Enabling Model-Based Aircraft Certification

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Abstract

The aircraft certification process for both civil and military air systems carries the reputation of being a costly, document-centric process. Applicants seeking to achieve certification must provide copious amounts of data and test evidence to establish the engineering pedigree of the aircraft. One of the promises of digital engineering is the use of high-fidelity engineering models as a primary source of data for authorities to find compliance with airworthiness regulations. This approach uses engineering simulation models as the authoritative source of truth for making airworthiness determinations and risk assessments. However, there are practical obstacles to full adoption of model-based aircraft certification. This paper details these challenges to achieving model-based aircraft certification in four areas: culture, competency, collaboration, and credibility. Opportunities to overcome these challenges are discussed and recommendations provided.

Introduction

All aircraft, both civil and military, must be certified as airworthy for their configuration, intended use (e.g., mission), and environment. Initial airworthiness certification – the focus of this paper - is achieved through showing compliance to the aircraft certification basis, a set of standards agreed upon by the applicant (e.g., original equipment manufacturer) and the certification authority. Showing airworthiness compliance is essential to substantiate a safe design and is achieved through extensive analysis, simulation, and testing, but it is cost intensive. For example, the initial certification program for the Airbus A350-900 cost approximately 2.4 billion euros, or about one-fifth of the aircraft program budget [1]. Notably, the traditional aircraft certification process relies heavily on test reports and other forms of documented evidence – a "paper trail" that supports the pedigree of the aircraft design to provide evidence that the design complies with its certification basis. In the United States, the Federal Aviation Administration (FAA) is the certification authority for civil aircraft. Initial certification, also called type certification (TC), is carried out through a collaborative, but deliberate process, shown in Figure 1. The military airworthiness process in the U.S. is similar and also relies heavily on documented evidence such as analysis and test reports. In the U.S., the Department of Defense MIL-HDBK-516C "Airworthiness Certification Criteria" provides the starting point for developing the initial aircraft certification basis for military aircraft [2]. This document mentions "report" or "reports" over 100 times.

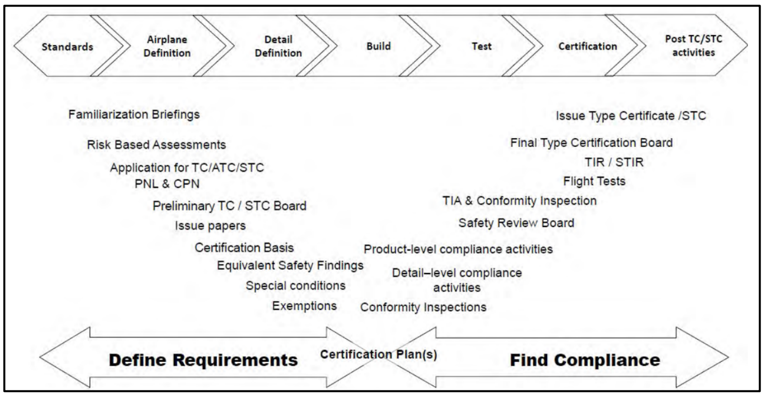

Figure 1: The FAA Type Certification Process (from [3]).

Digital transformation has enormous potential to improve the aircraft certification process. Industry asserts that the benefits of a model-based certification approach are "…ultimately manifested through its use to reduce physical testing and improve decision confidence (risk reduction) and tractability" [4]. Additionally, industry believes that a model-based certification approach can reduce cost and accelerate schedule. Recent Northrop Grumman experience has shown the promise of an integrated digital design environment to reduce rework and redesign to less than 1%, down from 15-20% on a traditional program [5]. Military and civil airworthiness authorities also see the benefits of a model-based certification approach. A recent U.S. Air Force vision for digital materiel management states "Models must replace documents. . . [d]igital collaboration must break down decision stovepipes" [6]. The higher level of insight that the certification authority can gain from a model instead of a report provides opportunities to improve safety and improve efficiency. The FAA shows in Figure 2 that optimum safety is not achieved when the safety innovations are not implemented. It is noted in the figure that symbols representing stacks of paper are used to graphically represent the "extent of the safety effort".

