Failure analysis of composite structures through global-local methods

Margarita Akterskaia, Sina Hühne, Eelco Jansen, Raimund Rolfes
Institute of Structural Analysis, Leibniz Universität Hannover

19th International Conference on Composite Structures
5-9 September 2016 – Porto, Portugal

Outline

1. Motivation

- How can the structural failure loads and total behavior be evaluated with reasonable economical costs?

2. Two-way loose coupling approach

- How can an efficient approach for structural failure analysis be realized?

3. Application and verification

- How can the procedure be applied to a concrete example - progressive damage analysis for a 1-Stringer and Two-Stringer stiffened composite panel?

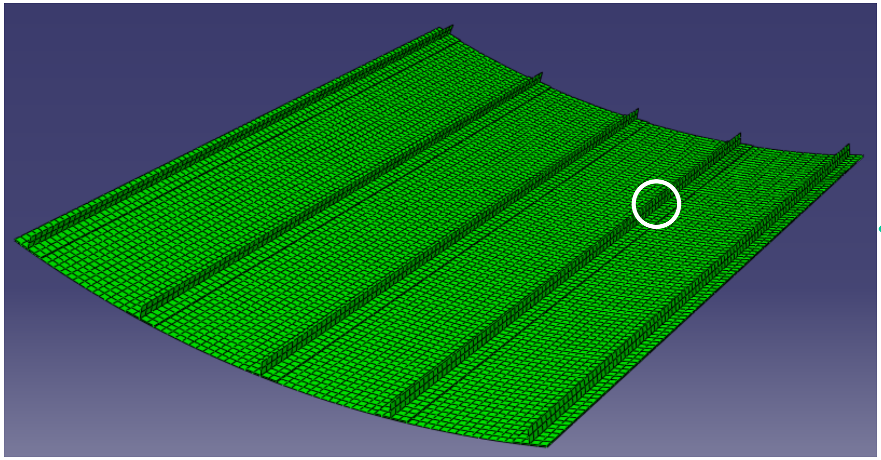
4. Enhancements to the method

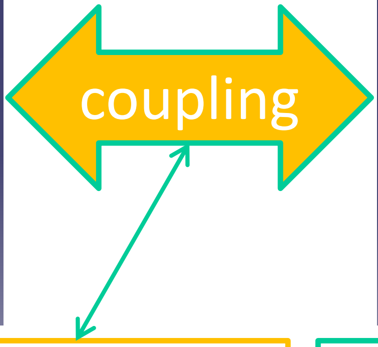
- How can the method be improved in terms of computational time and reliability?

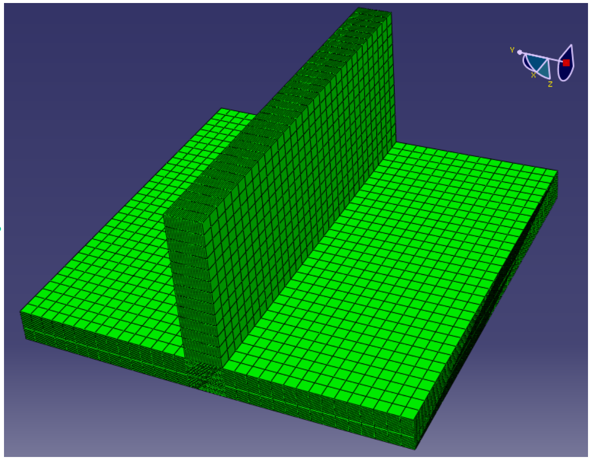
5. Conclusions and Outlook

- What is the status and what are the next steps?

Motivation







Coarse whole model
= global model
• fast computation
• buckling and post buckling behavior
(global effect)

Investigation of interaction between global and local effects

Detailed fine model
= local model
• accurate computation
• damage progression
• fast computation
(local effect)

Overview of the procedure

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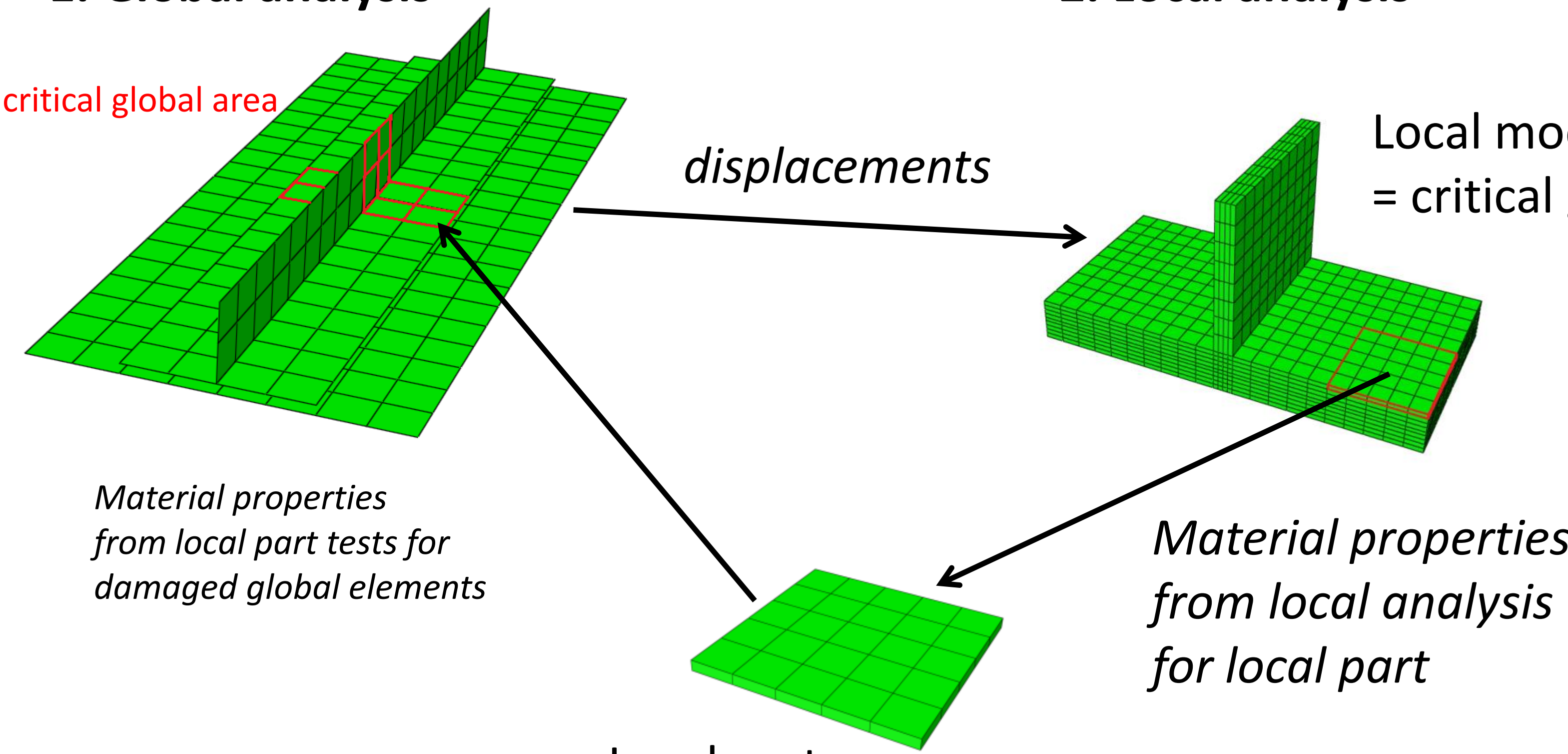
1. Global analysis

