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A Digital Twin for solid mechanics : How can we use images to build more predictive models ?

Motivations

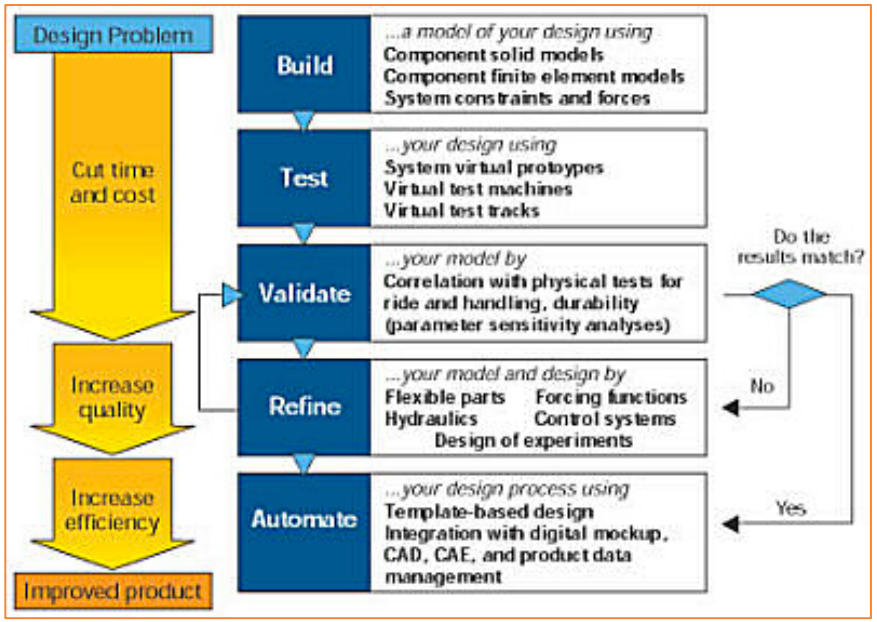
- S. Bouissou, Airbus : “We have to develop the next generations of planes in 30% less time, which means we have to perform **30% less testing**.
  *But the certification agencies need the **same amount of data**.”*

- D. Mellé, Safran Landing Systems : “In a landing gear, **every kg counts** and can help keeping our seller’s performance promises.
  *But our designs already seem to be at the top of what we can do, at least with the **safety margins** we’re currently using.”*

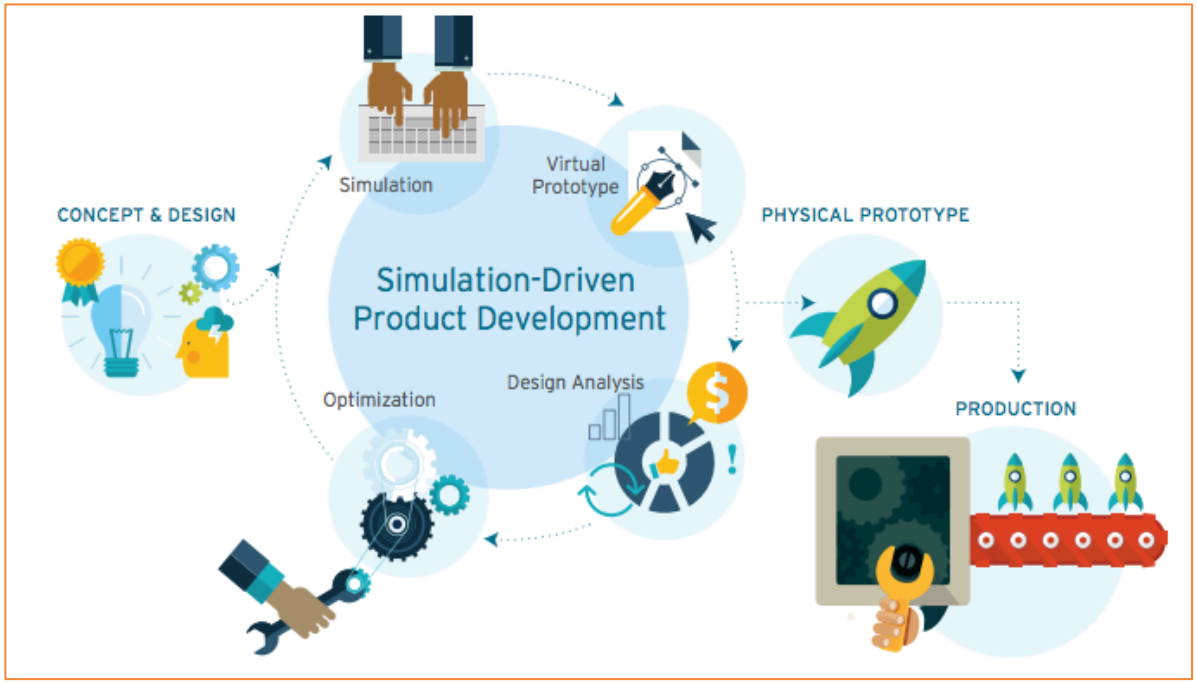
Goal: more data points, less development time

Experiences : what is currently done

Digitalisation of the design process (PLM, SDM)



© MSC Software



An Integrated Simulation Tool Framework for Process Data Management, Cognizant, 2015

