Chicago Tribune

NEWS

`GERIATRIC AIRCRAFT` RAISE NEW CONCERNS

By David Evans and Chicago Tribune
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ICAF

International Committee on Aeronautical Fatigue and Structural Integrity

Life extension and management of ageing fleets

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| 27 June 2023

Age is nothing but a number

- 80-year-old DC-3 aircraft OH-LCH still in use (~ 100 FH / year)

- The aircraft is owned by Airveteran Ltd, operated and serviced by DC Association
  - *“Our vision is to keep this aircraft flying a hundred years. That is the first milestone.”*

Figure: DC Association Finland

Introduction

- Ageing aircraft is still a key topic for both civil and military aviation
- Always the same objectives :
  - prevent catastrophic failure of ageing aeroplanes (safety)
  - managing ageing fleet with minimum costs and maximum availability (operational and economical stakes)
    - MIL-STD-1530D[1]: "*The goal of the ASIP is to ensure the desired level of structural safety, performance, durability, and supportability with the least possible economic burden throughout the aircraft's service life.*"
      → to minimize all in-service maintenance actions during service
- Efficient design concepts, optimized maintenance programmes, global strategy for management of ageing fleets are key domains for ageing A/C

[1] http://everyspec.com/MIL-STD/MIL-STD-1500-1599/MIL-STD-1530D_55392/

Key features

- Civil fleets include old A/C, military aviation either even with some very old aircraft and with discrepancies between actual usage and design assumptions
- Lessons learnt : huge number of in-service events are related to ageing fleets issues affecting safety but also aircraft availability and maintenance burden
- Regulation is constantly updated on this topic
- Life extension : a strong need in military aviation (longer A/C usage and/or more severe A/C usage), existing demand in civil world for second hand (or more !) aircraft
- Digital engineering is transforming the way of managing ageing fleets

Regulation for large aeroplane

Ageing Aircraft Structure Rule

On August 6, 2020 the European Commission published Commission Implementing Regulation (EU) 2020/1159.

The '**ageing aircraft**' rule addresses safety risks related to ageing phenomena in the structures of large aeroplanes. These risks include fatigue of the basic type design, widespread fatigue damage (WFD), corrosion, fatigue of changes and repairs, and continued operation with unsafe levels of fatigue cracking. Design approval holders are required to develop data to support continuing structural integrity programmes for specific categories of large aeroplanes. At the same time, operators of those aeroplanes need to revise their aircraft maintenance programmes to incorporate those data and to address the adverse effects of changes and repairs on each airframe and its associated maintenance requirements.

[1] https://www.easa.europa.eu/en/domains/aircraft-products/ageing-aircraft-structure-rule

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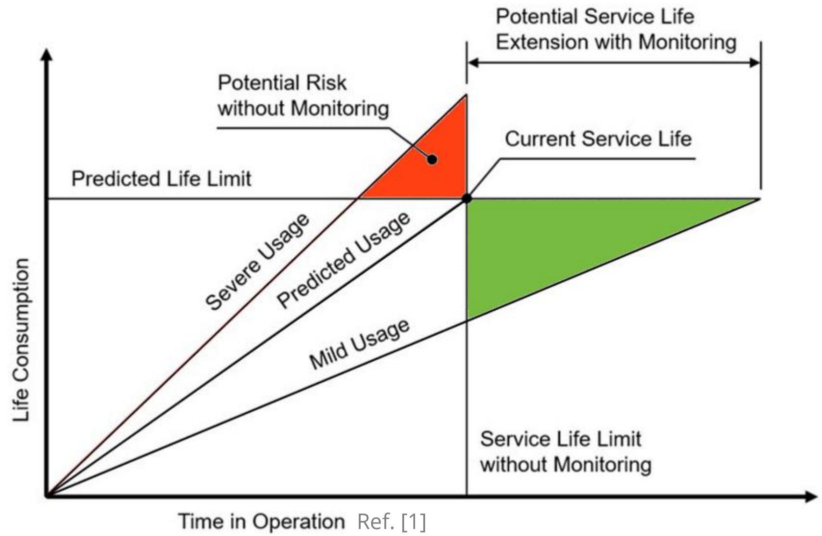
Structural Integrity Programme in civil aviation (EU regulation, large A/C)

