Novel Stability Design Scenario for Aircraft Structures
–
Simulation and Experimental Validation

J. Teßmer

A. Kling, R. Degenhardt, H. Klein, R. Zimmermann

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Introduction

Aims of (aerospace) industry:

- Optimal leight-weight structures (geometry, material, etc.)
- Low costs / low weight
- Shorter development cycles

Fast/validated simulation tools

Competitiveness

Safety

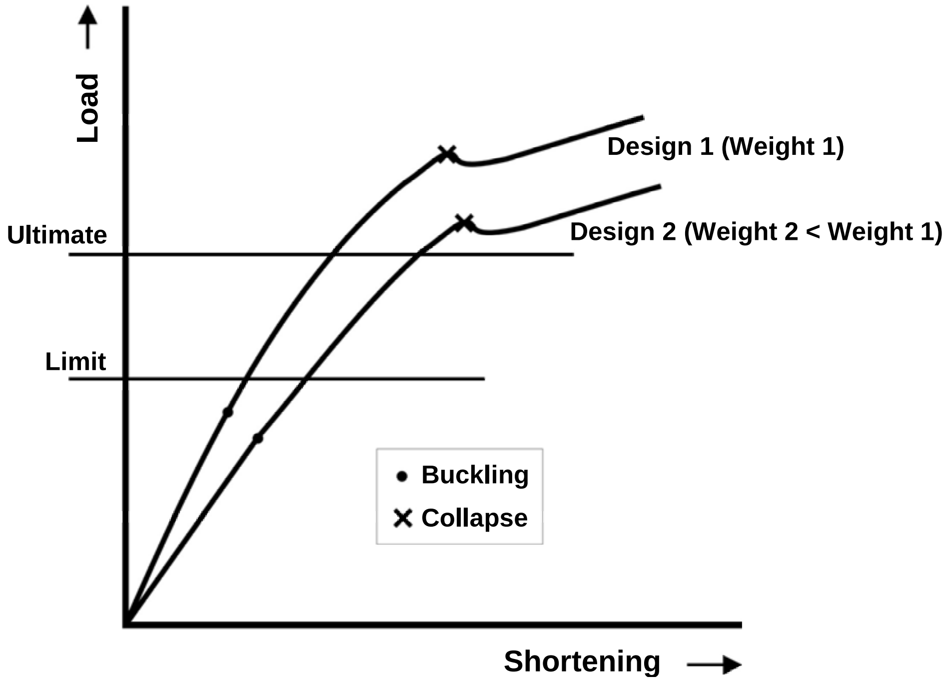
Not at the expense of

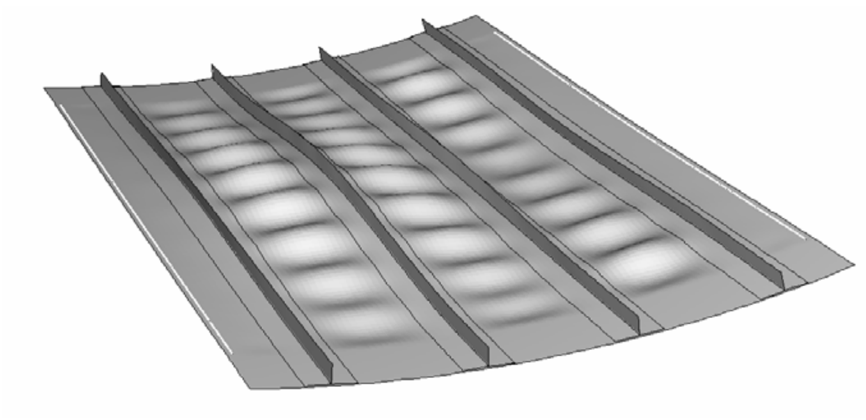
⇒ **Increasing the exploitation of structural reserves**

⇒ **No reduction of safety for aerospace structures**

⇒ **Focus on thin-walled composite aerospace structures prone to loss of stability**

New Design Scenario for Stiffened Panels





⇒ **Design 1 (Weight 1) constrained by limit load (first buckling load is close to limit load) - currently common practice**

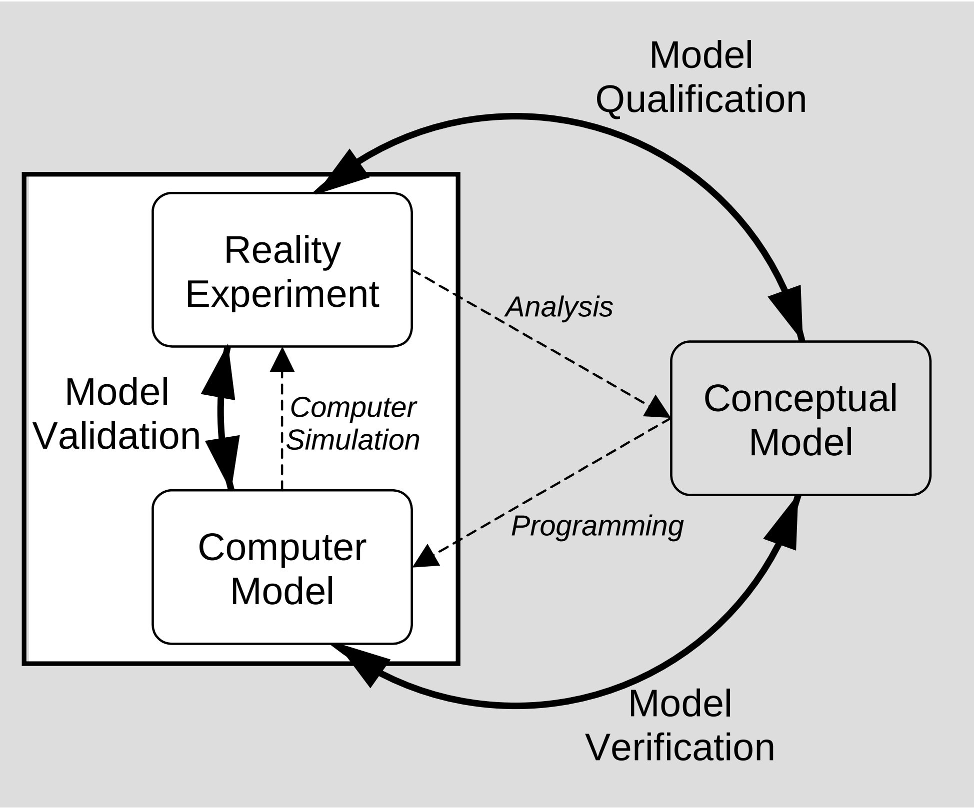
⇒ **Design 2, (Weight 2 < Weight 1) constrained by ultimate load definition (ultimate load is slightly below collapse) - new design scenario**

