Aviation Regulations and Project Management: Developing a New System for an Aircraft Piston Engine

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Abstract

International civil aviation regulations affect every aspect of development of new aircraft systems. On the one hand, the procedures are comprehensive and clearly defined, on the other hand they are complex and costly to implement. Possibly for this reason, and quite surprisingly, civil aviation is far from being in the avant-garde of innovation. The paper is a case study. It presents lessons learned in the course of a project aimed at developing a new fuel injection system for an existing piston engine. The main difficulty was not creating a new system, but fulfilling the requirements of the European Aviation Safety Agency (EASA) certification process related with changing the type certificate so the engine equipped with the new system could be used in practice. The effect of the aviation regulations on the project scope, structure of the project team, schedule and budget has been described together with the set of project-specific risks.

Keywords: aircraft certification, civil aviation, innovation, project management, project risks.

Introduction

The main directions of development in civil aviation point towards reduction of environmental impact, including energy consumption, and improvement of reliability and safety (ICAO, 2007, ACARE, 2012). Although the same directions are being observed in other branches of industry including construction and civil engineering, aviation is subject to exceptionally strict and detailed international regulations and standardization that cover every aspect and any procedure of aircraft system design and production, air traffic services, and crew training and certification to assure safety – the unquestioned priority of aviation (ICAO, 2006). Accident statistics prove that the procedures work: air transport is leading in passenger safety, and equipment failures account for only about one third of accidents (Oster et al., 2013). However, the necessity to conform to numerous procedures naturally increase time and cost of introducing innovations.

For many years aviation designs have been the quintessence of cutting-edge engineering, especially in terms of engines and power transmission; a synonym of innovation in system design (mechanical fuel injection, water injection, turbo charge), material science (aluminum, titanium, ceramics) and manufacturing technology (pressure casting, nitrogen hardening). The automotive industry was an eager copier who further developed these novelties to make them cheaper and easier to implement in mass production, but stayed one step behind.

This was changed as aviation matured and focused on safety. When electronic systems were introduced to engine control, the automotive industry embraced them with enthusiasm,

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whereas the aviation turned it down because of high failure frequency of the first devices. Thus, electronics gave the automotive technology a competitive edge over aeronautics. Car engines became more flexible, stable, reliable and easier to maintain thanks to self-diagnostics not available in the case of purely mechanical systems. Of course, electronic control worked its way into civil aviation, slowly due to long product life cycles, but this time airplane engines copied solutions that were well established in automobiles.

The paper presents an analysis of the impact of aviation regulations on the design of an electronic ignition system for a piston engine to be mounted in the general aviation vessels as well as in transport aircrafts (classification according to Special Federal Aviation Regulation No. 23 and No.25, respectively). The ignition system was developed in a R&D project and implemented to be offered commercially as a product of a Polish aircraft engine manufacturer. Information on this case was collected by participant observation, and the paper presents an insider's (subcontractor's project manager's) account of the project initiation and subsequent delivery stages.

Project Overview

Background

The project was aimed at reengineering the ASz-62IR-16 engine (Figure 1), a product of a Polish company supplying it to customers in Eastern Europe, South America, and Canada, with good prospect to enter the Chinese market. The engine is used in small and medium-sized aircrafts used mostly in transport of goods (Antonov AN-2) and agriculture (M18 Dromader). The engine is an air-cooled, four-stroke gasoline unit of 9 cylinders in radial setup, mechanically charged by a radial compressor powered by an engine crankshaft. Total engine cubic capacity is 29.87 dm^3, and the compression ratio is 6.4:1. The maximum take-off power is 1000 HP at 2200 rpm. The maximum fuel consumption is 300 kg/h.

Figure 1. ASz-62IR-16E Engine on test stand. Front view.

The original design was created in nineteen-forties, and its last modernization took place in nineteen-eighties. The engine uses the Avgas 100LL fuel – one of the last fuels with lead compounds. It is being gradually withdrawn from the world markets for environmental reasons. The engine's high fuel consumption combined with poor availability and growing prices of the fuel provide rationale for the engine's modernization.

The customers of the engine manufacturer were expected to welcome an engine that sparingly uses some popular type of fuel. However, this meant profound changes to the engine's fueling system. After preparation studies, the manufacturer decided to develop an electronic injection system.

Project Aim And Scope

The aim of the project was to upgrade the existing design of the engine by equipping it with an electronic fuel injection system (hardware and software).

