Design Optimization of Layered Composite Structures

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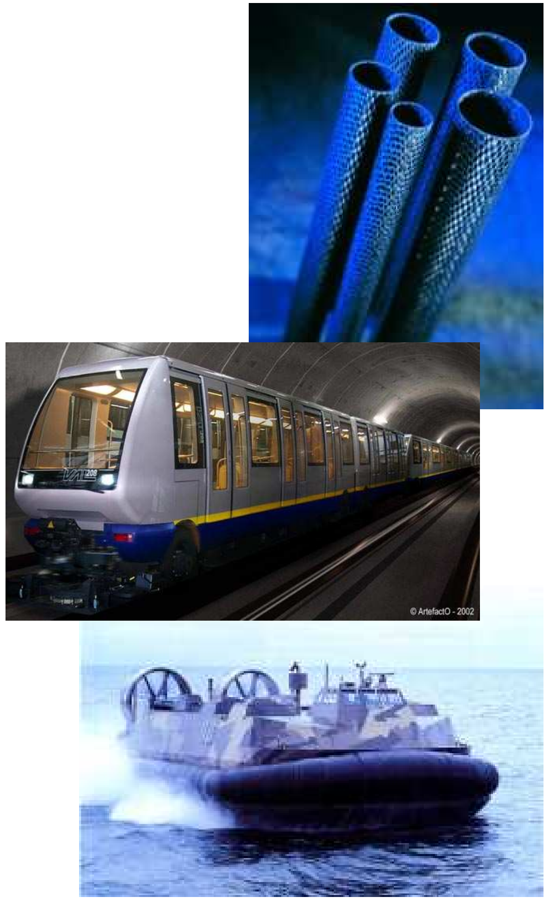
OUTLINE

- Challenges of composites optimization
- Parameterization of laminate structures
- ESAComp-modeFRONTIER development
- ESAComp in use: Electric sports car
- Conclusions

Photos courtesy of ESA, Oerlikon Space AG, FACC AG,
FY-Composites Oy, EC-Engineering Oy, Exel Oyj

CHALLENGES OF COMPOSITES OPTIMIZATION

- Optimization problems quickly become overwhelming in terms of designs; material selection for each layer, number of layers, layer orientations, stacking sequence
- Possibility to use solid laminate, sandwich and stiffened structures
- Composite failure modes are numerous: fiber failure, matrix degradation, interlaminar shear, core shear failure, face sheet wrinkling, …
- Primary concerns are typically the global behavior; stiffness, strength, stability, vibration
- The advantages of expensive composite materials can be utilized only with the use of appropriate design and analysis methods



Photos courtesy of Exel Oyj,
EC-Engineering Oy, FY-Composites Oy

LAMINATE FORMULATION CONCEPT

- Layer multiplier concept is applied
- All layer orientations simply stacked one after the other in predefined order

$$\Theta_1, \Theta_2, \ldots, \Theta_k$$

- Number of layers in the same orientation is defined by multipliers N_k

$$[(\Theta_1)_{N_1}/(\Theta_2)_{N_2}/\ldots/(\Theta_k)_{N_k}]$$

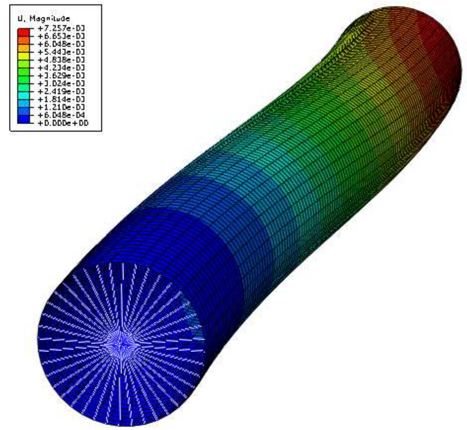
- Stacking sequence is considered utilizing a permutation vector
  - e.g., for 3 allowed layer orientations

