Presented by

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Integrating Materials Modeling Aspects into the Industrial Analysis of Composite Structures

Composites Testing & Model Identification 2008

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Context for the Industrial Analysis of Composite Structures

- Constant innovation is necessary in order to reach the objectives (Weight, Cost and Time) set by new aircraft programmes.
- The introduction of new materials and technologies shall not degrade the current already agreed safety level (i.e., metallic structures).
- The developments must fit the industrial context, taking into account:

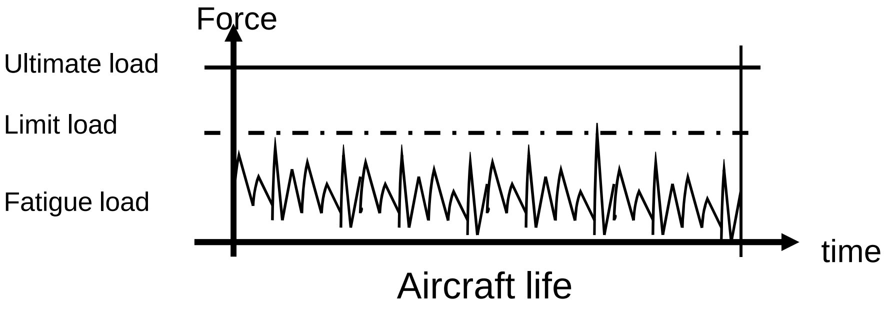
CERTIFICATION → FAR25/CS25; AC20-107A/AMC25.603; etc.

IN-SERVICE EXPERIENCE → f.y.i. : "How, over the past 30 years, 'Part 25' Composite Structures have been coping with metal minded F&DT requirements, J. Rouchon, 24th ICAF Symposium, Naples, Italy, 16 May 2007.

VERIFICATION & VALIDATION STATIC-F&DT ANALYSES → Improvement often refers to Virtual testing: This requires the development of physical and robust approaches to predict the deformation and failure of composite structures.

Context – Airworthiness requirements for Loads

- (FAR/CS25.301/.305/.307) Proof of structure:
  - *Limit load* without detrimental permanent deformation,
  - *Ultimate load* (1.5*LL) during 3s without failure,
  - *Maintain* in the time this ability.



- *Load Cases are combined Mechanical & Thermal, Example (Rudder) :*
  - 400 load cases such as mechanical (gusts, manoeuvres, ground), fail-safe, system failures, etc.
  - Combined with relevant hot/cold cases

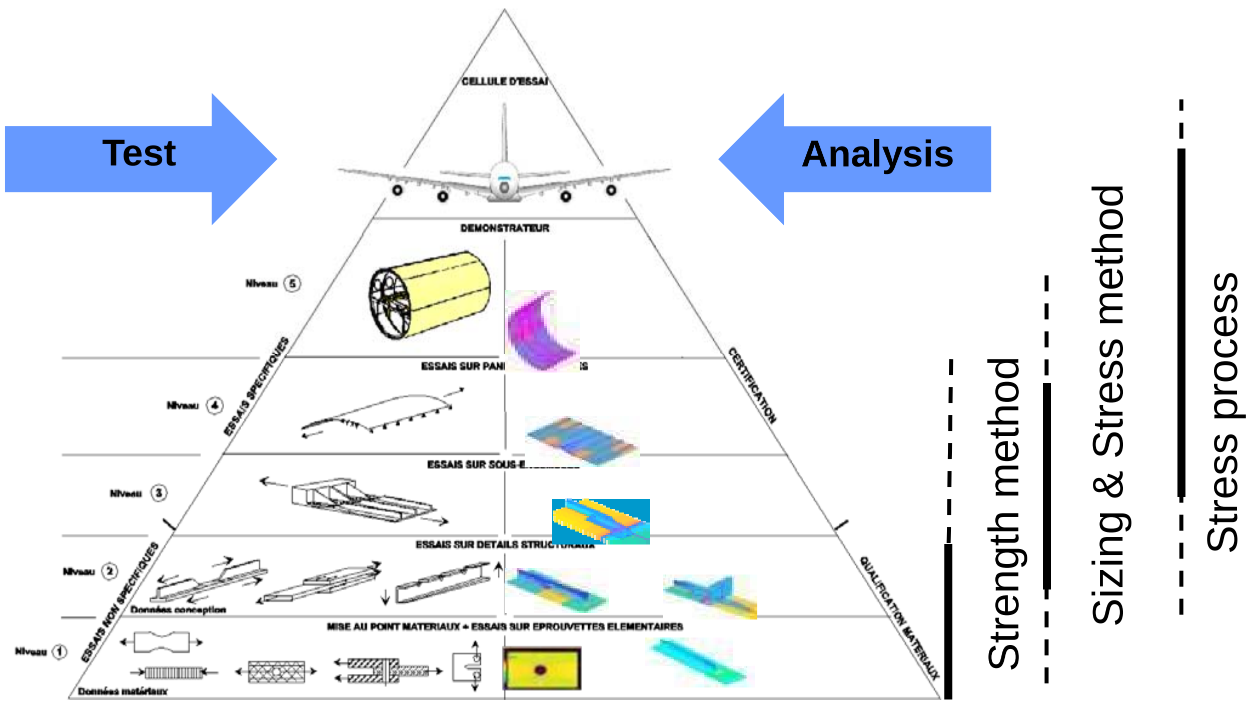
→ around 800 load cases, multi-axials.

