Micromechanical Models of Transverse Cracking in Ultra-thin Fiber-Reinforced Composite Laminates

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Ultra-thin Fiber Reinforced Polymer Composite (FRPC) Laminates: an Introduction

Technological origins and applications

Solar Impulse 2, from [1].

Nuon Solar team's car, from [2].
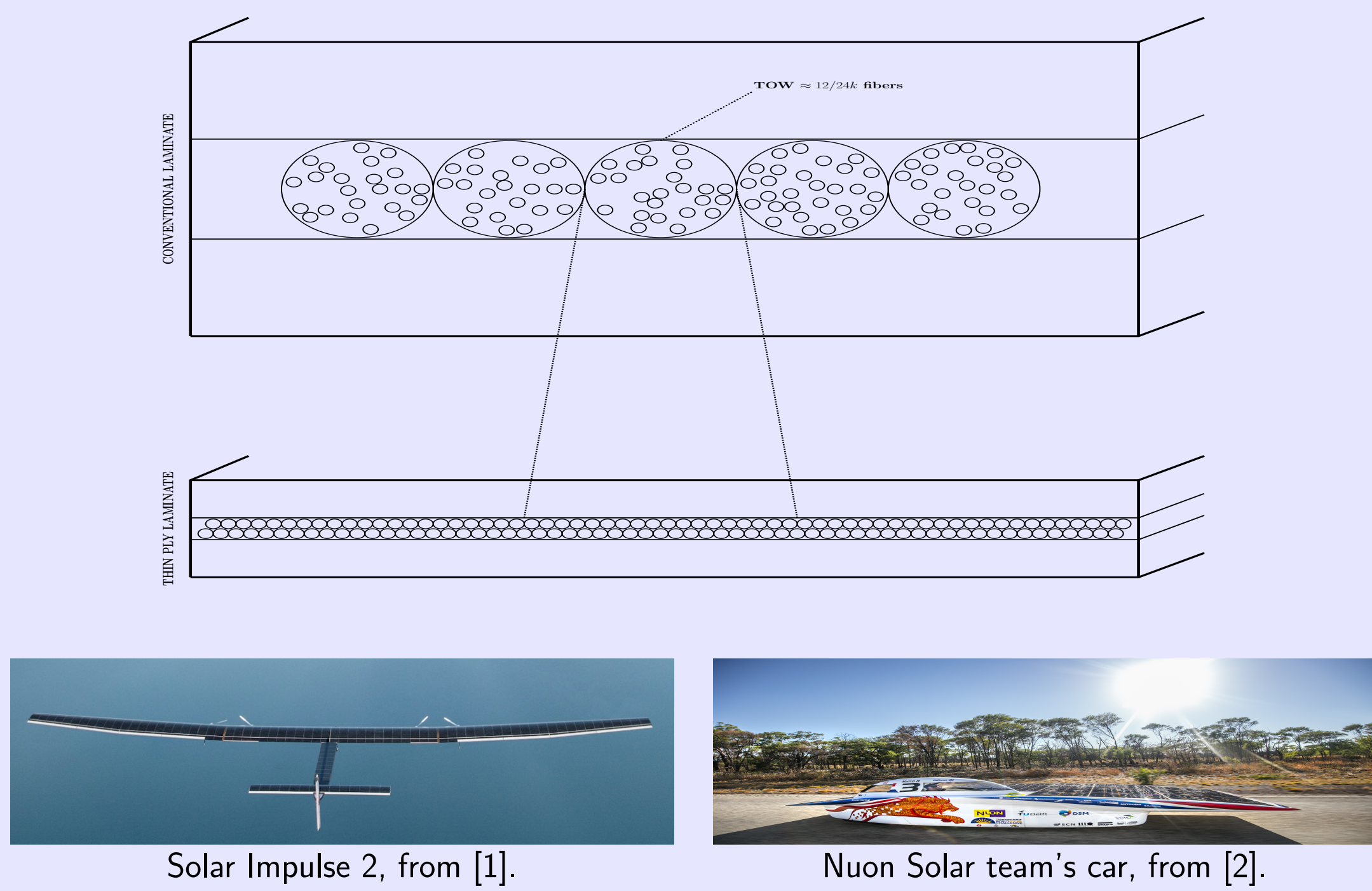
Damage in FRPCs: a visual introduction

matrix crack   90°

fibre fracture   0°

delamination

By Dr. R. Olsson, Swerea, SE.