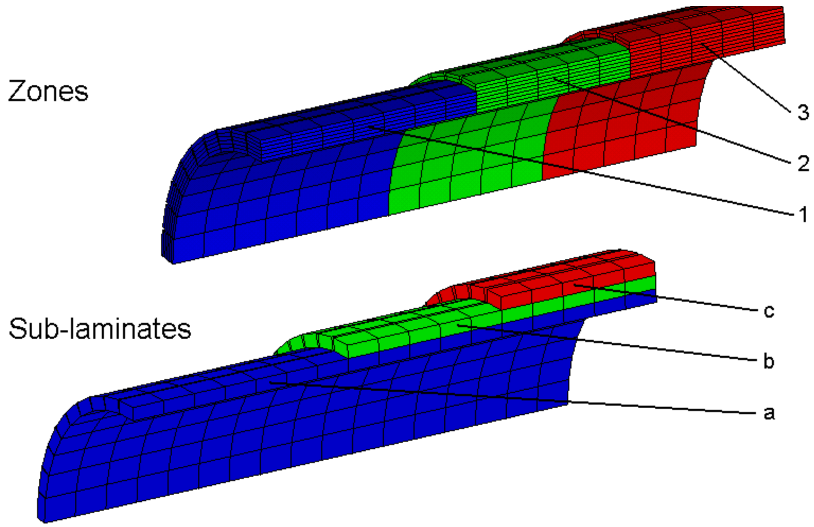
$$\vec{s} \in \mathbf{S} \quad \text{with} \quad \mathbf{S} = \left\{ \begin{pmatrix} 1 \\ 2 \\ 3 \end{pmatrix}, \begin{pmatrix} 1 \\ 3 \\ 2 \end{pmatrix}, \begin{pmatrix} 2 \\ 1 \\ 3 \end{pmatrix}, \begin{pmatrix} 2 \\ 3 \\ 1 \end{pmatrix}, \begin{pmatrix} 3 \\ 1 \\ 2 \end{pmatrix}, \begin{pmatrix} 3 \\ 2 \\ 1 \end{pmatrix} \right\}$$

- Multiple material systems are supported

ZONE-BASED vs. PLY-BASED MODELING

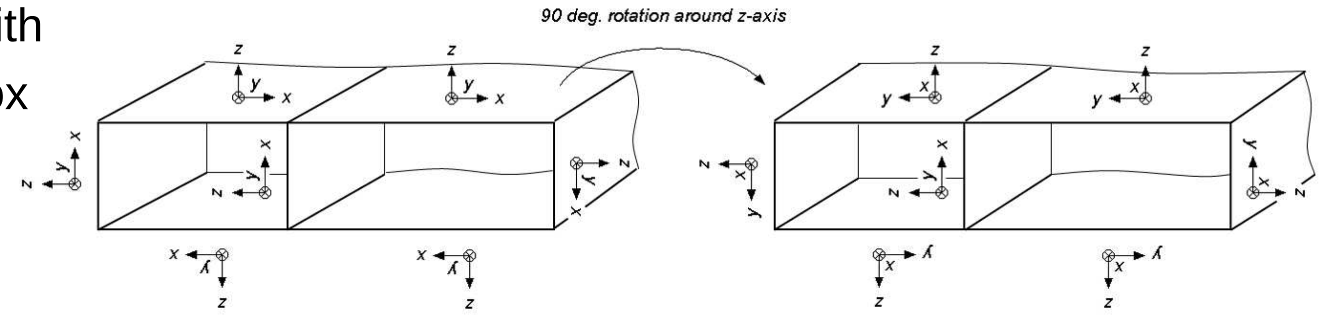
- In traditional FE modeling the structure is divided in zones for which laminate lay-ups are defined
- In ply-based modeling the model is constructed from the manufacturing point of view from individual plies
- In the ESAComp optimization process these concepts are joined
  - instead of dealing with individual layers, sub-laminates are used
- Dependencies between the laminate lay-ups of different zones are described with sub-laminates

