



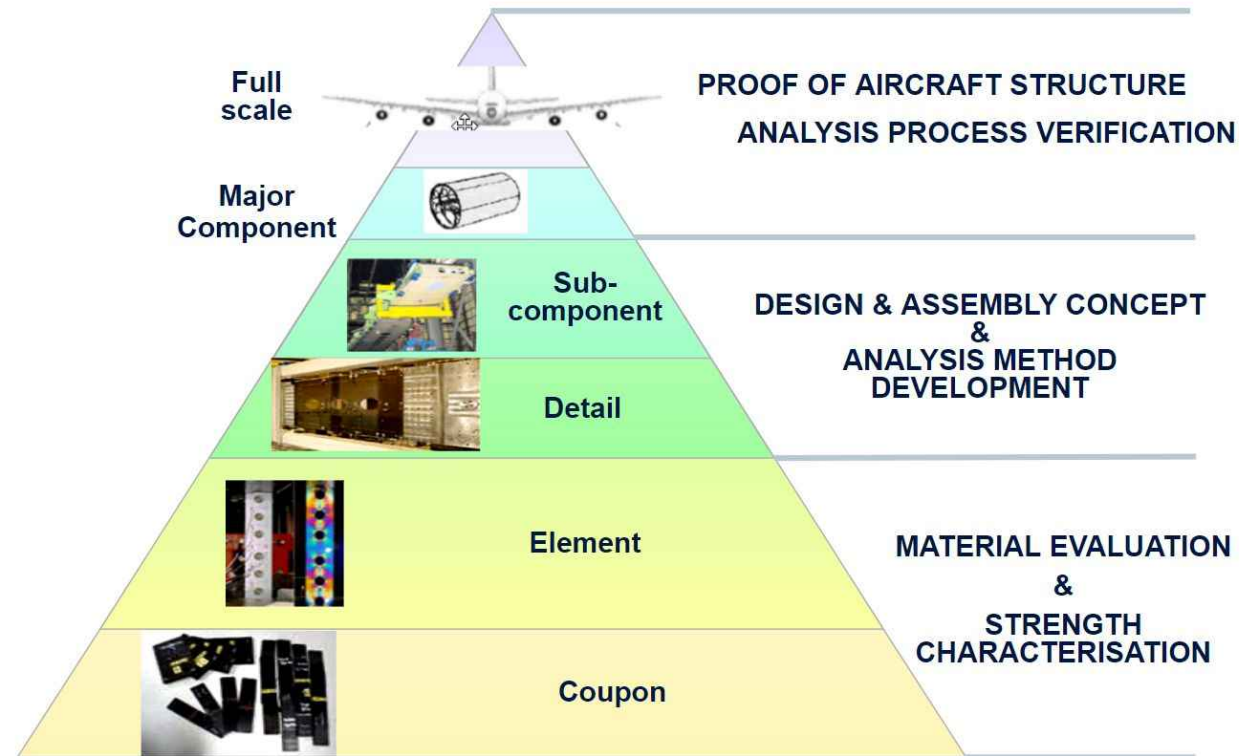
Structural Integrity – The Journey Towards Zero Emission Commercial Aircraft

ICAF 2023 – Plantema Lecture

Claudio Dalle Donne - Head of Materials, Process and Test, Airbus Airframe Engineering
Airbus Operations GmbH
26 June 2023

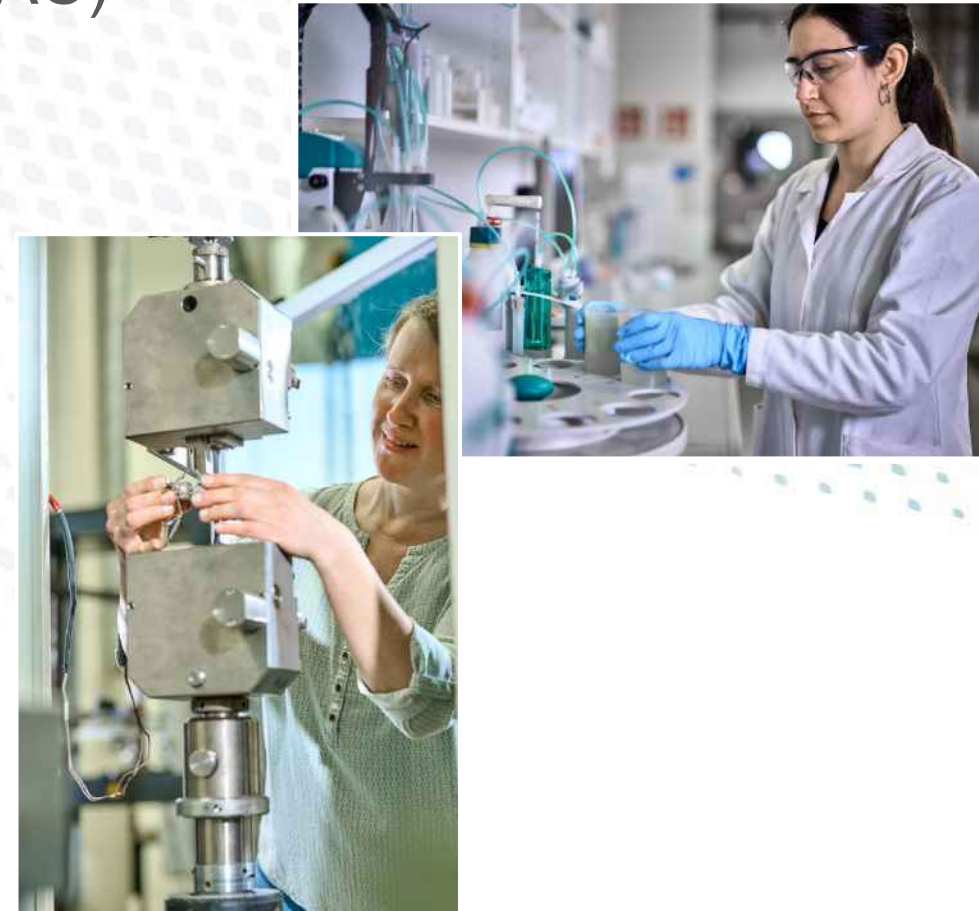
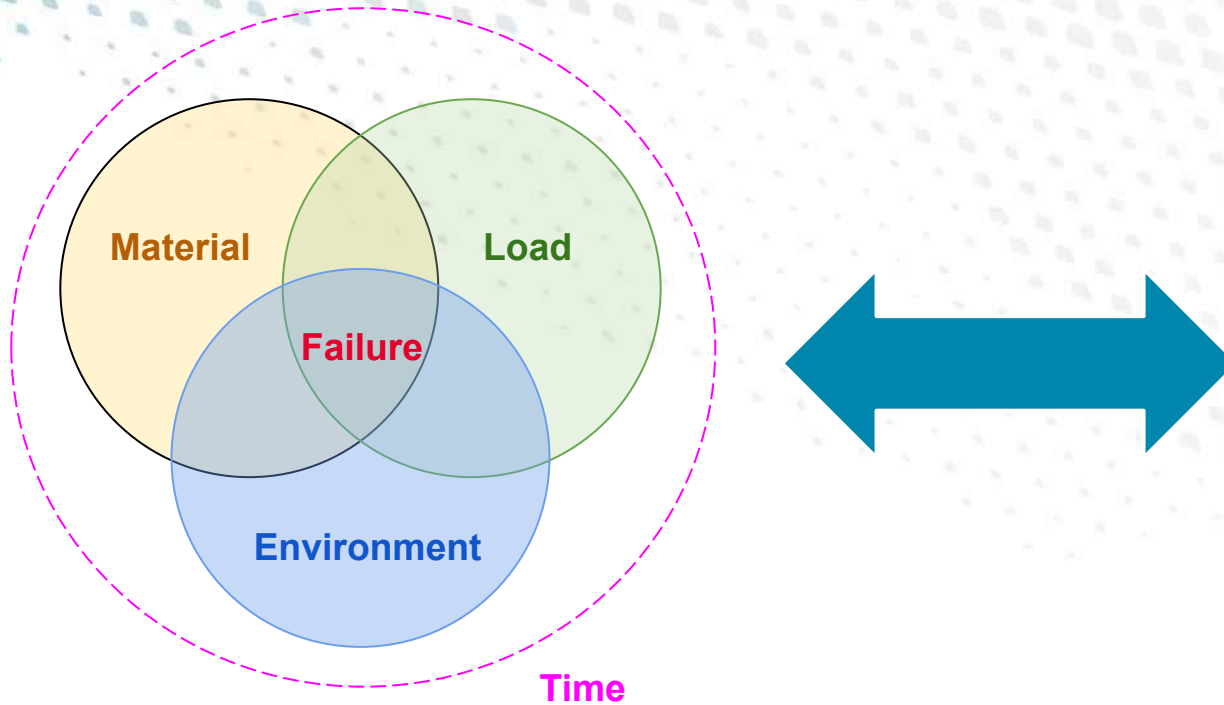
Content

- Get Material's Data Right
- The Power of Data
- Smarter Testing
- Testing for ZeroE



Get Materials Data Right - Accelerated Testing ?

- Hydrogen-Environment Assisted Cracking (HEAC)
- Basic Primer



H-Environment Assisted Cracking (EAC) in new generation 7xxx Alloys



Safety Information Bulletin Airworthiness

SIB No.: 2018-04R2

Issued: 04 March 2021

Subject: Environmentally Assisted Cracking in certain Aluminium Alloys

Revision:

This SIB revises EASA SIB 2018-04R1 dated 13 September 2018.

Ref. Publications:

None.

Applicability:

Type Certificate (TC) holders, Supplemental Type Certificate holders, equipment maintenance organisations, production organisations and aluminium alloy producers.

Description:

EASA received reports of brittle cracking of aluminium alloy components. Additional testing of some new generation 7xxx series alloys has shown that these have a sensitivity to a phenomenon known as environmentally assisted cracking (EAC), when subject to certain conditions in the normal operating environment. The type of EAC encountered appears to be caused by hydrogen embrittlement along the grain boundaries, leading to crack initiation and subsequent propagation. These cracks typically start from holes or other areas of stress concentration and usually propagate in a plane perpendicular to the short transverse (ST) direction. This phenomenon has been linked to the chemical composition of the alloy, notably a high zinc/magnesium ratio, combined with low copper content. Brittle fractures have been reproduced under laboratory environment and cracking has proven to be driven by time exposure (ageing) and is not fatigue related, although further crack propagation under operative loads cannot be excluded.

EASA SIB No.: 2018-04R2

EASA-SIB Alloys:

- 7037, 7040*, 7055, 7085, 7099, 7140*
- ST direction
- Not all alloys used in A380

