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A Strategic Approach to the Traceability of Life-Limited Items in Aviation: From Manual Spreadsheets to Digital PLM Solutions

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Abstract

The sustainability of flight safety is of vital importance for the aviation industry. However, maintaining this sustainability is only possible by properly identifying, monitoring, and managing the life cycle of equipment and components. Information regarding the parts is defined as Life Limited Items. The service life of critical parts is defined within certain limits. Even if there are no flaws in the part, it has to be replaced for the reasons of age, fatigue, and environmental factors [1] (EASA Part-M / M.A.504 a,c), [5] (FAA 14 CFR 91.409(e)).

This study addresses the data and processes defined under the heading of Life Limited Items, based on parameters such as total life, service life, overhaul time interval, and shelf life. It explains the relationship between these parameters and operational data, including flight time, flight cycle, and calendar time. To ensure the traceability of Life Limited Items, the environment in which this information is managed is crucial. For managing critical components, risks associated with the use of manual tools, such as Excel, are addressed. On the other hand, managing Life Limited Items (LLI) in a digital environment using Product Lifecycle Management (PLM) systems provides strategic advantages in terms of traceability, control, and risk management. The purpose of this study is not only to examine the maintenance activities and processes of Life Limited Items but also to demonstrate a risk- and safety-focused approach.

Keywords: *Life-Limited Items (LLIs), Product Lifecycle Management (PLM), Aviation Safety & Airworthiness, Digital Twin, Traceability, Operational Metrics (FH, FC).*

1. Introduction

Safety in aviation is ensured by managing risk within engineering limits before a malfunction occurs. Not all aircraft components share the same criticality levels. Even if some components appear to be in perfect condition, they are subject to metal fatigue. They age or the chemical bonds within their composite structures weaken and suffer from material degradation. Risks can cause sudden and major catastrophic events. The phrase "run-to-failure" does not apply to critical aviation components [8].

The service life of Life Limited Items is specified by exact measurements such as flight hours, flight cycles, and calendar time [4] (FAA 14 CFR 43.10(a)). These measurements are established in the manufacturer's manual and airworthiness requirements released by competent authorities [4]. This period cannot be extended by performing maintenance.

The life parameters and main principles of Life Limited Items management are emphasized in this study. In terms of operational safety and audit, the benefits of managing the traceability of Life Limited Items in digital twin-based environments such as PLM are being evaluated with regard to process control and efficiency [13], [16].

2. Materials and Methods

In this paper, this study aims to demonstrate how critical it is to manage "Life Limited Items" in the aviation world. Methods of engineering rules, limits based on regulation and digital traceability related to Life Limited Items are examined conceptually and systematically in aviation. Instead of an experimental application, existing maintenance documents, operational usage data, and digital Product Life cycle management systems cycle are evaluated both theoretically and practically. This approach clarifies the connection between Life Limited Items management and digital traceability.

The research is structured as follows:

2.1 Data Sources and Parameters

To establish the technical validity of the research, recommended practices and procedures for maintenance published by aviation authorities (EASA/FAA) and aircraft manufacturers (AMM) are analyzed. The main parameter considered for applicability is the estimation of the lifetime of components: Flight Hours (FH), Flight Cycles (FC), and Calendar Time. The influence of these parameters in operational environments is assessed, and airworthiness limits assigned.

2.2 Manual and Digital Systems

In this study, two types of tracking methods are compared: customary tracking methods (e. g. Excel-based tracking) and new types of tracking methods in product lifecycle management (PLM) systems. The criteria to assess these methods include operational safety, the accuracy of records and official audit requirements [2] (EASA Part-21/ 21.A.305, 21.A.447, 21.A.804, 21.A.805).

2.3 Criticality and Risk Assessment

Aircraft parts have varying levels of criticality, regardless of observable damage due to the cumulative effects of metal fatigue and corrosion from environmental exposure. They should be withdrawn from service when they reach their certified limits so the system integrity is not compromised [2] (EASA Part-21/ 21.A.305, 21.A.447, 21.A.804, 21.A.805).

This study seeks to:

Metal Fatigue: Micro-cracks within the structure that form due to pressure differential and impact during landings, which cannot be detected through standard inspection practices.

Material Aging: The bonds between composite and elastomer portions can degrade, so Shelf Life applies even if composite portions are not in service.

