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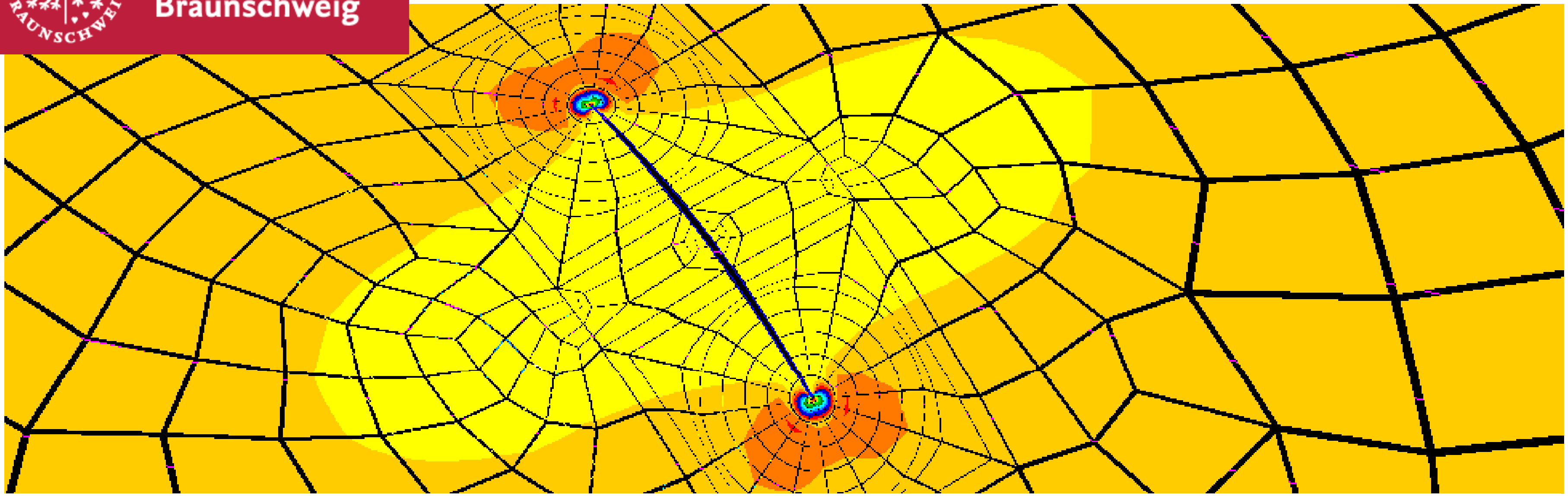

1st EASN Association Workshop on Aerostructures

Crack propagation in buckling plates: Test results and a simplified numerical approach

Julia Bierbaum and Peter Horst, 07/10/2010

Outline

- Motivation
- Test set-up
- Test performances and results
- Numerical analysis
- Conclusion

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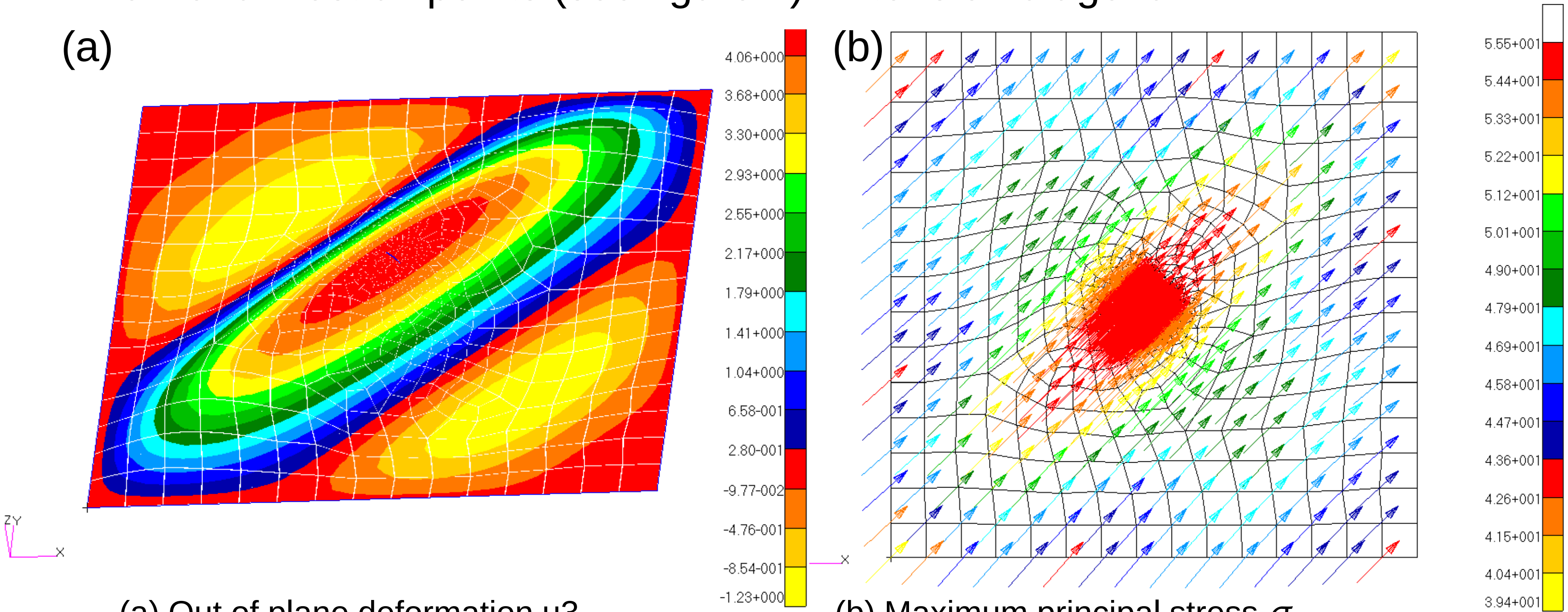
Motivation

- In general buckling and crack propagation are examined separately
- Combination accidental damages and torsion are likely at fuselage shells
- Shear forced, quadratic panels results in a maximum principle stress direction of 45° for almost all points (see figure 1) → tension diagonal



(a) Out of plane deformation u3

(b) Maximum principal stress $\sigma_{princ,\ max}$ at middel layer

Fig. 1: Finite element results

Motivation

- In general buckling and crack propagation are examined separately
- Combination impact damages and torsion are likely at fuselage shells
- Shear forced, quadratic panels results in a maximum principle stress direction of 45° for almost all points (see figure 1) → tension diagonal
- Large bending moment m_{12} in the plate (see figure 2)

