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Development of thermoplastic composite aircraft structures for contribution to the greening of aircrafts

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Outline

- Green aspects
- Why thermoplastic composites?
- Introduction: Automated Fiber Placement technique (AFP)
- Thermoplastic composite helicopter tailboom
- Thermoplastic composite landing gear for helicopter

Green aspects of the AFP-made thermoplastic composites

Thermoplastic composites

- Light weight → less fuel consumption
- Recyclable (as opposed to thermoset composites)

Automated Fiber Placement technique

- Reduce the material waste
- In-situ consolidation→ avoid autoclave→ save energy

Thermoplastic composite aircraft structures

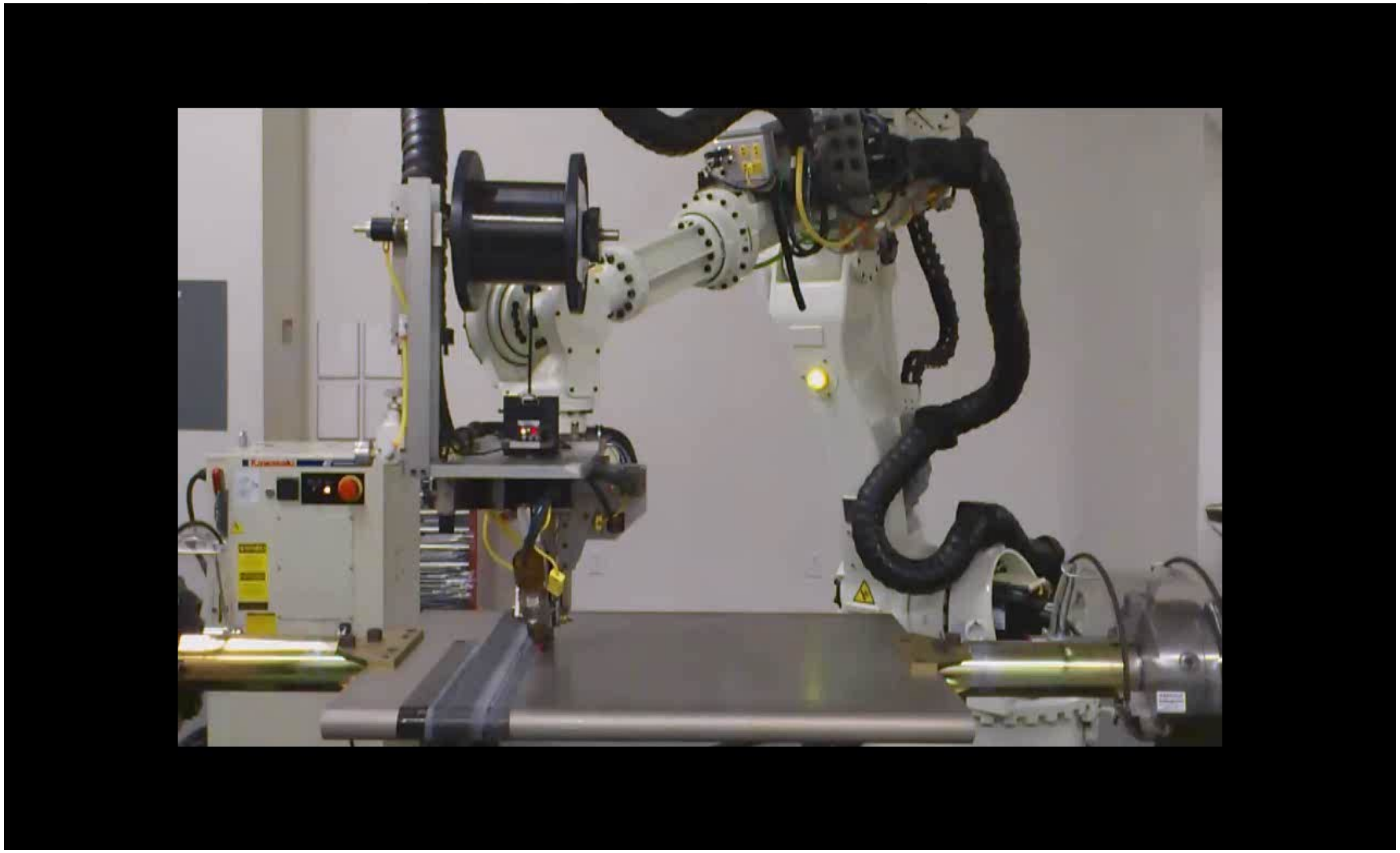
- Helicopter tailboom
- Helicopter landing gear

Why thermoplastic composites?