The project was divided in two phases. The R&D phase was to produce a new design of the engine's fuel system, capable of running on standard motor gasoline, and fulfilling international safety requirements for commercial aeronautical products. It comprised the design process, preparing test models, conducting optimization tests, constructing a prototype and developing production manual. The implementation phase was devoted to conducting airworthiness tests and obtaining the European Aviation Safety Agency (EASA) type certificate. The first phase received public support (a grant of the Polish Ministry of Science Higher Education No. 04305/C.ZR6-6/2008 "Multi-fuel injection system for ASz-62IR engine"). The implementation phase (certification procedure) was funded by the manufacturer themselves.

Project Participants

The project's leader, sponsor and the main beneficiary was WSK „PZL-Kalisz" S.A. – a Polish company with 50 years experience in aircraft engine production and servicing, currently the world's only provider of piston engines of power over 700 HP. Their tasks covered design and provision of subassemblies and conducting certification tests.

As WSK „PZL-Kalisz" S.A. do not employ specialists in electronic fueling systems, they subcontracted related tasks to a team of scientists and engineers from Lublin University of Technology, experienced in design and implementation of automotive systems. Their responsibility was to design the electronic injection system, to develop control algorithms (including identification and verification tests), and to provide support during certification tests.

Project Schedule

Initially the project was scheduled to take 4 years, from January 2009 till December 2012. The first three stages (Figure 2) constitute the research and development phase led by the university team. The certification tests could start only after the prototype was completed; however, the certification procedure started prior to that phase as design process must be supervised by the authorities.

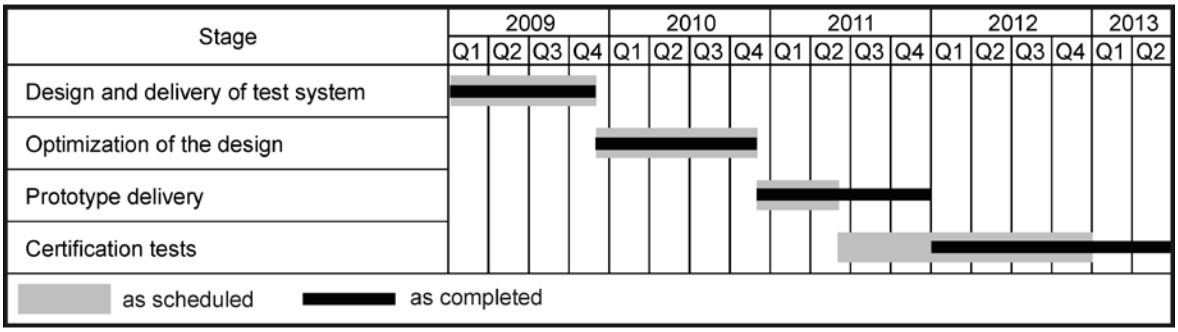

Figure 2. Project schedule

The baseline schedule proved overoptimistic. The prototype delivery stage was finished with seven months delay, and the award of the EASA type certificate on completion of supervised certification tests took place six month after the scheduled project completion. In the chapters to follow, the authors explain how the aviation regulations affected the project aspects, including its scope and schedule.

Aviation Law And Project Development

Brief Overview Of Aviation Regulations And Standards

The basis for practically all aviation rules worldwide is the Convention on International Civil Aviation, often referred to as Chicago Convention (ICAO, 2006). Its Article 31 requires that "Every aircraft engaged in international navigation shall be provided with a certificate of airworthiness issued or rendered valid by the State in which it is registered". The states are thus obliged to issue their own laws and regulations to conform to the Convention (e.g. Polish Aviation Act 2013). However, the national laws fully conform to the Convention.

Article 31 mentioned above implies that no aircraft is allowed to fly without some form of official consent. Standardization of particular requirements the aircrafts must conform to is the task of national authorities, such as EASA in the European Union, Federal Aviation Authority (FAA) in the US, or Civil Aviation Safety Authority (CASA) in Australia; most countries' regulations are derived directly from the regulations established by FAA and EASA. In general, the regulations are convergent, and even classification and numbering of particular guidelines are the same. The project described in the paper was conducted under EASA procedures, so the authors are going to refer only to European regulations.