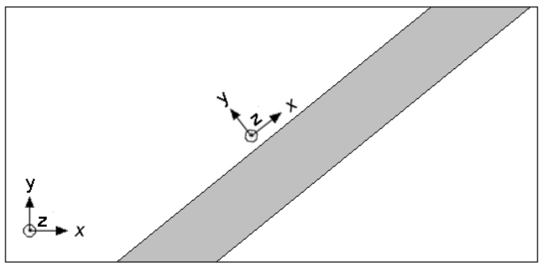


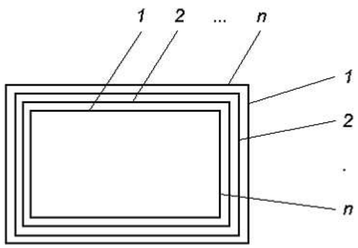


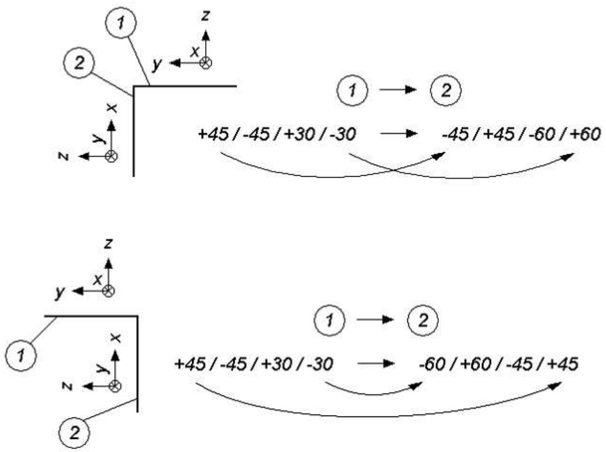
COORDINATE SYSTEMS

- Adjacent laminate structures may have common sub-laminates but different element coordinate systems
  - examples: plate with patch (left), beam box (right)
- In the ”slave” zones the sub-laminate is re-oriented









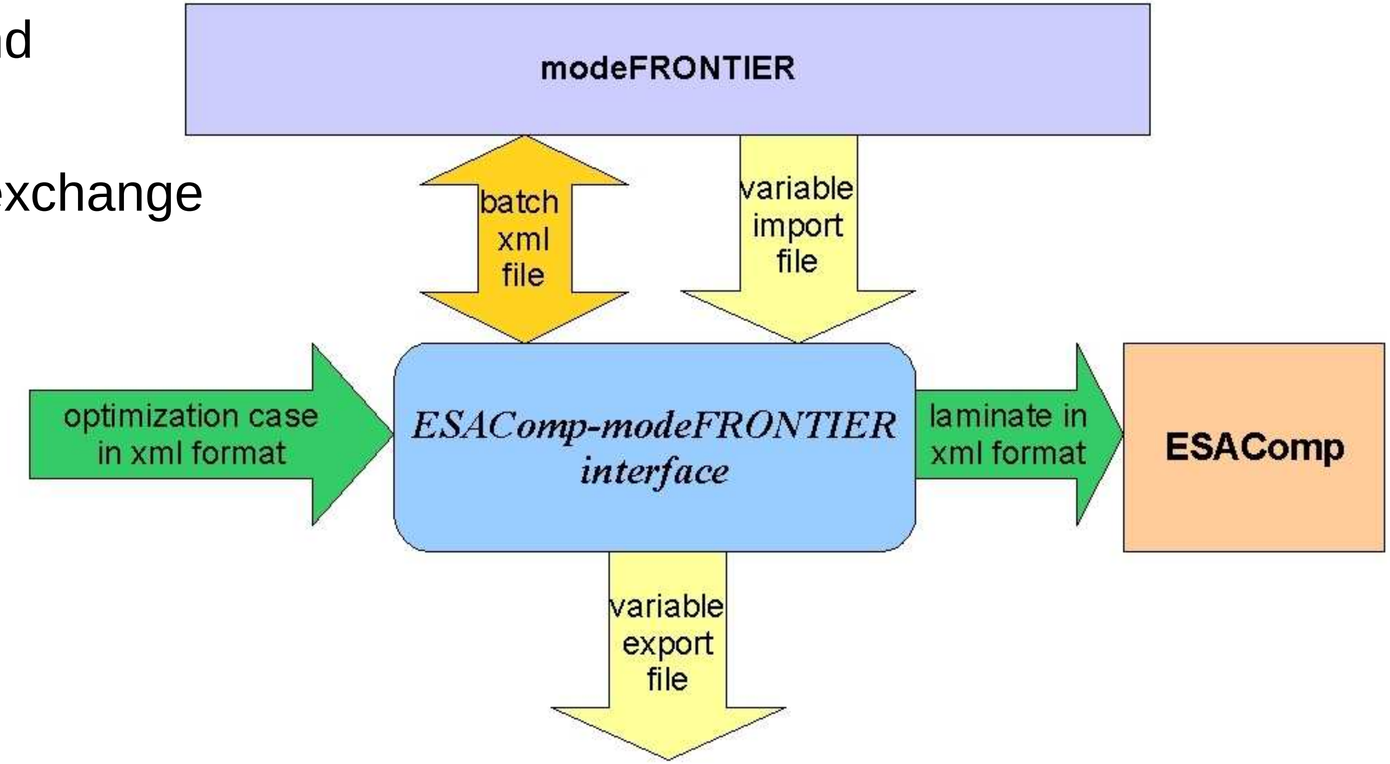
ESAComp-modeFRONTIER FOR COMPOSITES OPTIMIZATION