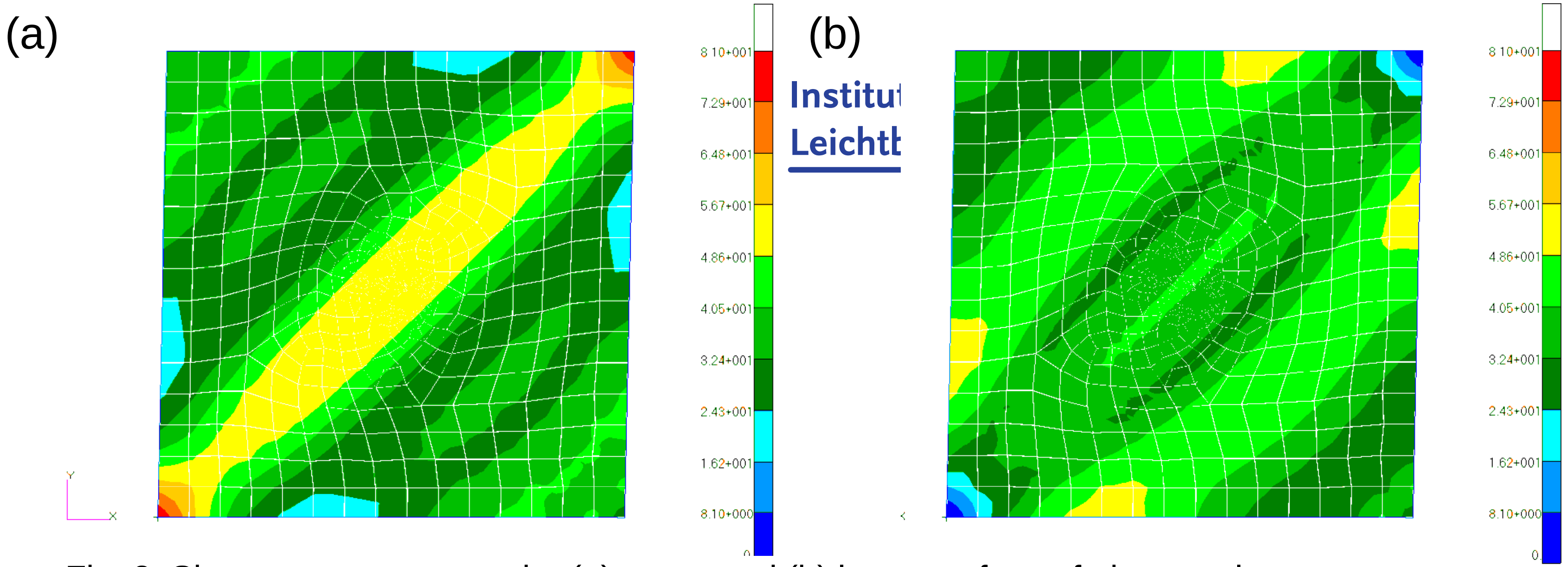


Fig. 2: Shear stresses m_{12} at the (a) upper and (b) lower surface of the panel

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Test set-up

- Picture frame with special designed pivot bearings → pure shear loading
- Panel is clamped into the picture frame
- Cylinder applies load F_s
- Displacement transducer and camera for crack propagation

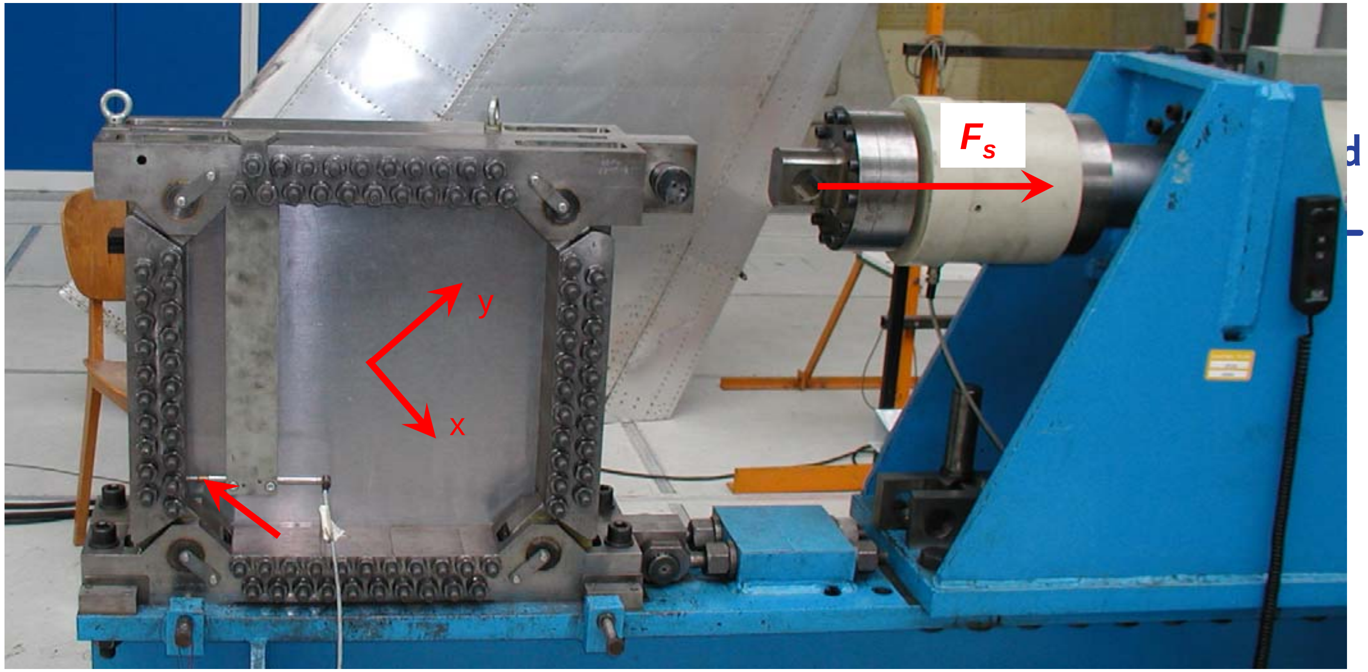

Fig. 3: Test set-up (front panel)

Test set-up

ARAMIS® system

- Optical measurement system for out of plane deformation u_3
- Two cameras
- Undisturbed surface with high contrast stochastic pattern

