The assessment of Smarter Testing for credibility and maturity

Why is it so important?

Linden Harris
Expert for Test, Airbus SAS.
Nov 2019

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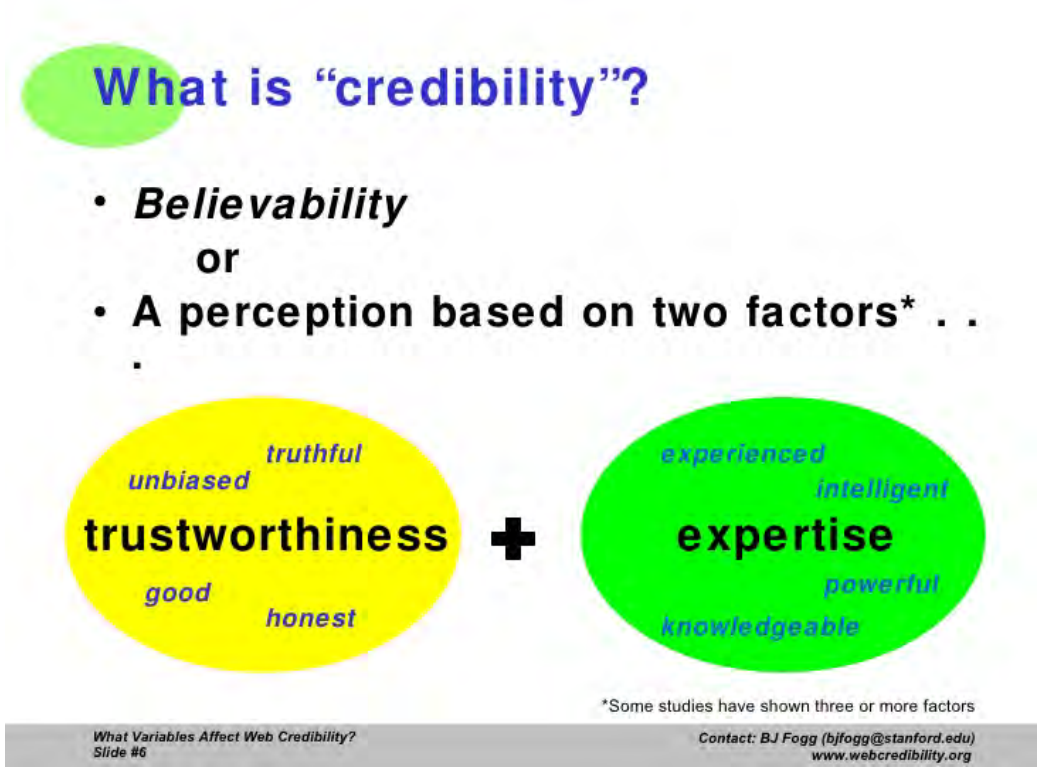
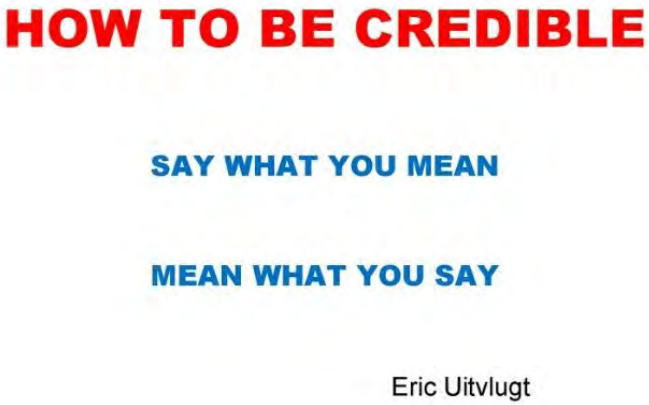
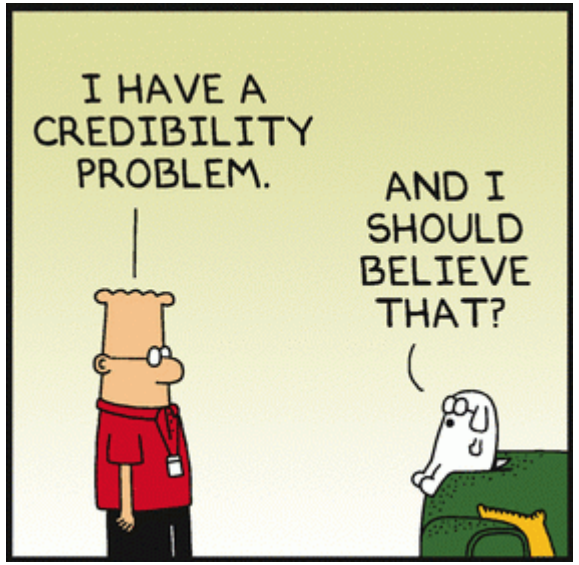
What is Credibility?







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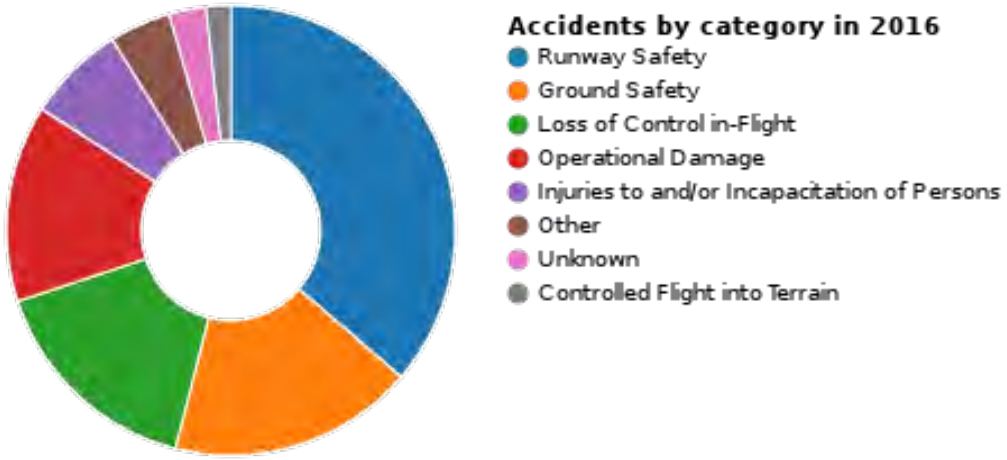
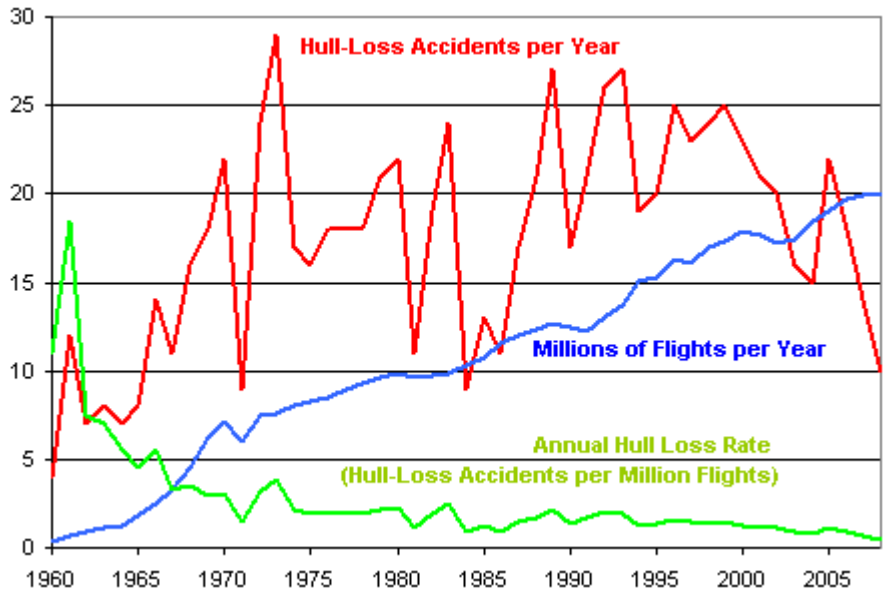
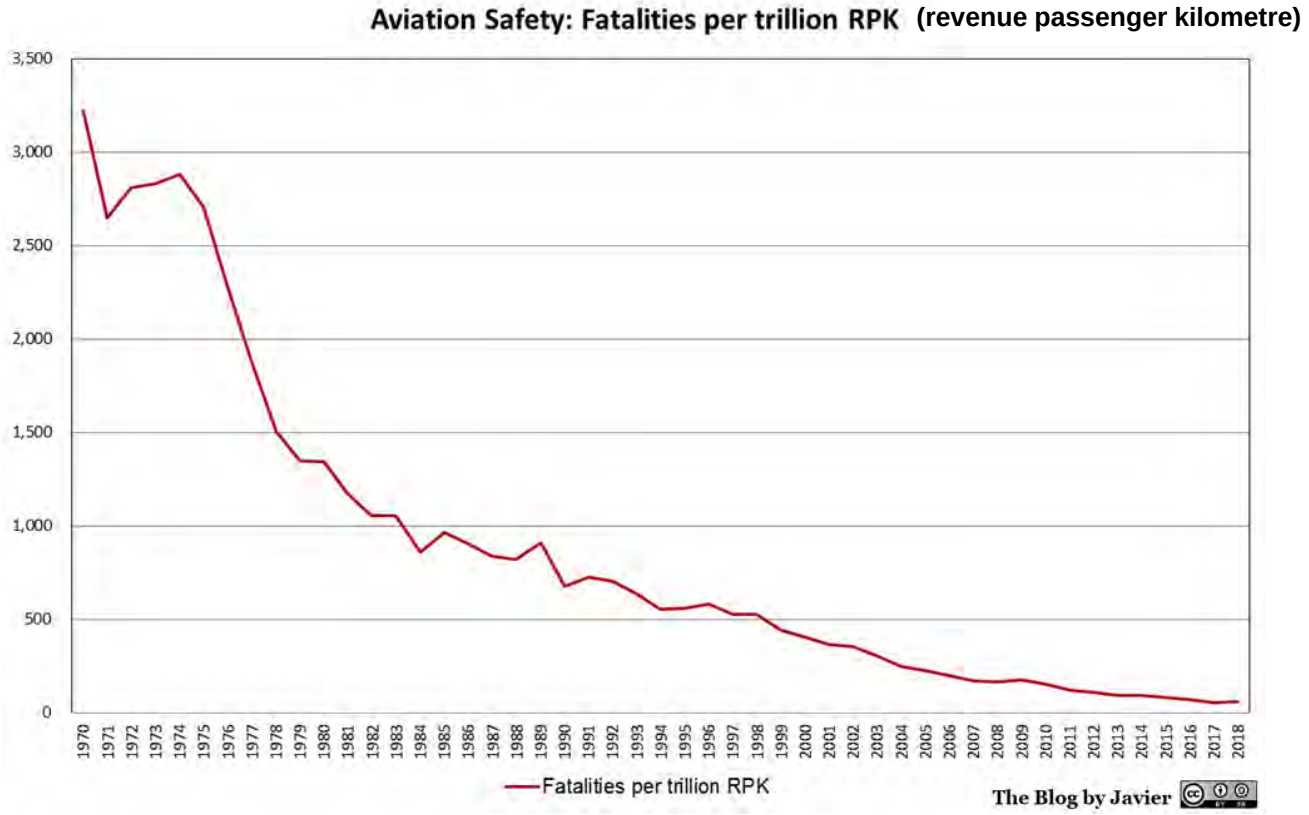
Why is Credibility Important for the Airbus and the Aircraft Industry?