- Componeering develops ESAComp-modeFRONTIER based composites optimization solutions in collaboration with EnginSoft / Esteco
- modeFRONTIER provides
  - multi-objective optimization capabilities
  - process integration environment
  - visualization of results
- ESAComp provides
  - material libraries, preliminary design capabilities
  - laminate and structural element level analyses
  - integration with FEA
  - advanced post processing capabilities (ComPoLyX)
  - concept of elementary laminates (under development) for defining realistic engineering oriented lay-up optimization tasks
- General FE software tools are used for the analysis of the complex structure

modeFRONTIER Multi-Objective Optimization and Design Environment

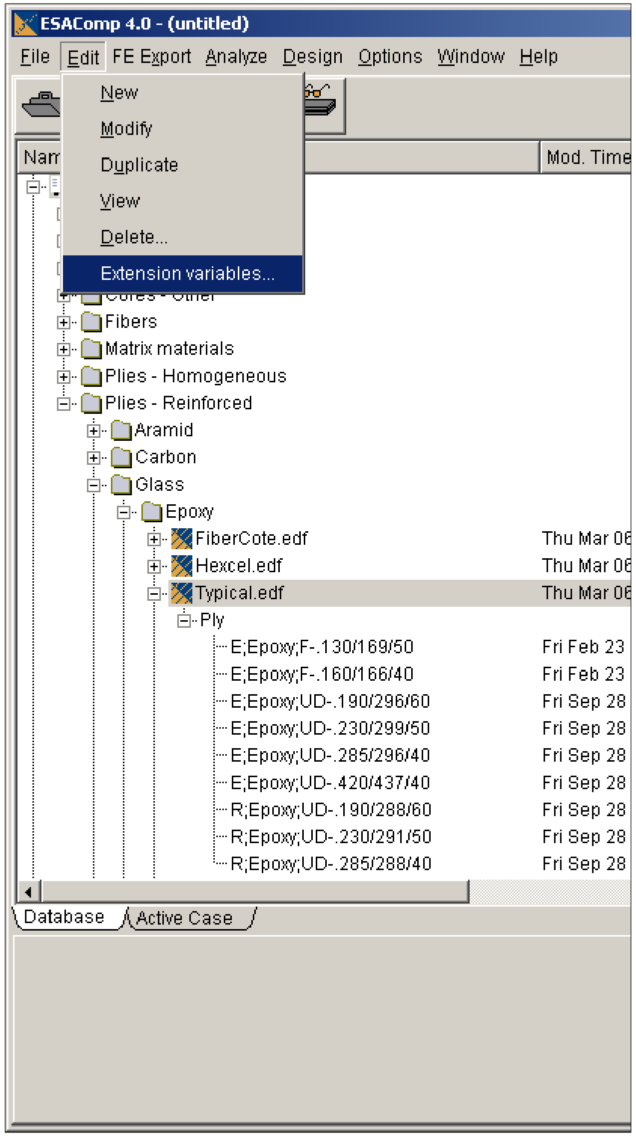
ESAComp-modeFRONTIER INTERFACE

- Tool for the description composite optimization problems including the dependencies between zones and sub-laminates
- XML based data exchange



MATERIAL DATA

- All material data is stored in ESAComp case file
- User preferred material names can be used
  - FE model specific material ID's are specified through ESAComp
- Later, also shell section ID's (elset), reference planes, and section orientations are specified
  - in the current implementation this data is specified in input files



INPUT FILE STRUCTURE

- Divided into 3 main parts:
  - Materials and material groups
  - Sub-laminates
  - Laminates

