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Optimization of Laminated Composites – Overcoming Challenges in Design

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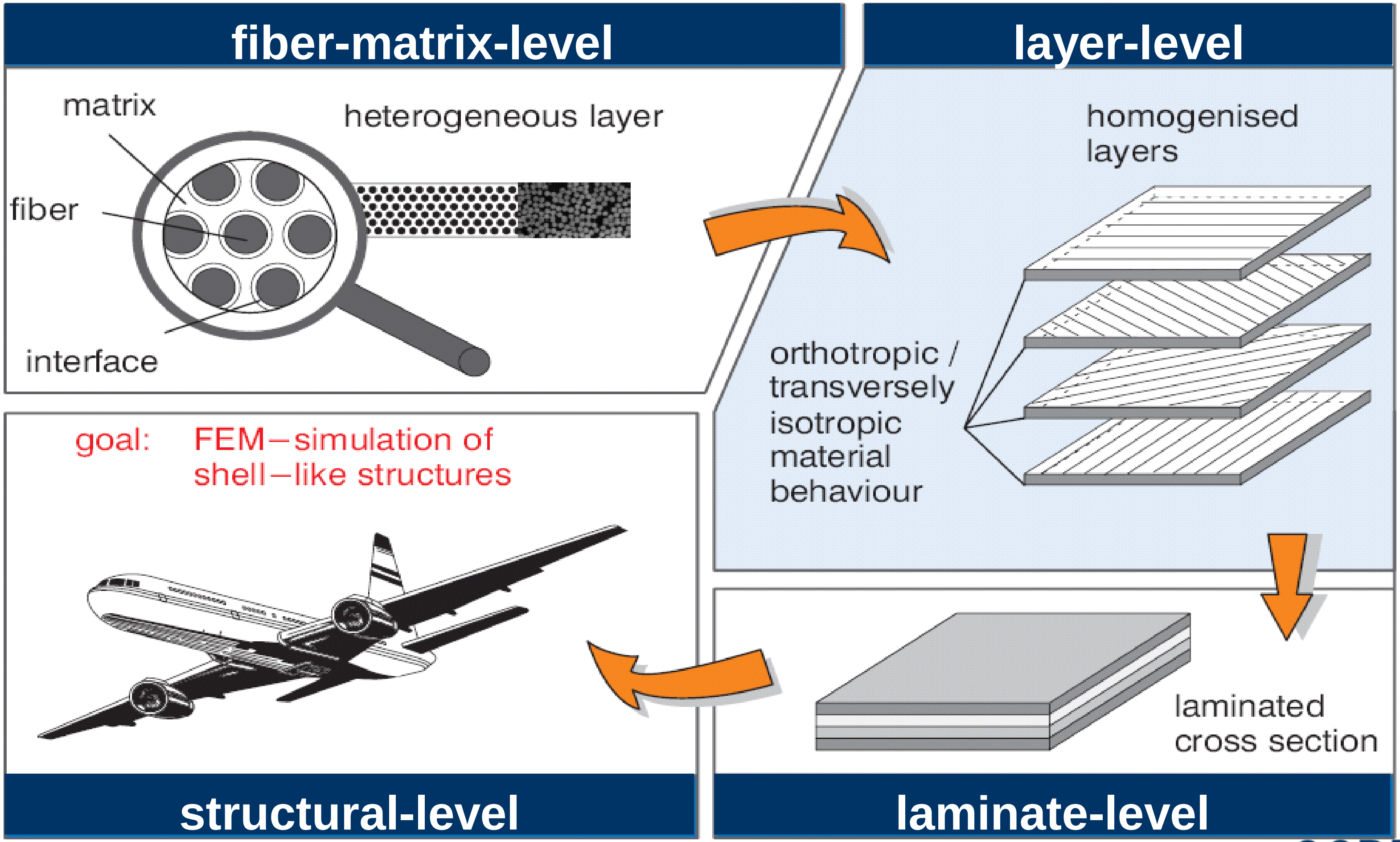
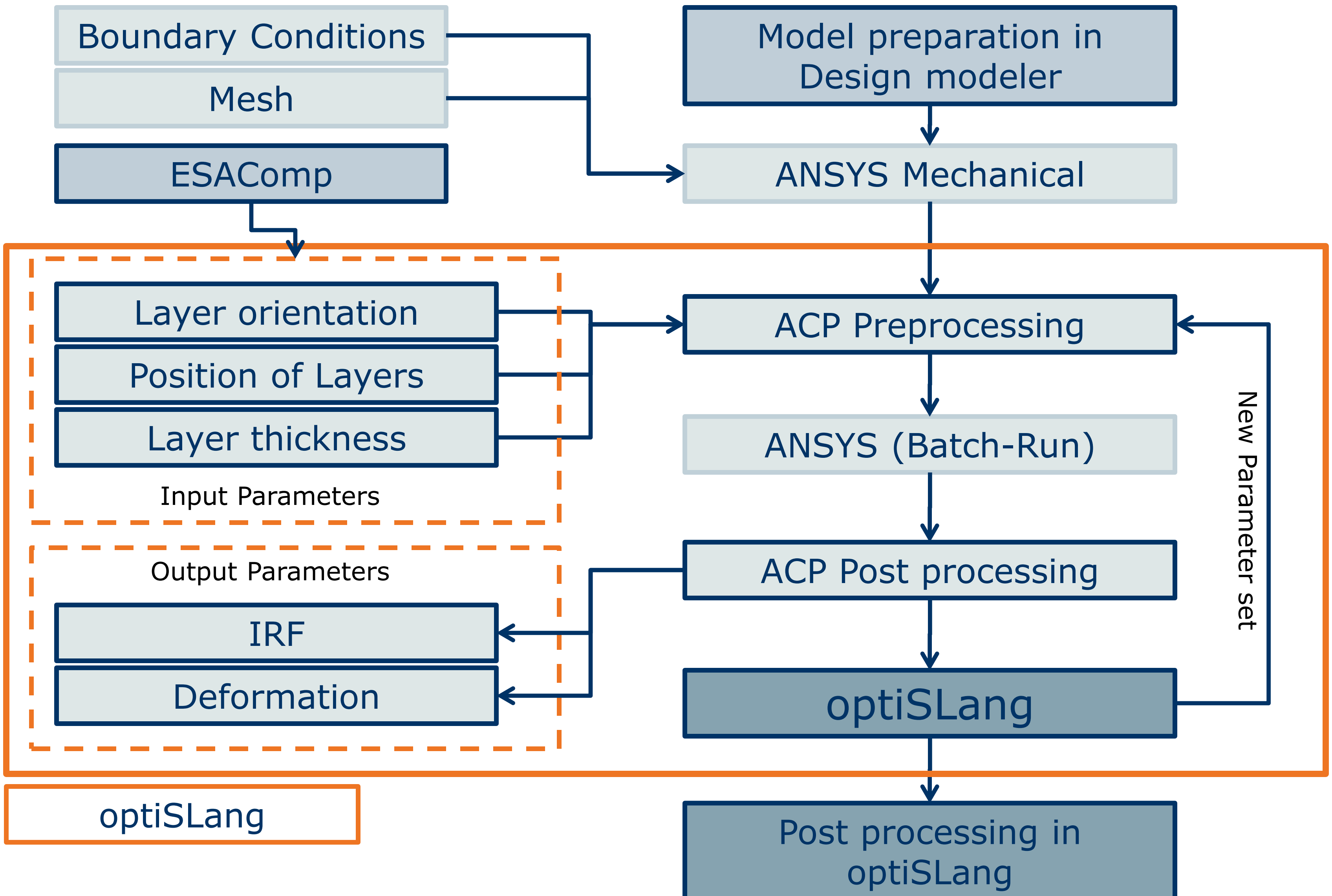
Motivation

