CleanSky2
LPA - Platform 1

Efficient simulation of multiple impacts on double-curved composite structures

presented by
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DLR

Paris, 7th of September 2017

Clean Sky 2

The Big Picture

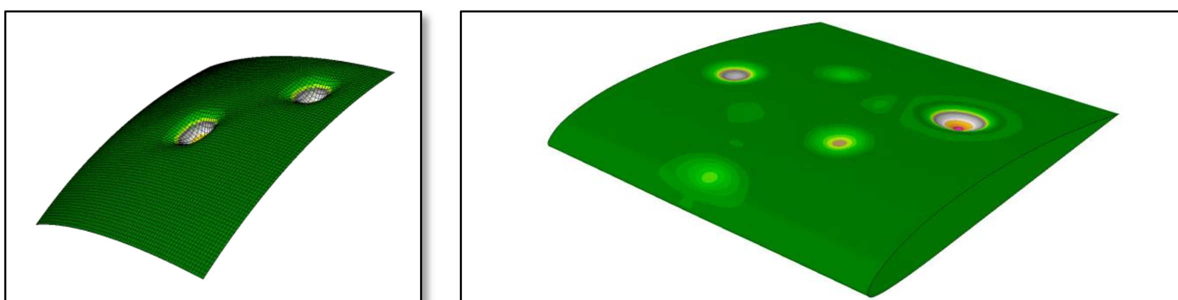
adapted from [1]

Composite aircraft structures are vulnerable to impacts by foreign objects, e.g.

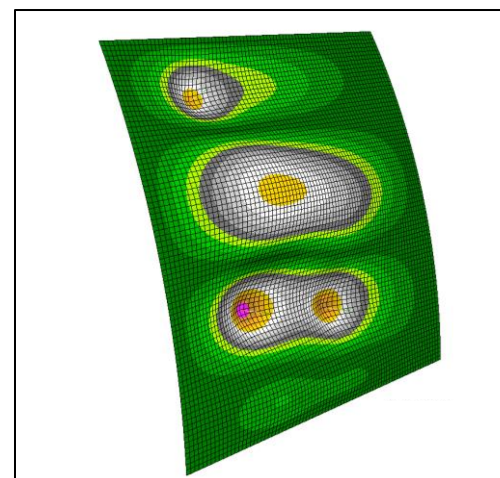
- in-flight & ground hail
- ice-shedding
- tool-drop (production & maintenance)

… leading to barely visible impact damage (BVID), potentially

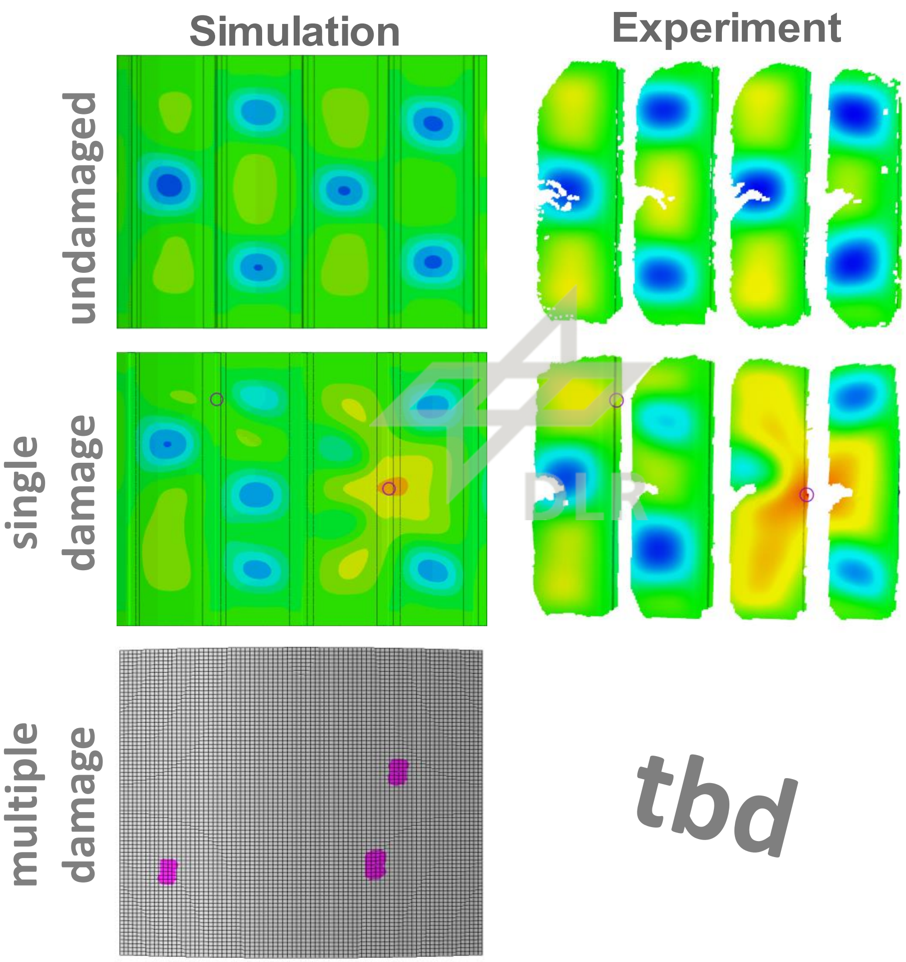
- remaining undetected in the structure
- accumulating up to the next maintenance date

