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SYSTEM ENGINEERING THINKING ON COMMERCIAL AIRCRAFT FLIGHT TEST

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Abstract

This paper wants to discuss flight test in a system engineering manner to analyze and understand relation, activities and behavior in flight test, then make suggestions to make it more safe and efficient, thus generate high quality aircraft product. The paper will use some methods in model-based system engineering (MBSE) [1] such as stake holder identification and scenario analysis. Then flight test planning and management, enabling tools/methods and flight test role in system engineering V-model are discussed while suggestions are made based on commercial aircraft flight test characteristics.

Keywords: System Engineering, Commercial Aircraft, Flight Test

1. Introduction

Entering 21st century new generation commercial aircraft entering market continuously. Some of them went through flight test in a very short period, for others especially those designed by new comers into commercial aviation market the process could be painful and take years. Except from design problems, flight tests contribute a lot to the delay of these projects.

Before 2020, people can observe how fast a Boeing or Airbus new aircraft type from its maiden flight to delivery to airline. But 2019 Boeing 737 MAX accidents raise global concern on aircraft safety. Flight test did not play an effective role in finding the system design flaw and prevent accident happen before 737MAX entering market. From a system engineering perspective, the verification and certification process in Boeing met problems. And now in 2021, FAA call for 777X program TIA (Type Inspection Authorization) delay is a big remark to changing of attitude between the giant two (Boeing and Airbus) with authority.

These two problems above all relates to commercial aviation flight test. And problem met could be summarized as how to improve the flight test and airworthiness system to generate safer product and maintain project schedule. The author would rely on system engineering to reach these goals. Act as verification process in V model in whole aircraft project, flight test should apply system engineering philosophy in its planning/management/fault correction and product change procedures better and feed back to previous system engineering steps better, especially in a model-based system engineering era.

Also, from the real working experience of Chinese commercial aircraft flight test. This paper wants to discuss the issues found in flight test and give some advises on improving the flight test for Chinese aviation industry.

There are several books introduce domain technologies of flight test such as flight dynamics, flutter testing, telemetry, instrumentation or data processing [2] [3] [4] [5] [6] [7] [8] [9]. This paper won't fall into these domain technologies, instead the focus is on how to taking the system engineering philosophy, methods and tools into flight test to improve its efficiency and quality. This paper focuses on system engineering's role, which can facilitate flight test activity and generate better aircraft product, in coping with the commercial aircraft flight test characteristics. It will start with stake holder analysis in the complicated environment and then discuss the planning and management of flight test, finally to deeper to the technology and organization level to find points that could perfect the process.

2. Commercial Aircraft Flight Test

Flight test is among other nine means to show compliance to airworthiness regulation [10] like ground test, lab test, calculation, and perhaps the closest to the real using environment. It is the final design phase of an aircraft type before it can enter into markets. There are several characteristics of commercial flight test that would deeply affect the planning and execution of it, include:

- Multi-stake holders: as the design process has come into an end, and starting of authority and customer involvement the direct stake holders are high in this phase;
- Multidisciplinary: include all aspects from system engineering and project life cycle as well as all aircraft system/major;
- Validation &verification (V&V) process in system engineering process: any type of test is designed to try to validate or verify something, especially for aircraft project which following system engineering process that would require V&V activities to complete the design cycle;
- Complicated configuration management: configuration is not fix and constantly changing affected by supplier delivery, product change, subsystem flight test planning and execution;
- Certification activities deeply involved: whole flight test process is under authority's inspection.

Multi-stake holder, multidisciplinary and configuration management requires high level of project management and coordination, which thus generate high demand for IT and efficient enterprise architecture (EA). V&V process would require all previous system engineering steps input and give a close loop result as a good ending for product design phase. Dual role of validation &verification (V&V) process in system engineering process and show compliance to airworthiness regulation require same result closing different processes.

The general process of commercial aircraft flight test (some represented by key output document) is: flight test requirement−flight test plan−manufacturing/configuration conformity inspection−flight test mission list−flight test execute/telemetry−flight test data process−flight test result report. This process is categorized by aircraft systems, majors and different subjects. Each subject will go through a complete process above and most of these activities would require airworthiness authority's inspection. Commercial aircraft is a typical complex system of systems, the number of items of flight tests of an aircraft type finally would reach a level of hundreds.

