International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-9, Issue-10; Oct, 2022
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.910.31

Study of Practices and Criteria Used in the Military Aviation Certification to Improve the Satellite Product Assurance

Cristiane M. Z. Silva[1], Guilherme M. B. Moreira[2], Marcelo L. O. Souza[3]

[1]MTI- Coordination of Project Management and Technological Innovation, INPE - National Institute for Space Research, Brazil
[2]PPGAO - Graduate Program in Operational Applications, ITA - Aeronautics Institute of Technology, Brazil
[3]ETE - Graduate Program in Space Engineering and Technology, INPE - National Institute for Space Research, Brazil

Received: 21 Sep 2022,

Received in revised form: 13 Oct 2022,

Accepted: 19 Oct 2022,

Available online: 25 Oct 2022

***Keywords*— military aviation, certification, satellite, product assurance.**

***Abstract*— The aerospace industry is experiencing the problem of producing higher quality products under faster changes in technologies and complexities. This worsens ensuring product functionality and supporting product assurance. This is especially true in the space industry. One punctual solution is to study and adapt practices and criteria used in the military aviation industry to improve the satellite industry, as done here. So, this paper studies practices and criteria used in the military aviation certification to improve the satellite product assurance. Their comparison allows the proposal of a new model for a satellite product assurance process, especially at INPE. To contextualize the subject, a brief history of product certification in Brazilian military aviation is presented with its current principles and relevance. In addition, essential concepts and international standards adopted by several organizations are mentioned. Some differences between aeronautical and space products and their features are also highlighted. In the end, a harmonization of MoCs (Means of Compliance) strategy is suggested to align the understanding between suppliers and satellite program organizations. Some of the practices discussed in this paper may aid the requirements compliance control for the space field, which can boost some projects with limited funds, stringent deadlines, and high costs.*

I. INTRODUCTION

The Problem: The aerospace industry, as other major industries, is experiencing the problem of producing higher quality products under 1) faster advances in the technologies and 2) higher increases in the complexities of their products and relative items (systems, subsystems, equipment, components, etc.) [12]. This is worsened by 3) a growing concern about the implementation of the stakeholders' requirements on the product. Furthermore, 4) aerospace projects are costly and 5) require stringent deadlines for development. Such projects commonly lead to 6) new research for specific developments, 7) qualification of such items, and 8) search for new materials, usually using 9) state-of-the-art resources. On the other hand, even with high market demand, 10) the capacity of production of this industry is usually quite limited [12]. Therefore, governments often need to create or promote aerospace projects from their industries to encourage them to remain on business [16].

Due to reasons 1-10, the evaluation and control processes to 11) ensure product functionality and 12) support product assurance, are progressively difficulted. This is especially true in the space industry, leading to.

The Solution: To reach goals 11-12, such processes must consider 13) all the phases that begin in the mission analysis/needs identification and finalize with the product disposal; and 14) a collection of standards, guidelines, and other documents rich in content and good practices, especially in the more seasoned and mature branches, like the aeronautics industry, to improve other less seasoned and mature branches, like the space industry, as punctually done here.

For instance, in the aeronautics industry, adopting a robust process is imperative to ensure requirements compliance and monitor the product life cycle. The **certification process, especially for civil and military aviation,** keeps in its kernel the concern with the compliance of the established requirements.

Therefore, in the space industry, we should consider adopting certain certification practices to improve the evaluation and control processes to 11) ensure product functionality and 12) support product assurance. This is especially true in Brazilian organizations responsible for developing small and medium-sized satellites, as the National Institute for Space Research (*Instituto Nacional de Pesquisas Espaciais* - INPE) [11].

So, this paper studies practices and criteria used in the military aviation certification to improve the satellite product assurance. To do that, it presents the sections: ii-scenario definition; iii-some similarities and differences between satellite products and military aviation products; iv-some regulations of space quality assurance and international aeronautical certification; v-model proposal; vi-conclusion. Other paper will study the civil equivalent.

Some Previous Works: See parts of 1-19, as commented below.

The Contributions: in short: it identifies precautions used internationally in military aircraft certification and it adapts them in proposals to standardize and strengthen the satellite product/quality assurance process. In this paper, satellite product/quality assurance is considered part of a large organization, responsible for: a space program, a final product design, some systems and subsystems, or a final set integration. But the satellite product/quality assurance characterized here is not the internal set of activities of equipment and subsystems suppliers.