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Airworthiness Assurance through Certification

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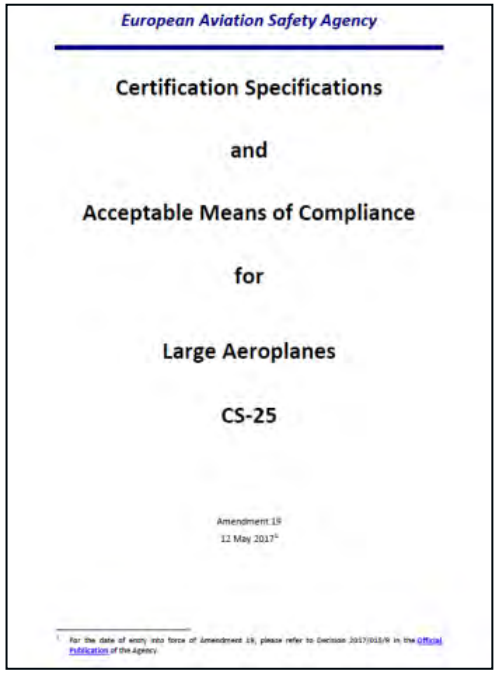
Relevant Certification Requirements for Modelling


European Aviation Safety Agency

Certification Specifications

and

Acceptable Means of Compliance

for

Large Aeroplanes

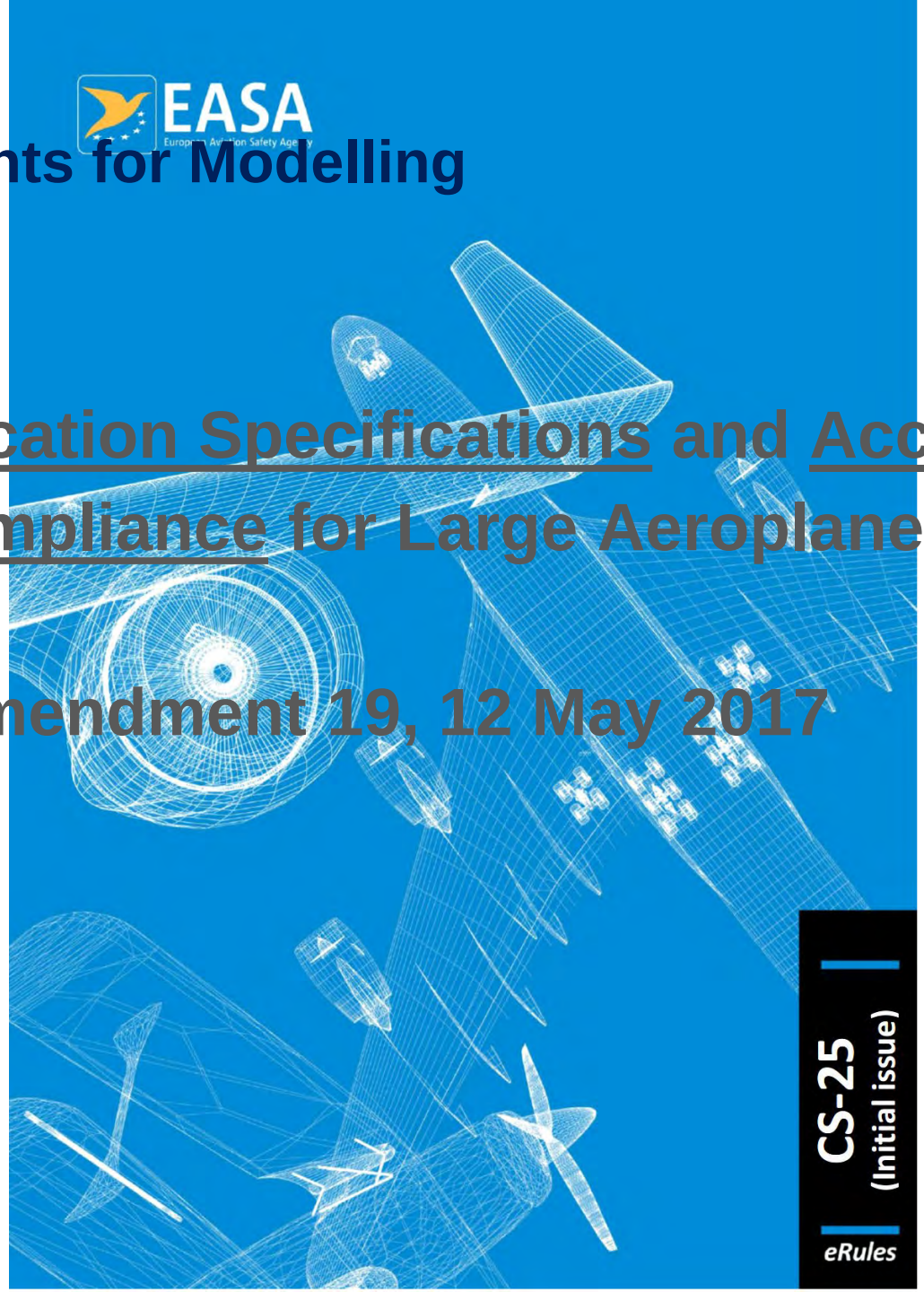
CS-25

Amendment 19
12 May 2017[1]

[1] For the date of entry into force of Amendment 19, please refer to Decision 2017/013/R in the Official Publication of the Agency.

EASA Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes CS-25

Amendment 19, 12 May 2017



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Relevant Certification Requirements

CS25-305(a) & (b)

CS 25.305 Strength and deformation

(a) The structure must be able to support limit loads without detrimental permanent deformation. At any load up to limit loads, the deformation may not interfere with safe operation.

(b) The structure must be able to support ultimate loads without failure for at least 3 seconds. However, when proof of strength is shown by dynamic tests simulating actual load conditions, the 3-second limit does not apply. Static tests conducted to ultimate load must include the ultimate deflections and ultimate deformation induced by the loading. When analytical methods are used to show compliance with the ultimate load strength requirements, it must be shown that –

(1) The effects of deformation are not significant;

(2) The deformations involved are fully accounted for in the analysis; or

(3) The methods and assumptions used are sufficient to cover the effects of these deformations.

The Model must predict limit load deformations and ultimate load failures.

Relevant Certification Requirements

AMC-307

AMC 25.307 Proof of structure

This AMC establishes methods of compliance with CS 25.307, which specifies the requirements for Proof of Structure.

It includes:

- **Definitions of Details, Sub Components, Full Scale, etc.**
- **Classifications of Structure – New, Similar New and Derivative/Similar**
- **Descriptions of Four Certification Approaches:**
  - (a) *Analysis, supported by new strength testing of the structure to limit and ultimate load.* This is typically the case for New Structure…
  - (b) *Analysis validated by previous test evidence and supported with additional limited testing*. This is typically the case for Similar New Structure…
  - (c) *Analysis, supported by previous test evidence .* This is typically the case for Derivative/ Similar Structure…
  - (d) *Test only*…
- **Comments with respect to the 'Need and Extent of Testing' and the need for methods such as FEM to be validated by full scale tests – SEE OVER: …**
- **A paragraph on 'INTERPRETATION OF DATA' to the effect that discrepancies between Analysis and Test should be investigated and lead to adjustment in analysis/modelling techniques.**

New Structure. Structure for which behaviour is not adequately predicted by analysis supported by previous test evidence. Structure that uses significantly different structural design concepts such as details, geometry, structural arrangements, and load paths or materials from previously tested designs.

Relevant Certification Requirements

AMC-307

Pertinent Comments with respect to the 'Need and Extent of Testing' and the need for methods such as FEM to be validated by full scale tests: …

NEED FOR TESTING depends on 'classification of structure' and 'consequence of failure'

6. **NEED AND EXTENT OF TESTING**

"The following factors should be considered in deciding the need for and the extent of testing including the load levels to be achieved:

(a) The classification of the structure (as above);

(b) The consequence of failure of the structure in terms of the overall integrity of the aeroplane;

(c) The consequence of the failure of interior items of mass and the supporting structure to the safety of the occupants.

Relevant service experience may be included in this evaluation."

FEM is considered reliable only when validated by full scale tests

4. **INTRODUCTION**

…

"The application of methods such as Finite Element Method or engineering formulas to complex structures in modern aircraft is considered reliable only when validated by full scale tests (ground and/or flight tests). Experience relevant to the product in the utilisation of such methods should be considered."

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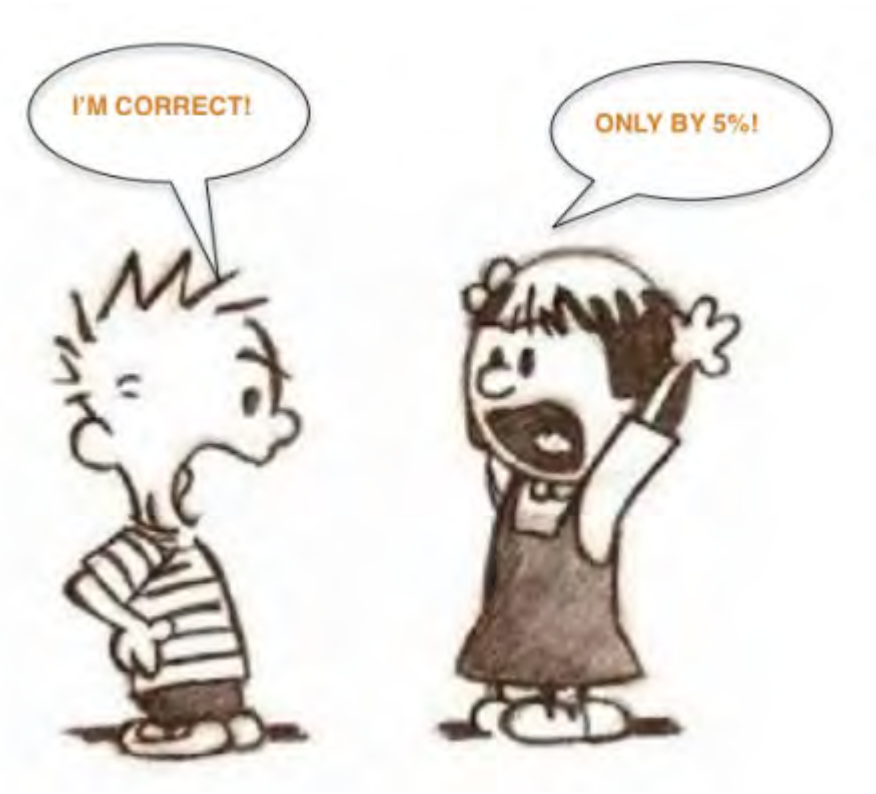
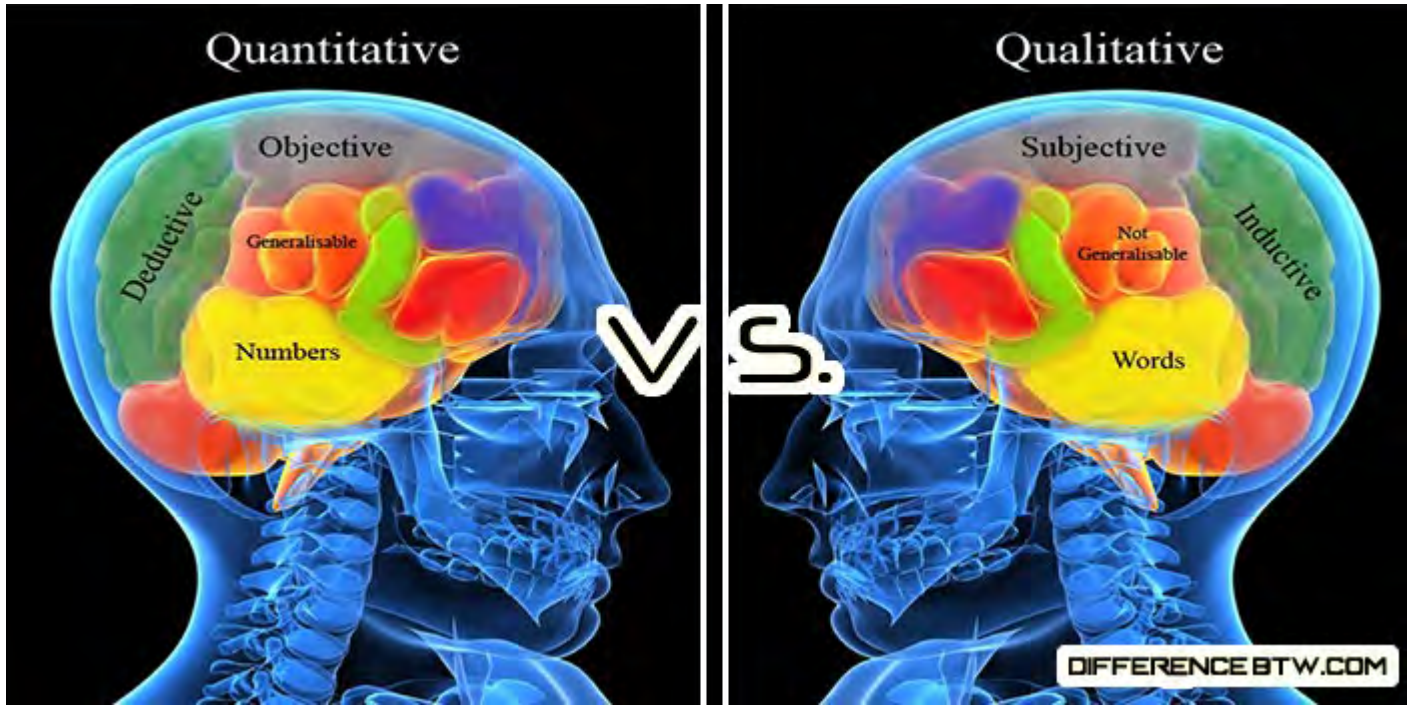
What models are there?
Quantitative v Qualititative





