DEFENCE AND SPACE

A Holistic Digital Twin For Service Life Extension Programs

31st ICAF Symposium – Delft, 26-29 June 2023

Javier Gomez-Escalonilla, Fernando Sanchez, Oscar Valencia, Manuel Rebollo

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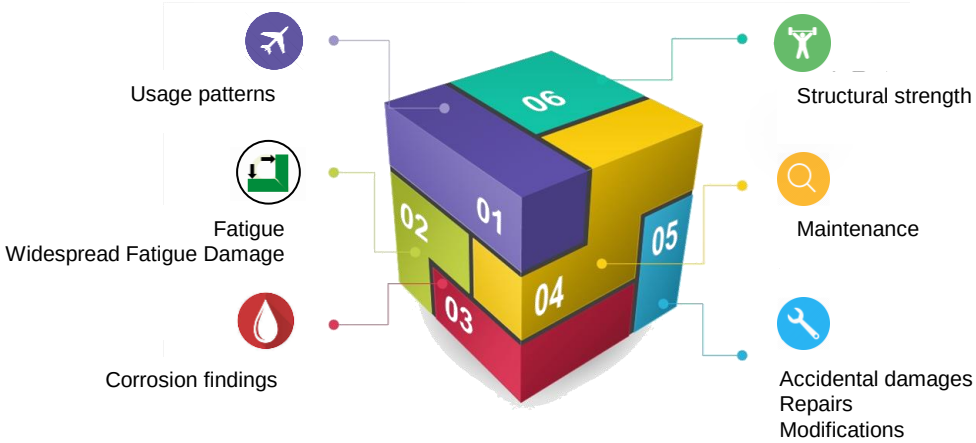
Context

The evaluation of the condition of an airframe and its associated life potential is a **holistic process** including the assessment of aspects such as usage patterns, fatigue data, widespread fatigue damage data, corrosion prevention data, corrosion findings, maintenance tasks, structural strength data, accidental damages, repairs and modifications.



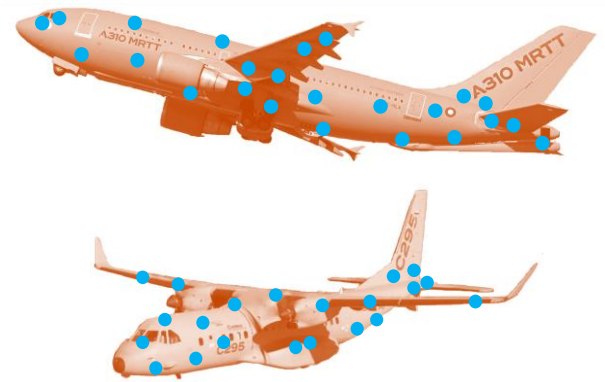
This analysis has to be done individually **in each MSN** and has to consider the possible interactions among the different effects.

Fatigue Digital Equivalent

This evaluation is enabled by the creation of a '**Fatigue Digital Equivalent**' (FDE) of each aircraft of the fleet, which comprises all the relevant information of the so-called '**Degradation Assessment Locations**' (DALs). Currently, the standard FDE includes 200 to 1200 DALs, depending on the aircraft type, and the number is higher in the FDE+ version.

Real aircraft

Digitalization



Fatigue Digital Equivalent

Fatigue Digital Equivalent

The long-term roadmap of the digital twin for fatigue life prediction includes three ‘waves’ in addition to the FDE. The definition of the waves includes the coordinated allocation of progressively more sophisticated features corresponding to five main development axes (Analysis type, Configuration, Modelling fidelity, Structural scope, Degradation phenomena covered),

IN-SERVICE MODELS

NEW DEVELOPMENTS

[STANDARD] FATIGUE DIGITAL EQUIVALENT (FDE)

- Partially probabilistic
- As-design/as-built/as-operated
- Medium fidelity models
- Critical primary structure

[HOLISTIC] FATIGUE DIGITAL EQUIVALENT (FDE+)

- Isolated very-high fidelity models
- Holistic analyses

FATIGUE DIGITAL RELATIVE (FDR)