Certification is a big concern in commercial aircraft flight test, it is the purpose of flight test. And it is the conjunction point between flight test and public safety. For countries don't have much experience in commercial aircraft project, certification is a challenge both for aircraft manufacturer and airworthiness authority. Authority's prudent attitude toward new aircraft type with no organization design approval for new aircraft OEM may prolong flight test and cause delay.

3. Flight Test System Engineering

System engineering has multi-effect which include helping project planning, facilitate R&D process, increase process efficiency, fulfill system objective, reduce unexpected behavior, reduce change, and cost. It has infiltrated all aeronautical engineering aspects including design, manufacturing and project management, but system engineering was seldom discussed in the background of flight test. This section using system engineering modelling method to analysis commercial aircraft flight test activities. Start with stake holder analysis in the complicated environment and then discuss the planning and management of flight test, finally to deeper to the technology and organization level to find points that could perfect the process. There are two kinds of discussions between system engineering and flight test, one is how system engineering method and thinking could promote and facilitate flight test, the other is flight test's role in whole aircraft design system engineering

process(V-model). This section will discuss both these topics.

3.1 Scenarios and Stake Holder Identification and in Commercial Aircraft Flight Test

As aircraft design V-model coming to an end, stake holders accumulate to a peak. Understand the interests and position in this activity is important. Stake holders of flight test are identified from the business flow. From up, middle and downstream of business flow stake holders are identified and shown in Figure 1.

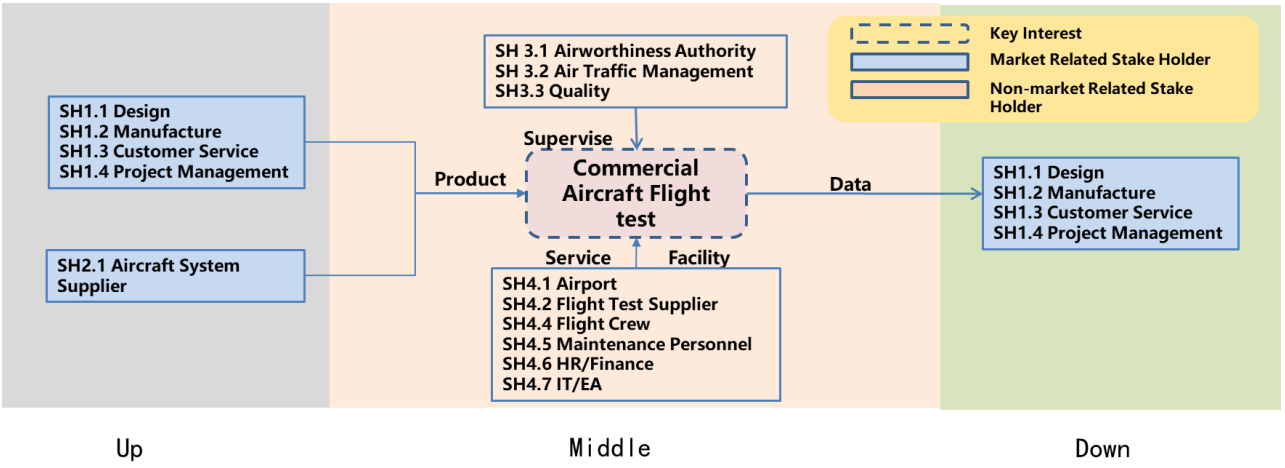

Figure 1 – Example of a figure.

Stake holders are also identified from operation scenario, the steps are shown below.

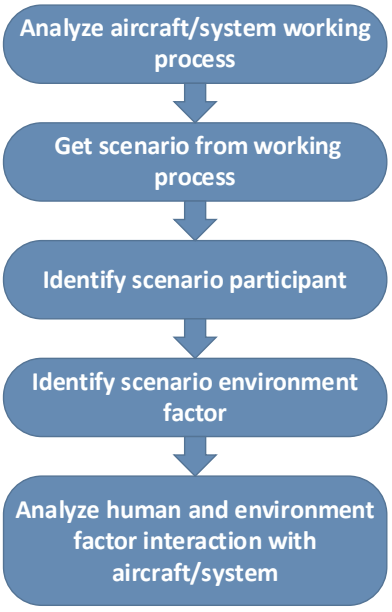

Figure 2 – Scenario Analysis Process

As introduced in section 2, general process of commercial aircraft flight test could be used as different scenarios in commercial stake holder identification. So, scenarios are identified as: test plan and document preparation and submission, planning, manufacturing/configuration conformity inspection, flight test/telemetry, result generation, feedback, certification activities and aircraft modification. Stake Holders action at each scenario are show below.