Current performance levels

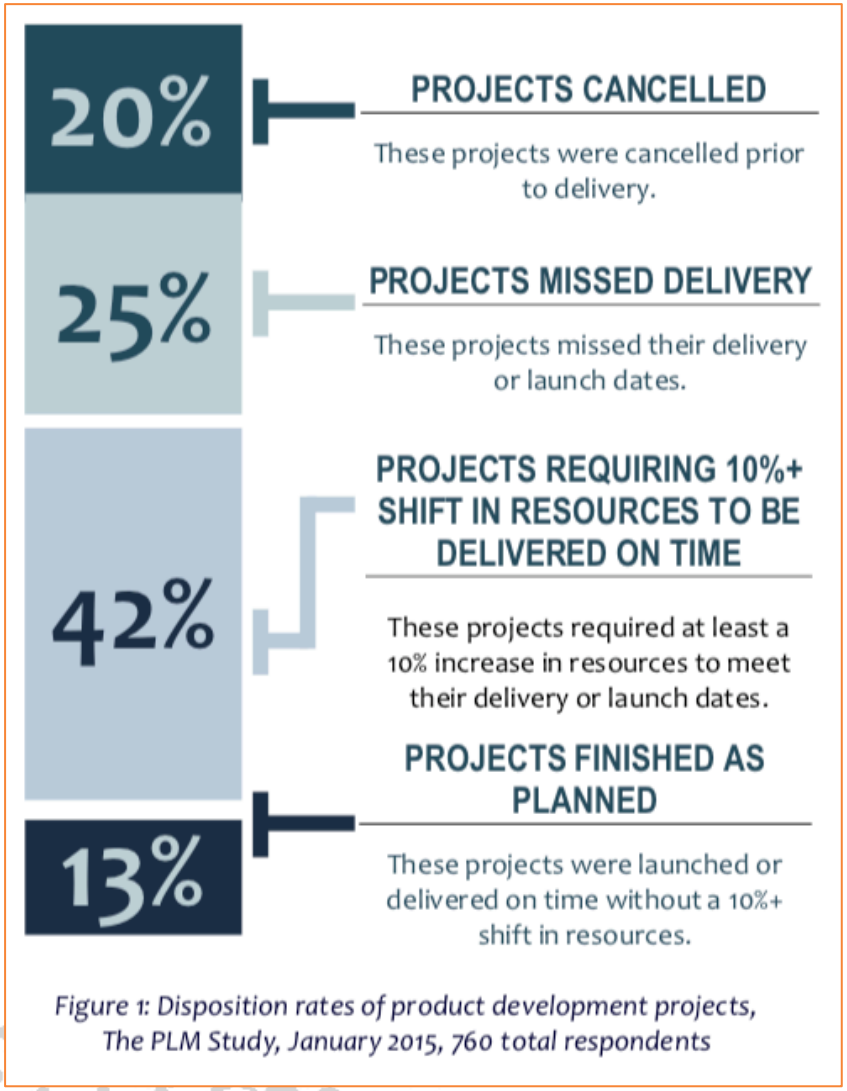


Figure 1: Disposition rates of product development projects, The PLM Study, January 2015, 760 total respondents

Causes :

- Increasing complexity of the products
- Lack of foresight of product performances (leading to design iterations)

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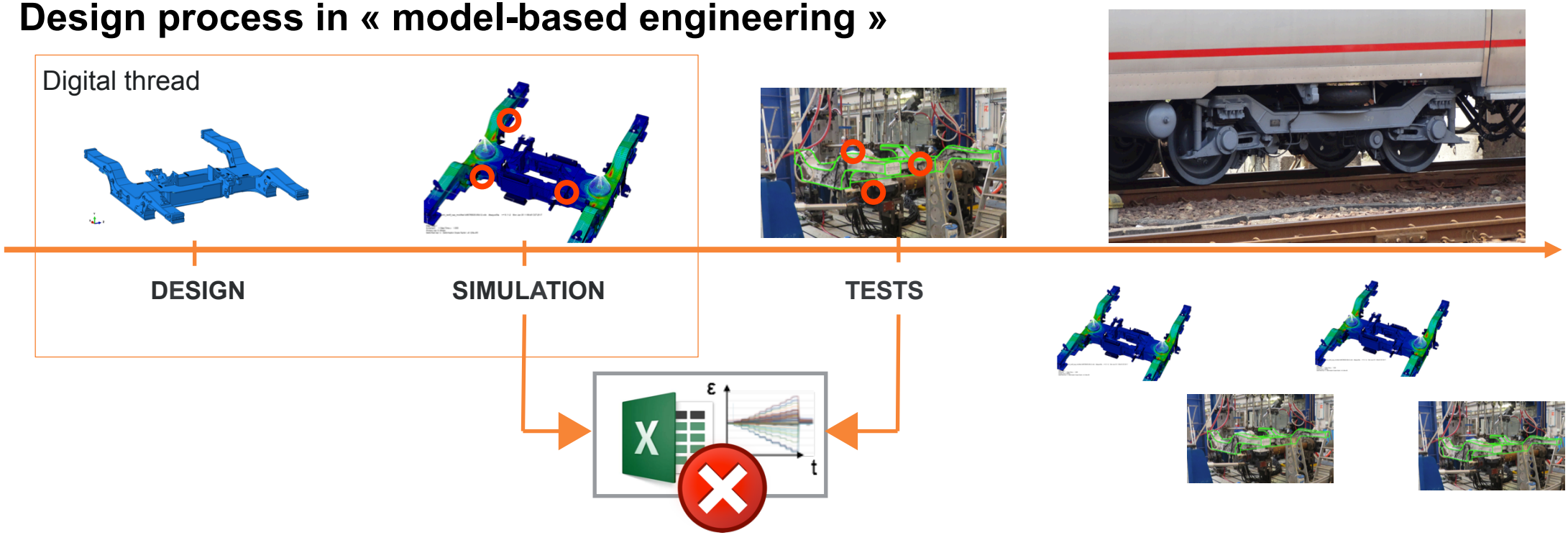
Client problem : Simplify model validation

Design process in « model-based engineering »



PAIN POINTS :

- Time of study
- Budget overrun
- Risks of delaying production

- Additional time: 10 to 100% of the project
- 1 test = 5k€ - 200k€

Solution : 2 patents, 2 tools

Design process in « model-based engineering »