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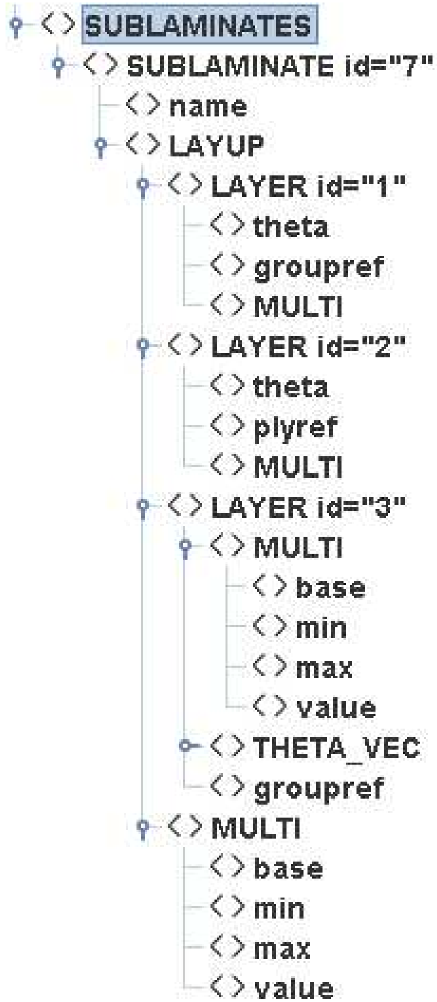
SUB-LAMINATE STRUCTURE

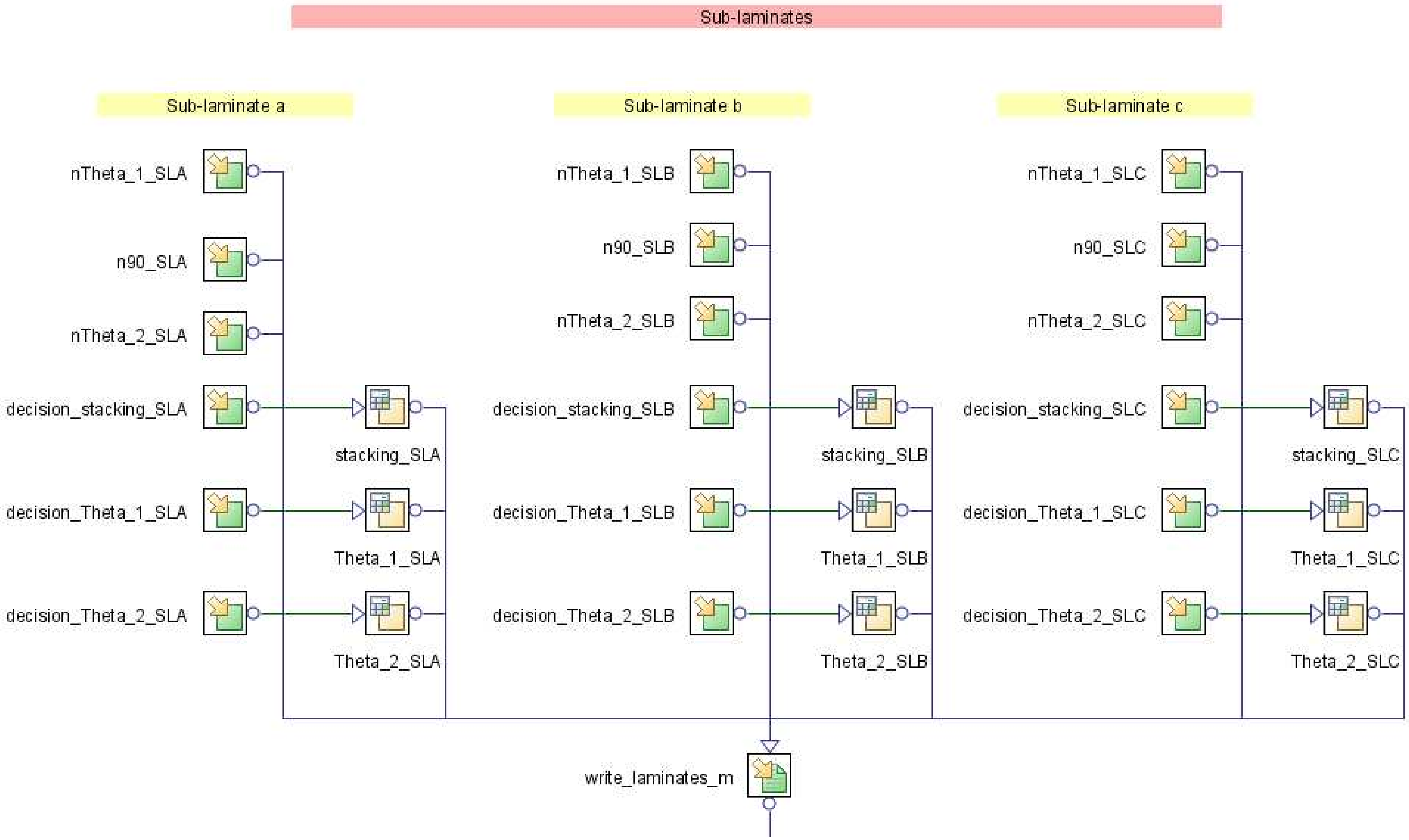
- Two different types for sub-laminate definition
  - simple
  - with stacking sequence permutation