- ✓ Recyclable for other processes
- ✓Higher temperature performance (compare with thermoset)
- ✓ Better fracture toughness and fatigue resistance properties
- ✓ Light weight, good strength, good stiffness
- ✓ Low cost fabrication (by avoiding autoclave treatment)
- ✓Infinite shelf life
- ✓Chemical resistant
- ✓Greater compressive strength
- ✓less-toxic to produce

Automated Fiber Placement (AFP)

- Apply heat → by heating system (hot gas torch or laser)→ make the resin flow
- Apply pressure→ by means of compaction roller → consolidate the material
- Can be used for manufacturing of both thermoset and thermoplastic composites



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Automated Fiber Placement (AFP); advantages

- ✓ Reduce the wastage
- ✓ Can speed up the production
- ✓ More repeatable results
- ✓ Can produce straighter fibers
- ✓ Seamless transfer from design to manufacturing
- ✓ Reduce the labor cost (more level playing field between countries of low and high labor cost)
- ✓ Can make structures that none of the other techniques can (thermoplastic composite tubes)

Thermoplastic composite helicopter tailboom

Motivation and objectives

- Low-cost thermoplastic composite tailbooms
- Consolidation by automated fiber placement (AFP) technology (avoid autoclave)
- Performance evaluation of the AFP made tailboom

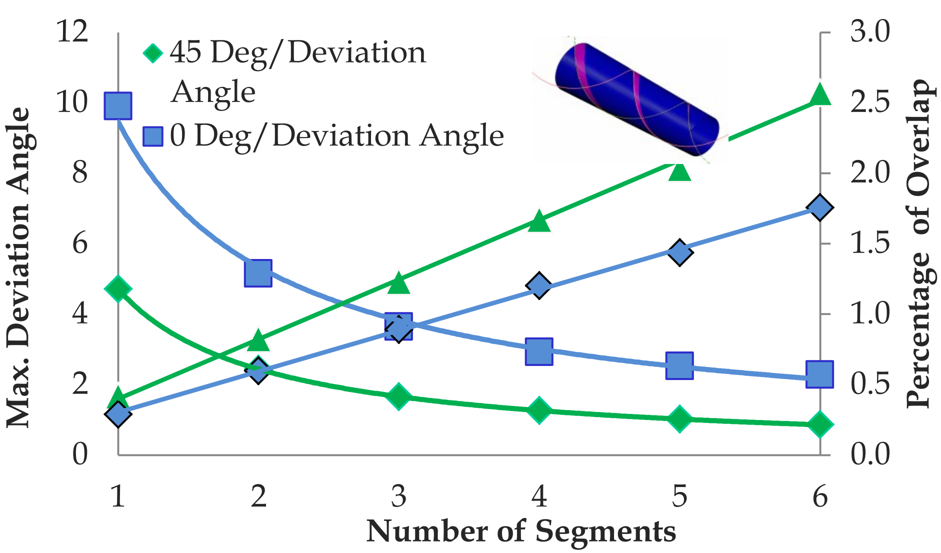
Material

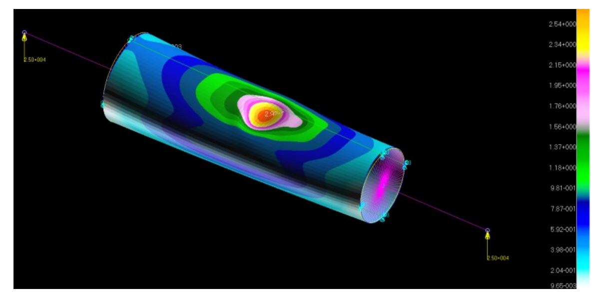
Feedstock Material: APC-2/AS4 (unsized 12k) Slit Tape

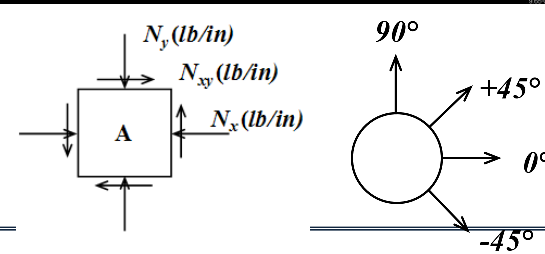
Manufacturer: Cytec Engineered Materials

- Semi-crystalline thermoplastic matrix,
- Service Temperature up to 500° F/260° C
- Indefinite shelf life at ambient conditions

Sizing the laminate and analysis of Fiber Placement Path







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Optimum process conditions for processing thermoplastic composites by AFP

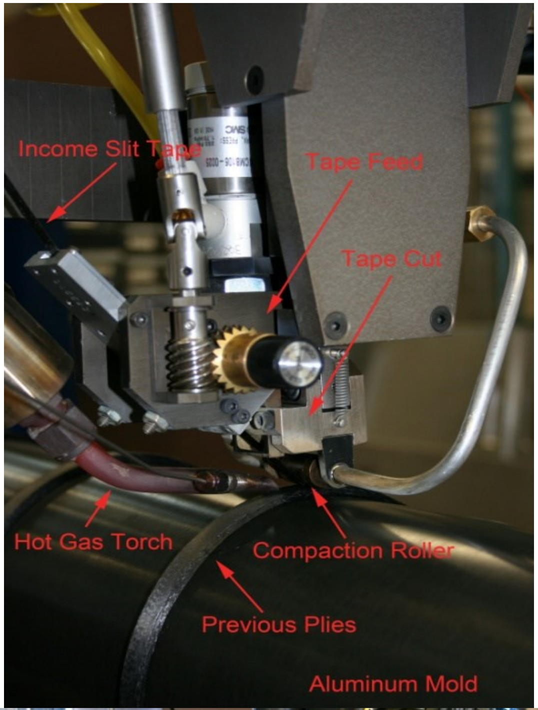
Laminate quality strongly depends on:

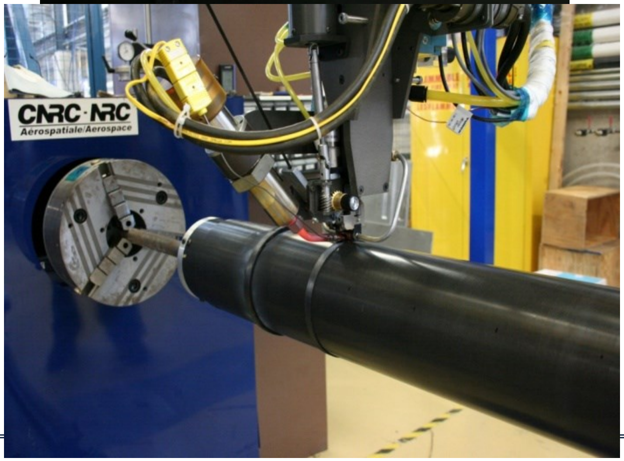
1. heat flux
2. lay-down speed
3. consolidation pressure

Factor	Level 1	Level 2	Level 3
Nozzle Temperature (°C)	900	925	950
Process Rate (mm/sec)	25.4	50.8	76.2
Compaction Force (kgf)	30	40	50
Nozzle Location (mm)	11.38	17.77	21.62

Taguchi's method

Trial	Nozzle Temperature (Deg C)	Process Rate (mm/sec)	Compaction Force (kgf)	Nozzle Location (mm)
1	900	25.4	30	11.38
2	900	50.8	40	17.77
3	900	76.2	50	21.62
4	925	25.4	40	21.62
5	925	50.8	50	11.38
6	925	76.2	30	17.77
7	950	25.4	50	17.77
8	950	50.8	30	21.62
9	950	76.2	40	11.38





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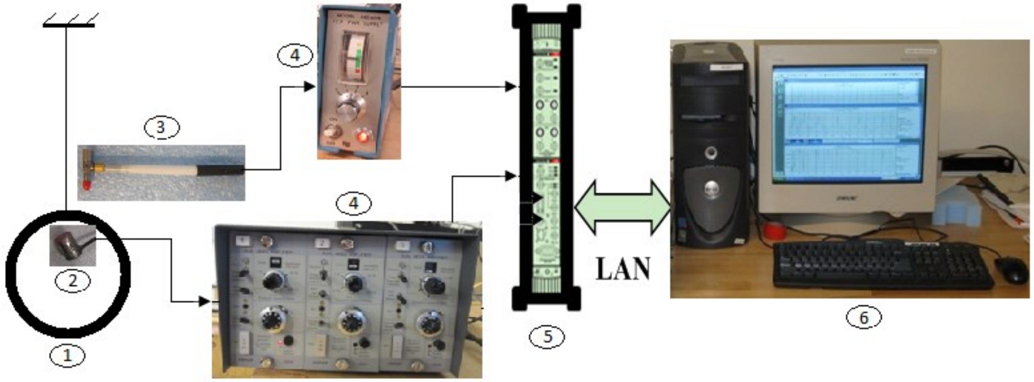
Optimum process conditions: stiffness and strength criteria



Experimental set-up: (1) composite ring; (2) accelerometer; (3) hammer; (4) amplifier; (5) B&K data acquisition system; (6) computer system (PC)

Natural frequency results

Trial	Fundamental Natural freq. (Hz)	Normalized Fundamental Natural freq. (Hz)
1	862	183.74
2	854	184.33
3	988	175.29
4	722	182.68

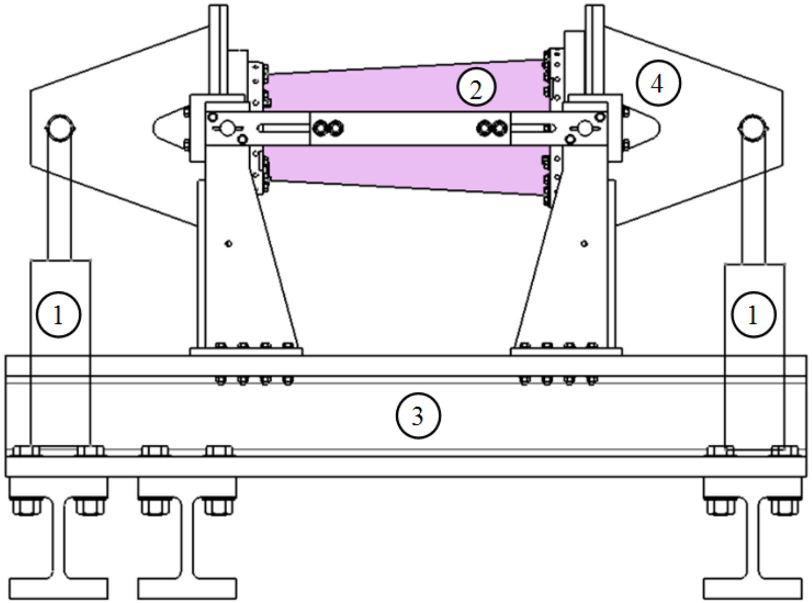
Optimum manufacturing parameters:

1. Torch temperature = 925 (˚C)
2. Process rate = 50.8 (mm/sec)
3. Compaction force = 40 (kgf)
4. Nozzle location = 11.38 (mm)