To propose a simple workflow for optimizing laminated composite properties (particularly layer orientations, position of layers, and layer thickness) using ESAComp, ANSYS Composite Prep-Post(ACP) and optiSLang.



Workflow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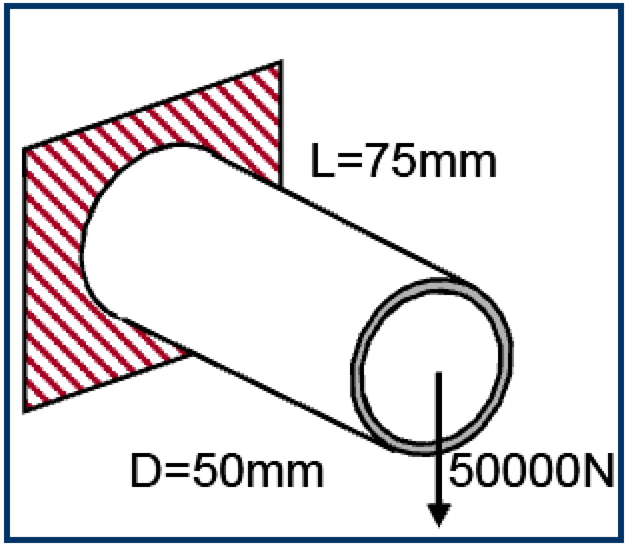
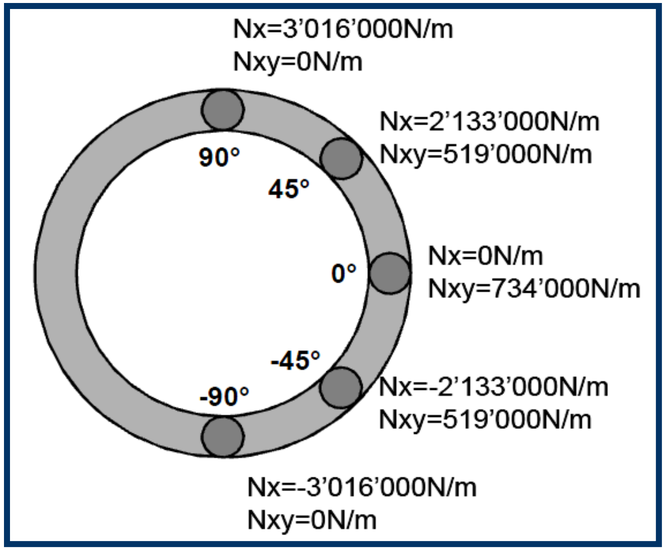
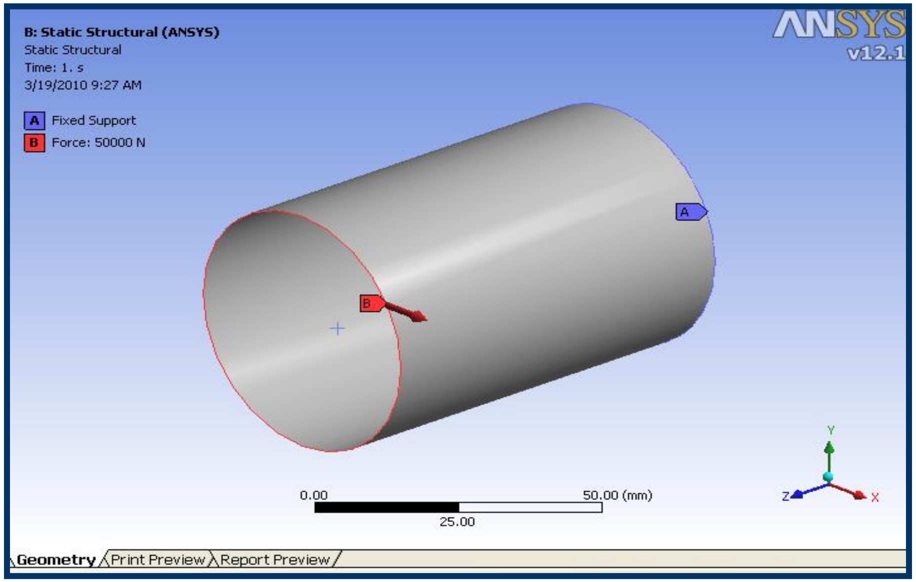
Simulation Model