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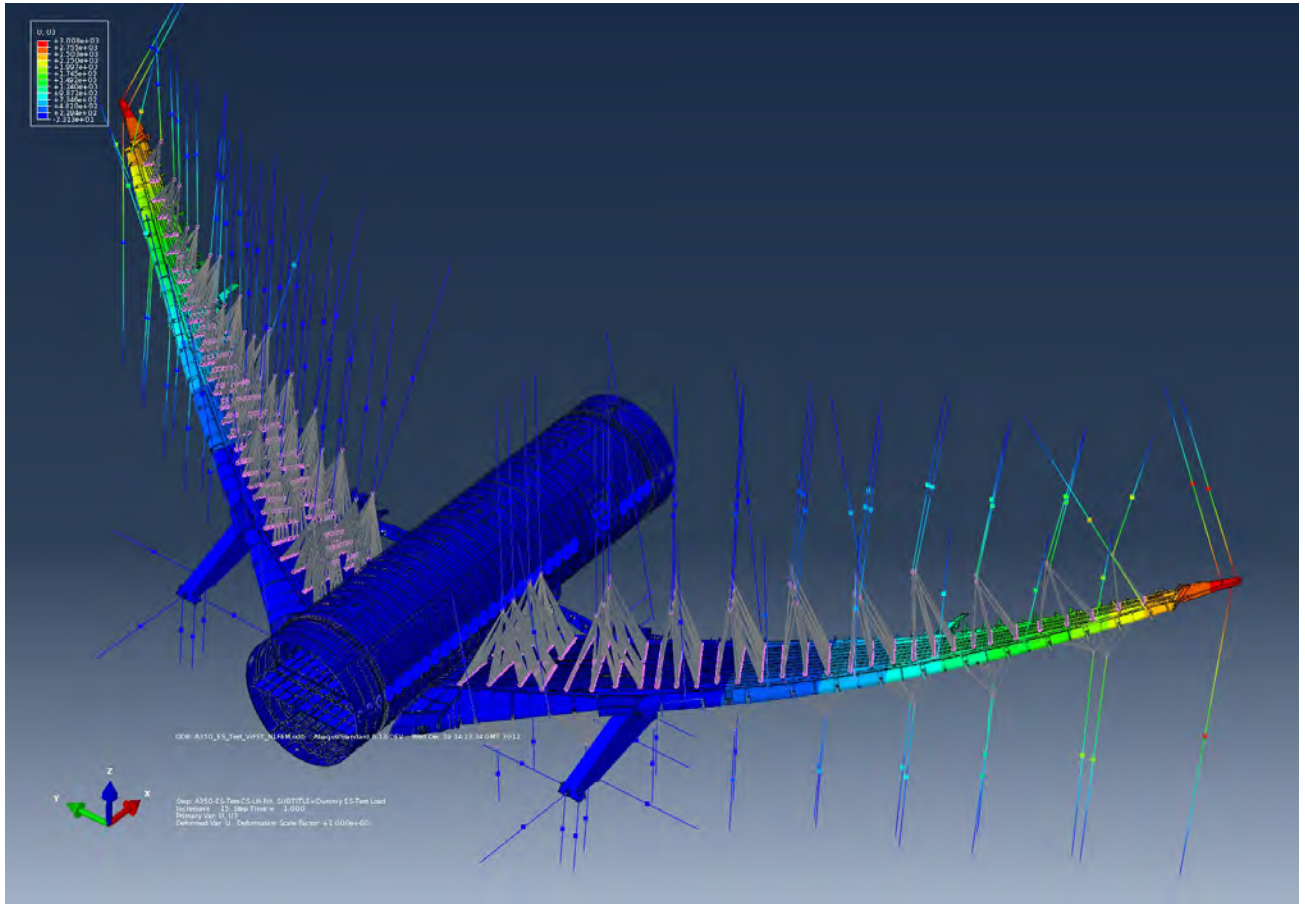
What models are there?

New Predictive



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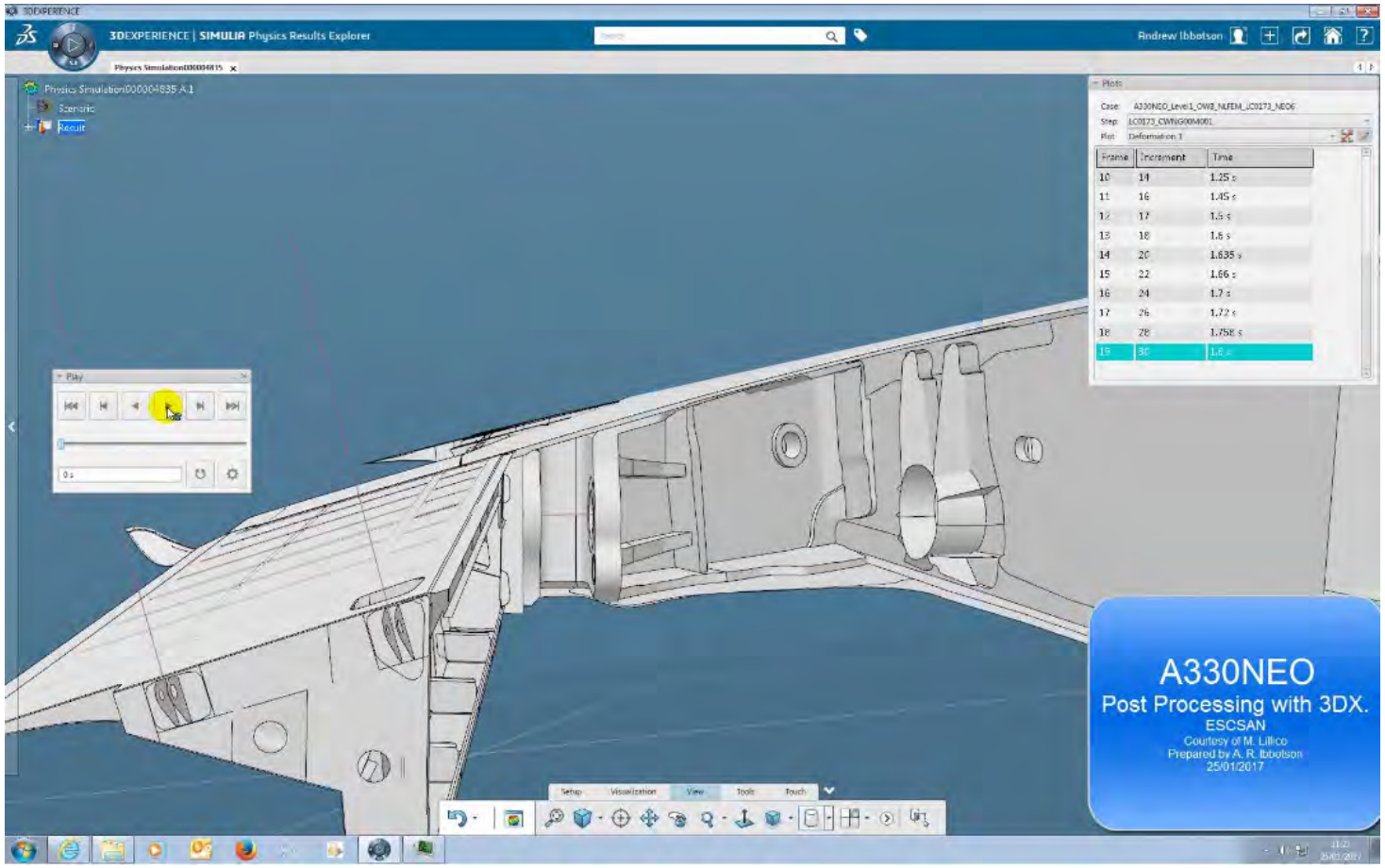
What models are there?

New Predictive



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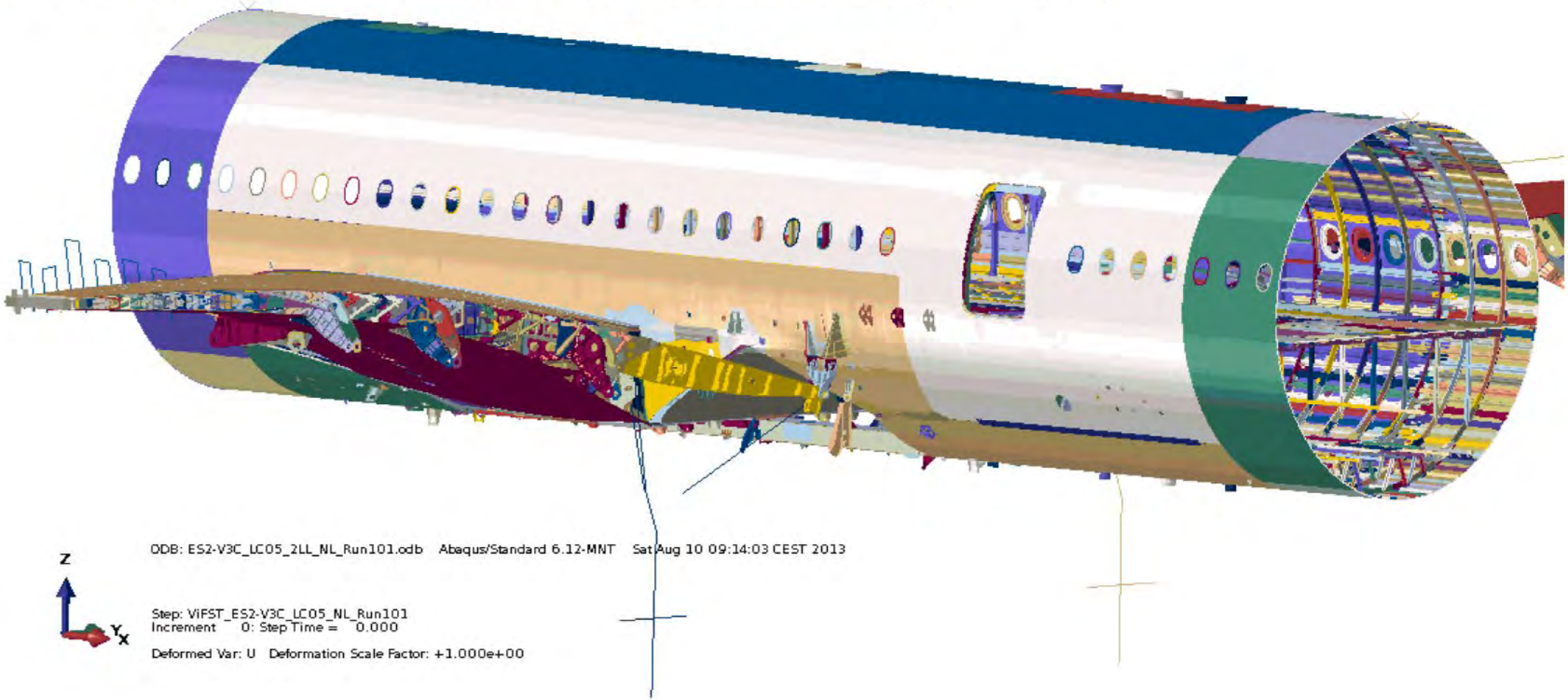
Predictive Models are large

CPU time per load case: from 12 hours up to 48h depending on level of non-linearity
(HPC with typically 500 CPUs / 3000 cores used for large models)



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Why are Decisions needed?

"For God's sake, just pick one! I'm nearly seventeen!"

"My job is to make decisions.
Your job is to make them good decisions."

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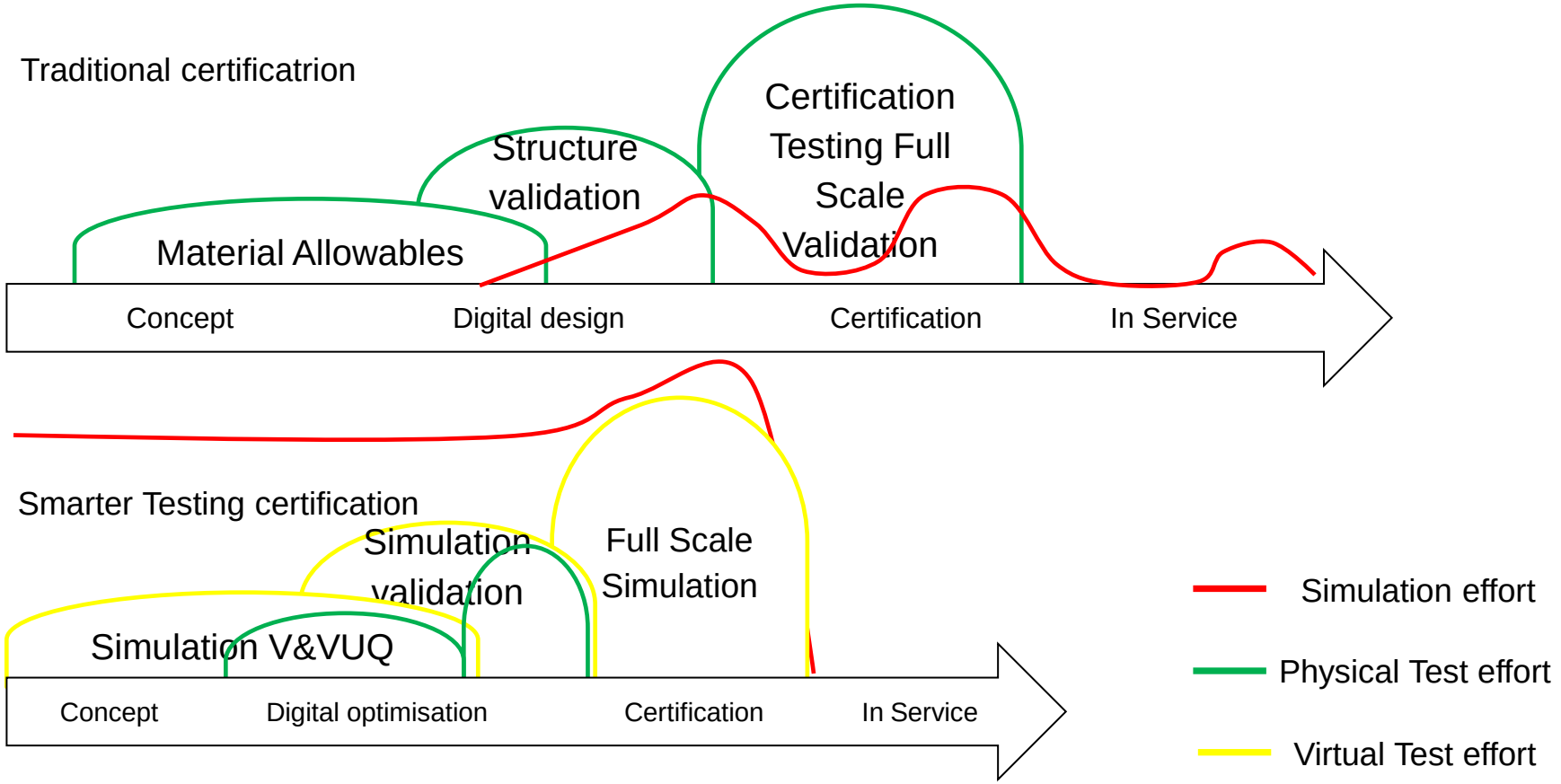
What Engineering Decisions are needed for Airbus?

