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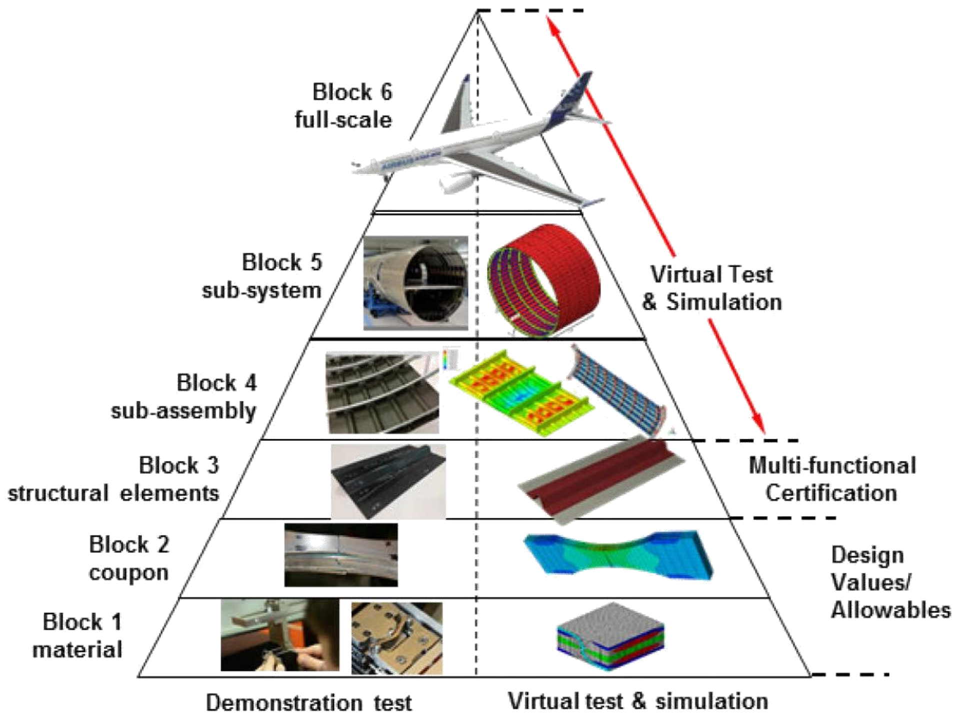
Le Jumeau numérique pour la mécanique des structures : Quels usages et quelles priorités ?

Florent Mathieu - Séminaire Aristote- 21/09/23

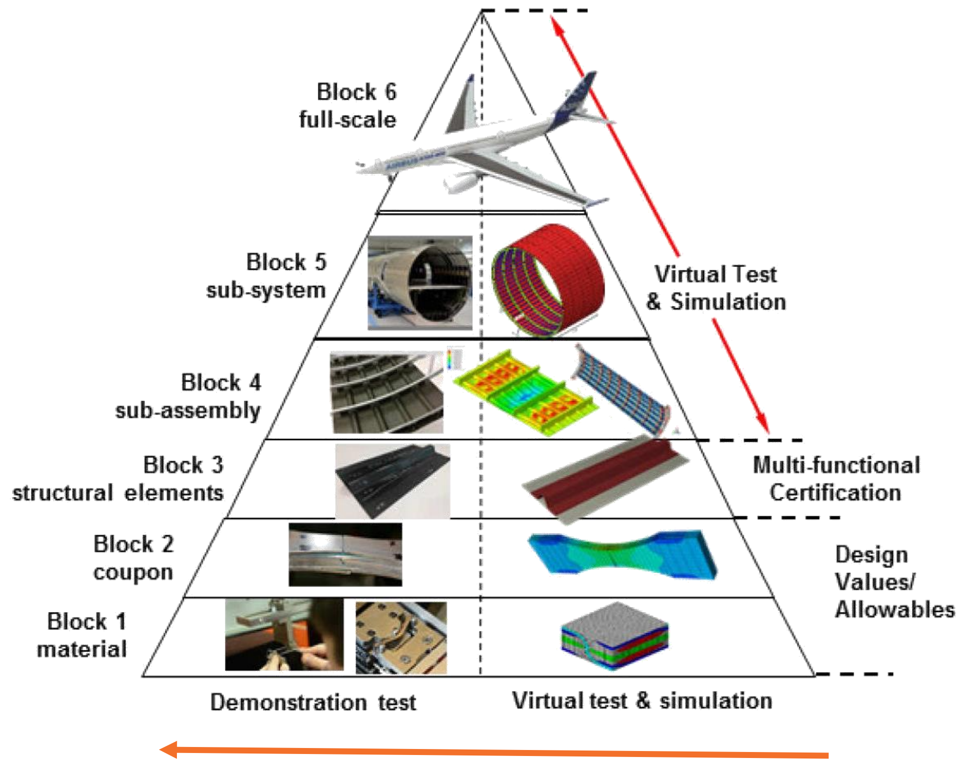
Structural mechanics: climbing the pyramid