* only T7651 temper

Airbus Identifies Heat, Humidity As Causes Of A380 Wing-Spar Cracking

Jens Flottau May 17, 2023

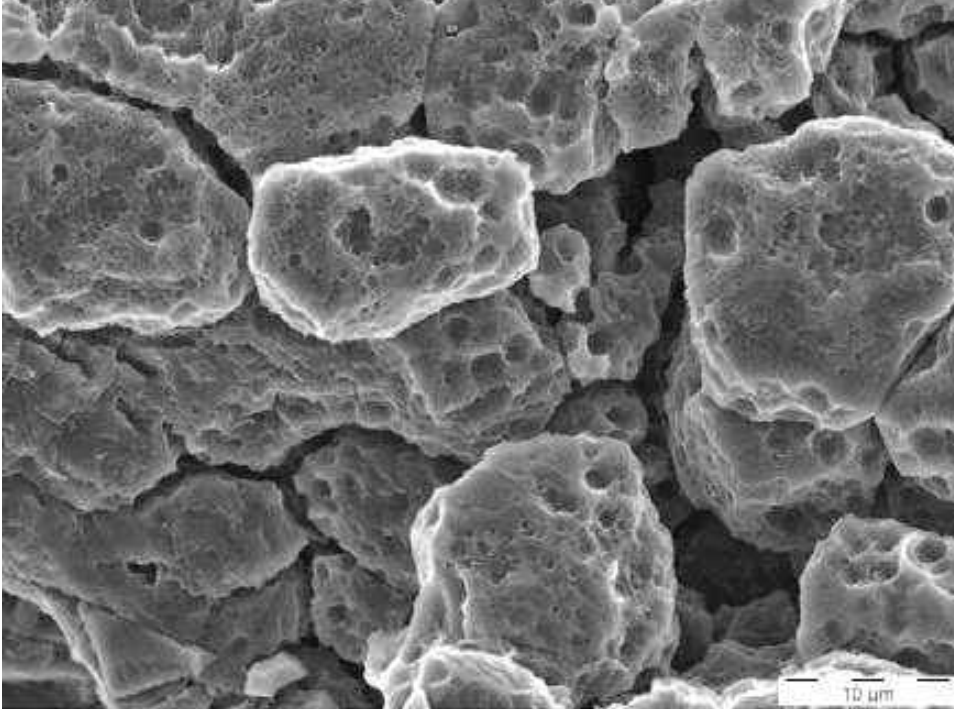
AVIATION WEEK
NETWORK



Credit: Ovidiu Dugulan/Alamy

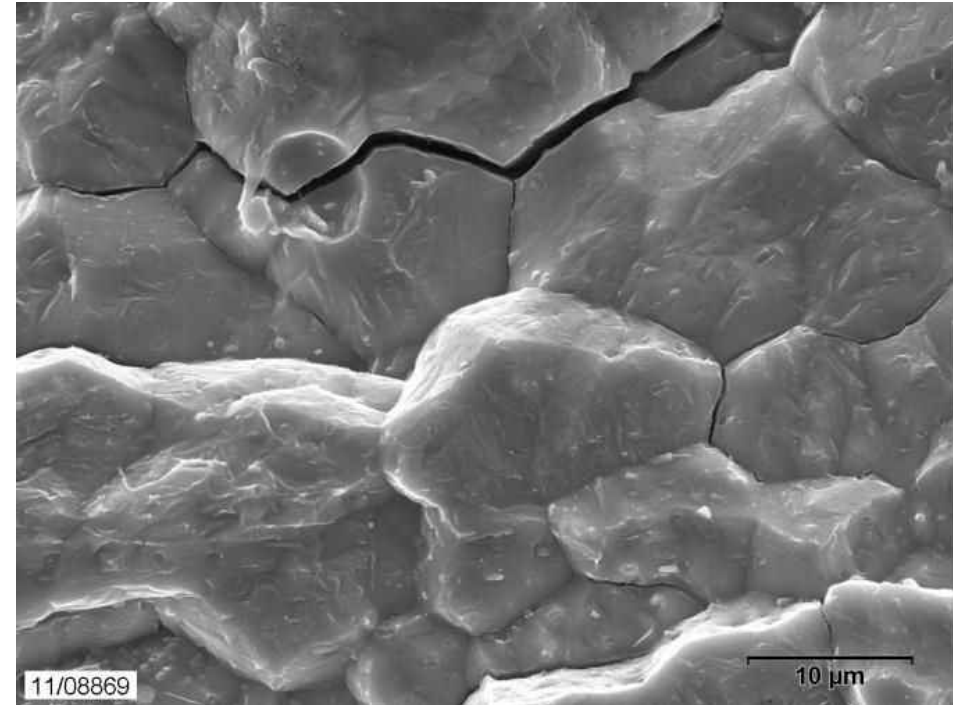
SCC vs HEAC Failure Modes

SCC test acc. to ASTM G 47



AA7037 @ 3,5% NaCl & 240MPa
Intergranular fracture with grains affected by corrosion

HEAC crack from Airbus Asset

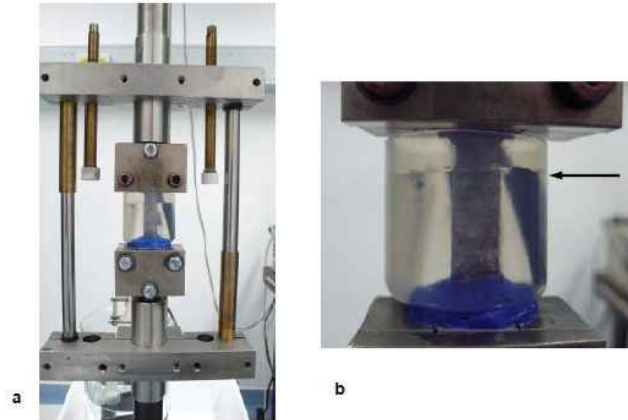


AA7037 - Crack Surface
Intergranular fracture with no obvious corrosion attack or pitting

Mismatch between ASTM accelerated test and real-life failure mode

SCC vs HEAC Failure Modes

SCC test acc. to ASTM G 47



Experimental Conditions

- **Specimen:** 60mm round bar
- **Load:** Constant 30-85 % Rp0.2
- **Environment:** 3,5% NaCl alt. immersion
- **Temperature:** RT

HEAC Testing according to Airbus Test Standard



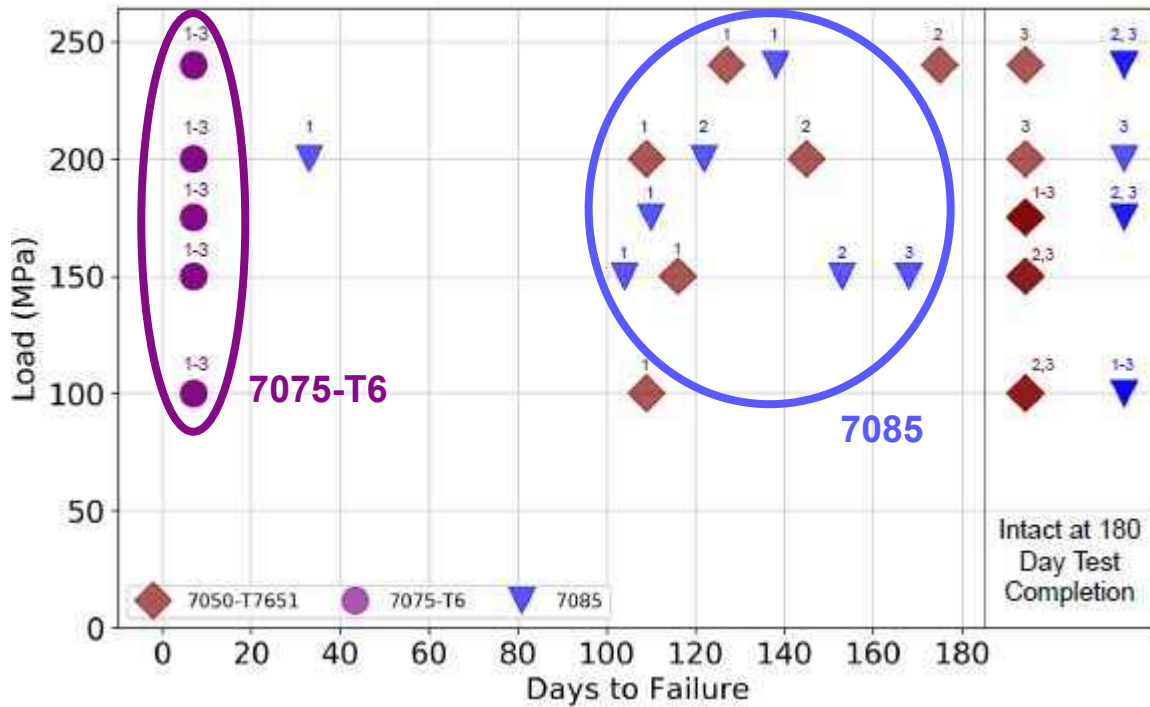
Experimental Conditions

- **Specimen:** 60mm round bar
- **Load:** Constant 85 % Rp0.2 (70 °C)
- **Environment:** air at different humidity levels
- **Temperature:** 70°C

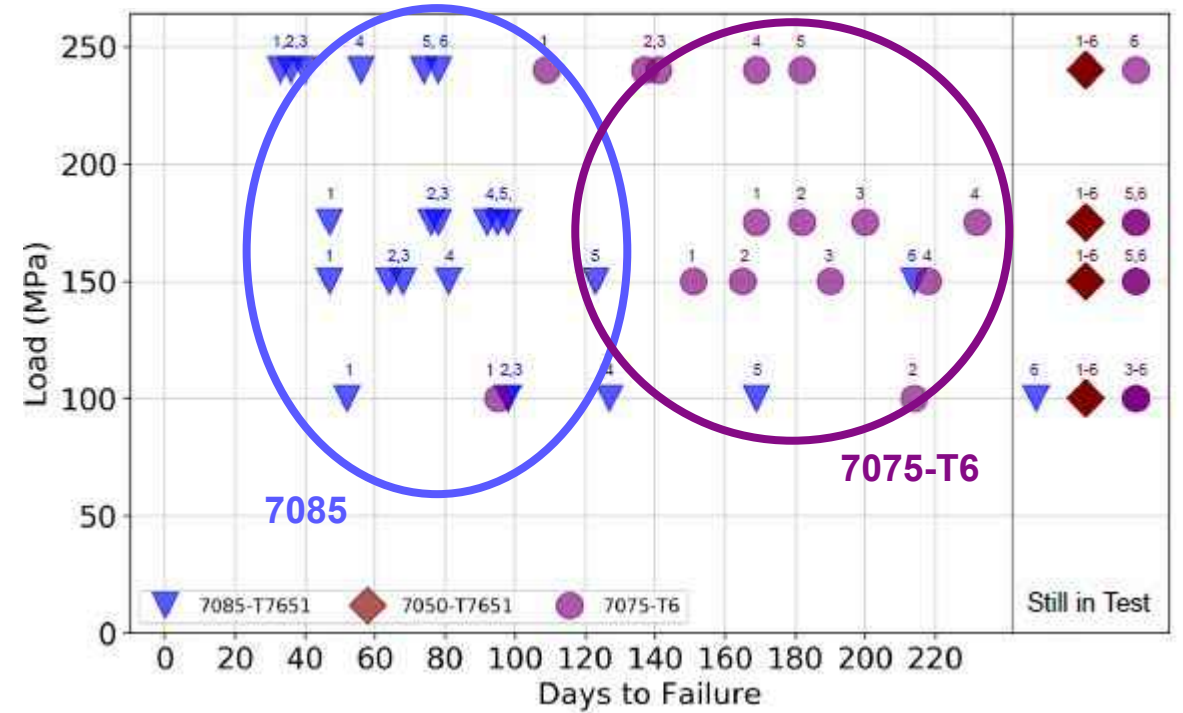
Test output: time to failure in days

SCC vs HEAC Test - Time to Failure

SCC test acc. to ASTM G 47

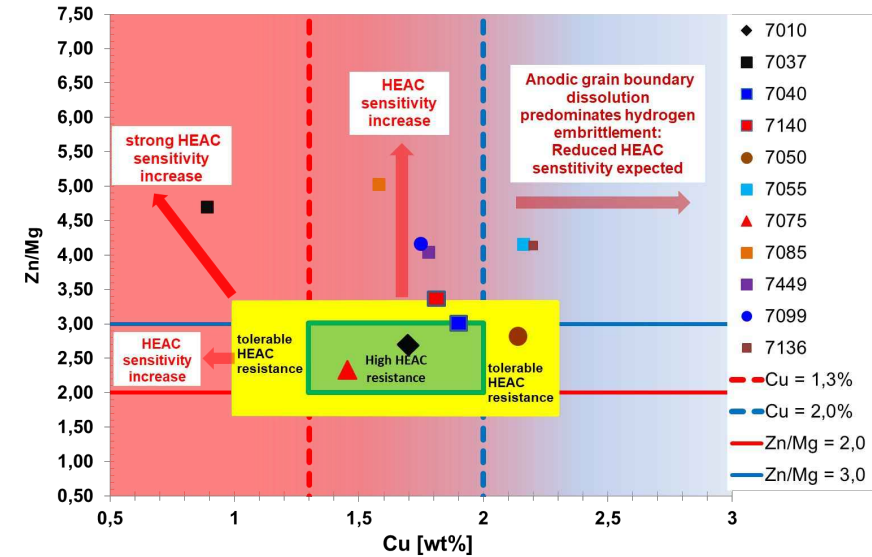
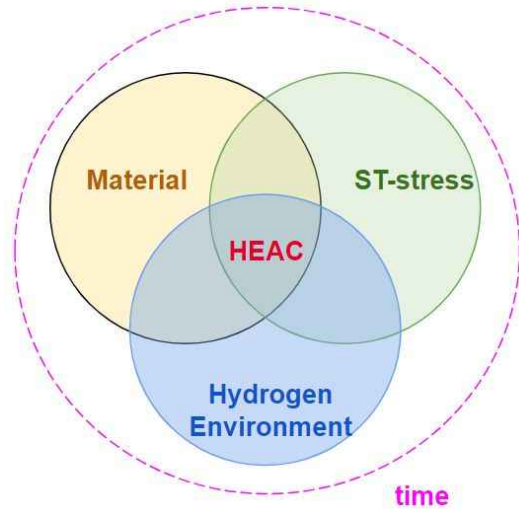