Each aircraft, and separately its engines and propellers, must comply to requirements described in the regulations (in the considered case – the Commission of the European Community regulations that are practically the same as their US counterparts), namely:

- Commission Regulation (EC) No. 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC, 2008 OJ L 79/1 [hereinafter Regulation (EC) 216/2008],
- Commission Regulation (EC) No. 1702/2003 of 24 September 2003 laying down implementing rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances, as well as for the certification of design and production organizations, 2003 OJ L 243/6 [hereinafter Regulation (EC) 1702/2003],
- Commission Regulation (EC) No. 2042/2003 of 20 November 2003 on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks, 2003 OJ L 315/1 [hereinafter Regulation (EC) 2042/2003].

The approval of the design of the aircraft, engines and propellers is signified by the issue of a Type Certificate. Regulation (EC) 1702/2003 does not directly specify detailed technical requirements the certified element is to comply to; instead, it regulates the basic rules of the certification process. Acceptable means of compliance and guidance for the certification are referred to in the Annex, Part 21, section 21A.16A: "The Agency shall issue (…) airworthiness codes as standard means to show compliance of products, parts and appliances with the essential requirements of Annex I to the basic Regulation". In the case of the aircraft engine and the considered project, these codes take are the following Certification Specifications (CS) and Acceptable Means of Compliance (ACM):

- CS-Definitions, introduced by the Decision No. 2007/016/R of the Executive Director of the European Aviation Safety Agency of 7 December 2007 on definitions and abbreviations used in certification specifications for products, parts and appliances,
- CS-E together with its AMC, introduced by the Decision No. 2003/009/RM of the Executive Director of the European Aviation Safety Agency of 24 October 2003 on certification specifications, including airworthiness codes and acceptable means of compliance, for engines.

CS-E lists the requirements the engine must meet to be eligible for certification, whereas its AMC refines these requirements and proposes how one can prove that these requirements are met. AMC base on experience and provide the potential user with tools and procedures that were previously accepted by the certification agency (EASA). They are not obligatory, but using them may speed up the certification process.

The engine being the object of modernization was to be equipped with an electronic control system – in this case, the CS-E refers to another set of guidelines, introduced by the Decision No. 2007/019/R of the Executive Director of the European Aviation Safety Agency of 19 December 2007 on general acceptable means of compliance for airworthiness of products, parts and appliances: AMC 20-1 – acceptable means of compliance in the case of certification of propulsion systems equipped with electronic control systems, and AMC 20-3 – these for certification of engines with electronic engine control systems. The AMC accompanying CS-E refer to further documents – three standards on design, provision, and testing of aircraft electronic systems by the Radio Technical Commission for Aeronautics (RTCA):

- DO-160E *Environmental Conditions and Test Procedures for Airborne Equipment* (RTCA, 2004) that defines a series of minimum standard environmental test conditions and test procedures to determine the performance characteristics of airborne equipment in conditions that may be encountered in airborne operation of the equipment, like low temperatures, fire, magnetic effects, or dust;
- DO-178B *Software Considerations in Airborne Systems and Equipment Certification* (RTCA, 1992) on design methods and requirements towards testing the software used in aircrafts;
- DO-254 *Design Assurance Guidance for Airborne Electronic Hardware* (RTCA, 2000).

As AMC, these standards describe recommended ways of proving conformance to the requirements; however, according to the authors experience, in the certification process, EASA treats them as obligatory.

In the chapters to follow, the authors describe how the standardization and regulation affected the project's scope, structure of the project team, schedule, budget, and risks.

The Team

According to the Regulation (EC) 1702/2003, only a "design organization" can apply for a type certificate. It is the organization responsible for the design of products, parts and appliances or for changes or repairs, able to prove its capabilities in these areas in a way also described by Regulation (EC) 1702/2003 to assure quality and safety in the design process as well as of the final product. This means disposing of a design insurance system to control and supervise the design process, the design changes, the products, parts and appliances. Therefore, for any implementable research and development project (i.e. ending with a type certificate for its product) on the aircraft engine, the organization that conducts it needs to be officially approved and regularly audited by a certification agency (in this case, EASA).

The design organization needs to dispose of highly qualified staff to assure effective organization and control as well as engineering expertise. It may resort to subcontracting, or hire external specialists, on condition that their work and the whole process is controlled under the organization's design quality assurance system. Regulation (EC) 1702/2003 sets no requirements on the minimum qualifications of the staff to be documented by e.g. university diplomas or course certificates, but such documents are useful in the process of the organization's certification and then in verifying its capabilities that is done on regular basis. Further requirements towards the design staff can be found in RTCA standards (RTCA, 1992 and RTCA, 2000). They recommend that testing and verification of, respectively, software and hardware modules, was conducted by people who have not been involved in designing and making them. Thus at least two specialists need to be involved, and one of them is only to check the results of work of the other.