Need for credible simulations

- Development teams try to rely more and more on simulations, in order to
  - Explore **more configurations** than with tests alone
  - **Remove tests** from campaigns

In order for customers and certification agencies to trust simulations more, **credibility** has to be built



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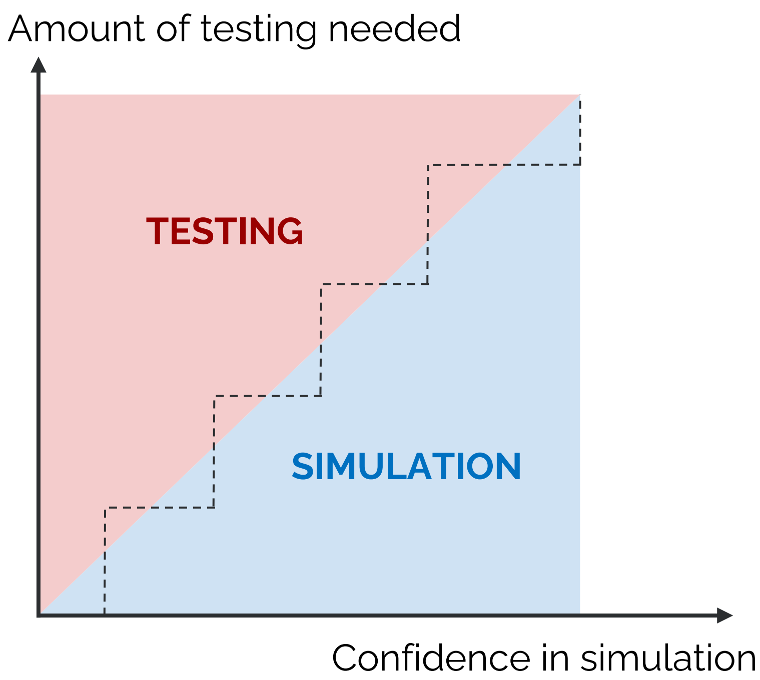
Why is it important to measure credibility?



- Confidence in a certain family of simulations allows to limit the number of tests for a certain level of the pyramid

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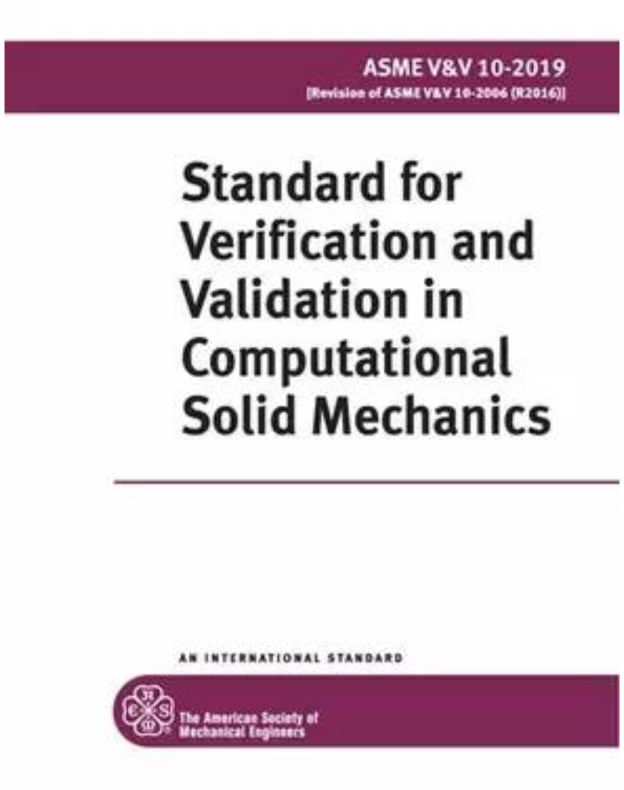
What does model credibility mean

