Modelling and testing of hail impact on aircraft composite laminates

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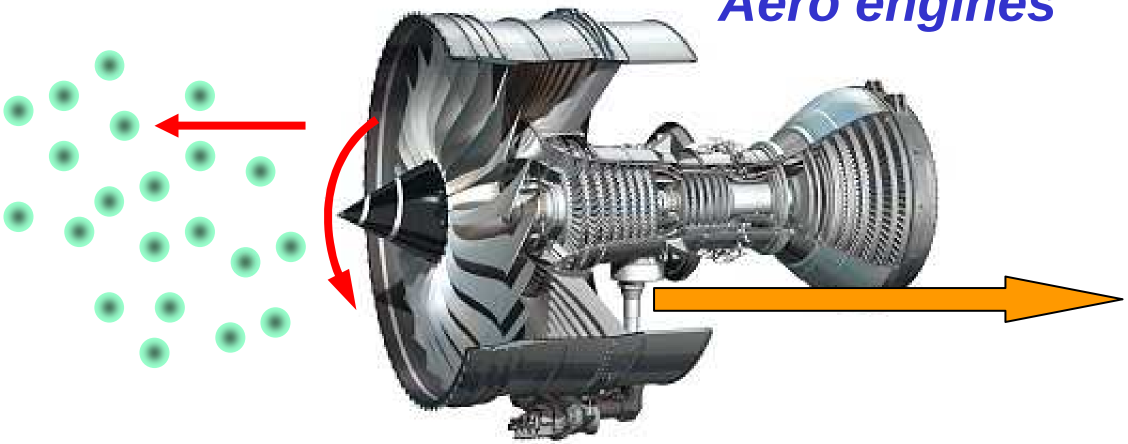
EASN Workshop, Paris, 7-8 Oct 2010