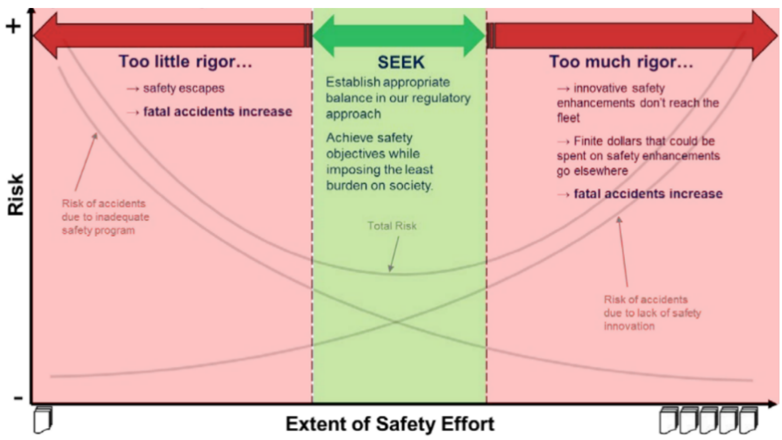

Figure 2: Risk versus extent of safety effort (from [7]).

Mindful of these benefits of model-based certification, it must be noted that there are several key challenges to full implementation. Without addressing these challenges and discussing potential opportunities to overcome them, the full promise of model-based airworthiness certification will be difficult to achieve. There are four key categories of challenges discussed here that the aircraft certification process will encounter when moving toward model-based certification: culture, competency, collaboration, and credibility, graphically represented in Figure 3. The next four sections of the paper will discuss these challenges and outline opportunities to address them.

Figure 3: Four challenges for model-based aircraft certification.

Culture

The first area concerns aircraft certification culture. Aircraft certification is foundational to aviation safety. Globally, commercial air travel is the safest form of mass transportation in the world today, characterized by an accident rate of one accident per 1.26 million flights [8]. As a result, the institutions and individuals who perform these certification practices and procedures are reluctant to change them. To underscore that point, the National Academies of Sciences noted for the United States Federal Aviation Administration (FAA) "…fear of making a mistake drives a risk culture at the FAA that is too often overly conservative…" [9]. In view of this conservative culture, moving away from finding compliance through documents and instead in models may face resistance. Additionally, recent proposals for Certification by Analysis (CbA) – a process that moves from certification evidence produced by a combination of methods and verified by flight testing to certification evidence based on analysis, modelling, and simulation alone – will certainly be seen as novel and face a cultural hurdle. How will certification personnel be convinced to migrate to more digital certification basis, provided the “fear of making a mistake” culture that exists?

An opportunity to address the challenge of culture would be to understand how the certification authorities have operated in the past when faced with new technologies. As aircraft have grown increasingly complex, certification authorities have begun to not only depend on the compliance data but to instead depend on the industry engineers that produce those data for insight [10]. A similar dynamic could be fostered around model-based aircraft certification. Innovative programs where certification officials interact not only with the digital tools but the personnel and processes by which those tools are matured throughout design and development could be helpful to build trust in the digital ecosystem itself. Once trust is established, cultural change becomes more feasible.

Competency

The second challenge area relates to the digital competency of the industry and the airworthiness authority. Many of the engineering modelling and simulation tools require unique skillsets to be able to navigate, explore, and fully comprehend the information in the models. A certification workforce that is not equipped with the necessary competencies to use these tools will struggle to find compliance, no matter how superior the pedigree of the data within the models. A European industry consortium noted about the model-based aircraft certification workforce that “. . . industry and regulators alike will need to be developed against standardised competencies, with these new skills promoted and recognised” [11]. It will be essential that all stakeholders in the aircraft certification process are trained and credentialed to be proficient in understanding the features, intricacies, and limitations of the engineering models used as certification evidence.