II. SCENARIO DEFINITION

First of all, it is crucial to show the scenario considered by the authors in this work. To do that, this section begins with the Brazilian scenario of small and medium-sized satellites. Then it shows the relevance of Space Product Assurance and Space Quality Assurance. Afterwards, it gives a brief history of the Brazilian Aviation Certification. In time, it clarifies some differences between Military Aviation Certification and Civil Aviation Certification. Finally, it presents some principles of the Military Aviation Certification, according to [16] and [17].

1- Brazilian Scenario for Small and Medium Satellites

INPE is a scientific and technological institution whose purpose is to lead scientific research, technological development, operational space activities, and human resource qualification in the space science, engineering, and technology areas, mainly small and medium satellites [11].

INPE attributions are to perform research & development projects and lead scientific-technical cooperation activities with national and foreign entities. In addition, the Institute qualifies the Brazilian industries to provide technologies for space activities and related areas [11].

Quality Assurance (QA), a branch of Product Assurance (PA), is one of the activities performed by INPE's space engineering and technology area. This area is responsible for monitoring the following tasks: the Reliability and Safety of software/hardware, parts and materials; Quality Assurance activities and processes; and Configuration Management. It is applied to space projects and programs. Additionally, QA establishes the procedures and technical standards for process control. All those information is available in Ordinance No. 897, December 2008, INPE Internal Rules [1].

In this scenario, it is important to introduce the Brazilian Space Agency (*Agência Espacial Brasileira* - AEB), which is the central organization of the National System for the Development of Space Activities (*Sistema Nacional de Atividades Espaciais* - SINDAE). It aims to promote peaceful access to space, its benefits, and ensure the safety of Brazilian space activities. Furthermore, AEB regulates Brazilian space activities. In summary, the Agency works closely with INPE in the Brazilian space projects at higher/strategic levels, as CBERS 1-4 satellites.

2- Relevance of Space Product Assurance and Space Quality Assurance

According to the European Cooperation for Space Standardization (ECSS) standard ECSS-Q-ST-20C [4], "**Quality Assurance is** a branch of Product Assurance, and the prime objective of the **Product Assurance is** to ensure that space products accomplish their defined mission objectives in a safe, available, and reliable way".

The ECSS-Q-ST-20C [4] defines **Quality Assurance (QA)** as the minimum requirements for establishing and implementing a Quality Assurance program for products of space projects, respecting the project life cycle and their phases.

According to ECSS-S-ST-00-01C [7] **Product Assurance** is a discipline devoted to the study, planning and implementation of activities intended to assure that the design, controls, methods and techniques in a project result in a satisfactory degree of quality in a product.

Furthermore, a commitment to quality by the entire organization is a key point to the success of a space mission. The management of Product Assurance (PA) must be fully embedded in the Project Management (PM) and receive the highest priority from the organization management.

The early identification of aspects potentially detrimental to the mission safety and mission success, and the cost effective prevention of any adverse consequence of such aspects are the basic principles for the ECSS PA requirements.

The focus of **Product Assurance Planning is**: the definition of a PA organization with the allocation of adequate resources, personnel and facilities; definition of PA requirements for lower-tier suppliers; and finally, the definition of a PA plan describing the PA program and how it fulfills project objectives and requirements [6].

To implement these activities is vital to control the following items: management and control of the PA tasks performed by the PA disciplines; progress reporting of all PA matters; management of audits, critical items, non-conformities, and alerts; support to the risk management, in coordination with the PM functions; support to the documentation and data control, quality records and configuration management; and lower tier supplier control for ensuring implementation of PA requirements by such suppliers [15].

3- A Brief History of the Brazilian Aviation Certification

For the purpose of this work, we must clarify the meaning of the term "certification". Although there are many definitions, the Brazilian (ex. Civil and still) Military Aviation Authority, named Institute for Industrial Fostering and Coordination (*Instituto de Fomento e Coordenação Industrial* - IFI) considers **Certification as** "the verification of a preset requirements compliance" [5]. According to [15] certification is the act of verifying the compliance of a set of requirements, established by a competent authority, for a specific product, after an adequate technical verification process of its design.

The first important initiative regarding this activity was the EMBRAER EMB-110 Bandeirante certification process, which was conducted to comply, in 1972, with the Title 14 (Aeronautics and Space) of the Code of Federal Regulations (CFR) Part 23 [8] requirements of the American Federal Aviation Authority, named Federal Aviation Administration (FAA) [10].

IFI initiated some negotiations with FAA in 1974 for an aviation certification bilateral agreement. The C-95 Bandeirante received its FAA Certificate in 1978. Due to this hard work, it was also possible to certificate it with French and British Authorities in 1977. The certification of the following aircraft generation, the EMB-120 Brasília, was conducted jointly by IFI and FAA, culminating with the Type Certificate publication by both countries in 1985.

