AIRCRAFT DX IN COMMERCIAL AVIATION SYSTEMS

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Abstract

MHI (Mitsubishi Heavy Industries, Ltd.) is developing the innovative process for commercial aviation systems applying DX (Digital Transformation) /MBSE (Model Based Systems Engineering). The targets in our DX challenge are to establish the digital thread of aircraft lifecycle data in order to improve the visibility from all the stakeholders and enhance the QCD (Quality, Cost, Delivery) for customers. Our DX activity can be categorized into two areas, national DX project for future airplane development and company internal DX activity as Tier 1 manufacturer. This paper introduces our DX challenges for both future and on-going programs.

Keywords: DX, MBSE, Commercial Aviation Systems, Digital Thread, Traceability

1. Introduction

In the commercial aviation domain, MHI group has 3 major capabilities, OEM (Original Equipment Manufacturer) mainly obtained in MSJ (Mitsubishi Space Jet) program, Structure Tier 1 including 787 main wing production with the advanced composite material, and MRO (Maintenance, Repair and Overhaul) in MHI RJ Aviation (see Figure 1). MHI believes we have a potential ability to explore new business schemes by integrating these various capabilities.

Figure 1 – MHI 3 major capabilities in the commercial aviation domain

The importance of DX is increasing in commercial aviation. In general, DX can contribute to realizing common language for multidiscipline collaboration, digital thread for increased visibility, process improvement for standardized way of work, and agile work process. Recently major OEMs started requesting model-based data exchange capability to stakeholders in their supply chain. For example, Boeing plans to implement MBE (Model Based Engineering) framework for new project together with partners [1]. In this framework, Boeing stated MBE is an approach to product development, manufacturing, and lifecycle support that uses a digital model and simulation to drive first time quality and reliability. Partner's capability of model-based data exchange will be assessed by OEM before the selection in future programs because the data interoperability will drive the level of digital integration in the program. Boeing mentions that the capability of model-based data exchange creates the value of risk management for OEM and market competitiveness for suppliers [2]. It means MBE capability will be a kind of tickets to join the new aircraft development with major OEMs.

DX/MBSE is one of the key methodologies to maximize the profitability of company resources in new business scheme. With supports from Japanese national project by NEDO (New Energy and industrial technology Development Organization), MHI is conducting the research program on the innovative aircraft development and production process applying DX/MBSE to integrate the overall development process and establish the digital thread of lifecycle data. In NEDO aircraft DX project, MHI is participating in three activities, Design DX, Certification DX, and Production DX utilizing MBSE and advanced analysis tools. On the other hand, MHI needs to continuously proceed DX for on-going program as Tier 1 manufacturers to keep the market value of our products. In this paper, company internal DX challenges for Tier 1 products are also described.

2. MHI Commercial Aviation Systems

2.1 OEM Capability

MHI launched MSJ regional jet program in 2007. Although the program was terminated in 2023 due to the change of market environment, MHI has established the variety of internal procedures for type certification and acquired capabilities as follows.

- Aircraft integration with global partners
- Whole aircraft manufacturing
- Development assurance complying ARP4754 [3]
- Safety analysis complying ARP4761 [4]
- Software / complex hardware development assurance complying DO-178 [5] / 254 [6]
- Type certification process against the latest regulatory requirement
- Flight test operation with 8 flight test aircrafts
- Over 3000hr flight test

Figure 2 [7] shows the overview of MHI's aircraft development capability acquired in MSJ program. MHI experienced whole aircraft development V process from top level customer requirement to the aircraft level verification. In the system verification, MHI prepared various test facilities including Iron Bird, flight simulator, structure test facility, and worked together with global system partners. Through the entire program, aircraft integration was a critical issue.

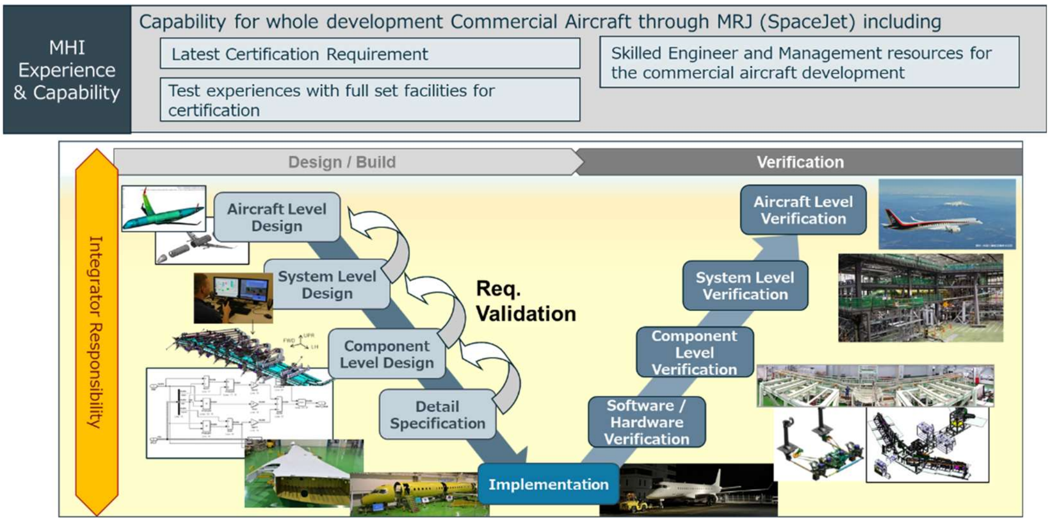


Figure 2 – OEM Capability obtained in MSJ program.

One of the lessons learned in the program is the importance of traceability in development process. MHI prepared internal detail procedures to secure the process assurance according to ARP4754 and DO-178/254. However, in MSJ development, the procedures needed to be modified to keep the traceability against considerable design changes within acceptable schedule impacts. Huge amount of workload for design change activity were also required due to the low visibility of design data traceability. Through these experiences, MHI decided to start MBSE/DX research activity to establish more advanced development assurance process for next program to increase MHI competitiveness in the market.

2.2 Structure Tier 1 Capability

Figure 3 shows the overview of MHI Tier 1 products. MHI supplies a diversity of commercial airplane products to the world leading aircraft manufacturers. A lot of advanced technology are applied to achieve the high production rate and high quality, like 787 advanced composite wing production. As a result, MHI achieved remarkable accomplishments as high production rate (14 shipsets per month) and stable production with over 1100 shipsets deliveries.