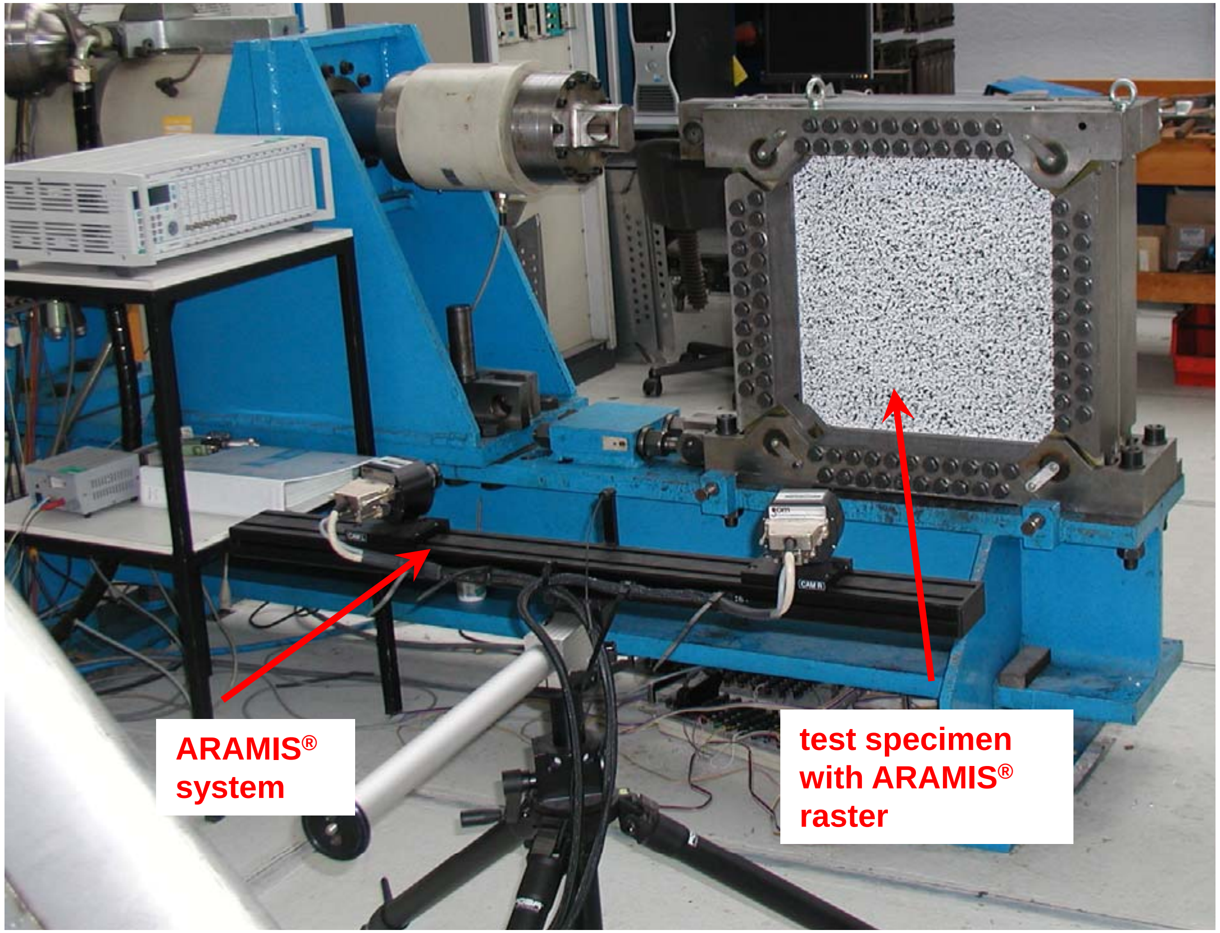

Fig. 4: Test set-up (back panel)

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Test performances and results

- Test specimen
  - Unstiffed aluminium panel (material: Al 6056 T4, thickness t = 2 mm)
  - Free field of 500 x 500 mm²
- Test performance
  - Static test for reference data (uncracked)
  - Initial crack length $2a_0$ = 20 mm
  - Static test with cracked panel
  - Certain amount of dynamic cycling N_0 to sharpen the crack
  - Static tests to measure crack length $2a$ and out of plane deformation u_3
- Variation of initial crack conditions
  - Crack position (x_0, y_0)
  - Crack orientation (δ_0)
  - Shear force $F_{s,\ max}$

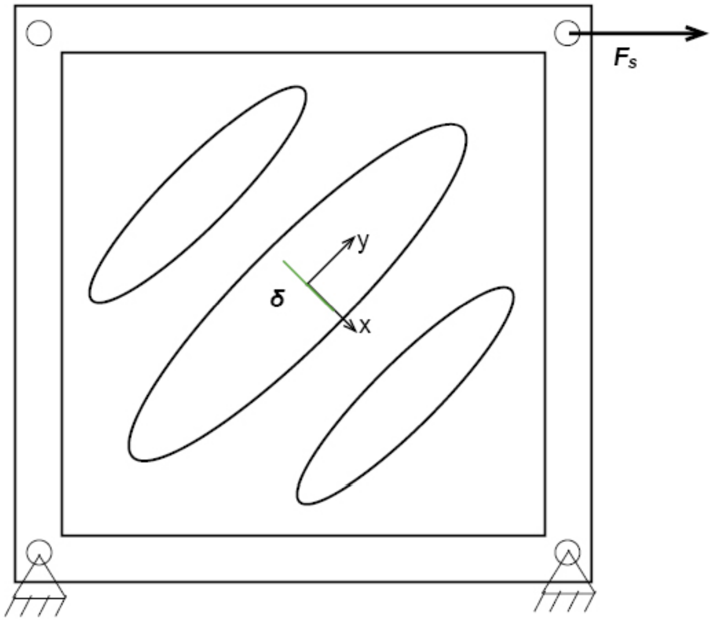


Fig. 5: Initial crack conditions

Test performances and results – panel 01

- Initial crack conditions of panel 01

panel	01	02	04	06
x_0 / mm	0.0	0.0	0.0	80.0
y_0 / mm	0.0	0.0	0.0	0.0
δ_0 / °	0.0	45.0	0.0	0.0
$F_{s,\,max}$ / kN	40.0	40.0	50.0	40.0
u_{3M0} / mm	4.2	4.63	5.4	4.64

Tab. 1: Initial crack conditions

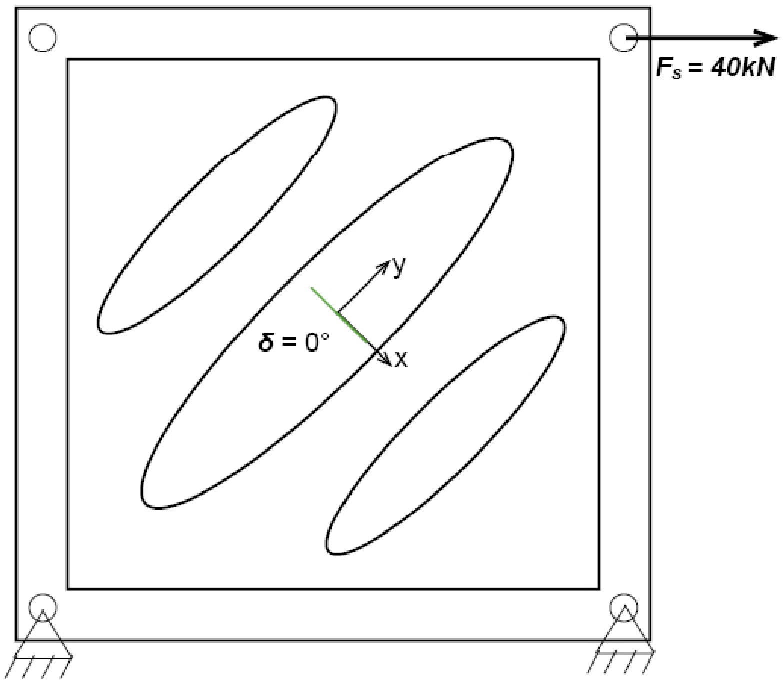
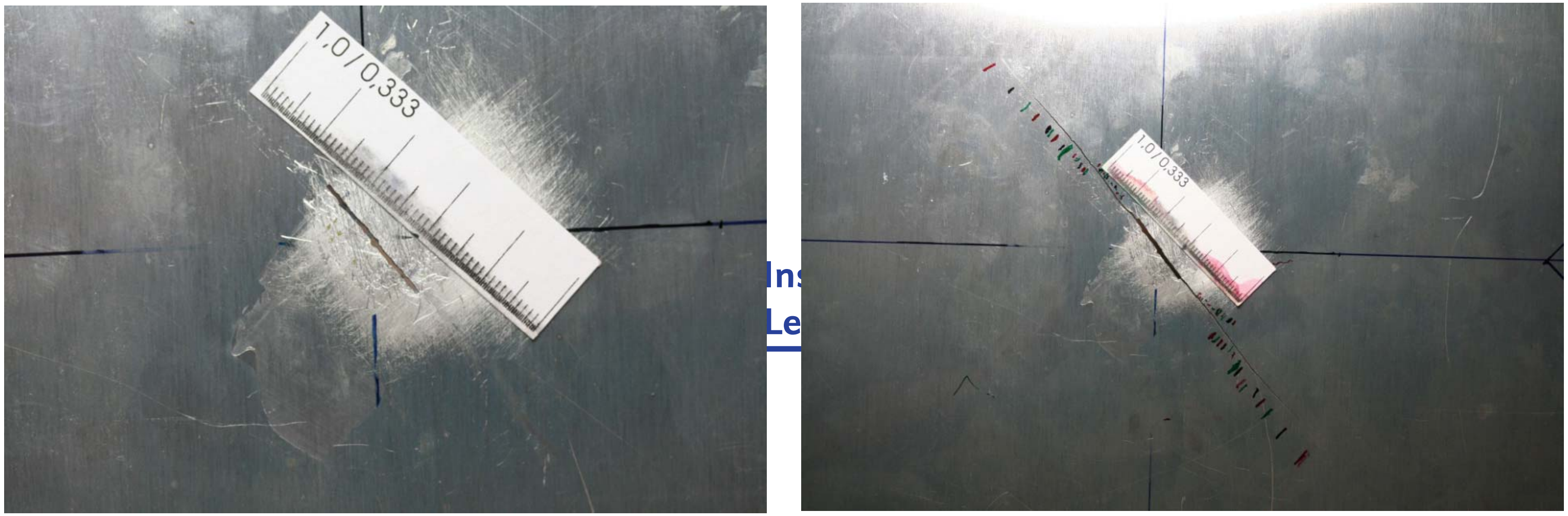