After this, IFI was pushed to elaborate its own set of requirements, known as the Brazilian Regulation of Civil Aviation (Regulamento Brasileiro da Aviação Civil-RBAC), still in use by ANAC. To harmonize somehow American and Brazilian regulations, RBACs are numbered in almost the same way as the 14 CFR Code.

In September 27th, 2005 the Brazilian Federal Law 11.182 created the Brazilian Civil Aviation Agency – ANAC (*Agência Nacional de Aviação Civil*). Initially the agency was made by several Brazilian Air Force organizations (including their military personnel) that, together, regulated and supervised civil aviation activity in Brazil at the time [1]. One of such organizations was IFI's Division of Civil Aviation Certification.

After the Civil Aviation Division transfer to ANAC, the Brazilian Air Force (Força Aérea Brasileira-FAB) published the necessary regulation for the military aviation certification process [15] which has many peculiarities. The most important ones are the Policy DCA 800-2 (Quality and Safety Assurance of Systems and Products) [2] and the Instruction ICA 57-21 (Military Airworthiness Regulations) [3].

During the last three decades, some remarkable projects helped IFI to accumulate a tremendous experience in the certification of complex systems such as the medium ground attack jet A-1, the trainer and light attack turboprops AT-27 Tucano and A-29 Super-Tucano, the civil domestic flight jets EMB-145 and EMB-170, the SRAAM (Short Range Air-to-Air Missile) Piranha, the SRAAM A-Darter and several other military air defense systems [15].

Today, both IFI and ANAC have their own set of Aviation Regulations to conduct their certification process.

4- Some Differences between Civil and Military Aviation Certifications

Civil aviation authorities worldwide consider **certification as** evaluating and attesting that a product (aircraft or its components) has the minimum characteristics to assure its safe operations [10]. However, the military authorities need to go further [8] and [9].

The civil authorities are typically considered a third party since the manufacturers are the first and operators are the second ones. However, this works differently for some military authorities since they are on the “same side” of the project operators. For instance, although Denel Dynamics have developed the SRAAM A-Darter missile, its certification has been held by IFI and will be used by Brazilian Air Force Aviation Groups. Nevertheless, IFI is also a military organization, and so, in the end, the certification authority and the end user belong to the same Air Force [15]

IFI is commonly asked to evaluate performance requirements, which are typically found on the DoD MIL-STDs (American Department of Defense Military Standards), DoD MIL-HDBKs (American Department of Defense Handbooks), STANAG (NATO Standardization Agreement), DEF STANs (United Kingdom Defense Standards), and specific contract documents for each program. This portion of the military certification process is quite similar to the space products verification process. Although all space devices must comply with some safety requirements for operation, those are less critical. The most important part of a satellite quality assurance program, for example, must be the evaluation of the compliance of its specifications, since once into operation, it is practically impossible to perform project modifications or repairs [15].

5- Some Principles of Military Aviation Certification

The military aviation certification follows a consistent process, which has been improved throughout the years. As the defense systems are much more at the leading edge of technology than civil aviation systems, the military certification authorities are pushed to enhance their knowledge on many defiant subjects. However, establishing a certain level of partnership between applicants and certification organisms is crucial for project achievement when any technology is not well known by the authority. Therefore, there are many remarkable planned meetings according to Order 8110.4C [13] before the official application. Although Order 8110.4C [13] is an American internal procedures document, the Brazilian Military Aviation Authority uses it as a reference.

Sometimes the applicants also need some orientation regarding the certification process. Such a process is commonly seen as an obstacle to project development. On the contrary, the certification process can often predict many errors or possible weaknesses for the project feasibility, in addition to assuring an adequate level of safety and reliability.

Many **Familiarization Briefings** are needed to acquaint the certification team with the project, mainly regarding the technical issues and unique or novel features, which may need particular emphasis. After this, the developer should put effort into the application for the certification process, meaning to elaborate the **Certification Plan**.

The certification process applicant often does not fully know some vital information that must be integrated into the Certification Plan while establishing the proper requirements. Therefore, the authority may accept the application for the certification process with an incomplete Certification Plan, which must be completed before entering the implementation phase.

The Certification Plan is the most important document for the certification process. It must contain or address all the necessary documentation that will be used to show the compliance of the project with the established requirements. It consists (at least) of:

(a) general information about the applicant;

(b) a description of the proposed design;

(c) the intended regulatory operating environment;

(d) the proposed certification basis;

(e) a description of how compliance will be shown (ground test, flight test, analysis, similarity, simulation, etc.);

(f) a list of documentation that will be submitted to show compliance with the certification basis;

(g) a list of test articles to be used to generate compliance data;

(h) a description of how the continued operational requirements will be met after the end of the certification process; and

(i) project schedule including significant milestones and expected final certification date.