Requirements for the New Design Szenario

- Accurate and experimentally validated analysis up to the deep postbuckling region → **Validation**
- Coverage of all relevant loading conditions → **e.g. Dynamic loading**
- Coverage of real geometry → **Robust design**
- Fast tools for design process
- etc.

$\Rightarrow$ Prediction of structural response with high reliability

Validated Postbuckling Simulation of Stiffened CFRP-Panel



Model Verification

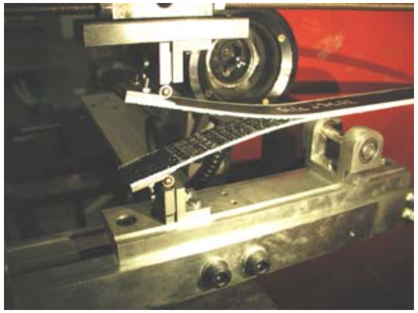
„Solve the equations *right*"

Model Validation:

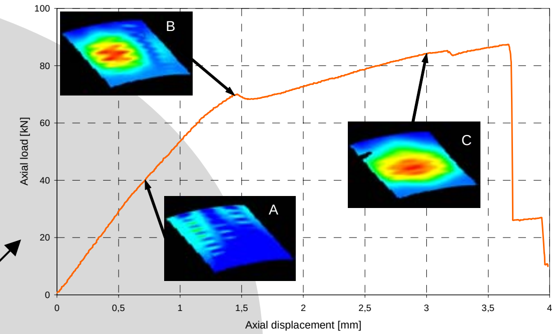
„Solve the *right* equations"

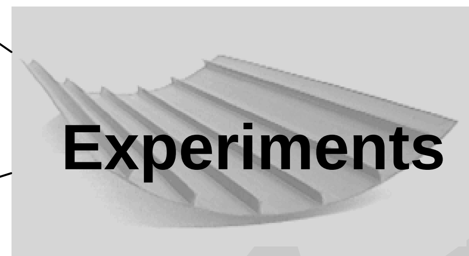
Experiments

Material Characterization



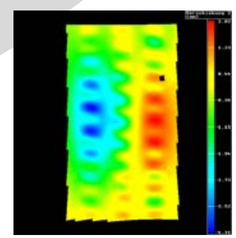
Phenomenological



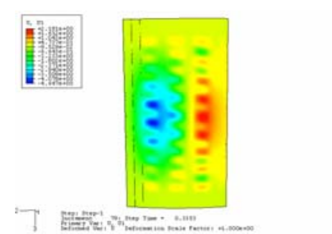


Qualification

Validation



Experiment



Computation

Pre-Test Planing

Goal: Load-shortening curve:
- Distinct skin buckling – combined with a change in axial stiffness
- Significant load-carrying capacity in the post-buckling regime.

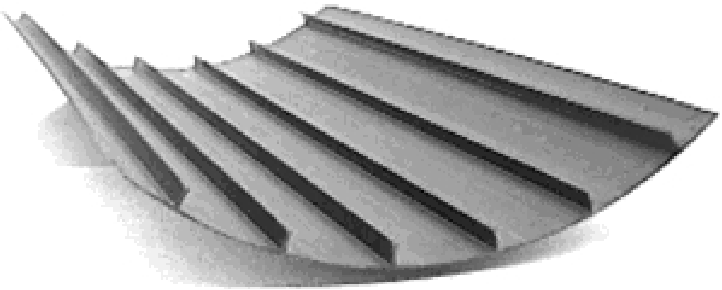
⇨ FEM Pre-test analysis:
- panel geometry
- influence of imperfections
- influence of different boundary conditions

⇨ Determine appropriate
- loading conditions
- sensor locations

Test Specimen and Test Facility

DLR Test facility

Test specimen – CFRP panel



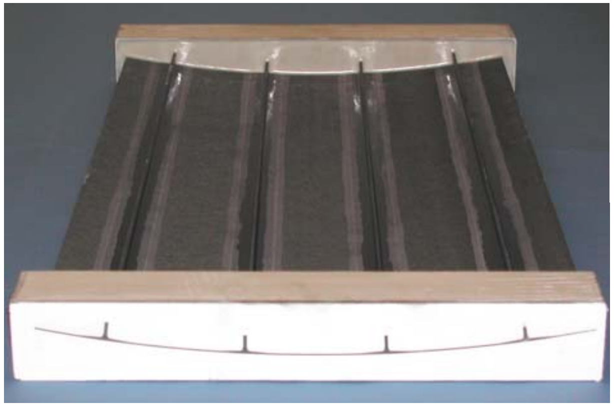
Specifikation:

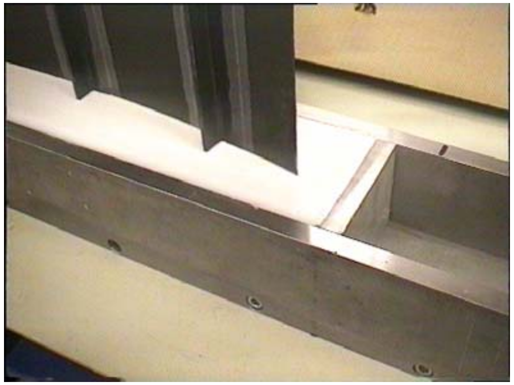
Panel length:	≤ 1600 mm
Panel width:	≤ 1200 mm
Axial load :	≤ 1000 kN
Axial displacement:	≤ 40 mm

Shear / dynamic loading possible

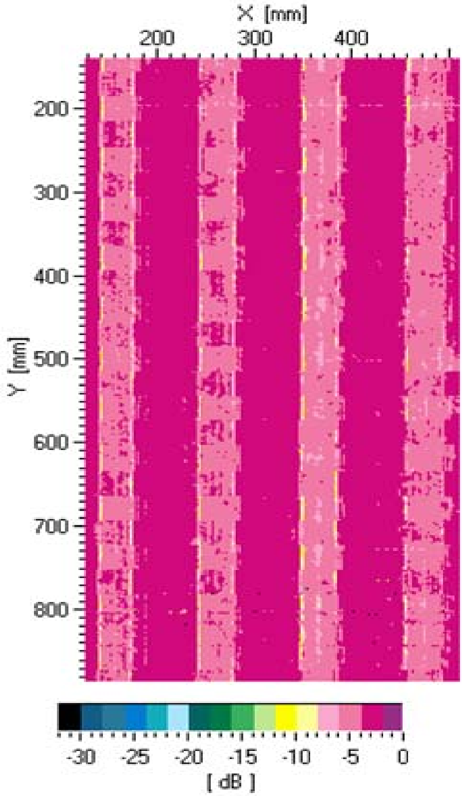
Preparation of Test Specimen

Test specimen

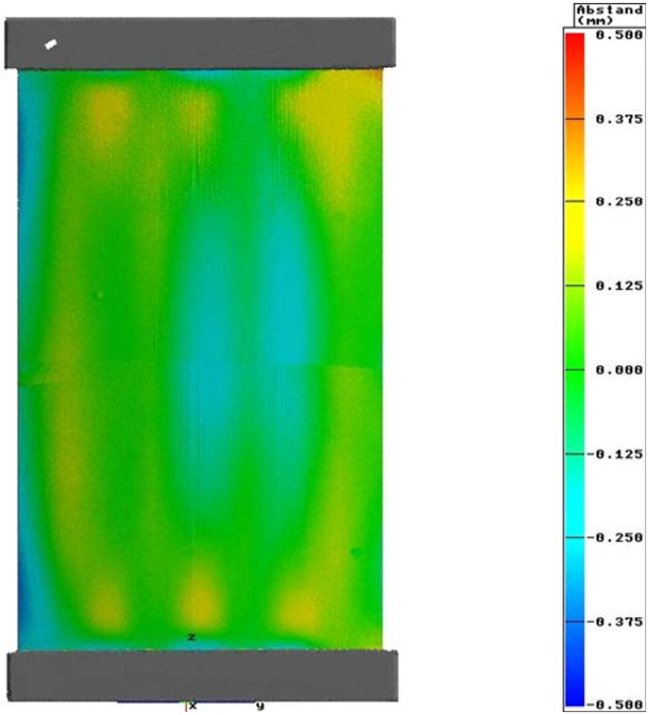




Ultrasonic flaw echo



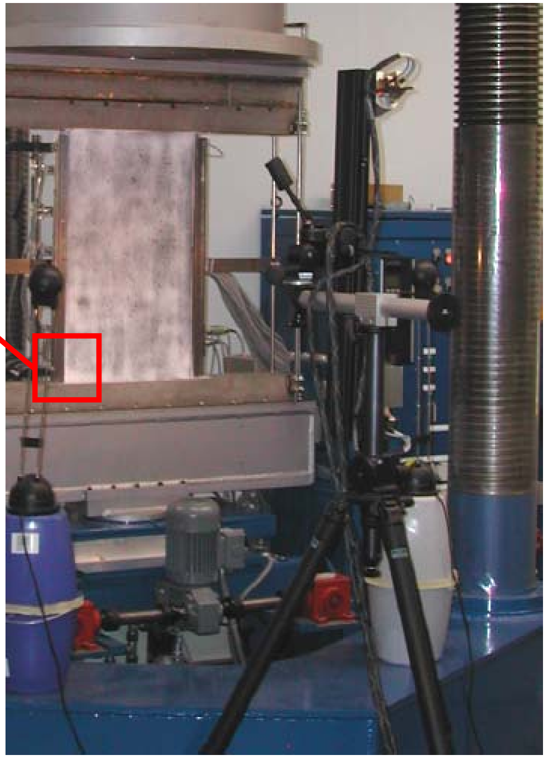
Measured imperfections



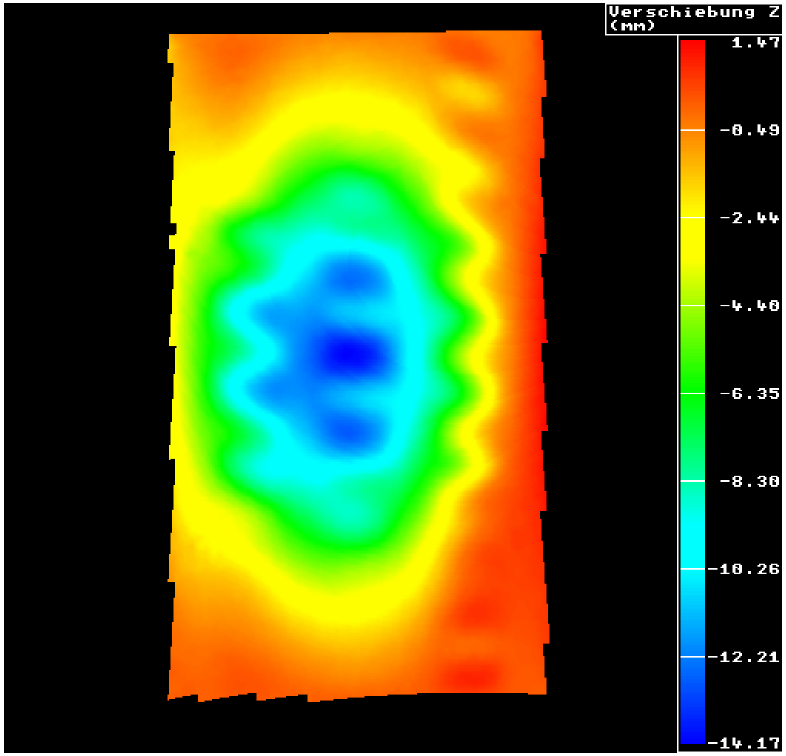
Optical 3D-Digitizing During the Experiment

Quantitative deformation pattern of Panel 12 at 89 load levels (≈0.044 mm axial displacement/image)