20 µm

By Prof. Dr. E. K. Gamstedt, KTH, SE.

The thin ply effect

In situ transverse lamina strength Y_T as a function of thickness and ply orientation

Measurements of in-situ transverse strength from Flaggs & Kural, 1982 [3].
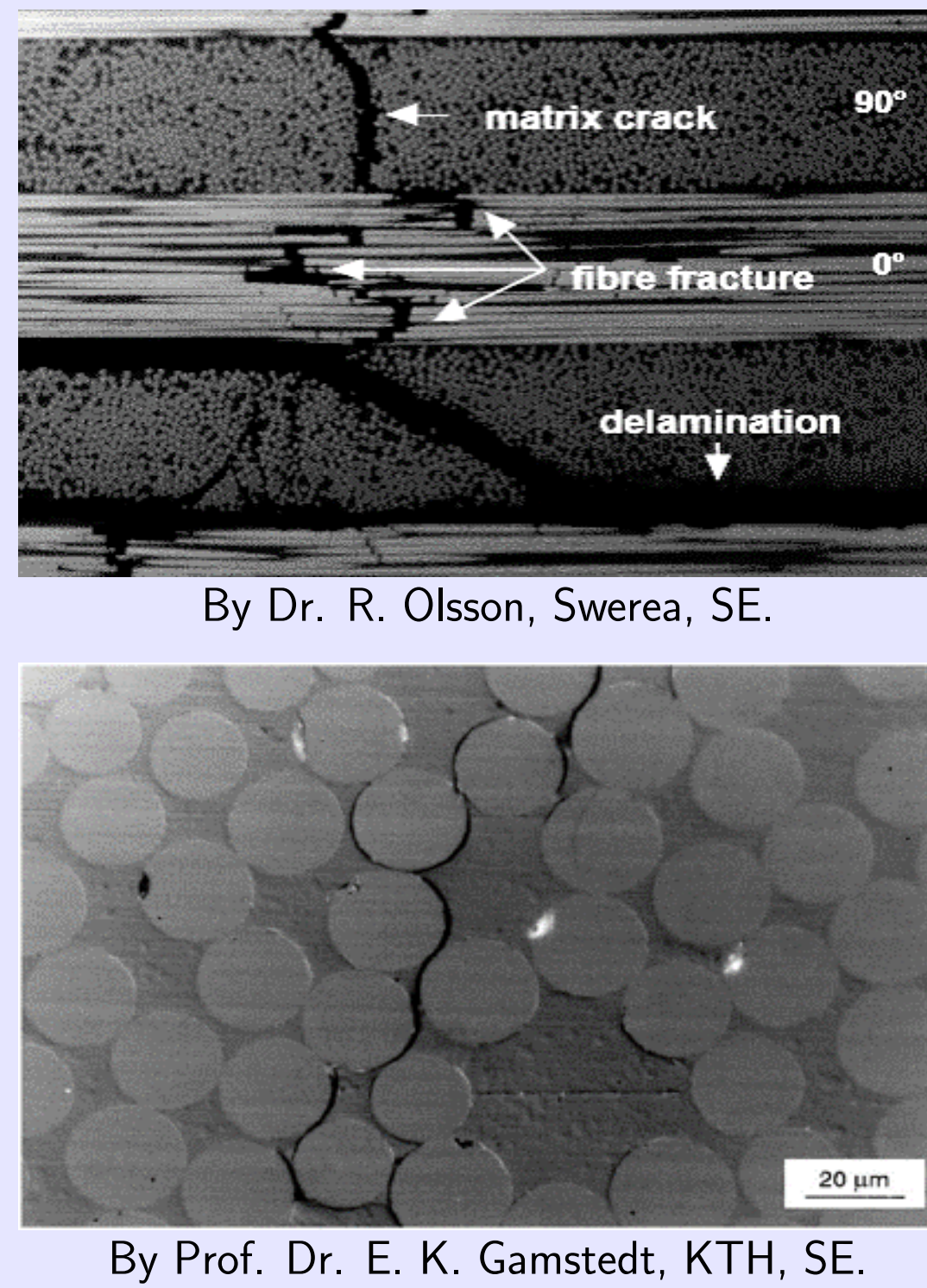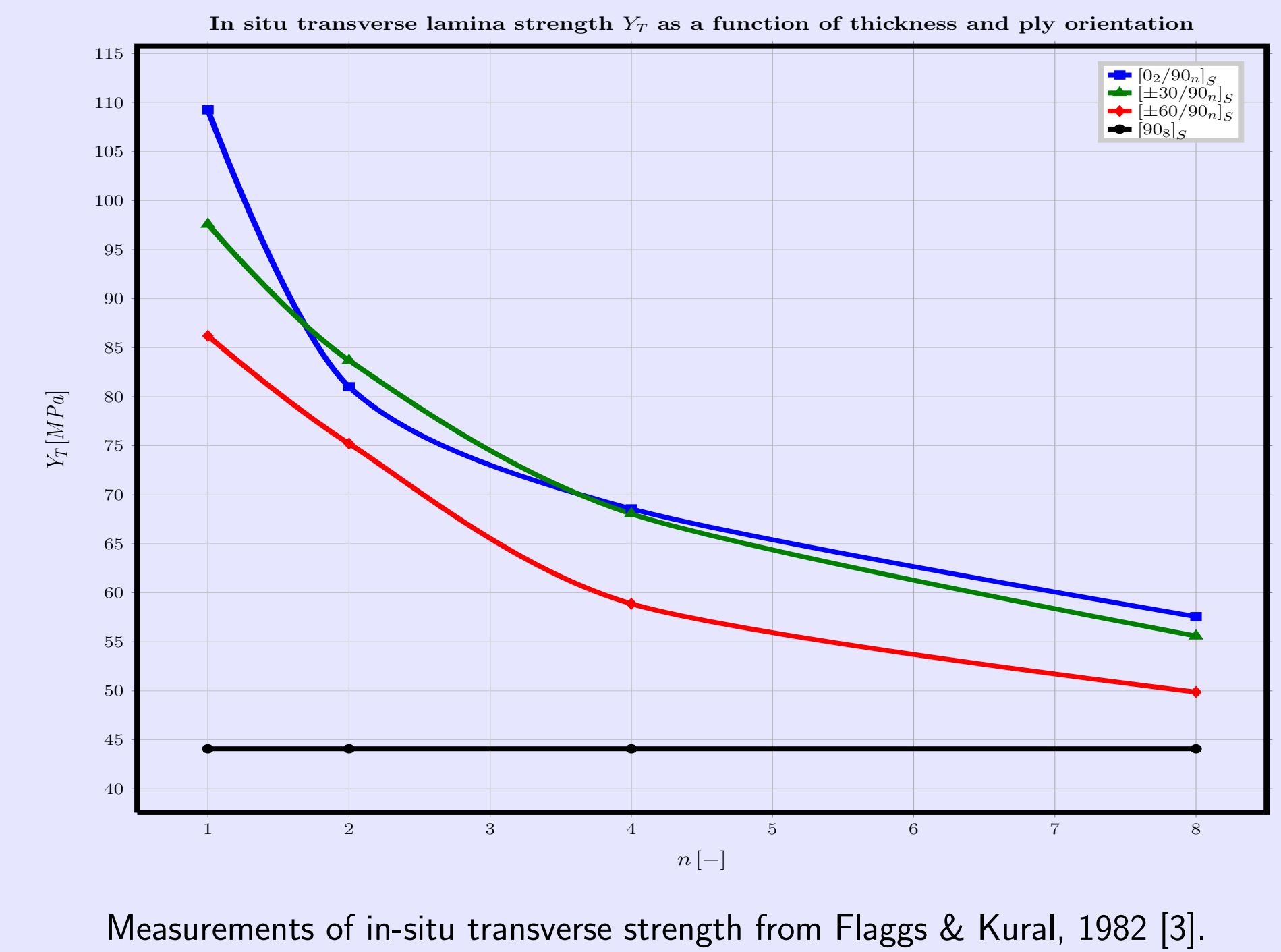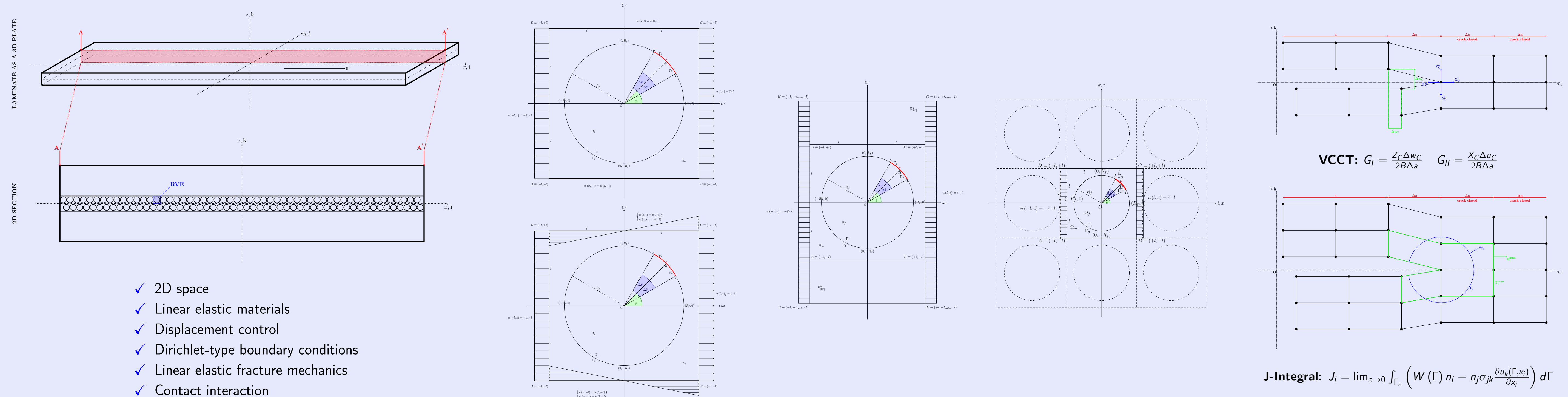
Objectives & Approach