Of all the Certification Plan contents, the most relevant section is the **Certification Basis**. It is proposed by the applicant and accepted by the certification authority. It provides a common understanding of the project's features to assure safety and mission accomplishment. Typically, it is made by the product technical specifications, standards, regulations, and additional technical requirements that may be necessary.

After concluding the Certification Plan implementation, with the whole process and its documentation approved, the Certification Authority will provide a **Type Certificate (TC)** that will characterize the project as unique. The type is considered a fingerprint. Small changes to the project may be done by the TC holders, since they inform the Certification Authority. Any future significant modifications to the project shall demand a similar process known as an Amendment to the TC, if the applicant is the

TC holder. If the modification's applicant is not the TC holder, we call it Supplemental Type Certification. Furthermore, if the applicant proposes substantial changes to a certified project, it will require an entirely new Type Certification process.

III. SOME SIMILARITIES AND DIFFERENCES BETWEEN SATELLITE PRODUCTS AND MILITARY AVIATION PRODUCTS

Based on [16], space and aeronautical products have peculiar acceptance criteria compared to most other industry sectors. Both products must be submitted to rigorous campaigns of development and testing, as they operate in hostile environmental conditions. Thus, the acceptance criteria for such products are very restrictive. But space products operate in an environment even more restrictive than aeronautical products, as follows.

Space products operate in an environment with differentiated hostilities. In addition to the enormously strong aerodynamic loads they are subject to during launch and re-entry operations, they may operate for long periods into outer space with less protection from cosmic rays and other kinds of radiation. The space products' temperature variation is higher in comparison to aircraft. Space hardware can rarely be repaired after the beginning of its operation. Also, the technologies used in space products are often novel, demanding new experiments featuring a certain level of technical and scientific challenge, based on [16].

Aeronautical products have specificities related to the aerodynamic loads developed in the aircraft movement into the atmospheric fluid. There is a considerable lack of protection against cosmic rays due to aircraft operations in high altitudes and significant temperature variations, ranging from approximately -50 ° C to 50 ° C. In addition, safety requirements have profound importance for aircraft operations because they usually carry human lives and fly over populated areas, often at low altitudes when taking off and landing, based on [16].

For military aviation products, important pillars are mission accomplishment and safety concerns. The mission accomplishment aims to ensure that the product will operate as expected at the requested time, within certain safety boundaries. **Military** missions often need new technologies and features not employed in **civil** aviation, based on [16].

After these explanations, it is possible to draw a parallel between the **military aviation** and **satellite industries**. The first intersection of these industries is the lack of specific rules and regulations established for certain activities. Consequently, it gives these areas more freedom of action. This feature causes the lack of open standards for most activities, based on [16].

A certain level of freedom of action is relevant because the technology involved usually does not have a similar resemblance to the civilian area. Moreover, because many products are almost artisanal manufacturing, the amount of items featuring a sample of these two areas (military aviation and satellite) is limited. Consequently, the obligation of adopting specific regulations perhaps would become impracticable. Then the entities responsible for product acceptance usually adopt specific rules and only a part of some regulations, as follows, based on [16].

IV. SOME REGULATIONS OF SPACE QUALITY ASSURANCE AND INTERNATIONAL AERONAUTICAL CERTIFICATION

According to [16], [17] and [18], the European Cooperation for Space Standardization (ECSS) is a cooperative effort of the European Space Agency (ESA), national space agencies, and European industry associations to develop common standards, maintain its harmonization, and avoid misunderstandings. The ECSS standards focus on what shall be accomplished rather than how to organize and perform the necessary work. Some are akin with this paper, as follows.

1- ECSS-Q-ST-20C - Space Product Assurance, Quality Assurance [4]

The ECSS-Q-ST-20C [4] aims the product assurance in space projects and applications. The ECSS-Q-ST-20C defines **Quality Assurance (QA) as** the minimum requirements for establishing and implementing a Quality Assurance program for products of space projects, respecting the project life cycle and their phases.

2- ECSS-M-ST-10C Rev.1- Project planning and implementation [5]

According to ECSS-M-ST- 10C [5], the life cycle of space projects is typically divided into 7 phases, as follows: phase 0 - mission analysis/needs identification; phase A - feasibility; phase B - preliminary definition; phase C - detailed definition; phase D - qualification and production; phase E – utilization; and phase F – disposal. Programmed reviews are distributed into those phases, respecting each TRL (Technology Readiness Level - ECSS-E-HB-11A, [6]). Figure 1 shows a typical project life cycle.