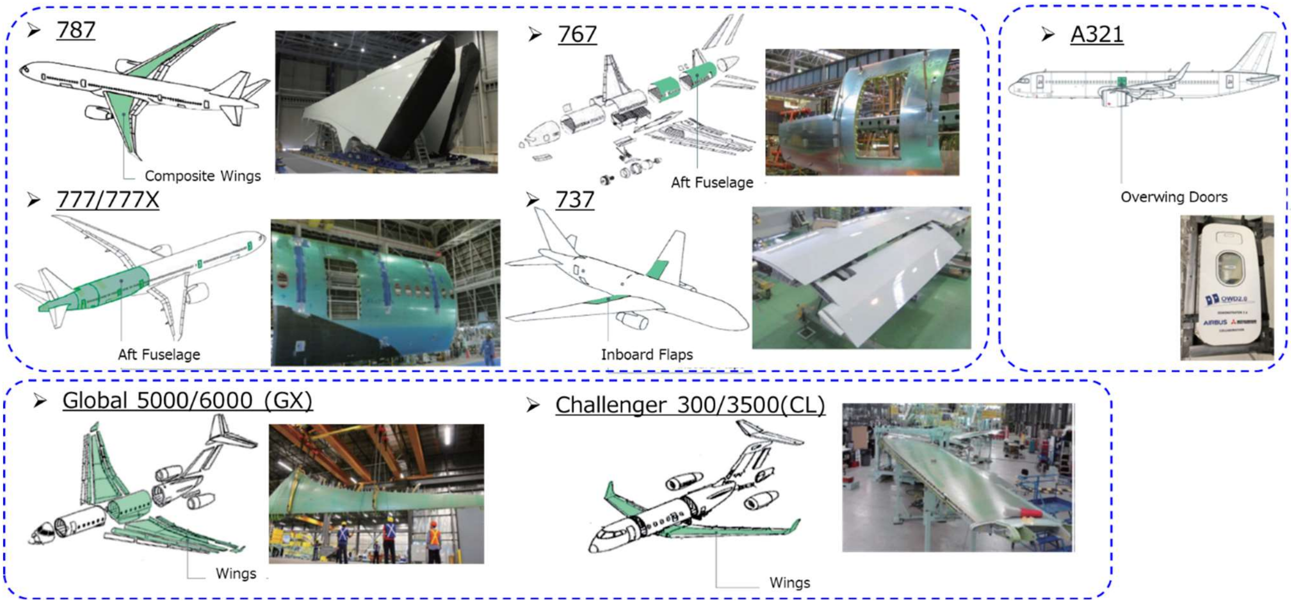


Figure 3 – MHI Tier1 Products (from MHI Homepage)

The enhancement of QCD in Tier 1 business is always required to keep the market value of the products. MHI believes DX will contribute to QCD, however, the critical challenge is that DX should be implemented with keeping the current stable production.

3. DX Activity in MHI Commercial Aviation Systems

MHI DX activities in commercial aviation systems can be categorized into the two areas, NEDO aircraft DX project for future commercial airplane and company internal DX challenges for Tier 1 production. MHI plans to integrate these two outputs for future developments.

NEDO aircraft DX project is top-down approach to create innovative development process, and Tier 1 DX challenge is bottom-up approach which can be applied to the existing program step by step. In aircraft industry, these both sides DX approaches are inevitable because the lifecycle of the products is more than 20 years. Therefore, aircraft manufacturer needs to prepare new DX process and tool for next development while continuously improving QCD in the existing programs. This section shows the overview of NEDO aircraft DX and Tier 1 DX.

3.1 Overview of NEDO Aircraft DX Project

Figure 4 [8] shows the concept of NEDO aircraft DX project organized by JAXA (Japan Aerospace Exploration Agency). The project objective is the innovation and process integration in aircraft development, and the goal is to enhance the international competitiveness of the Japanese aircraft industry. The advanced technologies for development and manufacturing processes will be demonstrated by utilizing DX such as MBSE methodology. In the project, we will apply the developed process to next generation aircraft which will contribute to decarbonization. Advanced air mobility, automobiles, ships and space vehicle are also candidates to be applied and the outcome can be used in any future program.

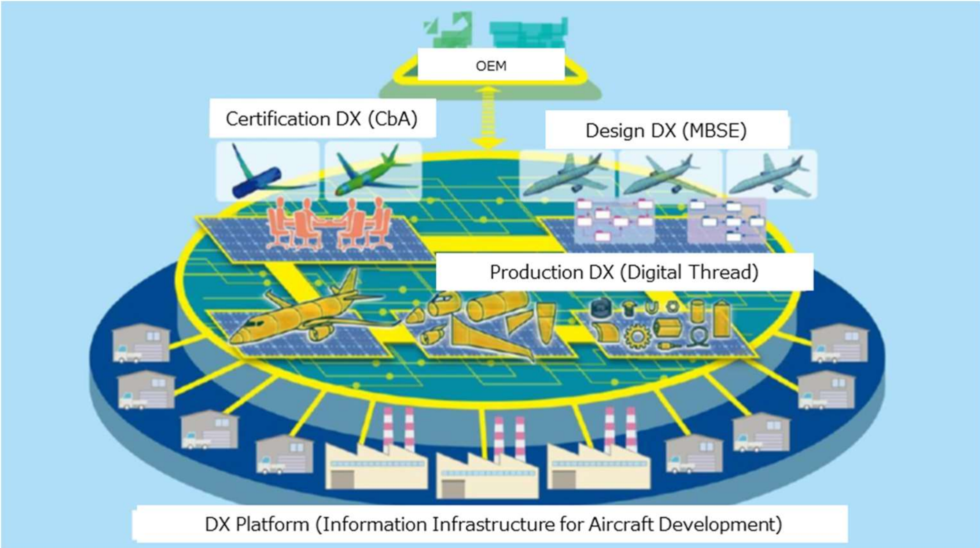


Figure 4 – NEDO Aircraft DX Project

The activity consists of the 4 categories, Design DX, Certification DX, Production DX, and DX Platform. Figure 5 [8] shows the map of each activity in V process. The project is being executed in the collaboration with Japanese major aircraft and engine manufacturers under the leadership of JAXA. Design DX covers the upper left portion, from the stakeholder requirement to aircraft and typical system design as air management system, propulsion system, and actuator design in flight control system. The bottom of Design DX activity overlaps the top of Production DX with model-based specification in MBSE methodology. Production DX covers the lower portion from model-based specification to 3D geometric model, MBI (Model Based Instruction), and other manufacturing preparation. The research on Digital APQP (Advanced Product Quality Planning) and Smart Supply Chain are also conducted in Production DX. Certification DX covers upper potion in V process, starting from regulatory requirements in the left side, reaching to TC (Type Certification) compliance document using CbA (Certification by Analysis) approach. Between them, certification plan using model-based MoC (Means of Compliance) will support the discussion with authority. With CbA approach, some of TC tests will be replaced with analysis in order to reduce the cost and time in TC activity. DX platform, being developed by JAXA, will host the required data and manage the interface with stakeholders.