Hail impact – a problem in aviation

Aero engines

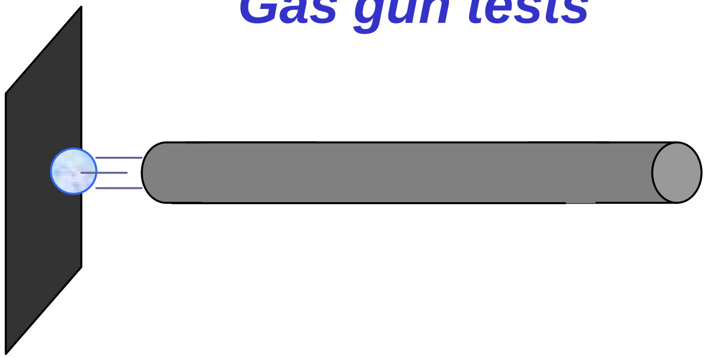


Composite prototype
FP6-project VITAL

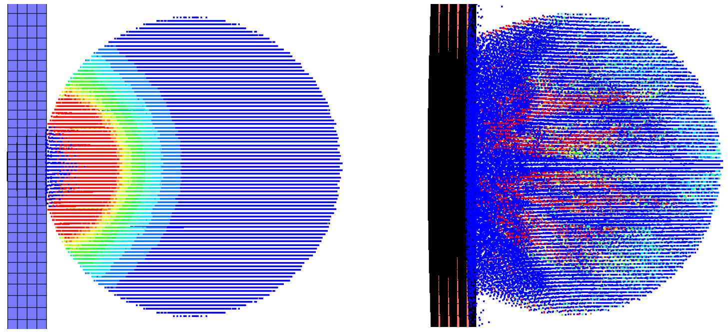
Pictures from www.volvoaero.com

Hail studies at Swerea SICOMP 2005-2010

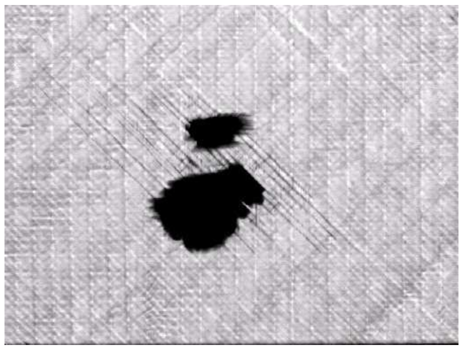
Gas gun tests



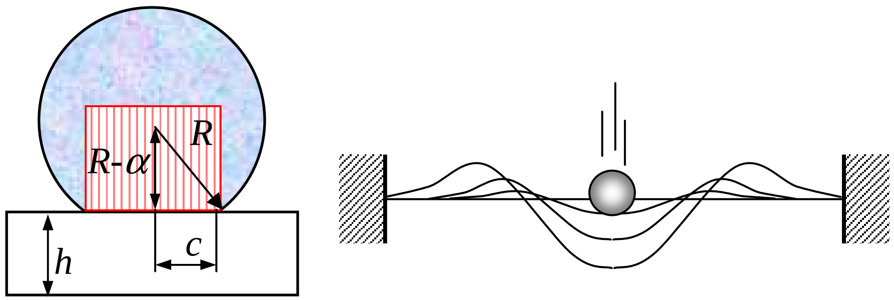
FE simulations



Fractography

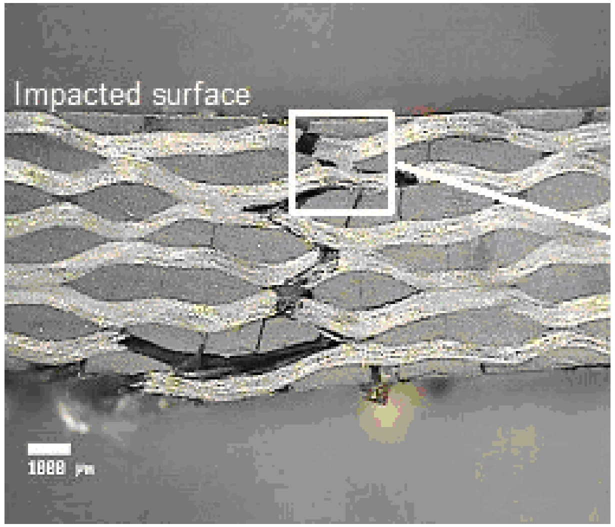


Analytical models

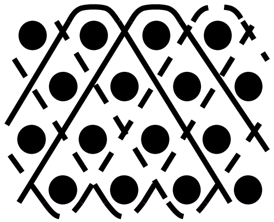


Materials considered

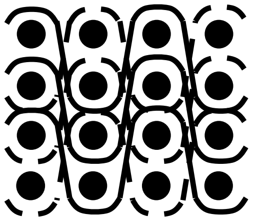
3D weaves



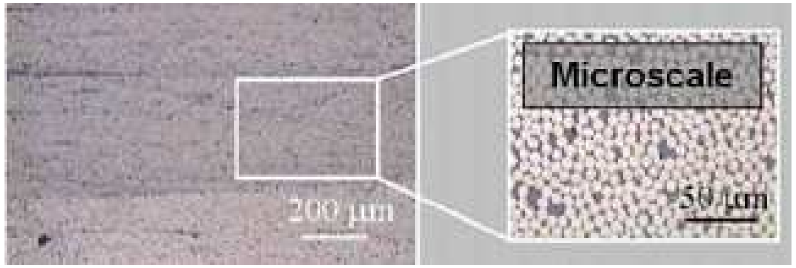
Angle interlock



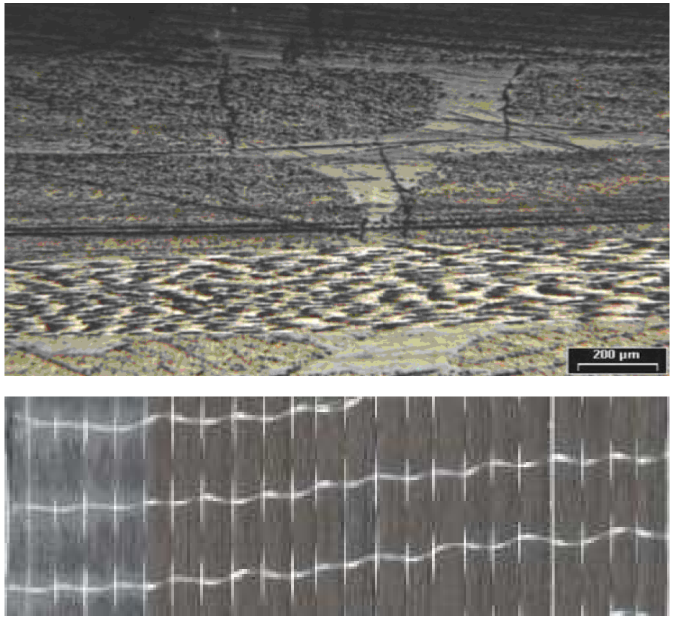
Layer-to-layer interlock



UD tape prepreg

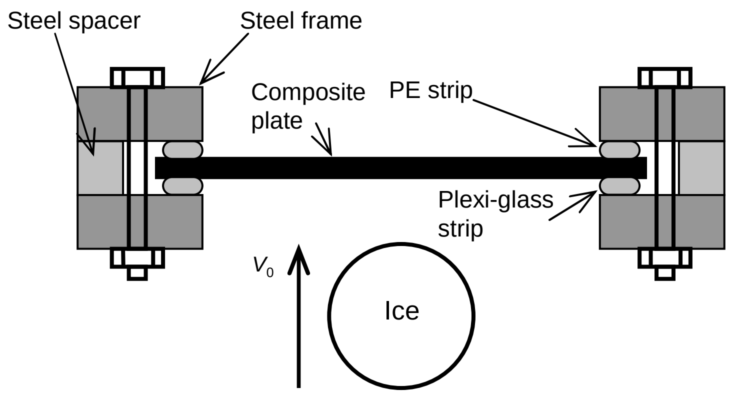


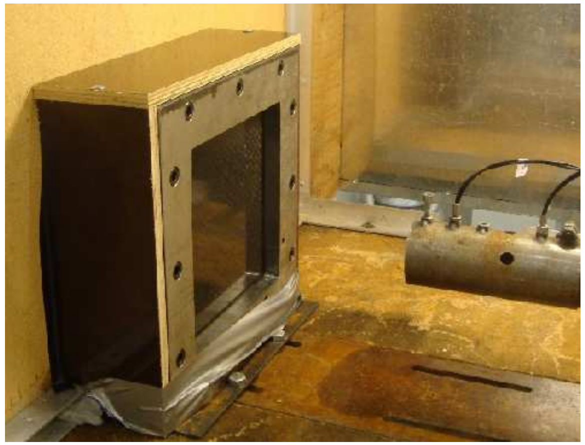
Non-crimp fabrics (NCF)



