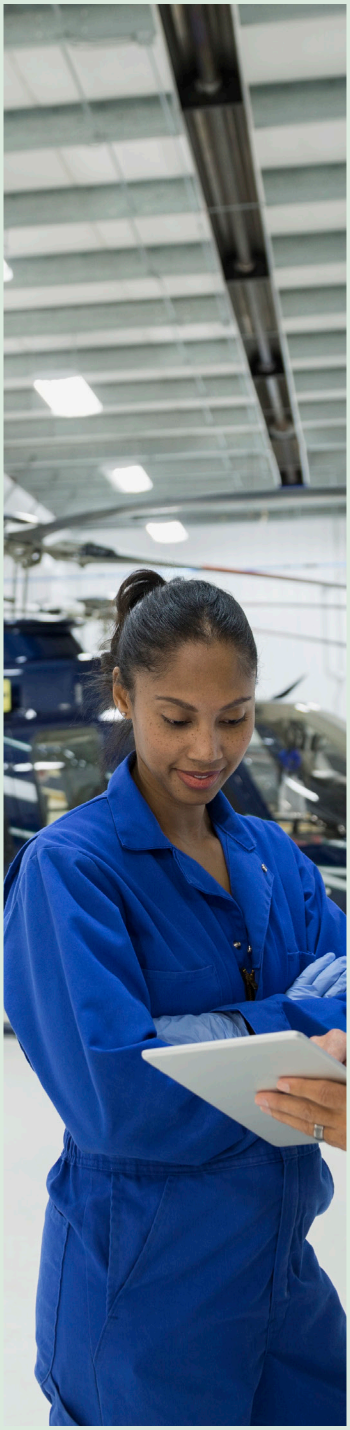
WHITE PAPER



MODEL-BASED SYSTEMS ENGINEERING: DIGITIZED REQUIREMENTS MANAGEMENT FOR AEROSPACE AND DEFENSE PRODUCTS

Abstract

The need for the aerospace and defense (A&D) industries to comply with strict regulations is driving the shift from document-based systems engineering to model-based engineering. However, the application of model-based systems engineering (MBSE) is yet to be institutionalized across the industry. The digital paradigm of MBSE coupled with better standardization of methods, model/data exchanges and intellectual property rights can accelerate the product development cycle. It can help various stakeholders view concepts by collating multiple threads of digital information and connecting different models. This interdisciplinary connectivity and collaboration will ensure greater integrity of the final product. But, transitioning to digital MBSE presents several challenges apart from financial ones. It essentially depends on the digital infrastructure maturity, company's readiness for migration of old models and data into the latest infrastructure. This white paper proposes a framework to help A&D companies shift from paper-based requirements management to MBSE based digital requirements management. It also lists out the potential gains to be derived from implementing MBSE on large-scale aerospace and defense programs.

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Introduction

In the traditional systems engineering, large number of documents are generated during the lifecycle from product concept to retirement of large complicated systems in aircraft and defense programs. The inherent challenge with the data in the documents is that the dependencies are not established. Any change in one specification or requirement need to be manually updated in all the effected documents of the system. The process of updating the documents and related requirements is laborious and error prone. Since documents are created in free flowing languages, they are not in amenable format to verify and validate with initial requirements.

Model-based systems engineering (MBSE) enables digitalization of physical systems. In this approach, IT and OT integration can capture and harmonize information from various disciplines. This integration enables MBSE to drive faster realization of aerospace and defense products.

Drawbacks of traditional systems engineering

The numerous documents generated and maintained during a product's lifecycle contain detailed information in text and diagrams format, most of them contain repeated information. These documents are used by systems engineers during various life cycle stages of the systems development. They include information about functional requirement, material information, assembling information, 2D & 3D models, interface description and additional information for various departments, design matrices, test and launch plans.

As mentioned earlier, information stored in documents lack dependencies. This necessitates manual updation for every change, which is time consuming and error prone. Further, when quoted during for communication/collaboration, it is difficult to be assured of the completeness and consistency of information and may led to contradictory information.