Context – Proof of structure

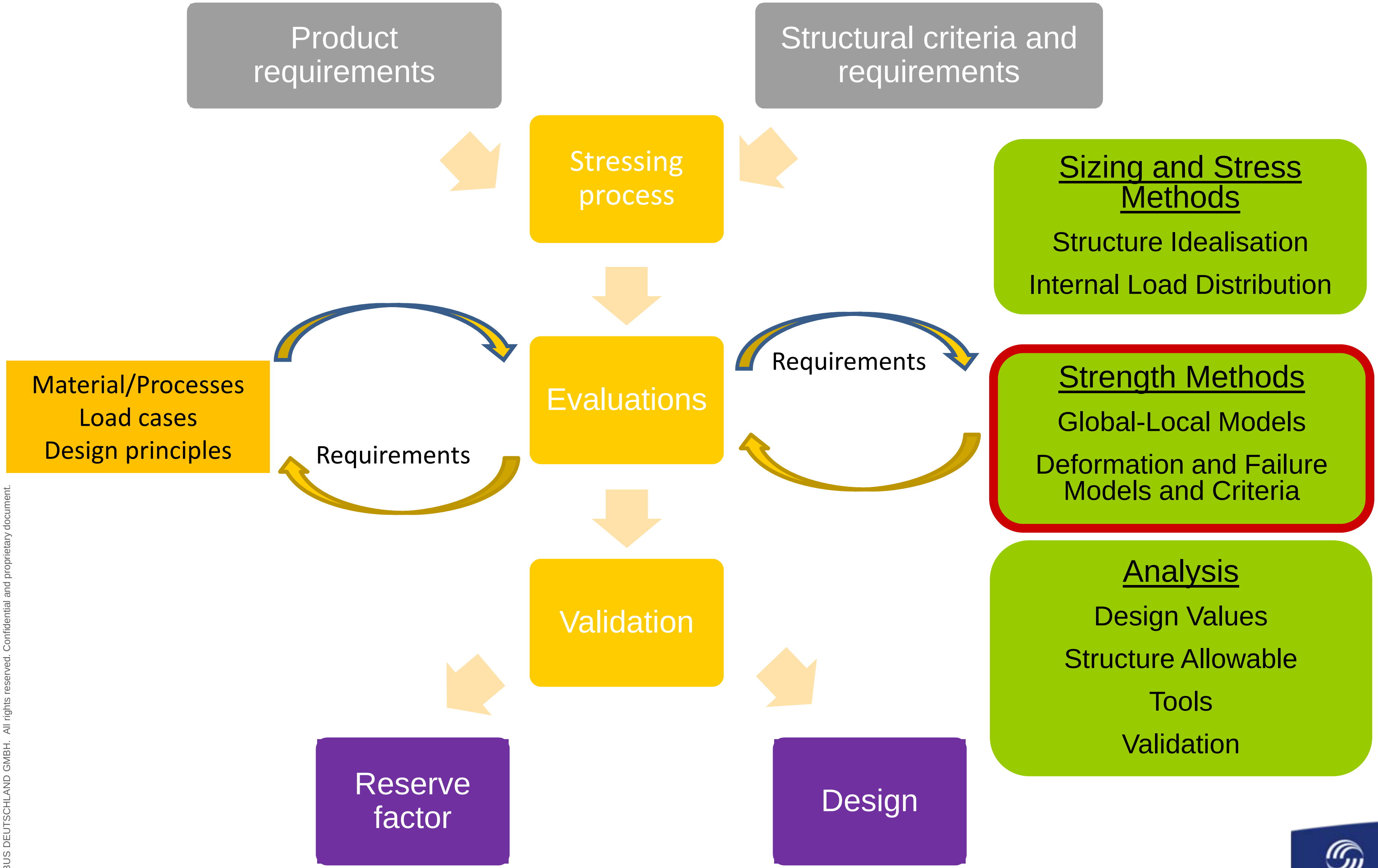
AMC25.307:… Compliance can be shown by :

- analysis supported by previous test evidence (best),
- analysis supported by new test evidence (most likely) or,
- by test only (impractical in most cases).