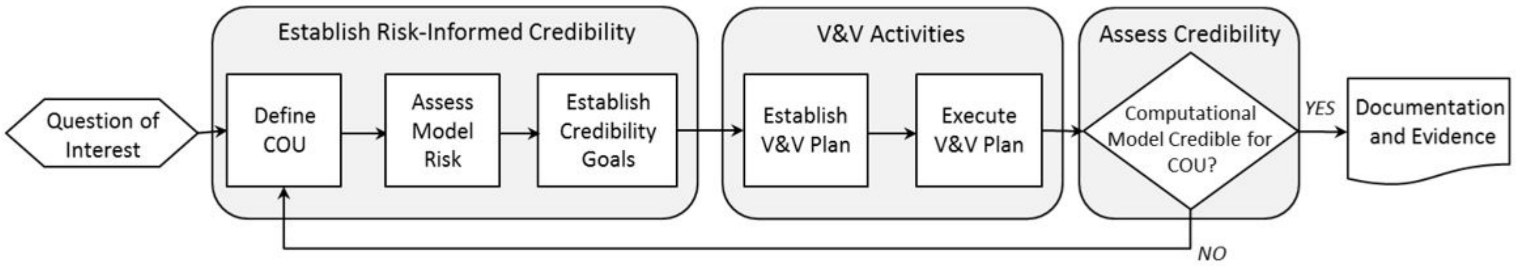
“ A model is deemed credible when concepts and processes in the model are considered acceptable as an approximation of the modelled system” [van Koon, 2016]

Utimately, a credible model convinces people.

How can this be ensured, or quantified ?

VVUQ (Verification, validation and Uncertainty Quantification)





VVUQ is a systematic approach to assessing the quality and reliability of computational simulations, by assessing (in the case of structural mechanics):

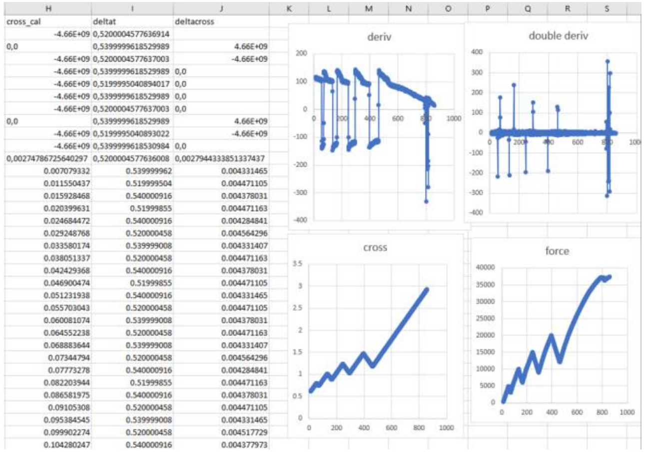
- code quality
- representativity of physics and geometry
- general agreement with test results
- uncertainties

What do we need to achieve a credible model?

Table 4: Example of PCMM Table Assessment and Project Maturity Requirements

MATURITY / ELEMENT	Maturity Level 0	Maturity Level 1	Maturity Level 2	Maturity Level 3
Representation and Geometric Fidelity		Assessed	Required	
Physics and Material Model Fidelity			Assessed Required	
Code Verification		Assessed Required		
Solution Verification	Assessed		Required	
Model Validation		Assessed	Required	
Uncertainty Quantification and Sensitivity Analysis	Assessed			Required

A framework



Tools

Credibility framework : the PCMM example

- **Predictive Capability Maturity Model for Computational Modeling and Simulation,** William L. Oberkampf, Martin Pilch, and Timothy G. Trucano, 2007
- *"The Predictive Capability Maturity Model (PCMM) is a new model that can be used to **assess the level of maturity** of computational modeling and simulation (M&S) efforts."*

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Solution Verification	Assessed		Required	
Model Validation		Assessed	Required	
Uncertainty Quantification and Sensitivity Analysis	Assessed			Required

Estimating model maturity

- makes evidence-based decision making easier when deciding on a testing policy
- allows to decide for necessary improvements in the modeling process