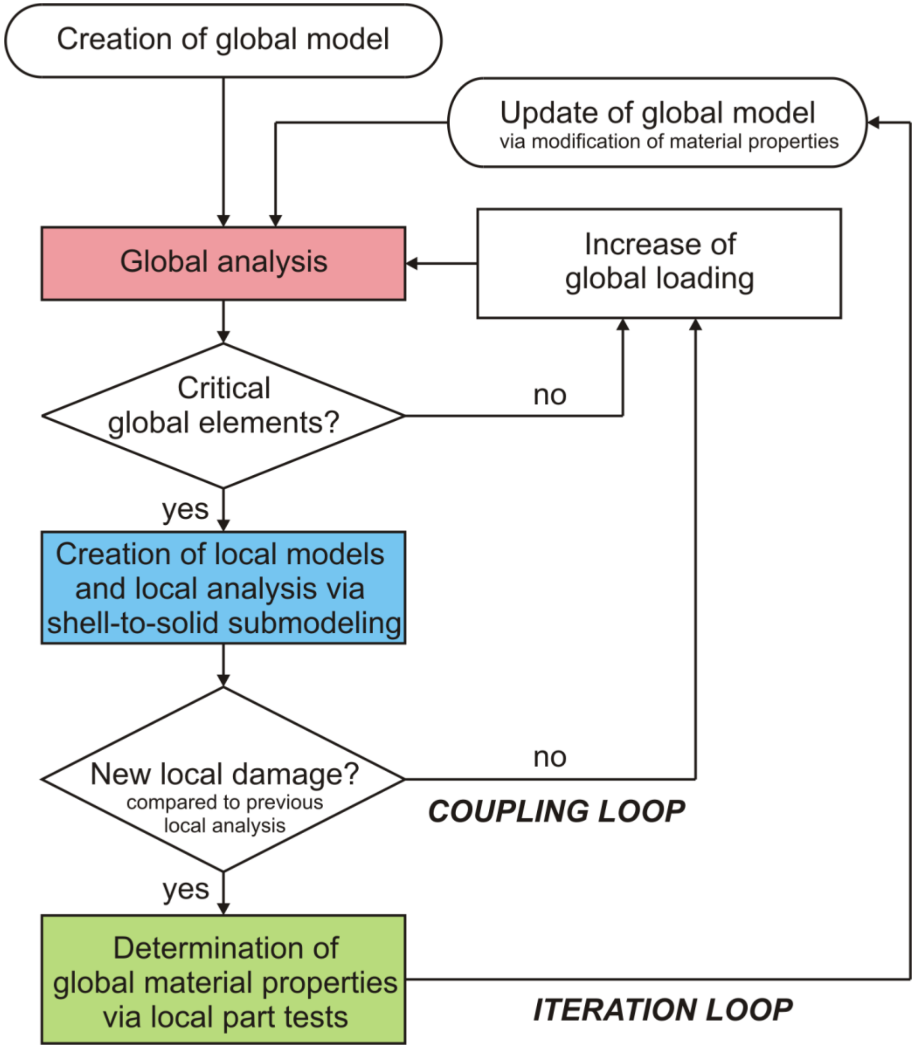
2. Local analysis



Local part
= 1 global element
= 1 laminate layer

3. Local part tests for determination of global material properties for each damaged global element

Iteration process



Reduced material properties from the local part tests do not correspond to the initial displacements of the global model:

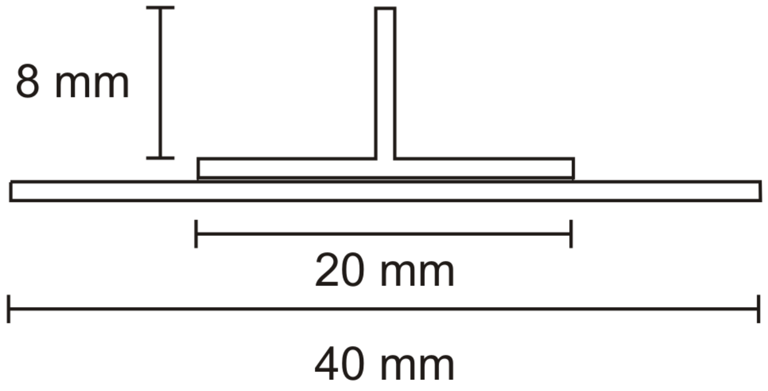
- Update of global displacements required
- Updated properties at global level applied by steps

Coupling models

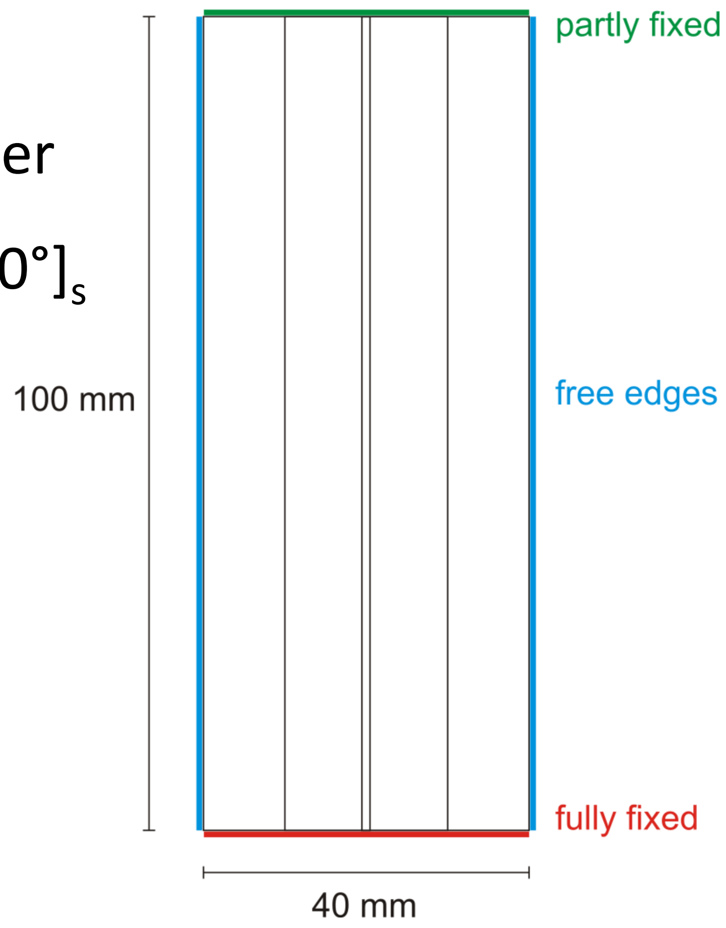
Model description

- Flat stiffened panel with one T-stringer
- Layup with 4 composite layers: $[0°, 90°]_s$
- Compression in axial direction