Fig. 5a: Initial crack conditions panel 01

Test performances and results – panel 01

- No significant crack turning can be recognized

(a) (b)



(a) N_0 = 10,000 cycles (b) N_{max} = 85,000 cycles

Fig. 6: Crack length of panel 01

Test performances and results – panel 01

- Crack symmetric to buckle → both crack tips propagate with the same rate
- Longer cracks influence the shape of the buckle → bulging of crack edges

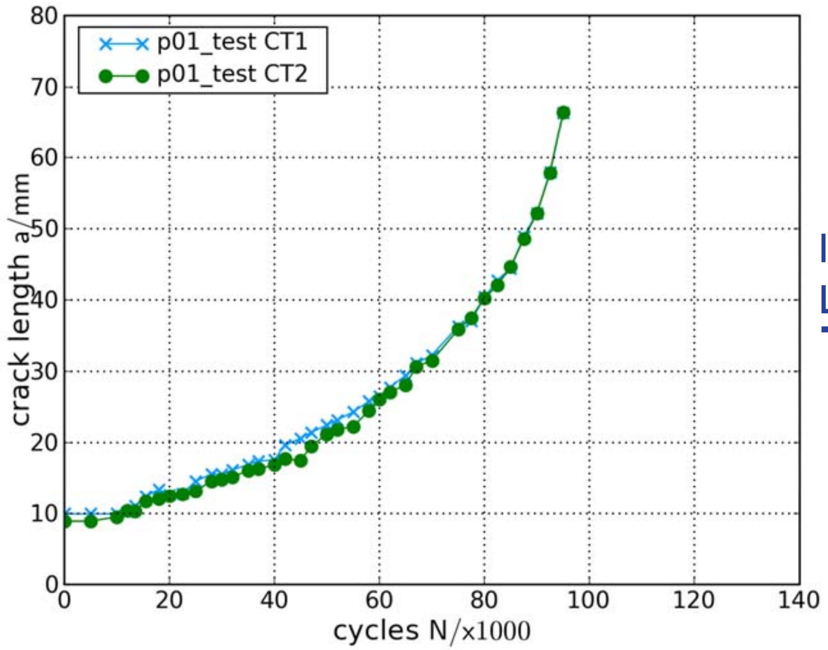


Fig. 7: Crack propagation at both crack tips of panel 01

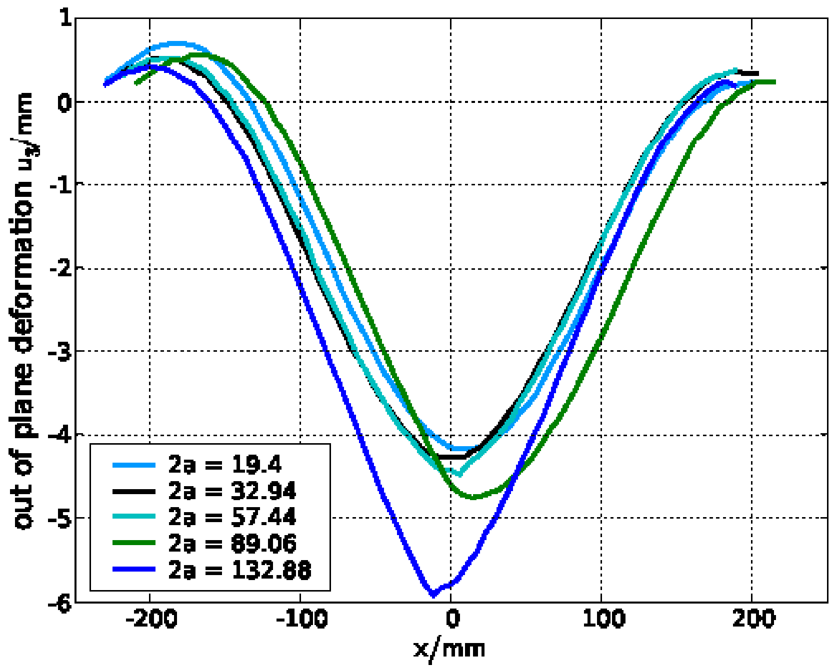
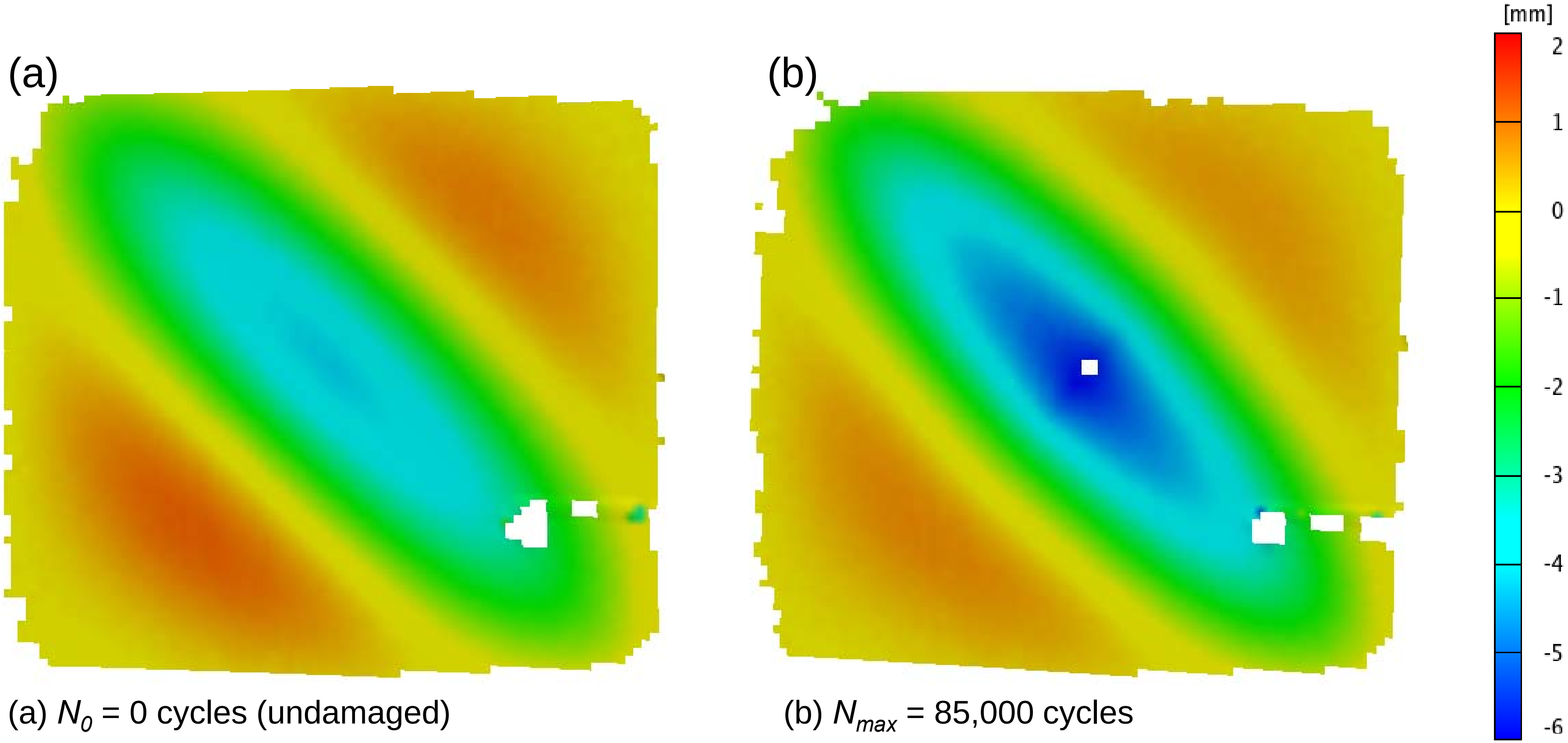