Powder spray coating with irregular pattern

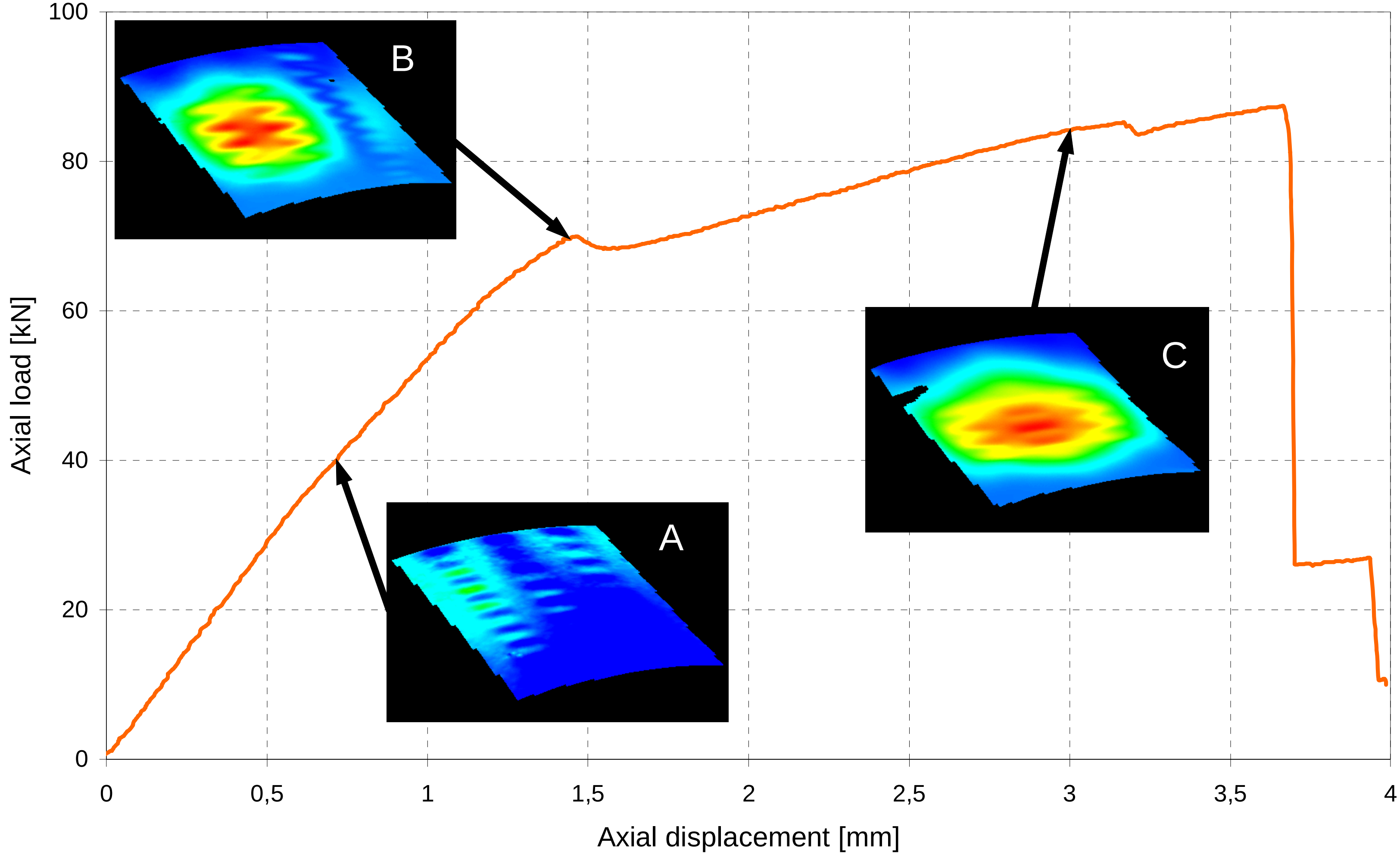


ARAMIS-System



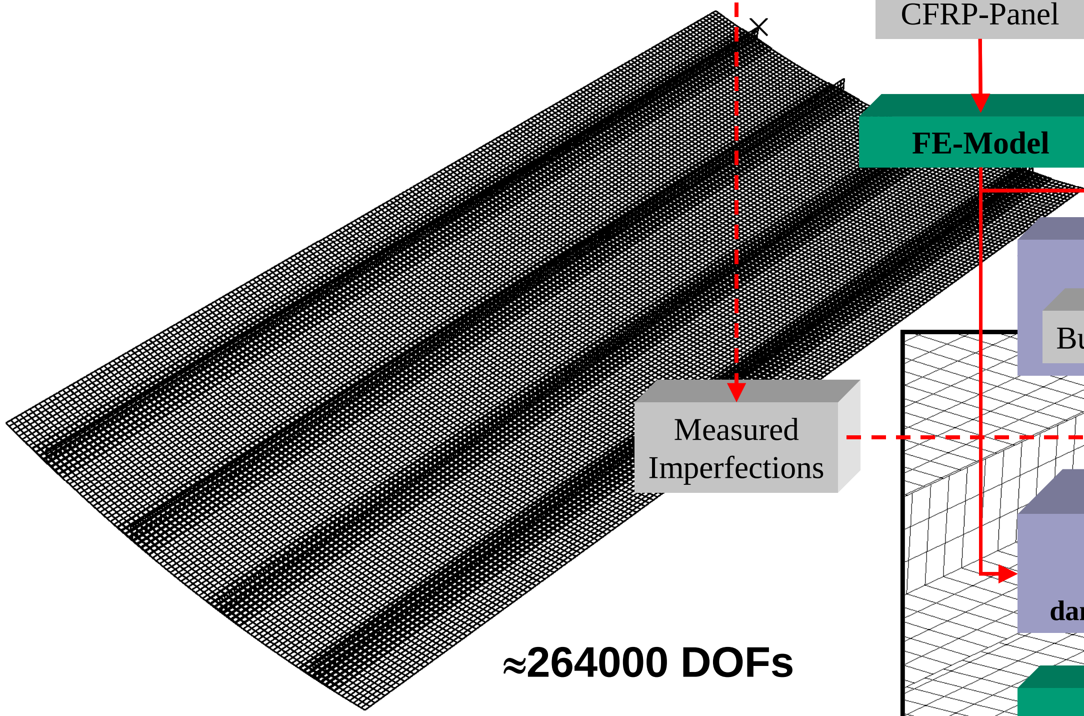
Quantitative deformation pattern
Accuracy: ≈ 0.05 mm

