

T.R.
GEBZE TECHNICAL UNIVERSITY
ENERGY TECHNOLOGIES INSTITUTE

PRODUCT LIFE CYCLE MANAGEMENT
FOR ORIGINAL AVIATION PROPULSION SYSTEMS

GAMZE BAYRAM
A THESIS SUBMITTED for THE DEGREE of
MASTER of SCIENCE
ENERGY TECHNOLOGIES INSTITUTE

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THESIS SUPERVISOR
PROF. DR. İLYAS KANDEMİR

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JÜRİ

ÜYE

(TEZ DANIŞMANI)

: Prof. Dr. İlyas KANDEMİR

ÜYE

: Doç. Dr. Bora ÇEKYAY

ÜYE

: Dr. Öğr. Üyesi Özay ÖZAYDIN

ONAY

Gebze Teknik Üniversitesi Enerji Teknolojileri Enstitüsü Yönetim Kurulu'nun

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SUMMARY

Product life cycle (PLM) refers to management of all information on a product and processes connected with it during its life cycle. It provides quick access to the required and accurate information on product. Aim of Product Lifecycle Management is assurance of quality, increased communication and collaboration across the enterprise and cost reduction.

PLM is easy to understand from one side, as it is almost common sense, and extremely complicated and hard to implement and apply from the other side [1]. Including all benefits, this thesis study contains a set of methodologies for product life cycle management for original aviation propulsion systems in design and manufacturing phases for hard-to implement side of PLM.

There is currently no widely acknowledged PLM approach for measuring the competitiveness of technically sophisticated industrial items, such as aircraft engines. It complicates the performance of set requirements to a product based on stage-by-stage planning, as well as the control of a product's conformity to set flight-technical, technological, and operational requirements and the maintenance of such conformity to requirements throughout the steps of the life cycle.

The idea of the product marks the beginning of the product's life cycle, which is completed by its disposal. This thesis covers the period of the product's life cycle that occurs after the contract has been signed but before the product is used in the field. Maintenance studies will be future work.

This thesis is recommended to be read by business analysts, process development engineers, process engineers, product engineers, PLM-projects-personnel in the companies, PLM-consultants, IT-personnel.

Key Words: Product Life Cycle Management, Propulsion Systems, Aviation

ÖZET

Ürün yaşam döngüsü (PLM), bir ürün ve prosesin yaşam döngüsü boyunca onunla bağlantılı tüm bilgilerin yönetimini ifade eder. Ürünle ilgili gerekli ve doğru bilgilere hızlı erişim sağlar. Ürün Yaşam Döngüsü Yönetiminin amacı, kalite güvencesi, kurum genelinde artan iletişim ve işbirliği ve maliyetlerin düşürülmesidir.

PLM aslında ortak akıl olması sebebiyle bir taraftan anlaşılması kolay olmakla birlikte diğer taraftan son derece karmaşık ve uygulanması ve yürürlüğe koyması oldukça zordur (Kovács, 2019). Bahsi geçen tüm bu faydaları içeren bu tez çalışması, PLM'nin uygulanması zor tarafı için tasarım ve üretim aşamalarında özgün havacılık itki sistemleri için ürün yaşam döngüsü yönetimi için bir dizi metodoloji içermektedir.

Günümüzde, hava aracı motorları gibi teknik olarak sofistike endüstriyel öğelerin rekabet gücünü ölçmek için yaygın olarak kabul gören bir PLM yaklaşımı bulunmamaktadır. Bu durum aşama aşama planlamaya dayalı olarak bir ürüne yönelik belirlenmiş gereksinimlerin performansının yanı sıra bir ürünün belirlenen uçuş teknik, teknolojik ve operasyonel gereksinimlere uygunluğunun kontrolünü ve yaşam döngüsünün adımları boyunca bu tür gereksinimlere uygunluğun sürdürülmesini karmaşıktır.

Ürün fikri, ürünün bertaraf edilmesi ile tamamlanan yaşam döngüsünün başlangıcını işaret eder. Bu tez, sözleşmenin imzalanmasından sonra başlayan ve ürünün sahada kullanımı öncesinde sonlanan zaman aralığındaki ürün yaşam döngüsünü kapsamaktadır. MRO süreçleri gelecekteki çalışmalar olarak tavsiye edilmiştir.

Bu tezin iş analistleri, süreç geliştirme mühendisleri, süreç mühendisleri, ürün mühendisleri, şirketlerde PLM projesinde çalışan personeller, PLM danışmanları, BT personelleri tarafından okunması önerilir.

Anahtar Kelimeler: Ürün Yaşam Döngüsü Yönetim,, İtki Sistemleri, Havacılık

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I would want to offer my heartfelt and genuine gratitude to my parents, Tazegül and Hamza Mert, for all of the love and support they have given me. I am unable to adequately convey my appreciation for their love, support, and encouragement via the use of words.

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TABLE of CONTENTS

SUMMARY	iv
ÖZET	v
ACKNOWLEDGEMENTS	vi
LIST of ABBREVIATIONS and ACRONYMS	ix
LIST of FIGURES	xi
LIST of TABLES	xii
1. INTRODUCTION	1
2. PROJECT AND SCHEDULE MANAGEMENT	3
3. REQUIREMENT MANAGEMENT	5
4. DOCUMENT AND DATA MANAGEMENT	7
5. ENGINEERING DESIGN DATA MANAGEMENT	10
5.1 Engine Performance Design Management	10
5.2 Aerodynamic Design Management	13
5.3 Thermal Design Management	16
5.4 Structural Design Management	18
5.5 Mechanical Design Management	20
5.6 Harness Design Management	22
5.7 PCB Design Management	24
5.8 Software Design Management	26
6. CHANGE MANAGEMENT	28
7. MATERIAL DATA MANAGEMENT	32
8. MANUFACTURING DATA MANAGEMENT	34
8.1 Part Manufacturing Management	34
8.2 Additive Manufacturing Management	36
8.3 Composite Manufacturing Management	39
8.4 Fixture Management	42
9. V&V AND CERTIFICATION MANAGEMENT	44
9.1 V&V Management	44
9.2 Certification Management	48
10. CONCLUSION	50
11. FUTURE WORKS	51
	vii

REFERENCES

52

BIOGRAPHY

58



LIST of ABBREVIATIONS and ACRONYMS

<u>Abbreviations</u>	<u>Explanations</u>
<u>and Acronyms</u>	
3D	: 3 Dimensioning
ALM	: Application Life Cycle Management
AM	: Additive Manufacturing
AO	: Application Orders
BT	: Bilişim Teknolojileri
CAD	: Computer-Aided Design
CADMID	: Concept, Assessment, Demonstration, Manufacture, In-service and Disposal
CAE	: Computer-Aided Engineering
CAM	: Computer-Aided Manufacturing
CFD	: Computational Fluid Dynamics
CIB	: Change Implementation Board
CIL	: Change Implementation Leader
CL	: Change Leader
CM2	: Configuration Management 2
CN	: Change Notice
CNC	: Computer Numerical Control
CR	: Change Request
CRB	: Change Review Board
DCR	: Dataset Change Record
ECA	: Enterprise Change Assessment
ECAD	: Electronic Computer-Aided Design
EECAD	: Electrical Engineering Computer-Aided Design
FCM	: Fatigue Cracking Model
FEM	: Finite Element Methods
IC	: Integrated Circuits
IP	: Intellectual Property
IR	: Investigation Request
IT	: Information Technologies

<u>Abbreviations</u>	<u>Explanations</u>
<u>and Acronyms</u>	
ITAR	: International Traffic in Arms Regulations
LCA	: The Life Cycle Assessment
MBSE	: Model-Based Systems Engineering
MCAD	: Mechanical Computer-Aided Design
MRO	: Maintenance, Repair and Overhaul
OEM	: Original Equipment Manufacturers
PCB	: Printed Circuit Board
PDM	: Product Data Management
PERT	: Program Evaluation and Review Technique
PLM	: Product Life Cycle Management
R&D	: Research and Development
RACI	: Responsible / Accountable / Consulted / Informed
SAM	: Stress Analysis Model
SDM	: Structural Dynamics Model
V&V:	: Validation and Verification

LIST of FIGURES

<u>Figure No:</u>	<u>Page</u>
3-1 Where Defects are Detected	5
3-2 The Cost to Find and Correct a Defect	5
5-1 Number of Interfaces - Comparison between Direct Tool Coupling and Usage of a Central Data Model	14
5-2 Schematic of Current Life Prediction Process	18
5-3 Functional Schematic of the Digital Twin Life Prediction Concept	19
6-1 Intervention Resources	29
6-2 CM2 Change Process	30
9-1 Requirement Capture and Validation in PLM	45

LIST of TABLES

<u>Table No:</u>	<u>Page</u>
4-1 Example of a Sub-Categories of System Engineering Documents	8
5-1 Estimation of Enhancement in Items of Quality Failure	25
8-1 Typical Composite Material Systems in Aerospace	39



INTRODUCTION

Product Lifecycle Management (PLM) is the business activity of managing, in the most effective way, a company's products all the way across their lifecycles; from the very first idea for a product all the way through until it is retired and disposed of [2]. PLM is not just a management activity for the aviation industry. It is also used in different sectors such as automotive, transportation, energy, heavy equipment, marine, media, telecommunication, medical devices, pharmaceuticals. While best practices have been developed for the route to be followed in other industries, these assessments for air propulsion systems are still in the debate and development stages. This thesis study was carried out in order to create a method set for aviation propulsion systems, which is a sub-sector of the aviation industry. After a literature assessment and review, this study adopts a more efficient and sector-appropriate strategy and explains it for several disciplines. A methodology set was built using each discipline's methodologies throughout the thesis.

The product's life cycle starts with its sight and ends with its disposal but the time period of the product that occurs after the contract has been signed but before the product is implemented in the field is the focus of this thesis.

Following the signing of the contract, the first step of the process is to plan the project. The actual business process for the management of projects is referred to as project management and mentioned in second chapter.

Requirements are fundamental components and definers of products that establish the product's whole design and serve as its final output which explained in chapter three.

Chapter four including when working on projects that are both complicated and sophisticated, it is necessary to provide and manage a different category and even if different sub-categories of documentation.

Design processes indicated in chapter five and its sub-chapters. In the area of performance, aerodynamic, thermal and structural disciplines life cycle depend on the digital twin for improvement. Digital twin, when used correctly, can help you glimpse into the future and estimate the effects of design modifications on product qualities. Physical design of mechanics, harness and electronics needs for common environment to co-create. In the context of the life cycle of aircraft propulsion systems, the

integration of PLM and ALM is of critical significance in terms of visibility across all assets.

Chapter six focuses on change management when working with high-quality aviation products, notably aero-engines, it is important to monitor and document changes and their impacts on safety, certification and intervention resources.

Chapter seven interest on material management. PLM is a methodology that prevents material data silos, expensive material test repetitions, design start with the wrong material, supply chain function invisibility.

Manufacturing processes outlined in chapter eight and related subsections. When it comes to products that have complicated geometries and strict certification procedures, however, it is simply not enough to outline the standard technique of component manufacture. Connecting people, systems, and machines via digital process planning helps enhance component production productivity. Additive manufacturing empowers especially aviation companies to reshape everything for ideal execution at diminished fetched, in comparison to conventional fabricating strategies that require different steps, instruments to attain the specified result. The production methods of composites are intricate and specialized. To do this, production engineers need a precise and efficient method of consuming the engineering product requirements.