Cross section



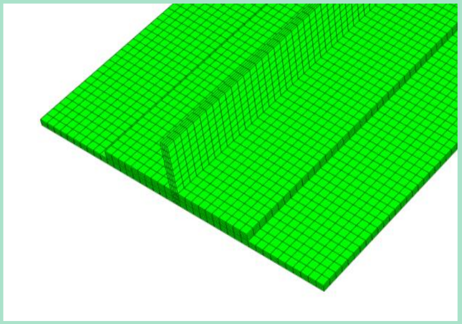
Top view



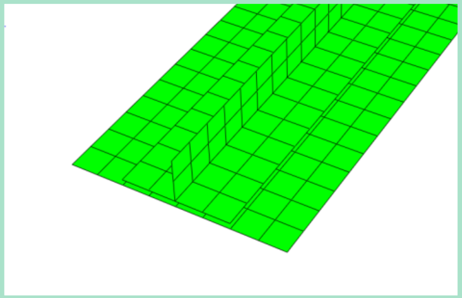
Academic Stiffened Panel

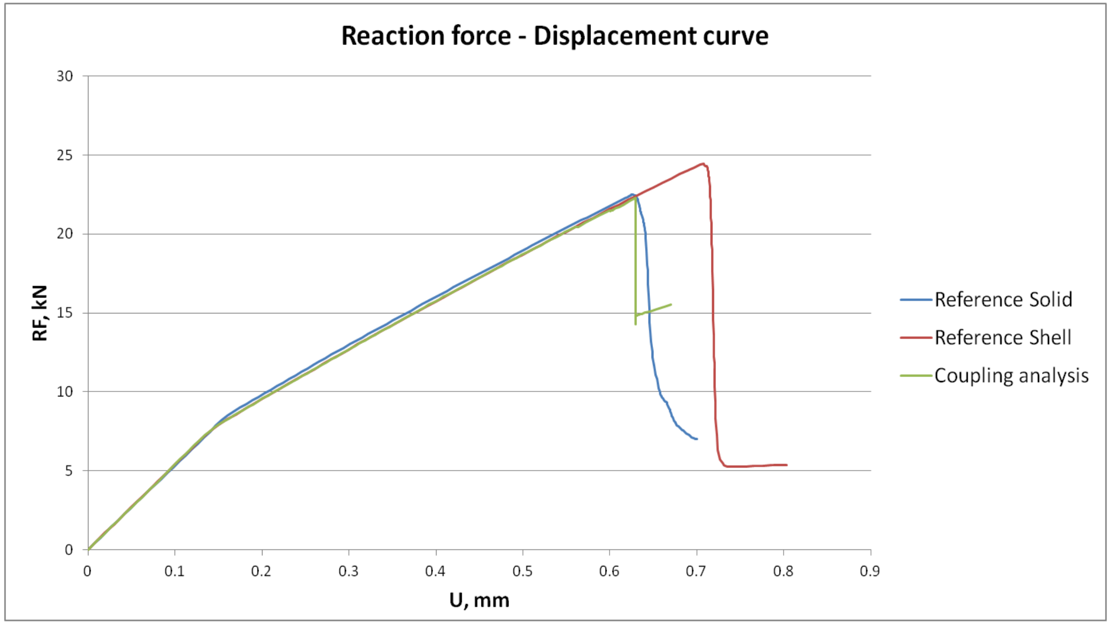
Reference models

Reference model
Solid elements (C3D8)



Reference model
Shell elements (S4R)





	Reference Solid	Reference Shell
Matrix failure, mm	0.53	0.50
Fiber failure, mm	0.62	0.64
Total failure, mm	0.63	0.72

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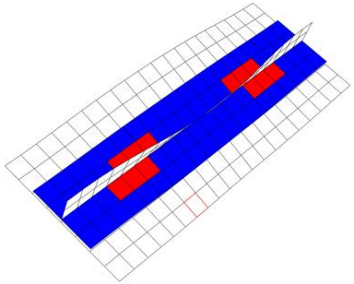
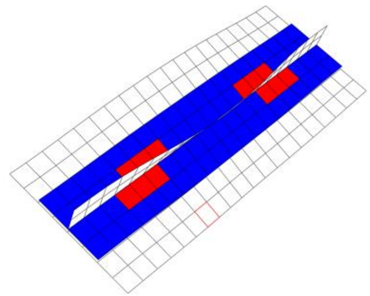
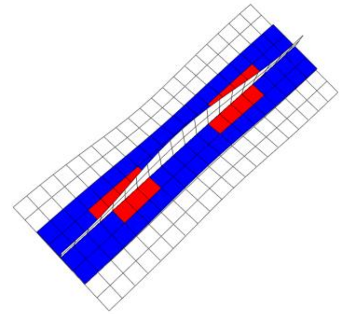
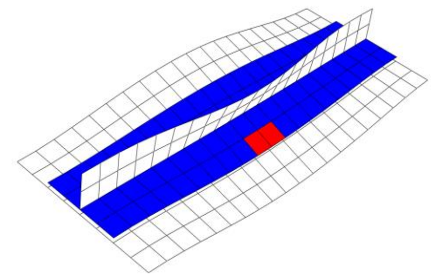
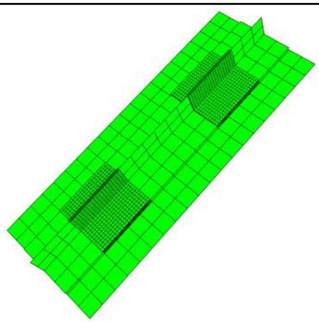
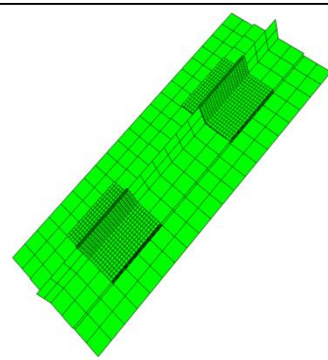
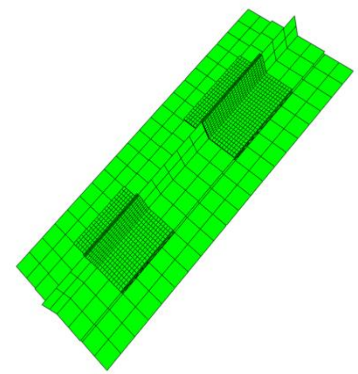
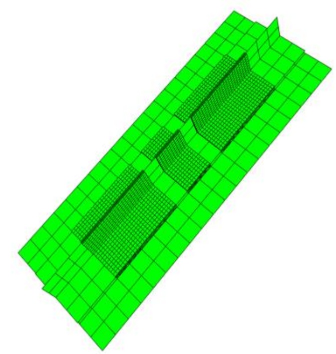
Performance of four coupling loops with progressing damage

Loop 1 (u = 0.56 mm) Matrix damage initiation	**Loop 2 (u = 0.60 mm)** Damage	**Loop 3 (u = 0.63 mm)** Damage progression	**Loop 4 (u = 0.67 mm)** Fiber damage initiation
 Global model with critical areas			
 Plot overlay of separated models			