- Partially probabilistic
- As-design/as-built/as-operated
- High-fidelity models
- Primary structure
- Holistic analyses

FATIGUE DIGITAL BROTHER (FDB)

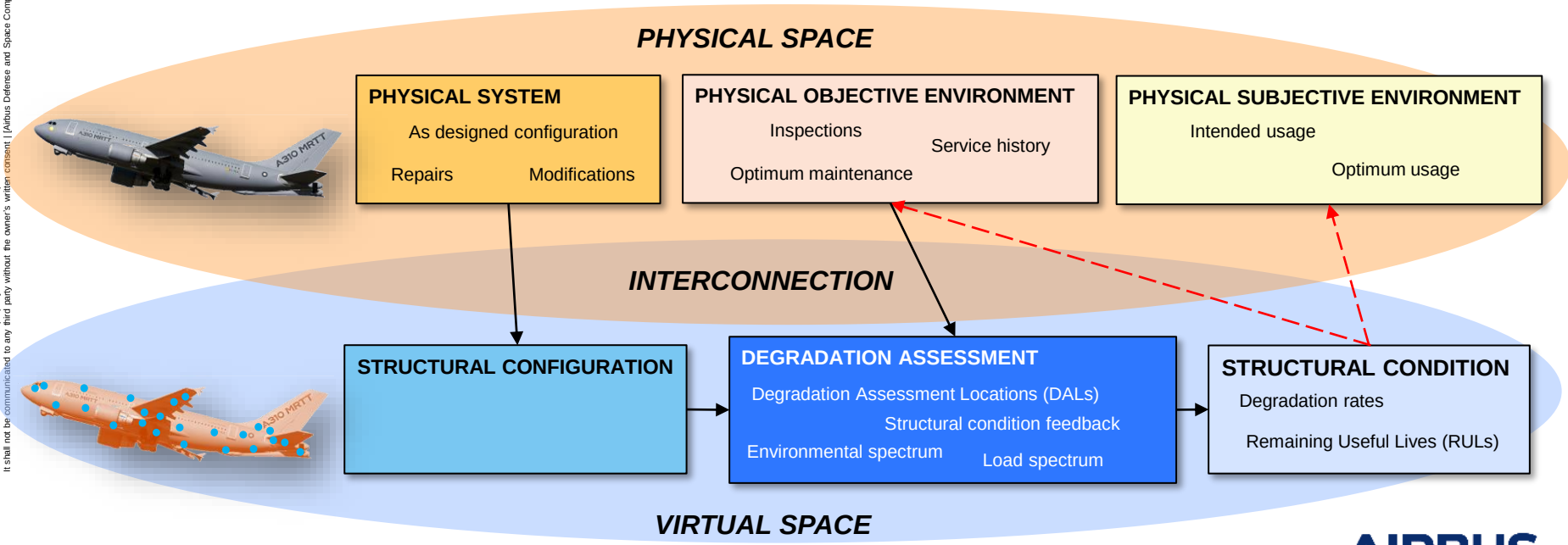
- Full probabilistic
- As-design/as-built/as-operated
- Very-high fidelity models
- Primary structure + critical secondary
- Holistic analysis

FATIGUE DIGITAL TWIN (FDTw)

- Full probabilistic
- As-design/as-built/as-operated
- Ultra-high fidelity models
- Whole structure
- Holistic analyses