What do we want to achieve?

- Investigate the influence of volume fraction, material properties, thin ply thickness and bounding plies' thicknesses on crack initiation
- $G_{*c} = G_{*c}\left(\theta_{debond}, \Delta\theta_{debond}, E_{(..)}, \nu_{(..)}, G_{()}, VF_f, t_{ply}, \frac{t_{ply}}{t_{bounding\ plies}}\right)$
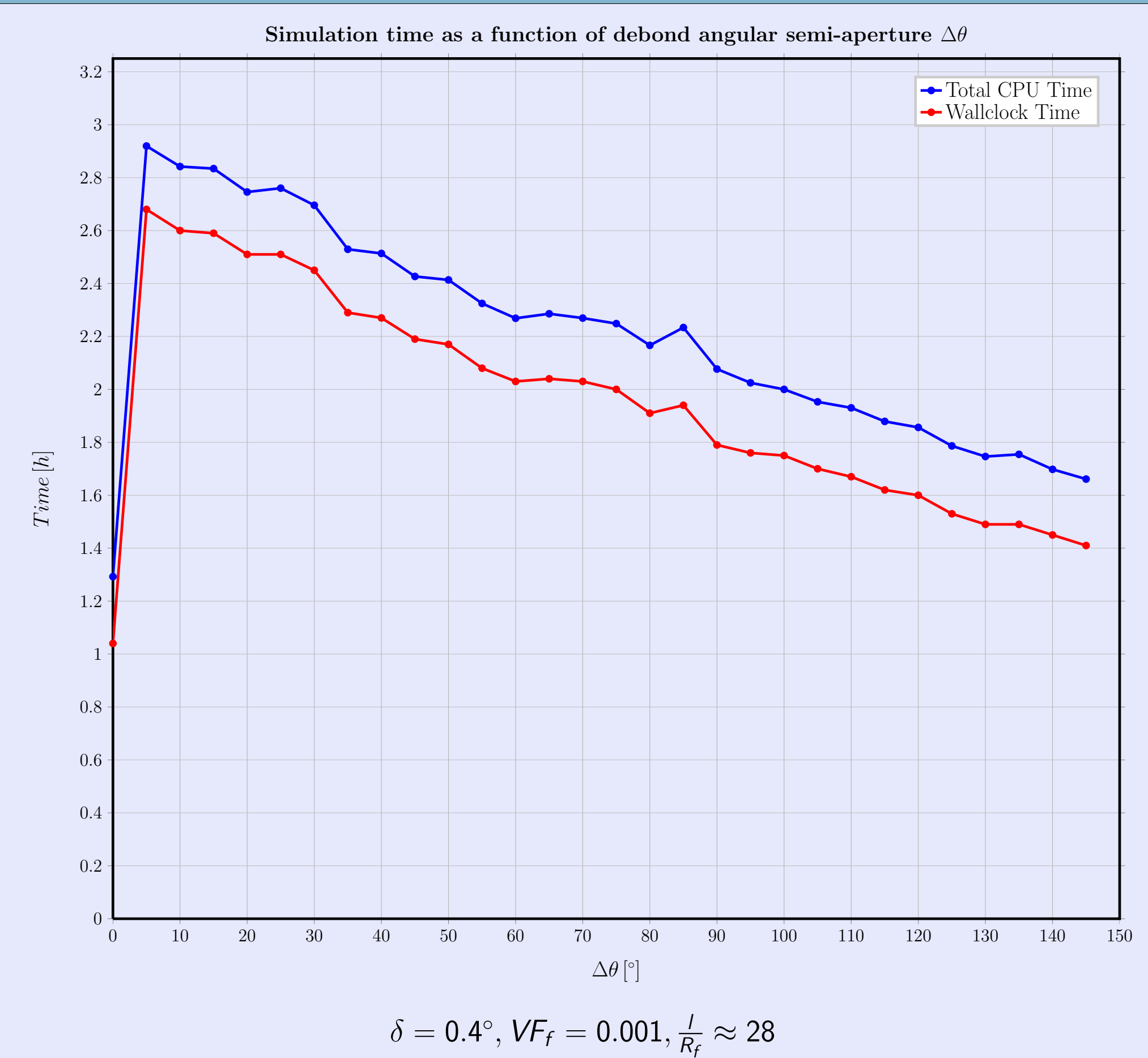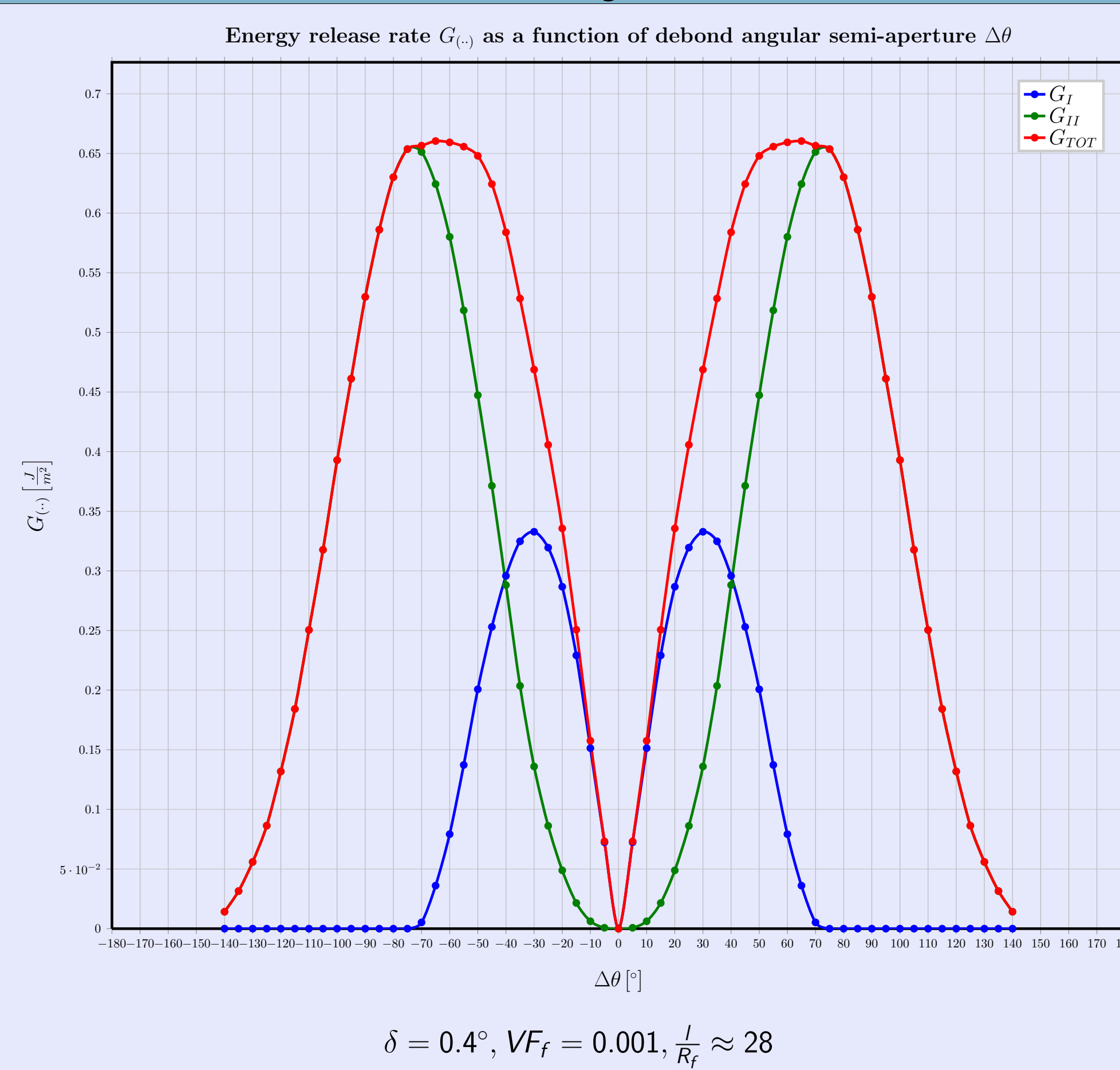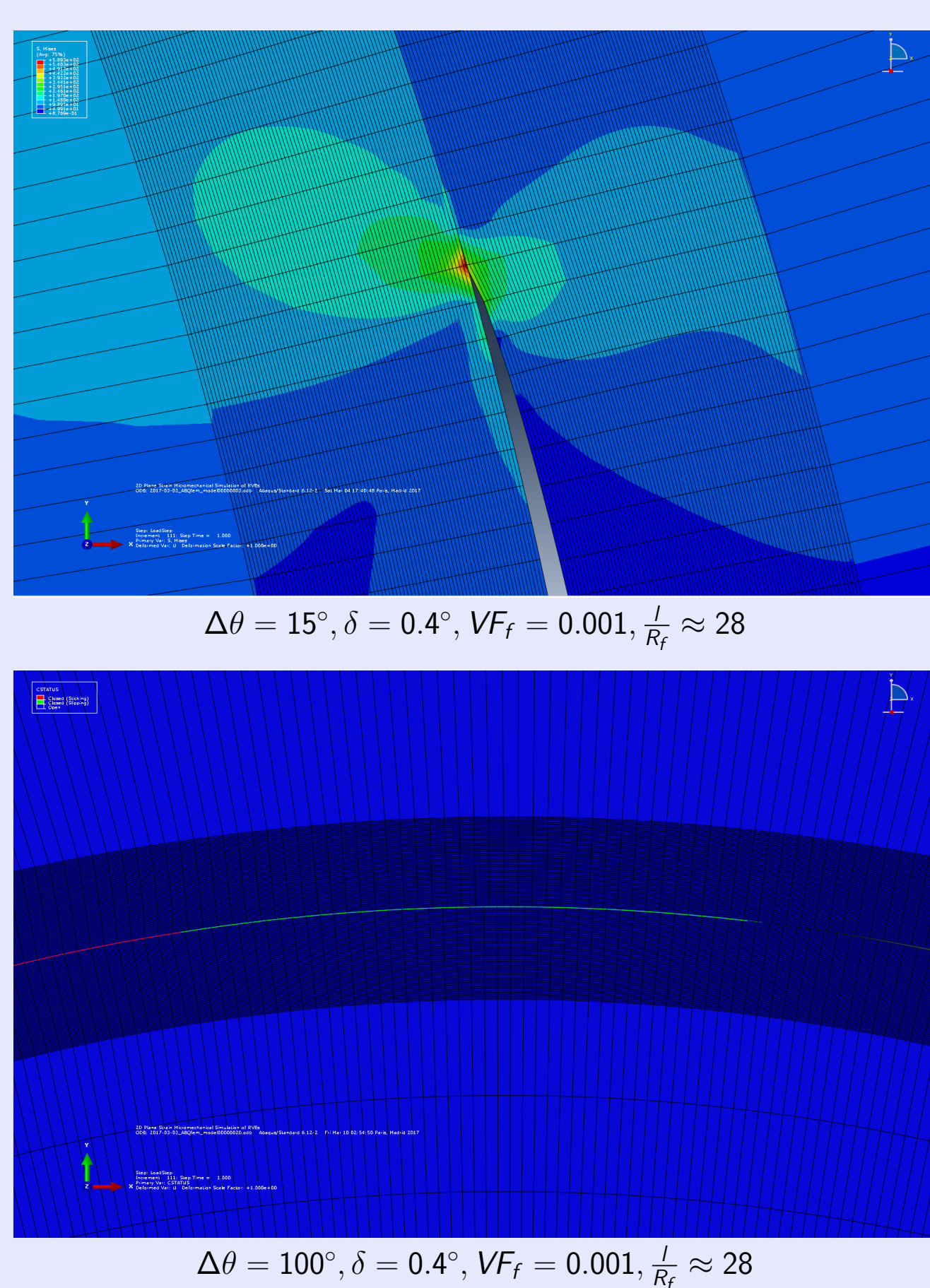
How do we want to achieve it?