MBSE can address these challenges by providing information in visual and textual formats with consistent notations, relationship definitions and traceability paths that are shared across domains.

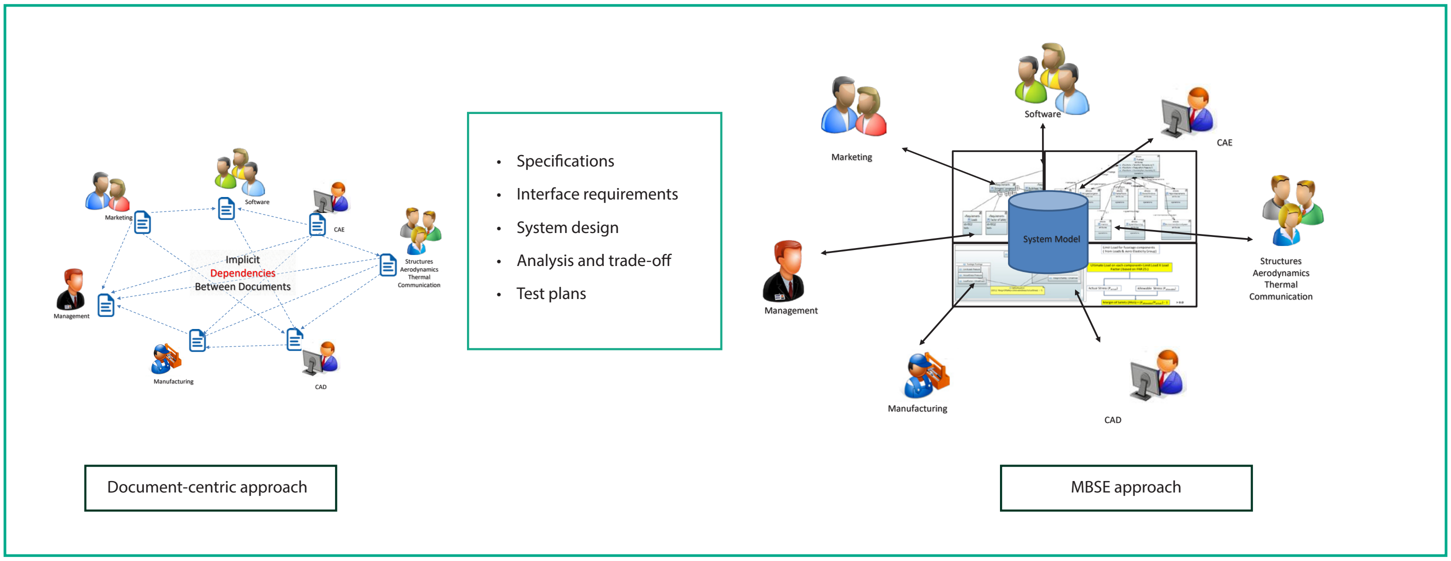


***Fig 1:** Systems engineering approach – Document centric vs. MBSE*

MBSE – A digital paradigm for requirements management

MBSE based on SysML helps capture and process information from multiple departments within a single model accessible to all stake holders. The user can define dependencies within each diagram, changes in one diagram of the model are automatically reflected in other model or user will know other diagram that need to be updated based on changes. This feature allows organization to maintain consistency, accuracy and updated information easily understandable in the MBSE model. Moreover, different checks can be performed to ensure the completeness of the model. MBSE also enables in defining hierarchy of model from top level system to subsystem and the detailed component level.

MBSE approach

For complex products developed in the aerospace industry, the requirements at various system and subsystem levels must be captured and linked appropriately. Initially, the product is broken down into major assemblies. The requirements for each assembly at various product lifecycle stages are captured in detail. Fig 2 provides a general view of how multiple systems are affected by one product system. This system of systems (SoS) diagram helps identify requirements and activities, and simulates the system in the real world.