Validation, verification and certification methods presented in chapter nine and associated subchapters. The goal of verification is to demonstrate that, given a set of input data, the parts available for delivery at each stage fulfill the stage's requirements in every way. The objective of validation is to demonstrate that the system under consideration fully meets the requirements at any stage of development and after installation. Verification tasks are inherent to the overall work of achieving the requirements for an aircraft in accordance with its intended use and are included in all stages of the life cycle. Verification tasks are an integral part of satisfying the criteria for an aircraft in line with its intended usage and are performed throughout the whole aircraft's life cycle. Throughout the lifespan, every effort is made to properly conclude the certification process.

The establishment of PLM environment clearly fits the requirements of the current stage of development in the fields of aviation engine's complex design, manufacture, and operation.

PROJECT AND SCHEDULE MANAGEMENT

Project could be defined as a temporary activity conducted by a company to achieve a specific goal. Project management is the actual business process for the management of projects. Project schedule is a list of tasks for projects that also shows other information including planned start and finish dates for each task. Overall approach or method picked to realize the project is called project plan. Paton and Andrew define interface gap as “the gap between the submission of a solicited bid and the delivery work that commences on the eventual award of contract.” [3, p. 44].

Various roles could exist in a project in accordance with the size of the project, such as project sponsor, track leader, subject matter expert, business process architect, solution architect, system analyst.

Cross-functional, enterprise-wide project and schedule management is about facilitating the review and approval of scope changes, managing projects on daily basis, planning detailed activities, executing assigned tasks, interpreting business needs, monitoring solution implementation, communicating proposals to executives

A better visibility to achieve more accurate project management across projects, domains and the life cycle of a product could best be provided by project planning, which is an integral part of Project Lifecycle Management (PLM). PLM data enables confidence by planning in accordance with requirements and goals of the project in question. Product lifecycle model is usually associated with operations management mechanisms [3, p. 45]. In line with this model, defense industry firms are organized in line with the principle of CADMID: Concept, Assessment, Demonstration, Manufacture, In-service and Disposal [4, p. 13]. CADMID based product lifecycle model ultimately leads to interface gaps [3, p. 49]. If PLM is applied to sophisticated technology products, the result is high duration interface gaps [3, p. 46].

The use of PLM in project management and scheduling provides a number of benefits, including the following:

- The same system could work on project management planning and execution
- It would be possible to estimate a complete work package definition, using the criteria of past performance, cost, schedule, requirements, processes, inputs and outputs.
- PLM is the single source for executing all information, including risk and opportunity management.

- Thanks to the visibility and accessibility of PLM, it is easier to manage coordinating resources in cross-functional teams and understanding impacts of possible changes to the projects.
- PLM leads to improvement in projects and business performance by better processes, common structure, tools, resource management and forecasting.
- PLM ensures integration, coordination and supports activity within the organization [3, p. 46].

PLM and innovative product development can be linked to have successful innovations. Göksidan claims that PLM fueled project management has been dictated by most of the defense companies with regard to the strategies covering all aspects of product and process life-cycle [5, p. 725]. He further proposes a project actors' collaboration for delivering value via reduction of cost and/or increase in target benefits [5, p. 726]. Orienting the market needs under PLM ensures companies maintain indigenously designed end-products and the connection between strategic mission and implementation phases [5, p. 730].

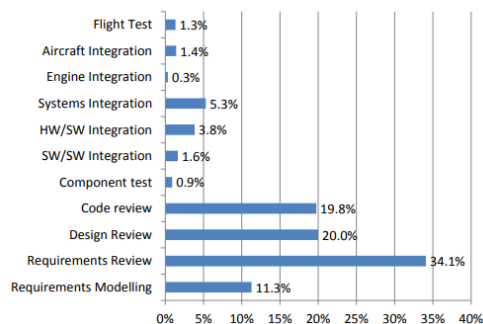
Project management tools and templates PERT and GANTT charts, which can be visualized through dash boards, are also included in PLM. PLM can define roles and responsibilities as RACI diagram. Risk management however is more visible in common environment. Dashboards that display data in real-time provide users instant access to real-time information about an operation, allowing stakeholders to prevent and manage delays more effectively.

Using real-time dashboard displays makes it feasible to ensure that data is constantly in sync with the state of what is really being done.

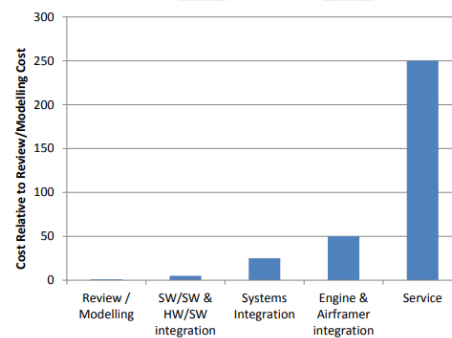
REQUIREMENT MANAGEMENT

Requirements are fundamental components and definers of products that establish the product's whole design and serve as its final output. When it comes to handling this essential and foundational part of product, management is not sufficient for complicated aircraft projects. Traditionally, the life cycle of a product consists of basically four main steps, including project definition, implementation, test & integration, and verification & validation [6]. Requirements and architecture definition are the first steps, which are part of the project definition. Multiple layers of requirements documentation, interface standards, and specified tool outputs have been used to define the established needs of a product. Most of the time, this data is created independently by various members of staff inside the company, with different disciplines being accountable for different technical decisions [7].

In terms of finding design errors in the final output design, Figure 3-1 [8, p. 3] shows the most common part of the project process for error detection. Although Requirement Modelling and Requirements Review processes cover almost half of the error detection, the cost of this correction is nearly zero according to Figure 3-2 [8, p. 3].



3-1 Where Defects are Detected



3-2 The Cost to Find and Correct a Defect

System engineers, system architects and requirements engineers play a critical role in detecting those errors. Systems engineers, together with system architects, evocate user requirement specifications, functional requirement specifications and design specifications. Requirements engineering not only records requirements, but it also relates requirements to each product decision across the product's life cycle [9].

In light of this data, it is essential to find design errors at the beginning of the whole life cycle. What has to be done is to engineer requirements in such a way that

they are connected to the product lifecycle and create a platform that allows independently working personnel to work from a single source.

Product lifecycle management using model-based system engineering gathers requirements and assigns them to different downstream features while simultaneously creating reports and documentation in real time for each product decision across the lifetime [10].

Model-Based Systems Engineering is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases [11]. The use of Model-Based Systems Engineering (MBSE) maps requirements to metadata, metrics, and validation with the sub-components of a product like hardware, software, and human-product interface.

With particular closed-loop requirement management, it is realistic to claim that not manage but engineer requirements status is attainable. These criteria include authoring, assignment, tracelink, aspects of the operations, revision, validation, verification, and integration ALM.

DOCUMENT AND DATA MANAGEMENT

Documents are not cheap to produce as well as having most of the time longer life than the actual products. In aviation industry, there are various complex documents that cover a very wide range, such as, analysis reports, 2D/3D illustrations, spreadsheets, test results, and technical publications that are supposed to meet stringent criteria.

Document management is when metadata is used to describe documents which are then saved in a data vault. Each document could be visualized and be linked to one or more system objects [12, p. 214].

Digital documentation is a beneficial tool to facilitate document production by limiting the manual effort. They include tools like familiar office applications integrated in PLM. Datasets and content management, which ensures a quick access to the topic are also included in digital documentation [13, p. 806]. Also, intellectual property rights and export control, which are among the most challenging topics specifically in defense industry, are also addressed in data management [14]. Digital datasets are used in identifying and managing IP (Intellectual Property) and ITAR (International Traffic in Arms Regulations) information among metadata.

One needs to make different categories of documentation while working on complex and sophisticated projects. For instance, a project on mechanical aircraft parts could have documentation categories such as system engineering, assembly and certification.

Digital datasets visibly improve the overall work quality by making use of templates, it is ensured that documents conform to the required structure and content, improving compliance. That way, planning and verification of product and document changes are also enabled [15, pp. 193-195].

In light of what is discussed above, it could be argued that document categorization would be a beneficial tool. Some possible document categories are as follows: Assembly, Disassembly and Instrumentation Documents, Certification Documentation, Configuration Management Documents, Design Definition Documents, Integrated Logistics Support Documents, Material and Process Development Documents, Product Management Document, Project Management Documents, System Engineering Documents and Test Documents.

An Example of a sub-categories of System Engineering Documents is given in Table 4-1 as follows:

4-1 Example of a Sub-Categories of System Engineering Documents

Category	Sub-Category
System Engineering Documents	Interface Control Document
	Interface Control List
	Interface Definition Document
	Interface Definition Form
	Sub-System Interface Requirements Document
	Sub-System Requirements Document
	System Engineering Management Plan
	System Requirements Document
	Technical Requirements Verification Matrix
	Test and Verification Master Plan
	Validation and Verification Plan
	Interface Control Document
	Interface Control List
	Interface Definition Document
	Interface Definition Form

In documentation, it is imperative to standardize the numbering and template structure. Search feature should also be enabled with the help of metadata [16, p. 40].

Metadata is data about data and other means data describing other data. It is the key information about a larger volume of data, such as its name, its status, its location, and its owner. Metadata is similar to the catalogue information of a book in a library. That might contain the book title, author name, book number and book location [2, p. 170].

Datasets have to be associated with products and in case of a change, impact analysis has to be conducted.

Intersecting roles are recognized and even capitalized on by product lifecycle management. PLM provides a common platform for effective integration of isolated information assets and streamlining cross-discipline tasks in the enterprise. Product data refers to all data linked with both a product and processes used to imagine, design, produce, use, support and dispose of it. In order to use, manage and communicate information efficiently, all the information would have to be converted to digital form. Paper documents have visible issues compared to digital datasets, some of them being;

- slow search/accessibility,
- slow distribution,
- easy to misplace,
- hard to keep track of copies,
- hard to access,
- high storage costs,
- hard to share,
- easy to lose and
- high risk of deterioration and damage.

Digital datasets, on the other hand, may reduce;

- duplication of product data
- volume of data that has been re-entered manually as number of different copies of same document
- product data with no owner
- product data not under change control

Under the umbrella of PLM, product structure has a defining role in the relationship between the modules and components of a product. Furthermore, all the product related information and documents are integrated this way [12, p. 213].

It is argued that only the product-related digital datasets discussed in this chapter can provide up-to-date product information.

ENGINEERING DESIGN DATA MANAGEMENT

5.1 Engine Performance Design Management

Aero-engines are exemplary cases of products that are typically complicated in terms of structure, the criteria for performance, the manufacturing process, real-world test, and the management of the project. Known as the "Pearl of the Crown" in modern industry, aero-engine reflects a long research and development (R&D) cycle [17].

A significant number of essential demands have been placed on the design of engines, including improvements in thrust, pollution control, fuel economy, speed to market, and power-by-the-hour service agreements. For complex aviation engine systems, achieving performance standards for emissions, noise, energy efficiency, safety, and reliability needs a platform that gives an integrated picture of a wide collection of disciplines working together cooperatively.

The design and manufacturing stages of turbine engines make it more difficult to control traditional procedures in terms of cost, scope, and quality, as well as the amount of time it takes to bring a product to market. At present, the traditional R&D mode of aero-engine cannot satisfy the growing demands of high quality, superior performance and low cost [18].

For the development of aviation engines, the most innovative tools are required for their respective applications. PLM is responsible for the careful integration and combination of design process to assist aviation engine design from the idea stage all the way through the certification process. This enables industry-leading design exploration, scalable multi-physics, dynamics, and CFD capabilities. The use of digital twin technology is essential to the creation of designs that are more time- and cost-efficient. In order to virtually imitate the operation of physical things and the production of such entities, digital twin is constructed. It is possible to gain the following advantages using digital twin:

- Creating and managing scalable models according to the propulsion system's architecture
- Supporting dynamic simulation of multiple systems with flight representative boundary conditions
- Securing and ensuring traceability of models and data

- Creating architectures for simulation on an open platform and configuring them for trade-off studies
- Harmonizing and complementing the transition towards model-based systems engineering, and the implementation of its principles

As a result, the complex modeling process is harmonized and secured, and the know-how developed within the organization is capitalized. Finally, an earlier integration of the models representing the engine systems can be achieved, their interactions evaluated, and different architectures compared [19].

