembled satellite could be measured.

Figure 20: Metrology equipment measuring a rail

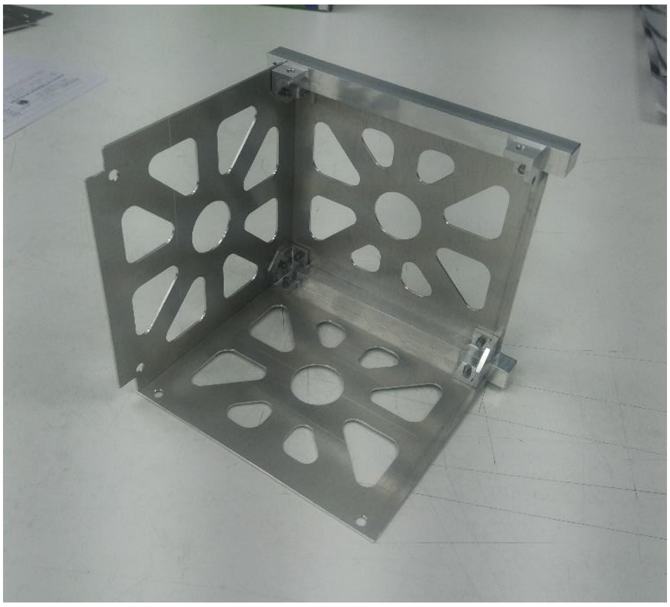


Figure 21: Integration process

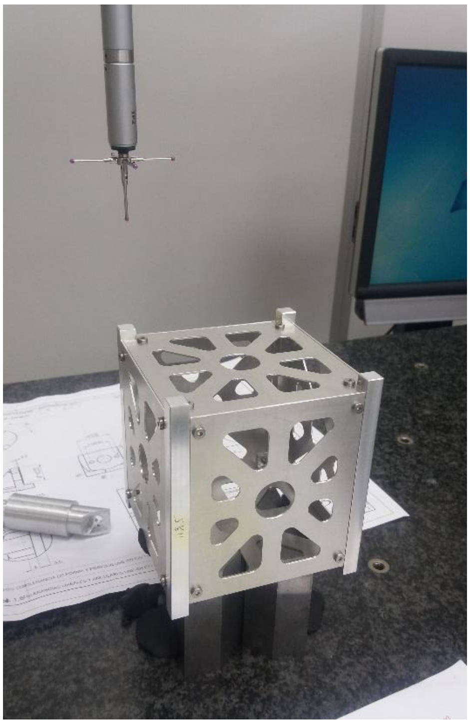


Figure 22: metrology equipment measuring the assembled CubeSat

7.3. Verification

Verification process involved in this project follows indications from "Verification and testing tailored standards" [28] attached in appendix D. This document contains the tailored requirements applicable for CubeSats in terms of verification (standard ECSS-E-ST-10-02C [29], [30]) and testing (standard ECSS-E-ST-10-03C [31]). Tailoring for CubeSats is based on [7].

The overall objective of verification is to demonstrate, through a dedicated process, that the deliverable product meets the specified requirements. This process is formed by:

- Verification planning;
- Verification execution and reporting;
- Verification control and close-out.

7.3.1. Verification Planning

To reach the verification objectives the verification approach is established in early phases of a project by analysing the requirements to be verified. First, it is necessary to identify "what" are the products and requirements subject of the verification process. Next step is identifying "how" to verify them by considering the methods stated in the technical specification.

7.3.1.1. Requirements

Requirements to be fulfilled for this bachelor thesis are 29. They are exposed in "Requirements for CubeSats to meet in bachelor thesis"[15] attached in appendix B.

These specifications are related to CubeSat dimensions, mass, material, center of gravity and natural frequencies, and to the launch and space environment nanosatellite has to survive, like pressure and thermal conditions, sinusoidal and random vibrations, quasi-static loads and shocks.

7.3.1.2. Verification levels

The verification is performed incrementally at different product decomposition levels. The number and type of verification levels depends upon the complexity of the project and on its characteristics. The usual verification levels for a space product are equipment, subsystem, element, segment and overall system.

In this case, CubeSat structure is studied, so verification process will be at subsystem level as it is specified in Figure 4.

7.3.1.3. Verification stages

The verification process is implemented in subsequent verification stages along the project life cycle. The stages depend upon project characteristics and identify a type of verification. The verification stages are qualification, acceptance, prelaunch or protoflight, inorbit and postlanding. Each stage has different verification procedures based on different safety factors and test durations.

For CubeSats, at system and subsystem level, qualification and acceptance shall be performed simultaneously on the protoflight model. Therefore, verification previous to launch will be carried out only at protoflight stage.

7.3.1.4. Verification methods

The verification is executed by one or more of the following verification methods: test, analysis, review of design and inspection. This list shows the order of precedence that, in general, provides more confidence in the results.

- **Test:** Verification by test shall consist of measuring product performance and functions under representative simulated environments.
- **Analysis:** Verification by analysis shall consist of performing theoretical or empirical evaluation.
- **Review of design (ROD):** Verification by Review-of design shall consist of using approved records or evidence that unambiguously show that the requirement is met.

  NOTE Examples of such approved records are design documents and reports, technical descriptions, and engineering drawings.

- **Inspection**: Verification by inspection shall consist of visual determination of physical characteristics.

Depending on the stage of the study, in order to verify a specification, test may be held obligatory. In Table 1 protoflight tests are exposed. Only mechanical tests related to requirements from “Verification and testing tailored standards”[28] (see appendix D) are concerning this project. It means that the following tests must be held to verify CubeSat structure:

- Physical properties test
- Static test.
- Random vibration test. As the space segment is small and compact, an acoustic test is not useful, so a random vibration is needed. This is specified in Table 1.
- Sinusoidal vibration test
- Shock test. It is needed as structure is a shock-critical item.

Modal survey test will not be needed because lifetime of CubeSat is not long enough (1 year approximately) to justify it.

Besides, static, random vibration, sinusoidal vibration and shock tests will not be part of this bachelor thesis because of extension and lack of operational test equipment at the Instituto de Astrofísica de Canarias. Only physical properties tests will be held.

In order to verify requirements which do not need tests or substitute tests which cannot be held, CubeSat developer is free to choose other verification method based on his own criteria.

Test	Reference clause	Ref. to Level & Duration & Number of applications	Applicability	Conditions
Mechanical				
Physical properties	6.5.2.1		R	
Modal survey	6.5.2.2		X	
Static	6.5.2.3	Table 6-6 No 1	X	Mandatory if not performed at structure subsystem level
Spin	6.5.2.4	Table 6-6 No 2	X	Mandatory for spinning space segment elements with an acceleration greater than 2 g or more to any part of the space segment element
Transient	6.5.2.5	Table 6-6 No 3	X	
Acoustic	6.5.2.6	Table 6-6 No 4	X	Acoustic test may be replaced by random vibration. For a small compact space segment element, acoustic testing does not provide adequate environmental simulation, and random vibration may replace the acoustic test. If acoustic test is performed, random vibration may be avoided.
Random vibration	6.5.2.7	Table 6-6 No 5	X	
Sinusoidal vibration	6.5.2.8	Table 6-6 No 6	R	Sinusoidal vibration may be replaced by transient combined with modal survey
Shock	6.5.2.9	Table 6-6 No 7	X	
Micro-vibration susceptibility	6.5.2.10	Table 6-6 No 8	X	
R Mandatory X To be decided on the basis of design features, required lifetime, sensitivity to environmental exposure, and expected usage.				

Table 1: Mechanical protoflight test baseline [28]

In appendix E, there is the Verification Matrix attached. It includes requirements to be verified (with reference to the specifications involved), verification methods, levels, stages and results of verification process that will be explained in the section.

7.3.1.5. Load check

For analysis whose requirements involve a load, two checks are necessary: the yield strength of the material must be higher than stress caused by design yield load (DYL); and deformation cannot be higher than gap between CubeSat and deployer walls shown in envelope image, based on requirement:

5. JX-2.1.4.4

The main structures of a satellite in +/-X and +/-Y shall not exceed the side surface of the rails. Any components in these surfaces shall not exceed 6.5mm normal to the side surface of the rails including the RBF pin.

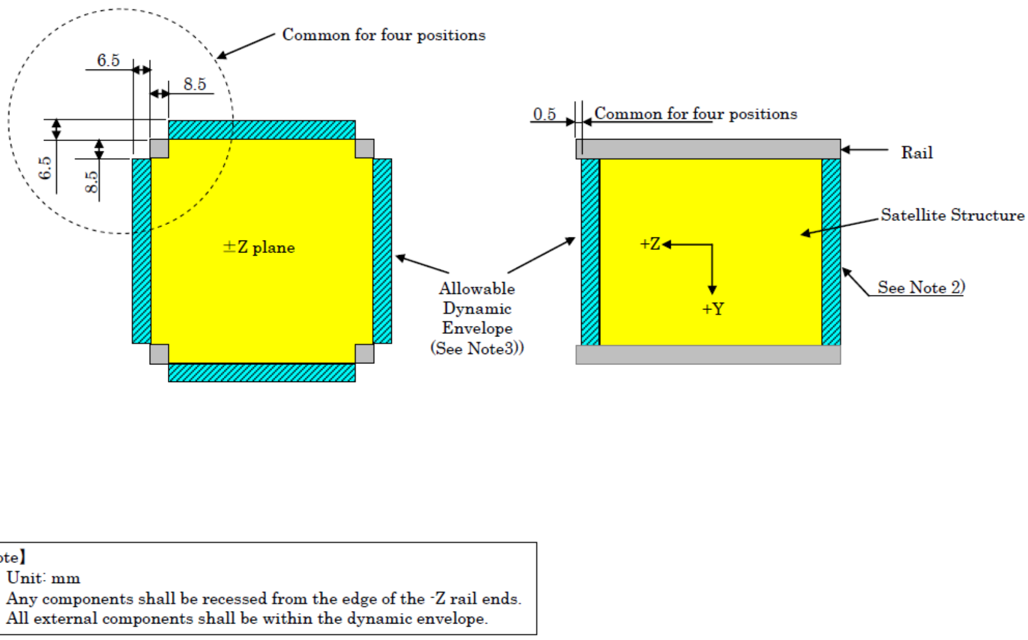


Figure 23: CubeSat envelope requirements

In conclusion, limits not to be surpassed are:

Tensile yield strength of Al 6061 T6	Deformation
275.79 MPa	6.5 mm

Table 2: Limits to be respected to fulfil requirements

DYL is the one to be included in FEM analysis data. It is also possible to compare the ultimate strength, but as permanent deformation must be avoided for the structure of the spacecraft, the restricting parameter will be the yield strength (275.79 MPa for Al 6061 T6 [32]).

For the purpose of calculating DYL, the limit loads specified by requirements will be multiplied by Coefficient A and Coefficient B, as it is shown in Figure 24 from the ECSS standard about Structural factors of safety for spaceflight hardware [33]. Those coefficients depend on factors of safety and others (Table 3).

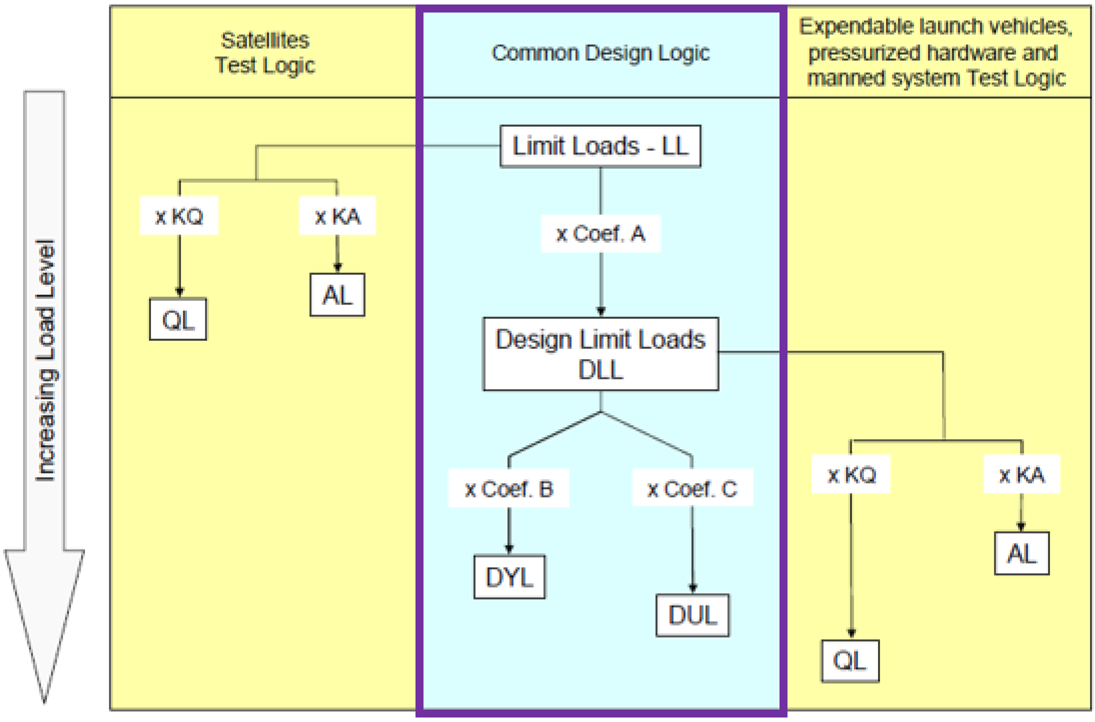


Figure 24: Logic for Factors of Safety application (Figure 4-1 [33])

Coefficient	Satellite	Launch vehicles and pressurised hardware	Man-rated systems
Coef A or Design factor	KQ x K_P x K_M	K_P x K_M	K_P x K_M
Coef B	FOSY x K_{LD}	FOSY x K_{MP} x K_{LD}	FOSY x K_{LD}
Coef C	FOSU x K_{LD}	FOSU x K_{MP} x K_{LD}	FOSU x K_{LD}

Table 3: Relationship among (structural) factors of safety, design factors and additional factors (Table 4-1 [33])

Therefore, DYL will be calculated as,

$$DYL = LL * Coef\ A * Coef\ B = LL * KQ * K_P * K_M * FOSY * K_{LD}$$

where,

KQ ≡ Qualification factor, used to define qualification test loads.

K_P ≡ Project factor, "factor which takes into account at the beginning of the project the maturity of the design and its possible evolution and programmatic margins which cover project uncertainties or some growth potential when required."[33]

K_M ≡ Model factor, factor which takes into account the representativity of mathematical models.

FOSY ≡ Yield design factor of safety.

K_{LD} ≡ Local Design factor, factor used to take into account local discontinuities.

Factor	Value	Justification
KQ	1.25	Table 4
K_P	1.2	**ECSS-E-ST-32-10C- 4.1.4.3a:** KP shall be applied to account for the maturity of the program and the confidence in the specification given to the project. Typical values of 1,2 are used for satellites at the beginning of new development.
K_M	1.2	**ECSS-E-ST-32-10C- 4.1.4.2a:** KM shall be applied to account for uncertainties in mathematical models when predicting dynamic response, loads and evaluating load paths. Typical values of 1,2 are used for satellites at the beginning of new development.
FOSY	1.25	Table 5
K_{LD}	1	**ECSS-E-ST-32-10C- 4.1.5.2a:** KLD shall be applied when the sizing approach or the local modelling are complex. It is not this case.
TOTAL	**2.25**	-

Table 4: Safety factors used in ANSYS analysis [33]

To this end, the resultant safety factor applicable to Limit Loads given by requirements will be 2.25, as shown in the equation below.

$$DYL = LL * KQ * K_P * K_M * FOSY * K_{LD} = LL * 1.25 * 1.2 * 1.2 * 1.25 * 1 = 2.25 * LL$$

Load type	Requirements				Comments
	Vehicle		KQ	KA	
Global flight loads	Satellite		1,25 [a]	1	
	Launch vehicle		1,25corrected [b]	1 or J_p [c]	Typical value to be considered for dimensioning are J_p=1,05 to 1,1
	Man-rated S/C	Launch loads	1,4	1,2	
		On orbit loads	1,5		

Table 5: Test factor values (Table 4-2 [33])

Structure type	Vehicle	Requirements			
		FOSY	FOSU	FOSY verification by analysis only	FOSU verification by analysis only
Metallic parts	Satellite	1,1	1,25	1,25	2,0
	Launch vehicle	1,1	1,25	See Note [c]	2,0
	Man-rated S/C Launch On Orbit	1,25 1,1	1,4 1,5	See Note [c]	See Note [c]

Table 6: Factors of safety for metallic structural parts (Table 4-3 [33])

7.3.2. Verification execution and control

Depending on verification method assigned to each requirement (see Verification Matrix in appendix E), a different tool will be used. For inspections, just visual determination of physical characteristics is needed.

The next stage is to obtain real data from this CubeSat and compare them with the required specifications. Each requirement has a verification process that will be listed and explained below.

1	**CDS-3.2.1**	The origin of the CubeSat coordinate system is located at the geometric center of the CubeSat.	Inspection

Just visual determination of engineering drawings is needed to determine that reference frame coincides with the geometric center of the CubeSat.

Therefore, this requirement is met.

2	**JX-2.1.2.2**	The dimensional requirements for a CubeSat are defined in the Figure 25.	Test

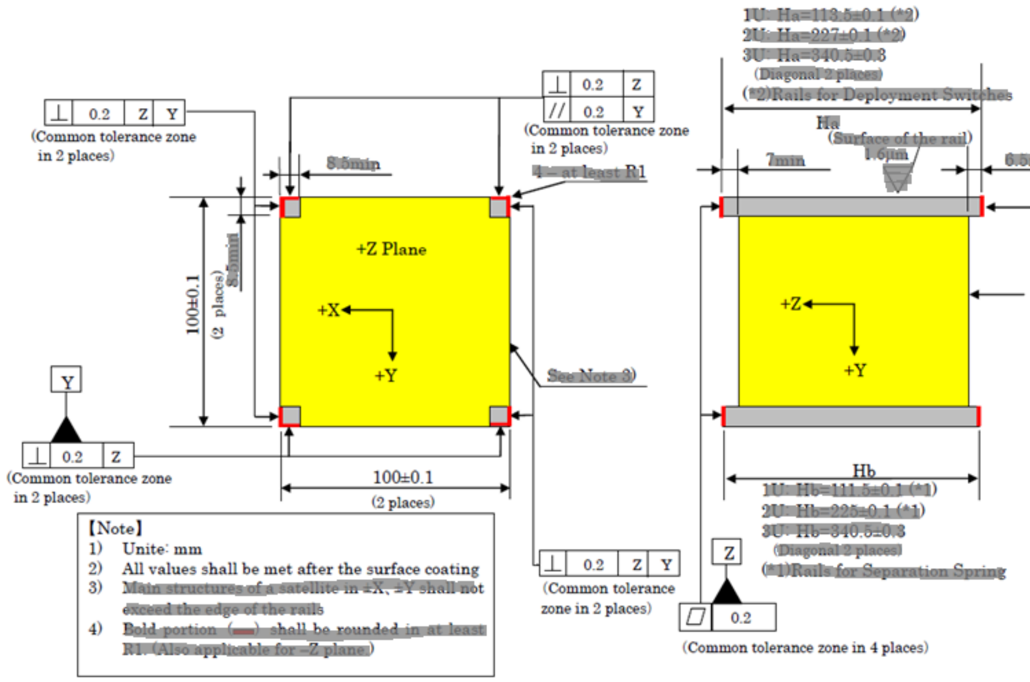


Figure 25: Dimensional requirements for CubeSats

In Figure 25 there are some crossed out dimensional requirements because those will be verified in other requirements. By measuring the assembled CubeSat (see Metrology report in appendix F) it is possible to check its width in X and Y axis, apart from flatness, parallelism and perpendicularity of rails faces. In Table 7 there is a comparison between the most restrictive real measurements and the required values.

Parameter	Limitation	Measured value
+X face width [mm]	100 ± 0.1	100.179
-X face width [mm]	100 ± 0.1	100.181
+Y face width [mm]	100 ± 0.1	100.083
-Y face width [mm]	100 ± 0.1	100.295
Flatness of ±Z face of deployment switches rails [mm]	0.2	0.027
Flatness of ±Z face of separation spring rails [mm]	0.2	0.014
Perpendicularity between X and Y deployment switches rail faces [mm]	0.2	0.038
Perpendicularity between X and Y separation spring rail faces [mm]	0.2	0.047
Parallelism between X and Y deployment switches rail faces [mm]	0.2	0.068
Parallelism between X and Y separation spring rail faces [mm]	0.2	0.049

Table 7: Requirement 1: Comparison table of required and measured values

In this regard, not all tolerances are respected, hence this requirement is not met.

3	**JX-2.1.4.2**	The **main structure** of a satellite in +Z shall be **recessed** more than 7.0mm from the edge of the rails. All components in +Z shall be recessed more than 0.5mm from the edges of the rails.	Test

The distance from the main structure (+Z face) to the edge of the shorter rail was measured (see Metrology report in appendix F). Table 8 shows the comparison between the key values for this measurement. As there are no components attached to the main structure of the CubeSat, 0.5mm requirement is not applicable.

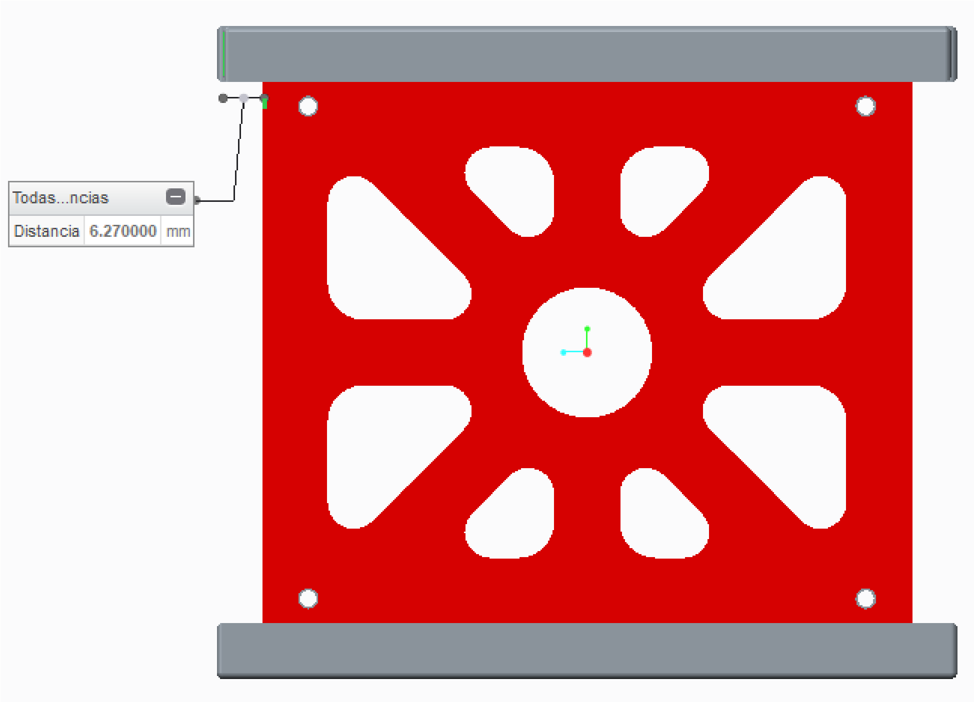


Figure 26: Distance from requirement 3

Parameter	Limitation	Designed value	Measured value
Distance [mm]	Minimum 7.0	6.27	6.064

Table 8: Requirement 3: Comparison table of values

The problem with this requirement was that plate thickness was not taken into account for design the length of the separation spring rails. Therefore, once parts are assembled, measured value for this distance is not the required one. In conclusion, this requirement is not met.

In order to solve this inconvenient, length of main structure in Z axis should be reduced, so that standoff of rails in +Z face are larger than 7 mm.

4	**JX-2.1.4.3**	The **main structure** of a satellite in -Z shall be **recessed** more than 6.5mm from the edge of the rails. All components in -Z shall be recessed from the edges of the rails.	Test

The distance from the main structure (-Z face) to the edge of the shorter rail was measured (see Metrology report in appendix F).

Parameter	Limitation	Designed value	Measured value
Distance [mm]	Minimum 6.5	6.27	6.064

Table 9 shows the comparison between values for this measurement.

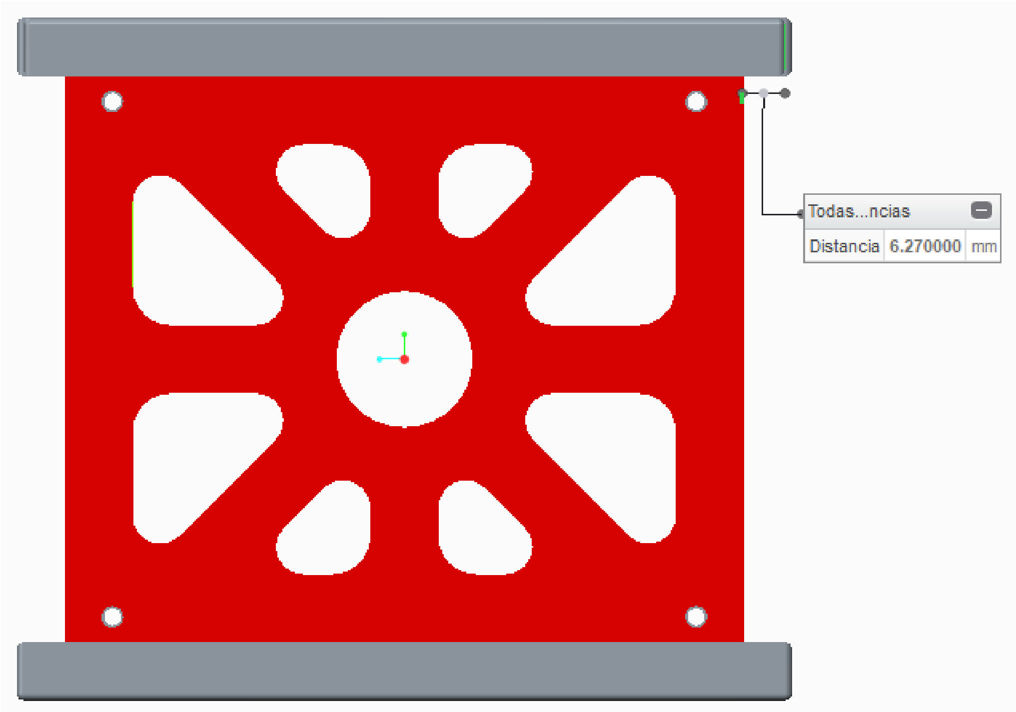


Figure 27: Distance from requirement 4

Parameter	Limitation	Designed value	Measured value
Distance [mm]	Minimum 6.5	6.27	6.064

Table 9: Requirement 4: Comparison table of values

The problem with this requirement was that plate thickness was not taken into account for design the length of the separation spring rails. Therefore, once parts are assembled, measured value for this distance is not the required one. In conclusion, this requirement is not met.

In order to solve this inconvenient, length of main structure in Z axis should be reduced, so that standoff of rails in –Z face are larger than 6.5 mm.

5	**JX-2.1.4.4**	The main structures of a satellite in +/-X and +/-Y shall not exceed the side surface of the rails. Any components in these surfaces shall not exceed 6.5mm normal to the side surface of the rails including the RBF pin.	Test

±X and ±Y do not exceed surface rails because the standoff of the rails to support lateral plates has a gap of 1.27mm and plate has 1mm of thickness. Even for the manufactured piece this gap measures 1.238mm in the worst case (see Metrology report in appendix F), so there are 0.238mm of difference between the main structure and the rails surfaces.

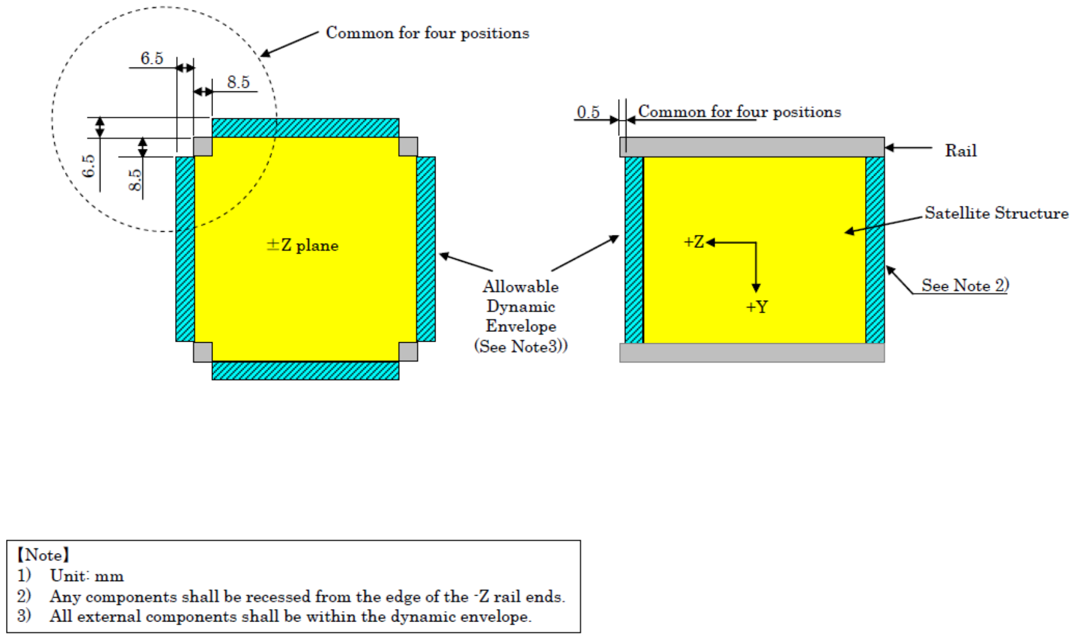


Figure 28: Distances for requirement 5

As a result, this requirement is fulfilled.

6	**CDS-3.2.3.1**	When completing a CubeSat Acceptance Checklist (CAC), protrusions will be measured from the plane of the rails.	Review of Design

As there are not components that cause protrusions, this requirement is met.

7	**JX-4.2.2.1.1**	In order to protect crewmembers from sharp edges and protrusions during all crew operations, they need to be rounded or planed greater than 0.7mm to the utmost. If a satellite has any potential sharp edges which cannot be rounded or planed (ex. An edge of a solar cell), a satellite provider shall identify the sharp edge positions with an acceptance rationale for JAXA approval. Holes (round, slotted) without covers need to be 25 mm or longer, or be 10 mm or shorter in diameter.	Review of Design

By reviewing engineering drawings (appendix C), it can be seen that not all holes of lateral and top/bottom plates fulfil this requirement. However, it is expected that these panels are covered with solar panels and other equipment.

Hence, this requirement is conditionally met.

8	**JX-2.1.5.1**	The mass of a satellite shall be larger than 0.13kg per 1U.	Test

Using a scale, integrated CubeSat with bolts was weighted. In Table 10 there is a comparison between required and the real mass.

Parameter	Limitation	Measured value
Mass [kg]	Minimum 0.13	0.2099

Table 10: Requirement 8: Comparison table of required and measured values

Real mass is higher than the limitation, so this requirement is met.

9	**CDS-3.2.10**	The maximum mass of a 1U CubeSat shall be 1.33 kg.	Test

Using a scale, integrated CubeSat with bolts was weighted. In Table 11 there is a comparison between required and real mass.

Parameter	Limitation	Measured value
Mass [kg]	Maximum 1.33	0.2099

Table 11: Requirement 9: Comparison table of required and measured values

Real mass is lower than the limitation, so this requirement is met. However, it must be remarked that this is just the mass of the structure. This requirement will be a critical limitation when integrating all other CubeSat subsystems.

10	**NRCSD-ICD-4.4**	The CubeSat center of gravity shall be within 2cm of its geometric center.	Review of Design

As CubeSat is symmetric is every single plane, logically, the center of gravity will coincide with the geometric center. Nevertheless, it can be checked in CREO.

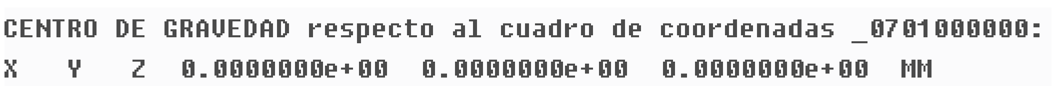


Figure 29: Center of gravity location

Therefore, this requirement is met

11	**CDS-3.2.15**	Aluminium 7075, 6061, 5005, and/or 5052 will be used for both the main CubeSat structure and the rails.	Review of Design

Material chosen for CubeSat manufacturing is Al 6061 T6.

Hence, this requirement is met.

12	**CDS-3.1.8.1**	CubeSats materials shall have a **Total Mass Loss** (TML) < 1.0 %	Review of Design

Al 6061 T6 is a typical material for aerospace usage. It is in ESA, NASA and JAXA list of approved materials [34].

In conclusion, it is widely proved that it fulfils limitations of mass loss, so this requirement is met.

13	**CDS-3.1.8.2**	CubeSat materials shall have a **Collected Volatile Condensable Material** (CVCM) < 0.1%	Review of Design

Al 6061 T6 is a typical material for aerospace usage. It is in ESA, NASA and JAXA list of approved materials [34].

In conclusion, it is widely proved that it fulfils limitations of volatile condensable material collection, so this requirement is met.

14	**NRCSD-ICD-4.6.1**	A CubeSat shall have **four (4) rails**, one per corner, along the Z axis.	Inspection

Just visual determination of CubeSat is needed to determine that there are 4 rails along Z axis.

Hence, this requirement is met.

15	**CDS-3.2.5**	Rails shall have a minimum **width** of 8.5mm.	Test

Rails width were measured (see Metrology report in appendix F) in the manufactured pieces. In Table 12 there is a comparison between required and the lower value measured for all rails.

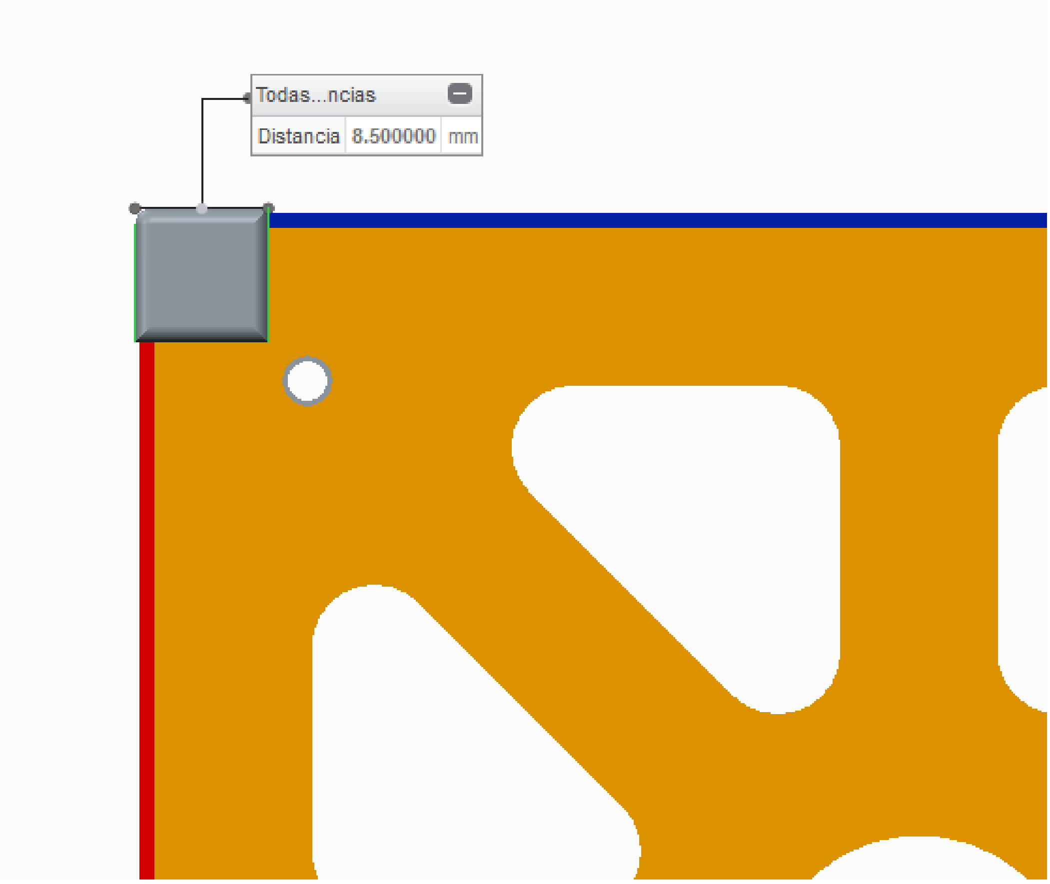


Figure 30: Distance from requirement 15

Parameter	Limitation	Measured value
Distance [mm]	Minimum 8.5	8.422

Table 12: Requirement 15: Comparison table of required and measured values

In this case requirement is not met for this rail as measured distance does not meet the minimum value. It was not due to tolerancing error because it was designed as 8.5 (-0, +0.05), but due to manufacturing lack of precision, so piece should be manufactured again in order to fulfil this requirement.

16	**NRCSD-ICD-4.6**	**Rail length variance** in the Z axis between rails shall not exceed ± 0.1 mm.	Test

Rails length were measured (see Metrology report in appendix F) in the manufactured pieces. In Table 13 there is a comparison between the required and the most restrictive value measured for each type of rail.

	Lenght [mm]	
Parameter	**Limitation**	**Measured value**
Deployment switch rail	113.5± 0.1	113.542
Separation spring rail	111.5± 0.1	111.536

Table 13: Requirement 16: Comparison table of required and measured values

In all cases, real length is inside tolerance limits, hence this requirement is met.

17	**CDS-3.2.6**	Rails will have a **surface roughness** less than 1.6 µm.	Test

Rails surface roughness was measured (see Metrology report in appendix F) in the manufactured pieces. In Table 14 there is a comparison between required and worst surface roughness for all rails.

Parameter	Limitation	Measured value
Surface roughness [µm]	1.6	1.22

Table 14: Requirement 17: Comparison table of required and measured values

In all cases, real length is inside tolerance limits, hence this requirement is met.

18	**CDS-3.2.7**	The **edges of the rails** will be rounded to a radius of at least 1 mm	Analysis

During manufacturing a radius was not machined, but a chamfer. However, their function is the same, so they are comparable.

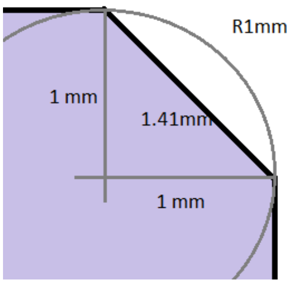


Figure 31: Chamfer

The equivalent chamfer for R1 must be at least 1.41 mm. In Table 15 there is a comparison between required and measured value (see Metrology report in appendix F) for the chamfer.

Parameter	Limitation	Measured value
Equivalent chamfer [mm]	Minimum 1.41	0.569

Table 15: Requirement 18: Comparison table of required and measured values

Real value of the chamfer does not reach the minimum value to be equivalent to an edge with a minimum radius of 1mm. In consequence, this requirement is not met.

19	**JX-2.1.3.8**	The rail surfaces which contact with the rail guides of the J-SSOD Satellite Install Case and the rail standoffs which contact with adjacent satellites shall be hard anodized aluminum after machining process. The thickness of the hard anodized coating shall be more than 10µm according to MIL-A-8625, Type3.	Inspection

In this case, rails of model verified are not anodized, so requirement is not fulfilled. However, more advanced models will be anodized in order to meet this specification.

Then, this requirement is not met.

20	**CDS-3.2.8**	The ends of the rails on the +/- Z face shall have a **minimum surface area** of 6.5 mm x 6.5 mm **contact** area for neighbouring CubeSat rails.	Test

This requirement can be checked with measurements appearing in Metrology report in appendix F. Supposing that chamfer forms a right angle, it is possible to calculate X value in Figure 32; 7.618 mm. Supposing again that this measurements are the same all sides of ±Z rail face, then we have a surface area of 7.618 mm x 7.618 mm contact area for neighbouring CubeSat rails.