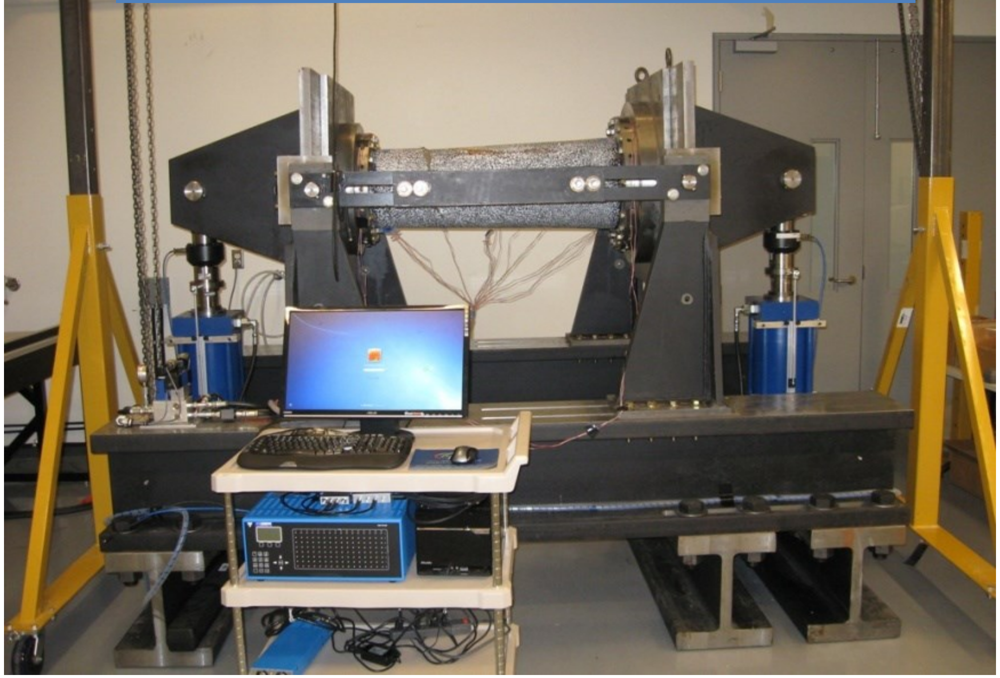
Manufacturing the thermoplastic composite tailboom

- Pre-set process parameters:
  - Torch temperature: 925 °C
  - Process Rate: 50.8 mm/sec

Experimental approach



1- Hydraulic cylinders, 2- Test specimen, 3- Reaction frame, 4- Moment Arm assembly