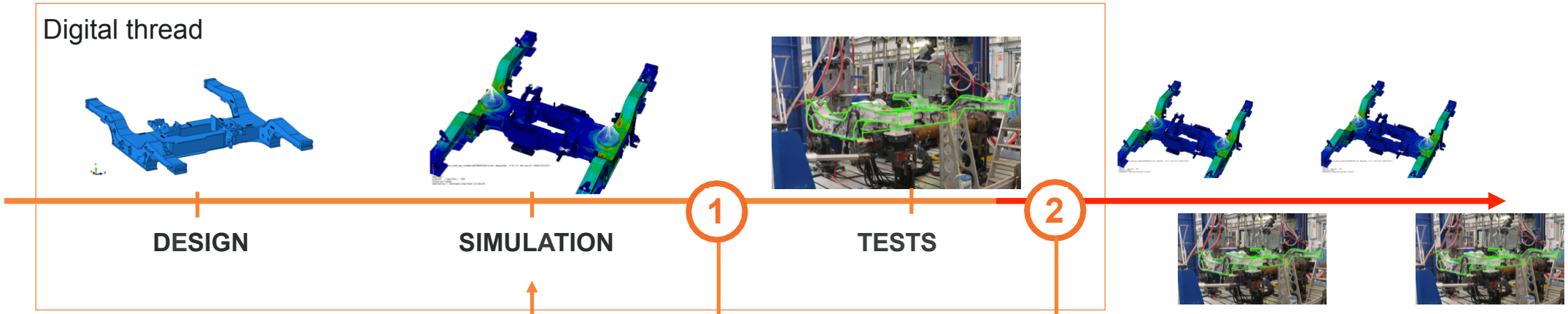


IMAGE PROCESSING
Digital Image Correlation, multi-camera

DIGITAL TWIN
Model comparison & correction

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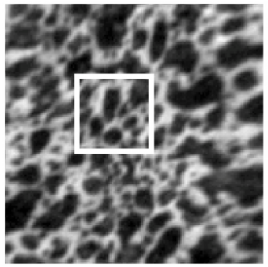
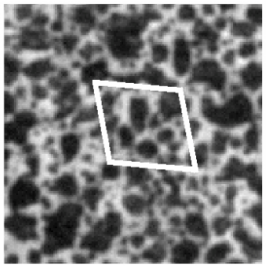
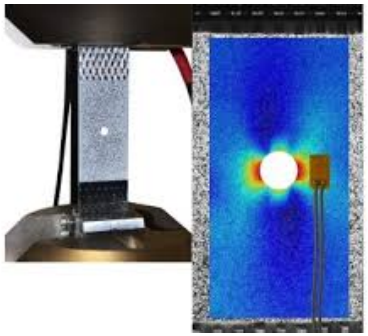
Digital Image Correlation : images to the rescue

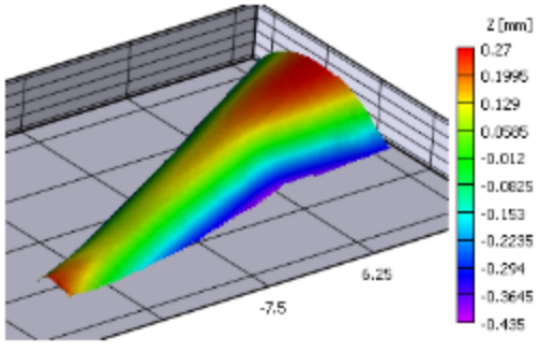
DIC = Following visible strains and displacements



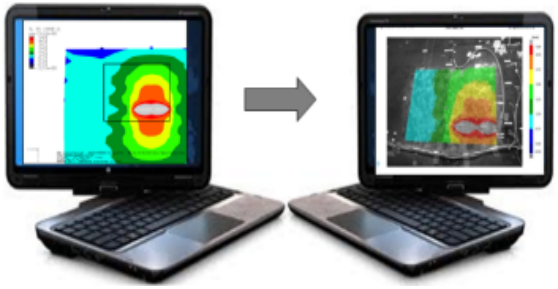


Various applications, from the sample to the structure





Main limitations :
- standardization
- “two-screen syndrome” : comparing to the simulation is even more complex



-> qualitative measurement tool

Subset-base vs FE-Based DIC (in theory)

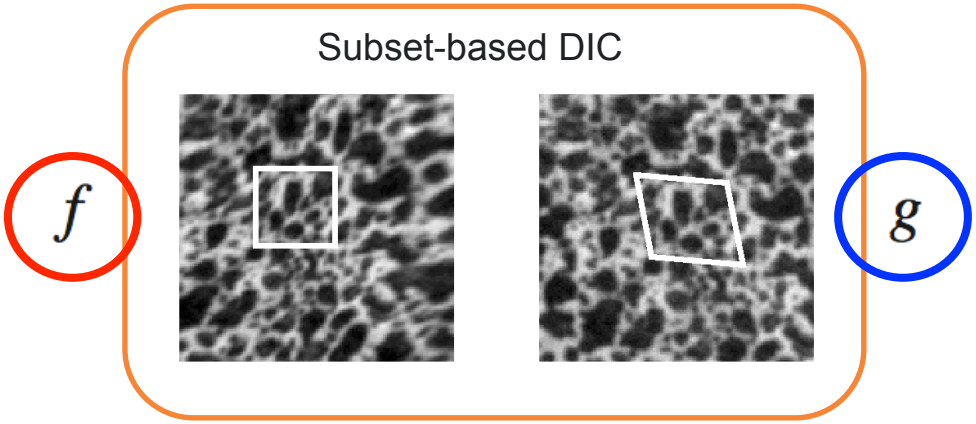
Deformed image

Reference image $f(x) = g(x - u(x))$ Displacement field

DIC = minimizing a correlation residual (reference image-deformed image)

