Flying bits and their fundaments

Basic research on composite materials and processing
Or: how industry can help science and vice versa

Remko Akkerman

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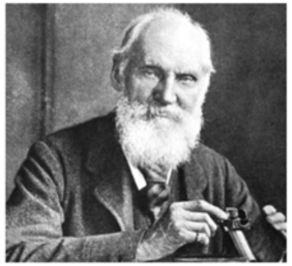
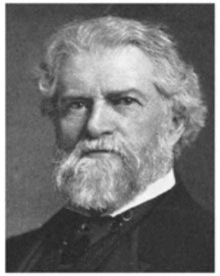
Science and Technology



- I have not the smallest molecule of faith in aerial navigation other than ballooning, or of the expectation of good results from any of the trials we heard of. So you will understand that I would not care to be a member of the Aeronautical Society.

— Lord Kelvin, replying to an invitation from Major B. F. S. Baden-Powell to join the Royal Aeronautical Society, 1896.



- Flight by machines heavier than air is unpractical and insignificant, if not utterly impossible.

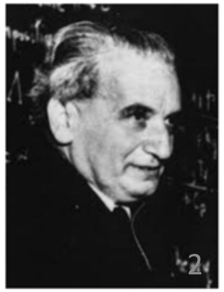
—Simon Newcomb, 1902.

- All attempts at artificial aviation are not only dangerous to human life, but foredoomed to failure from the engineering standpoint.

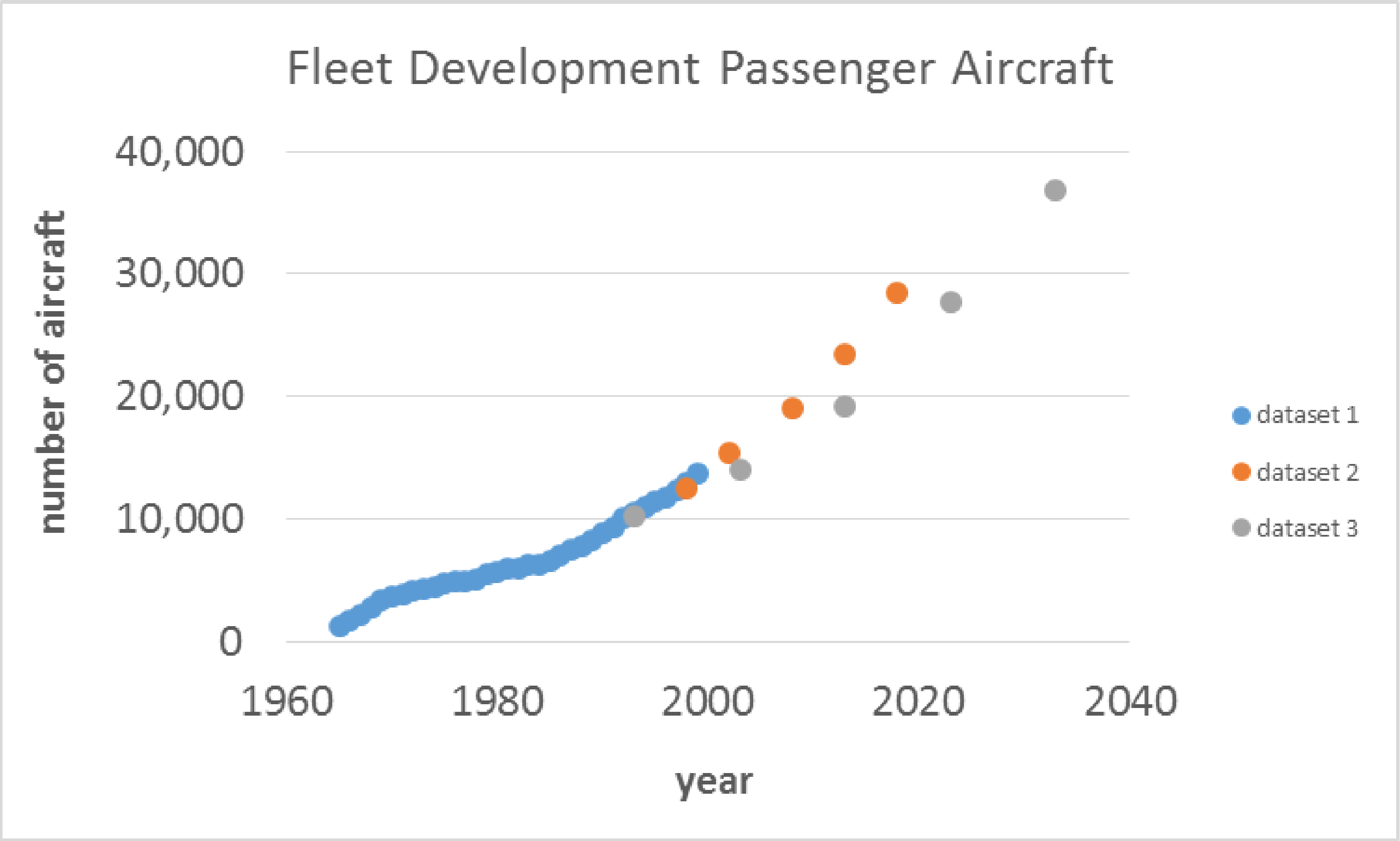
— *Engineering Editor,* The Times*, 1906.*

- The scientist describes what is; the engineer creates what never was.

- Theodore von Kármán



Meanwhile…

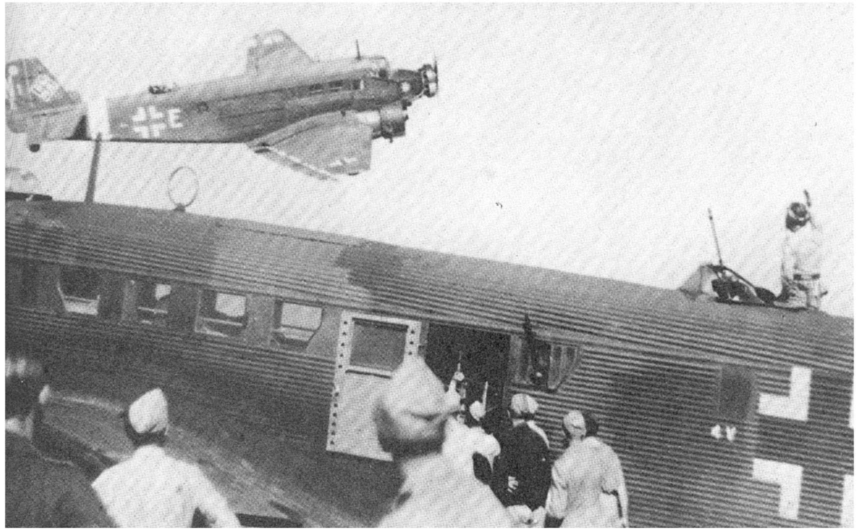


Fleet Development Passenger Aircraft
40,000
30,000
20,000
10,000
0
number of aircraft
1960
1980
2000
2020
2040
year
dataset 1
dataset 2
dataset 3

Materials?

- Wood & canvas
- Plywood
- Iron & steel ► very thin plate

plywood on the
Fokker FVII-B (1929)



corrugated iron on the
Junkers JU 52/3m (1932)

Novel Materials

- Aluminium
- Titanium
- Composites
- Thermoplastic Aromatic Polymer Composites

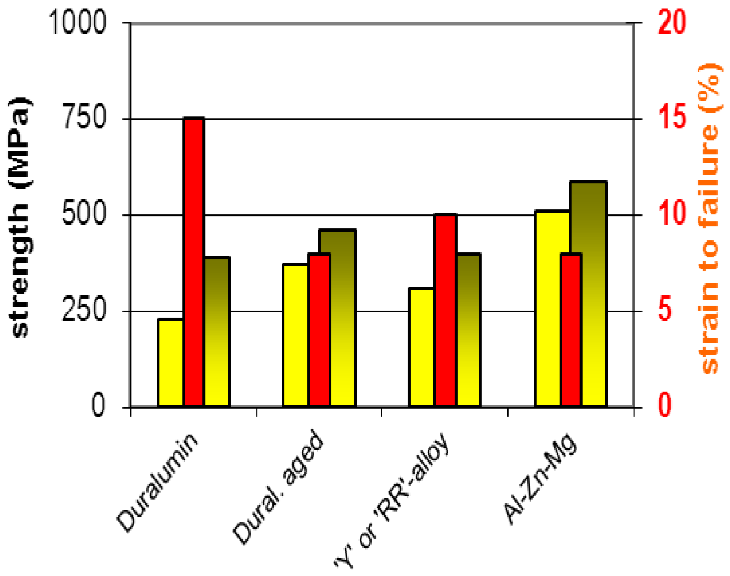
Aluminium Alloys

- evolved from 1909 ("Duralumin")
  copper + magnesium + quenching from 480ºC
  ageing since 1934
- structural application since 1917 (Junkers)
- dominant material for aerostructures from the late 1930s

Aluminium Alloys

Food for science!