Fig. 8: Out of plane deformation u_3 of panel 01 for different crack length

Test performances and results – panel 01



(a) N_0 = 0 cycles (undamaged)   (b) N_{max} = 85,000 cycles

Fig. 9: ARAMIS® measurements: out of plane deformation u_3 of panel 01

Test performances and results – panel 02

- Initial crack conditions of panel 02

panel	01	02	04	06
x_0 / mm	0.0	0.0	0.0	80.0
y_0 / mm	0.0	0.0	0.0	0.0
δ_0 / °	0.0	45.0	0.0	0.0
$F_{s,\,max}$ / kN	40.0	40.0	50.0	40.0
u_{3M0} / mm	4.2	4.63	5.4	4.64

Tab. 1: Initial crack conditions

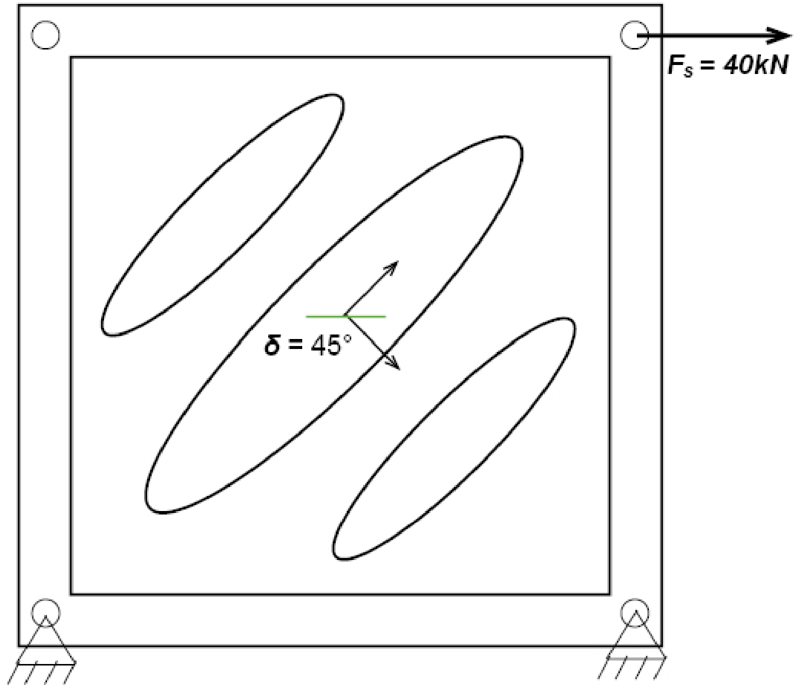


Fig. 5b: Initial crack conditions panel 02

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Test performances and results – panel 02

- Crack propagation normal to the maximal principal stress direction (δ_{prop} = 0°)

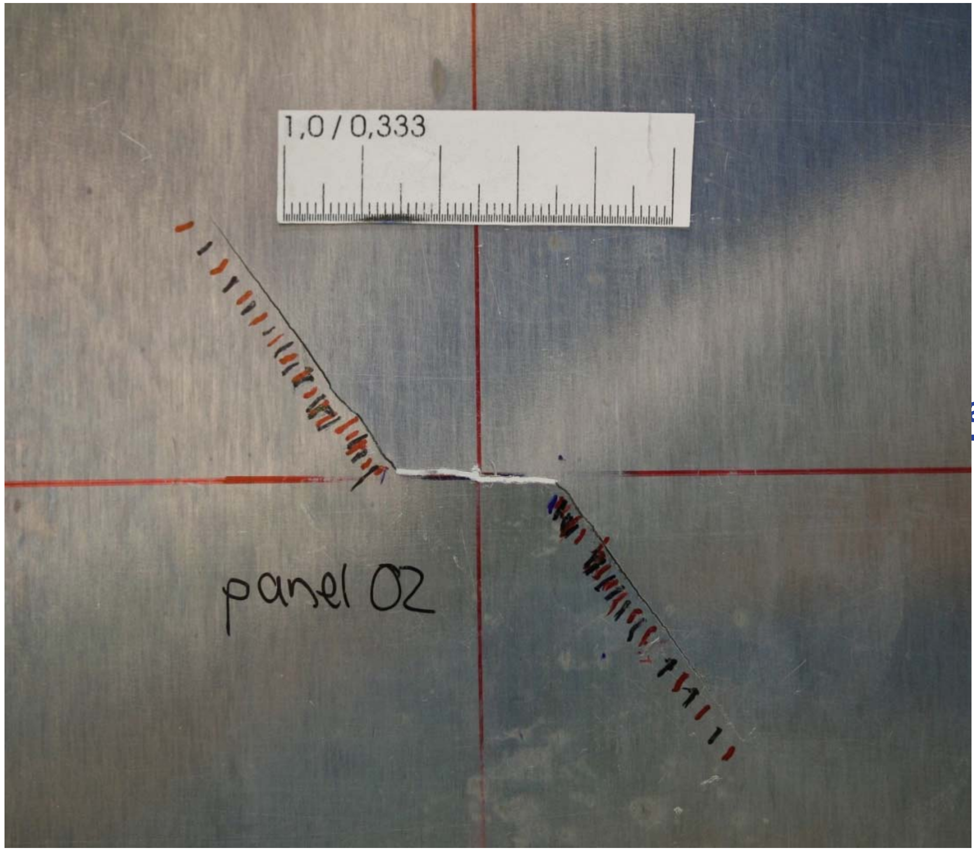

Fig. 10: Crack propagation direction of panel 02 at N = 85,000 cycles

Test performances and results – panel 04

- Initial crack conditions of panel 04

panel	01	02	04	06
x_0 / mm	0.0	0.0	0.0	80.0
y_0 / mm	0.0	0.0	0.0	0.0
δ_0 / °	0.0	45.0	0.0	0.0
$F_{s,\,max}$ / kN	40.0	40.0	50.0	40.0
u_{3M0} / mm	4.2	4.63	5.4	4.64