Impact experiments

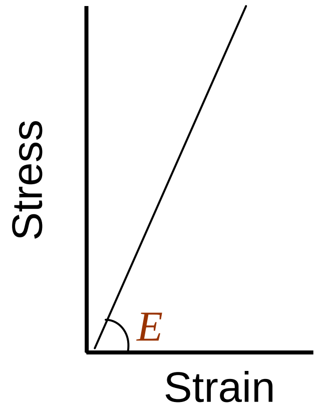
- Gas gun using compressed air
- Ice diameters 32 and 48 mm
- Composite plates, thickness 2-6 mm
- Some plates equipped with strain gauges



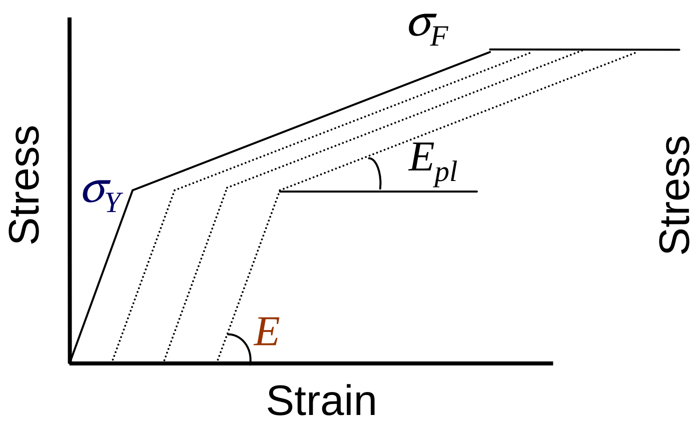


Material models for the ice

Elastic



Semi-brittle

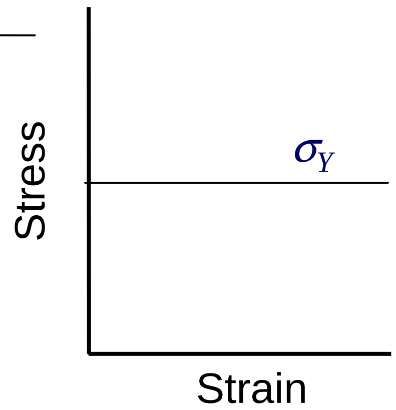


Kim & Kedward (2000)