- Thermal treatment,
- Tune the alloy to the loading,
- Fracture mechanics,
- …



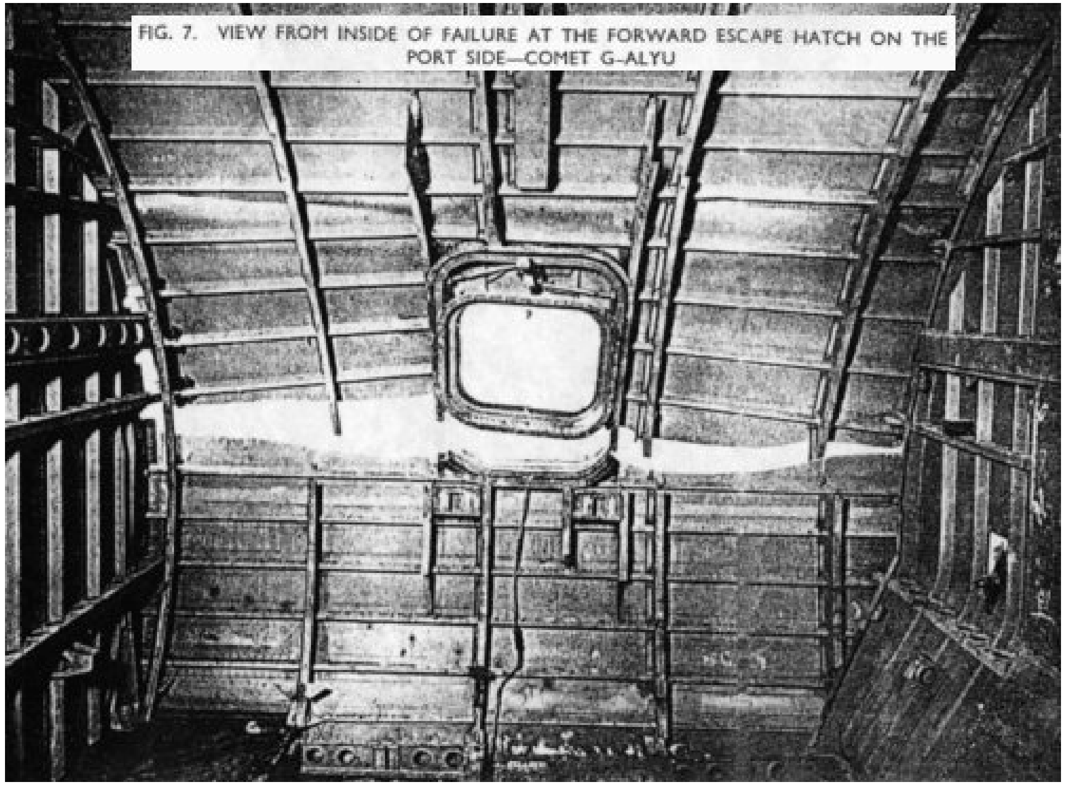
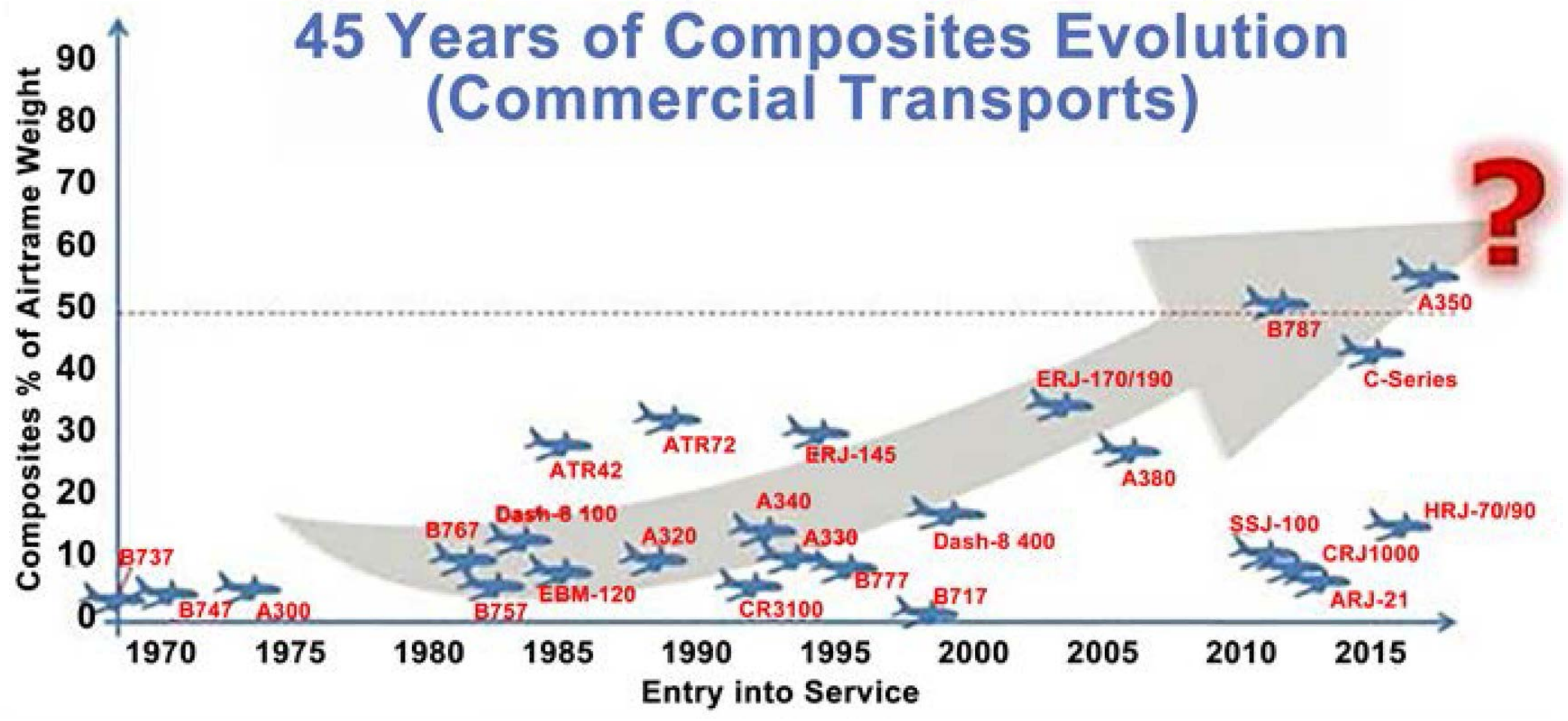


FIG. 7. VIEW FROM INSIDE OF FAILURE AT THE FORWARD ESCAPE HATCH ON THE PORT SIDE—COMET G-ALYU

Composites



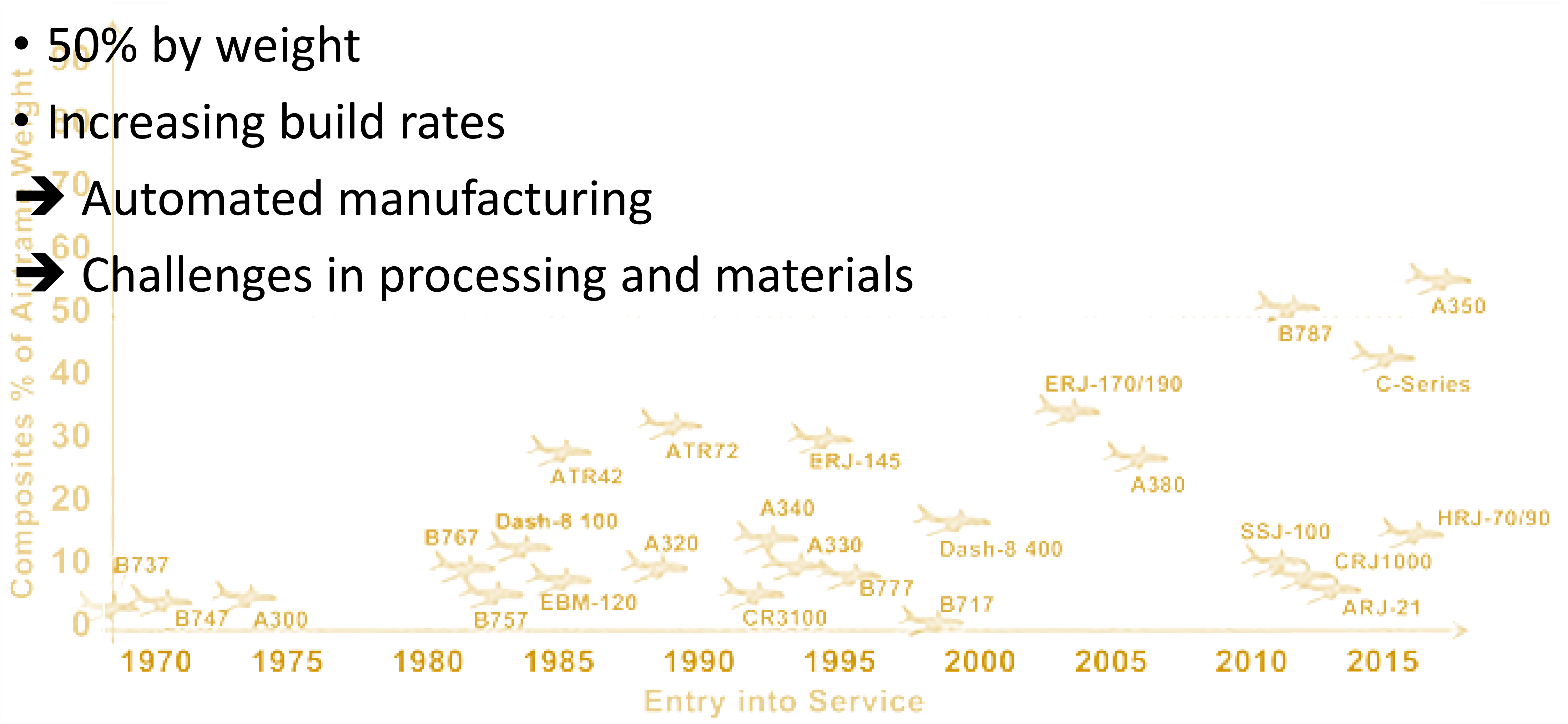
45 Years of Composites Evolution
(Commercial Transports)
Composites % of Airtrame Weight
90
80
70
60
50
40
30
20
10
0
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Entry into Service
B737
B747
A300
B767
B757
Dash-8 100
EBM-120
ATR42
ATR72
A320
A340
A330
CR3100
ERJ-145
B777
B717
Dash-8 400
ERJ-170/190
A380
B787
A350
C-Series
SSJ-100
CRJ1000
ARJ-21
HRJ-70/90
?

Composites

- 50% by weight
- Increasing build rates

➔ Automated manufacturing

➔ Challenges in processing and materials

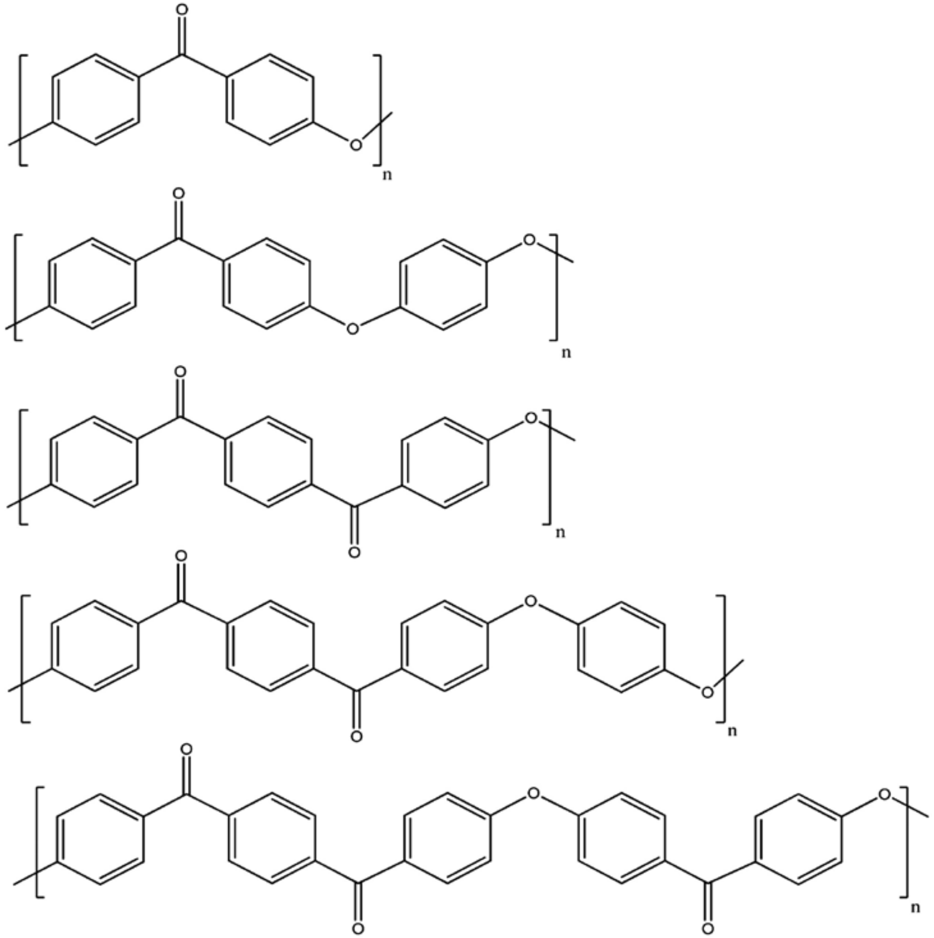


Thermoplastic Composites (TPCs)

- Light weight
- High toughness
- No chemistry during part manufacturing
- Excellent fire, smoke and toxicity performance
- Solvent resistant
- Corrosion resistant
- Infinite shelf life
- Suited for recycling
- Suited for welding (no adhesives needed)
- Rapid processing (only heating and cooling)
- ….
- For large series production

Thermoplastic Composites (TPCs)

- PAEKs discovered early 1960s (ICI, DuPont)
- 1982 Victrex PEEK patented (polyether synthesis) T_m=343°C, T_g=143°C
- 1982 thermoplastic prepreg manufacturing patented → Carbon/PEEK, APC-2 Aromatic Polymer Composite
- Superior properties!