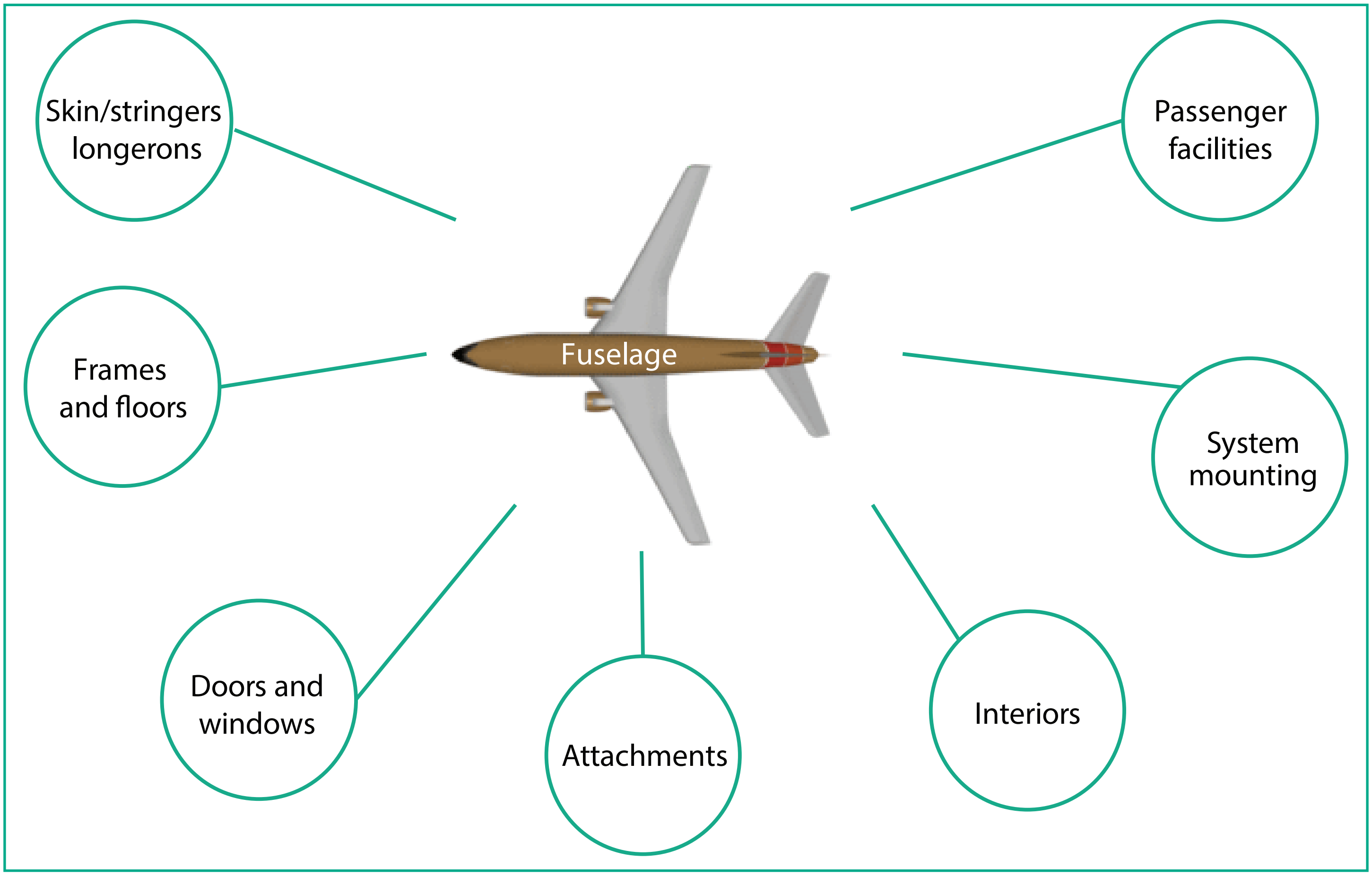
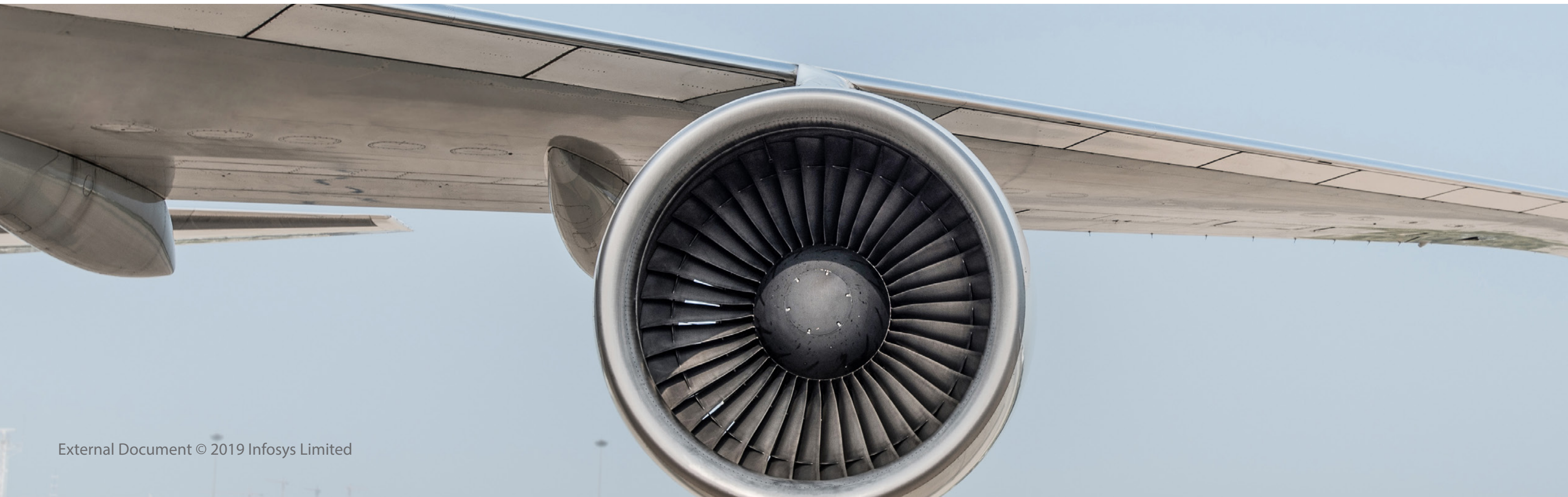