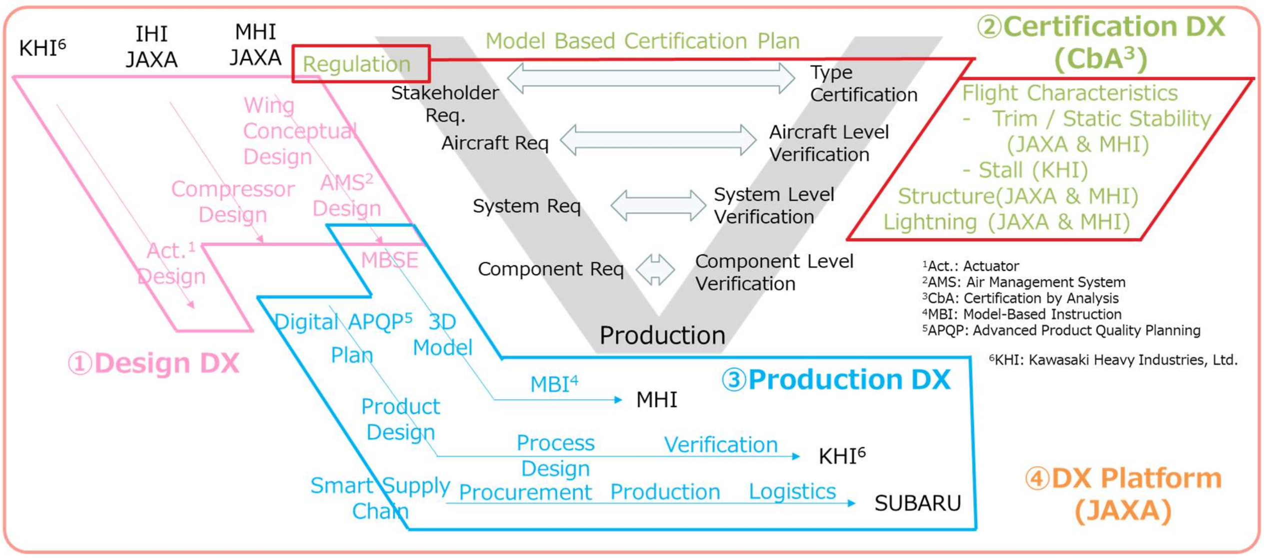


Figure 5 – Map of NEDO Aircraft DX Project

The details of MHI activity in the project will be explained in Section 4.

3.2 Tier 1 Production DX

The target of tier 1 production DX challenge is customer satisfaction by enhancing quality, improving cost and reducing lead-time. The strategy is to apply DX in the following domains.

- Integrated Supply Chain
- Stable Production
- High Quality
- Digital Traceability

In this section, some typical examples are explained. The first one is DX in “Integrated Supply Chain” and “Stable Production” shown in Figure 6. MHI is establishing the supply chain control system to collect digital data from global suppliers. This system can be used as a communication tool to solve issues by improving the visibility of global supply chain, analyzing the reason of troubles, and supporting the execution of necessary countermeasures. The data will be shared with OEM and suppliers to maintain the total stable production.

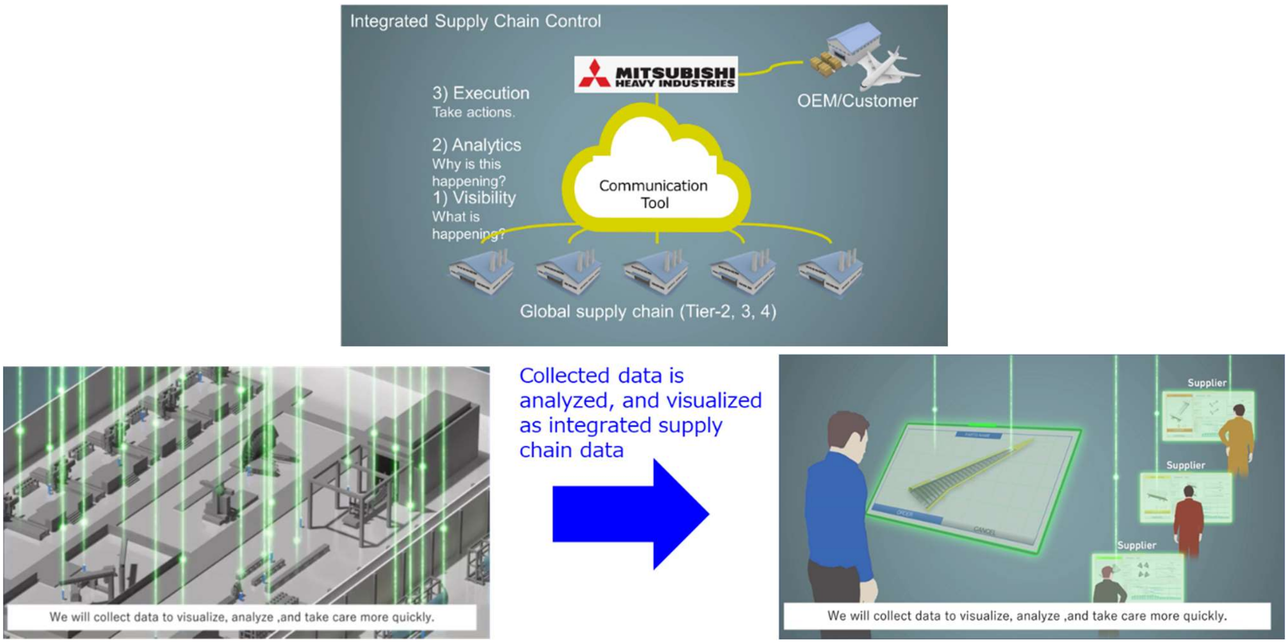
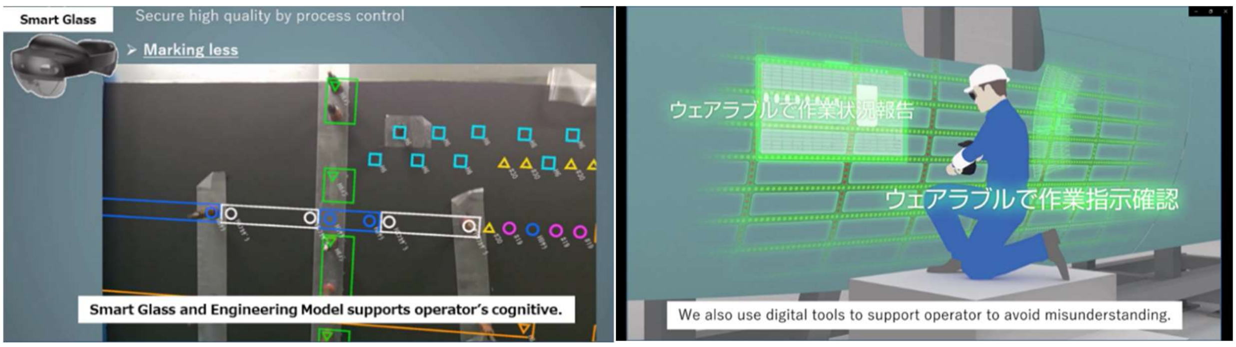