Three-phase digital twin optimization method is quite useful and significant for any complex mechanical systems. Using this three-phase process, it is possible to realistically optimize the complicated system in an efficient and exact manner.

Ideation is the first phase in the digital twin stages, and it covers all the requirements based on the demands of the contract. The most influential part of the product development process is the ideation phase, which focuses on performance engineering. A phase of ideation that is realistic and integrated allows turbomachinery to create a single prototype in a manner that is more time and cost effective.

Realization phase is manufacturing the one prototype product which provide measurement of real-life product. The one physical prototype is used to gather data from the real environment in order to incorporate it into the digital world. It is necessary to monitor the correlation between the physical environment test and the digital twin simulation environment test. Real-world tests are performed before optimization, and the real-time data that is gathered from these tests is sent back to the virtual modules in a continuous manner during the optimization process. This serves to rectify and improve the input that the virtual models get. Digital prototypes may eventually reach a level of sophistication where they can reproduce the actual world. This digital prototype, which will serve as the foundation for the creation of new concepts, may enable a variety of design trials while also reducing the overall testing costs.

Follow-up phase is about using the one prototype measurements are used to generate another digital prototype with a new range of complexity. Then this new digital prototype will be validated using a different range of aerodynamic behavior. Follow-up phase is important if it is rightly applicable because that correct/right follow-ups should support complete digital twin of turbomachinery with all complex

thermos-dynamic interoperability, transient effects be a part of analysis and optimization, create know-how and methodologies for future engine design architectures, prevent extensive work with physical prototypes.

By the means, a large number of tests conducted in the real world are avoided or reduced may be eliminated, and the optimization processes can be carried out and decided completely in the virtual world. Advanced aero-engine manufacturers have commenced supporting the integration of virtual and real worlds of design and manufacturing [20]. Therefore, to improve the accuracy and optimization quality, virtual modules should have the same rigorous structure as the physical things they represent so that they may function as digital mirrors. By the real-time feedback and correction, the virtual engine model is strictly similar to the practical case, which is more reliable and precise than the conventional simulations [21].

In the area of performance, the digital twin is more capable than the traditional approach due to its capabilities of real-time feedback with continuous correction, iterative calculation, real-time variable behavior, and environment. This contrasts with the capabilities of the traditional approach, which include no test feedback with correction, tentative calculation, and constant conditions, respectively.

In conclusion, it is essential in order to achieve the status of designing the aircraft engine with demanding performance criteria if an accurate digital twin is used to offer performance forecast and design enhancements.

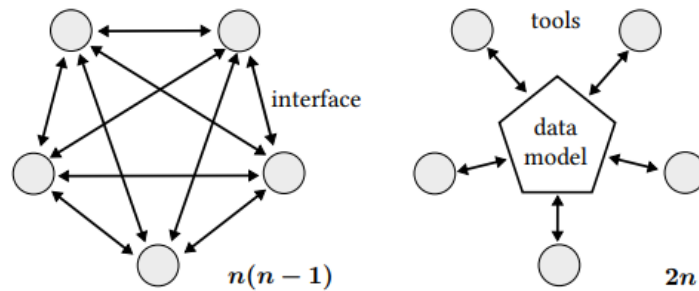
5.2 Aerodynamic Design Management

Optimizing engine aerodynamic performance is essential in order to guarantee both efficient operation and complete safety. The key to help to maximize the performance of aero-engine in real-life conditions is to provide an accurate representation of the underlying physical behavior of the various fluid and solid phases. The product's success in the operation is contingent on the manner in which it communicates with fluids, whether they gases, liquids, or any mix of the two.

The traditional aerodynamic design life cycle begins with the mechanical design team and the performance team cosigning the requirement set, and then it moves on to the aerodynamic design team. The initial one-dimensional design is generated with the help of the requirement list, and it was emplaced to envelope to be developed by the aerodynamic design team in a one-dimensional compiler environment. The aerodynamic design team then began the process of developing a two-dimensional design in a two-dimensional compiler environment after being positioned to do so. After this point, the aerodynamic design team began to deal with a variety of different disciplines and the varying results produced by a variety of different enabling software. Following the placement of the blades and the beginning of the three-dimensional design, the thermal, mechanical, and Secondary Air System Design teams were involved in the iterative process. The feedback received from these teams is included into the preliminary design up to the off-design reviews. When it came to the final stage of the precise blade design process, the structural analysis team was also engaged. The development of overly complicated designs in a co-operative way that make use of different outcomes belonging to different software which alien to each other requires a significant amount of time, a substantial budget, and engineers that are as stable as rocks.

A major challenge of multidisciplinary engine design is the management and transfer of data throughout the entire design process. Usually, the individual design tasks are handled by teams with the appropriate expertise. These teams can be part of different organizational units or even different companies. This leads to the fact that the exchange of data and the communication between the individuals involved can easily become complex and confusing. Furthermore, the handling of the input and output data of the utilized tools can differ considerably. Another challenge is the readability, reusability and traceability of the data across the entire design process as

well as the continuity of the data across different levels of detail [22]. Figure 5-1 [22] shows the number of interfaces required between teams using the conventional technique and the single-environment method.



5-1 Number of Interfaces - Comparison between Direct Tool Coupling and Usage of a Central Data Model

The sharing same habitat capability in PLM approach offers an effective and precise set of fluid dynamics models and solvers with excellent parallel performance and scalability. It provides a solid foundation for multidisciplinary design exploration. It is necessary to use specialized interfaces in order to integrate with several additional working environments. This makes it possible to do multi-physics simulations with diverse time scales ranging from microseconds to hundreds of seconds, conduct analyses that are both faster and more accurate, and reduce the amount of time needed for the creation and evaluation of complicated designs. Instead of just simulating a single operating point, it is possible to explore how a product performs under a complete range of operating conditions of operating environment that it will face during the course of its lifetime. This type of intelligent design exploration can be used to find better designs more quickly.

Not only simulation but also physical testing is one of the major challenges of product with trial-and-error method. Design by testing is time-consuming, costly, and unable to maintain pace with the present competitive environment. Living in single environment with performance requirements, mechanical design solutions, and structural analysis enables many viewpoints on the whole picture to test.

In addition, developing a design using a multi-discipline habitat offers a simplified and automated technique for comprehending the design, and enables to rapidly optimize design for realistic operational conditions. The use of a single environment solution throughout the process of creating the aerodynamic design enables that:

- With the aid of digital twin technology, virtually improve all areas of the aerodynamic performance of the engine.
- Determine the stability of the structure while taking into account loads and drag on the blade.
- Ensure that you are in compliance with the regulations by using the requirements of the performance and the contract.
- Maintain compliance with safety requirements and strive to enhance operational safety at all times, under extreme operating conditions.

Vieweg, Hollmann, Reitenbach, & Schnoes claims that single environment methodology proposed in this thesis statement is promising for air propulsion vehicles. Therefore, it gives reason to believe that the multi-disciplinary process chain was applied successfully on a real hands-on example [23].

As conclusion assess critical situations early in the design process by using multiphysics simulation solutions to analyze structure in single source information environments.

5.3 Thermal Design Management

Thermal management analysis optimizing thermal loads in equipment integration and allowing thermal trade-off analysis early in the design process. It is difficult to engineer a thermal balance that is appropriate for a sophisticated aircraft engine. Thermal design of engine needs a great deal more data than simply geometry, and for simulation-driven design, performance must be evaluated before commit to design decisions. It is essential to evaluate alternative architectures or control strategies while taking thermal interactions between subsystems into consideration. Thermal management also take into consideration to electrification, innovative mechanical designs using a vast array of materials, and secondary air flows which guarantee increased heat rejection while maintaining system security.

Thermal phenomena include several features to account for a variety of circumstances. In the aviation propulsion systems, heat transfer phenomena occur between both mechanical and electronic parts. Thermal conduction is the movement of heat from higher-temperature areas to lower-temperature regions through a material. This naturally occurs and continues until thermal equilibrium is achieved. Turbine blades are a classic example of conduction in the operation of an aircraft engine. Thermal convection happens when a hotter substance moves into a colder location and transfers heat via a gas or liquid. Convection is a significant mode of heat transport that is found in a vast array of applications, processes, and natural occurrences. For maximum performance and durability, several subsystems depend on a robust heat management strategy. As an example, natural convection flows occur inside of gas turbine casings during shutdown [24]. Radiative heat transfer takes place when things emit electromagnetic radiation because of their temperatures. As an example, the liner is heated by radiation and convection from the hot gas. It is cooled by radiation to the casing and by convection to the annulus air [25]. Thermal design of electronics is vital to the achievement of cost-effective, dependable devices that satisfy performance objectives. To create effective thermal management systems for heat dissipation in the face of growing complexity, miniaturization, and power density, engineers must precisely forecast temperature and fluid flow and analyze cooling in the earliest phases of development.

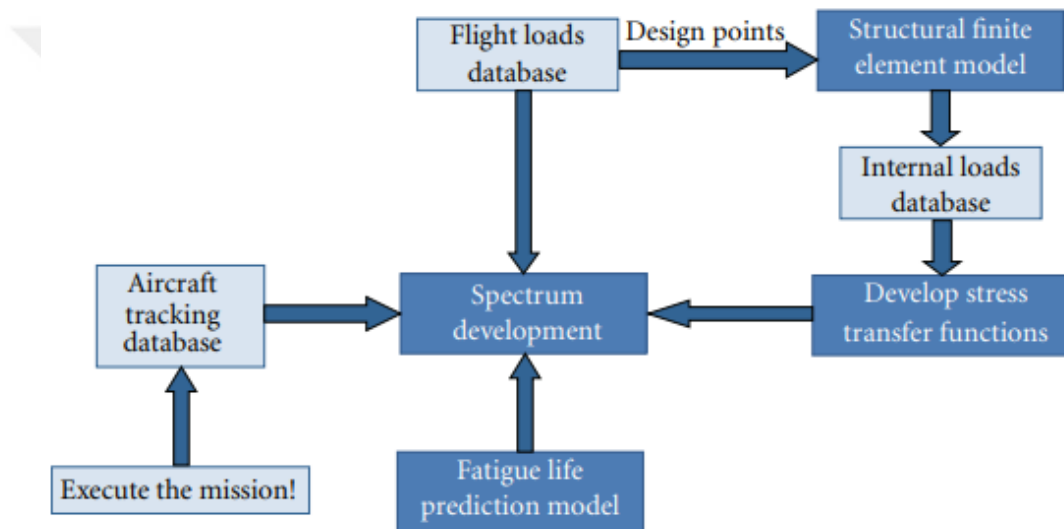
Enhanced electronics systems, the design of pioneer flow paths combined with other trends like the implementation of composite materials introduces new thermal

management issues regardless of whether it is for commercial or military aviation purposes. In this point as a solution proposal, give a cohesive virtual thermal management analysis by optimizing thermal loading, equipment integration, and allowing thermal trade-off analysis early in the design with the help of integrating diverse tools that belong to the different disciplines. Utilizing an integrated environment methodology makes it possible to combine model-based systems engineering with modeling and simulation, as well as verification and testing, so that a digital twin can be created to address increased thermal loads and a decreased ability to reject heat. This not only lowers the cost of design and development, but it also results in safer thermal designs. In order to attain the maximum possible accuracy for all of the systems housed under one roof, thermal test solutions may provide thermal model calibration. It should be feasible to model any kind of thermal management system in the same environment by modeling heat transfer between solids, liquids, and gas as well as phase transition events. Integrating mechanical and electronic computational fluid dynamics software with specialized electronics cooling simulation capabilities for chip package level, PCB level, or sub-system level simulations. By simulating convection, conduction, radiation, and solar loads, this approach helps eliminate board re-spins and reduce the costs associated with prototyping for both air-cooled and liquid-cooled electronic components.