Architecture

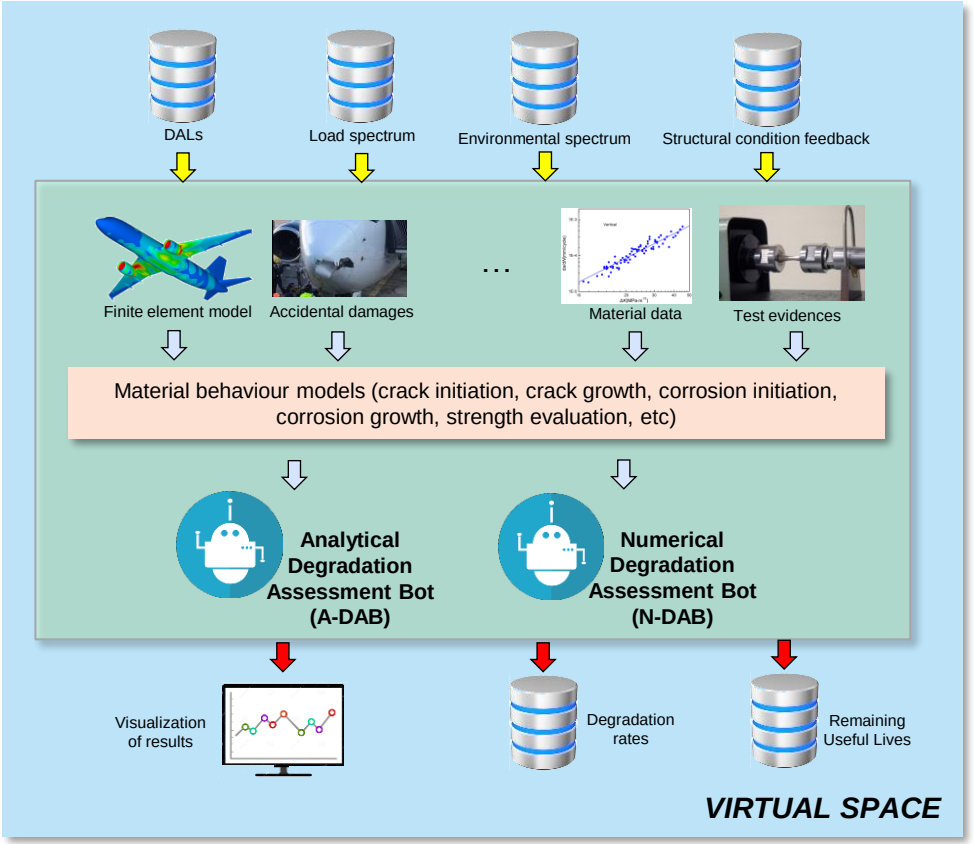
Following the classical digital twin definition, three essential parts are considered in the FDE: physical space, virtual space, and interconnection between physical and virtual spaces.



Architecture

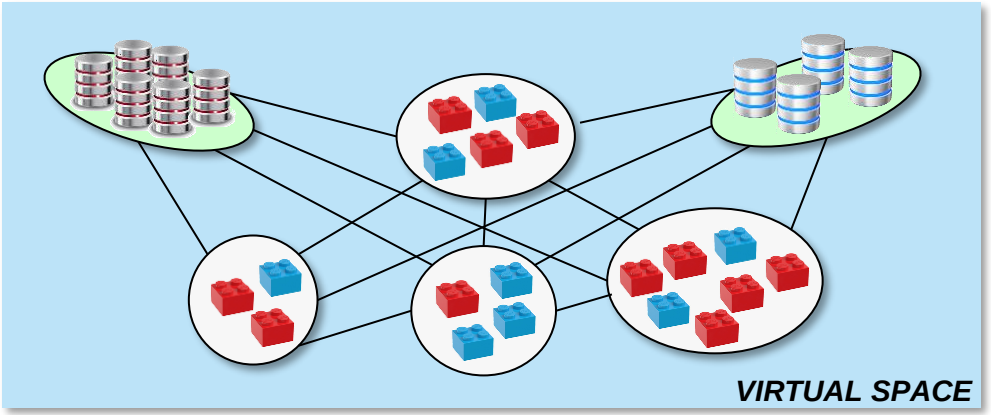
The virtual space is organized in terms of '**Degradation Assessment Bots**'(DABs) corresponding to Degradation Assessment Locations (DALs).

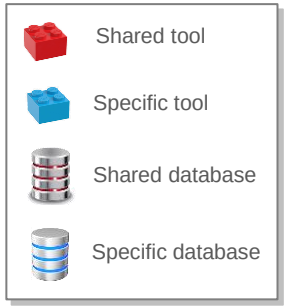
Many of the DABs are based on analytical medium-/high-fidelity life prediction models, as far as they are compatible with the required level of accuracy and the complexity of the scenario. When needed, other numerical high-/very high-fidelity models –based on virtual fatigue testing principles– can be used for certain hotspots of interest.