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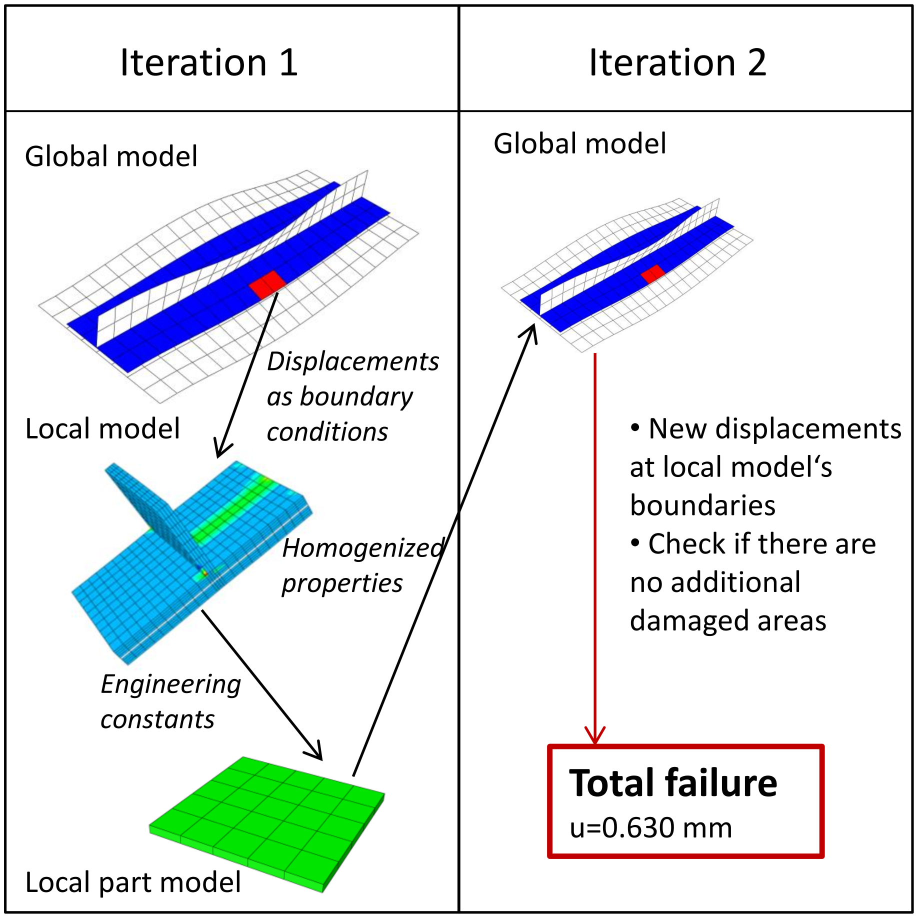
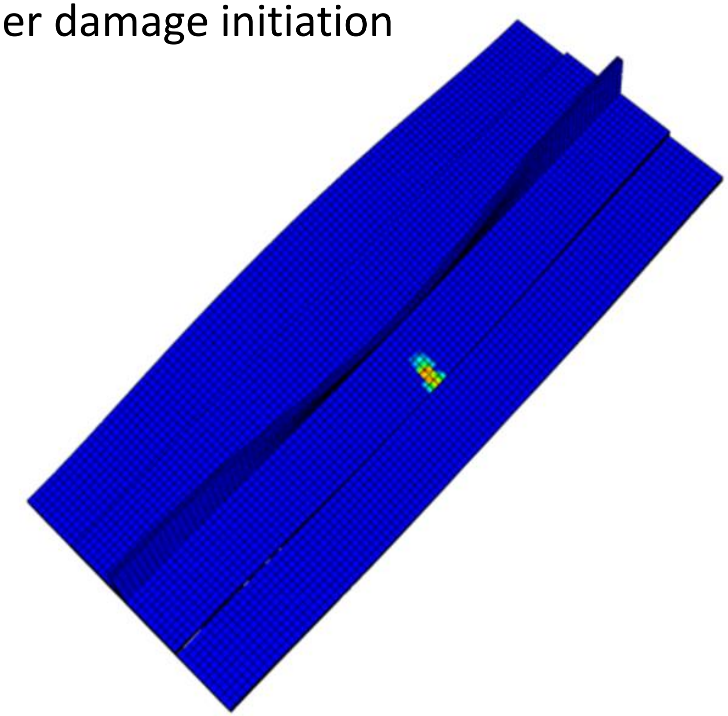
Loop 4 (u = 0.670 mm)
Fiber damage initiation



Reference solid model
(u=0.616 mm)
Fiber damage initiation



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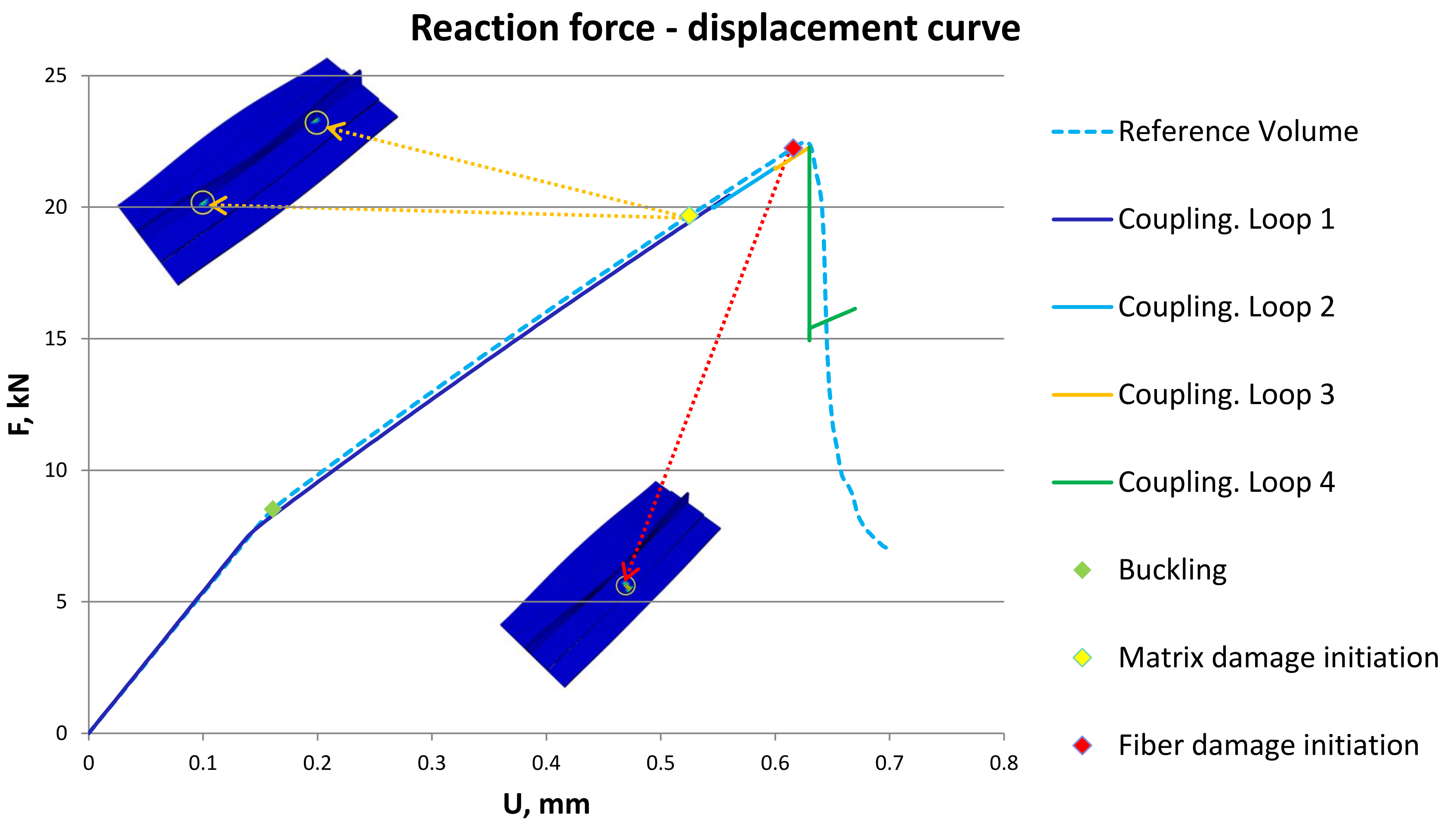
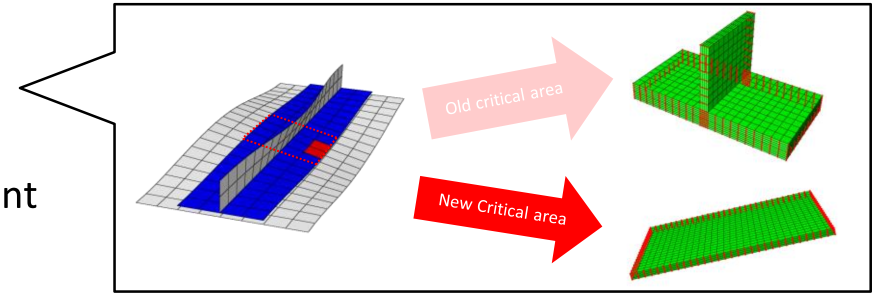