EAC Testing according to Airbus Test Standard



3,5 % - NaCl immersion test is not lower boundary for 7085

HEAC Contributing Factors



Microstructure

Amount of metallic Zn/Mg and grain structure

Stress

Low levels of stress in ST promote HEAC

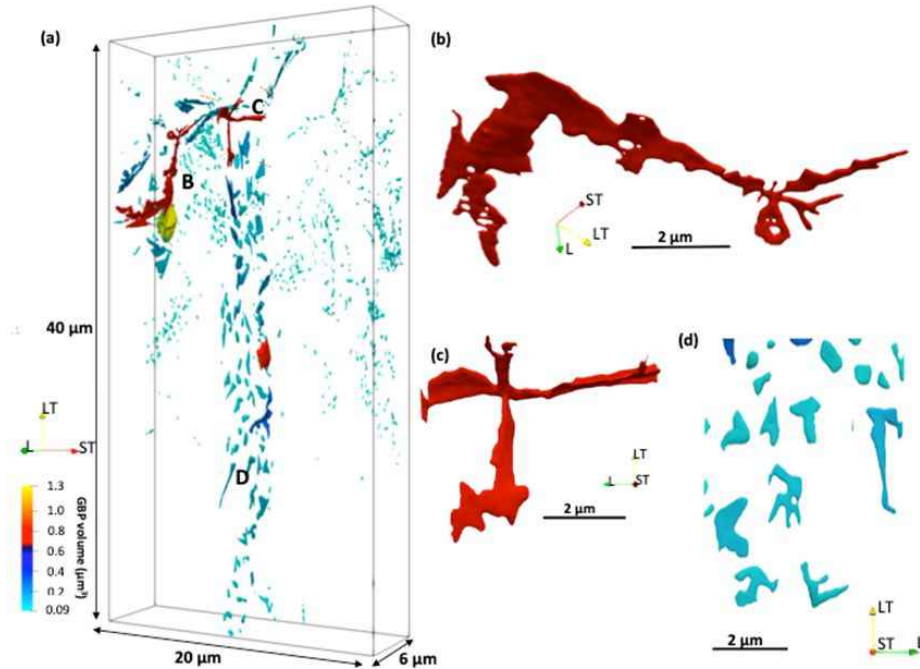
Temperature

Below 0°C negligible, above 0°C the higher the faster

Humidity

Always present H-source (cap at high values)

Advanced Metals Research Programme (AMRP)



Reconstructed and segmented particles present in a PFIB AA7050 alloy (grain boundaries)

Corrosion Science 171 (2020) 108701



Contents lists available at ScienceDirect

Corrosion Science

journal homepage: www.elsevier.com/locate/corsci



Environmental cracking performance of new generation thick plate 7000-T7x series alloys in humid air

Elisabeth Schwarzenböck^a, Eric Ollivier^a, Alistair Garner^b, Alex Cassell^b, Theo Hack^a, Zak Barrett^a, Christian Engel^a, Tim L. Burnett^b, N.J. Henry Holroyd^{b,c}, Joseph D. Robson^b, Phil B. Prangnell^{b,*}

^a Airbus S.A.S., 1 Rond Point Maurice Bellonte, BP 33, F-31707 Blagnac Cedex, France

^b Department of Materials, The University of Manchester, M13 9PL, UK

^c Department of Materials Science and Engineering, Case Western Reserve University, Cleveland, Ohio, USA



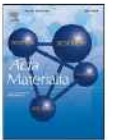
Acta Materialia 202 (2021) 190–210



Contents lists available at ScienceDirect

Acta Materialia

journal homepage: www.elsevier.com/locate/actamat



Multiscale analysis of grain boundary microstructure in high strength 7xxx Al alloys

Alistair Garner^{a,*}, Ryan Euesden^a, Yichao Yao^a, Yasser Aboura^a, Huan Zhao^b, Jack Donoghue^a, Michele Curioni^a, Baptiste Gault^{b,c}, Pratheek Shanthraj^a, Zak Barrett^d, Christian Engel^e, Tim L. Burnett^a, Phil B. Prangnell^a

^a Department of Materials, The University of Manchester, M13 9PL, UK.

^b Max-Planck-Institut für Eisenforschung, Max-Planck-Str. 1, 40237 Düsseldorf, Germany

^c Dept. of Materials, Royal School of Mines, Imperial College, Exhibition Road, London, SW7 2AZ, UK.

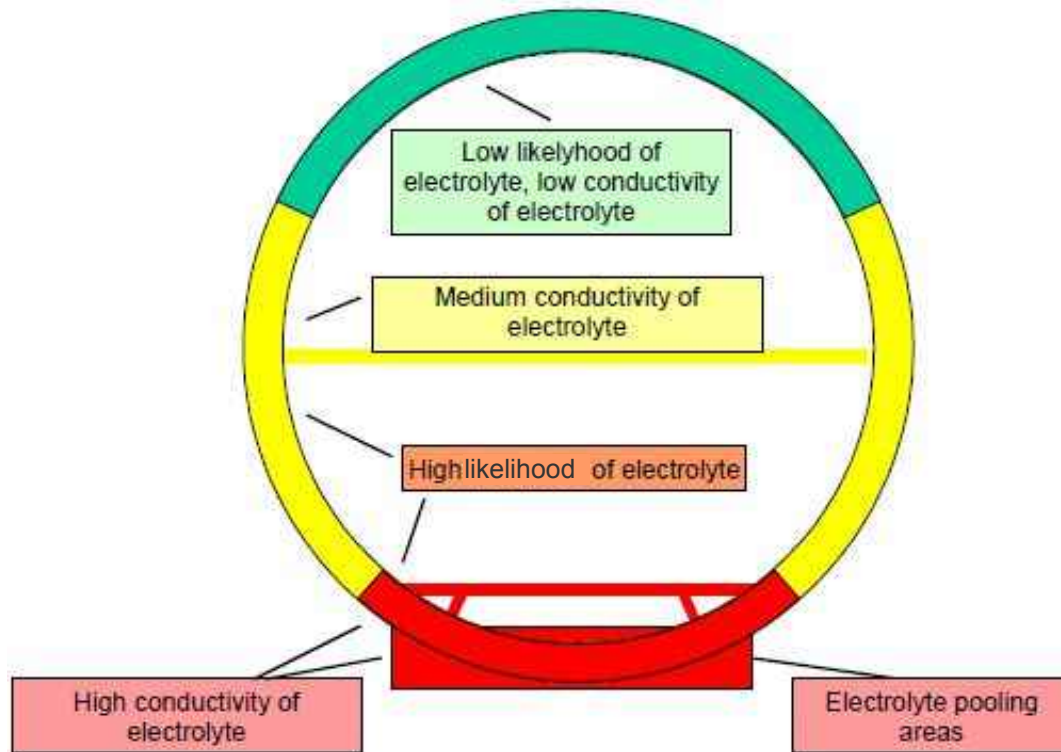
^d Airbus UK, Pegasus House, Aerospace Ave, Filton, Bristol, BS34 7PA, UK.

^e Airbus, Airbus, Airbus Operations GmbH, Airbus-Allee 1, 28199 Bremen, Germany

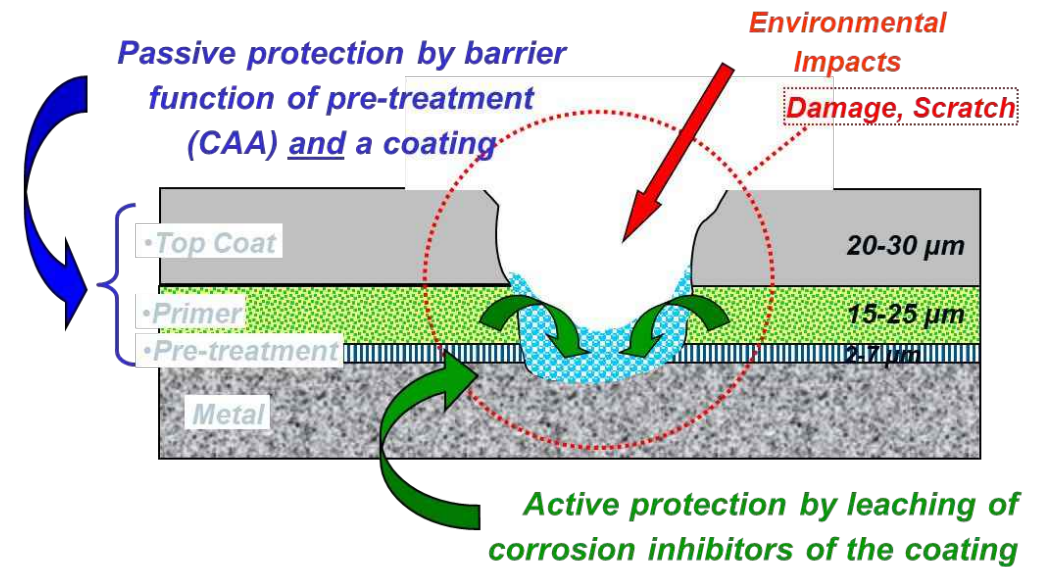


Airbus Corrosion Prevention Principles

Severity of electrolyte and typical water pooling area in the fuselage



- **Passive barrier layers:**
 - Physical barrier function
- **Active protection**
 - Chemical inhibitors protect the free metal surface after damage



REACH** Ban of Chromates*

Pioneering sustainable aerospace

- Relevant EU REACH** Authorisation decision on Chromates*: **stop to use in Jan 2026**
- Increasing regulatory pressure foreseen in other countries
- Chromates*: state of the art in corrosion protection → **high technical challenge** to find alternatives maintaining in-service performances



Development, qualification and deployment of **alternatives** to meet regulations deadlines.

Chromate-free primers are new technologies

- The validation of new inhibition mechanisms requires additional testing
- **New laboratory tests developed** to simulate in-service operations
- **Correlation with in-service behaviour to be confirmed** before full scale deployment



Introduce a **chromate-free Basic Primer in-service in a controlled way** and correlate the performance with laboratory tests before the full-scale deployment.



* Chromates (Chromium VI compounds) in the scope of this document: Strontium Chromate and Potassium hydroxyoctaoxodizincatedichromate (Zinc Potassium Chromate)

** REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals, Regulation (EC) 1907/2006

New Cr-free primers introduction: new tests and in-service verification



Standard Salt Spray Test:

- Neutral NaCl Sol (50 g/l)
- 35 °C const. temp



Cyclic Corrosion testing with adapted conditions

- Temperature Cycles: -60°C to 80°C
- Humidity: 30% to 100%
- Limited amount of salt vapour