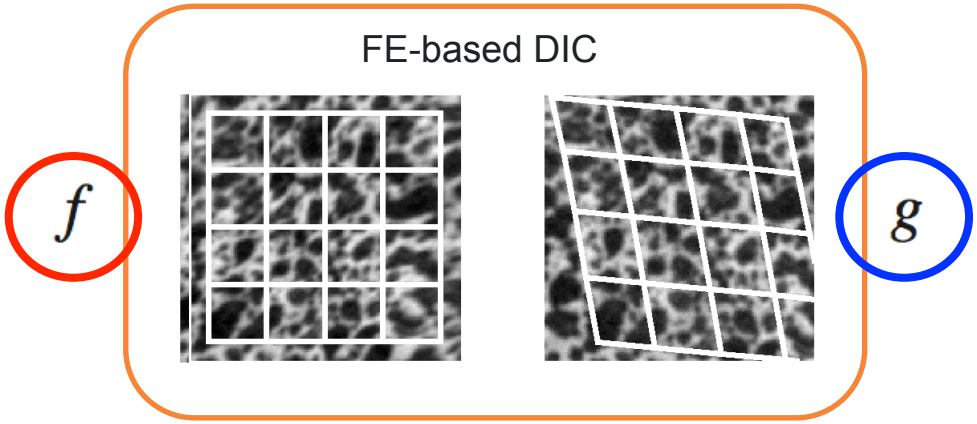
$$\Phi_c{}^2 = \iint_\Omega [u(x).\nabla g(x) + g(x) - f(x)]^2 \, dx$$

Subset-based DIC



Repeated minimizations of Φ_c over the subsets

FE-based DIC



Global minimization of Φ_c over the region of interest ("gray level equilibrium")

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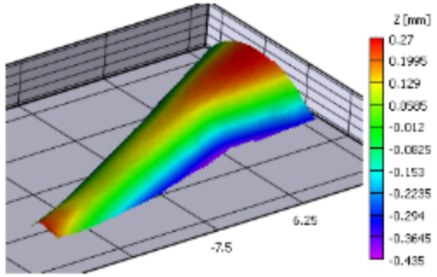
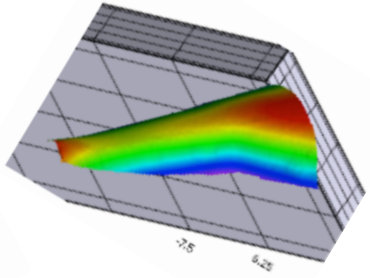
Subset-base vs FE-Based DIC (in practice)

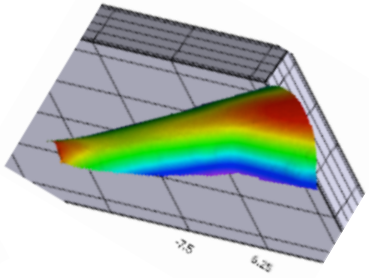
CLOUD POINT MEASUREMENT
(camera reference system)



CLOUD POINT MEASUREMENT
(part reference system)



MESH-PROJECTED MEASUREMENT

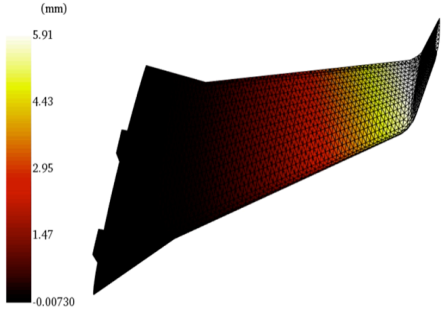


Reference system transfer
(Tools ? Errors ?)

Mesh mapping
(Tools? Errors ?)