This is what we started with

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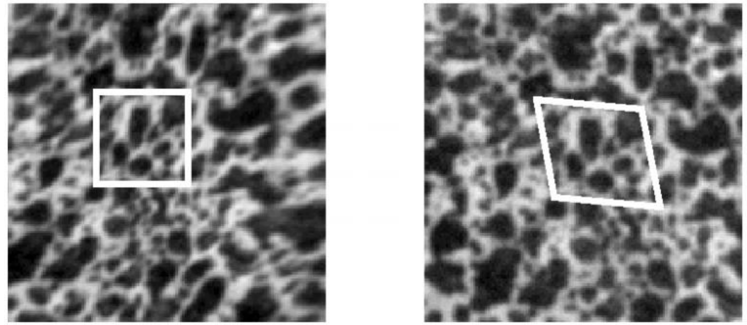
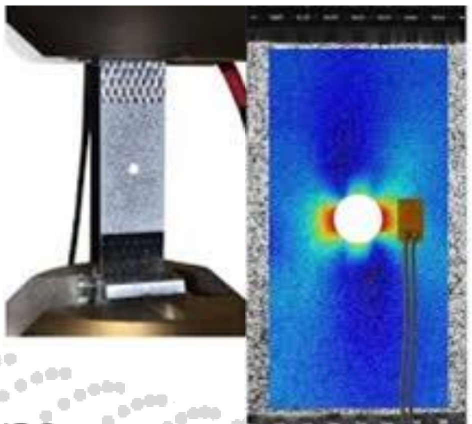
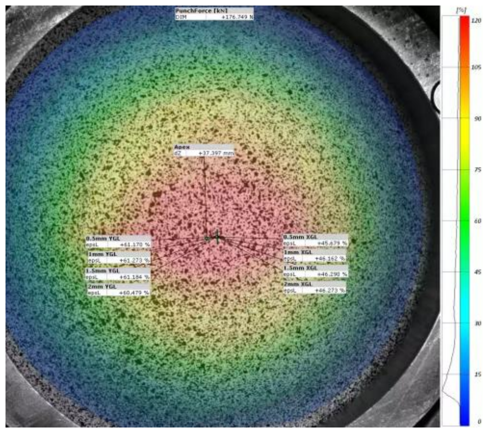
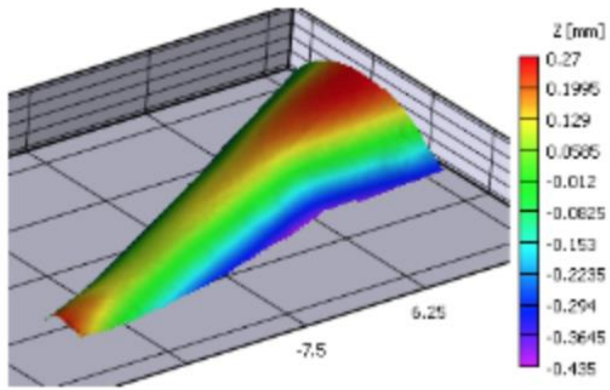
Tools: how about Digital Image Correlation?

DIC is an optical measurement technique that measures **displacement and strain fields** by following a pattern in a series of images









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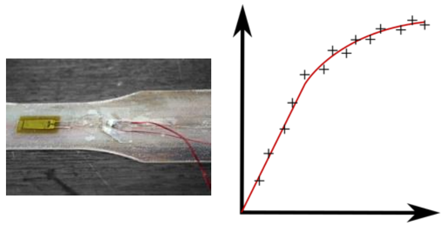
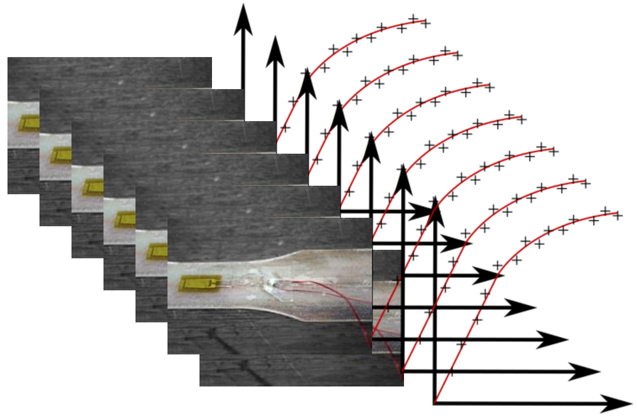
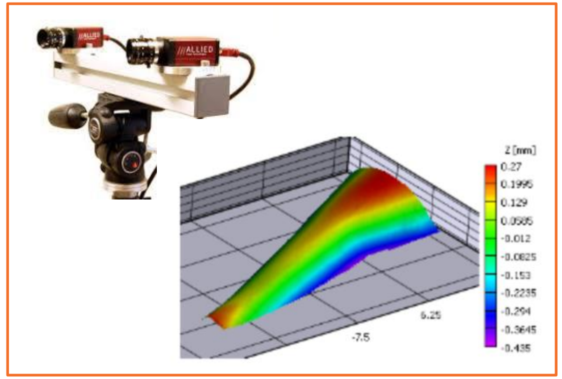
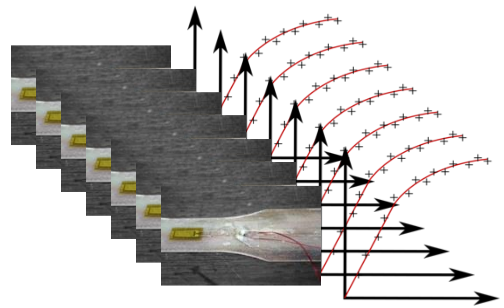
Tools: current challenges for validation (structures mechanics)