Good decisions come from experience, and experience comes from bad decisions



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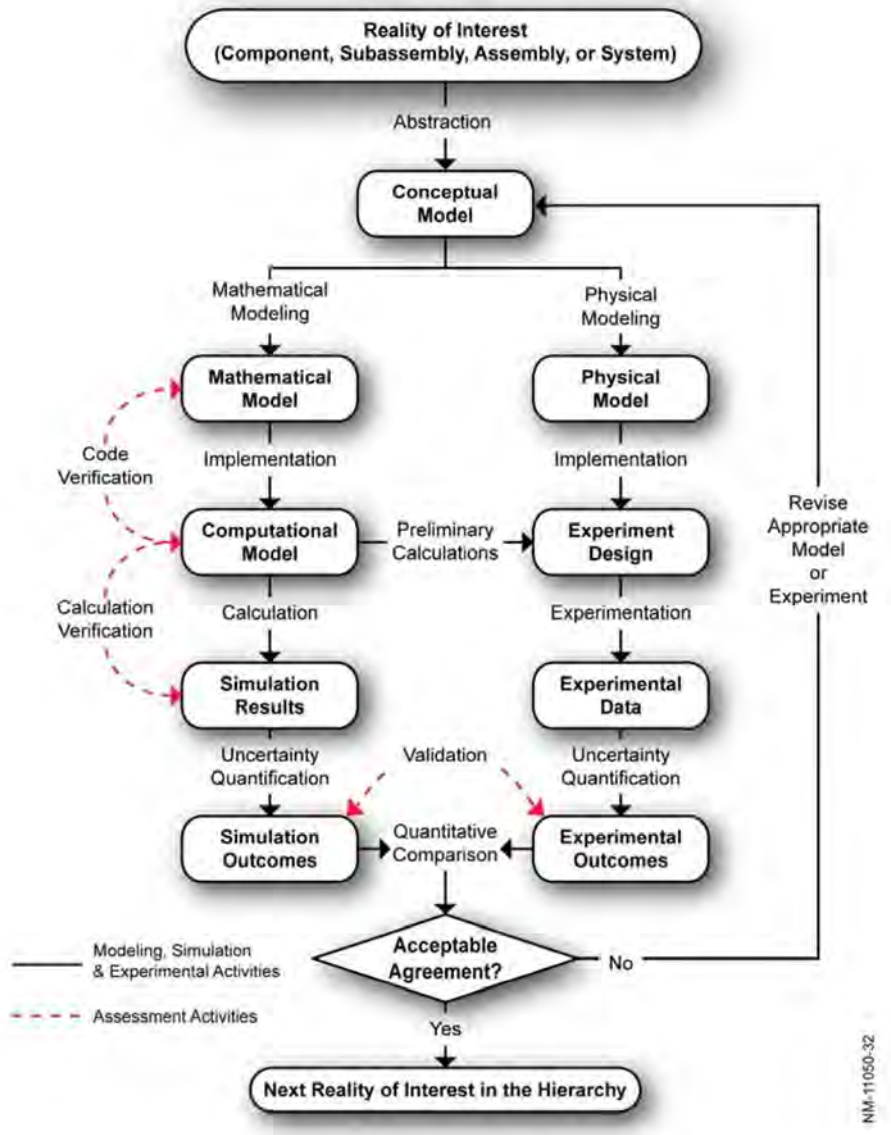
Quantification through V&V (ASME V&V 10)



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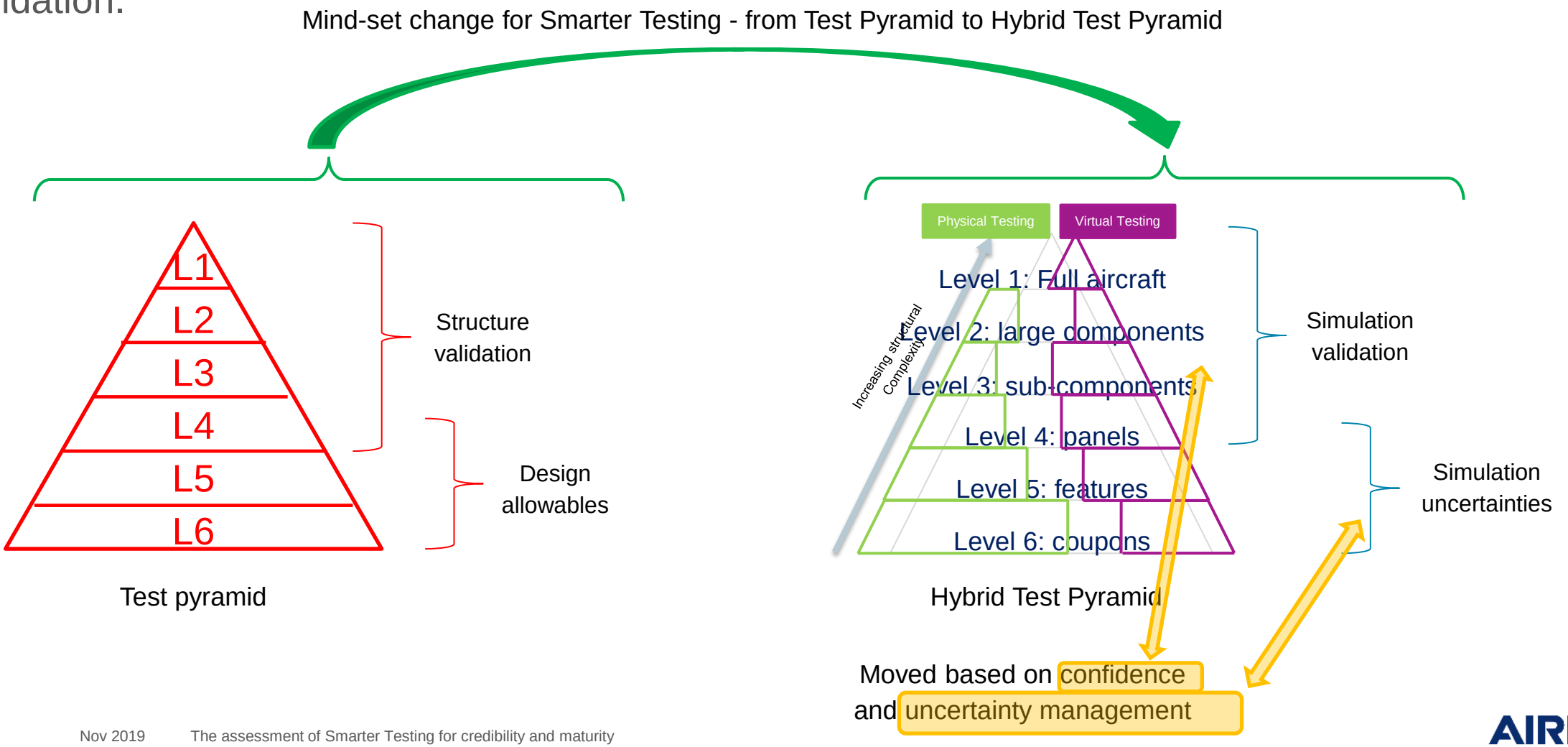
Mindset change needed for decision making

- Change from test pyramid to Hybrid Test pyramid i.e. from Structural validation to Simulation validation.



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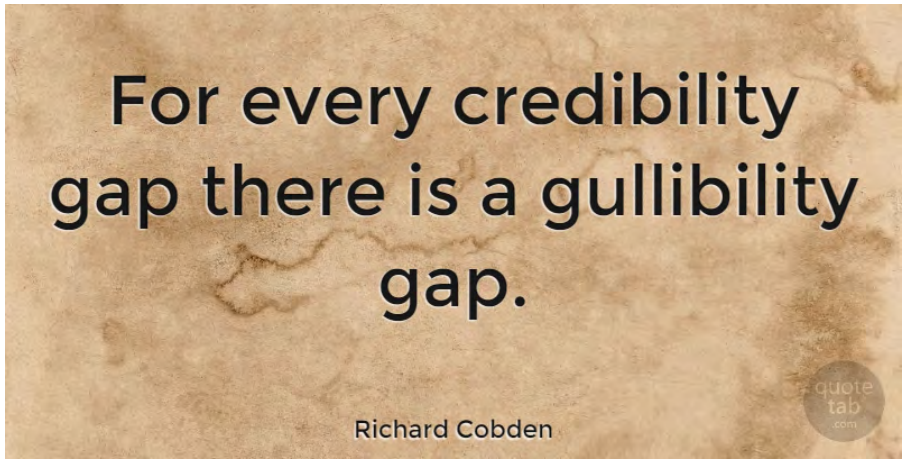
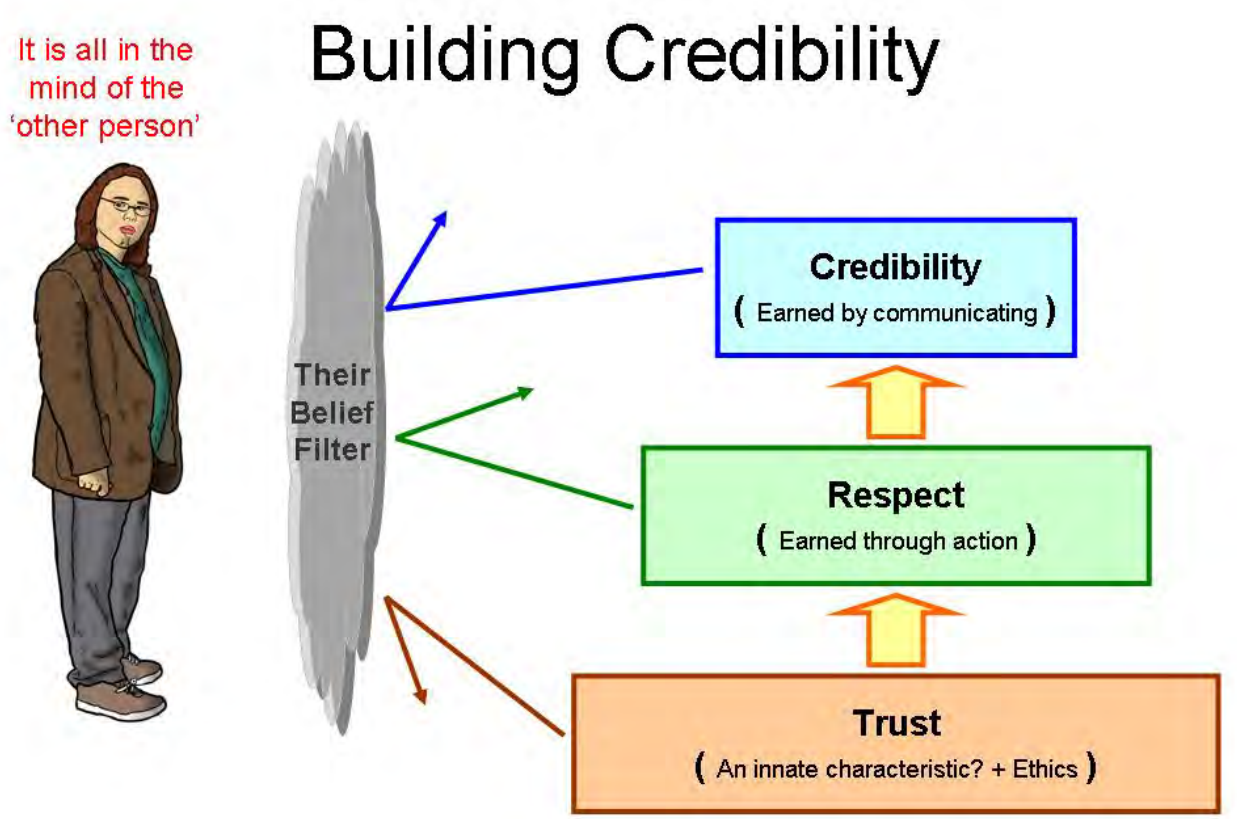
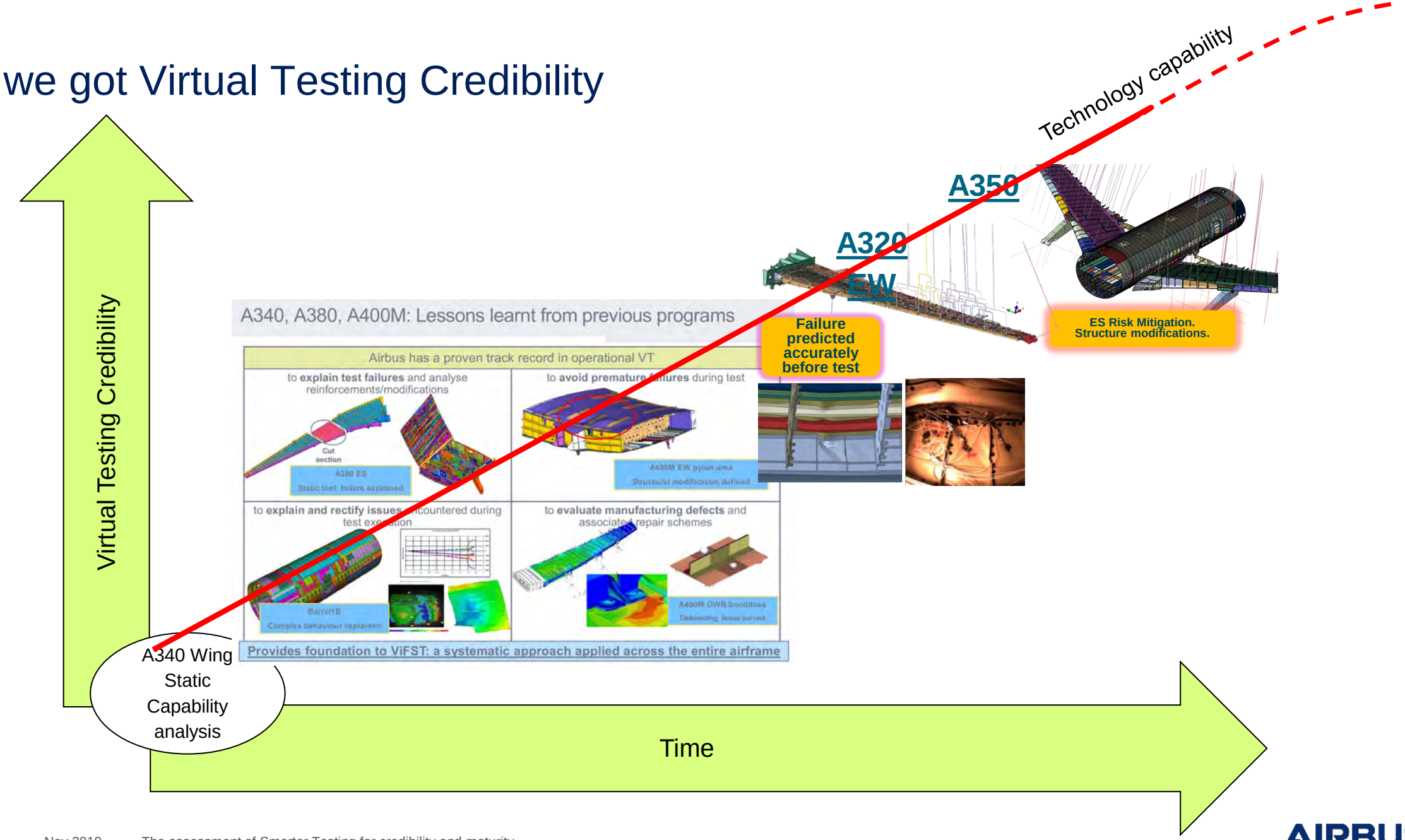
Why Quantify Credibility?