This challenge invites the opportunity for a digital engineering competency model. Competency models have been used successfully across multiple scientific and technical industries to include medicine, energy, and engineering. Academia has proposed a digital engineering competency framework based on work with the U.S. Navy that defines five core digital competency groups: digital enterprise environment, data engineering, digital engineering and analysis, systems software, and configuration management. [12]. Additionally, Northrop Grumman has implemented a “T-shaped” competency model within its airworthiness directorate, benchmarking against accepted standards the breadth of airworthiness process knowledge and expertise (horizontal part of “T”) and the depth of knowledge and expertise in a specific technical area (vertical part of the “T”) [13]. A possible future expansion of this model would be to adapt the “T” competency model for model-based aircraft certification as shown in Figure 4.

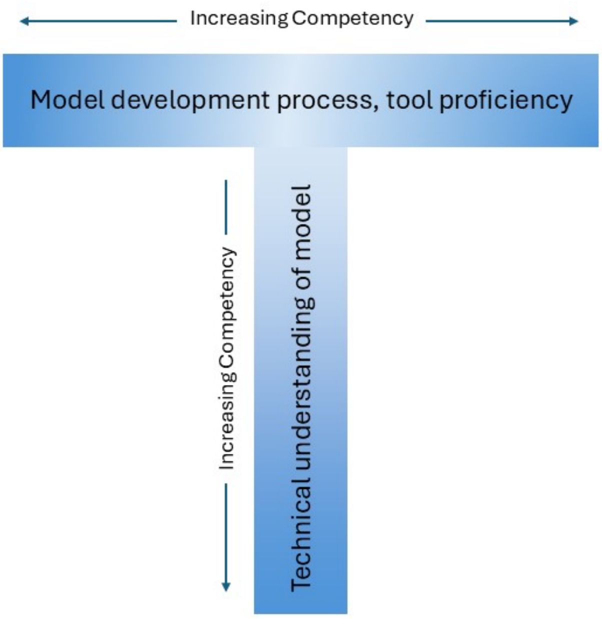

Figure 4: Example of model-based certification competency model.

Collaboration

"Seamless and persistent collaboration between airworthiness stakeholders and digital technologists" is part of the vision of digital airworthiness according to the U.S. Air Force [14]. However, for that vision to become reality all airworthiness stakeholders must have access to the models, permissions to query the models to gain insights into the data needed for certification, and the availability to collaborate. Many government agencies have restrictions on the types and kinds of software that can be installed on their computers. Moreover, it is common for certification engineers support more than one aircraft project, hampering their ability to freely collaborate in real-time with their industry counterparts. Finally, different industry partners may bring disparate modelling formats and environments to the certification authority, creating a challenge for seamless collaboration.

While collaboration may seem straightforward to solve through increasing the budget and workforce of the airworthiness authority, airworthiness stakeholders have little control over these decisions. Industry should instead focus on software solutions that are highly compatible with available software tools that are already at the disposal of the certification authority. Air systems integrators should ensure that their suppliers use compatible data formats and supply models that seamlessly work together [15]. Additionally, industry should consider automation (to possibly include artificial intelligence) that could facilitate the airworthiness authority's ability to derive insights from the models. Instead of "living in the model" as the preferred mode of collaboration, “learning from the model” may be a more feasible objective. To illustrate the point, one proposed approach is to automatically curate certification evidence into assurance cases that relate the certification claim to the available evidence in the model, facilitating the work of the airworthiness authority [16].

Credibility

The final challenge area is the credibility of the model that is used in the certification process. A joint academia-government-industry guide on CbA noted that, “Developing methods to ensure credible simulation results is critically important for regulatory acceptance of CbA” [17]. What are the means for the airworthiness authority to know that they can rely on the models in the same way that they rely on physical tests? Additionally, as the models are updated based on aircraft configuration changes or updated analyses it will be critical for the airworthiness authority to understand how model configuration control is performed. Finally, many airworthiness standards are concerned with air system functionally in the presence of failures. For example, MIL-HDBK-516C paragraph 6.2.1.5 for vehicle control functions states in part that, “No single failure, combination of single independent failures and failures of unique functions (e.g., flaps, speed brakes including single hard-over) may result in a departure or loss of control” [2]. Much of the work in the engineering modelling community has been focused on accurately modelling nominal performance of the system, not the off-nominal failure cases that are essential to assessing airworthiness compliance.

