International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-9, Issue-8; Aug, 2022
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.98.63

Quality Assurance Requirements Tailoring Approach for Small Satellite Projects

João Manoel Zaninotto[1], Jose Eduardo May[1]*, Gledson Hernandes Diniz[1], Mauricio Gonçalves Vieira Ferreira[1]

[1] Instituto Nacional de Pesquisas Espaciais, São Jose dos Campos, SP, Brazil
*Email: jose.may@inpe.br

Received: 28 Jul 2022,

Received in revised form: 22 Aug 2022,

Accepted: 26 Aug 2022,

Available online: 31 Aug 2022

Keywords*— *tailoring, requirements, quality assurance, small satellites.

***Abstract*— *In regulated environments, which have impacts on the society, standards are adopted to determine rules to be followed, since the society expects to receive safe and reliable products and services. Regulatory agencies usually require adherence to requirements established in norms and standards so the product can be approved. In this context, space programs Quality Assurance standards are applicable to satellite projects with a wide responsibility range, from experimental small satellites to manned spaceships. Applying the full contents of these standards may be unfeasible to small missions with low responsibility, considering the cost and schedule constraints inherent to this type of project. Therefore, a customization of the requirements must be conducted in a thoughtful and disciplined manner, considering the project characteristics. The tailoring process presented in this work includes the analysis of the risk to the mission due to the reduction of the set of requirements. Each requirement was evaluated in view of its maintenance, modification, or elimination. This paper presents a process of tailoring mission-specific requirements, using a mission risk rating and the risk analysis tool FMECA. The result was a structured process for tailoring requirements, which provided a subset of Quality Assurance requirements applicable to small satellite projects.*

I. INTRODUCTION

In Regulated Environments (RE), which have impacts on the society, regulatory agencies standards usually require adherence to standards to demonstrate that a product is safe and reliable [1].

Standards published by committees, international technical entities, or regulatory agencies influence product development through risk-based software process and product guidelines. Typically, each domain of knowledge has its own standard, which has to be customized based on knowledge acquisition from domain experts. Despite the existence of several techniques and methods of knowledge acquisition, mostly based on interviews and analysis, there is still the need for methods that provide systematic support for customization of requirements [2, 3].

For space projects, the ECSS (European Cooperation for Space Standardization), a regulatory body for European space companies, including the ESA (European Space Agency), has a series of standards containing requirements used in the development of high responsibility and high-cost satellites. The use of these standards, however, is intrinsically associated with the characteristics of each project, such as type of product, role of the product in the system, size of the system and level of risk. According to ECSS System - Description, implementation, and general requirements [4]

Literature reports that low responsibility satellite projects do not necessary fulfill the whole set of requirements from the standards, due to cost and time constraints. Tailoring these standards may have several drivers, such as dependability and safety aspects, development constraints, product quality and business objectives [5].

The low-responsibility satellites, notably the small satellites, whose denomination in this work applies to those with a mass up to 180 kg, belong to the class of satellites whose share is increasingly representative in the artifacts launched into space accordingly to NASA State-of-the-art Spacecraft Technology Report [6]. Therefore, there is an increasing number of organizations that need to demonstrate adherence with standards-based regulations, and the lack of appropriate processes may have negative consequences such as missing important activities or having limited ways to demonstrate their quality and be recognized in their domain [7].

Since 2013, ESA has released documents related to CubeSats projects, associated with its In-Orbit Demonstration (IOD) program, highlighting:

- Review Objectives for ESA In-Orbit Demonstration (IOD) CubeSat Projects [8];
- Tailored ECSS Engineering Standards for In-Orbit Demonstration CubeSat Projects [9];
- Product and Quality Assurance Requirements for In-Orbit Demonstration CubeSat Project [10].

Although the last document presents tailored requirements for the Product and Quality Assurance disciplines, the tailoring process and the risks associated with the modification are not described.

In 2020, the standard ECSS System Tailoring DRAFT 1 [11] was published, still in a preliminary version, presenting the process for tailoring ECSS standards to CubeSats is, considering economic characteristics and design techniques. According to this document, after identifying the main characteristics, the project must be analyzed to identify cost, schedule, main technical characteristics, as well as critical aspects and specific constraints.

Among these characteristics, the main strategic, organizational, economic or technical characteristics to be considered in a project are:

- Mission objectives (e.g., scientific, commercial, institutional);
- Product type;
- Mission characteristics (e.g., orbit, lifetime, availability);
- Restrictions on the environment in which the project is inserted (e.g., external interfaces, external regulations, purchases);
- Expected cost until final assembly;
- Main impact factors on the schedule;
- Level of commitment (e.g., partnership, supplier) or type of commercial arrangement (e.g., fixed price, reimbursement of expenses);
- Maturity of the project or technology (e.g., recurrent development, level of technical readiness);
- Technical complexity of the product;
- Organizational or contractual complexity;
- Supplier maturity.

This standard also proposes a series of steps for tailoring the ECSS requirements, based on the risks associated with the project. However, the process to be followed is not specified. Additionally, it has on its cover the information that it was published in the preliminary form, so still needs a pilot project to be validated.