Modifications for efficiency

Local models

New rule for local models:

- Elements adjacent to damaged element included
- If blade is not damaged – not examined

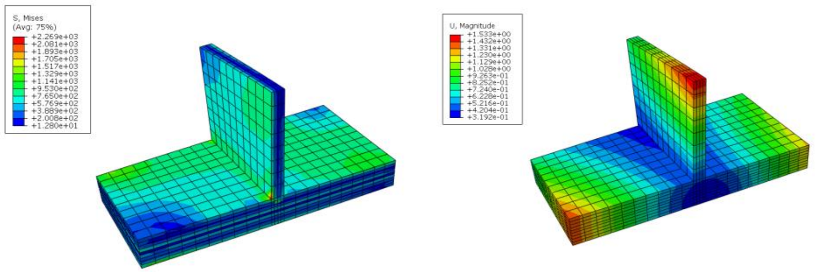


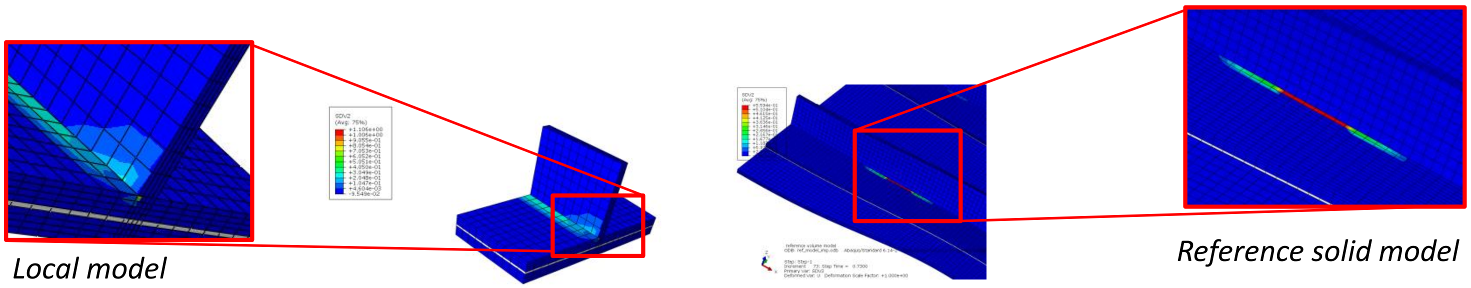
Advantages

1. Damage pattern is similar to reference solid model
2. Stress concentrations on edges are not considered
3. No risk of missing damage propagation

Disadvantages

1. Stress and displacement fields in current local models are more realistic



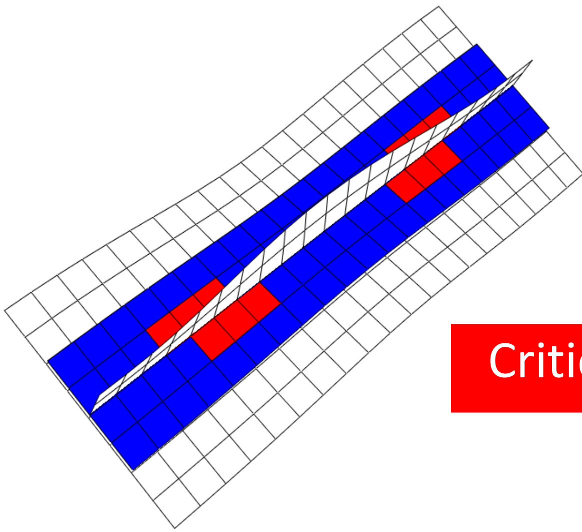


Local model

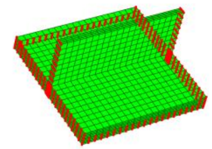
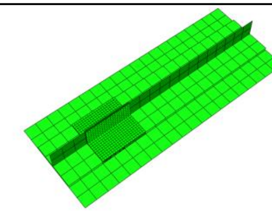
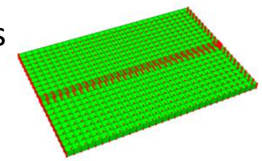
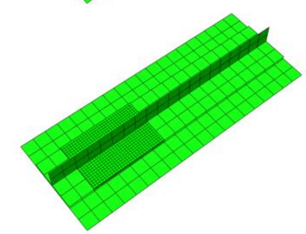
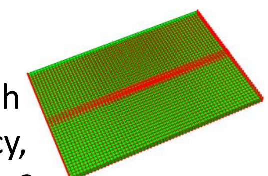
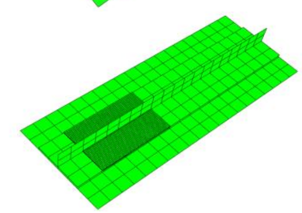
Reference solid model

Modifications and verification

Global model



Critical area

Local models		Plot overlay
Previous approach		
New rules to define local model		
Verify mesh dependency, linear factor 2		

- Shell elements
- Linear elastic material
- Damage initiation criterion determines critical areas

- Volume elements
- Degradation model by Linde
- Represents critical global area

Coupling models

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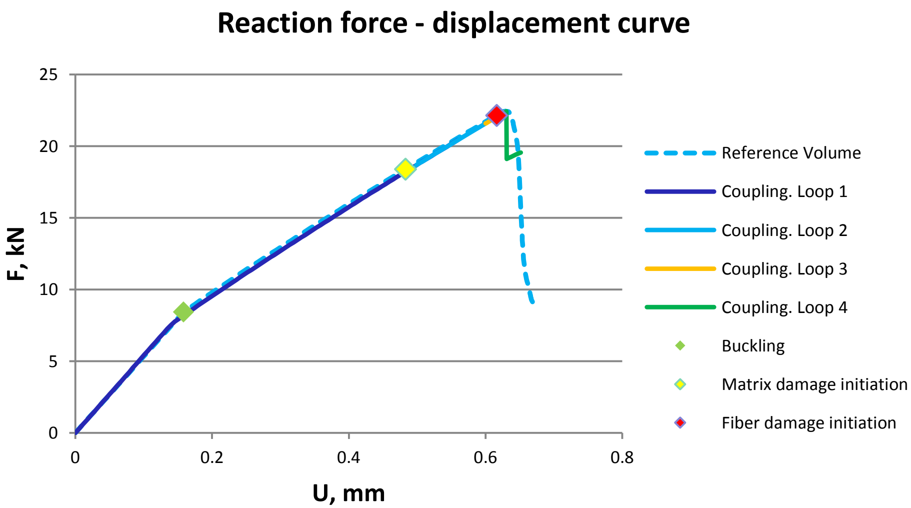
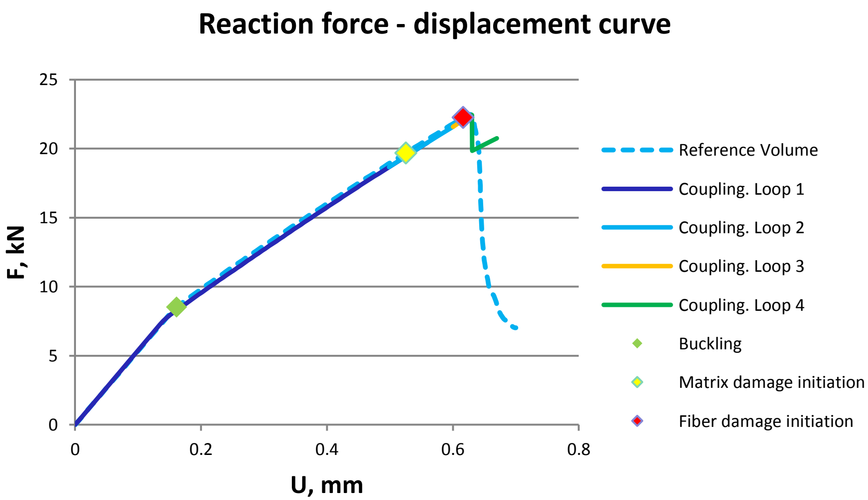
Mesh dependency