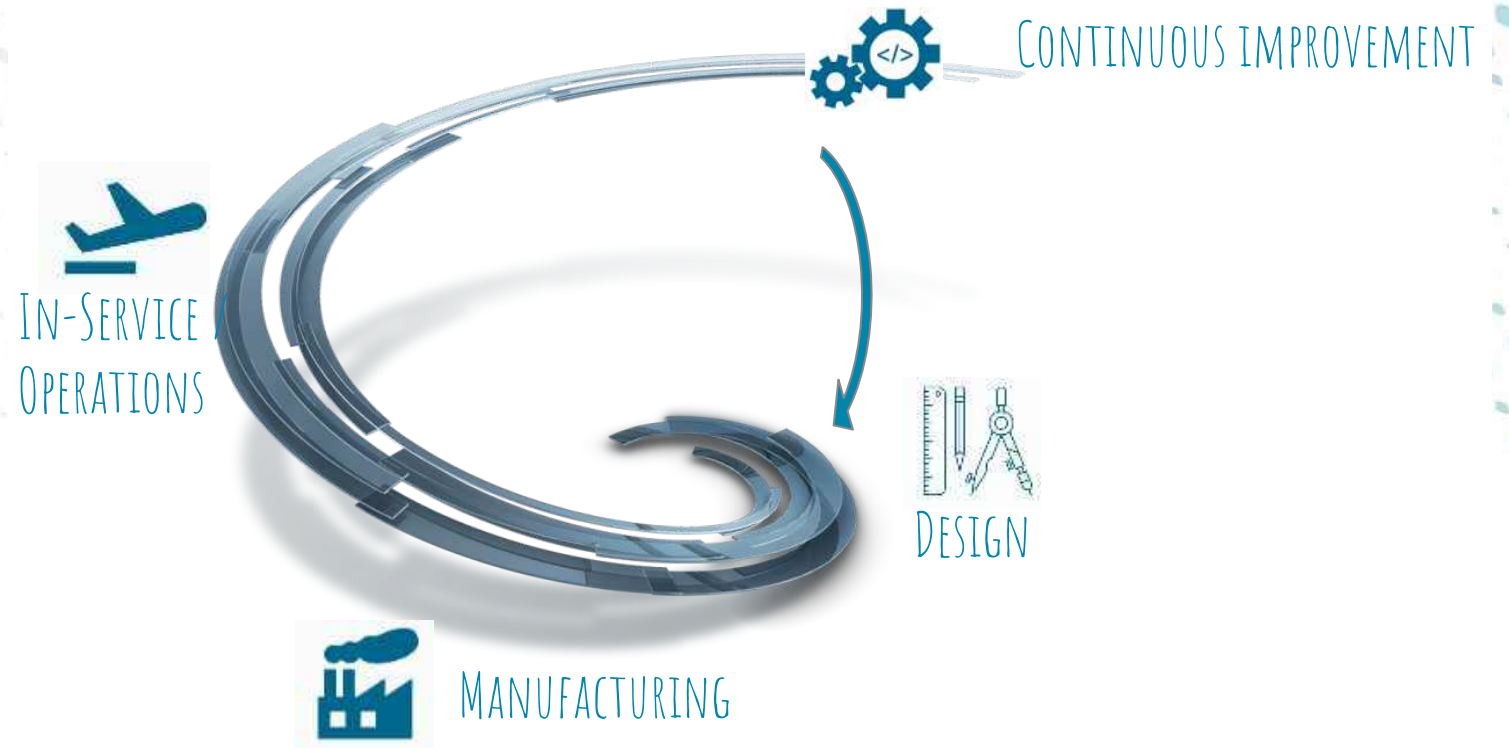


In-service validation of the paint system

- Lead Fleet Approach

The Power of Data

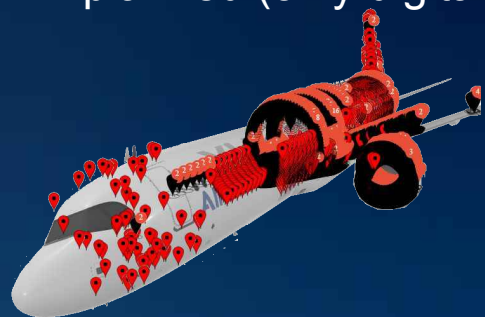
– Airframe Digital Twin



Digital Twin Concept

NOT A TWIN !

Models representing A/C as planned (only digital)



Develop

DIGITAL MODELS



Feedback loop to product development (incremental)

Manufacture



Deliver



Operate

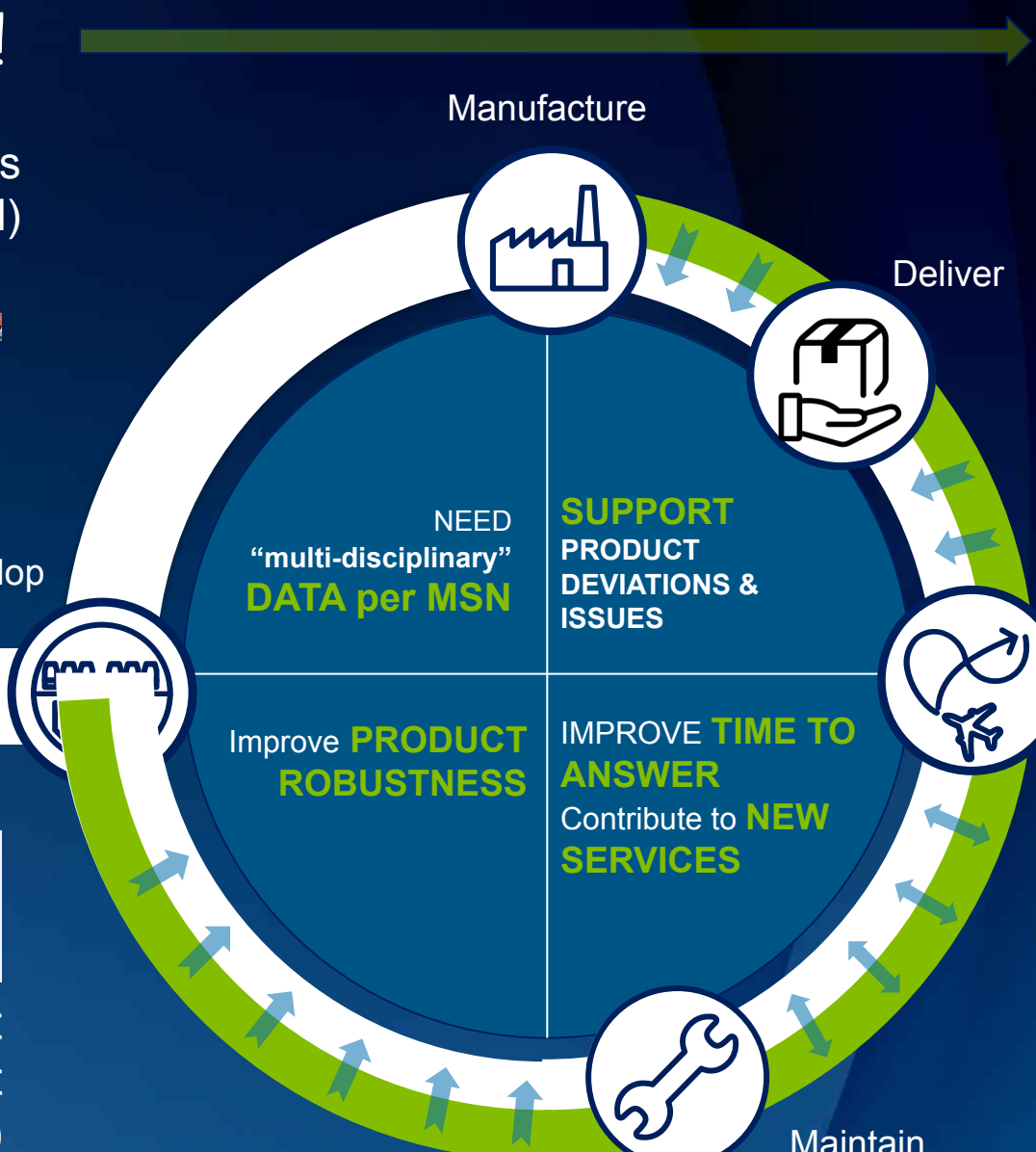
TWIN OF REAL PRODUCT



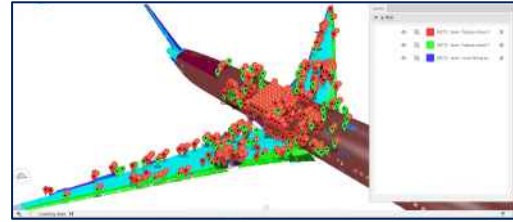
Use twin data for services (internal or external)

BECOMES A DIGITAL TWIN

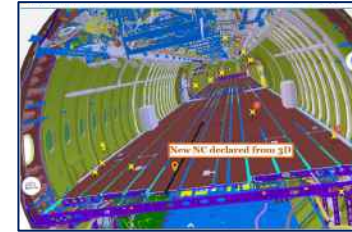
Enrich digital models with data coming from REAL product



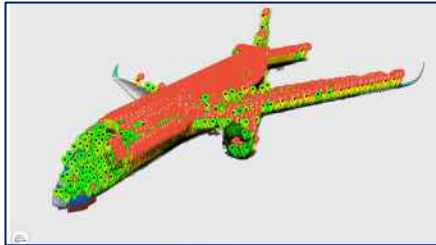
Digital Footprint



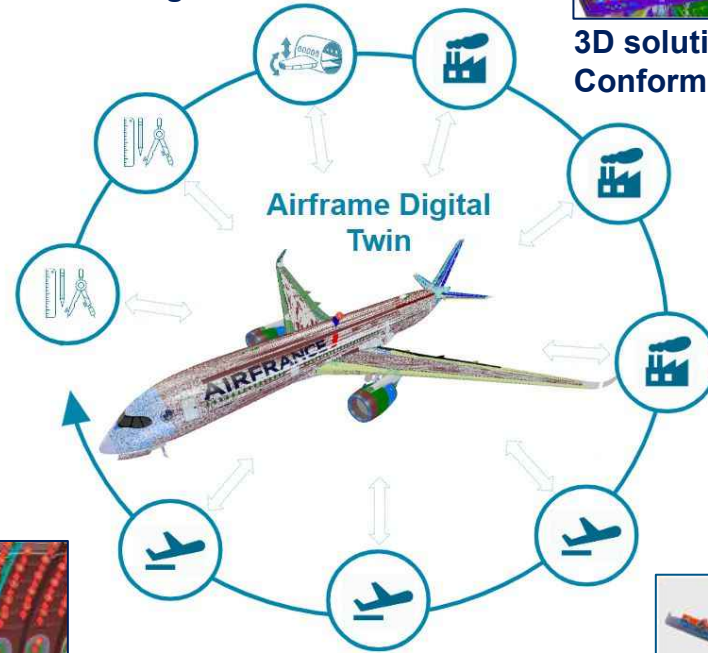
Structural Test findings



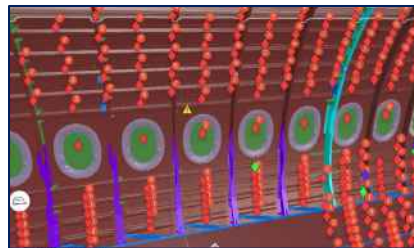
3D solutions and services for Non Conformities Process



Quick access to stress results



"As delivered" view for customers



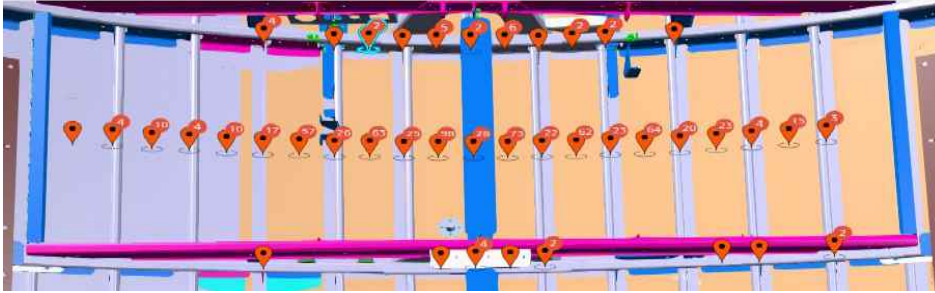
End to end digital repair scenarios



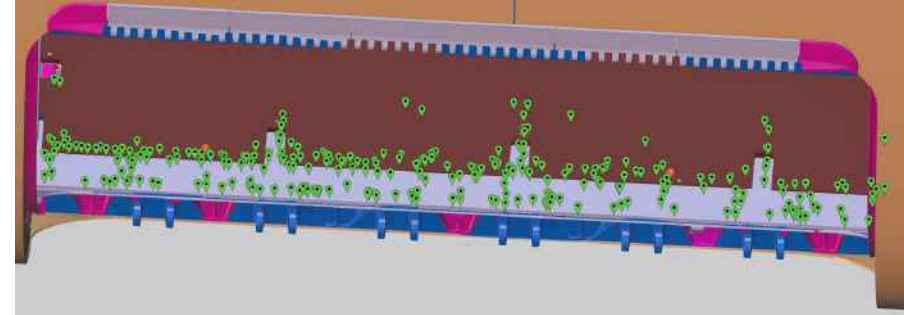
In-service corrosion & NDT findings

Example of Added Value - Corrosion Digital Twin

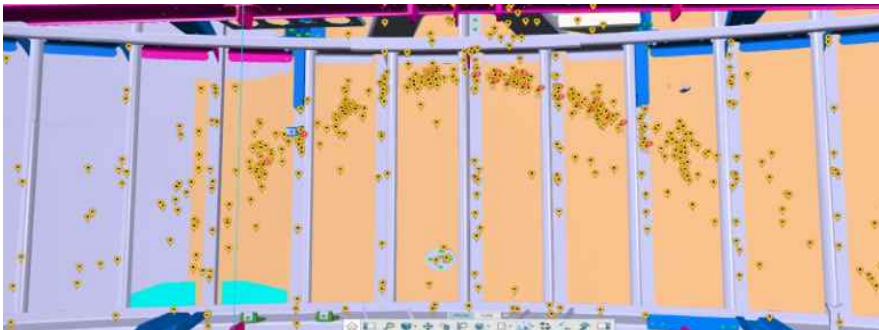
Mapping of corrosion findings with **average** location



