Virtual Testing of Aircraft Structures, considering Postcritical & Thermal Behavior

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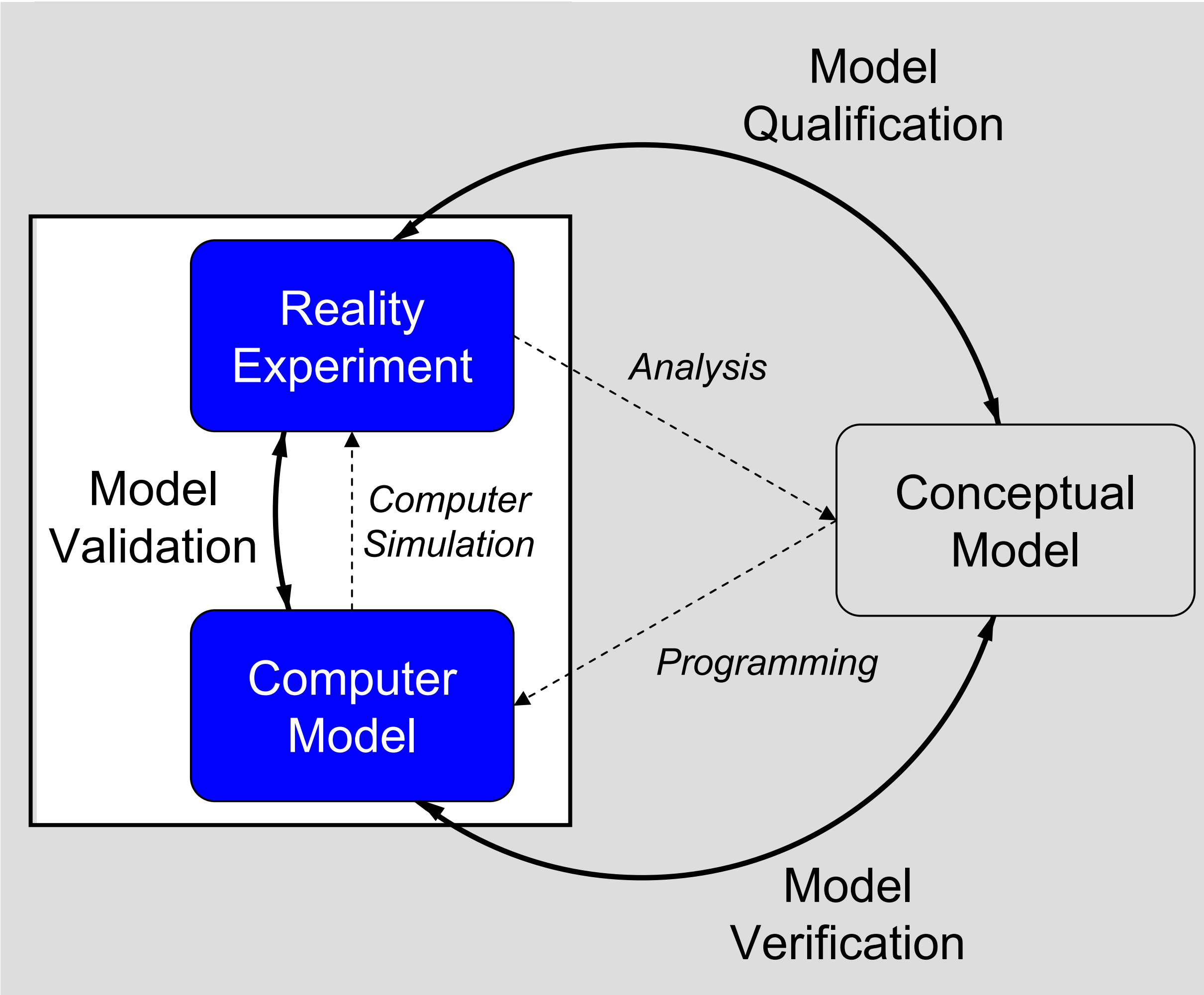
COMPOSIT Thematic Network,
Workshop on Modeling and Prediction of Composite Transport Structures
in Zaragoza, Spain, 30.06.2003

Validation / Verification

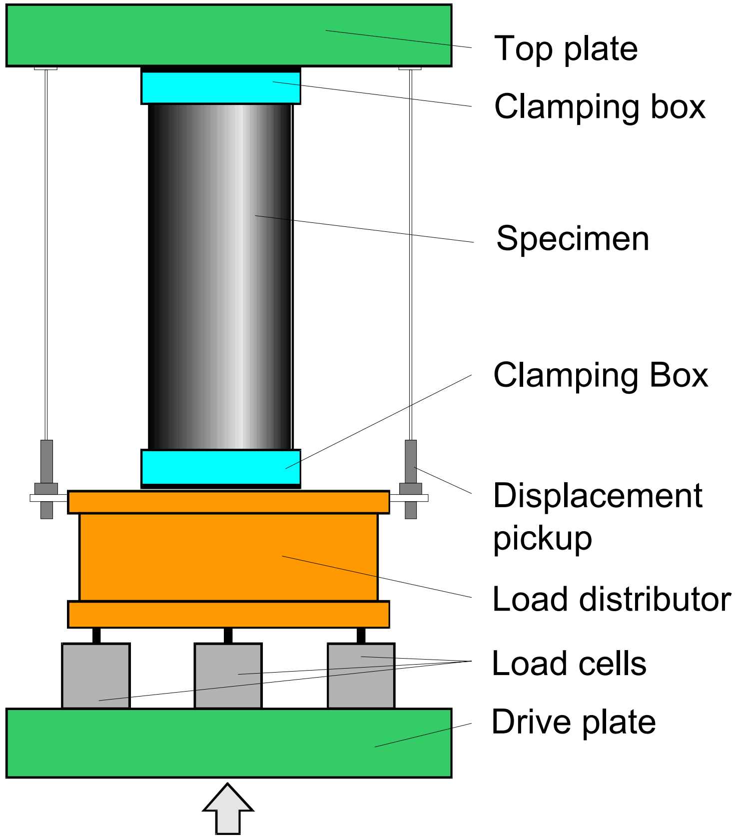


Model Verification:
„Solve the equations <u>right</u>“

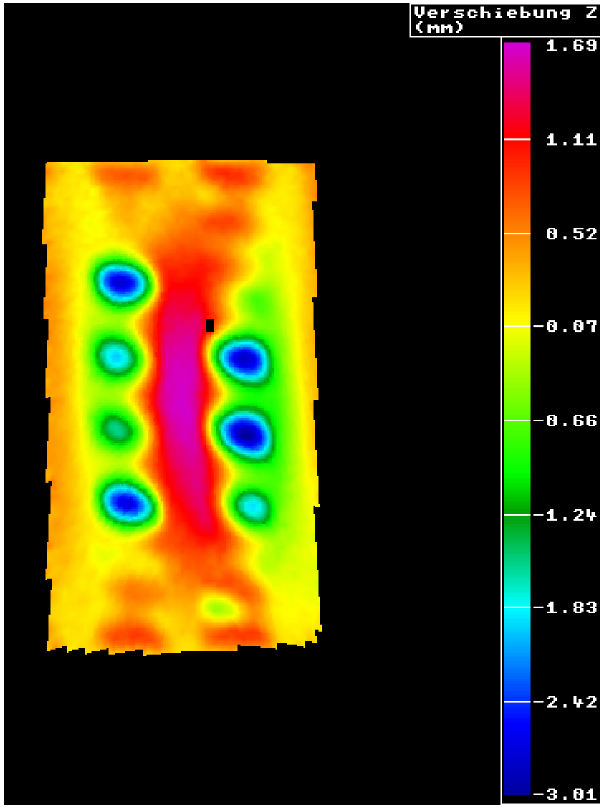
Model Validation:
„Solve the <u>right</u> equations“

Postcritical behavior of stiffened panels

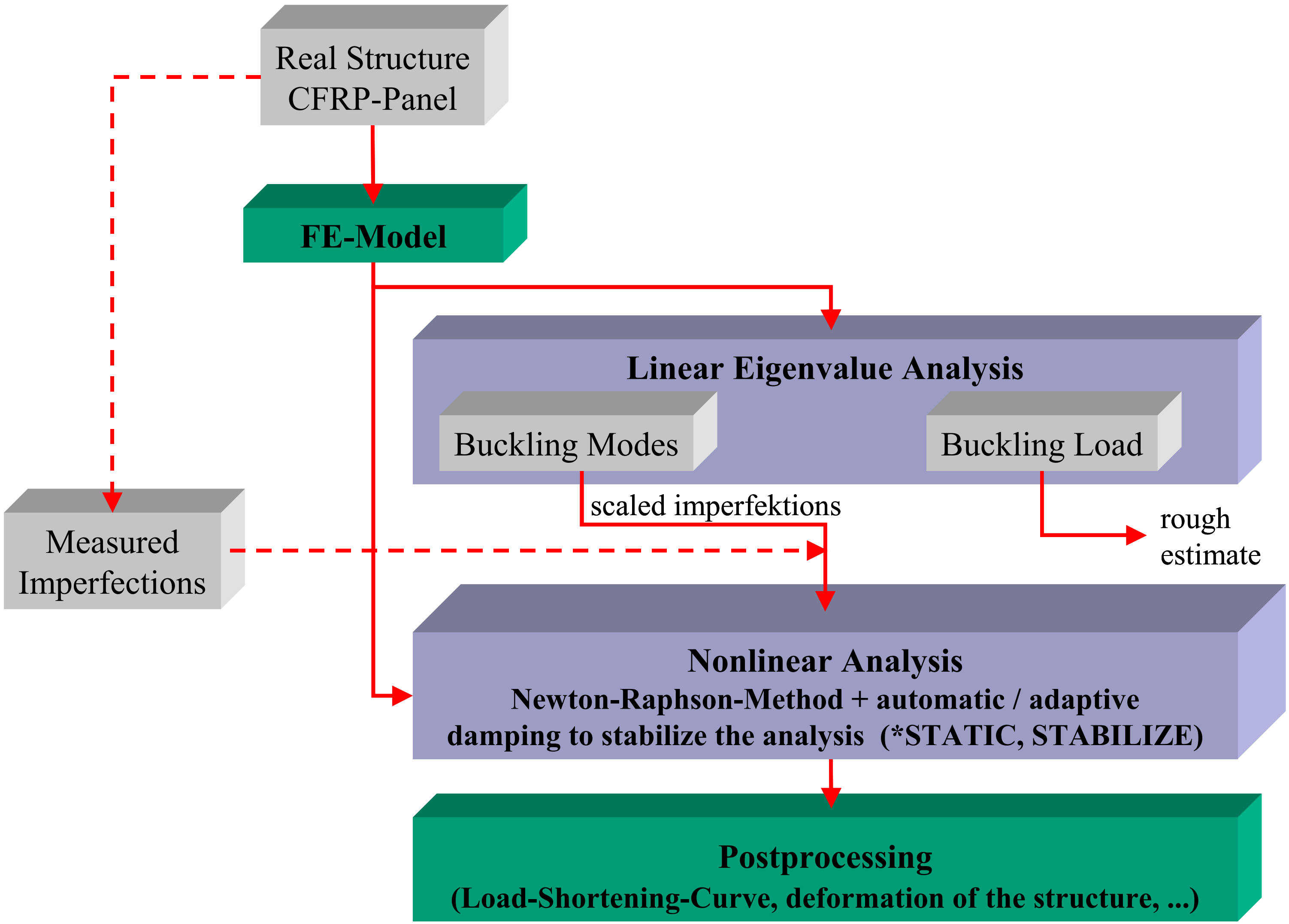
Panel in Buckling Test Facility



Deformation pattern (ARAMIS)