- Design and categorization of several Representative Volume Elements (RVEs)
- Automated generation of RVEs geometry and FEM model
- Finite Element Simulations (in Abaqus)

Design & Analysis of Representative Volume Elements (RVEs)

- ✓ 2D space
- ✓ Linear elastic materials
- ✓ Displacement control
- ✓ Dirichlet-type boundary conditions
- ✓ Linear elastic fracture mechanics
- ✓ Contact interaction

VCCT: $G_I = \frac{Z_C \Delta w_C}{2B\Delta a}$ $G_{II} = \frac{X_C \Delta u_C}{2B\Delta a}$

J-Integral: $J_i = \lim_{\Gamma_c \to 0} \int_{\Gamma_c} \left(W(\Gamma) n_i - n_j \sigma_{jk} \frac{\partial u_k(\Gamma, x_i)}{\partial x_i}\right) d\Gamma$

Preliminary Results & Validation

$\Delta\theta = 15°, \delta = 0.4°, VF_f = 0.001, \frac{L}{R_f} \approx 28$

$\Delta\theta = 100°, \delta = 0.4°, VF_f = 0.001, \frac{L}{R_f} \approx 28$

Energy release rate $G_{(-)}$ as a function of debond angular semi-aperture $\Delta\theta$

$\delta = 0.4°, VF_f = 0.001, \frac{L}{R_f} \approx 28$

Simulation time as a function of debond angular semi-aperture $\Delta\theta$

$\delta = 0.4°, VF_f = 0.001, \frac{L}{R_f} \approx 28$

Conclusions & Perspectives

What has been accomplished?

- 2D micromechanical models have been developed to investigate crack initiation in thin ply laminates
- A numerical procedure has been devised and implemented to automatize the creation of FEM models
- Validation for $VF_f \to 0$ (matrix dominated RVE) with respect to previous literature [4, 5]

What's next?

- Investigate the dependence on VF_f, t_{ply}, $t_{ply}/t_{bounding\ plies}$ and different material systems
- Study numerical performances with respect to model's parameters
- Repeat for different RVEs and compare

Acknowledgements

References

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[4] Toya, M.; A crack along the interface of a circular inclusion embedded in an infinite solid. Journal of the Mechanics and Physics of Solids, 1974; 22(5), pp. 325-348.
[5] París, F., Cano, J., and Varna, J.; The fiber-matrix interface crack - a numerical analysis using boundary elements. Int. J. Fract., 1990; 82(1), pp. 11-29.