- 4 times more elements in local models
- Significant increase of computational time
- Relatively small increase in accuracy

New local models

- Only damaged elements and neighboring in-plane elements
- Significant decrease of computational time
- Relatively small decrease in accuracy





Academic Stiffened Panel

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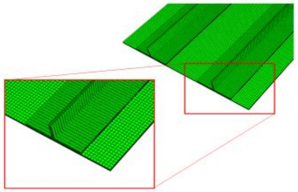
Coupling method applied to Academic Stiffened Panel:

- Local damage initiation => NO need to take all model into account => advantage of the Coupling method
- For 1-Stringer stiffened panel failure areas predicted by Linde criteria are similar for Reference Shell and Solid models => we can rely on shell model for the coarse analysis
- Total failure predicted by coarse Shell Reference Model with 13.72% accuracy (compared with Reference Solid Model)
- **Total failure** detected with **Coupling Method** with **0.53%** accuracy (compared with Reference Solid Model), with **0,65%** for new local models and with **0,19%** for 4 times finer mesh applied to local models

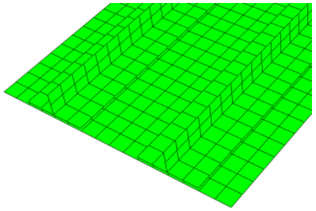
Two-Stringer Stiffened Panel

Reference models

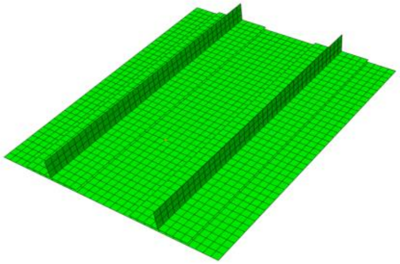
Reference model
Solid elements (C3D8)

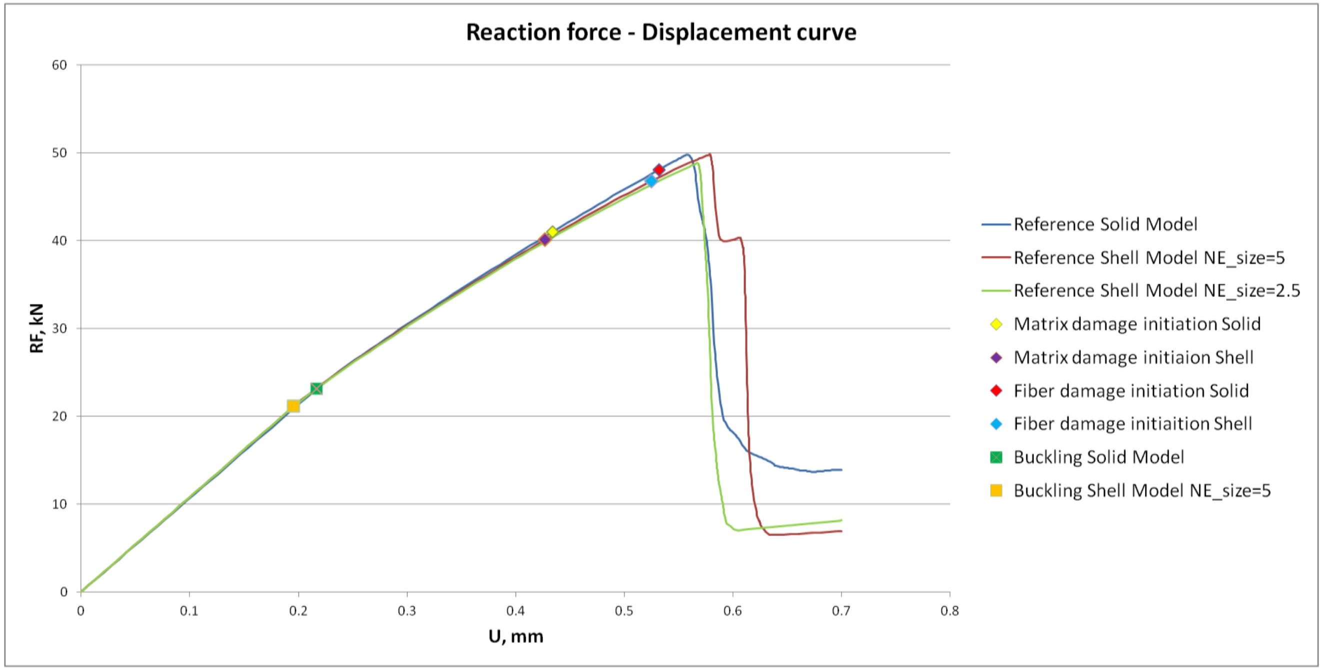


Reference model 1, NE size=5
Shell elements (S4R)



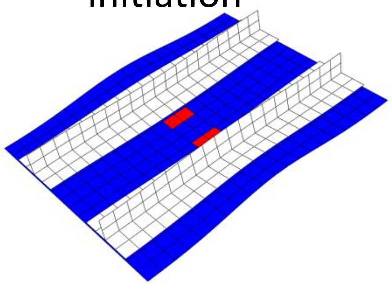
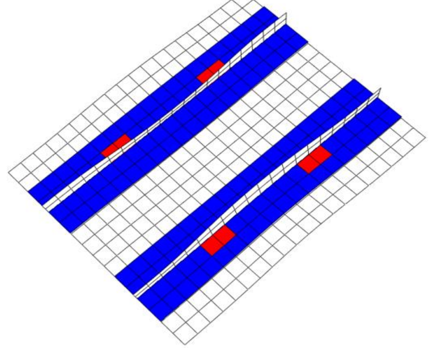
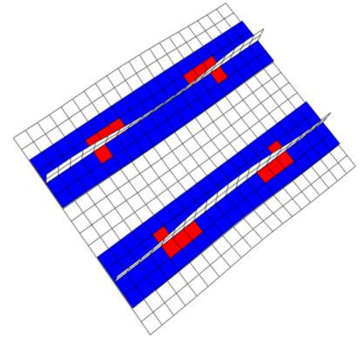
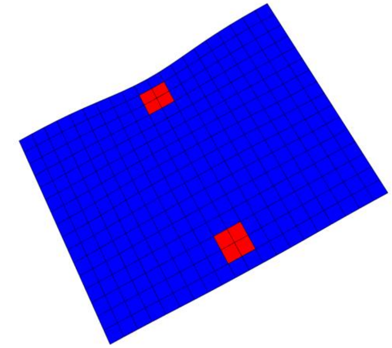
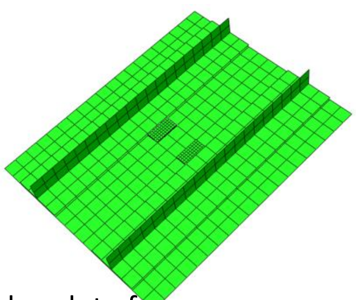
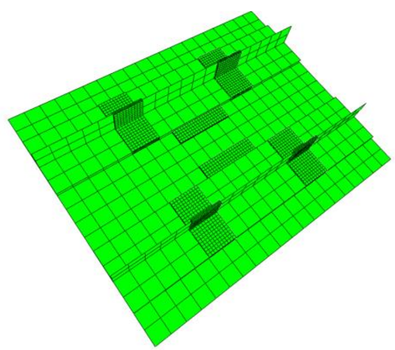
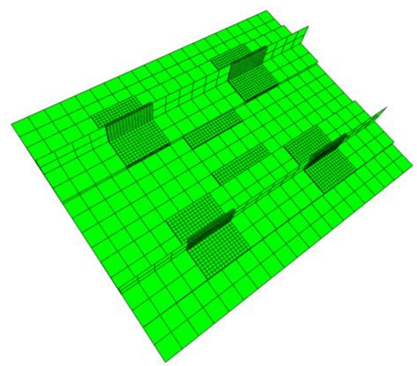
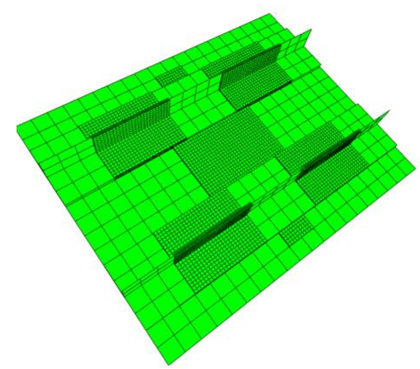
Reference model 2, NE size=2,5
Shell elements (S4R)