A single source of information provides reliable data and the ability to account for phase change in thermal and fluid-thermal simulations which is similar to the conclusion that aerodynamic design solution offering.

5.4 Structural Design Management

The structural complexity involved in the design of aircraft propulsion systems has a significant bearing on the amount of money saved on one-time project expenditures due to structural design. The increasing competitiveness, pressure on design costs, and inventive design have all contributed to a rise in the structural complexity of engines, which has in turn put a burden on profitability. Engineering teams need partners for risk sharing in order to develop and evaluate engine structures and demanding enhanced traceability for certification. Under these circumstances current life cycle process of structural design given in Figure 5-2 [26] are unable to fulfill the quest.

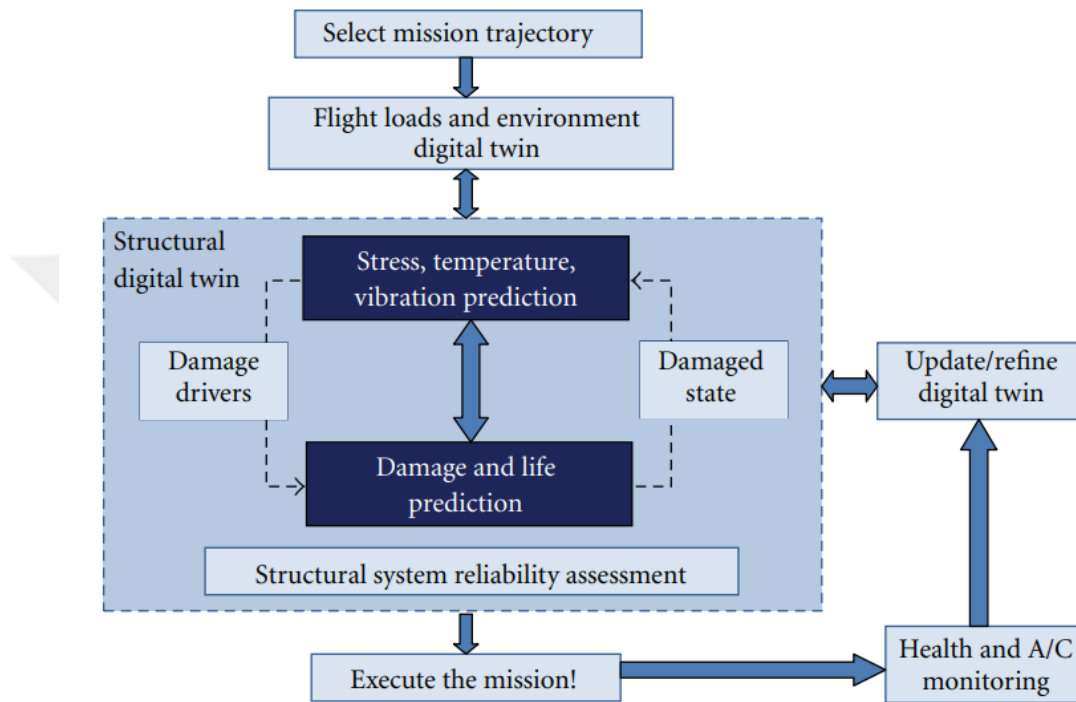


5-2 Schematic of Current Life Prediction Process

The structural analysis, which includes design, load calculation, finite element methods (FEM), and margin of safety, is not completely integrated. As a consequence, there are delays in communication, a lack of traceability for certification, the possibility of mistakes, and delays in implementing design modifications. In the current life prediction process for aircraft, each type of physics has its own separate model. There is the computational fluid dynamics (CFD) model, the structural dynamics model (SDM), the thermodynamic model, the stress analysis model (SAM), and the fatigue cracking model (FCM) [26]. The siloed approach, which involves isolated systems, people, and tools, is at the root of the problem that troubles the present processes for aero structural design.

As a solution suggestion for re-configuration of the structural design management process is using digital twin of engine which covers life cycle from beginning to finish.

With the Digital Twin, the SDM, the SAM, the FCM, and possibly other material state evolution models would be integrated into a single unified structural model that is tightly coupled to a CFD Digital Twin [26]. An end-to-end structural analysis links design integrates CAD/CAE/CFD and create infrastructure for certification traceability. Figure 5-3 [26] presents the implementation schematic that represents the digital twin prediction for structural design environment.



5-3 Functional Schematic of the Digital Twin Life Prediction Concept

End-to-end design accompanied by digital twin features a complete range of integrated linear analysis functionality, including analysis for linear statics, normal modes and buckling. Integrated explicit dynamic capabilities let perform metal forming analysis or evaluate electronic hardware performance during a structural dynamic testing like high impact drop test or vibration test. Furthermore, these budget- and program-wasting tests are run in test simulation space.

With an end-to-end design that is supported by a digital twin, it is conceivable to achieve the status of creating the aircraft engine while managing a stressful design-budget balance.

5.5 Mechanical Design Management

For many businesses, Product Lifecycle Management (PLM) begins with take control of engineering data and processes. This makes it simpler for individuals to discover one another, facilitate people's ability to work to be done, exchange information, and work together in collaborative manner. The general strategy to gain these possibilities, such as accelerating design collaboration throughout the business, begins with the integration of MCAD software and processes with PLM's main domain. Users are able to explore huge volumes of information fast, which is necessary to build a design context, load product structure, and re-use component designs. Users may also access sophisticated techniques for validating design requirements and engaging in change processes.

The general approach does not take into account the fact that the life cycle of electronic design products is an integral component of the product lifecycle, just as the life cycle of mechanical products is. In recent years, electronics has emerged as the primary driver of added value, revenue, and profit in the aircraft sector, while simultaneously upending more established processes for mechanical design. The primary processes for both the mechanical and electrical professions are focused with design, and design is simply geometry. It is not enough to just know that the thing being developed will have an acceptable level of performance. An integration of the most recent technological advances in the interchange of geometric data between ECAD and MCAD is a crucial aspect. At this point, the integration of MCAD and ECAD ought to be regarded as a significant milestone in the process of providing business-wide design collaboration as a solution methodology. Additionally, this value should be added to the step that is instinctively taken, PLM and MCAD integration. ECAD-MCAD co-design has long been recognized as a potential enabler to increasing productivity and ensuring a robust design [27].

The first challenge of integration is multidisciplinary design. As a result of the problem of siloed processes across disciplines, 59% [28] of complex products require at least two additional design iterations to address electro-mechanical concerns. With the implementing of integration solution end up with reduced physical prototypes by %thirty-seven [29].

The second difficulty associated with integration is the use of traditional methods and data sources that are unconnected. It has been shown that 26% [30] of

development time is spent resolving data integrity problems, and that 17% [31] of projects are terminated as a direct result of the problem of siloed data across diverse sources. With the integration solution, the end result is improved knowledge and awareness in data traceability of projects, which released on time with a surge in resources per 10% increase in employees [31].

The potential for confusion, misunderstanding, and misinterpretation in the process of developing a product is quite high when design environments for electrical, electronic, and mechanical disciplines are not integrated. Business wide design management methodology is one of the capabilities offered by the MCAD-ECAD integration management capabilities. This management makes it possible for people from a variety of technical disciplines, in a variety of locations, and all throughout the supply chain to work closely together to streamline product development processes. Aligning the tool ecosystem and allowing it to coexist in a shared environment with integration would reduce barriers between the domain silos of the past, so facilitating more interdisciplinary collaboration and productivity.

The electronics and mechanical design processes should be more connected, integrated, and collaborative than they are today. Seamless cross-probing between the two domains enables closer integration and collaboration, by enabling the design in each domain to be completed with contextual information from the other [27]. When given the circumstances attaining the status of business-wide design collaboration is feasible with sophisticated data integration interfaces that are compatible with all ECAD and MCAD systems.

5.6 Harness Design Management

Cable and wire harnesses are equivalent to human circulatory and nervous systems. They deliver energy, transmit command and control instructions, and collect and distribute sensory data describing not only the environment external to the system, but the health and status of the system itself [32]. The developed harness design for aviation subsystems such as the propulsion system needs to be improved with essential information such as those that harness component information and material quantity requirements for peer level consumption by mechanical, thermal, and material engineering. This information is necessary for the improvement of the developed harness design. Some examples of these sorts of particulars are those that provide information about the components, the amounts of the materials, and the cooling information.

Within the framework of a business approach for staying on course on-time delivery and first-time yield of aviation systems is possible with harness design based on advanced tools that enable enhanced functionality. These sophisticated tools are based on a set of rules and libraries, and for this specialized design branch they are called EECAD tools. The main purpose of an Electrical Engineering CAD system is to model the functional design of an electrical plant or control unit. This is done through the generation and modification of several types of schematics including wiring and ladder and diagrams [33]. A more electric aircraft propulsion system can be designed by optimizing its electrical network and accounting for thermal integration. Like the previous chapters' main ideas, integration between EECAD and MCAD environments helps design reliable harnesses, electromechanical actuators, and analyzes the impact of re-configuration in case of failure. Domain silos are eliminated through direct usage of the common environment. Using co-simulation and co-design ecosystems can allow high-fidelity physical models.

CAD tools in a single design domain are only able to accommodate the work of a single design purpose at a time. This is because CAD tools are specialized for specific design domains. It is rare for the designer to have an awareness of the whole design process. Because design engineers from either domain, EECAD or MCAD, typically are not knowledgeable with the design consequences their decisions may induce at the other domain or counterpart systems, such consequences are frequently discovered later on during the design process, which consequently leads to additional

revision cycles, time sanctions, and cost involved. Throughout the process of developing electromechanical products, changes made in the MCAD domain might result in major design changes being made in the EECAD domain, and vice versa. It should come as no surprise that there is a large number of requirements that need to be fulfilled in order to have a valid design configuration between the mechanical component of an electromechanical product and its electrical equivalent. Such interdisciplinary constraints between models of different engineering design domains cannot be handled in a multidisciplinary Computer-Aided Engineering environment due to the lack of appropriate multidisciplinary data models [34]. A fundamental criterion for eliminating superfluous cycles, corresponding time delays, and spending intervention resources is early knowledge of the cross-disciplinary design consequences.

The ideal method of simultaneous and synchronous engineering is characterized by the parallel work of a feasibly decentralized community of designers who are aware of the sequential work that their colleagues are doing and collaborate, as necessary. Because of the direct connection that takes place between MCAD and EECAD domains, the designer is aware of the whole design process. This is because the designer is able to hold the knowledge of design ramifications from both the mechanical and electrical sides of the design. The disciplines of electrical and mechanical engineering are able to function independently of one another, but they are also able to simply exchange data with one another when it becomes available. The designers are able to interact across disciplines at any frequency, which allows them to maintain participants in their respective systems inside their comfort zones while cooperate remaining in their own native environments. Thereafter, the designer of the harness product merges the mechanical information with the electrical data in order to completely describe the product.

This type of work can be done in either a single location or across multiple locations. Because a shared database is the location where all of the design requirements are merged, the sharing of information inside a common database is an essential building block for the process of co-operative design. Powerful data integration interfaces that are compatible with all domains specific tools are required in order to realize the goal of business-wide design collaboration.

5.7 PCB Design Management

Printed Circuit Boards (PCBs) can be defined as rugged nonconductive boards built on substrate-based structure [35]. A PCB consists of an electrically insulating base onto which conducting metal tracks are patterned to form electrical connections for electronic components mounted to the top, and sometimes the bottom, of the insulating based. The PCB has electrical, mechanical, and thermal properties that must be considered when creating a design for a particular application [36].