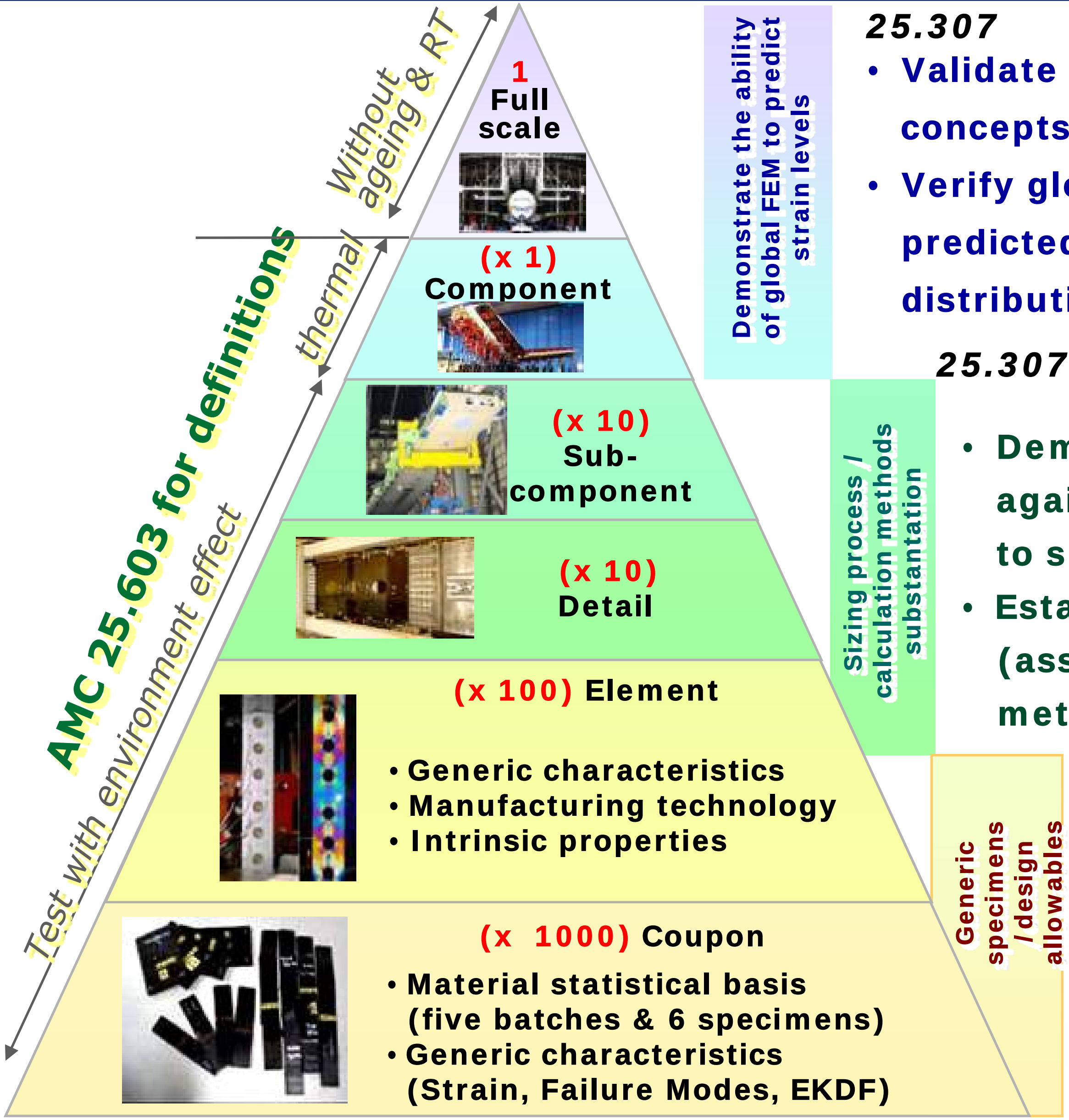
… The application of methods … to complex structures … is considered reliable only when validated by full scale tests …



Context – Structure Analysis



Context – Building-Block approach



25.307

- **Validate design & assembly concepts**
- **Verify global FEM predicted stress/strain distribution & analysis methods**

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- **Demonstrate / Validate accuracy against predicted failure mode up to specific features**
- **Establish process capabilities (assembly/parts vs inspection methods)**

25.603-605-613

- **Establish standards specification (materials / manufacturing)**

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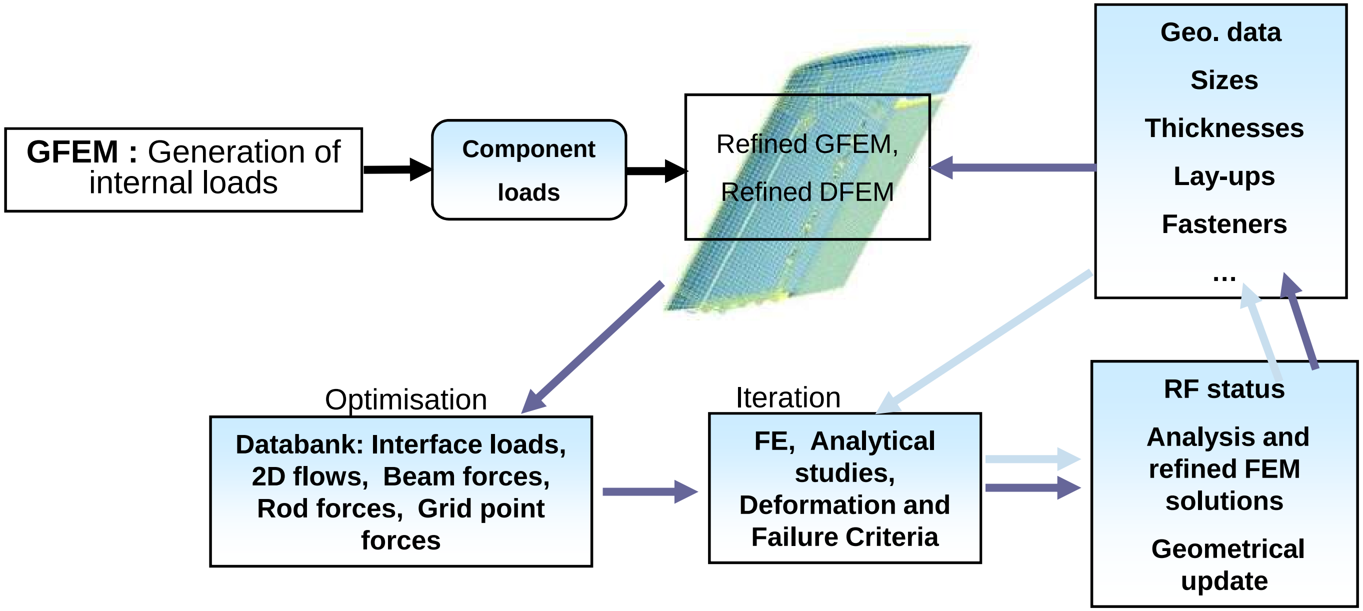
Stress Process

Several Design/Calculation loops taking into account all load configurations.