- Several alternatives to define available materials, multipliers and set of orientation for each layer

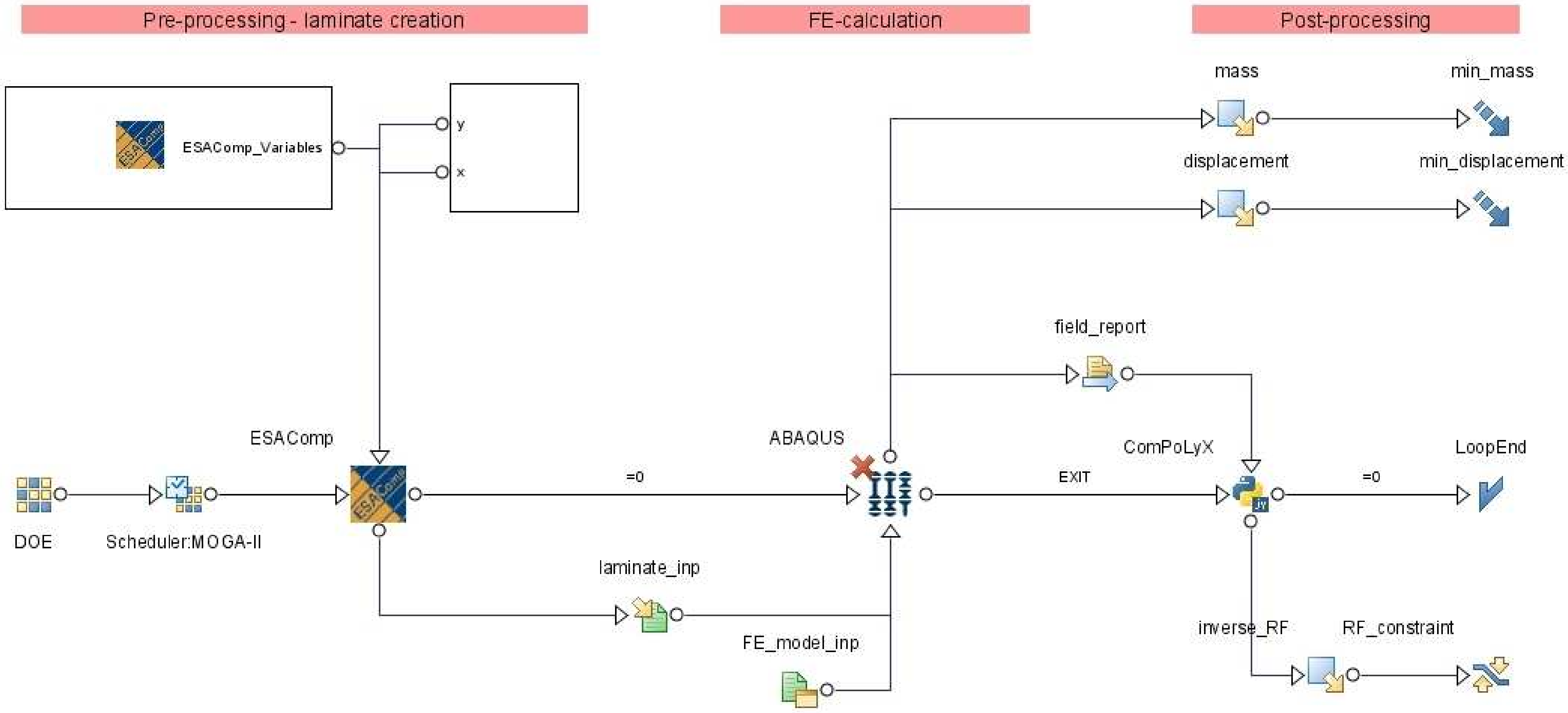


modeFRONTIER EXAMPLE - A SHAFT WITH THREE SUB-LAMINATES

- Illustration of traditional repre-sentation of design variables for composite optimization in mF