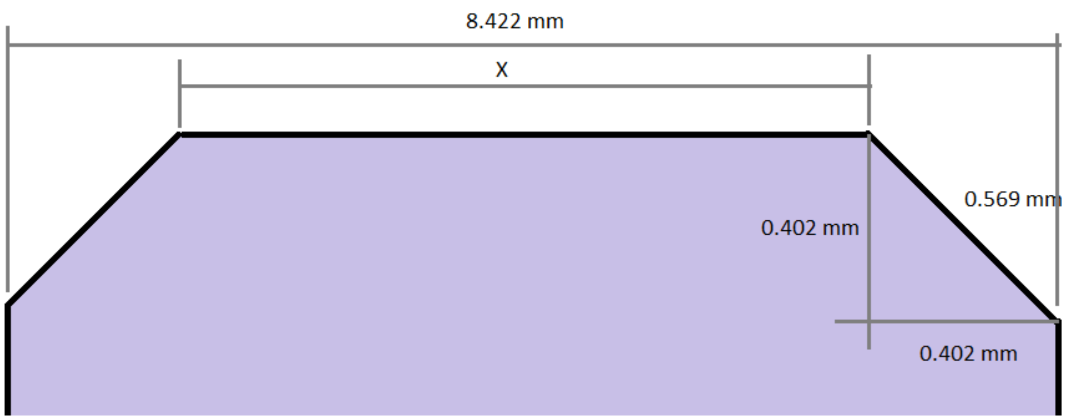


Figure 32: ±Z rail face

In short, this requirement is fulfilled. However, this specification will be critical when requirement **18**. **CDS-3.2.7** is met.

21	**JX-2.1.8.2**	Each rail shall have a sufficient structural strength with considering that the rail is subject to compression force at 46.6 N due to a preload from the Backplate and main spring of deployer.	Analysis Test

Report of this analysis is in Compressive force section in the FEM Analysis attached in appendix A. Test will not be held for the reasons explained in Verification Planning section. Limitations to avoid permanent deformation and overlapping (see Table 2) and results of the analysis are shown in Table 16.

Parameter	Limitation	Analysis result
Tensile Yield Strength [MPa]	275.79	7.8911
Deformation [mm]	6.5	0.0019426

Table 16: Requirement 21: Comparison table of required and measured values

In consequence, as analysis results are lower than limitation values, this requirement is met.

22	**JX-2.1.9**	The minimum fundamental frequency of a satellite shall be no less than 100 [Hz] on the condition that the four rails +/-Z standoffs are rigidly fixed. If the minimum fundamental frequency of the satellite is less than 100 [Hz], coordination with launcher is needed since a random vibration environment subjected to the satellite may exceed the environment.	Analysis

Report of this analysis is in Modal analysis section in the FEM Analysis attached in appendix A. Limitations to avoid permanent deformation and overlapping (see Table 2) and results of analysis are shown in Table 17.

Parameter	Natural frequency [Hz]
Limitation	100
Analysis mode 1	574.15
Analysis mode 2	587.68
Analysis mode 3	588.02
Analysis mode 4	588.53
Analysis mode 5	645.52
Analysis mode 6	659.88

Table 17: Requirement 22: Comparison table of required and measured values

Hence, as natural frequencies are higher than limitation, this requirement is met.

23	**CDS-3.1.11**	The CubeSat shall be designed to accommodate ascent venting per ventable volume/area < 50.8 [m]. NOTE Volume refers to satellite internal volume (V [m3]) and the area refers to area of exhaust ports (A [m2]).	Analysis

Using CREO it is possible to calculate total ventable area of the CubeSat (0.0143 m^2) and total internal volume (0.000885 m^3). In Table 18 ventable volume/area calculated and limitation are compared.

Parameter	Limitation	Analysis result
Ventable volume/area [m]	50.8	0.0619

Table 18: Requirement 23: Comparison table of required and measured values

Real ventable volume/area is much lower than limitation hence, this requirement is met, even when payload has not been taken into account for deducting its volume from the total internal volume.

24	**NRCSD-ICD-7**	CubeSats shall be designed to withstand overall temperature range of -40C to +65C.	Review of Design

Al 6061 T6 is a typical material for low-temperature service (down to -195 ºC). Maximum service temperature can reach up to 250 ºC, far away from the limits established. [35], [36]

As a result, this requirement is met.

25	**SOYUZ-CSG-3.2.5**	Random vibrations at the spacecraft base are generated by propulsion system operation and by the adjacent structure's vibro-acoustic response. Maximum excitation levels are obtained during the first-stage flight. Acceleration power spectral density (PSD) and root mean square vibration levels (GRMS) are given in the table below along each of the three axes. NOTE Spacecraft is not	Analysis Test

Frequency [Hz]	PSD [g^2/Hz]
20	0.05
50	0.05
100	0.1
200	0.25
500	0.25
1000	0.1
2000	0.05

Report of this analysis is in Random vibrations section in the FEM Analysis attached in appendix A. Test will not be held for the reasons explained in Verification Planning section. Limitations to avoid permanent deformation and overlapping (see Table 2) and maximum values resulting from the analysis are shown in Table 19.

Parameter	Limitation	Analysis result
Tensile Yield Strength [MPa]	275.79	26.506
Deformation [mm]	6.5	0.16393

Table 19: Requirement 25: Comparison table of required and measured values

Therefore, as analysis results are lower than limitation values, this requirement is met.

26	**MRR-2.2.5**	The satellite shall withstand the most demanding combination of limit levels of sine-equivalent vibrations obtained from Vega and Ariane 5 launcher requirements. The limit levels of sine-equivalent vibrations to be taken into account for the design and dimensioning of the spacecraft are the highest values	Analysis Test

Frequency band [Hz]	Direction	Sine amplitude [g]
1-25	**Longitudinal**	1
	Lateral	0.8
25-110	**Longitudinal**	1
	Lateral	0.6
110-125	**Longitudinal**	0.2
	Lateral	0.2

Report of this analysis is in the Sinusoidal vibrations section in the FEM Analysis attached in appendix A. Test will not be held for the reasons explained in Verification Planning section. Limitations to avoid permanent deformation and overlapping (see Table 2) and maximum values resulting from analysis are shown in Table 20.

Parameter	Limitation	Analysis result
Tensile Yield Strength [MPa]	275.79	0.4493
Deformation [mm]	6.5	0.002666

Table 20: Requirement 26: Comparison table of required and measured values

Therefore, as analysis results are lower than limitation values, this requirement is met.

27	**JX-2.4.1.1a**	The satellite shall withstand a quasi-static acceleration in any direction during launch: ATV : 12.37 [g].	Analysis Test

Report of this analysis is in the Quasi-static Loads section in the FEM Analysis attached in appendix A. Test will not be held for the reasons explained in Verification Planning section. Limitations to avoid permanent deformation and overlapping (see Table 2) and maximum values resulting from analysis are shown in Table 21.

Parameter	Limitation	Analysis result
Tensile Yield Strength [MPa]	275.79	7.8911
Deformation [mm]	6.5	0.0019426

Table 21: Requirement 27: Comparison table of required and measured values

Therefore, as analysis results are lower than limitation values, this requirement is met.

28	**NRCSD-ICD-4.9**	During deployment, the CubeSats shall be compatible with deployment velocities between 0.5 m/s to 1.5 m/s and accelerations no greater than 2g's in the +Z direction.	Analysis Test

Since requirement 27 is met, this requirement is fulfilled also, because load in this case is much lower than in the former one.

<table>
<tr><td rowspan="2">29</td><td rowspan="2">VEGA-3.2.7</td><td rowspan="2">The envelope acceleration shock response spectrum (SRS) at the spacecraft base (computed with a Q-factor of 10) is presented in the table below. These levels are applied simultaneously in axial and radial directions. NOTE Spacecraft is not the launch vehicle, but the CubeSat.
<table>
<tr><td>Frequency [Hz]</td><td>100</td><td>1600</td><td>10000</td></tr>
<tr><td>SRS (Q=10) [g]</td><td>30</td><td>2000</td><td>2000</td></tr>
</table></td><td>Analysis</td></tr>
<tr><td>Test</td></tr>
</table>

Report of this analysis is in the Shocks section in the FEM Analysis attached in appendix A. Test will not be held for the reasons explained in Verification Planning section. Limitations to avoid permanent deformation and overlapping (see Table 2) and maximum values resulted from analysis are shown in Table 21.

Parameter	Limitation	Analysis result
Tensile Yield Strength [MPa]	275.79	143.49
Deformation [mm]	6.5	1.114

Table 22: Requirement 29: Comparison table of required and measured values

In conclusion, as analysis results are lower than limitation values, this requirement is met.

In the Verification Matrix attached in appendix E, all requirements are listed and compliance is specified for each of them.

8. Conclusions

As a result of the verification process, it was checked that not all requirements applicable to the CubeSat mechanical structure were fulfilled. Hence, this design cannot be sent to the space.

The non-compliant specifications are related to design and manufacturing measurements. It is easy to solve these issues by making opportune modifications to design and making machining processes more accurate as it was mentioned in the Verification execution and control section.

In terms of stiffness, the CubeSat structure clearly fulfils requirements. It means that such a stiff structure is not needed and material from the plates can be removed, so that structure mass is less and payload can leverage this margin to the limit of mass required. Holes of the plate can be bigger. Nevertheless, it is not a good solution to weaker the structure if there is no necessity. Therefore, TeideSat project should make more progresses to define whether mass limitation is critical. If that is the case, reducing material from the plates will be a useful action.

For better integration of the CubeSat, some solutions for the positioning of pieces could be applied. Specifically, lateral panels do not have any support surface in Z axis and positioning is just derived from bolts connection. To solve it, there are some solutions like lowering or extruding any surface or using a calibrated pin.

It should be taken into account that rails will need some inner free space in their ends to insert deployment switches and separation springs that were not part of the scope of this bachelor thesis. In consequence, some analysis may vary.

It is remarkable that the most restrictive requirements were verified during this project as it is at the beginning of the development of the mission TeideSat. This is just the first iteration of the CubeSat structure design that will be adjusted to the concrete needs of the mission as its specifications and conditions are determined. By the end of the iteration process, the result will be a CubeSat structure that fulfils the engineering major objective: to cover up necessities of society with high-quality products consuming less resources.

In San Cristóbal de La Laguna, on 4th July 2018.

Laura Feria del Rosario

Fdo:

ESCUELA SUPERIOR DE INGENIERÍA Y TECNOLOGÍA

Final Bachelor Thesis

DESIGN OF THE MECHANICAL STRUCTURE FOR THE TEIDESAT CUBESAT

APPENDIX A: FEM ANALYSIS

Studies:

Mechanical Engineering Bachelor

Author:

Laura Feria del Rosario

July 2018

Table of appendix A contents

A-1. Mesh model

The Finite Elements Method analysis was developed using ANSYS Workbench, version 19.0.

A-1.1 Material and geometry

All the analysis have in common the Engineering Data, where material of parts is specified; geometry; and the model or mesh. First, in order to fulfil material requirement established for CubeSats, aluminium 6061 T6 is chosen for all the parts. Its mechanical properties are collected from [32] and shown in Table 23.

Property	**Symbol**	**Magnitude**
Density	ρ	2700 kg/m^3
Poisson's Ratio	ν	0.33
Young's Modulus	E	68258 MPa
Tensile Yield Strength	σ_y	275.79 MPa
Tensile Ultimate Strength	σ_u	317.16 MPa

Table 23: Al 6061 T6 Properties

No material damping will be considered for Al 6061 T6. Even though a constant damping ratio was found [37], it could not be contrasted because of lack of free-access information about this issue. In specific material data handbooks for space usage [32] there is no information about damping coefficient for aluminium 6061. Thus, the most restrictive option was chosen, setting no damping for the material; the higher the damping, the lower the equivalent stress.

For the geometry, the CubeSat 3D model built is used. However, drills and rounded chamfers will be deleted so that the resultant mesh is simpler. This simplification will enhance the FEM analysis and resulting values will be closer to real ones. The holes in the plates are maintained, otherwise mass and rigidity loss will be considerable.

Relative to contacts, an approximation will be made for contact between two plates: it will be set as frictionless to simplify the calculation. "Frictionless behaviour allows the bodies to slide relative to one another without any resistance"[38]. The contact between the rails and the plates will be bonded.

A-1.2 Mesh

Next, the mesh can be generated. Based on their geometrical characteristics, there are three main structural elements: the beam element (Figure 33), the shell element (Figure 34), and the solid element (Figure 35).

- Beam elements (unidimensional): defined only in one direction.
- Shell elements (bidimensional): are defined along two directions.

- Solid elements (three-dimensional): defined along all three directions of the space.[39]

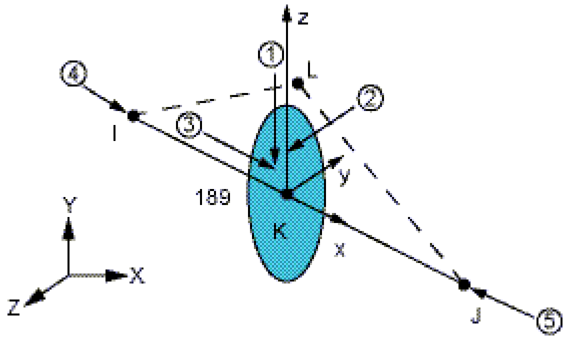


Figure 33: Beam element [39]

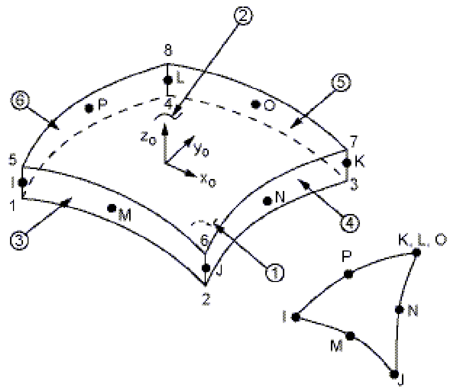


Figure 34: Shell element [39]

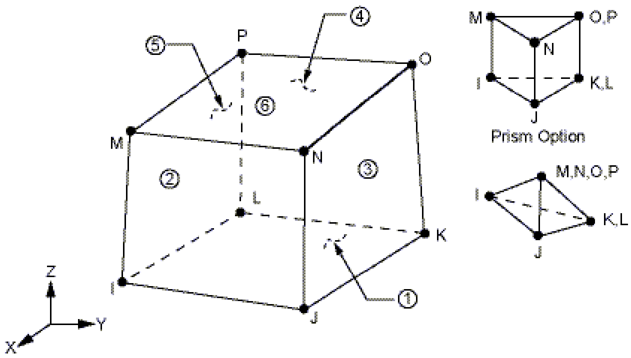


Figure 35: Solid element [39]

Ideally, plates should be modelled like shells and rails should be modelled like beams, like it was done in the referenced bachelor thesis [12]. However, the brackets of the rails make impossible to set the rails as beams, so they will be modelled as solid with Hexagon Dominant Elements. The consequent inconvenient is that plates must be modelled like solids as well, because ANSYS Workbench does not allow to easily work with both shells and solids in the same model. “When try to model a plate this way, the resulting numerically obtained displacements are much smaller when compared to known analytical solutions. This phenomenon is called mesh locking."[40] In order to avoid this phenomenon, plates will be modelled with Solid Shell Elements [41].

In terms of sizing, plates elements must measure a maximum length of 1 mm, whereas rails elements can reach up to 2 mm. On this basis, 56624 elements and 144197 nodes are obtained. This mesh will be used for all the FEM analysis.

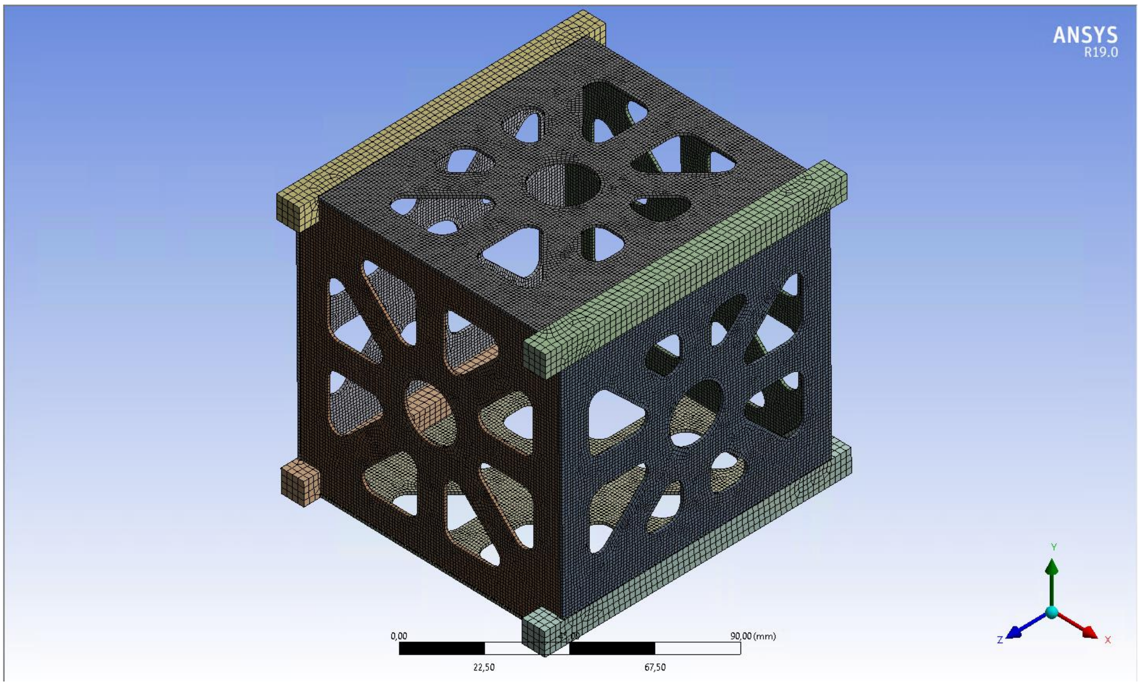


Figure 36: FEM model of the CubeSat

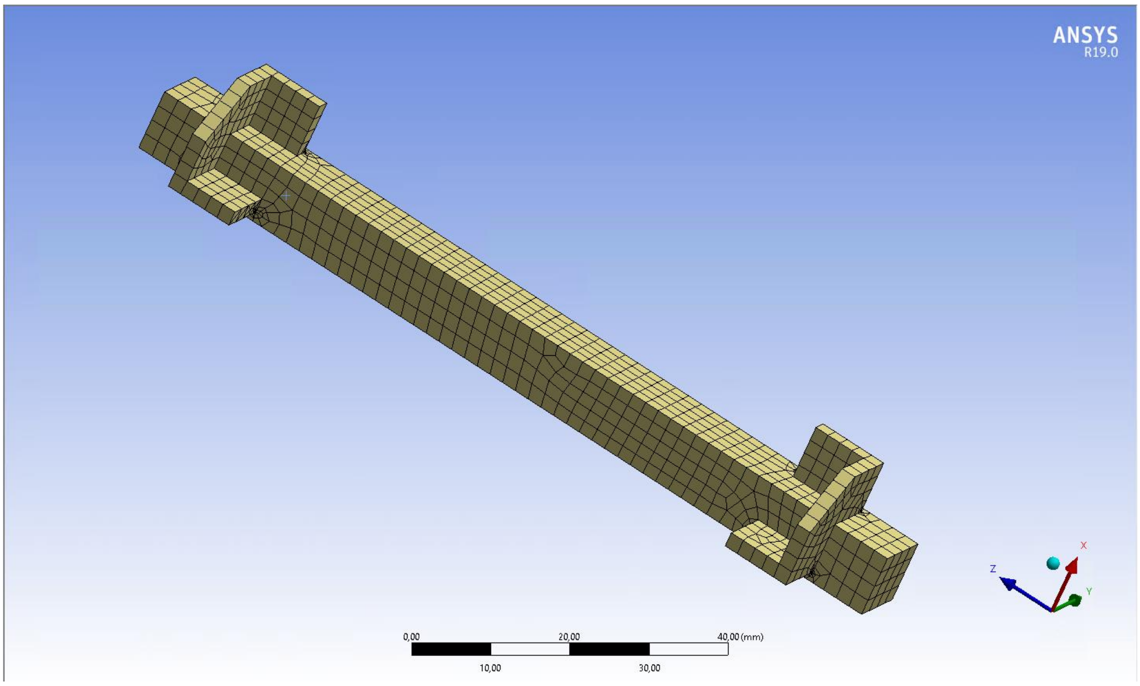


Figure 37: FEM model of a switch rail

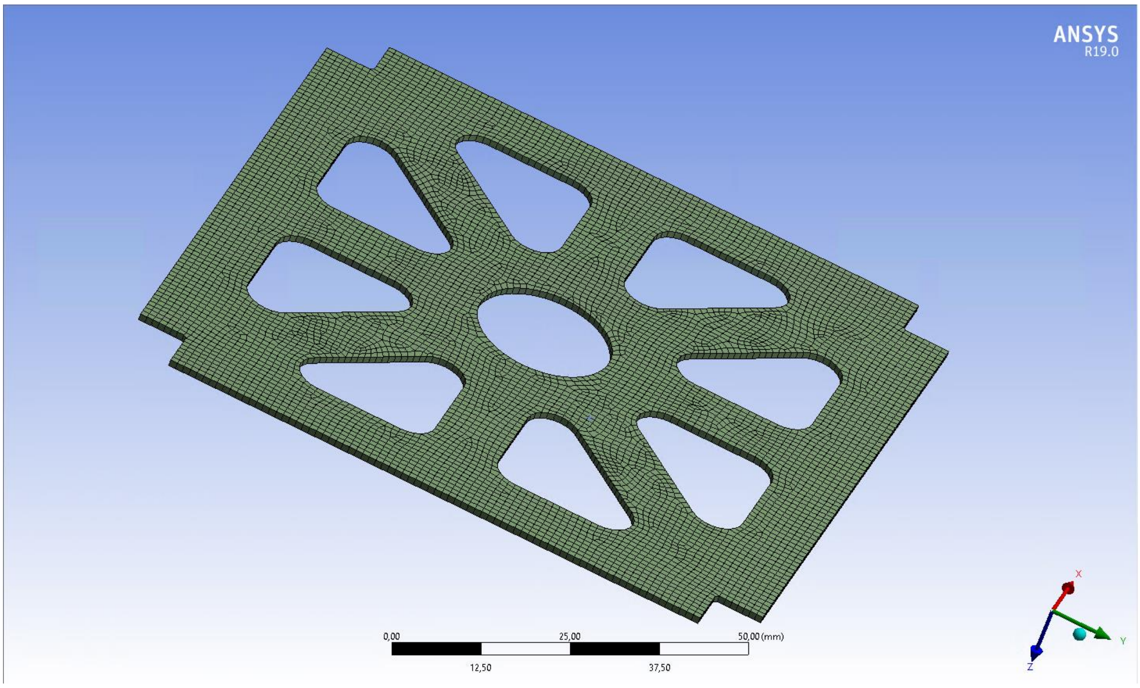


Figure 38: FEM model of the top panel

Relative to rails, elements are almost lineally ordered, apart from disturbance caused by the brackets. The size of these elements seems appropriate: not too big to avoid missing information about the piece, not too small to avoid complicating the calculations. The same conclusion can be referred to plates. However, there are more irregularities in this pieces due to rounded holes.

Moreover, ANSYS provides some tools to check mesh quality.

- **Orthogonal Quality**, measures perpendicularity of elements. The range for orthogonal quality is 0-1, where a value of 0 is worst and a value of 1 is best.[42]

  In Figure 39, results from the mesh are presented. Around 85% of cells have 0.95 factor of orthogonal quality and when quality decreases, percentage of cells also decreases.

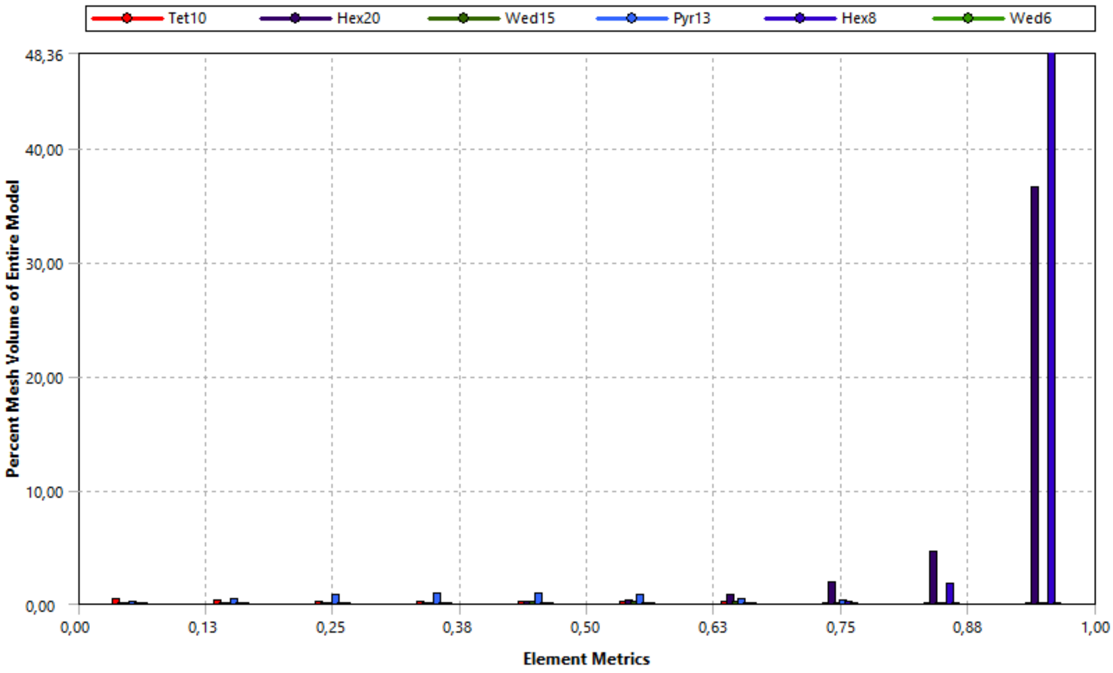


Figure 39: Orthogonal Quality of mesh

- **Skewness**, determines how close to ideal a face or cell is. A value of 0 indicates an equilateral cell (best) and a value of 1 indicates a completely degenerate cell (worst).[43]

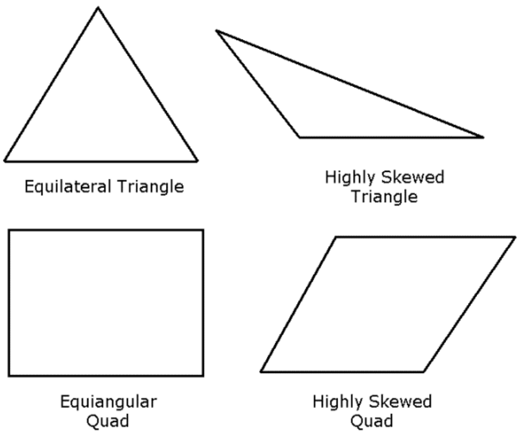


Figure 40: Ideal and Skewed Triangles and Quadrilaterals [43]

Table 24 lists the range of skewness values and the corresponding cell quality.

Value of skewness	Cell quality
1	Degenerate
0.9 – 1	Bad (sliver)
0.75 – 0.9	Poor
0.5 – 0.75	Fair
0.25 – 0.5	Good
0 – 0.25	Excellent
0	Equilateral

Table 24: Cell quality depending on skewness [43]

In Figure 41, results from the mesh are presented. Around 80% of cells are under 0.25 of skewness, so with excellent quality and when quality decreases, percentage of cells also decreases.

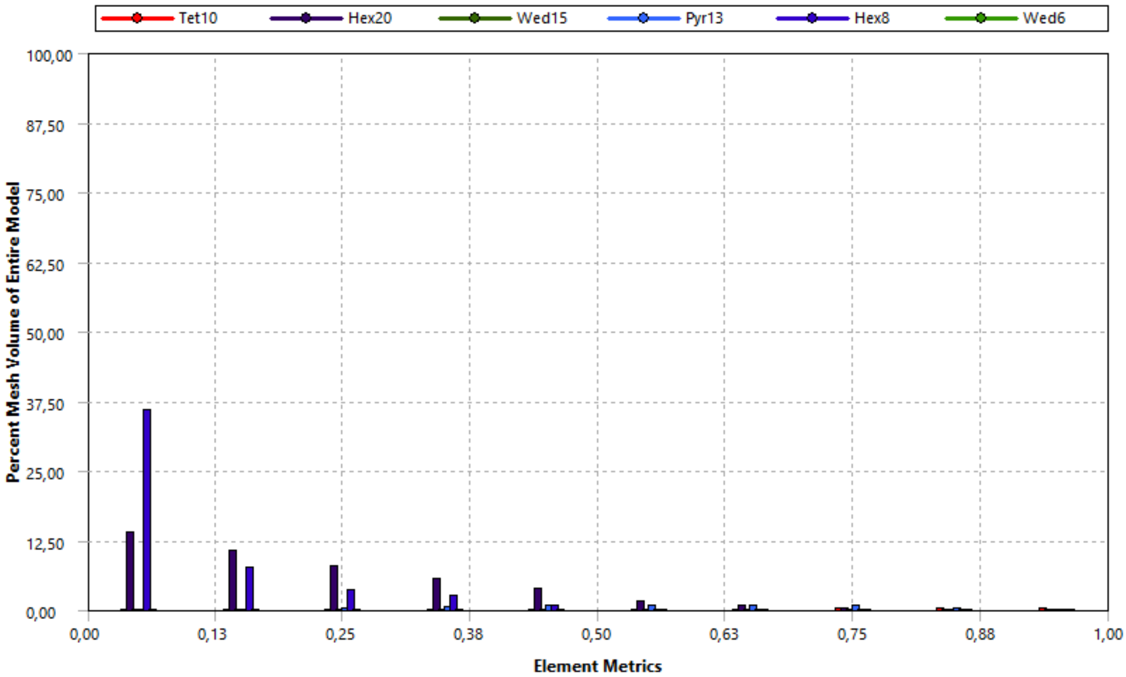


Figure 41: Skewness of the mesh

To this end, mesh is considered a realistic model of the real CubeSat.

A-1.3 Boundary Conditions

The boundary conditions for the static analysis are Displacement type. In this cases, displacement was set to 0, simulating a infinite stiff solid (deployer inside walls) that prevents the elements located in the face chosen to move in the direction specified. Actually, there is a small gap of 0.6 mm between both devices (as required in **NRCSD-ICD-4.5** [14]), but it will not affect calculations because plates will be the critic elements.

To get some deformation in rails, force should be so high that plates will break. In short, this gap will not be taken into account because it will not almost alter calculations.

By contrast, Fixed supports were used in dynamic analysis because it was required by **JX-2.1.9**[15]**,** in order to determine fundamental modes. In consequence, the next analysis based on the modal study has the same boundary conditions.

A-2. Compressive force (Requirement 21)

Requirement 21 is outlined below.

21. JX-2.1.8.2

Each rail shall have a sufficient structural strength with considering that the rail is subject to compression force at 46.6 N due to a preload from the backplate and main spring of deployer.

To obtain the stress suffered related to this requirement, it is necessary to set a Static Structural analysis with a compressive force in Z axis (rails axis). As it will be applied in the 4 faces of the rails as seen in Figure 42, the value of the force will be 4 times 46.6 N. In addition, safety factors from Table 4 are applied. On account of this, force applied will be 419.4 N.

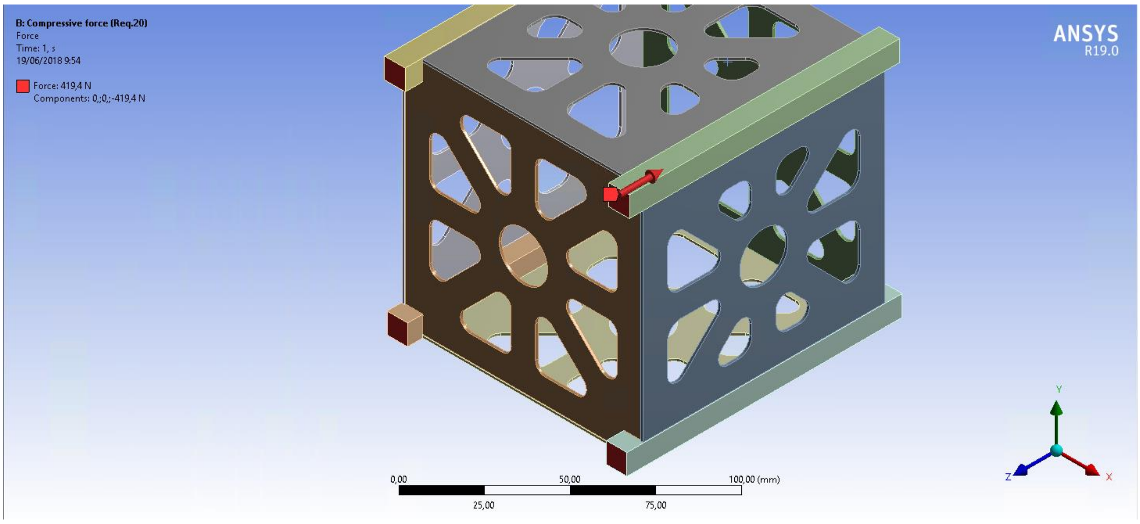


Figure 42: Compressive force (Requirement 21)

The analysis settings are displayed in Table 25.

Analysis settings	Value	Description
Compressive Force	-419.4 N	Applied in +Z faces of rails
Boundary Condition 1	Displacement Z = 0	Applied in – Z faces of rails
Boundary Condition 2	Displacement X = 0	Applied in ± X faces of rails
Boundary Condition 3	Displacement Y = 0	Applied in ± Y faces of rails

Table 25: Compressive Force (Req.21): Analysis settings

The equivalent stress and deformation suffered by the CubeSat are shown in Table 26, Figure 43 and Figure 44.

Analysis results	Value
Maximum equivalent stress [MPa]	7.8911
Maximum deformation [mm]	0.0019426

Table 26: Compressive Force (Req.21): Analysis results

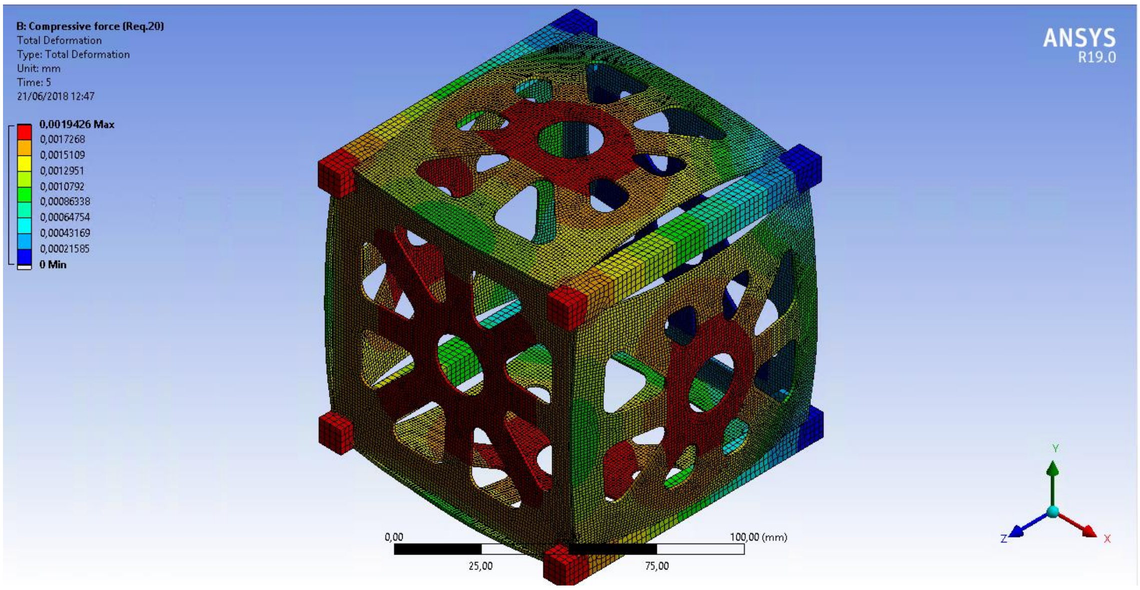


Figure 43: Compressive Force (Req.21): Deformation (4,7e+003 (Auto Scale))

Logically, maximum deformations are in the center of the plates, far from the bolts and at the edge of the rails where force is applied. Meanwhile, –Z faces of the rails stay undeformed due to support boundary conditions.

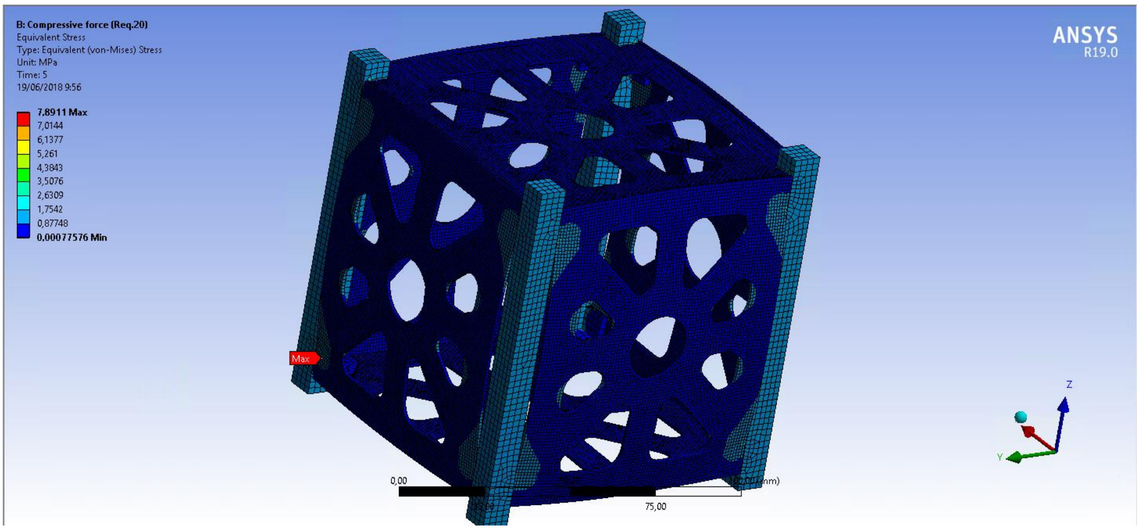


Figure 44: Compressive Force (Req.21): Equivalent stress

It should be pointed out that the maximum stress location (Figure 45) does not correspond to the real situation. Actually, the plate and rail will be jointed with bolts. It will not exist such a change between plate and rail contact as in the model because the plate will have the possibility to slightly bend. The critical point will be the bolt, but joints will not be studied in this project due to the already wide extension of it.

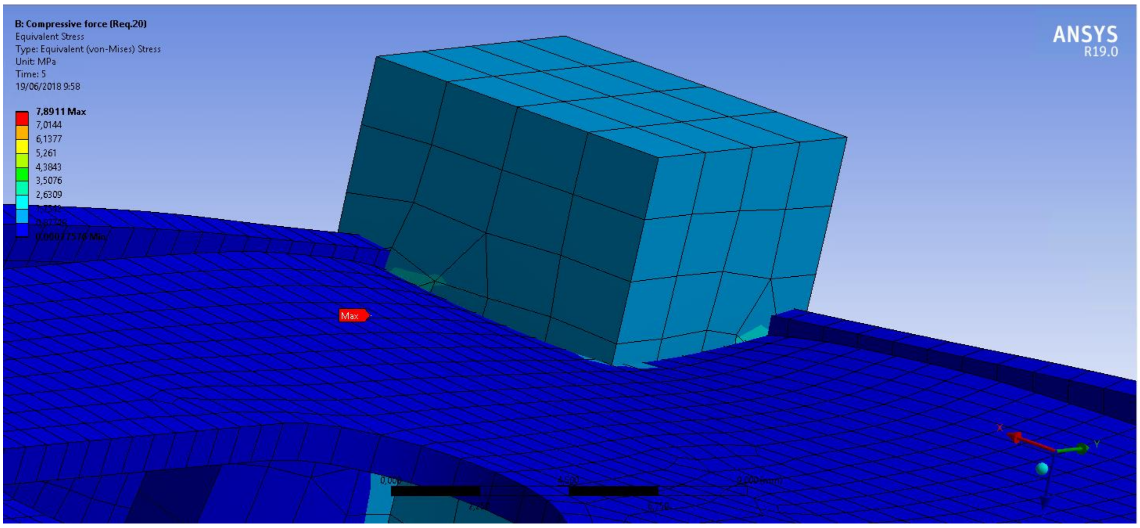


Figure 45: Compressive Force (Req.21): Maximum stress

To this end, this requirement is fulfilled as both stress and deformation are lower than the limits established in the Load check section.

A-3. Quasi-Static Loads (Requirement 27)

Requirement 27 is outlined below.

27. JX-2.4.1.1a

The satellite shall withstand a quasi-static acceleration in any direction during launch:

- *ATV : 12.37 [g].*

To obtain the stress suffered related to this requirement, it is necessary to set a Static Structural analysis with an acceleration in all axis. As the structure is response will be the same by applying load in X and Y axis, only analysis in Z and X axis will be developed. Safety factors from Table 27 are used. Using 9.81 m/s^2 as gravitational acceleration, the acceleration to be applied is 273.04 m/s^2.