PCB design data management is a key challenge that may drive growth and save time. This can be accomplished by documenting, preserving, locating, and reusing the correct design data. The capacity to access and store design files, cooperate across engineering domains, produce simulation files, exchange manufacturing and assembly data with suppliers, and construct a comprehensive product index are all vital elements of electronic design data life cycle. The design and manufacturing processes should be carried out separately by establishing an analogy as the city planner plans the city, while local governments are responsible for its upkeep. PCB processes design data should be considered as a special process and an effective database on obsolescence management should be developed. These special needs are met with Electronic CAD tools, which refer to computer-aided design systems that are used to design printed circuit boards (PCB), integrated circuits (IC), and other logic-driven designs (Chen & Schaefer, 2007).

The unification of ECAD and MCAD is beneficial to the creation of modularized products, which are encountering rising levels of both requirement and complexity. It is very necessary for cross-functional design teams to have enhanced visibility across domains in order to optimize their productivity. In a similar vein, sophisticated technology in the design process as well as the management of data sharing frees up more time for designers to concentrate on design validation and indigeneity, both of which contribute to an increase in overall design quality. Because the electrical and mechanical components of the design are equally important, having a thorough awareness of both will, in the end, result in improved product.

When discussing the benefits of integration, it is typical to touch on the topic of concurrent engineering at least briefly. Concurrent engineering, known as simultaneous engineering, is a way of designing products in which the various phases operate concurrently, instead of in the traditional sequential order. The first result of

the combination of ECAD and MCAD was the realization of how important it is to use a simultaneity-driven design approach while developing the physical design of electronic components. It reduces the amount of time required for product development, which consequently cuts down on the amount of time needed to bring a product to market. As a result, productivity is increased, and expenses are cut thanks to standardized data sharing infrastructure throughout a whole company.

By applying project-based collaborative design work process, total MCAD–ECAD related errors in physical verification step are reduced about 30% given in Table 5-1 [37]. Son, Na, Kim and Lee claims that the total number of errors of eight related categories are reduced about 46% and they assume that their contribution is about 60–70% of the reduction [37].

5-1 Estimation of Enhancement in Items of Quality Failure

Function	Category	2011 (Before)	2012 (After)	Contribution (60–70%)
Electrical design failures	PCB design rule	30	7	
	PCB – placement	14	8	O
	SI/PI/noise/timing	9	9	
	DFM – mfg	11	8	O
	Part – reliability	11	11	
	PCB – layout	2	1	O
	PCB – routing	2	2	O
	EMC	2	2	
Mechanical design failures	Interference/clearance	39	14	O
	Mould/machining	37	35	
	Exterior/design	31	25	
	Thermal/structure	31	17	
	Part – reliability	13	13	
	Industrial design	10	8	O
	SET assemblability	10	7	O
	Mechanical layout	2	1	O
Total sum of failures		254	168	

Co-Design environment properly define a design change, designers indicate the changed item before implementing the update in their design. Consistent, iterative communication encourages team alignment. Increased communication among teams, together with flexible and more intelligent user interfaces, may actually facilitate modularization and standardization in the design process. This can be accomplished by connecting the domains of various disciplines.

For the aim of obtaining the status of business-wide design collaboration it is necessary to have robust data integration systems that are compatible with all domains.

5.8 Software Design Management

Product Lifecycle Management (PLM) is traditionally considered to be the ideal methodology and tool that service this methodology to address the hardware lifecycle of a product. It could best be described as a management activity of products all through their lifecycles in the most efficient way possible. It is used to organize CAD drawings and to manage product data like bills of materials and project management processes [38].

PLM is consisted of four phases. Conceive phase is when information is gathered in accordance with customer needs and technical specifications of the product are defined accordingly. In the design phase, the initial design of the product is finalized. Mechanical, electrical, electronic and software engineer knowledge are used in this phase. Realize phase includes the completion of the product design, decision of the method of manufacturing and carrying out different analyses on the product model. Finally, there is service phase that consists of maintenance services, waste management and disposal [39].

ALM can be thought of as PLM for software. Similarly, to Product Lifecycle Management, ALM encompasses the entire lifecycle, from requirements management, through development, testing, maintenance, all the way to the release and maintenance of software products. Project management, integrated data management and collaboration are important parts of any ALM solution [40].

ALM has eight phases. Initial one is application project and portfolio management where an investment analysis is conducted, and business case developed. Project inception and requirements gathering is when market and potential customer information among other documents are gathered. Requirements management means analyzing the changing requirements whereas design and use-case analysis sets out the software code and several use-cases are developed in line with foreseen customer behavior. Coding is the actual code writing phase, followed by Testing & QA, after which code is revised, if necessary. Build release is when the product is manufactured and deployed. The last phase is application performance, where lifelong maintenance takes place until the end of the product's life [39].

ALM-PLM integration enables product development organizations to have a single, cohesive product ecosystem, with multi-directional linking of ALM and PLM data and processes. It also allows for visibility across all assets, accurately links

firmware with hardware, enables traceability of assets for engineers in all lifecycle phases, and supports maintenance, repair, and operations. In order to achieve an efficient ALM/PLM integration, the underlying data model must provide comprehensive access to all data created for or by an asset, it must be possible to link an ALM work item with a PLM item and vice versa, linking a PLM item with an ALM document must be allowed, accessing the data of any attribute of an ALM work item from the linked PLM item and vice versa must be enabled and linking more than one ALM work item with one PLM item in a single action must be possible.

The increasing amount of software is provided to aerospace and defense systems because of demanding more sophisticated functionality but it presents unique challenges, regulations to minimize risk and ensure safety. In the Aerospace and Defense industry, airborne software compliance is governed by DO-178, which ensures that all software requirements have been developed to support system requirements. End-to-end traceability of product and software life cycles from requirement to product will be ensured and data duplication will be prevented. This linking and visibility across the domains can help the fulfilment of DO-178 standard needs. End-to-end traceability of product and software life cycles from requirement to product will be ensured and data duplication will be prevented. With the workflow orchestration feature of the integration tool, product-based siloization will be prevented by linking PLM and ALM object types that are subject to change management, problem reporting, document management, software release management.

PLM-ALM integration has a crucial importance on aviation propulsion systems' life cycle in terms of visibility across all assets with improve locate and manage information mission. Accurate links between software, firmware with hardware can also provide avoiding errors and damage costs. Therefore, it reduces the risks of reputation loss when deducted in the long term. Detectable and identifiable information of assets reduce time waste all phases of life cycle.

To conclude it would be fair to argue that achieving the status of end-to-end quality across electrical, mechanical and software systems is only possible with PLM-ALM integration, specifically on the aviation propulsion systems.

CHANGE MANAGEMENT

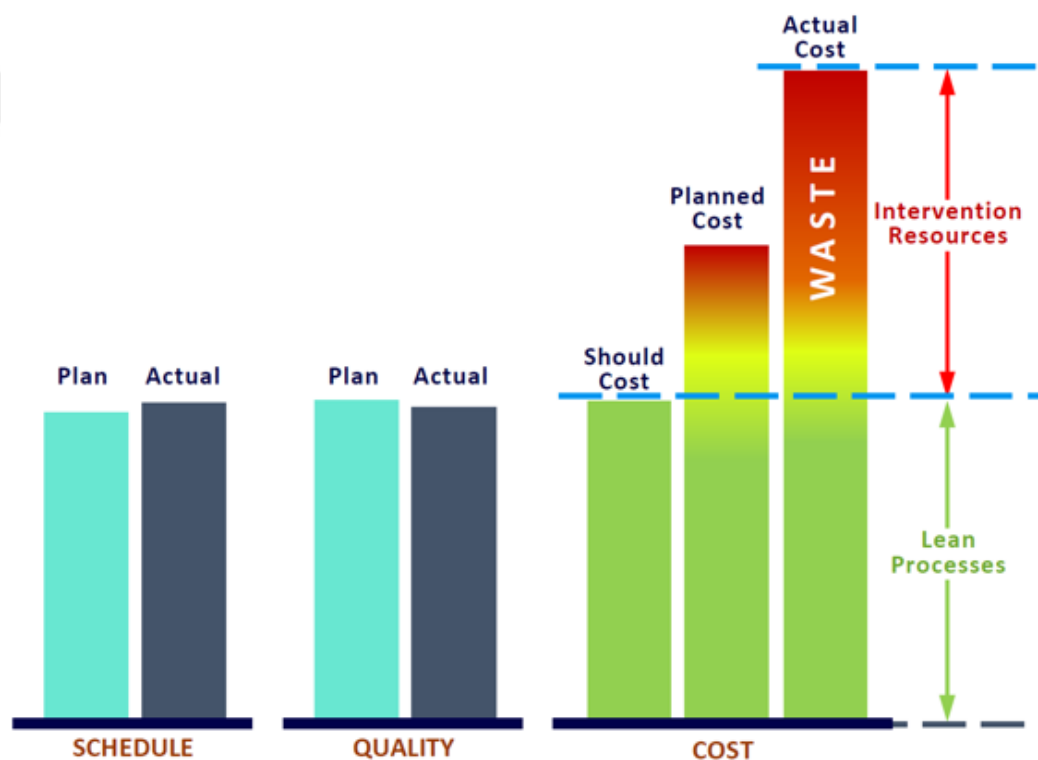
The culture of an organization is the most important factor in determining its success. This culture undoubtedly has to include not just the process but also learning, people, and technology. It is quite required to achieve a suitable re-alignment of organizational processes and technology in order to provide support for the preserving historical versions of data. An effective product change management strategy that seeks for process excellence enables continuous and systematic product improvement, which in turn leads to a rise in employee engagement, that in ultimately generates in more cooperation, transparency, and accountability. Life cycle product change management facilitates the management of change processes across all involved disciplines, domains, and resources.

When taking a step back and considering the whole picture, change management is neither its own distinct process, nor can it operate in isolation. Change management is inextricably linked to configuration management, the goal of which is to guarantee that existing configurations are in accordance with the criteria outlined for them. The management of changes to the requirements is an essential part of the life cycle of a product. Requirement management should not only guarantee the correct linking and structure of requirements the first time around, but also when the requirements are updated. Due to the fact that requirement management relies on change management as its foundation throughout the product life span. Change Management also closely relative to Release Management, which is responsible for ensuring that datasets have been approved and published before they are used. Change management not only systematically preserves knowledge assets but also prevents unauthorized modifications to relationships. This is a result of data management, which has as one of its primary objectives ensuring that datasets are correct and deliverable data is protected. As the level of complexity of the product rises, the linkages that have been discussed get more intricate.