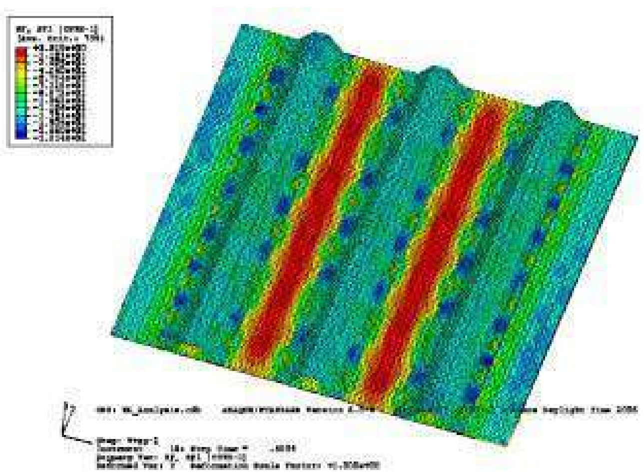
A Stress Process is required defining different level of analyses, e.g:

- Pre-sizing: fast evaluation (max. simplifications, gross accuracy),
- Quick Sizing with accuracy in line with simplifications,
- Advanced Sizing for state-of the-art calculations.

Sizing and Stress methods

- Multi-criteria analyses are performed on details, components, elements:
  - Stiffened panels, Lugs, Joints, etc.
- These can be analytical/numerical with assumption in-line with the levels of analysis (Pre-sizing, Quick Sizing or Advanced Sizing).

Ex: Advanced Stiffened Panel sizing

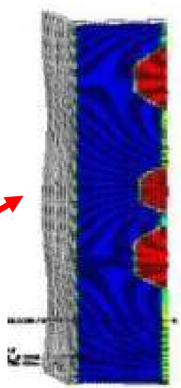


	Skin local buckling	Crippling	Global buckling	Stringer disbonding	Plain Strength
Prediction					
TEST					

Global-Local Analyses

(Strength Methods

after critical area selection)



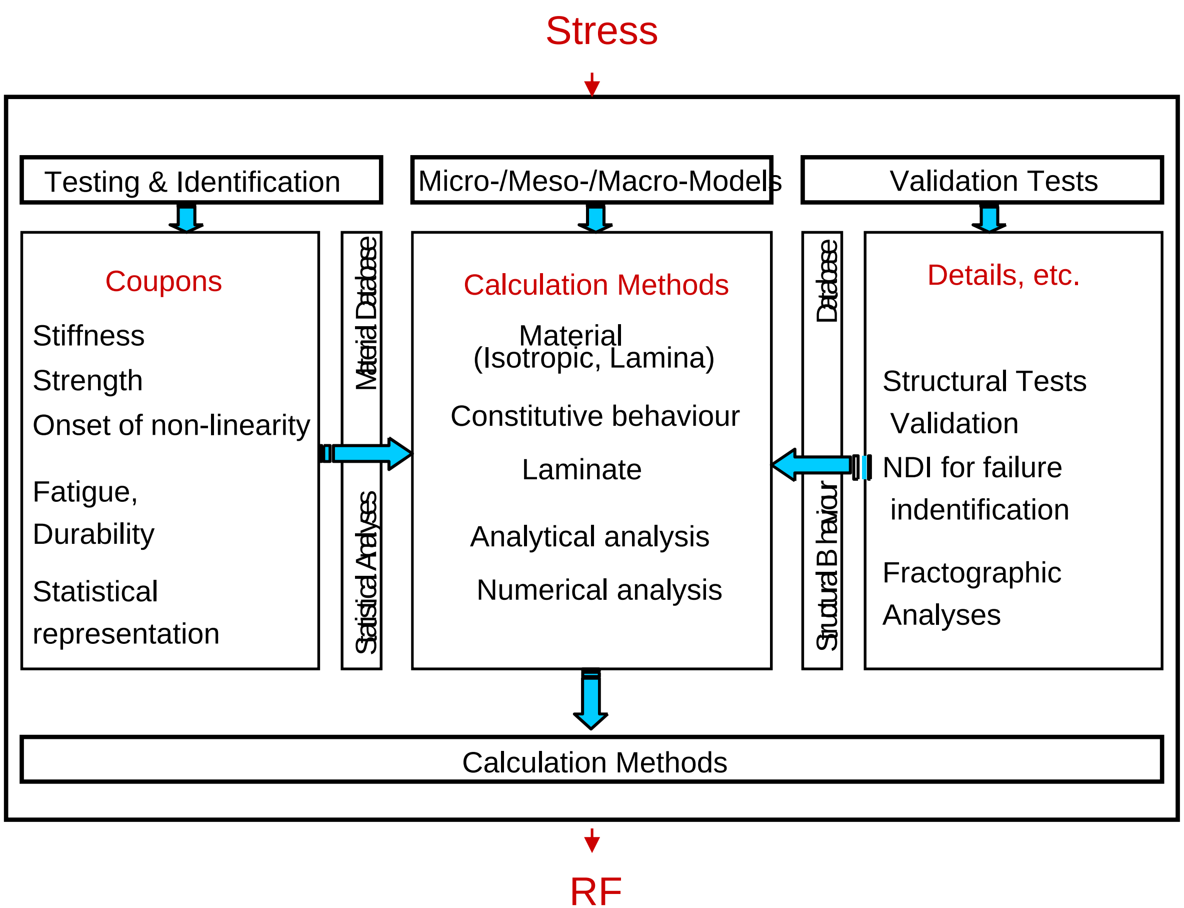
- Disbonding analysis

- Classical Laminate Analysis,
- Degradation law,
- Fibre & Matrix Failure Criteria

Integrating Materials Modeling Aspects - Strength Methods

- Stress Process and Sizing Methods secure Internal Load Distributions.