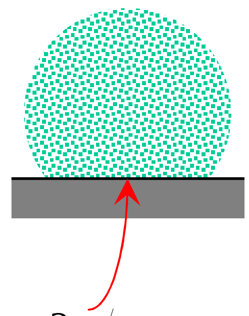
E = 9.2 GPa E_{pl} = 6.9 GPa

σ_Y = 10.3 MPa σ_F = 34.3 MPa

Ideally plastic

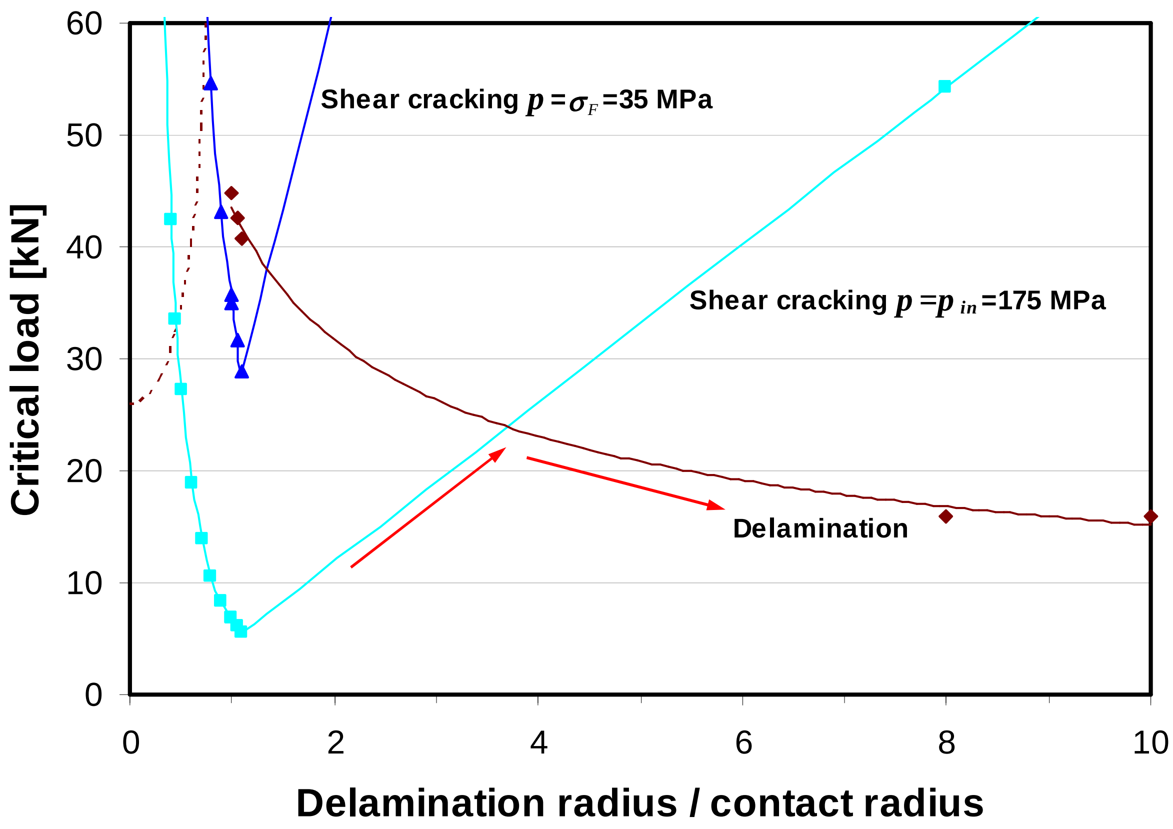


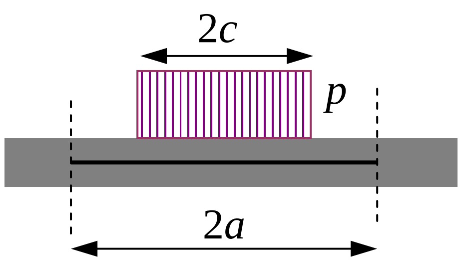
Free particles



$$p = \rho V_{rel}^2 / 2$$

Load for shear cracks and delamination





Distributed load => higher delamination load

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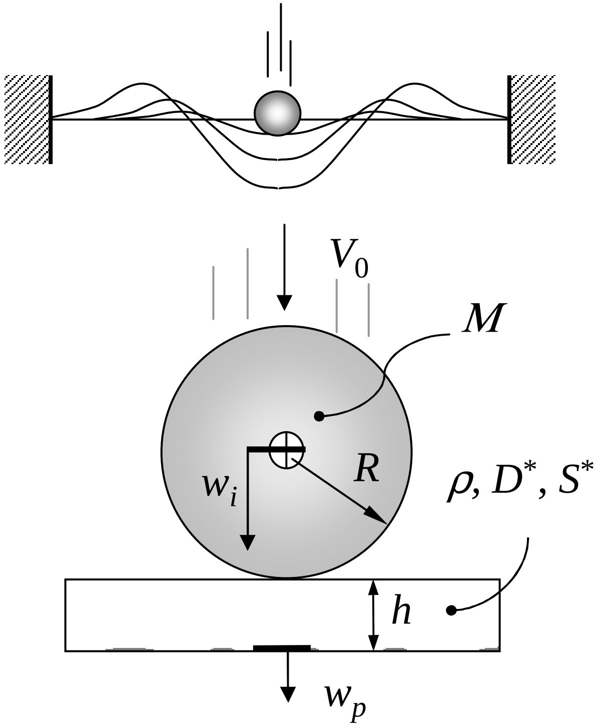
Small mass impact response of plate



$$\text{Indentation:}\quad \alpha \approx \underbrace{V_0 t - \frac{1}{M}\int_0^t F(\tau)(t-\tau)\,d\tau}_{w_i} \underbrace{- \int_0^t \frac{F(\tau)}{8\sqrt{mD^*}}\,d\tau - \int_0^{t-t_0} \frac{F(\tau)\,d\tau}{2\pi S^*(t-\tau)}}_{w_p}$$

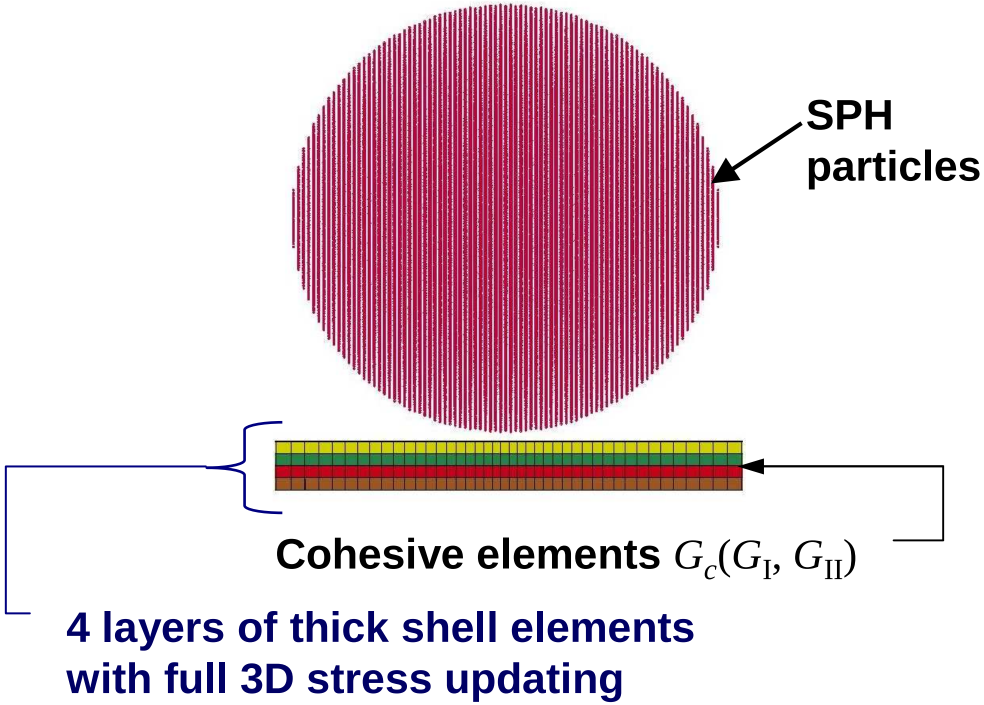
F written as function of α + stepwise solution of F