Figure 6 – DX for Integrated Supply Chain

The next is about “High Quality” in assembly manufacturing process. Figure 7 shows the system with smart glass to support worker’s cognitive by avoiding misunderstandings of the tasks. The supporting information is overlayed on the working object as AR (Augmented Reality) through the smart glass. MHI also established the system that worker can check the instructions with tablet PC. In the future, this tool will be integrated into MBI linked with the data in PLM (Product Lifecycle Management) developed by NEDO aircraft DX project.



(a) View from Smart Glass (b) Operation Image with Tablet PC

Figure 7 – DX for High Quality in Assemble Phase

The final example is about "Digital Traceability" in parts and assembly manufacturing phases, shown in Figure 8. From the material purchase phase to delivery, various production data related in suppliers and MHI is collected and linked. MHI is developing database system with scanning barcode to provide the quality record of material, parts and assembly to customer OEM. With tablet PC linked with the system, OEM and MHI will be able to assess the impacts and execute the countermeasures efficiently once any troubles happen in the production lifecycle.

Figure 8 – DX for Digital Traceability

The results of these Tier 1 DX are continuously applied to the on-going program, furthermore, they can be integrated into new innovative production process developed in NEDO aircraft DX project.

4. NEDO aircraft DX Project

NEDO aircraft DX project started in 2023, plans to complete in March 2028. MHI is participating the activities in Design DX, Certification DX and Production DX. The Figure 9 shows the overview of MHI activity in this project. SysML (System Modeling Language) application plays core role to establish the digital thread among design, certification and production. The compatibility between analysis tools and the SysML models enables more automated design trade-off and optimization, which reduces the manual tasks in design activity. Furthermore, the linkage between SysML model and 3D model can integrate design and production regardless of the boundaries among sections or companies once standardized process be established. SysML model is also applicable to certification activity as a single source data set in the discussion with authorities. Another core technical player is advanced analysis tool. The significant progress of simulation technology can reinforce its availability from the beginning to the certification phase in the program. The adequate ROM (Reduced Order Model) method makes easier to apply simulation analysis in the conceptual design phase, more accurate simulation realizes less type certification test in the final phase of development. MHI plans to utilize these advanced DX technologies in overall aircraft development.