PEK

PEEK

PEKK

PEEKK

PEKEKK

Thermoplastic Composites (TPCs)

- Light weight
- High toughness
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- Excellent fire, smoke and toxicity performance
- Solvent resistant
- Corrosion resistant
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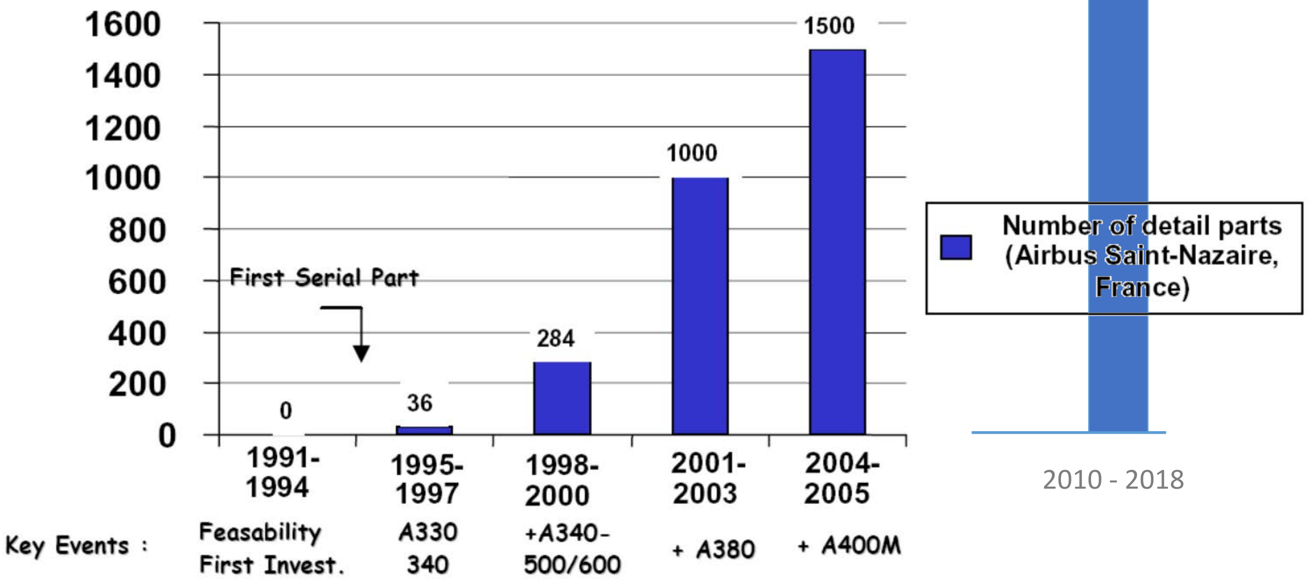
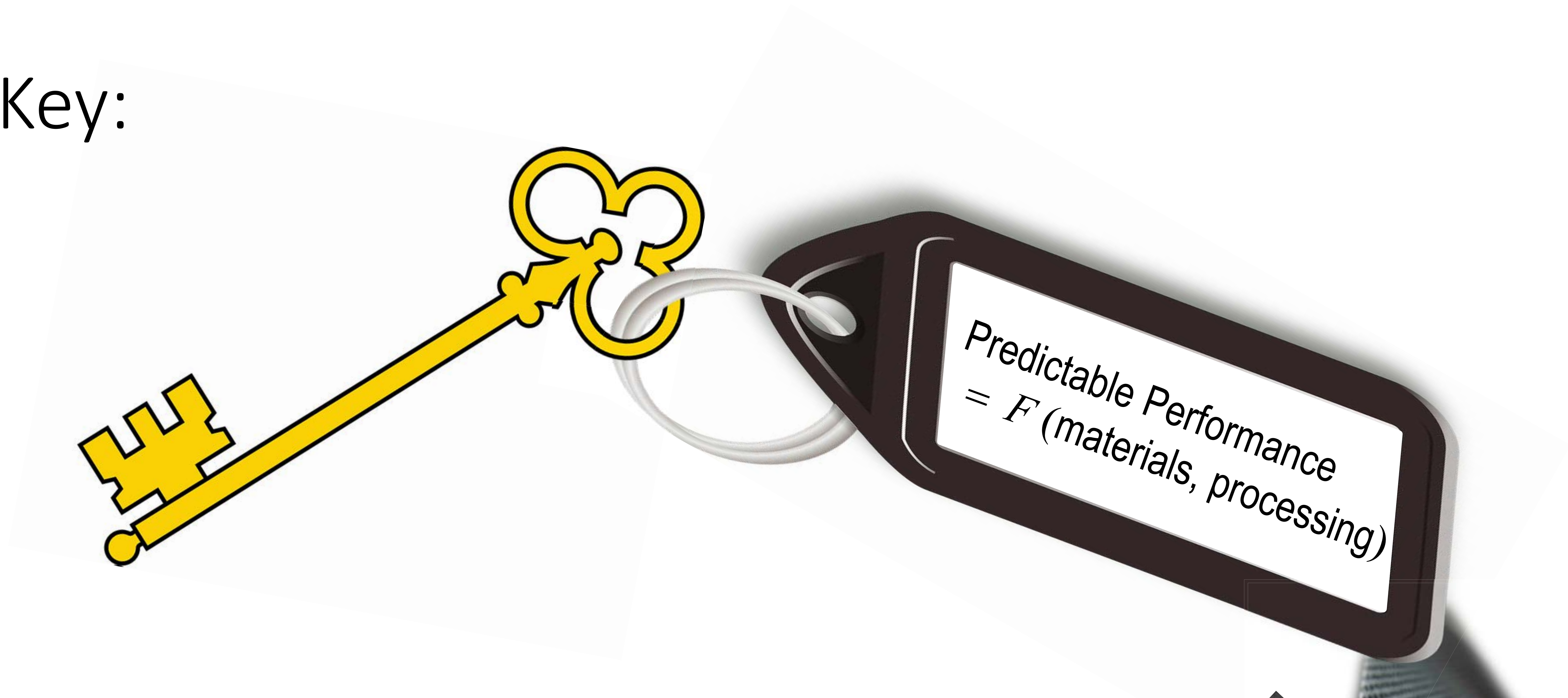
- Suited for recycling
- Suited for weldin… …dhesives needed)
- Ra… …ing (only heating and cooling)
- ….
- For large series production

- A long standing promise for the future

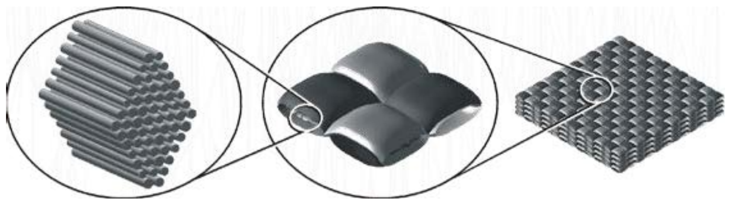
Aerospace Applications of TPCs

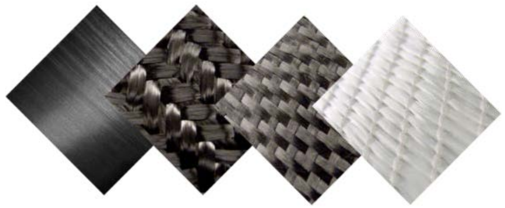


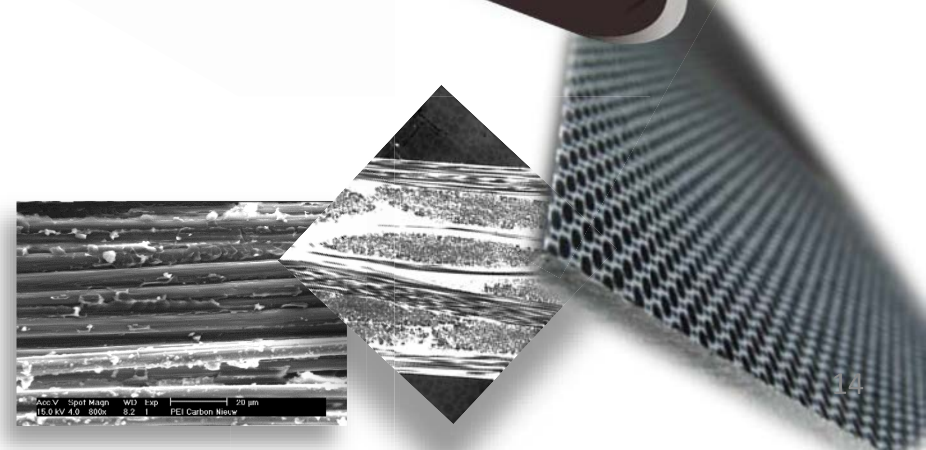
Key:



- $F(m,p)$ determined by structure (multiscale)

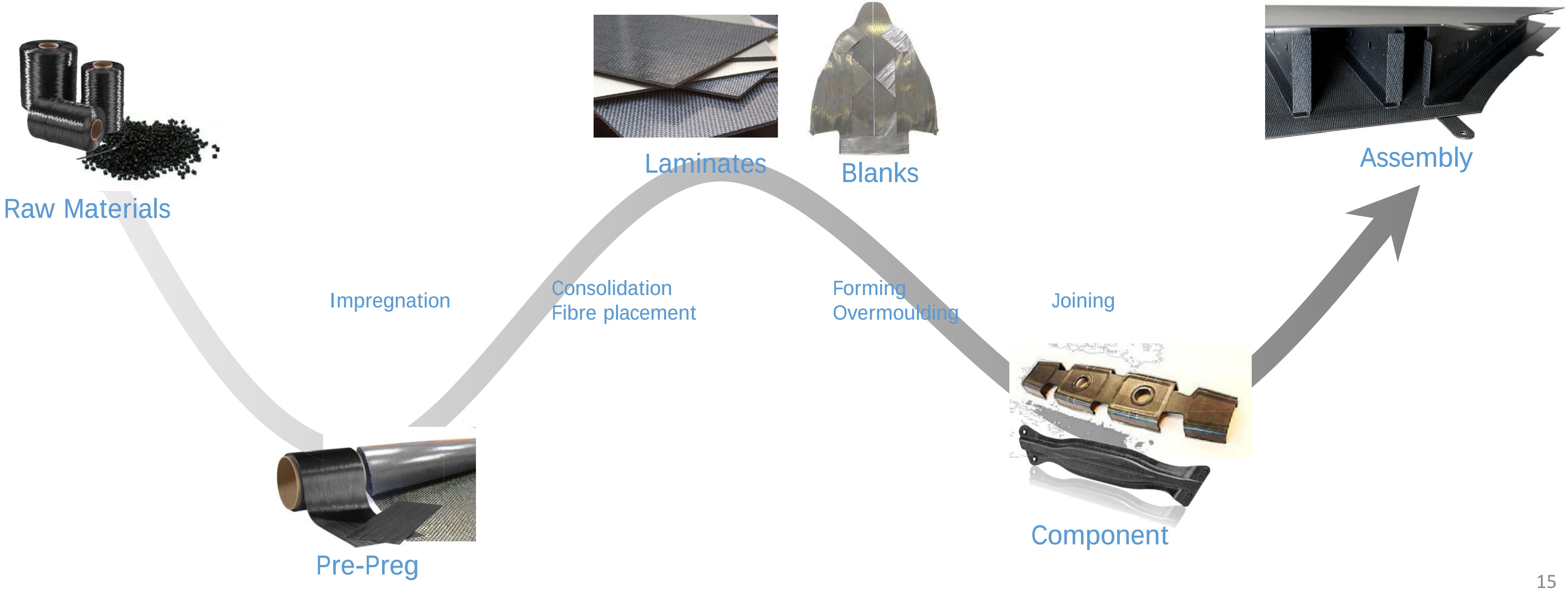






Key

- The structure is determined by the processing history



Evolving state and structure

- Fibre orientation and distribution
- Consolidation (void generation, migration and dissolution; lamination/healing)
- Crystallinity
- Degradation (matrix, fibre, interphase)
- Residual stresses
- ….

… in a PPP *

TPRC

BOEING, TENCATE, Fokker, UNIVERSITY OF TWENTE., SAXION, Alcoa Fastening Systems & Rings, ALCOA, victrex

Tier 1 Members

dtc, CORIOLIS composites, ANIFORM VIRTUAL FORMING, DAHER, TU Delft Delft University of Technology, KVE COMPOSITES GROUP, webindustries Listen. Create. Deliver.