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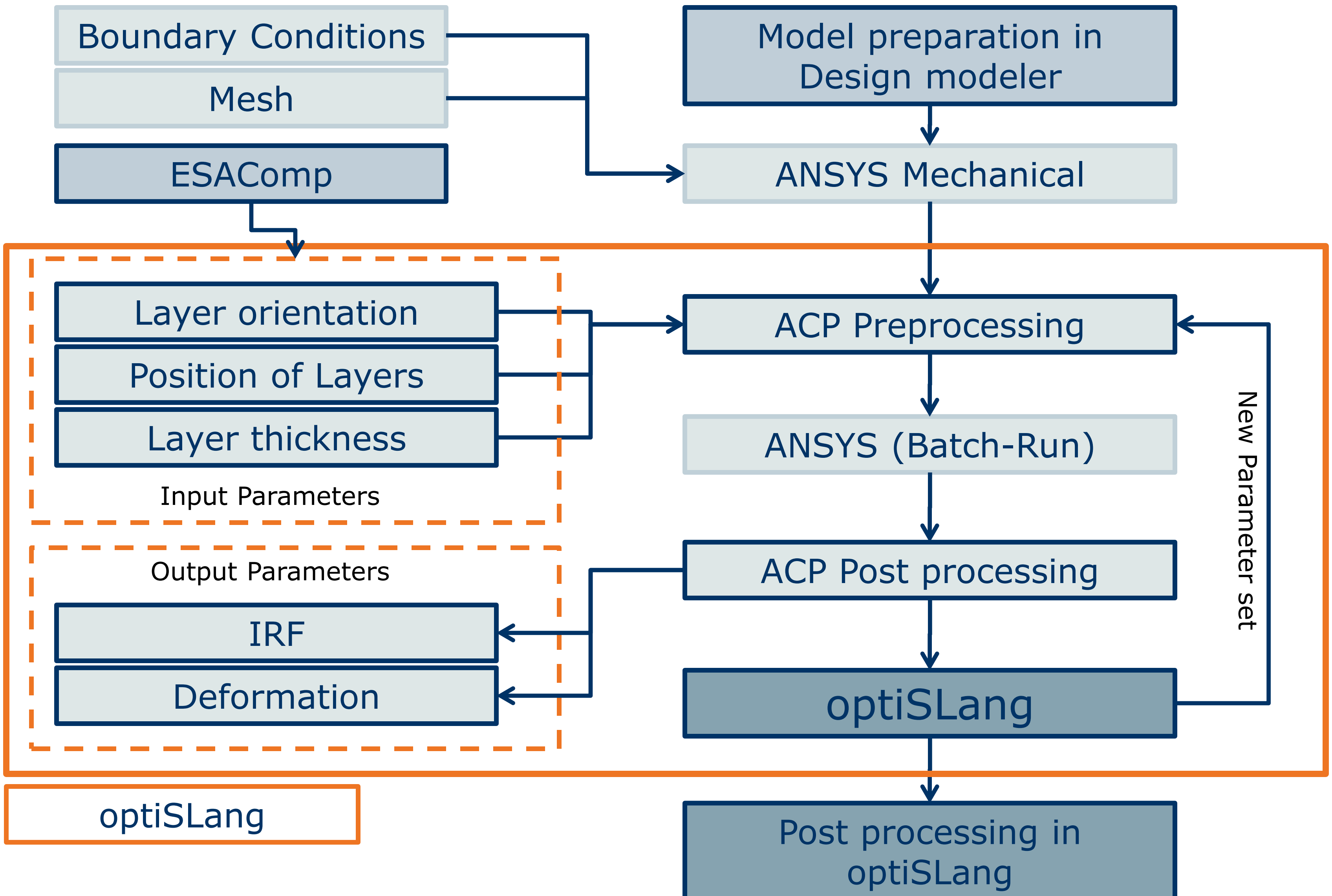
Workflow



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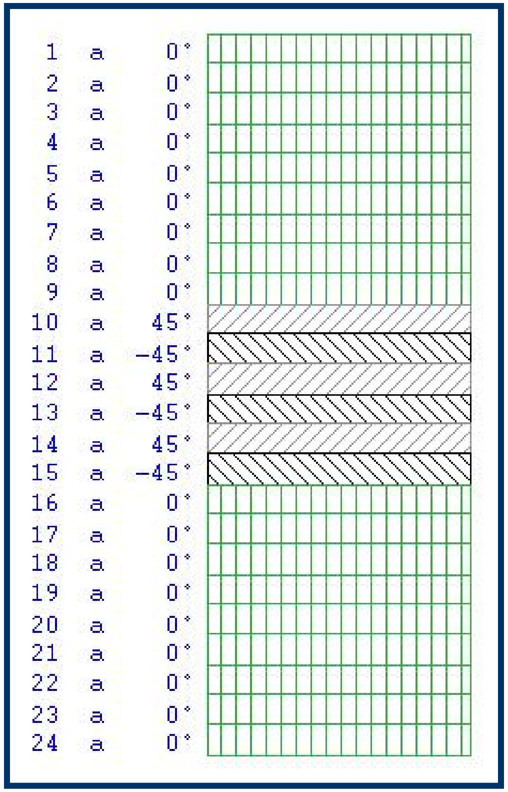
Composite Material Analysis in ESAComp

- A simple laminate was considered (Refer table below for layer properties)
- This laminate (shown below) was checked for load carrying capability using Load response (with First Ply Failure) in ESAComp
- Using the results at this stage, laminate layup was further modified to withstand failure

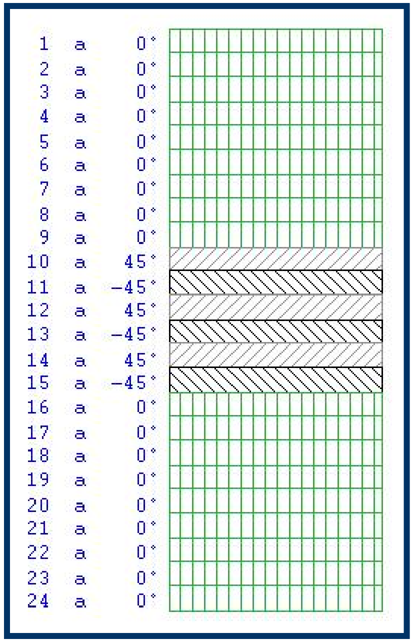
S.No	Engineering Constants	Units	Property
1	Each Layer thickness	mm	0.3
2	Density	Kg/m3	1600
3	Longitudinal Elastic modulus (Ex)	MPa	115000
4	Transverse Elastic modulus (Ey)	MPa	6500
5	Shear modulus (Gxy) in XY plane	MPa	6000
6	Poisson's ratio (Nuxy) in XY plane		0.28
7	Poisson's ratio (Nuyz) in YZ plane		0.34
Failure stresses			
8	X_t	MPa	2200
9	X_c	MPa	810
10	Y_t	MPa	40
11	Y_c	MPa	190
12	S	MPa	50
13	Q	MPa	50

Pin_Layup_1

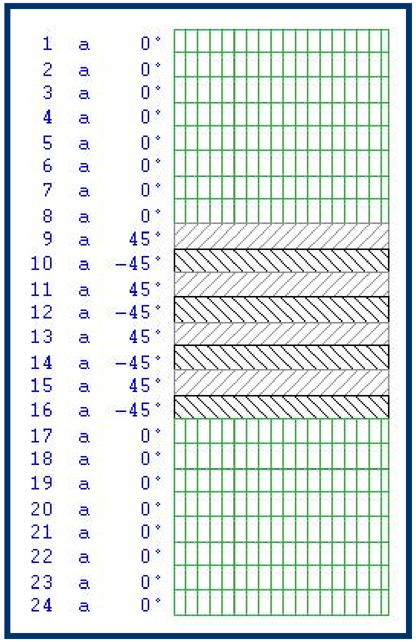


X_t – Tensile failure stress in x direction
Y_t - Tensile failure stress in Y direction
S – In plain shear failure stress in XY plain
X_c – Compressive failure stress in X direction
Y_c – Compressive failure stress in Y direction
Q – Out of plane failure stress in YZ plain