Non linear FEM using ABAQUS/Standard



Numerical Pre-Test Analysis

„Experimental Validatition of computational Analysis is expensive & time consuming“

„Pre-Test Analysis and Pre-Test Planing“

„Validation Experiments“ versus „Phenomenological Experiments“

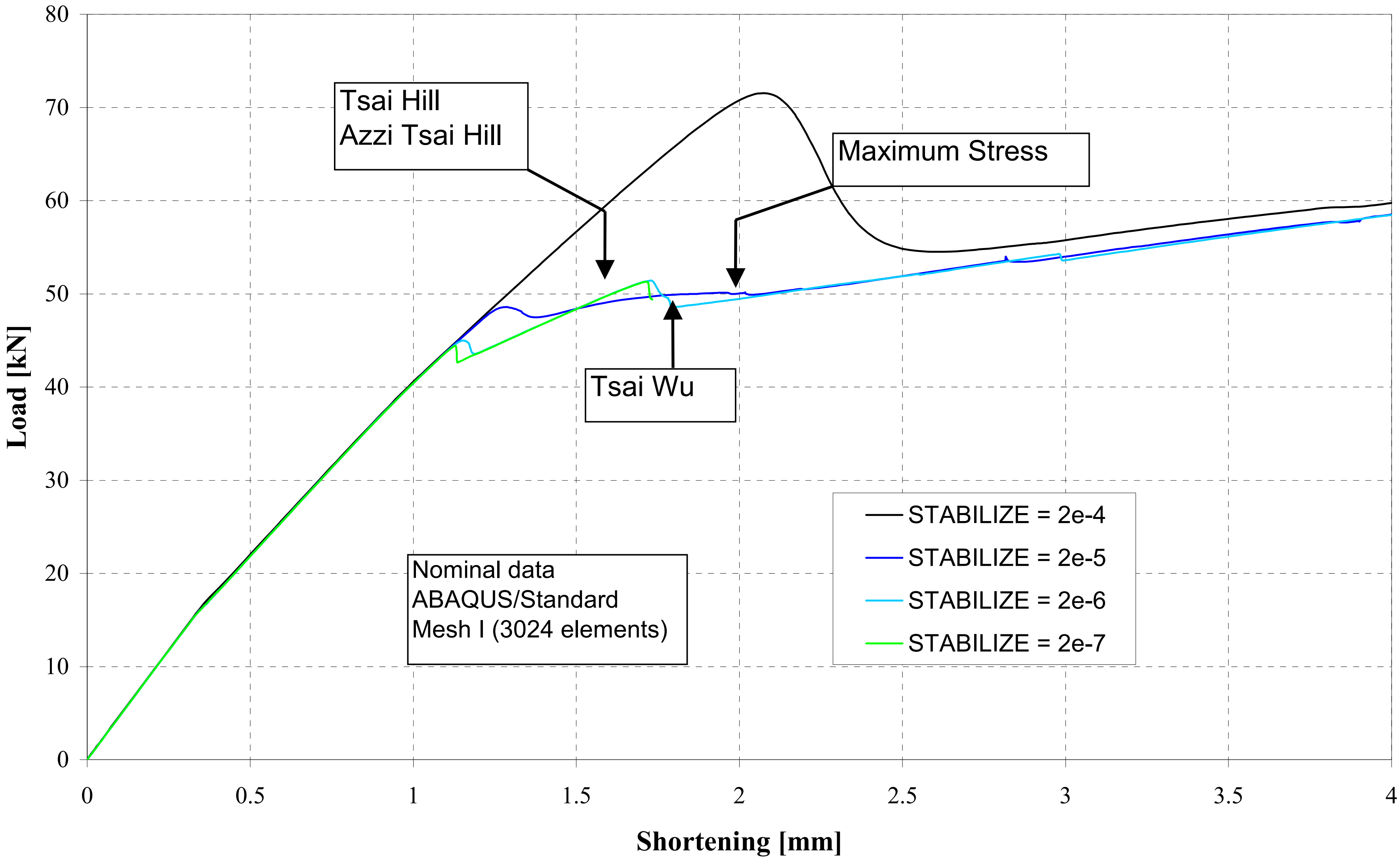
Goal: Load – Deformation curve showing:
- characterristic skin buckling, coupeled with axial stiffness reduction
- large load bearing capacity during postbuckling without structural failure

FEA investigation w.r.t.: panel geometrie
discretisation
experimental boundary conditions
initial imperfections
...

Pre-Test Analysis

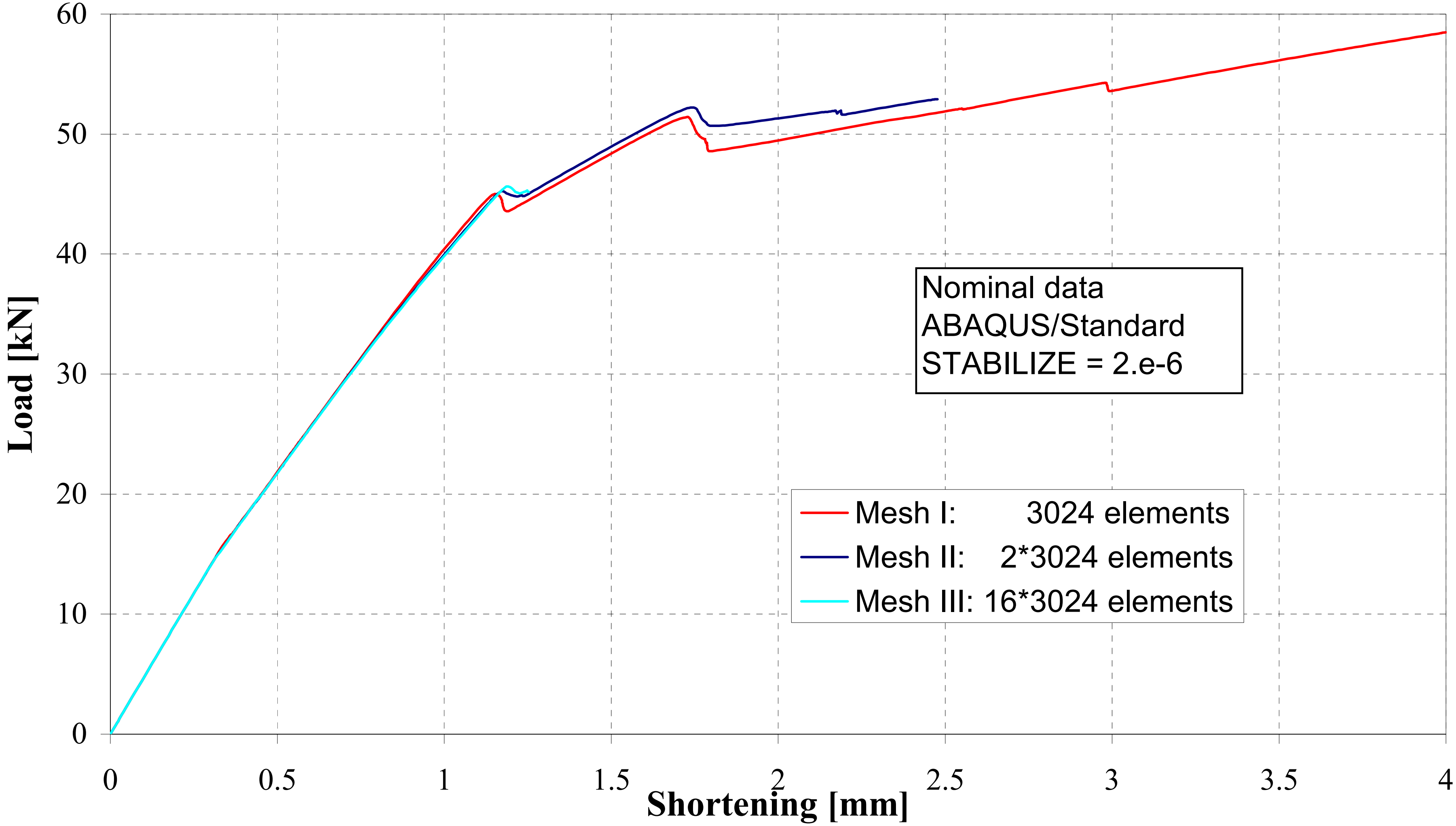
1. Influence of different STABILIZE parameters

