V&V-UQ framework to assess credibility of simulation of composite structures

Ludovic Barrière, PhD

Project Leader – TRUST (Towards cRedible simUlation of compositeS sTructures)

Futur Investment Program : multidisciplinary thematic institutes.

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Our purpose

Reinforce competitiveness for French industry

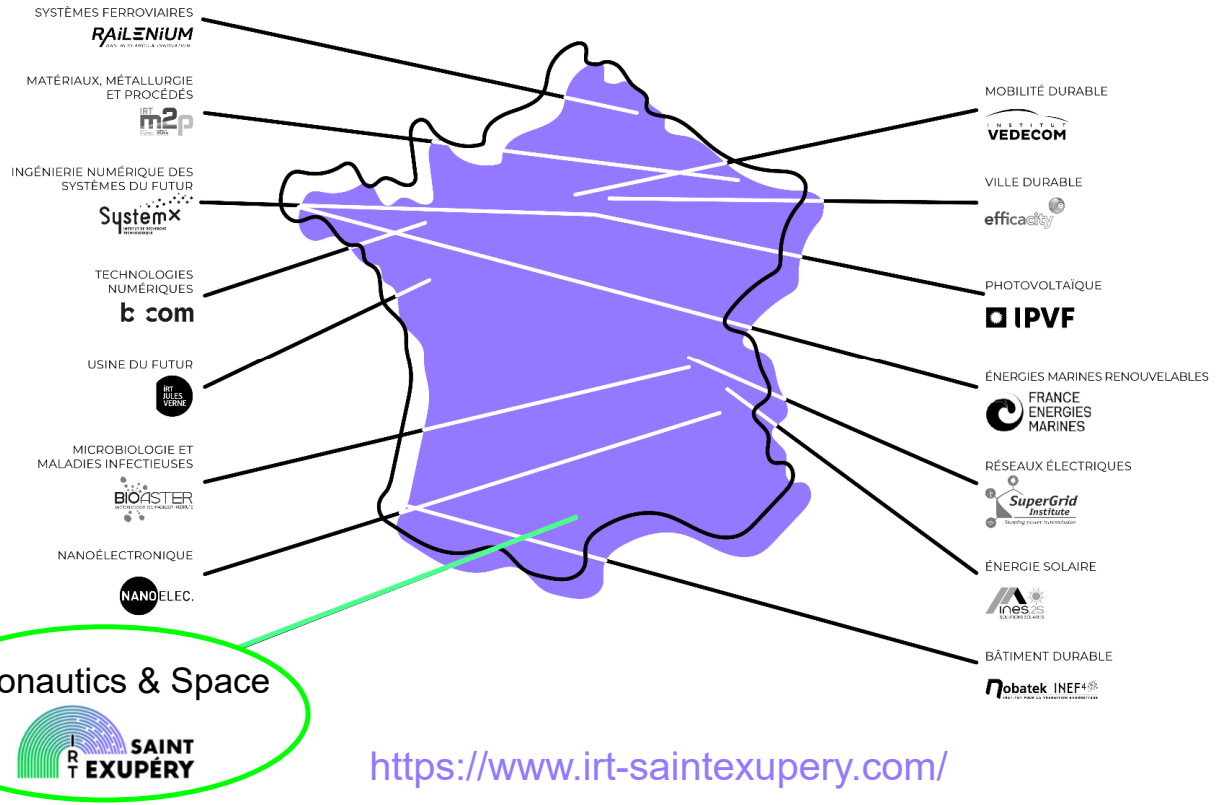
Our mission

Accelerate innovation & transfer from science to industry

Our DNA

Collaborative research with academia and industry

8 technological research institutes & **7 energy transition institutes**



https://www.irt-saintexupery.com/

Credible simulations for composite structures?

"Clean Aviation aims to develop, integrate and demonstrate disruptive technological innovations into new aircraft concepts by 2030-2035".
+30% energy efficiency by 2035. Paving the way towards « Net-zero emission aviation by 2050 »

What does that mean for industry?