Tier 2 Members

italmatic, UBE, BRANSON

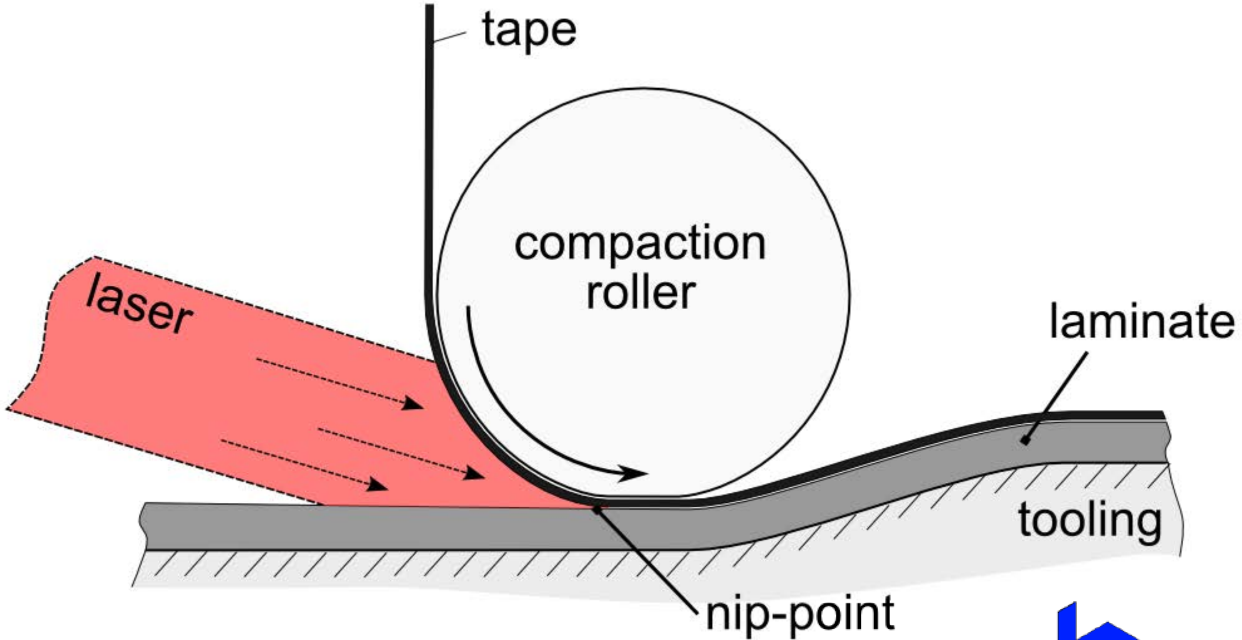
Sponsors

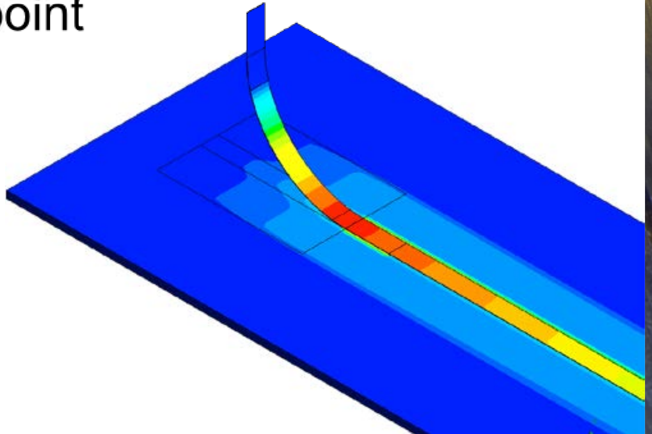
provincie Overijssel, oost nv, Kennispark Twente, regio Twente

Support, financial and in-kind

*) *Public Private Partnership*

Examples - (1) Laser Assisted Fibre Placement



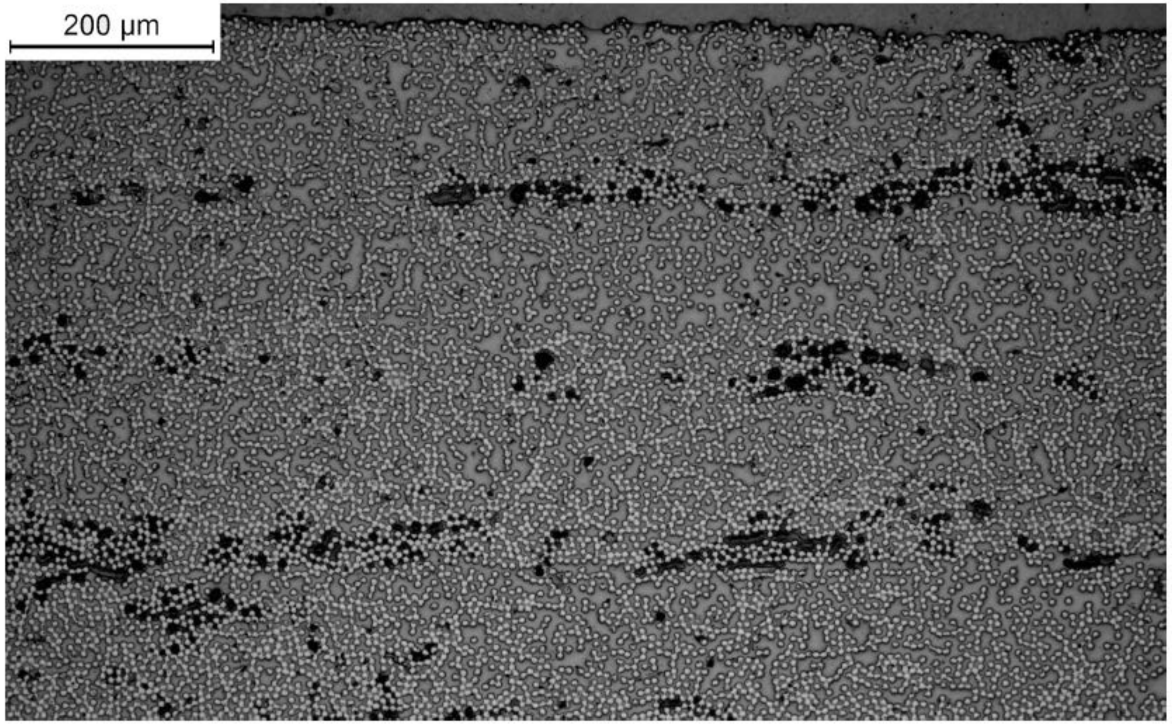


Examples - (1) Laser Assisted Fibre Placement

Challenges:

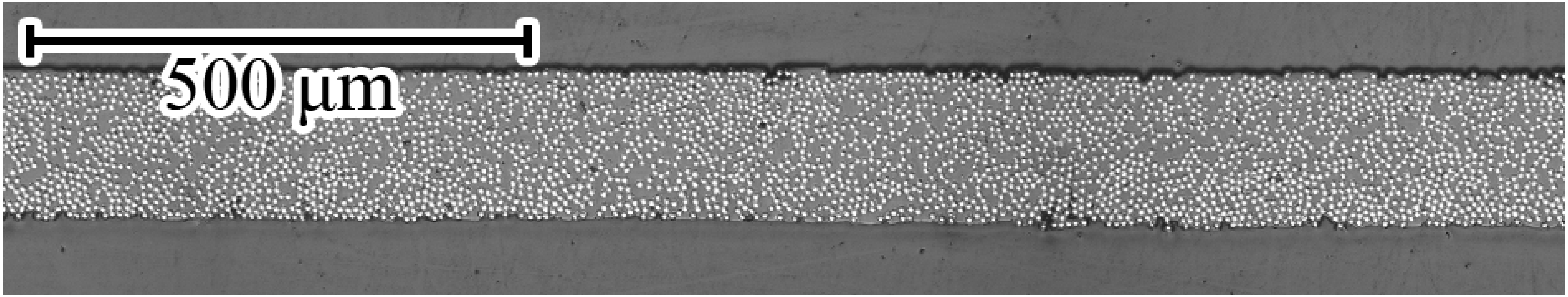
- Heating / degradation / cooling
- Air entrapment
- Deconsolidation
- Intimate contact
- Healing

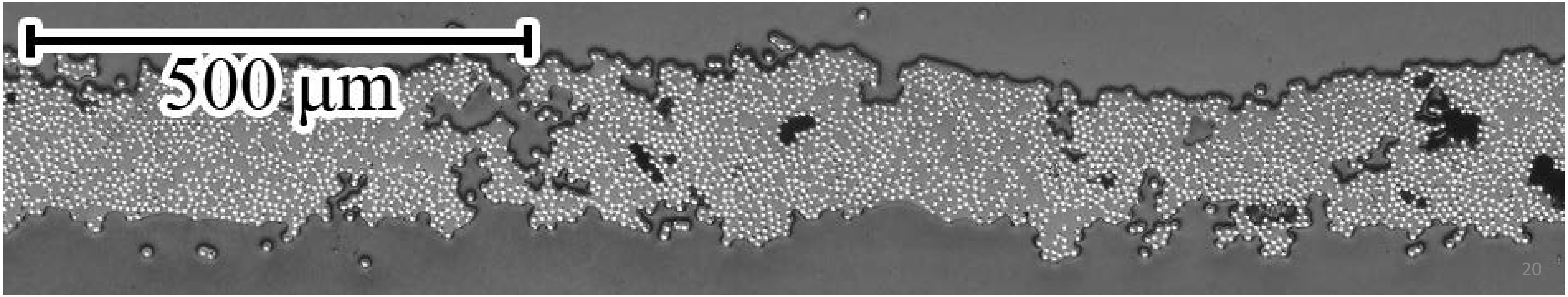
within O(1 ms)!



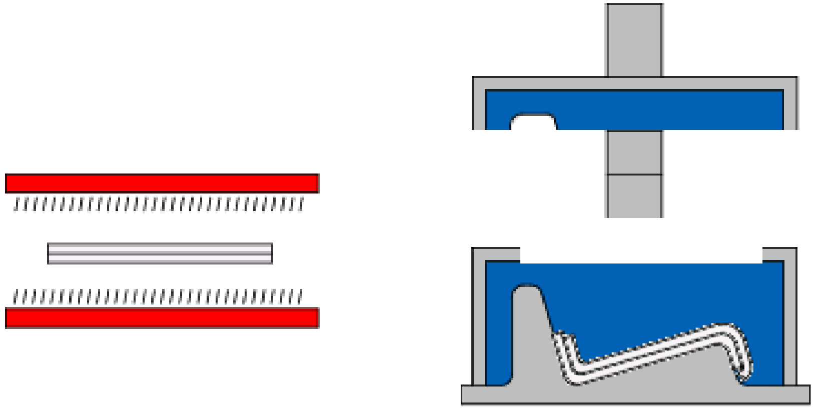
AFP (∼ 4% voids)

