



AEROSPACE INFORMATION REPORT

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Considerations for Requirements, Specifications, and Framework of
a Digital Thread in Aircraft Data Life Cycle Management

RATIONALE

In the aerospace community, the digital thread is a powerful concept to facilitate the tracking, analyzing, and enhancing the performance of an asset across its entire lifecycle. The digital thread constitutes numerous flows of information as a digital representation of events related to product information throughout the product lifecycle. The digital thread provides the data and structure necessary to obtain data from real-world events and align that data with the virtual design objects and their real-time physical transformations over the object lifecycle stages and as the operational state changes. There are three main aspects to the data involved:

1. Operational data collected from physical device sensors and system monitoring the environment interacting with physical devices.
2. Lower-level data that needs to be exchanged between various systems and the interoperability constraints that facilitate these exchanges.
3. Higher level information or meta data that needs to be defined, stored, retrieved, and analyzed throughout the lifetime of the asset to make engineering and business decisions.

While there is a lot of work being carried out in areas one and two—i.e., in ensuring that all players in the lower-level data layers work compatibly—there is less work being done in identifying exactly what kinds of data and information that needs to be gathered, stored, and analyzed at higher levels. This SAE Aerospace Information Report (AIR) aims to describe the higher-level requirements, specifications and framework for the digital thread and the benefits that can accrue from the application of digital thread.

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1. SCOPE

The scope of this SAE Aerospace Information Report (AIR) is to describe the considerations for requirements, specifications, and framework of digital thread in the aircraft product life cycle management. This document is not intended to define an overarching rendition of implementation-dependent features around software or architecture.

1.1 Purpose

The components, sub-systems, and systems of an aircraft are being managed for long life from its design requirements (birth) to final disposition (disposal) across various stakeholders in the aircraft ecosystem. Digital thread can facilitate increased efficiency, transparent traceability, accountability, and provenance across the ecosystem. Hence the purpose of this document is to summarize the considerations for requirements, specifications, and framework of digital thread in the aircraft life cycle management.

1.2 Approach

This document starts with an overview of aircraft data lifecycle, an overview of digital thread, and the applicability of digital thread in aircraft data lifecycle. The document then outlines the challenges, motivation, and benefits of digital thread. The document further describes the requirements, specifications, and framework for digital thread bringing together the lifecycle and stakeholder perspectives.

1.3 Intended Users

The intended users of this document are engineers, practitioners, academicians, original equipment manufacturers (OEMs); suppliers; operators; and maintenance, repair, and overhaul (MRO) service providers who are interested in exploring the usage of digital thread in the aircraft industry.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR6904 Rationale, Considerations, and Framework for Data Interoperability for Health Management within the Aerospace Ecosystem

AIR7501 Aircraft Asset Lifecycle and Digital Data Standards Overview

2.1.2 Other Publications

Hedberg, T. Jr., Lubell, J., Fischer, L., and Maggiano, L. (2016). Testing the digital thread in support of model-based manufacturing and inspection. *Journal of Computing and Information Science in Engineering*, 16(2). <https://doi.org/10.1115/1.4032697>.

Kinard, D.A. (2018, April 2-5). *Digital thread and industry 4.0* [Conference presentation]. NIST MBE Conference, Gaithersburg, MD, USA. Available at https://www.nist.gov/system/files/documents/2018/04/09/2p_kinard_digitalthreadi4pt0.pdf.

Bajaj, M. and Hedberg, T. Jr. (2018, July 7-12). *System lifecycle handler—Spinning a digital thread for manufacturing* [Conference paper]. 28th Annual INCOSE International Symposium, Washington, DC, USA. Available at <https://www.nist.gov/publications/system-lifecycle-handler-spinning-digital-thread-manufacturing>.

2.2 Abbreviations

ADs	Airworthiness Directives
AIR	SAE Aerospace Information Report
AMM	Aircraft Maintenance Manual
AMP	Aircraft Maintenance Program
API	Application Programming Interface
BOM	Bill of Materials
BOP	Bill of Processes
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CFD	Computational Fluid Dynamics
CM	Configuration Management
CMM	Components Maintenance Manual
CNC	Computer Numerical Control
COTS	Commercial Off-the-Shelf
DDG	Dispatch Deviations Guide
DFMA	Design for Manufacturing and Assembly
eBOM	Electronic Bill of Materials
FEA	Finite Element Analysis
ICA	Instructions for Continued Airworthiness
ISV	Independent Software Vendor
IVHM	Integrated Vehicle Health Management
mBOM	Manufacturing Bill of Materials
MBSE	Model-Based Systems Engineering
MEL	Minimum Equipment List
MMEL	Master Minimum Equipment List

3. INTRODUCTION

3.1 Overview of Aircraft Data Life Cycle Management

The aircraft lifecycle involves hundreds of thousands of transactions and an enormous amount of data being exchanged across the stakeholders in the aircraft ecosystem. This data pertains to various aircraft life cycle stages design, manufacturing, certification, operations, maintenance, and disposal of the aircraft. [Figure 1](#), which is extracted from AIR6904, represents the data consuming and data producing activities within the aircraft lifecycle from its birth to disposal.