Analysis settings	Value	Description
Acceleration	-273.04 m/s^2	Applied in geometric center
Boundary Condition 1	Displacement Z = 0	Applied in ± Z faces of rails
Boundary Condition 2	Displacement X = 0	Applied in ± X faces of rails
Boundary Condition 3	Displacement Y = 0	Applied in ± Y faces of rails

Table 27: Quasi-Static Loads (Requirement 27): Analysis settings

The equivalent stresses and deformations suffered by the CubeSat are shown in Table 28, Figure 46, Figure 47, Figure 48 and Figure 49.

	Analysis results	Value
Acceleration in X	Maximum equivalent stress [MPa]	5.9978
	Maximum deformation [mm]	0.034949
Acceleration in Z	Maximum equivalent stress [MPa]	3.4545
	Maximum deformation [mm]	0.028943

Table 28: Quasi-Static Loads (Requirement 27): Analysis results

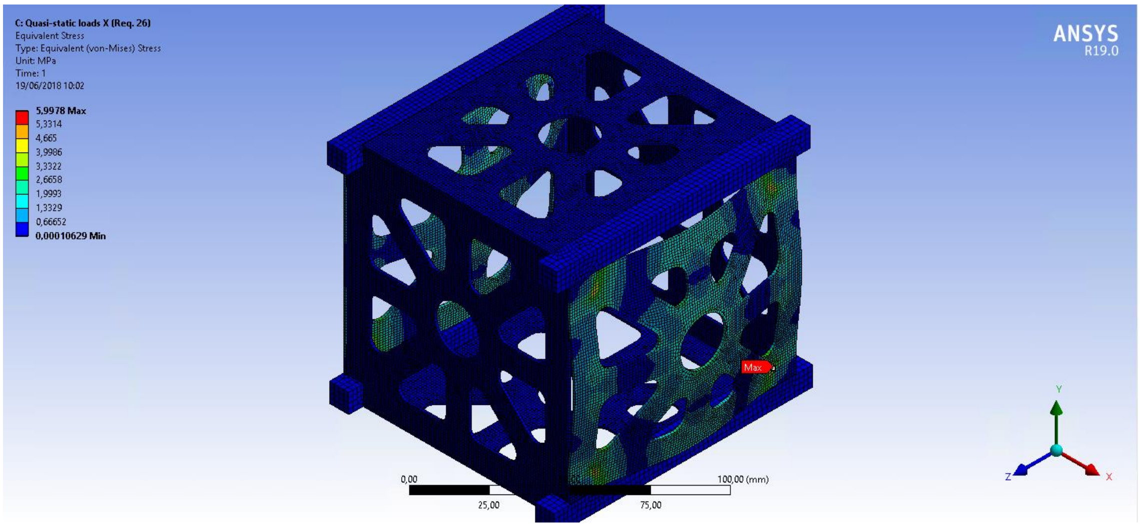


Figure 46: Quasi-Static Loads (Requirement 27): Equivalent stress with X acceleration

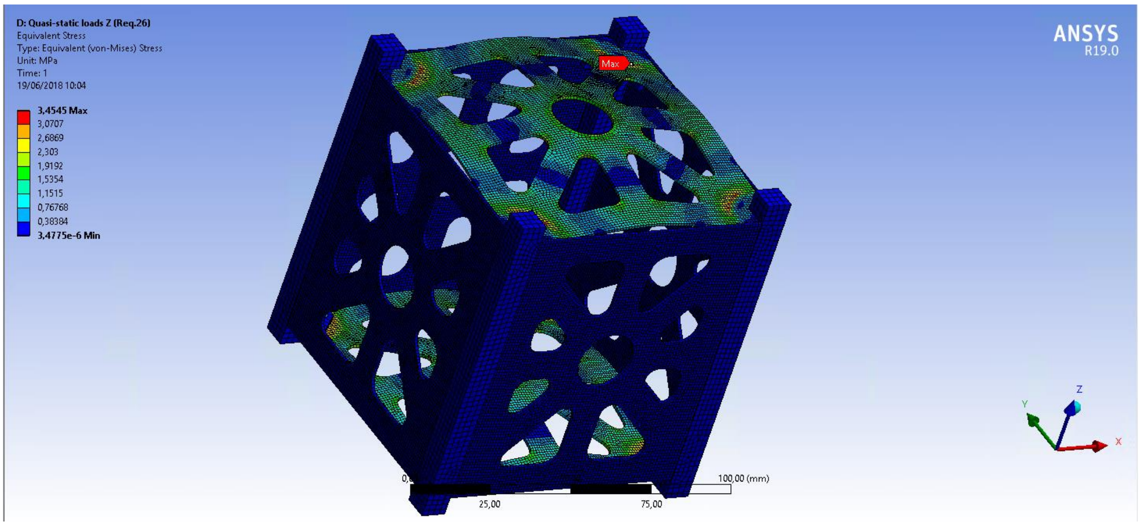


Figure 47: Quasi-Static Loads (Requirement 27): Equivalent stress with Z acceleration

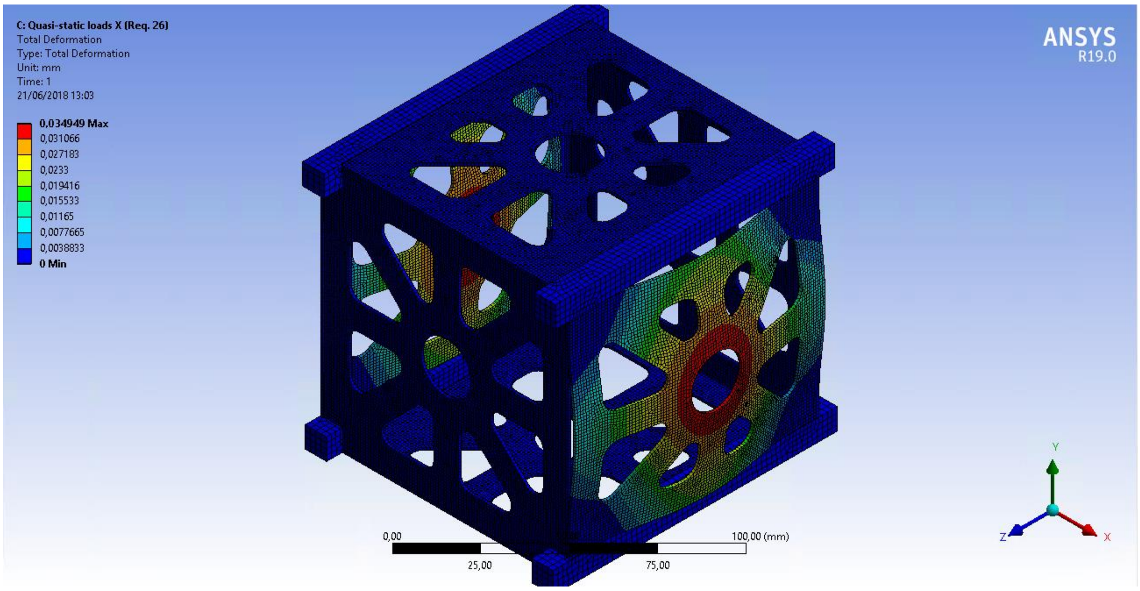


Figure 48: Quasi-Static Loads (Requirement 27): Deformation with X acceleration (2,6e+002 (Auto Scale))

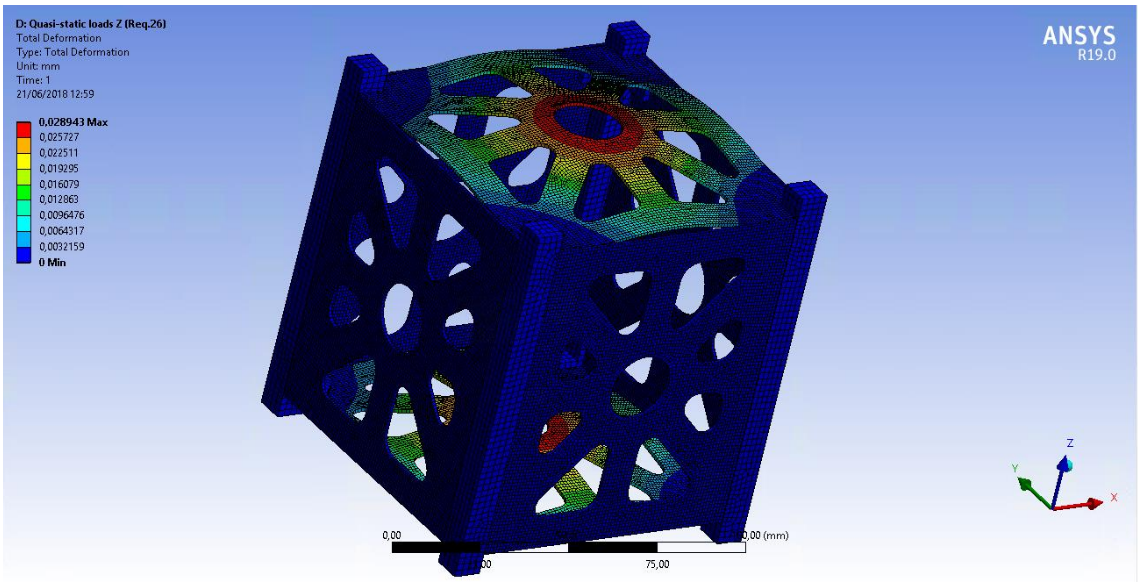


Figure 49: Quasi-Static Loads (Requirement 27): Deformation with Z acceleration (3,1e+002 (Auto Scale))

As expected, the maximum stress corresponds to the bonded contact between plate and rail bracket; and maximum deformation is in the center of the plate perpendicular to the acceleration direction. It is remarkable that top and bottom plates (±Z faces) have lower displacement than lateral ones. It means the former is stiffer than the latter ones.

In short, this requirement is fulfilled as both stress and deformation are lower than the limits established in the Load check section

A-4. Modal analysis (Requirement 22)

Requirement 22 is outlined below.

22. JX-2.1.9[15]

The minimum fundamental frequency of a satellite shall be no less than 100 [Hz] on the condition that the four rails +/-Z standoffs are rigidly fixed. If the minimum fundamental frequency of the satellite is less than 100 [Hz], coordination with launcher is needed since a random vibration environment subjected to the satellite may exceed the environment.

For the purpose of calculating the first natural frequencies (the critical ones), a Modal analysis is carried out. No pre-stress is set. The first 6 modes are calculated to obtain deformation in different directions. As it is required, fixed supports are placed in ±Z faces of the rails.

Analysis settings	Value	Description
Modes to find	6	-
Boundary Condition	Fixed support	Applied in ± Z faces of rails

Table 29: Modal analysis (Requirement 22): Analysis settings

The natural frequencies of the CubeSat are shown in Table 30. Deformation in all directions is achieved in the very first mode. Figure 50 shows the deformation occasioned in case that CubeSat is in resonance at its first mode (external mechanical vibration coincides with fundamental frequency). In fact, this deformation will never take place, because the pieces will break before reaching this limit. Figure 50 is just a representation with a large deformation scale factor.

Mode	Frequency [Hz]
1	574.15
2	587.68
3	588.02
4	588.53
5	645.52
6	659.88

Table 30: Modal analysis (Requirement 22): Analysis results (characteristic modes)

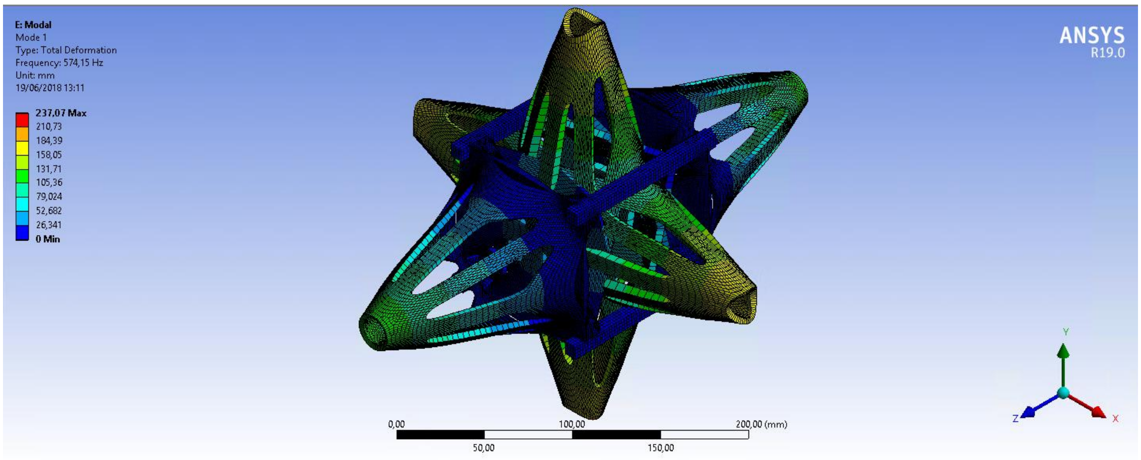


Figure 50: Modal analysis (Requirement 22): Resonance deformation

In conclusion, fundamental modes of the structure fulfil the requirement.

A-5. Random vibrations (Requirement 25)

Requirement 25 is outlined below.

25. SOYUZ-CSG-3.2.5

Random vibrations at the spacecraft base are generated by propulsion system operation and by the adjacent structure's vibro-acoustic response. Maximum excitation levels are obtained during the first-stage flight. Acceleration power spectral density (PSD) and root mean square vibration levels (GRMS) are given in the table below along each of the three axes.

NOTE Spacecraft is not the launch vehicle, but the CubeSat.

Frequency [Hz]	PSD [g^2/Hz]
20	0.05
50	0.05
100	0.1
200	0.25
500	0.25
1000	0.1
2000	0.05

A Random Vibration analysis is settled. Data from Modal analysis is needed in order to carry out the random vibration study because primary modes are needed. Consequently, boundary conditions will be the same.

As requirement specifies, analysis will be held in the 3 axis, even though X and Y response will be similar. This is necessary because the fundamental modes may have different responses in each axis. After applying the safety factors from **¡Error! No se encuentra el origen de la referencia.**, amplitude vibration takes the shape of Figure 51.

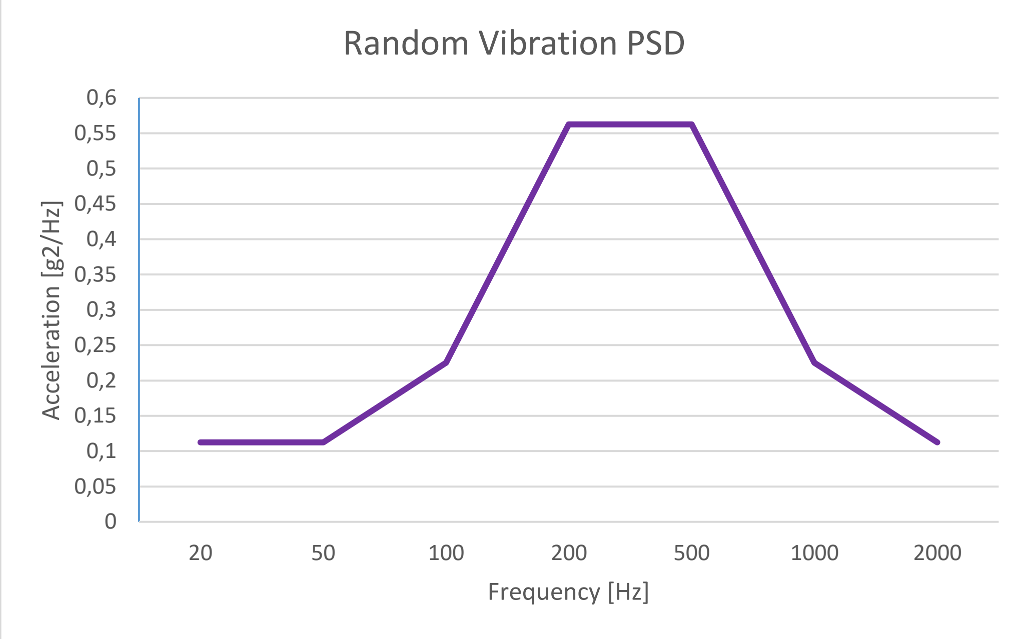


Figure 51: Random Vibration (Requirement 25): Vibration amplitude

In random vibration analysis, structure damping is usually defined. Similar works [12] use 3% as constant damping ratio, however the lower the value, the higher stress is developed, therefore, the most restrictive situation is chosen. On this basis, 1% of critical damping is applied following ANSYS recommendation.

Analysis settings	Value	Description
Boundary condition	Fixed support	Applied in ± Z faces of rails
Constant Damping Ratio	0.01	-
Frequency [Hz]	**Acceleration [g^2/Hz]**	**-**
20	0.1125	-
50	0.1125	-
100	0.225	-
200	0.5625	-
500	0.5625	-
1000	0.225	-
2000	0.1125	-

Table 31: Random Vibration (Requirement 25): Analysis settings

Response maximum stresses and deformations are exposed in Table 32, Figure 52, Figure 53, Figure 54 and Figure 55.

Acceleration applied in axis		
X	Maximum equivalent stress [MPa]	25.518
	Maximum deformation [mm]	0.1636
Y	Maximum equivalent stress [MPa]	26.506
	Maximum deformation [mm]	0.16393
Z	Maximum equivalent stress [MPa]	13.23
	Maximum deformation [mm]	0.14078

Table 32: Random Vibration (Requirement 25): Analysis results

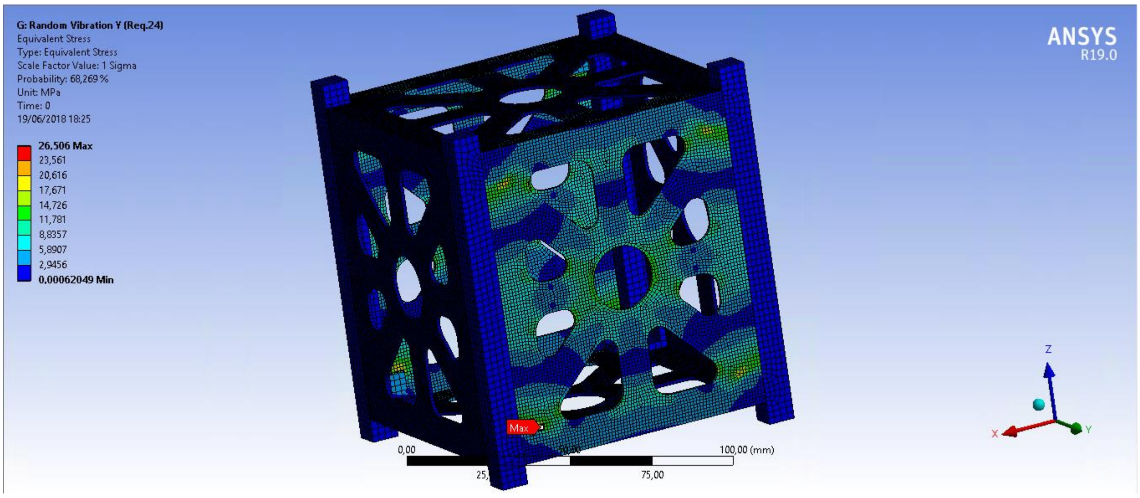


Figure 52: Random Vibration (Requirement 25): Equivalent stress with Y acceleration

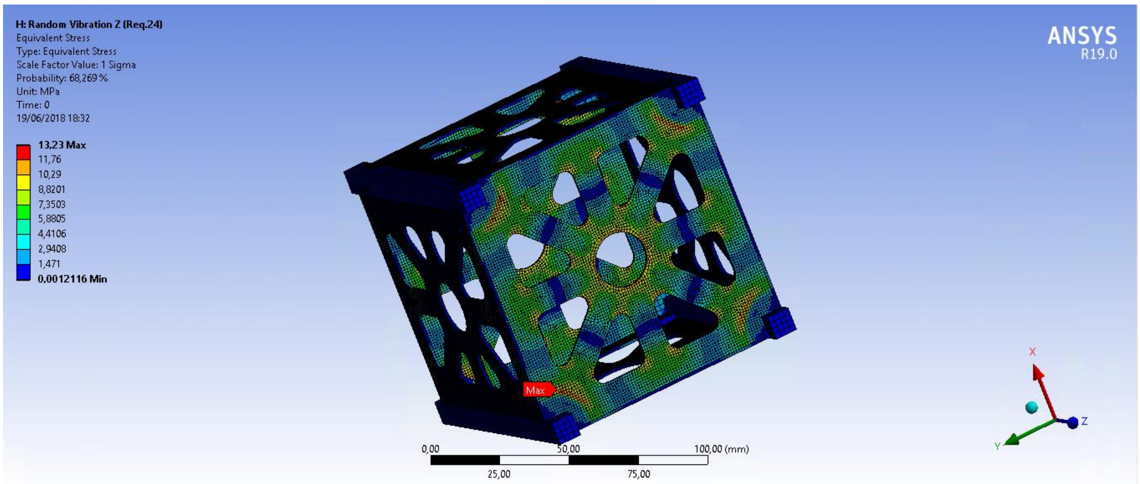


Figure 53: Random Vibration (Requirement 25): Equivalent stress with Z acceleration

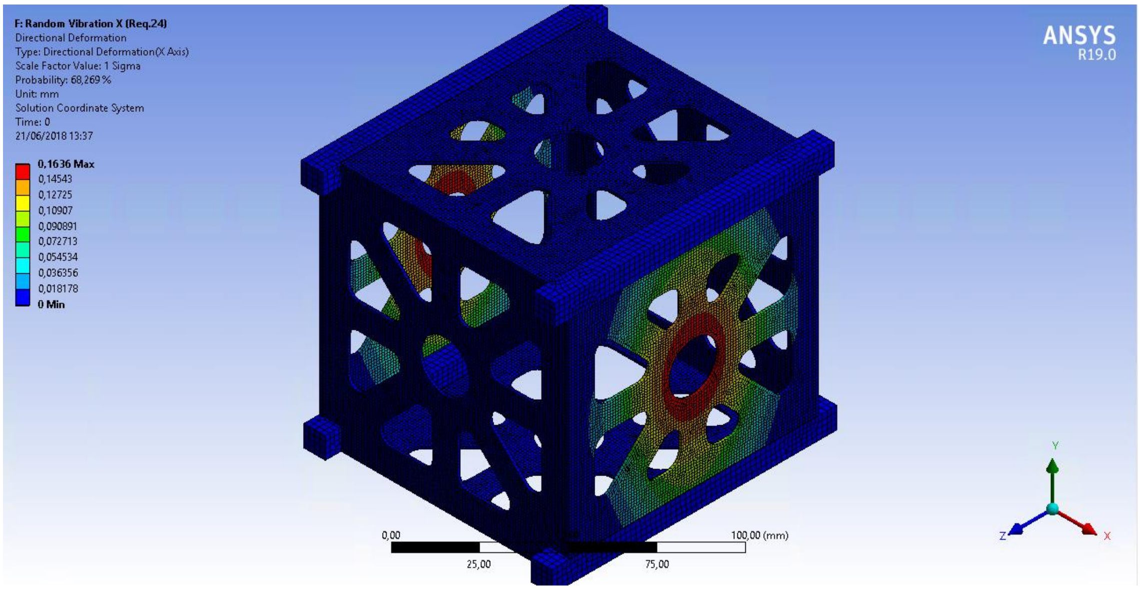


Figure 54: Random Vibration (Requirement 25): Deformation with X acceleration

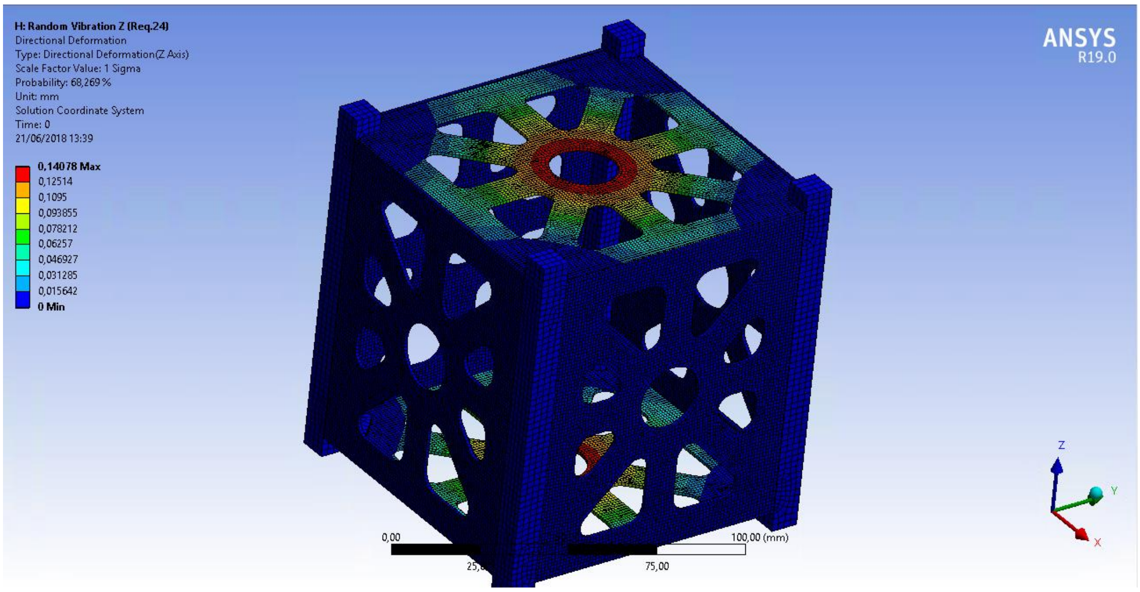


Figure 55: Random Vibration (Requirement 25): Deformation with Z acceleration

As expected, X and Y responses are similar, and the maximum stresses are close to the connections between rails and plates, remarking that the critical items are the bolts, not covered by this project. It should be pointed out that top and bottom plates (±Z faces) have lower displacement than lateral ones because of its different geometry. It means that the former are stiffer than the latter ones.

In short, this requirement is fulfilled as both stress and deformation are lower than the limits established in the Load check section.

A-6. Sinusoidal vibrations (Requirement 26)

Requirement 26 is outlined below.

26. MRR-2.2.5

The satellite shall withstand the most demanding combination of limit levels of sine-equivalent vibrations obtained from Vega and Ariane 5 launcher requirements. The limit levels of sine-equivalent vibrations to be taken into account for the design and dimensioning of the spacecraft are the highest values that the launch vehicle can suffer.

Frequency band [Hz]	Direction	Sine amplitude [g]
1-25	Longitudinal	1
	Lateral	0.8
25-110	Longitudinal	1
	Lateral	0.6
110-125	Longitudinal	0.2
	Lateral	0.2

A Harmonic Response analysis is needed in order to check the structure response for the different frequency bands. Data from Modal analysis is needed in order to carry out the sinusoidal vibration study because primary modes are needed. Consequently, boundary conditions will be the same. Safety factors from Table 4 must be taken into account for acceleration definition. A value of 9.81 m/s^2 is used as gravitational acceleration.

It is not specified in requirements which CubeSat axis corresponds to longitudinal direction. In this regard, 3 analysis will be held:

- **X axis = longitudinal load.** Y and Z axis = lateral loads.
- **Y axis = longitudinal load.** X and Z axis = lateral loads.
- **Z axis = longitudinal load.** X and Y axis = lateral loads.

Analysis settings	Value	Description
Boundary condition	Fixed support	Applied in ± Z faces of rails
Frequency band [Hz]	**Direction**	**Sine amplitude [m/s^2]**
1-25	Longitudinal	22.0725
	Lateral	17.658
25-110	Longitudinal	22.0725
	Lateral	13.2435
110-125	Longitudinal	4.4145
	Lateral	4.4145

Table 33: Sinusoidal Vibration (Requirement 26): Analysis settings

Before making this analysis, it can be deduced that sdeformation will not be critical because analysis frequencies are far from CubeSat natural frequencies. Moreover, as Quasi-static loads are higher than the accelerations taken into account in this chapter, it is logic that whether that requirement was fulfilled, this one will be satisfied more than enough.

Response parameters are exposed in Table 34. As it was expected, stresses and displacements are really low. This analysis will be critical if frequency band for analysis includes CubeSat modes, then stresses and deformations will be considerable.

Longitudinal Load	Frequency band [Hz]	Maximum stress [MPa]	Maximum deformation [mm]
X	1-25	0.4137	0.002547
	25-110	0.4277	0.0026346
	110-125	0.4322	0.0026627
Y	1-25	0.4299	0.00255
	25-110	0.4446	0.0026378
	110-125	0.4493	0.002666
Z	1-25	0.3576	0.0022629
	25-110	0.3697	0.0023275
	110-125	0.3736	0.0023481

Table 34: Sinusoidal Vibration (Requirement 26):Analysis results

Despite what it was mentioned above, it is seen that as frequency gets higher, stress and deformation get slightly higher also because it is gets closer to fundamental modes. It is also remarkable that Z faces are stiffer because of its different geometry, so they can support the same loads causing less displacement, meanwhile results from X and Y longitudinal acceleration are similar. In Figure 56, maximum stress response is shown. Logically, location of maximum stress corresponds to connection between rails and plates. By contrast, maximum deformation is exposed in Figure 57 and it located in the center of the plate.

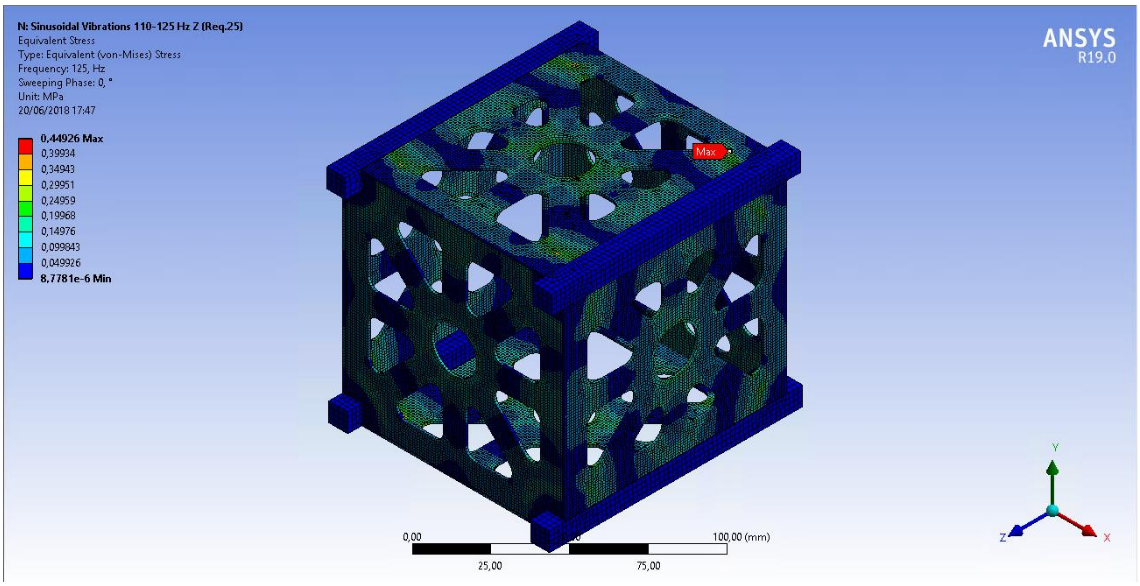


Figure 56: Sinusoidal Vibration (Requirement 26):Equivalent stress (110-125 Hz, Y axis)

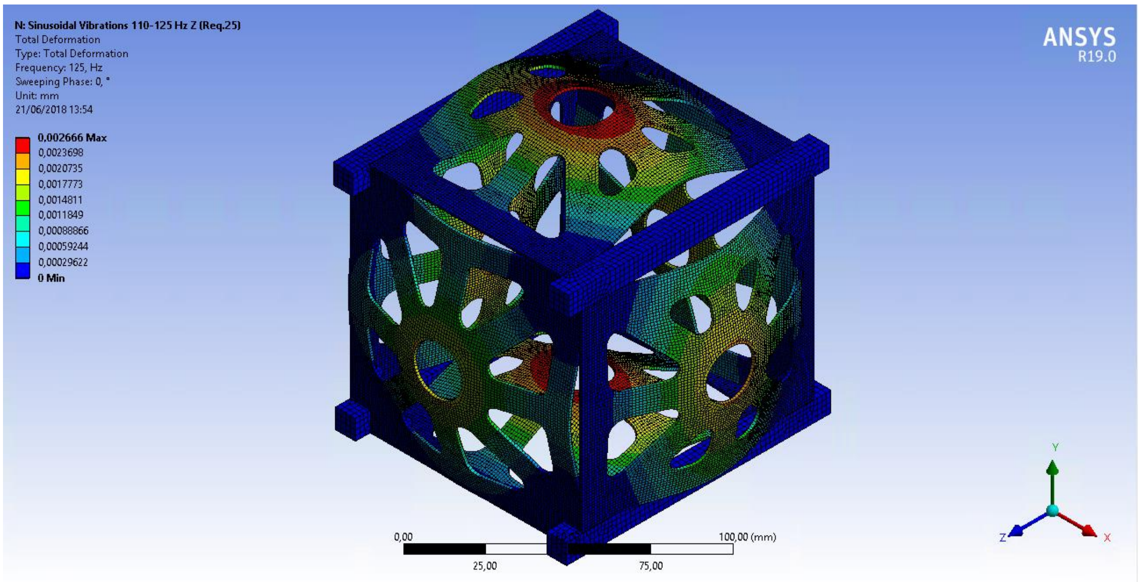


Figure 57: Sinusoidal Vibration (Requirement 26): Deformation (110-125 Hz, Y axis) (6,8e+003 (2x Auto))

In this end, this requirement is fulfilled as both stress and deformation are lower than the limits established in the Load check section.

A-7. Shocks (Requirement 29)

Requirement 29 is outlined below.

29. VEGA-3.2.7

The envelope acceleration shock response spectrum (SRS) at the spacecraft base (computed with a Q-factor of 10) is presented in the table below. These levels are applied simultaneously in axial and radial directions.

Frequency [Hz]	100	1600	10000
SRS (Q=10) [g]	30	2000	2000

A Response Spectrum analysis is settled, because structure response has to be measured when loads given by requirement are present. Primary modes are needed, so data from Modal analysis is transferred to shocks study. Consequently, boundary conditions will be the same.

A single-point response spectrum (SPRS) analysis is settled to obtain one response spectrum curve at a set of points in the model, in this case at all the supports.

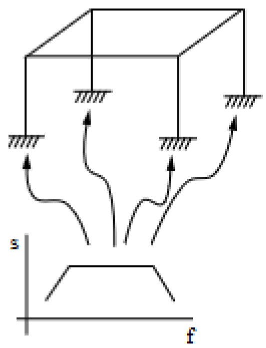


Figure 58: Single Point Response Spectrum [44]

Output of a response spectrum analysis is the maximum response of each mode to the input spectrum. In order to combine responses, Complete Quadratic Combination Method (CQC) is used because a constant damping ratio of 10 is needed. The other combination methods are: Square Root of the Squares Method, which does not allow to apply damping; and Rosenblueth Method, which may be overly conservative in some applications [44]–[46].

There are 3 types of Response Spectrum depending on the searched reaction (velocity, displacement and acceleration). In this case, acceleration Response Spectrum is used. As requirement specifies, loads must be applied in all axis at the same time. Safety factors from Table 4, are used. Gravitational acceleration takes the value of 9.81 m/s^2. The output of a response spectrum analysis is the maximum response of each mode to the input spectrum.

Analysis settings	Value	Description
Boundary condition	Fixed support	Applied in ± Z faces of rails
Constant Damping Ratio	10	-
	Single Point Spectrum	
Modes combination type	CQC	
Frequency [Hz]	**Acceleration [m/s^2]**	**-**
100	662.175	-
1600	44145	-
10000	44145	-

Table 35: Shocks (Requirement 29): Analysis stings

Response maximum stress and deformation are exposed in Table 36, Figure 59 and Figure 60.

Parameter	Maximum value
Equivalent stress [MPa]	143.49
Deformation [mm]	1.114

Table 36: Shocks (Requirement 29): Analysis results

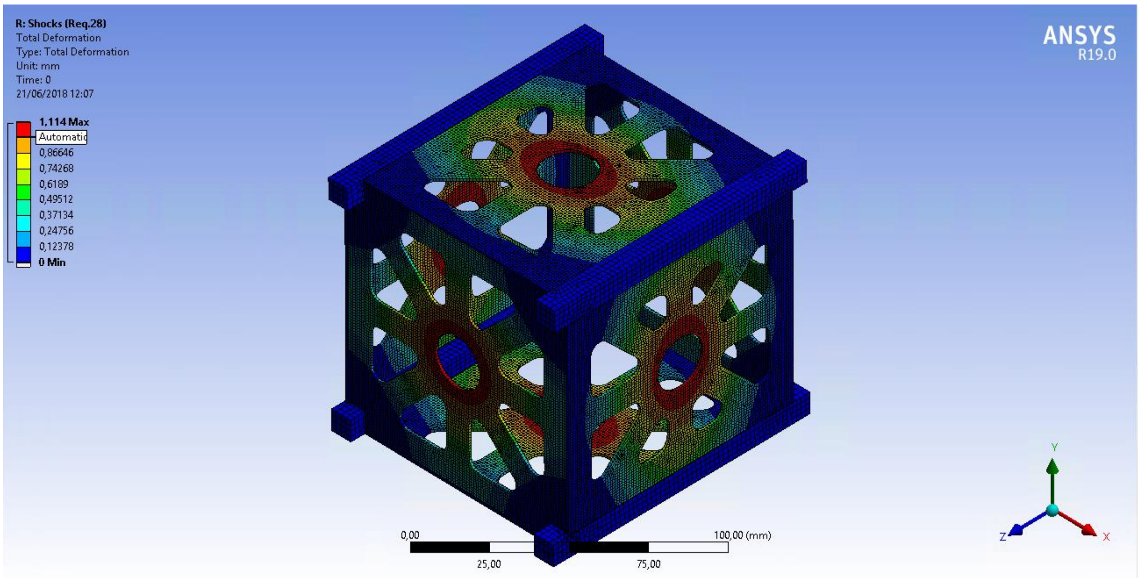


Figure 59: Shocks (Requirement 29):Deformation

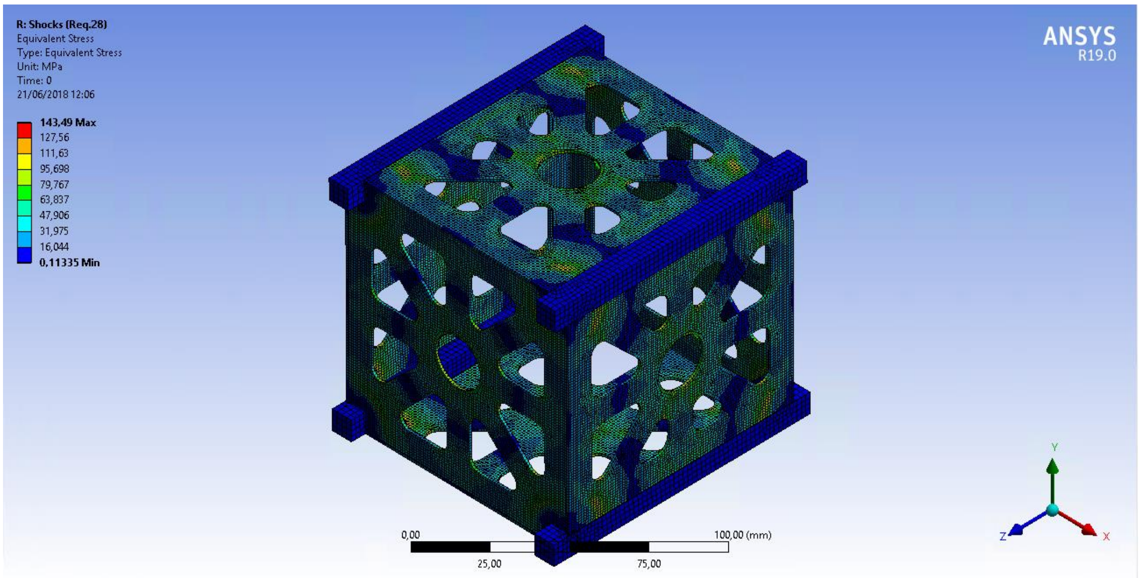


Figure 60: Shocks (Requirement 29):Equivalent stress

Singularity in bracket's corner

There is a singularity in the corner bracket of the rail shown in Figure 61. It is possible to confirm this because the stress gradient is extremely large at this point. It means that the problem is in the limit element between both bodies (computational error). Apart from that, it can be proved by refining the mesh in this zone. The result will be that the maximum stress is still in the limit element. This stress concentration is due to the sharp corner in the contact. This situation is not real due to the machining of the parts that will make those corners rounded. The inconvenient is that the maximum stress is located at this point, so if this value is compared to material yield strength, it will be a non-real comparison. However, stress in the same range is found in plates close to the contact with the rails. Hence, it is not a big error to take maximum stress value for comparison.