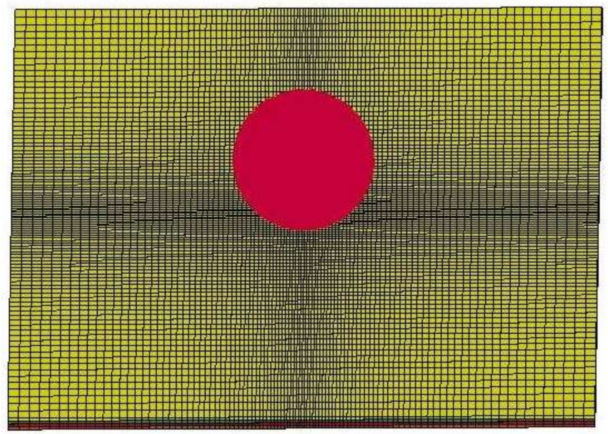
$$m = \rho h$$

$$D^* \approx \sqrt{D_x D_y}\,(1+\eta)/2 \qquad \text{where } \eta = \left(D_{xy} + 2D_t\right)/\sqrt{D_1 D_2}$$

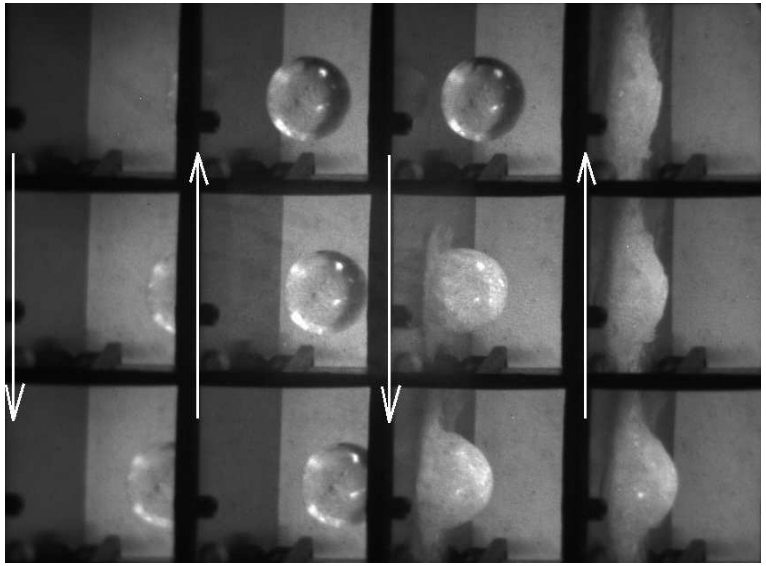
$$S^* \approx \sqrt{A_{zy} A_{zx}} = \sqrt{K_{zy} G_{zy} K_{zx} G_{zx}} \qquad \text{where } K_{ij} \approx 5/6$$