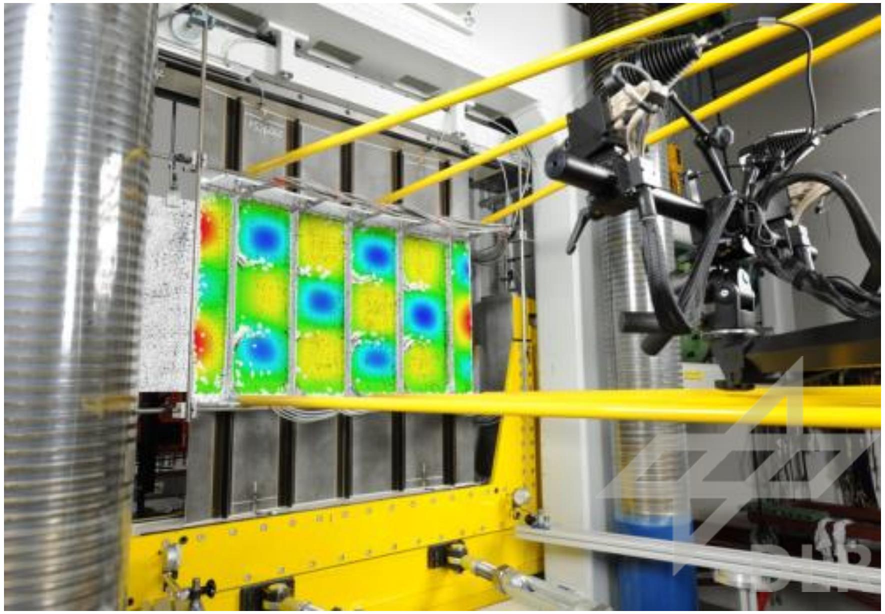


Double-curved panel



Single-curved panel



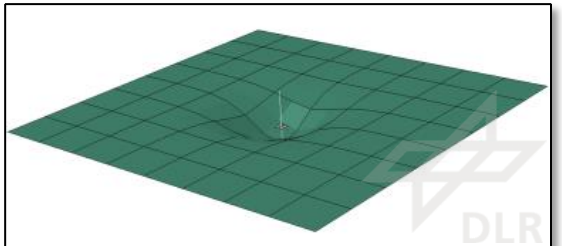


[2][3]

Project objectives:

- Assessment of multiple impact damage in composite aircraft components
- Simulation methodology to evaluate the impact response and the residual properties of the structure

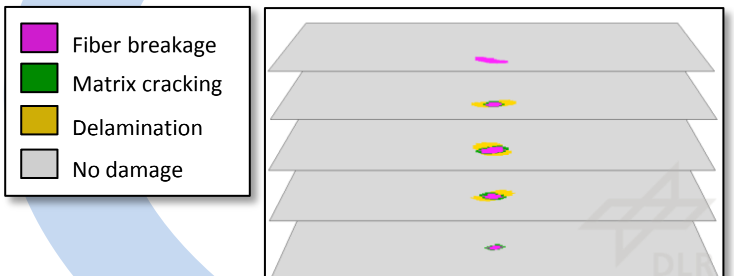
Low-fidelity simulation methodology…



Structural modeling

- Contact modeling by using contact laws
- Discretization with a single layer of shell elements

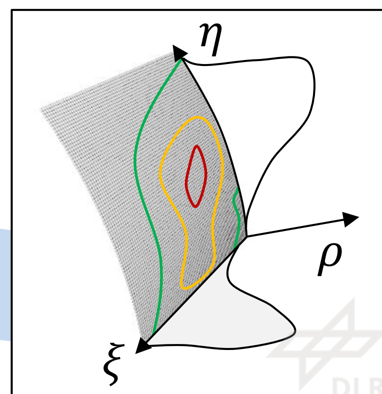
… in a nutshell

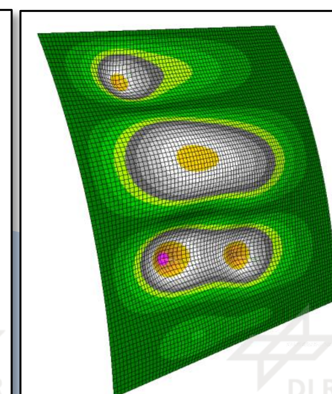


Material modeling

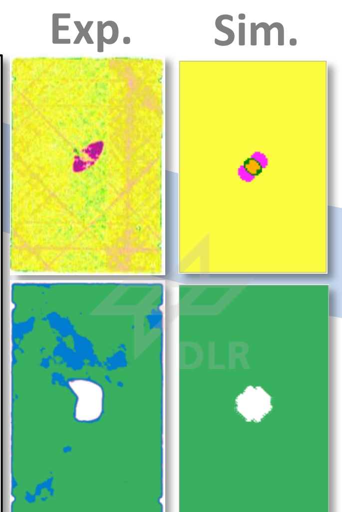
- Three-dimensional stress state recovery
- Use of modern three-dimensional failure criteria (Puck, Cuntze, LaRC04)
- Material degradation with a lookup table