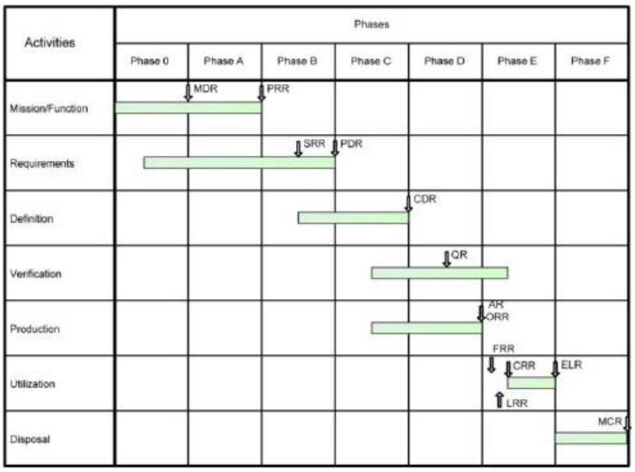

Fig.1: Typical Project Life Cycle (cf. ECSS-M-ST-10C Rev.1) [5].

3- Order 8110.4C- Type Certification [13]

The U.S Department of Transportation issued a document called “Order 8110.4C - Type Certification” [13], which focuses on aircraft certification service, flight standards service, aircraft evaluation groups, and persons and organizations designated by the FAA associated with the certification processes required by Title 14 of the American Code of Federal Regulations (14 CFR) Part 21. It prescribes the responsibilities and procedures that FAA must follow to certify new designs for civil aircraft, aircraft engines, and propellers, or changes to them, as required by 14 CFR Part 21. Adherence to the procedures of this order is essential for the administration standardization of this directive material, according to [16], [18] and [19].

The CFR §21.21 focus on type certificate as: normal, utility, acrobatic, commuter, and transport category aircraft; manned free balloons; special classes of aircraft; aircraft engines; and propellers, according to [16], [18] and [19].

The Order 8110.4C shows a model of the type certification process and how to comply with the CFR [1]. This document shows the stakeholder's responsibilities and presents, in its following sections, a high-level flow diagram of the certification events that typically make up the life cycle of an aircraft before its Entry Into Service (EIS). It explains the type certification process, but does not dictate exactly how the project should flow. Certain assumptions and simplifications are made so that the model clearly shows the relationship between the various events and milestones. Although the model shows the proper sequence of events for certificating a product, the diverse aspects of an aeronautical project generally progress through the process at different times and at different rates. It depends on the applicant's characteristics. It is helpful to see a project as multiple certification items but with interrelated schedules, according to [16] and [19].

The document presents an important picture as a typical type certification process (Figure 2).

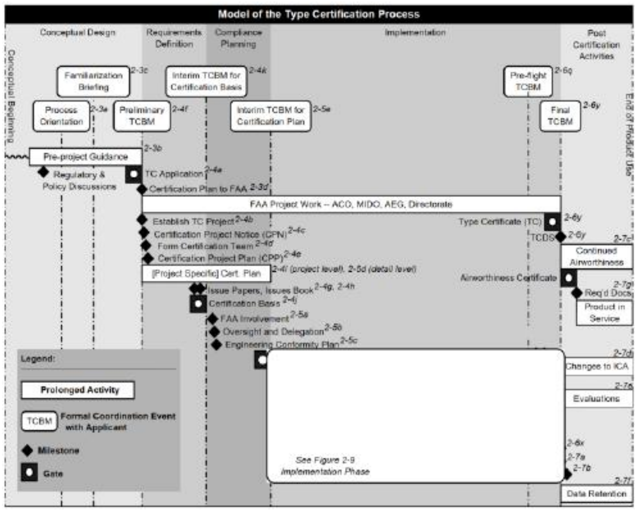

Fig.2: Model of the Typical Type Certification Process (cf. Order 8110.4C) [13].

For the **military** aviation certification, the Order 8110.4C [13] can be adopted for type certification activities (new projects) to drive the process. However, since military aircraft specifications may differ (often called "delta") from those used by **civil** aviation certification, a specific contract must reflect the applicant-authority agreement regarding that "delta" [16].

Nevertheless, for other military products certification, e.g., bombs, missiles, rockets, etc., the Order 8110.4C model must be adapted due to the differences between an aircraft and those products already discussed in this text [16].