Fig 2: *System of systems*



Fuselage: Major assemblies	Requirements	Design and simulations	Materials and manufacturing	Testing and validation	Maintenance
Skin, stringers and longerons	• Load and safety factors • Limit load without permanent deformation • Approved materials • Protection for weathering and corrosion • Damage tolerance and fatigue • Decompression	• Skin - Pressure and shear • Longerons bending • Stringers axial loads and skin stabilization • Skin panel buckling • Fail-safe design • Least number of joints • Minimum weight • Fatigue evaluation • Concentrated loads	• CFC prepreg • Automated fiber placement-CTLM • Co-cured and co-bonded	• Strength tests • Coupons • Elements • Details • Subcomponents • Components • Assembly tests • Complete airframe test • Stiffness test • Ground vibration tests • Structural coupling tests • Notch filter design	• Periodic inspection • Maintenance as per schedule • Replace worn-out, failed or broken components due to operations • Define new maintenance schedules
Frames and floors			• Braiding/resin transfer molding and triaxial-2D braids • Fastened to skin		
Doors and windows	• Safeguards against opening during flight • No inadvertent manual operations • Emergency exit type, location and number FAR 25.807 • Emergency exit access FAR 25.813	• Interchangeability • Wind load while opening • Flight load and pressure (ultimate load) • Design for ultimate factor	• CFC • Aluminum • Stops/hinges		• Periodic inspection as per schedule • Replacement of movable parts and hinges
Major attachments	• Transfer concentrated loads • Safe dissipation of load • Strength and fatigue requirements	• Selection of type of attachment • Major bulk heads • Load distribution to shell • Structural deflection and instability • Discontinuity in the fuselage	• Aluminum • Titanium		• Periodic inspection • NDT inspection • Replace after designed life
Wind screens	• Clear vision • Splinter-proof inner pane • Withstand bird impact • Cyclic and pressure loads	• Minimum vision after damage • Clear vision • Glare and reflection avoidance • Pressure and aerodynamic loads	• Strengthened glass • Stretched acrylic • Polycarbonate • Polyvinyl butyric • Gold iridium tin oxide • protective coating • transparent forming and laminating	• Optical, electrical, environmental, and system interface tests • Strength test along with aircraft pressurization	• Electrical and environmental system maintenance • Cleaning • Replacement of transparent glass when defects are beyond repair
Interiors	• Protection from harmful impact • Fire, smoke and toxic requirements • Slow fire propagation • Maximizing comfort and transport capacity	• Aluminum • Fabric • Fire-resistant leather	• Aluminum • Fabric • Fire-resistant leather	• Flammability tests • Functionality tests • Impact tests • Evacuation tests	