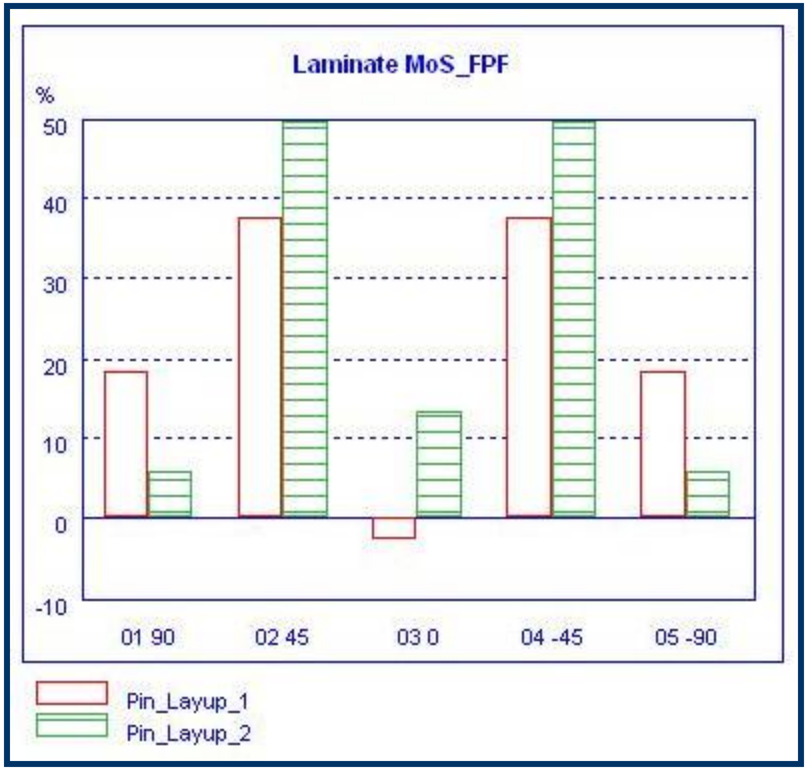
Laminate Level – Load response / failure



Pin_Layup_1



Pin_Layup_2

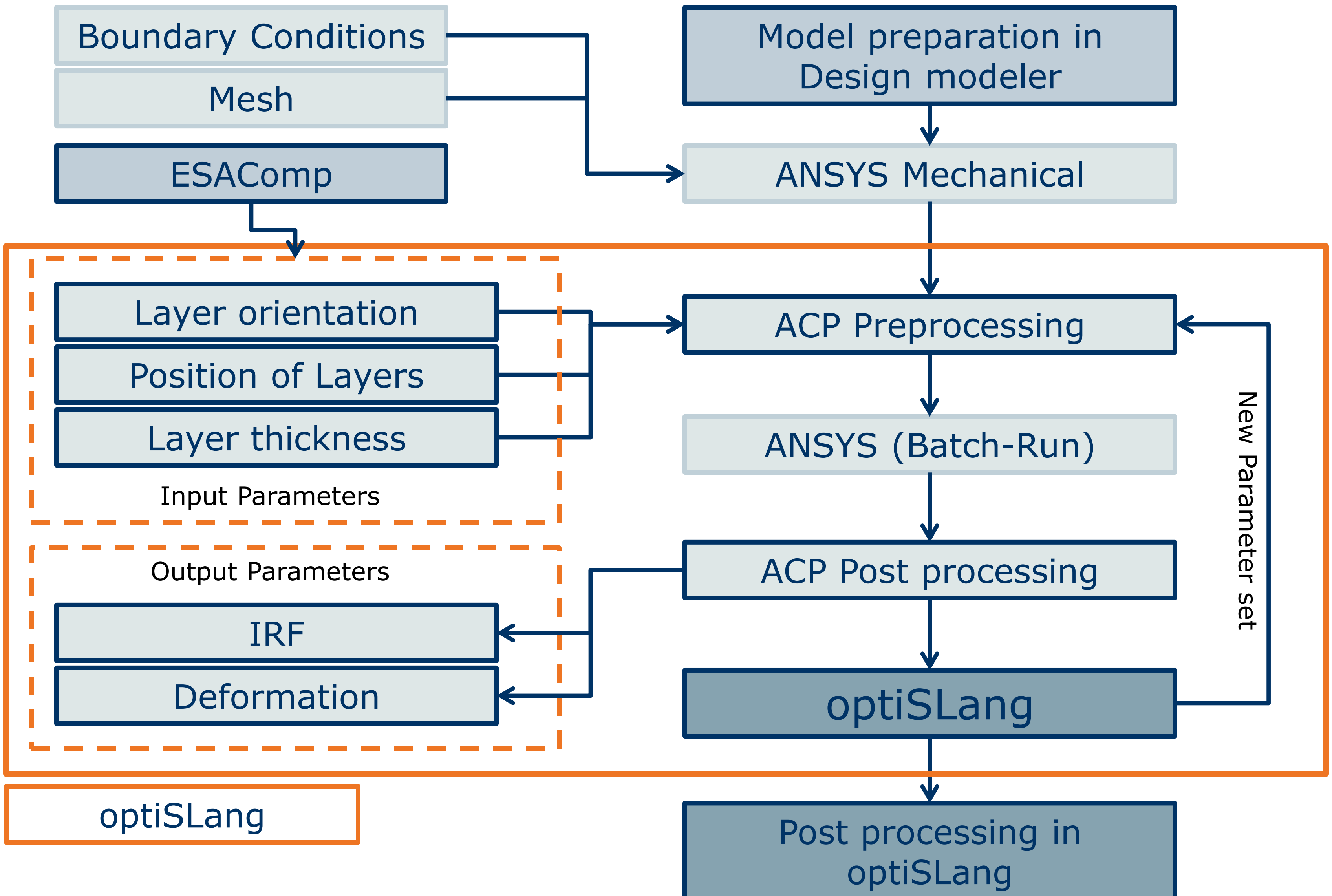


MOS_FPF			
S.No	Load	MoS_ FPF (%)	
		Pin_layup_1	Pin_layup_2
1	90	18.424	5.901
2	45	37.5612	49.742
3	0	-2.732	13.3414
4	-45	37.5612	49.742
5	-90	18.424	5.901

Laminate was found to be safe with modified layup, i.e., Pin_Layup_2

Factor of safety : FoS^v = 1
Failure criterion : Max stress 3D; Max strain; Von Mises; Out-of-plane shear; Out-of-plane shear; None (UD; non-UD; homogeneous; honeyc. core; foam/other core; adhesive)
Stress/strain recovery : layer top/bottom