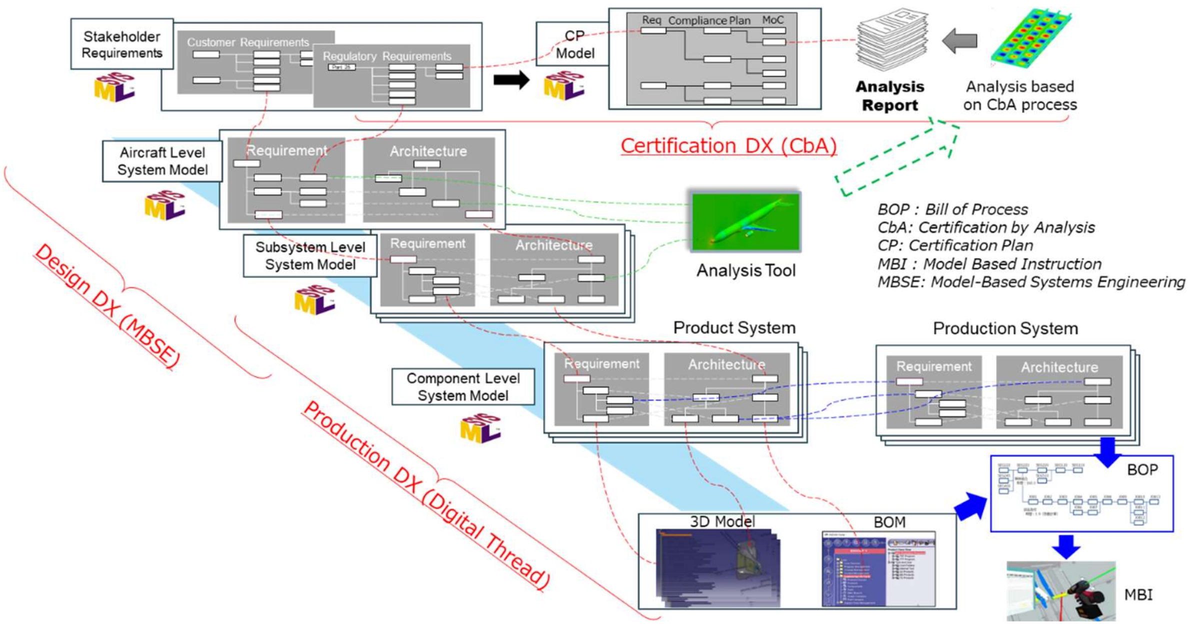


Figure 9 – MHI Scope in NEDO aircraft DX Project

4.1 Design DX

In Design DX, MBSE methodology is applied to integrate the complicated aircraft systems. System Model, which describes aircraft requirements, architectures, and parameters in SysML, is prepared to manage the aircraft development with rigorous information in single data source. Another advantage of applying SysML is the compatibility with various analysis tools. MHI and JAXA plan to develop low calculation load but high-fidelity analysis tools which will be linked with System Model to realize more automatic optimization in the design process. From development assurance point of view, System Model combined with the analysis tool can reduce the efforts to show compliance with ARP4754. In general, V&V process is one of the most time-consuming tasks in recent commercial aircraft development. The proposed integrated process and tool can potentially reduce the workload to prepare the artifacts for requirement validation, especially by the method of traceability, analysis and engineering review. The template of System Model contains the information to support showing compliance with ARP4754. The harmonization with the activity in SAE (Society of Automotive Engineers) S-18 "Aircraft and System Development and Safety Assessment Committee" is also considered in our new process and System Model development.

Figure 10 shows the image of the linkage between System Models and analysis tools. In each design level, such as aircraft level or subsystem level, candidates of design parameters are defined in System Model. The parameters are transferred to the analysis tools like CFD (Computer Fluid Dynamics) and performance analysis tool. The pass or fail against design requirement is automatically judged for multiple design candidates. This process can support set-based design approach [9], which enables to deal with multiple design solutions through the development phase especially of novel design aircraft program.

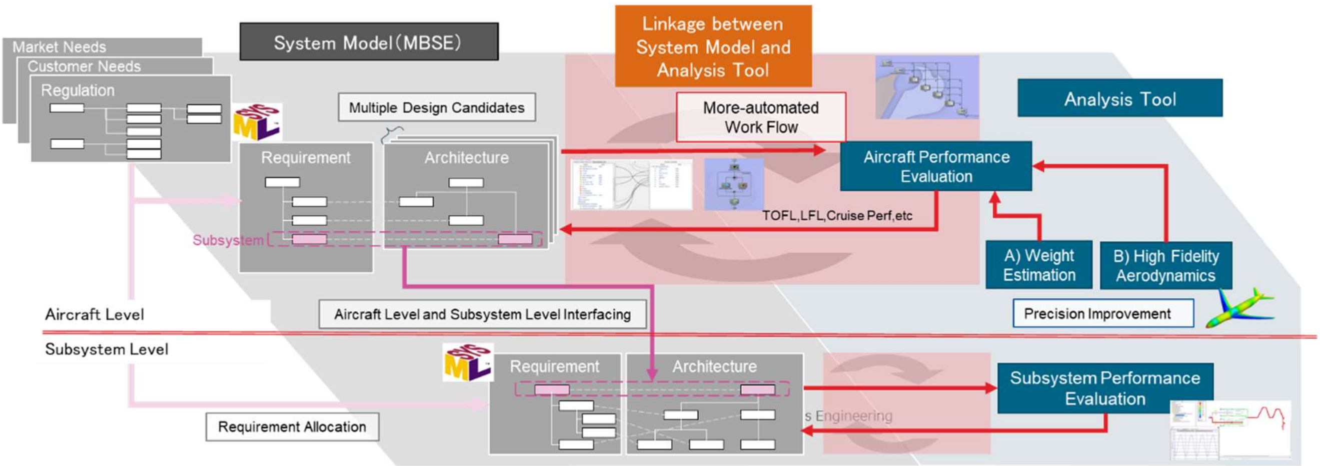
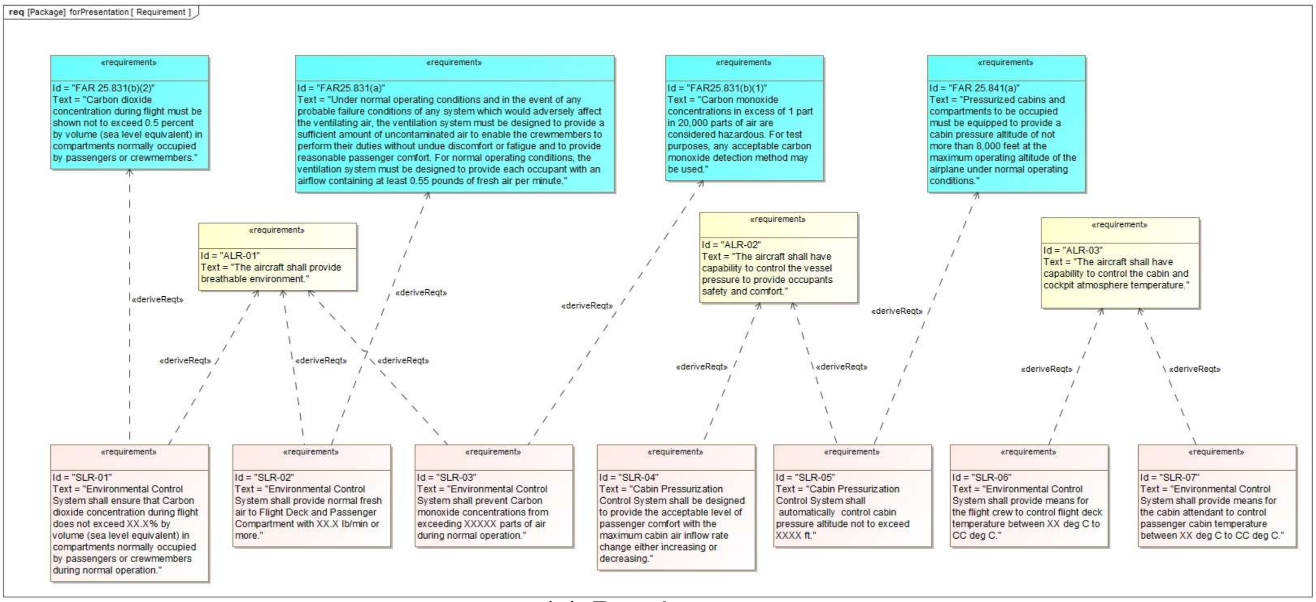
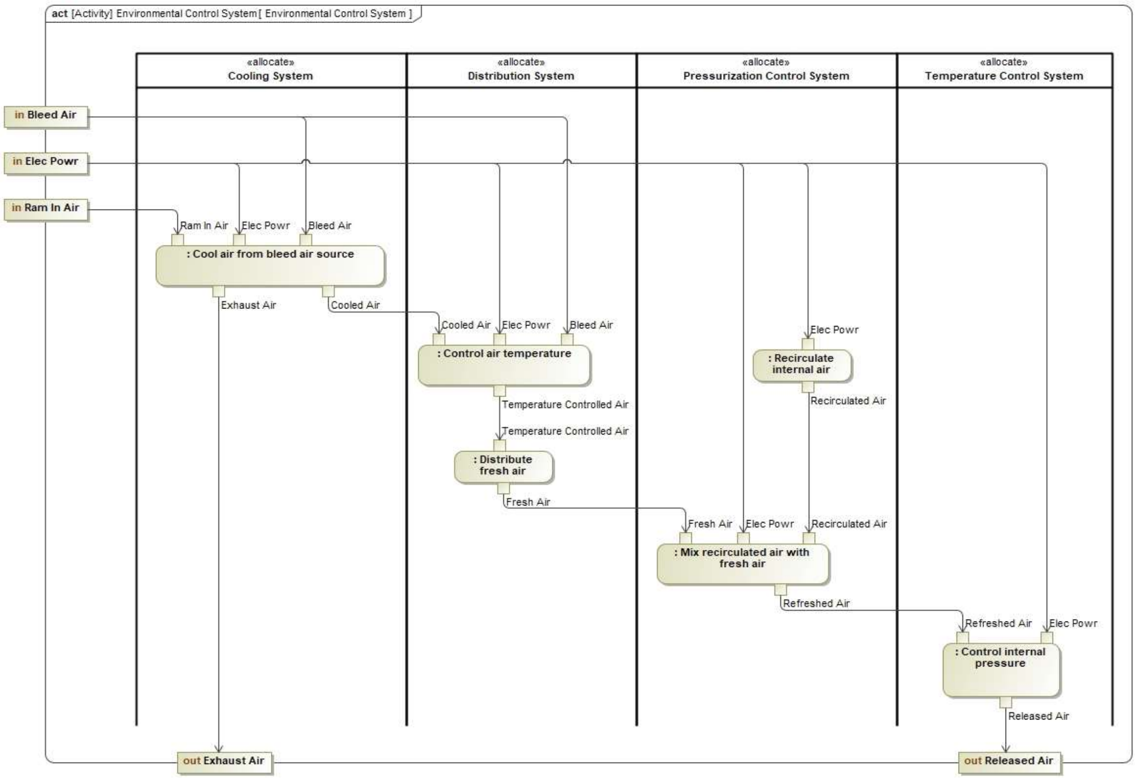