- Is now formally introduced mainly with new part 26
- (R-)TCH shall establish and implement a process that ensures that the continuing structural integrity programme remains valid throughout the operational life of the aeroplane, taking into account service experience and current operations
  - Point also inserted in Part 21 point 21.A.65 (Commission Delegated Regulation 2021/699)
  - Refer to AMC 20-20A (appendix 5)
- More commonality with military practices/regulation

OLM/IAT/SHM in military aviation

- Objectives :
  - Check actual usage versus design assumption, supported by test evidence
  - Allow optimized maintenance and fleet management keeping the required safety level
  - Give inputs for condition based maintenance (CBM)

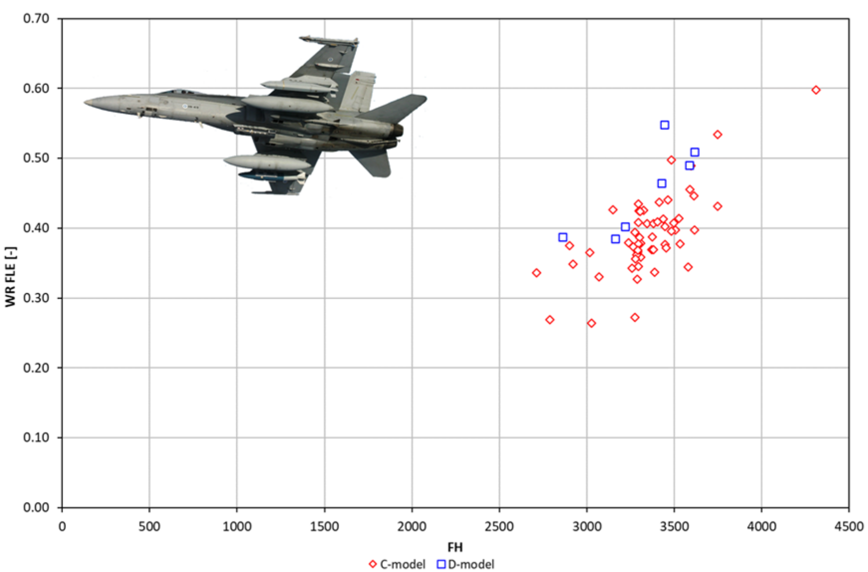


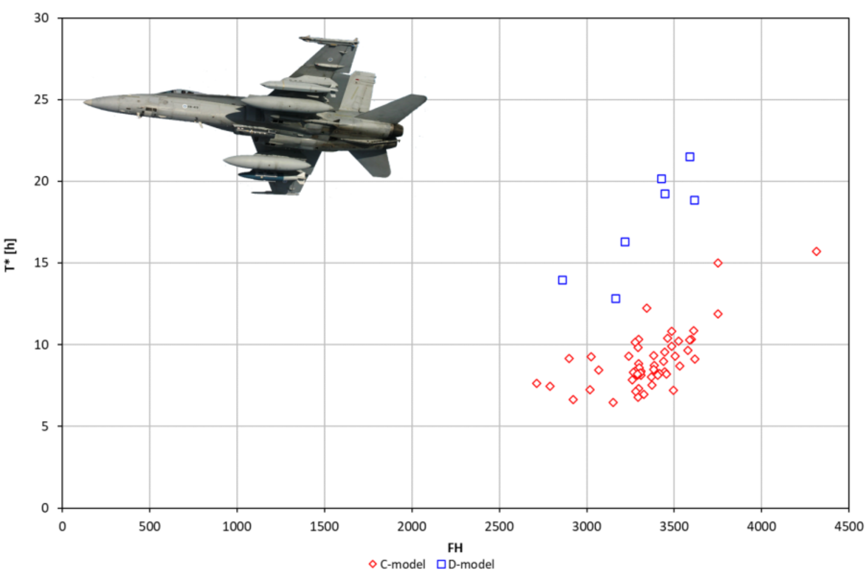
Ref. [1]

[1] Romero, R., Summers, H. and Cronkhite, J. 1996. Feasibility Study of a Rotorcraft Health and Usage Monitoring System (HUMS): Results of Operator's Evaluation. NASA CR-198446, ARL-CR-289, DOT/FAA/AR-95/50.