Workflow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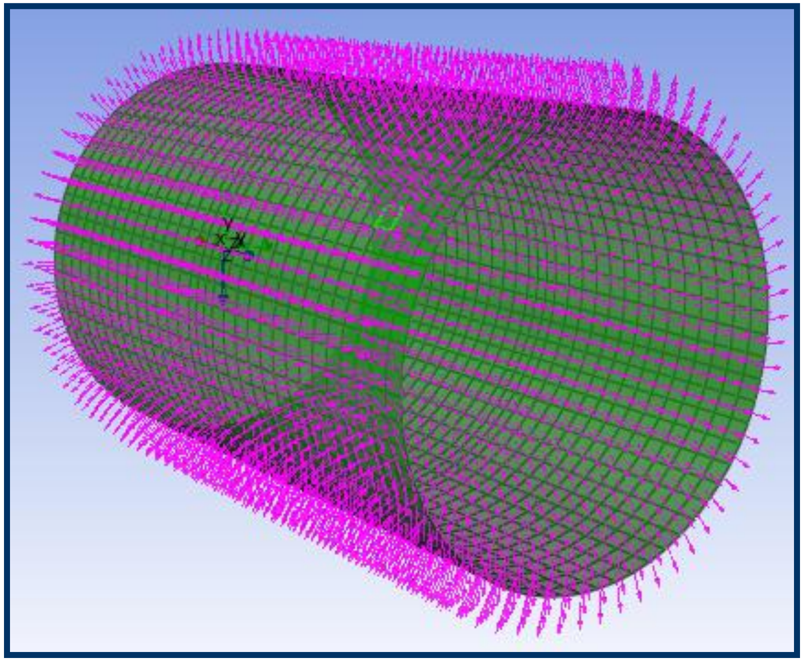
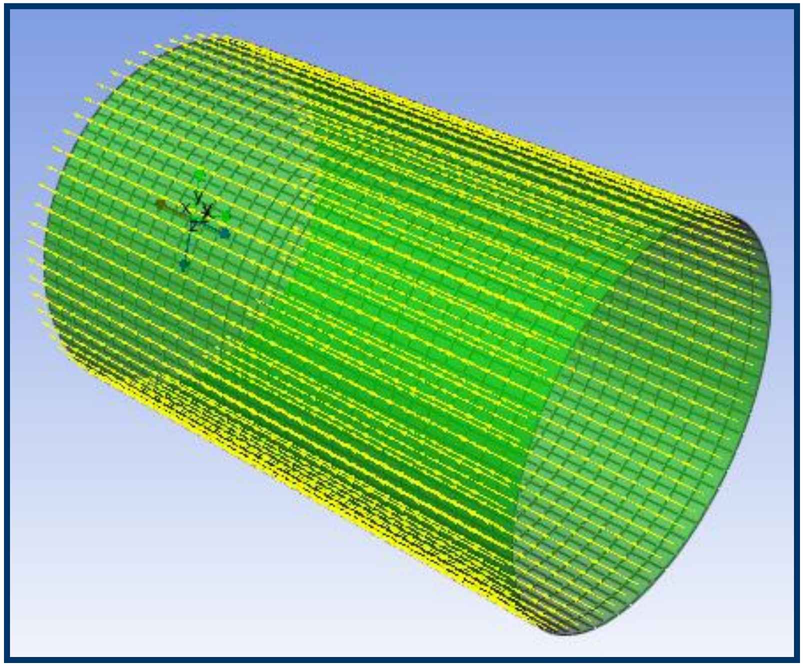
Structural Analysis in ACP

- Finalized material properties is exported into ACP.
- Before the solving the model in ACP using ANSYS, it is to be ensured that, all element sets have proper orientation
- All element normal's should be on the same side (to be aligned to the local Z axis)

Z axis of each element being aligned to the element normals and shown in pink



X-axis of each element being aligned to global X-axis and is shown in yellow.



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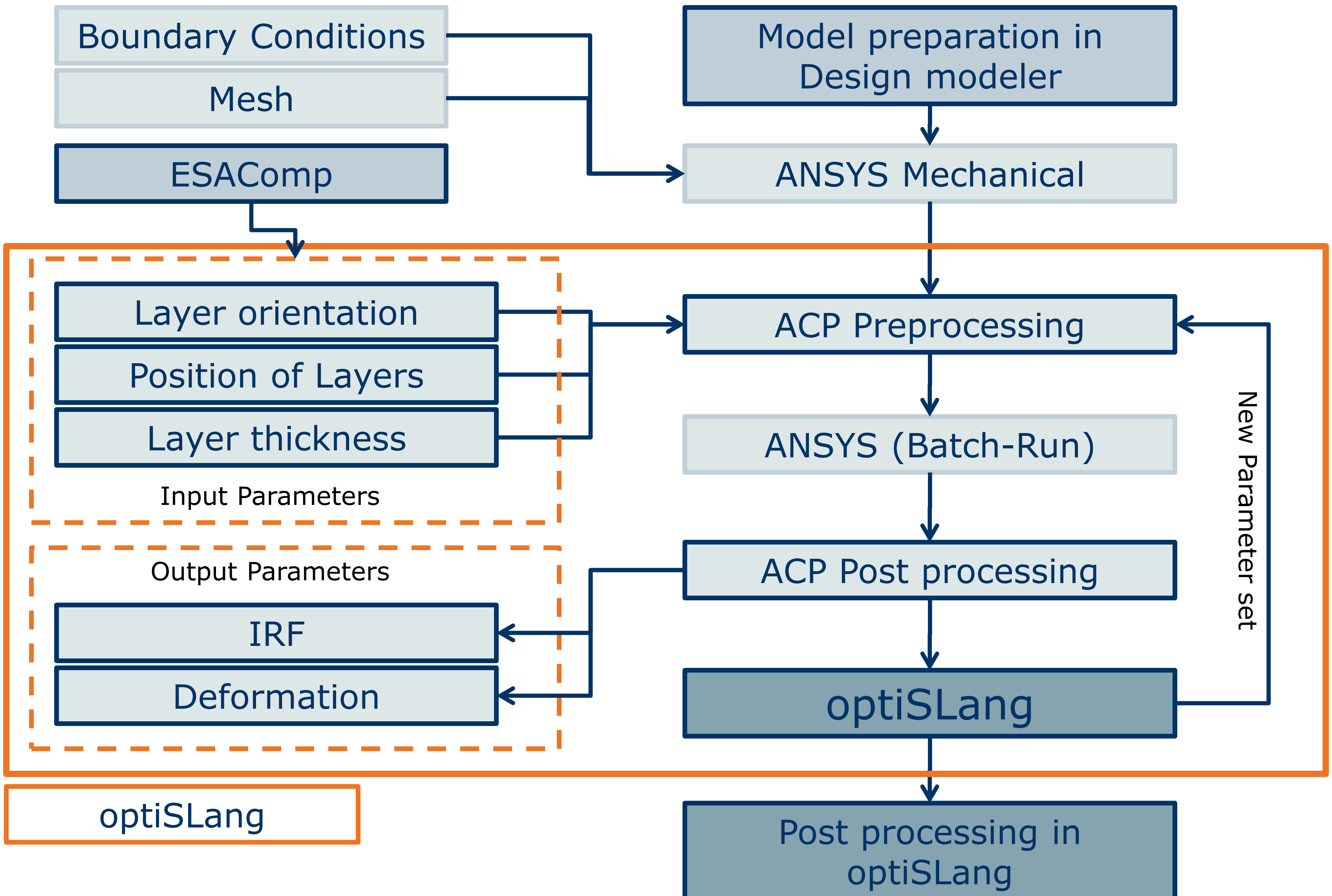
Workflow