Recently, a work on the related topic [12] proposed a method for tailoring Product Assurance requirements for small satellites, in which the requirements were evaluated in blocks, covering the seven disciplines of the Product Assurance area, without addressing the requirements individually.

The present work deals with the tailoring of the Quality Assurance requirements presented by ECSS to small satellite projects, through a process applied to the complete set of requirements of the standard ECSS-Q-ST-20C Rev.2 - Space product assurance - Quality assurance [13]. By applying this process, a minimum subset of requirements to be used in small satellite projects was obtained, meeting the principles of lower cost and shorter schedule, with adequate risk for the mission.

II. STATE-OF-ART

2.1 Quality Assurance Requirements

According to ECSS-S-ST-00C Rev.1 - ECSS System Description, implementation and general requirements [4], the development of a space system is supported by four major branches, represented by knowledge areas: Project Management, Product Assurance, Engineering and Space Sustainability. These areas of knowledge, can be broken down into disciplines. Figure 1 shows the disciplines of the Product Assurance.

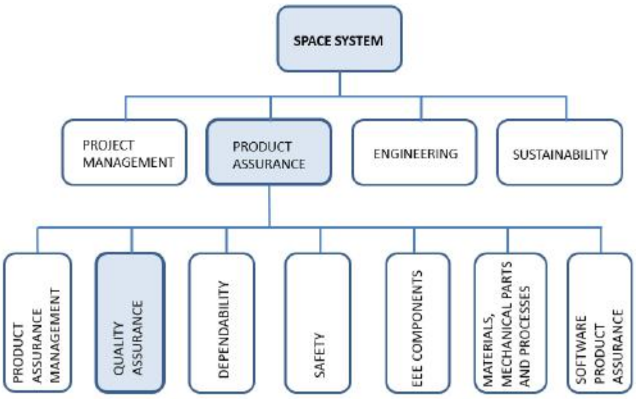


Fig. 1: Development of a Spatial System, with emphasis on the disciplines of the Product Assurance, extracted from [4].

According to ECSS-Q-ST-10C Rev. 1, Space product assurance - Product assurance [14], Product Assurance aims to “ensure that space products meet their defined mission objectives, safely, reliably and with desired availability”.

As shown in Figure 1, the Product Assurance disciplines are:

- Product Assurance Management;
- Quality Assurance;
- Dependability;
- Safety;
- EEE components;
- Materials, Mechanical Parts and Processes; and
- Software Product Assurance.

This work focuses on the analysis of the requirements of the Quality Assurance discipline, presented in ECSS-Q-ST-20C Rev.2 Space product assurance - Quality assurance [13] and the development of a process of tailoring of these requirements aimed at to small satellite missions.

The proposed process was developed from the project classification, given its complexity and cost, considering its exposure to risk related, to the introduced tailoring. The process assesses the risk of not using a requirement, using the FMEA/FMECA tool, shown in ECSS-Q-ST-30-02C - Space product assurance - Failure modes, effects (and criticality) analysis (FMEA/FMECA) [15].

2.1 Mission Risk Classification

In the early 2000´s [16] in a work entitled The Intelligent Application of Quality Management to Smallsat Programs published in the 19th Annual AIAA/USU, Conference on Small Satellites, the authors pointed out that the key to the success of small satellite missions is the risk management and the intelligent use of Quality Management principles. In this work, the authors mentioned that, with the challenge proposed in the 1960´s by President Kennedy to NASA, to safely take and bring astronauts to the Moon, efforts were made to elaborate design, acquisition, production, testing, qualification and acceptance processes so that human errors are minimized, and failures do not occur. This leads to the understanding that the engineering and assurance requirements of the mission were defined by what was most innovative at that time.

Subsequently, these authors reminded that, with the declining world economy in the following years, a new management culture came into action that began to promote faster, better and cheaper space products (known by the acronym FBC). In this way, the quality system was directed into this new policy to meet the increasingly restrictive cost/benefit ratio. As a consequence, the result in the following decades was the occurrence of disasters, including manned missions.

In this same context, the authors warned that what was lacking in the FBC policy was a fourth decision element: “doing it intelligently”. They state that the risks in small-satellite contexts are either technical risks associated with not meeting requirements or programmatic risks associated with not meeting cost and schedule. Continuing this reasoning, the authors propose the use of the FMEA/FMECA tool, for the assessment of risks, mainly associated with materials and the use of COTS components.

The FMEA/FMECA tool, initially proposed by the aerospace industry in the 1960´s, was adopted by the automotive industry in the following decade. Currently, this tool is used in other areas such as medicine, energy generation, among others. In the aerospace area, it is an important tool for risk analysis, mainly used by the Dependability discipline [17].

In 2011, Aerospace published the document Mission Assurance Guidelines for A-D Mission Risk Classes [18], which classifies space missions based on their associated risks. This document proposes that the risk of a mission could be defined based on economic and technical criteria specific to each project and recommends tailoring the requirements for the different engineering areas. The characteristics taken for the risk classification proposed in this Aerospace publication are similar to those proposed by the ECSS in its requirements tailoring document, ECSS System Tailoring DRAFT 1 [11], previously mentioned.

Table 1 shows the characteristics adopted for the mission risk classification, based on the Aerospace publication [19], in which space projects are divided in four classes: A, B, C or D.