In the considered project the client organization, WSK PZL Kalisz, was the approved design organization with design assurance system based on the company's basic organizational structure and highly qualified engineering staff. However, the company had previously no experience with electronic fueling systems, and the design team needed to be reinforced by new members – researchers from the Lublin University of Technology. The project team consisted of 20 employees of WSK PZL Kalisz and 18 specialists from the University, divided into four thematic working groups to deal, respectively, with issues of internal combustion engine control, electronics, control system programming, and simulation tests.

Apart from the design team, the whole process involved 3 EASA auditors who scrutinized the design organization itself as well as verified the project outcomes from the start of the design phase.

The Scope

The project's scope was defined, firstly, by functional requirements (in short: reduce fuel consumption, use motor fuels), and secondly, by operating quality and safety requirements defined by regulations. One needs to know what type of tests are required, and what they consist in, to be able to design particular components and the whole systems that pass them. This way, knowing what tests need to be conducted, one is able to set a major part of the design's brief. Moreover, knowing the scope of tests, their procedures, methods, time and resources required for them, one is able to properly embed testing activities in the schedule of each stage of the project.

As CS-E does not enforce the method of testing, the project planning process involved thorough studies of the CS-E's AMC and AMC 20-3 that define how many and what kind of tests would be applicable. The AMCs are quite general. For instance, according to AMC 20-3 "the applicant should perform all necessary testing and analysis to ensure that all Control Modes, including those which occur as a result of control Fault Accommodation strategies, are implemented as required" and thus a set of experiments needs to be planed to prove conformance with this requirement.

The tests that accompanied the design of the new electronic control system were related mainly with the works on software and hardware. RTCA standards (RTCA, 1992 and RTCA, 2000) require that the systems are tested on every stage of their design and physical provision to prove that functional and structural assumptions are met, that the systems are protected against errors at each stage of their development, and that they are properly implemented. In short, they are needed to prevent errors in creation of the electronic systems.

The next group of tests are to check the component's immunity to environmental loads. These tests were crucial for electronic components and conducted according to RTCA (2004). The list of environmental effects to be considered is long:

- Temperature and Altitude,
- Temperature Variation,
- Humidity,
- Operational Shock and Crash Safety,
- Vibration,
- Explosion Proofness,
- Waterproofness,
- Fluids Susceptibility,
- Sand and Dust,
- Fungus Resistance,
- Salt Spray,
- Magnetic Effect,
- Power Input,
- Voltage Spike,
- Audio Frequency Conducted Susceptibility – Power Inputs,
- Induced Signal Susceptibility,
- Radio Frequency Susceptibility (Radiated and Conducted),
- Emission of Radio Frequency Energy,
- Lightning Induced Transient Susceptibility,
- Icing,
- Electrostatic Discharge,
- Fire and Flammability,

and so was the list of tests to be planned and conducted. However, resistance of the components and systems to some of them was proved without experimental evidence – by providing sufficient arguments. For instance, the elements were icing-, fungus- and salt spray-proof because of the design of the components and materials used to construct them.

The final certification tests, so the basis for the award of the Type Certificate, were conducted on the prototype: the engine integrated with the new electronic system. These tests were based on CS-E Subpart C (Piston Engines; Type Substantiation) and comprised:

- vibration tests according to CS-E 340 – to define the level of torsional and bending vibrations of the elements that fix the engine to the airframe;
- calibration tests according to CS-E 350 – to define power characteristics of the engine under normal operating conditions;
- detonation tests according to CS-E 360 – to check and prove that the engine operates without detonations under normal operating conditions, between minimum and maximum engine rotational speed;
- starting tests according to CS-E 370 – to check and prove the starting quality and repeatability with the new system;
- low temperature starting tests according to CS-E 380;
- acceleration tests 390 CS-E [6] – to confirm that the engine's assumed dynamics was achieved;
- over-speed tests according to CS-E 400– to test the structural safety,
- water spray tests according to CS-E 430 – to confirm that rain cannot affect the engine's operation;

- endurance tests according to CS-E 440 – to check durability and physical reliability of the engine and all its components;
- ignition tests according to CS-E 450 – to prove that the ignition system works properly;
- backfire tests according to CS-E 460 – to prove that the engine does not have a natural tendency to backfiring and that forced backfiring does not cause a serious damage.

plus the single-failure tests of the project's team own design to prove that the engine complies to CS-E 50. These experiments consumed a lot of time (some of them run in series, and one repetition could mean 20-150 hours of continuous engine work).