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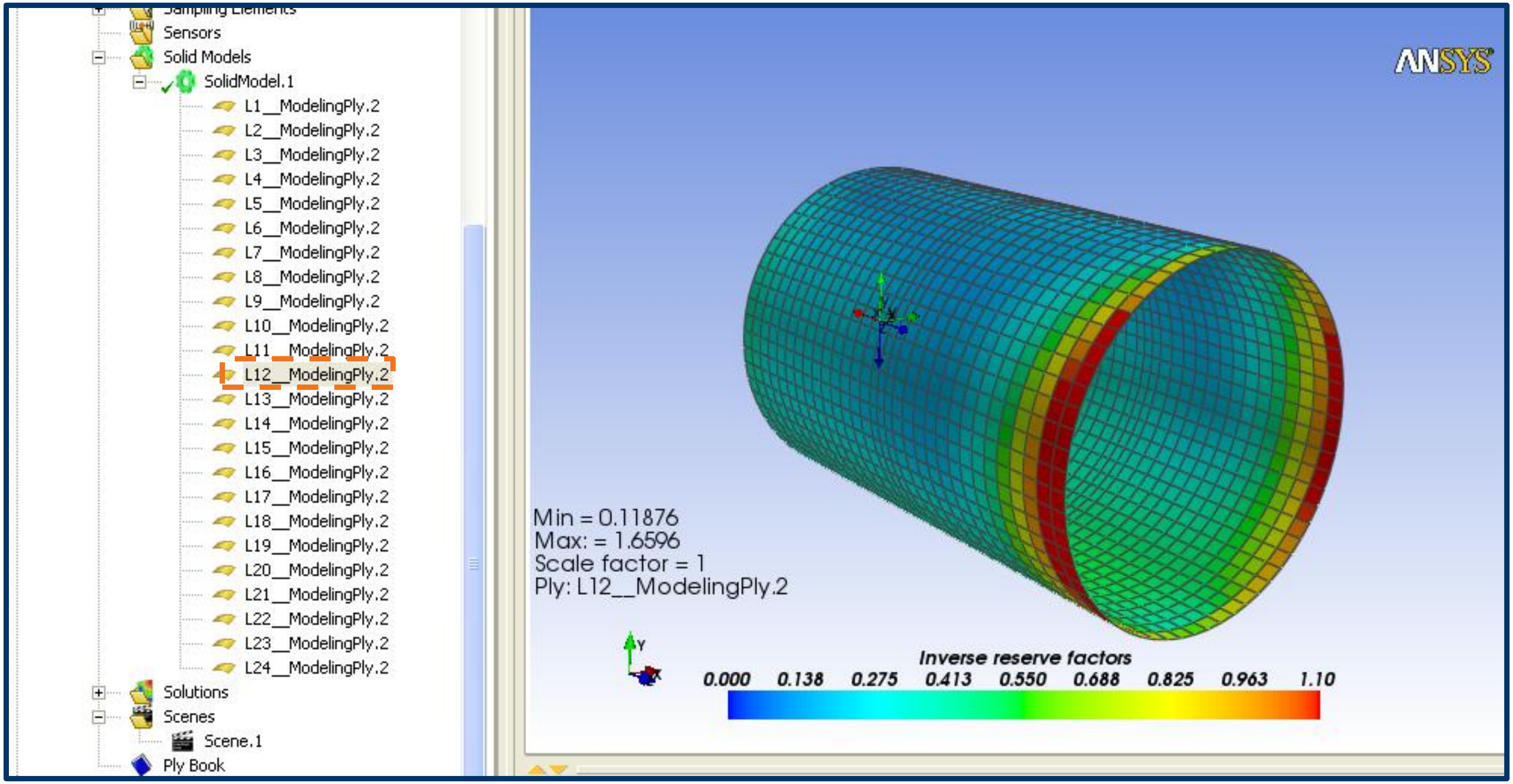
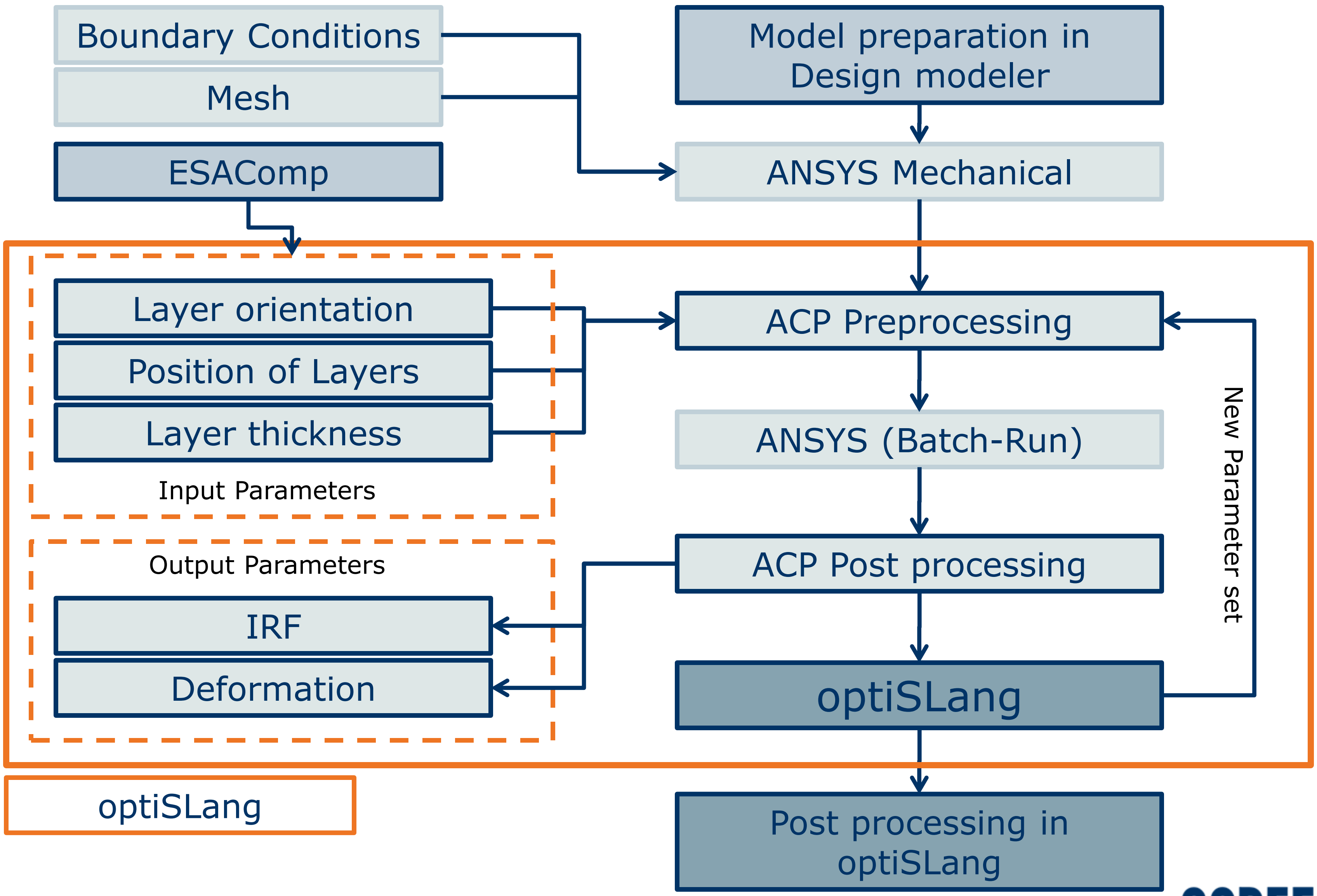
Post Processing using ACP: IRF