How we got Virtual Testing Credibility



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Credibility assurance History

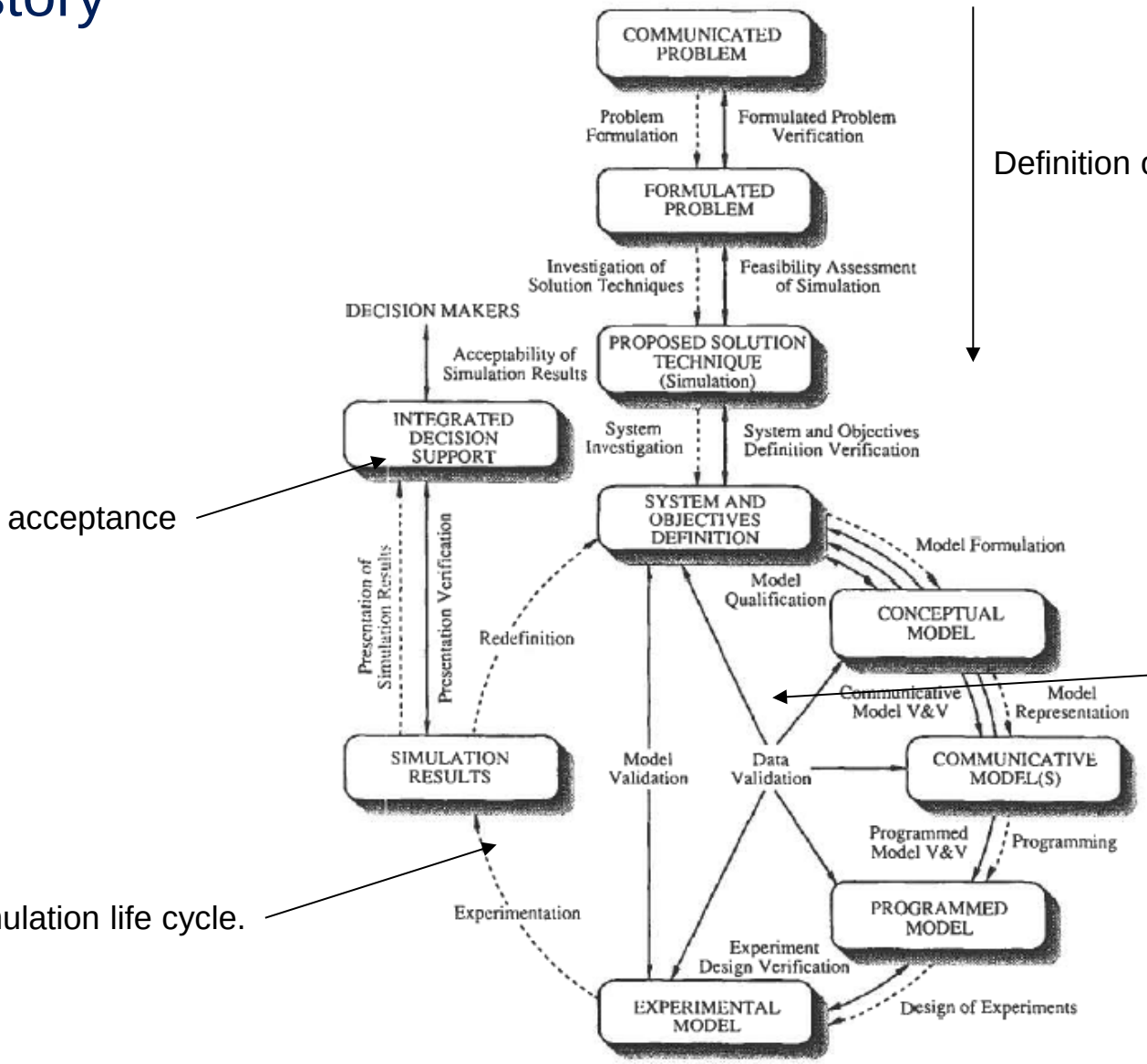

Figure 1: The Life Cycle of a Simulation Study

Definition of problem and solution

Results acceptance

V and V

Simulation life cycle.

Ref; 1989 Simulation conference; E MacNair, K Musselman, P Heidelberger

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Development of PCMM Methodology

First generation **Predictive Capability Maturity Model** (PCMM) circa 2007

MATURITY / ELEMENT	Maturity Level 0 Low Consequence, Minimal CS Impact, e.g. Scoping Studies	Maturity Level 1 Moderate Consequence, Some CS Impact, e.g. Design Support	Maturity Level 2 High-Consequence, High CS Impact, e.g. Qualification Support	Maturity Level 3 High-Consequence, Decision-Making Based on CS, e.g. Qualification or Certification
Representation and Geometric Fidelity What features are neglected because of simplifications or stylizations?	• Judgment only • Little or no representational or geometric fidelity for the system and BCs	• Significant simplification or stylization of the system and BCs • Geometry or representation of major components is defined	• Limited simplification or stylization of major components and BCs • Geometry or representation is well defined for major components and some minor components • Some peer review conducted	• Essentially no simplification or stylization of components in the system and BCs • Geometry or representation of all components is at the detail of "as built", e.g., gaps, material interfaces, fasteners • Independent peer review conducted
Physics and Material Model Fidelity How fundamental are the physics and material models and what is the level of model calibration?	• Judgment only • Model forms are either unknown or fully empirical • Few, if any, physics-informed models • No coupling of models	• Some models are physics based and are calibrated using data from related systems • Minimal or ad hoc coupling of models	• Physics-based models for all important processes • Significant calibration needed using separate effects tests (SETs) and integral effects tests (IETs) • One-way coupling of models • Some peer review conducted	• All models are physics based • Minimal need for calibration using SETs and IETs • Sound physical basis for extrapolation and coupling of models • Full, two-way coupling of models • Independent peer review conducted
Code Verification Are algorithm deficiencies, software errors, and poor SQE practices corrupting the simulation results?	• Judgment only • Minimal testing of any software elements • Little or no SQE procedures specified or followed	• Code is managed by SQE procedures • Unit and regression testing conducted • Some comparisons made with benchmarks	• Some algorithms are tested to determine the observed order of numerical convergence • Some features & capabilities (F&C) are tested with benchmark solutions • Some peer review conducted	• All important algorithms are tested to determine the observed order of numerical convergence • All important F&Cs are tested with rigorous benchmark solutions • Independent peer review conducted
Solution Verification Are numerical solution errors and human procedural errors corrupting the simulation results?	• Judgment only • Numerical errors have an unknown or large effect on simulation results	• Numerical effects on relevant SRQs are qualitatively estimated • Input/output (I/O) verified only by the analysts	• Numerical effects are quantitatively estimated to be small on some SRQs • I/O independently verified • Some peer review conducted	• Numerical effects are determined to be small on all important SRQs • Important simulations are independently reproduced • Independent peer review conducted
Model Validation How carefully is the accuracy of the simulation and experimental results assessed at various tiers in a validation hierarchy?	• Judgment only • Few, if any, comparisons with measurements from similar systems or applications	• Quantitative assessment of accuracy of SRQs not directly relevant to the application of interest • Large or unknown experimental uncertainties	• Quantitative assessment of predictive accuracy for some key SRQs from IETs and SETs • Experimental uncertainties are well characterized for most SETs, but poorly known for IETs • Some peer review conducted	• Quantitative assessment of predictive accuracy for all important SRQs from IETs and SETs at conditions/geometries directly relevant to the application • Experimental uncertainties are well characterized for all IETs and SETs • Independent peer review conducted
Uncertainty Quantification and Sensitivity Analysis How thoroughly are uncertainties and sensitivities characterized and propagated?	• Judgment only • Only deterministic analyses are conducted • Uncertainties and sensitivities are not addressed	• Aleatory and epistemic (A&E) uncertainties propagated, but without distinction • Informal sensitivity studies conducted • Many strong UQ/SA assumptions made	• A&E uncertainties segregated, propagated and identified in SRQs • Quantitative sensitivity analyses conducted for most parameters • Numerical propagation errors are estimated and their effect known • Some strong assumptions made • Some peer review conducted	• A&E uncertainties comprehensively treated and properly interpreted • Comprehensive sensitivity analyses conducted for parameters and models • Numerical propagation errors are demonstrated to be small • No significant UQ/SA assumptions made • Independent peer review conducted

From W.L.Oberkampf, M. Pilch, and T.G. Trucano, "Predictive Capability Maturity Model for Computational Modeling and Simulation," Sandia National Laboratories, SAND2007-5948.

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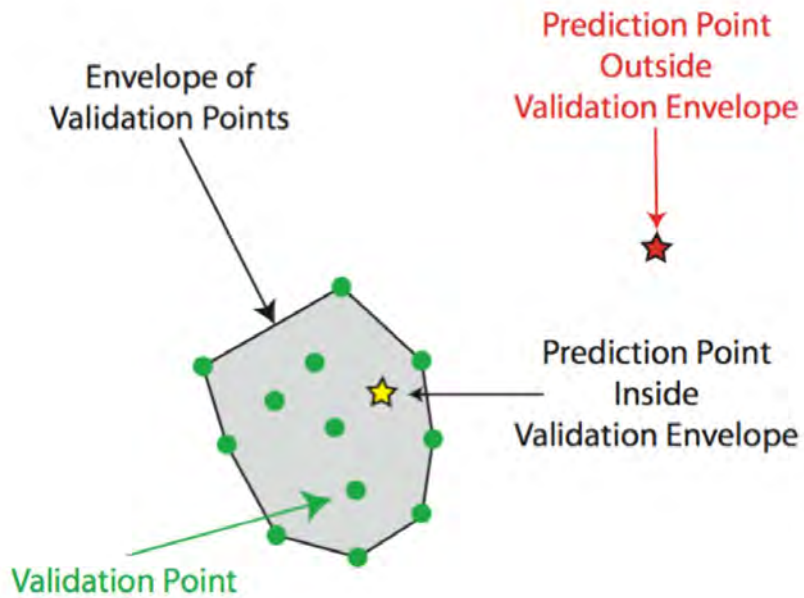
Towards a Credibility Assessment of Models and Simulations

Steve R. Blattnig,* Lawrence L. Green,† James M. Luckring,‡ Joseph H. Morrison,§ Ram K. Tripathi,** and Thomas A. Zang††
NASA Langley Research Center, Hampton, Virginia, 23681

A scale is presented to evaluate the rigor of modeling and simulation (M&S) practices for the purpose of supporting a credibility assessment of the M&S results. The scale distinguishes required and achieved levels of rigor for a set of M&S elements that contribute to credibility including both technical and process measures. The work has its origins in an interest within NASA to include a "Credibility Assessment Scale" in development of a NASA standard for models and simulations.