It is critical to monitor and record changes and their impacts on the mentioned processes both safety and certification when dealing with the high-quality product of aviation, especially the aero-engine. The aviation business is having difficulty meeting its targets for both time and quality, while also spending significant unforeseen expenses. The resources that are committed to making changes are referred to as intervention resources. These resources take on the responsibility of ensuring that the

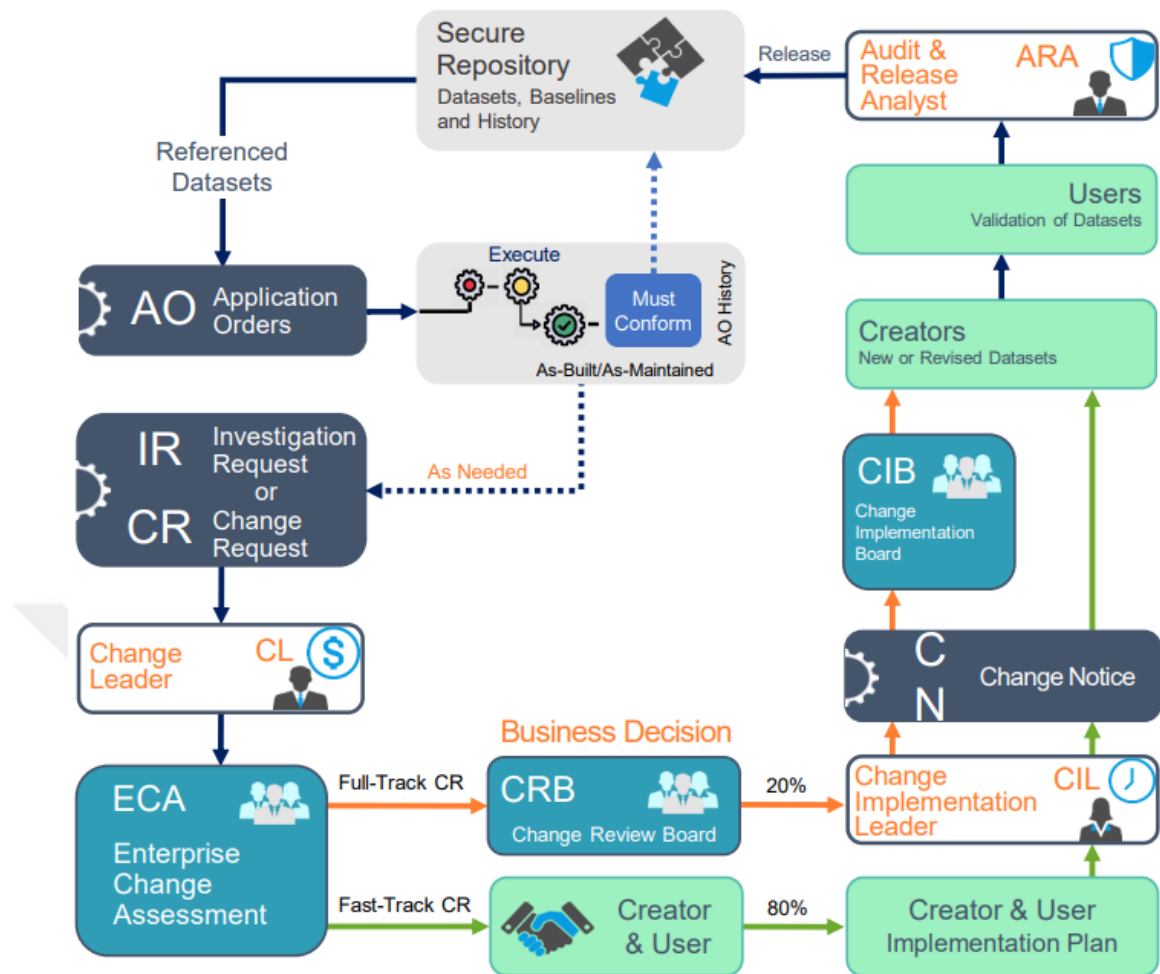
rescue operation meets all of the certification, safety, and time requirements. CM2 claims that most organizations spend over 40% [41] of their resources on intervention given in Figure 6-1 [41].

The most effective strategy for managing changes is to use consistent closed-loop processes of the CM2 methodology. This process is provided comprehensive traceability for audit history and recordkeeping. CM2 is a reengineered version of configuration management and a prerequisite for achieving integrated process excellence [42]. According to the philosophy of Integrated Process Excellence, the unification and digitization of enterprise applications leads to a considerable decrease in the usage of intervention resources owing to a closed-loop change process.



6-1 Intervention Resources

Closed-loop change management provides those new data packages are distributed and maintained at the organizational level, as well as the management of change processes to which existing data is accessible, with a scope on operational excellence. Closed-loop change management additionally ensures that existing data is subject to change management.



6-2 CM2 Change Process

In the closed-loop change process used by Change Management, communication serves as an undeniable cornerstone for the purpose of accumulating knowledge that is distinct, condensed, and accurate in order to create an atmosphere in which a business can effectively make decisions. Various functions are fulfilled by roles, objects and at different meetings in closed-loop change process represented in Figure 6-2 [42]. Investigation Request (IR) is a request for an inspection in which the issue has been presented, but the solution is either in the midst of being worked on, has not been resolved, or is currently unknown. A Change Request (CR) is a document or form that is used to conduct an analysis of proposed change and offer information about the schedule, costs and benefits of those changes. An impact matrix is included in the Change Notice (CN), which is a document or form that is used to implement authorized change requests. It gives one the authority to update or release a dataset. Application orders (AO) are documents or forms that are used to approve and regulate the operation or actions that are being carried out on items that are relevant to the application. This

approach includes a role known as the Change Leader (CL), which is responsible for managing investigation requests and change requests all the way through the analysis phase of the change process. The Change Implementation Leader (CIL) is a role that handles change notices all the way thru implementation planning and execution stages of the change process. Audit and release analyst is a function that analyzes change implementation packages and confirms the integrity of data. This methodology puts significance on the importance of communication and collaboration among team members. It is not practicable to enforce change management in the boundary based just on roles and datasets. There are three significant meetings that are recommended, but this number may be expanded according to the needs of the organization if the functions of the meetings are split up. An investigative request or change request might be subjected to a process called an Enterprise Change Assessment (ECA), which analyzes the request from a technical and/or practical viewpoint. The Change Review Board (CRB) is a committee of senior-level managers that analyzes the costs, risks, and consequences of proposed changes and takes strategic decisions. The Change Implementation Board (CIB) is a cross-disciplinary committee that is responsible for developing an executable implementation strategy. In addition, the CM2 closed-loop change process mandates A Dataset Change Record (DCR). A Dataset Change Record (DCR) records the changes made to a dataset. It shows the prior and subsequent states of its content. In the certification process of an aircraft propulsion system, the was-is state reports with their eliciting visibility and links provide the upper hand.

As a concluding remark through the implementation of aligned people, processes and closed-loop change management, it is feasible to realize the level of standardized and industry leading solutions.

MATERIAL DATA MANAGEMENT

Reputable aero-engine companies can ensure that products and related content are in perfect sync. The fundamentals of using approved material information across the enterprise are important to mission-critical product functions such as design, purchasing, compliance and manufacturing. Design decisions can be leveraged by integrating multiple aspects of material, including density, cost, material, appearance, procurement, regulation, and interoperability with CAD programs.

PLM is a platform that prevents material data silos, expensive material test repetitions, design start with the wrong material, supply chain function invisibility. Material information is required in life cycle analysis whenever the material is used in a manufacturing, product or needs as an auxiliary input. Materials must be selected at each stage of the PLM to ensure traceability and stability checks during the PLM. Since the product and material cycles intersect in parallel, the PLM must be aligned with the material life cycle. The Life Cycle Assessment (LCA) approach can help determine the impact of products or systems on a range of environmental and resource related issues. Some researchers are use PLM for material selection and recommend enabling PLM for material selection [43, p. 2].

The Materials Selection and Analysis Tool is an enabler for material selection approaches integrated with life cycle management. Materials Selection and Analysis Tool, which was developed by The US Army Research Laboratory, is the single source of material properties for the Army and its contractors and other supporters. The system includes the physical, mechanical, and environmental properties of metallic and non-metallic materials. All data operations are tracked with version control to facilitate technological collaboration and innovation [43, p. 4].

It is possible to integrate material selection into the PLM process. The definition of material properties includes only acoustic, atomic, chemical, physical, electrical, environmental, magnetic, manufacturability, mechanical, optical, radiative, thermal and ultra-thermodynamic properties. These properties could be extended to also include conflict resource, referring to how you are hired, work conditions and smuggling involved trade, sustainable properties referring to natural resource depletion, air impacts, terrestrial and aquatic impacts, climate effects, human health and ecosystem quality, and lastly environmental properties referring to embodied energy and water. Choosing materials for designing a new product involves several

steps; determining application requirements in terms of mechanical, thermal, environmental, electrical and chemical properties, selecting the material for application and understand what changes in material properties are needed [43, p. 5].

Material selection can be done throughout the product life cycle with the involvement of suppliers and rule makers, so it is necessary to implement a substance compliance check against regulations [44]. Life-long impacts of a product or process should be assessed in PLM. The method is saved as metadata and sets of data. All data manipulations are tracked using a version control system, which simplifies technical collaboration and innovation [45].

Further research areas need to be concerned with contemporary information on the matter. Integration of Material Selection Process across PLM with the help of Life Cycle Assessment (LCA) approach and threats for PLM if not addressing compliance and sustainability requirements in material selection are the concerns to be addressed. Providing the required detailed compliance data for the form, creating form validation criteria, translating social and sustainable impact in terms of the cost of production and presenting social cost functions in a measurable manner based on material properties are the criteria to bear in mind. The main decisions in material selection are usually made during product design and must meet driving forces such as market demand, cost savings, legal requirements, and social pressures on environmental sustainability. Compliance violations can occur due to lack of resources and defined processes. As a result, the exact compliance status of the product may be determined and eventually product recalls, fines and penalties may be imposed. The main risks to consider are data availability, quality of supplier chain, scale and complexity [43, p. 7].

In conclusion, in order to build up the status of managing compliance-related materials, it is possible to do so by covering the complete spectrum for everyday design life.

MANUFACTURING DATA MANAGEMENT

8.1 Part Manufacturing Management

Manufacturing is defined simply as part manufacturing, done by means of CNC machine tools, robots and other tools [1]. The objective of raising production while simultaneously enhancing productivity is one that is continuously present in the thoughts of manufacturers. As a consequence of this, brand-new manufacturing equipment has to be designed to successfully manage the growing loads that are the direct result of increased demand, all while maintaining an absence of downtime and malfunctions. When it comes to products that have complicated geometries and strict certification procedures, however, it is simply not enough to outline the standard technique of component manufacture. Engineers need an efficient process that includes full histories such as realistic views and accurate fatigue life predictions in order to deal with such complex product, which can also be delivered in a wide array of different configurations, particularly in the prototype phase, which is especially the case when the equipment is being developed.

PLM is the total life-span of the product it contains distributed data-and knowledge bases, files, memories, with unique and/or redundant information framework keeping programs of the digital production under control [1]. When manufacturing expertise can be transferred inside and across software environments, there are enormous potential advantages for the part manufacturing of engine parts. Utilizing a single source of information to ensure that the creation of high-quality components is based on precise planning data, clear communication and machines that work efficiently thanks to digital thread. CAD/CAM systems with proper quality eliminate the need of re-modeling the CAD model of machined part for CAM system [46]. It is healthier to connecting development, planning, and production, use a single source of information as a point of interconnection. It is providing the reliable data to the production equipment, such as CNC machines and robots, in a direct and immediate manner. Using digital thread to link all stages of development and production in order to provide accurate data to the manufacturing floor is the course of action that is recommended. As a consequence of this, the entire operation efficiency was improved, and this was accomplished by converting the machine shop into a data-driven environment.

The continuous digital thread helps to make sure manufacturing data is used throughout the production process. It is easy to understand, hard to manage in real, interconnected, networked design offices, workshops and factories of any kind, even with appropriate software support, however large organizations need and use similar systems to keep in hand all processes and products in an economic, transparent way [47]. Every single step that goes into the CAM process should have some overlap with the phases that go into the creation of software and should be carried out in the ALM environment. Integration to PLM can be achieved by the establishment of centralized digital library that are capable of being directly accessible from ALM environments. Categorization and database administration are both advantages provided by the centralized library for the production engineering resources. A tool library, in which data about tool components and assemblies can be handled, is an example of a typical application. Users of CAM have unrestricted access to the library, which contains a variety of instruments, fixtures, and blueprints. Extensive search, continue to display, and retrieving functions can provided throughout a whole domain by the continuous digital thread that runs across ALM and PLM while utilizing a single point of source. Additionally, considerable cost reductions and increased revenues can be achieved by replicating machining programs on a ALM and PLM environment rather than doing potentially dangerous tests on an actual CNC machine.