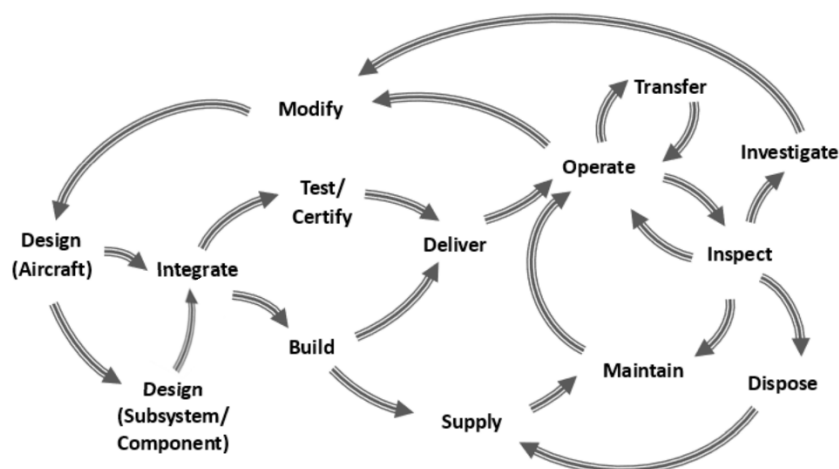


Figure 1 - Data producing and consuming processes in the aerospace ecosystem
(Extracted from AIR6904)

Various stakeholders come and participate in the aerospace ecosystem to provide various products and services for the aircraft industry while taking care of various responsibilities. [Table 1](#) provides this information, which is taken from AIR7501. Further, [Figure 2](#) provides information on various stakeholders involved in the aircraft ecosystem. All participants in the aerospace ecosystem want to leverage the data to deliver insight and add value to their customers through existing and new services while protecting their own intellectual property. The exchange of data between stakeholders in the ecosystem is involved and growing exponentially. [Figure 2](#) represents many of the stakeholders involved in the aerospace ecosystem and the data interactions amongst them. This necessitates the need for data interoperability to support efficient maintenance, logistics, operations, and design improvements for both commercial and military aircraft ecosystems.

Table 1 - Aerospace asset key stakeholder description and responsibilities

Key Stakeholder	Description	Responsibilities (Not an All-Inclusive List)
Manufacturer	Original Equipment Manufacturer (OEM) of airframe or engine.	- Design, build, and test of aircraft and engines. - Sales and marketing, regulatory conformance, warranty.
Supplier	Component, sub-system and system provider.	- Manufacture aircraft parts and components - Supply of parts to airline, MRO, and OEM
Regulator	State designated agency tasked with certification of aircraft, parts, organizations, and personnel, as well as regulating all civil aviation related design, production, operation activities in the respective geographic jurisdiction.	- Certification of manufacturing and design. - Supervision and certification of airworthiness. - Investigations.
Lessor	Lessor of aircraft or engine assets.	Leasing aircraft or engines to operators.
Owner	Owner of aircraft or engine.	May be operator, lessor, OEM (capital investment), government agencies, or private ownership.
Operator	Operates the aircraft fleet.	- Operations. - Meeting aircraft airworthiness/complying with regulations.
Maintenance, Repair and Overhaul (MRO) Organization	Provider of aftermarket repair and overhaul services.	- Scheduled and unscheduled maintenance. - Airworthiness records creation and verification. - Part replacement and repair.
Parts Supplier/Distributor, Used Serviceable Material (USM) Provider/Broker	Supplier and distributor of new and USM.	Purchase and sale of spare parts.
Disposer	Responsible for disposing aircraft at the end of its life.	- Inventorying spares. - Recycling. - Environment friendly disposal.

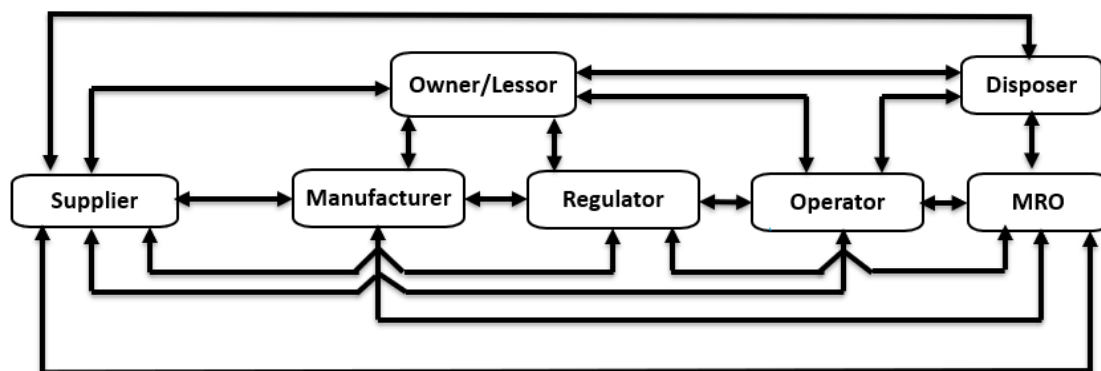


Figure 2 - Aerospace asset stakeholder interaction
(Extracted from AIR7501)

3.2 Overview of Digital Thread

A digital thread defines an approach and a system which connects the data flows and represents a holistic view of an asset data across its lifecycle. The digital thread framework addresses data flow procedures, data security, and data governance aspect.