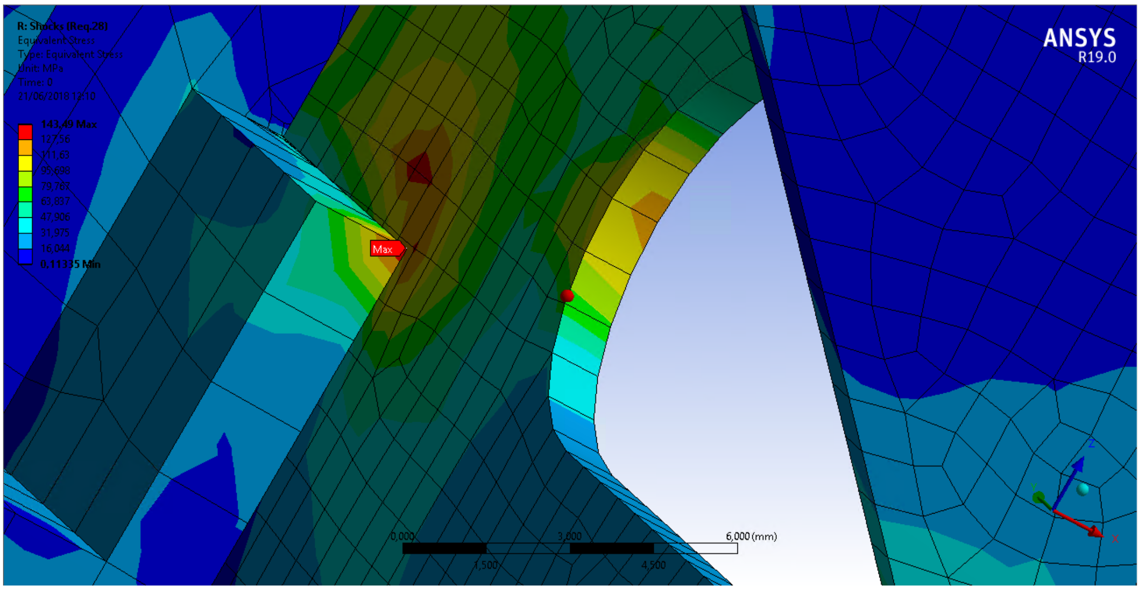


Figure 61: Shocks (Requirement 29): Singularity – Maximum stress

In short, this requirement is fulfilled as both stress and deformation are lower than the limits established in the Load check section.

A-7.1 Convergence graph

Convergence graph is a useful tool typical in FEM analysis. Its objective is to check whether mesh metric is the appropriate and results are close enough to the real ones. For this purpose, different element sizes were settled in critical points marked in Figure 62. It is remarkable that those critical points are all in the plates, the weakest parts. By running the same analysis for the different metrics, the most critical one, shocks analysis, different values of Von-Mises stress were obtained.

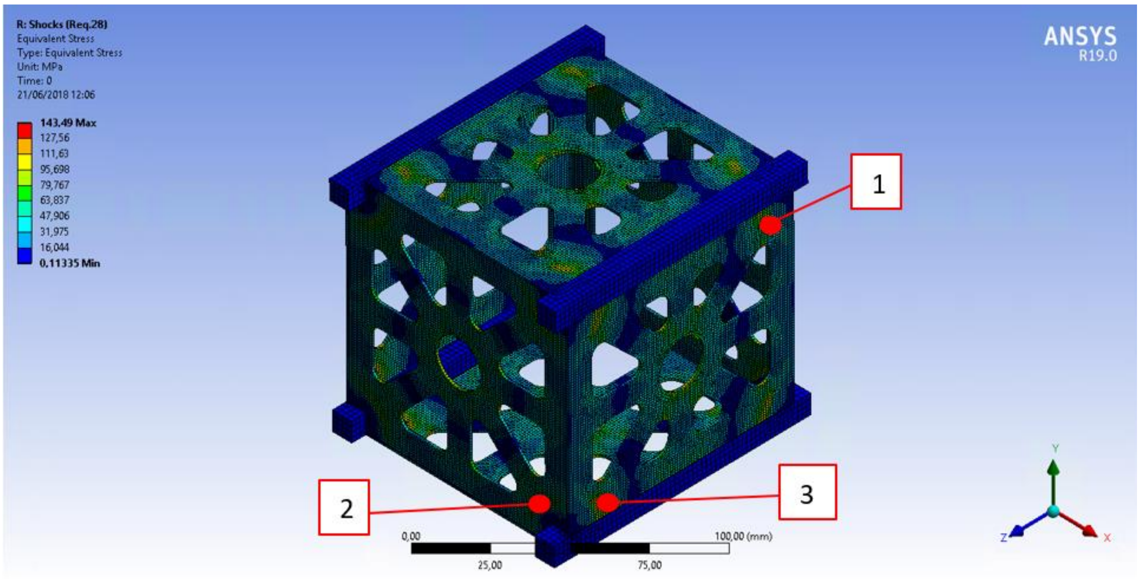


Figure 62: Points to be studied in convergence graphs

Figure 63, Figure 64 and Figure 65 are the convergence graphs for the different points. For the plates where points are located, four element sizes were meshed: 3, 2, 1 and 0.7 mm. It must be pointed out that previous analysis were done with a maximum size of 1 mm for plates elements. It was not possible to compare results for smaller element sizes because it was computationally unviable.

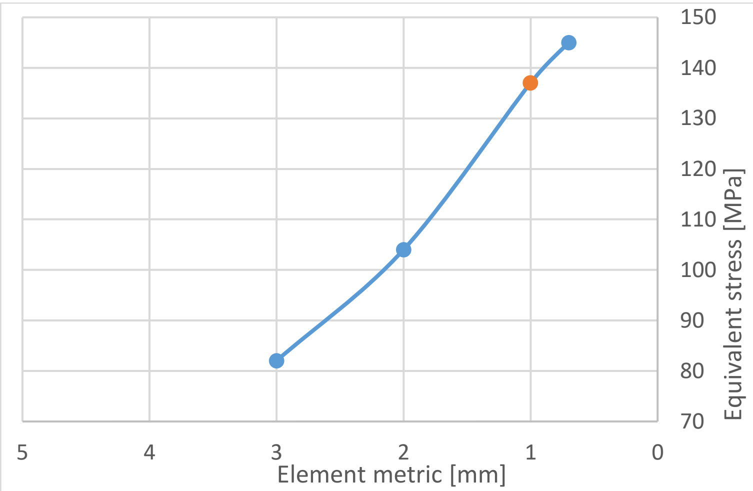


Figure 63: Convergence graph for point 1

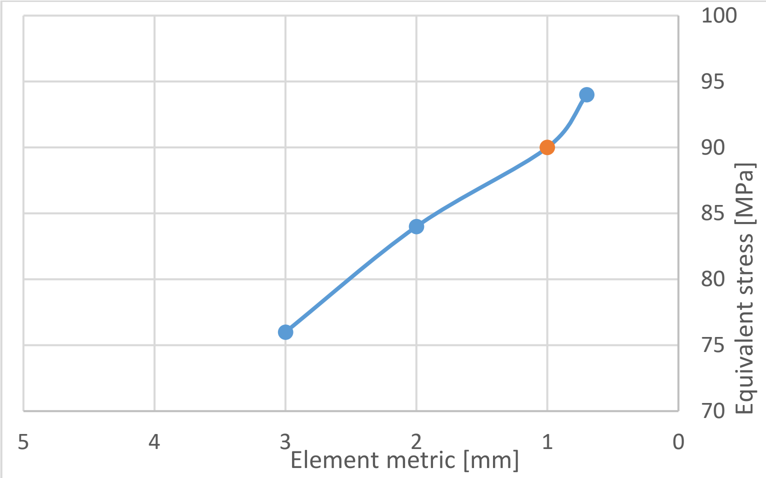


Figure 64: Convergence graph for point 2

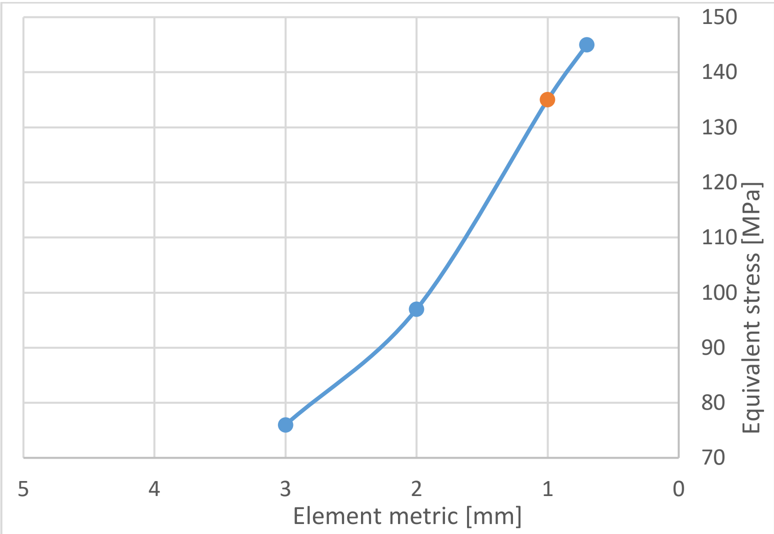


Figure 65: Convergence graph for point 3

In the three cases, differences between stresses for 1mm and 2 or 3 mm are larger than differences between stresses for 1mm and 0.7 mm. In other words, the element size used for the previous analysis (1mm) tends to the convergence, to the real result. In short, mesh chosen is considered a realistic model of the CubeSat.

ESCUELA SUPERIOR DE INGENIERÍA Y TECNOLOGÍA

Final Bachelor Thesis

DESIGN OF THE MECHANICAL STRUCTURE FOR THE TEIDESAT CUBESAT

APPENDIX B: REQUIREMENTS FOR CUBESATS TO MEET IN BAHELOR THESIS

Studies:

Mechanical Engineering Bachelor

Author:

Laura Feria del Rosario

July 2018

Table of contents of Appendix B: Requirements for CubeSats to meet in bachelor thesis

1. Acronyms

1U	1 unit CubeSat
1.5U	1.5 unit CubeSat
2U	2 unit CubeSat
3U	3 unit CubeSat
AIT	Assembly, Integration and test
AITP	Assembly, Integration and test Plan
AKE	Absolute Knowledge Error
AOCS	Attitude Orbit Control System
APE	Absolute Performance Error
ARPT	Analysis Report
ATV	Automated Transfer Vehicle
CAC	CubeSat Acceptance Checklist
CoG	Centre of Gravity
COPV	Composite Overwrapped Pressure Vessel
CS	CubeSat
CVCM	Collected Volatile Condensable Material
DDF	Design Definition File
DJF	Design Justification File
DL	Design Load
DLL	Design Limit Load
DRD	Document Requirement Definition
DUL	Design Ultimate Load
DYL	Design Yield Load
ECSS	European Cooperation for Space Standardization
EGSE	Electrical Ground Support Equipment
EMC	Electromagnetic Compatibility
EPFM	Elastic-Plastic Fracture Mechanics
ESA	European Space Agency
ESD	Electrostatic Discharge
FAR	Flight Acceptance Review
FD	Flight Dynamics
FFT	Full Functional Test
FOS, FS, SF	Factor Of Safety
GEO	Geostationary Earth Orbit (35786 km)
GSE	Ground Support Equipment
HTV	H-II B Transfer Vehicle
I/F	Interface
ICD	Interface Control Document
IOD	In-Orbit Demonstration
ISS	International Space Station
JAXA	Japanese Aerospace Exploration Agency
JEM	Japanese Experiment Module
JEMRMS	JEM Remote Manipulator System
J-SSOD	JEM Small Satellite Orbital Deployer
LV	Launch Vehicle
LBB	Leak-Before-Burst
LEFM	Linear Elastic Fracture Mechanics

LEO	Low Earth Orbit (160 – 2000 km)
LL	Limit Load
MDP	Maximum Design Pressure
MECO	Main Engine Cut-Off
MEO	Medium Earth Orbit (2000 – 36000 km)
MEOP	Maximum Expected Operating Pressure
MIUL	Material Identification Usage List
MoI	Moment of Inertia
MOS	Margin Of Safety
MPV	Metallic Pressure Vessel
MRD	Mission Requirement Document
MUA	Material Usage Agreement
NA	Not Applicable
NCR	Non-Conformance Report
NDI	Non-Destructive Inspection
NRB	Non-conformance Review Board
NRCSD	NanoRacks CubeSat Deployer
OA	Over All
PAF	Payload Attach Fitting
PCDU	Power Conditioning and Distribution Unit
PFCI	Potential Fracture-Critical Item
PFM	Proto-Flight Model
PIM	Passive Intermodulation
P-POD	Poly-Picosatellite Orbital Deployer
PSD	Power Spectral Density
PT	Performance Test
PTR	Post Test Review
PV	Pressurized pressure vessel
QM	Qualification Model
RBF	Remove Before Flight
RF	Radio Frequency
RFT	Reduced Functional Test
RKE	Relative Knowledge Error
RoD	Review of Design
RPE	Relative Performance Error
SEP	System Engineering Plan
SMS	Specific Mechanism Specification
SoW	Statement of Work
SpX	Space-X
SRD	System Requirement Document
SRS	Shock Response Spectrum
SSN	Space Surveillance Network
TBS	To Be Specified
TC	Telecommand
TCS	Thermal Control System
TM	Telemetry
TML	Total Mass Loss
TML	Total Mass Loss
TRB	Test Review Board
TRPT	Test Report

TRR	Test Readiness Review
UM	User Manual
VCB	Verification Control Board
VCD	Verification Control Document
VCM	Volatile Condensable Material
VP	Verification Plan
VUA	Volatile Organic Compound Usage Agreement

2. Introduction

2.1. Purpose

The aim of this document is to unify the most restrictive specifications applicable to the engineering model available that may affect the mechanics of a CubeSat 1U made of Al 6061 T6, based on the ones gathered in the document "Most restrictive mechanical requirements for CubeSats".

2.2. Scope

This document will be focused on space segment, more concretely in a CubeSat subsystem: the mechanical structure. A 1U CubeSat model will be developed. Propulsion system and re-entry CubeSats specifications will not be taken into account, as it will not be needed for the mission of TeideSat. The thermal control system will not be part of this document apart from those aspects concerning structure or AOCS systems.

Concerning the launch vehicles requirements, only launch and flight environments will be taken into account.

As a result of the documents applied, the ECSS standards tailored for CubeSats are considered. Furthermore, 3 deployer systems are considered,

1. P-POD: Poly Picosatellite Orbital Deployer
2. J-JSSOD: JEM Small Satellite Orbital Deployer
3. NRCSD: NanoRacks CubeSat Deployer;

and 8 launch vehicles are studied,

1. HTV: H-II B Transfer Vehicle
2. ATV: Automated Transfer Vehicle
3. SpX Dragon: Space-X Dragon
4. Orbital Cygnus
5. Vega, operated by Arianespace from the Guiana Space Centre.
6. Ariane 5, operated by Arianespace from the Guiana Space Centre.
7. Delta II
8. Soyuz, operated by Arianespace from the Guiana Space Centre.

2.3. Applicable documents

The main document applied is the "Most restrictive mechanical requirements for CubeSats", also written by the author. The following documents form a part of it to the extent specified above.

Document Number	Document Title	Issue/ Rev	Date	Reference
-	Most restrictive mechanical requirements for CubeSats	0/0	04/2018	MRR
-	Mechanical Requirements Collection for CubeSats	0/0	04/2018	MEC
CDS 13	CubeSat Design Specification, California Polytechnic	Rev. 13	02/02/2014	CDS
JX-ESPC-101133-B	JEM Payload Accommodation Handbook - Vol. 8 - Small Satellite Deployment Interface Control Document	Rev. B	01/2015	JX
NR-SRD-029	NanoRacks CubeSat Deployer (NRCSD) Interface Control Document	Rev. 0.36	10/12/2013	NRCSD-ICD
NR-SRD-052	Document Change Notice (DCN): Maximum CubeSat Mass and Vibration Test Spectra	Rev. 0.1	30/04/2014	-
NR-SRD-063	Document Change Notice (DCN): NRCSD Guide Rail Width	Rev. 0.1	11/08/2014	-
-	Vega User's Manual	4/0	04/2014	VEGA
-	Ariane 5 User's Manual	5/2	10/2016	ARIANE5
-	Soyuz User's Manual	2/0	03/2012	SOYUZ-CSG
06H0214	Delta II Payload Planners Guide	Version 2006	12/2006	DELTAII

2.4. Document conventions

All requirements in this document are denoted as

Reference-Source-N.N.N

Requirement text.

NOTE

Where:

- **Reference-Source-N.N.N:** indicates the requirement ID number according to chapter and section found in its document reference source.
- Requirement text: describes the requirement.
- *NOTE:* (optional) provides supporting information regarding the requirement.

2.5. Nomenclature

The following nomenclature applies throughout this document:

a. The word "shall" is used to express requirements.
b. The word "should" is used to express recommendations.

NOTE It is expected that, during tailoring made by T-ECSS-E-ST-IOD-CS, recommendations in this document are either converted into requirements or tailored out.

c. The word "may" is used to express positive permission.

d. The words “need not” are used to express negative permission.
e. The word “can” is used to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.
f. The present and past tenses are used to express statements of fact, and therefore they imply descriptive text.

2.6. Terms and Definitions

For the purpose of this collection of standards, the terms and definitions from ECSS-ST-00-01 apply.

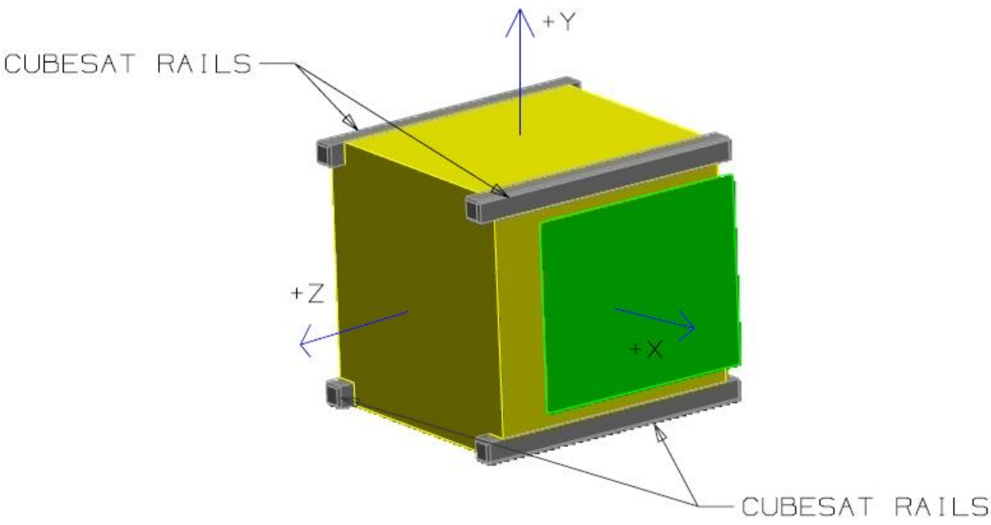
3. Launcher and Deployer Requirements

3.1. CubeSat physical interface

3.1.1 REFERENCE FRAME

1. **CDS-3.2.1**

   The CubeSat shall use the coordinate system as defined in the figure below for the appropriate size. The origin of the CubeSat coordinate system is located at the geometric center of the CubeSat.



CubeSat Configuration

(Source: CDS 13)

3.1.2 CUBESAT DIMENSIONS

2. **JX-2.1.2.2**

   The dimensional requirements for a CubeSat are defined in the Figure 2.1.2-1.

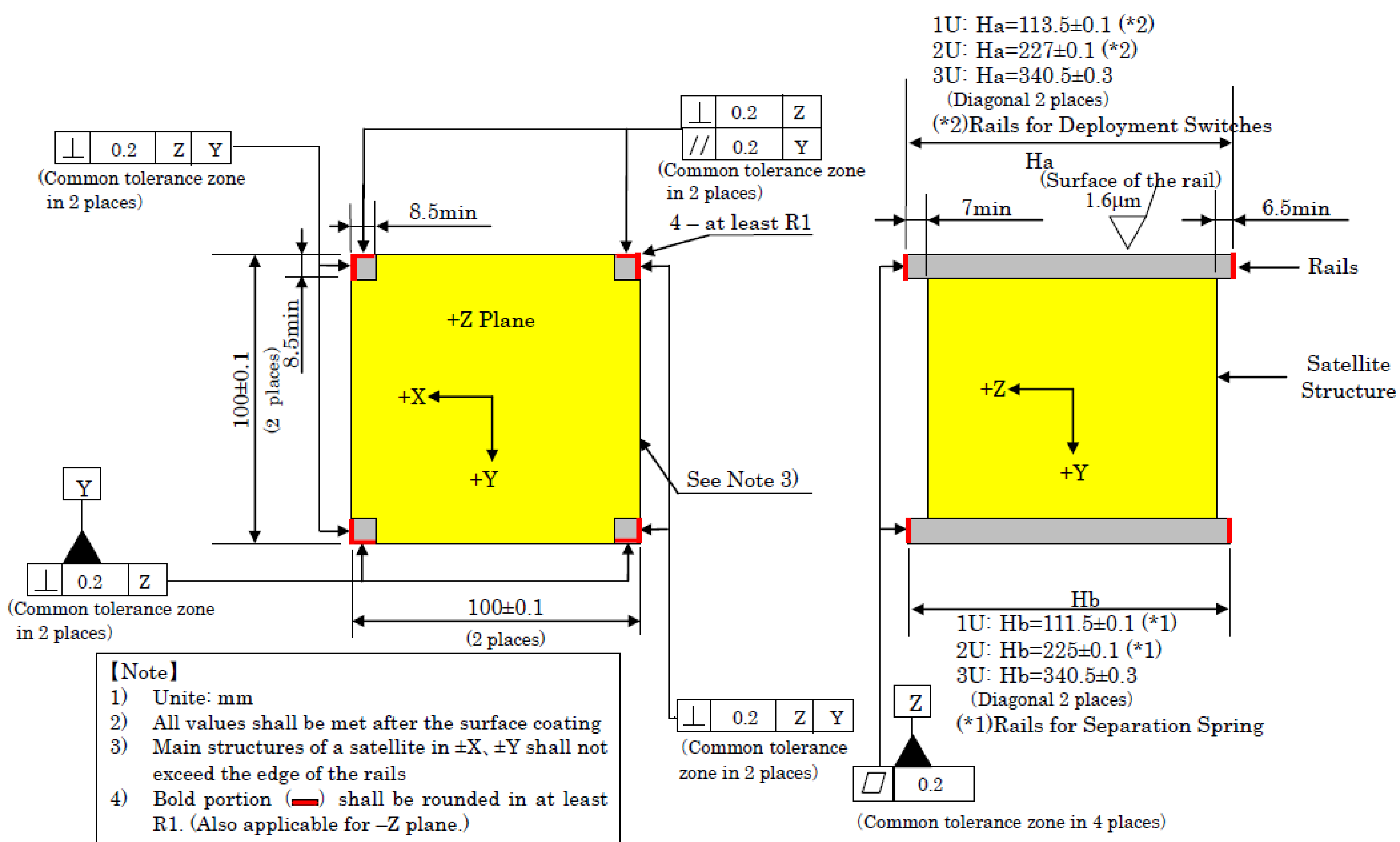


Figure 2.1.2-1 Dimensional Requierments for Satellite

3. **JX-2.1.4.2**

   The **main structure** of a satellite in +Z shall be **recessed** more than 7.0mm from the edge of the rails. All components in +Z shall be recessed more than 0.5mm from the edges of the rails.

4. **JX-2.1.4.3**

   The **main structure** of a satellite in -Z shall be **recessed** more than 6.5mm from the edge of the rails. All components in -Z shall be recessed from the edges of the rails.

5. **JX-2.1.4.4**

   The main structures of a satellite in +/-X and +/-Y shall not exceed the side surface of the rails. Any components in these surfaces shall not exceed 6.5mm normal to the side surface of the rails including the RBF pin.

6. **CDS-3.2.3.1**

   When completing a CubeSat Acceptance Checklist (CAC), protrusions will be measured from the plane of the rails.

7. **JX-4.2.2.1.1**

   In order to protect crewmembers from sharp edges and protrusions during all crew operations, they need to be rounded or planed greater than 0.7mm to the utmost. If a satellite has any potential sharp edges which cannot be rounded or planed (ex. An edge of a solar cell), a satellite provider shall identify the sharp edge positions with an acceptance rationale for JAXA approval.

   Holes (round, slotted) without covers need to be 25 mm or longer, or be 10 mm or shorter in diameter.

3.1.3 MASS PROPERTIES

8. **JX-2.1.5.1**

   The mass of a satellite shall be larger than 0.13kg per 1U.

9. **CDS-3.2.10**

   The maximum mass of a 1U CubeSat shall be 1.33 kg.

3.1.4 CENTER OF GRAVITY

10. **NRCSD-ICD-4.4**

    The CubeSat center of gravity shall be within 2cm of its geometric center.

3.1.5 MATERIAL

11. **CDS-3.2.15**

    Aluminum 7075, 6061, 5005, and/or 5052 will be used for both the main CubeSat structure and the rails.

12. **CDS-3.1.8.1**

    CubeSats materials shall have a **Total Mass Loss** (TML) < 1.0 %

13. **CDS-3.1.8.2**

    CubeSat materials shall have a **Collected Volatile Condensable Material** (CVCM) < 0.1%

3.1.6 RAILS

3.1.6.1 Number of rails

14. **NRCSD-ICD-4.6.1**

    A CubeSat shall have **four (4) rails**, one per corner, along the Z axis.

3.1.6.2 Dimensions

15. **CDS-3.2.5**

    Rails shall have a minimum **width** of 8.5mm.

16. **NRCSD-ICD-4.6**

    Rail length variance in the Z axis between rails shall not exceed ± 0.1 mm.

3.1.6.3 Surface roughness

17. **CDS-3.2.6**

    Rails will have a **surface roughness** less than 1.6 µm.

3.1.6.4 Edges

18. **CDS-3.2.7**

    The **edges of the rails** will be rounded to a radius of at least 1 mm

3.1.6.5 Material

19. **JX-2.1.3.8**

    The rail surfaces which contact with the rail guides of the J-SSOD Satellite Install Case and the rail standoffs which contact with adjacent satellites shall be hard anodized aluminum after machining process. The thickness of the hard anodized coating shall be more than 10µm according to MIL-A-8625, Type3.

3.1.6.6 Contact area

20. CDS-3.2.8

The ends of the rails on the +/- Z face shall have a **minimum surface area** of 6.5 mm x 6.5 mm **contact** area for neighbouring CubeSat rails.

3.1.6.7 Structural strength

21. JX-2.1.8.2

Each rail shall have a sufficient structural strength with considering that the rail is subject to compression force at 46.6 N due to a preload from the Backplate and main spring of deployer.

3.1.7 Frequency

22. JX-2.1.9

The minimum fundamental frequency of a satellite shall be no less than 100 [Hz] on the condition that the four rails +/-Z standoffs are rigidly fixed. If the minimum fundamental frequency of the satellite is less than 100 [Hz], coordination with launcher is needed since a random vibration environment subjected to the satellite may exceed the environment.

3.2. Environmental requirements

3.2.1 Atmospheric Pressure

23. CDS-3.1.11

The CubeSat shall be designed to accommodate ascent **venting** per ventable volume/area < 50.8 [m].

NOTE Volume refers to satellite internal volume (V [m3]) and the area refers to area of exhaust ports (A [m2]).

3.2.2 Thermal conditions

24. NRCSD-ICD-7

CubeSats shall be designed to withstand overall temperature range of -40C to +65C.

3.2.3 Random Vibrations

25. SOYUZ-CSG-3.2.5

Random vibrations at the spacecraft base are generated by propulsion system operation and by the adjacent structure's vibro-acoustic response. Maximum excitation levels are obtained during the first-stage flight.

Acceleration power spectral density (PSD) and root mean square vibration levels (GRMS) are given in the table below along each of the three axes.

Frequency [Hz]	PSD [g^2/Hz]
20	0.05
50	0.05
100	0.1
200	0.25
500	0.25
1000	0.1
2000	0.05

NOTE Spacecraft is not the launch vehicle, but the CubeSat.

3.2.4 Sinusoidal vibrations

25. MRR-2.2.5

The satellite shall withstand the most demanding combination of limit levels of sine-equivalent vibrations obtained from Vega and Ariane 5 launcher requirements. The limit levels of sine-equivalent vibrations to be taken into account for the design and dimensioning of the spacecraft are the highest values that the launch vehicle can suffer.

Frequency band [Hz]	Direction	Sine amplitude [g]
1-25	Longitudinal	1
	Lateral	0.8
25-110	Longitudinal	1
	Lateral	0.6
110-125	Longitudinal	0.2
	Lateral	0.2

3.2.1 Quasi-static Loads

The highest quasi-static acceleration in any direction during launch that structure shall withstand is obtained from JX requirements, specifically for ATV vehicle.

26. JX-2.4.1.1a

The satellite shall withstand a quasi-static acceleration in any direction during launch:

- ATV : 12.37 [g].

NOTE Orbital Cygnus, obtained from JX requirements, is a special case whose value can reach up to 18.1 g.

27. NRCSD-ICD-4.9

During deployment, the CubeSats shall be compatible with deployment velocities between 0.5 m/s to 1.5 m/s and accelerations no greater than 2g's in the +Z direction.

3.2.2 Shocks

The satellite shall withstand the envelope acceleration shock response spectrum (SRS) at the spacecraft base (computed with a Q-factor or damping ratio of 10) obtained from the highest values of acceleration for the same frequencies, that is Vega vehicle. These levels are applied simultaneously in axial and radial directions.

28. VEGA-3.2.7

The envelope acceleration shock response spectrum (SRS) at the spacecraft base (computed with a Q-factor of 10) is presented in the table below. These levels are applied simultaneously in axial and radial directions.

Frequency [Hz]	100	1600	10000
SRS (Q=10) [g]	30	2000	2000

NOTE Spacecraft is not the launch vehicle, but the CubeSat.

ESCUELA SUPERIOR DE INGENIERÍA Y TECNOLOGÍA

Final Bachelor Thesis

DESIGN OF THE MECHANICAL STRUCTURE FOR THE TEIDESAT CUBESAT

APPENDIX C: ENGINEERING DRAWINGS

Studies:

Mechanical Engineering Bachelor

Author:

Laura Feria del Rosario

July 2018

Table of engineering drawings

CODIGO/CODE:	NOMBRE FICHERO PIEZA/PART FILENAME	EDICION/ISUUE	
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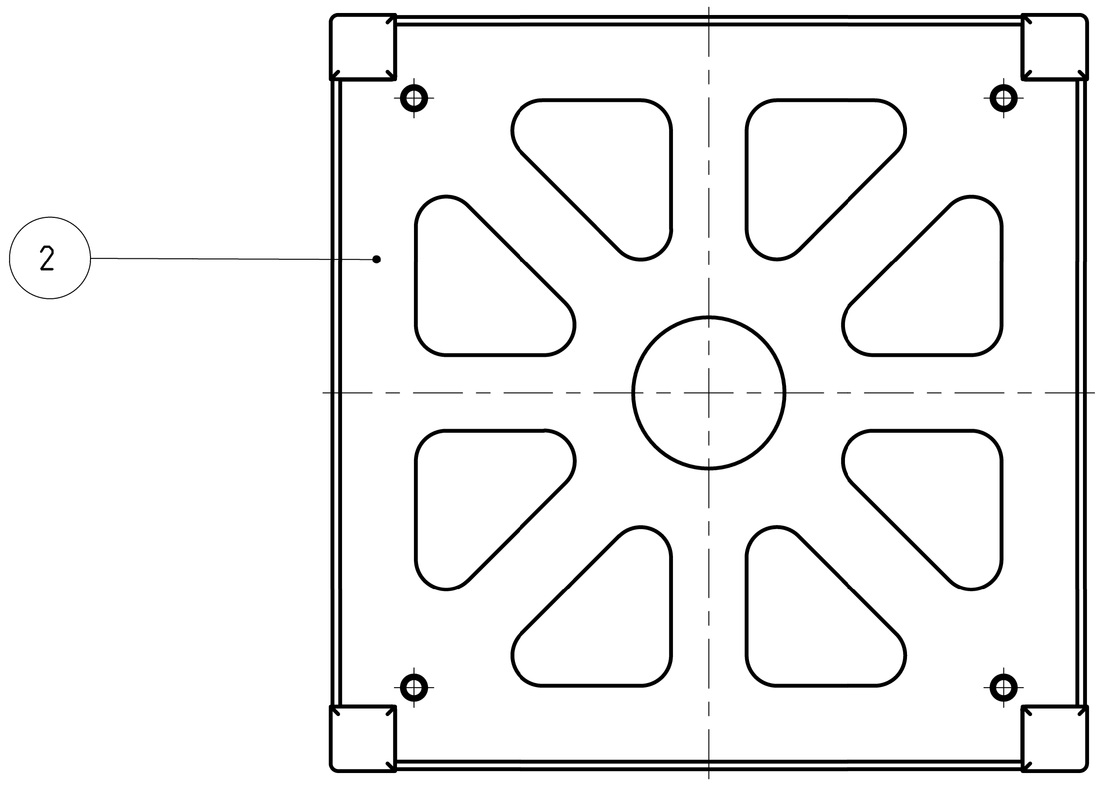

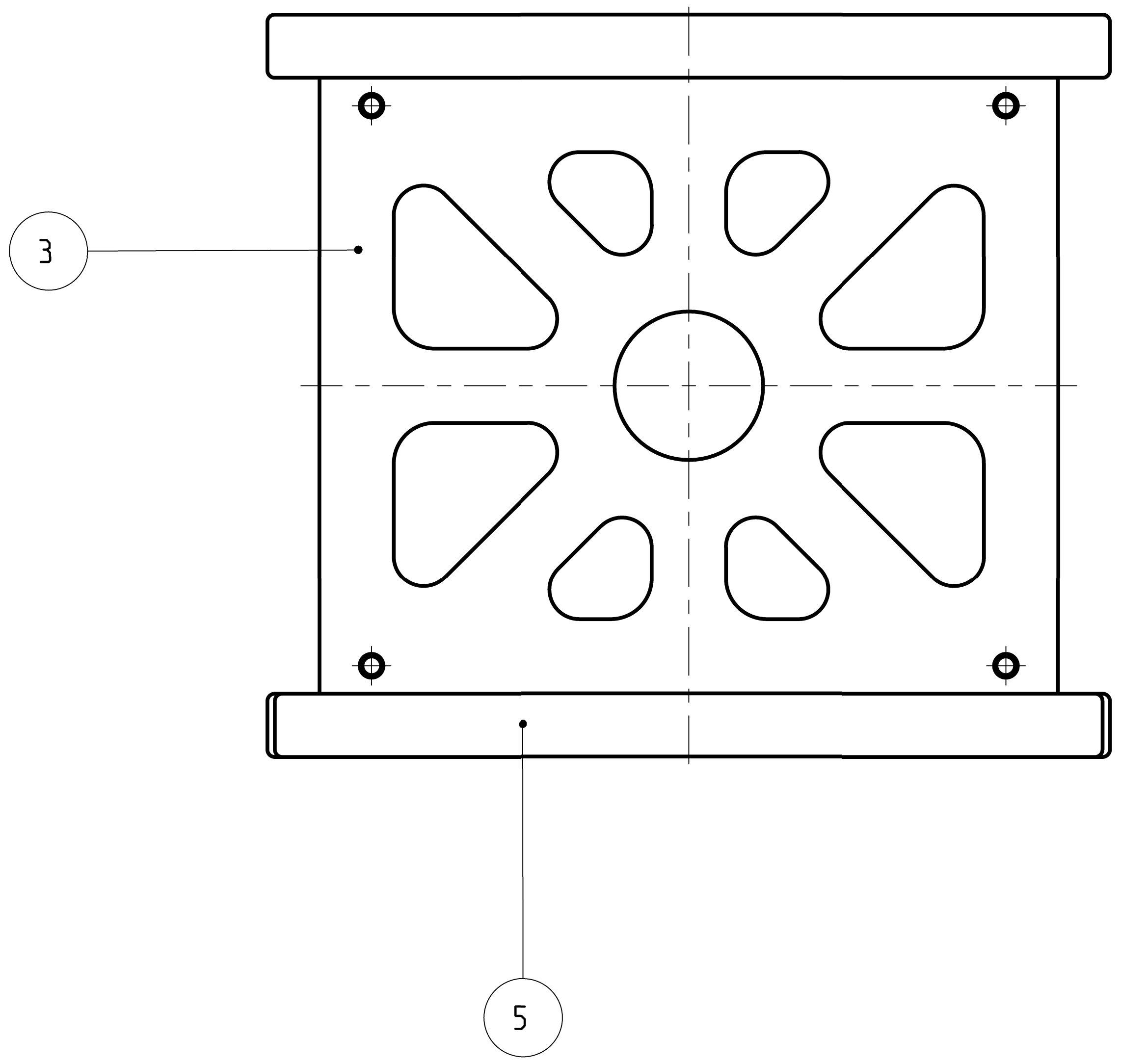

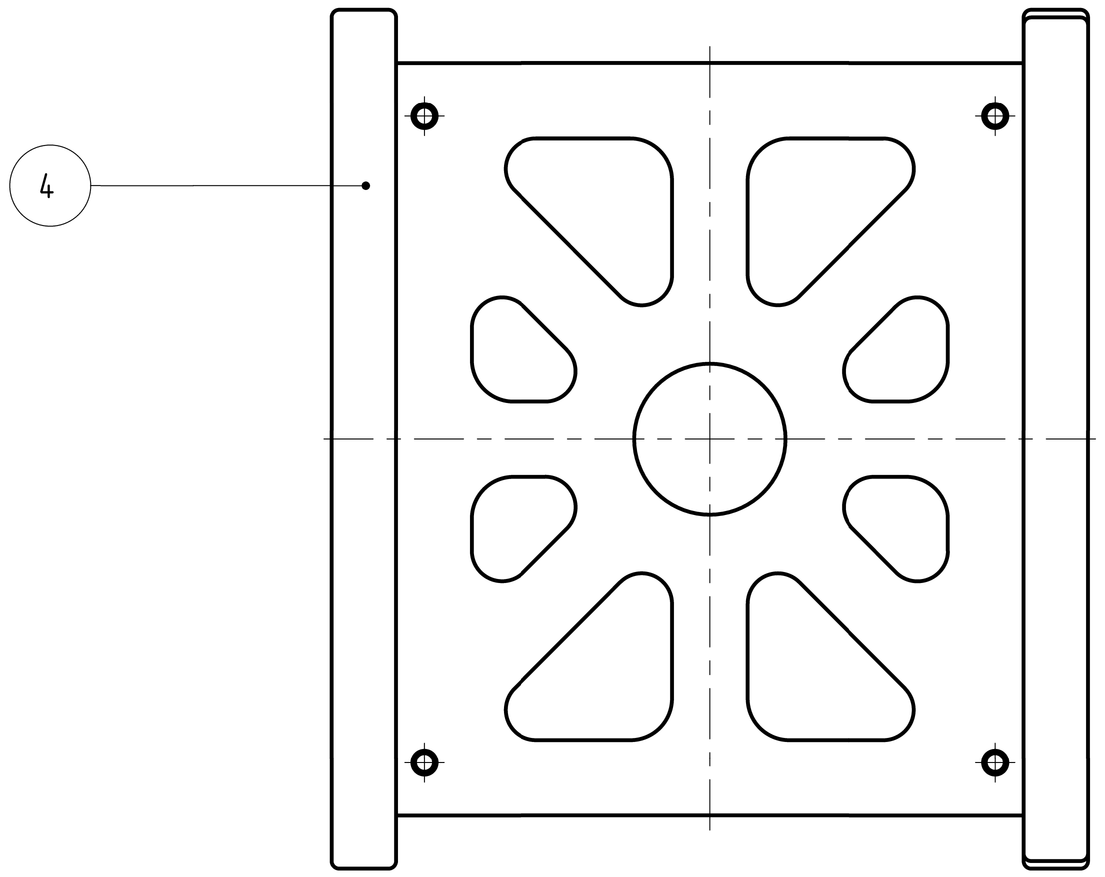

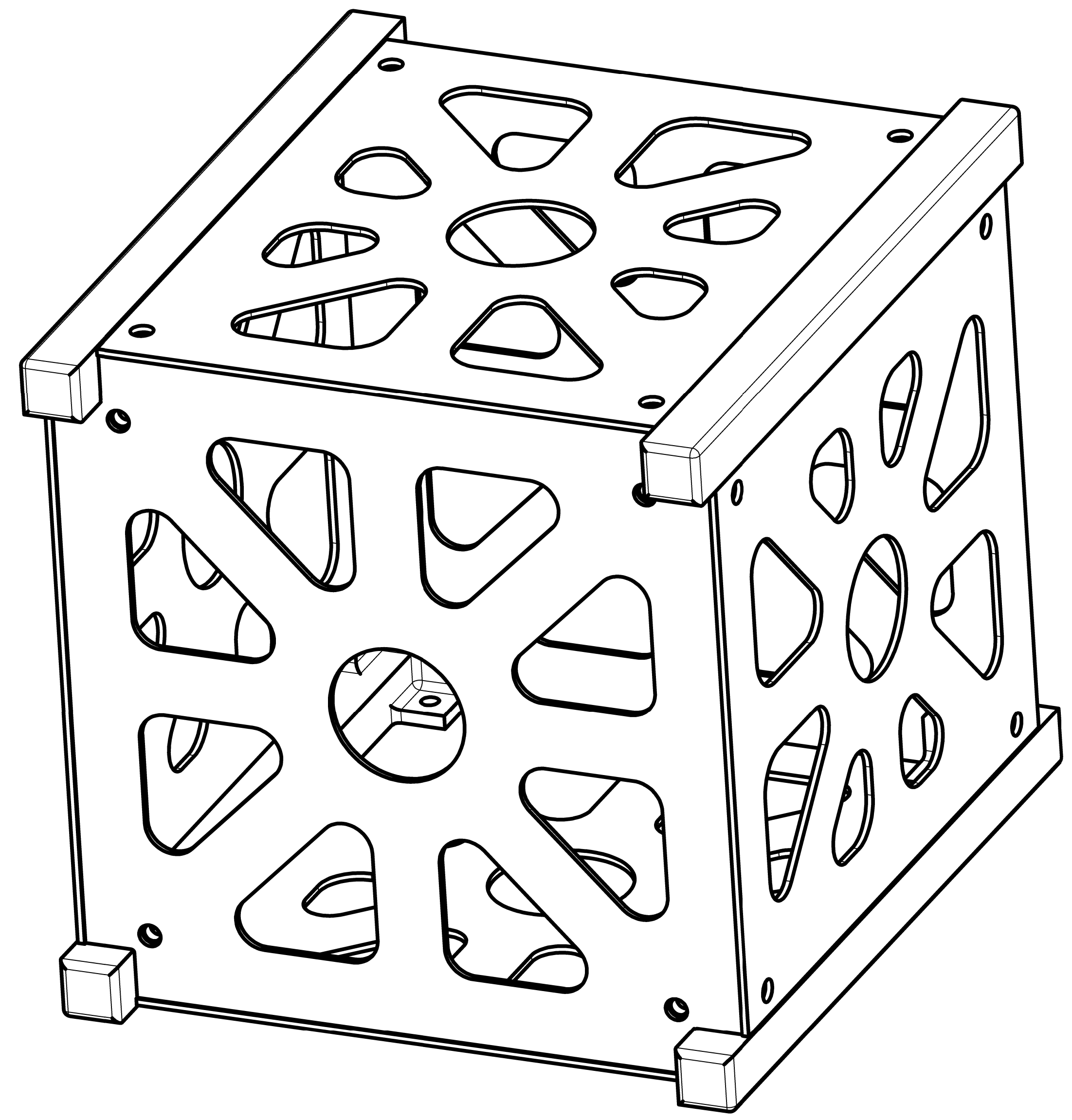

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4	0701100010	GUIA 1	AL_6061_T6	2	
3	0701100020	CHAPA LATERAL	AL_6061_T6	4	
2	0701100030	CHAPA FRONTAL	AL_6061_T6	2	
1			AL_6061_T6	1	