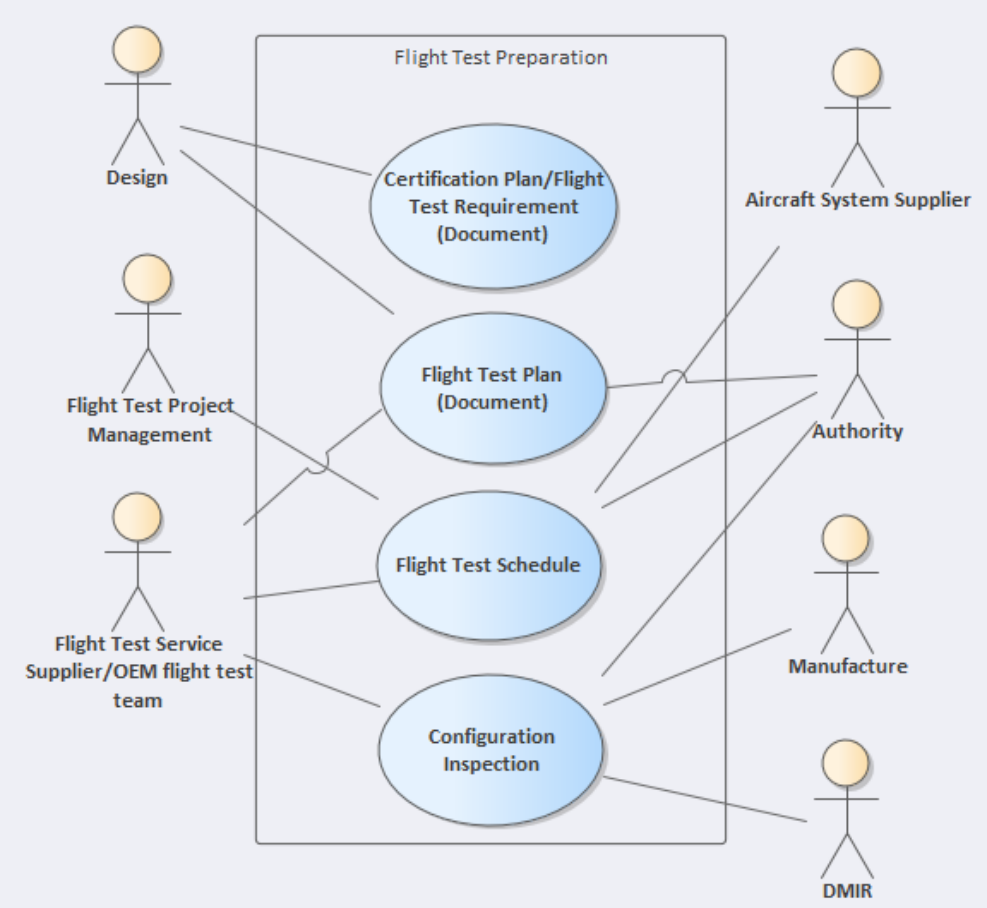

Fig 3 Flight Test Preparation

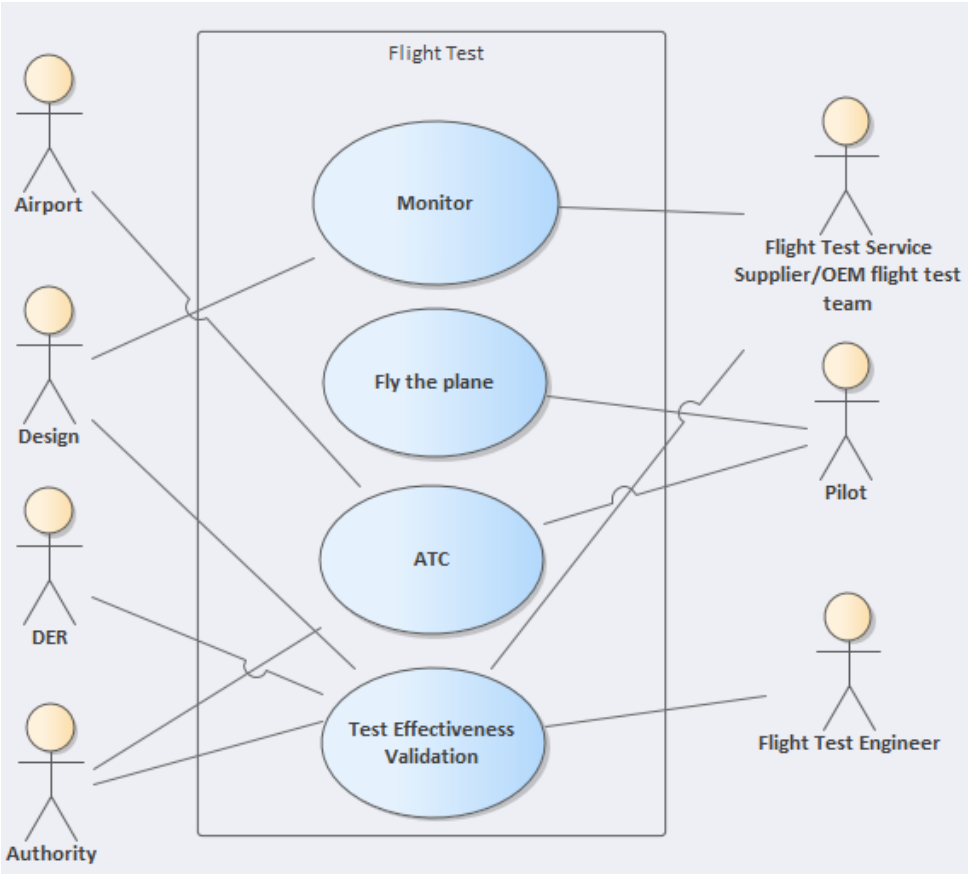

Fig 4 Flight Test Scenario