- ❑ Combination of disruptive technologies related to the airframe with new propulsion systems and their integration.
- ❑ Reduce development time, product certification and overall time to market
- ❑ Ensure that disruptive new technologies meet high levels of safety and reliability
  - ❑ while shorter time for maturation of technology
  - ❑ while limited in service experience for some disruptive technologies

Key Enabler:

Credible simulation capabilities

Composite structures need to adapt to:

- ❑ New designs to integrate innovative systems, and further reduce mass
- ❑ New threats (e.g. exposure to cryogenic temperatures)
- ❑ New materials with possibly higher intrinsic variabilities (e.g. bio-sourced)
- ❑ New manufacturing/assembly processes (e.g. Out-Of-Autoclave, Welding)

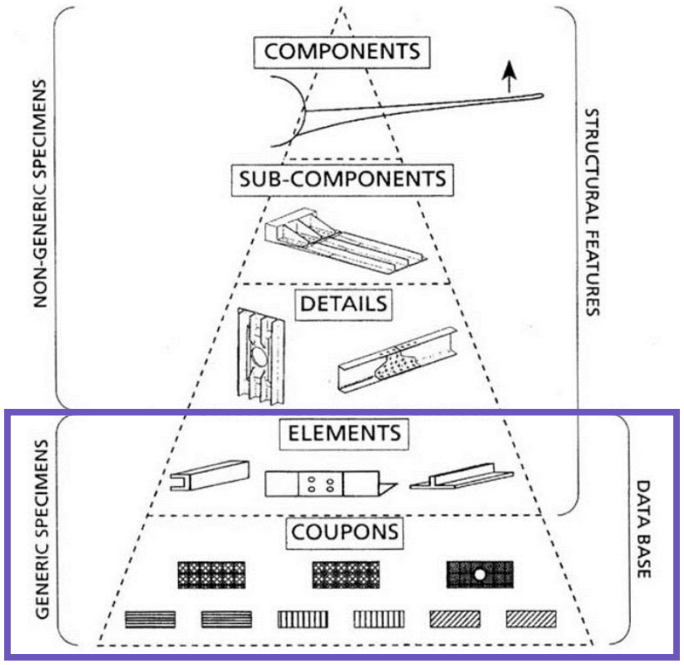
How to assess credibility?

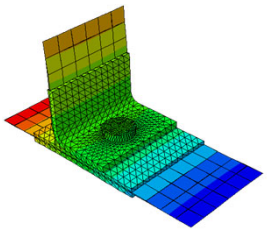
Building credibility of simulations for composite structures

Building block approach – system decomposition

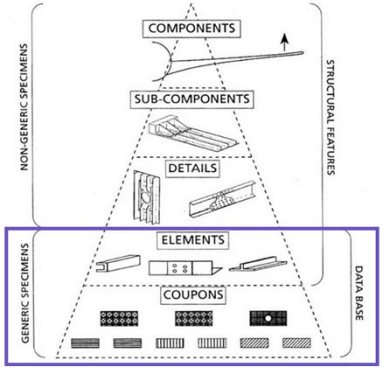
Considering lower-levels of the test pyramid :

- ❑ Composite damage models are already tractable at this scale
- ❑ A lever to reduce the lead-time to provide material allowables and/or validate design principles for (new) composite materials
- ❑ De-risk introduction of new materials, accounting for new physical phenomena, predict the KDF of manufacturing defects/singularities
- ❑ Build validated generic analysis capabilities



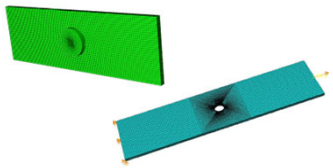


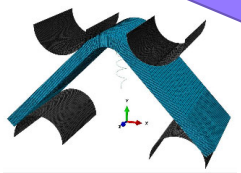
Building credibility of simulations for composite structures