Category	Code Verification	Solution Verification	Validation	Prediction Uncertainty	Technical Review	Process Control	Operator & Analyst Qualifications
Level 4	Well defined and documented Software Quality Assurance (SQA) processes. Numerical algorithm test suite with significant coverage of required features and capabilities.	Rigorous numerical error bounds quantified for actual application. These error estimates are provided for all results that affect a critical decision.	Quantified validation has been performed with thorough determination of M&S uncertainty and experimental error. The system has been comprehensively validated.	Thorough determination of prediction uncertainty using non-deterministic approach. Prediction uncertainties for most of the results that affect a critical decision have been quantified.	Formal external peer review board. All results that affect a critical decision are reviewed.	Independently certified and audited processes.	Independent certification for the specific M&S activity. Extensive training and experience directly related to the M&S activity.
Level 3	Software and test cases maintained in configuration control system. Numerical algorithm test suite with moderate coverage of required features and capabilities.	Numerical errors estimated on actual application. These error estimates are provided for more than half of the results that affect a critical decision.	Quantified validation has been performed with estimates of M&S uncertainty and experimental error. Most aspects of the system have been validated.	Prediction uncertainties inferred from validation problems using non-deterministic approach. Prediction uncertainties for more than half of the results that affect a critical decision have been quantified.	Formal internal peer review. More than half of the results that affect a critical decision are reviewed.	Formally documented, internally monitored processes.	Extensive training and experience directly related to the M&S activity.
Level 2	Software version archived and results repeatable. Numerical algorithm test suite with sparse coverage of required features and capabilities.	Expert opinion based on numerical errors estimated for similar problems. These error estimates are provided for some results that affect a critical decision.	Quantified validation has been performed with estimates of experimental error. Few aspects of the system have been validated.	Prediction uncertainties inferred from validation problems based on expert opinion and deterministic estimates. Prediction uncertainties for some results that affect a critical decision have been quantified.	Informal subject matter expert review. Some results that affect a critical decision are reviewed.	Informally documented, self monitored processes.	Moderate training or experience directly related to the M&S activity.
Level 1	M&S results achieved with no or ad hoc code verification.	M&S results achieved with no or ad hoc solution verification.	M&S results achieved with no or ad hoc validation.	M&S results achieved with no or ad hoc estimate of prediction uncertainty.	M&S results achieved with no or ad hoc technical review.	M&S results achieved with no or minimal process control.	Minimal training and experience directly related to the M&S activity.

Table 1. Rigor level definitions

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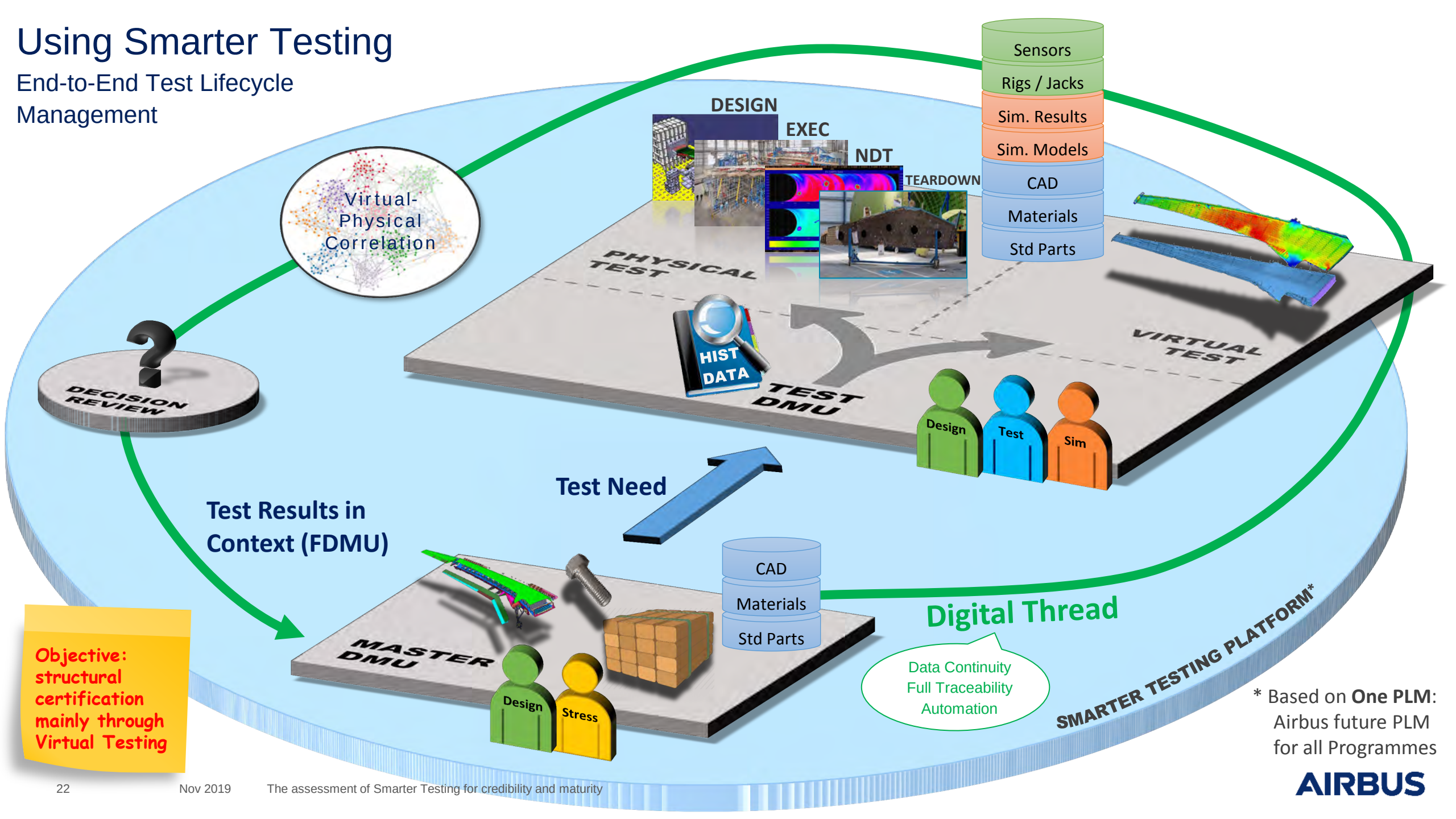
Using Smarter Testing

End-to-End Test Lifecycle Management



Objective: structural certification mainly through Virtual Testing

* Based on **One PLM**: Airbus future PLM for all Programmes

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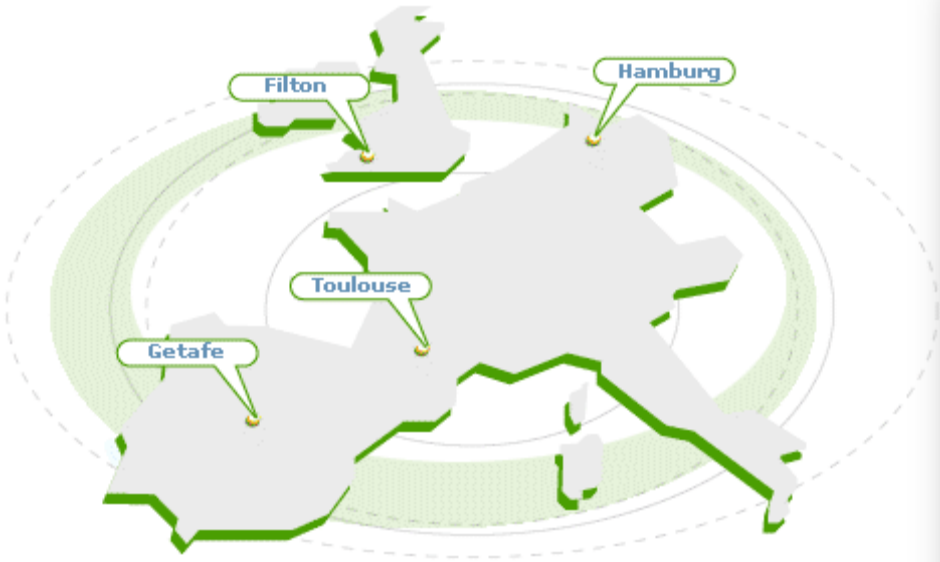
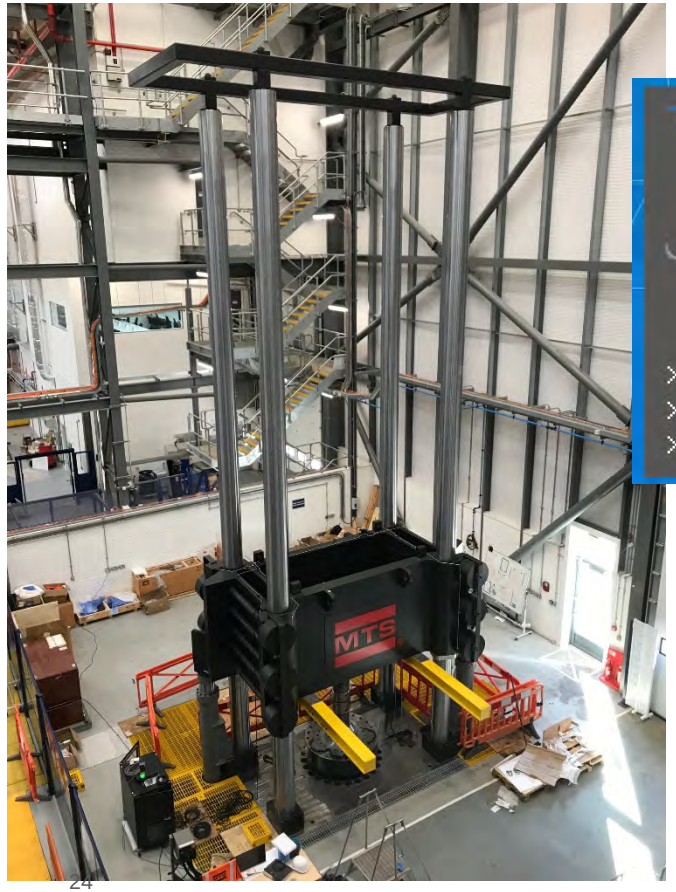
Airbus Structures Test Centres



A closer look inside: Design of Innovative Test Jigs & Tools

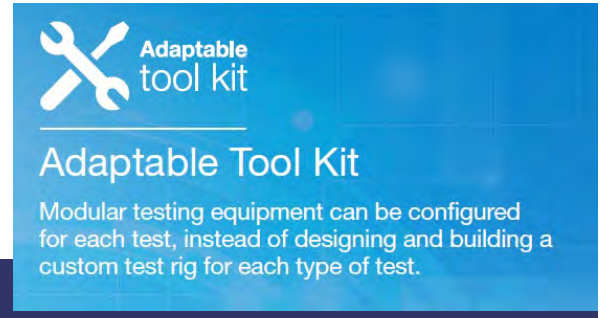
High Capacity Test Machine

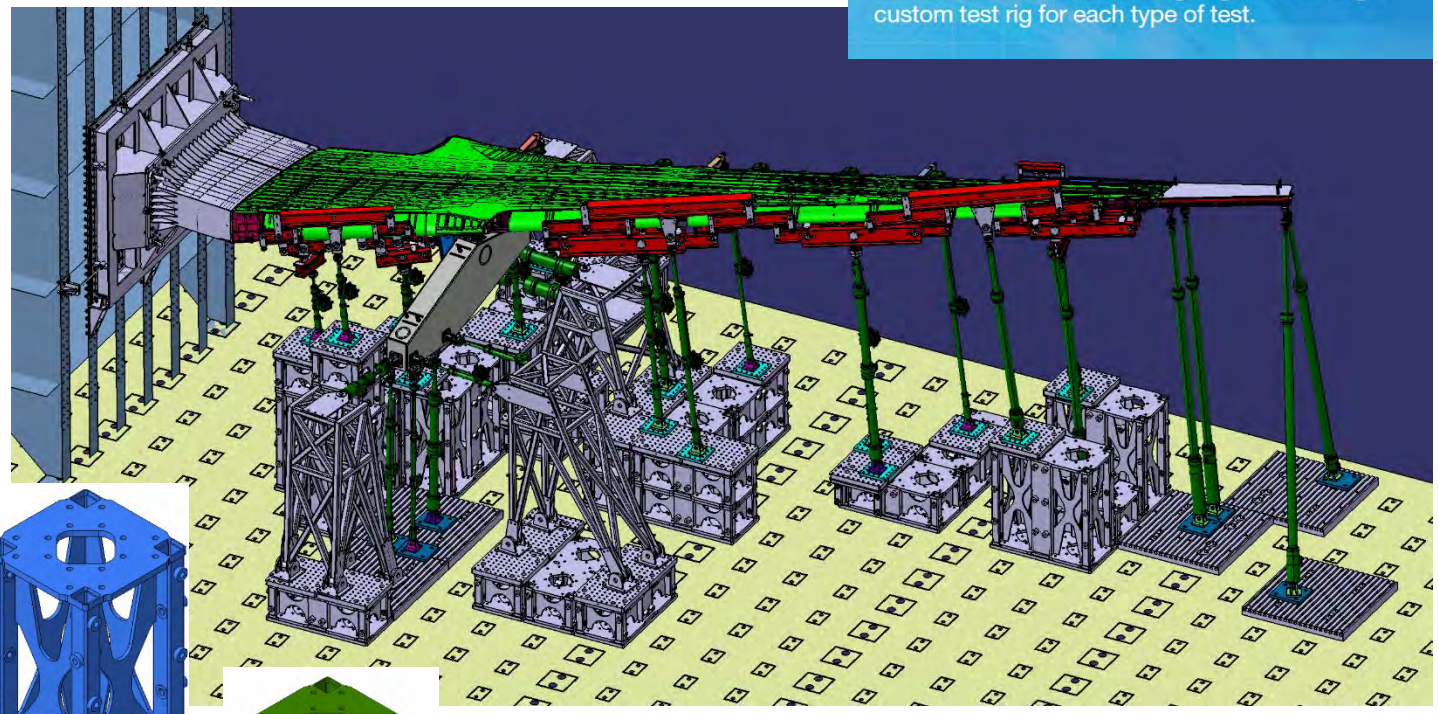
- 25MN capability
- Enable testing at up to 10x current speed