Table.1: Mission Risk Class Profiles [19]

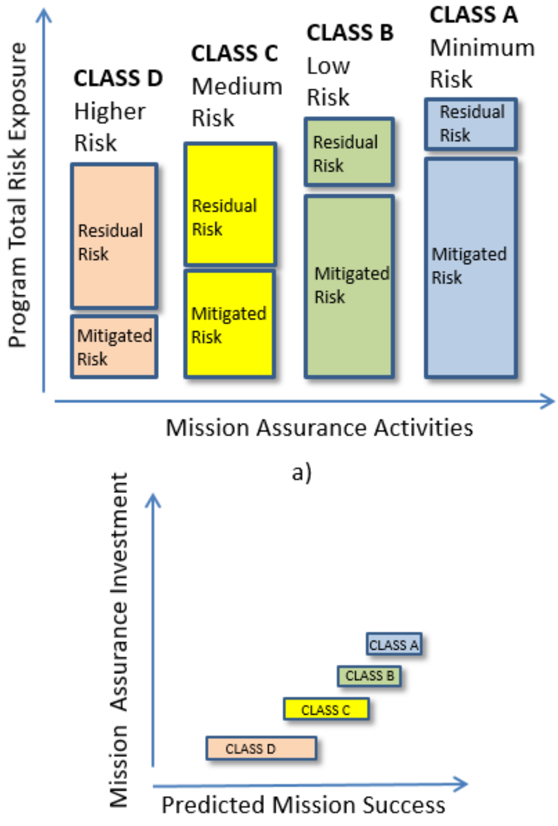
Characteristic	**Class A**	**Class B**	**Class C**	**Class D**
Risk Acceptance	Minimum	Low	Moderate	Higher
Payload type	Operational	Operational or Technology Qualification	Exploratory or Experimental	Experimental
Cost	Highest	High	Medium	Lowest
Complexity	Very high	High	Medium	Low
Mission Life (ML)	ML ≥ 7 years	4 years ≤ ML < 7 years	1 year ≤ ML < 4 years	ML < 1 year
National Significance	Extremely Critical	Critical	Less Critical	Not Critical
Launch Constraints	Very high	High	Medium	Low
Alternatives	None	Few	Some	Signifi-cant
Mission Success	All PA measure	Few comprom	Reduced set of PA	Few PA measures

In this context, the Aerospace Mission Classification Guide [18] provides the definition of Mission Assurance requirements based on risk analysis. This guide is based on the documents Risk Classification for NASA Payloads [19] and DOD HDBK34 3- Military handbook: design, construction, and testing requirements for one-of-a-kind space equipment [20]. The risk profiles presented above are associated with technical and quality issues, which can impact the success of a mission. Evaluation criteria are also proposed resulting in a set of characteristics associated with mission risk, allowing space missions to be categorized into four classes. They are:

- Class A - Extremely critical operating systems, where all practical measures must be taken to ensure mission success, through a minimal risk profile. These are missions with a long-life cycle (typically longer than 7 years), high cost and high investment associated with national interest. This class includes manned missions;
- Class B - Critical operating systems, exploratory and technical demonstrators, in which only minor adjustments are assumed in the application of Mission Assurance standards, to balance cost-effectiveness and ensure mission success. This is achieved through a low risk profile. These are medium lifecycle missions (typically between 4 and 7 years), high cost and with high to moderate complexity;
- Class C - Defined as missions of minor national importance, exploratory or experimental, with a reduced set of Mission Assurance standards applied, resulting in a moderate risk profile. These are short lifecycle missions (typically between 1 and 4 years), with moderate cost and complexity; and
- Class D - These are missions defined as having low national criticality, presenting a higher risk profile. They have a very short life cycle (typically less than 1 year), and a minimal set of Mission Assurance requirements, with low cost and complexity.

The Aerospace Mission Classification Guide [18] schematically illustrates this classification, Figure 2a, showing that, while the amount of Mission Assurance activities increases from Class D to Class A, the Residual Risk to which the project is exposure decreases, and, as a consequence, although a class A mission presents greater risk exposure, its residual risk is lower.

Figure 2b, from the same guide [18], shows that the greater the investment in Mission Assurance, the greater the predictability of the success of the mission, in addition to the lower variability of its success.



a)

b)

Fig. 2: Adaptation of classification showing Residual Risk and Classes A to D, extracted from [18]

In parallel with NASA/Aerospace activities, ESA developed a process to tailor ECSS standards shown in its IOD project mentioned before. This project brings together the ESA efforts in the construction of CubeSats from 2U to 6U, in several countries, in universities and associated research institutes, and proposes, in the sense of standardization, a minimum set of requirements for the construction of small satellites [9].