The Risks

Three main groups of risk were identified during the project preparation stage. The first group was expert staff availability. The interdisciplinary character of the design work implied that a number of specialists need to be involved, and it might have been difficult to provide them in time. The client organization had no experience with electronic control systems yet (so no available staff nor organizational knowledge resources in this field). Additionally, it had been some time since they conducted a R&D project ending with an award of the type certificate. In spite of being an approved design organization, they could not rule out the possibility of "forgetting" some procedural activities to the detriment of the project's schedule. The University team had no experience with the requirements of aircraft designs, and there was a risk of not finding an extra expert to solve some specific problems on time – if such emerged. Unexpectedly, the staff availability risk materialized on the side of the certification authority: EASA could not provide a Polish auditor with aviation electronics programming expertise. As the auditors need to be present during the design development (the certification procedure involves supervision of the design process), the project was suspended for about 4 months until an expert from Germany could attend to the duties of the auditor. This explains the delay visible in the third task and the shift in the final task of the schedule presented in Figure 2 in the *Project overview* chapter.

The second group was related with the scope, duration, and cost of tests forming about a half of the project duration and roughly 45% of the budget. The program of each engine certification test was to be previously approved by the certification authority, and the decisions took between 1 and 4 weeks, which was accounted for in the scheduling process. However, the authority is entitled to introduce changes to the scope of tests. Due to this fact, two additional time-consuming and costly experiments must have been included in the program, and one of the tests needed to be prolonged by 50 hours of continuous engine operation. This had a serious impact on the schedule. Automatically, this increased the project costs.

The third group was the effects of potential damage to the tested systems. Most test procedures disallow failures of any of parts of components in the course of experiment. If such failure occurs, the test needs to be repeated after repairs, and if any change to the design is made to prevent the failures, all tests conducted so far need to be repeated. It is logical that only the final configuration of the system is subject to certification procedure, and possibility of repetitive testing is inherent in any R&D project. The risk of project delays grows with the number of tests to be conducted, and this number was considerable. With the tight budget, the project team took a risky decision of not conducting an endurance experiment for checking the product in-house prior to the series of final certification tests. This saved a lot of money. One hour of such test is about EUR 1000 per hour solely in fuel, lubricants and direct labor, and the endurance test should take at least 150 hours of continuous engine operation. However, the cost of the engine's failing during the final certification experiments would be much higher. Luckily, this risk did not materialize.

Conclusions

The issue of innovation in aviation is concisely summarized by Szodruch et al. (2011): "After entering the market, aircrafts are sometimes produced for more than 30 years … the conclusion is that the majority of aircraft in service in 2050 will have 2015 or 2020 technology". It is not the problem of a lack of materials, technology, or ideas. By nature, aviation is not a branch able to promptly implement an invention made in the garden shed. Putting safety first, introducing strict design quality assurance procedures, and proving the technology's readiness only by hard, time-consuming and costly experimental evidence imposes considerable barriers to entry for any new solution.

The case study presented in the paper is a live illustration of the above – a design of nineteen-forties has just matured enough to be modernized by means of automotive solutions from the first decade of this century, to serve for maybe twenty more years, on the basis of a quite reasonable business justification. The project team, partly not familiar with, and partly rusty about aviation project design and implementation procedures, managed to work their way through them, and learnt in the process that:

- there is no sense in planning an aviation project without big time buffers and considerable contingency in the budget; lack of recent experience made the scale of these difficult to estimate;
- it is difficult to combine the traditional project management and fixed baseline schedules preferred by the public funding bodies (supporting the first phase of the project) with the naturally agile environment of a R&D project and its scope changes; one of the side-effect was unexpectedly high workload with "paperwork";
- if a country is not a leader in aviation technology development, the authorities may be not ready to provide assistance on time (long waiting time to get test approvals, limited availability of expert auditors as the main causes of delay).

Acknowledgements

This work was supported by National Centre of Research and Development, Poland, as a part of „EPOCA Device for power supplying and controlling on-board and ground equipment" INNOLOT/I/1/NCBR/2013. The authors gratefully acknowledge the support.

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