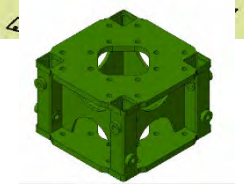


Modular Testing

- Focus on reuseability & flexibility
- Reconfigurability







A closer look inside: Strong Wall/Floor

Will allow us to…

- Develop innovative and flexible test solutions
- Focus on reusability & flexibility
- Get faster delivery of test results
- Use advanced technologies

Strong floor

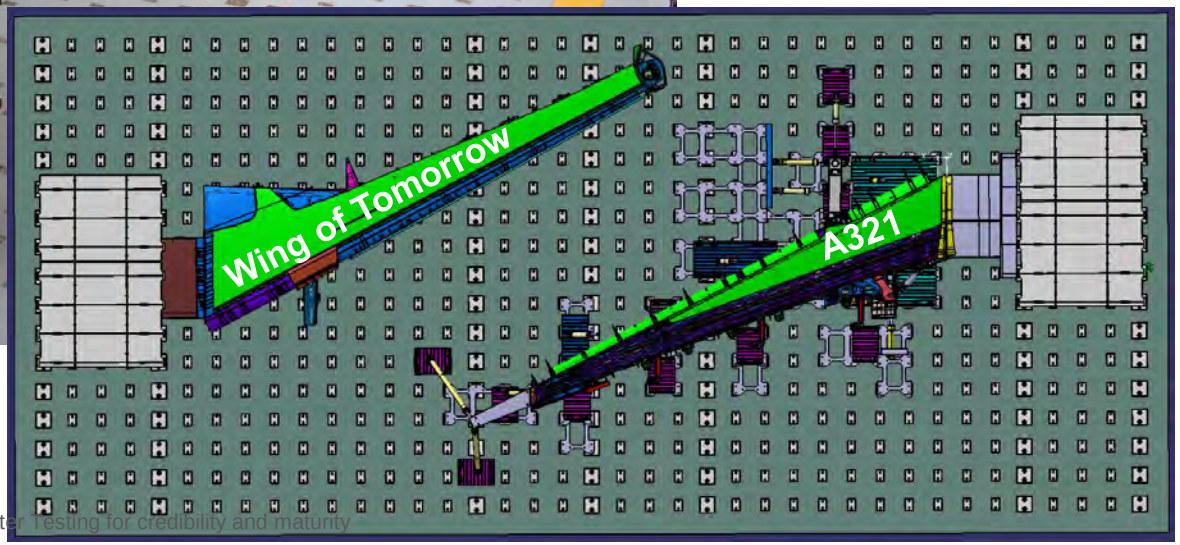
40m long, **18m** wide,
2m thick containing
1450m^3 of concrete

Strong wall

13m wide, **10m** high

Strong floor

24 hour continuous pour
240 lorry loads
1 lorry every **six** minutes



Precision needed as pouring around:

1m x 1m grid of anchor points
782 anchor points
230 tonnes of steel reinforcement
55 piles @ **1050mm** diameter
16m longest pile
431m total pile length

One of the **biggest single** concrete pours in the UK this year

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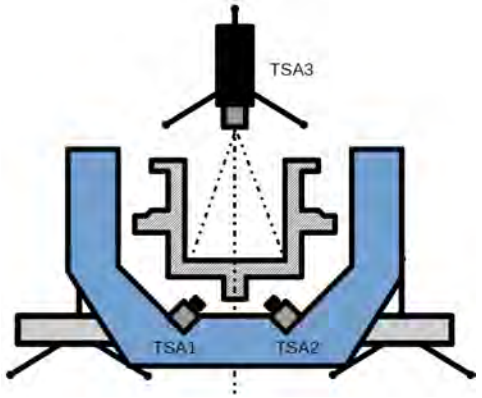
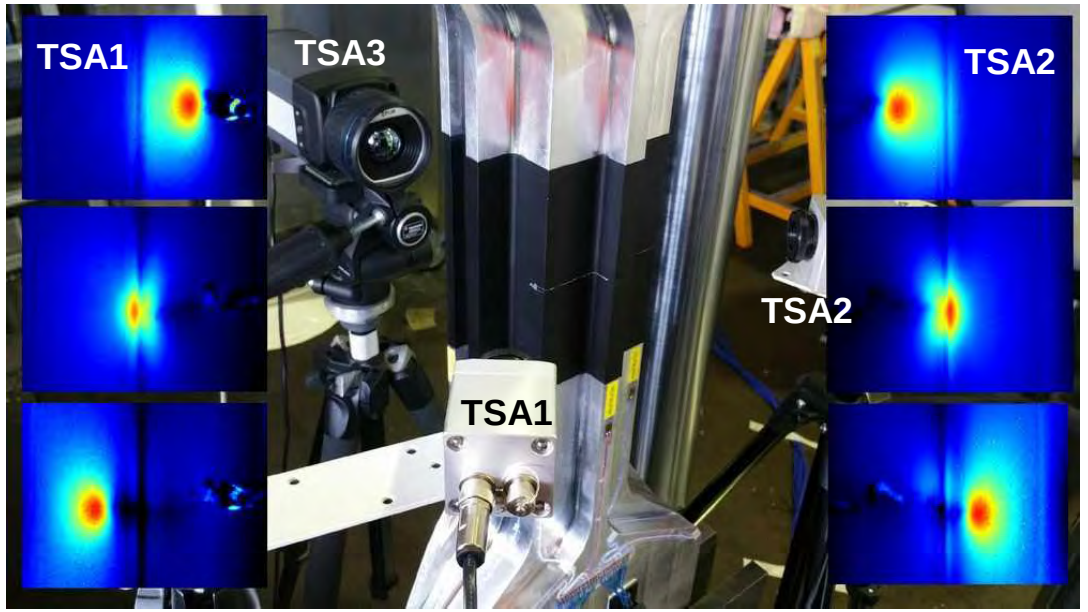
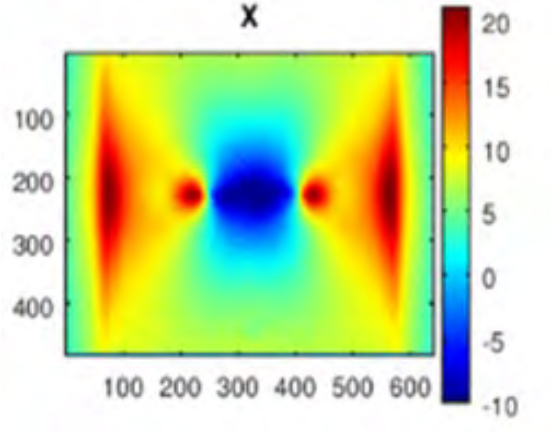
Crack Growth Monitoring







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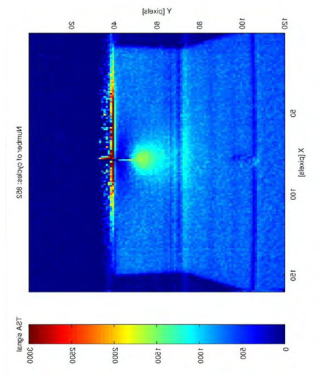

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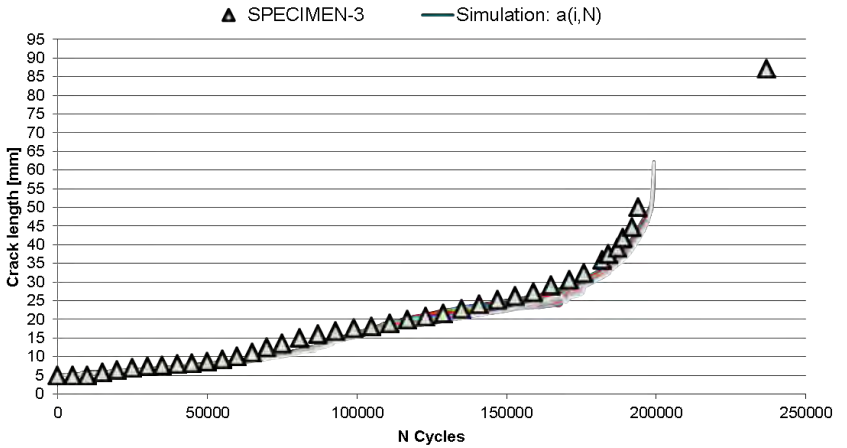

Rear pocket of specimen

*uncalibrated units for X

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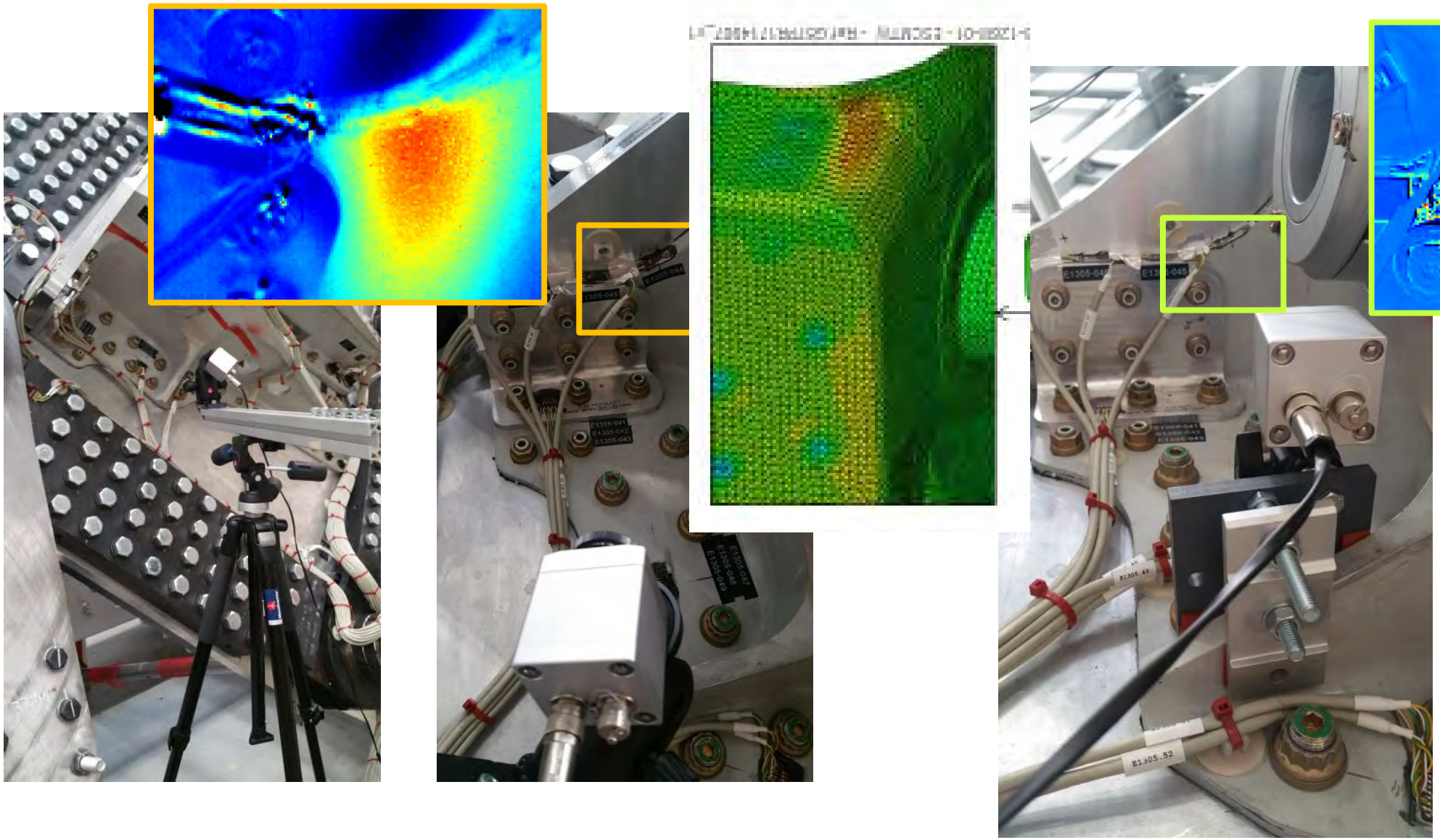
Hot spot monitoring – INSTRUCTIVE project