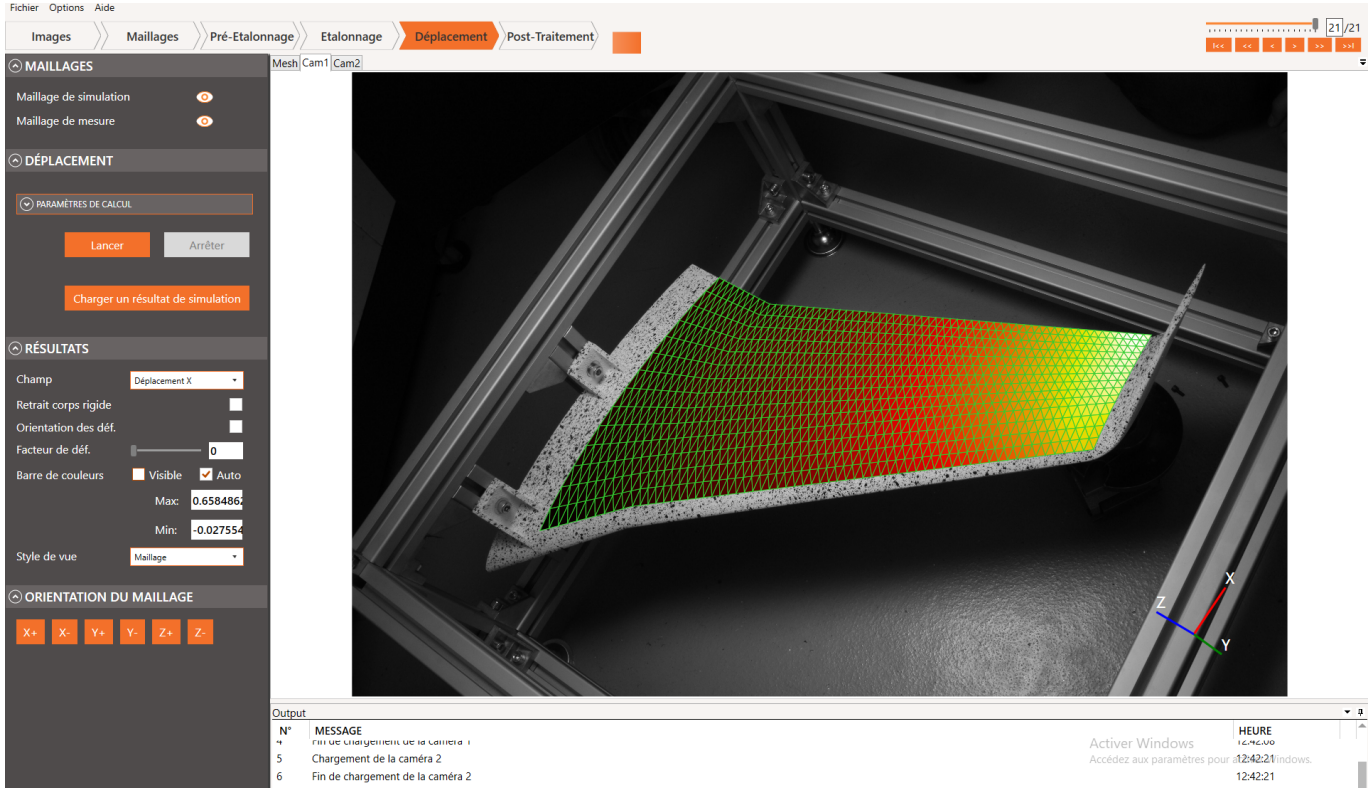
Subset-based DIC

FE-based DIC



MESH-BASED MEASUREMENT

Software solution – DIC on the FE simulation Mesh



FEATURES

- Image processing
- Displacements/strain measurements
- Test/Simulation direct comparison
- External data importation

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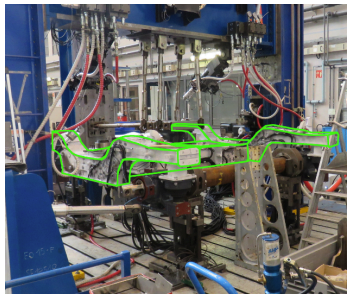
Our next proposition : a digital twin for 3D solid mechanics



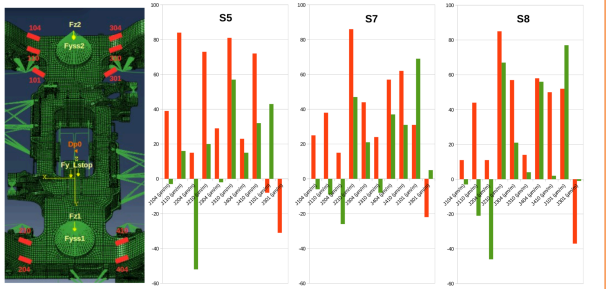
Load sensors

Strain gauges

LVDT

Cameras

Testing

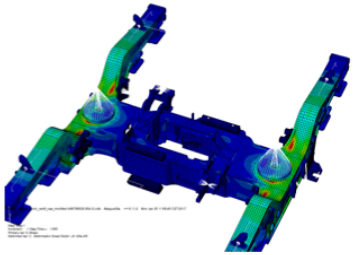


Digital Twin

Computed forces

Computed displacements

Computed strains



3D Simulation

Boundary conditions,
updated simulation parameters

Challenges :

- Format compatibility (simulation & test)
- “Heavy client” software development

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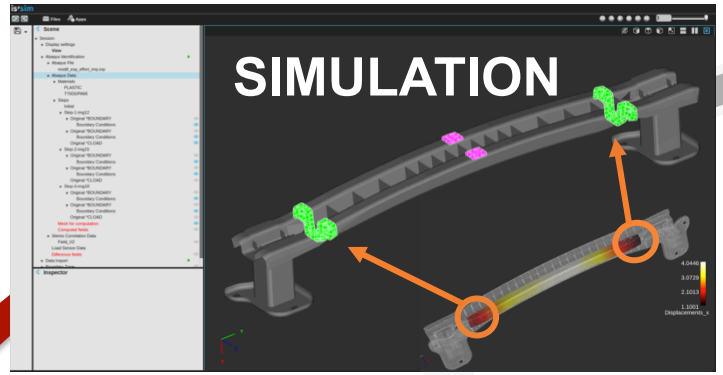
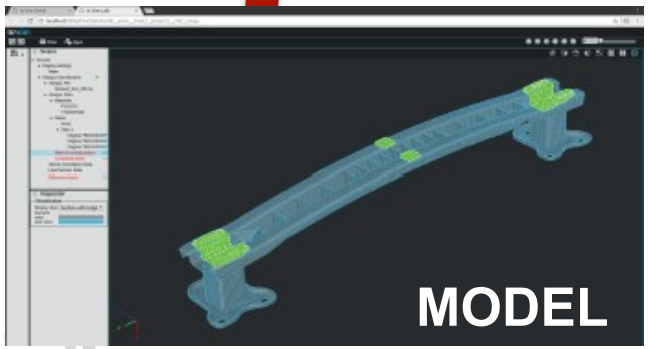
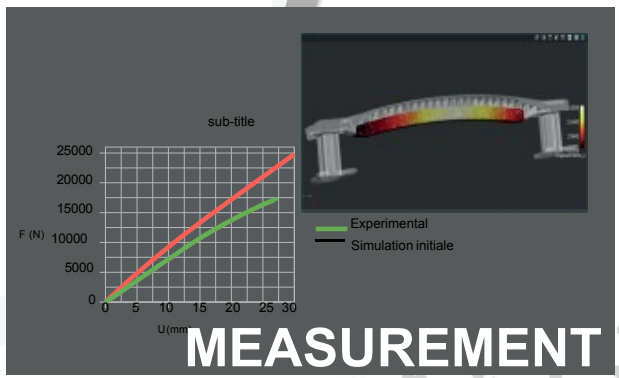
Use case – Composite bumper beam



Unification of test and simulation data





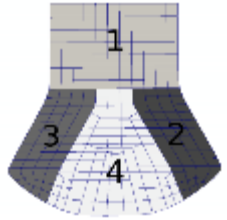
Not an image-based geometry, but an image-based loading !