Architecture

In practice, the virtual space of the FDE/FDE+ is implemented by means of an **ecosystem of 'integrated tools'** that work as LEGO bricks. Thus, an integrated tool is built by combining one or several 'general/shared tools' (e.g., a tool to find the model that is applicable to a particular structure zone) with other 'specific tools' (e.g., a tool to perform the structure repair analysis for the service repair manual), thus yielding one or several DABs. The resultant tools can be combined with others so new tools can be easily created to enhance an existing process or to create new processes. This flexible and adaptive development methodology enables a quick increase of the range of applications of the FDE/FDE+.

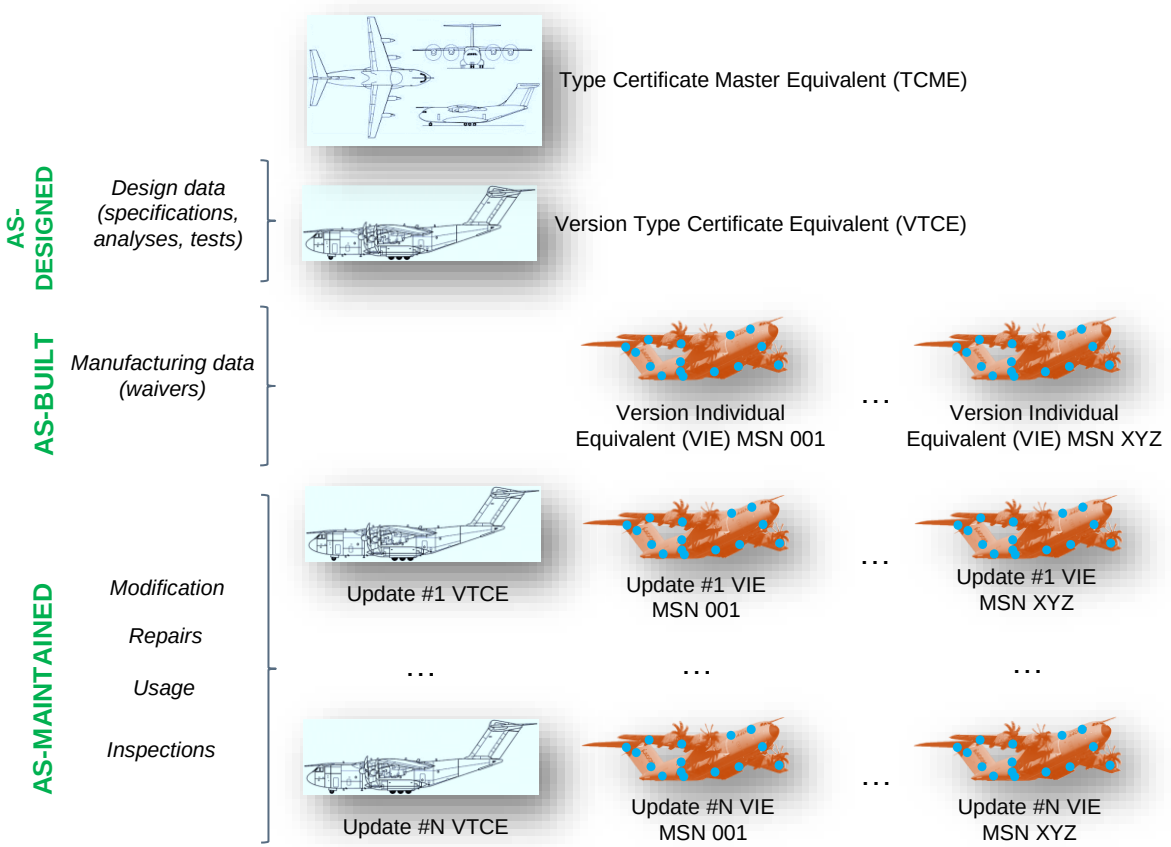




Architecture

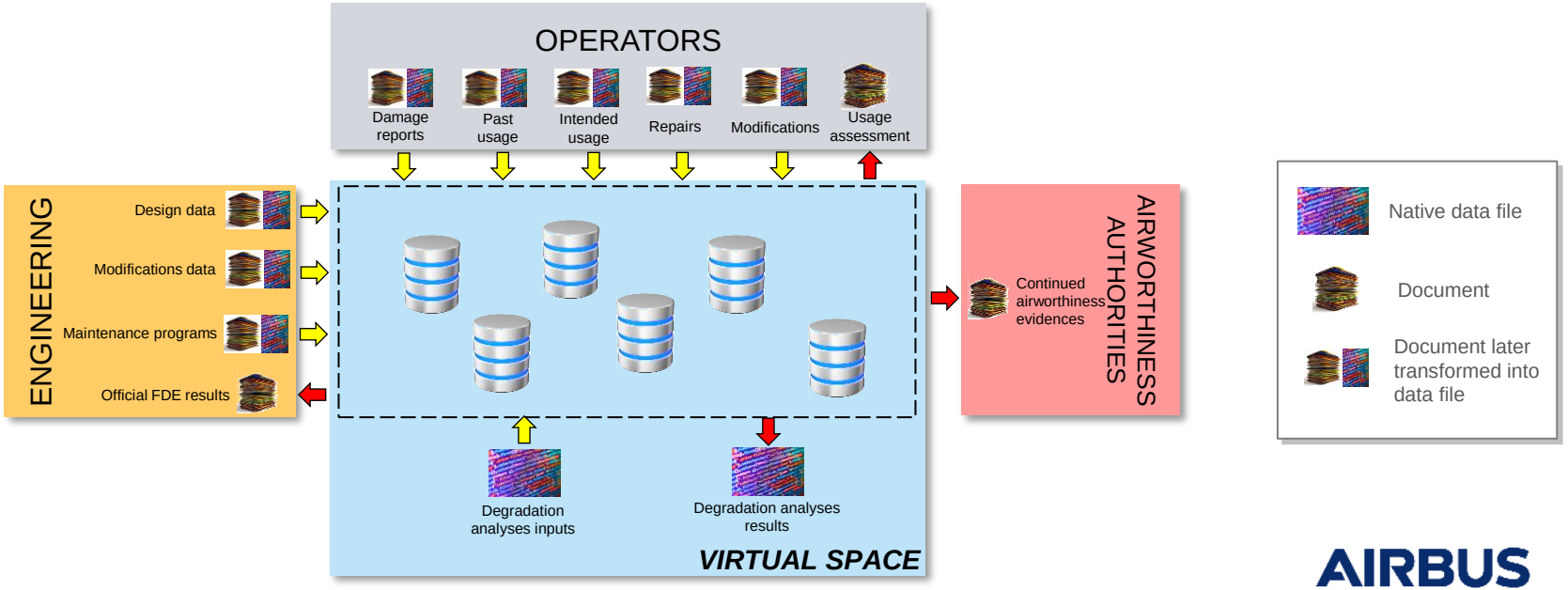
The FDE is initiated at certification date with the creation of a '**Version Type Certificate Equivalent**' (VTCE). There may be several VTCEs of the same aircraft type (all of them derived from the so-called '**Type Certificate Master Equivalent**').

Once the deliveries of specific Manufacturer Serial Numbers (MSNs) start, individual instances of the VTCE, called '**Version Individual Equivalents**' (VIEs), are produced containing the specific combination of modifications, manufacturing waivers, inspection findings (or nil findings), changes of usage, etc that make each airframe unique.



Interfaces

The FDE has been designed to work with data and, therefore, reduce the number of documents involved in the engineering processes, **documents are still needed and will be needed for a long time**, particularly in the output side. Since the models cannot be viewed directly by humans, documents as ‘written reports on the models’ remain part of the loop.