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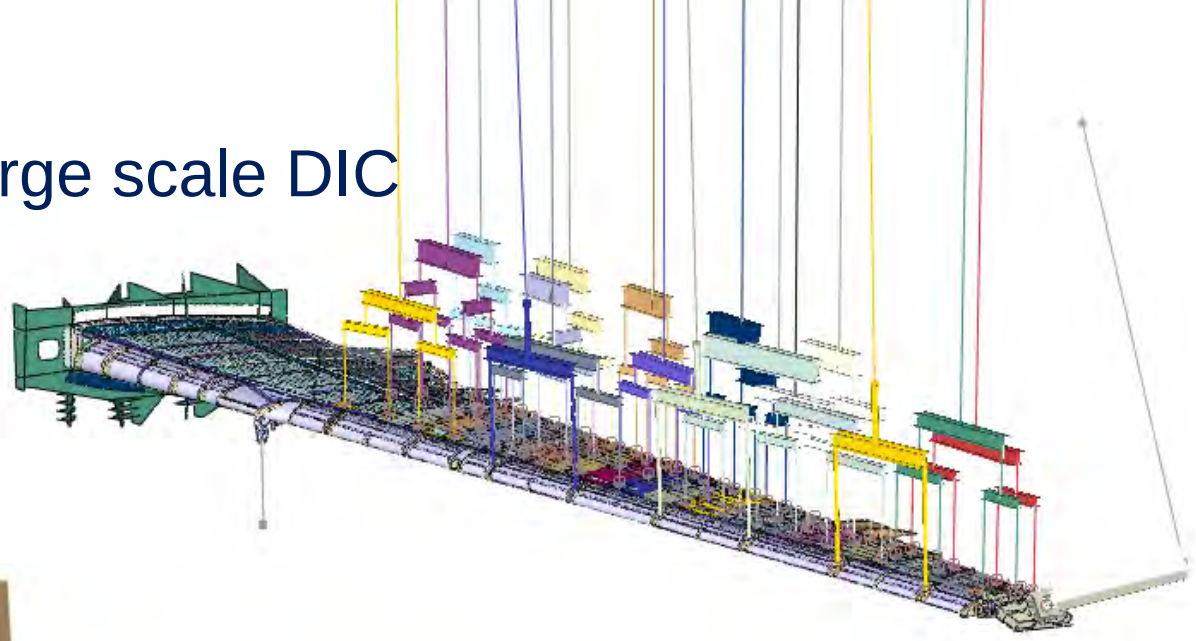
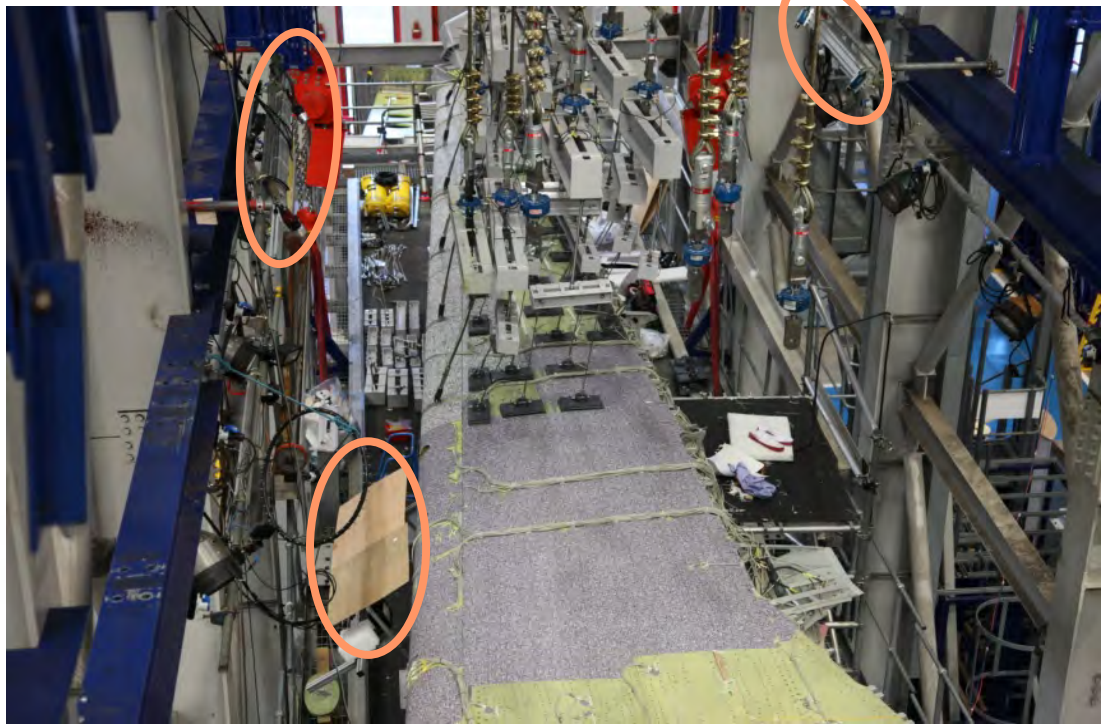
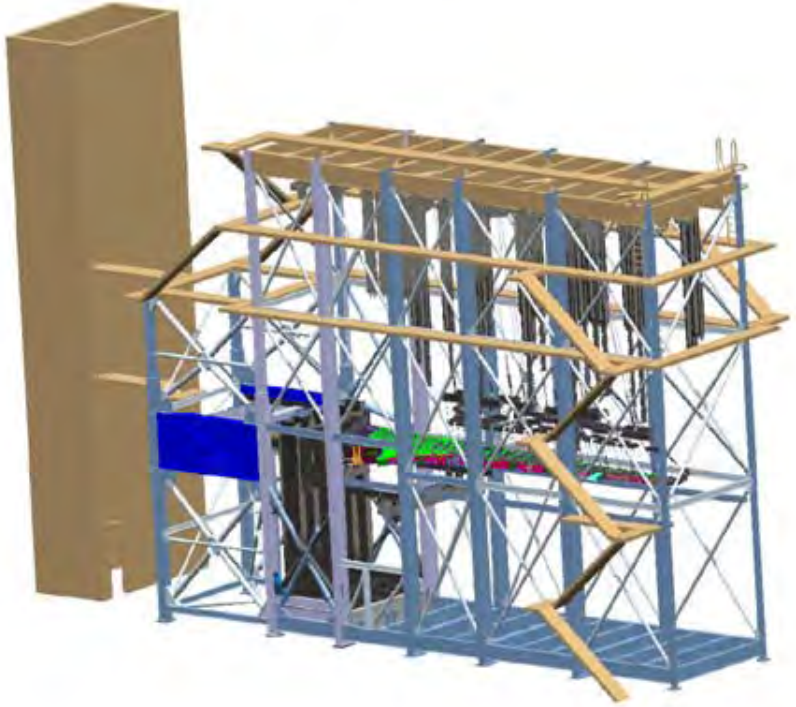
Large scale DIC







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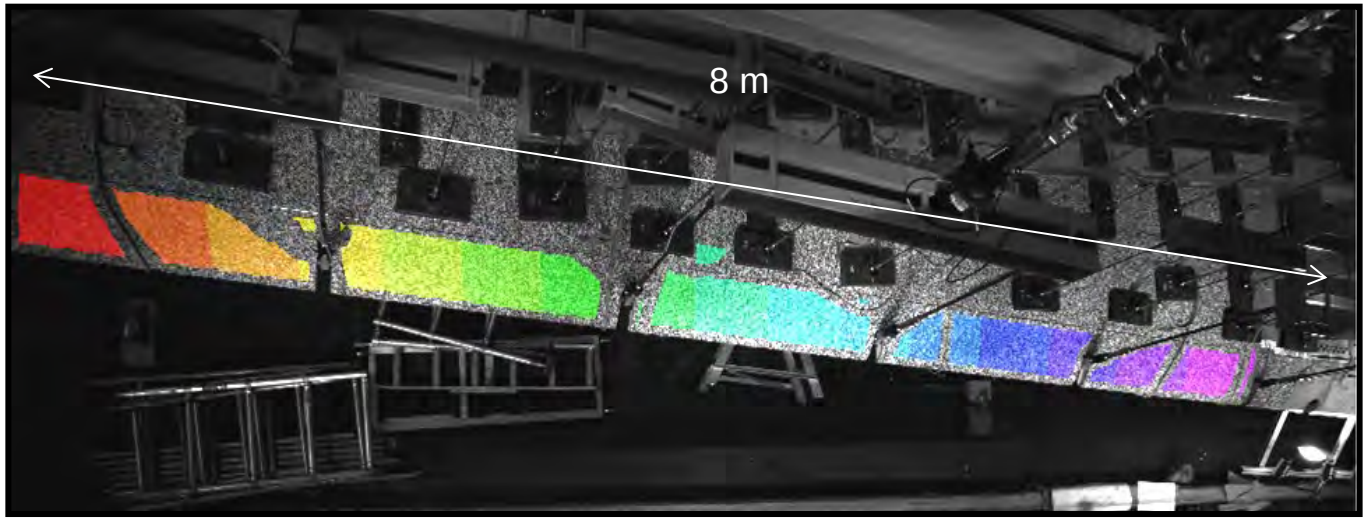
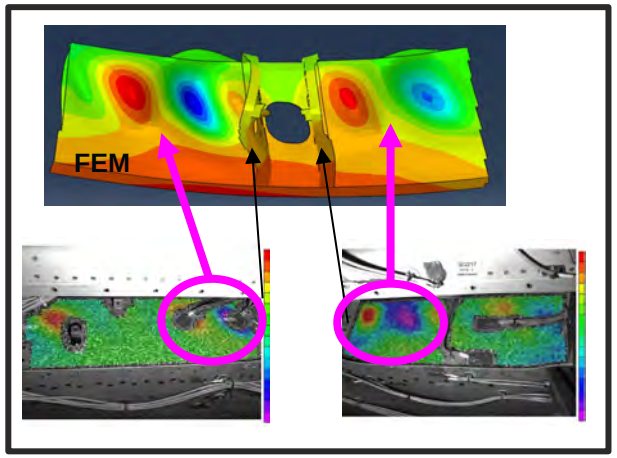
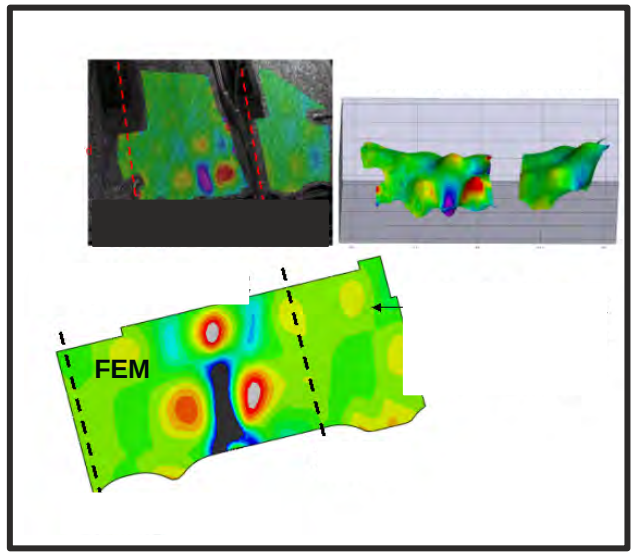
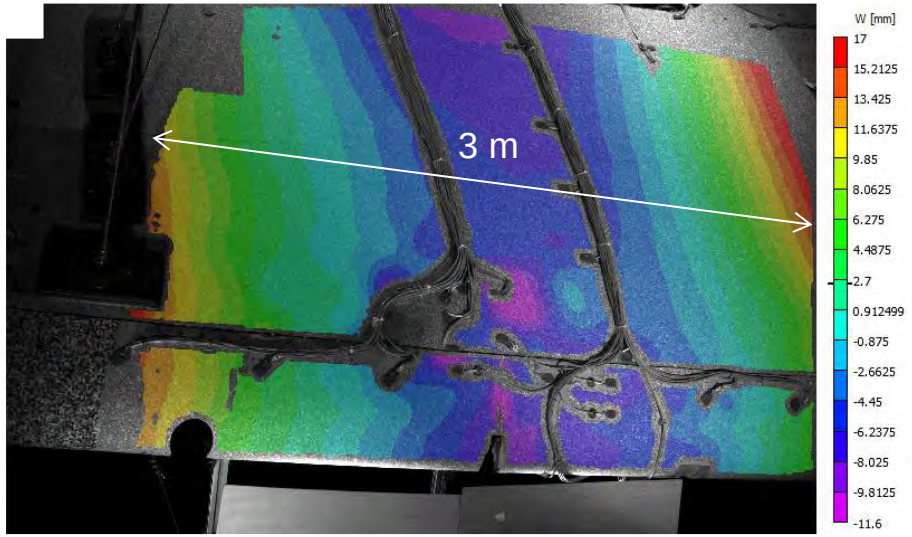
Large Scale DIC Test results and data correlation









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Thank you

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