→ Integration of material modelling aspects and strength calculation is done in Strength Methods.



Consequences for Methods and Tools

⇨ Methods and Tools are validated inside a specific perimeter that include: technologies, design features, loading, …

⇨ This means we cannot just use any calculation methods combined with any material data.

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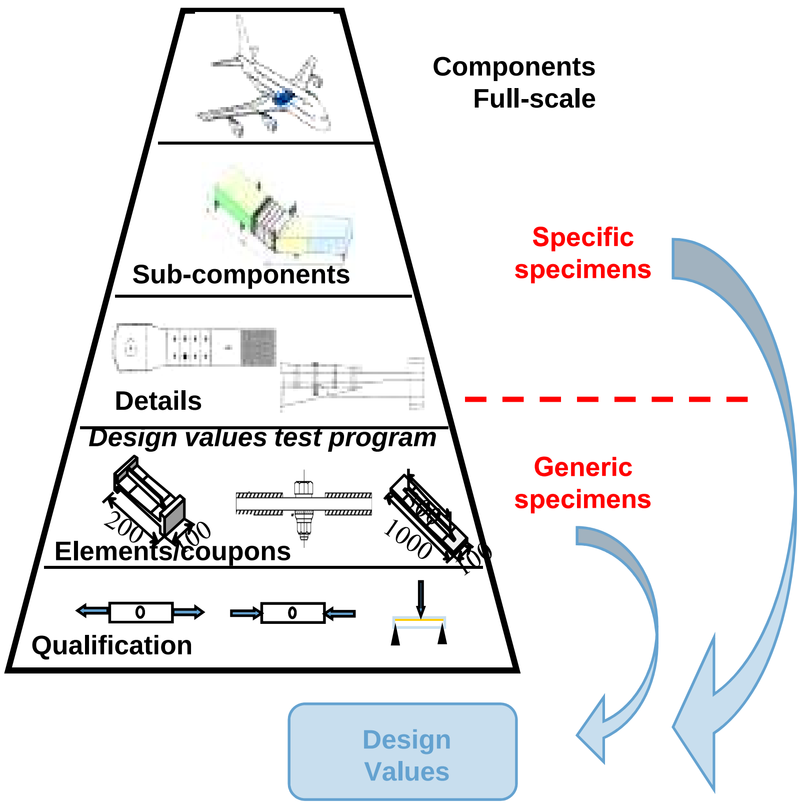
Development of Plain Strength Criteria

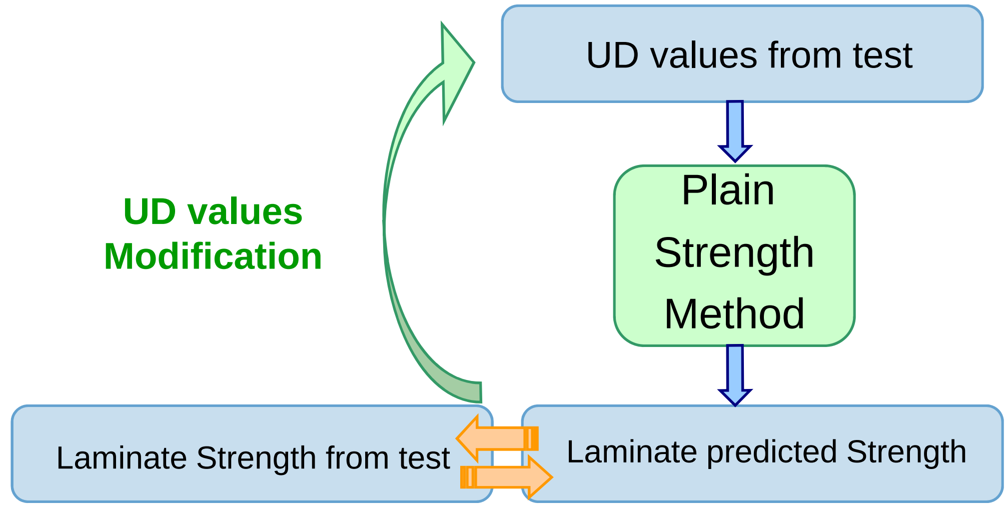
Determination of Design Values (CS25.603/.605/.601, see *AC20-107A / AMC25.603):* assessment of environmental effects on the design properties through tests and established on a statistical basis.