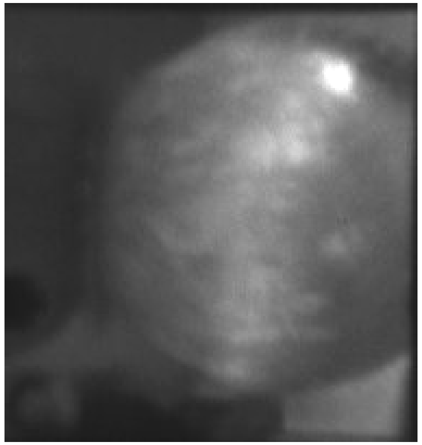
FEM-simulation with LS-Dyna

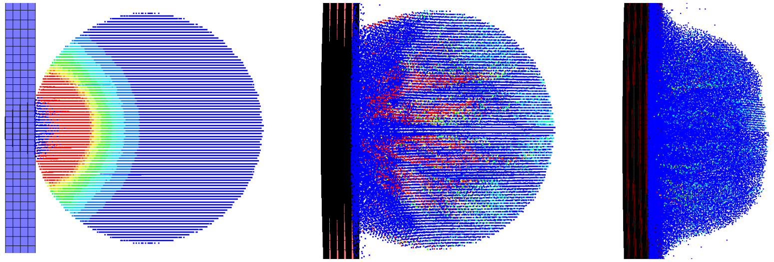




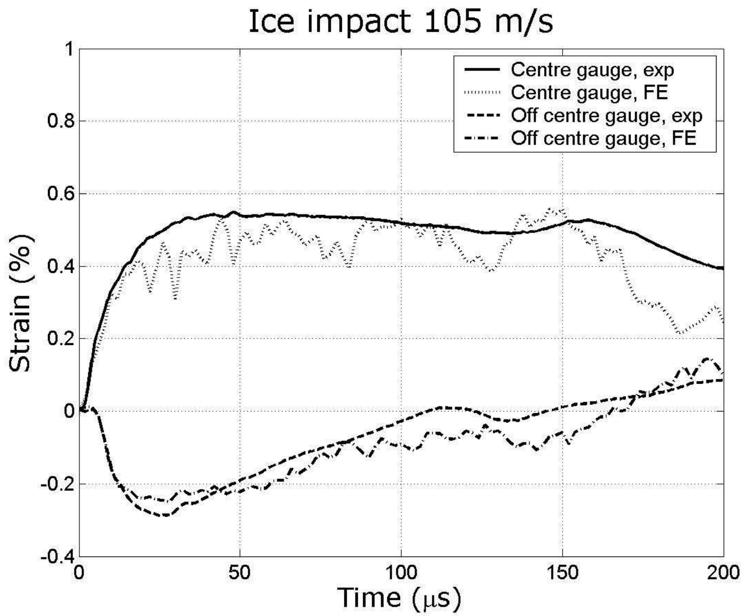
Experiments compared with FEM







In-house ice model after fitting



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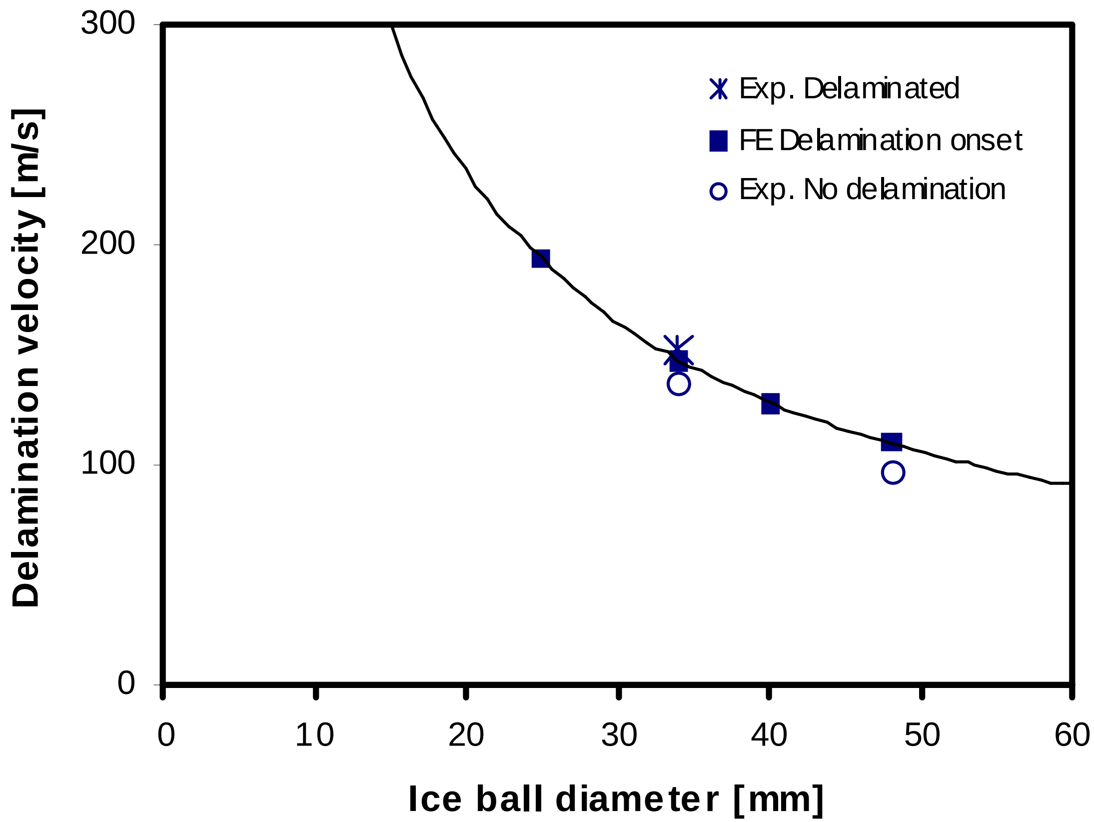
FE prediction of delamination velocity