The digital thread provides a method and system for controlled interplay of authoritative technical and As-Manufactured data with the ability to access, integrate, transform, and analyze data from disparate systems throughout the product lifecycle into actionable information. The product lifecycle includes design, procurement, test and evaluation, production, field operation, and sustainment services. The digital thread include as-designed requirements, validation and inspection records, certification information, as-manufactured data, as-operated data, and as-maintained data.

A digital thread will have and integrated data from both the physical system and its digital twin (the digital replica of the physical system). The data will be identified to ensure that its traceability is ensured (that is, whether it comes from the physical system or the digital twin).

3.2.1 Relevance and Applicability in Aircraft Lifecycle

A digital thread can help capture and manage data as it is exchanged between various stakeholders across the aircraft lifecycle stages.

Within the aerospace community, the digital thread forms a powerful concept to track, analyze and improve the performance of an aircraft asset over the course of its lifecycle. The digital thread constitutes the digital representation of information of associated events related to the aircraft throughout the lifecycle of the aircraft. The digital thread data is obtained from the real-world events and then aligned with the digital twin design objects and their real-time physical transformations over the product lifecycle stages and as the operational state changes.

There are three main aspects to the data involved:

1. Operational data collected from physical device sensors and system monitoring the environment interacting with physical devices.
2. Low-level data that needs to be exchanged between the various systems and the interoperability constraints that facilitate these exchanges.
3. High-level meta-data and operational data that needs to be defined, stored, retrieved, and analyzed throughout the lifetime of the aircraft to support engineering and business decision making.

A typical aircraft digital thread across the life cycle phase and the data exchanged between various stakeholders is shown in [Table 2](#).

Table 2 - Aircraft digital thread from its birth to disposal

Life Cycle Phase	Origin Stakeholder	Destination Stakeholder	Data Exchanged
Aircraft Order(s)	Owner/operator/lessor	OEM	Request for quotation, negotiations, and fulfilled request.
	OEM	Owner/operator/lessor	Fulfilled aircraft orders (public information).
	Owner/operator/lessor	OEM	Aircraft order (service data and customer originated changes).
Aircraft Design and Build	OEM	Supplier	Request for raw materials, components, and sub-systems.
	Supplier	OEM	Quotation comprising pricing, status, invoicing, stock information, authorized release certificate, barcoded shipping label, and spares metrics.
	OEM	Supplier	Material/components/subsystem order.
	Supplier	Regulator	Contacts the regulator for the quality certification of materials, components, and subsystems.
	Supplier	OEM	Delivers raw material, components, and sub-systems.
	OEM	Regulator	Completion status information of the aircraft manufacturing.
Aircraft Certification	OEM/supplier	Regulator	Certification request.
	Regulator	OEM/supplier	Certification of the aircraft.
Aircraft Delivery	OEM	Owner/operator/lessor	Aircraft delivery along with actual aircraft configuration, engine part list, allowable configuration, concessions, master minimum equipment list (MMEL), dispatch deviations guide (DDG), service bulletins (SBs), aircraft maintenance manual (AMM), maintenance planning data (MPD), maintenance training information (MTI), and instructions for continued airworthiness (ICA).
Aircraft Lease	Operator	Lessor	Lease quotation request.
	Lessor	Operator	Lease quotation.
	Operator	Lessor	Lease order placement.
	Lessor	Regulator	Certification request.
	Regulator	Lessor	Aircraft certification for lease.
	Lessor	Operator	Aircraft delivery along with actual aircraft configuration, engine part list, allowable configuration, MMEL, DDG, SBs, MPD, MTI, and ICA. Delegation of interactions to the operator.
	Operator	Lessor	Return of aircraft meeting contractual obligations that might require retrofits and regulator's approval (e.g., might be required to return to the original configuration complying with global or regional mandates).
Aircraft Operations	Operator	Regulator	Communication of the scheduled maintenance plan, minimum equipment list (MEL), configuration management (CM), supplementary type certificate (STC), and special program data.
	Regulator	Operator	Issue of airworthiness directives (ADs) on maintenance planning and engineering to the owner/lessor/operator. Approvals on operator aircraft maintenance program (AMP), MEL, MMEL, CM, STC, and special programs.
			Authorization of exceptions on maintenance planning.
	Operator	Regulator	Operational reports.