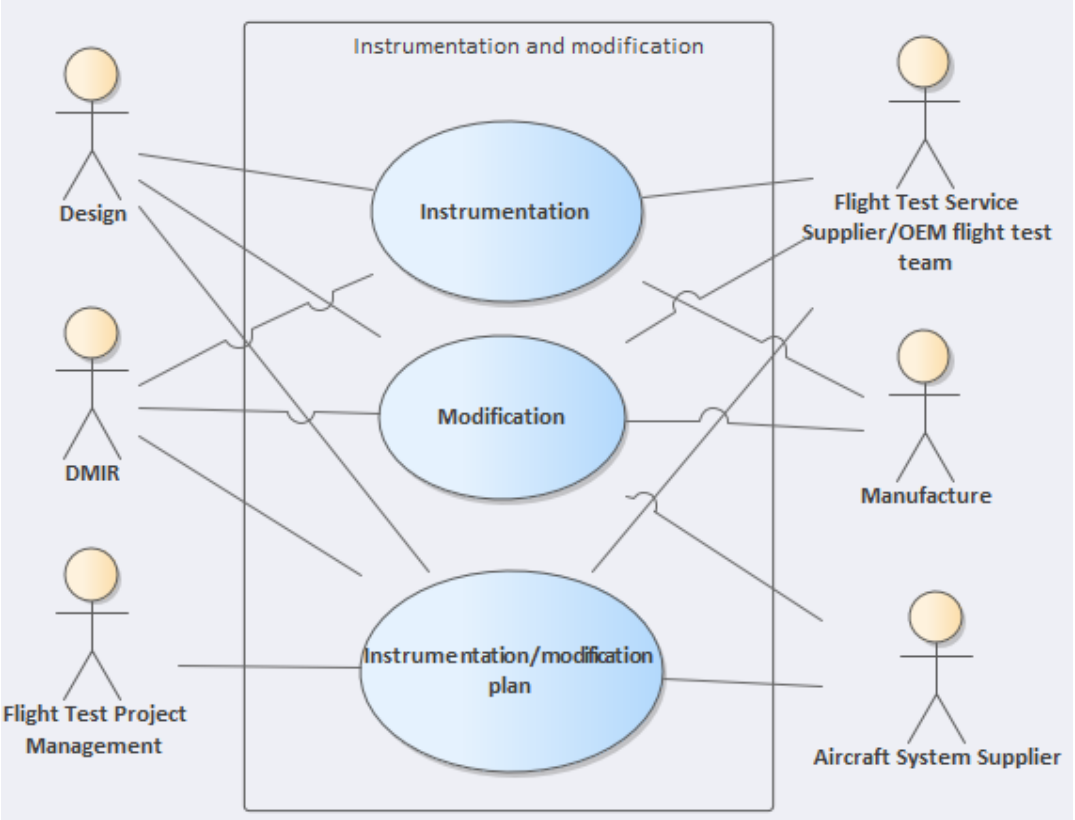

Fig 5 Instrumentation and modification

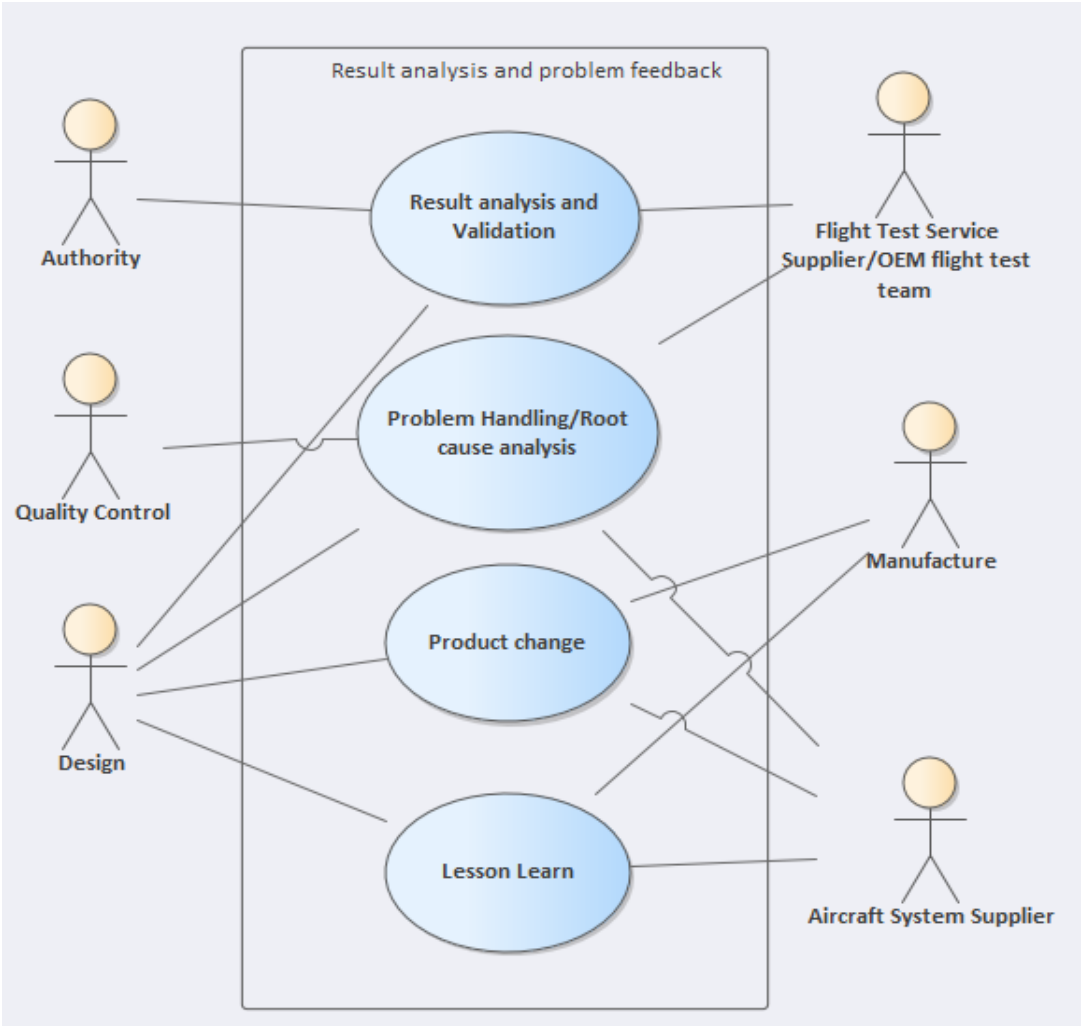

Fig 6 Data analysis and product change

As the stake holders' involvement is clear, it is possible to discuss other key aspects that would affect flight test.