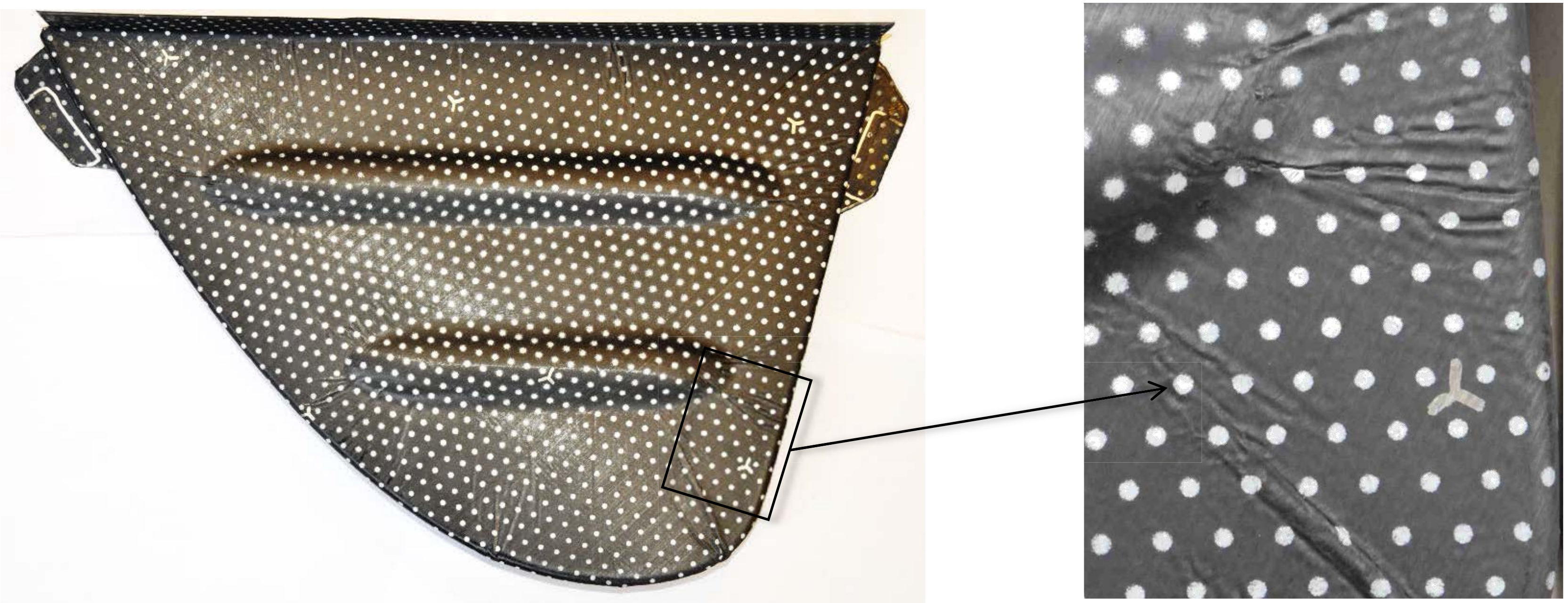
Deconsolidation of a single tape





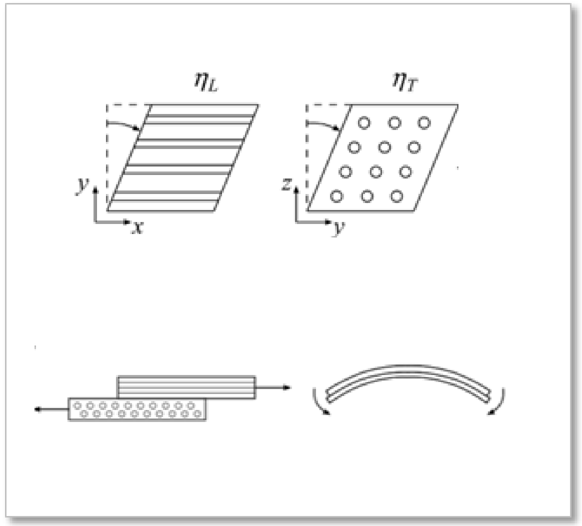
Examples - (2) Composites Forming

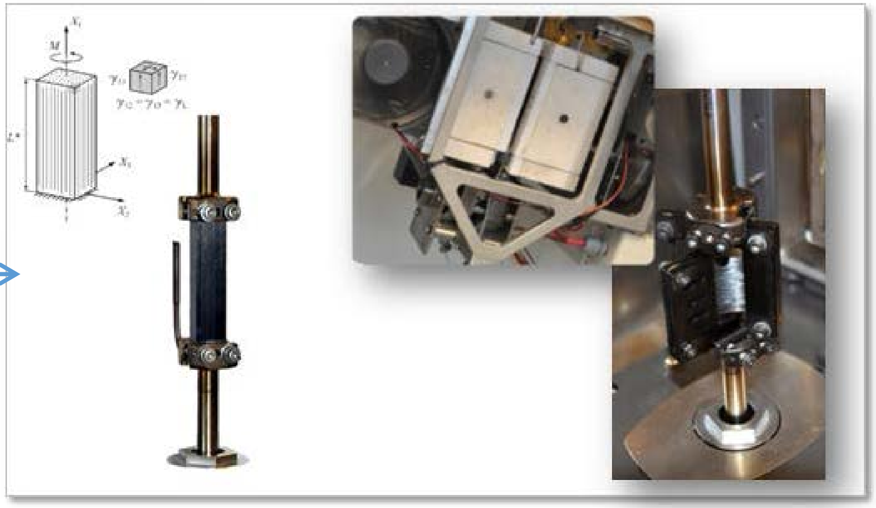


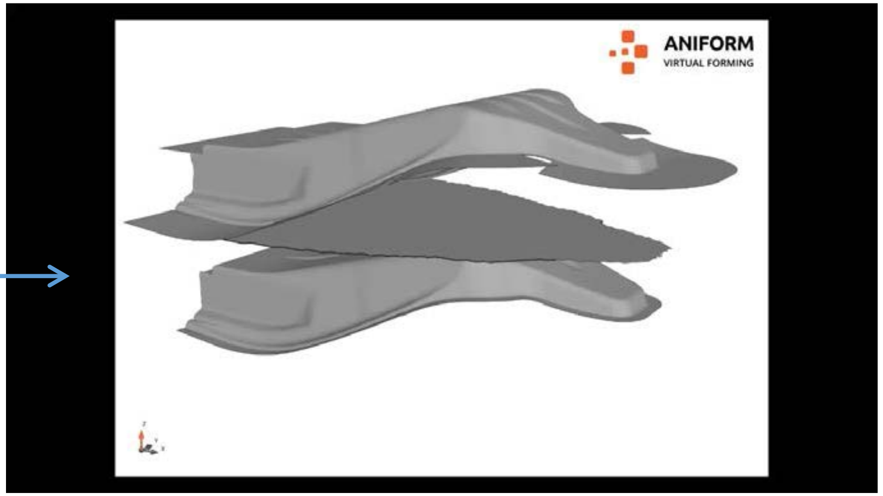


Examples - (2) Composites Forming

Multi-scale, multi-phase







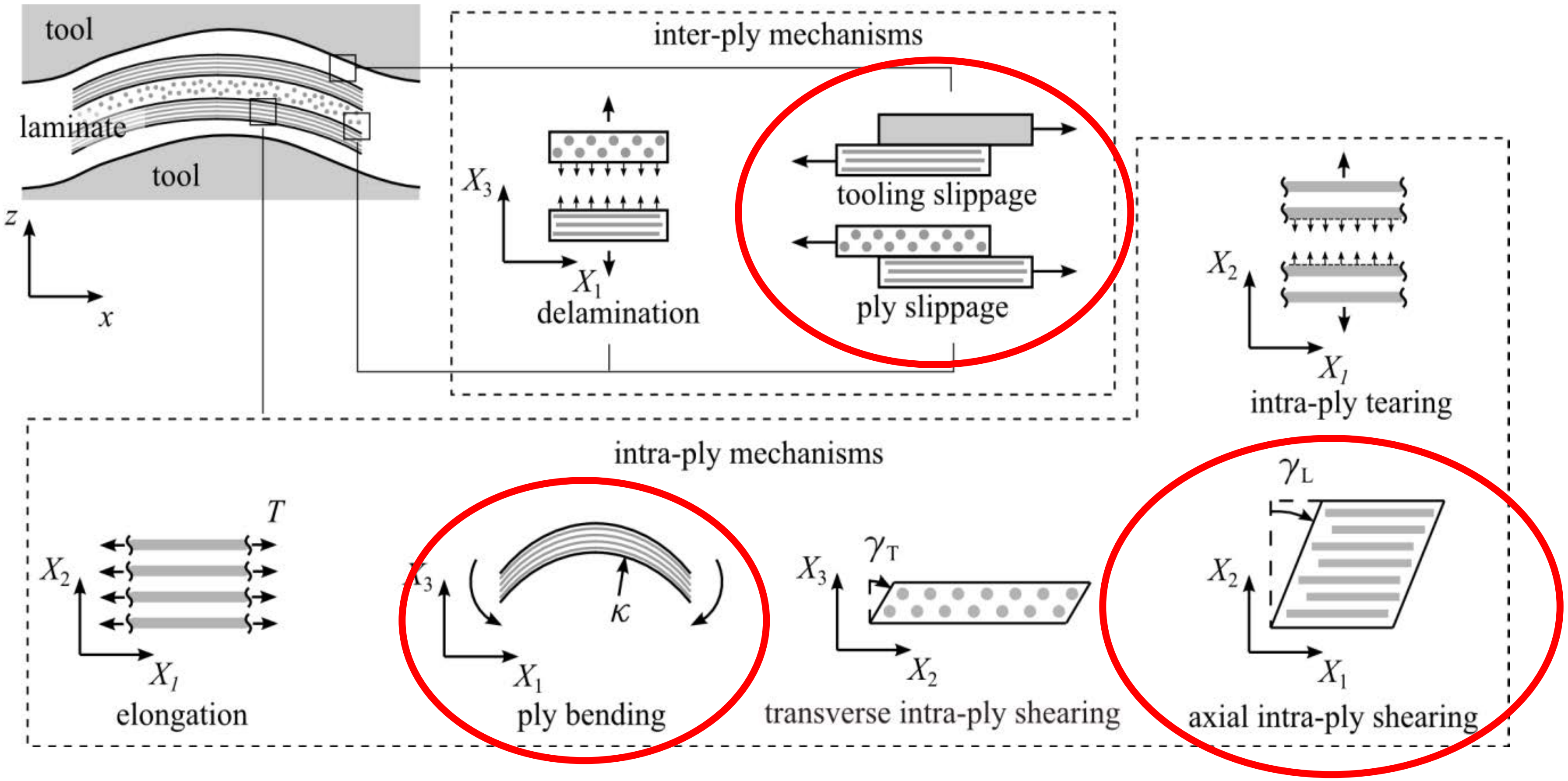
Deformation mechanisms

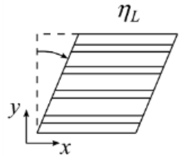
Develop characterizations tests

Develop CAE tools

Deformation Mechanisms

- UD laminates

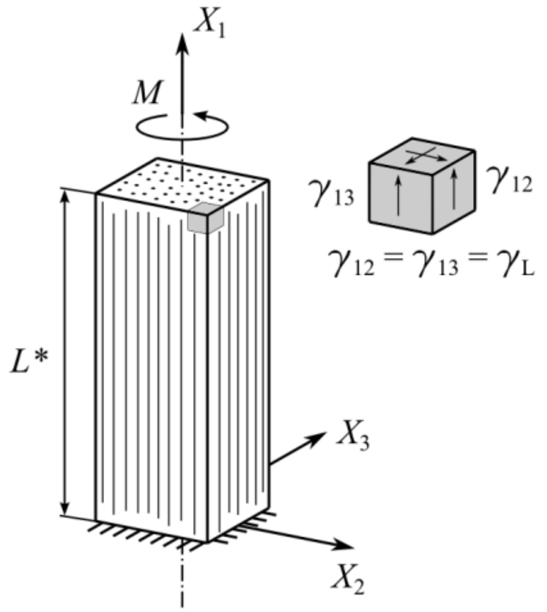


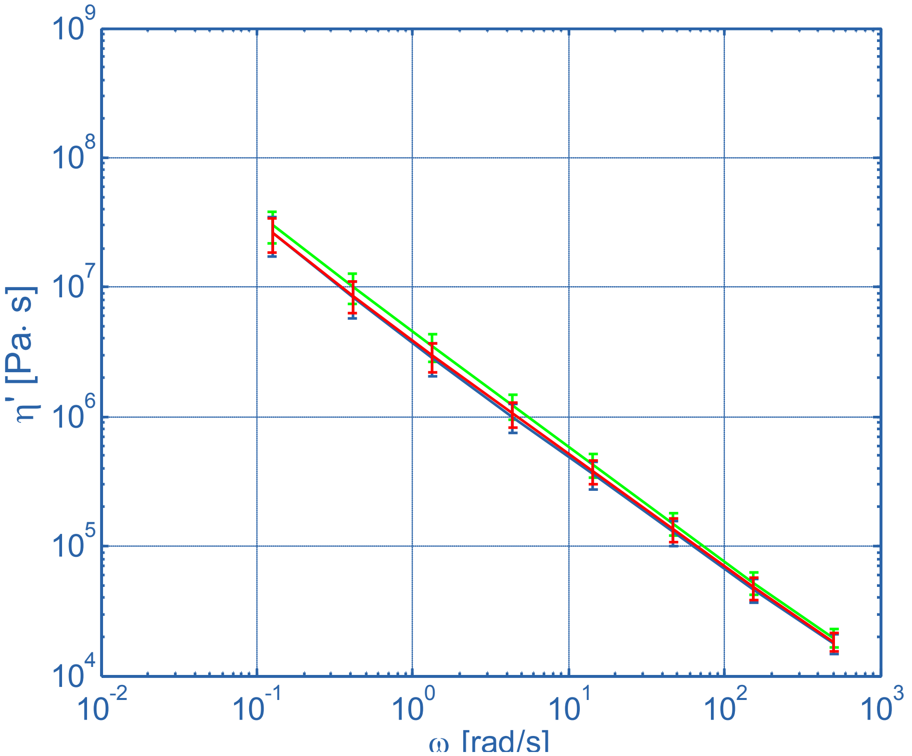


A. Intra-ply Behaviour

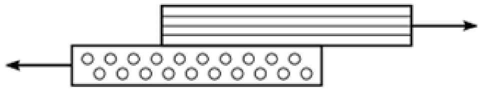
- CHARACTERISATION & CONSTITUTIVE MODEL

UD shear testing: torsion bar (rheometer)