IACTEC MICROSATELITES

TEIDESAT

CONJUNTO

CANTIDAD/QUANTITY	MATERIAL	MASA/MASS	PROTECCION SUPERFICIAL/SURFACE TREATMENT
1		198.194 gr	

COTAS/DIMENSIONS	ESCALA/SCALE	VALIDO PARA/ISSUED FOR	FUENTE/SOURCE
mm	1:1	FABRICACION	IAC

	NOMBRE/NAME
DISEÑADO/DESIGNED: FECHA/DATE:	L.FERIA 6-6-18
DIBUJADO/DRAW: FECHA/DATE:	J.PERDIGON 11-6-18
REVISADO/REVISED: FECHA/DATE:	J.COZAR 11-6-18
AUTORIZADO/AUTHORIZED: FECHA/DATE:	P.REDONDO 11-6-18

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e-mail: secins@iac.es - http://www.iac.es

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DIN-A2

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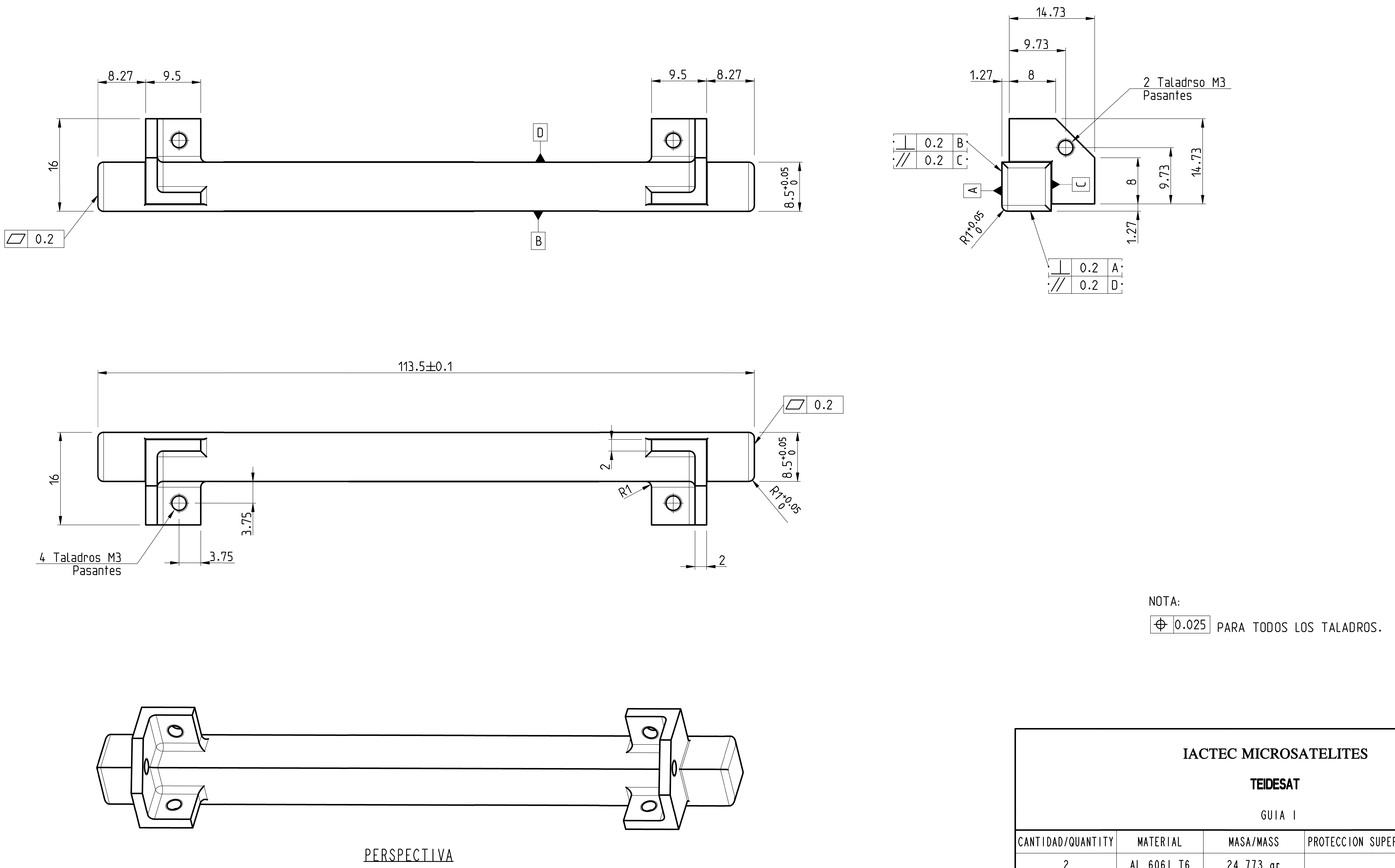

NOTA:

⌖ 0.025 PARA TODOS LOS TALADROS.

IACTEC MICROSATELITES

TEIDESAT

GUIA I

CANTIDAD/QUANTITY	MATERIAL	MASA/MASS	PROTECCION SUPERFICIAL/SURFACE TREATMENT
2	AL_6061_T6	24.773 gr	
COTAS/DIMENSIONS	ESCALA/SCALE	VALIDO PARA/ISSUED FOR	FUENTE/SOURCE
mm	2:1	FABRICACIÓN	IAC

	NOMBRE/NAME
DISEÑADO/DESIGNED: FECHA/DATE:	L.FERIA 6-6-18
DIBUJADO/DRAW: FECHA/DATE:	J.PERDIGON 11-6-18
REVISADO/REVISED: FECHA/DATE:	J.COZAR 11-6-18
AUTORIZADO/AUTHORIZED: FECHA/DATE:	P.REDODNDO 11-6-18

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e-mail: secins@iac.es - http://www.iac.es

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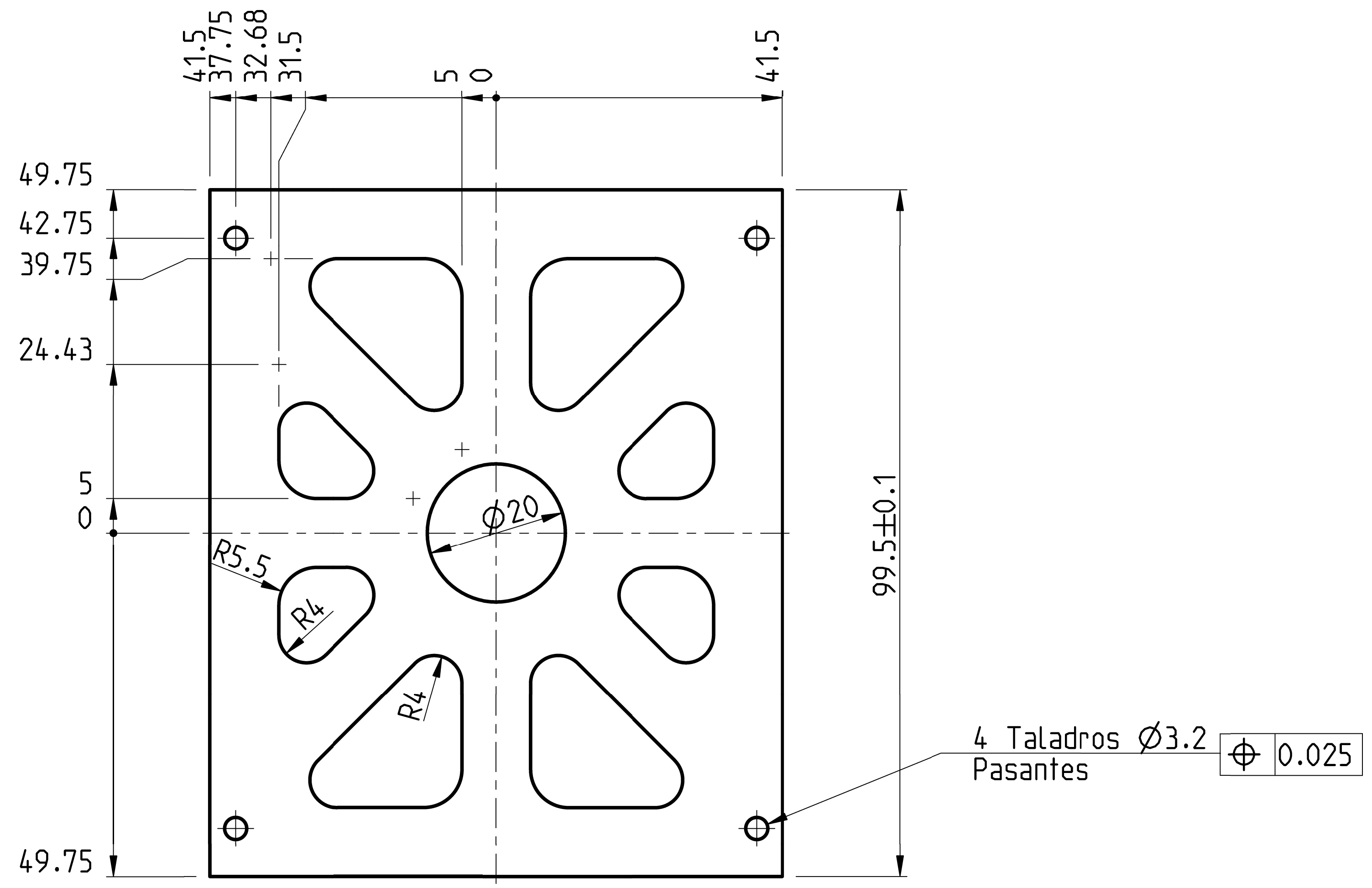

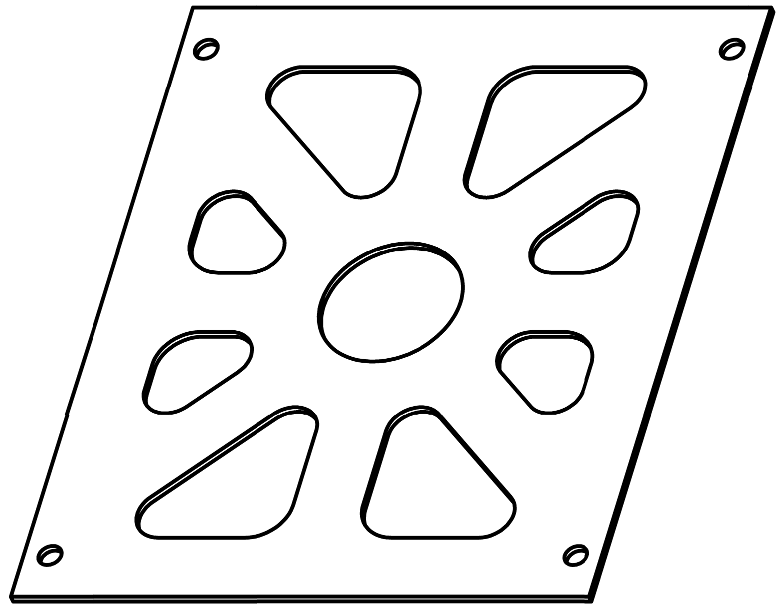

PERSPECTIVA

IACTEC MICROSATELITES

TEIDESAT

CHAPA LATERAL

CANTIDAD/QUANTITY	MATERIAL	MASA/MASS	PROTECCION SUPERFICIAL/SURFACE TREATMENT
4	AL_6061_T6	16.242 gr	
COTAS/DIMENSIONS	ESCALA/SCALE	VALIDO PARA/ISSUED FOR	FUENTE/SOURCE
mm	1:1	FABRICACIÓN	IAC

	NOMBRE/NAME
DISEÑADO/DESIGNED: FECHA/DATE:	L.FERIA 6-6-18
DIBUJADO/DRAW: FECHA/DATE:	J.PERDIGON 11-6-18
REVISADO/REVISED: FECHA/DATE:	J.COZAR 11-6-18
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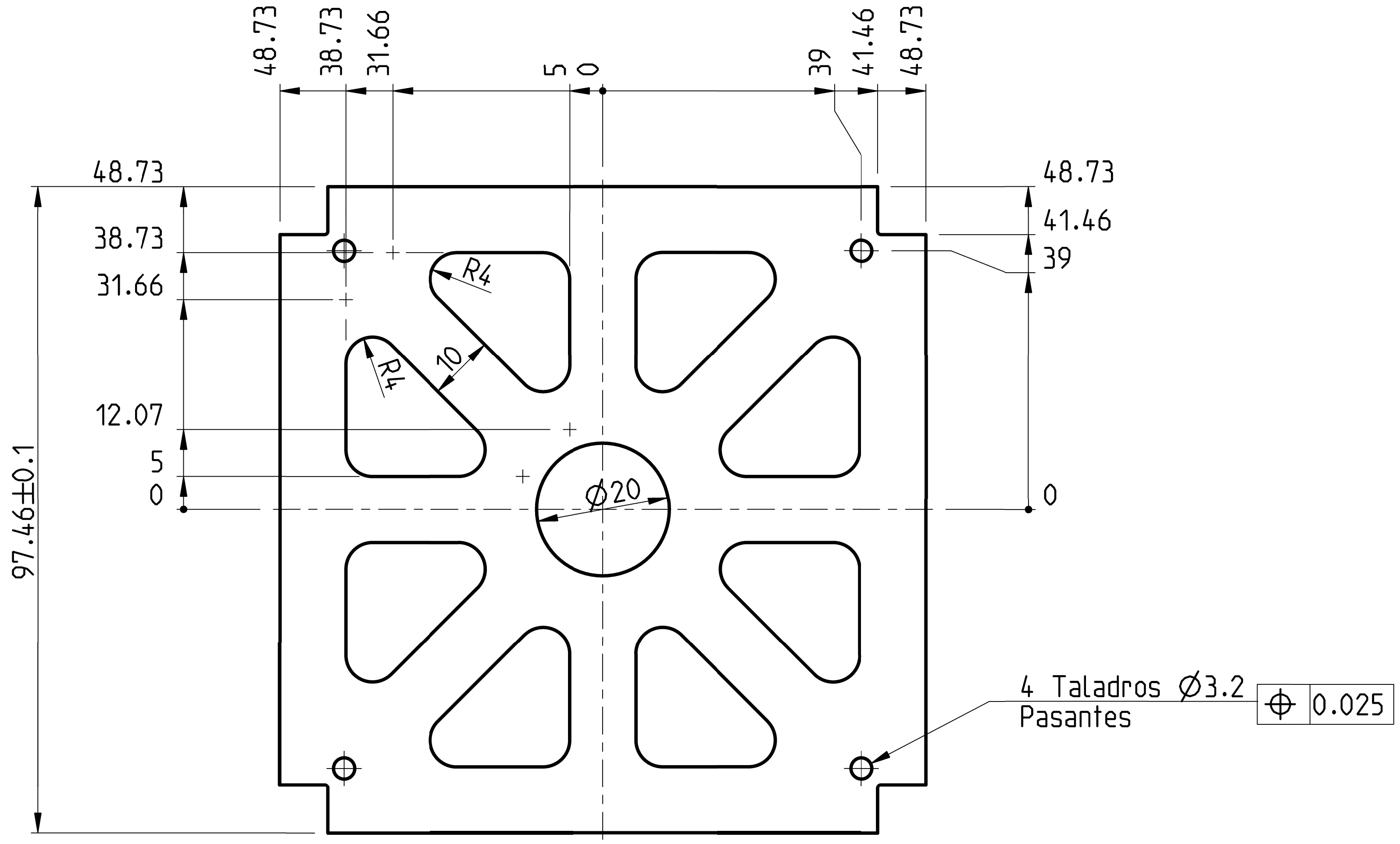

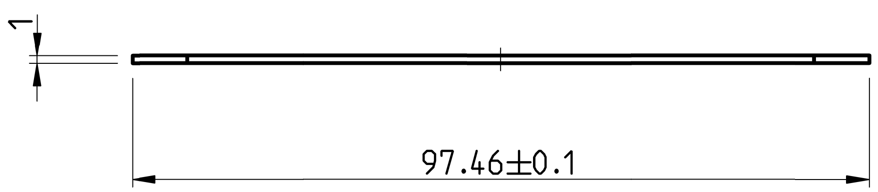

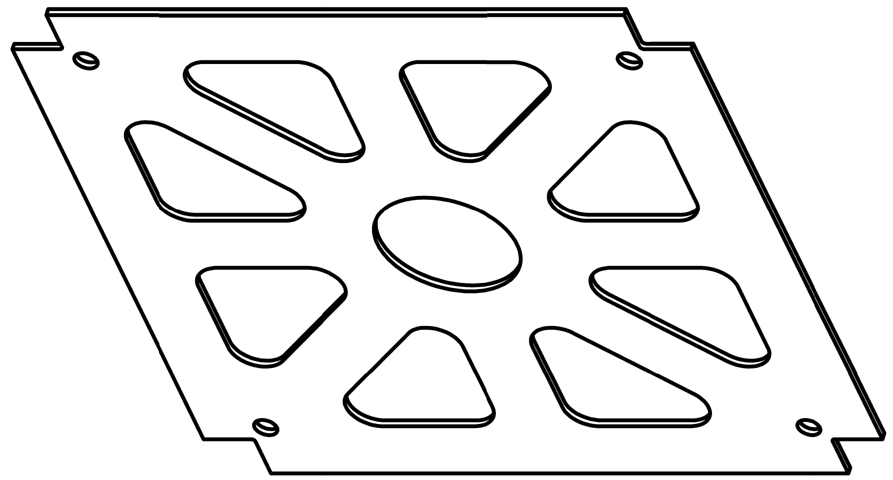

PERSPECTIVA

IACTEC MICROSATELITES

TEIDESAT

CHAPA FRONTAL

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2	AL_6061_T6	17.458 gr	
COTAS/DIMENSIONS	ESCALA/SCALE	VALIDO PARA/ISSUED FOR	FUENTE/SOURCE
mm	1:1	FABRICACIÓN	IAC

	NOMBRE/NAME
DISEÑADO/DESIGNED:	L.FERIA
FECHA/DATE:	6-6-18
DIBUJADO/DRAW:	J.PERDIGON
FECHA/DATE:	11-6-18
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FECHA/DATE:	11-6-18
AUTORIZADO/AUTHORIZED:	P.REDONDO
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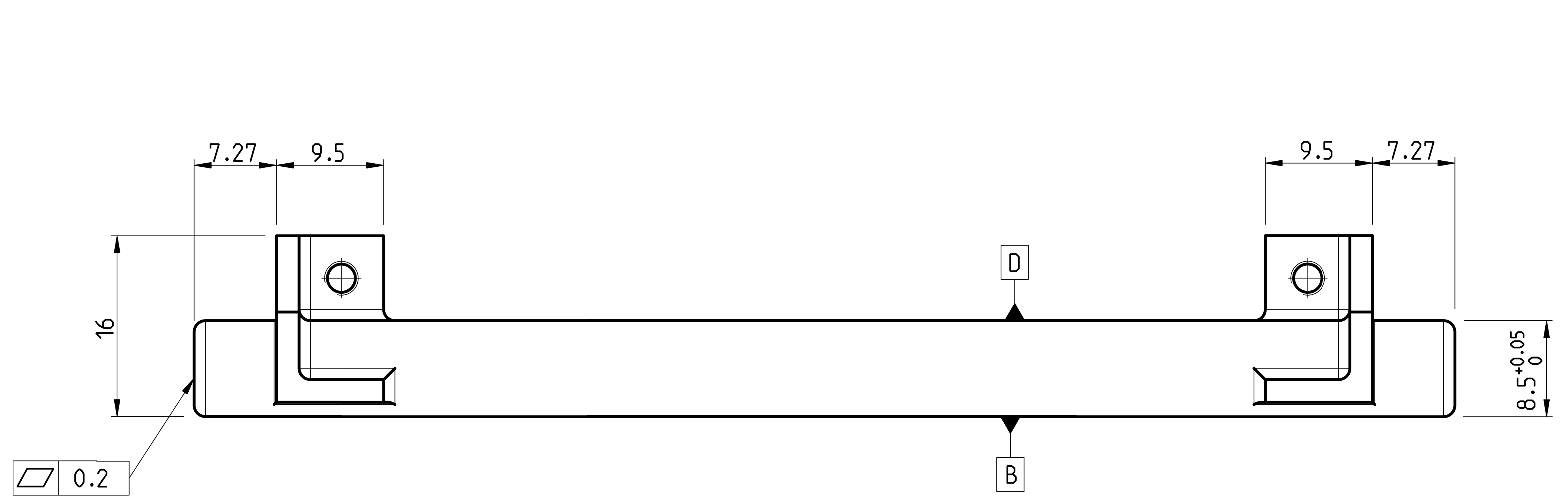

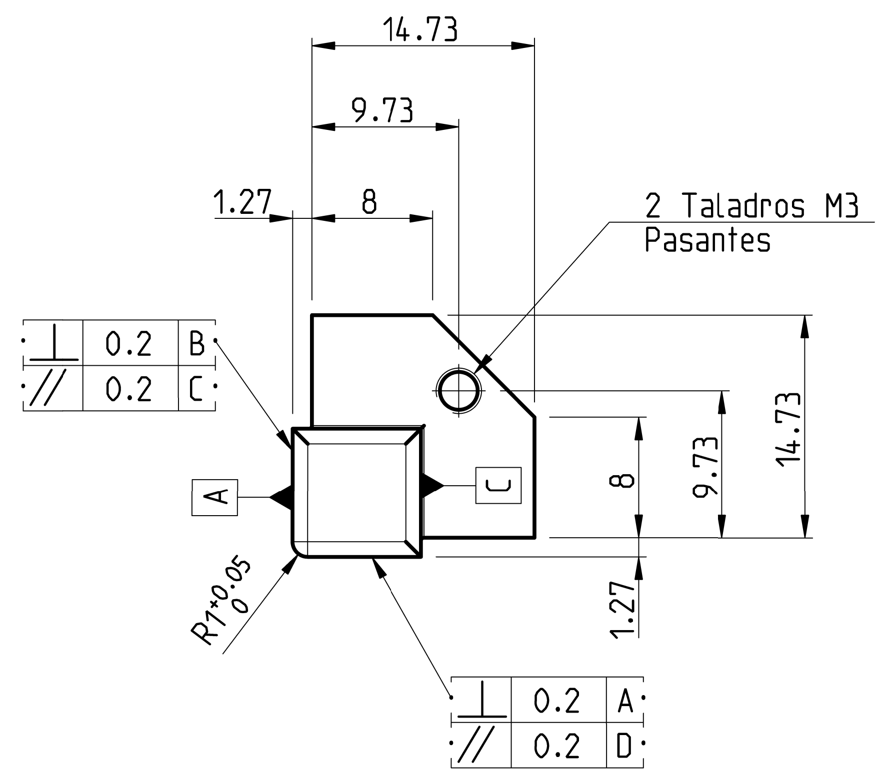

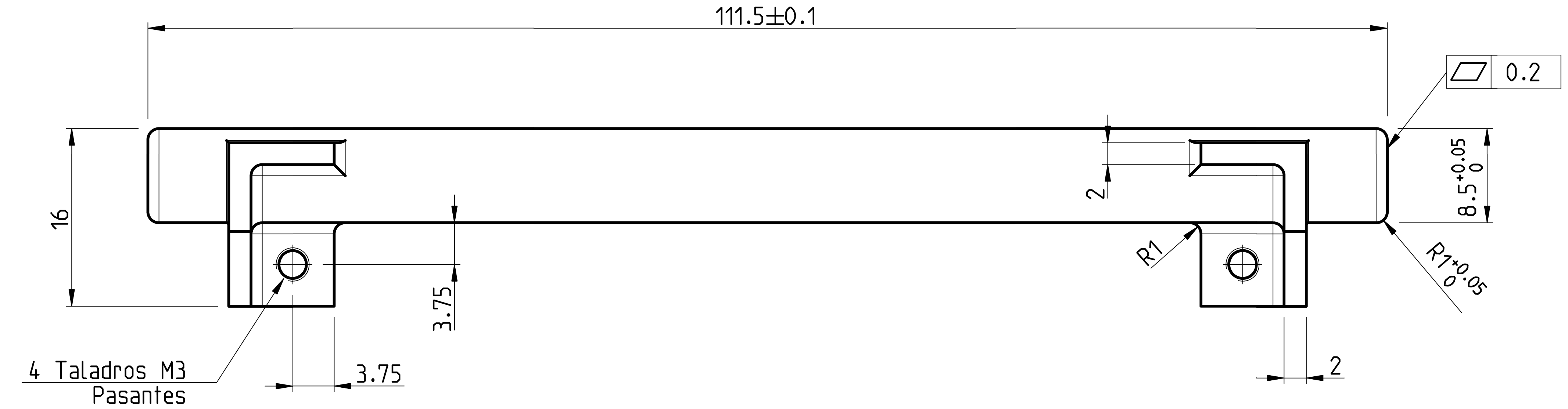

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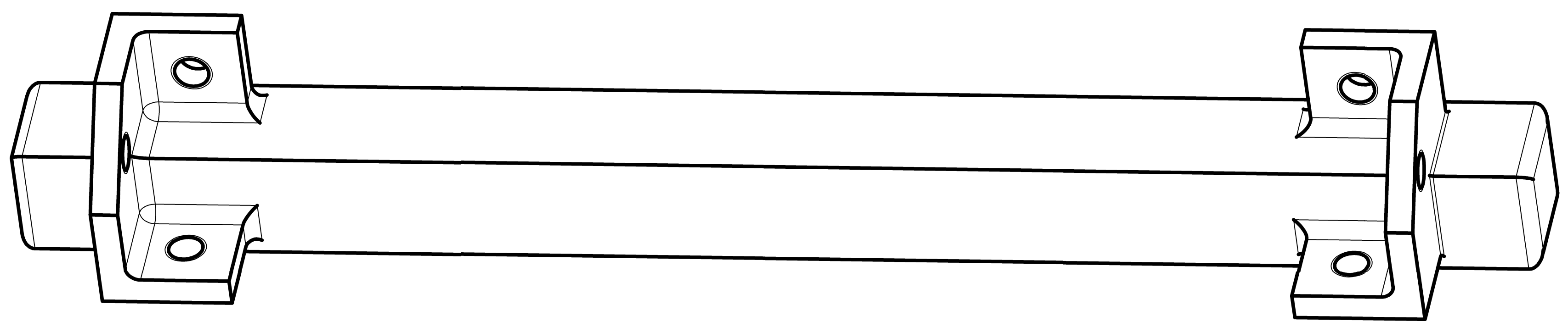

PERSPECTIVA

IACTEC MICROSATELITES

TEIDESAT

GUIA 2

CANTIDAD/QUANTITY	MATERIAL	MASA/MASS	PROTECCION SUPERFICIAL/SURFACE TREATMENT
2	AL_6061_T6	24.382 gr	

COTAS/DIMENSIONS	ESCALA/SCALE	VALIDO PARA/ISSUED FOR	FUENTE/SOURCE
mm	2:1	FABRICACIÓN	IAC

	NOMBRE/NAME
DISEÑADO/DESIGNED: FECHA/DATE:	L.FERIA 6-6-18
DIBUJADO/DRAW: FECHA/DATE:	J.PERDIGON 19-6-18
REVISADO/REVISED: FECHA/DATE:	J.COZAR 19-6-18
AUTORIZADO/AUTHORIZED: FECHA/DATE:	P.REDODNDO 19-6-18

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DIN-A2

ESCUELA SUPERIOR DE INGENIERÍA Y TECNOLOGÍA

Final Bachelor Thesis

DESIGN OF THE MECHANICAL STRUCTURE FOR THE TEIDESAT CUBESAT

APPENDIX D: VERIFICATION TESTING AND TAILORED STANDARDS

Studies:

Mechanical Engineering Bachelor

Author:

Laura Feria del Rosario

July 2018

Table of contents of Annex D: Verification and testing tailored standards

Acronyms

1U	1 unit CubeSat
1.5U	1.5 unit CubeSat
2U	2 unit CubeSat
3U	3 unit CubeSat
AIT	Assembly, Integration and test
AITP	Assembly, Integration and test Plan
AKE	Absolute Knowledge Error
AOCS	Attitude Orbit Control System
APE	Absolute Performance Error
ARPT	Analysis Report
ATV	Automated Transfer Vehicle
CAC	CubeSat Acceptance Checklist
CoG	Centre of Gravity
COPV	Composite Overwrapped Pressure Vessel
CS	CubeSat
CVCM	Collected Volatile Condensable Material
DDF	Design Definition File
DJF	Design Justification File
DL	Design Load
DLL	Design Limit Load
DRD	Document Requirement Definition
DUL	Design Ultimate Load
DYL	Design Yield Load
ECSS	European Cooperations for Space Standarization
EGSE	Electrical Ground Support Equipment
EMC	Electromagnetic Compatibility
EPFM	Elastic-Plastic Fracture Mechanics
ESA	European Space Agency
ESD	Electrostatic Discharge
FAR	Flight Acceptance Review
FD	Flight Dynamics
FFT	Full Functional Test
FOS, FS, SF	Factor Of Safety
GEO	Geostationary Earth Orbit (35786 km)
GSE	Ground Support Equipment
HTV	H-II B Transfer Vehicle
I/F	Interface
ICD	Interface Control Document
IOD	In-Orbit Demonstration
ISS	International Space Station
JAXA	Japanese Aerospace Exploration Agency
JEM	Japanese Experiment Module
JEMRMS	JEM Remote Manipulator System
J-SSOD	JEM Small Satellite Orbital Deployer
LV	Launch Vehicle
LBB	Leak-Before-Burst
LEFM	Linear Elastic Fracture Mechanics

LEO	Low Earth Orbit (160 – 2000 km)
LL	Limit Load
MDP	Maximum Design Pressure
MECO	Main Engine Cut-Off
MEO	Medium Earth Orbit (2000 – 36000 km)
MEOP	Maximum Expected Operating Pressure
MIUL	Material Identification Usage List
MoI	Moment of Inertia
MOS	Margin Of Safety
MPV	Metallic Preddure Vessel
MRD	Mission Requirement Document
MUA	Material Usage Agreement
NA	Not Applicable
NCR	Non-Conformance Report
NDI	Non-Destructive Inspection
NRB	Non-conformance Review Board
NRCSD	NanoRacks CubeSat Deployer
OA	Over All
PAF	Payload Attach Fitting
PCDU	Power Conditioning and Distribution Unit
PFCI	Potential Fracture-Critical Item
PFM	Proto-Flight Model
PIM	Passive Intermodulation
P-POD	Poly-Picosatellite Orbital Deployer
PSD	Power Spectral Density
PT	Performance Test
PTR	Post Test Review
PV	Pressurized pressure vessel
QM	Qualification Model
RBF	Remove Before Flight
RF	Radio Frequency
RFT	Reduced Functional Test
RKE	Relative Knowledge Error
RoD	Review of Design
RPE	Relative Performance Error
SEP	System Engineering Plan
SMS	Specific Mechanism Specification
SoW	Statement of Work
SpX	Space-X
SRD	System Requirement Document
SRS	Shock Response Spectrum
SSN	Space Surveillance Network
TBS	To Be Specified
TC	Telecommand
TCS	Thermal Control System
TM	Telemetry
TML	Total Mass Loss
TML	Total Mass Loss
TRB	Test Review Board
TRPT	Test Report

TRR	Test Readiness Review
UM	User Manual
VCB	Verification Control Board
VCD	Verification Control Document
VCM	Volatile Condensable Material
VP	Verification Plan
VUA	Volatile Organic Compound Usage Agreement

Symbols/Abbreviated terms

j_{burst}	Value of burst factor
j_{proof}	Value of proof factor
FOSU	Value of ultimate factor of satety
FOSY	Value of yield factor of safety
K_c	Fracture toughness for stress conditions other than plane strain
K_{IC}	Plane strain fracture toughness
K_{ISCC}	Threshold stress-intensity factor for stress-corrosion cracking
T_{min}	Minimum actuator torque required
F_{min}	Minimum actuator force required
g	Gravity acceleration

1. Introduction

1.1. Document purpose

The aim of this document is to establish the requirements for the verification and testing of a CubeSat 1U.

1.2. Scope

This document is a tailored version of the standards ECSS-E-ST-10-02C and ECSS-E-ST-10-03C. This tailoring comes from the document T-ECSS-E-ST-IOD-CS.

1.3. Applicable documents

The applicability of the T-ECSS-E-ST-IOD-CS is based on the ECSS-E standards approved as of 24 January 2013. Nevertheless, this standard have an updated versions that have also been applied to his document.

Document Number	Document Title	Issue/ Rev	Date	Reference
-	Most restrictive mechanical requirements for CubeSats	0/0	04/2018	MRR
-	Mechanical Requirements Collection for CubeSats	0/0	04/2018	MEC
TEC-SY/128/2013/SPD/RW	Tailored ECSS Engineering Standards for In-Orbit Demonstration CubeSat Projects	1/3	24/11/2016	T-ECSS-E-ST-IOD-CS
ECSS-E-ST-10-02C	Space engineering - Verification	2/0	06/03/2009	ECSS-E-ST-10-02C
ECSS-E-ST-10-02C Rev.1	Space engineering - Verification	2/1	01/02/2018	ECSS-E-ST-10-02C Rev.1
ECSS-E-ST-10-03C	Space engineering – Testing	2/0	01/06/2012	ECSS-E-ST-10-03C

1.4. Document conventions

All requirements in this document are denoted as

Reference-Source-N.N.N

Requirement text.

NOTE

Where:

- **Reference-Source-N.N.N:** indicates the requirement ID number according to chapter and section found in its document reference source.

- Requirement text: describes the requirement.
- *NOTE:* (optional) provides supporting information regarding the requirement.

The standards of the ECSS applied, are customised by the Tailored ECSS Engineering Standards for In-Orbit Demonstration CubeSat Projects. The requirements classified as 'non applicable' in the T-ECSS-E-ST-IOD-CS, are not mentioned. If there is any section in the requirement not applied for CS, it is written '*not applicable'*. If there is any comment related to CubeSat projects, it will appear as a *CS NOTE*, meanwhile the *NOTEs* provide general supporting information regarding the requirement.

The applicability of the T-ECSS-E-ST-IOD-CS is based on the ECSS-E standards approved as of 24 January 2013. In consequence, the standards' updates after that date until March 2018, are added as comments to the applicable requirement in blue.

1.5. Nomenclature

The following nomenclature applies throughout this document:

a. The word "shall" is used to express requirements.
b. The word "should" is used to express recommendations.

   NOTE It is expected that, during tailoring made by T-ECSS-E-ST-IOD-CS, recommendations in this document are either converted into requirements or tailored out.

c. The word "may" is used to express positive permission.
d. The words "need not" are used to express negative permission.
e. The word "can" is used to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.

   NOTE In ECSS "may" and "can" have completely different meanings: "may" is normative (permission), and "can" is descriptive.

f. The present and past tenses are used to express statements of fact, and therefore they imply descriptive text.

1.6. Terms and Definitions

For the purpose of this collection of standards, the terms and definitions from ECSS-ST-00-01 apply. Furthermore, there is a clause with definitions in all ECSS standards applied for this document.

2.ECSS tailored standards

2.1. Verification

2.1.1 Verification process

ECSS-E-ST-10-02C-5.1

The verification process shall demonstrate that the deliverable product meets the specified customer requirements and is capable of sustaining its operational role through:

1. Verification planning;
2. Verification execution and reporting;
3. Verification control and close-out.

2.1.2 Verification planning

ECSS-E-ST-10-02C-5.2.1b

The requirements specified in ECSS-E-ST-10-02C-5.2.1a shall always include those of the technical specification.

ECSS-E-ST-10-02C-5.2.1c

The supplier shall define the verification approach by conducting the following steps:

1. Identify and agree with the customer the set of requirements to be subject of the verification process.
2. Select the methods and the levels of verification, the associated model philosophy and the verification tools.
3. Identify the stages and events in which the verification is implemented.

ECSS-E-ST-10-02C-5.2.1d

The verification approach shall be defined by the supplier in the Verification Plan (VP) for approval by the customer prior to implementation.

ECSS-E-ST-10-02C-5.2.1e

For each requirement to be verified, the verification strategy shall be defined in terms of the combination of the selected verification methods for the different verification levels at the applicable verification stages, in the initial issue of the Verification Control Document (VCD) also called verification matrix (see Annex B of ECSS-E-ST-10-02C), for approval by the customer.

2.1.2.1.1. Verification methods

ECSS-E-ST-10-02C-5.2.2.1a

Verification shall be accomplished by one or more of the following verification methods:

1. test (including demonstration);
2. analysis (including similarity);
3. review of design;
4. inspection.

ECSS-E-ST-10-02C-5.2.2.1b *(deleted)*

All safety critical functions shall be verified by test.

ECSS-E-ST-10-02C-5.2.2.1c *(deleted)*

Verification of software shall include testing in the target hardware environment.

2.1.2.1.2. Test

ECSS-E-ST-10-02C-5.2.2.2g *(deleted)*

The test programme shall be defined in the Assembly, Integration and Test plan (AITP).

2.1.2.1.3. Analysis

ECSS-E-ST-10-02C-5.2.2.3e

An analysis programme shall be defined in the Verification Plan (VP).

2.1.2.1.4. Review-of-design (ROD)

ECSS-E-ST-10-02C-5.2.2.4b

A review-of-design programme shall be defined in the Verification Plan (VP).