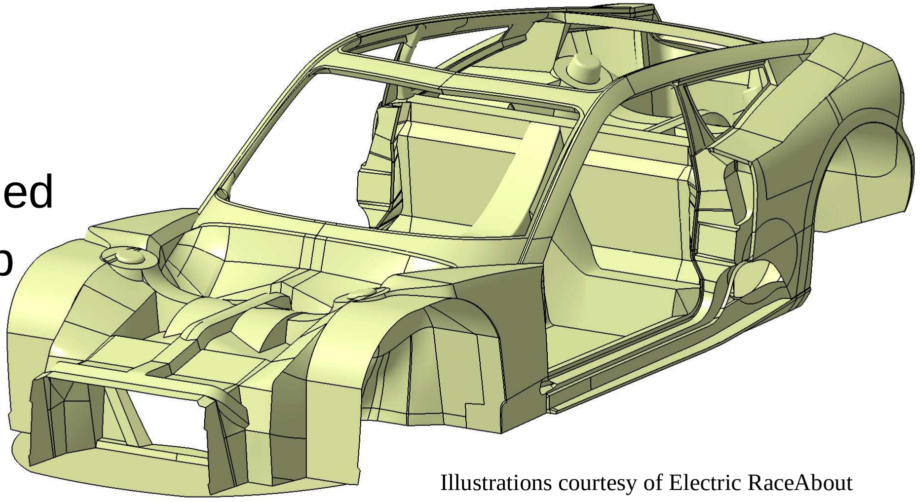


modeFRONTIER EXAMPLE WITH ”ESAComp NODE” in the DESIGN PROCESS



ESACOMP IN USE: ELECTRIC RACING CAR, ERA

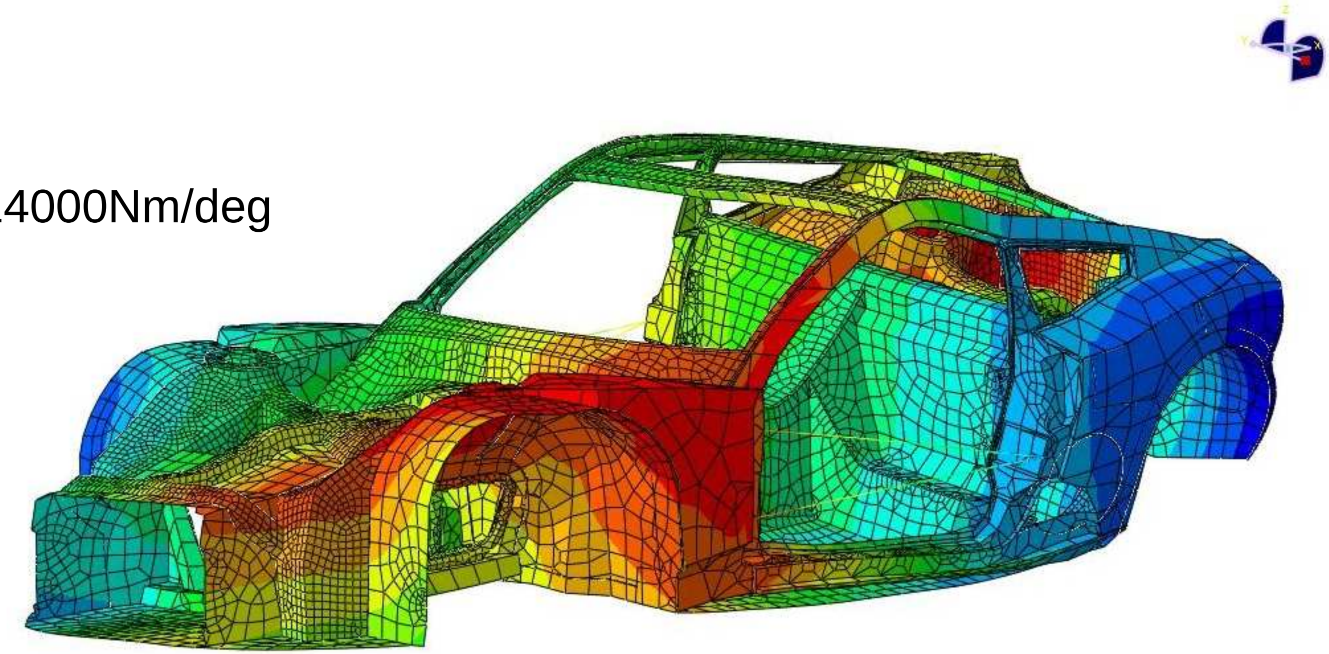
- ERA, Electric RaceAbout, is a next generation sports car, noiseless and clean
- Developed by Helsinki Polytechnic team for the Progressive Automotive X-Prize Competition
- With electric powertrain and ultra light body construction, both based on the latest technology, the energy consumption will be extremely low
- The composite monocoque has been designed and analyzed using ABAQUS and ESAComp
- ERA will be introduced in September 2009