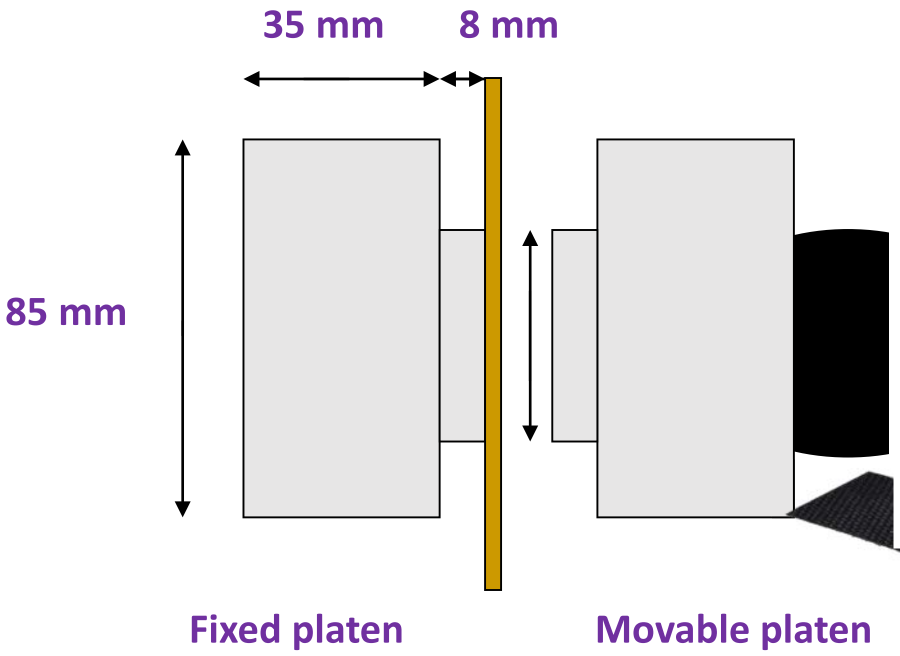


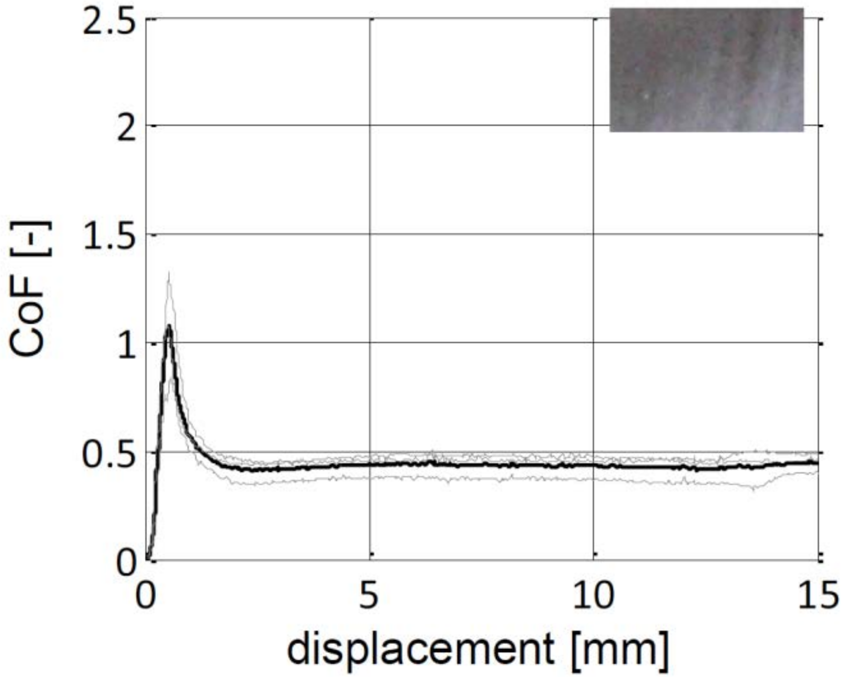
Cetex Thermo-Lite TC1200

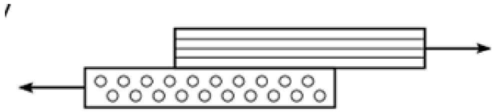


B. Inter-ply Behaviour

- CHARACTERISATION & CONSTITUTIVE MODEL







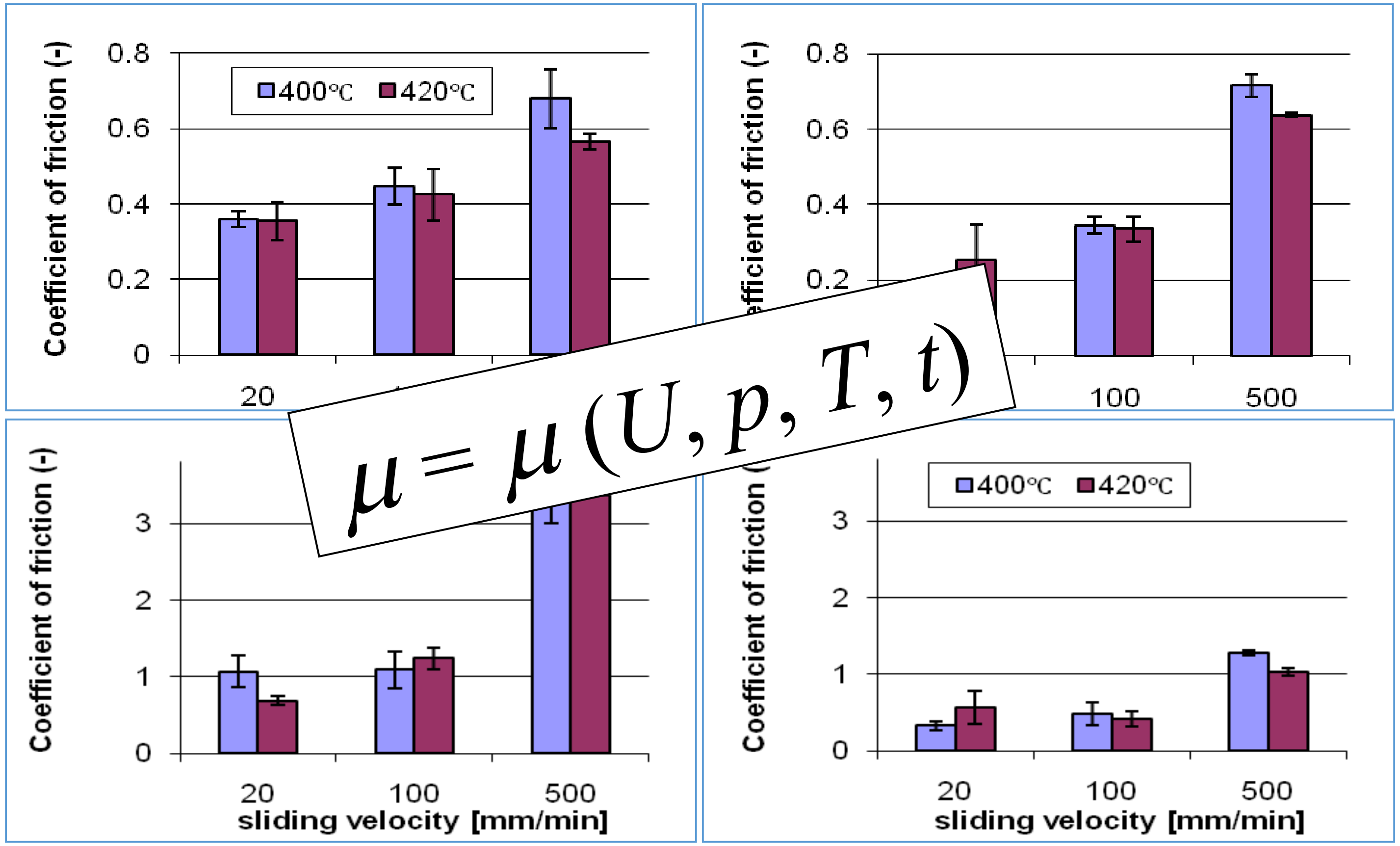
B. Inter-ply Behaviour

- Ten Cate UD C/PEEK – tool/ply

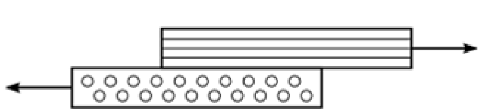
P=10 kPa | P=50 kPa

Steady state

Peak



$$\mu = \mu\,(U, p, T, t)$$



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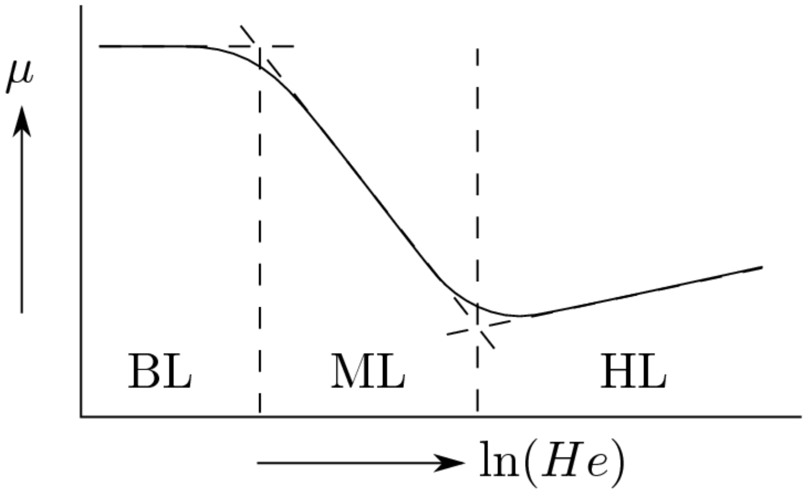