Model definition / parametrisation

Validation Testing activities





Model implementation

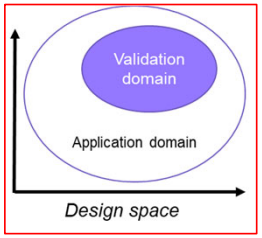
Calibration testing activities

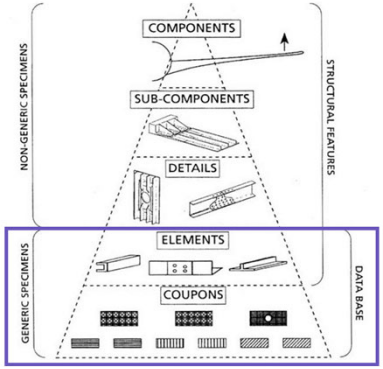
Model calibration

Model validation

Building credibility of simulations for composite structures

Selection of load cases / responses of interest / layups / important phenomena



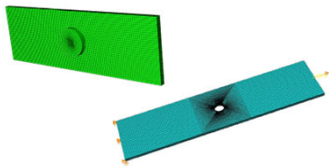


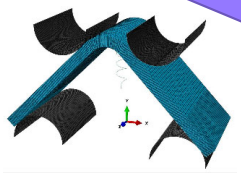
UQ

Model definition / parametrisation

Validation Testing activities

UQ





Model implementation **and verification**

Documentation

UQ

Calibration testing activities

Model calibration

UQ

UQ

Model validation

Inspired from : ASME V&V 10 standard for verification and validation in computational mechanics

Building credibility of simulations for composite structures

Example of PCMM after maturity assessment [Oberkampf 2007]

Credibility element

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

Maturity levels

Usage / Level	Scoping study	Preliminary design	Final design	Final design based on M&S
0	Individual judgment and experience			
1	Internal peer review & partially traceable data			
2	Formal assessment by internal peer review group, detailed characterisation and traceable data			
3	Formal assessment of accuracy and completeness by independent peer review group, precise characterisation and all data are traceable to formal references			

V&VUQ process should support the evidence-building for each credibility element

The need for a V&VUQ framework

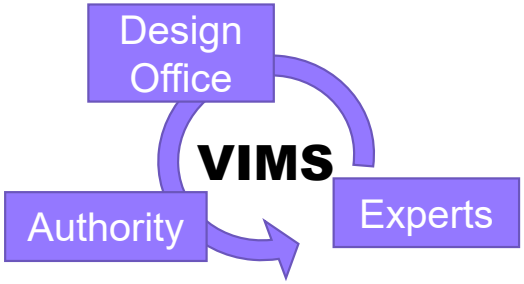
Building credibility is a complex process, relying on advanced methodologies.

Some challenges:

- ❑ Methodologies for Quantification of Uncertainties require expertise and should be adapted to the particular context of composite structures and models
- ❑ Provide model developers with established guidelines, tools, workflows, database management, to assess credibility of their models – identify limits and rooms for improvement for further modelling developments
- ❑ Allow comprehensive/unbiased comparison of models with complementary domains of validity
- ❑ Decision-making bodies should validate the process of establishing credibility
- ❑ Once credibility is assessed, models should be usable for particular design purposes within their domain of validity (optimisation, calculation of design values, structural sizing)

Proposal: capitalise V&VUQ capabilities/process into software platform(s) to support the community tackling these challenges

Software platform(s) for V&VUQ capabilities



A library for virtual testing integration and decision-making support

Develop V&VUQ specific capabilities

- ❑ Framework for model + knowledge integration / verification
- ❑ Configurable tools/workflows to implement the V&VUQ process
- ❑ Extraction of credibility indicators
- ❑ Visualisation dashboard to support decision-making
- ❑ Traceability of models and analyses / link with database
- ❑ Application-specific plugins (e.g. Composites)

GEMSEO

https://gemseo.readthedocs.io/en/stable/index.html

gemseo / dev / gemseo · GitLab

Develop generic capabilities for:

- ❑ (multi-disciplinary) analyses / optimisation / calibration
- ❑ DOE, Sensivitity analyses, Uncertainty quantification / Propagation
- ❑ Machine Learning / Surrogate modeling / Active Learning
- ❑ Wrapping of simulators (pure python, executables, …)
- ❑ Parallelisation / execution on HPC
- ❑ Generic visualisation

Focus on Validation

Choice of relevant error metrics (deterministic / stochastic)

Loading the model:

```
from vims.api import create_model, load_database
model = create_model("OpfmAbaqusPlate")
```

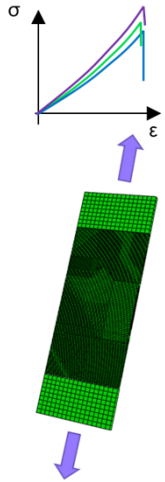
loading the validation tool:

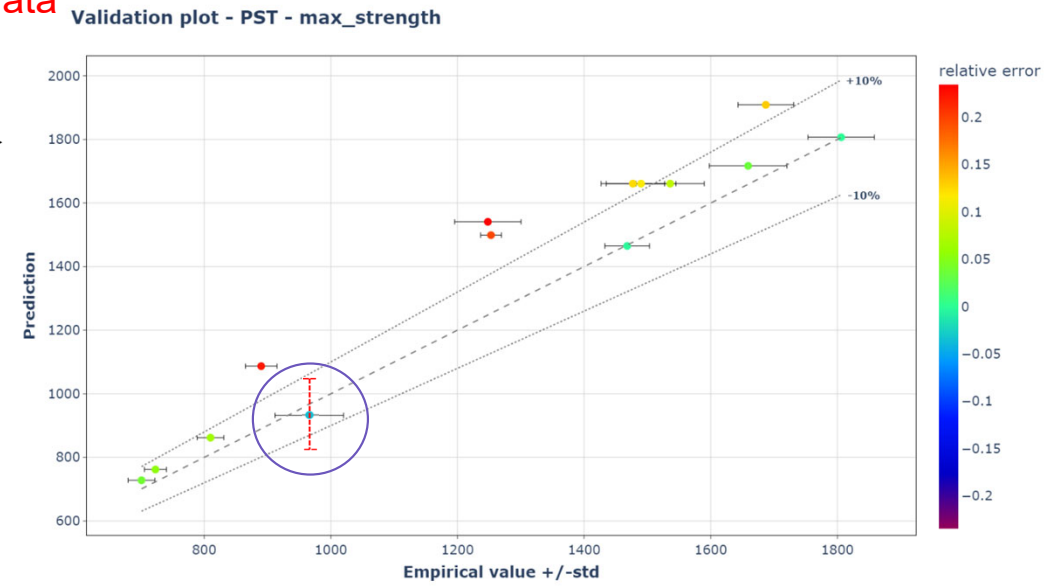
```
from vims.tools.validation_tool import ValidationTool
validation_tool = ValidationTool()
```

```
validation_tool.execute(model, data, property_database=pro
```

1 2 3

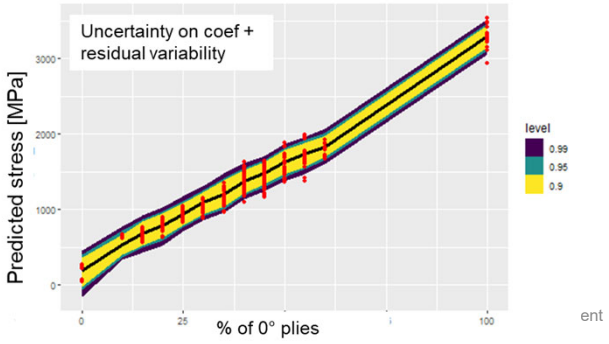
Validation data





Towards « global probabilistic» validation

Building a bayesian Linear Regression for Plain Strength Tension

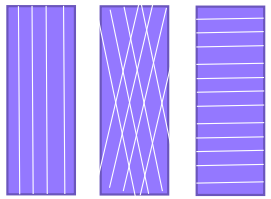


Validate the model prediction against trends/statistics captured by the data-driven model over the validation domain

Ongoing activities on related challenges (PhDs started end of 2022)

Smarter testing for calibration

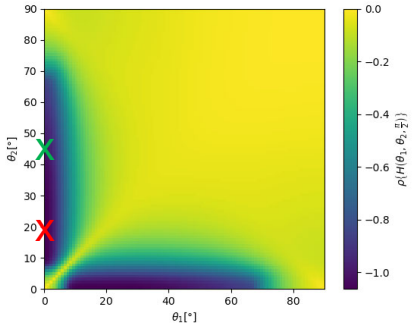
Define an optimal set of test specimen to calibrate composite constitutive models:



$\theta_{i=1,3} \in [0, \frac{\pi}{2}]$

Minimise uncertainty of the calibrated constitutive parameters

Results for elastic properties: [0°, 19°, 90°]

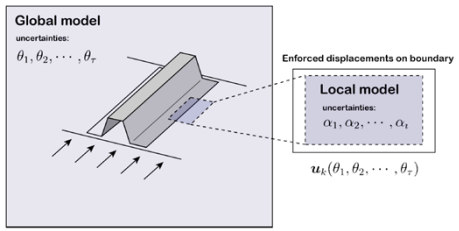


Collaboration

ICA

Scaling up / Bridging scales

Propagation of uncertainties through the scales:



Combination of HOST, Global/local techniques, Surrogate modelling for Composite Damage Models