Concordia composite tube bending setup

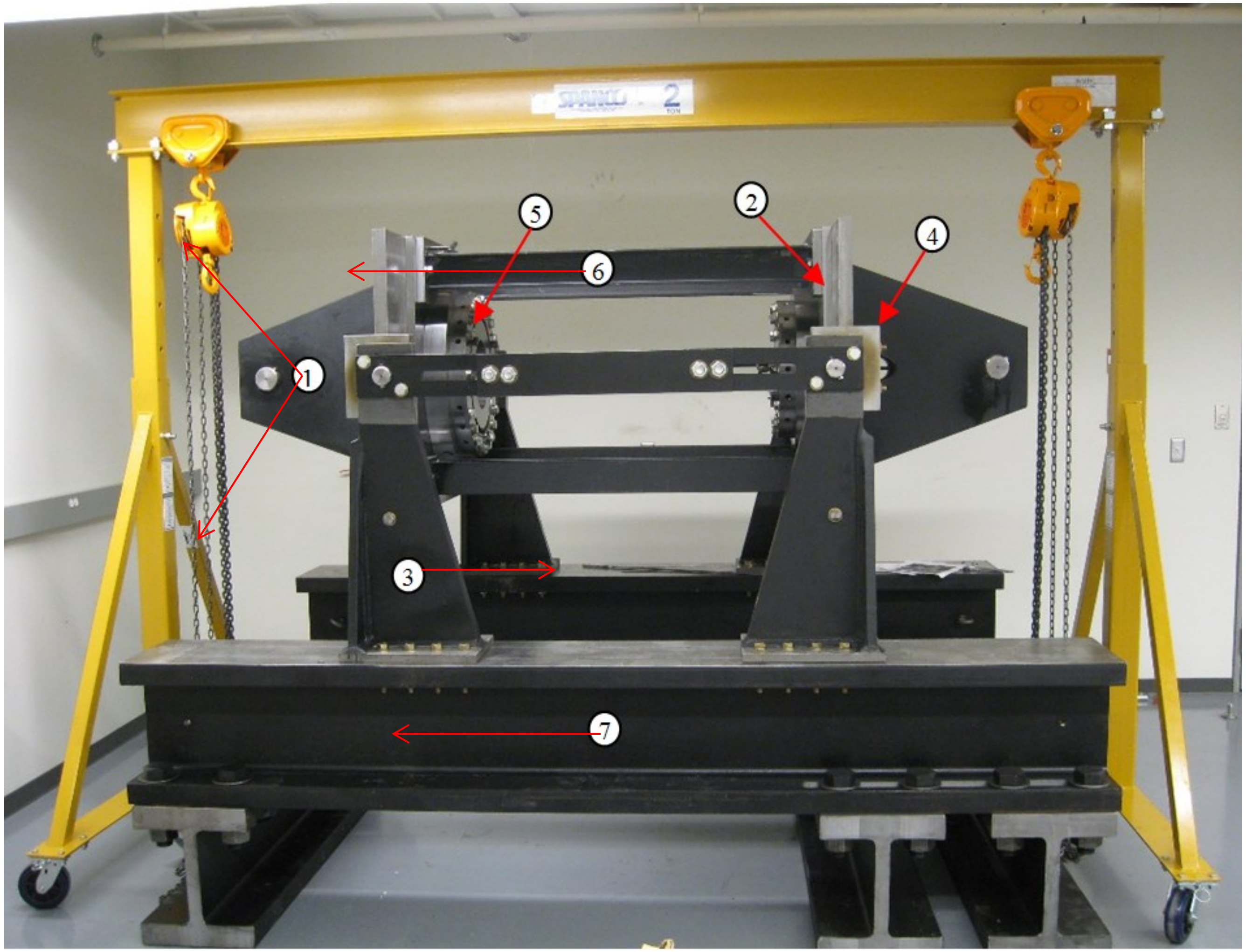
Set-up components

- ❖ Structural components
- ❖ Loading unit
- ❖ Instrumentation

Set-up features

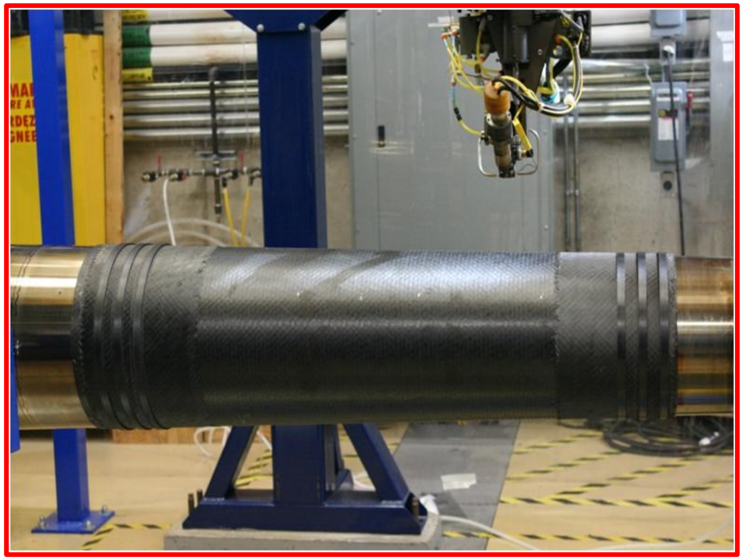
- ❖ Moment capacity: 1,500,000 lb-in
- ❖ Sample length flexibility: 30”-48” (adjustable)
- ❖ Sample cross-section size flexibility: 1”-33”
- ❖ Sample cross-section shape flexibility

Composite tube bending setup
(Structural components)



1- Moment Arm assembly, 2- Adaptor Plate, 3- Vertical Support, 4- Pivot Bracket, 5-inner and outer ring, 6- Installation Spacer Beam, 7- Reaction Frame