@ SAFRAN Aircraft Engines

SAFRAN AIRCRAFT ENGINES

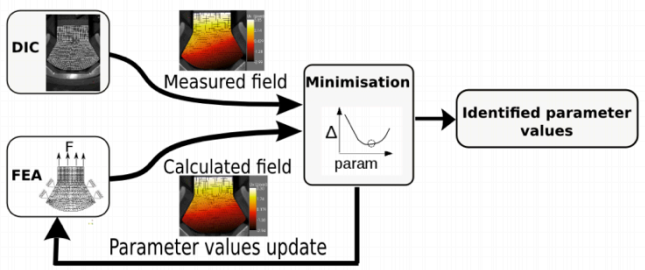
Context

- FAN composite blade (LEAP engine)
- Complex internal structure
- Local behavior impossible to identify
- Equivalent modeling was not satisfying



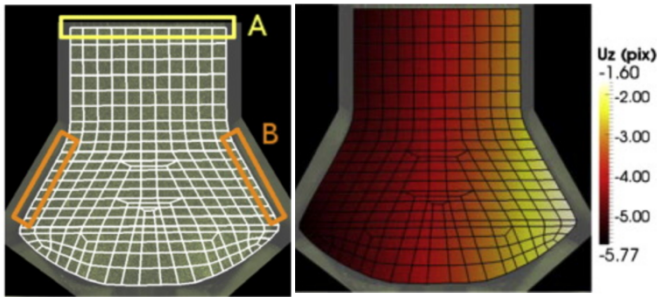
Solution

- Development of a custom SAMCEF connection module to DIC (then LS-DYNA, Abaqus, Zebulon)
- Automated parameter identification
- Integration to the R&D team toolbox



Results

- Automated data processing



- "These methods are undeniably faster than what we were able to do before, and give us results we didn't have"
- "We think that will allow us to reduce the number of tests by capitalizing more on them, to reduce testing costs and processing time"

J. Schneider, composites expert

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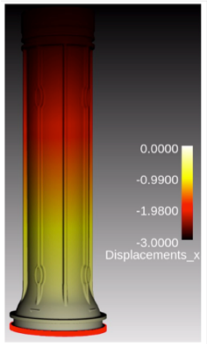
@ SAFRAN Landing Systems

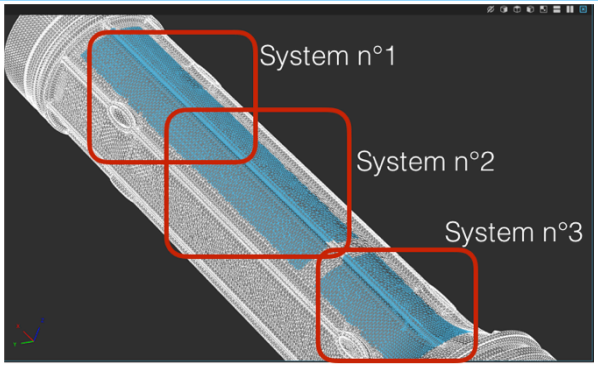
SAFRAN LANDING SYSTEMS

Context

- “Demo” part : short fiber composite
- Compression test
- Goal : validation of the simulation

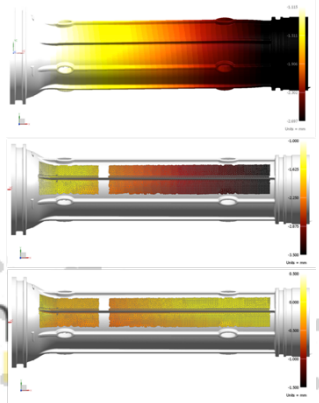


Solution



- Multi-camera DIC systems (6)
- Strain & displacement surface measurement
- Global test/simulation comparison

Results



- Global quality evaluation
- Direct boundary conditions correction from measured data
- Creation of an “augmented” simulation
- *“The comparison is way simpler and more complete than what we usually have”*

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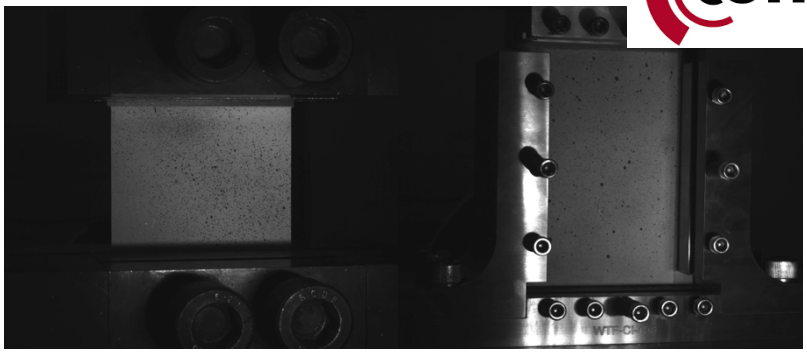
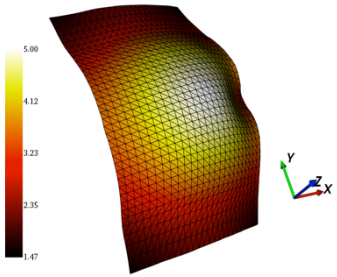
Context