2.1.2.1.5. Inspection

ECSS-E-ST-10-02C-5.2.2.5b

An inspection programme shall be defined in the Verification Plan (VP).

2.1.2.2 Verification levels

ECSS-E-ST-10-02C-5.2.3a

Verification shall be accomplished through the selected verification levels.

NOTE Usual levels are defined in ECSS-E-ST-10-02C-4.2.3.

Replaced by: Verification shall be accomplished through the verification levels in conformance with those defined with the Annex A Verification Plan DRD in ECSS-E-ST-10-02C.

NOTE Usual levels are defined in ECSS-E-ST-10-02C-4.2.3.

ECSS-E-ST-10-02C-5.2.3b

When a requirement is fully verified at lower level, the traceability to lower level verification evidence shall be identified.

ECSS-E-ST-10-02C-5.2.3c

Formal close-out of qualification and acceptance at lower levels shall be performed prior to close-out at higher level.

2.1.2.3 Verification stages

ECSS-E-ST-10-02C-5.2.4.1a

Verification shall be accomplished through the selection of the appropriate stages on the basis of project specificity from the following:

1. qualification,
2. acceptance,
3. pre-launch,
4. in-orbit (including commissioning),
5. post-landing.

Replaced by: The Verification Plan shall state which verification activities are to be accomplished in each of relevant verification stages.

ECSS-E-ST-10-02C-5.2.4.1b

Qualification, acceptance and pre-launch stages shall be completed before launch.

ECSS-E-ST-10-02C-5.2.4.1c

When the verification programme includes an in-orbit stage, the verification shall not rely only on in-orbit activities.

ECSS-E-ST-10-02C-5.2.4.1d

When the verification programme includes a post landing stage, the verification shall not rely only on in-orbit activities or post landing activities.

2.1.2.3.1. Qualification

CS NOTE At system-level, qualification and acceptance shall be performed simultaneously on the protoflight model

ECSS-E-ST-10-02C-5.2.4.2a

In the qualification stage the verification shall demonstrate that the design, including margins, meets the applicable requirements.

ECSS-E-ST-10-02C-5.2.4.2b

In Qualification shall be carried-out on hardware and software which is representative of the end item configuration in terms of design, materials, tooling and methods.

ECSS-E-ST-10-02C-5.2.4.2c

The qualification programme shall be prepared considering the product category according to heritage as defined in Table 5-1.

Table 5-1: Product categories according to heritage

Category	Description	Qualification programme
A	Off-the-shelf product without modifications and • subjected to a qualification test programme at least as severe as that imposed by the actual project specifications including environment and • produced by the same manufacturer or supplier and using the same tools and manufacturing processes and procedures	None
B	Off-the-shelf product without modifications. However: It has been subjected to a qualification test programme less severe or different to that imposed by the actual project specifications (including environment).	Delta qualification programme, decided on a case by case basis.
C	Off-the-shelf product with modifications. Modification includes changes to design, parts, materials, tools, processes, procedures, supplier, or manufacturer.	Delta or full qualification programme (including testing), decided on a case by case basis depending on the impact of the modification.
D	Newly designed and developed product.	Full qualification programme.

ECSS-E-ST-10-02C-5.2.4.2d

For product categories A, B and C, the supplier shall state the qualification status at the EQSR (Equipment Qualification Status Review).

2.1.2.3.2. Acceptance

CS NOTE At system-level, qualification and acceptance shall be performed simultaneously on the protoflight model

ECSS-E-ST-10-02C-5.2.4.3a

In the acceptance stage the verification shall demonstrate that the product is free of workmanship errors and is ready for subsequent operational use.

ECSS-E-ST-10-02C-5.2.4.3b

Acceptance shall be carried-out on the final hardware and software

Replaced by: Acceptance shall be carried-out on the product which is declared as the acceptance article with a defined configuration of hardware and software.

ECSS-E-ST-10-02C-5.2.4.3.2a

The acceptance article shall be manufactured in agreement with the qualified design.

ECSS-E-ST-10-02C-5.2.4.3.2b

The acceptance article shall perform as the qualified product.

2.1.2.3.2.1. Pre-launch

ECSS-E-ST-10-02C-5.2.4.4a

In the pre-launch stage the verification shall demonstrate that the product is properly configured for launch activities and early operations.

ECSS-E-ST-10-02C-5.2.4.4b

In the pre-launch stage the verification shall confirm that the product is capable of functioning as planned during launch and early operations.

2.1.2.3.2.2. In-orbit

ECSS-E-ST-10-02C-5.2.4.5a

In the in-orbit stage the verification shall ensure no degradation occurred during the launch, early orbit phase, at periodical intervals and before specific operational use.

Replaced by: In the in-orbit stage the verification shall address the minimum set of requirements that cannot be verified on ground.

ECSS-E-ST-10-02C-5.2.4.5b

In the in-orbit stage the verification shall supplement/confirm ground verification by providing operating conditions which cannot be fully or cost effectively duplicated or simulated on ground.

ECSS-E-ST-10-02C-5.2.4.5c

In the in-orbit stage the verification shall characterize the system under operational conditions especially for the aspects that cannot be determined before the launch.

ECSS-E-ST-10-02C-5.2.4.5d

In the in-orbit stage the verification shall confirm that the space and ground elements are compatible with each other.

Added: NOTE The working arrangement between the elements suppliers (e.g. satellite, ground segment) and the final customer defines the share of responsibilities for preparing, conducting and reporting the in orbit - commissioning activities. The completion of this stage allows declaring readiness for routine operations (Phase E2-exploitation).

ECSS-E-ST-10-02C-5.2.4.5e *(deleted)*

In the in-orbit stage the verification shall perform calibration and tuning activities specific to the mission payload.

NOTE The working arrangement between the elements suppliers (e.g. satellite, ground segment) and the final customer defines the share of responsibilities for preparing, conducting and reporting the in orbit - commissioning activities. The completion of this stage allows declaring readiness for routine operations (Phase E2-exploitation).

2.1.2.4 Verification tools

2.1.2.4.1. Software tools for verification by analysis

ECSS-E-ST-10-02C-5.2.6.5a

Suitability of previously validated analytical software tools shall be assessed for the intended application.

ECSS-E-ST-10-02C-5.2.6.5b

Non-validated analytical software tools shall be subjected to a validation process prior to their use.

2.1.2.4.2. Integration and test facilities and test tools

ECSS-E-ST-10-02C-5.2.6.6a

The capability of the integration and test facilities and test tools to perform their intended function in terms of performance and calibration shall be verified as part of the overall integration and test process.

NOTE See ECSS-Q-ST-20-07 for test facilities.

2.1.2.5 Verification planning documents

CS NOTE Verification plan and AIT plan are covered by one single System AIV Plan in the project Deliverable Item List and its associated DRD

2.1.2.5.1. Verification plan (VP)

ECSS-E-ST-10-02C-5.2.8.1a

The supplier shall provide a Verification plan (VP) for the reviews as agreed with the customer

NOTE Guidelines are in ECSS-E-ST-10-02C, Annex G.

Replaced by: NOTE See ECSS-E-ST-10 Table A-1 for review deliverables.

ECSS-E-ST-10-02C-5.2.8.1b

The contents of the Verification plan (VP) shall be in conformance with the DRD in Annex A in ECSS-E-ST-10-02C.

2.1.2.5.2. Verification Control Document (VCD)

ECSS-E-ST-10-02C-5.2.8.2a

The supplier shall provide a Verification Control Document (VCD) for the reviews as agreed with the customer

NOTE Guidelines are provided in Annex G in ECSS-E-ST-10-02C.

Replaced by: NOTE See ECSS-E-ST-10 Table A-1 for review deliverables.

ECSS-E-ST-10-02C-5.2.8.2b

The Verification Control Document (VCD) shall be in conformance with the DRD in Annex B in ECSS-E-ST-10-02C.

2.1.2.5.3. Other verification planning Document

ECSS-E-ST-10-02C-5.2.8.3a

The supplier shall provide the AITP for the reviews as agreed with the customer

NOTE Guidelines are provided in Annex G in ECSS-E-ST-10-02C.

Replaced by: NOTE See ECSS-E-ST-10 Table A-1 for review deliverables.

ECSS-E-ST-10-02C-5.2.8.3b

The AIT plan shall be in accordance with the DRD in ECSS-E-ST-10-03 Annex A.

2.1.3 VERIFICATION EXECUTION AND REPORTING

ECSS-E-ST-10-02C-5.3.1a

The supplier shall assign clear responsibility for the implementation of the verification programme.

ECSS-E-ST-10-02C-5.3.1b *(deleted)*

The requirements for the test preparation and execution (including Test Readiness Review (TRR) and Post Test Review (PTR)) shall be as per ECSS-E-ST-10-03.

ECSS-E-ST-10-02C-5.3.1c

When nonconformity is detected during the verification process, a Nonconformance Report (NCR), in conformance with Annex A of ECSS-Q-ST-10-09, shall be raised and processed according to ECSS-Q-ST-20.

ECSS-E-ST-10-02C-5.3.1d

The verification results shall be recorded by the supplier in reports for review by the Verification Control Board (VCB) through the VCD.

2.1.3.1 Verification execution and reporting documentation

2.1.3.1.1. Test report (TRPT)

ECSS-E-ST-10-02C-5.3.2.1a

The test report (TRPT) shall be submitted to the Verification Control Board (VCB) after the test completion, within the time frame agreed with the customer.

ECSS-E-ST-10-02C-5.3.2.1b

The content of the Test report (TRPT) shall be in accordance with the DRD in Annex C in ECSS-E-ST-10-02C.

ECSS-E-ST-10-02C-5.3.2.1c

The supplier shall provide the Test reports (TRPT) for the reviews as agreed with the customer

NOTE Guidelines are provided in Annex G in ECSS-E-ST-10-02C.

Replaced by: NOTE See ECSS-E-ST-10 Table A-1 for review deliverables.

ECSS-E-ST-10-02C-5.3.2.1c

A Test report (TRPT) shall be provided for each Test verification task as identified in the VP or AITP.

2.1.3.1.2. Analysis report (ARPT)

ECSS-E-ST-10-02C-5.3.2.2a

The Analysis report (ARPT) shall be submitted to the Verification Control Board (VCB) after analysis completion, within the time frame agreed with the customer.

ECSS-E-ST-10-02C-5.3.2.2b *(deleted)*

The Analysis report (ARPT) shall be in conformance with the DRD in Annex Q of ECSS-E-ST-10.

ECSS-E-ST-10-02C-5.3.2.2c

The supplier shall provide an Analysis report (ARPT) for the reviews as agreed with the customer

NOTE Guidelines are provided in Annex G in ECSS-E-ST-10-02C.

Replaced by: NOTE 1 See ECSS-E-ST-10 Table A-1 for review deliverables.

NOTE 2 For each discipline specific analysis reports is covered in the respective ECSS standard. A generic guideline for the content of an Analysis Report is given in Annex S of ECSS-E-ST-10.

ECSS-E-ST-10-02C-5.3.2.2d

An Analysis report (APRT) shall be provided for each Analysis verification task identified in the VP.

2.1.3.1.3. Review-of-design report

ECSS-E-ST-10-02C-5.3.2.3a

The Review-of-design report (RRPT) shall be submitted to the Verification Control Board (VCB) after the Review-of-Design completion, within the time frame agreed with the customer.

ECSS-E-ST-10-02C-5.3.2.3b

The Review-of-design report (RRPT) shall be in conformance with the DRD in Annex D in ECSS-E-ST-10-02C.

ECSS-E-ST-10-02C-5.3.2.3c

The supplier shall provide a Review-of-design report (RRPT) for the reviews as agreed with the customer

NOTE Guidelines are provided in Annex G ECSS-E-ST-10-02C.

Replaced by: NOTE See ECSS-E-ST-10 Table A-1 for review deliverables.

ECSS-E-ST-10-02C-5.3.2.3d

A Review-of-design report (RRPT) shall be provided for each Review-of-design verification task identified in the VP.

2.1.3.1.4. Inspection report

ECSS-E-ST-10-02C-5.3.2.4a

The Inspection report (IRPT) shall be submitted to the Verification Control Board (VCB) after the inspection completion, within the time frame agreed with the customer.

ECSS-E-ST-10-02C-5.3.2.4b

The Inspection report (IRPT) shall be in conformance with the DRD in Annex E in ECSS-E-ST-10-02C.

ECSS-E-ST-10-02C-5.3.2.4c

The supplier shall provide an Inspection report (IRPT) for the reviews as agreed with the customer

NOTE Guidelines are provided in Annex G in ECSS-E-ST-10-02C.

Replaced by: NOTE See ECSS-E-ST-10 Table A-1 for review deliverables.

ECSS-E-ST-10-02C-5.3.2.4d

An Inspection report (IRPT) shall be provided for each Inspection verification task identified in the VP.

2.1.3.1.5. Verification report

ECSS-E-ST-10-02C-5.3.2.5a

The supplier shall prepare a Verification report when more than one of the defined verification methods are utilized to verify a requirement or a specific set of requirements.

ECSS-E-ST-10-02C-5.3.2.5b

The Verification report (VRPT) shall be in conformance with the DRD in Annex F in ECSS-E-ST-10-02C.

ECSS-E-ST-10-02C-5.3.2.5c

The Verification report shall be submitted to the Verification Control Board (VCB) after the completion of the last contributing verification activities, within the time frame agreed with the customer.

ECSS-E-ST-10-02C-5.3.2.5d

The supplier shall provide a Verification report (VRPT) for the reviews as agreed with the customer

NOTE Guidelines are provided in Annex G in ECSS-E-ST-10-02C.

Replaced by: NOTE See ECSS-E-ST-10 Table A-1 for review deliverables.

2.1.3.1.6. Other verification execution and reporting document

ECSS-E-ST-10-02C-5.3.2.6a *(deleted)*

The supplier shall provide the Test specifications (TSPE) for the reviews as agreed with the customer

NOTE Guidelines are provided in Annex G in ECSS-E-ST-10-02C.

ECSS-E-ST-10-02C-5.3.2.6b *(deleted)*

The Test specifications (TSPE) shall be in conformance with the DRD in Annex B of ECSS-E-ST-10-03.

CS NOTE Test specifications shall be included in the Test procedures

ECSS-E-ST-10-02C-5.3.2.6c *(deleted)*

The Test procedures shall be in conformance with the DRD in Annex D of ECSS-E-ST-10-03.

CS NOTE Test procedures shall be in conformance with the DRD specified in the project SoW

ECSS-E-ST-10-02C-5.3.2.6d *(deleted)*

The supplier shall provide the Test procedures (TPRO) for the reviews as agreed with the customer

NOTE Guidelines are provided in Annex G in ECSS-E-ST-10-02C.

ECSS-E-ST-10-02C-5.3.2.6e

The rules for the analysis, inspection and review of design shall be defined in writing before their execution.

NOTE 1 For example, analysis, inspection or review of design procedures.

Added: NOTE 2 The rules for Test are as detailed in ECSS-E-ST-10-03.

2.1.3.2 Verification control and close-out

ECSS-E-ST-10-02C-5.4.1b

The verification process control shall be supported by a computer based verification database.

ECSS-E-ST-10-02C-5.4.1c

The verification database shall be delivered to the customer in an electronic form to be agreed with the customer.

ECSS-E-ST-10-02C-5.4.1d

The supplier shall provide to the customer verification evidence for the customer's applicable requirements agreed to be verified, independently from the level where verification has been accomplished.

2.1.3.2.1. Re-verification

ECSS-E-ST-10-02C-5.4.3a

The extent of the re-verification to be performed shall be determined by Supplier and agreed with the customer, in the following cases:

1. failure and repair as decided by Nonconformance Review Board (NRB);
2. unplanned disassembly or demating;
3. refurbishment, maintenance or design changes;
4. changes of requirements after initial verification;
5. long duration storage in case of storage duration in excess to the qualified storage duration;
6. flight use of qualification hardware.

ECSS-E-ST-10-02C-5.4.3b

The Verification Control Document (VCD) shall be updated by the supplier to record as open, those requirements subject to re-verification until this is performed and closeout agreed by the customer.

2.1.3.2.2. Verification control and close-out documentation

2.1.3.2.2.1. Verification Control Document (VCD)

ECSS-E-ST-10-02C-5.4.4.1a

The content of the completed Verification Control Document (VCD) shall be in conformance with the DRD in Annex B in ECSS-E-ST-10-02C.

ECSS-E-ST-10-02C-5.4.4.1b

The supplier shall update the Verification database within one week of the approval of a report.

Replaced by: The supplier shall update the Verification database after approval of a report in line with the timescale agreed with the customer and stated in the Verification Plan.

ECSS-E-ST-10-02C-5.4.4.1c

The intermediate issues of the Verification Control Document (VCD), reflecting the current status of the verification database, shall be made available to the Verification Control Board (VCB) upon request.

ECSS-E-ST-10-02C-5.4.4.1d

The intermediate issues of the Verification Control Document (VCD), reflecting the current verification and compliance status, shall be delivered at each formal review as agreed with the customer

NOTE Guidelines are provided in Annex G in ECSS-E-ST-10-02C.

Replaced by: NOTE See ECSS-E-ST-10 Table A-1 for review deliverables.

ECSS-E-ST-10-02C-5.4.4.1e

The final issue of the Verification Control Document (VCD) shall be submitted to the Verification Control Board (VCB) after the approval of the last report, within the time frame agreed with the customer.

2.1.3.2.2.2. Other close-out documents

ECSS-E-ST-10-02C-5.4.4.1e

The supplier shall make available to the customer for consultation the evidences mentioned in the VCD in addition to the deliverable reports.

2.2. Test

2.2.1 TEST PROGRAMME

ECSS-E-ST-10-03C-4.1a

A coherent test programme shall be established, encompassing each verification stage and level to implement the verification by testing.

NOTE 1 The testing programme is performed incrementally at different product decomposition levels.

NOTE 2 Refer to clause ECSS-E-ST-10-03C-3.1 for determining the type of item for which the test programme is defined (i.e. space segment equipment or space segment element), in particular the example table.

NOTE 3 The number and type of testing levels depends upon the complexity of the project and on its characteristics in accordance with the Verification programme (see ECSS-E-ST-10-02).

NOTE 4 The test programme documentation is defined in ECSS-E-ST-10-03C-4.3.3.

ECSS-E-ST-10-03C-4.1b

The customer and the supplier shall agree the need to treat a space segment element as a space segment equipment.

NOTE This is typically the case for small instrument.

ECSS-E-ST-10-03C-4.1c

AITP and test specifications shall be derived from the product requirements, verification plan and verification control document (VCD).

NOTE Verification plan and VCD are defined in ECSS-EST-10-02.

ECSS-E-ST-10-03C-4.1d

Test procedures shall be derived from test specifications and AITP.

ECSS-E-ST-10-03C-4.1e

Test programme and its implementation shall be in conformance with safety requirements of ECSS-Q-ST-40 and ECSS-Q-ST-20-07.

2.2.2 DEVELOPMENT TEST PRIOR QUALIFICATION

ECSS-E-ST-10-03C-4.2a

Development test of a product shall be completed prior to the start of its formal qualification testing.

NOTE Development tests are conducted over a range of operating conditions that can exceed the design range.

ECSS-E-ST-10-03C-4.2b

Development tests shall not be conducted on qualification or flight models or parts of it.

ECSS-E-ST-10-03C-4.2c

Records of test configuration, test results and other pertinent data shall be maintained.

NOTE This kind of information can be used for investigation when failure occurs during the qualification and acceptance, or for other investigations.

2.2.3 TEST MANAGEMENT

ECSS-E-ST-10-03C-4.3.1a

The supplier shall assign clear responsibility for the implementation of the test programme.

ECSS-E-ST-10-03C-4.3.1b

The customer, or its duly appointed representative, shall have the right to participate to all test phases.

2.2.3.1 Test reviews

2.2.3.1.1. Test programme

ECSS-E-ST-10-03C-4.3.2.1a

The test programme shall be decomposed in blocks.

NOTE The general test programme is reviewed at the CDR as per ECSS-M-ST-10.

ECSS-E-ST-10-03C-4.3.2.1b

The definition of the blocks of requirement ECSS-E-ST-10-03C -4.3.2.1a shall be agreed between the customer and supplier.

NOTE 1 Test block definition depends mainly on the item under test, the facility and the contractual agreement. A test block can include one or more tests. For equipment, usually one test block covers the full test programme.

NOTE 2 Typical test blocks for space segment elements are:

- *Integration*
- *Alignment*
- *Leak/proof pressure*
- *Mechanical (Static load test, sinusoidal, acoustic, random, modal survey, shock)*
- *EMC conducted*
- *EMC radiated/auto-compatibility/RF*

- *Thermal (TB/TV test)*
- *Functional and performance test*
- *Final preparation*

CS NOTE The test review board shall be part of the post-test review

ECSS-E-ST-10-03C-4.3.2.1c

Each test block shall include the following formal reviews:

1. test readiness review (TRR);
2. post test review(s) (PTR);
3. test review board (TRB).

NOTE 1 TRRs from several blocks can be combined, TRRs can also be combined with a PTR of the previous block.

NOTE 2 Depending on the nature of the test, the customer can decide to establish additional key-points between formal reviews. Typical examples are transition between level and axes in vibration tests and transition between test phases in TV/TB tests.

2.2.3.1.2. Test readiness review (TRR)

ECSS-E-ST-10-03C-4.3.2.2a

A TRR shall be held before the start of the test activity to verify that all conditions allow to proceed with the test.

ECSS-E-ST-10-03C-4.3.2.2b

The TRR shall address the following topics:

1. test documentation availability and suitability, including:
   (a) approved AITP,
   (b) approved test specification,
   (c) test predictions (when relevant),
   (d) approved test procedures (including contingency and emergency procedures),
   (e) approved measurement point plan,
   (f) approved test facility readiness report,
   (g) approved test schedule, and
   (h) acceptance data package of lower level items.
2. item under test configuration;
3. test configuration/set-up;
4. inspection status report of KIP, MIP, or both;
5. test facility, environmental conditions, test instrumentations, calibration, maintenance status;

6. cleanliness condition, hazard and safety;

7. ground support equipment (GSE) and infrastructures;

8. status of nonconformances that affect the item under test, its associated GSE, or the test facility;

9. waivers status, and deviations;

10. personnel qualification and availability;

11. results from test rehearsal using the test facility with or without the item under test, when relevant;

12. test pass/fail criteria completeness;

13. assignment of responsibilities;

14. test schedule.

NOTE 1 For ECSS-E-ST-10-03C-4.3.2.2b.1(f), the content of the facility readiness report is defined in ECSS-Q-ST-20-07.

NOTE 2 The level of details according to which each topic is addressed, is different for the general test programme TRR than for each block test TRR.

ECSS-E-ST-10-03C-4.3.2.2c

The following parties shall participate to the TRR:

1. the chairperson, who is the product assurance manager of the authority responsible for the test;

2. product assurance from all involved parties;

3. project engineer from all involved parties;

4. AIT from all involved parties;

5. specialists, when necessary from all involved parties;

6. facility representative;

7. other as relevant.

NOTE For example launcher authority for tests related to launcher interface or other company representative that will take over the responsibility of the hardware after delivery.

ECSS-E-ST-10-03C-4.3.2.2d

All the open points shall be clearly identified and actions assigned with closure date before the execution of the test.

ECSS-E-ST-10-03C-4.3.2.2e

The output of the TRR shall be a decision to proceed with the test or not.

2.2.3.1.3. Post test review (PTR)

ECSS-E-ST-10-03C-4.3.2.3a

A PTR shall be held in order to formally declare the test completed and allow the release of the item under test and test facility for further activity.

NOTE The release of the test facility includes the breaking of the test configuration.

ECSS-E-ST-10-03C-4.3.2.3b

The PTR shall address the following topics:

1. verification that all test data were acquired, recorded, and archived in conformance with the test specification and test procedure requirements;

2. verification that the process for test anomalies and NCRs, raised during the test, was initiated, and all needed inspection, test data and test configuration were acquired;

3. confirmation that tests were performed according to the AITP, the test specification and the test procedures, with the exceptions of what is covered by agreed procedure variations or NCRs;

4. status of compliance of the item under test to the relevant requirement;

5. post test status of GSE;

6. post item under test configuration based on inspection and cleanliness report;

7. identification of the open points with assignment of actions for their closure, as well as lessons learned drawn.

ECSS-E-ST-10-03C-4.3.2.3c

The following parties shall participate to the PTR:

1. product assurance;

2. project engineer;

3. AIT;

4. facility representative;

5. other, including specialist, as relevant.

NOTE For example launcher authority for tests related to launcher interface or other company representative that will take over the responsibility of the hardware after delivery.

2.2.3.1.4. Test review board (TRB)

CS NOTE The TRB shall be combined with the post-test review

ECSS-E-ST-10-03C-4.3.2.4a

A TRB shall be held to review all results and conclude on the test completeness and achievement of objectives.

ECSS-E-ST-10-03C-4.3.2.4b

The TRB shall address the following topics:

1. test documentation availability, including:

(a) test report as per ECSS-E-ST-10-02 Annex C,

(b) facility report when relevant,

(c) inspection report including cleanliness report,

(d) list of NCRs,

(e) copy of NCRs raised during test with the related NRB minutes of meeting, and associated request(s) for waiver, and

(f) list of procedure deviations.

2. compliance with the test specification, and variations to the AITP;

3. status of compliance of the item under test to the relevant requirement;

4. post test status of GSE;

5. post item under test configuration based on inspection and cleanliness report;

6. review of all still open NCRs raised during test in order to assess that there is no impact on the test objectives achievement;

7. lessons learned to be drawn.

ECSS-E-ST-10-03C-4.3.2.4c

The following parties shall participate to the TRB:

1. product assurance;

2. project engineer;

3. AIT;

4. facility representative;

5. other, including specialist, as relevant.

NOTE For example launcher authority for tests related to launcher interface or other company representative that will take over the responsibility of the hardware after delivery.

2.2.3.2 Test documentation

Clauses ECSS-E-ST-10-03C-4.3.3.2 to ECSS-E-ST-10-03C-4.3.3.5 define the Test programme documentation (AITP, Test specification, Test procedure, and Test report) generated at all product levels.

These documents are derived from the System Engineering Plan (SEP) and from the Verification Plan (VP).

2.2.3.2.1. Assembly, Integration and Test Plan (AITP)

ECSS-E-ST-10-03C-4.3.3.2a

The supplier shall establish the AITP in conformance with the DRD in Annex A in ECSS-E-ST-10-03C.

NOTE At space segment equipment level, the AITP can be called test plan.

CS NOTE The AITP is encompassed by the system-level AIV Plan whose DRD is included in the project DRD specification.

ECSS-E-ST-10-03C-4.3.3.2b

The agreed AITP shall be available, at the latest, for the TRR of the test programme.

ECSS-E-ST-10-03C-4.3.3.2c

The way the requirement ECSS-E-ST-10-03C-4.3.3.2b is achieved shall be agreed between the customer and the supplier.

2.2.3.2.2. Test specification (TSPE)

ECSS-E-ST-10-03C-4.3.3.3a

The supplier shall establish the test specification in conformance with the DRD in Annex B in ECSS-E-ST-10-03C.

CS NOTE The Test specification shall be included in the test procedure and shall follow the project DRD specification.

ECSS-E-ST-10-03C-4.3.3.3b

The agreed test specification shall be available at the relevant test block TRR and on time to allow procedure preparation.

ECSS-E-ST-10-03C-4.3.3.3c

The way the requirement ECSS-E-ST-10-03C-4.3.3.3b is achieved shall be agreed between the customer and the supplier.

2.2.3.2.3. Test procedure (TPRO)

ECSS-E-ST-10-03C-4.3.3.4a

The supplier shall establish the test procedure in conformance with the DRD in Annex C in ECSS-E-ST-10-03C.

CS NOTE Test procedures shall be in conformance with the DRD specified in the project SoW

ECSS-E-ST-10-03C-4.3.3.4b

The test procedure, derived from the agreed test specification, shall be available at the relevant test block TRR.

ECSS-E-ST-10-03C-4.3.3.4c

The way the requirement ECSS-E-ST-10-03C-4.3.3.4b is achieved shall be agreed between the customer and the supplier.

2.2.3.2.4. Test report (TRPT)

ECSS-E-ST-10-03C-4.3.3.5a

The supplier shall establish the test report in conformance with the DRD in Annex C of ECSS-E-ST-10-02.

NOTE The test report describes test execution, results and conclusions in the light of the test requirements. It contains the test description and the test results including the as-run test procedures, the considerations and conclusions with particular emphasis on the close-out of the relevant verification requirements including any deviation.

ECSS-E-ST-10-03C-4.3.3.5b

The test report shall be available prior to the TRB.

2.2.3.3 Anomaly or failure during testing

ECSS-E-ST-10-03C-4.3.4a

Any failure or anomaly during testing shall be recorded.

ECSS-E-ST-10-03C-4.3.4b

All nonconformances shall be managed in conformance with ECSS-Q-ST-10-09.

CS NOTE Non-conformances shall be managed according to project procedures established with the Agency

ECSS-E-ST-10-03C-4.3.4c

The NRB shall decide on the necessity and extent of any retest activity in order to demonstrate the correctness of the disposition made.

CS NOTE Non-conformances shall be addressed to the Agency at the post-test review, and any re-test activity shall be decided at this point.

2.2.3.4 Test data

ECSS-E-ST-10-03C-4.3.5a

Test measurements and the environmental conditions shall be recorded for subsequent evaluation.

ECSS-E-ST-10-03C-4.3.5b

A database of parameters shall be established for trend analysis.

ECSS-E-ST-10-03C-4.3.5c

Trend analysis shall be performed using test data acquired across test sequences.

2.2.4 TEST CONDITIONS, TOLERANCES AND ACCURACIES

2.2.4.1 Test conditions

ECSS-E-ST-10-03C-4.4.1a

Test conditions shall be established using predicted environment plus margins.

NOTE This can be done using previous mission flight data, relevant ground environments, analytical prediction, relevant previous test results, or a combination thereof.

ECSS-E-ST-10-03C-4.4.1b

Tests shall be performed simulating the mission envelope, including operational and non-operational conditions with margins.

ECSS-E-ST-10-03C-4.4.1c

For items tested in an environment different from the one it is expected to operate, the possible differences in behaviour shall be accounted for in the test levels and duration.

NOTE In this case, the test levels and duration are modified based on analyses. For example to prevent effects of convective heat transfer that reduce thermal gradients.

ECSS-E-ST-10-03C-4.4.1d

Cleanliness and contamination control for test programmes shall conform to ECSS-Q-ST-70-01.

CS NOTE Cleanliness and control shall conform to the tailored version of ECSS-E-ST-10-03C.

ECSS-E-ST-10-03C-4.4.1e

The quality and safety management system used to operate and maintain test facility(ies) shall be recognized by the customer.

NOTE As example, in accordance to quality and safety management system requirements from ECSS-QST-20-07.

ECSS-E-ST-10-03C-4.4.1f

Test facilities, tools and instrumentation shall not prevent to fulfil the tests objectives.

ECSS-E-ST-10-03C-4.4.1g

The EGSE or other support systems of the item under test shall:

1. not jeopardize the results of tests;
2. be immune to signals used for susceptibility tests;
3. be designed to comply with the applicable legislation, including safety (e.g. EC Directives).

ECSS-E-ST-10-03C-4.4.1h

The combination of test set-up, test levels durations, and operational modes shall not create conditions that can:

1. induce failures of the item under test,
2. lead to rejection of adequate item under test, or
3. create hazardous conditions.

2.2.4.2 Test tolerances

ECSS-E-ST-10-03C-4.4.2a

Test tolerances bands shall be specified in test error budgets and agreed by the customer prior to start of test.

ECSS-E-ST-10-03C-4.4.2b

For the purpose of 4.4.2a test tolerances shall be justified by reference to the uncertainty budget and confidence level of the measurement instrument(s) used.

NOTE 1 EA-4/16 and EA-4/02 (section 2) guidelines can be used to build up the uncertainty budget.

NOTE 2 The tolerances specified in Table 4-1 are the allowable ranges within which the test parameters can vary, they include instrumentation accuracy.

NOTE 3 SeeTable 4-1 in annex A.

ECSS-E-ST-10-03C-4.4.2c

Quantitative requirements demonstrated by measured test values shall account for test inaccuracies and tolerances, and be compared with the specified requested values.

ECSS-E-ST-10-03C-4.4.2d

The tolerances specified in Table 4-1 shall be applied to the test values.

NOTE SeeTable 4-1 in annex A.

ECSS-E-ST-10-03C-4.4.2e

Changes to the tolerances specified in Table 4-1 shall be approved by the customer.

NOTE 1 For example, when tolerances of Table 4-1 are detected to be inconsistent with test accuracy values of Table 4-2.

NOTE 2 See Table 4-1 and Table 4-2 in annex A.

2.2.4.3 Test accuracies

CS NOTE MOI: not applicable, due to the small mass/dimensions, it is sufficient to verify MOI at system-level by analysis of the detailed CAD model to an accuracy of +/-5%. Audible noise: not applicable

ECSS-E-ST-10-03C-4.4.3a

Test accuracies shall be specified in test error budgets and agreed by the customer prior to test performance.

NOTE EA-4/16 and EA-4/02 (section 2) guidelines can be used to build up the overall test measurement accuracy.

ECSS-E-ST-10-03C-4.4.3b

The accuracy of test instrumentation shall be verified in accordance with approved calibration procedures, with traceability to international measurement standards.

ECSS-E-ST-10-03C-4.4.3c

All test instrumentation shall be within the normal calibration period at the time of the test.

ECSS-E-ST-10-03C-4.4.3d

Any anomaly of test instrumentation, detected at the first calibration sequence after the test, shall be reported.

ECSS-E-ST-10-03C-4.4.3e

The accuracy of measurement shall be as follows:

1. as per Table 4-2 for the parameters listed, or
2. at least one third of the tolerance of the variable to be measured.

NOTE The values of Table 4-2 are typical from test centre capabilities.

NOTE 2 See Table 4-2 in annex A

2.2.5 TEST OBJECTIVES

ECSS-E-ST-10-03C-4.5.1a

The test programme shall be defined taking into account the agreed model philosophy.

NOTE The model philosophy, including model definition, is detailed in ECSS-E-HB-10-02.

ECSS-E-ST-10-03C-4.5.1b

When preparing the overall test programme of a space segment element tests linked to compatibility with ground and launch segment shall also be included.

NOTE This covers in particular the system validation test.

2.2.5.1 Qualification testing

CS NOTE Not applicable. A system-level protoflight approach is used for testing of new/heavily modified equipment

2.2.5.2 Acceptance testing

CS NOTE Applies to off-the-shelf equipment or slightly modified equipment, whose status is confirmed at PDR to be qualified for the project.

ECSS-E-ST-10-03C-4.5.3a

Acceptance testing shall be performed to provide evidence that the space segment element or equipment performs in accordance with the specifications in the intended environments with the specified acceptance margins.

NOTE This evidence is used, further to analysis as relevant, to provide via verification reports (defined in ECSS-E-ST-10-02 Annex F) the elements for the close-out of the VCD (defined in ECSS-EST-10-02 Annex B).

ECSS-E-ST-10-03C-4.5.3b

Acceptance testing shall be performed on each flight product, except the one used as Protoflight, to assure freedom from workmanship defects and flawed materials in conformance with ECSS-E-ST-10-02.

ECSS-E-ST-10-03C-4.5.3c

The acceptance programme shall be performed, after a qualification programme has been completed (as per clause ECSS-E-ST-10-03C-4.5.2 or clause ECSS-E-ST-10-03C-4.5.4).

NOTE The FM is built from the same design file than the QM or the PFM used for qualification, as specified in the ECSS-E-ST-10-02 clause 5.2.4.3.

ECSS-E-ST-10-03C-4.5.3d

The acceptance test levels and durations shall be as specified in Table 5-4 for space segment equipment, and in Table 6-4 for space segment element levels.

NOTE 1 The test durations identified in Table 5-4 and Table 6-4 are the minimum values.

NOTE 2 See Table 5-4 in annex A

CS NOTE Table 6-4 is not applicable as acceptance test for space segment elements is substituted by a system-level protoflight approach.

2.2.5.3 Protoflight testing

CS NOTE Not applicable. A system-level protoflight approach is used for testing of new/heavily modified equipment

2.2.6 SPACE SEGMENT EQUIPMENT TEST REQUIREMENTS

ECSS-E-ST-10-03C-5.1a

The test baseline and sequencing shall be tailored to the specific space segment equipment type for each project.

NOTE 1 The types of space segment equipment are uniformly listed at the end of Table 5-3, and Table 5-5.

NOTE 2 See Table 5-3, and Table 5-5 in annex A

ECSS-E-ST-10-03C-5.1b

Where space segment equipment falls into two or more types, the combination of all required tests specified for each type shall be applied.

NOTE For example: A star sensor can be considered to fit both "electronic space segment equipment" and "optical space segment equipment" types, therefore, an EMC test is conducted since it is applicable for electronic space segment equipment, even though there is no requirement for optical space segment equipment.

ECSS-E-ST-10-03C-5.1c

The test sequence shall be performed, taking into account tests' applicability, as defined for qualification in Table 5-1, for acceptance in Table 5-3, for protoflight in Table 5-5.

NOTE This sequence reflects the principle "Test as you fly". It is based on a combination of:

- *the order in which the environments are encountered during flight, and*
- *the capability to identify defects as early as possible in the test sequence.*

NOTE 2 See Table 5-3, and Table 5-5 in annex A

ECSS-E-ST-10-03C-5.1d

Any unusual or unexpected behaviour shall be evaluated to determine the existence of any trend potentially leading to anomaly or failure situation.

ECSS-E-ST-10-03C-5.1e

The PT and FFT shall be performed at the beginning and at the end of the test programme under ambient conditions.

NOTE Those tests provide the criteria for judging the integrity of the space segment equipment thought the overall test programme. The results of both tests should be identical within the test tolerances.

ECSS-E-ST-10-03C-5.1f

RFT shall be performed before and after each environmental test block as well as before and after transportation.

NOTE This test allows verifying the integrity of the space segment equipment.

ECSS-E-ST-10-03C-5.1g

PT, FFT or RFT, as relevant, shall be performed:

1. during thermal test(s), or

2. when the space segment equipment is expected to be operational under another type of imposed environment.

NOTE The test definition corresponds to the expected operation of the item when the environment is being imposed.

ECSS-E-ST-10-03C-5.1i

Any space segment equipment pressurized during ascent shall be tested as specified in ECSS-E-ST-32-02 clause 5.4.4, and verified for internal pressure decay.

ECSS-E-ST-10-03C-5.1j

Adjustable protection functions shall be tested.

2.2.6.1 Qualification test requirements

CS NOTE Not applicable. A protoflight approach is used for new/heavily modified equipment.

2.2.6.2 Acceptance test requirements

ECSS-E-ST-10-03C-5.3a

The space segment equipment acceptance test baseline shall consist of the tests specified in Table 5-3 in line with requirement ECSS-E-ST-10-03C-5.1b, according to the type of the space segment equipment.

NOTE See Table 5-3 (acceptance test baseline) and Table 5-4 (Acceptance test levels and duration) in annex A

CS NOTE 1 The following tests are NOT applicable: humidity, life, burn-in, physical properties, static load, spin, transient, acoustic, shock, micro-vibration, pressure cycling, design burst pressure, burst, thermal ambient, ESD, PIM, multipaction, corona and arc discharge, audible noise.

The following tests are tailored:

- *EMC (equipment type "a" only, test approach to be defined in project AIV plan);*
- *magnetic (equipment type "a" only, if justified by mission needs).*

CS NOTE 2 For mechanics, only random vibrations, sinusoidal vibrations, leak, proof pressure and thermal vacuum tests are applicable.

2.2.6.3 Space segment equipment test programme implementation requirements

2.2.6.3.1. General tests

2.2.6.3.1.1. Functional and performances tests

ECSS-E-ST-10-03C-5.5.1.1a

The Functional tests shall verify the complete function of the space segment equipment, under the specified operating and environment conditions and in all operational modes.

CS NOTE Solar array deployment test shall be performed at ambient pressure and temperature

ECSS-E-ST-10-03C-5.5.1.1b

Performance tests shall verify that the space segment equipment performances, under the specified environment, are compliant with the performances specification.

ECSS-E-ST-10-03C-5.5.1.1c

Functional and performance test may be combined as single test depending on their complexity and time duration.

NOTE In this case the test is called functional and performance test.

ECSS-E-ST-10-03C-5.5.1.1d

In case of internal redundancy, functional tests shall be performed on both chains taking into account the type of redundancy (e.g. hot or cold).

ECSS-E-ST-10-03C-5.5.1.1e

In case of cross-strapped configurations, requirements for testing shall be agreed with the customer.

ECSS-E-ST-10-03C-5.5.1.1f

Test parameters shall be varied throughout their specification ranges and the sequences expected in flight operation.