Preparation of the composite tailboom for test

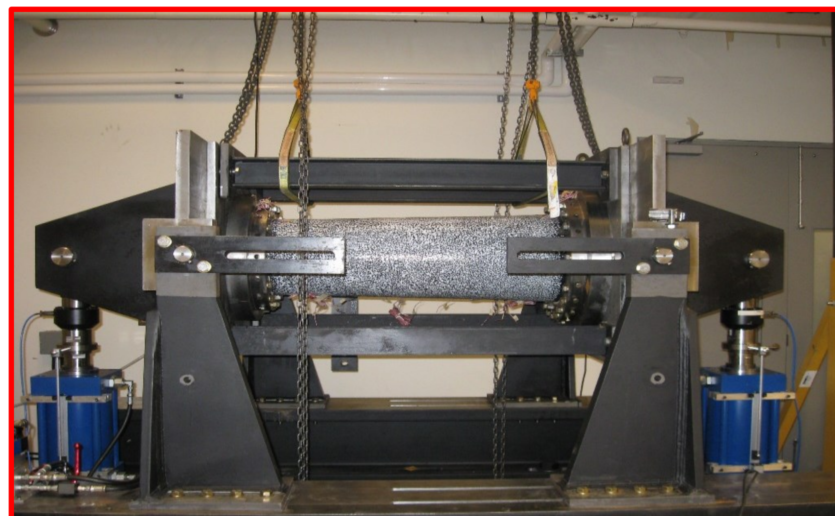


Tabs & rings at AMTC

Random pattern

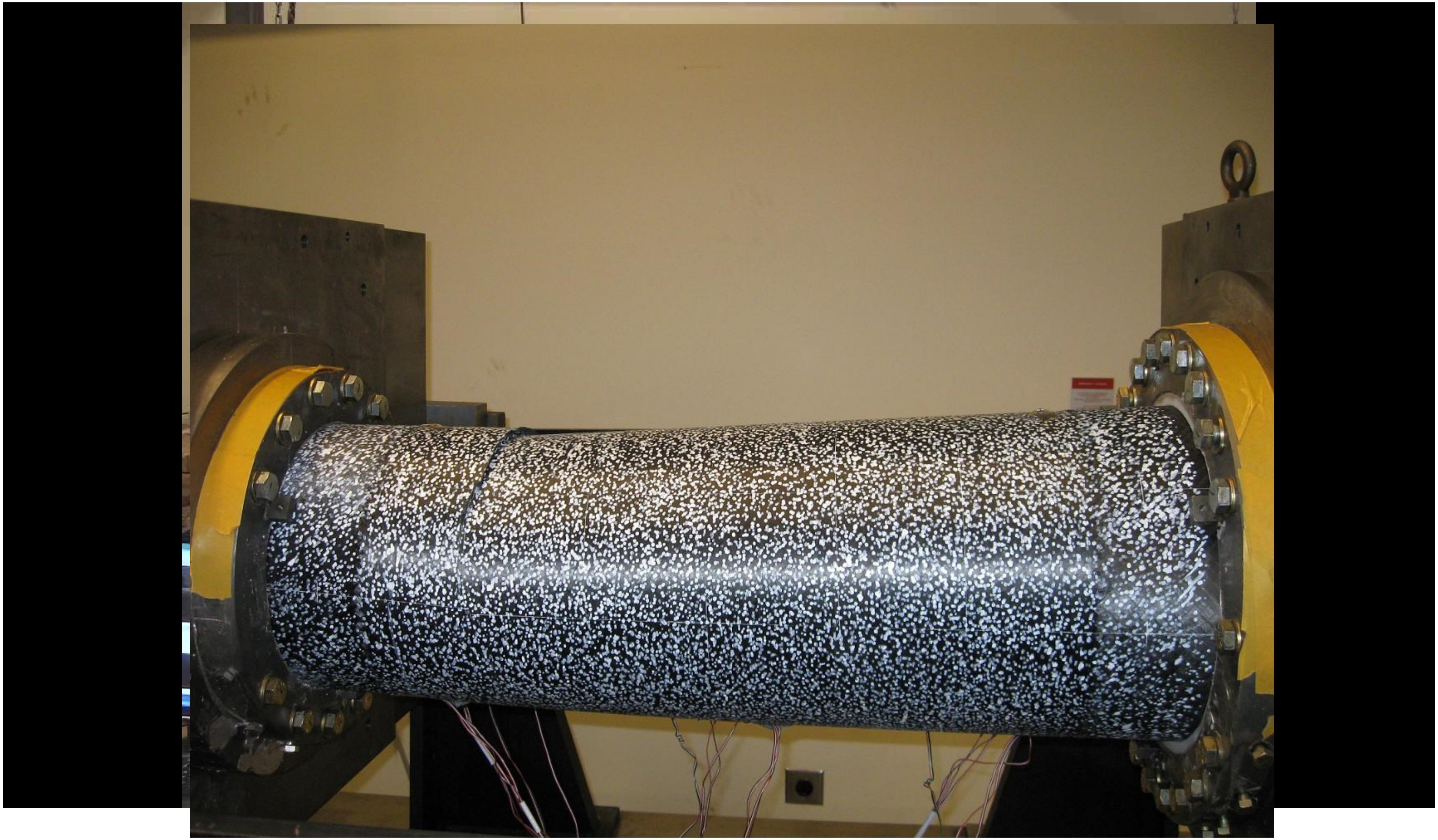