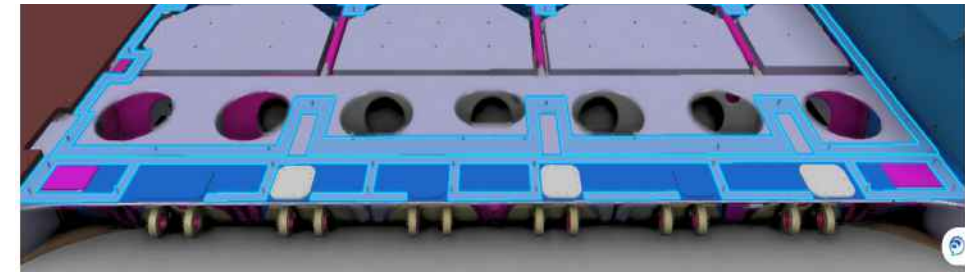
Mapping of corrosion findings on a cargo door sill



Mapping of corrosion findings with **exact** location



Mapping of application of open foam tape



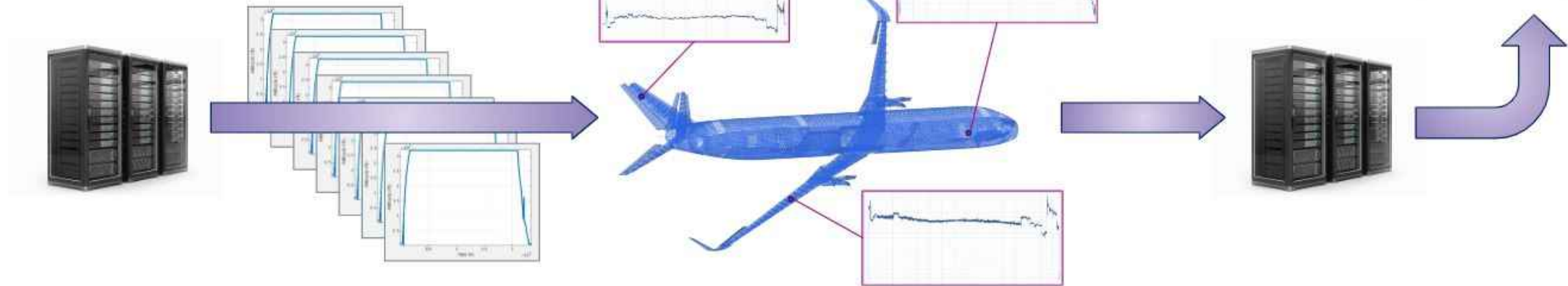
Map of corrosion findings → tailored design, tailored surface protection & tailored maintenance

And the Fatigue Digital Twin ??

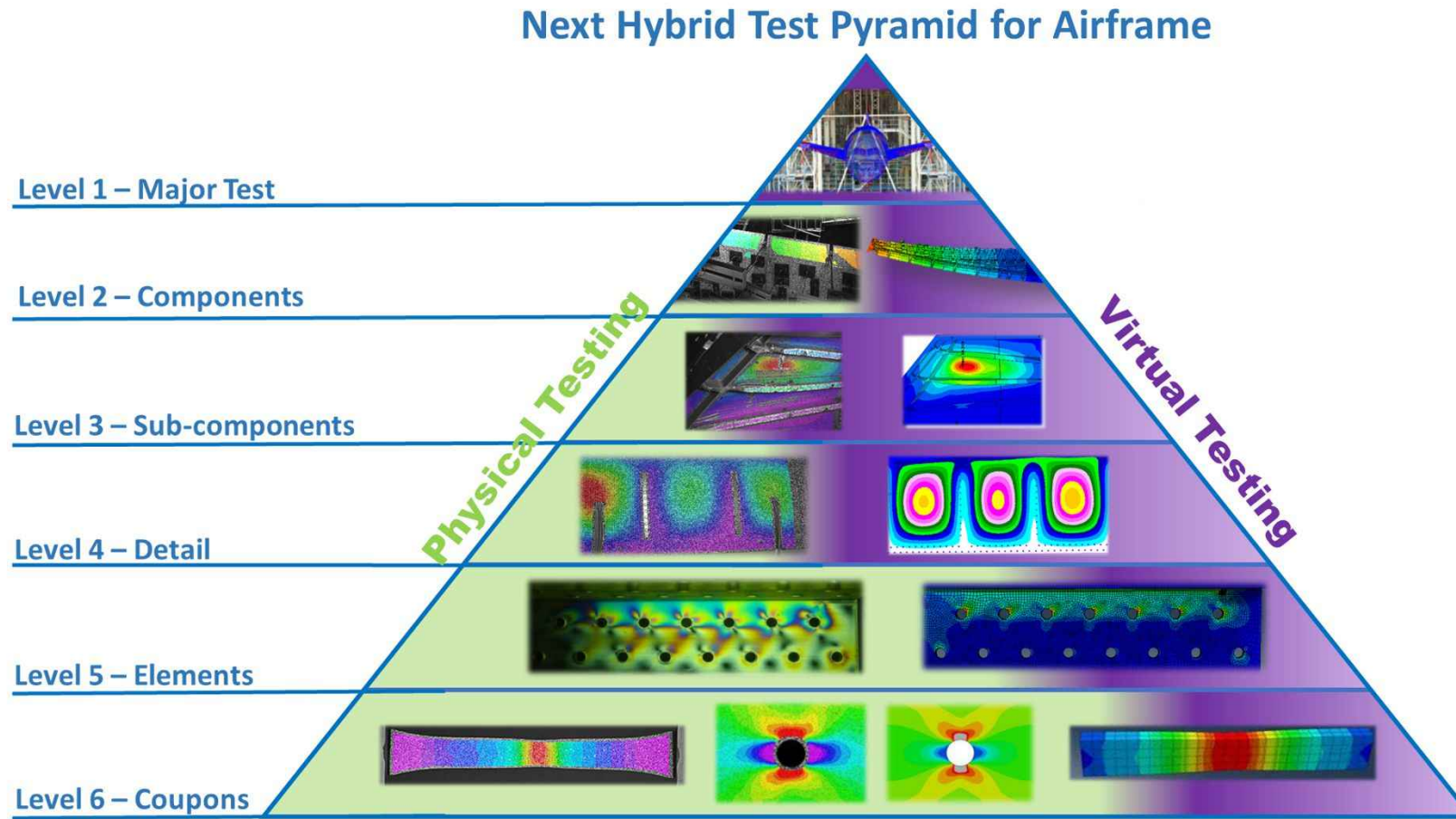


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0000020: 0000 7000 00 0000 0100 0300 0100  
0000030: 0400 0000 00 0000 1400 0100 0300  
0000040: 0000 7000 00 0000 0200 0000 0000  
0000050: 0800 0000 15 1305 7000 7800 0000  
0000060: 0000 7000 00 7000 0000 0400 0000  
0000070: 7000 0000 00 0000 0000 0000 0000  
0000080: 0000 0000 00 7000 7000 7800 0000  
0000090: 0000 0000 00 0000 0100 0000 0100  
0000100: 0000 0000 00 0000 0000 0000 7000  
0000110: 7000 0000 00 0000 0000 0000 0000  
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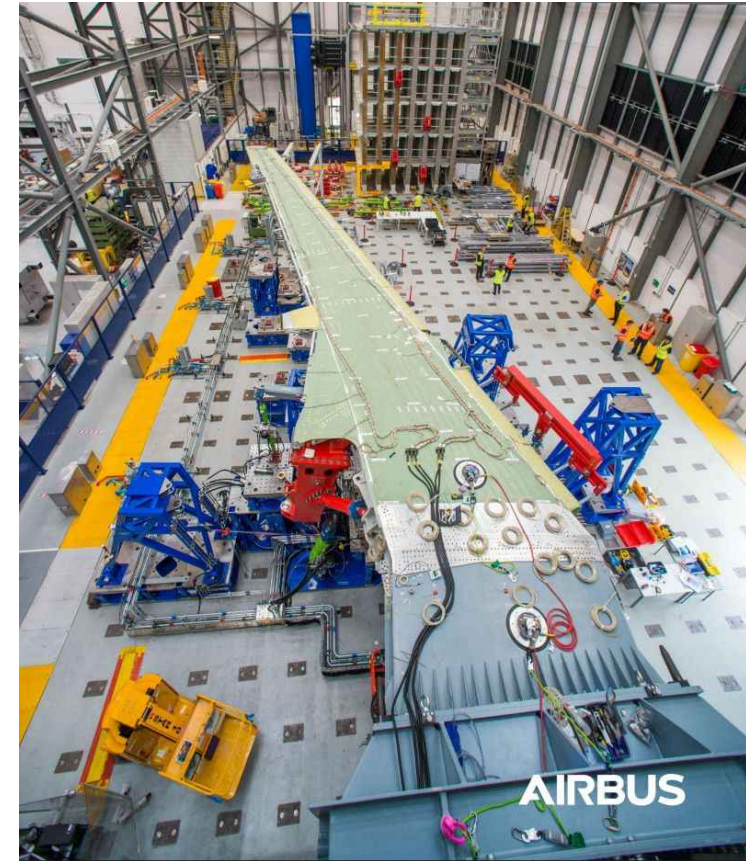
- Reduction of maintenance effort possible thanks to customization
- Operational monitoring airframe digital twins can be combined with other digital services
- Large-scale application require automation



Smarter Testing



Do we still need full scale fatigue testing ?

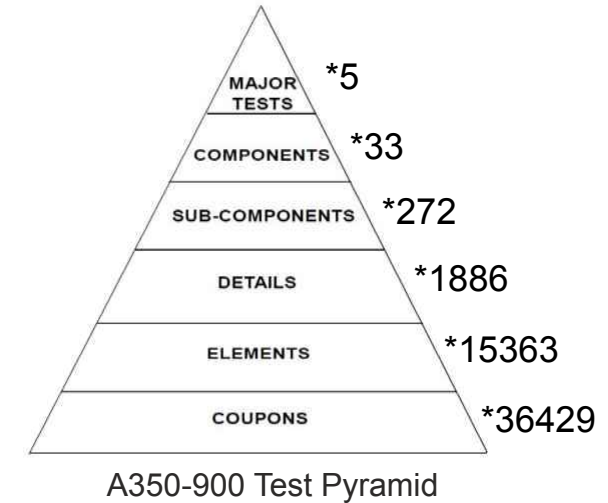


A321 Wing - Wing Fatigue Test

Current Testing Approach

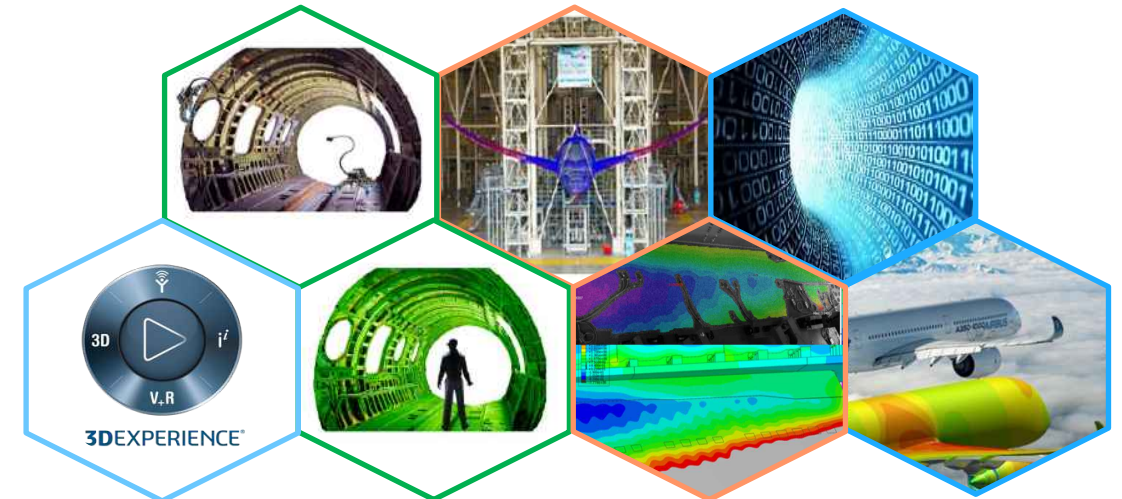
AS-IS today

- Extensive and expensive structural testing
- Structural certification requirements CS25
- Test validated stress methods and analysis processes
- Working in silos (physical-virtual-customers)
- No single point of access to data