Tab. 1: Initial crack conditions

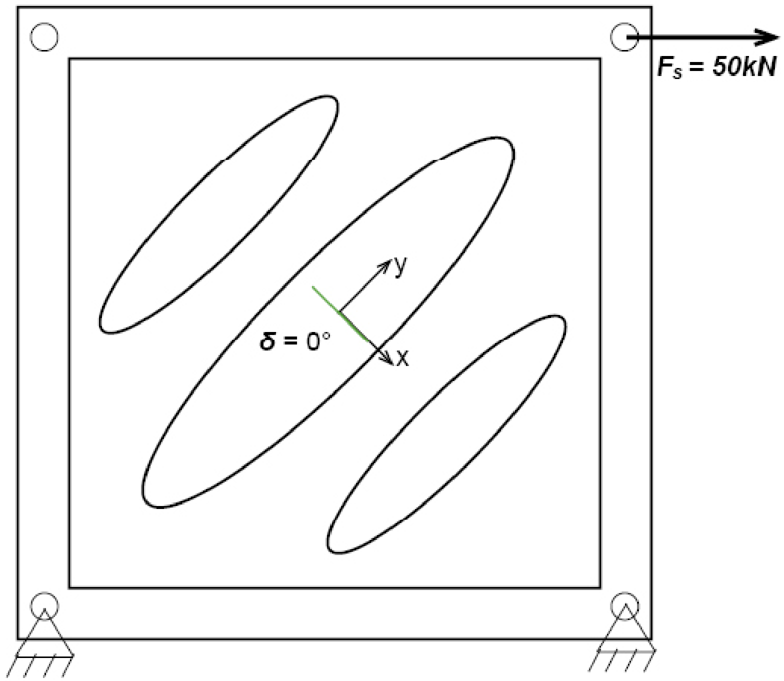

Fig. 5c: Initial crack conditions panel 04

Test performances and results – panel 04

- Increase of F_s by 25 %
  - Decrease of lifetime by 50 %
  - Symmetric crack propagation

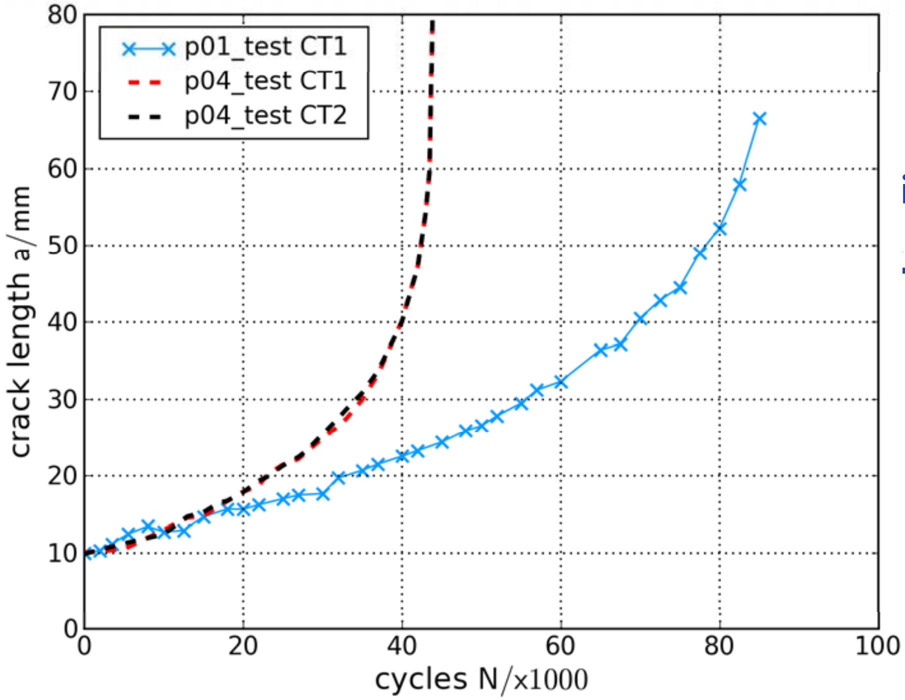

Fig. 11: Crack propagation of panel 04

Test performances and results – panel 06

- Initial crack conditions of panel 06

panel	01	02	04	06
x_0 / mm	0.0	0.0	0.0	80.0
y_0 / mm	0.0	0.0	0.0	0.0
δ_0 / °	0.0	45.0	0.0	0.0
$F_{s,\,max}$ / kN	40.0	40.0	50.0	40.0
u_{3M0} / mm	4.2	4.63	5.4	4.64

Tab. 1: Initial crack conditions

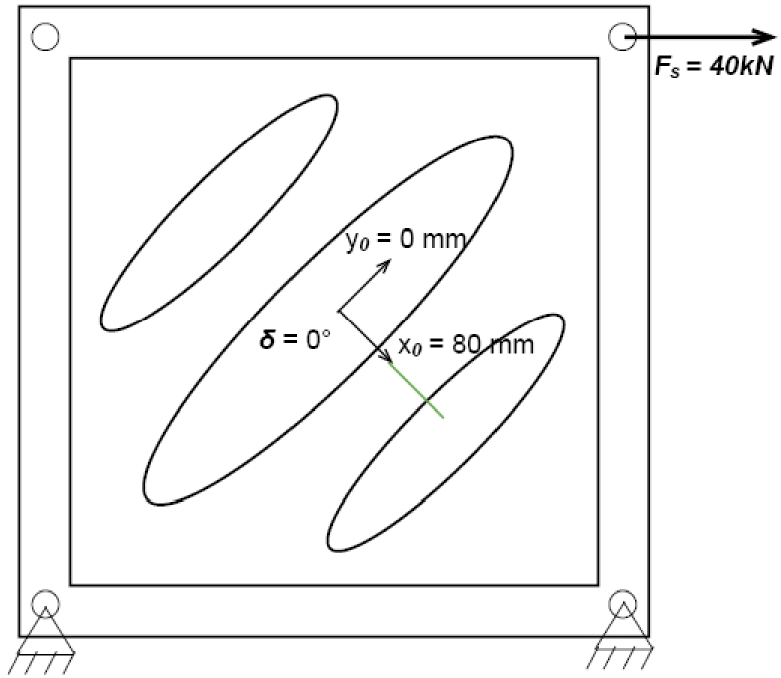

Fig. 5d: Initial crack conditions panel 06

Test performances and results – panel 06

- Crack asymmetric to buckle
  - Different crack propagation rate for both crack tip
  - Slower crack propagation rate due to smaller maximum principal stress