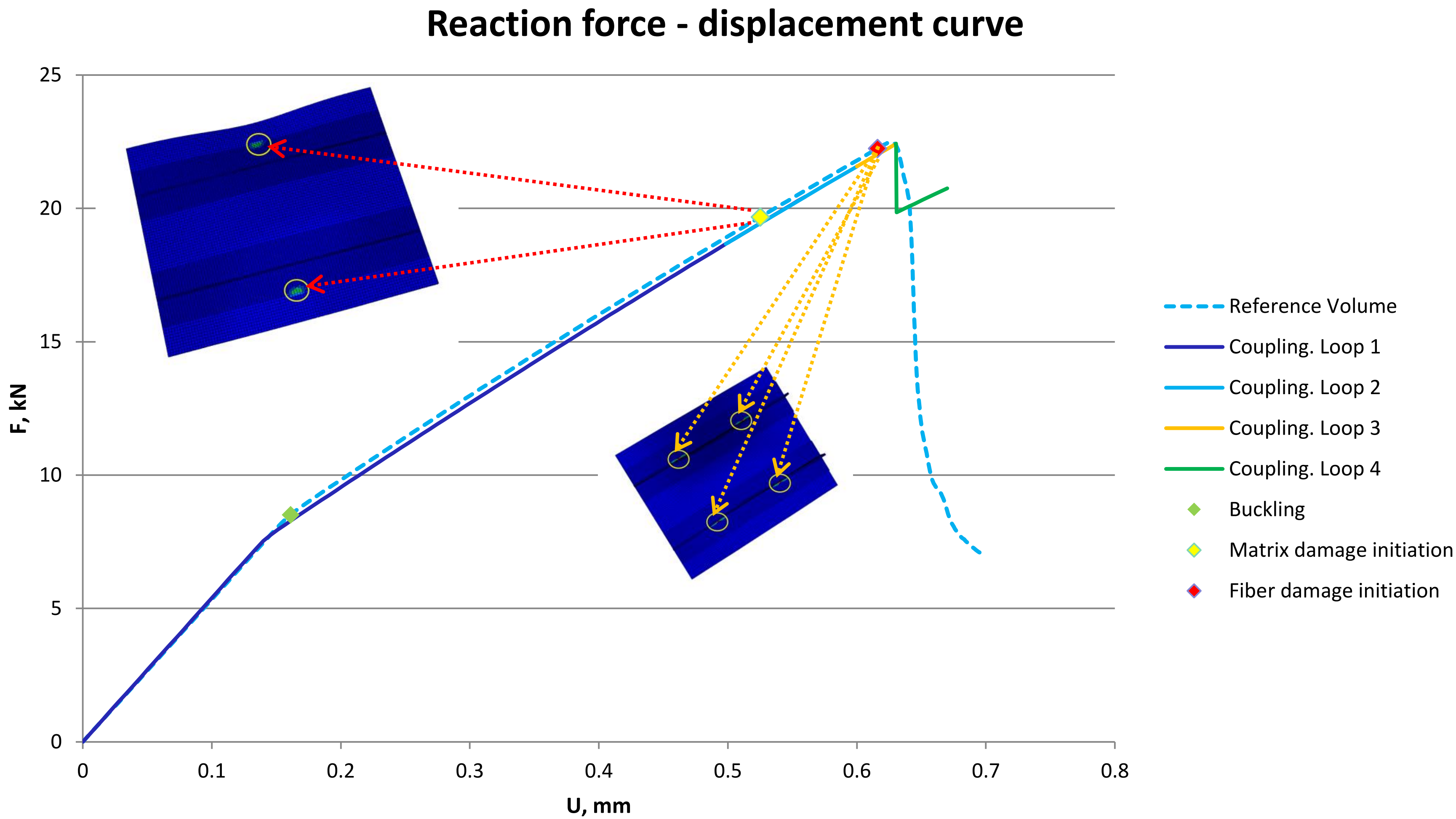


	Reference Solid, NE=101600	Reference Shell, NE=560	Reference Shell, NE=2160
Matrix failure, mm	0.434	0.413	0.392
Fiber failure, mm	0.532	0.525	0.511
Total failure, mm	0.559	0.579	0.568

Performance of four coupling loops with progressing damage

Loop 1 (u = 0.42 mm) Matrix **skin** damage initiation	**Loop 2 (u = 0.45 mm)** Matrix **foot** damage initiation	**Loop 3 (u = 0.48 mm)** Damage progression in **foot** area	**Loop 4 (u = 0.54 mm)** Fiber skin damage initiation
 Global model with critical areas			
 Overlay plot of separated models			