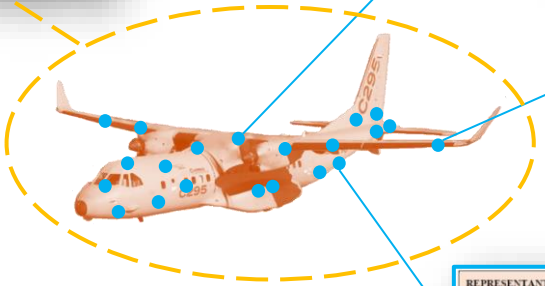


Credibility

A **Credibility Assessment Framework** (CAF) based on the Predictive Capability Maturity Model (PCMM), is used to structure the credibility assessment into complementary elements that cover the different contributions to the accuracy, correctness and traceability of the results of the FDE.

PHYSICAL SPACE FIDELITY	PHYSICAL-VIRTUAL CONNECTION	VIRTUAL SPACE CODE VERIFICATION	VIRTUAL SPACE SOLUTION VERIFICATION	RESULTS INTERPRETATION VERIFICATION	UNCERTAINTY QUANTIFICATION AND SENSITIVITY ANALYSIS
What critical elements of the physical system are neglected?	Is the information exchanged between the physical and the virtual space reliable? Is it properly synchronized?	Are algorithm deficiencies, software errors, and poor software quality practices corrupting the simulation results?	Are human procedural errors corrupting the FDE results?	Is the outcome of the FDE unambiguous? Has the domain of application of those results been carefully determined?	How thoroughly are uncertainties and sensitivities characterized and propagated?

Overall PCMM evaluation



REPRESENTANTION AND GEOMETRIC FIDELITY	PHYSICS AND MATERIAL MODEL FIDELITY	CODE VERIFICATION	SOLUTION VERIFICATION	MODEL VERIFICATION	UNCERTAINTY QUANTIFICATION AND SENSITIVITY ANALYSIS
What features are neglected because of simplifications or stylizations?	How fundamental are the physics and material models and what is the level of model calibration?	Are algorithm deficiencies, software errors, and poor software quality practices corrupting the simulation results?	Are numerical solution errors and/or human procedural errors corrupting the simulation results?	How carefully is the accuracy of the simulation and experimental results assessed at various tiers in a validation hierarchy?	How thoroughly are uncertainties and sensitivities characterized and propagated?

PCMM evaluation for DAB #1

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PCMM evaluation for DAB #2

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REPRESENTANTION AND GEOMETRIC FIDELITY	PHYSICS AND MATERIAL MODEL FIDELITY	CODE VERIFICATION	SOLUTION VERIFICATION	MODEL VERIFICATION	UNCERTAINTY QUANTIFICATION AND SENSITIVITY ANALYSIS
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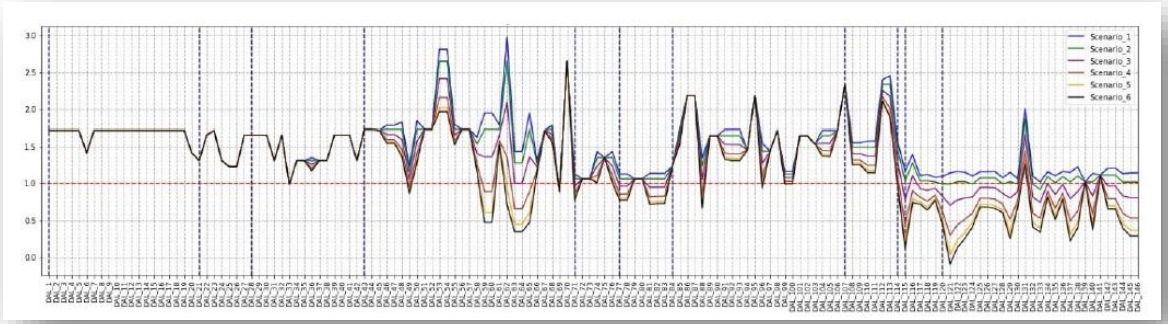
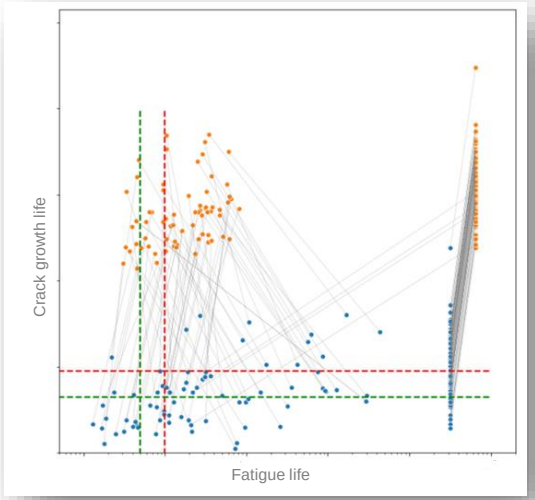
PCMM evaluation for DAB #N