Experimental Results



Numerical Analysis

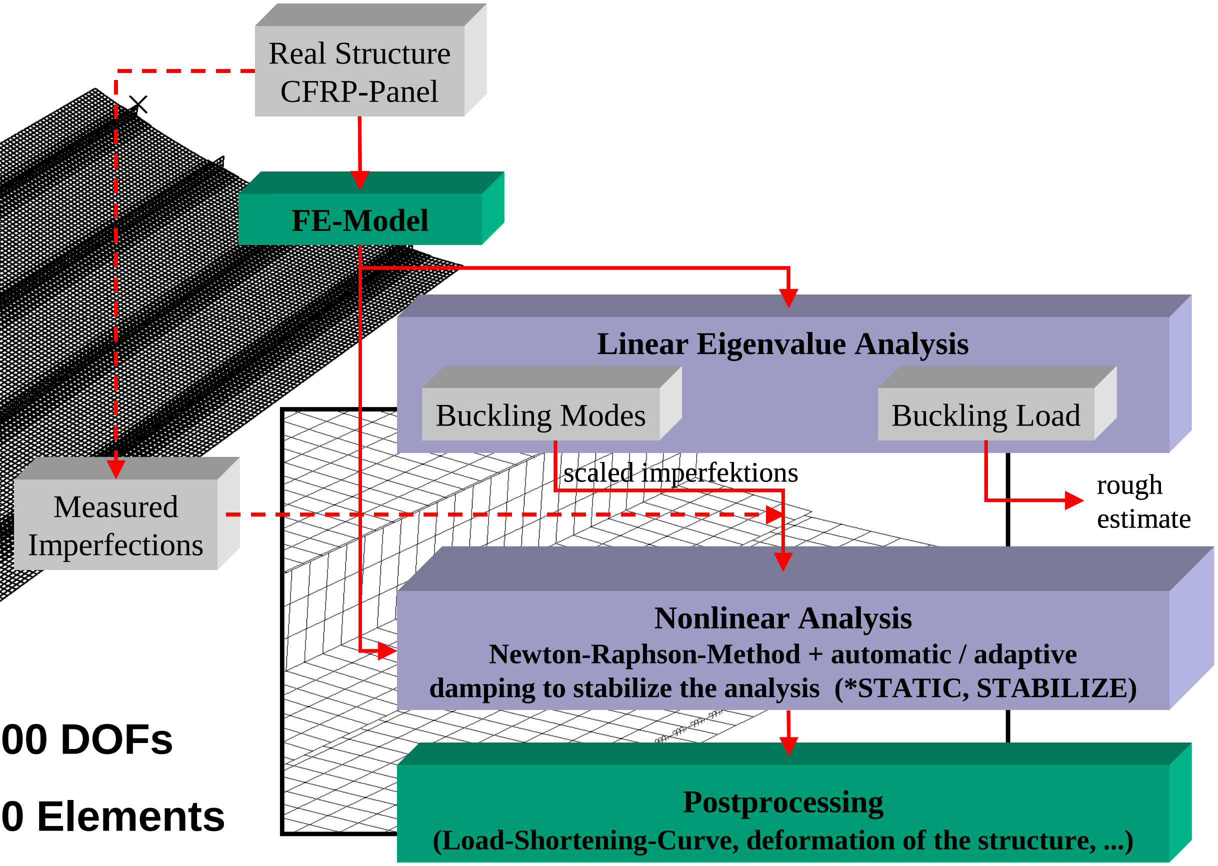
Numerical model