Particularly the document Review Objectives for ESA In-Orbit Demonstration (IOD) CubeSat Projects [8] provides an assessment of the documents required for their flight equipment and performs a tailoring of the required engineering standards for CubeSats, as well as indicating the requirements, applicable or not, in each of them. In this document, the indication is that CubeSat projects for in-orbit demonstration, in low earth orbit (LEO), are generally characterized by the following attributes:

- Complete autonomous systems, including platform, payload, ground segment and operations;
- Profile of greater risk acceptance;
- Low level of complexity (compared to other ESA space projects);
- Low cost (< 1M Euro) and short development schedule (<2 years for flight readiness);
- Short operational life (typically <1 year in LEO orbit);
- Single-Point of Failure (SPF) acceptance;
- Limited redundancy (whenever possible within the constraints);
- Limited fault tolerance (whenever possible within the constraints);
- Robust security mode (thermal and energy robustness in any attitude);
- Extensive use of off-the-shelf commercial elements (COTS) - modules that have flight heritage and are supplied by small industrial suppliers at a fixed price;
- Extensive testing focused on the system level (functionality and qualification/acceptance environment);
- Simple project organization with well-integrated teams: single entity for systems engineering, AIV (Assembly, Integration and Verification), and operations, few suppliers or sub-contractors.

These are characteristics with greater acceptance of mission risk and low associated cost.

Within the same project, the document Product and Quality Assurance Requirements for In-Orbit Demonstration CubeSat Project [10] brings Quality Assurance and Product Assurance requirements for satellites classified in the IOD project. It addresses the minimum requirements for quality assurance of a CubeSat.

Other documents available for this project are: IOD CubeSat Deliverable Items List [21] and the IOD CubeSat Deliverable Requirements Definition [22].

III. METHODS

For the purpose of classifying a space mission, the criteria used by Aerospace [18] shown in section 2.2 are adopted in this work. Based on these criteria, the small satellites addressed in this work are categorized into Classes C and D, with their associated risk profiles.

The document Aerospace Mission Assurance Guidelines for A-D Mission Risk Classes [18] addresses considerations for each class and discipline in the Product Assurance area. These considerations guided the decision-making on maintaining, modifying, or eliminating a certain requirement during the tailoring process carried out for the Quality Assurance discipline, based on the complete the set of requirements of ECSS-Q-ST-20C Rev.2 Space product assurance - Quality assurance [13]

The process adopted is based upon the use of the FMEA/FMECA tool [15] to evaluate the possible failures resulting from the eventual non-use of each requirement. That is, a failure in this process is defined as “a restrictive event potentially caused by the absence of the requirement”.

These failures were evaluated in terms of their probability of occurrence, the severity of their effects and their probability of detection. The objective of this process was the assessment of each requirement individually, as well as the associated risks and potential effects.

3.1 Process Development

The tailoring process was conducted in two weekly meetings of approximately 2 hours each, over a period of 10 months, with the authors experienced in Product Assurance for space projects in the National Institute for Space Research (INPE). During this period, the specialists interacted in online meetings, exposing their perceptions about each requirement, pointing out the criteria adopted and discussing until common agreement. Further analyses of the requirements were performed to prevent a requirement from being scored differently from another similar requirement.

3.2 Process

Among the possible ways to represent processes, the Integration Definition for Function Modeling (IDEF0) diagram has been chosen, as presented in 1993 by the FEDERAL INFORMATION PROCESSING STANDARDS PUBLICATION – FIPS in the Integration Definition for Function Modeling (IDEFO) [23]. This representation defines the function that the process performs, the inputs that will be transformed into outputs, the controls required to produce a correct output, the mechanism by which the inputs are transformed and, finally, the outputs with the output data of the process.

IV. RESULTS AND DISCUSSION

Figure 5 shows the IDEF0 representation of the proposed process “Tailoring”, showing the input (ECSS Space product assurance - Quality assurance [13] the control Aerospace Mission Assurance Guidelines for A-D Mission Risk Classes [18] and ECSS-S-ST-00-02C ECSS System Tailoring DRAFT 1 [11], the mechanism (ECSS Space product assurance - Failure modes, effects (and criticality) analysis (FMEA/FMECA) [15], and the output (“Quality Assurance Requirements for Small Satellite Projects”).

Figure 5 shows that the input had each of its requirements evaluated individually, according to defined criteria. At the end of this assessment, the requirement received one of three possible qualifications: maintained, modified or removed. Those requirements qualified as maintained or modified become part of the subset called “Quality Assurance Requirements for Small Satellite Projects”, shown in Figure 3 as the process output.

During the evaluation of each requirement, those that maintained similarity with the ones from the ESA document Product and Quality Assurance Requirements for In-Orbit Demonstration CubeSat Project [10], used as a reference, were also analyzed.

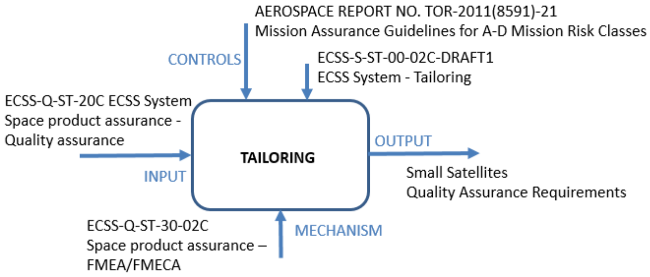


Fig. 3: IDEF0 representation for the tailoring process for quality assurance requirements.

Figure 4 shows the process step-by-step. For each input requirement, its related failure (restrictive event potentially caused by the absence of the requirement) and probable consequences for the project are defined. Thus, the characteristics of this failure are defined, that is, are highlighted the effects produced in four dimensions of the project: safety, product, process and programmatic. Subsequently, possible ways of detecting these effects and a possible preventive or compensatory provision to mitigate them are evaluated.