Way forward

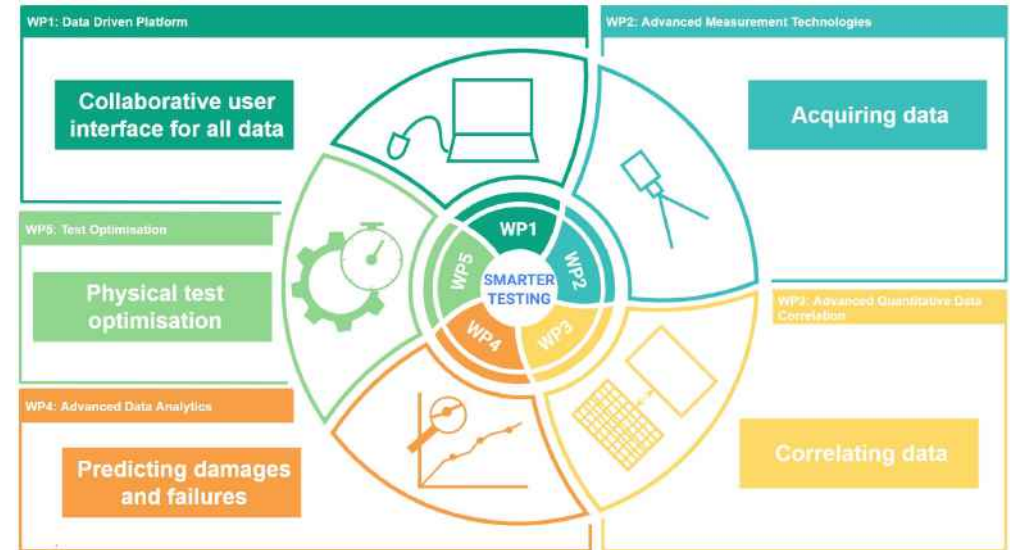
- Traditional testing pyramid approach needs to be optimized
- Radical rethinking of conventional certification processes
- New and novel ways of testing and data acquisition
- Integrate Virtual Testing and physical testing
- Exploit data analytics and design of experiments



Smarter Testing and Rapid EF

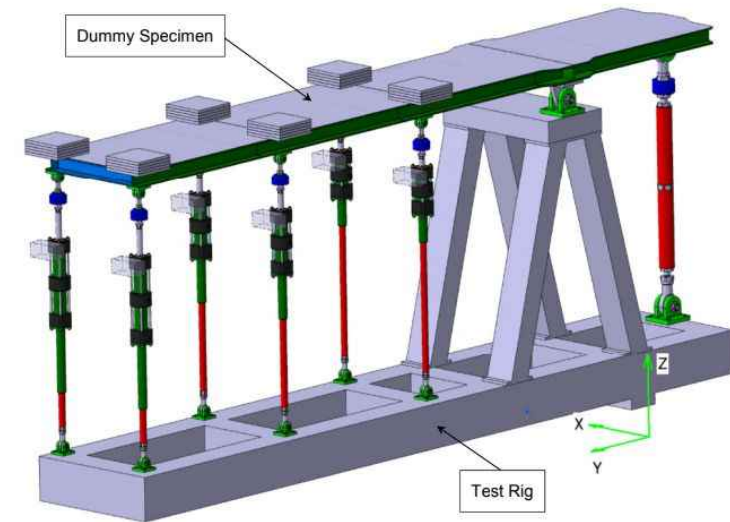
Smarter Testing (ATI funded)

- Data driven platform providing a single point of access to virtual and physical test data
- Physical Testing Solutions: measurement technologies, quantitative data correlation, analytics and test optimization



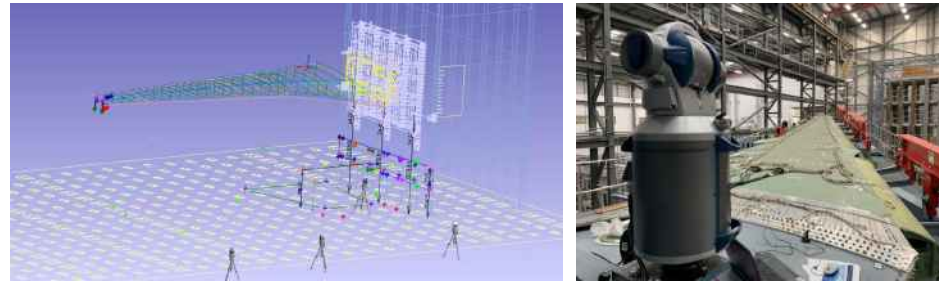
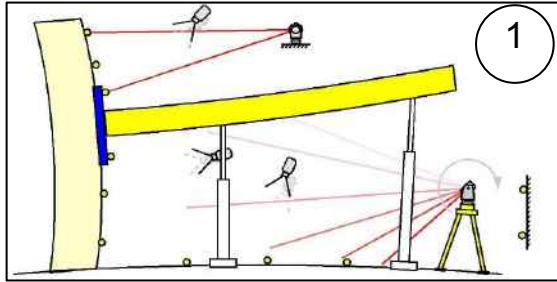
Rapid EF (Lufo funded)

- Loading technology demonstrator
- Virtual Sensors linked to Digital Test Twin
- Cycling in Resonance
- Damage prediction by AI

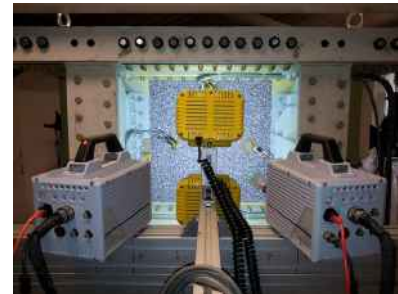
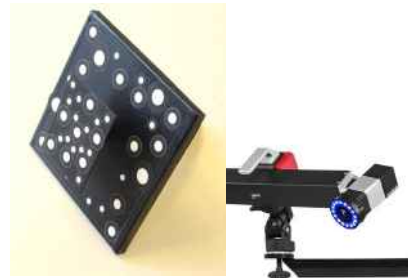
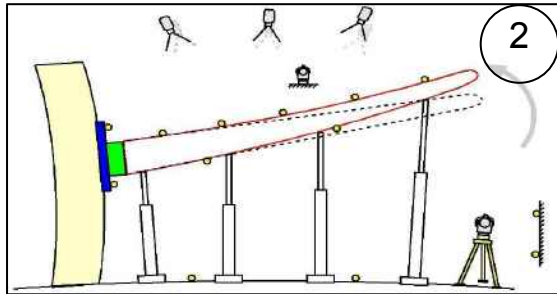


EF: essai fatigue - full scale atigue test

Data Acquisition Toolbox

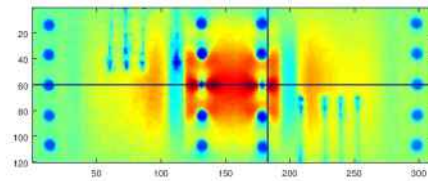
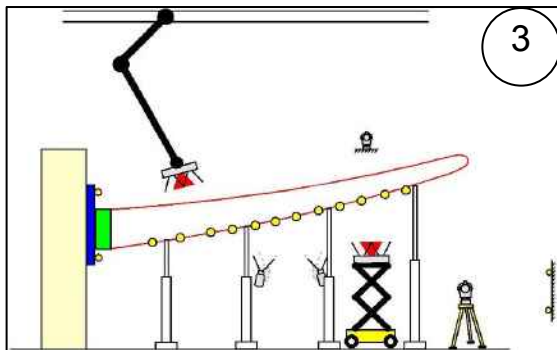


Laser Tracking



Photogrammetry

Digital Image Correlation



Thermal Stress Analysis

Photoelasticity

High Speed Cameras

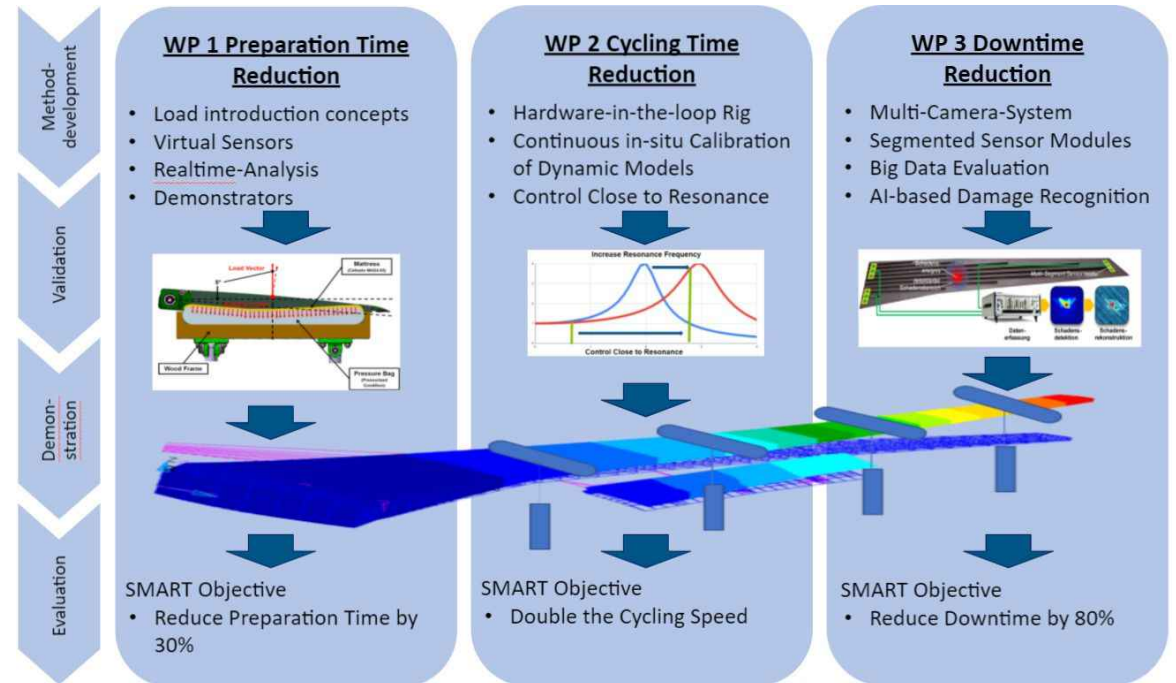
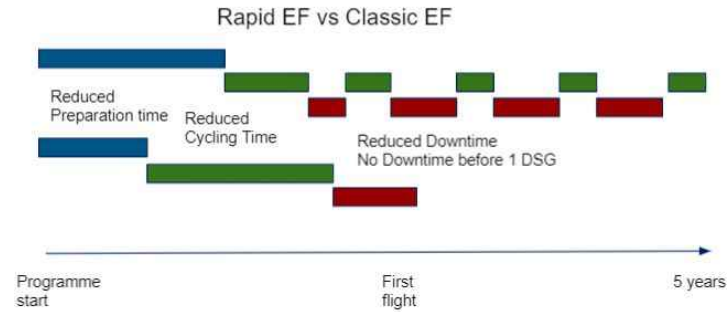
Rapid EF

Objectives

- Reduce testing time for complex fatigue tests by 50%
- Perform 1 DSG before first flight

Enablers:

- Reduced instrumentation
 - Virtual sensors coupled with digital twin
- Smart fast cycling close to the resonance frequency
 - Prediction of response function
- Automated inspection and evaluation