Illustrations courtesy of Electric RaceAbout Team, Helsinki Polytechnic Stadia.

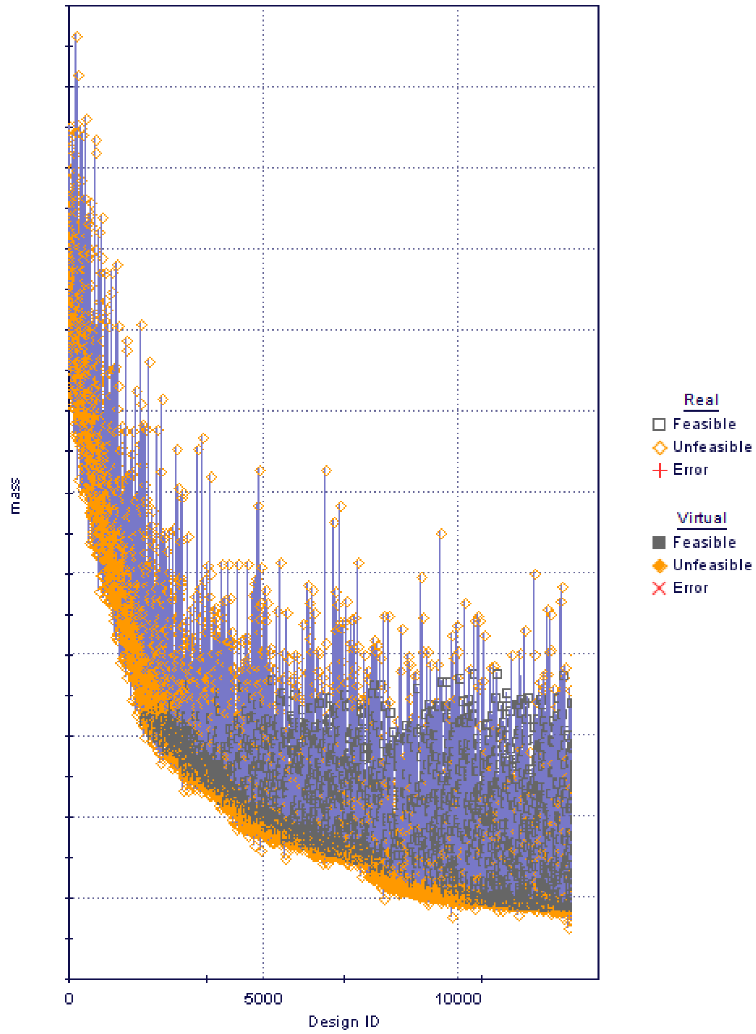
ESACOMP IN USE: ELECTRIC RACING CAR, ERA

- Objective: weight mimimization
- Calculation of 2 load cases:
  - cornering
  - torsion
- Constraints:
  - torsional stiffness >14000Nm/deg
  - target weight 90kg



CONCLUSIONS

- The approach has been successfully tested with real-life applications
- Design and analysis of composite structures involves specific issues that are not addressed in general finite element analysis tools
- Ignoring composite specific failure modes in design and analysis may lead to catastrophic failure
- Only laminate lay-ups that are feasible in the manufacturing point of view are generated
- ESAComp represents an industry proven solution that covers a vast set of tools needed at different stages of the design process integrated under a user friendly graphical user interface



www.esacomp.com