OLM/IAT/SHM in military aviation

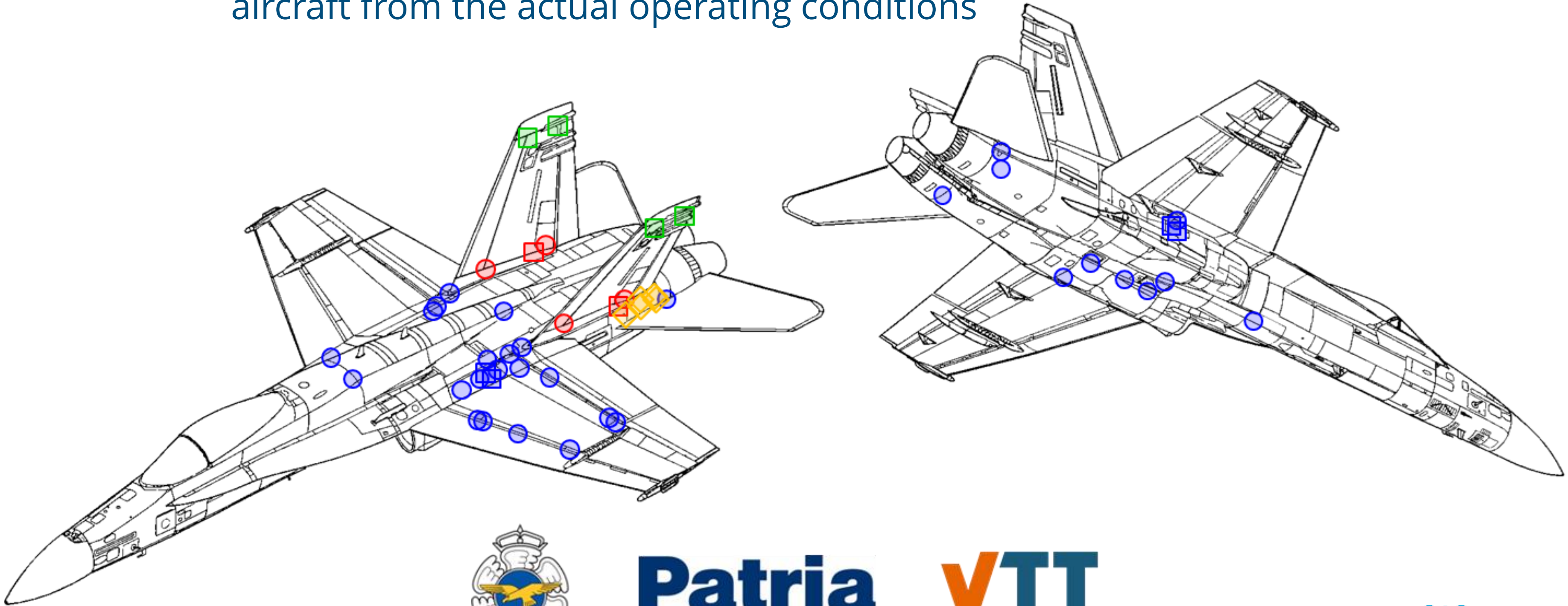
- The fatigue tracking of the FINAF F/A-18C/D fleet is based on
  - Flight Hours (FH),
  - Wing Root Fatigue Life Expended (WR FLE) –value (L/H fig.), and
  - T*-value (time spent in buffet-dominating PITS) for the Vertical Tail (R/H fig.)