\+

- Lot of time spent (underestimated)
- **Human errors**

\+

Industry-leading workflow

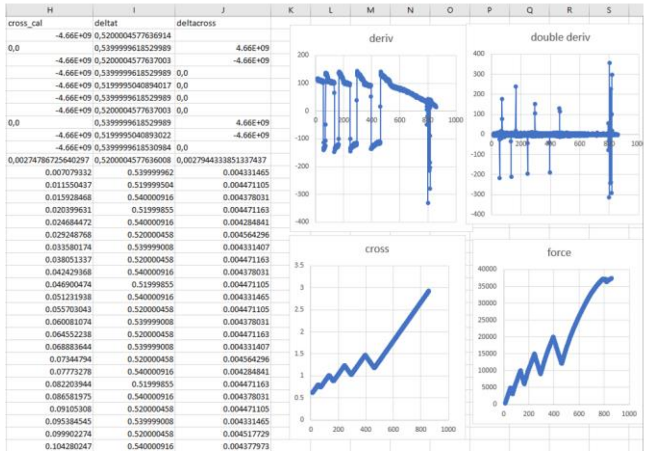
Test lab

Strain

Force

Displacements

Temperature



Results extracts

Simulation team

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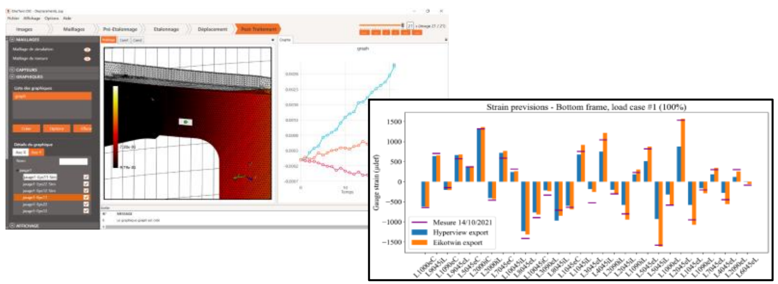
EikoTwin - a data fusion platform for FEA

Hardware

Image data
Strain
Force
Displacements
Temperature

Key features:
- Global test/simulation comparison
- DIC displacement/strain fields measurement
- Model parameters calibration



EikoTwin platform

Disp/Strain Fields
Sensors
Mesh
Sim. result
Sensor location
Sensitivities
Solver control

FE platform

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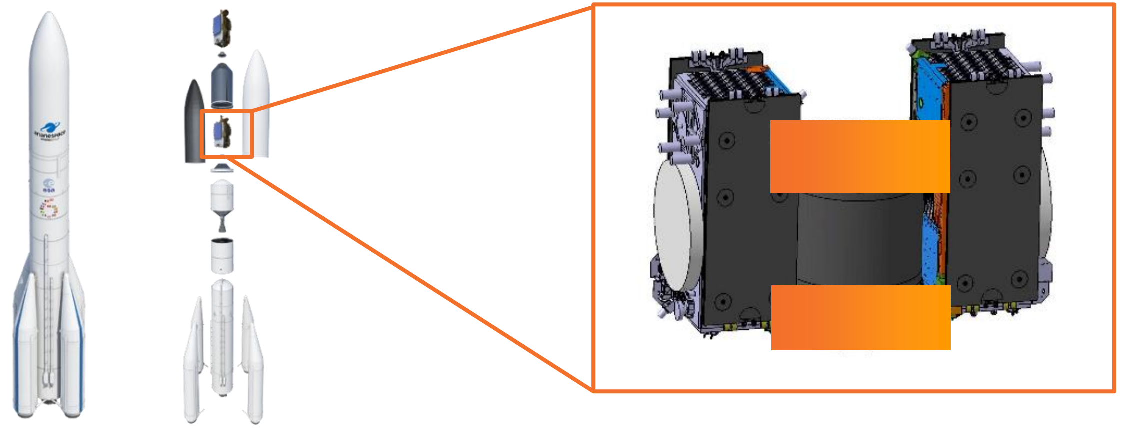
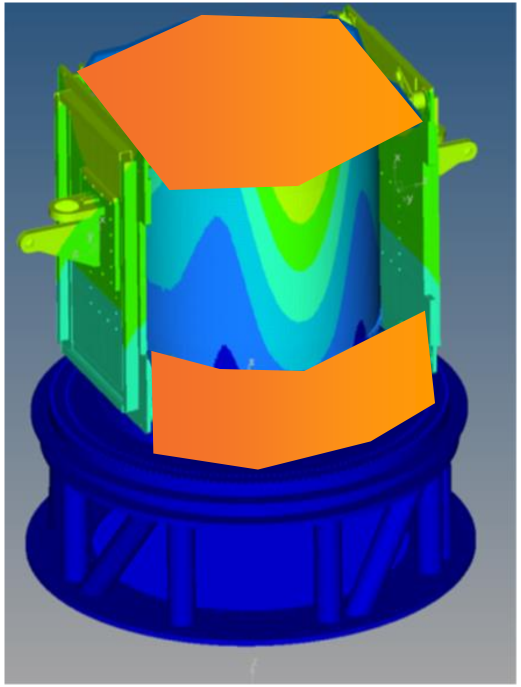
Example: Ariane 6 Galileo dispenser