Applications

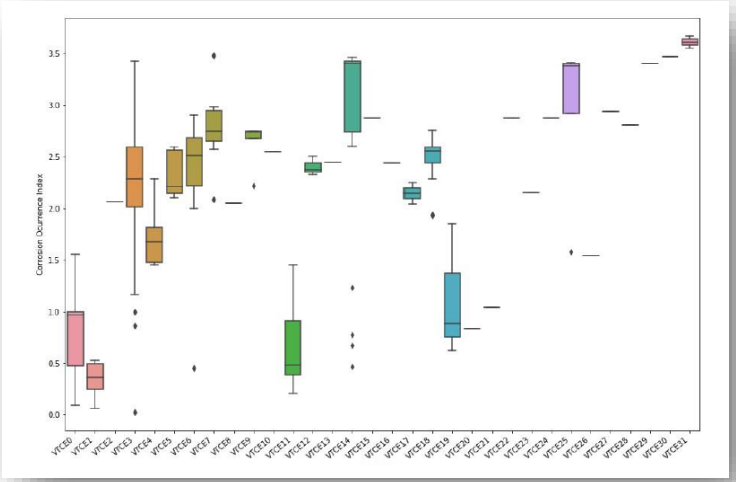
The FDE/FDE+ can extrapolate the **future condition of each individual aircraft** in case of expected changes in the operational scenarios, thus suggesting the appropriate targeted maintenance actions in advance. This evaluation is made for the whole airframe at the same time in terms of severity relative to a given reference.

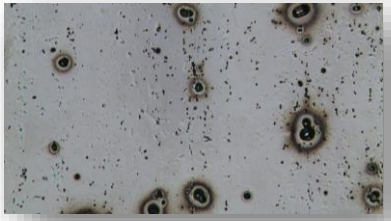


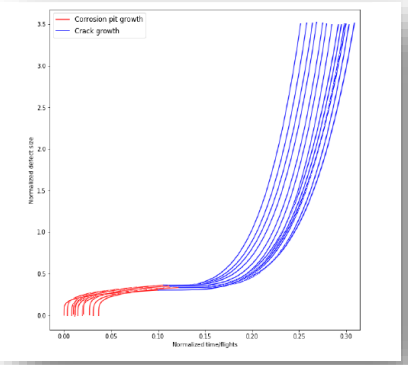


Applications

The FDE+ version is able to integrate different degradation models in order to calculate the **Remaining Useful Life** (RUL), rather than focusing on just one aspect of the degradation of the materials. For this purpose, **environmental spectra projections** can be made for different Version Individual Equivalents (VIEs) of the same fleet or even for several Version Type Certificate Equivalents (VTCEs) with completely different environmental conditions.







Conclusions

- A digital twin –called Fatigue Digital Equivalent (FDE) in its initial wave– has been developed to determine the **condition of the structure** by simulating the occurrence, growth and eventual interaction of the different degradation sources

- At its core, the FDE is an **ecosystem of deterministic and probabilistic models** representing all the aspects involved in the airframe's safety including design, manufacturing, maintenance, repair, configuration management and flight operations. The models are then incorporated into a set of holistic analyses used to estimate the remaining useful life of the relevant elements

- One of the main challenges of the construction of the FDE is the **integration into a single repository of heterogeneous sources of data**, including design information created in many cases years ago, maintenance records generated over the years following different formats and standards, and external in-service inputs provided by the operators

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Thank you

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