Drilling holes

Potting with LMPA

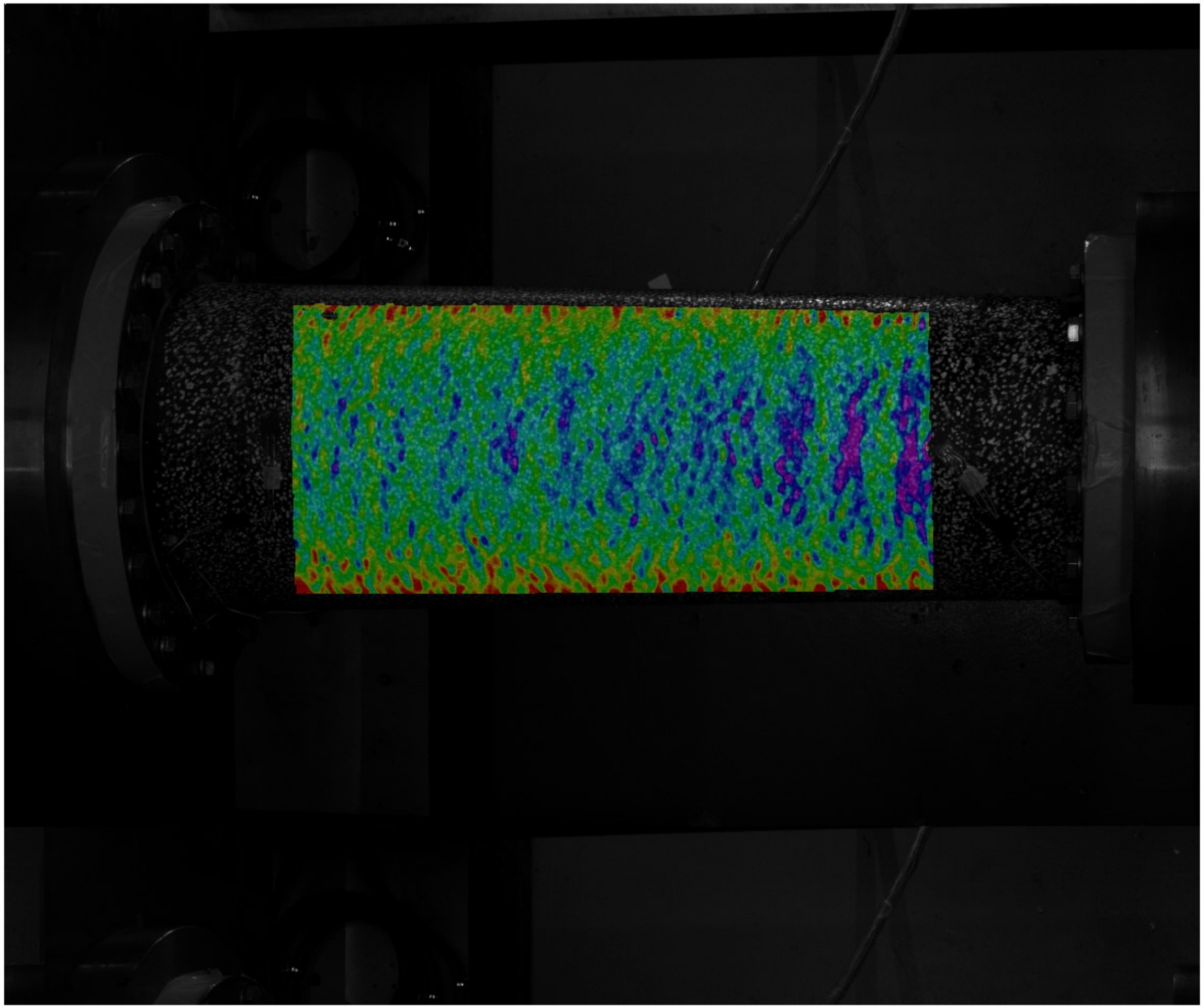


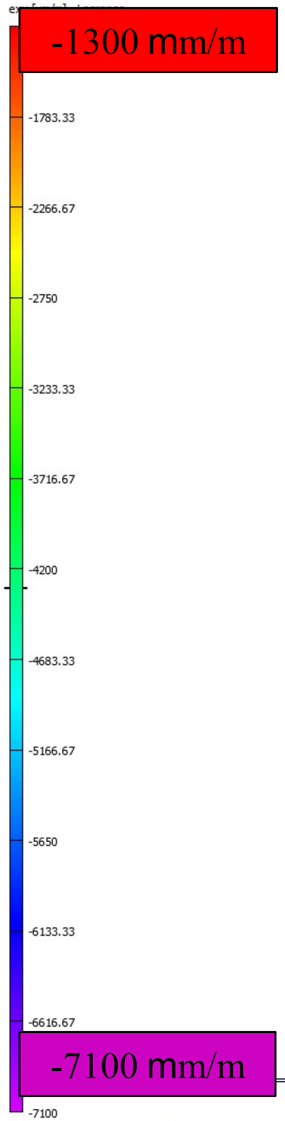
Installing strain gages & sample assembly