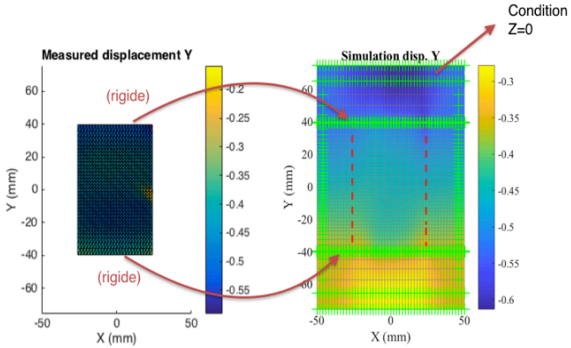
- New material – long fiber composite
- Defects in structural parts
- Goal : measure sensitivity to defects
- Tests: traction and compression



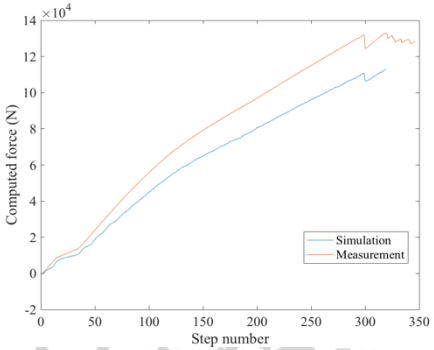
Solution



- Displacement measurement on the FE mesh of the part
- Use of measurement as input for boundary conditions
- Global test/simulation comparison



Results

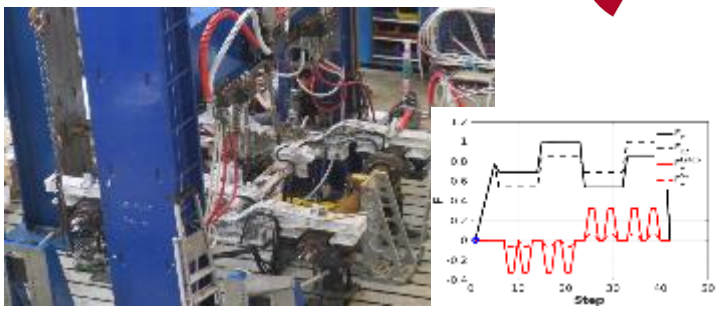


- Evaluation of the model quality
- Correction directly from the measurement data
- “Augmented” and calibrated FE model

ALSTOM cetim

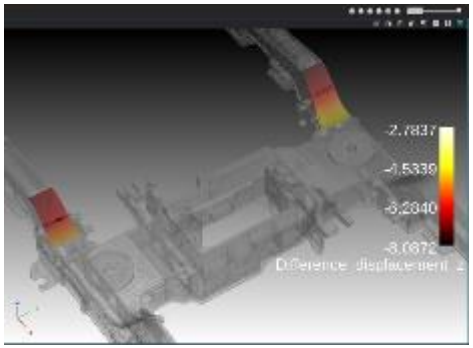
Context

- Fatigue testing of a train bogey
- Problems with simulation results validation
- Questions about a possible loading evolution in time

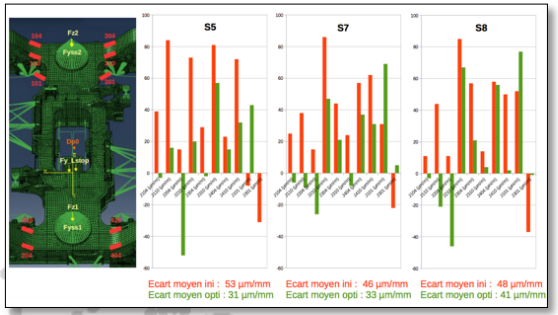


Solution

- Displacement measurement on the FE mesh
- Integration of other sensors results (gauges, LVDT)
- Automatic matching of simulation on the test results data set (forces, displacements, strains)