3.2 Flight Test Planning and Management

In commercial aircraft project, certification process, project management and system engineering V process go parallel and correlated between each other. FAA certification guide [11] lists project phase together with certification phase. And International Council on Systems Engineering (INCOSE) has worked with Project Management Institute (PMI) to combine the force of project management and system engineering applied in real aviation project [12]. As a test of system of systems, items of commercial aircraft flight test could reach hundreds to thousands. Therefore, planning and management to such a complex task is crucial. The flight test planning and management team should work closely with aircraft project management and system engineering team since they all face most of aircraft majors and flight test is key to whole aircraft project certification and success.

The first aspect discussed here is the possible combination of different kinds of flight tests and reduce test point. In Chinese commercial aircraft projects, there are three categories of flight test: research and development flight test, which is designed for aircraft OEM design department to verify the real produced aircraft performance is close to simulation and design target; compliance flight test is used to show the test result conform to airworthiness regulation; certification inspection flight test fly by authority's pilots check selected item among compliance flight test. Planning and combination of these three types of tests is a big task and could save a lot of flights to reach certification. But it will require many stake holders to corporate in this planning. The reduction of flight test point should base on functions and requirements need to be tested, so link of flight test to function design and requirements should be constructed at early phase of flight test.

The considered ways include:

- Do as much as mock up test and on ground test to increase system maturity and confidence to reduce R&D flight test;
- Use statistics method (hypothesis testing) to select proper test point, if the test point is reduced the flight will be reduced accordingly;
- If the R&D flight test is good the result could direct used to show conformity (need configuration management record);
- If the aircraft manufacturer is confident enough and well prepared the OEM can ask authority to do certification test directly and the result of course can used to show conformity.

Second, good configuration management is key to success of flight test. This is shown in several aspects:

- Configuration control is important for flight test safety;
- Configuration is necessary information provide to authority for certification;
- For the reason of system supplier development and delivery time, flight test aircraft hardware/software may not be mature part, which may need constant upgrade;
- Certain test subject would require specific configuration, so configuration is often bounded with flight test execution thus affect flight test planning and schedule;
- Flight test instrumentation would have big impact on configuration and onboard instrument will also need configuration management.

In aircraft design, requirement traceability and testability design go down into system, subsystem level, as the left part of V-model. Same thing should be considered for design of verification methods. Flight test is one of these verification methods.

Some commercial aircraft projects choose flight test service supplier to do the flight test together with aircraft OEM. But this would not always be an easier way to certification. The cooperate flight test would involve in huge amount of coordinate task and cause a big triangle relation between

aircraft OEM, flight test service supplier and certification authority. Careful decision should be made before choosing this mode and clear working mode should be considered and defined as early as possible before execution.

Last but the most important thing is balancing flight test safety and schedule. Schedule is bounded tightly with fiscal and market success but too much emphasis on it would fail the project. B737 MAX has raised alarm on this topic. B787 also cause many troubles [13] when it first entry into market. A proper design would require a state of art technique and true ingenuity to reach this balance, so dedicated flight test personnel and department would be necessary for large OEM to steady accumulate flight capability and their opinion has to be respected by management level to reach a full success for the project. Another possible solution to this contradictory topic is through risk management [14].

3.3 Flight test from a system engineering point of view

There are two aspects in system engineering: one is from V-model design break down and synthesis point of view, the other is from a multidisciplinary point of view which combines system of systems from all engineering majors [15] [16] and RAMS (Reliability, Availability, Maintainability, Safety) majors. Flight test matter much in both these two aspects.

So, in the first perspective requirements capture flow down and traceability is key. At beginning of aircraft project, system engineering team in charge of aircraft level requirement capture and architectural/functional design phase should include flight test requirements in the requirement architecture. And the part of aircraft level requirements verification plan related flight test should be validated with flight test department as early as possible.