Certification test pyramid



Example of definition of DV

For Plain Strength

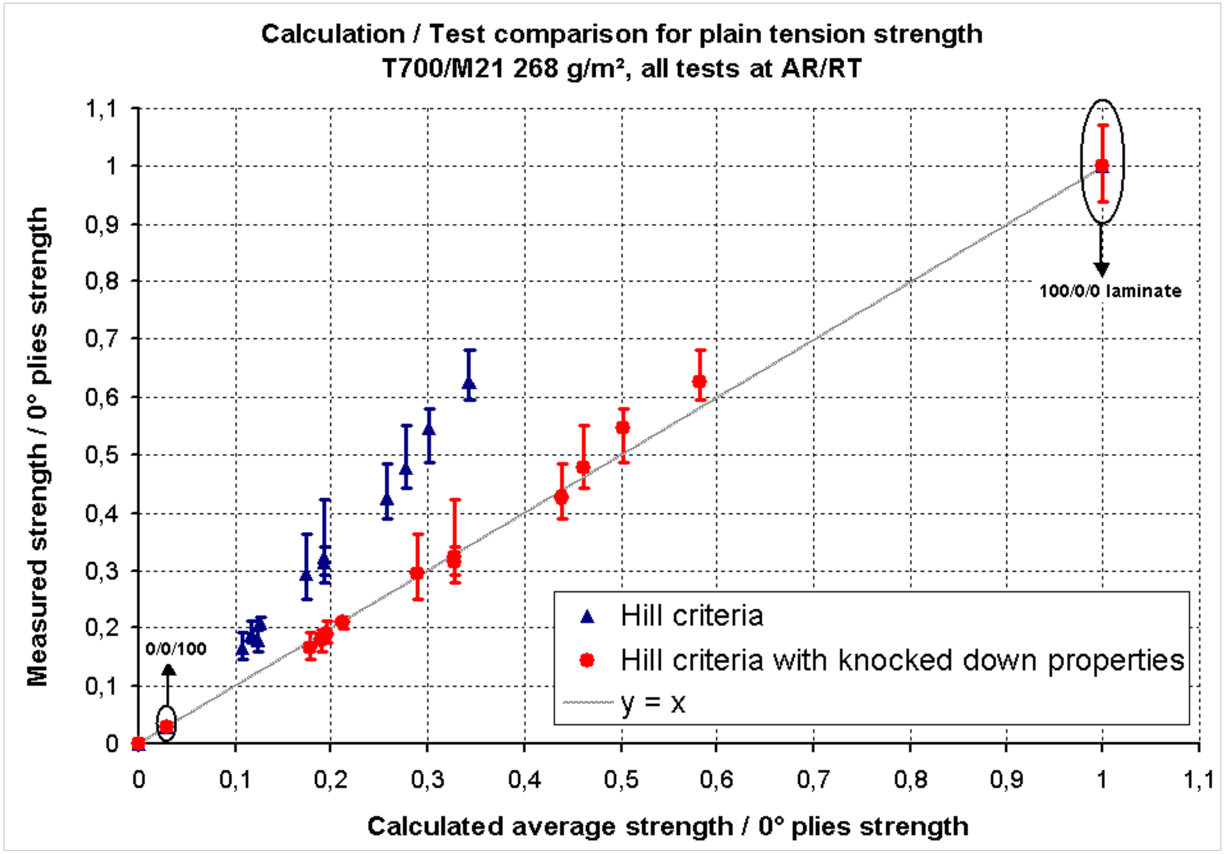


Development of Plain Strength Criteria
Early developments

Early method based on Tsai-Hill criteria & first ply failure:

- Direct use of UD properties values lead to underestimation

⇒ UD properties tuned (resin moduli knocked down) to cover the structural space.



Design Values are defined and validated for a particular design/structural space (technology, design features, loading, etc.) and are always linked to a calculation method

Development of Plain Strength Criteria State-of-the-Art

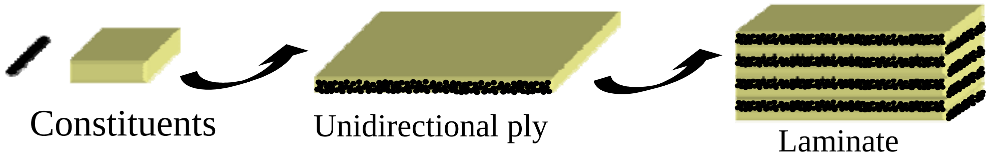
Later approach: Progressive matrix degradation + fibre failure

- Matrix failure analysed with Matrix criteria & stiffness degradation
- Load redistribution until Fibre failure analysed with Fibre criteria

Current development – Physically-based Multi-scale analyses

Choice of the modelling scale

- *Macroscopic scale*
- *Mesoscopic scale*
- *Microscopic scale*

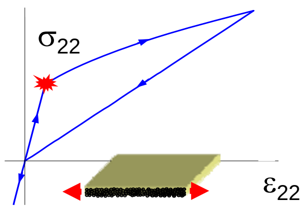


Mesoscopic behaviour

- *Linear elastic behaviour*
- *Non linear elastic behaviour*
- *(Visco)-plastic behaviour*
- *Visco-elasticity*

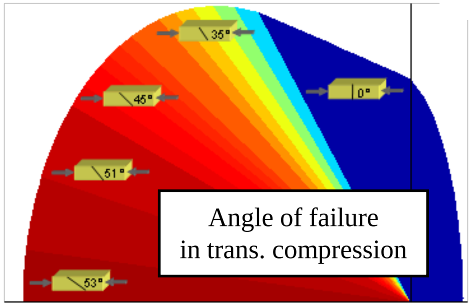
Degradation model

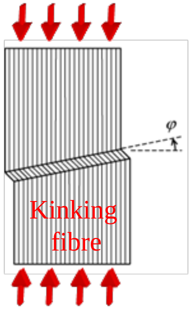
- *Instantaneous degradation*
- *Micromechanical model*
- *Damage model*



Mesoscopic failure criterion

- *Maximum stress criterion*
- *Quadratic criterion*
- *Puck criterion*
- *LARC failure criterion*
- *Etc.*