OLM/IAT/SHM in military aviation

- HOLM: Hornet Operational Loads Measurement program (2006-)
  - Employs two extensively instrumented F/A-18Cs
  - Provides reliable structural response data of the Finnish Air Force (FINAF) aircraft from the actual operating conditions



OLM/IAT/SHM in military aviation

- HOLM: Hornet Operational Loads Measurement program (2006-)
  - The HOLM data have been utilized in national research activities like NN, CFD, and flight maneuver identification (FMI) programs

28th ICAF Symposium – Helsinki, 3–5 June 2015

Practical Experience of Neural Network Based Fatigue Life Monitoring

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Patria Aviation, Finland

Abstract: Patria Aviation uses a neural network based fatigue life monitoring system for Finnish Air Force F-18 fleet since 2007. After being in operational use for several years, practical experiences of analysis performance and usefulness are now reviewed.

The fatigue life results cover each aircraft, being one tool for Aircraft Structural Integrity Program's individual aircraft tracking task. Based on in-service performance assessment, modelling error is below 20% in fatigue life expenditure, when comparing results to direct strain gauge measurements.

The neural network analysis uses as input flight parameter data, which is recorded by each aircraft, and flight. This data is used to model strain history at critical locations using neural networks. Based on the modelled strain history, fatigue life consumption for selected details can be calculated.

Results of vertical tail attachment area, which experiences a high amount of buffet, indicate that neural networks can model the fatigue life consumption at reasonable accuracy. These results are used to select only a subset of aircraft to high-cost non-destructive inspections. Similar use of results is feasible to fuselage longeron and engine door former, where dynamic loading content is smaller. One detail, where neural network modelling capability fails, is horizontal tail attachment area. In this detail available inputs are insufficient to model structural response.

Based on our experience it can be stated that neural network based analysis brings, at low cost, valuable data to aircraft and location specific fatigue life tracking and Aircraft Structural Integrity Program.

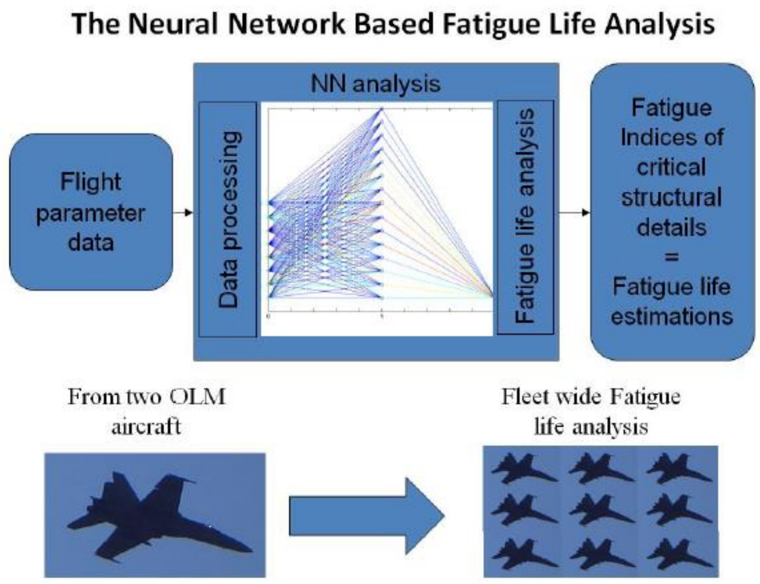


Figure 1. Data flow of the applied monitoring method.

OLM/IAT/SHM in military aviation

- Trends and areas of interest :
  - Artificial Intelligence/Maching Learning for better processing of flight parameters for loads assessment and subsequent fatigue calculation
  - Rotorcraft usage assessment
  - Improve existing IAT approach through implementation in ADT (Aircraft Digital Twin) framework moving to a probabilistic and prognostic IAT
  - Improvement of SHM techniques
  - Improvement of NDI techniques

Life extension

- Economic conditions often require the use of civil and military aircraft beyond their original design service objectives
- Many A/C life extension programmes around the world. Among the reasons leading to set up these life extension programmes :
  - Upgraded aircraft (avionics, armament…) keeping the same platform
  - Evolution of aircraft usage
- Life extension substantiation often supported by Full Scale Fatigue Test or at least Component Fatigue Test
  - Several national reviews showing examples (US, Canada, France, Sweden, Finland, …)