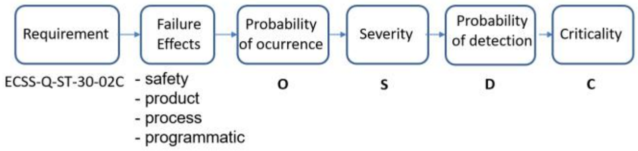


Fig. 4: Obtaining the criticality, or residual risk, associated with the failure.

Table 2 shows an extract of this analysis on each requirement.

Table.2: Extract from the analysis of effects, detection and provision in each assessed requirement.

ECSS Quality Assurance ECSS-Q-ST-20C		**Effects** A – safety B – product C – process D - programmatic	**Detection** (in effect)	**Provision** P – preventive C - compensatory
5.5.9	**Specific requirements for assembly and integration**			
5.5.9.1	**Control of temporary installations and removals**			
a	The supplier shall ensure the control of flight items which are temporarily removed or non-flight items which are temporarily installed to facilitate assembly, integration, testing, handling or preservation of the end item.	A – worker injury B – product damage C – unfeasible activities D – increase in cost and time	A – perception B – inspection and tests C – perception D – schedule and budget analysis	C – activities logbook
b	The control shall be initiated upon installation or removal of the first temporarily installed or removed item and be maintained through delivery and use of the end item.	A - Not Applicable B - Not Applicable C - Not Applicable D - Not Applicable	A - Not Applicable B - Not Applicable C - Not Applicable D - Not Applicable	-
c	The supplier shall establish and maintain records of temporary installations and removals.	A - worker injury B - product damage C - unfeasible activities D - increase in cost and time	A - Not Applicable B - Not Applicable C – perception D - schedule and budget analysis	-
d	Temporarily installed items shall be accounted for to prevent their being incorporated in the final flight configuration. NOTE Temporary installations and removals are also called respectively, red tag items and green tag items.	A - Not Applicable B - Not Applicable C - Not Applicable D - Not Applicable	A - Not Applicable B - Not Applicable C - Not Applicable D - Not Applicable	-

Table.3: Extract of the Quality Assurance requirements assessment matrix.

ECSS Quality Assurance **ECSS-Q-ST-20C**		**(O) Class C**	**(O) Class D**	**(S) Class C**	**(S) Class D**	**(D) Class C**	**(D) Class D**	**(C) Class C**	**(C) Class D**
		Q-ST-30-02C page 36 Table 8.2		Q-ST-30-02C page 36 Table 8.1		Q-ST-30-02C page 36 Table 8.3		critical (O) = 4; (D) = 4; (S) ≥ 3; (C) ≥ 12	
5.5.9	**Specific requirements for assembly and integration**								
5.5.9.1	**Control of temporary installations and removals**								

a	The supplier shall ensure the control of flight items which are temporarily removed or non-flight items which are temporarily installed to facilitate assembly, integration, testing, handling or preservation of the end item.	4	3	4	3	3	3	**48**	**27**
b	The control shall be initiated upon installation or removal of the first temporarily installed or removed item and be maintained through delivery and use of the end item.	1	1	2	2	3	3	**6**	**6**
c	The supplier shall establish and maintain records of temporary installations and removals.	1	1	3	2	3	3	**9**	**6**
d	Temporarily installed items shall be accounted for to prevent their being incorporated in the final flight configuration. NOTE Temporary installations and removals are also called respectively, red tag items and green tag items.	1	1	2	2	3	3	**6**	**6**

Then, the three factors related to the failure are scored, based on the ECSS Space product assurance - Failure modes, effects (and criticality) analysis (FMEA/FMECA) [15]. Initially, the probability of occurrence (O) of the failure in the project is evaluated, that is, in the perception of the specialists on what is the probability of that failure to occur. Then, the severity (S) of the possible consequences of the failure occurrence is analyzed and, finally, its probability of detection (D). These 3 factors are analyzed based on the description of the criteria in ECSS standard (ECSS-Q-ST-30-02C [15] Tables 8.1, 8.2 and 8.3.

The parameter probability of Occurrence (O) of the failure can be graded from 1 (very unlikely), 2 (unlikely), 3 (likely) or 4 (very likely).

The parameter Severity (S) of the failure is associated with the effects of the possible failure in four dimensions: safety, product, process and programmatic. In this case, the standard ECSS-Q-ST-30-02C [15] recommends the adoption of four values, from 1 to 4, being 1 for minor losses and 4 for damages of greater impact.

The parameter Detectability (D) of the failure is associated with the probability that the effects of the failure will be detected, and considers four values, from 1 to 4, being 1 (very likely), 2 (likely), 3 (unlikely) and 4 (very unlikely).

With these three parameters (O, S and D) in hand, the value of the Criticality (C) of the failure, also known as Residual Risk (RR) is defined as their product, that is: C = O x S x D

Finally, the ECSS-Q-ST-30-02C [15] provides the steps to identify the critical processes (requirements), that for this study means “a requirement that cannot be eliminated”. In other words, the “C” metric will be used to identify requirements that must be maintained (or eventually modified), in opposition to those that can be eliminated.