Layer wise failure can be visualized i.e., failure mode in 12th layer was shown above. Maximum value of IRF being higher than 1, the above laminate failed

Workflow



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Problem Overview

First whole process is completely automated

Input Parameters

25 Input/Design parameters

- 1 continuous variables – Thickness of whole structure
- 24 discrete variables – Angles of each Ply with variation between – 90 to 90 with 5^{o} increment

Response Parameters

26 Response parameters

- 2 Displacements –> Max x disp. and Max y disp.
- 24 Inverse Reserve Factor(IRF) –> IRF of each ply

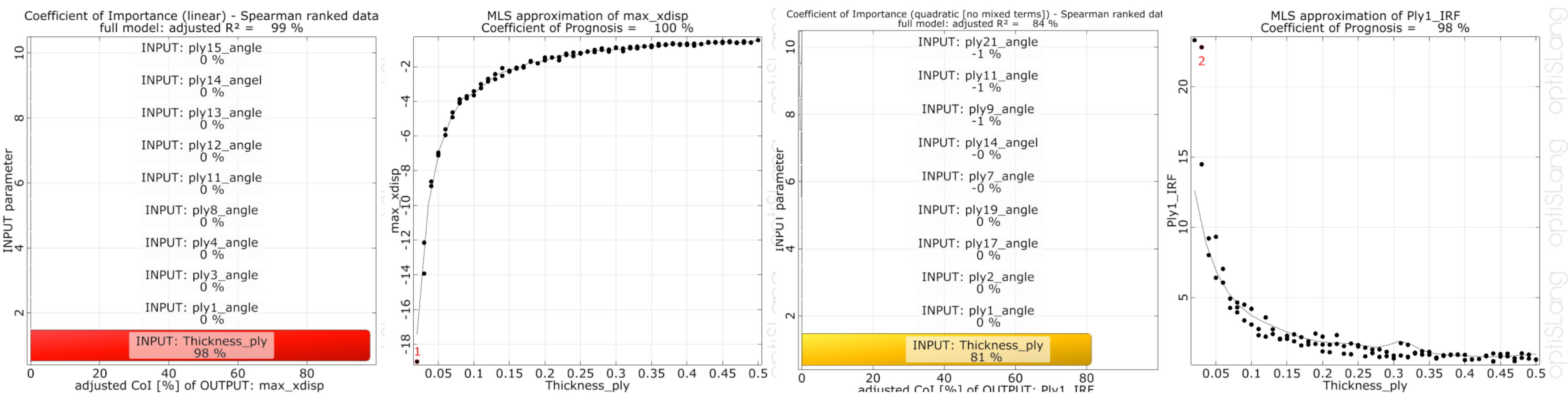
Objective and Constraint

- Minimize the mass and max displacement
- IRF value of each ply less than 1 as constraints.

Sensitivity Analysis

Design of Experiment (DoE) is carried out using 100 Latin Hypercube samples

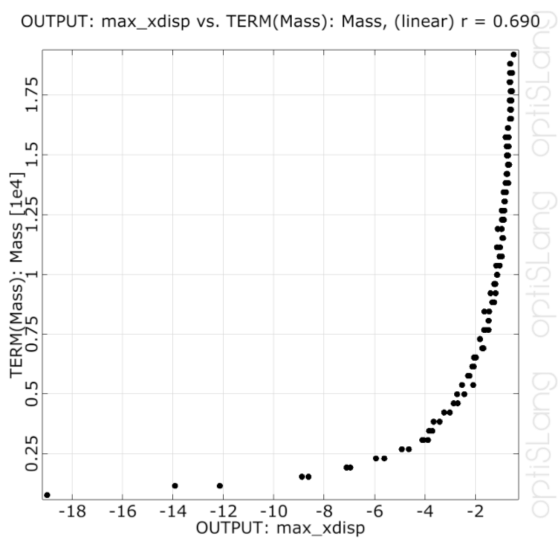
Result Evaluation - Responses

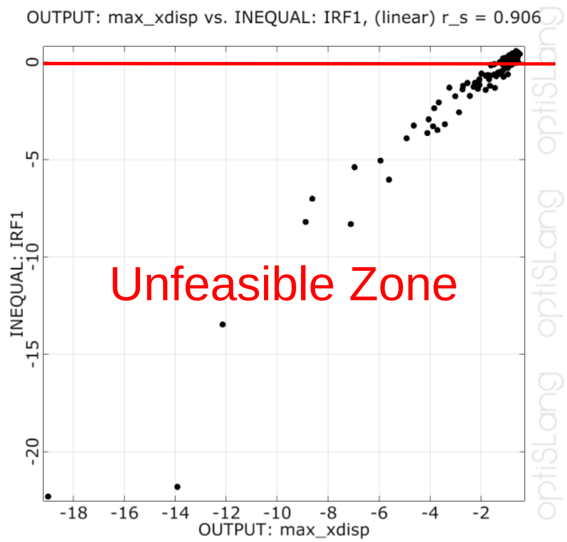


- Maximum Coefficient of Importance (CoI) more than 80% for both the Max_xdisp and Ply1_IRF
- Only Thickness_ply has influence on responses
- Responses vary non linearly with the variation of the input variable.