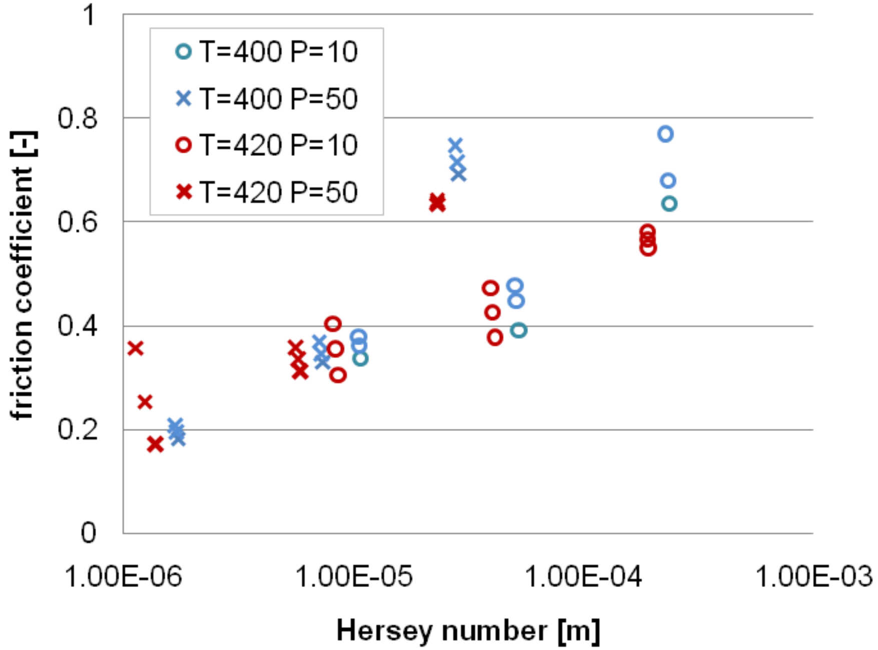
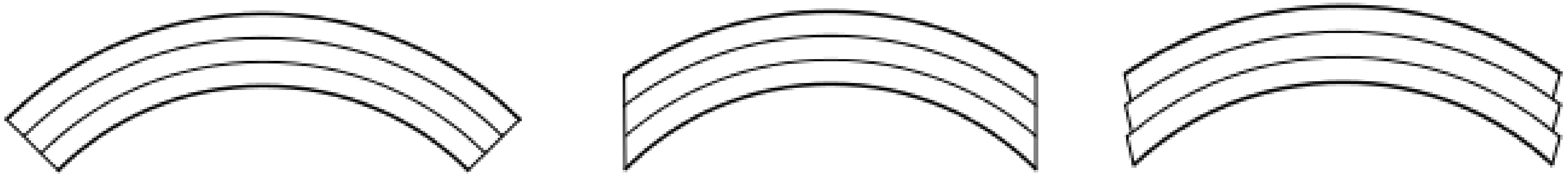


$$He = \frac{\eta U}{p}$$

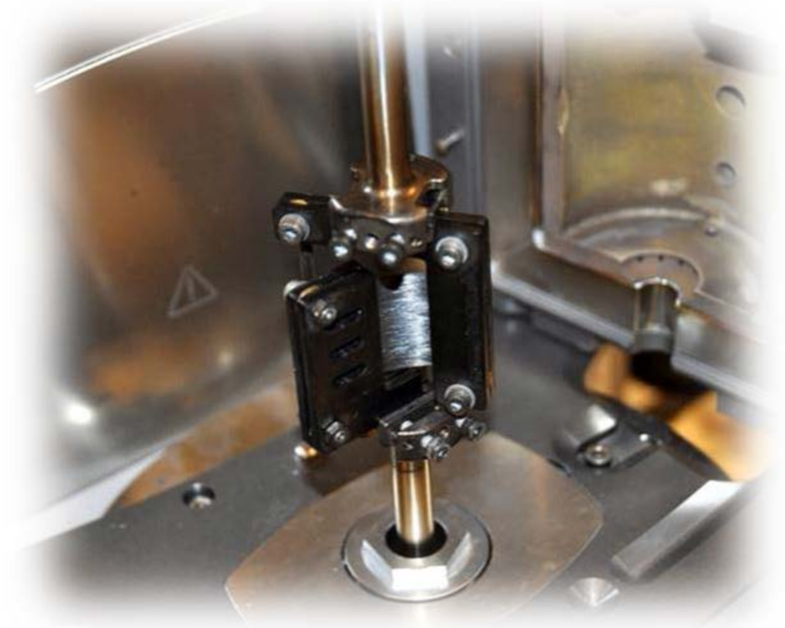


Not the ideal Stribeck curve
/ hydrodynamic lubrication

C. Bending

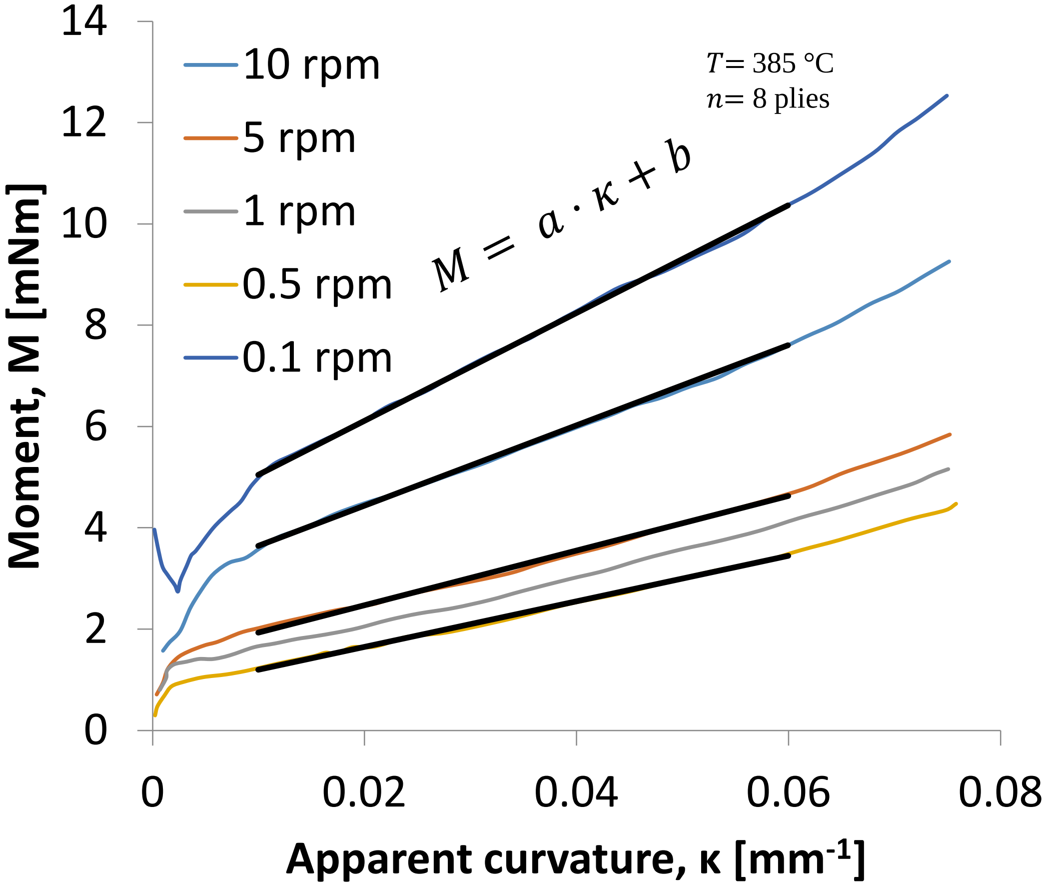


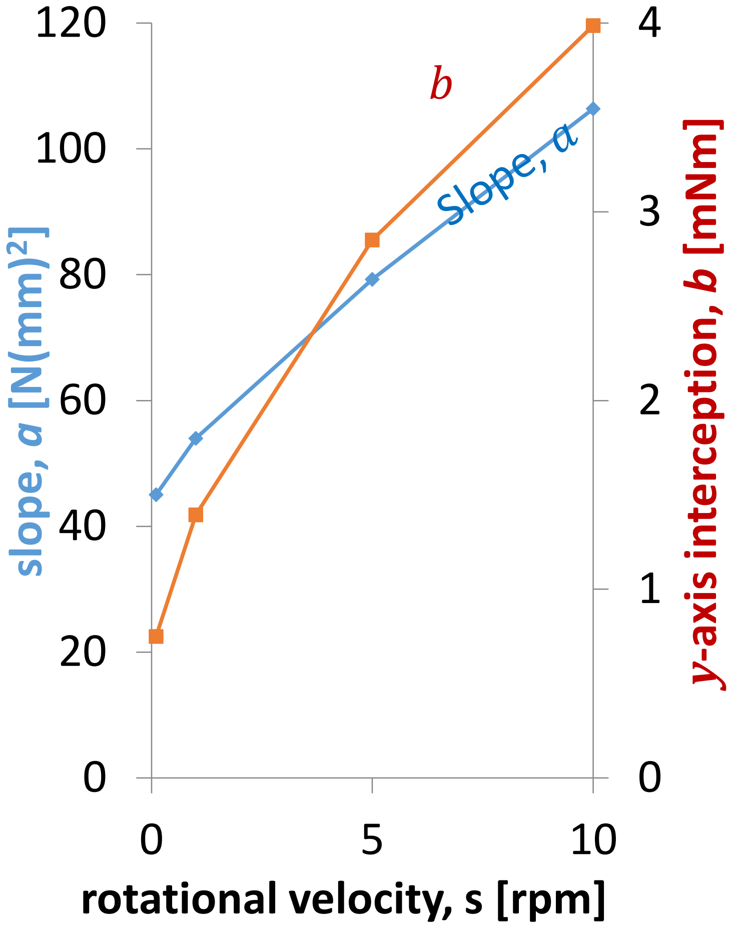
Kirchhoff … transverse shear … both …?



C. Bending Characterization

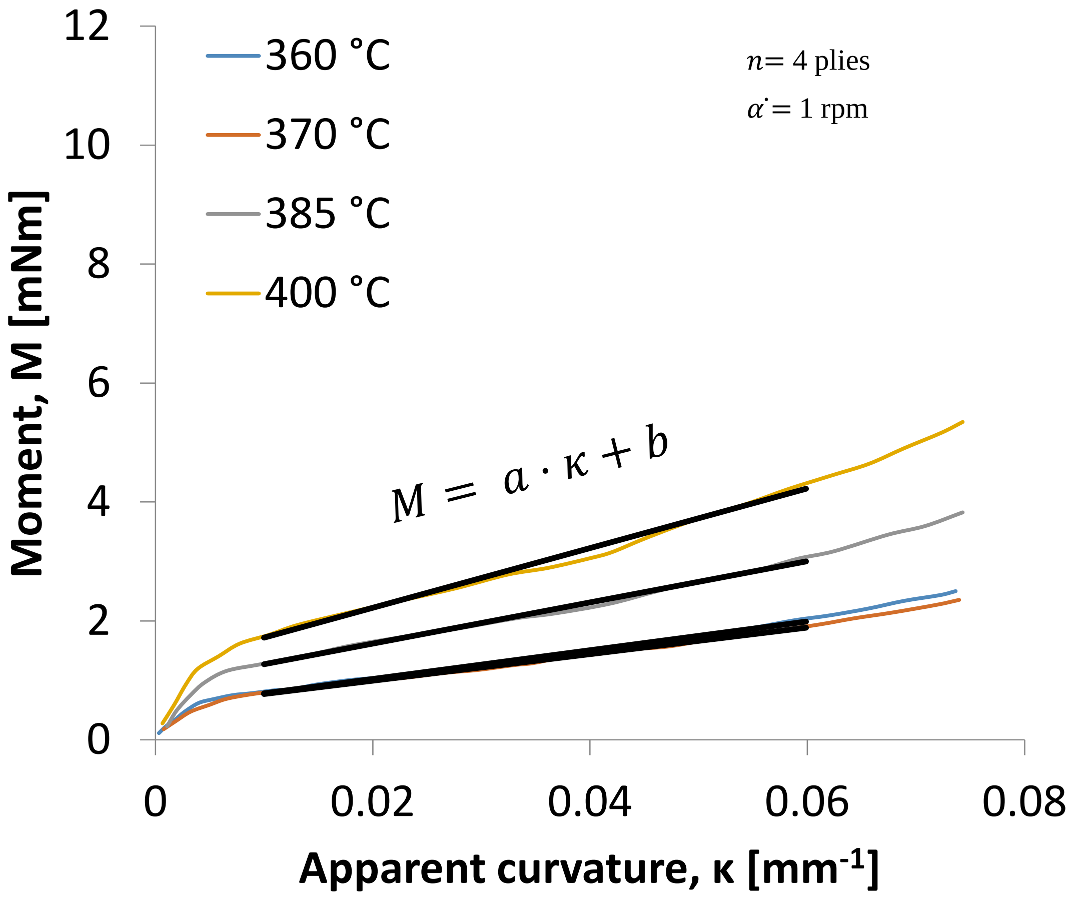
- Rate variation (UD carbon/PEEK)