Example: Ice balls impacting 5.4 mm CFRP NCF



- ***FEM can predict the delamination threshold velocity***

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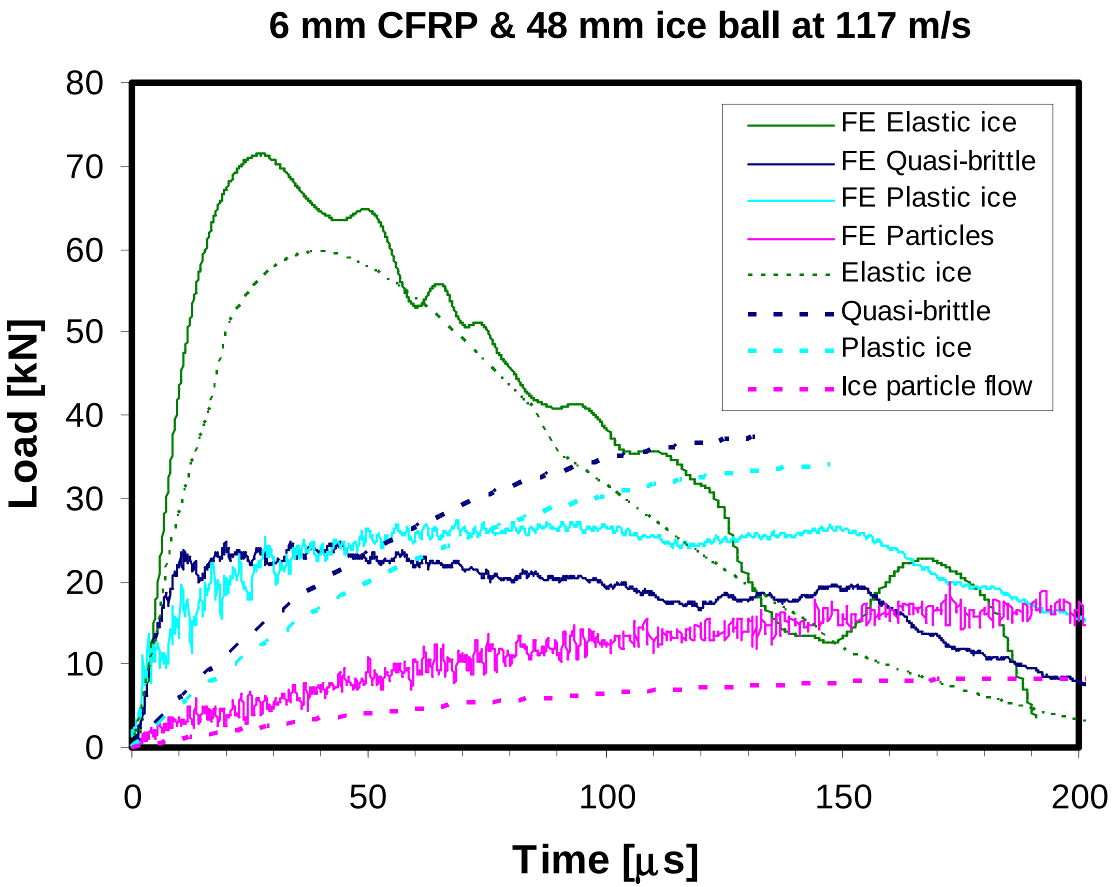
Analytical models compared to FEM



- *FEM predicts much higher loads in the early part of the impact*
- *The free particle model predicts very slow response and low loads*

Contact stresses: FEM vs theory

Stress wave generated in plate

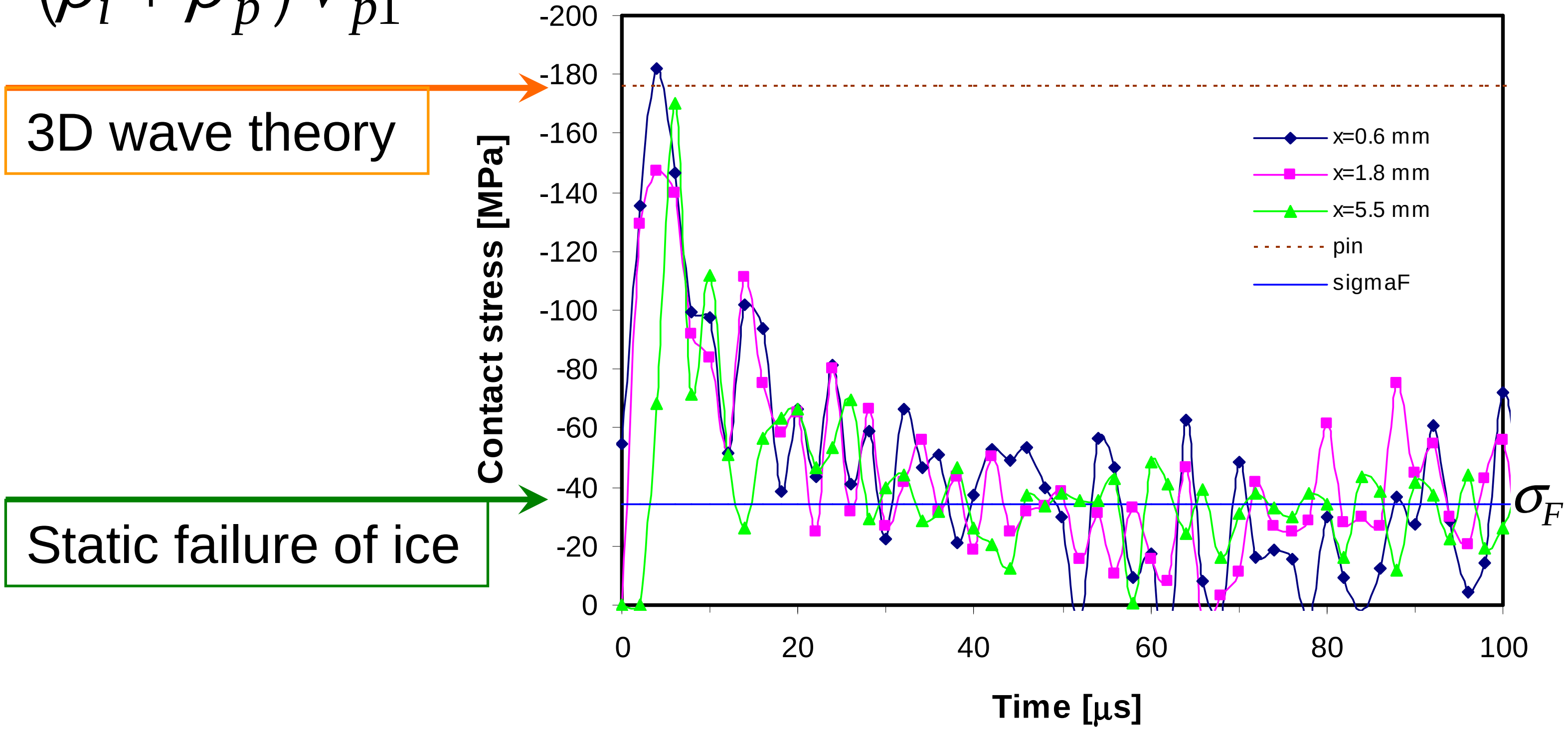
$$\sigma_{pz} = -V_{p1}\sqrt{\rho_p E_{pz}}$$