Shift towards composite construction

- The use of FRP composites in A/C structures has increased significantly over the past few decades
- FAR/CS 25.571 + guidance documents
  - FAA: Advisory Circular (AC) 20-107B
  - EASA: Acceptable Means of Compliance (AMC) 20-29
- Two certification concepts: "**no growth**" or "slow growth"
- Slow growth can be allowed, on the conditions that
  - the residual strength does not decrease below limit load
  - the growth is "slow, stable, and predictable"
- "*Unified metric is needed that relates the material and loading parameters to a stable crack growth rate.*"[1]

[1] O'Gara, J. and Sangid, M.D. (2023). Examining slow crack growth metrics and competing failure modes in IM7/5320-1 carbon fiber reinforced polymer laminates with pre-existing damage states. Composites Science and Technology 232 (2023) 109864. https://doi.org/10.1016/j.compscitech.2022.109864

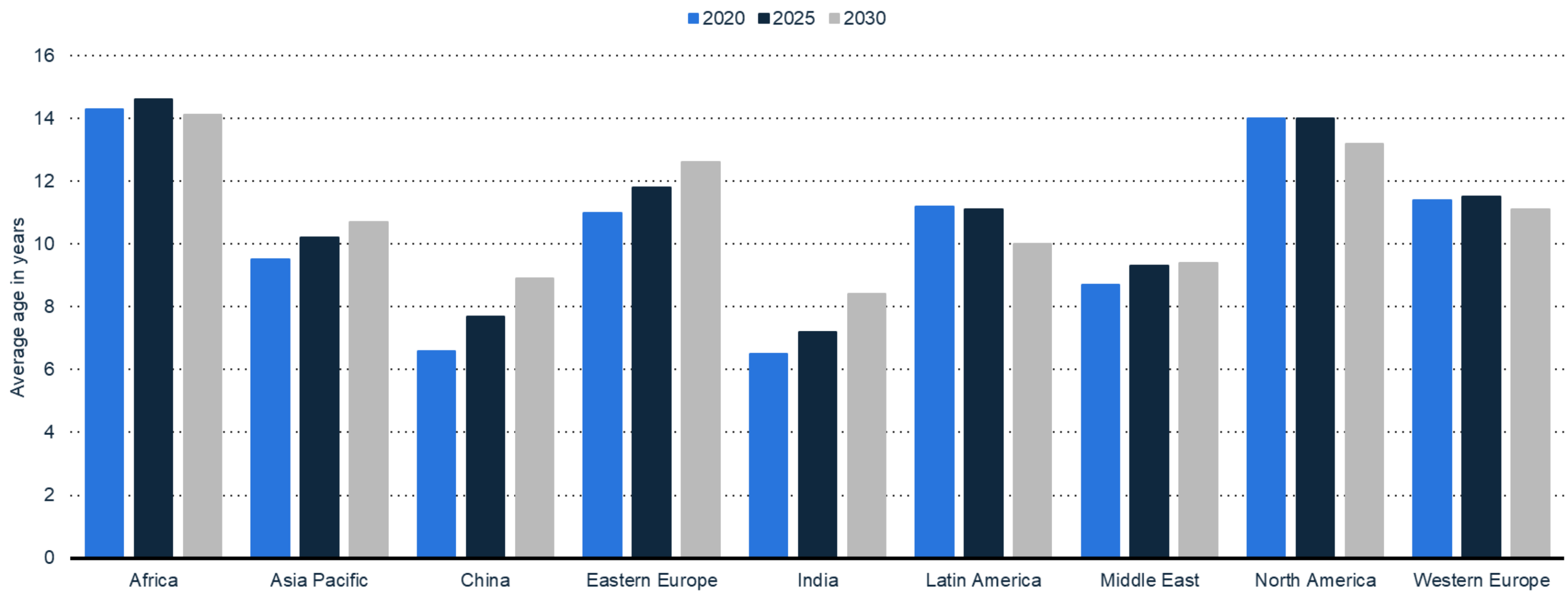
Life extension and management of ageing fleets