2. Investigation of different failure criteria



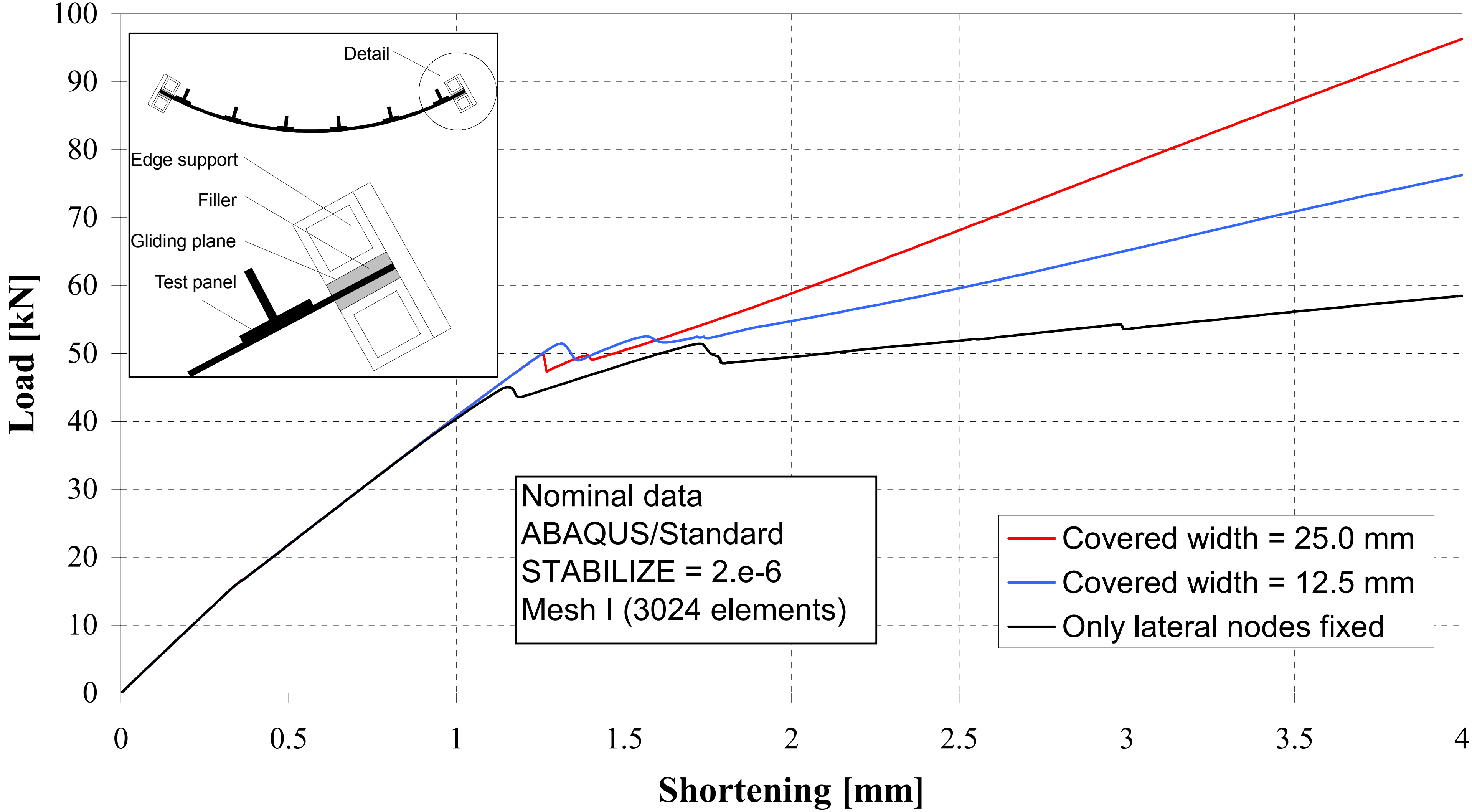
Pre-Test Analysis

Convergence study



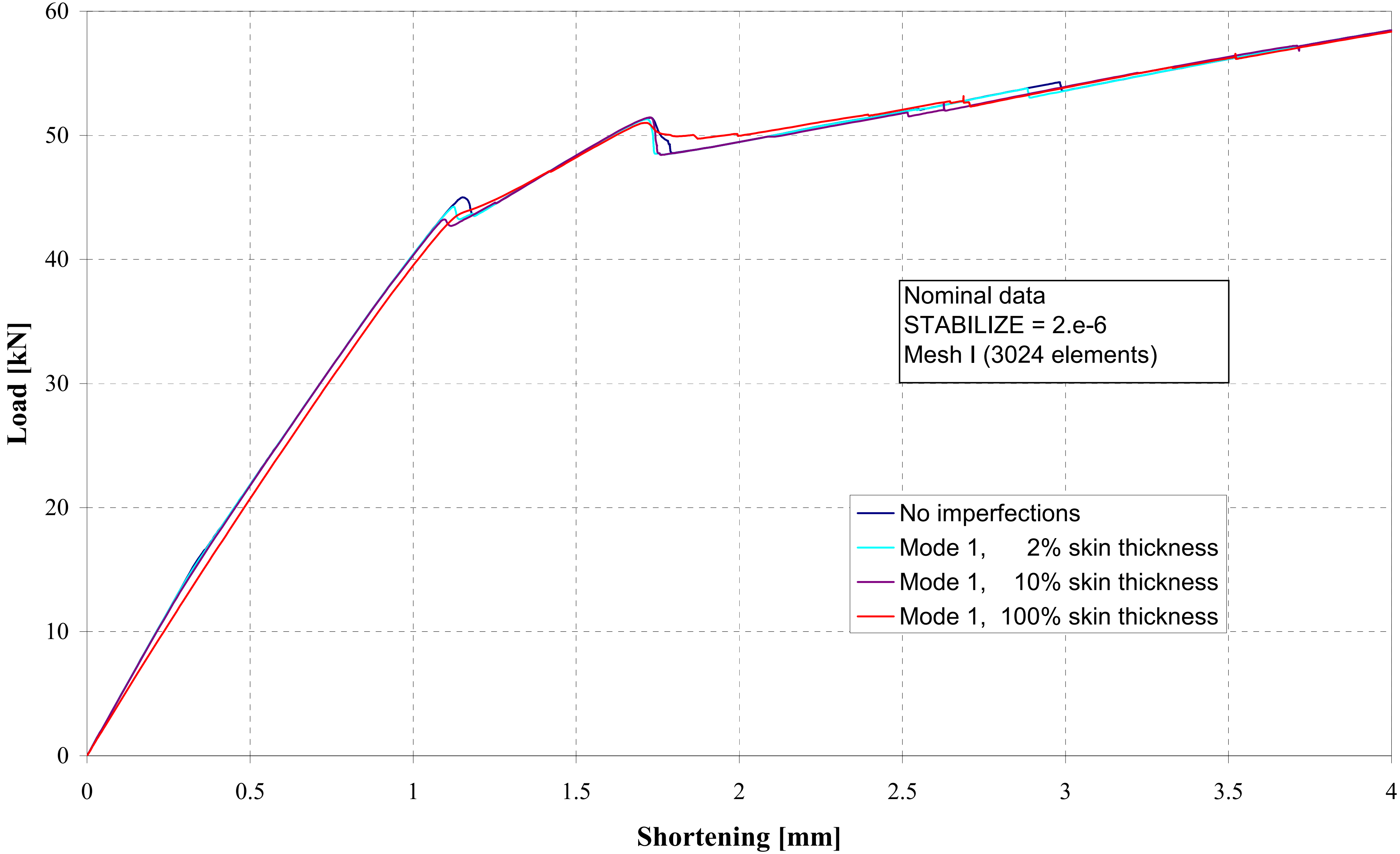
Pre-Test Analysis

Influence of lateral boundary conditions



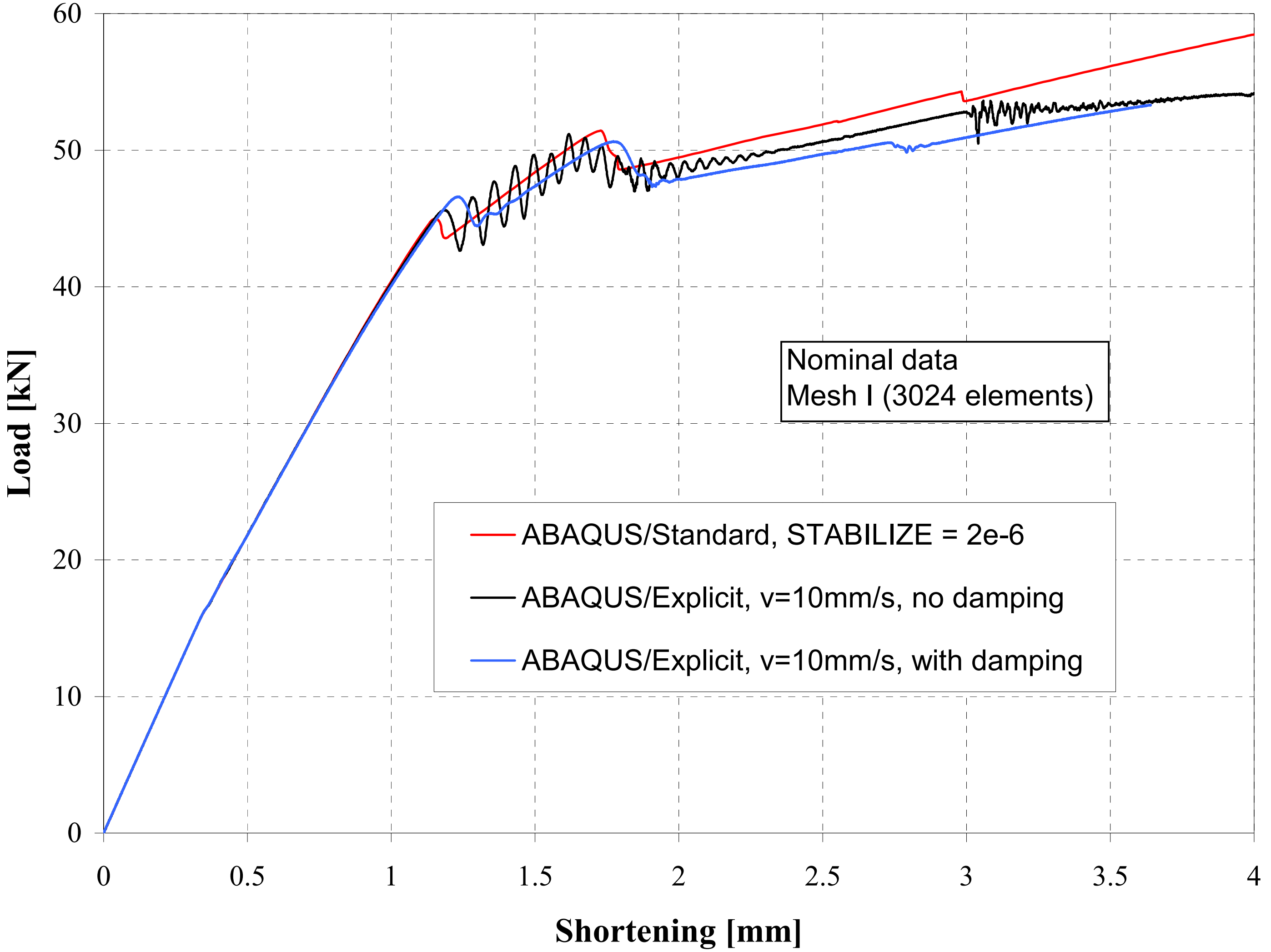
Pre-Test Analysis

Influence of imperfections



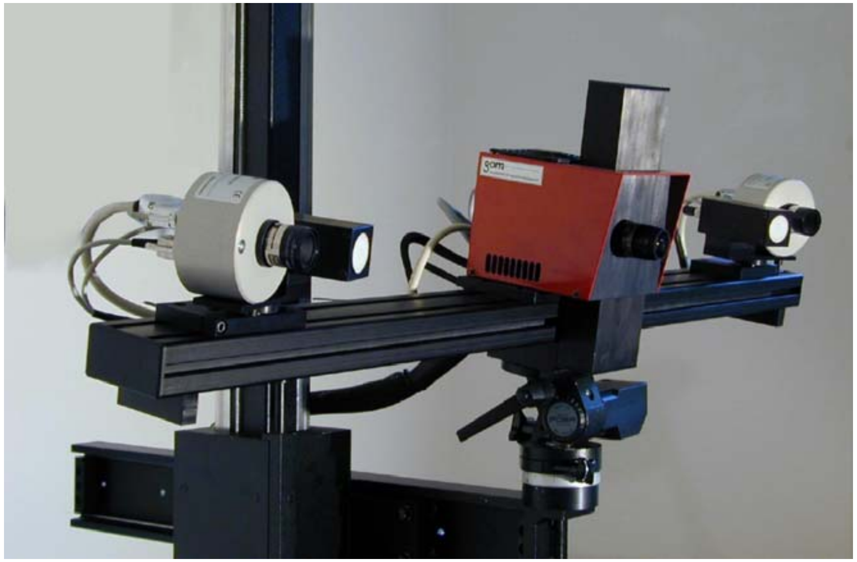
Pre-Test Analysis

ABAQUS/Standard vs. ABAQUS/Explicit

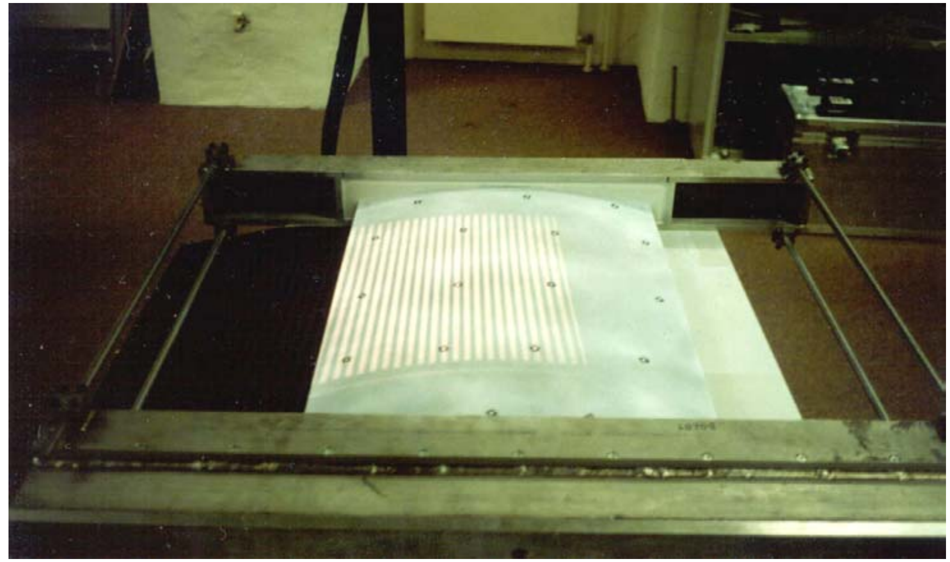


Measurement of geometrical Imperfections (1)