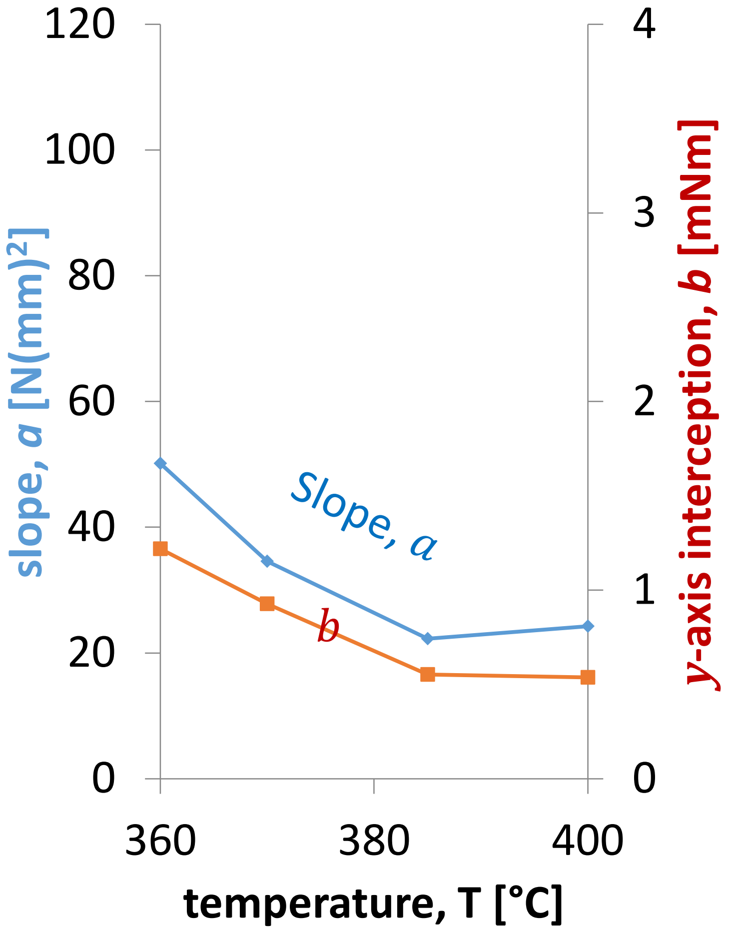




C. Bending Characterization

- Temperature variation





Implementation

Numerical aspects:

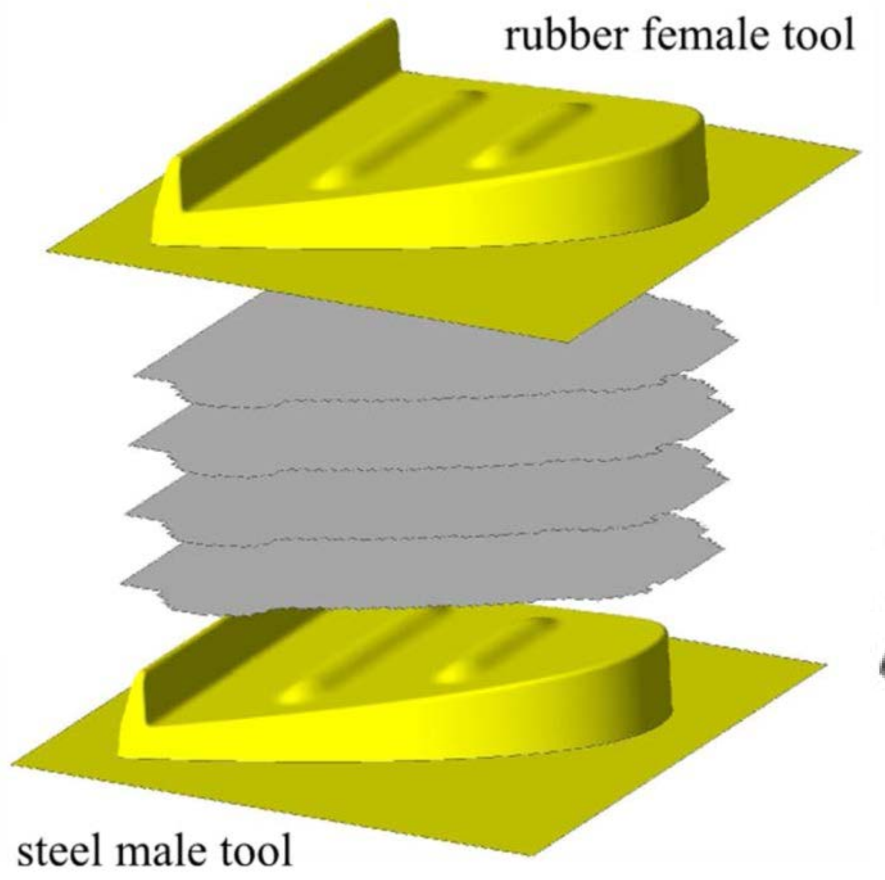
- Very high anisotropy
- Highly Sensitive to Fibre Directions –
  Use exact (non linearised) strain definition
- Shear Locking for non-aligned meshes
- 'Stiff systems' –
  Consistent Tangent Operators to prevent divergence

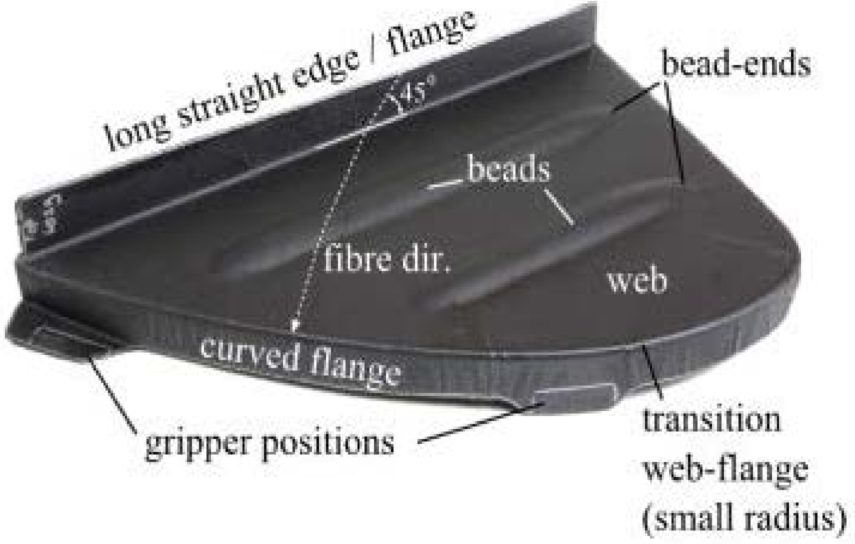
Multi-layer approach

- With discrete layers
- Including bending, intra- & inter-ply behaviour

ANiFORM
VIRTUAL FORMING

Application & Results





Application & Results

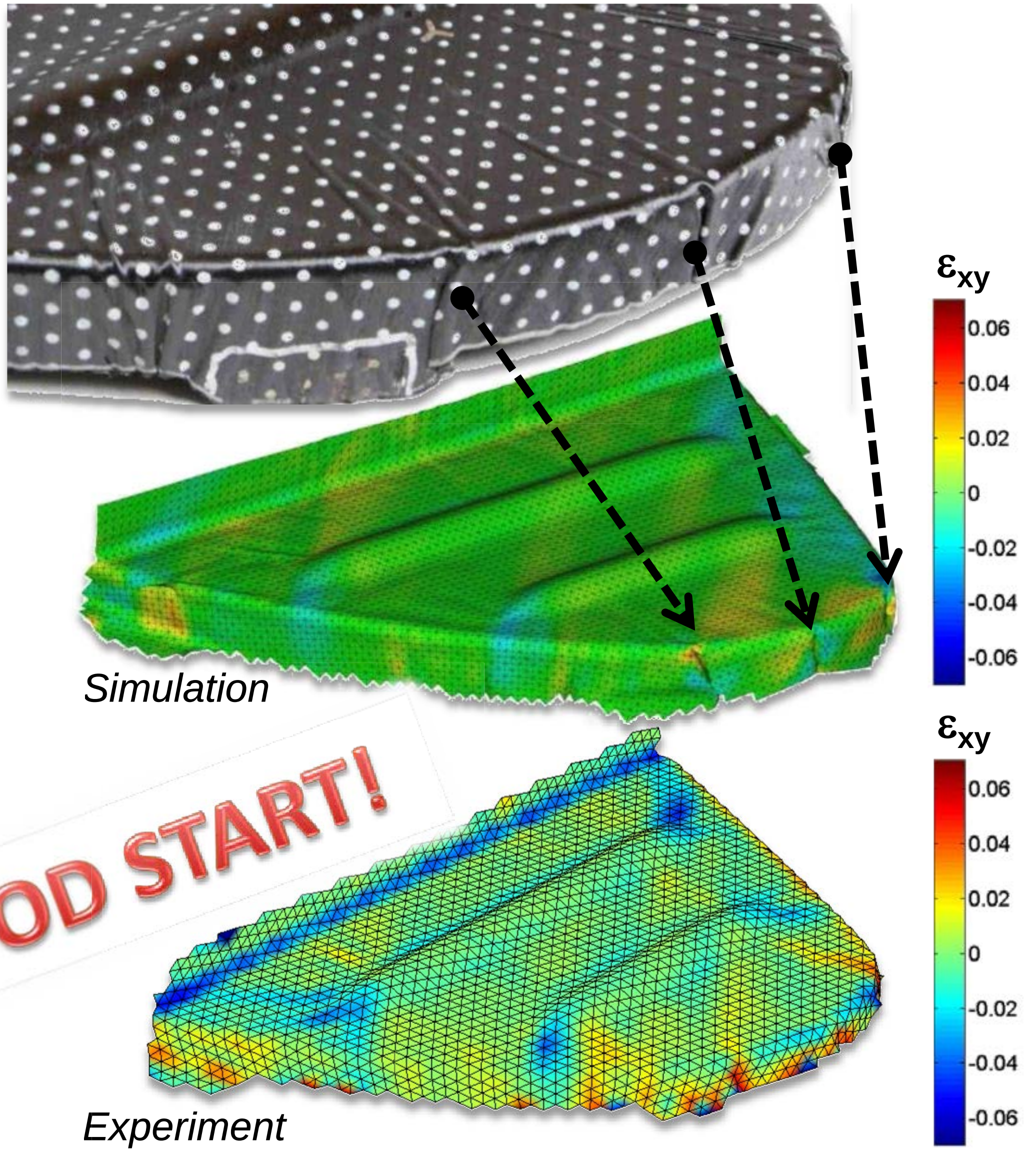
Small shear strains predicted in wrinkle free areas

Diagonal shear patterns are recognised in both simulation and experiment

Waviness in mesh near critical spots with local wrinkling in practise

Global wrinkling correctly predicted

A PRETTY GOOD START!



On the fundaments of flying bits:

Understand – Predict - Control

Where the application provides the topic

And science provides the tools

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UNIVERSITY OF TWENTE.