Conservation of momentum

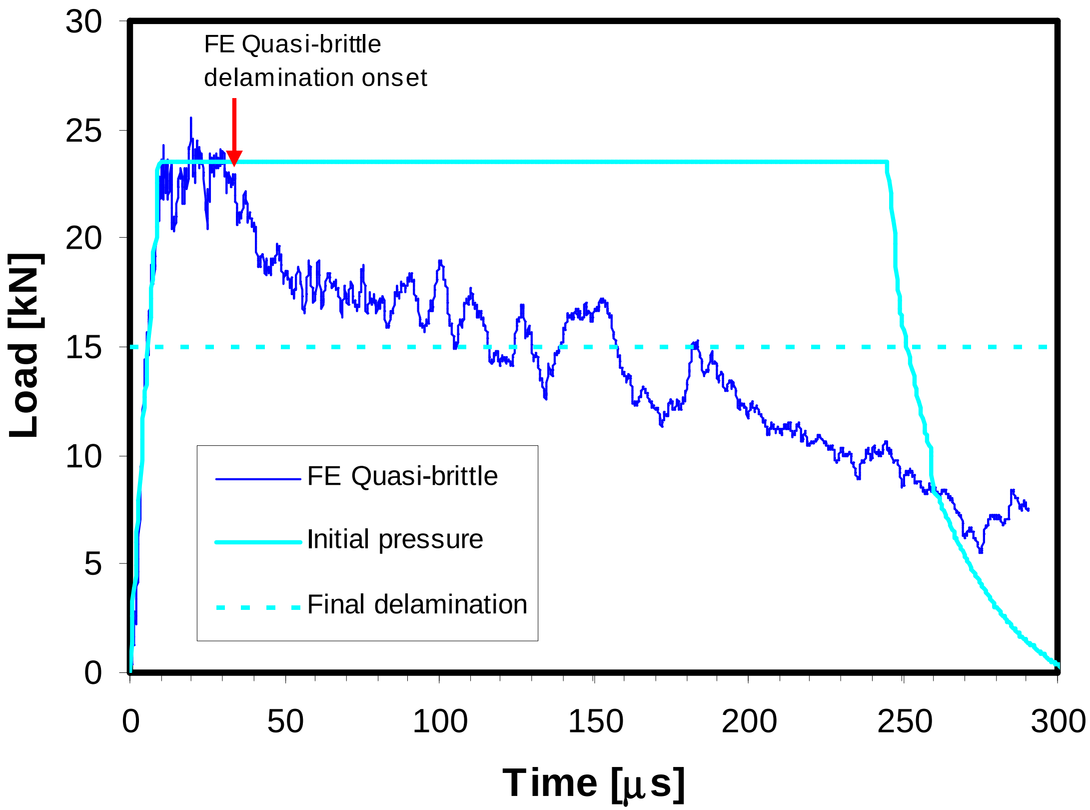
$$\rho_i V_0 = (\rho_i + \rho_p) V_{p1}$$

$$p_{in} = \sqrt{\rho_p E_{pz}}\, V_0 \Big/ \left(1 + \rho_p / \rho_i\right)$$

Semi-brittle ice



Analytical model including peak stress



- *Inclusion of initial peak stress improves agreement with FEM*
- *Decay of contact stress required to get correct load history*

Conclusions

- **Hail impact is a severe threat to composite structures in aircraft**
- **Delaminations are primary damage in NCF laminates**
- **For 3D weaves fibre fracture and kinking also appears**

- **FEM with tuned ice models can predict response and damage onset**
- **3D wave propagation first 50 μs is crucial for damage onset**
- **Analytical models must be adjusted to consider initial stress peak**

Acknowledgement

Our work on hail impact has been funded by:

- **Swerea Competence Development Funds**
- **Volvo Aero Corporation**
- **Project FP6-VITAL**

Swerea SICOMP (Swedish Institute of Composites)

- a member of the Swerea Group

Thanks for listening!

Questions?