Collaboration

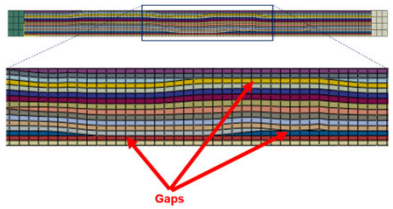
inegi driving science & innovation

AMADE ANALYSIS AND ADVANCED MATERIALS FOR STRUCTURAL DESING — Universitat de Girona

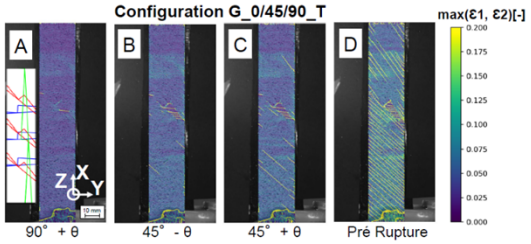
Modeling capabilities

Accounting for AFP defects:

Parametric multi-gap/overlap model



Tensile/compression tests with defects



Collaboration

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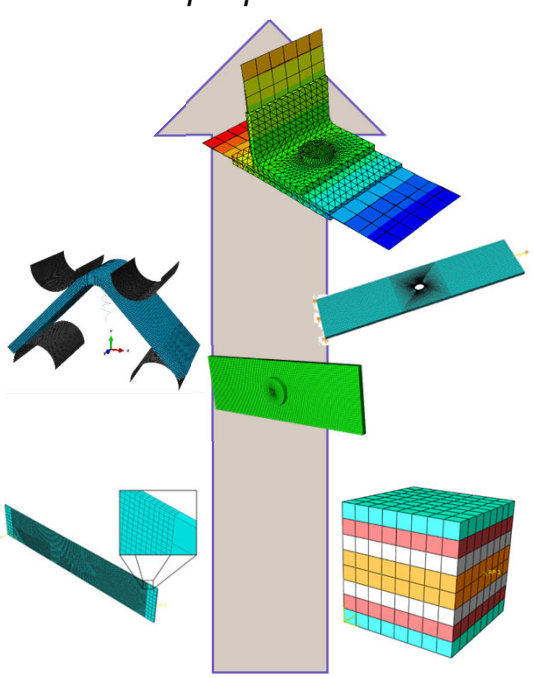
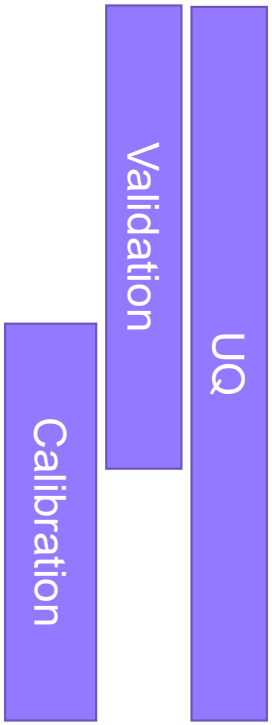
ICCM 23 INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS BELFAST 2023 30 JULY – 4 AUGUST

Conclusion

Multiple phenomena



Single phenomenon



- ❑ The topic of V&VUQ for composite damage models comes with numerous scientific issues
- ❑ It is an opportunity for the scientific community to transfer modeling capabilities and identify/cover the gaps
- ❑ It is a must for developping usage of advanced simulation to support certification of composite structures (in complement of V&VUQ-oriented experimental plan)
- ❑ Development of software capabilities should contribute to speed-up the setup and adoption of the V&VUQ framework

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TRUST Team

Stéphanie Miot
Bénédicte Reine
Florent Grotto
Sébastien Bocquet
Clément Laboulfie
Matthias De Lozzo
Stéphane Guinard (seconded from Airbus)
Jean-Philippe Navarro (seconded from Airbus)
Attilio Chiappini (seconded from Airbus)
Pierre Baudoin (seconded from Eikosim)
Romain Lopez-Surjus (PhD student) – *under the supervision of Jean-Charles Passieux, Robin Bouclier, Jean-Noel Perié*
Paolo Minigher (PhD Student) – *under the supervision of Albertino Arteiro, Albert Turon, Pedro Camanho*
Loic Marquet (PhD Student) – *under the supervision of Cédric Huchette, Christian Fagiano, Alain Rassineux*

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