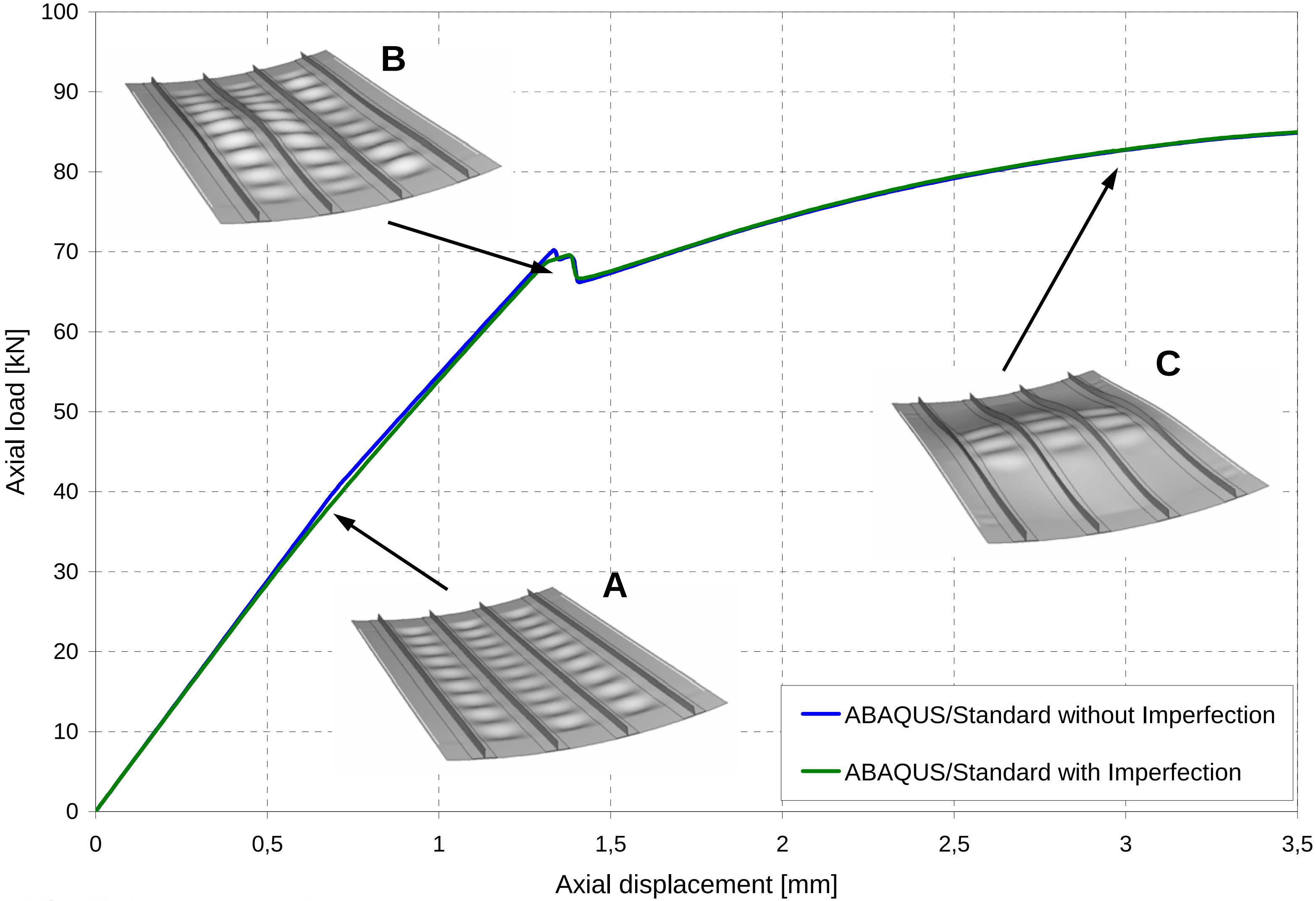
≈264000 DOFs

≈42000 Elements

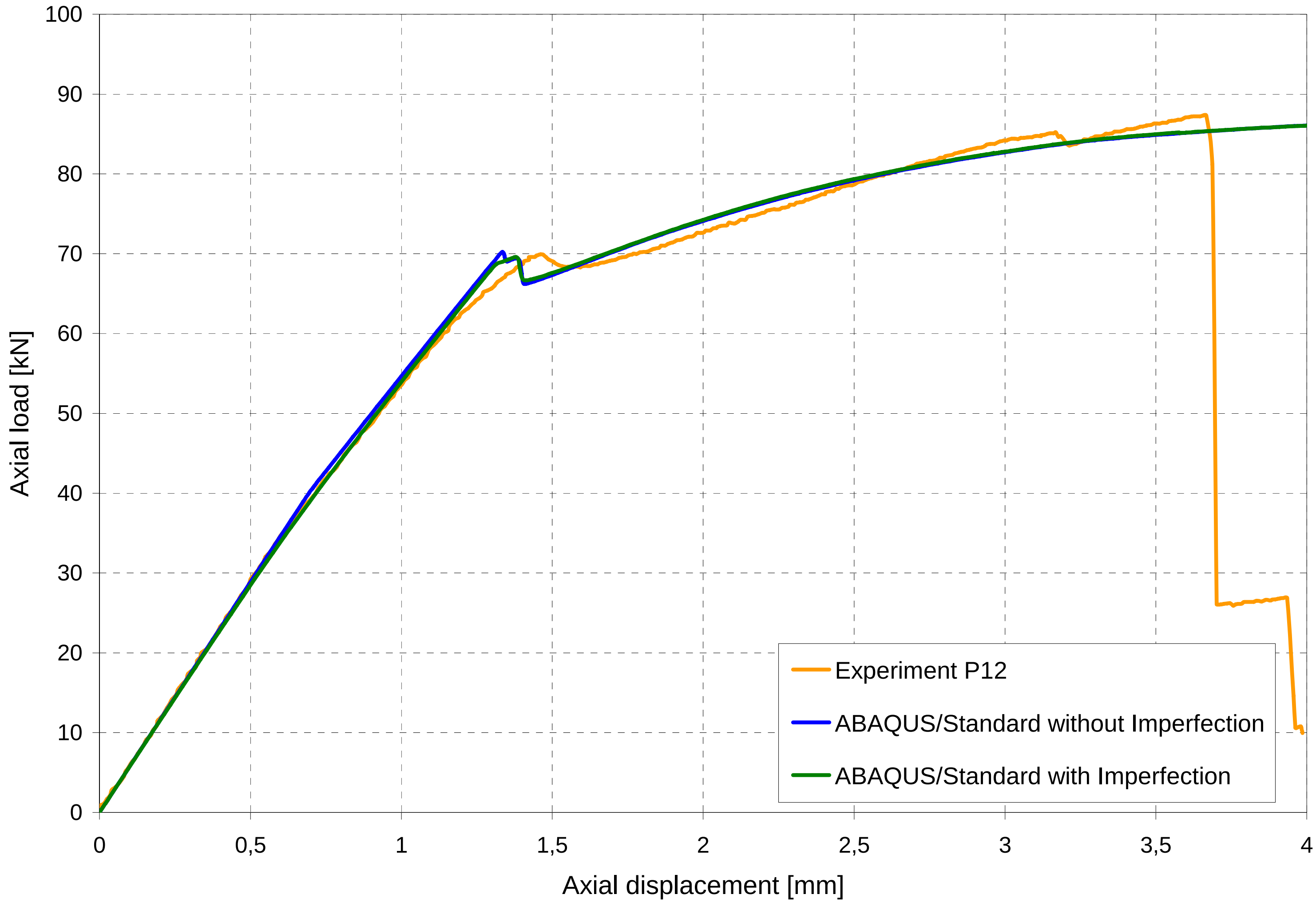