Thus, a requirement will be considered critical if the score associated with its potential failure is:

- Occurrence A = 4, or
- Severity S ≥ 3, or
- Detectability D = 4, or
- Criticality (Residual Risk) C ≥ 12

The applied process is shown in Table 3, which shows a clipping of the ECSS requirements assessment matrix, for the Quality Assurance discipline [13], object of this study.

In this matrix, the requirements of the ECSS standard [13] are allocated on the left, that in this example are the requirements belonging to section 5.5.9.1 – Control of Temporary Installation. In this section four requirement are allocated, respectively 5.5.9.1a to 5.5.9.1d, which were evaluated with the proposed process.

The effects of the failure in the safety, product, process and programmatic dimensions; the means of detecting these effects; and eventual preventive or compensatory provisions to minimize them; were evaluated. These evaluations served as a benchmark for the analysis of the parameters of Probability of Occurrence (O), Severity (S), Detectability (D) and Criticality (C). Table 2 shows pairs of columns associated with these parameters, respectively for satellites classes C and D [18].

Taking the requirements of family 5.5.9.1 as example, it can be seen in Table 2 that the parameter (O) for requirement 5.5.9.1a was considered to have a high probability of occurrence for class C satellites, grade 4 (very likely), while for Class D it received grade 3 (probable). The failures referring to the other requirements of this same family, 5.5.9.1b to 5.5.9.1d, received grade 1, with a very low probability of occurrence for both classes of satellites. The Severity parameter (S) received grades 4 and 3 for classes C and D, while the Detectability parameter (D) received 3 for both classes. With these three parameters (O, S and D) for requirement 5.5.9.1a, the Criticality (C) value of the potential failure was obtained as 48 for Class C and 27 for Class D.

According to the criteria for inclusion or exclusion of requirements described above, the potential failure regarding requirement 5.5.9.1a was considered critical, therefore the requirement must be maintained for both classes of satellites. However, requirements 5.5.9.1b and 5.5.9.1d did not have their potential failures considered critical, and therefore were excluded from the set of requirements for both classes. Moreover, the potential failure referring to requirement 5.5.9.1c received a grade 3 in severity for class C (critical) and 2 for class D (non-critical), and thus the requirement was maintained for class C and eliminated for the class D.

Following this analysis process, all 193 requirements present in the standard ECSS Space product assurance - Quality assurance [13] were evaluated, and the resulted requirements (maintained or modified) are shown in Table 4.

Table.4: Results from the tailoring process.

Document		**Requirements**	
		Qty	**%**
ESA - ECSS standard	*ECSS-Q-ST-20C* [8]	193	100
ESA - IOD project	PA and QA for IOD CubeSat [5]	125	65
This work	Tailored *ECSS-Q-ST-20C for Class C*	145	75
	Tailored *ECSS-Q-ST-20C for Class D*	102	53

It is observed that the proposed tailoring process resulted in a reduction in the amount of requirements to be used in projects with low responsibility. This reduction was on the order of 50% of the requirements originally present in the ECSS-Q-ST-20C [13] In comparison to the number of requirements presented in the document Product and Quality Assurance Requirements for In-Orbit Demonstration CubeSat Project [10] it is observed that there is also a reduction of the same order of magnitude in the amount of requirements. In spite of the arrangement requirements in IOD Project does not follow the same text and arrangement as provided for in the ECSS-Q-ST-20C [13], a direct comparison between their results is possible but limited, Figure 5.

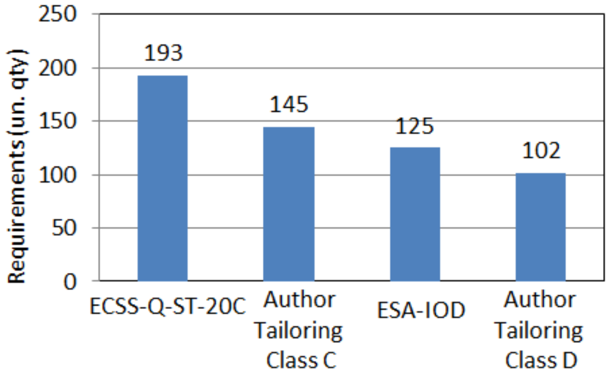


Fig. 5: Comparison between author results, OID Project and ECSS-Q-ST-20C requirements.

However, even though the method used is based on risk analysis and counting on experts with experience in Product Assurance in INPE satellites, notably in the CBERS and AMAZONIA1 satellites, the results still lack validation in a small satellite project.

The complete results of the application of this methodology are available in the Appendix A to this work and an extract can be seen in Table 5.

Table.4: Extract of the final result.

ECSS-Q-ST-20C Rev.		**Class C**	**Class D**
5.1	QA managment requirements		
5.1.1	Quality assurance plan		
	a	x	x
	b	x	x
5.1.2	Personal training and certification		
	a	x	x
	b	x	x
	c	x	x
	d		
5.2	QA general requirements		
5.2.1	Critical items control		
	a	x	x
5.2.2	Nonconformance control system		
	a	x	x
5.2.3	Managements of alerts		
	a	x	x
5.2.4	Acceptance authority media		
	a	x	x
	b	x	x
	c	x	
	d	x	
	e	x	
	f	x	
5.2.5	Traceability		
	a	x	x
	b	x	x
	c	x	
	d	x	
	e	x	

V. CONCLUSION

In the proposed process, the Quality Assurance requirements presented in the standard ECSS-Q-ST-20C [13] could be individually evaluated by specialists from the perspective of a risk analysis based on the FMECA tool. In this process, the potential failures associated with the requirements received grades that, when combined, became reference for choosing the requirements to be maintained, modified or eliminated for use in projects of low responsibility satellites. This process and its resulting set of requirements must be validated in a satellite project that meets these characteristics.