Fig 3: *System requirements at various lifecycle stages*

Once the requirements for assembly are identified, they are linked at the most granular level with different layers of MBSE – conceptual, functional, logical, and physical (CFLP). The systems model represents the logical relationships among requirements, design, analysis, and verification elements.

Functional requirements diagram

Functional requirements play an important role in modeling. The hierarchy of requirement is easier to understand and visualize in MBSE models. Viewer can easily trace the requirements instead of having to read hundreds of document pages. The requirements model can also generate documents/Excel sheets to provide information to external suppliers. This ensures better collaboration between engineering, manufacturing and service operations (on-field/remote).

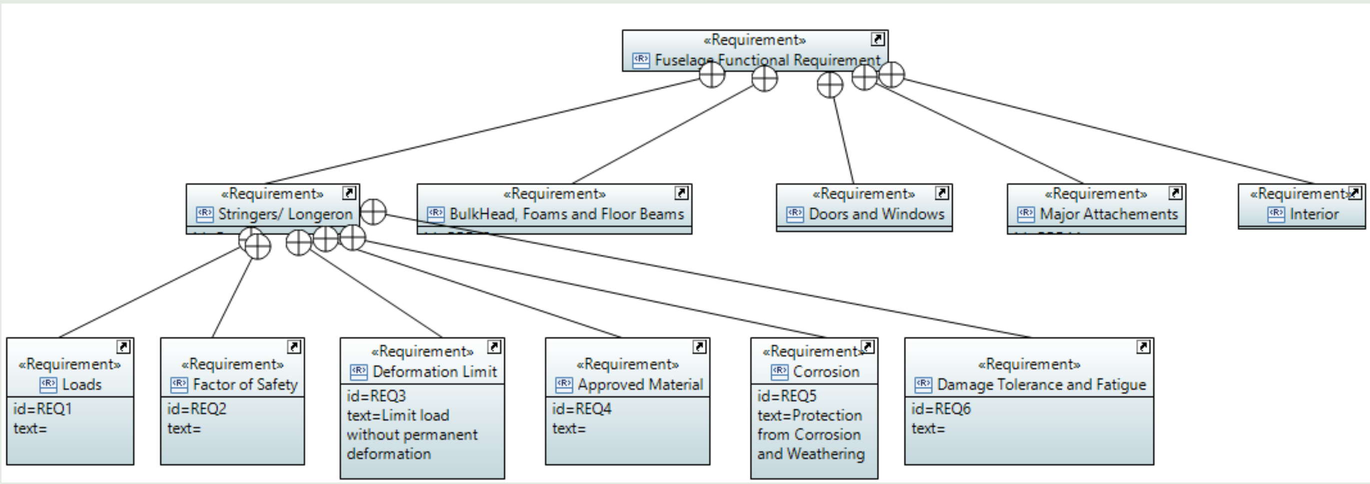


***Fig 4:** Functional requirements diagram*

Structure diagram

The 'structure' is a representation of mechanical, electronic and software components that are assembled to create the end product. It generates the actual hierarchy present in the bill of materials (BoM). In case of software component, unified modeling language (UML) diagrams can be defined by generating the code on successful compilation of model.