- Scale 1 static test
- Complex structure and loading paths
- Numerous measurement devices: **200 strain gauges, fiber optics, multi-camera measurements** (Digital Image Correlation) for three distinct regions

-> Approach comparison : traditional vs EikoTwin

Maturity assessment and goals

MATURITY / ELEMENT	Maturity Level 0	Maturity Level 1	Maturity Level 2	Maturity Level 3
Representation and Geometric Fidelity			X	X
Physics and Material Model Fidelity		X		
Code Verification	*Out of scope*			
Solution Verification	*Out of scope*			
Model Validation			X	X
Uncertainty Quantification and Sensitivity Analysis		X	X	

X assessed
X targeted

+ Additional target: **efficiency**

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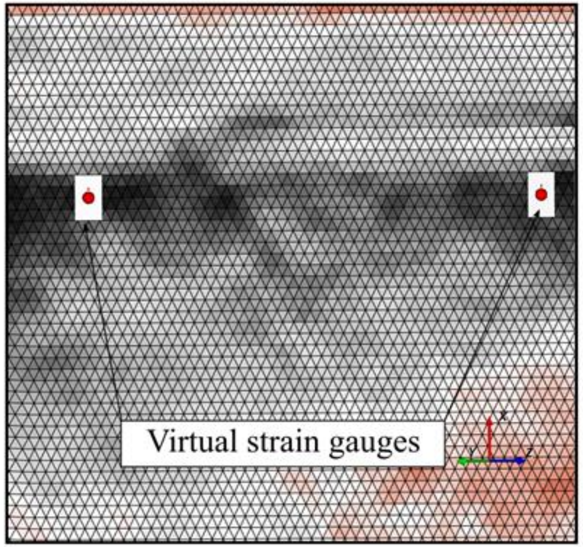
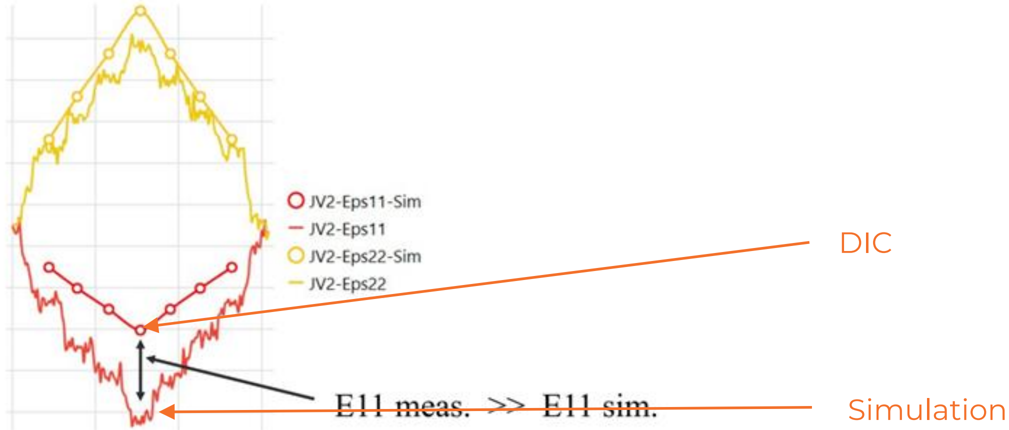
Building simulation credibility



(a) Normalised difference strain field (detail, Measured - Simulated)



(b) Local strain comparison : Simulation and virtual strain gauge (DIC)

Test results analysis

- Strain field differences allow to highlight areas of maximum test simulation discrepancies.
- Virtual strain gauges can be used to investigate these differences over time.