3. Technical Identification and Life Metrics for LLIs

3.1 Configuration and Traceability Attributes

Sequence Number: A unique task number assigned to a component for tracking. Every item shall be listed individually, with one specific task per ID. The sequence number is used in the tracking of the order of tasks and historical records.

Supplier: Refers to the organization that designs, manufactures and provides maintenance data for the equipment or system.

Part Number (P/N): The standardized identification number assigned by the manufacturer to a specific part design [10] (ASD/AIA S3000L Chapter 4/5.2.3, Chapter 19/3.25.1).

Serial Number (S/N): A unique identifier assigned to an individual component after production. The S/N provides singular traceability, enabling the tracking of maintenance, repair, and overhaul (MRO) history, as well as the specific aircraft on which the part was previously installed [2] (EASA Part-21/ 21.A.804, 21.A.805), [4] (FAA 14 CFR §43.10(a)), [7] (FAA AC 20-154/6.f.7, 6.h.2, 6.i), [10] (ASD/AIA S3000L Chapter 4/5.2.3).

System Name: This field identifies the specific aircraft system or sub-system to which the component belongs.

Equipment Name: The equipment/component in the system is defined for maintenance and monitoring purposes.

The purpose of defining the equipment name:

- Correct Part Identification,
- Traceability of maintenance and repairs,
- Ensuring technical document matching,
- Reduction of errors and operational risks.

Effectivity: The effectivity information defines the compatibility of the part with aircraft model, serial range, or modification configurations.

Quantity: This is the exact quantity of parts required in the system.

Company No: Engineering model number of the system/equipment/item assigned by the organization.

3.2 Life Limits and Utilization Parameters

The establishment of these life limits is a mandatory requirement for the issuance and maintenance of a Certificate of Airworthiness (CofA), as governed by international standards [8] (ICAO Annex 8/1.3), [10] (ASD/AIA S3000L Chapter 10/2.2).

Total Life: Total life is the maximum period a part may remain in service on an aircraft under its approved design and applicable regulations [3] (EASA CS 25 Appendix/H Section H25.4). This period cannot be extended by overhaul or maintenance activities. When a part's total life ends, it must be permanently removed from service and scrapped to ensure flight safety [1] (EASA Part-M/M.A.504 c), [3] (EASA CS 25 Appendix/H Section H25.4), [4], [10] (ASD/AIA S3000L Chapter 16). This limit is one of the most important engineering disciplines to keep the structural integrity and flight safety of the aircraft.

According to CS-25 Appendix H (H25.4) [3], mandatory replacement times and inspection intervals must be defined within the Airworthiness Limitations Section (ALS). These limits, including Critical Design Configuration Control Limitations (CDCCL), ensure the structural and functional integrity of critical installations, making their digital traceability via PLM systems a regulatory necessity rather than an operational choice.

Overhaul Time Interval: At the end of a specified flight time, flight cycle, or calendar period, the part is removed from the aircraft [5] (FAA 14 CFR Part 91e, f), [6] (FAA AC 120-17B, Chapter 2). The relevant part is subjected to comprehensive maintenance and overhaul / refurbishment process in the authorized workshop. The time spent in this period is called the "overhaul time interval". After this process, the part can be re-serviced within the approved limits [10] (ASD/AIA S3000L Chapter 4/6.3, Chapter 7.4.1.1.2, Chapter 11, Chapter 17).

The Overhaul Time Intervals management involves:

• Flight Hours (FH)

• Flight Cycles (FC)

• Calendar Time

When one or more of the times mentioned above expires, the part:

• Removed from the aircraft,

• Enters the overhaul / refurbishment process in the authorized workshop,

• Worn parts are replaced,

• It undergoes functional tests,

• Returned to the service.

Shelf Life:

Shelf life is independent of its use of the part/ equipment, only the time spent in storage. This limit applies to parts subject to chemical or physical degradation over time.

Key examples include:

- Rubber / elastomer seals,
- Chemical Sealants,
- Fire extinguishers,
- Cartridge filters, pyrotechnic elements.

Even if a part has never been installed on an aircraft, once its shelf life expires, it is unserviceable, considered out of service [1] (EASA Part-M / M.A.504 a).

Example:

- Shelf Life: 5 years
- Part entered storage after production
- 5 years have passed
- Part was never installed on an aircraft

In this case, the part is discarded or it is subjected to life extension / recertification process.