In the second perspective, systems and engineering majors will need to use this chance to verify its design meet the aircraft/system requirements they got. And the verification activity is used to close the aircraft design V-model. The flight test engineer should also work as a system engineering V&V engineer to consider combination of flight test point used to close verification process in system engineering related to system requirements and aircraft requirements and the test point to show conformity to airworthiness regulation. While validating and verifying the real product, process and simulation/analysis models built during design and analysis phase should also be included.

In execution of flight test, faults and product changes made in flight test not only should feedback to aircraft system/major but also trace back and link to functional design and requirement, especially safety related requirement capture as a standard fault handling process. This is already done by some of PLM system suppliers like Siemens.

3.4 Tools and IT/EA Relate to Flight Test

In the age of industrial 4.0 to perform complex engineering activities like flight test a set of applicable digital tools and system is necessary whether to ease the process and to keep the project’s quality. So, this part different kinds of system engineering digital system or tool would be discussed.

As a project itself, flight test’s sub activities are deep correlated together. One system’s flight test schedule, ground test or configuration readiness would affect the other system’s flight test execution. For the planning and project management, integrated master plan [17] and project management IT tool that automatic change by the correlation could be considered for planning and schedule of flight test.

Further, if goes deeper into process, activity and behavior level need-function-requirement-physical (NFRP) [18][19] and MBSE modelling method will be useful for system and process analysis. From real experience, it is found that EA and process architecture are crucial to project since commercial aviation is a process-based system to keep the operation safety, so as the commercial aircraft flight test. The document, hardware/software flow would rely on the process and IT system. But with too much stake holders in the loop the process has become enormously complicated and has even became a social-technical system that would affect the efficiency of flight test operation. This conclusion is also extending to the whole aircraft design project. So, EA system should be emphasized here. The Enterprise Architect's job is to design organizations and enterprise IT systems,

seen as social-technical systems, in other words as the result of the coupling of business organizations and computer systems. The key activities of the Enterprise Architect are:

- Needs and requirements engineering
- Enterprise architecture & modelling
- Collaborative Steering

The skills of the Enterprise Architect

1. Needs and requirements engineering
- Building and modelling the enterprise's needs architecture
- Building and modelling the enterprise's requirements architecture

2. Enterprise architecture & modelling
- Analyzing and building the architecture of the environment of an enterprise
- Analyzing and building the enterprise's business architecture
- Analyzing and building the IT architecture of an enterprise
- Building an integrated enterprise transformation roadmap
- Modelling the architecture of the environment of an enterprise
- Modelling the business and IT architecture of an enterprise
- Modelling an integrated enterprise transformation roadmap

3. Collaborative Steering
- Building the organizational architecture of a transformation project
- Ensuring collaboration between the actors of an enterprise transformation project

So, system engineering modelling language like SysML [20] [21] or ARCADIA [22] are necessary to help EA architect the process of flight test. Then requirement management tools are necessary to keep the flight test system goes as designed as well as to trace system/aircraft requirements and regulation articles to flight test item, thus to keep up with all previous steps in aircraft design V model.

In configuration area the traditional PLM (Product Life Cycle Management) system can applied in document control and worked partly as enterprise process control. And in the hardware control area configuration management currently is done by 3D CATIA product which can extend to the latest digital twin philosophy.

Although not applied now new technologies should find its good application opportunities in flight test. Like digital twin for configuration management and preventive maintenance in aircraft health condition control.

Finally, in the solving big aircraft engineering problem found in flight test NFRP should be applied to reach a systematic result and fulfill the safety requirement.

4. Future Works and Discussion

This paper discusses the possible system engineering application in commercial aircraft flight test based on pain and gain from real engineering experience. Characteristics of commercial aircraft flight test are summarized and system engineering solution are presented. Some new idea like MBSE, EA and digital tools are put up as new advancement happened in system engineering.

Still there are much to do to complete the job presented here.

The stake holder identification could expand to a full need-function-requirement-physical analysis of flight test to better analyze the activities and optimize the process and EA system go with it.

The application of new technologies like digital twin and aircraft health management in flight test could be further explored. Combination of health management/aircraft monitor system [23] with flight test instrument system could be considered.

Lack of valid testing in flight test phase and path to certification on innovative technologies still hinder the incorporation of new technologies into commercial aviation, thus slow the evolution speed of commercial aviation.

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