V. MODEL PROPOSAL

After analyzing the regulations explored in section IV and verifying the similarities between the space product & quality assurance and civil & military aviation certification processes, focusing on product acceptance, the authors suggest the enforcement of some gates and documents used in the **military aviation** certification. The proposal involves controlling and standardizing satellite product assurance activities by the implementation of:

(a) **A Process Orientation** for quality assurance activities that will be driven during the space product development [13];

(b) **A Familiarization Briefing** [14];

(c) **A Product/Quality Assurance Workgroup** and specific meetings [16];

(d) **A Qualification Plan** [14] and [16]; and

(e) **A Harmonization of MoCs** - Means of Compliance (also known as Verification Methods) strategy [16].

1- Proposal Description

This proposal intends to improve the space product development process monitoring for the **Quality Assurance** activities of the organization, who is responsible for the integration of space parts and final assembly, as follows:

(a) The **Process Orientation** is established at the beginning of the process and focuses on setting an agreement between the Product/Quality Assurance Workgroup and the supplier. This event will be essential to explain all quality assurance needs during the product life cycle and the supplier's responsibilities [14].

(b) The **Familiarization Briefing** happens just after the establishment of the Process Orientation. This briefing is intended to acquaint the Product/Quality Assurance Workgroup with the proposed design solution. In addition to the design features, this briefing must clarify the intended operation, present other involved suppliers and their unusual relationships, show reliability on approved equipment, and present the project schedule. This event focuses on guiding quality assurance efforts during the entire product development [14].

(c) **The Product/Quality Assurance Workgroup** is composed of quality assurance specialists, who know about the quality assurance activities, regulations and specific areas (software, propulsion, etc.). The team will participate in essential actions such as the Review Board and specific meetings [16].

In addition, the Product/Quality Assurance Workgroup shall establish some applicable milestones during the program, such as:

c.1- Preliminary Quality Assurance Board Meetings (QABM);

c.2- Interim QABM for Requirements Basis;

c.3- Pre Acceptance QABM; and

c.4- Final Acceptance QABM.

For those 4 proposals, instead of having an Authority responsibility, according to the Order 8110.4C [14], it must have a Space Quality Assurance Board in charge.

The Product Assurance (PA) activities may operate during the space product development and shall have a formal parallel schedule for important PA events, respecting the product development progress.

The **Quality Assurance Board Meetings** (QABM) are similar to the Type Certification Board Meeting (TCBM). Those events shall be on the **Quality Assurance Schedule**, in the following moments:

- process beginning (preliminary);
- before and during the manufacturing (interim);
- before entering into service (pre-utilization); and
- before the disposal (final).

Except for the final one, all those activities are performed with the suppliers during the space project development. Some of those meetings may be combined, duplicated, or divided by disciplines (technologies), subsystems, or systems, as necessary. Members of the **Quality Assurance Board** (QAB) should be acquainted with the project during the development phases and in advance of QAB meetings. Those members come from the Product/Quality Assurance Workgroup previously selected, and their attributions are previously established.

(d) The **Qualification Plan** is a high-level document that contains a **Technical Specification** of the project, a **Qualification** (verification) **Basis** and a **Compliance Checklist** [14] and [16]. The Qualification Plan shall address specific Subsystems Qualification Plans that will deal with subsystems requirements. The Technical Specification must be a project description of their features, intended functions, limitations and objectives. The Qualification Basis, as done by a Certification Basis, reflects the stakeholders' understanding of the applicable regulations, standards and guidelines that will be transformed in requirements in order to demonstrate the project adherence to its technical specification. Finally, the Compliance Checklist is a matrix that must list, for each requirement, at least:

(i) a brief headline;

(ii) the agreed MoCs;

(iii) the Plan, Drawing, or Report Number;

(iv) Responsible Entity for showing the compliance;

(v) scheduled date for the intended compliance; and

(vi) the applicable rules and strategies for the planned MoCs.

As the Compliance Check List may be such a vast matrix, it can be referenced instead of being on the Qualification Plan. The Qualification Basis and the Compliance Checklist may suffer some modifications during the Requirements Definition phase (as happens in civil aeronautical certification - Figure 2).

(e) **The Harmonization of Means of Compliance (MoCs) Strategy** [16], [17], [18] and [19] must be agreed upon a contract between the suppliers and the customer, always driven by the stakeholders. Such a contract must reflect the understanding of how a requirement will be considered demonstrated. This *modus operandi* is already used in the Brazilian military aeronautical industry relationship with its respective Authority.

It will happen as soon as the product's suppliers are contracted. It will promote a common understanding of the requirements and how and when a compliance activity will demonstrate those requirements.