Optical 3D - digitalization



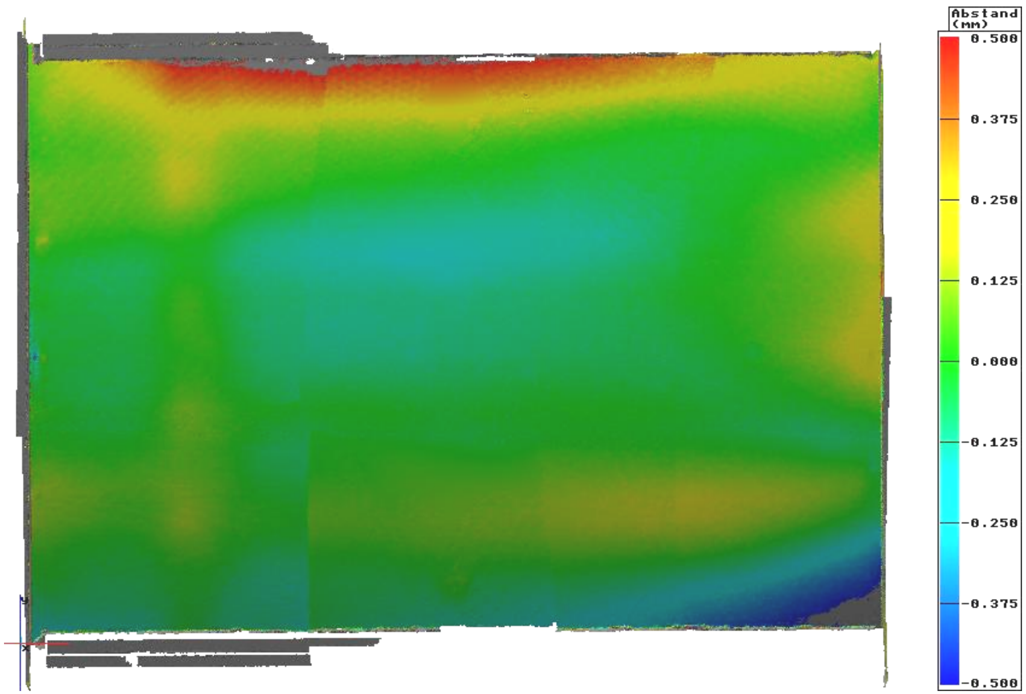
ATOS – Sensor



strip sequenz

- **Measurment of real radius vs. nominal radius (ca. 6% deviation)**
- **Measurement of initial imperfection**

Measurement of geometrical Imperfections



Fringe – plot w.r.t.
perfect shell

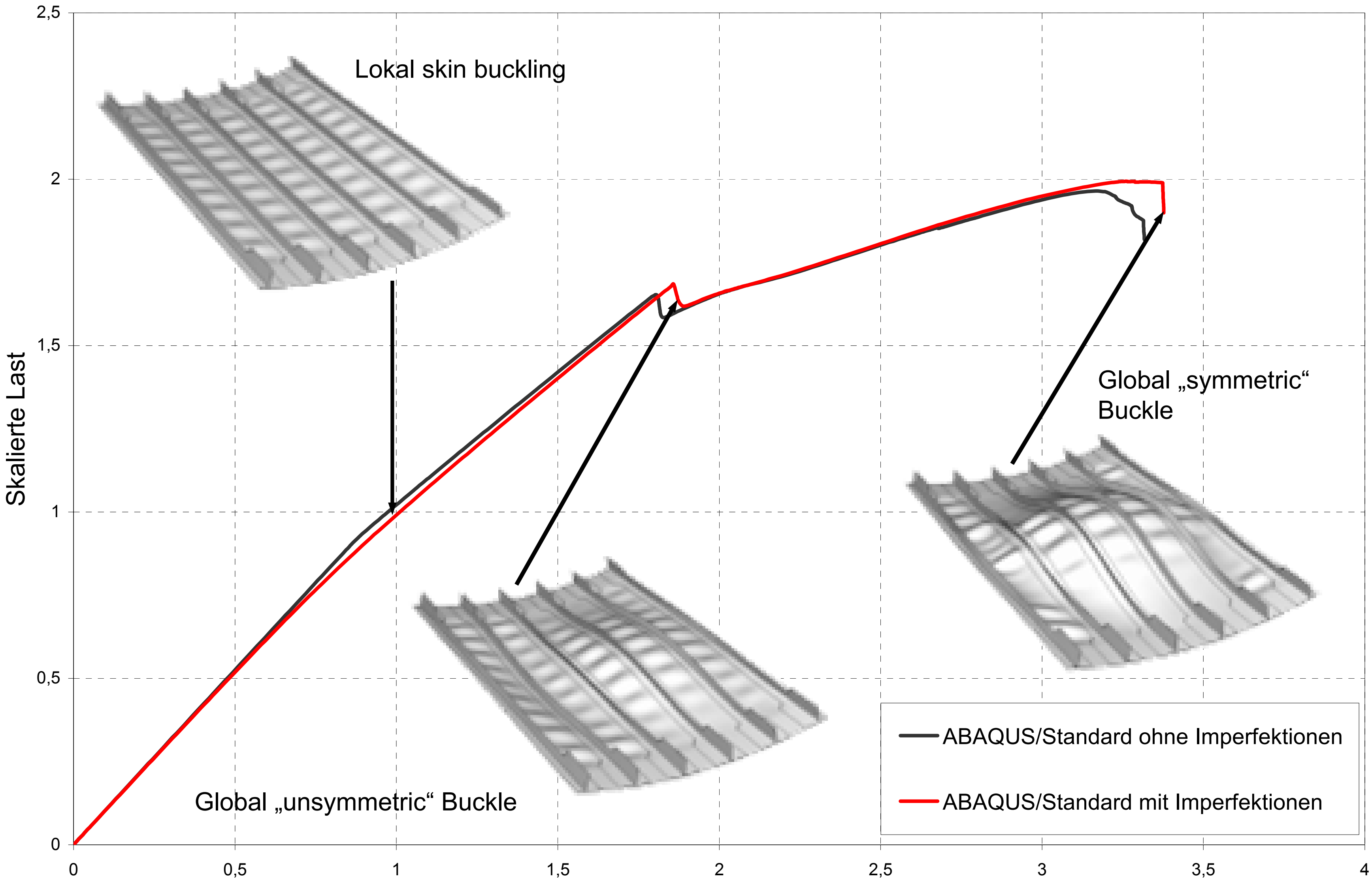
Data points (ASCII-Format):

1093.6441	211.5491	1.6805
1093.1718	211.1541	1.6764
1093.8102	210.6003	1.6764
1093.0879	210.3660	1.6910

…

Modification of „perfect“
FE – geometry
Application of initial
imperfection

Results of FEA using ABAQUS/Standard

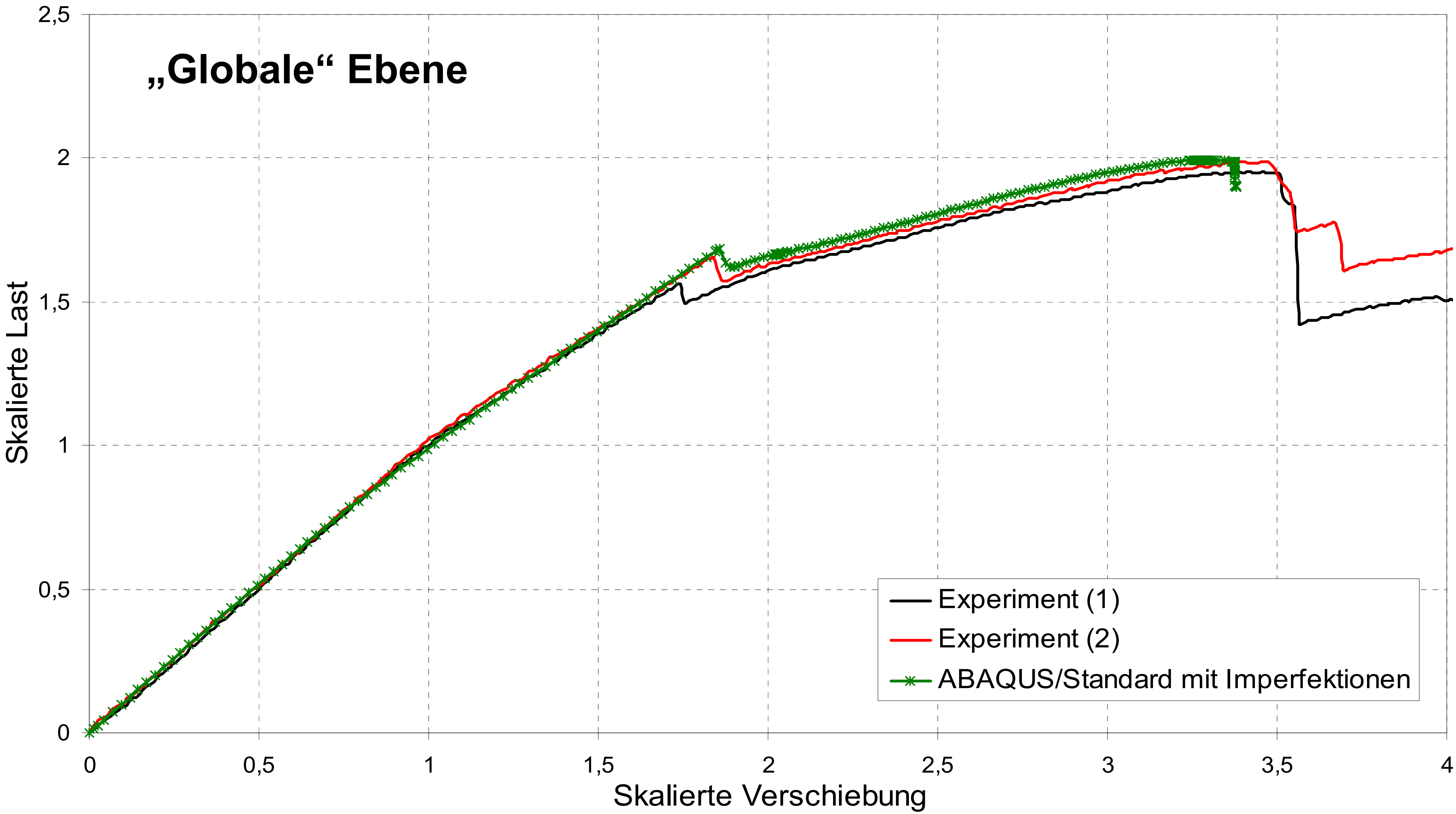


Validation of FEA (Animation)