ACKNOWLEDGEMENTS

The author thanks INPE to provide the structure to carry out the analysis from this work.

REFERENCES

[1] Munch, J., Armbrunt, O., Kowalczyk, M., & Soto, M. (2012) - Software Process Definition and Management. DOI: 10.1007/978-3-642-24291-5

[2] Diniz, G. H.; Ambrosio, A. M., Lahoz, C. H. N. (2019) - Critical Software Processes Tailoring and Very Small Entities (VSE): A Literature Review. DOI: 10.22161/ijaers.611.43

[3] Eito-Brun, R.; Amescua-Seco, A. (2020) - Developments in Aerospace Software Engineering practices for VSEs: An overview of the process requirements and practices of integrated Maturity models and Standards. DOI: 10.1016/j.asr.2021.05.026

[4] ECSS-S-ST-00C-Rev.1 (2020) ECSS System - Description, implementation and general requirements

[5] O'Connor, R., & Coleman, G. (2009). Ignoring 'Best Practice': Why Irish Software SMEs are rejecting CMMI and ISO 9000. DOI: 10.3127/ajis.v16i1.557

[6] NASA (2021) TP 20210021263 State-of-the-art - Spacecraft Technology Report

[7] Rodríguez-Dapena, P., & Lohier, P. (2017). How small organizations could participate in Space projects. DOI: 10.1109/MetroAeroSpace.2017.7999557Aerospace (2011) Report No. TOR-2011(8591)-21 Mission Assurance Guidelines for A-D Mission Risk Classes

[8] TEC-SY.78.2016.REV.RW (2016) Review Objectives for ESA In-Orbit Demonstration (IOD) CubeSat Projects

[9] TEC-SY.128.2013.SPD.RW (2013) Tailored ECSS Engineering Standards for In-Orbit Demonstration CubeSat Projects

[10] TEC-SY.129.2013.SPD.RW (2013) Product and Quality Assurance Requirements for In-Orbit Demonstration CubeSat Project

[11] ECSS-S-ST-00-02C DRAFT1 (2020) ECSS System - Tailoring

[12] Albuquerque, I. S.; Brito, A.C.; Perondi, L.F.; Ferreira MGV (2021) Selection and Customization of Product Assurance Requirements applied to Small Satellites. DOI: 10.22161/ijaers.85.8

[13] ECSS-Q-ST-20C-Rev.2 (2020) ECSS System - Space product assurance - Quality assurance

[14] ECSS-Q-ST-10C-Rev.1 (2016) Space product assurance - Product assurance management

[15] ECSS-Q-ST-30-02C (2009) Space product assurance - Failure modes, effects (and criticality) analysis (FMEAFMECA)

[16] Cox, B; Aktik, M. (2005) The Intelligent Application of Quality Management to Smallsat Programs. SSC05-11-6. 19Th Annual AIAA/USU Conference on Small Satellites. Cal Poly (2020) CubeSat Design Specification (1U-12U) Rev.14 DRAFT

[17] ECSS-Q-ST-30C-Rev.1 (2017) Space product assurance - Dependability

[18] AEROSPACE REPORT [2011]

[19] NASA (2004) NPR 8705.4 Risk Classification for NASA Payloads

[20] DOD-HDBK-343 (2017) Military handbook design, construction, and testing requirements for one-of-a-kind space equipment

[21] TEC-SY.126.2013.LST.RW (2013) IOD CubeSat Deliverable Items List

[22] TEC-SY.127.2013.DR.DRW (2013) IOD CubeSat Deliverable Requirements Definition.

[23] FIPS 183 (1993) Federal Information Processing Standards Publication - FIPS. Integration Definition for Function Modeling (IDEFO).