To summarize everything up connecting systems, shop floor, library people and machines via digital thread is one way to increase productivity in the production of parts. This makes it possible to realize the objective of boosting component production productivity.

8.2 Additive Manufacturing Management

Additive manufacturing or additive layer manufacturing is a computer-controlled method that makes three-dimensional things by depositing materials, usually in layers. It is widely known outside the industry as 3D printing. Companies may reimagine products, retool manufacturing, and rethink business models using additive manufacturing [48].

Producing additive produced parts on a large scale, particularly in metal, necessitates several manufacturing and post-processing steps that must be coordinated.

While conventional way of thinking has the obvious disadvantages of design parts, complicated supply chains, expensive production values, lead time being too long, with additive manufacturing, product mounting effort is decreased, production time is minimized, assembly is done in a quicker manner and markets could be penetrated swifter. In addition, conventional way of thinking also generally does not have the infrastructures to allow the supply chain, production, and post-processing processes to coexist. PLM stores all the information needed to complete the whole additive manufacturing process, from design to print, in the same environment. Having additive manufacturing designs on PLM has the main advantages of unified arrangement for added substance idea-to part, multi-disciplinary building proceeds life in single environment, additive manufacturing machine mechanization, control and network and managed environment from order-to-service. Living in single environment has advantage of plan checkers utilizing mechanical CAD devices aid rapidly recognize manufacturability challenges. For execution and plan optimization, software-driven generative engineering, which can best be described as the digital enterprise portfolio offers tools for design space exploration, can be leveraged [49, p. 580].

The following information include the additive manufacturing solution packages given as part of the original product lifecycle management approach for aero-propulsion systems.

Keeping track of all data associated with the additive manufacturing process is an essential factor. PLM data management approaches can be used to capture the full additive manufacturing process. With this approach not only information about part geometry, but also information about the build tray configuration and printing parameters. In addition to build strategies, post-processing, and validation methods, additive manufacturing is a complex puzzle. Effective data management is necessary

for a quality and repeatable additive manufacturing process. Using the same infrastructure and shared-data benefits of PLM, data management for this process is straightforward and efficient.

Another key aspect of additional manufacturing is managing the process. Producing fabricated components at a mechanical scale, especially in metal, necessitates the supervision of several fabricating forms and post forms. Setup and planning of the printer as well as post-print steps such as substrate division, warm treatment, wrapping up, and assessment are all steps that must be firmly controlled. Additive manufacturing flow has a circular process, including design software, simulation software, print preparation software, AM Process, heat treatment, finishing/inspection, and end-use part. Since the tools used during the flow are different, uncontrollable workflows and disconnected process flows could be resulted [50]. Synchronized process flows with workflows and work instructions can create simplicity of operation and high productivity

One of the challenges of additive manufacturing is making sure operations are running as efficiently as possible. The establishment of an operations management environment for additive manufacturing makes it possible to control the whole production process with greater precision. This approach permits that to make, select, and expedite work orders; provide shop floor administrators direction; and pass serial numbers to the appropriate system to implant them within the print work when required. The environment for operations management provides information about which operations should be performed and when they should be performed within the appropriate grouping. This allows for the optimization of assets by using the appropriate machine at the appropriate moment within the handle. These processes are all a part of an efficient strategy for mechanical fabrication, and they assist computerize your generation so that you can get the most out of your facility.

Another challenge that additive manufacturing presents is optimizing the use of the fabric. Additive substance fabrication process that has to be strictly regulated is the management of the materials used in the process. In order to keep track of the materials that are used in printing processes, it is essential to check the number of reuses and blended powder clumps. This is something that can be done in an environment devoted to operations management. This traceability is one of the powerful characteristics of PLM, and it is essential since it is not possible to disassemble mixed powders, and the

amount of reused powder that is used may have an effect on the quality of the print that is produced in the end.

Obtaining data on the fabrication of additive substances is critical for this recently flourished manufacturing technology.

Taking stringent information security precautions in order to protect the intellectual property of the firm. PLM provides tools to ensure the safety of information on the fabrication of additive substances. PLM's system provides a safe and reliable computerized holder that can be used to transfer and modify information about additive substance fabrication as the improved process flow is processing it. Every one of the critical components' coordinates are entered into the PLM system and sent to the machine controllers.

Increased competition, destitute program execution, and developing arrange accumulations are driving aviation and protection companies to progress effectiveness wherever conceivable. Additive manufacturing empowers aviation and resistance companies to reshape everything for ideal execution at diminished fetched, in comparison to conventional fabricating strategies that require different steps, instruments, and medicines to attain the specified result. Our coordinates computer program applications for added substance fabricating assist you reimagine items, retool fabricating, and reconsider trade models [51, p. 1127].

8.3 Composite Manufacturing Management

A material that is created from two or more materials may be described as being of the kind known as a composite material. These main advantages of composite have physiochemical qualities that differ significantly from one another, and when combined, they produce a material that has properties that are distinct from those of the separate elements. Since the various components of the completed structure have their own identity and location, composites are distinguished from mixtures and solid solutions by having this property. The methods associated with producing composites are complicated and require specialization. In order to be successful, this discipline of manufacturing require a method that is both precise and time-effective for analyzing the engineering product requirements. The number of aero-engine applications that make use of composite materials is continually growing. Composites provide original equipment manufacturers in the aerospace industry with the chance to meet vital criteria by lowering fuel consumption and decreasing the engine's overall weight. The typical applications of composite materials in aircraft systems are outlined in Table 8-1 [52].

8-1 Typical Composite Material Systems in Aerospace

Material system	Application area
◆ 175°C curing high strength-carbon-epoxy – Zero-bleed (neat resin content) UD prepregs – 5HS or 8HS bi-directional fabric prepreg – toughness, good out-life and shelf-life ◆ 175°C curing intermediate modulus carbon with epoxy + BMI/cynate-ester – Zero-bleed (neat resin content) UD prepregs – 5HS or 8HS bi-directional fabric prepreg – high toughness, good out-life and shelf-life – low environmental degradation	Structural components of fighter aircraft and helicopters. e.g. wing skins, spars, fin, rudder, elevons, doors, etc. Frames, stiffeners, rotor blades
◆ 120°C curing HS-carbon-epoxy – Zero-bleed (neat resin content) UD prepregs – 5HS or 8HS bi-directional fabric prepreg – toughness, good out-life and shelf-life	Structural components of helicopters or transport aircraft. e.g. spars, fin, rudder, elevons, doors, etc. Frames, stiffeners
● Aramid fibre in low-loss polyester/cynate esters	Radome
● Cu-mesh epoxy prepreg	For Lightning Strike protection Wing-skin, others
◆ E-glass fabric in epoxy resins – High temp curing – RT/moderate temp curing	Fighters fairings, fin-radome, drop-tanks Small transport aircraft structural components : Fuselage, wing, other

As new commercial aeroengines extend the footprint of composites in the cold section, the advantages of using composite materials in aeroengines are becoming more obvious. Additionally, recent developments in the hot section are making use of ceramic and metal matrix components, which indicates that composites may also be effective in the hot section. In order for OEMs to harvest these advantages, they need to have the capability to design and manufacturing process advanced composites engines that that meet the commercial and regulatory requirements of challenging aero-engine environments while also having high accuracy for design, better manufacturing outputs, long operating durability, and straightforward reparability.

The simultaneous and confidential cooperation that takes place throughout the product design, planning, production and assembly operations is a necessary piece of the manufacturing of aircraft parts. Every component of the engine life cycle, from domains to personnel, requires a demanding environment for collaboration that is also effectively secured. The PLM approach contributes to the formation of a single source of product and process information in a vault of shared knowledge which enables the reuse of existing best practices and the management of available resources in order to achieve continuous improvement. A benefit of utilizing PLM for aircraft propulsion systems makes it possible to establish an end-to-end relationship between the understandings of engineering, cybersecurity, analysis, reliability, manufacturing, in-service and repair as well as the systems that are used in these territories.

Manufacturers are facing increasing challenges of better product quality with tighter delivery requirements for customers and more profitability for shareholders. Thus, an effective collaboration between customers, developers, suppliers, and manufacturers throughout the entire product lifecycle is becoming much more important for the most advanced competitiveness. PLM enables manufacturing organizations to obtain competitive advantages by creating better products in less time, at lower cost and with fewer defects than ever before [53]. The use of composite materials for several aerospace components in current programs worldwide has resulted in considerable weight savings estimated to be about 30%. The future aerospace composite structures can therefore be expected to be highly optimized and smart [52]. In order to properly meet the one-of a-kind requirements of composite product creation knowledge management, there must be relationship between the design, manufacturing and maintenance. PLM is a function that gives a solution for the design and manufacture of aero-engine composites. This solution enables the

connected and confident development of high - quality aero-engine products. In the most difficult applications, it helps original equipment manufacturers to achieve requirements for deadline, power, price, reliability, production first-time yield, and service maintenance.



8.4 Fixture Management

In the aviation industry, the profitability of specific projects is strongly reliant on the effective implementation of the production process. There is a lot of demand on original equipment manufacturers and suppliers in the aerospace industry to drastically raise their efficiency while also reducing their expenses and increase their business agility. Companies that are superior at managing the tools and instruments involved in manufacturing often come out on top.

Tooling and fixtures used in aerospace production are typically difficult to develop and challenging to use. However, the end result is directly impacted by their performance, both in terms of quality and manufacturing consistency. Because of the usage of stand-alone digital applications, the design of the product is indeed detached from the design of the tooling and the manufacturing process, which has resulted in an interruption of the flow of information. In order to build effective tools, one must have a comprehensive knowledge of the working circumstances that will be encountered throughout manufacturing.

Utilizing an integrated approach that not only enables design for manufacturability but also specifies the manufacturing process, plans, and tooling simultaneously with the design is essential. The key is to adopt an integrated method. The PLM approach offers centralized management of all resources used in production, such as machines, tools, and fixtures, via the use of a unified environment that contains digital libraries. Because of this, it is possible to access the required information directly from the shared environment. Because the fixture designs are entirely associative to the part model, the objects are able to update information of fixtures in a precise and reliable manner in response to changes in the part model. It is very necessary to have a two - way data interchange between the various component parts of the fixture and the part itself while running in the same environment. If indeed the fixture design is dynamically coupled with the component or product model, then the fixture model responsible can be automatically updated whenever the design is modified.

A common environment solution may also unlock the benefits of digital twin technology. Transformation of the design and production processes into a digital model with the same capabilities as their real-world counterparts. This digital twin enables the development of, and the driving of, efficient shop floor activities, from

model-based product requirements through virtual commissioning. Because of this, it is possible to leverage manufacturing as well as manufacturability.

As a consequence of that one, it is essential to have a data exchange that is both systematic and reliable between the design and its fixture. One of the effective approaches that may be used to secure this collaboration is the usage of digital twin.