This event involves the suppliers, the customer technical specialists, the customer product assurance, the program managers, the operators, and the product end users. For instance, on CBERS (China-Brazil Earth-Resources Satellite) satellites, the operators are the staff responsible for operating the control room, and the end users are the staff responsible for the Earth observation.

Such harmonization avoids possible misunderstandings of the requirements, their Means of Compliance, and deadlines. Additionally, it promotes requirements reformulation, as they show as necessary. Therefore, the contract must have a clause for some consequences when a requirement modification generates a financial impact.

Military customers usually adopt this operating mode for new aircraft projects and sometimes for major modifications on aircraft already certified.

The authors' experience in military aviation certification and space quality assurance activities indicates that the minimum relevant items for the harmonization of MoCs strategy are, for each requirement, the following:

(i) Customer requirement number;

(ii) Supplier requirement number;

(iii) Complete contract requirement description;

(iv) Customer requirement Focal Point;

(v) Involved technologies (according to the System Engineering project areas);

(vi) Supplier requirement Focal Point;

(vii) Complete supplier understanding of the requirement;

(viii) Supplier's proposal for MoCs: how the compliance will be achieved (strategy) and necessary resources;

(ix) Supplier's proposed Schedule;

(x) Customer approval on the whole MoCs and their strategy of compliance, necessary resources, and proposed Schedule;

(xi) An analysis of the financial impact due to a requirement modification in case of MoCs, strategy, resources, and/or schedule misunderstanding;

(xii) Customer's requirement acceptance; and

(xiii) Budget Manager's acceptance.

Those thirteen items may take weeks and perhaps months to be achieved (authors' experience indicates 9/ 10 months for a military aircraft, but it depends on several variables). However, this harmonization aims to approximate suppliers' and customers' expectations. Its administration should be assigned to the Project Manager and its implementation may be delegated to the Product/Quality Assurance Workgroup.

The involvement of all stakeholders and the participation of the Product/Quality Assurance Workgroup is essential since the result of this action is a process input for subsequent activities.

Despite the estimated person-hour increase in this activity implementation, space programs organizations should realize the positive contribution to the requirements compliance and verification control, projects traceability, and time and resources savings thanks to the avoidance of late retrofits.

The Product/Quality Assurance Workgroup shall have a certain level of institutional independence to develop this proposed model.

Finally, for Silva (2017) [16], the proposals made herein present positive outcomes according to experts' evaluation; and its conclusions will allow a continuation of this work. The implementation of those good practices will bring up some lessons learned in a real case, for study and check their impacts, thus analyzing the benefits, constraints and phases particularities.

VI. CONCLUSION

After an introduction, this work presented the scenario studied, including: the Brazilian scenario of small and medium-sized satellites, the relevance of Space Product Assurance and Space Quality Assurance, a brief history of the Brazilian Aviation Certification, some differences between Military Aviation Certification and Civil Aviation Certification, some principles of the Military Aviation Certification,

Then, it presented some similarities and differences between satellite products and military aviation products, followed by some regulations of space quality assurance and international aeronautical certification, and ended in a model proposal.

Such sections summarized some national and international aeronautical Type Certification regulations, and showed some similarities between the Military Aviation Certification and Space Product/Quality Assurance (for large organizations responsible for space programs).

Due to such recognized similarities, a model was proposed, adapting some practices and criteria used in the Military Aviation Certification to improve the Satellite Product/Quality Assurance

Particularly, a proposal for harmonization of MoCs (Means of Compliance) strategy, was presented as a way to align the expectations between the space product suppliers and the customer.

The positive contribution to the requirements compliance and verification control, projects traceability, and time and resources savings thanks to the avoidance of late retrofit shall overcome the impacts generated by the implementation of the good practices explored in this work.

It can be noted that the Product/Quality Assurance shall have a certain level of institutional independence in order to develop those suggested proposals.

For Silva (2017) [16], the proposals made herein present positive outcomes according to experts' evaluation.

The following steps to this work involve the implementation and analysis of the good practices proposed here and in a real case to verify the outcomes; and, hopefully, validate the proposed model for a product/quality assurance process for space products.

The practices proposed by the authors should been seen as a reinforcement to space product requirements compliance control. This guarantee may provide a substantial advantage to their quality, whereas space products are characterized by stringent deadlines, high cost, high complexity and requires a high-level integration of their parts.