Figure 10 – System Model linked with Analysis Tool

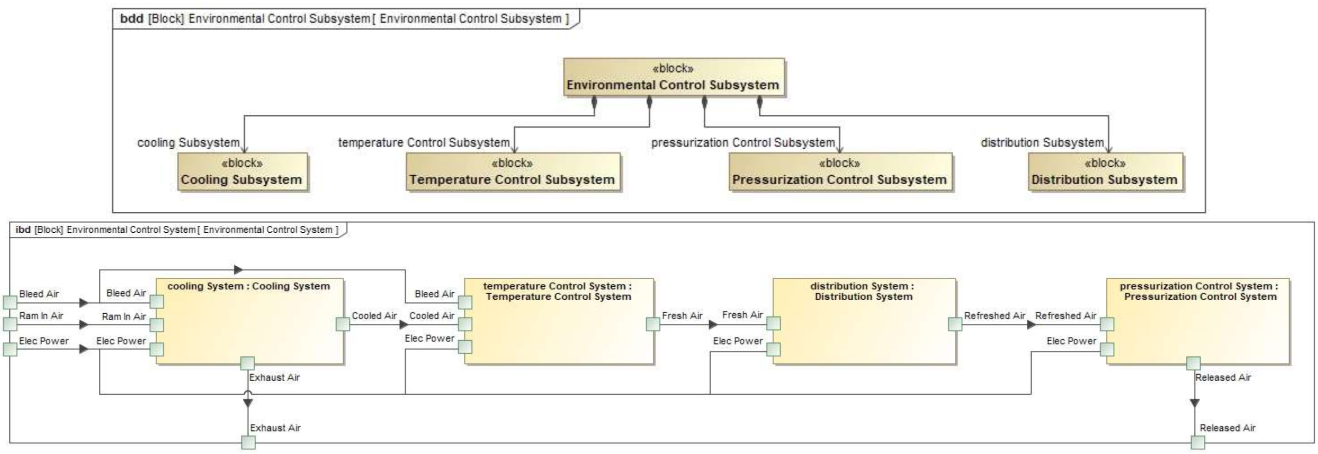
Figure 11 shows the snapshots of System Model for air management system in subsystem level. These System Models will be integrated from aircraft level to subsystem level based on MSJ development data, and they will be linked to the analysis tools.



(a) Requirement



(b) Functional Architecture



(c) Physical Architectures

Figure 11 – Snapshots of Air Management System Model

4.2 Certification DX (CbA)

In Certification DX, MHI and JAXA are developing CbA process in 3 areas, flight characteristics, structure, and lightning. Replacing some certification tests with analysis will provide a lot of benefits such as certification at lower costs while maintaining equivalent level of safety. Figure 12 shows the overview of our CbA challenges, the results will be summarized as a practical guideline which will be published. The benefits of CbA provide a strong motivation for developing the advanced modeling and simulation, VVUQ (Verification, Validation, and Uncertainty Quantification) process, and other related technologies. In a public space, the discussions about guidelines and recommended practices are in progress at the working group of ASME (The American Society of Mechanical Engineers), AIAA (American Institute of Aeronautics and Astronautics), and SAE.