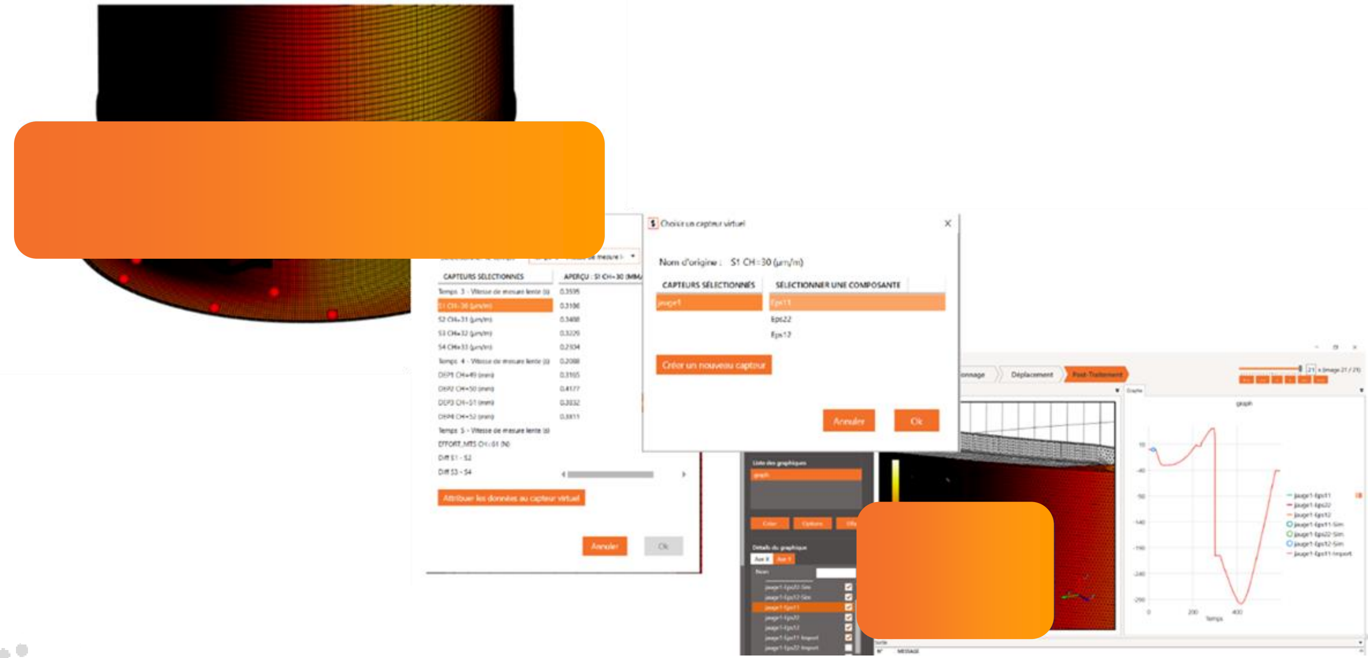
Data aggregation

EikoTwin Lite

EikoTwin DIC

Fluid model validation

- Automated sensor import and processing for one-click test/simulation comparison
- Dedicated analysis tools



Key results

- Seamless data management : save **hundreds of hours of post-processing time**

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Maturity improvements

MATURITY / ELEMENT	Maturity Level 0	Maturity Level 1	Maturity Level 2	Maturity Level 3
Representation and Geometric Fidelity			X	X X
Physics and Material Model Fidelity		X		
Code Verification	*Out of scope*			
Solution Verification	*Out of scope*			
Model Validation			X	X X
Uncertainty Quantification and Sensitivity Analysis		X	X X	

X assessed
X targeted

+ Additional target: **efficiency**

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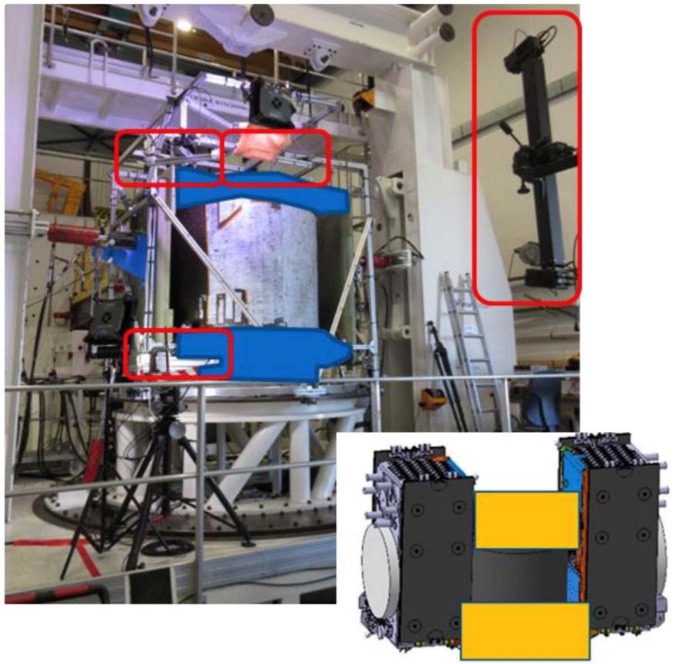
Impact