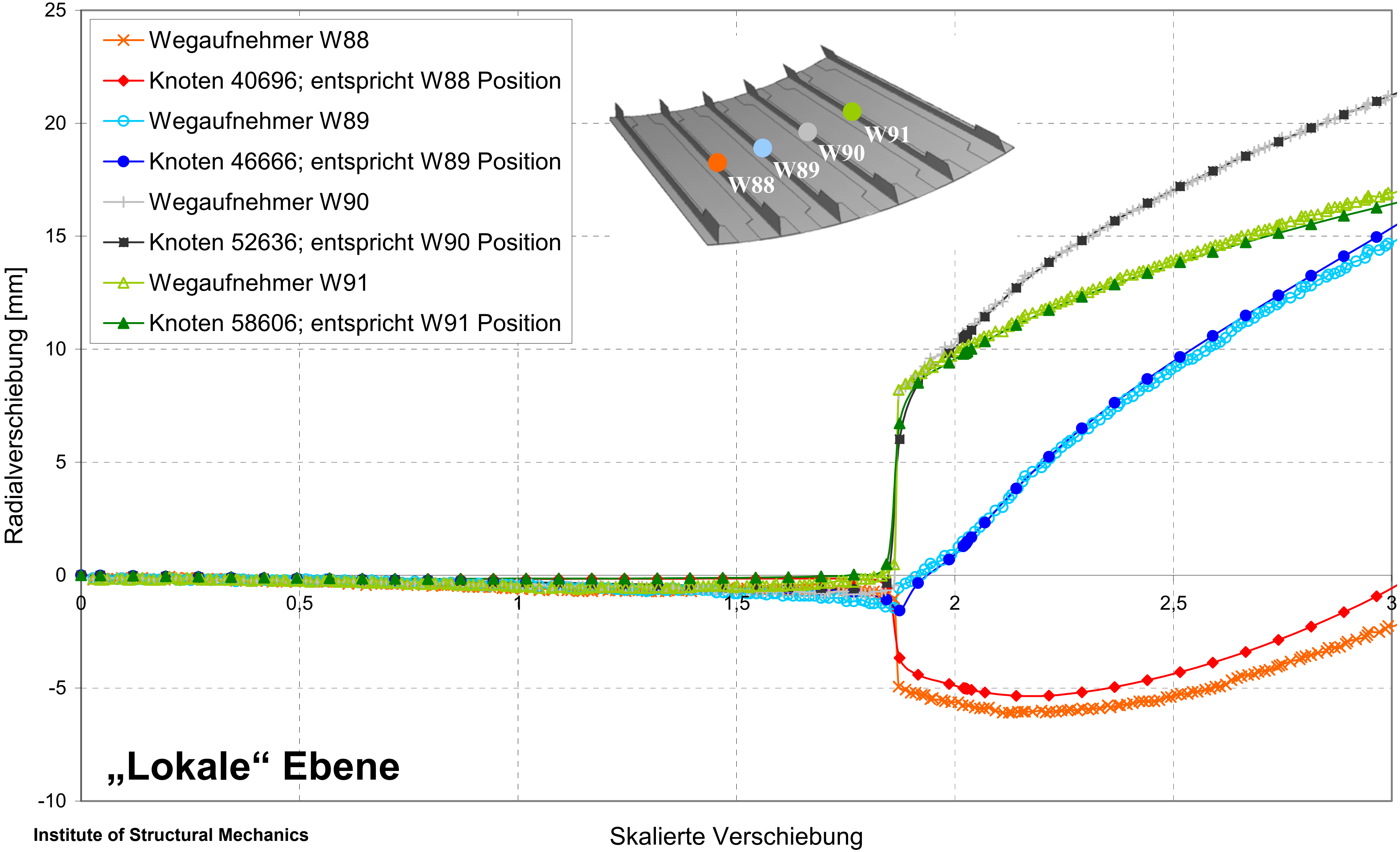
Validation of Nonlinear FEM (ABAQUS/Standard)