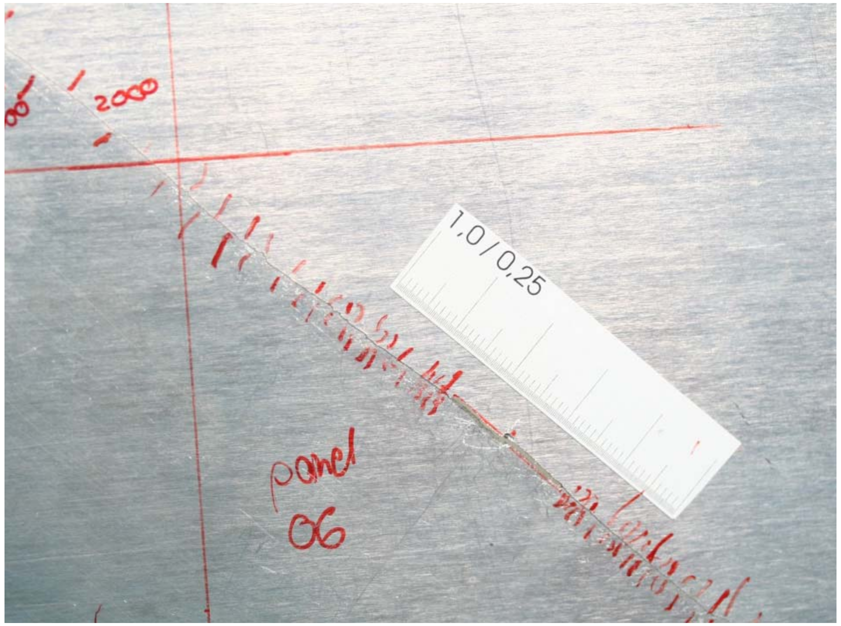

Fig. 12: crack of panel 06 at N_{max} = 137,000 cycles

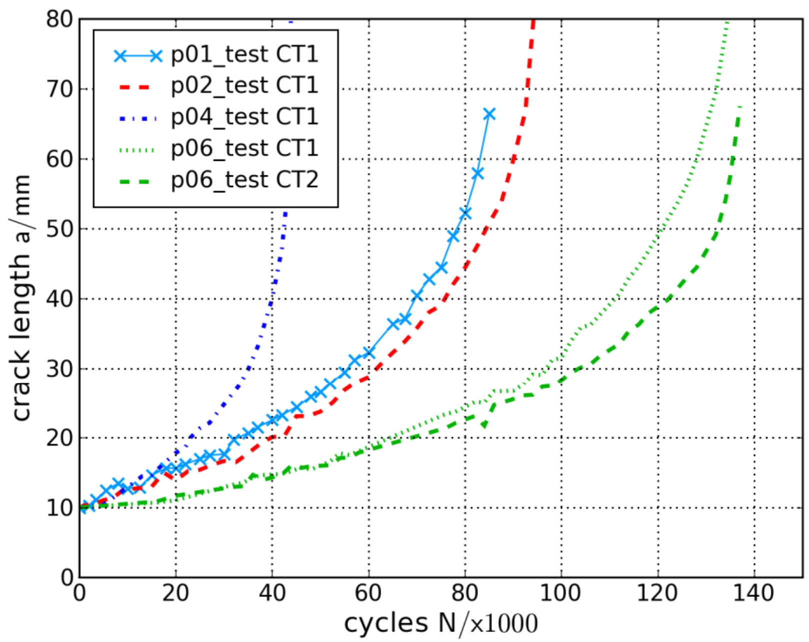

Fig. 13: Crack propagation of all panels

Test performances and results – comparison

panel	01	02	04	06 (CT1)
N_0 **/ cycles**	10,000	5,000	0	20,000
N_{max} **/ cycles**	85,000	94,000	44,600	137,000
δ_0 / °	0.0	0.0	0.0	0.0
$2a_{Nmax}$ / mm	132.88	171.66	251.34	169.69
$u_{3M,\ Nmax}$ **/ mm**	5.92	5.8	9.0	6.31

Tab. 2: Comparison of the test results

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- Cracks, symmetric to the buckle, both crack tips propagate with the same rate
- Cracks, asymmetric to the buckle, have different crack propagation rates (stress distribution)
- Increase of the shear force by 25 % reduces the life time by approximately 50 %
- Larger cracks influence the shape of the buckle
- No significant crack rotation can be remarked

  → Bending moment not of great importance, but the maximum principle stress direction

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Numerical analysis

- FE analysis with ABAQUS of an uncracked model
- Input data: angle φ calculated by data from displacement transducer
- Simple assessment to validate the maximum principal stress theory
  - Input data for maximum principal stress $\sigma_{princ,max}$ → uncracked panel

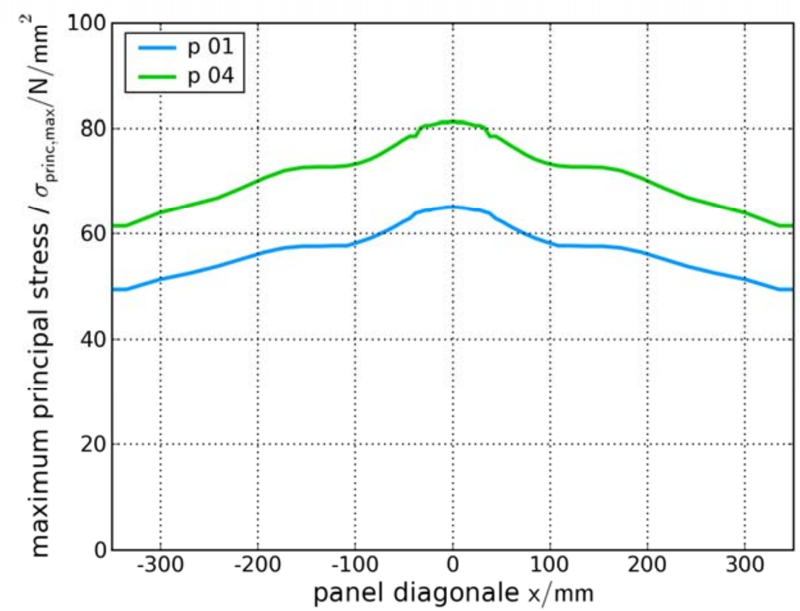


Fig. 14: Maximal principal stress $\sigma_{princ,max}$ distribution of uncracked model

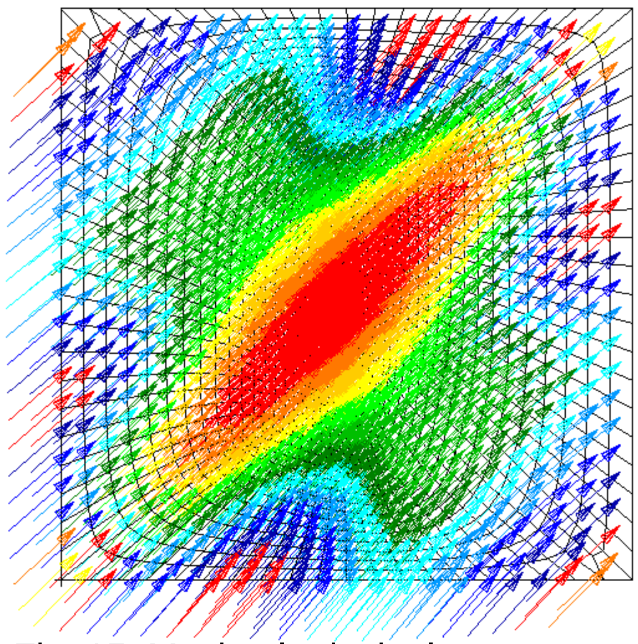
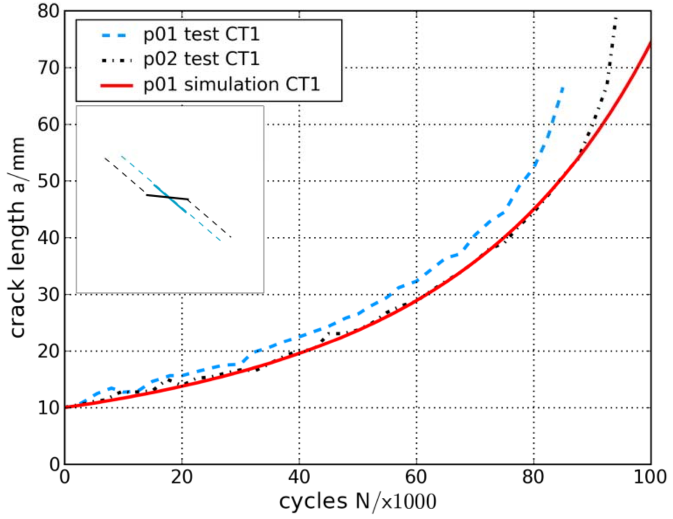