Service Life:

Service Life is the active usage time a part remains in operation in accordance with the maintenance rules. The period of time a part is permitted to remain in service in aviation [9], [10] (ASD/AIA S3000L Chapter 7.4.1.1.2, Chapter 11, Chapter 17).

The concept of Service Life consists of two main components starting criteria (DOM, DOI, DOFU) and service life metrics (FH, FC, Calendar). The start-up criterion is essential for initializing the tracking process, whereas metrics measure the operational aging of the component [9].

Service Life Metrics:

- Flight Hours (FH): The cumulative airborne time.
- Flight Cycles (FC): The number of take-offs and landings.
- Calendar Time: The absolute duration since installation or manufacture.

The service life of some critical components (e.g. landing gear or engine disks) is tracked based on total Flight Cycles (FC) rather than Flight Hours (FH). This is essential to accurately measure metal fatigue caused by mechanical stress with pressure changes during take-off and landing cycles [3], [14], [15].

Lifecycle Commencement Triggers:

These dates determine when the specific “counters” (FH, FC, Calendar) on a component will start from zero:

- Date of Manufacture (DOM): Critical for parts with a "Shelf Life." For components such as gaskets or fire extinguishers, the counter begins the moment the part leaves the production line. Even if the part remains in the warehouse, its life is being consumed.
- Date of Installation (DOI): For mechanical parts (e.g., a landing gear pin), the service life counter typically begins once it is installed on the aircraft. Time spent in the warehouse does not count against its "Service Life."
- Date of First Use (DOFU): This represents the moment the part is operationally activated for the first time (e.g., opening a vacuum-sealed package).

Table 1 Risk Analysis of Life Commencement Triggers

Start Type	Risk of holding inventory in storage	Risk Level
Date of Manufacture (DOM)	The part's lifespan begins from the date of manufacture. It loses lifespan while waiting in storage.	High
Date of Installation (DOI)	The part's lifespan begins when it is installed on the aircraft. There is no loss of lifespan while it is in storage.	Low
Date of First Use	The part's life begins the moment it is first used. The effect of storage time is limited.	Medium

Example Scenario: Integrated Lifecycle of an Actuator

To illustrate the complexity, let's analyze a part with the following limits:

- Shelf Life: 5 Years (Based on DOM)
- Overhaul Interval (OTI): 2,000 FH (Based on DOI)
- Service Life: 6,000 FH (Based on DOI)
- Total Life: 12,000 FH (Based on DOM)

The Timeline:

1. DOM (Day 0): Part is manufactured. Shelf Life and Total Life chronometers start.
2. DOI (Year 2): After 2 years in storage, the part is installed on an aircraft. Overhaul and Service Life counters start from zero. (Note: The part is 2 years old but has 0 flight hours).
3. 2,000 FH (Post-DOI): The first Overhaul limit is reached. The part is removed, serviced, and reinstalled.
4. 6,000 FH (Post-DOI): Service Life is reached. A major renewal or replacement is required per documentation.
5. 12,000 FH (Total) or Calendar Limit: The Total Life (Absolute Limit) is reached. The part is now irreparable, permanently retired, and scrapped.

As demonstrated, a single component is governed by three distinct chronometers. Managing these overlapping timelines manually via spreadsheets is not only labor-intensive but also significantly increases the risk of safety-critical data entry errors.

Table 2 Difference Shelf Life - Overhaul Time Interval - Service Life - Total Life

Concept	**Primary Metric / Measurement**	**Operational Stage**	**End-of-Period Outcome**
Shelf Life	Storage Duration	Pre-Installation (In Warehouse)	Discard of Recertify
Overhaul Time Interval (OTI)	Maintenance Frequency (FH/FC/Cal)	In-Service (Active Operation)	Restoration & Return to Service
Service Life	Cumulative Operational Limit	In-Service (Active Operation)	Replacement or Evaluation
Total Life	Absolute Design Limit	Entire Lifecycle (Cradle to Grave)	Mandatory Retirement / Scrapping

4. Comparative Analysis of Life-Limited Item Traceability Methods

4.1 Conventional Tracking: Limitations and Risks of Manual Spreadsheets

Managing and tracking Life limited Items with manual tools such as Excel involves serious operational risks.