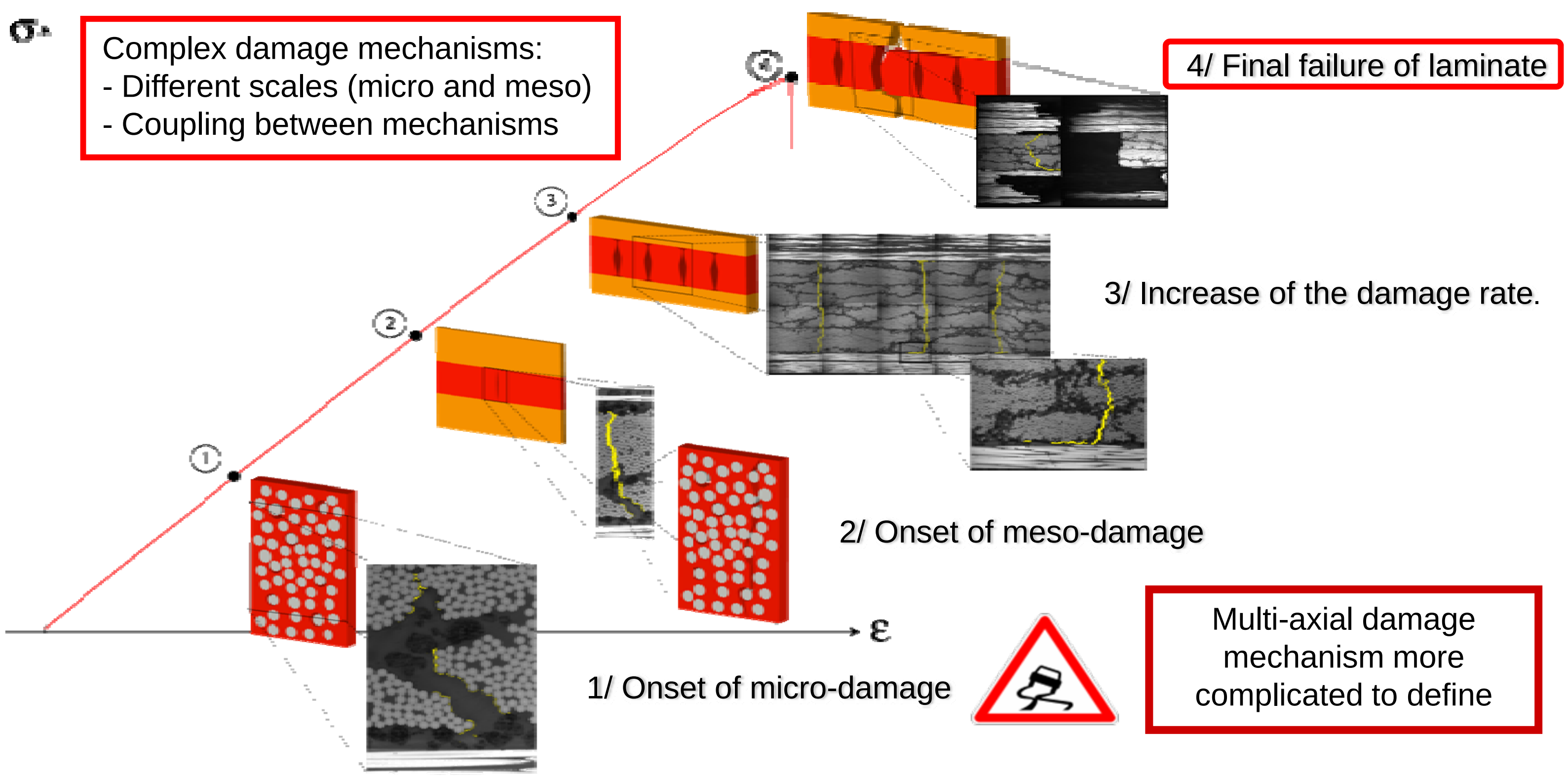


Development of Plain Strength Criteria State-of-the-Art

▪Multi-Scale analyses aims at predicting deformation and final fracture of composites. Difference with semi-empirical approaches:

- •Physically-based, allowing for greater predictive capability,
- •But more complex in terms of testing (model identification) and analyses.

e.g., Multi-scale Approach of Laurin, Maire & Carrere (ONERA):



Development of Plain Strength Criteria Perspectives

Challenges still ahead of us for wide-scale industrialisation:

- High strain gradient areas (notches and holes)
- Out-of-plane failure modes
- Effect of Defects, Damage Tolerance, Durability.
- Guidance and Standardisation on Tests / D&F parameters.

There remains still Experimental vs. Theoretical views…

Validate approach against:

- Multi-axial loading,
- Different stacking sequences and realistic design features,
- Manufacturing – NDI capabilities,
- Consider scale effect, Natural variability in results, Etc.

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Conclusions and Perspectives

The industrial context:

- Constant innovation is required.
- Safety is secured through means of compliance.
- Analyses must be accurate, robust & adapted to the need.

The perception from research:

- Precise, but Often limited (UD, non industrial lay-ups),
- Accuracy / Volume of analyses not considered,
- Experimental / Theoretical could be better bridged:

⇨Interaction between Model and Identification could be clarified, Standardisation of tests is crucial.

⇨Investigation of Effect of Constituents and manufacturing deviations on performance is rarely addressed.

Conclusions and Perspectives
Drivers for new developments

INCREASED PERFORMANCE

REDUCED DEVELOPMENT CYCLE

CONTROLLED STRUCTURAL INTEGRITY

CONTROLED MATURITY FOR NEW MATERIALS AND TECHNOLOGIES

REDUCTION OF DIRECT AND INDERECT (repair, maintainability) COSTS

Understanding of D&F properties of materials

Physical understanding (failure modes, fibre/resin functions)

Calculation methods adapted to the need : from Pre-Design to Advanced Calculations.