Fig. 15: Maximal principal stress $\sigma_{princ,max}$ of uncracked model panel 01

Simple assessment

- $\sigma_{princ,max}$ load for crack propagation analysis
- Centre through crack with weight function solution
- „Simple tensile model“ with same Forman parameters for all tests



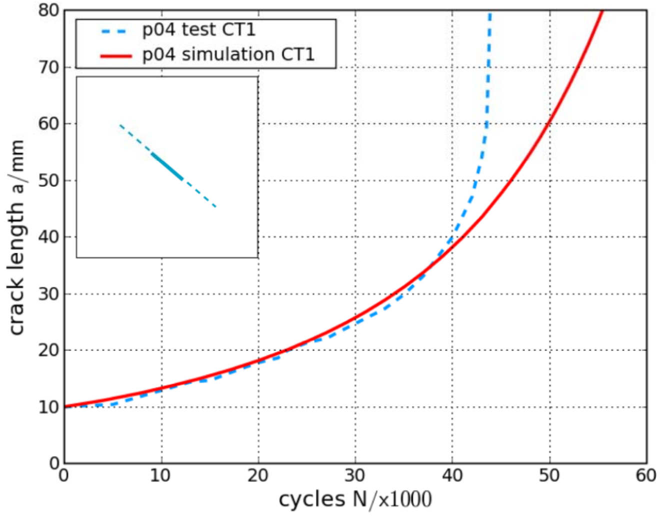


Fig. 17: Maximum principal stress: simulation vs. test for panel 01/02 and panel 04

Simple assessment

- For panel 06 load is asymmetric
- Each crack tip is analyzed separately with simplifications for the panel width and the crack centre

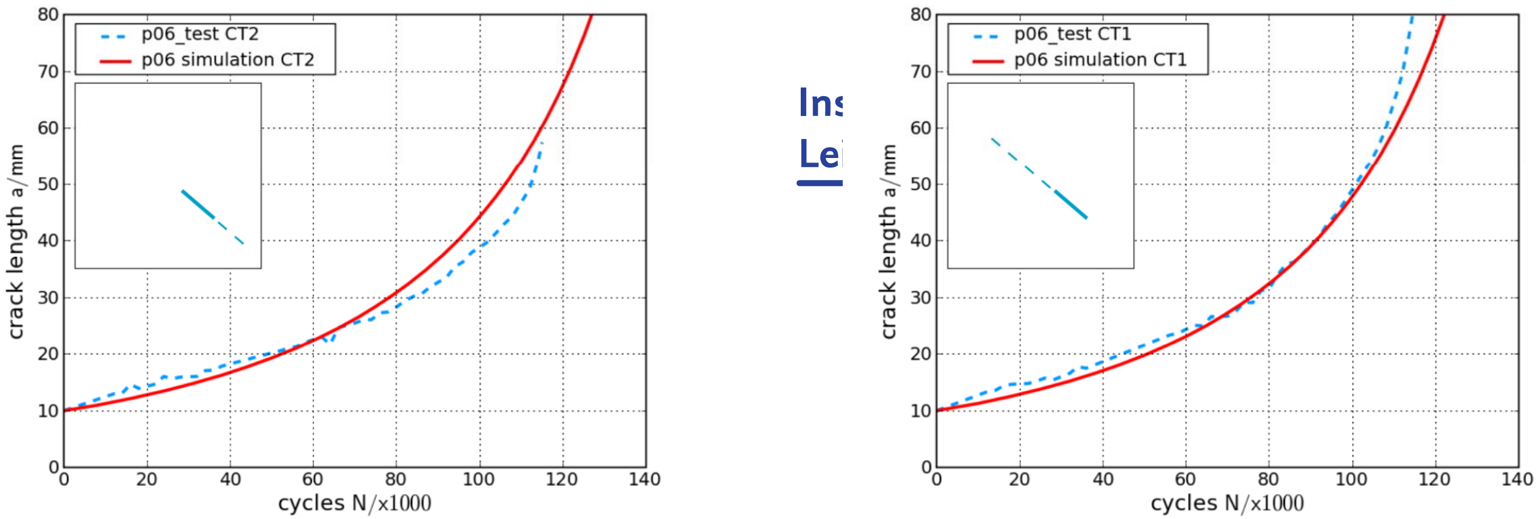


Fig. 18: Maximum principal stress: simulation vs. test for panel 06, crack tip 1 and 2

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Conclusion

- Central cracks from accidental damages can become critical due to buckling loads
- Cracks, symmetric to the buckle, propagate with the same rate at both crack tips
- Cracks, asymmetric to the buckle, propagate with the same rate at both crack tips
- No significant rotation can be remarked at any test
- The maximum principal stress is the main factor for crack propagation rate and direction
- Out of plane deformation of the buckle increases with the propagation of the crack
- Bulging does not show great influence on the crack propagation
- Verification with a simplified numerical approach

Outlook

- Programm for crack propagation
- FE analyses with ABAQUS
- Investigation of “preloaded” panels
- Tests for “material parameters”

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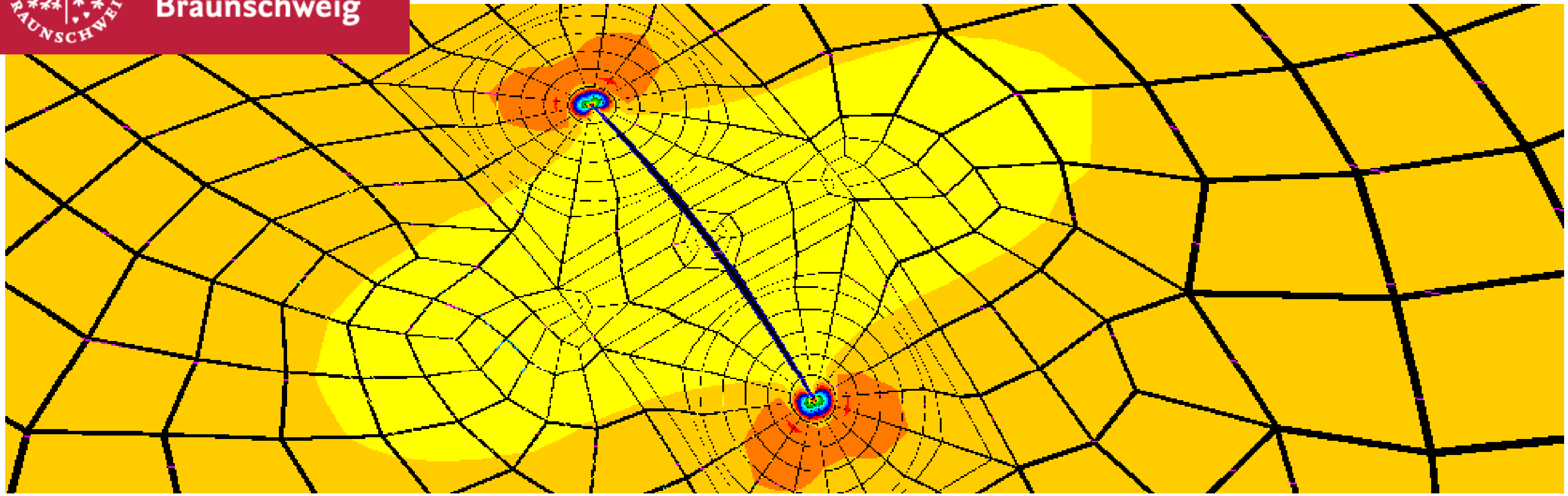

Thank you very much!

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Julia Bierbaum and Peter Horst, 07/10/2010