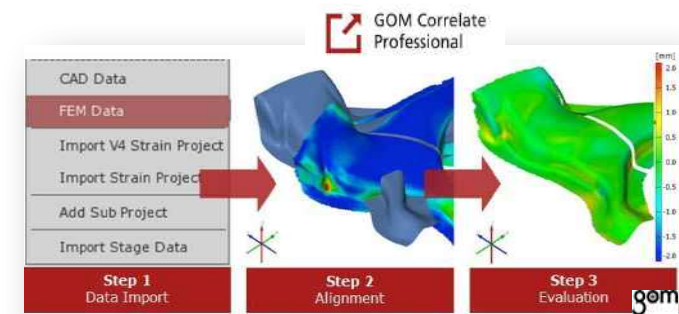
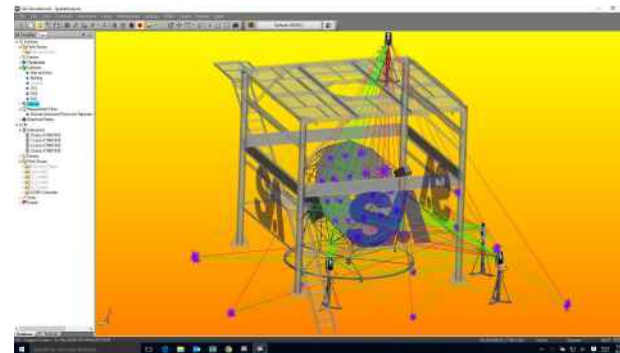
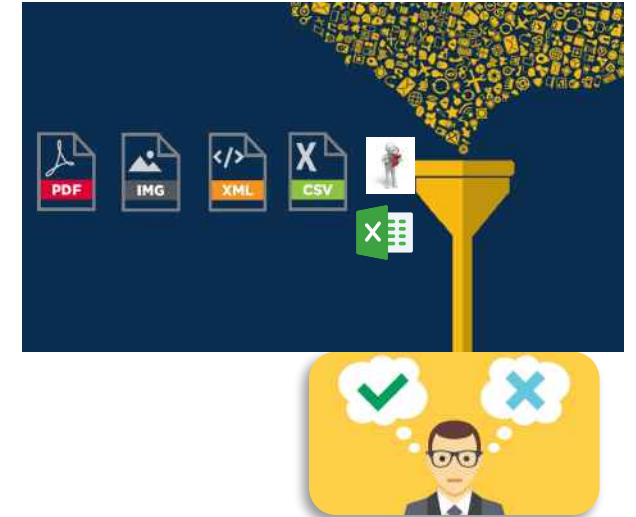
Advanced Quantitative Data Correlation

Automated quantitative data correlation methods and processes to be developed:

- To enable comparison between physical and virtual test data
- To see a real deterministic value of coherence and variance in a complex structure
- To reduce analysis times.

Main Challenges

- Data fusion
 - Data from multiple systems
 - Different native tools
 - Coordinate systems alignment
 - Spacial/temporal differences
- Uncertainty quantification
- Decision making
-and many more



Leading the way in the decarbonisation of aviation

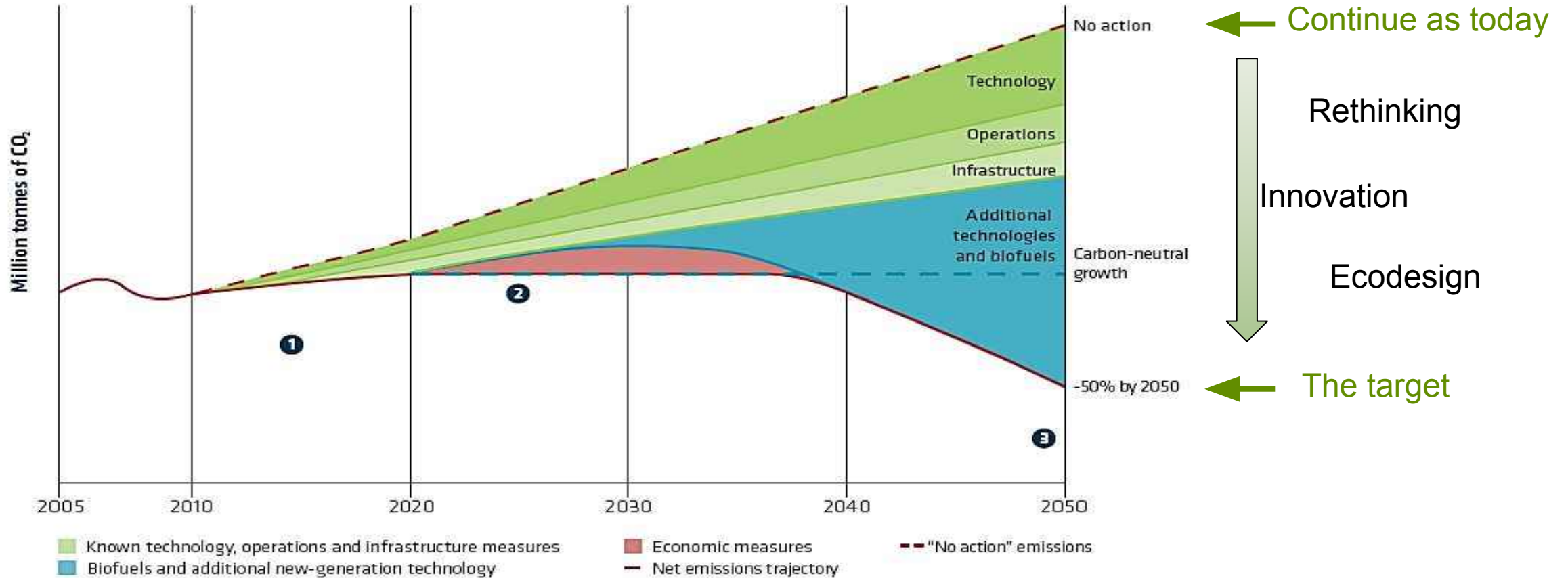


Ambition to be the first to offer a zero-emission commercial aircraft by 2035

ZEROe concept aircraft powered by hydrogen

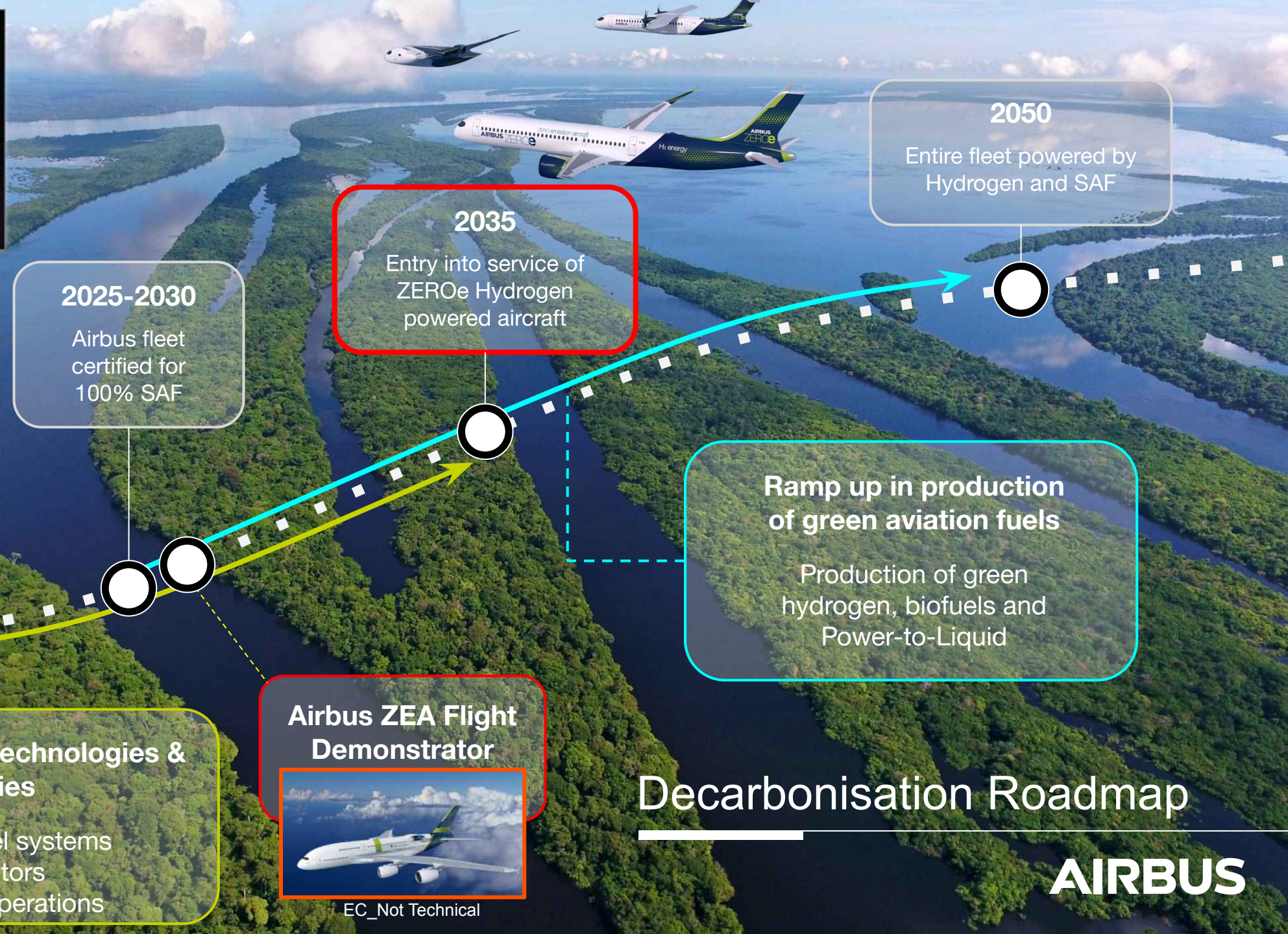
The Aviation Sector Commitments – CO₂ Emissions

Emissions reduction roadmap (schematic, indicative diagram)



In October 2016, The International Air Transport Association (IATA) reaffirms commitments to reducing emission..

A350 emissions measurement with 100% SAF



Today
All Airbus aircraft fuelled with Jet A1
SAF approved up to 50% blends

2025-2030
Airbus fleet certified for 100% SAF

2035
Entry into service of ZEROe Hydrogen powered aircraft

2050
Entire fleet powered by Hydrogen and SAF

Ramp up in production of green aviation fuels
Production of green hydrogen, biofuels and Power-to-Liquid

Development of H2 technologies & Capabilities
LH2 tank and fuel systems
Electric motors
Refuel ground operations

Airbus ZEA Flight Demonstrator



EC_Not Technical

Decarbonisation Roadmap





Why hydrogen?