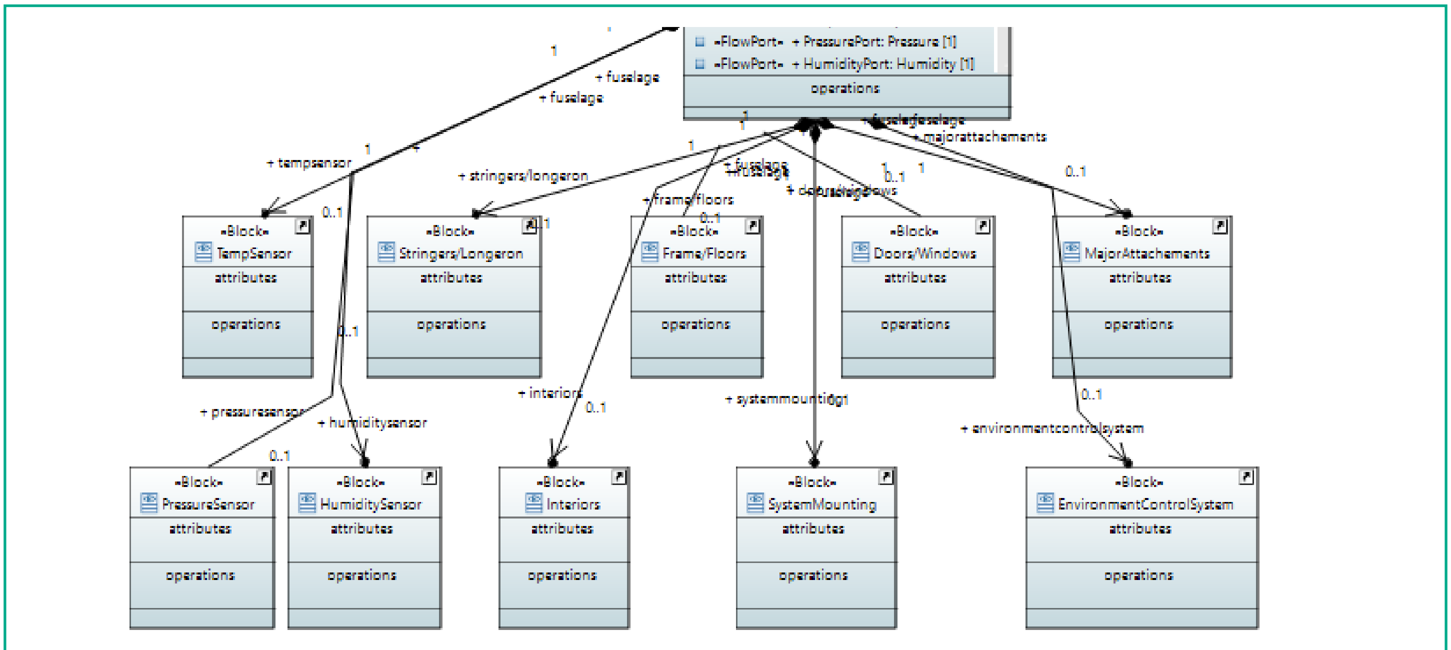


***Fig 5:** Structure diagram*

Behavior diagrams

These diagrams simulate the behavior of the system to meet the requirements. The system actions are executed based on the transformation of input to output. For aerospace products, system behavior can range from a simple taxiing scenario to a complete flight, maintenance of cabin pressure, etc.