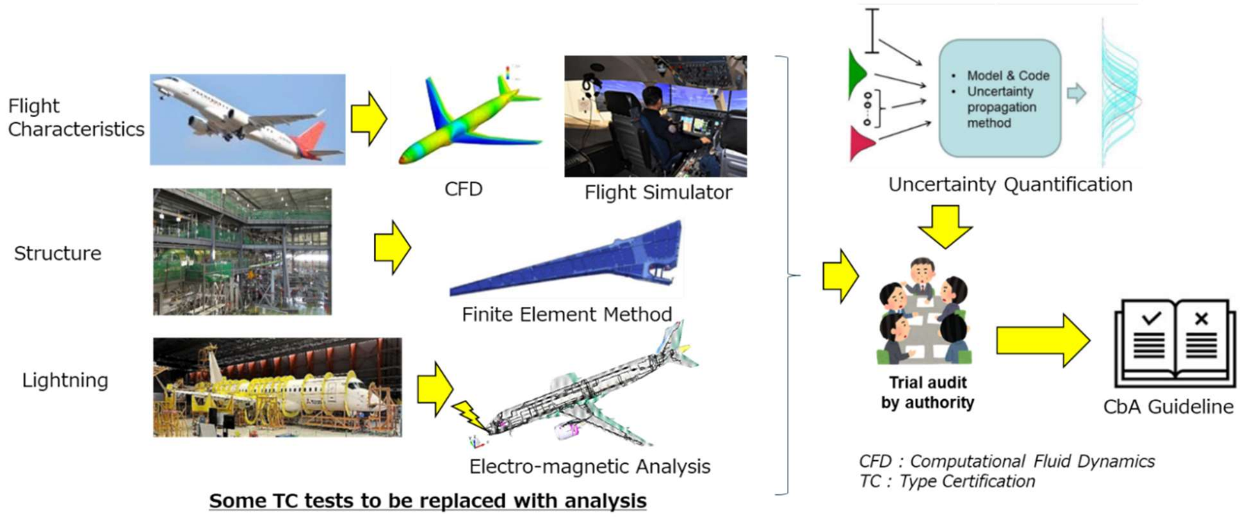


Figure 12 – Overview of CbA Activity

In flight characteristics, a recommended practice [10] was released and continuously under discussion in AIAA. Based on this recommended practice, we plan to conduct CbA trial certification process with Japanese authority for static stability (14 CFR §25.173, 175) and trim (14 CFR §25.161(a), (c)) [11]. The aerodynamic parameters of MSJ estimated by CFD will be installed into a dynamic simulation tool, and tool verification and validation will be conducted by utilizing MSJ flight test data. The dynamic simulation program will be installed into MSJ flight simulator, and pilot-in-the-loop test will be conducted to check the compliance.

In structure, ASME VVUQ subcommittee is preparing CAF (Credibility Assurance Framework) guideline which covers the recommended practice of VVUQ process. Appling this draft guideline, we plan to conduct CbA trial certification process for metal static strength (14 CFR §25.307(a) Proof of structure) [11] with Japanese authority. In the project, some additional aircraft ground tests using MSJ test vehicle are planned for analysis tool verification and validation.

In lightning, SAE AE-2 Lightning Committee is preparing a draft guideline ARP7093 for the use of simulation for aircraft certification of lightning. Considering this draft guideline, we plan to conduct the research activity to prepare the analysis tool which can be potentially used for future CbA process. More precise analysis tool will be developed in the project, and it will be verified and validated with existing ground test data of MSJ.

In the trial certification process for structure CbA, MBSE approach will be applied [12]. In this process, MoC in certification plan will be described with SysML and managed by MBSE methodology to avoid the time-consuming process caused by multiple documents or cross reference one another in the authority discussion.

From the total point of view, the guidelines and tools to be developed will support the applicant to reduce the certification cost and focus on aircraft development itself. It will contribute to encouraging Japanese new entering companies to commercial aviation business including air mobility.

4.3 Production DX

In the manufacturing engineering process of commercial aircraft, various manual desk work with 2D drawings and paper documents still survive due to the long lifecycle of programs even after 3D CATIA models are popularized. Moreover, the huge number of parts makes the manual tasks more complicated, and engineer's skill and experiences are required for manufacturing planning. The more integrated process utilizing digital thread with DX/MBSE methodology need to be established to improve QCD by eliminating these manual tasks.

In Production DX, it is assumed that System Model and 3D geometric model will be prepared to describe aircraft requirement and specification as "product system" models. In general, manufacturing engineers start discussion with design engineers before 3D CATIA model release to make inputs about the limitation from the production viewpoint in the beginning of design phase. However, the discussion with text-based information in the document sometimes results in considerable reworks in the later development phase due to the lack of traceability or misunderstandings about new design features. Therefore, more integrated approach is required to improve the comprehensiveness in total production process. To resolve this, MHI plans to build System Models and 3D geometric models in "production system" V aligned with models in "product system". The feasibility check among models in product and production at the early stage of development will contribute to reduce the lead-time for production start and mitigate the risk of production delay in the program. Figure 13 shows the total view of two V processes and digital thread between them. Data and digital thread will be managed by PLM tool to enhance the visibility of the program. The simulation analysis on production process is also important to make appropriate feedbacks to the aircraft design. Therefore, the knowledge and lessons learned in the previous programs should be digitalized adequately and utilized prior to the beginning of new development programs.

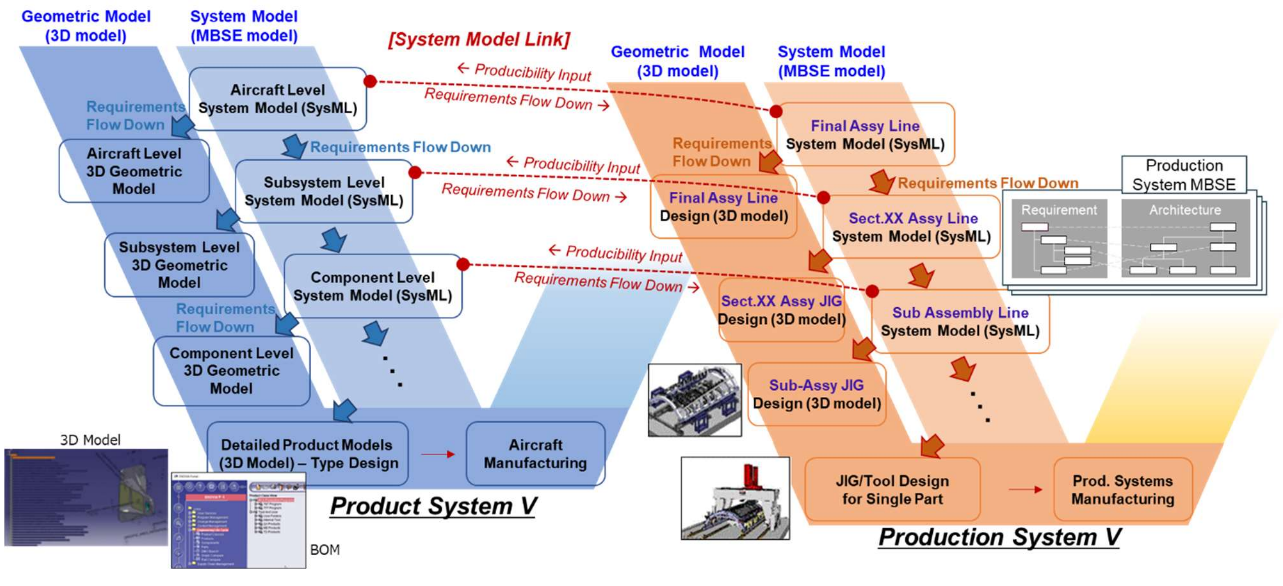


Figure 13 – Integrated Development with "Product V" and "Production V"