Trade off between Complexity ↔ Accuracy

Robust Validation by testing and analysis at all levels of the test pyramid

Predictive ⇔ cost savings

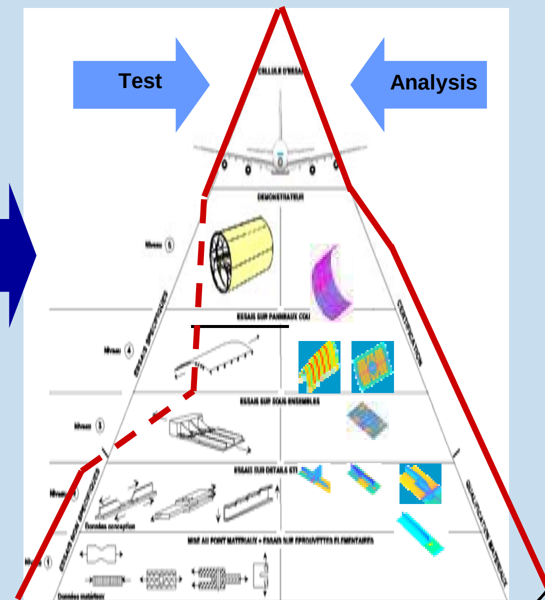
Accurate ⇔ weight savings

Tool development and deployment to extended enterprise

Control of design/stress space

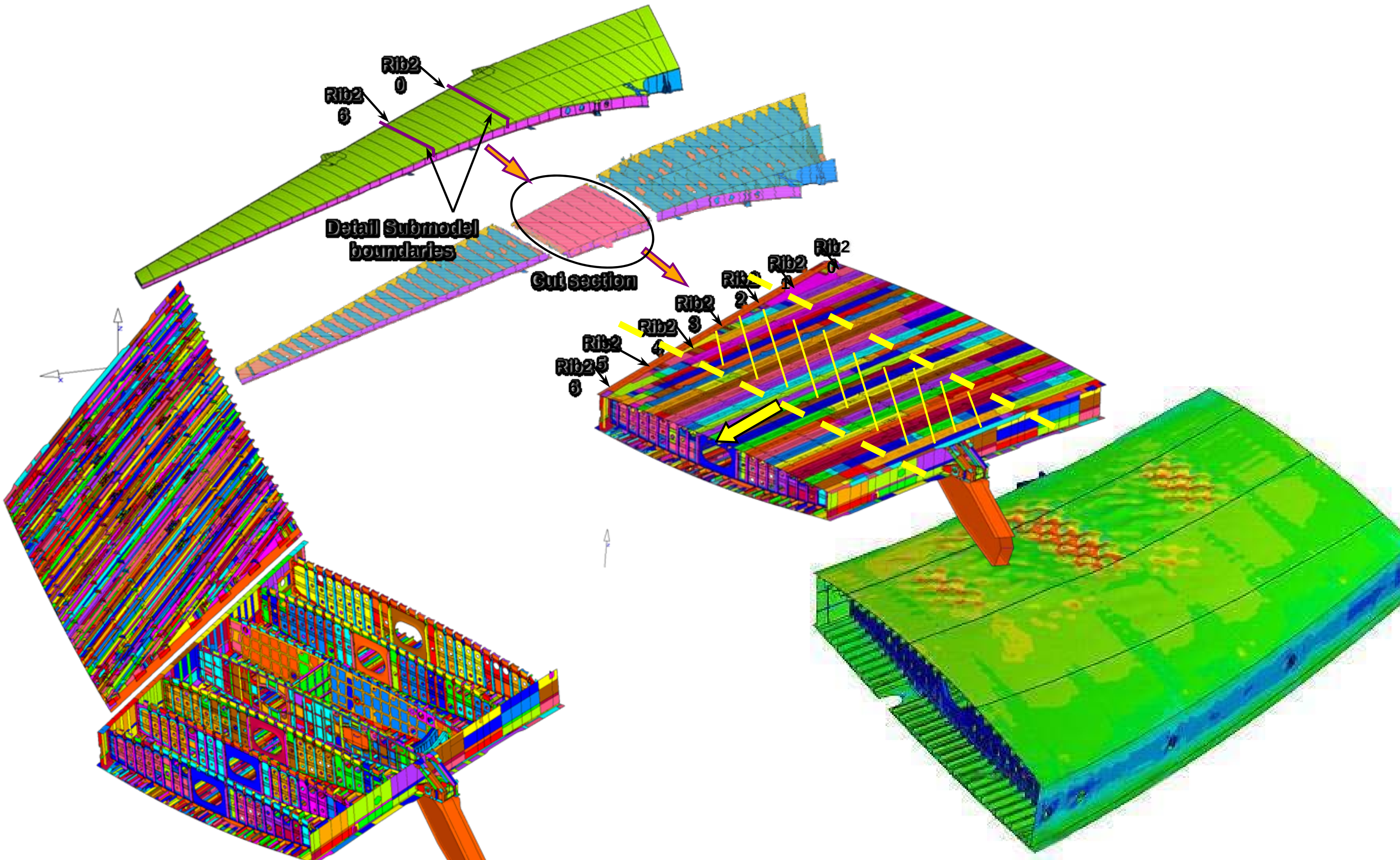
Aircraft Development

Enable Virtual Testing



Conclusions & Perspectives
The not so distant future

Implementation of industrial and validated multi-scale, multi-level, robust, analyses into large NL simulations



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