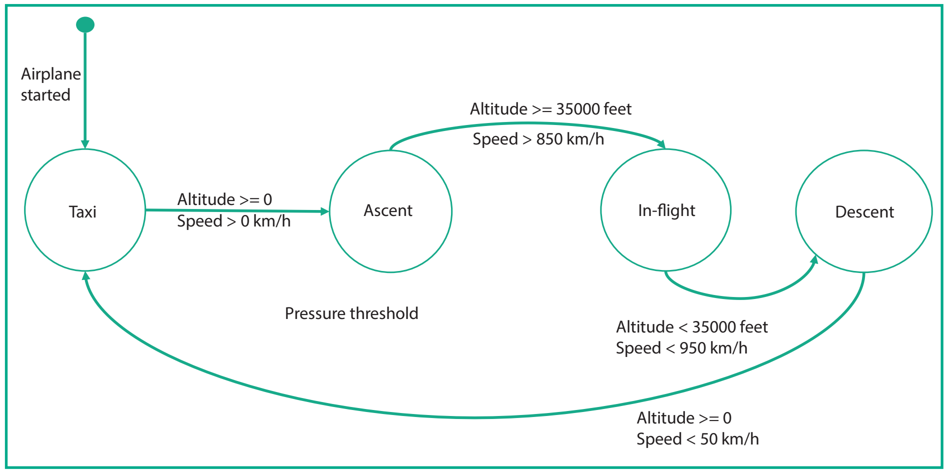


***Fig 6:** Behavior diagram*

Parametric diagram

These diagrams capture the relationship among system properties to support engineering analysis such as performance, reliability or mass properties analysis. During the design and sizing of various system components, each component is allowed a stipulated range of stress based on its material and design. Actual stress can be evaluated for each component using simulations that check if the complete system model is compatible with the sizing. Similar constraints can be applied to ensure that each component meets the required conditions.

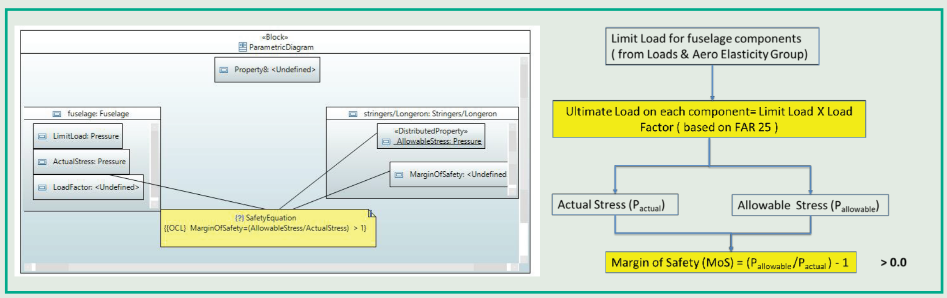


***Fig 7:** Parametric diagram*

MBSE – Digital integration for aerospace and defense product development

All the requirements must be defined and interlinked in the above diagrams in the MBSE model. Once this is done, they can be further linked to various digital repositories of the lifecycle stages, creating a closed loop. In this way, any updated requirements and their impact can be immediately verified and the required modifications implemented in the product development