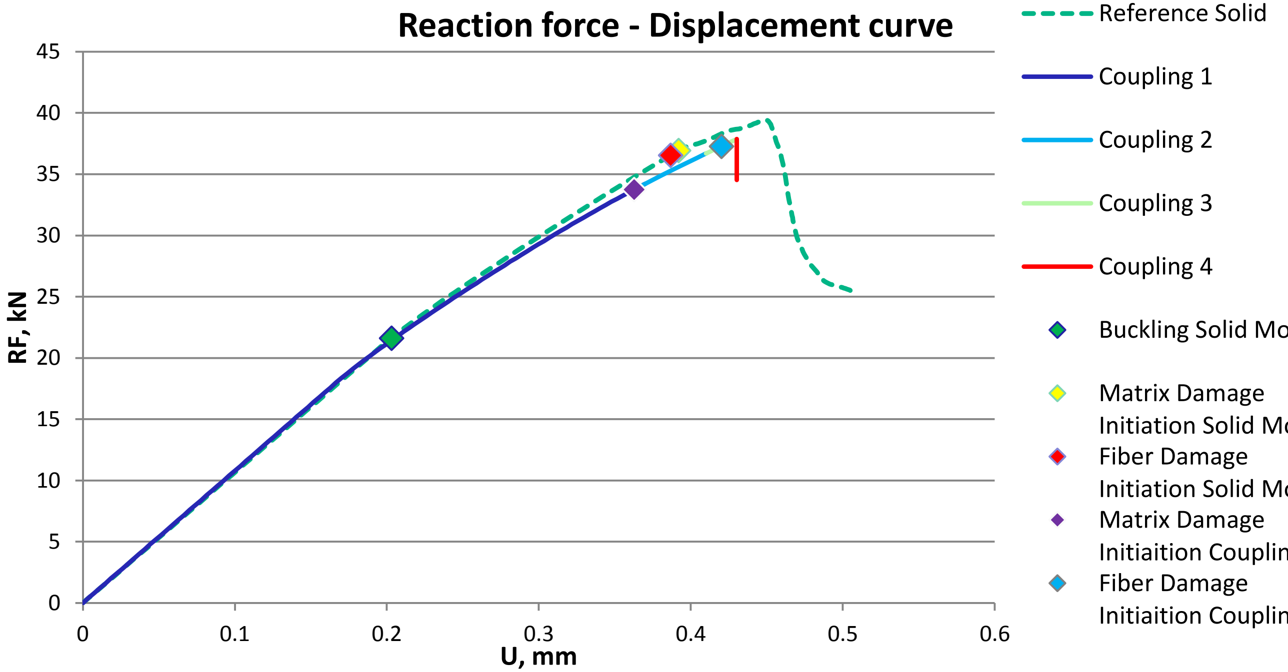
Two-Stringer Stiffened Panel



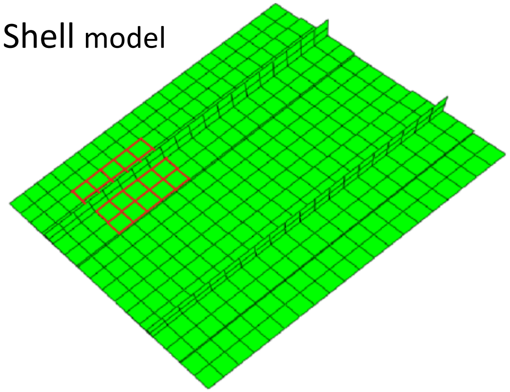
Two-Stringer Stiffened Panel

Model with local defect

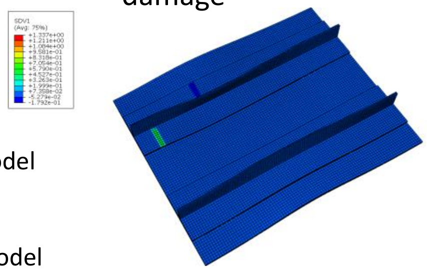
- Local defect: between skin and foot (L=25 mm)
- New local model technique



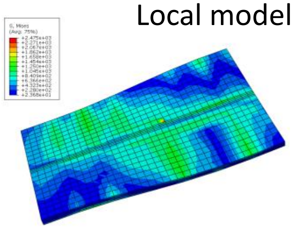
Shell model



Solid model, fiber damage



Local model



Coupling method applied to Two-Stringer Stiffened Panel:

Without defect

- Models with coarse mesh show no significant overestimation of load capacity:
  - 3.66% for Shell Model, NE=560
  - 1.10% for Shell Model, NE=2160
- Damaged areas are quite big => no advantages in computational time using Coupling method

Local defect

- Model with local defect demonstrated the advantages of the method during progressive damage analysis as total failure happened before local models started to be too large (compared with the size of the whole model)

Next steps

Global-local step

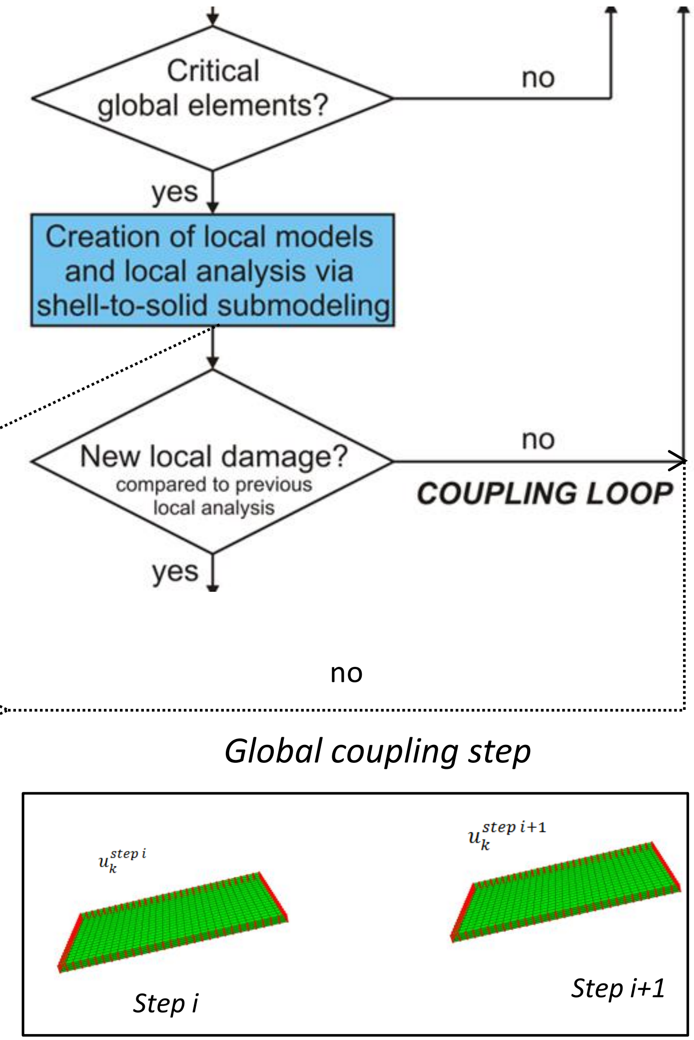
To be investigated

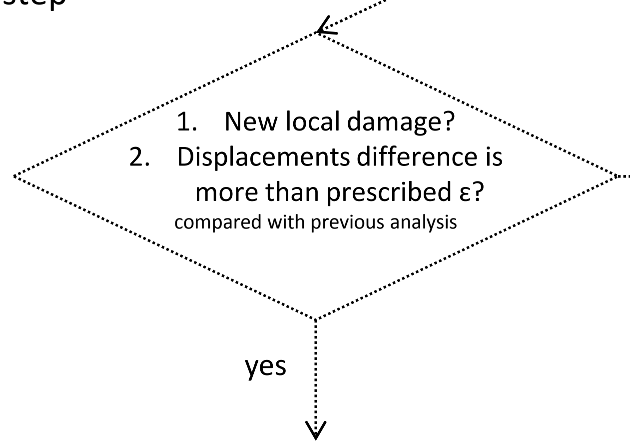
- Displacements difference on the driven nodes within 1 coupling loop

$$\left\|u_k^{step\,i+1} - u_k^{step\,i}\right\| \le \varepsilon, k = \overline{1, NN}$$

NN – number of driven nodes

step i – iteration step





Next steps

Application to realistic and larger structures, including structures with local defects

- Advantages of the global-local approach to be assessed
- Available experimental results
- Realistic imperfections

Delamination

- Delamination between skin and foot
- Free edge effects

Conclusions

- A two-way loose coupling approach for investigation of local material damage in composite structures has been further verified and the efficiency has been improved for specific test cases
- Larger structures have been examined (two-stringer panel)
- Application of the coupling procedure to a stiffened panel with local defect demonstrates the potential of the method

Thank you for your attention!

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Acknowledgement: FULLCOMP project

- **FULLCOMP** - **FULLy** integrated analysis, design, manufacturing and health-monitoring of **COMPosite** structures. The FULLCOMP project is funded by the European Commission under a Marie Sklodowska-Curie Innovative Training Networks grant for European Training Networks (ETN).