V&V AND CERTIFICATION MANAGEMENT

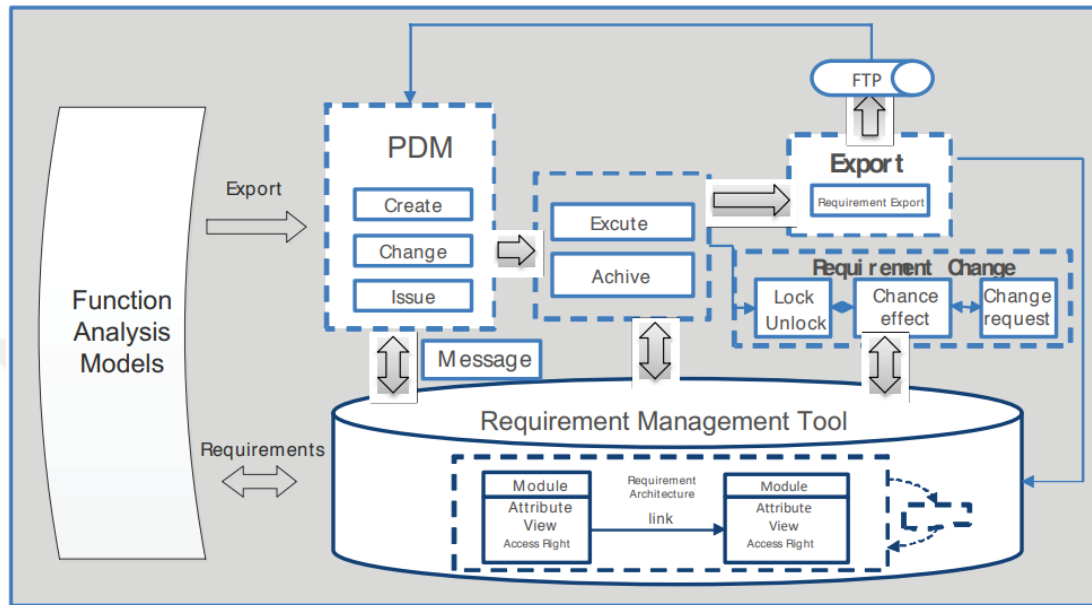
9.1 V&V Management

The validation process is part of a product development phase in which, during this phase, it is confirmed that the requirements of customers, users, suppliers, maintainers, and certification authorities are properly established according to compliance methods. The purpose of the validation is to prove that the system under consideration at any stage of development and after installation fully meets the requirements [54]. It is determined whether or not the product has been designed appropriately so that it may be put to the purpose for which it was intended. Validation activities consist of tests and activities for qualification and certification, and they may be carried out at the level of a part, equipment, component, subsystem, or system. Throughout the lifetime of a product's cycle, validation can be broken down into two categories: requirement validation and system validation. Requirement Validation is the process that meets the requirements of stakeholders and certification authorities and ensures that the product's requirements are established that the requirements for the product are determined consistently, accurately and completely. System Validation can be summarized as an integral part of a product development effort. System acceptance tests are conducted for the authority and/or client as a part of system validation.

Despite the fact that validation is just a sub-process of verification and certification processes, it nevertheless contains a considerable amount of specialized knowledge that is necessary for engineering specialties. Validation of the engine design at the component level is performed for reliability, vibrational behavior, life, functionality by testing for spin, load on casing, burst, overspeed, vibration, flow, and other parameters. Validation is also performed for the engine level. Validation of the engine design is carried for endurance, ingestions such as bird strike, ice, hail, water, and sand, as well as emission and rotor stress tests. The fact that validation studies cover such a vast and complicated spectrum, as is the case with verification, causes leads to preventing communication accidents and prioritizing cooperation.

The life cycle validation method aims at collecting and linking requirements with verification and certification requirements on complete cycle of closed the loop. PLM-based validation management provides a communicating environment that ensures all product validation events, whether component or engine level simulation or physical tests, are driven by requirements, observed in the particular sequence, keep a close

watch on individual tests and analyses to the necessary resources, as well as provide tracking and tracing. Within the domain of V&V studies, validation studies are able to profit from all of the advantages offered by digital twin technology. Figure 9-1 [11] presents the implementation schematic that represents the capturing of the requirements for validation in the PLM environment.



9-1 Requirement Capture and Validation in PLM

Engineers working on aviation engines need a linked validation framework that facilitates an integrated testing strategy that combines modeling and physical testing in order to effectively address design difficulties and reduce the probability of catastrophic failures.

The purpose of verification is to prove that, with certain input data, the elements ready for delivery at each stage meet the requirements of this stage in every respect [54]. The verification processes are to manage the integrity of the data generated in the design validation processes using a variety of methods such as statement, identification, design review, calculation, analysis, safety assessment, laboratory tests, flight tests, simulation/modelling, inspection, and equipment qualification studies at each tier of the system hierarchy, which includes parts, equipment, components, subsystems, and systems. Throughout this step of the process, the concerned authority role gives its stamp of approval to both the technique such as analysis, simulation, inspection, demonstration, or test as well as the data utilized to achieve an acceptable and adequate outcome. The verification process determines whether or not the design was executed correctly.

Recent years have shown a rapid progress in the area of formal specification/verification to overcome the increased verification gap and to face the test/cost problem of complex designs [55]. Traditionally, the complexity of a product is measured by the complexity of its physical testing; and given this context, aircraft engines stand out as one of the unquestionably obvious examples of this. When it comes to the verification process, reliance on physical testing not only necessarily involves a considerable investment of both time and resources, but it also leaves very little room for design flexibility. In the aero-engine industry, safety and performance requirements that guide design are of the utmost importance, which necessitates for rigorous airworthiness verification processes to be performed out throughout the lifespan of an aircraft sub-system.

It is typically not realized how the inability of cooperation and communication between design and certification operations constitutes revisions and inefficiencies. Without this communication, engineering and even production will adopt modifications without considering how these revisions would affect verification activities further down the chain. Research shows that even despite the widespread use of automated systems of design, reverse engineering, and engineering data management CAD/CAM/CAE/PDM, the following problems remain:

- only 28% of projects are compliant with the planned terms and budget;
- over 45% of the development budget can be spent on corrections and alterations;
- up to 50% of the total amount of work is spent on correcting errors in the design [56].

An insufficiency of traceability makes it difficult to establish total control over the verification processes of a product, which in turn hurts the business's reputation in the eyes of the customer. Verification rapidly becomes problematic when it is dependent on a collection of documentation that is both unstructured and isolated. As a possible consequence, it is difficult to deliver critical information in an organized and accordance to the objectives. In addition, this may lead to usage of intervention resources.

Any inconsistencies in verification processes can be eliminated with the use of verification management using the digital twin approach. Through the use of the capabilities of digital thread, the powerful digital twin guarantees complete traceability and visibility. It focuses on gathering the verification artifacts in real-time information while they are being completed, rather than having to gather them all together at the

conclusion of the verification process. It is one of the solutions to make use of centralized dashboards with the assistance of digital twin, which have the potential to generate a report that gives the current state of all verification processes. The provision of such detailed reports makes it feasible to take preventative measures against delays that have an effect on verification operations. The use of digital twin enables full traceability from requirement to verification across all disciplines and across the whole supply chain using a single eco-system. This unified and integrated environment guarantees that verification practices are implemented by requirements, schedule for, and carried out in the appropriate order. It is achievable for digital twin to minimize bottlenecks, decrease the rate of rework that has to be done, strengthen predictability, and enable improved communication between stakeholders, all of which may make it simpler to carry out more complicated verification procedures. The digital twin is able to sustain the stream of thinking throughout the whole cycle while also managing test cell software configurations and related test article.

The idea of a digital twin will facilitate to implement an all-encompassing strategy for verification management that is integrated with the entire rest of an organization's general product execution efforts. This will also make it possible to remove any barriers that exist between verification addressees. In conclusion, it is feasible to achieve the status of verified product by carefully interlacing the digital thread with the digital twin.

9.2 Certification Management

The complexities of the product development process for aero engine, as well as the volume of the requirements imposed by stakeholder, is always rising. These kinds of products are known as systems of systems because they include electronic and electrical components, harness, software, and mechanical parts. Because of the project scope, obtaining certification has become more problematic. As a result, there is a pressing need for higher use of system engineering, improved management of requirements cascade down into sub-system and system design, and enhanced assistance from verification.

The certification of an engine's airworthiness is a significant step along the way of lifecycle. But even so, the precision and understandability of the records are not always connected to or derived from the engineering assessments that are used for the engine design and service planning. This can have significant repercussions across the product lifecycle in terms of both the quality of the product and its ability to remain on duty. Due to the fact that many enterprises are still using paper records, the airworthiness team loses time sorting through a large number of papers as they struggle to monitor requirements of verification in order to establish compliance. Other stakeholders are unable to observe how the modifications they make effect requirements either further upstream or further downstream when airworthiness is only the concern of a handful of individuals. Due to this lack of integration and coordination, compliance concerns may go unnoticed, which may take a substantial amount of time and effort to rectify. It is unavoidable that program plans may encounter long waits and experience an increase in expense if the organization does not take a comprehensive strategy to certification.

New cyberphysical systems and intellectual devices create huge amounts of data and require complex integration, coordination and optimization in a single multidimensional dynamic system [56]. The degree to which the design process utilizes digitalization is rapidly expanding, and it is also a vital feature of the certification. The ability to include certification into the overarching program plan is made possible by a verification digital twin and digital documentation. Multiple data formats are included in certification, each of which are related to one another via distinct structures of the respective data types. The CAD data is what is being used for any drawings or components design. The Bill of Materials for Engineering must have

connection to the Bill of Materials for Manufacturing, which describes how the product is put together at the stage of production when actual physical stage of production starts. When it comes to hardware, keeping track of the material specifications for repairs and maintenance components is just as important. In addition, a large number of engineering files will detail the tests and studies that were carried out to demonstrate validity. The traditional technique has trouble handling data of this magnitude and variety when it comes to both types and size.

When using the PLM approach, which begins from the moment an idea for a product is conceived, the usage of the digital twin, which is supplied with data in real time from the very first minute, will be of tremendous assistance throughout the process of obtaining certification. Digital twin eliminates communication and priority roadblocks and make it possible for stakeholders to coordinate their efforts throughout the whole enterprise to enhance mutual trust and distribute the role of protecting airworthiness.

Certification is becoming more difficult due to the increasing challenges of products and regulations. Certification of aircraft engine need to be a concurrent process, and it must not to be postponed until the engineering phase is completely finished. The digital twin strategy makes it easier to transition away from the costly and confusing paper-based certification system and toward the more effective digital certification program. As a conclusion, obtaining the title of certified aero-engine is attainable via the careful growth of a digital twin from the very beginning of the project and the careful construction of a digital thread link between the requirements and the engine.

CONCLUSION

This research aimed to create a set of methodology of product lifecycle management of original aviation propulsion system.

Methodology evaluations for aviation propulsion systems are still in the debating and development phases, despite the fact that best practices have been defined for the path that should be followed in other sectors such as automotive, telecommunication or medical devices.

Balanced assessment of the above information would be reached with following a review and evaluation of the relevant literature.

Although it is very obvious that more data must be collected and more research must be done on the topic because of the vastness of the life span, it would be fair to argue that this research proposes a more effective and sector-appropriate technique and explains it for many disciplines.

FUTURE WORKS

Equipment and systems that have extended service lifetimes and complicated configurations causes a challenge for those working in the aviation sector. It is not the create design or obtain certification or selling an engine that contributes to the financial performance of the company; rather, it is the maintenance of aircraft engine during their expected lifetime of thirty years or more. Maximizing their availability and dependability is the key to getting the most out of these products and achieving company goals. Both the firms who purchase aircraft engines and the companies that are responsible for their maintenance and upkeep find value in well-designed aircraft engines that have lengthy usable lifetimes.

As the life span of an aircraft is over 30 years, opportunities abound for the application of PLM in aviation maintenance, repair and overhaul (MRO) [57].

Future research should consider the potential effects of maintenance, repair and overhaul on lifecycle of an aviation propulsion system. It is recommended that future studies be related to a solution must be provided by the environment that consolidates the knowledge and skills in maintenance, repair and overhaul that are required for product engineering, operations, manufacturing, and support into a single body of information.

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BIOGRAPHY

Gamze BAYRAM started her career as an Avionics System Design Engineer in the aviation industry. Currently, she continues as a Configuration Engineer in the aviation industry.