Q&A

[1] https://web.archive.org/web/20060622045922/http://www.dm.af.mil/amarc/images/arials/Aerial13-1.jpg

Global fleet aging trends

- Average age of the global operating aircraft fleet by region or country[1]



[1] https://www.statista.com/statistics/751440/aviation-industry-aircraft-fleet-age-by-region

Local fleet aging trends

- Passenger airline fleet age (may be approximated)[1]

FINNAIR

AIRCRAFT	NUMBER	AGE
Airbus A319	6	21.3 years
Airbus A320	10	20.6 years
Airbus A321	15	8.6 years
Airbus A330	8	13.4 years
Airbus A350	17	5.4 years
TOTAL	56	11.8 years

AIRFRANCE

AIRCRAFT	NUMBER	AGE
Airbus A220	16	0.9 years
Airbus A318	9	16.6 years
Airbus A319	17	21.8 years
Airbus A320	39	13.2 years
Airbus A321	17	20.4 years
Airbus A330	15	20.3 years
Airbus A350	20	1.9 years
Boeing 777	63	16.8 years
Boeing 787	10	4.8 years
TOTAL	206	13.8 years

[1] https://www.airfleets.net/

Regulations

- Evolutionary history of airworthiness regulations[1]
- Changes in requirements have evolved thru the accidents