Sensitivity Analysis

Result Evaluation – Objective





- Two objectives are conflicting -> Pareto optimization
- Mass increase non linearly with the decrease in displacement
- Constraint of IRF<1 curtails the displacement
- Due to above reason only mass can be chosen as objective
- Objectives are reduced from 2 to 1 -> No Pareto Optimization
- Global optimum design from sensitivity analysis is chosen as a starting point for optimization, to reduce computation time

Optimization

Overview

- All input parameters are considered for optimization
- Mass is considered as the only objective. It depends only on ply thickness
- To choose best design with less displacement among the designs with same mass, max displacement in x and y direction terms are added to the objective

#	Name	Formula	Type	Active
1	Mass	Thickness ply*1600*24	term	☐
2	xdisp1	fabs(max xdisp)	term	☐
3	ydisp1	fabs(max ydisp)	term	☐
4	Mass	10.0*Mass+1.0*xdisp1+1.0*ydisp1	objective	☑

- 24 constraints -> IRF of each ply < 1
- More than 15 discrete input parameters -> Evolutionary algorithm for optimization

Optimization

Initial vs. Optimized Design

- 25 input variables
- N = 100 + 400 = 500 No. of design evaluations
- Total mass of the composite structure as well as the displacement of best design are less compared to initial design

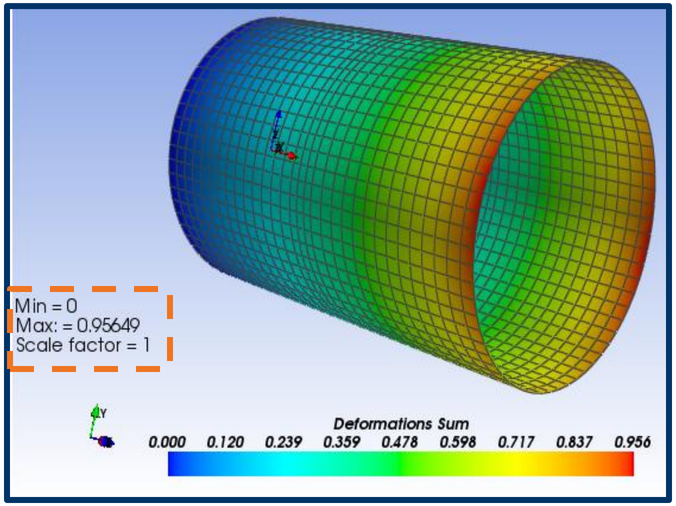
Output	Initial	SA	EA	EA – Improvement
Mass	11520	13824	11136 (3.5%)	10752 (7%)
Displacement Sum	0.96	0.80	0.86 (10%)	0.90(6.3%)

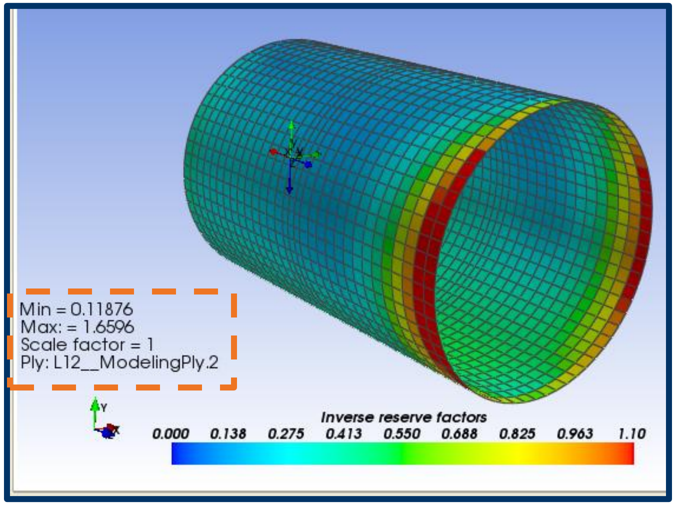
SA – Sensitivity Analysis

EA – Evolutionary Analysis

Optimization

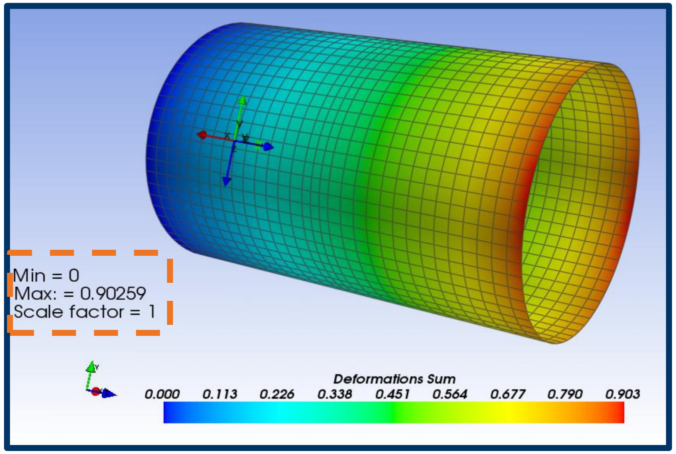
Initial vs. Optimized Design

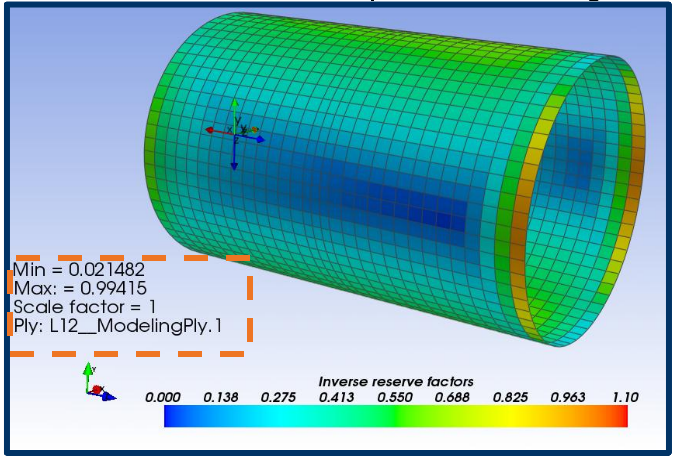




Deformation : Above – Initial Design; Below – Optimized Design

IRF : Above – Initial Design; Below – Optimized Design





Summary

- **Behavior of laminates** is **studied without using FE analysis** (using Classical Laminate Theory), by an industrial approved software solution called **ESAComp** -> **Avoid FE simulation**
- **Second composite material** is designed based on the **suggestion from ESAComp** -> **Better performance** compared to the initial material
- Second composite material is **applied and investigated on model** using FE Analysis
- **Model setup** using composite material and the **post processing of the results** is carried out by a software tool called **ACP**
- **Structural failure occurred** for given load condition -> **optimization** has to **carried with failure constraints**
- Complete **optimization process** is **automated** using a tool called **optiSLang**

Summary

- **Sensitivity analysis** is using 100 Latin Hypercube sampling due to following advantages:
  1. **Better understanding** of design space to **define objective and constraints** -> **Save’s computation time**
  2. **Global optimum design** as **start up** for optimization -> **Less computation time**
  3. To choose **important design parameters** for optimization -> **Save’s computation time**
- **Optimization** is carried out using **Evolutionary / Genetic algorithm**
- **7% and 6.3% of reduction in mass and deformation** was achieved for the best design
- Goal of optimizing the laminate was achieved

Thank You