Appendix A

Requirements from ECSS Quality Assurance (ECSS-Q-ST-20C [2020])			
5.1	QA management	Class C	Class D
5.1.1	Quality assurance plan		
	a	x	x
	b	x	x
5.1.2	Personnel training and		
	a	x	x
	b	x	x
	c	x	x
	d		
5.2	QA general requirements		
5.2.1	Critical-items control		
	a	x	x
5.2.2	Nonconformance control		
	a	x	x
5.2.3	Management of alerts		
	a	x	x
5.2.4	Acceptance authority media		
	a	x	x
	b	x	x
	c	x	
	d	x	
	e	x	
	f	x	
5.2.5	Traceability		
	a	x	x
	b	x	x
	c	x	
	d	x	
	e	x	
5.2.6	Metrology and Calibration		
	a	x	x
	b	x	x
	c	x	
	d	x	
	e	x	
	f	x	x
	g	x	
	h	x	
	i	x	
	j	x	
	k	x	
	l	x	
	m	x	x
	n	x	x
	o	x	
	p	x	
	q	x	
5.2.7	5.2.7 Handling, storage,		
5.2.7.	Handling, storage and		
	a	x	x
5.2.7.	Storage (deleted)		
5.2.7.	Preservation		
	a	x	x
5.2.8	Statistical quality control and		
5.2.8.	General		
	a		
	b		
	c		
	d		
	e		
	f		
5.2.8.	Sampling plans		
	a		
	b		
5.3	QA requirements for design		
5.3.1	Design rules		
5.3.1.	Producibility		
	a	x	x
5.3.1.	Repeatability		
	a	x	x
5.3.1.	Inspectability and testability		
	a	x	x
5.3.1.	Operability		
	a	x	x
5.3.2	Verification		
5.3.2.			
	a	x	
	b	x	
	c	x	
	d	x	
	e	x	
5.3.2.	Design verification analysis		
	a	x	x
	b	x	x
5.3.2.	Design reviews		
	a	x	x
5.3.2.	Qualification process		
5.3.2.	Qualification		
	a	x	x
	b	x	
	c	x	
	d		
	e	x	
5.3.2.	Qualification by similarity		
	a	x	x
	b	x	
	c	x	
	d	x	
5.3.2.	Qualification testing		
	a	x	

	b	x	x
5.3.2.	Qualification status		
	a		
5.3.2.	Maintenance of qualification		
	a	x	
	b	x	x
	c	x	x
5.3.2.	Design changes		
	a	x	x
5.4	QA requirements for		
5.4.1	Selection of procurement		
5.4.1.	General		
	a	x	
5.4.1.	Selection criteria		
	a	x	x
	b	x	x
5.4.1.	Record and list of		
	a	x	x
	b	x	x
5.4.2	Procurement documents		
	a	x	x
	b	x	x
	c	x	x
	d		
5.4.3	Surveillance of procurement		
	a	x	x
	b	x	x
	c	x	x
	d	x	x
	e	x	x
5.4.4	Receiving inspection		
5.4.4.	General		
	a	x	x
	b	x	x
	c	x	x
5.4.4.	Receiving inspection		
	a	x	x
5.4.4.	Customer furnished items		
	a	x	x
5.4.4.	Receiving inspection records		
	a	x	x
5.5	QA requirements for		
5.5.1	Planning of manufacturing,		
	a	x	x
	b		
	c		
	d	x	x
	e	x	x
	f		
	g		
5.5.2	Manufacturing readiness		
	a	x	x
	b	x	x
5.5.3	Control of processes		
5.5.3.	General		
	a		
	b	x	x
	c	x	x
	d	x	x
5.5.3.	Special processes		
	a	x	x
5.5.3.	Statistical process control		
	a		
5.5.4	Workmanship standards		
	a	x	x
	b	x	
	c	x	
5.5.5			
	a	x	x
	b	x	x
	c	x	
5.5.6	Equipment control		
5.5.6.	Tooling		
	a		
	b	x	x
	c		
	d		
	e		
	f		
	g		
	h	x	x
	i		
5.5.6.	Equipment for computer-		
	a	x	x
	b	x	
5.5.7	Cleanliness and		
5.5.7.	General		
	a	x	x
5.5.7.	Cleanliness levels		
	a	x	x
	b	x	x
5.5.7.	Cleaning materials and		
	a	x	x
5.5.7.	Contamination control		
	a	x	
	b	x	
	c	x	x
5.5.7.	Cleanliness of facilities		
	a	x	x
5.5.8	Inspection		
	a	x	x
	b	x	x
	c	x	x
	d	x	x
	e	x	x
	f	x	x
	g		
	h		
	i	x	
	j		
	k		
5.5.9	Specific requirements for assembly and integration		
5.5.9.	Control of temporary installations and removals		
	a	x	x
	b		
	c	x	
	d		
5.5.9.	Logbooks		
	a	x	x
	b		
	c		

	d		
	e		
5.5.1	Manufacturing, assembly		
	a	x	x
5.5.1	Electrostatic discharge		
	a		
	b	x	x
5.6	QA requirements for testing		
5.6.1	Test facilities		
	a		
5.6.2	Test equipment		
	a	x	
	b		
	c	x	x
5.6.3	Test documentation		
5.6.3.	Test procedures		
	a	x	x
	b		
5.6.3.	Test reports		
	a		
	b		
5.6.4	Test performance monitoring		
	a		
	b		
	c		
	d	x	x
	e		
	f	x	x
	g	x	x
	h		
5.6.5	Test reviews		
	a	x	x
	b		
5.7	QA requirements for		
5.7.1	Acceptance and delivery		
	a	x	x
	b		
5.7.2	End item data package		
	a	x	x
	b	x	x
	c	x	
5.7.3	Acceptance review board		
	a	x	x
	b	x	x
	c	x	x
	d	x	x
	e	x	x
	f	x	x
	g	x	x
5.7.4	Preparation for delivery		
5.7.4.	Packaging		
	a	x	x
5.7.4.	Marking and labelling		
	a	x	x
5.7.5	Delivery		
5.7.5.	Shipping control		
	a	x	x
	b	x	x
5.7.5.	Transportation		
	a	x	x