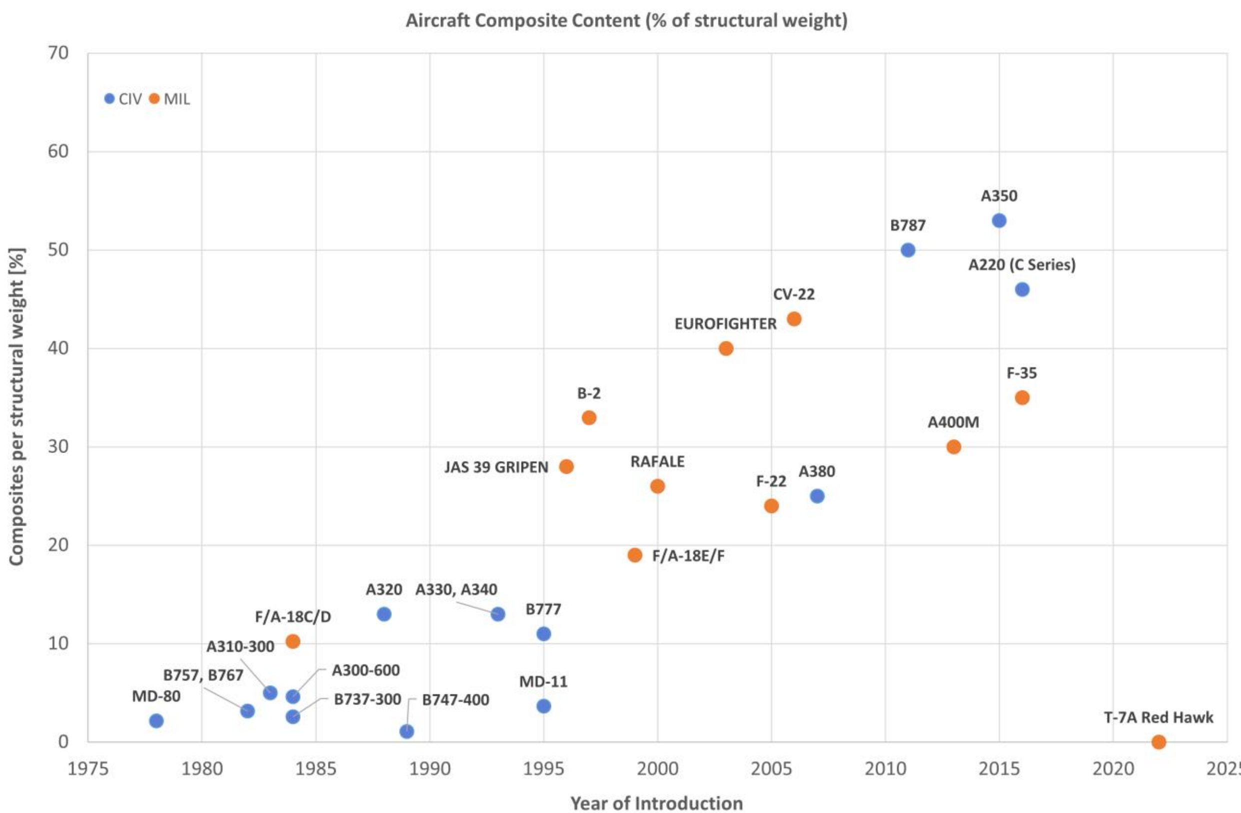
Periods	Events	Evolution Stories
1949	CAR 4b.316	Introduced the concept of fatigue strength into aircraft designs (based on SBR)
1954	HavillandD.H.106	The full-scale fatigue tests must be separated with static tests. SBR cannot secure the free of fatigue
1956	CAR 4b.270	Introduced option of fail-safe, and test validation requirement to the SBD concept
1958	B-47	Only fatigue analysis cannot secure aircraft safety. Design Loads must be close to real operations.
1958–1969	ASIP & series Doc.	Established ASIP for all of military aircraft, to determine the fatigue life with full-scale fatigue tests.
1964	14 CFR §25.571	CAR 4b.270 has been recodified to 14 CFR §25.571 without significant changes
1968	ASD-TR-66-57	Required tests for 1) Materials; 2) Machining processes; 3) Joints to final assemblies
1969	F-111	A metallic material with high strength/low toughness is not a good option for airframe structures.
1970	F-5	Balance designs between static and fatigue are needed. Introduced cold working as fatigue enhancing technique
1966–1977	KC-135	Balance designs between static and fatigue are needed, and important for material selections
1972	MIL-STD-1530	For ASIP, required the validation tests for coupons, small elements, splices and joints, panels fittings, control system components, and structural operating mechanisms and major components
1974	MIL-A-83444	Raised Damage Tolerance Requirements for all of military aircraft
1977	B 707-300	Designed with Fail-safe concept, not executed inspections properly
1978	Amdt.25-45AC 25.571-1	Raised Damage Tolerance Requirements for all civil aircraft, included in-service fleets
1986	AC 25.571-1A	Included consideration to discrete source damages
1988	Aloha B 737-200	Widespread damages with over DSG operations and poor maintenances
1996	MIL-HDBK-1530	Required to avoid the WFD occurred in the economic operation life for military aircraft
1997	AC 25.571-1B	Introduced the concept of scatter factors into certification requirements
1998	Amdt.25-96/AC 25.571-1C	Required test validations for No WFD occurred before DSG for civil aircraft
1998	JSSG-2006	New detail DT design guidelines for military aircraft
2002	MIL-HDBK-1530A	Required the predictions of WFD onset time for military aircraft
2004	MIL-STD-1530B	Superseded MIL-HDBK1530B, in which the requirement items for corrosion was included
2005	MIL-STD-1530C	Linked ASIP with airworthiness certification, added risk analysis into ASIP
2010	Amdt.25-132/AC 25.571-1D	Set LOV validation requirements for civil aircraft, applicable to all of in-service aircraft
2016	MIL-STD-1530D	Adding requirements for composite, economic service life, and capabilities of NDI techniques

Aloha Airlines' Boeing 737-297, N73711

[https://www.thisdayinaviation.com/tag/aloha-airlines-flight-243/]

[1] Lin, J. (2022). *Durability and damage tolerance analysis methods for lightweight aircraft structures: Review and prospects*, International Journal of Lightweight Materials and Manufacture 5 (2022) 224-250.

Composite construction trend



[1] Various sources, e.g., https://avaloncsl.files.wordpress.com/2013/01/avalon-the-use-of-composites-in-aerospace-s.pdf
Note: Values are indicative only