Results

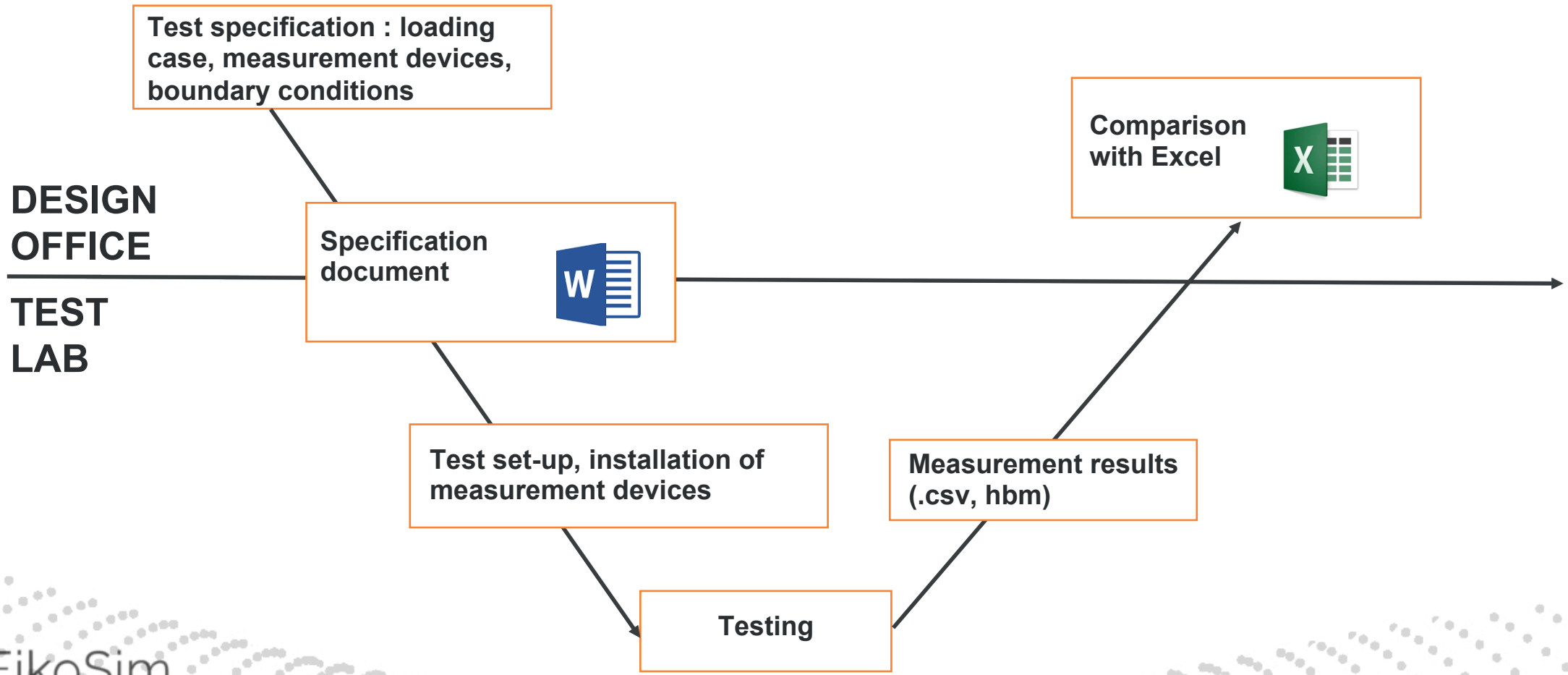


- Evaluation of the model quality
- Correction directly from the measurement data
- Physical explanation for the lack of performance (boundary conditions identification)
- Reduction of simulation gauge error by 30%

What to do in the future ?

- Current state of our work : proving that a better validation is possible (mostly on our side) through adapted tools
- Next step : proving that a better validation needs adapted processes

Current validation process



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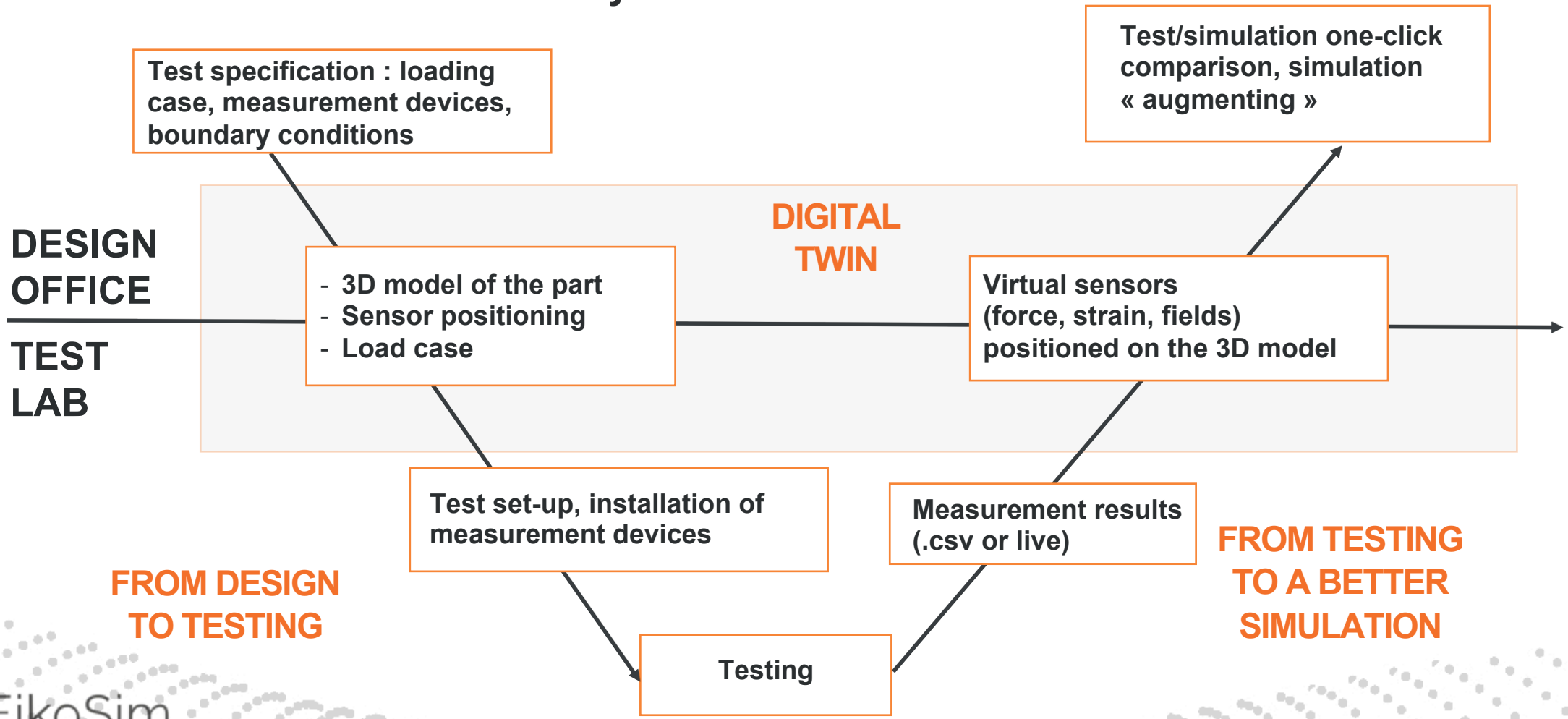
In the future

Validation as a cross-team activity



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Key messages

- Simulation will not be (for a long time) the only way to develop high-risk products : testing has to be integrated to the validation digital thread, for performance and for risk management
- Test-simulation comparison has to be addressed with adapted tools, and imaging can play a central role (field measurements, FEA model “augmenting”)
- **Challenges** : implementing new tools and new processes for an unknown (ie not measured yet) gain

- How do you deal with validation ? Are there technical limitations ?

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COMBLEZ L'ECART ENTRE ESSAIS ET SIMULATIONS

- Intégration des essais dans la chaîne numérique
- Réduction des coûts de développement et de conception