DLR 2002

Validation of computational results

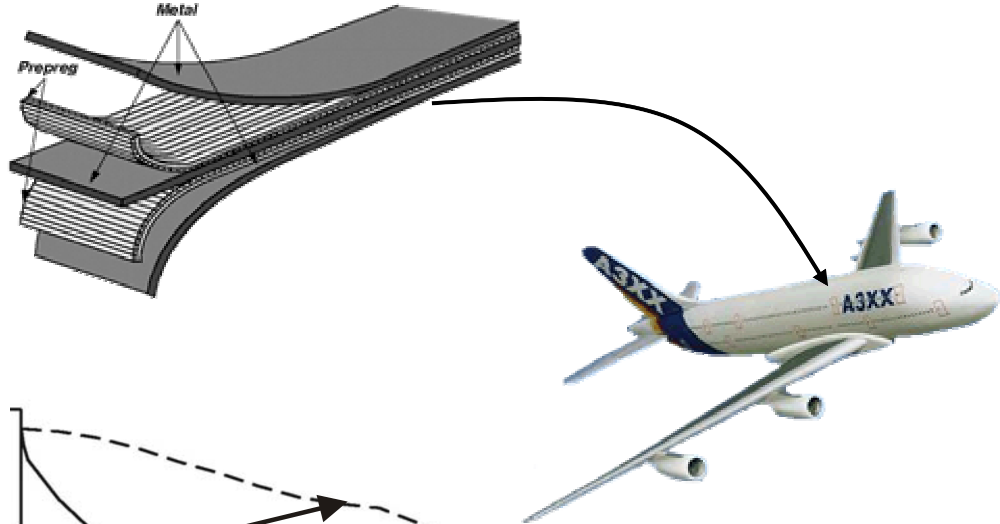


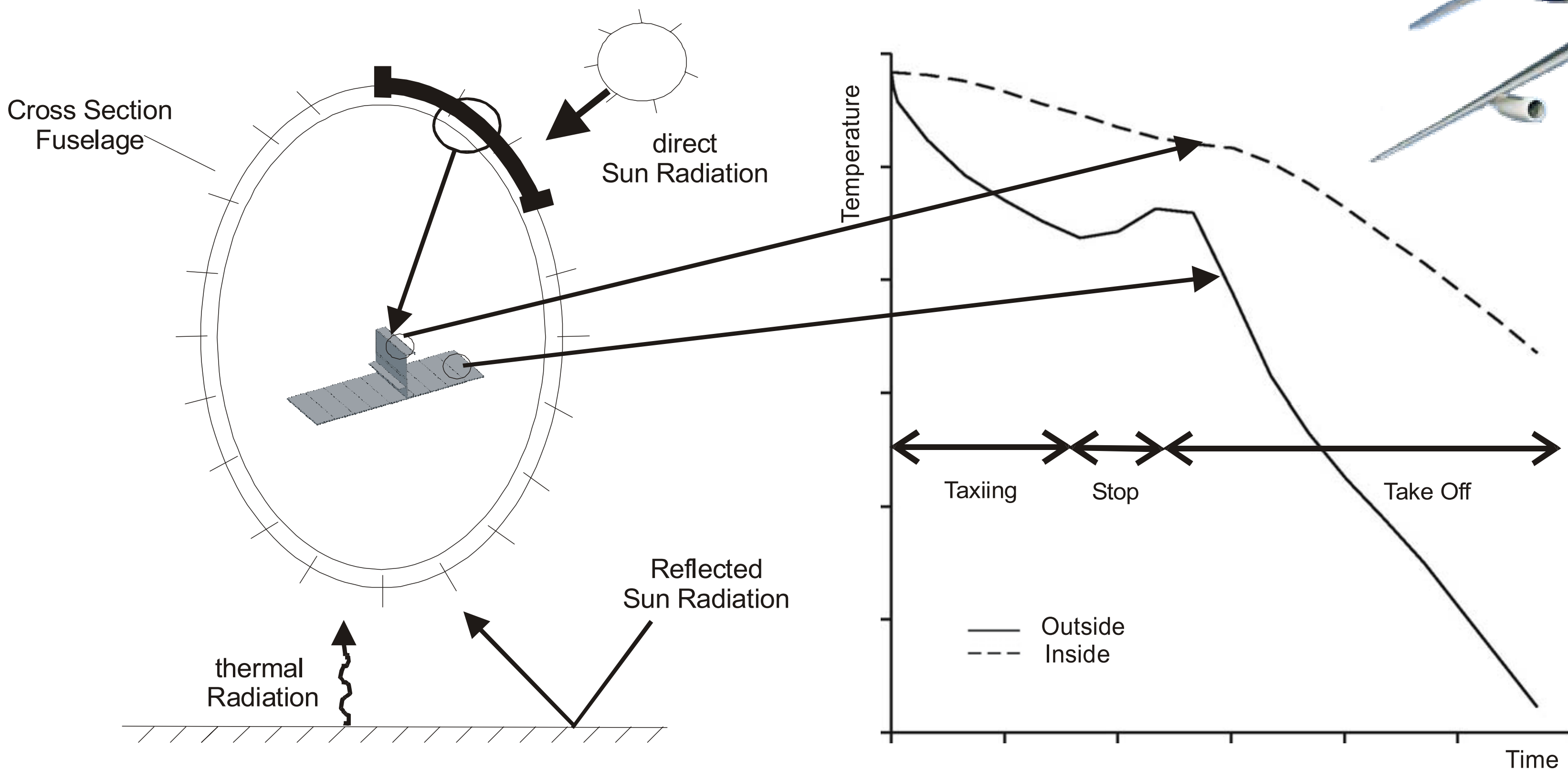
Validation of computational results



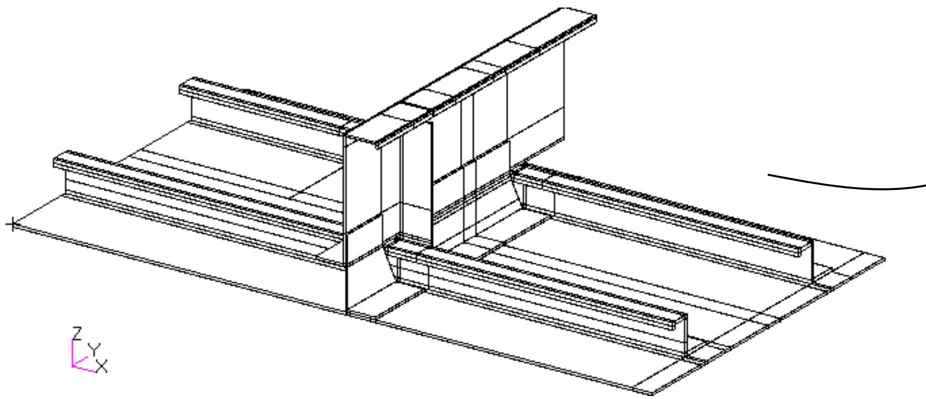
Thermal Problem

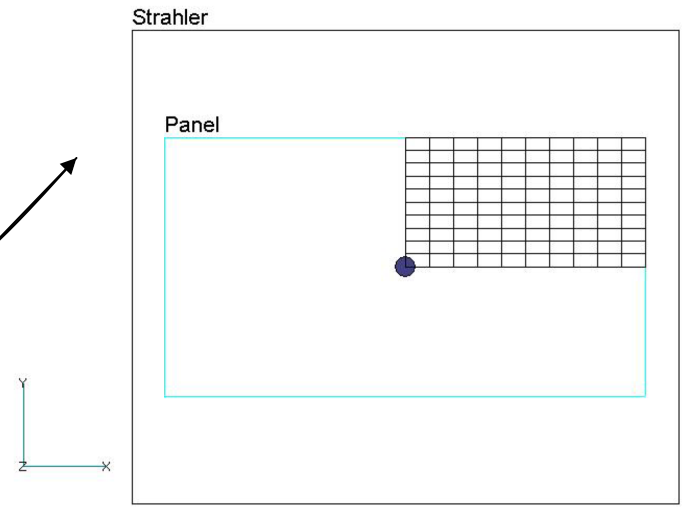
FML’s in future aircraft structures

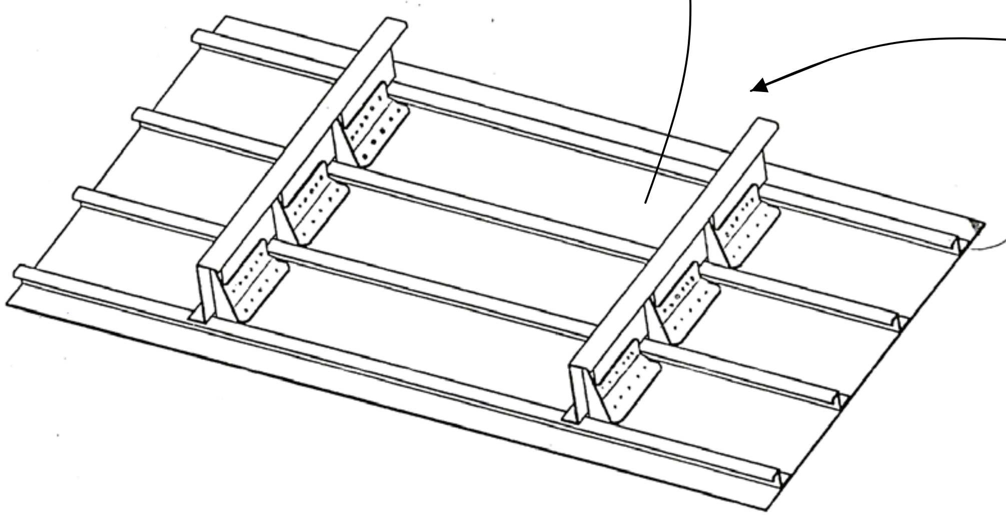




Modeling (on panel level)





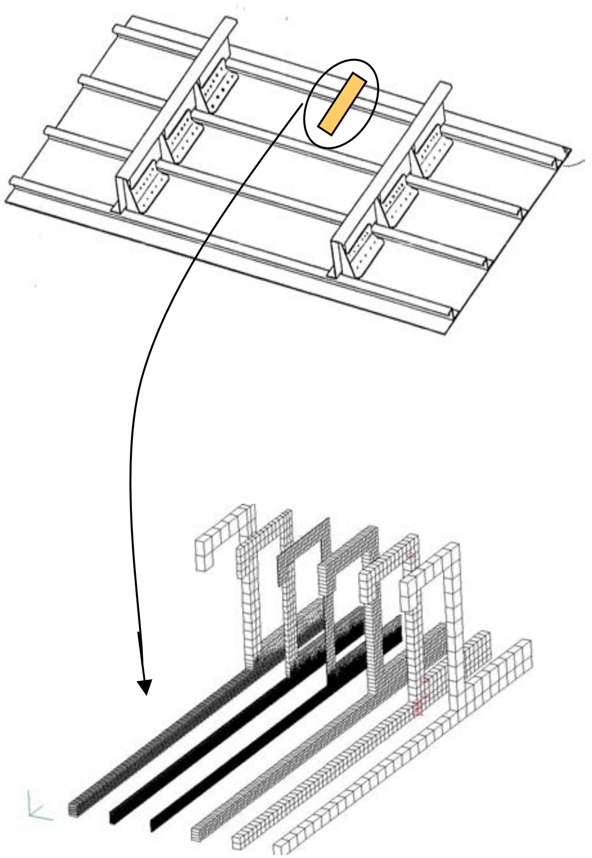


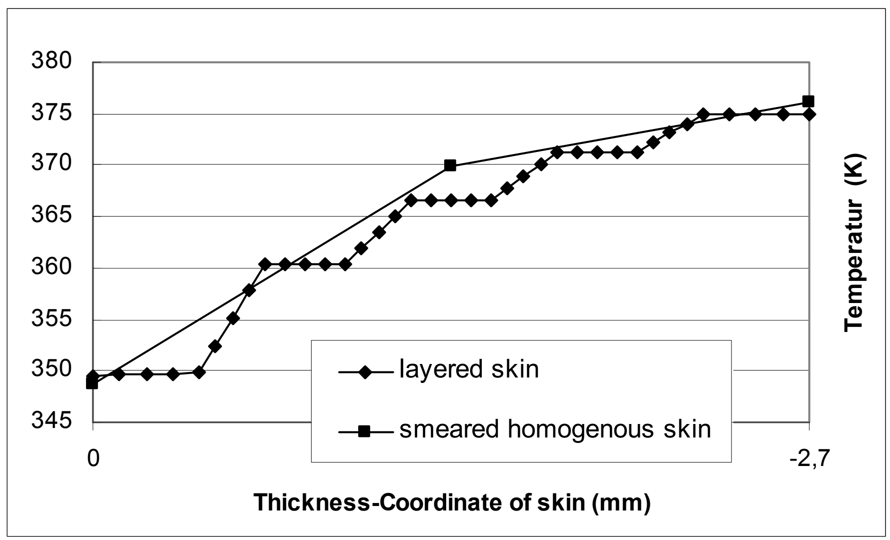
Model Verification

- **Convergence study with 6 different discretisations (1 to 36 elements in thickness direction)**
- **Homogenisation of smeared layers with:**

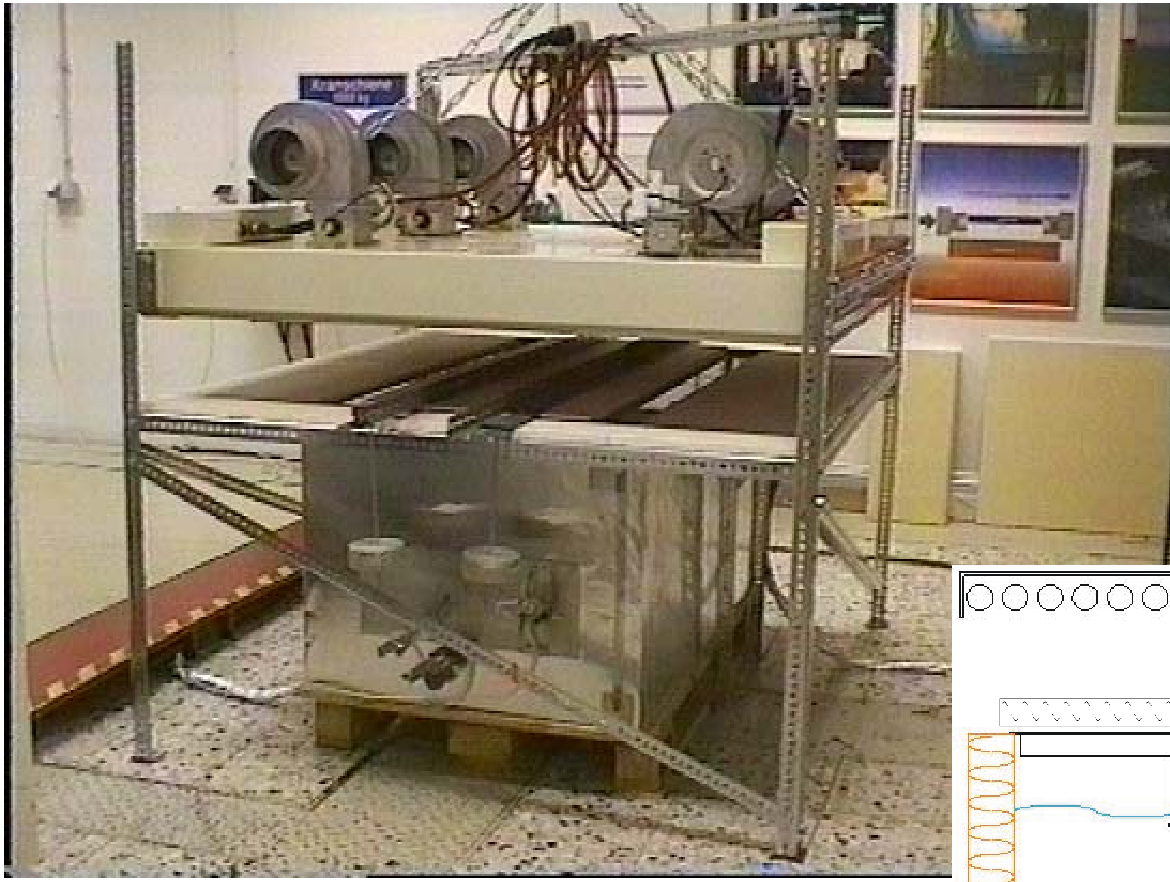
$$k_{out\_plane} = \sum_i t_i / \sum_i (t_i / k_{i,normal}) \ ,$$

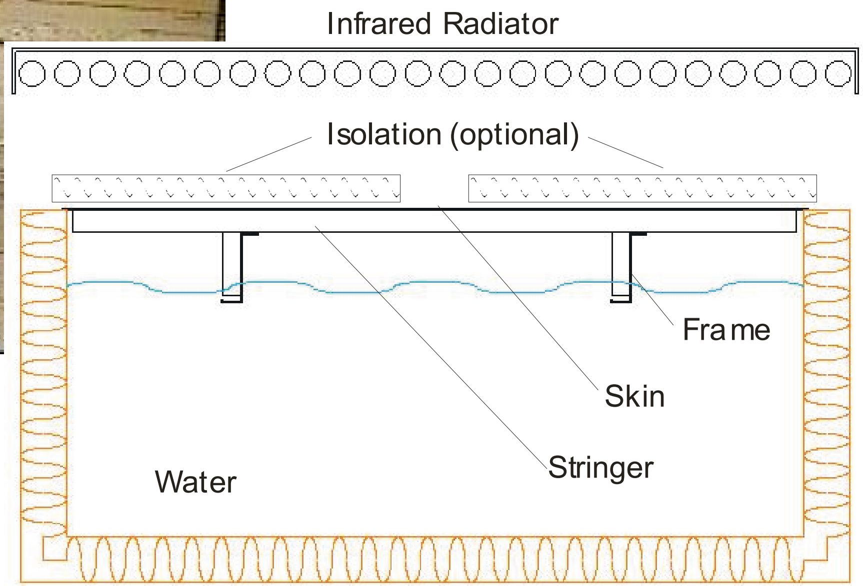
$$k_{in\_plane} = \sum_i (k_{i,plane} \cdot t_i) / \sum_i t_i \ .$$