Procedure of Nonlinear FEA



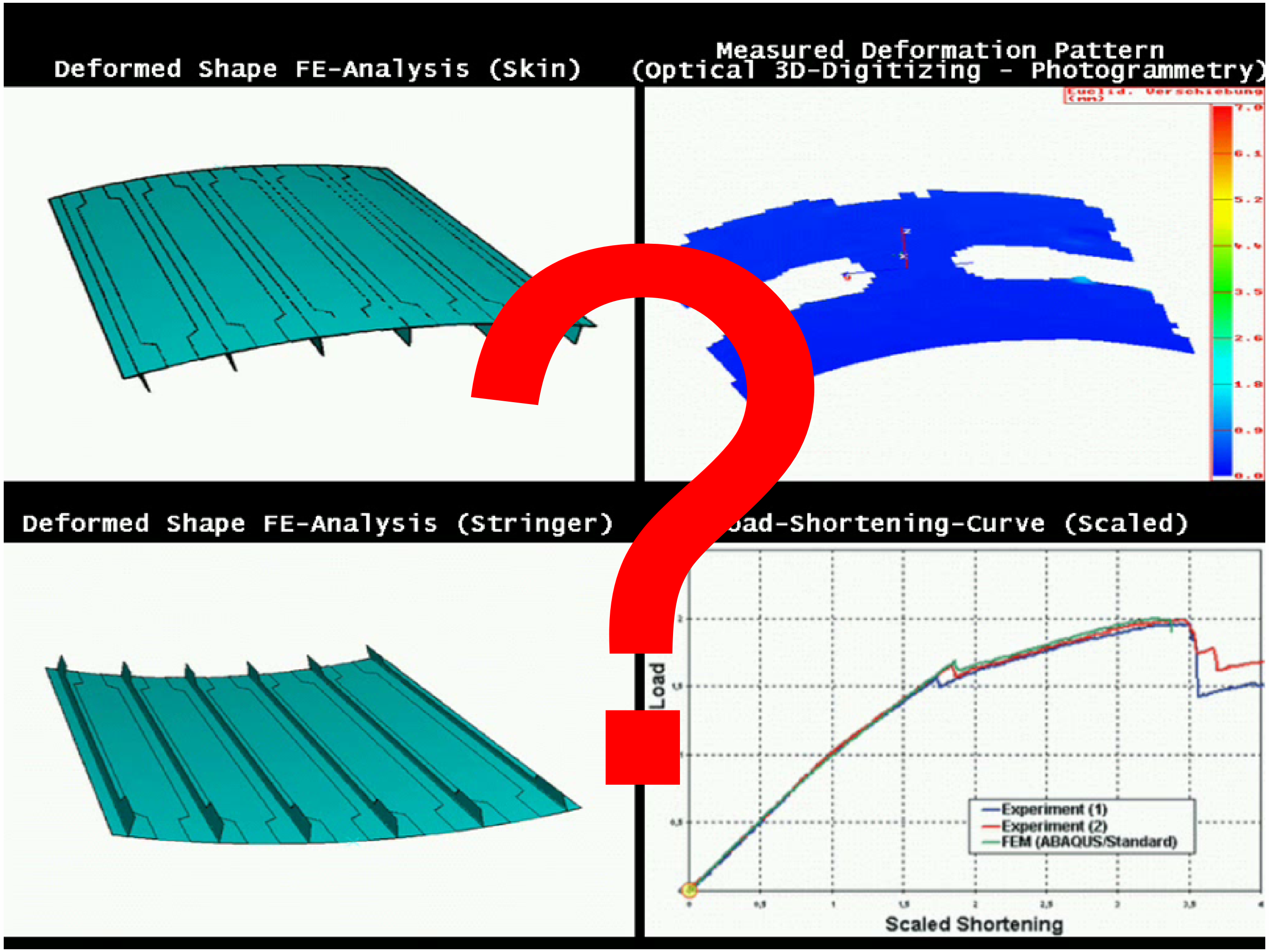
Results of Nonlinear Finite Element Analysis