ACKNOWLEDGEMENTS

The authors thank the support of the Brazilian National Institute for Space Research (*Instituto Nacional de Pesquisas Espaciais* - INPE), and of the Graduate Program in Operational Applications (*Programa de Pós-Graduação em Aplicações Operacionais* - PPGAO) from the Brazilian Aeronautics Institute of Technology (*Instituto Tecnológico de Aeronáutica* - ITA).

REFERENCES

[1] Brazilian Minister of Internal Affairs. Ordinance nº 5,731, March 20th 2006. Dispõe sobre a instalação, a estrutura organizacional da Agência Nacional de Aviação Civil - ANAC e aprova o seu regulamento.Brazilian Minister of Internal Affairs. Ordinance nº 5,731, March 20th 2006. Dispõe sobre a instalação, a estrutura organizacional da Agência Nacional de Aviação Civil - ANAC e aprova o seu regulamento.

[2] COMAER, Ministério da Defesa Comando da Aeronáutica, DCA-800-2 (2014), Diretriz do Comando da Aeronáutica, "Garantia da Qualidade e da Segurança de Sistemas e Produtos no COMAER".

[3] COMAER, Ministério da Defesa Comando da Aeronáutica, ICA 57-21 (2014), Instrução do Comando da Aeronáutica, "Regulamento de Aeronavegabilidade Militar – Procedimentos para Certificação de Produto Aeronáutico".

[4] ECSS, European Cooperation for Space Standardization: ECSS-Q-ST-20C - Space Product Assurance, Quality Assurance (2013), European Cooperation for Space Standardization, March, Rev1.

[5] ECSS, European Cooperation for Space Standardization: ECSS-M-ST-10C- Space Project Management, Project Planning and Implementation, (2009). Noordwijk, The Netherlands.

[6] ECSS, European Cooperation for Space Standardization: ECSS-E-HB-11A: Space Engineering, Technology Readiness Level (TRL) Guidelines (2017). Rev 1 Noordwijk, The Netherlands, 62 p.

[7] ECSS, European Cooperation for Space Standardization: ECSS-S-ST-00-01C: Glossary Terms (2012), European Cooperation for Space Standardization, Rev C.

[8] FAA, Federal Aviation Administration: CFR (Code of Federal Regulations) Title 14, Chapter I, Subchapter C, Part 21 (2016), Certification Procedures for Products and Articles, U.S.

[9] FAA, Federal Aviation Administration: AC 25.1309-1A, System Design and Analysis (1988, June 06), EUA.

[10] FAA, Federal Aviation Administration, "The FAA and Industry Guide to Product Certification" of U.S Department of Transportation Federal Aviation Administration.

[11] MCTI, Science and Technology Ministry (2008), LI 1420, Internal Rules, INPE.

[12] NASA, National Aeronautics and Space Administration (2007), NASA/SP-2007-6105: NASA - Systems Engineering Handbook. Rev 1 Washington, DC, 340 p.

[13] Order 8110.4C - Type Certification of U.S Department of Transportation Federal Aviation Administration (2007), Change 5.

[14] Young, R. R. The Requirements Engineering Handbook (2004). Norwood, MA, EUA: Artech House.

[15] Walter de Moura, "History of Certification and IFI Creation" (2016), Aerospace Product Certification Course, 14º Edition, Presentation.

[16] SILVA, Cristiane Mariano Zavati. Identificação de um processo da garantia do produto espacial (INPE) e proposição de seu aperfeiçoamento baseada na sumarização de um correspondente processo aeronáutico (ANAC) – São José dos Campos: INPE, 2017. xxx + 191 p.; (sid.inpe.br/mtc-m21b/2017/02.06.19.45-TDI).

[17] Silva, Cristiane Mariano Zavati, G. M. D. Souza, and M. L. D. O. E. Souza, "Proposals for a space product assurance process improvement based on an aeronautical process," in IEEE Aerospace Conference, 2018, DOI: 10.1109/AERO.2018.8396376

[18] Silva, Cristiane Mariano Zavati, G. M. D. Souza, and M. L. D. O. E. Souza, " Harmonização de Meio de Cumprimento (MoC) de requisito", 2018, WETE-INPE.

[19] Silva, Cristiane Mariano Zavati, G. M. D. Souza, and M. L. D. O. E. Souza, "SUMARIZAÇÃO DO PROCESSO DE CERTIFICAÇÃO DE TIPO DA AERONÁUTICA BRASILEIRA", VI Simpósio de Engenharia de Produção - SIMEP 2018 < www.even3.com.br/Anais/6simep/79957-SUMARIZACAO-DO-PROCESSO-DE-CERTIFICACAO-DE-TIPO-DA-AERONAUTICA-BRASILEIRA> , ISSN: 2318-9258.