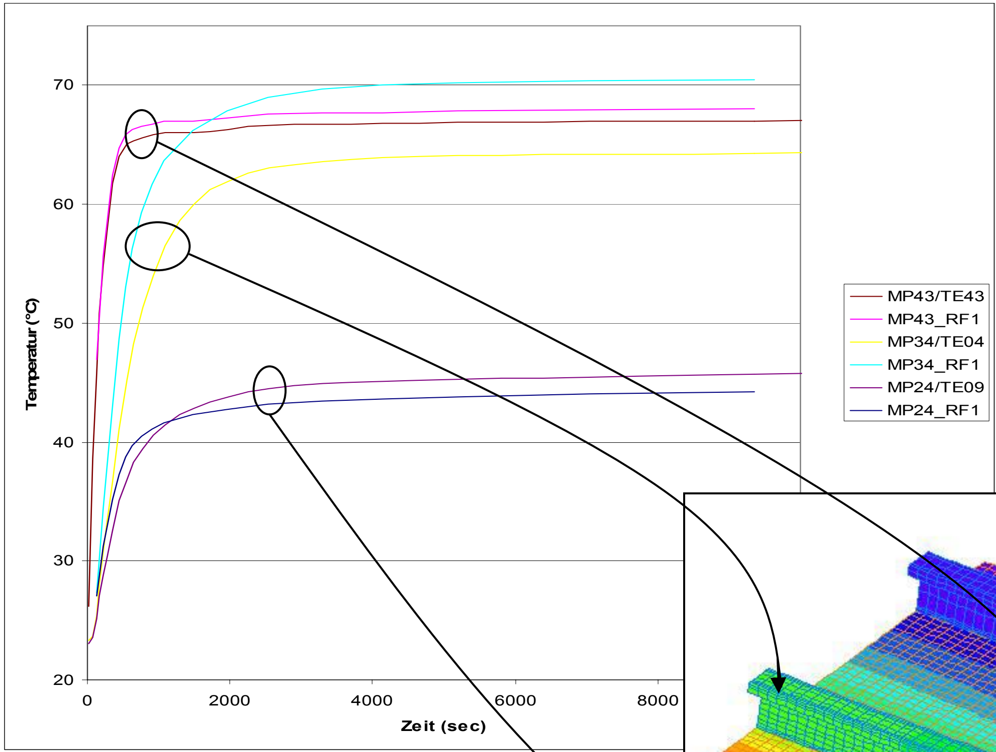
Experimental Test in THERMEX – B test site

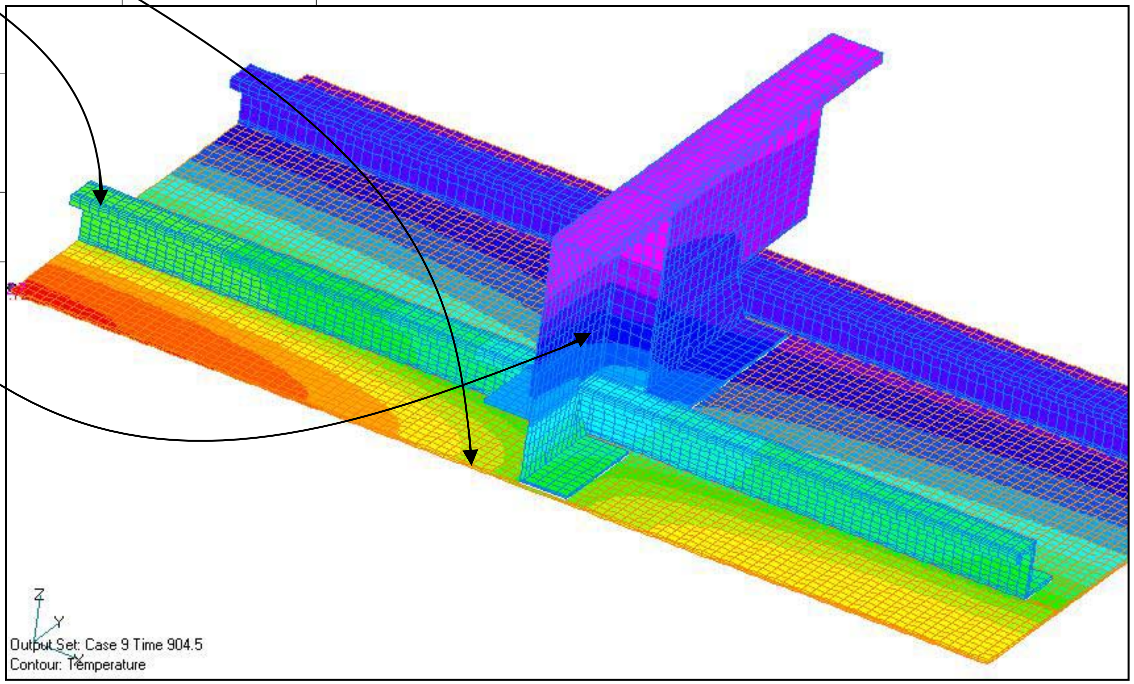




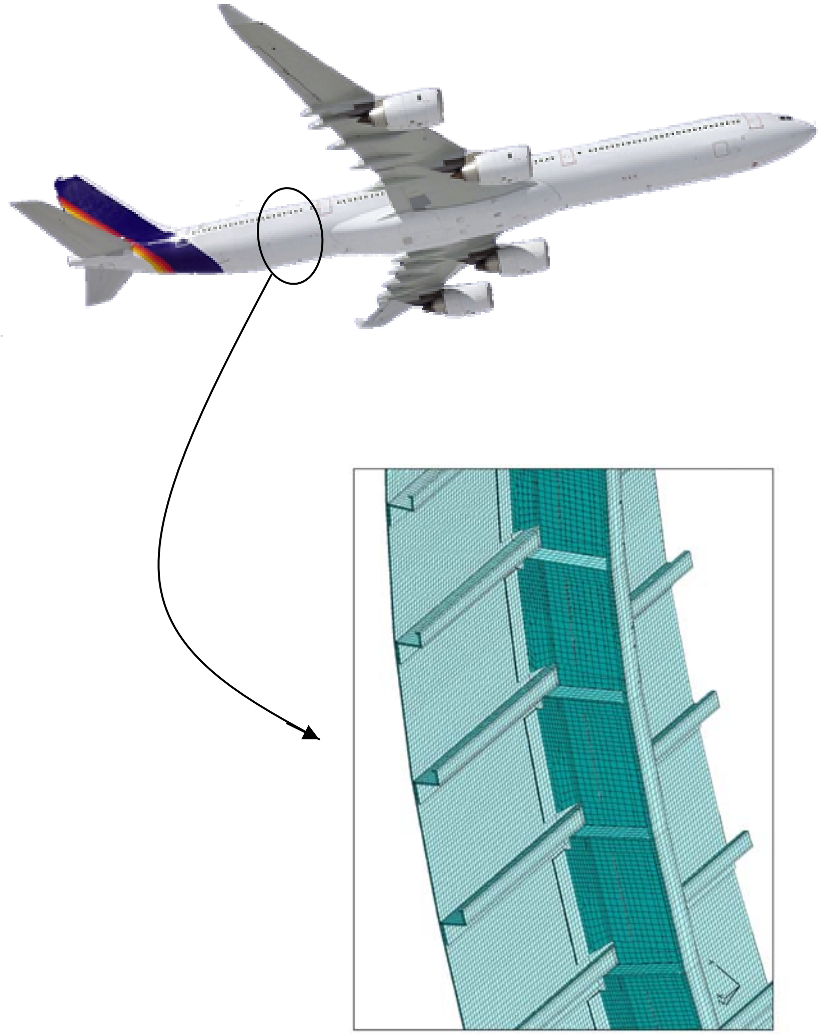
Validation

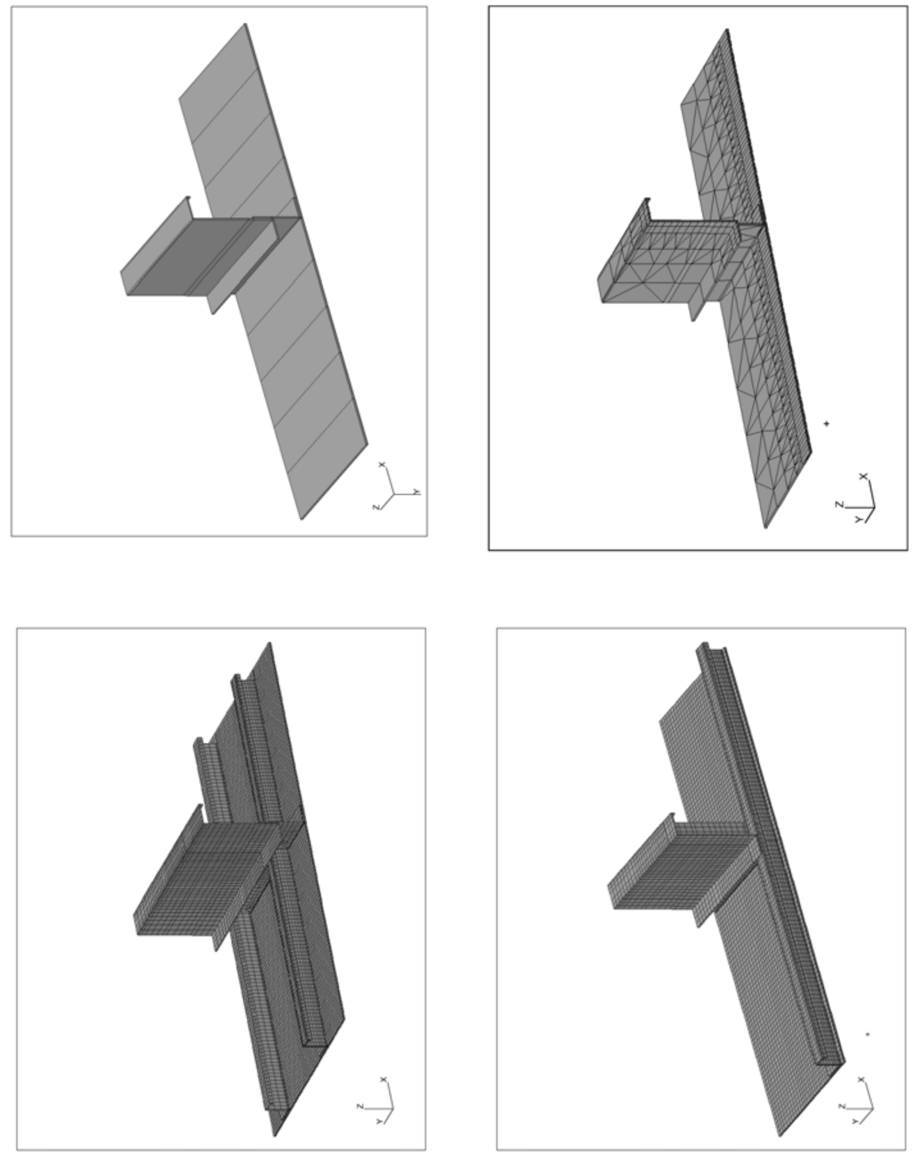
Experiment vs. Computation





Modeling of large fuselage structure





2D Finite Elements for Thermal Analysis of FML‘s

Motivation

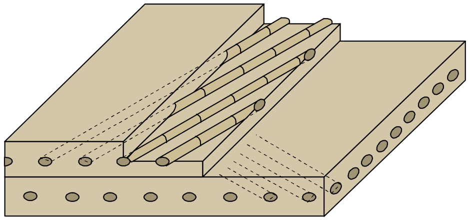
- Reduction of modeling effort by using 2D geometrical models
- Reduction of CPU-time
- Compatible temperature field for thermo-mechanical calculations

Scientific Challenge

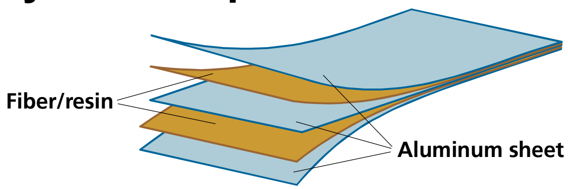
- 3D temperature field description based on 2D geometry
- Shape functions in z-direction
- 2D-3D-Coupling (Connection to local 3D meshes)