Results of Nonlinear Finite Element Analysis



Validation

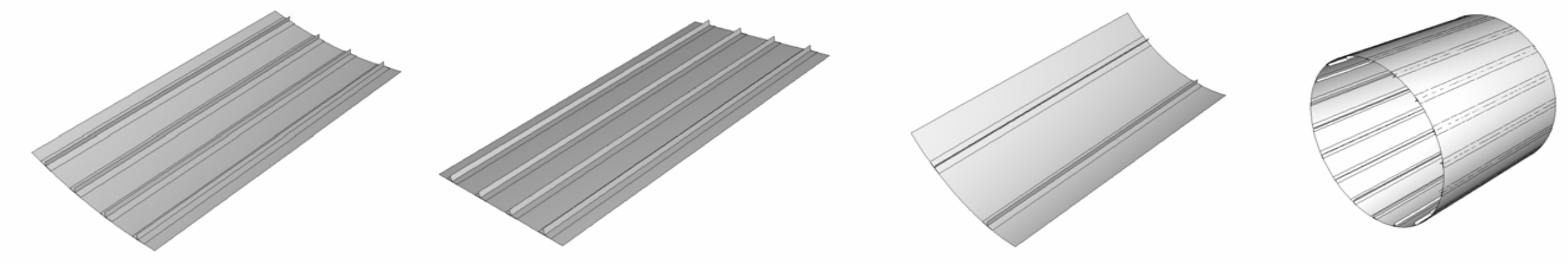


Deformed Shape FE-Analysis (Skin)
Measured Deformation Pattern
(Optical 3D-Digitizing - Photogrammetry)
Deformed Shape FE-Analysis (Stringer)
Load-Shortening-Curve (Scaled)
Load
Scaled Shortening
Experiment (1)
Experiment (2)
FEM (ABAQUS/Standard)

Transferability of Validated Results

<u>Possible question:</u>

-Transferability of validated results with respect to Geometry, Material, Manufacturing Process etc.



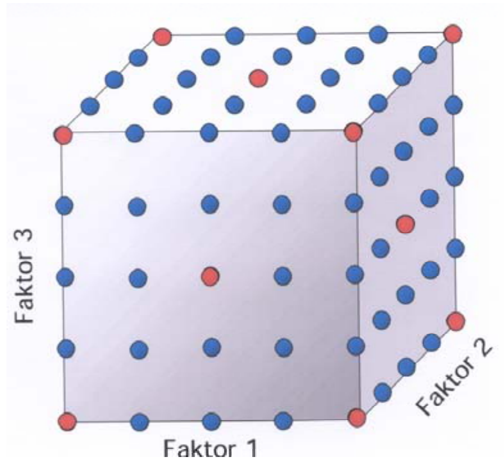
Validated Structure | Transfer - OK | Transfer - ? | Transfer - ???

- How many physical tests are necessary to cover a predetermined parameter range?

Design of Experiments“ (DoE)

Utilization of mathematical Methods for planning and evaluation of experiments

E.g. Experiments in parameter range:



Determination of the relevant points for the subsequent validation of the desired parametric range using multiple methods during the definition of the test structures.

Benefit:

- To obtain more information of the test structures (⇨To identify interdependencies)
- Reduction of the experimental effort (⇨optimal experimental strategy)
- Improvements of the experimental database(⇨ „Validation experiments“)

Conclusion

- Weight saving potential through new design scenario w.r.t. buckling
- Experimental validation is important for accurate computational methods
- Strong interaction between modelling and experimental boundary conditions

Perspective

- Speed-up of postbuckling analysis of stiffened panels
- Influence of degradation for collapse simulation
- Definition of validated parameter space
- Reduction of time and cost