Application in a multiple impact simulation

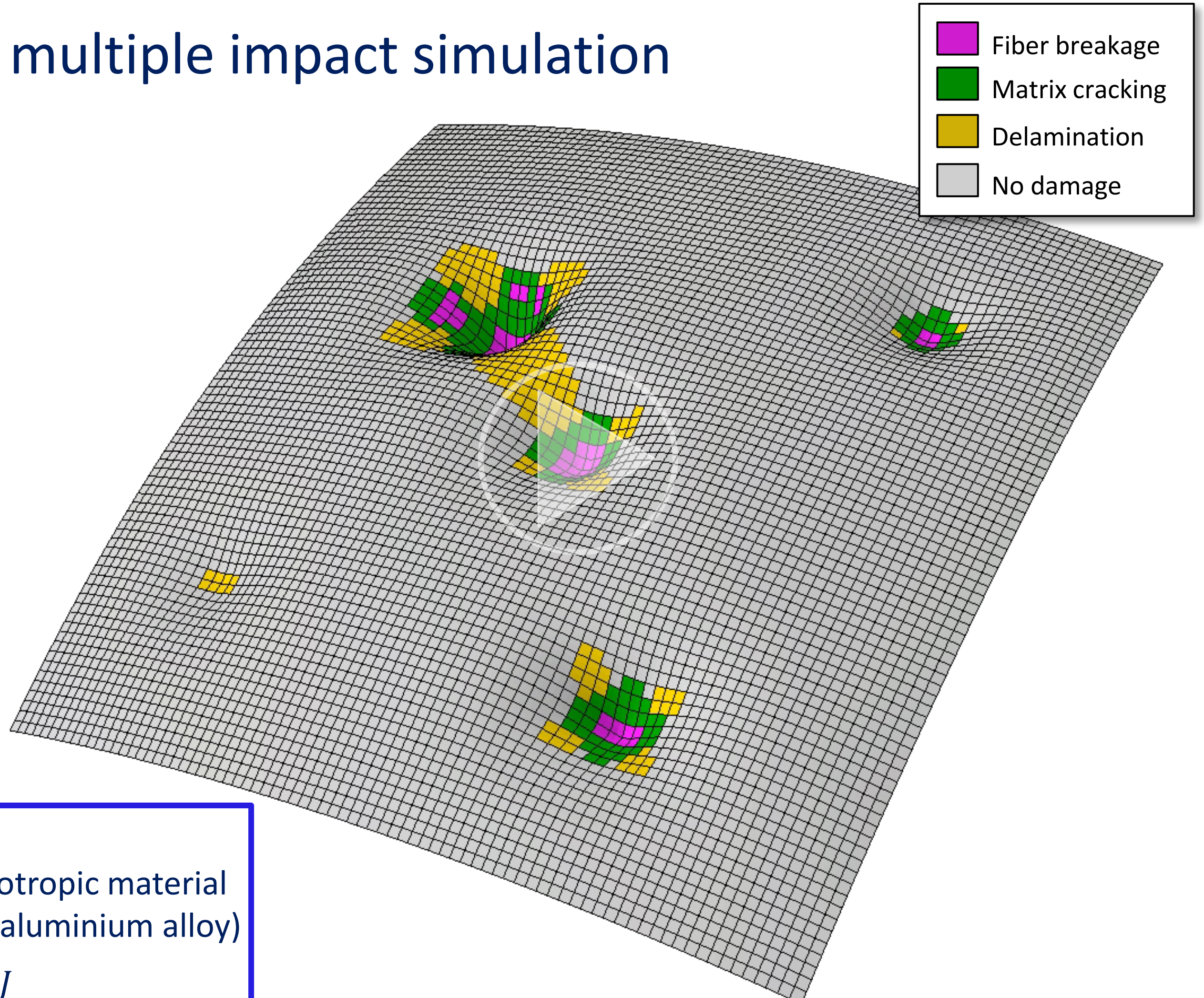




Experimental vs. virtual testing



- Application in a multiple impact simulation



Example:

- 5 unique impactors with isotropic material behavior (stainless steel & aluminium alloy)
- Kinetic energies $25\,J - 60\,J$

Outline

Modeling strategy

Three-dimensional stress state recovery:

- Transverse shear stresses
- Transverse normal stress

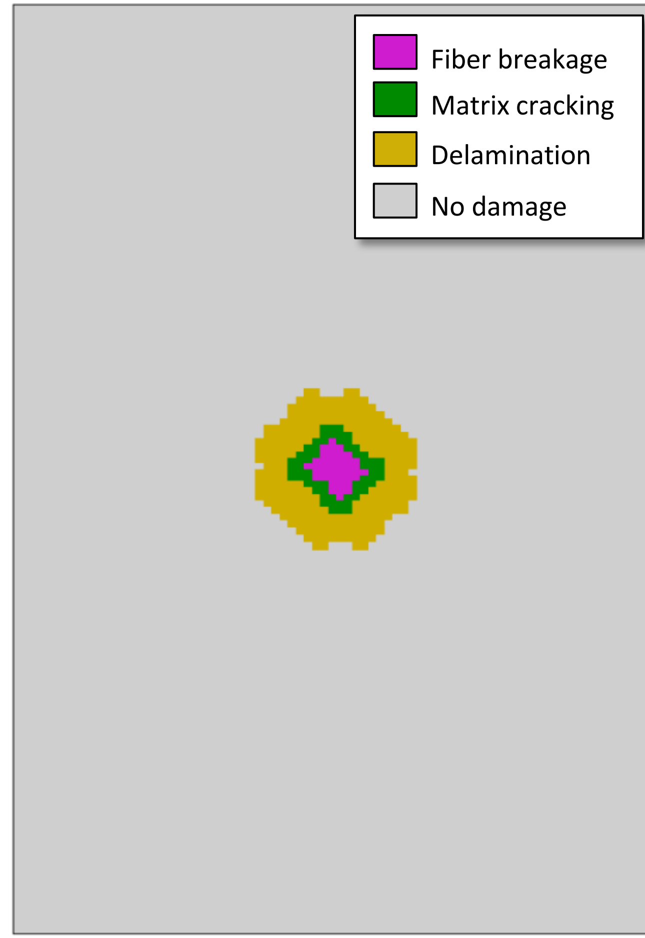
} Rolfes & Rohwer [4]

Damage initiation:

- Fiber breakage = Maximum Stress criterion
- Matrix cracking = Cuntze [5]
- Delamination = Choi & Chang [6]

Damage evolution:

Elastic constants in *Pa*									$e_{FB} \geq 1$	$e_{MC} \geq 1$	$e_{DEL} \geq 1$
E_{11}	E_{22}	E_{33}	ν_{12}	ν_{13}	ν_{23}	G_{12}	G_{13}	G_{23}	-	-	-
1.	E_{22}	E_{33}	0.	0.	0.	1.	G_{13}	G_{23}	X	-	-
E_{11}	1.	1.	0.	0.	0.	G_{12}	G_{13}	G_{23}	-	X	-
E_{11}	E_{22}	E_{33}	ν_{12}	ν_{13}	ν_{23}	1.	1.	1.	-	-	X
1.	1.	1.	0.	0.	0.	1.	1.	1.	X	X	-
E_{11}	1.	1.	0.	0.	0.	1.	1.	1.	-	X	X
1.	E_{22}	E_{33}	0.	0.	0.	1.	1.	1.	X	-	X
1.	1.	1.	0.	0.	0.	1.	1.	1.	X	X	X



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Modeling strategy

Contact modeling:

- Loading phase = Hertz
- Unloading phase = Crook
- Reloading phase = Tan & Sun [7]

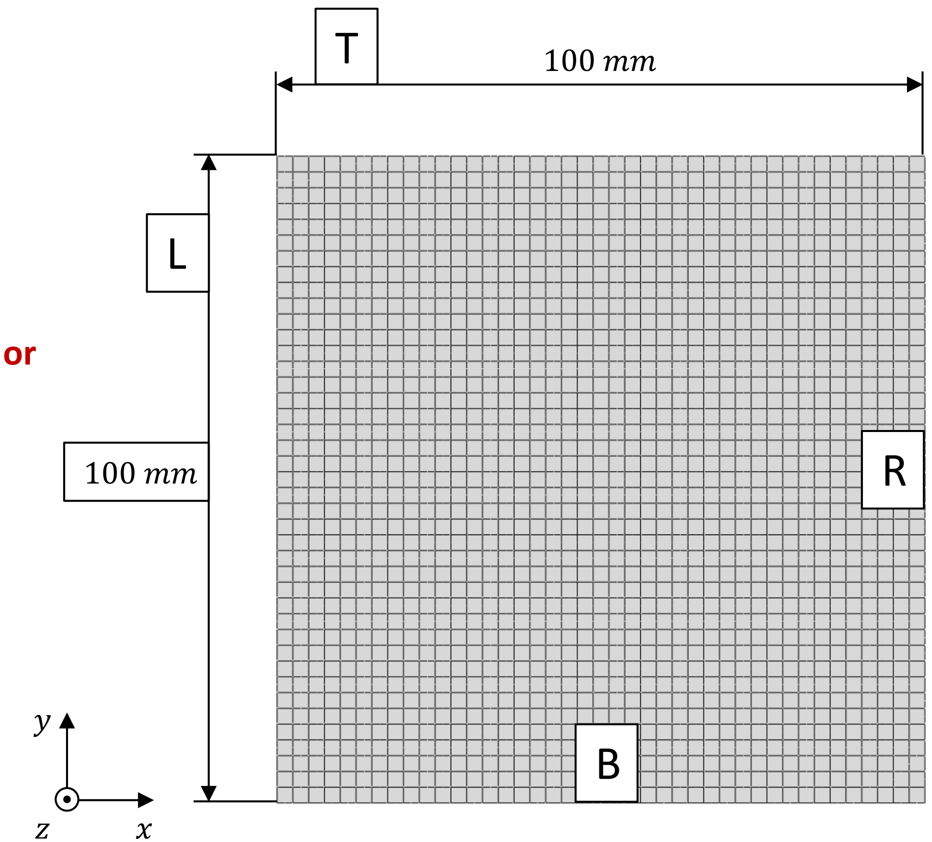
Element type:

- S8R (quadrilateral shell with eight nodes)

Boundary conditions (u_i, v_i = 0):

- $u_x, u_y, u_z, v_x, v_y, v_z$ at edges T & R (*clamped*) **or** u_x, u_y, u_z at edges T & R (*simple supported*)

- u_x, v_y, v_z at edge L (*symmetry in x-direction)*
- u_y, v_x, v_z at edge B (*symmetry in y-direction)*



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III. Numerical experiments

▪ Modeling strategy

Contact modeling:

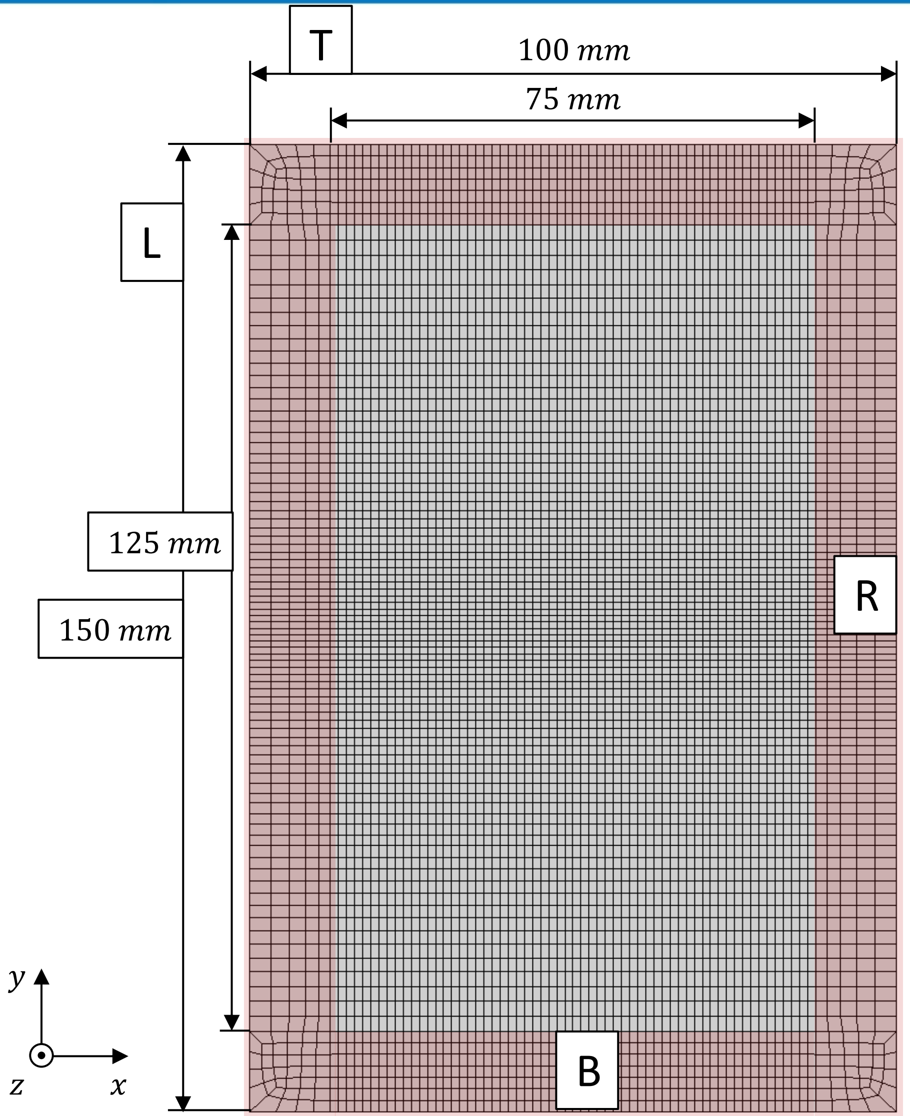
- Loading phase = Hertz
- Unloading phase = Crook
- Reloading phase = Tan & Sun [7]

Element type:

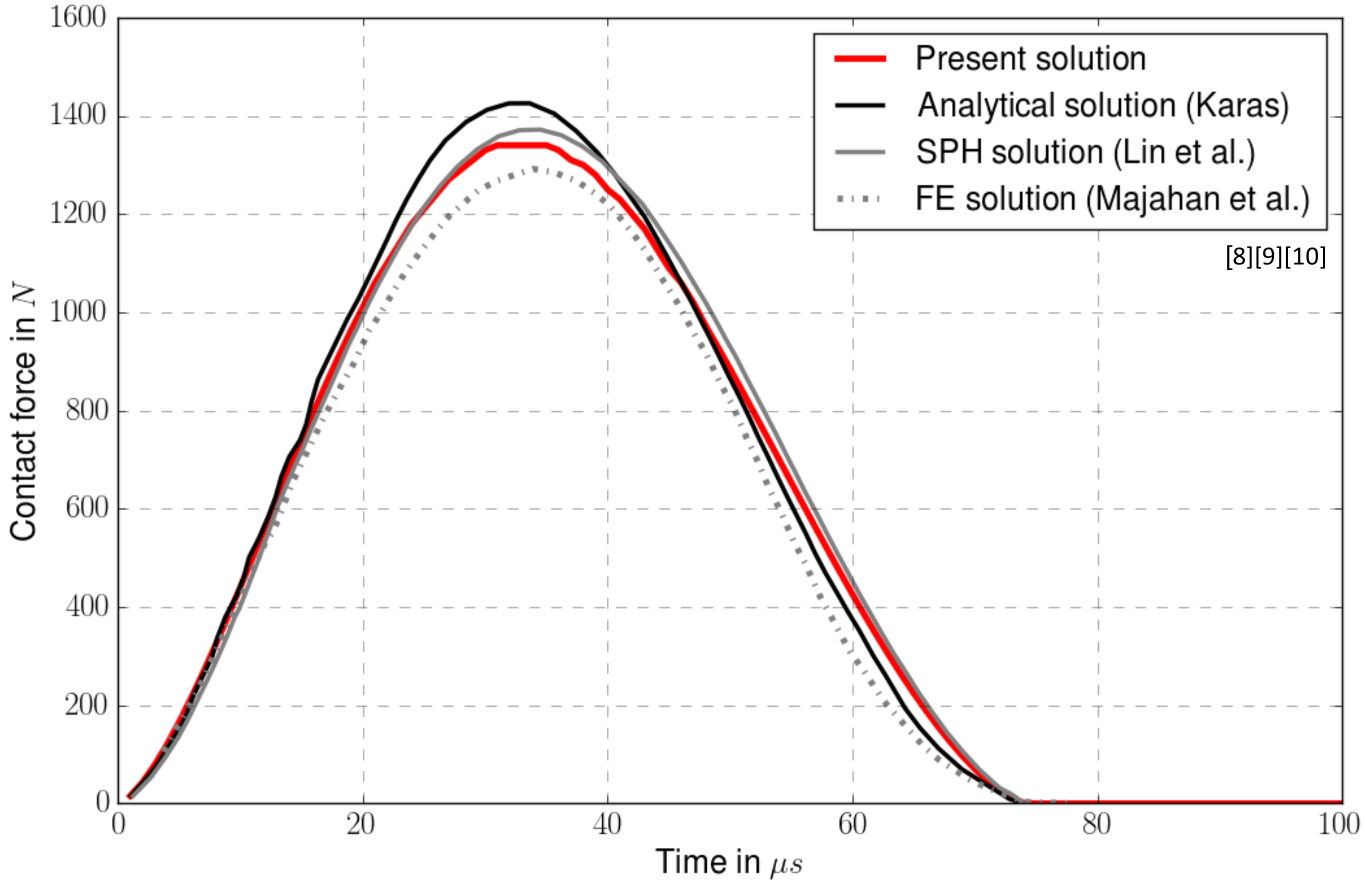
- S8R (quadrilateral shell with eight nodes)

Boundary conditions (u_i, v_i = 0):

- $u_x, u_y, u_z, v_x, v_y, v_z$ at edges T & B (*clamped*)
- u_x, u_y, u_z at edges L & R (*simple supported*)
- u_y in the **red-shaded area**



Verification by means of literature values



[8][9][10]

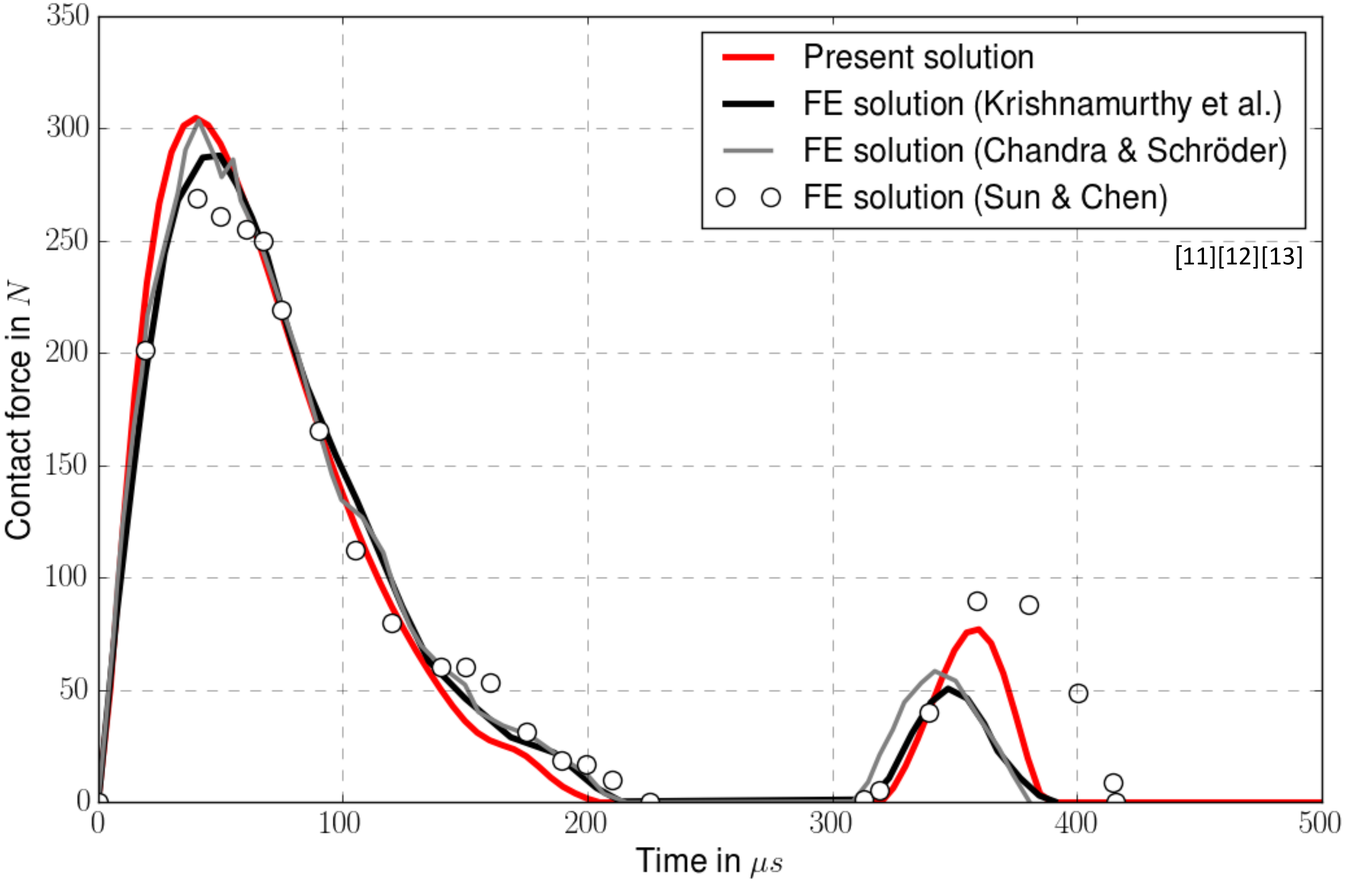
Impactor:

- stainless steel
- $32.67\ g$
- $v = 1\ ^{m}/_{s}$
- $\varnothing\ 20\ mm$

Target:

- $8\ mm$ thickness
- stainless steel
- clamped

- Verification by means of literature values



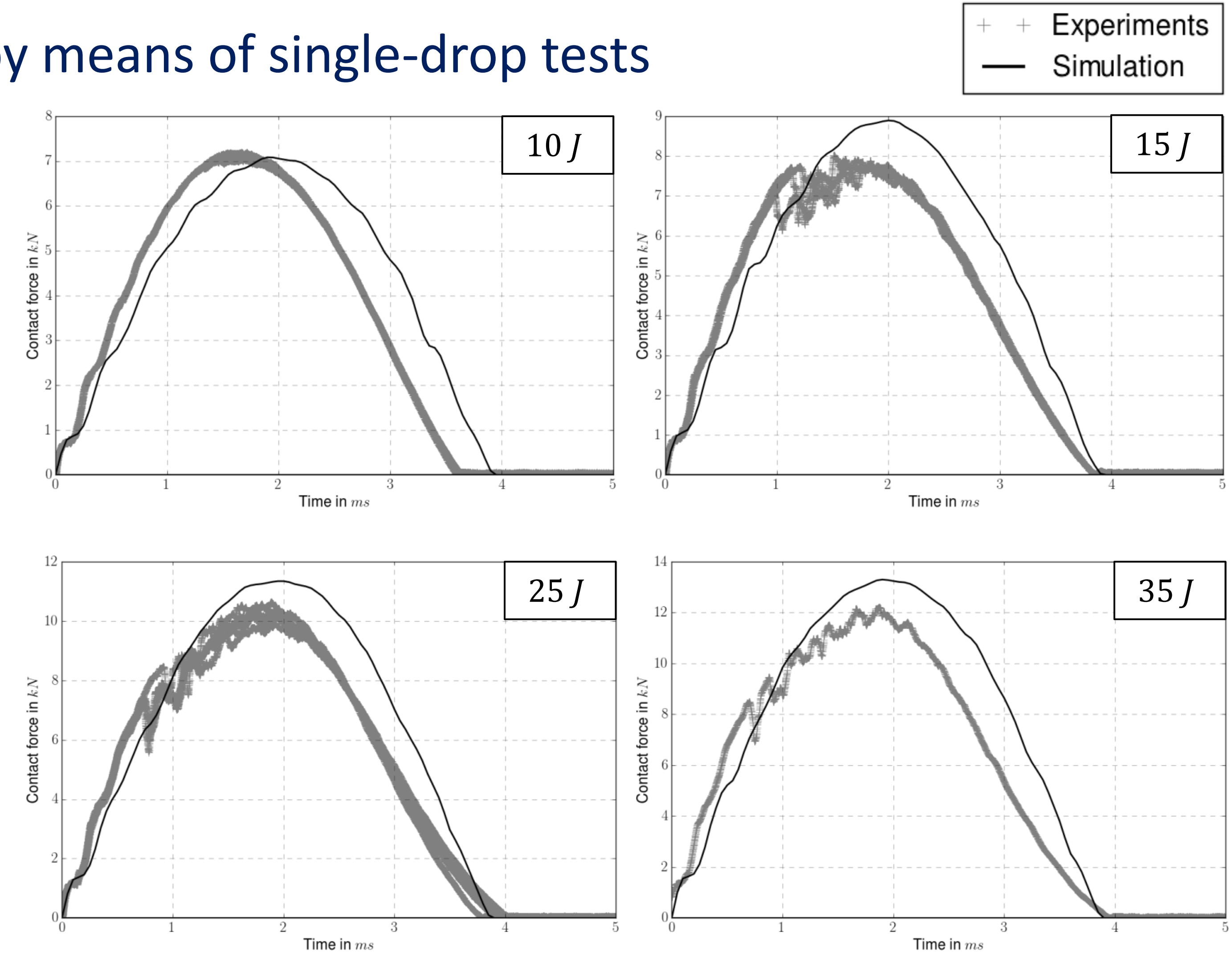
Impactor:

- stainless steel
- $8.84\ g$
- $v = 3\ ^m/_s$
- $\emptyset\ 12.7\ mm$

Target:

- $2.69\ mm$ thickness
- $[(0,90)_2, 0]_s$
- simple supported

- Validation by means of single-drop tests



Impactor:
- stainless steel
- $3.95\ kg$
- $\emptyset\ 16\ mm$

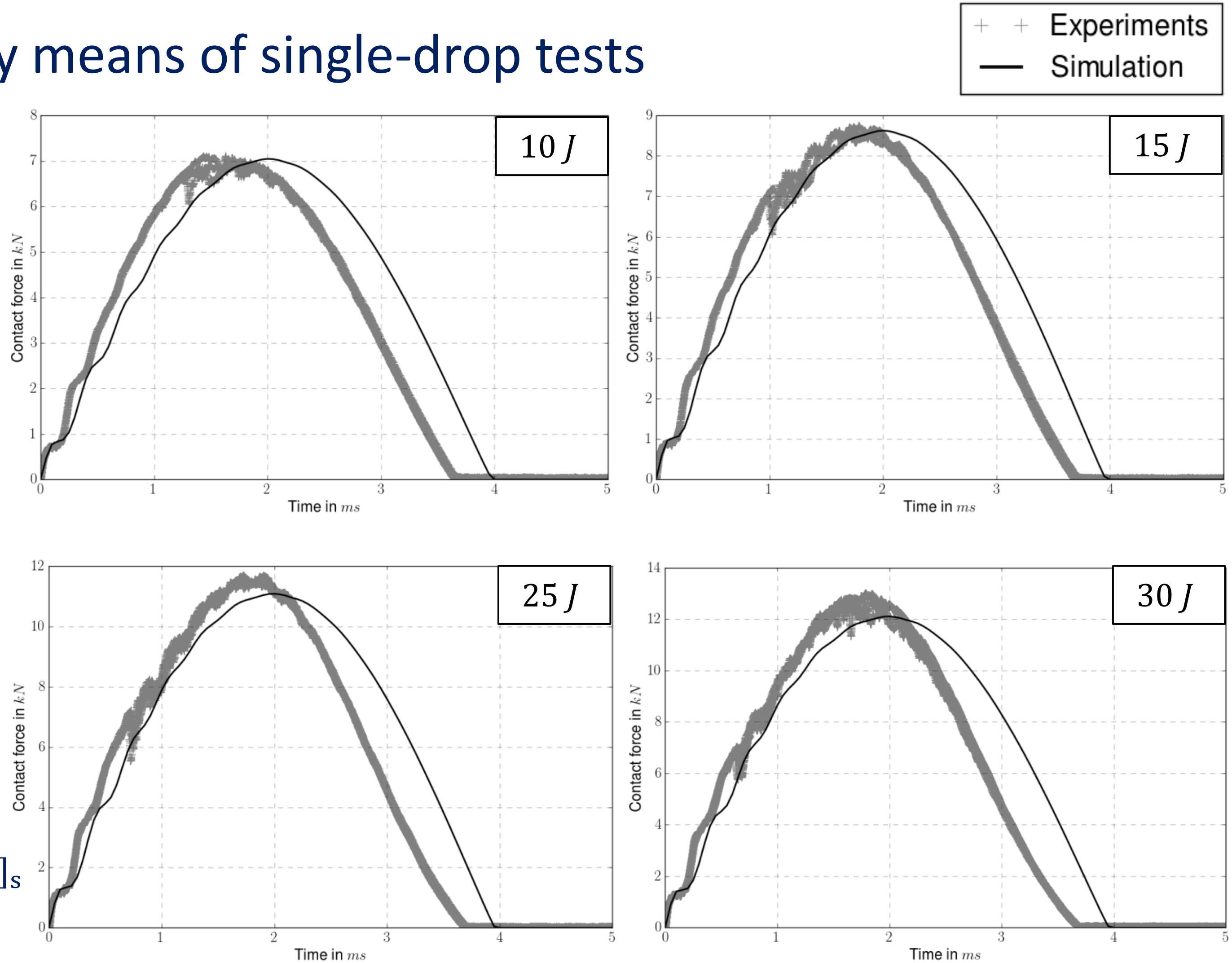
Target:
- $4\ mm$ thickness
- $[(\pm 45)_5, 45]_s$