Layerwise Thermal Lamination Theories

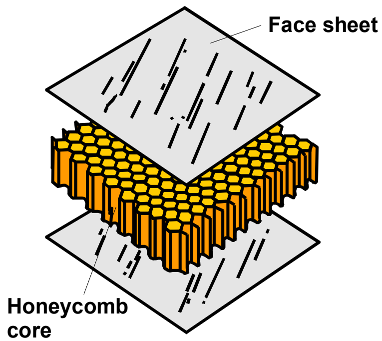
Composite structures



Hybrid composite structures

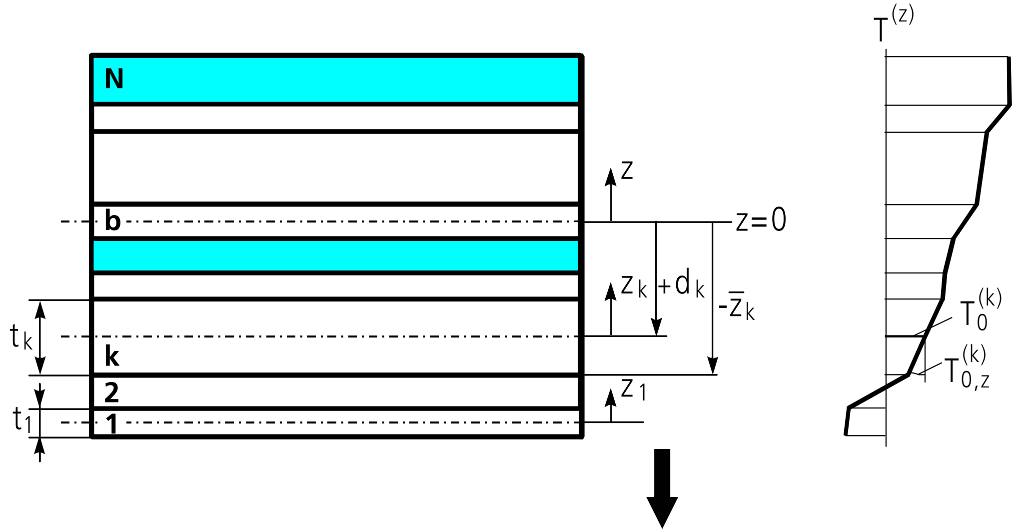


Sandwich structures



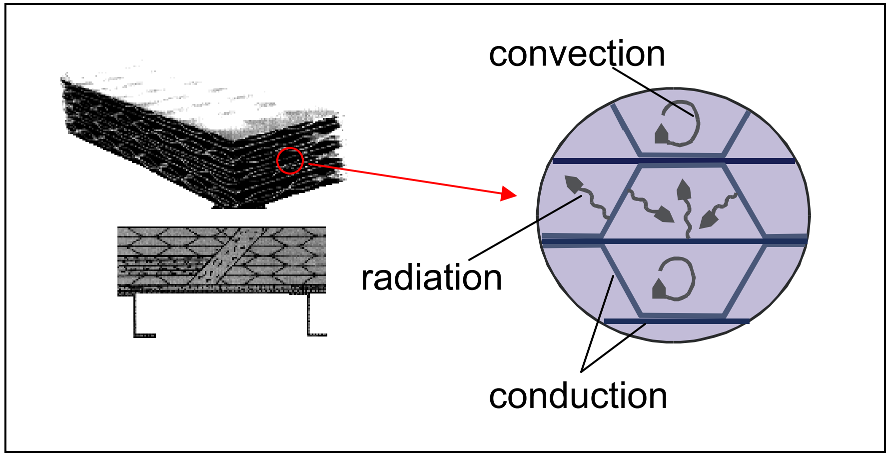
- Idealisation as layered structure
- Homogenisation of layers including heat conduction, radiation, convection

- Linear Layered Theory (LLT)
- Quadratic Layered Theory (QLT)



3D temperature distribution by 2D finite elements

Assumptions and Prerequisites

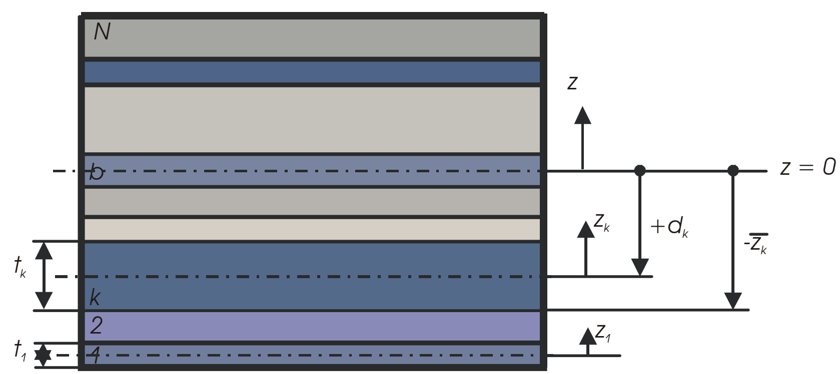


radiation → homogenisation
convection → homogenisation
conduction → homogenisation

homogenisation → equivalent thermal conductivity

- **perfect thermal contact at interfaces**
- **monolithic conduction within layers**
- **no internal heat sources**
- **temperature independent material properties**

approximation by layered construction



FE-Formulation

Weak form for heat conduction

$$\int_{\Omega} (grad\ \mathbf{v})^T\ \mathbf{K}\ grad\ \mathbf{T}\, \mathrm{d}\Omega \ +\ \int_{\Gamma} \mathbf{q}^T\ \mathbf{n}\ \mathbf{v}\, \mathrm{d}\Gamma \ +\ c\rho \int_{\Omega} \dot{\mathbf{T}} \mathbf{v}\, \mathrm{d}\Omega \ =\ 0$$

Boundary conditions $\quad \mathbf{q}^T \mathbf{n} = q_c + \bar{q}$

- Convection (Robin) $\quad q_c = \alpha_c \left(T_{\mathrm{Wand}} - T_{\infty} \right)$

- Heat flux density (Neumann) $\quad \bar{q}$

FE-Formulation

Weak form for heat conduction

$$\int_A \eta^T \int_z \mathbf{S}^T \mathbf{K} \mathbf{S} \,\mathrm{d}z \;\; \rho \,\mathrm{d}A + \alpha_c \int_\Gamma \eta^T \mathbf{R}^T \mathbf{R} \rho \,\mathrm{d}\Gamma + \int_A \eta^T \int_z c \mathbf{R}^T \mathbf{R} \,\mathrm{d}z \;\; \dot{\rho} \,\mathrm{d}A$$

$$= \left(\alpha_c T_\infty - \bar{q}\right) \int_\Gamma \eta^T \mathbf{R}^T \,\mathrm{d}\Gamma$$

Composite-heat-conduction-matrix

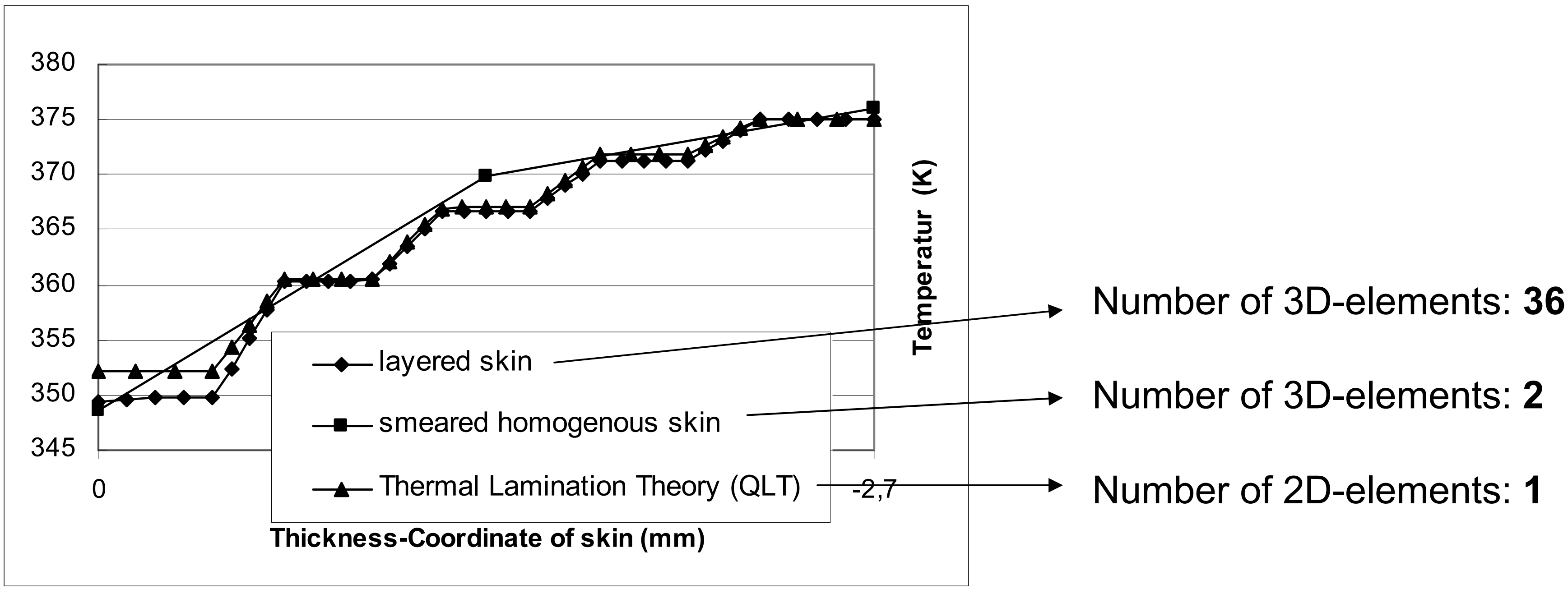
$$\hat{\mathbf{K}} = \int_z \mathbf{S}^T \mathbf{K} \mathbf{S} \,\mathrm{d}z = \sum_{k=1}^{N} \int_{\bar{z}_k}^{\bar{z}_{k+1}} \left(\mathbf{S}^{(k)}\right)^T \mathbf{K}^{(k)} \mathbf{S}^{(k)} \,\mathrm{d}z$$

Composite-heat-capacity-matrix

$$\hat{\mathbf{C}} = \int_z \bar{c} \mathbf{R}^T \mathbf{R} \,\mathrm{d}z = \sum_{k=1}^{N} \int_{\bar{z}_k}^{\bar{z}_{k+1}} c_k \rho_k \left(\mathbf{R}^{(k)}\right)^T \mathbf{R}^{(k)} \,\mathrm{d}z$$

Example: 3D vs. 2D FEA

GLARE skin with 3D finite elements (Nastran)



Summary

- Experimental data basis for validation of non linear FEA w.r.t. postbuckling of stiffened shells under axial loading
- Investigation of sensitivity w.r.t. to different modeling parameters
- Excellent agreement between experimental and computational results deep into elastic postcritical regime (global & local)

- Reliable thermal analysis of FML structures by verification of discretisation through fine 3D model on panel level
- Validation of thermal panel model by experiments in THERMEX – B test site
- Application of thermal model to large fuselage structures
- Description of fast 2D Finite-Element-Formulation

- Question: How many experiments are needed for validation of a specified parameter space?