There are multiple opportunities to improve model credibility and confidence in the authoritative source of truth. Strict configuration control procedures are required, including providing a means of documenting or timestamping the state of the model when the certification authority accessed it. More focus in the engineering simulation community should be placed on modelling failure scenarios. It is vital that model validation methodologies be developed and standardized to inform all stakeholders of the credibility level of the models. It has been said that the airworthiness process moves at the “speed of trust” – therefore a lack of confidence in the models as the authoritative source of truth will slow the process. Northrop Grumman has recently proposed nine-level model validation structure (Table 1). This approach accounts for the quality of the data supplied to the model, the level of stakeholder review of the model, and the statistical uncertainty quantification level of model. It is proposed that a model be accredited to model validation level (MVL) 8 for it to be used for CbA.

Model Validation Level (Authority)	MVL Characteristics						
	Referent	Accuracy to Referent	Stakeholder Review (SR) Completed	Component Variability Included	System Uncertainty Quantification	Requirement Pass/Fail Tolerance	Approved Model Use
MVL 1	Requirements / SME Judgement / Prescriptive	N/A	SR 1	No	None	100% *By Definition*	Architecture
MVL 2	Requirements / Predictive	Low	SR 2 (SRR/SFR)*	No	None	100% *By Physics*	Design
MVL 3	Component Lab Test Data	Medium	SR 3 (PDR)*	No	None	100% *Nominal Components*	Risk Reduction
MVL 4	Engineering HW/SW System Test Data	Medium	SR 4	No	None	100% *Nominal Components*	Risk Reduction
MVL 5	Engineering HW/SW System Test Data	High	SR 5 (CDR)*	Yes	UQ1	(x)% *Bounded Uncertainty*	Virtual Test Planning
MVL 6	Pre-Production HW/SW System Test Data	High	SR 6	Yes	UQ2	(x+)% *Reduced Uncertainty*	Targeted testing to further reduce uncertainty
MVL 7	Production HW/SW HIL/SIL Data	High	SR 7 (MFR)*	Yes	UQ3	(x++)% *Reduced Uncertainty*	Targeted testing to further reduce uncertainty / Safety of Flight
MVL 8	Flight Test HW/SW Data	Truth	SR 8	Yes	UQ4	95%/99.7%	CbA Accreditation MSC
MVL 9	"As-Built" Production Data	Truth	SR 9	Yes	None	100%	Sustainment LRIP

Table 1: Northrop Grumman Model Validation Levels (from [18]).

Conclusions and Recommendations

Digital transformation has enormous potential to improve aircraft certification. While existing certification processes have proven their effectiveness through an outstanding safety record for aviation, moving to model-based certification in a way that addresses the challenges is essential. This paper addressed challenges in four key areas:

- Culture – aircraft certification has a proven safety culture that is resistant to adopt new technologies.
- Competency – airworthiness authorities must be fluent in model-based certification.
- Collaboration – all stakeholders require access to models and the availability to interact in them.
- Credibility – as airworthiness moves at the speed of trust, confidence in the credibility of the models to represent the aircraft is essential.

It is recommended that all airworthiness stakeholders review these challenge areas and the suggested opportunities for improvement. Key areas for research and early adoption should be identified and pursued in academia, government, and industry. To the maximum extent practicable, lessons learned in pursuing model-based certification should be widely disseminated and eventually inform standards development. The aviation industry and the airworthiness authority should work together to address these challenges to enable a model-based aircraft certification approach has the potential to reduce cost, improve speed, and increase insight into the aircraft certification basis. Through teamwork, all airworthiness stakeholders can build on the outstanding safety record that current aircraft certification practices have produced and safely move aviation forward into a digital future.

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