- Validation by means of single-drop tests

Projected delamination areas:
- LHS → C-scan result
- RHS → Simulation

III. Numerical experiments

- Validation by means of single-drop tests



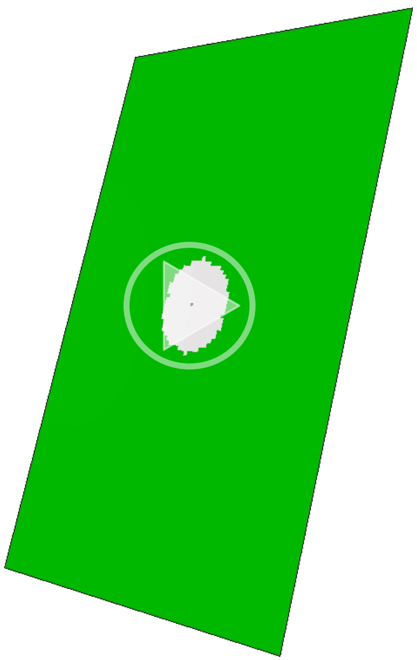
Impactor:

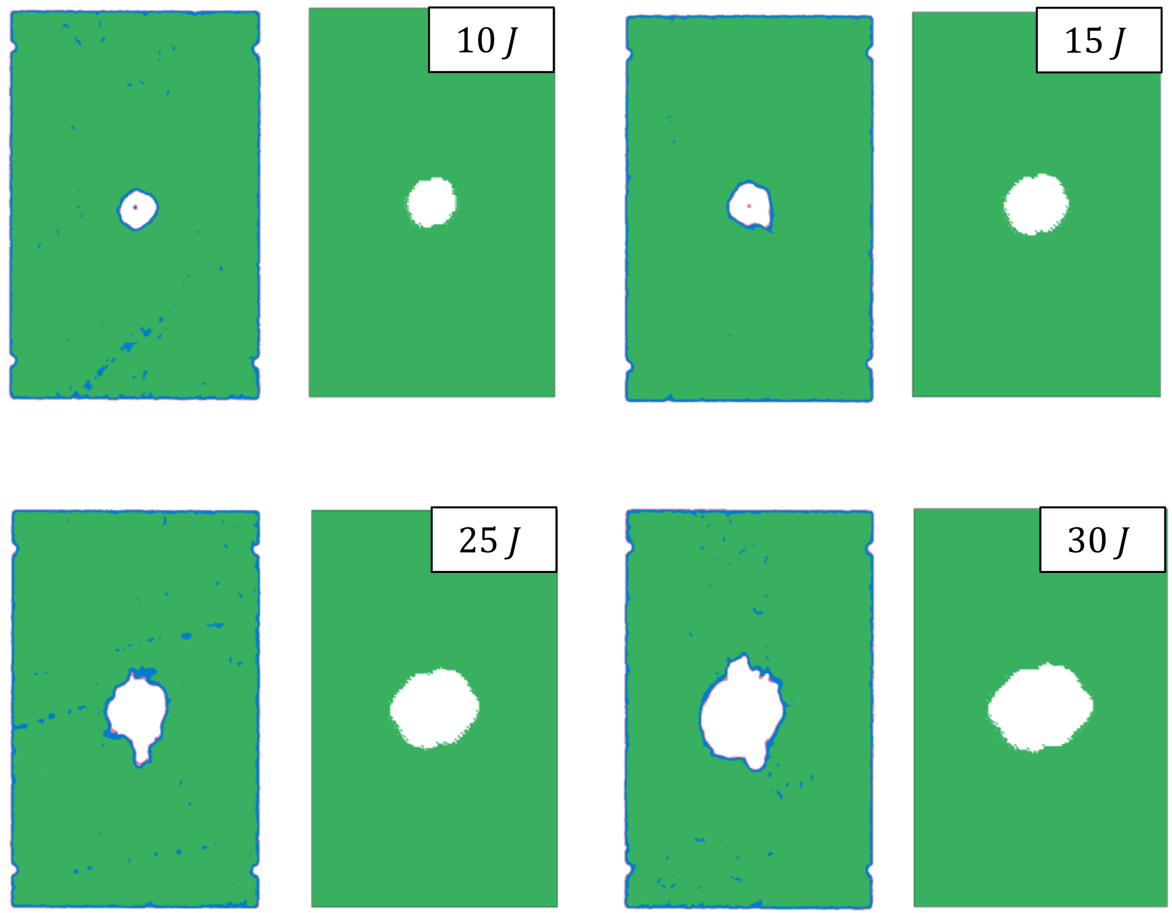
- stainless steel
- $3.95\ kg$
- $\emptyset\ 16\ mm$

Target:

- $4\ mm$ thickness
- $[(\pm 45, 0, 90)_2, \pm 45, 0]_s$

- Validation by means of single-drop tests





Projected delamination areas:

- LHS → C-scan result
- RHS → Simulation

IV. Conclusion

Verification by means of literature results:

- All results are in line with literature results

Validation by means of single-drop tests:

- Very satisfying results w.r.t. the projected delamination areas
- Good agreement between the measured & simulated contact force history

} conservative deviations

Points to optimize:

- Simulated contact stiffness is slightly too soft in all cases → explains the right-shift
- The effect of material degradation on the contact force history is slightly too small → results in overestimated contact force maxima

Next challenges:

- Validation of simulation methodology for multiple impact problems
- Implementation of an expression for brittle impact behavior (hail, ice-shedding)
- Implementation of subsequent analysis steps to assess the residual strength or fatigue behavior of the damaged structure

V. Acknowledgements

This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under H2020-CS2-CPW01-2014-01

VI. Contact

Thank you for your attention!

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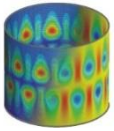

VII. References

[1] http://testcs.openimpact.be/green-regional-aircraft-gra (saved on 26.08.2017)

[2] Wolff, C. & Wilckens, D. (2015) Testing and simulation of impact damaged stiffened CFRP-panels. *3rd Int. Conference on Buckling and Postbuckling Behaviour of Composite Laminated Shell Structures*, 25.03.2015-27.03.2015, Brunswick.

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[10] Lin, J., Naceur, H., Coutellier, D., & Abrate, S. (2015). Numerical modeling of the low-velocity impact of composite plates using a shell-based SPH method. *Meccanica*.

[11] Krishnamurthy, K. S., Mahajan, P., & Mittal, R. K. (2001). A parametric study of the impact response and damage of laminated cylindrical composite shells. *Composites Science and Technology*, *61*(12), 1655–1669.

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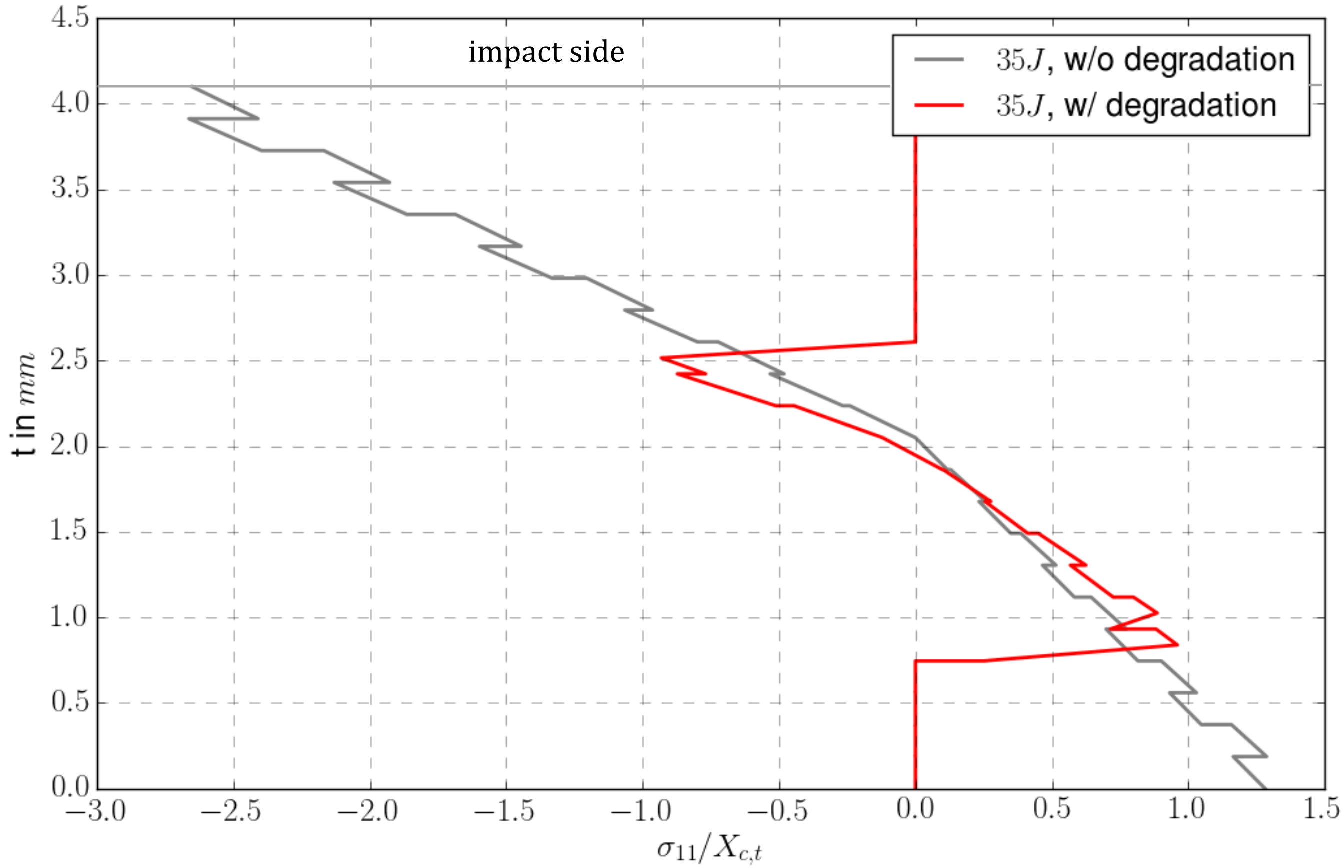
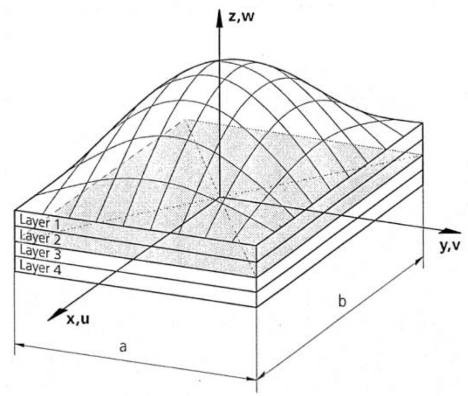
Verification of the material degradation lookup table



Damage evolution:

- Degradation model causes stress redistribution in cases of damage

- Verification of the extended 2D method



Double-cosine load:
- Amplitude of +1

Rectangular plate:
- 1 mm thickness
- 0.128 mm layer thickness
- $[(0,90)_2]_s$