Zero emission: H₂ emits no CO₂* & has the potential to reduce non-CO₂ emissions (i.e. NOx) & persistent contrails (*if generated from renewables via electrolysis)



Declining costs: the cost of producing H₂ is likely to decline over the next decade, which will make zero-emission flying increasingly economical



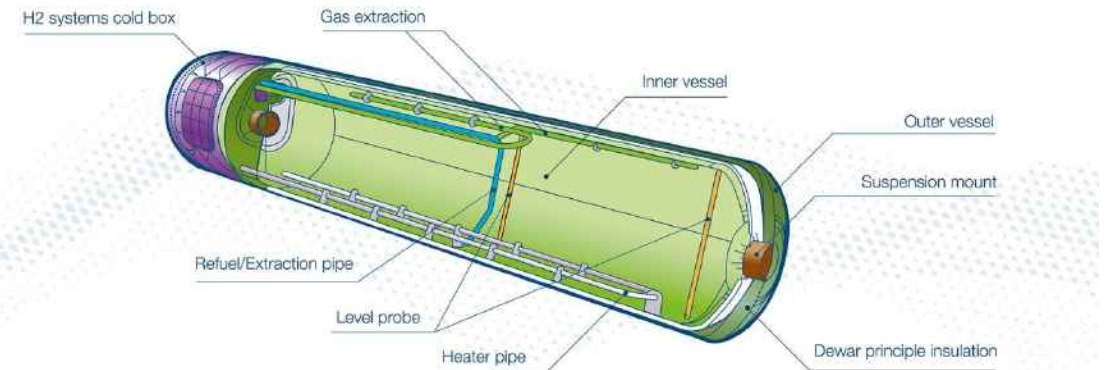
Energy dense: H₂ is 3X lighter than jet fuel but has a lower volumetric density, thereby requiring a different storage solution on aircraft

Physical Based H₂ Storage - How to store liquid hydrogen for zero-emission flight

Source : <https://www.airbus.com/en/newsroom/news/2021-12-how-to-store-liquid-hydrogen-for-zero-emission-flight>



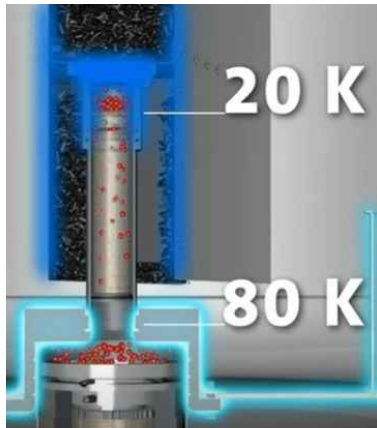
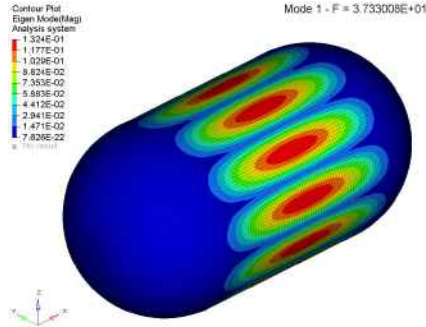
Liquid H₂ tank



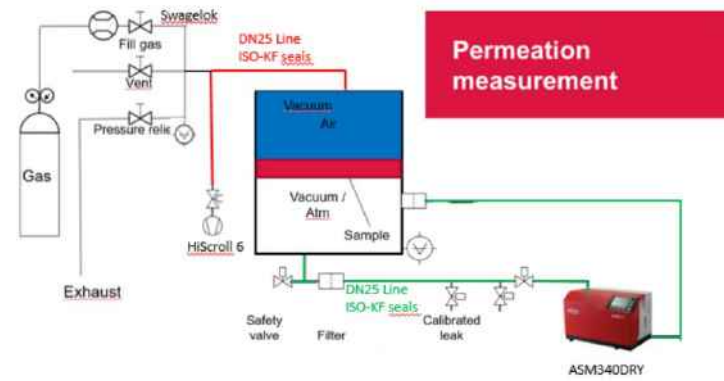
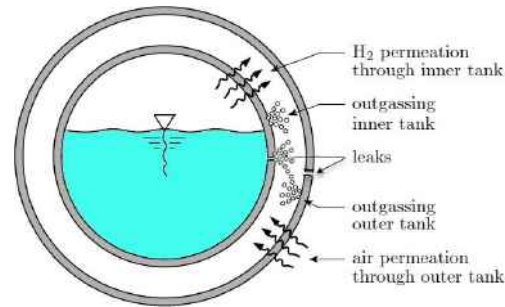
- ❑ **Storing hydrogen** on-board an aircraft poses several **challenges**
- ❑ Airbus is now designing cutting-edge liquid hydrogen tanks to facilitate a new era of sustainable aviation
- ❑ **Inner and outer tank with a vacuum in between**, and a specific material, such as a MLI (Multi-Layer Insulation)

ZeroE Testing Capability Development

Stress & Design



Permeation



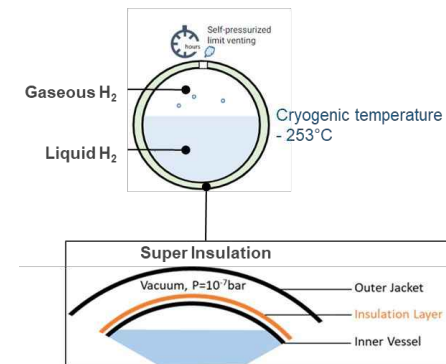
Embrittlement: low Temp and H

Thermal Cycling of Dissimilar Materials

Moveable Parts in Cryo-Conditions

Thermal Insulation and Outgassing

.....and some more



Smarter Coupon Testing....an idea

Reduction of test volume by using sub-sized specimens in combination with simulation and AI

Some examples

- Static properties
 - Small Punch Test
 - Profilometry-based indentation plastometry
- Toughness
 - Chevron testing for K_{Ic}
 - Kahn Tear for R-Curve
- Fatigue
 - Cyclic plane testing
-and many more

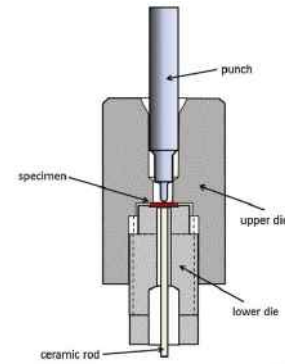
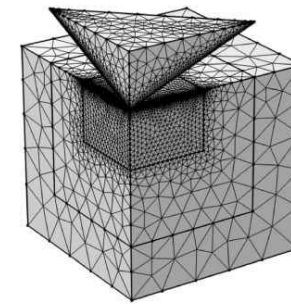
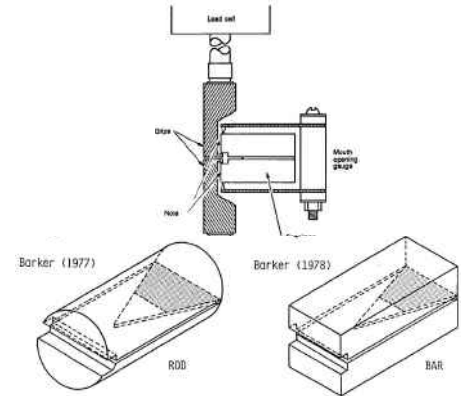


Fig. 1. A typical SP test setup. The basic dimensions are listed in Table 1.

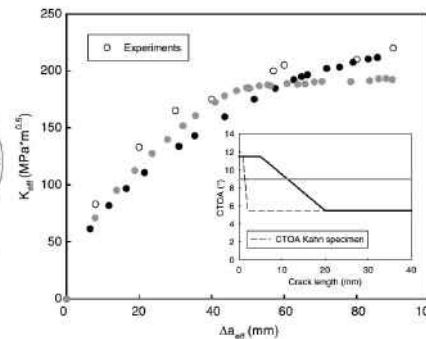
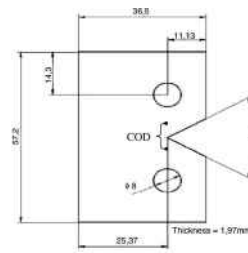
Bruchhausen et. al. (2016)



Ooi et al. (2023)



ASTM E1304, Newman (1984)



Pirondi et al. (2009)



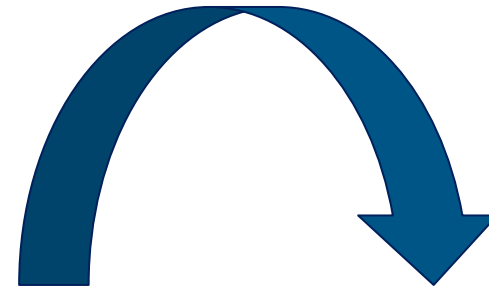
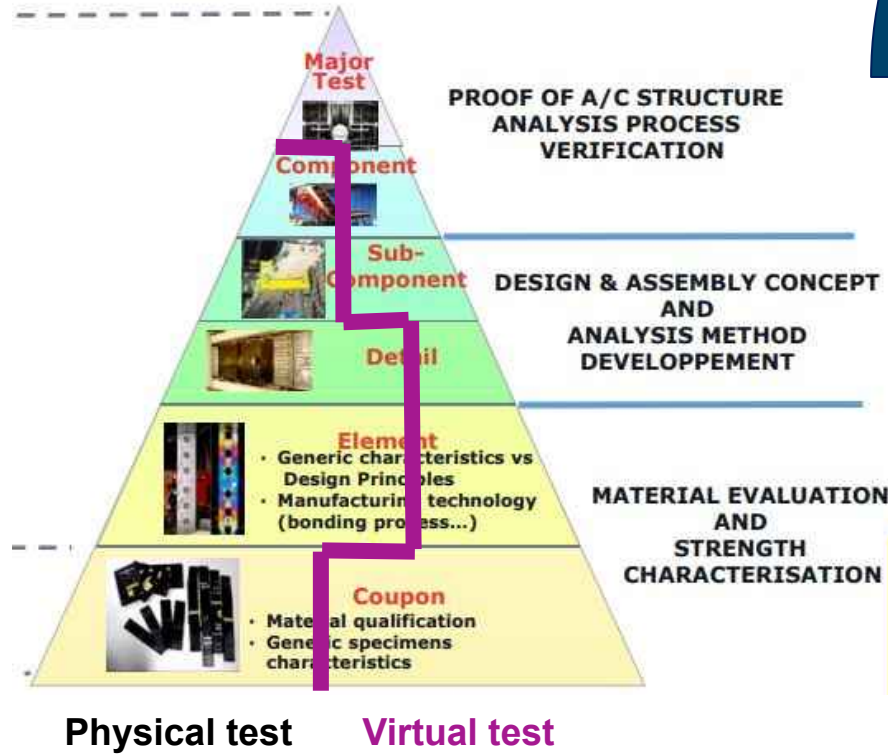
Fig. 2. Actual size (7 × 5 × 22 mm³) of a CTOD resistance fatigue specimen.



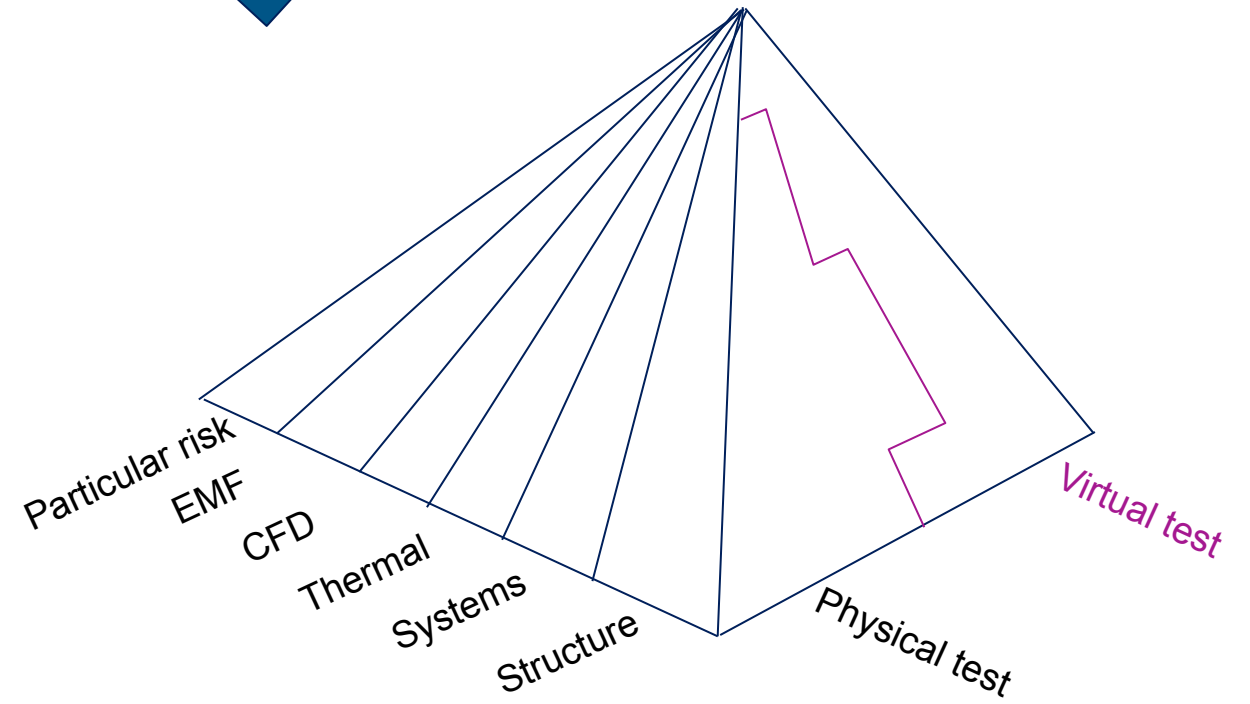
Nicoletto (2017)

Top level planning - test pyramid

Structure test pyramid ~~triangle~~



“True” pyramid.....



Wrap Up

- Get Material's Data Right - accelerated testing
- The Power of Data
- Smarter Testing
- Testing for ZeroE

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Thank you

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