- Manual Update and Error Risk: Even a small calculation error can lead to serious risks in terms of airworthiness [7] (FAA AC 20-154/6.d, 6.h).
- Lack of Version Control: It creates confusion and uncertainty about which file is up to date.
- Poor Traceability: Installation and Removal (I&R) history and limit resources can lead to errors as they cannot be managed holistically in the Excel environment [1] (EASA Part-M/M.A.504 b), [7] (FAA AC 20-154/6, 6.f.3, 6.f.11, 6.f.12, 6.i, 7.b, 5r).
- Inadequate Audit Compliance: It will be insufficient to provide a systematic and verifiable structure during audits [1] (EASA Part-M/M.A.504 b), [5] (FAA 14 CFR 91.409(f)), [6], [7] (FAA AC 20-154/6.b). Failures in record-keeping systems can jeopardize the state's oversight responsibilities regarding the aircraft's continuing airworthiness [8] (ICAO Annex 8/Chapter 4).
- Scalability Problem: As the number of parts increases, the data management with Excel becomes unsustainable.

Due to these operational risks, the transition from manual record-keeping systems to proactive and integrated digital ecosystems has become essential.

4.2 Digital Transformation: PLM-Based Integration and Digital Twin Concepts

In aviation, Life Limited Items (LLIs) are critical components that directly affect flight safety and have a defined lifespan with precise limits. Ensuring the traceability of these parts is a fundamental global regulatory requirement under ICAO Annex 8, which mandates that the current status of life-limited parts must be maintained as a permanent record [8] (ICAO Annex 8/6.7), [11] (ASD/AIA S1000D Chapter 4.3). Traceability of a part refers to the comprehensive monitoring of how long, where and in which situations it is used throughout the entire life cycle from production to retirement [7] (FAA AC 20-154/6, 6.f.3, 6.f.11, 6.f.12, 6.i, 7.b, 5r), [10] (ASD/AIA S3000L Chapter 4/3.3, 3.5, 5.2.7, 5.2.8, 6.4.2), [12] (ATA Spec 2000, Chapter 11, Chapter 13).

The environment in which the traceability of Life Limited Items (LLIs) is managed makes a very critical difference in terms of operational continuity and cost control in aviation. In this respect, whether Life Limited Items are integrated with the PLM-based digital twin concept [11] (ASD/AIA S1000D Chapter 6.3), [12] (ATA Spec 2000, Chapter 13, Chapter 17), [13], [16] or managed in traditional manual tools directly impacts the reliability of maintenance processes and the sustainability of airworthiness.

The fundamental differences and operational shifts between these two approaches are summarized in Table 3.

Table 3 Comparative Analysis of Manual Spreadsheets vs. Digital PLM Systems in LLI Management

Feature	**Manual Spreadsheets (Excel)**	**Digital PLM Solutions**
Data Integrity	High risk of manual entry errors	Automated data capture and validation
Audit Compliance	Fragmented and difficult to verify	Full digital trail for regulatory oversight
Scalability	Limited; grows complex with more parts	High; manages thousands of LLIs seamlessly
Real-Time Visibility	Static; requires manual updates	Dynamic; real-time "Digital Twin" status
Traceability (I&R)	Prone to missing history links	Continuous end-to-end traceability

5. Conclusion

This study deals with a full look at the basic concepts and limit values of managing life parts.

In this study, the differences between Total Life, Service Life, Overhaul Time Interval and Shelf life are clearly defined. It was shown how the Total Life, Service Life, Overhaul Time Interval, and Shelf life limits relate to aircraft data such as Flight Hour, Flight Cycle, Calendar Time, and System Hour. An assessment was made based on the FH/FC ratio and it was stated how the operation types affect the part life.

The environment in which Life Limited Items are traceable greatly affects the power of operational safety and regulatory oversight. The risks of monitoring Life Limited Items in manual environments such as Excel are specified. On the other hand, the advantages of ensuring the digital traceability of Life Limited Items in environments such as PLM are mentioned.

As a result, these attributes tracked under Life Limited Items are not just a data entry, but part of a large-scale risk management strategy [1] (EASA Part-M/M.A.504 b, c). A correctly managed data set prevents untimely failures, optimizes maintenance costs, and most importantly, keeps operational safety at the highest level.

Appendix

N/A

Acknowledgments

N/A

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[15] EASA CS-25: Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes (CS-25), Amendment 27. Appendix B. Section 4 Examples / B.4 EXAMPLE FOR PARAGRAPH 4.2.5.3 / B.4.3.

[16] Home Digital Twin, Tuan Anh Nguyen, February 2026.

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