From the harmonized models in product and production Vs, various data set required for manufacturing planning will be constructed with ensuring the digital traceability from models. 3D CATIA models, BOMs (Bill of Material), BOP (Bill of Process), MBI, manufacturing and inspection software should be developed, and digitally linked in product and production processes. Figure 14 shows the overview of digital thread in manufacturing data set. In case of design change occurs, the established digital thread will help to identify the impacted area quickly. The enhanced visibility can support to select the required countermeasures with the smallest negative impact on the program. The digital thread will assist manufacturing engineers to integrate the various data in each organization and prepare the model-based data set with minimum manual tasks by utilizing a single data source hosted in PLM. Another benefit of using PLM is that all stakeholders in supply chain can access to the single data source. In the project, Japanese DX platform called SACRA (Standards-based Active Collaboration Realization for Aviation) is under development by JAXA, which will encourage new manufacturers to join the aircraft development program.

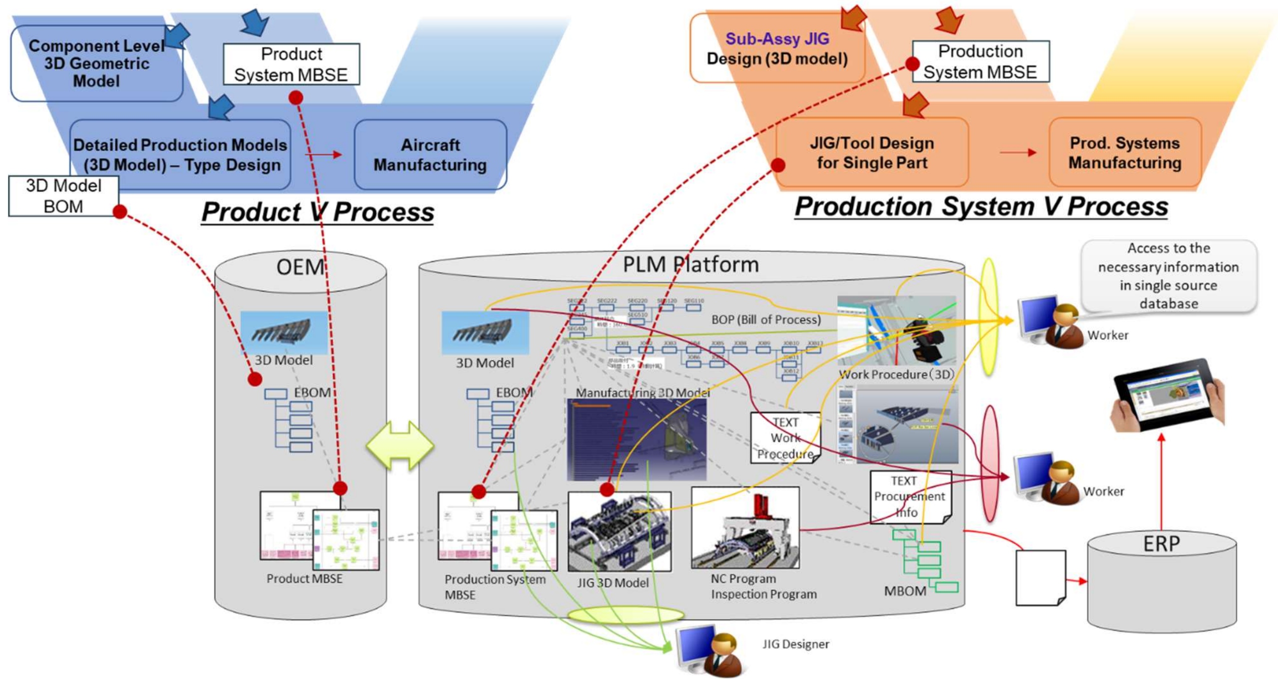


Figure 14 –V processes and PLM

5. Conclusion

This paper introduces various DX challenges in MHI commercial aviation systems, especially in NEDO aircraft DX project and Tier 1 programs. DX/MBSE capability is one of the tickets to join future commercial aviation program, but in addition, the improved process, knowledge database, and advanced simulation tool are mandatory to take advantages of DX. The guidelines and DX platform are also important to achieve the synergy benefit with all partners.

MHI will continue DX challenges and try to extend the activity to MRO domain to leverage the existing capabilities to new business opportunities.

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Copyright Statement

Abbreviations

AIAA : American Institute of Aeronautics and Astronautics

APQP : Advanced Product Quality Planning

AR : Augmented Reality

ASME : The American Society of Mechanical Engineers
BOM : Bill of Material
BOP : Bill of Operation
CAF : Credibility Assurance Framework
CbA : Certification by Analysis
CFD : Computational Fluid Dynamics
DX : Digital Transformation
JAXA : Japan Aerospace Exploration Agency
MBE : Model Based Engineering
MBI : Model Based Instruction
MBSE : Model Based System Engineering
MHI : Mitsubishi Heavy Industries, ltd.
MRO : Maintenance, Repair and Overhaul
MSJ : Mitsubishi Space Jet
NEDO : New Energy and industrial technology Development Organization
OEM : Original Equipment Manufacturer
PLM : Product Lifecyle Management
QCD : Quality, Cost, Delivery
ROM : Reduced Order Model
SACRA : Standards-based Active Collaboration Realization for Aviation
SAE : Society of Automotive Engineers
SysML : System Modeling Language
TC : Type Certification
VVUQ : Verification, Validation, and Uncertainty Quantification

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