ECSS-E-ST-10-03C-5.5.1.1g

Electrical tests shall include application of expected voltages, impedance, frequencies, pulses, and wave forms at the electrical interface of the space segment equipment, including all redundant circuits if any.

NOTE For antennas the electrical interface is understood to include the far field radiation pattern.

ECSS-E-ST-10-03C-5.5.1.1h

Electrical test shall include the measurement of the electrical properties at the interfaces as specified in the ICD.

NOTE For example, power consumption, inrush current, signal characteristics, response time, expected voltages, impedances frequencies, pulses and waves forms characteristic at the interfaces, including redundant circuits if any.

ECSS-E-ST-10-03C-5.5.1.1i

Fault voltage tolerance of interface circuit shall be tested to ensure absence of failure propagation risks.

ECSS-E-ST-10-03C-5.5.1.1j

When accessible, protection functions shall be tested.

NOTE Example of protection function are over-voltage, and over-current.

ECSS-E-ST-10-03C-5.5.1.1k

When protection function have the capability to be overwritten, the overwrite function shall be tested.

ECSS-E-ST-10-03C-5.5.1.1l

For the solar array, the performance tests shall include the flasher test.

ECSS-E-ST-10-03C-5.5.1.1m

Mechanical tests shall include application of torque, load and motion as specified.

ECSS-E-ST-10-03C-5.5.1.1n

When relevant, internal alignment shall be verified as part of the functional test.

2.2.6.3.1.2. Humidity test

CS NOTE This test is not applicable. Launch facility/launch pad relative humidity to be confirmed by Launch services provider. If humidity is >65%, then this test becomes applicable.

2.2.6.3.2. Mechanical tests

2.2.6.3.2.1. Physical properties measurements

CS NOTE Only the mass, dimensions and interfaces of the equipment shall be measured. CoG and MOI shall be calculated from the equipment CAD model.

ECSS-E-ST-10-03C-5.5.2.1a

The following physical properties of space segment equipment shall be determined using tools and techniques that conform to the required accuracy:

1. Dimensions and interfaces;
2. Mass;

3. Centre of gravity with respect to a given coordinate system for three mutually perpendicular axes;

4. Momentum of inertia with respect to the given coordinate system.

NOTE For space segment equipment with simple shapes, the centre of gravity location and momenta of inertia can be determined by calculation.

ECSS-E-ST-10-03C-5.5.2.1b

The space segment equipment shall be in launch configuration, unless this configuration cannot be reproduced on ground.

2.2.6.3.2.2. Acceleration test

CS NOTE Nominally, this is covered by the sinusoidal test with respect to launch loads. However, if the flight acceleration loads are calculated to be higher than the launch loads, then a specific static load test shall be performed on structural elements.

2.2.6.3.2.3. Random vibration test

ECSS-E-ST-10-03C-5.5.2.3a

Random vibration tests shall be conducted in launch configuration for all axes.

ECSS-E-ST-10-03C-5.5.2.3b

The induced cross axis accelerations at the attachment points shall be limited to the maximum test levels specified for the cross axis.

ECSS-E-ST-10-03C-5.5.2.3c

In order to evaluate the space segment equipment integrity a resonance search shall be performed before and after the random vibration test.

ECSS-E-ST-10-03C-5.5.2.3d

The success criteria for the resonance search shall be:

1. less than 5 % in frequency shift, for modes with an effective mass greater than 10 %;

2. less than 20 % in amplitude shift, for modes with an effective mass greater than 10 %.

ECSS-E-ST-10-03C-5.5.2.3e

Detailed visual checks shall be carried out when functional tests are not performed.

ECSS-E-ST-10-03C-5.5.2.3f

For space segment equipment which is designed to be re-flown, the qualification test duration per axis shall be in conformance with Table 5-2 plus 50 seconds per additional flight.

CS NOTE Table 5-2 is not applicable as qualification tests are not applicable. A system-level protoflight approach is used for testing of new/heavily modified equipment

2.2.6.3.2.4. Sinusoidal vibration test

ECSS-E-ST-10-03C-5.5.2.5a

Sinusoidal tests shall be conducted in the launch configurations for all axes.

ECSS-E-ST-10-03C-5.5.2.5b

A resonance search shall be performed before and after the sinusoidal vibration test to determine resonance frequencies to evaluate the space segment equipment integrity.

ECSS-E-ST-10-03C-5.5.2.5c

The success criteria for the resonance search shall be:

1. less than 5 % in frequency shift, for modes with an effective mass greater than 10 %;

2. less than 20 % in amplitude shift, for modes with an effective mass greater than 10 %.

ECSS-E-ST-10-03C-5.5.2.5d

Detailed visual checks shall be carried out prior and after test to check for visual damage.

ECSS-E-ST-10-03C-5.5.2.5e

The induced cross axis excitation shall be monitored to check that the response in the cross axis does not exceed the specification.

2.2.6.3.2.5. Shock test

CS NOTE Only applicable to protoflight models of items assessed during the project as shock-critical (ie. their shock susceptibility is lower than the expected shock environment).

The shock environment shall take into account attenuation at higher frequencies due to the fact that the CubeSat is not mechanically coupled to the deployment system. Shock test data from the deployment system supplier shall be used to define the applicable SRS.

ECSS-E-ST-10-03C-5.5.2.6a

Shock tests shall be conducted in the item under test configuration relevant to the event where the shock is produced.

NOTE The shock tests demonstrate the ability of the space segment equipment to withstand the shocks encountered during the lifetime, e.g.: fairing separation, space segment equipment separation, booster burn out, apogee boost motor ignition, solar arrays and antennas deployment, shocks from landing of reusable elements.

ECSS-E-ST-10-03C-5.5.2.6b

Equipment powered during the event where the shock is produced, shall be powered during the test.

ECSS-E-ST-10-03C-5.5.2.6c

The equipment shall be mounted to a fixture using its normal mounting points.

ECSS-E-ST-10-03C-5.5.2.6d

The selected test method shall achieve the specified Shock Response Spectrum with a representative transient, comparable in shape and duration to the expected in-flight shock.

ECSS-E-ST-10-03C-5.5.2.6e

To reduce the number of shock activations, axes and directions may be combined, provided the required environment is created.

ECSS-E-ST-10-03C-5.5.2.6f

Detailed visual checks shall be carried out.

ECSS-E-ST-10-03C-5.5.2.6g

Hardware integrity shall be verified after the test.

NOTE This is performed through several ways, like performance test, low level sinusoidal vibration pre and post test, modal survey, alignment.

ECSS-E-ST-10-03C-5.5.2.6h

The induced cross axis excitation shall be monitored to check that the response in the cross axis do not exceed the specification.

ECSS-E-ST-10-03C-5.5.2.6i

The homogeneity of the shock around the equipment under test shall be monitored by at least one pair of sensors mounted at opposite corners of the equipment.

2.2.6.3.3. Structural integrity tests

2.2.6.3.3.1. Leak tests

ECSS-E-ST-10-03C-5.5.3.1a

Leak tests shall be performed only on sealed or pressurized space segment equipment, sensitive to loss of pressure or vacuum.

ECSS-E-ST-10-03C-5.5.3.1b

The leak test shall demonstrate the ability of sealed or pressurized space segment equipment to conform to the leak rates stated in the specifications.

ECSS-E-ST-10-03C-5.5.3.1c

The leak test method employed shall have sensitivity and accuracy consistent with the space segment equipment specified maximum allowable leak rate.

ECSS-E-ST-10-03C-5.5.3.1d

The sensitivity of the leak test, in particular, shall be quantitatively less than the minimum leak rate to be detected by a factor of at least two to ensure reliability of measurements.

ECSS-E-ST-10-03C-5.5.3.1e

Leak tests shall be performed prior to and following the completion of space segment equipment thermal and mechanical tests.

ECSS-E-ST-10-03C-5.5.3.1f

Leak tests shall be conducted prior to and following proof pressure tests.

ECSS-E-ST-10-03C-5.5.3.1g

When temperature potentially affects the sealing materials or surfaces, an evaluation of the hardware design and operational characteristics shall be performed and, if technically warranted, the leak test conducted at the minimum and maximum qualification or acceptance temperature limits for respectively qualification or acceptance test.

ECSS-E-ST-10-03C-5.5.3.1h

If seals are dependent upon differential pressure for proper sealing, leak tests shall be performed with the space segment equipment pressurized at the maximum operating pressure and at the minimum operating pressure.

2.2.6.3.3.2. Proof pressure test

ECSS-E-ST-10-03C-5.5.3.2a

The proof pressure qualification test shall be performed to demonstrate absence of leak and permanent deformation.

ECSS-E-ST-10-03C-5.5.3.2b

The proof pressure acceptance test shall be performed to demonstrate absence of workmanship problem leading to leak above the specification.

ECSS-E-ST-10-03C-5.5.3.2c

The influence of temperature on test validity shall be in conformance with ECSS-E-ST-32-02 requirements 5.4.1c and 5.5.1b.

2.2.6.3.4. Thermal tests

2.2.6.3.4.1. Requirements applicable to thermal vacuum and thermal ambient tests

ECSS-E-ST-10-03C-5.5.4.1a

Both thermal vacuum and thermal ambient tests shall be performed for space segment equipment that operate under a non-vacuum environment after having been exposed to vacuum.

NOTE For example, in the case of a planetary mission, the space segment equipment is tested in vacuum and in the mission atmosphere pressure.

ECSS-E-ST-10-03C-5.5.4.1b

Thermal balance phase(s), if required, shall be included in the thermal vacuum or thermal ambient test at a pressure value corresponding to the type of mission.

NOTE E.g. for very dissipative equipment, equipment with important thermal gradients at vacuum conditions, Earth atmospheric pressure, space station pressure or Mars pressure.

ECSS-E-ST-10-03C-5.5.4.1c

All space segment equipment temperatures shall refer to the temperature reference point.

ECSS-E-ST-10-03C-5.5.4.1d

The space segment equipment temperatures shall be defined for the following conditions:

1. minimum and maximum operating qualification and acceptance;
2. minimum and maximum non-operating qualification, and acceptance;
3. minimum switch ON and maximum (as relevant).

ECSS-E-ST-10-03C-5.5.4.1e

The test level shall take into account the test tolerances as specified in Table 4-1.

ECSS-E-ST-10-03C-5.5.4.1f

The temperature rate of change shall be lower than 20 K per minute.

ECSS-E-ST-10-03C-5.5.4.1g

Functional test shall only start after a dwell time greater or equal to 2 hours.

ECSS-E-ST-10-03C-5.5.4.1h

Test profile, test configuration, number of cycles, extreme temperatures, temperature rate of change, stability criteria, dwell time duration, tests to be performed and success criteria shall be defined in the test specification.

ECSS-E-ST-10-03C-5.5.4.1i

The test profile shall include a non operating cycle.

ECSS-E-ST-10-03C-5.5.4.1j

The space segment equipment shall be subjected to functional test before and after the thermal test.

ECSS-E-ST-10-03C-5.5.4.1k

Functional tests shall be performed as a minimum at hot and cold operating temperatures.

NOTE Test during transition are subjected to case by case decision.

ECSS-E-ST-10-03C-5.5.4.1l

Cold (and as applicable Hot) switch on capabilities shall be demonstrated.

ECSS-E-ST-10-03C-5.5.4.1m

In case of internal redundancy, thermal tests shall be performed on both chains taking into account the type of redundancy (e.g. hot or cold).

ECSS-E-ST-10-03C-5.5.4.1n

In case of cross-strapped configurations, requirements for testing shall be agreed with the customer.

ECSS-E-ST-10-03C-5.5.4.1o

The space segment equipment operative configuration during the test shall be the most severe one in the power time domain and from the power consumption point of view.

ECSS-E-ST-10-03C-5.5.4.1p

Monitoring for corona shall be conducted during chamber pressure reduction for space segment equipment that are critical with regard to corona effect.

NOTE For thermal ambient test, this is justified by the fact that ambient pressure can be lower than Earth atmospheric pressure.

ECSS-E-ST-10-03C-5.5.4.1q

Test methods and test set-up shall be defined according to the thermal environment characteristics, the TCS thermal design and the space segment equipment itself.

ECSS-E-ST-10-03C-5.5.4.1r

The test set-up shall ensure appropriate orientation for space segment equipment containing two phases heat transport equipment (e.g. heat pipe).

NOTE This means that the two phases heat transport equipment is horizontal or works in reflux mode.

2.2.6.3.4.2. Requirements applicable to thermal vacuum tests

ECSS-E-ST-10-03C-5.5.4.2a

Thermal vacuum testing shall be performed for space segment equipment whose operation occurs in space vacuum environment at any time of its lifetime.

ECSS-E-ST-10-03C-5.5.4.2b

Space segment equipment shall be tested at a pressure of 10-5 hPa or less.

ECSS-E-ST-10-03C-5.5.4.2c

Conditions and test set-up shall be such as to avoid contamination of the equipment.

ECSS-E-ST-10-03C-5.5.4.2d

In line with requirement ECSS-E-ST-10-03C-5.5.4.2c the test profile should start with a maximum non-operating temperature.

ECSS-E-ST-10-03C-5.5.4.2e

For solar array, continuity and insulation resistance shall be monitored during the test as per ECSS-E-ST-20-08 requirements 5.5.3.11.2 f and g.

2.2.6.3.5. Electrical / RF tests

2.2.6.3.5.1. EMC test

CS NOTE EMC test approach for equipment shall be specified in the project AIV plan. The test concerns auto-compatibility since CubeSats are not operational during launch until typically 30 mins after separation.

ECSS-E-ST-10-03C-5.5.5.1a

The EMC test shall be performed in conformance with ECSS-E-ST-20-07 clause 5.

ECSS-E-ST-10-03C-5.5.5.1b

For acceptance stage, the space segment equipment shall be subjected to the following tests, as per ECSS-E-ST-20-07:

1. bonding verification;
2. power lines isolation;
3. inrush current;

4. conducted emission time domain (ripple and spikes) on power lines in the operating mode, which produces maximum emissions;

5. conducted emission frequency domain on power lines in the operating mode, which produces maximum emissions.

ECSS-E-ST-10-03C-5.5.5.1c

For RF space segment equipment sniff or spray test shall be performed at one or several frequencies used by the space segment equipment under test or in mission critical receive bands.

ECSS-E-ST-10-03C-5.5.5.1d

Sniff or spray test should be performed with a guide to coax transitions at a controlled distance.

2.2.6.3.5.2. Magnetic test

CS NOTE Only to be performed if justified by the mission needs, e.g. magnetic sensors/actuators, or payload instruments with high magnetic cleanliness requirements.

ECSS-E-ST-10-03C-5.5.5.2a

The magnetic test shall be performed in conformance with ECSS-E-ST-20-07 clause 4.2.5 and 5.4.5.

2.2.6.3.5.3. ESD test

CS NOTE Applicable only to items assessed during the project as an ESD risk

ECSS-E-ST-10-03C-5.5.5.3a

The ESD test on space segment equipment shall be performed in conformance with ECSS-E-ST-20-07 clause 5.4.12.

2.2.7 SPACE SEGMENT ELEMENT TEST REQUIREMENTS

2.2.7.1 General requirements

ECSS-E-ST-10-03C-6.1a

When it is not feasible to test a space segment element as a single entity, it may be tested separately as several space segment elements or space segment equipment.

NOTE 1 For example, when it is not feasible due to its size, which can exceed the capacity of a test facility.

NOTE 2 A satellite can be performed as service module on one end and as payload module test on the other.

ECSS-E-ST-10-03C-6.1b

The effects of item(s), which are interacting on the element level, but which are not present during tests, shall be included with the support of simulators.

NOTE Simulators can be fluid, mechanical, thermal, electrical item(s) or software.

ECSS-E-ST-10-03C-6.1c

The test baseline shall be tailored for each project.

ECSS-E-ST-10-03C-6.1d

The sequence of test shall be agreed by the customer depending on the nature of the space segment element and how performances are tested.

NOTE 1 For Infrared instrument or satellite including IR instrument the TV test is the one that allows performance verification, in this case it is often the last test performed.

NOTE 2 For RF radiometer the performance are verified in anechoic chamber, in this case the auto compatibility / Radiated EMC is often one of the last tests performed.

ECSS-E-ST-10-03C-6.1e

For space segment element undergoing a PFM approach, the equipment that are part of it, should be acceptance tested.

NOTE This implies that the equipment design is qualified on a QM.

ECSS-E-ST-10-03C-6.1f

Any unusual or unexpected behaviour shall be evaluated to determine the existence of any trend potentially leading to anomaly or failure situation.

ECSS-E-ST-10-03C-6.1g

Visual inspections shall be performed before and after each test.

2.2.7.2 Qualification test requirements

CS NOTE Not applicable. A system-level protoflight approach is foreseen for an IOD CubeSat.

2.2.7.3 Acceptance test requirements

CS NOTE Not applicable. A system-level protoflight approach is foreseen for an IOD CubeSat.

2.2.7.4 Protoflight test requirements

CS NOTE The following tests are NOT applicable: modal survey, spin, transient, acoustic, shock, micro-vibration, proof pressure, pressure cycling, design burst pressure, leak, thermal ambient, PIM, magnetic, HFE, toxic off gassing, audible noise.

The following tests are tailored:

- *launcher I/F (deployment system fit check);*
- *physical properties (mass and dimensions only, COG/MOI by analysis);*
- *EMC (equipment type "a" only, test approach to be defined in project AIV plan);*
- *magnetic (equipment type "a" only, if justified by mission needs);*
- *shock (applicable only to items assessed during the project as shock-critical);*
- *ESD (applicable only to items assessed during the project as an ESD risk)*

CS NOTE 2 For mechanics, only physical properties, static, random vibrations, sinusoidal vibrations, and thermal vacuum tests are applicable.

ECSS-E-ST-10-03C-6.4a

The space segment elements Proto-qualification test baseline shall consist of the tests specified in Table 6-5.

NOTE 1 Other special tests can be performed depending upon the project characteristics and product lifetime cycle.

NOTE 2 See Table 6-5 and 6-6 in annex A.

ECSS-E-ST-10-03C-6.4b

When part of the qualification is obtained on other model(s), then the PFM shall be tested in accordance with Table 5-3 for the relevant type(s) of test.

NOTE 1 For example, if mechanical qualification is obtained on a STM then the PFM is tested, for mechanical aspects, in accordance with the acceptance requirements.

NOTE 2 See Table 5-3 in annex A.

2.2.7.5 Space segment elements test programme implementation requirements

2.2.7.5.1. General tests

2.2.7.5.1.1. Optical alignment measurement

ECSS-E-ST-10-03C-6.5.1.1a

The measurements, conducted either in a suitable optical alignment facility or in normal clean room with adequate measurement system, shall be performed throughout space segment element test campaign; and as a minimum, at the start and at the end of the environmental test campaign.

NOTE Alignment verification is repeated to track any degradation or to ensure that variation of space segment equipment alignment in relationship with the reference axes remain within the specified limits.

2.2.7.5.1.2. Functional tests

ECSS-E-ST-10-03C-6.5.1.2.1a

The FFT shall be performed in order to verify that the space segment element functions in conformance with the specification requirements in all operational modes, including back-up modes, and transients.

ECSS-E-ST-10-03C-6.5.1.2.1b

The RFT content shall be agreed with the customer.

ECSS-E-ST-10-03C-6.5.1.2.1c

Functional tests shall be performed, under ambient conditions, at the beginning and at the end of the test programme providing the criteria for judging the integrity of the space segment element thought the overall test programme.

NOTE The results of both tests should be identical within the test tolerances.

ECSS-E-ST-10-03C-6.5.1.2.1d

Additional tests (PT, FFT or RFT as relevant) shall be performed during the thermal test.

NOTE The space segment element is expected to be operative under these conditions.

ECSS-E-ST-10-03C-6.5.1.2.1e

Additional functional tests to be performed before and after each environmental exposure and transport(s) shall be agreed with the customer.

NOTE Those tests are limited to RFT to provide the criteria for judging successful survival of the space segment.

ECSS-E-ST-10-03C-6.5.1.2.1f

The FFT activities should follow the expected mission sequence, properly involving the interested functions, with the element correct configuration for the particular mission phase.

ECSS-E-ST-10-03C-6.5.1.2.1g

If an on-board or an EGSE software update is needed during the test campaign, the step at which the software is loaded, as well as the level of retesting, shall be agreed with the customer.

ECSS-E-ST-10-03C-6.5.1.2.2a

The mechanical functions of the space segment element shall be tested under the specified operating conditions as a major input to verify that they conform to the specified performance.

NOTE 1 Test is complemented by analysis and test at equipment level to take into account other design parameters that cannot be tested at space segment element level and the effect of the environment simulation (zero G device).

NOTE 2 Examples of such mechanical functions are mechanisms, deployables, valves and other mechanical devices.

ECSS-E-ST-10-03C-6.5.1.2.2b

For all mechanical operations that can be disturbed by Earth's gravity field, suitable ground support fixtures shall be employed to enable operation and evaluation of the devices.

ECSS-E-ST-10-03C-6.5.1.2.2c

If, for test limitation reason, the function cannot be tested at space segment element level, alternative verification method, that can include test at a lower level, shall be proposed for customer approval.

ECSS-E-ST-10-03C-6.5.1.2.2d

Mechanical functional verification shall be performed prior and subsequent to environmental test campaign.

ECSS-E-ST-10-03C-6.5.1.2.3a

Electrical functional tests shall verify that the electrical functions of the space segment element can be performed under the specified operating conditions with the specified performance.

ECSS-E-ST-10-03C-6.5.1.2.3b

The following protection functions shall be tested:

1. over-voltage protection functions;
2. over-current protection functions;
3. inter-locks, if any;
4. overriding capabilities of protection functions.

ECSS-E-ST-10-03C-6.5.1.2.3c

During the electrical functional tests, all components shall be operated, including redundant space segment equipment and paths, taking into account the type of redundancy (e.g. hot or cold).

NOTE Pyrotechnic devices are replaced by simulators that can be energized and monitored.

ECSS-E-ST-10-03C-6.5.1.2.3d

For cross-strapped configurations, requirements for testing shall be agreed with the customer.

ECSS-E-ST-10-03C-6.5.1.2.3e

All TM/TC shall be tested with the actual data base used for operations.

ECSS-E-ST-10-03C-6.5.1.2.3f

It shall be verified that autonomous functions are performed when the defined conditions, for which they are designed, are present.

ECSS-E-ST-10-03C-6.5.1.2.3g

Any triggering of an autonomous action not in line with the conditions for which they are designed shall be tracked as an anomaly.

ECSS-E-ST-10-03C-6.5.1.2.3h

Autonomous lockout or shutdown sequences shall be verified to ensure that they do not adversely affect other system operations during or subsequent to the intended lockout or shutdown.

ECSS-E-ST-10-03C-6.5.1.2.3i

For non-regulated bus, one subset of functional tests, which is subject to agreement between customer and supplier, shall be run at both the minimum and maximum bus voltage level.

ECSS-E-ST-10-03C-6.5.1.2.3j

The electrical functional verification shall ensure that no function other than the intended function is activated and no spurious signals or effects are present.

NOTE For example, an LCL trip-off does not affect any other distributed line.

ECSS-E-ST-10-03C-6.5.1.2.3k

Actual tests of pyrotechnic devices may be conducted at space segment equipment or component levels.

ECSS-E-ST-10-03C-6.5.1.2.3l

The space segment element communication links shall be tested in a representative operational way.

NOTE This includes test of cross strapping and all redundancies. It also includes the TM/TC if the frequency used can lead to interference. It can be combined with the RF auto-compatibility test. The RF auto-compatibility test is part of the overall electromagnetic auto-compatibility defined in clause ECSS-E-ST-10-03C-6.5.5.

2.2.7.5.1.3. Performance test

CS NOTE Not applicable. The performance of IOD payloads on the CubeSat shall be measured and verified in-orbit as per *the mission objectives. Platform performance is verified at subsystem or equipment level.*

2.2.7.5.1.4. Mission test

CS NOTE Not applicable. Functions such as mode transitions and safe mode recovery shall be covered by the functional tests specified in ECSS-E-ST-10-03C-6.5.1.2.1

2.2.7.5.1.5. Polarity test

CS NOTE As a minimum, the test shall cover AOCS sensor/actuator polarity, as well as solar array – PCDU interface polarity and any drive mechanisms.

ECSS-E-ST-10-03C-6.5.1.5a

The polarity test shall cover all functional chains and equipment sensitive to polarity errors.

NOTE Polarity test is not limited to AOCS space segment equipment. For examples solar array drive mechanism.

ECSS-E-ST-10-03C-6.5.1.5b

Polarity tests shall be performed, with the validated final software installed, in all specific modes, on all chains from sensor to actuator, with the spacecraft in its final flight configuration.

ECSS-E-ST-10-03C-6.5.1.5c

During the polarity test the AOCS shall be operated in the mode where the chain is used in the control loop.

ECSS-E-ST-10-03C-6.5.1.5d

The polarity test shall be one of the last tests before shipment to the launch site.

2.2.7.5.1.6. Launcher interface test

CS NOTE For CubeSats, this is limited to deployment system fit check and interface with any launch service provided COTE.

ECSS-E-ST-10-03C-6.5.1.6a

The interface between the space segment element and the launcher shall be tested, using elements or subset of elements representative of the interfaces to be tested, under realistic conditions, to verify the related system requirements.

NOTE These tests cover the mechanical, electrical and data interfaces (e.g. clamp-band release test, space segment element-launcher fit check).

ECSS-E-ST-10-03C-6.5.1.6b

The interface between the space segment element and the launch facility shall be verified before actual spacecraft operation.

ECSS-E-ST-10-03C-6.5.1.6c

The test to be executed and approach shall be covered in the contractual documentation between space segment element authority and launch segment authority (e.g. ICD, or user manual).

2.2.7.5.2. Mechanical tests

2.2.7.5.2.1. Physical properties measurements

ECSS-E-ST-10-03C-6.5.2.1a

The physical properties measurement shall include:

1. Mass
2. Centre of Gravity
3. Moment of Inertia

CS NOTE Limited to mass measurements. COG and MOI shall be based on analysis of the final CAD model for all mission configurations

ECSS-E-ST-10-03C-6.5.2.1b

Physical properties shall be measured for the launch and orbit insertion configurations, and atmospheric entry when relevant.

NOTE Depending upon the mission profile other configurations can be used.

ECSS-E-ST-10-03C-6.5.2.1c

The tolerances shall be the minimum values specified in either Table 4-1 or in the launcher user's manual.

NOTE 1 Launch configuration balance requirements are stated in the launcher user's manual.

NOTE 2 See Table 4-1 in annex A.

ECSS-E-ST-10-03C-6.5.2.1d

For a large space segment element, the physical properties may be calculated using data from equipment individual measurements providing the final results meet the specified accuracy.

ECSS-E-ST-10-03C-6.5.2.1e

Spin balance tests shall be used for spin stabilized systems.

ECSS-E-ST-10-03C-6.5.2.1f

If spin balance tests are performed with an empty tank, a correlation with the analytical model (tank full) shall be performed.

NOTE Operational spin balance requirements vary widely depending on the mission profile and rate of spin; therefore, specific balance requirements and procedures are stated in the space segment element specifications.

2.2.7.5.2.2. Static load test

CS NOTE Limited only to cases where static flight loads exceed the launch loads covered by the sine vibration tests.

ECSS-E-ST-10-03C-6.5.2.3a

Boundary conditions, in the static load test, shall be demonstrated to be representative of flight boundary constraints or alternatively test forces on boundary constraints shall be measured.

ECSS-E-ST-10-03C-6.5.2.3b

When a dummy structure is used in the static load test, it shall be demonstrated that it is representative in terms of stiffness and as far as the constraints of the replaced flight component are concerned.

2.2.7.5.2.3. Random vibration test

ECSS-E-ST-10-03C-6.5.2.7a

Random vibration tests shall be conducted in launch configuration for all axes.

ECSS-E-ST-10-03C-6.5.2.7b

Random excitations shall cover the three mutually orthogonal directions, one being parallel to the thrust axis.

ECSS-E-ST-10-03C-6.5.2.7c

Propellant tanks shall be at least mass and stiffness representative during random testing.

NOTE Simulated propellant can be used.

ECSS-E-ST-10-03C-6.5.2.7d

The internal pressure decay shall be verified for pressurized space segment equipment being part of the space segment element under test.

ECSS-E-ST-10-03C-6.5.2.7f

Notching criteria and implementation shall be approved by the customer and, if relevant, by the launcher authority.

ECSS-E-ST-10-03C-6.5.2.7g

The induced cross axis accelerations at the attachment points shall be limited to the maximum test levels specified for the cross axis.

ECSS-E-ST-10-03C-6.5.2.7i

In order to evaluate the space segment element integrity a resonance search shall be performed before and after the random vibration test by determining resonant frequencies.

ECSS-E-ST-10-03C-6.5.2.7j

The success criteria for the resonance search shall be:

1. less than 5 % in frequency shift, for modes with an effective mass greater than 10 %;

2. less than 20 % in amplitude shift, for modes with an effective mass greater than 10 %.

2.2.7.5.2.4. Sinusoidal vibration test

ECSS-E-ST-10-03C-6.5.2.8a

Sinusoidal vibration tests shall be conducted in launch configuration for the three mutually orthogonal directions, one being parallel to the thrust axis.

ECSS-E-ST-10-03C-6.5.2.8b

Propellant storage tanks shall be at least mass and stiffness representative during sinusoidal vibration test.

NOTE Simulated propellant can be used.

ECSS-E-ST-10-03C-6.5.2.8c

The internal pressure decay shall be verified for pressurized space segment equipment being part of the space segment element under test.

ECSS-E-ST-10-03C-6.5.2.8d

Notching criteria and implementation shall be approved by the customer and, if relevant, by the launcher authority.

ECSS-E-ST-10-03C-6.5.2.8f

Automatic protection measures shall be implemented during the test to prohibit excessive resonance build-up leading to hardware damage.

NOTE This is achieved for example by means of abort and notch accelerometers control.

ECSS-E-ST-10-03C-6.5.2.8g

A resonance search shall be performed before and after the sinusoidal vibration tests to determine resonance frequencies to evaluate the product integrity and to compare the resonance frequency distribution with that of the mathematical model or modal survey.

NOTE 1 Any significant shift in resonance frequencies from those analytically determined is an indication of improper assembly or materials defects.

NOTE 2 This resonance search can be used to update the Finite Element Model in case of design modification w.r.t. the previously tested model.

ECSS-E-ST-10-03C-6.5.2.8h

The success criteria for the resonance search shall be:

1. less than 5 % in frequency shift, for modes with an effective mass greater than 10 %;

2. less than 20 % in amplitude shift, for modes with an effective mass greater than 10 %.

2.2.7.5.3. Structural integrity tests

2.2.7.5.3.1. Proof pressure test

ECSS-E-ST-10-03C-6.5.3.1a

The proof pressure test shall be performed before the environment tests.

ECSS-E-ST-10-03C-6.5.3.1b

Proof pressure tests shall be performed as follows:

1. pressurize the respective space segment equipment to proof pressure for at least 5 minutes;
2. verify that the proof pressure level is reached;
3. reduce the pressure to the maximum design pressure;
4. perform a leak test;
5. perform a visual inspection.

ECSS-E-ST-10-03C-6.5.3.1c

Requirements of ECSS-E-ST-32-02 clauses 5.4.1 and 5.4.2 for qualification and protoflight, and clauses 5.5.1 and 5.5.2 for acceptance shall be applied for proof pressure tests.

2.2.7.5.3.2. Leak test

ECSS-E-ST-10-03C-6.5.3.4a

All lines, joints and fittings shall be checked for leaks, on the fully assembled configuration of the space segment element.

ECSS-E-ST-10-03C-6.5.3.4b

When the fully assembled configuration precludes accessibility to perform requirement ECSS-E-ST-10-03C-6.5.3.4a, leak tests shall be conducted on a configuration to be agreed with the customer.

ECSS-E-ST-10-03C-6.5.3.4c

The method for checking leaks shall be selected according to the requirements to be met.

2.2.7.5.4. Thermal tests

2.2.7.5.4.1. Requirements applicable to thermal vacuum and thermal ambient tests

ECSS-E-ST-10-03C-6.5.4.1b

Test profile, test configuration, number of cycles, extreme temperatures, temperature rate of change, stability criteria, cycles and plateau duration, functional and performance tests to be performed and success criteria shall be defined in the test specification.

NOTE It is not mandatory to include the solar array or large appendages in a space segment element thermal vacuum test. If it is however included, precautions should be taken to avoid overstress.

ECSS-E-ST-10-03C-6.5.4.1c

A reduced functional test shall be performed prior the closing of the chamber to validate the test configuration.

ECSS-E-ST-10-03C-6.5.4.1d

The sequence of functional tests shall be defined in the test specification such that all space segment equipment are tested.

ECSS-E-ST-10-03C-6.5.4.1e

The most severe operative configuration should be tested with regard to the power time domain, the power consumption and the thermal dissipation point of view.

ECSS-E-ST-10-03C-6.5.4.1f

The equipment power ON/OFF status, throughout the test (including transitions), shall be defined in the test specification.

ECSS-E-ST-10-03C-6.5.4.1g

Functional tests shall be performed as a minimum at hot and cold plateaux.

NOTE Mechanical functional test can be part of the functional test, pending on configuration or test set-up constraint

ECSS-E-ST-10-03C-6.5.4.1h

Equipment switch on capabilities shall be demonstrated.

ECSS-E-ST-10-03C-6.5.4.1i

In case of redundancy, thermal tests shall be performed on both chains taking into account the type of redundancy (e.g. hot or cold).

ECSS-E-ST-10-03C-6.5.4.1j

In case of cross-strapped configurations, requirements for testing shall be agreed with the customer.

ECSS-E-ST-10-03C-6.5.4.1l

The temperatures of all the space segment equipment shall be monitored to ensure that the space segment equipment are not damaged during test.

ECSS-E-ST-10-03C-6.5.4.1m

Equipment temperatures within the space segment elements shall refer to the equipment temperature reference points.

ECSS-E-ST-10-03C-6.5.4.1n

Test methods and test set up shall be defined according to the thermal environment characteristics, the TCS thermal design, the space segment element itself and the need for thermal balance phases.

ECSS-E-ST-10-03C-6.5.4.1o

The rate of temperature change during cooling, and heating shall be the same as those projected for the mission, but not exceed them.

ECSS-E-ST-10-03C-6.5.4.1p

The test set-up and test modes shall be selected, in order to achieve the specified test temperatures within the specified stability and duration.

2.2.7.5.4.2. Requirements applicable to thermal vacuum test

ECSS-E-ST-10-03C-6.5.4.2a

The set-up shall ensure that outgassing does not contaminate the space segment element.

ECSS-E-ST-10-03C-6.5.4.2b

The pressure during the test shall be maintained at 10-5 hPa or less.

2.2.7.5.4.3. Thermal balance test

CS NOTE Need for a thermal balance test shall be determined on a per project basis.

ECSS-E-ST-10-03C-6.5.4.4a

The thermal balance test shall be performed in conformance with ECSSE-ST-31 clause 4.5.3.

2.2.8 PRE-LAUNCH TESTING

ECSS-E-ST-10-03C-7a

Pre-launch tests shall confirm that all elements needed for the launch, including their interfaces are verified, and that their parameters are within the specified limits.

NOTE 1 Elements needed for the launch are: Launch segment element, space segment element and associated GSE.

NOTE 2 For space segment element, the set of parameters checked as part of pre-launch testing is a sub set of those used during AIT. The definition of this sub set is subject to agreement with the customer.

ECSS-E-ST-10-03C-7b

Pre-launch tests results shall result in the authorizing the next pre-launch activities to be carried out.

NOTE For example leak test is performed to authorize fuelling.

ECSS-E-ST-10-03C-7c

The procedures to be executed during the launch campaign shall be rehearsed before the start of the launch campaign.

NOTE This means that procedure used in pre-launch activities have been rehearsed, at least once during AIT.

ECSS-E-ST-10-03C-7d

The impact of any change on the EGSE shall be evaluated and the rehearsal repeated if it is so derived from the evaluation.

ECSS-E-ST-10-03C-7e

Pre-launch functional tests shall be performed to verify that no damage or performance degradation of the space segment element and its constituents has occurred during shipment or handling.

NOTE Verification of redundancy is included.

ECSS-E-ST-10-03C-7f

When a space segment element is not transported fully assembled or is subsequently disabled, the final assembly at launch site shall be retested.

NOTE For example batteries, solar array. The level of retesting is subject to agreement with the customer.

ECSS-E-ST-10-03C-7g

The pre-launch functional test shall include a verification of electrical power interfaces and command and control functions as well as, when relevant, of radio frequency interference.

2.2.9 AIT PLAN DRD

CS NOTE Merged with the Verification Plan to form one single AIV Plan. See annex B.

2.2.10 TEST SPECIFICATION DRD

CS NOTE Merged with Test Procedure into a single document. See annex B.

2.2.11 TEST PROCEDURE DRD

CS NOTE Merged with Test Specification into a single document. See annex B.

3. Annex A

Table 4-1: Allowable tolerances

(Source: ECSS-E-ST-10-03C)

Test parameters	Tolerances
1. Temperature	Low High
above 80K	Tmin +0/-4 K Tmax -0/+4 K
T< 80 K	Tolerance to be defined case by case
2. Relative humidity	± 10 %
3. Pressure (in vacuum chamber)	
> 1,3 hPa	± 15 %
1,3 10-3 hPa to 1,3hPa	± 30 %
< 1,3 10-3 hPa	± 80 %
4. Acceleration (steady state) and static load	-0 / +10 %
5. Sinusoidal vibration	
Frequency (5 Hz to 2000 Hz)	± 2 % (or ±1 Hz whichever is greater)
Amplitude	± 10 %
Sweep rate (Oct/min)	± 5 %
6. Random vibration	
Amplitude (PSD, frequency resolution better than 10Hz)	
20 Hz - 1000 Hz	-1 dB / +3 dB
1000 Hz - 2000 Hz	± 3 dB
Random overall g r.m.s.	± 10 %
7. Acoustic noise	
Sound pressure level, Octave band centre (Hz)	
31,5	-2 dB /+4 dB
63	-1 dB /+3 dB
125	-1 dB /+3 dB
250	-1 dB /+3 dB
500	-1 dB /+3 dB
1000	-1 dB /+3 dB
2000	-1 dB /+3 dB
Overall	-1 dB /+3 dB
Sound pressure level homogeneity per octave band	+/- 2 dB
8. Microvibration	
Acceleration	±10 %

Test parameters	Tolerances
Forces or torque	±10 %
9. Audible noise (for Crewed Element only)	
Sound-power (1/3 octave band centre frequency)	
32,5 Hz - 160 Hz	±3 dB
160 Hz – 16 kHz	±2 dB
9. Shock	
Response spectrum amplitude (1/12 octave centre frequency or higher)	
Shock level	- 3 dB/ + 6 dB 50 % of the SRS amplitude above 0 dB
10. Solar flux	
in reference plane	± 4 % of the set value
in reference volume	± 6 % of the set value
11. Infrared flux	
Mean value	± 3 % on reference plane(s)
12. Test duration	-0/+10 %

Table 4-2: Test accuracies

(Source: ECSS-E-ST-10-03C)

Test parameters	Accuracy
1. Mass	
Space segment equipment and space segment element	± 0,05 % or 1 g whatever is the heavier
2. Centre of gravity (CoG)	
Space segment equipment	Within a 1 mm radius sphere
Space segment element	± 2,5 mm along launch axis ± 1 mm along the other 2 axes
3. Moment of inertia (MoI)	
Space segment equipment and Space segment element	± 3 % for each axis
4. Leak rate	One magnitude lower than the system specification, in Pa m^3 s^{-1} at standard conditions (1013,25 Pa and 288,15 K).
5. Audible noise (for Crewed Element only)	
32,5 Hz to 160 Hz	± 3 dB
160 Hz to 16 kHz	± 2 dB
6. Temperature	

above 80 K	± 2 K
T< 80 K	Accuracy to be defined case by case
7. Pressure (in vacuum chamber)	
> 1,3 hPa	± 15 %
1,3 10^{-3} hPa to 1,3 hPa	± 30 %
< 1,3 10^{-3} hPa	± 80 %
8. Acceleration (steady state) and static load	± 10 %
9. Frequency for mechanical tests	± 2 % (or ±1 Hz whichever is greater)
10. Acoustic noise	± 0,1dB
11. Strain	± 10 %
12. EMC	See ECSS-E-ST-20-07 clause 5.2.1.
13. ESD	See ECSS-E-ST-20-06 See ECSS-E-ST-20-07 clause 5.2.1 for ESD test on space segment equipment.