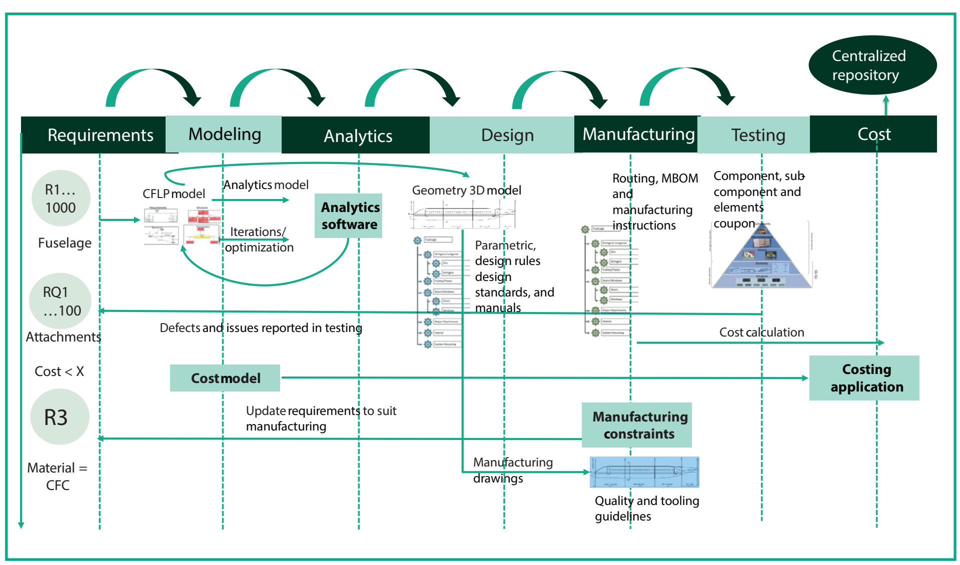


***Fig 8:** Digital integration of MBSE*

Benefits

Implementing MBSE for aerospace and defense product development provides the following benefits:

- Fosters common understanding between teams that define what is being built and those responsible for designing and implementing a system
- Replaces a document-centric approach with a digital landscape that enables faster and cheaper development cycles
- Improves productivity and quality by facilitating process workflows, shorter review cycles, improved traceability, and requirements integration with other solutions, thereby saving time and money
- Reduces risk by improving cost estimates, validating on-going requirements early on and verifying the design

Conclusion

The traditional approach of using documents to capture requirements for various systems across the product lifecycle in the aerospace and defense industry has several limitations. Changes to requirements must be manually updated across all related systems, which is a lengthy and error-prone process. A model-based system engineering (MBSE) approach can digitize extensive information captured in these records and make them available across the system landscape for easy traceability, accessibility, verification, and consistency. This can be achieved by linking the requirements of product assembly and configuration across all development stages to functional, structure, behavioral, and parametric diagrams in MBSE model. MBSE approach can help organizations enhance collaboration across teams, improve productivity and reduce the risk associated with cost, end-product quality and requirements validation.

About the author

Sastry Veluri holds a Masters in Structural Engg and currently works as Senior Industry Principal – Advanced Engineering Group, Engineering Services at Infosys. Sastry Veluri is a reputed technocrat and leader in aerospace. Has over 28 years of research, industrial and product design experience in prestigious Indian Space & Defense Research organizations and at Infosys. He is part of Infosys for close to 13 years now and currently working on Industrial Internet of Things (IIoT), Industry 4.0, Reliability based Frameworks and digitalization initiatives across manufacturing and process industries. Developed and mentored large teams and successfully guiding them to deliver quality products to Tier1/OEMs in aerospace. Built competent engineering teams in aerospace domain leading to high performing and motivated teams. Has experience in design and static testing of Polar synchronous (IRS class) and Geo synchronous (INSAT class) of satellites. Rich experience in defense, commercial aircraft industry and in design of business jets. Worked in airframe design and analysis of prestigious aircraft programs like Indian Light Combat Aircraft (LCA) and US major aircraft OEMs and Tier 1 suppliers. Setting new bench marks in delivering AS9100 Standards to clients all round the world by establishing processes and deliver value in aerospace domain.

Vishal Agarwal holds a Bachelor in Information and Communication Technology and currently works as Principal Consultant – IOTPLM, Engineering Services, Infosys. Vishal Agarwal is a Solution Architect and Consultant in PLM. Has over 14 years of PLM implementation in various industrial domains. He is part of PTC Center of Excellence practice in Infosys and working on automating tasks using IOT tools, implementing Industry 4.0 concepts, Application Lifecycle Management, Service Lifecycle Management. Currently Working on MBSE/SysML alignment to digital prototyping in the manufacturing industries with different tools and technologies.

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