3. Less testing, more simulation

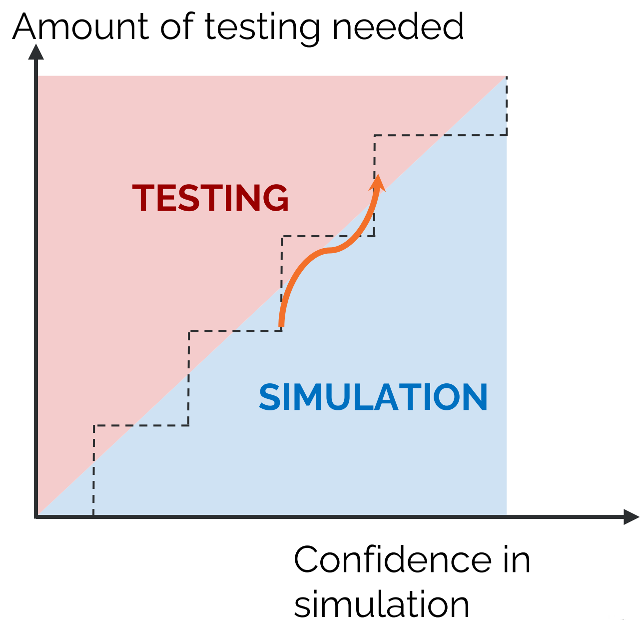
- Remove expensive tests from the campaign
- Cut corners et deliver faster durably

Scale 1 test for Ariane 6 "Galileo" dispenser



Key results

- *"We want to go to the next step and propose for **one of these tests to be removed from the campaign**"*
- General strategy to save **20% of the development budget** by cutting through testing



Key take-home messages

The use of maturity assessment allows

- to visualize and share advances on a certain model type
- to set goals for next steps

The use of data fusion

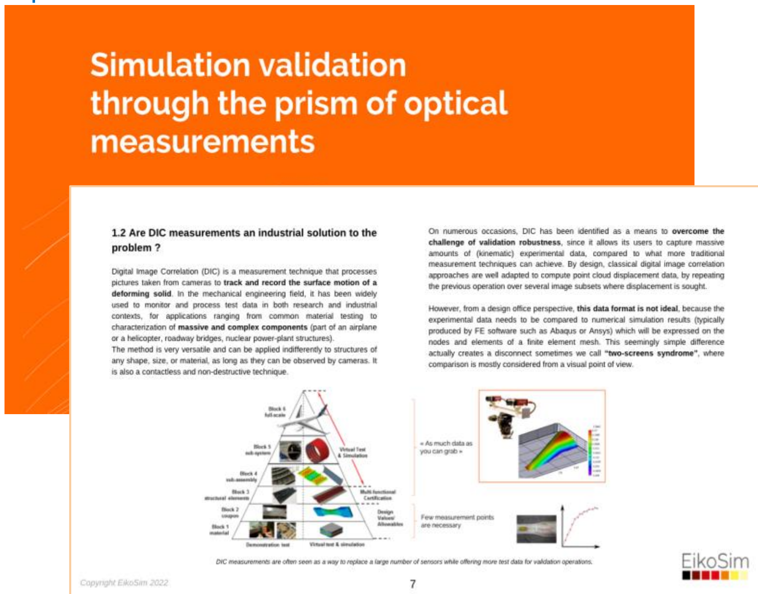
- helps using fixed processes for given data processing operation
- limits human errors due to Excel/in-house developments
- makes large volume processing humanly manageable (incl. but not limited to DIC)

We should tend to “actual” digital twins, but keep on evaluating their value

Questions?

Download our White Paper !

https://eikosim.com/en/download-white-paper/


Simulation validation through the prism of optical measurements

1.2 Are DIC measurements an industrial solution to the problem ?

Digital Image Correlation (DIC) is a measurement technique that processes pictures taken from cameras to **track and record the surface motion of a deforming solid**. In the mechanical engineering field, it has been widely used to monitor and process test data in both research and industrial contexts, for applications ranging from common material testing to characterization of **massive and complex components** (part of an airplane or a helicopter, roadway bridges, nuclear power-plant structures).
The method is very versatile and can be applied indifferently to structures of any shape, size, or material, as long as they can be observed by cameras. It is also a contactless and non-destructive technique.

On numerous occasions, DIC has been identified as a means to **overcome the challenge of validation robustness**, since it allows its users to capture massive amounts of (kinematic) experimental data, compared to what more traditional measurement techniques can achieve. By design, classical digital image correlation approaches are well adapted to compute point cloud displacement data, by repeating the previous operation over several image subsets where displacement is sought.

However, from a design office perspective, **this data format is not ideal**, because the experimental data needs to be compared to numerical simulation results (typically produced by FE software such as Abaqus or Ansys) which will be expressed on the nodes and elements of a finite element mesh. This seemingly simple difference actually creates a disconnect sometimes we call **"two-screens syndrome"**, where comparison is mostly considered from a visual point of view.

DIC measurements are often seen as a way to replace a large number of sensors while offering more test data for validation operations.

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