Table 5-3: Space segment equipment - Acceptance test baseline (Source: ECSS-E-ST-10-03C)

Test	Reference clause	Ref. to Level & Duration	Applicability versus types of space segment equipment												Application notes
			a	b	c	d	e	f	g	h	i	j	k	l	
General															
Functional and performance (FFT/RFT)	5.5.1.1		R	R	R	R	R	R	R	R	R	R	R	R	For k (solar array), the deployment test is mandatory before and after the environmental tests (manual deployment before the environmental tests).
Humidity			-	-	-	-	-	-	-	-	-	-	-	-	
Life			-	-	-	-	-	-	-	-	-	-	-	-	
Burn-in	5.5.1.4		X	-	-	X	-	-	X	-	-	-	-	-	To be performed, if the total duration of the acceptance test sequence is insufficient to detect material and workmanship defect occurring in the space segment equipment lifetime.
Mechanical															
Physical properties	5.5.2.1		R	R	R	R	R	R	R	R	R	R	R	R	Upon agreement with customer the CoG and MoI is not measured by test. but calculated.
Static load			-	-	-	-	-	X	-	-	-	-	-	-	General structural proof test is performed on pressure vessel if no covered by higher level test (e.g. sinusoidal with full tanks).
Spin			-	-	-	-	-	-	-	-	-	-	-	-	
Transient			-	-	-	-	-	-	-	-	-	-	-	-	
Random vibration	5.5.2.3	See Table 5-4 No 1	R	X	R	R	R	R	R	R	X	X	X	-	For k (solar array), the random vibration test should be added to acoustic test for fixed solar array mounted directly to the spacecraft side wall (without offset bracket). For b (antennas), i (optical), j (mechanism), random vibration or acoustic test is selected depending on the type, size and location of the space segment equipment. For k (solar array), acoustic acceptance testing of recurrent FMs (from the second FM) can be omitted on condition that they are subjected to acceptance testing at space segment element level.
Acoustic	5.5.2.4	See Table 5-4 No 2	-	X	-	-	-	-	-	-	X	X	R	-	
Sinusoidal vibration	5.5.2.5	See Table 5-4 No 3	-	-	-	-	-	-	-	-	-	-	R	-	For k (solar array), sinusoidal vibration acceptance testing of recurrent FMs (from the second FM) can be omitted on condition that they are subjected to acceptance testing at space segment element level, or in case of significant flight heritage on design, processes and manufacturers.
Shock			-	-	-	-	-	-	-	-	-	-	-	-	
Micro-vibration generated environment			-	-	-	-	-	-	-	-	-	-	-	-	
Micro-vibration suscep.	5.5.2.8	See Table 5-4 No 4	X	-	-	-	-	-	-	-	X	X	-	-	Test to be performed only if need is identified by analysis.

Test	Reference clause	Ref. to Level & Duration	Applicability versus types of space segment equipment												Application notes
			a	b	c	d	e	f	g	h	i	j	k	l	
Structural integrity															
Leak	5.5.3.1	See Table 5-4 No 5	X	-	R	R	R	R	X	-	-	-	-	-	For a (electronic, electrical and RF equipment) required only on sealed or pressurized space segment equipment. For c (battery) proof pressure, is performed at cell level (i.e. component level).
Proof pressure	5.5.3.2	See Table 5-4 No 6	-	-	-	R	R	R	X	-	-	-	-	-	
Pressure cycling			-	-	-	-	-	-	-	-	-	-	-	-	
Design burst pressure			-	-	-	-	-	-	-	-	-	-	-	-	
Burst			-	-	-	-	-	-	-	-	-	-	-	-	
Thermal															
Thermal vacuum	5.5.4.1 & 5.5.4.2	See Table 5-4 No 7	R	X	R	R	R	X	R	R	R	R	-	R	
Thermal ambient	5.5.4.1 & 5.5.4.3	See Table 5-4 No 8	R	X	R	R	R	X	R	R	R	R	-	-	Can be combined in thermal vacuum test. Tests not required for batteries that cannot be recharged after testing.
Electrical / RF															
EMC	5.5.5.1	See Table 5-4 No 9	R	X	X	X	X	X	X	X	X	X	X	X	For equipment without electronic test are limited to bonding test.
Magnetic	5.5.5.2		X	X	X	X	X	X	X	X	X	X	-	X	Magnetic test to be performed if justified by mission needs, in accordance with the EMCCP.
ESD			-	-	-	-	-	-	-	-	-	-	-	-	
PIM	5.5.5.4	See Table 5-4 No 10	X	X	-	-	-	-	X	-	X	-	-	-	
Multipaction	5.5.5.5		X	X	-	-	-	-	-	-	-	-	-	-	
Corona and arc discharge	5.5.5.6	See Table 5-4 No 11	R	R	R	-	-	-	-	-	-	-	-	-	For condition of applicability of test, refer to 5.5.5.6.
Mission specific															
Audible noise	5.5.6.1		R	R	-	R	R	-	R	-	-	R	-	-	Required for space segment equipment for crewed space segment element.

Types of space segment equipment				Key
a Electronic, electrical and RF equipment b Antenna c Battery	d Valve e Fluid or propulsion equipment f Pressure vessel	g Thruster h Thermal equipment i Optical equipment	j Mechanism k Solar array l Solar panel	R Required X To be decided by the customer - Not required

NOTE 1: Tests are categorized into "R" or "X" depending on the sensitivity of the space segment equipment type to the specific environment, the probability of encountering the environment, and project specificity.

NOTE 2: All tests type are listed independently of their application status:

- the black shading indicates that the type of test is never required or optional
- the grey shading indicates that there is no test level and duration specified in the Table 5-4 since it is not a test where an environment is applied to the item under test

Table 5-4: Space segment equipment - Acceptance test levels and duration (Source: ECSS-E-ST-10-03C)

No	Test	Levels	Duration	Number of applications	NOTES
1	**Random vibration**	Maximum expected spectrum +0dB on PSD values	1 minute	On each of 3 orthogonal axes	
2	**Acoustic**	Maximum expected acoustic spectrum +0dB	1 minute	1 test	
3	**Sinusoidal vibration**	KA x Limit Load Spectrum The acceptance factor KA is given in ECSSE-ST-32-10 clause 4.3.1	Sweep at 4 Oct/min, 5 Hz - 140 Hz	On each of 3 orthogonal axes	
4	**Microvibration susceptibility**	Maximum predicted environment	As needed for susceptibility determination	As specified by the project.	
5	**Leak**	MDP	Pressure maintained for 30 minutes as minimum	In conformance with Figure 5-1	
6	**Proof pressure**	jproof x MDP For the proof factor (jproof), apply ECSS-E-ST-32-02 Tables 4-1 to 4-9.	5 minutes minimum hold time	1	

No	Test	Levels	Duration	Number of applications	NOTES

7	**Thermal vacuum**	$T^{A}_{\max}\Big\vert_{Op/NOp} = T^{D}_{\max}\Big\vert_{Op/NOp} + 5^{\circ}C$ $T^{A}_{\min}\Big\vert_{Op/NOp} = T^{D}_{\min}\Big\vert_{Op/NOp} - 5^{\circ}C$ Lower acceptance margin than +/-5 °C, may be used for temperature below -170 C. Higher acceptance margin than +/-5 °C may be used for temperature above 120 C.	4 cycles or 1 or more cycles if combined with ambient cycles (See note 1 & 2) For solar panels, 5 cycles (See note 3)	1 test	Note 1: Thermal vacuum and thermal ambient tests are both performed for space segment equipment that operate under a non-vacuum environment after having been exposed to vacuum. Note 2: Number of cycles and operating condition in Vacuum and Ambient will be selected based on mission profile. Note 3: The number of cycles is modified on the following cases: 1. In case the solar panel design or manufacturing process or manufacturer does not have flight heritage, 10 cycles are performed., 2. In case the solar panel qualification is performed on one panel only, 10 cycles are performed as acceptance test 3. In case of significant flight heritage on design, processes and manufacturers it can be reduced to 3 cycles

No	Test	Levels	Duration	Number of applications	NOTES
8	**Thermal ambient**	$T^{A}_{\max}\big\|_{Op/NOp} = T^{D}_{\max}\big\|_{Op/NOp} + 5^{\circ}C$ $T^{A}_{\min}\big\|_{Op/NOp} = T^{D}_{\min}\big\|_{Op/NOp} - 5^{\circ}C$ Lower acceptance margin than +/-5 C may be used for temperature below -170 C. Higher acceptance margin than +/-5 C may be used for temperature above 120 C. (See note 1).	4 cycles (See Note 2) or 4 cycles minus the number of cycles performed during the vacuum test	1 test	Note 1: Ambient pressure depends on the type of mission (i.e. Mars mission, Venus mission) Note 2: Thermal ambient test without vacuum test is applicable only to space segment equipment that operate under a non-vacuum environment during their entire lifetime. In assessing this, depressurisation failure should be considered.
9	**EMC**	Apply ECSS-E-ST-20-07 clause 5.4	Apply ECSS-E-ST-2007 Clause 5.4	1 test	
10	**Passive intermodulation**	For equipment see ECSS-E-ST-20 clause 7.4		See ECSS-E-ST-20 clause 7.4	
11	**Corona and Arc discharge**	Maximum operational voltage and maximum RF output power for RF equipment Sweep over the critical pressure range over 10 hPa to 0,1 hPa	10 to 15 minutes	1 test	For a given frequency, minimum gap within the space segment equipment, and given pressure a Paschen curve is defined. This curve has a minimum of power within the pressure range.

NOTE: The table does not include tests for some ambient conditions such as humidity and toxic-off gassing because they are performed exposing the hardware to the environment without margin.

Table 6-5: Space segment element - Protoflight test baseline (Source: ECSS-E-ST-10-03C)

Test	Reference clause	Ref. to Level & Duration & Number of applications	Applicability	Conditions
General				
Optical alignment	6.5.1.1		R	
Functional (FFT / RFT)	6.5.1.2		R	
Performances (PT)	6.5.1.3		R	
Mission (MT)	6.5.1.4		R	
Polarity	6.5.1.5		R	
Launcher Interface	6.5.1.6		X	Mandatory for space segment element interfacing with launcher.
Mechanical				
Physical properties	6.5.2.1		R	
Modal survey	6.5.2.2		X	
Static	6.5.2.3	Table 6-6 No 1	X	Mandatory if not performed at structure subsystem level
Spin	6.5.2.4	Table 6-6 No 2	X	Mandatory for spinning space segment elements with an acceleration greater than 2 g or more to any part of the space segment element
Transient	6.5.2.5	Table 6-6 No 3	X	
Acoustic	6.5.2.6	Table 6-6 No 4	X	Acoustic test may be replaced by random vibration. For a small compact space segment element, acoustic testing does not provide adequate environmental simulation, and random vibration may replace the acoustic test. If acoustic test is performed, random vibration may be avoided.
Random vibration	6.5.2.7	Table 6-6 No 5	X	
Sinusoidal vibration	6.5.2.8	Table 6-6 No 6	R	Sinusoidal vibration may be replaced by transient combined with modal survey
Shock	6.5.2.9	Table 6-6 No 7	X	
Micro-vibration susceptibility	6.5.2.10	Table 6-6 No 8	X	
Structural integrity				
Proof pressure	6.5.3.1	Table 6-6 No 9	X	Mandatory for pressurized space segment elements or on pressurized equipment integrated in space segment element for which the test is feasible
Pressure cycling	6.5.3.2	Table 6-6 No 10	X	Mandatory for Pressurized space segment elements that will experience several re-entries.
Design burst pressure	6.5.3.3	Table 6-6 No 11	X	Mandatory for pressurized space segment element to be performed on a dedicated hardware
Leak	6.5.3.4	Table 6-6 No 12	X	Mandatory for pressurized space segment elements or on pressurized

Test	Reference clause	Ref. to Level & Duration & Number of applications	Applicability	Conditions
				equipment integrated in space segment element for which the test is feasible
Thermal				
Thermal vacuum	6.5.4.1 & 6.5.4.2	Table 6-6 No 13	R	
Thermal ambient	6.5.4.1 & 6.5.4.3	Table 6-6 No 14	X	Applicable to space segment elements that operate under a nonvacuum environment during their lifetime
Thermal balance	6.5.4.4		R	
Electrical / RF				
EMC	6.5.5.2	Table 6-6 No 15	R	
Electromagnetic autocompatibility	6.5.5.3		R	
PIM	6.5.5.4	Table 6-6 No 16	X	
Magnetic	6.5.5.5		X	
Mission Specific				
Aero-thermodynamics	6.5.6.1		R	For space segment element performing atmospheric entry
Crewed Mission Specific				
Micro-vibration emission	6.5.7.1		R	
HFE	6.5.7.2		R	
Toxic off gassing	6.5.7.3		R	
Audible noise	6.5.7.4		R	

R Mandatory

X To be decided on the basis of design features, required lifetime, sensitivity to environmental exposure, and expected usage.

Note: All tests type are listed independently of their application status:

- the dark grey indicates that the type of test is never required or optional
- the light grey indicates that there is no test level and duration specified in the Table 6-6 since it is not a test where an environment is applied to the item under test

Table 6-6: Space segment element - Protoflight test levels and duration (Source: ECSS-E-ST-10-03C)

No	Test	Levels	Duration	Number of applications	NOTES
1	**Static load**	KQ x Limit Load The qualification factor KQ is given in ECSS-E-ST-32-10 clause 4.3.1	As needed to record data	Worst combined load cases	Note: Worst combined load cases are determined by analysis
2	**Spin**	$\sqrt{KQ}$ x spin rate The qualification factor KQ is given in ECSS-E-ST-32-10	As specified by the project	1 test	
3	**Transient**	KQ x Limit Load The qualification factor KQ is given in ECSS-E-ST-32-10 clause 4.3.1	As needed to record data	On each of 3 orthogonal axes	
4	**Acoustic**	Maximum expected acoustic spectrum +3 dB If margins higher than 3 db are specified by the Launcher Authority, they apply	1 minute	1 test	
5	**Random vibration**	Maximum expected spectrum +3 dB on PSD values If margins higher than 3 dB are specified by the Launcher Authority, they apply	1 minute	On each of 3 orthogonal axes	
6	**Sinusoidal vibration**	KQ x Limit Load Spectrum The qualification factor KQ is given in ECSS-E-ST-32-10 clause 4.3.1	Sweep at 4 Oct/min, 5 Hz – 100 Hz	On each of 3 orthogonal axes	

No	Test	Levels	Duration	Number of applications	NOTES
7	**Shock**	See Note 1	See Note 2	1 activation	NOTE 1: Limited to a test where the shock generative device(s) is/are activated. This test is performed with no margins to consolidate the shock specification of the space segment equipment NOTE 2: Duration representative of the expected environment.
8	**Micro vibration susceptibility**	Maximum predicted environment	As needed for susceptibility determination	As specified by the project.	
9	**Proof pressure**	j_{proof} x MDP For the proof factor (j_{proof}), apply ECSS-E-ST-32-02 Tables 4-1 to 4-9.	5 minutes minimum hold time	1 test	
10	**Pressure cycling**	See Note	See Note	See Note	Test level, duration and number of application to be defined based on type of mission
11	**Design burst pressure**	j_{burst} x MDP For the burst factor (j_{burst}), apply ECSS-E-ST-32-02 Tables 4-1 to 4-9.	30 seconds as minimum	1 test	

No	Test	Levels	Duration	Number of applications	NOTES
12	**Leak**	MDP	To be agreed depending on test method	Before and after environmental tests taking into account that one is already performed as part of proof test	
13	**Thermal ambient** (See Note 1 & 2)	To ensure that all equipment maximum temperatures are: - above maximum predicted temperature, and - as close as possible to Tº Max, and - with no equipment temperature above Tº Max To ensure that all equipment minimum temperatures are: - below minimum predicted temperature, and - as close as possible to Tº Min, and - with no equipment temperature below Tº Min	3 cycles (see Note 2) or 3 cycles minus the number of cycles performed during the vacuum test	1 test	NOTE 1: Ambient pressure depends on the type of mission (i.e. Mars mission, Venus mission) NOTE 2: Thermal Ambient test without vacuum test is Applicable only to space segment elements that operate under a non-vacuum environment during their lifetime. In assessing this, depressurisation failure should be considered.

No	Test	Levels	Duration	Number of applications	NOTES
14	**Thermal vacuum**	To ensure that all equipment maximum temperatures are: - above maximum predicted temperature, and - as close as possible to Tª Max, and - with no equipment temperature above Tª Max To ensure that all equipment minimum temperatures are: - below minimum predicted temperature, and - as close as possible to Tª Min, and - with no equipment temperature below Tª Min The temperature excursion stops when the first unit reaches Tª Max or Tª Min	3 cycles +1 back up to be decided during test. or 1 or more cycles if combined with ambient cycles (see Note 1 & 2)	1 test	NOTE 1: Thermal vacuum and thermal ambient tests are both performed for space segment elements that operate under a non-vacuum environment after having been exposed to vacuum. NOTE 2: Number of cycles and operating condition in Vacuum and Ambient will be selected based on mission profile.
15	**EMC**	Apply ECSS-E-ST-20-07 clause 5.3 and EMCCP	Apply the project EMCCP (produced in conformance with ECSS-E-ST-20 Annex A).	1 test	
16	**Passive intermodulation**	Apply ECSS-E-ST-20 clause 7.4	Apply ECSS-E-ST-20 clause 7.4	1 test	

4. Annex B

4.1. Assembly, integration and test plan (AITP) - DRD

4.1.1 DRD IDENTIFICATION

A.1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-10-03, requirement 4.3.3.2a.

A.1.2 Purpose and objective

The assembly integration and test plan is the master plan for the product AIT process. It describes the complete AIT process and demonstrates together with the verification plan how the requirements are verified by inspection and test.

It contains the overall AIT activities and the related verification tools (GSE and facilities), the involved documentation, the AIT management and organization. It also contains the AIT schedule.

It is one of the major inputs to the project schedule and is used to provide the customer a basis for review and evaluation of the effectiveness of the AIT programme and its proposed elements.

An AITP is prepared for the different verification levels covering in detail the AIT activities at that level and outlining the necessary lower level aspects.

The AITP is complementary to the verification plan. It takes into account the test standards defined in the Customer requirements.

The availability of the verification plan is a prerequisite to the preparation of the AITP.

4.1.2 EXPECTED RESPONSE

A.2.1 Scope and content

<1> Introduction

a. The AITP shall contain a description of the purpose, objective, content and the reason prompting its preparation.

b. Any open issue, assumption and constraint relevant to this document shall be stated and described.

<2> Applicable and reference documents

a. The AITP shall list the applicable and reference documents in support to the generation of the document.

<3> Definitions and abbreviations

a. The AITP shall list the applicable dictionary or glossary and the meaning of specific terms or abbreviations utilized in the document.

<4> Product presentation

a. The AITP shall briefly describe the selected models and their built status with reference to the verification plan (see ECSS-E-ST-10-02).

<5> Assembly, integration and test programme

a. The AITP shall document the AIT activities and associated planning.

b. The AITP shall include test matrix(ces) that link the various tests with the test specifications, test procedures, test blocks and hardware model.

c. Assembly, integration and test programmes including inspections, should be detailed through dedicated activity sheets.

d. Activity sheets shall include descriptions of the activity including the tools and GSE to be used, the expected duration of the activity, and the relevant safety or operational constraints.

e. The sequencing of activities should be presented as flow charts.

<6> GSE and AIT facilities

a. The AITP shall list and describe the GSE, test software and AIT facilities to be used.

b. The AITP shall describe the logistics and list the major transportations.

<7> AIT documentation

a. The AITP shall describe the AIT documents to be produced and their content.

<8> Organization and management

a. The AITP shall describe the responsibility and management tools applicable to the described AIT process with reference to ECSS-E-ST-10-02.

b. The AITP shall describe the responsibilities within the project team, the relation to product assurance, quality control and configuration control (tasks with respect to AIT) as well as the responsibility sharing with external partners.

NOTE Tasks with respect to AIT include for example, anomaly handling, change control, safety, and cleanliness.

c. The planned reviews and the identified responsibilities shall be stated.

<9> AIT schedule

a. The AITP shall provide the AIT schedule as reference.

A.2.2 Special remarks

None.

4.2. Test specification (TSPE) - DRD

4.2.1 DRD IDENTIFICATION

B.1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-10-03, requirement 4.3.3.3a.

B.1.2 Purpose and objective

The test specification (TSPE) describes in detail the test requirements applicable to any major test activity. In particular, it defines the purpose of the test, the test approach, the item under test and the set-up, the required GSE, test tools, test instrumentation and measurement accuracy, test conditions, test sequence, test facility, pass/fail criteria, required documentation, participants and test schedule.

Since major test activities often cover multiple activity sheets, the structure of the TSPE is adapted accordingly.

The TSPE is used as an input to the test procedures, as a requirements document for booking the environmental test facility and to provide evidence to the customer on certain details of the test activity in advance of the activity itself.

The TSPE is used at each level of the space system decomposition (i.e. equipment, space segment element)

The TSPE provides the requirements for the activities identified in the AITP (as defined in Annex A of ECSS-E-ST-10-03).

The TSPE is used as a basis for writing the relevant test procedures (as defined in Annex C of ECSS-E-ST-10-03) and test report (as defined in Annex C of ECSSE-ST-10-02).

In writing the test specification potential overlaps with the test procedure is minimized (i.e. the test specification gives emphasis on requirements, the test procedure on operative step by step instructions). For simple tests, merging TSPE and TPRO is acceptable.

4.2.2 EXPECTED RESPONSE

B.2.1 Scope and content

<1> Introduction

a. The TSPE shall contain a description of the purpose, objective, content and the reason prompting its preparation.

b. Any open issue, assumption and constraint relevant to this document shall be stated and described.

<2> Applicable and reference documents

a. The TSPE shall list the applicable and reference documents in support to the generation of the document.

<3> Definitions and abbreviations

a. The TSPE shall list the applicable dictionary or glossary and the meaning of specific terms or abbreviations utilized in the document.

<4> Requirements to be verified

a. The TSPE shall list the requirements to be verified (extracted from the VCD) in the specific test and provides traceability where in the test the requirement is covered.

<5> Test approach and test requirements

a. The TSPE shall summarize the approach to the test activity and the associated requirements as well as the prerequisites to start the test.

<6> Test description

a. The TSPE shall summarize the configuration of the item under test, the test set-up, the necessary GSE, the test tools, the test conditions and the applicable constraints.

<7> Test facility

a. The TSPE shall describe the applicable test facility requirements together with the instrumentation and measurement accuracy, data acquisition and test space segment equipment to be used.

<8> Test sequence

a. The TSPE shall describe the test activity flow and the associated requirements.

b. When constraints are identified on activities sequence, the TSPE shall specify them including necessary timely information between test steps.

<9> Pass/fail criteria

a. The TSPE shall list the test pass/fail criteria, including their tolerance, in relation to the inputs and output.

b. In the TSPE, the error budgets and the confidence levels with which the tolerance is to be met shall be specified.

<10> Test documentation

a. The TSPE shall list the requirements for the involved documentation, including test procedure, test report and PA and QA records.

<11> Test organization

a. The TSPE shall describe the overall test responsibilities, participants to be involved and the schedule outline.

NOTE Participation list is often limited to organisation and not individual name.

B.2.2 Special remarks

None.

4.3. Test procedure (TPRO) - DRD

4.3.1 DRD IDENTIFICATION

C.1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-10-03, requirement 4.3.3.4a.

C.1.2 Purpose and objective

The Test Procedure (TPRO) gives directions for conducting a test activity in terms of description, resources, constraints and step-by-step procedure, and provides detailed step-by-step instructions for conducting test activities with the selected test facility and set-up in agreement with the relevant AITP and the test requirements. It contains the activity objective, the applicable documents, the references to the relevant test specification and the test facility configuration, the participants required, the list of configured items under test and tools and the step-by-step activities.

The TPRO is used and filled-in as appropriate during the execution and becomes the "as-run" procedure.

The TPRO is prepared for each test to be conducted at each verification level. The same procedure can be used in case of recurring tests.

It incorporates the requirements of the test specification (DRD Annex B) and uses detailed information contained in other project documentation (e.g. drawings, ICDs).

Several procedures often originate from a single test specification. In certain circumstances involving a test facility (for example during environmental tests) several test procedures can be combined in an overall integrated test procedure.

The "as-run" procedure becomes part of the relevant test report (see ECSS-E-ST-10-02).

Overlaps with the test specification are minimized.

4.3.2 EXPECTED RESPONSE

C.2.1 Scope and contents

<1> Introduction

a. The TPRO shall contain a description of the purpose, objective, content and the reason prompting its preparation.

b. Any open issue, assumption and constraint relevant to this document shall be stated and described.

<2> Applicable and reference documents

a. The TPRO shall list the applicable and reference documents in support to the generation of the document.

<3> Definitions and abbreviations

a. The TPRO shall list the applicable dictionary or glossary and the meaning of specific terms or abbreviations utilized in the document.

<4> Requirements mapping w.r.t. the TSPE

a. The TPRO shall provide a mapping matrix to the TSPE giving traceability towards the test requirement.

<5> Item under test

a. The TPRO shall describe the item under test configuration, including any reference to the relevant test configuration list, and any deviation from the specified standard.

b. The software version of the item under test shall be identified.

<6> Test set-up

a. The TPRO shall describe the test set-up to be used.

<7> GSE and test tools required

a. The TPRO shall identify the GSE and test tools to be used in the test activity including test script(s), test software and database(s) versioning number.

<8> Test instrumentation

a. The TPRO shall identify the test instrumentation, with measurement accuracy, to be used, including fixtures.

<9> Test facility

a. The TPRO shall identify the applicable test facility and any data handling system.

<10> Test conditions

a. The TPRO shall list the applicable standards, the applicable test conditions, in terms of levels, duration and tolerances, and the test data acquisition and reduction.

<11> Documentation

a. The TPRO shall describe how the applicable documentation is used to support the test activity.

<12> Participants

a. The TPRO shall list the allocation of responsibilities and resources.

<13> Test constraints and operations

a. The TPRO shall identify special, safety and hazard conditions, operational constraints, rules for test management relating to changes in procedure, failures, reporting and signing off procedure.

b. The TPRO shall describe QA and PA aspects applicable to the test.

c. The TPRO shall contain a placeholder for identifying:

1. procedure variations, together with justification, and
2. anomalies.

<14> Step-by-step procedure

a. The TPRO shall provide detailed instructions, including expected results, with tolerances, pass/fail criteria, and identification of specific steps to be witnessed by QA personnel.

b. The step-by-step instructions may be organized in specific tables.

c. When the procedure is automated, the listing of the automated procedure shall be documented to a level allowing consistency check with the TPRO and the TPSE.

C.2.2 Special remarks

None.

ESCUELA SUPERIOR DE INGENIERÍA Y TECNOLOGÍA

Final Bachelor Thesis

DESIGN OF THE MECHANICAL STRUCTURE FOR THE TEIDESAT CUBESAT

APPENDIX E: VERIFICATION MATRIX

Studies:

Mechanical Engineering Bachelor

Author:

Laura Feria del Rosario

July 2018

VERIFICATION MATRIX

Nº	Requirement Reference	Requirement Text	Status of Compliance	Verification Method	Stage and level	Comment
		CubeSat Physical Interface				
		Reference frame				
1	**CDS-3.2.1**	The origin of the CubeSat coordinate system is located at the geometric center of the CubeSat.	Compliant	Inspection	Protoflight at subsystem level	
		CubeSat Dimensions				
2	**JX-2.1.2.2**	The dimensional requirements for a CubeSat are defined in the Figure 2.1.2-1.	Non compliant	Test	Protoflight at subsystem level	CNC machine
3	**JX-2.1.4.2**	The **main structure** of a satellite in +Z shall be **recessed** more than 7.0mm from the edge of the rails. All components in +Z shall be recessed more than 0.5mm from the edges of the rails.	Non compliant	Test	Protoflight at subsystem level	CNC machine
4	**JX-2.1.4.3**	The **main structure** of a satellite in -Z shall be **recessed** more than 6.5mm from the edge of the rails. All components in -Z shall be recessed from the edges of the rails.	Non compliant	Test	Protoflight at subsystem level	CNC machine
5	**JX-2.1.4.4**	The main structures of a satellite in +/-X and +/-Y shall not exceed the side surface of the rails. Any components in these surfaces shall not exceed 6.5mm normal to the side surface of the rails including the RBF pin.	Compliant	Test	Protoflight at subsystem level	
6	**CDS-3.2.3.1**	When completing a CubeSat Acceptance Checklist (CAC), protrusions will be measured from the plane of the rails.	Compliant	Review of Design	Protoflight at subsystem level	
7	**JX-4.2.2.1.1**	In order to protect crewmembers from sharp edges and protrusions during all crew operations, they need to be rounded or planed greater than 0.7mm to the utmost. If a satellite has any potential sharp edges which cannot be rounded or planed (ex. An edge of a solar cell), a satellite provider shall identify the sharp edge positions with an acceptance rationale for JAXA approval. Holes (round, slotted) without covers need to be 25 mm or longer, or be 10 mm or shorter in diameter.	Conditionally compliant	Review of Design	Protoflight at subsystem level	Check engineering drawings
		Mass properties				
8	**JX-2.1.5.1**	The mass of a satellite shall be larger than 0.13kg per 1U.	Compliant	Test	Protoflight at subsystem level	Scale
9	**CDS-3.2.10**	The maximum mass of a 1U CubeSat shall be 1.33 kg.	Compliant	Test	Protoflight at subsystem level	Scale
		Center of gravity				
10	**NRCSD-ICD-4.4**	The CubeSat center of gravity shall be within 2cm of its geometric center.	Compliant	Review of Design	Protoflight at subsystem level	CREO
		Material				
11	**CDS-3.2.15**	Aluminum 7075, 6061, 5005, and/or 5052 will be used for both the main CubeSat structure and the rails.	Compliant	Review of Design	Protoflight at subsystem level	
12	**CDS-3.1.8.1**	CubeSats materials shall have a **Total Mass Loss** (TML) < 1.0 %	Compliant	Review of Design	Protoflight at subsystem level	Look for Al 6061 t6 datasheet and make the calculation.
13	**CDS-3.1.8.2**	CubeSat materials shall have a **Collected Volatile Condensable Material** (CVCM) < 0.1%	Compliant	Review of Design	Protoflight at subsystem level	
		Rails				
14	**NRCSD-ICD-4.6.1**	A CubeSat shall have **four (4) rails**, one per corner, along the Z axis.	Compliant	Inspection	Protoflight at subsystem level	
15	**CDS-3.2.5**	Rails shall have a minimum **width** of 8.5mm.	Non compliant	Test	Protoflight at subsystem level	CNC machine
16	**NRCSD-ICD-4.6**	**Rail length variance** in the Z axis between rails shall not exceed ± 0.1 mm.	Compliant	Test	Protoflight at subsystem level	CNC machine
17	**CDS-3.2.6**	Rails will have a **surface roughness** less than 1.6 μm.	Compliant	Test	Protoflight at subsystem level	A roughness measurement instrument is needed.
18	**CDS-3.2.7**	The **edges of the rails** will be rounded to a radius of at least 1 mm	Non compliant	Analysis	Protoflight at subsystem level	Chamfer will be measured and compared with the equivalent chamfer for the radious given.
19	**JX-2.1.3.8**	The rail surfaces which contact with the rail guides of the J-SSOD Satellite Install Case and the rail standoffs which contact with adjacent satellites shall be hard anodized aluminum after machining process. The thickness of the hard anodized coating shall be more than 10μm according to MIL-A-8625, Type3.	Non compliant	Inspection	Protoflight at subsystem level	
20	**CDS-3.2.8**	The ends of the rails on the +/- Z face shall have a **minimum surface area** of 6.5 mm x 6.5 mm **contact** area for neighbouring CubeSat rails.	Compliant	Test	Protoflight at subsystem level	
21	**JX-2.1.8.2**	Each rail shall have a sufficient structural strength with considering that the rail is subject to compression force at 46.6 N due to a preload from the Backplate and main spring of deployer.	Compliant	Analysis	Protoflight at subsystem level	
				Test	Protoflight at subsystem level	
		Natural frequency				
22	**JX-2.1.9**	The minimum fundamental frequency of a satellite shall be no less than 100 [Hz] on the condition that the four rails +/-Z standoffs are rigidly fixed. If the minimum fundamental frequency of the satellite is less than 100 [Hz], coordination with launcher is needed since a random vibration environment subjected to the satellite may exceed the environment.	Compliant	Analysis	Protoflight at subsystem level	
		Environmental Requirements				
		Atmospheric pressure				
23	**CDS-3.1.11**	The CubeSat shall be designed to accommodate ascent venting per ventable volume/area < 50.8 [m]. NOTE Volume refers to satellite internal volume (V [m3]) and the area refers to area of exhaust ports (A [m2]).	Compliant	Analysis	Protoflight at subsystem level	The areas of the holes will be measured.
		Thermal conditions				
24	**NRCSD-ICD-7**	CubeSats shall be designed to withstand overall temperature range of -40C to +65C.	Compliant	Review of Design	Protoflight at subsystem level	Check if Al 6061 t6 can work in this temperature. Datasheet.
		Random vibrations				
25	**SOYUZ-CSG-3.2.5**	Random vibrations at the spacecraft base are generated by propulsion system operation and by the adjacent structure's vibro-acoustic response. Maximum excitation levels are obtained during the first-stage flight. Acceleration power spectral density (PSD) and root mean square vibration levels (GRMS) are given in the table below along each of the three axes. NOTE Spacecraft is not the launch vehicle, but the CubeSat.	Compliant	Analysis	Protoflight at subsystem level	
				Test	Protoflight at subsystem level	Machine test is not available

Frequency [Hz]	PSD [g²/Hz]
20	0.05
50	0.05
100	0.1
200	0.25
500	0.25
1000	0.1
2000	0.05

Nº	Requirement Reference	Requirement Text	Status of Compliance	Verification Method	Stage and level	Comment
		Sinusoidal vibrations				
26	**MRR-2.2.5**	The satellite shall withstand the most demanding combination of limit levels of sine-equivalent vibrations obtained from Vega and Ariane 5 launcher requirements. The limit levels of sine-equivalent vibrations to be taken into account for the design and dimensioning of the spacecraft are the highest values that the launch vehicle can suffer.	Compliant	Analysis	Protoflight at subsystem level	
				Test	Protoflight at subsystem level	Machine test is not available

Frequency band [Hz]	Direction	Sine amplitude [g]
1-25	Longitudinal	1
	Lateral	0.8
25-110	Longitudinal	1
	Lateral	0.6
110-125	Longitudinal	0.2
	Lateral	0.2

Nº	Requirement Reference	Requirement Text	Status of Compliance	Verification Method	Stage and level	Comment
		Quasi-static Loads				
27	**JX-2.4.1.1a**	The satellite shall withstand a quasi-static acceleration in any direction during launch: ATV : 12.37 [g].	Compliant	Analysis	Protoflight at subsystem level	
				Test	Protoflight at subsystem level	
28	**NRCSD-ICD-4.9**	During deployment, the CubeSats shall be compatible with deployment velocities between 0.5 m/s to 1.5 m/s and accelerations no greater than 2g's in the +Z direction.	Compliant	Analysis	Protoflight at subsystem level	
				Test	Protoflight at subsystem level	Check type of test.

VERIFICATION MATRIX

<table>
<tr><th colspan="7">Shocks</th></tr>
<tr><td rowspan="2">29</td><td rowspan="2">VEGA-3.2.7</td><td rowspan="2">The envelope acceleration shock response spectrum (SRS) at the spacecraft base (computed with a Q-factor of 10) is presented in the table below. These levels are applied simultaneously in axial and radial directions. NOTE Spacecraft is not the launch vehicle, but the CubeSat.<table><tr><td>Frequency [Hz]</td><td>100</td><td>1600</td><td>10000</td></tr><tr><td>SRS (Q=10) [g]</td><td>30</td><td>2000</td><td>2000</td></tr></table></td><td>Compliant</td><td>Analysis</td><td>Protoflight at subsystem level</td><td>Proxima Space counsel.</td></tr>
<tr><td></td><td>Test</td><td>Protoflight at subsystem level</td><td></td></tr>
</table>

ESCUELA SUPERIOR DE INGENIERÍA Y TECNOLOGÍA

Final Bachelor Thesis

DESIGN OF THE MECHANICAL STRUCTURE FOR THE TEIDESAT CUBESAT

APPENDIX F: METROLOGY REPORT

Studies:

Mechanical Engineering Bachelor

Author:

Laura Feria del Rosario

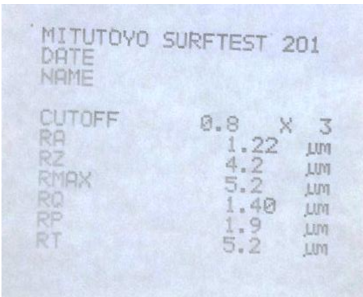
July 2018

In order to check dimensional requirements for the CubeSat TeideSat, manufactured pieces were sent to the metrology laboratory of Instituto de Astrofísica de Canarias.

To check surface roughness of rails, the MITUTOYO roughness tester shown in Figure 66 was used.

Figure 66: Roughness tester

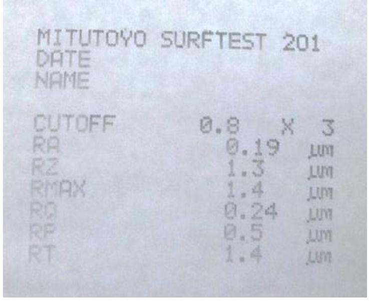
In Figure 67 the highest surface roughness from all rails for the value Ra is shown.


MITUTOYO SURFTEST 201
DATE
NAME

CUTOFF	0.8 X 3	
RA	1.22	µm
RZ	4.2	µm
RMAX	5.2	µm
RQ	1.40	µm
RP	1.9	µm
RT	5.2	µm

Figure 67: Surface roughness result 1

However, in Figure 68 another value for Ra surface roughness is obtained. It belongs to the same rail, but another face. This difference on values is due to different machining. In the first case, a lateral mill was used, whereas in the second face, the same mill but in frontal position was used. This change on the position of the tool may cause big differences on finishing. In any case, both actions achieve a surface roughness good enough to fulfil the requirement. It is possible to determine which faces were machined with the frontal mill because it leaves some grooves.


MITUTOYO SURFTEST 201
DATE
NAME

CUTOFF	0.8 X 3	
RA	0.19	µm
RZ	1.3	µm
RMAX	1.4	µm
RQ	0.24	µm
RP	0.5	µm
RT	1.4	µm

Figure 68: Surface roughness result 2

Specialists used the machine showed in Figure 69.

Figure 69: Metrology equipment

This machine MITUTOYO FJ-805 can measure in 3 spatial directions with an electronic ruby styli. It has 1 micra of repeatability. Measurement works are done over a marble base whose flatness has been calibrated.

Below, extracted data recorded from the different pieces and the assembly integrated are exposed. The name of the parts corresponds to numbering given in the Design section. There are some references to faces of rails that are located in Engineering drawings attached in appendix C.

	Design measurement [mm]	Tolerance [mm]	Real value [mm]
+X face wide	100	0.1	100.179
-X face wide	100	0.1	100.181
+Y face wide	100	0.1	100.084
-Y face wide	100	0.1	100.295
Standoff of deployment switches rails	7.27	-	7.233
Standoff of separation spring rails	6.27	-	6.064
Flatness of deployment switches rails	-	0.2	0.027
Flatness of separation spring rails	-	0.2	0.014
Rails width	8.5	0.050	8.422
Rail 1			
Length	111.5	0.1	111.526
Perpendicularity between faces B and A	-	0.2	0.047
Parallelism between faces C and A	-	0.2	0.047
Perpendicularity between faces B and C	-	0.2	0.012
Parallelism between faces B and D	-	0.2	0.047
Standoff of the rail from bracket in the section drawing	1.27	0.050	1.238
Rail 2			
Length	113.5	0.1	113.542
Perpendicularity between faces B and A	-	0.2	0.038
Parallelism between faces C and A	-	0.2	0.068
Perpendicularity between faces B and C	-	0.2	0.038
Parallelism between faces B and D	-	0.2	0.018
Standoff of the rail from bracket in the section drawing	1.27	0.050	1.283
Rail 3			
Length	111.5	0.1	111.536

Perpendicularity between faces B and A	-	0.2	0.012
Parallelism between faces C and A	-	0.2	0.049
Perpendicularity between faces B and C	-	0.2	0.0412
Parallelism between faces B and D	-	0.2	0.008
Standoff of the rail from bracket in the section drawing	1.27	0.050	1.280
Rail 4			
Length	113.5	0.1	113.542
Perpendicularity between faces B and A	-	0.2	0.018
Parallelism between faces C and A	-	0.2	0.009
Perpendicularity between faces B and C	-	0.2	0.018
Parallelism between faces B and D	-	0.2	0.047
Standoff of the rail from bracket in the section drawing	1.27	0.050	1.276