Bending test of the thermoplastic composite tailboom



Axial strain (exx) distribution -top view of the sample





Prior to failure

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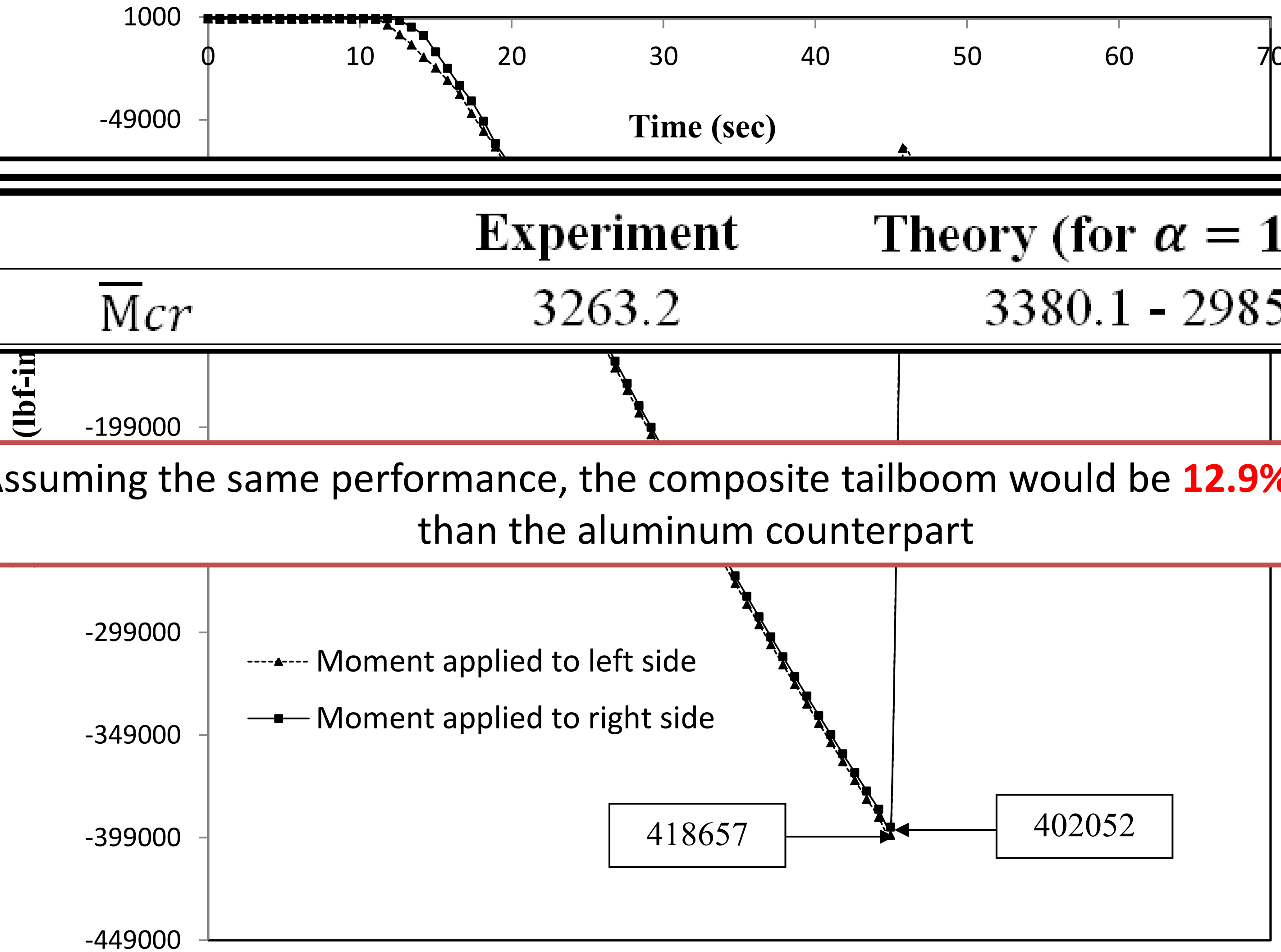
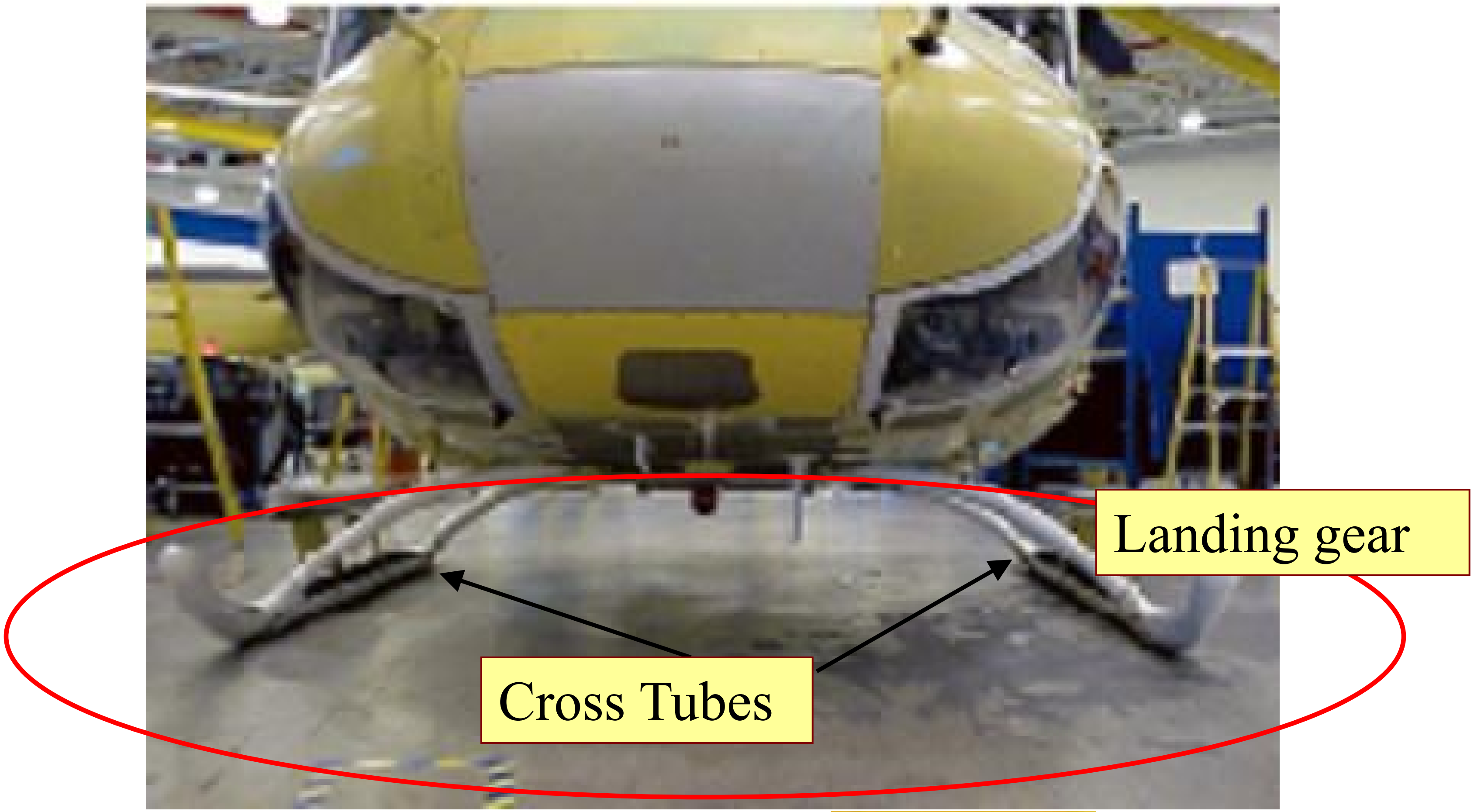
Moment vs. time graph and critical buckling moment



	Experiment	Theory (for $\alpha = 1^\circ - 3^\circ$)
$\overline{M}cr$	3263.2	3380.1 - 2985.2

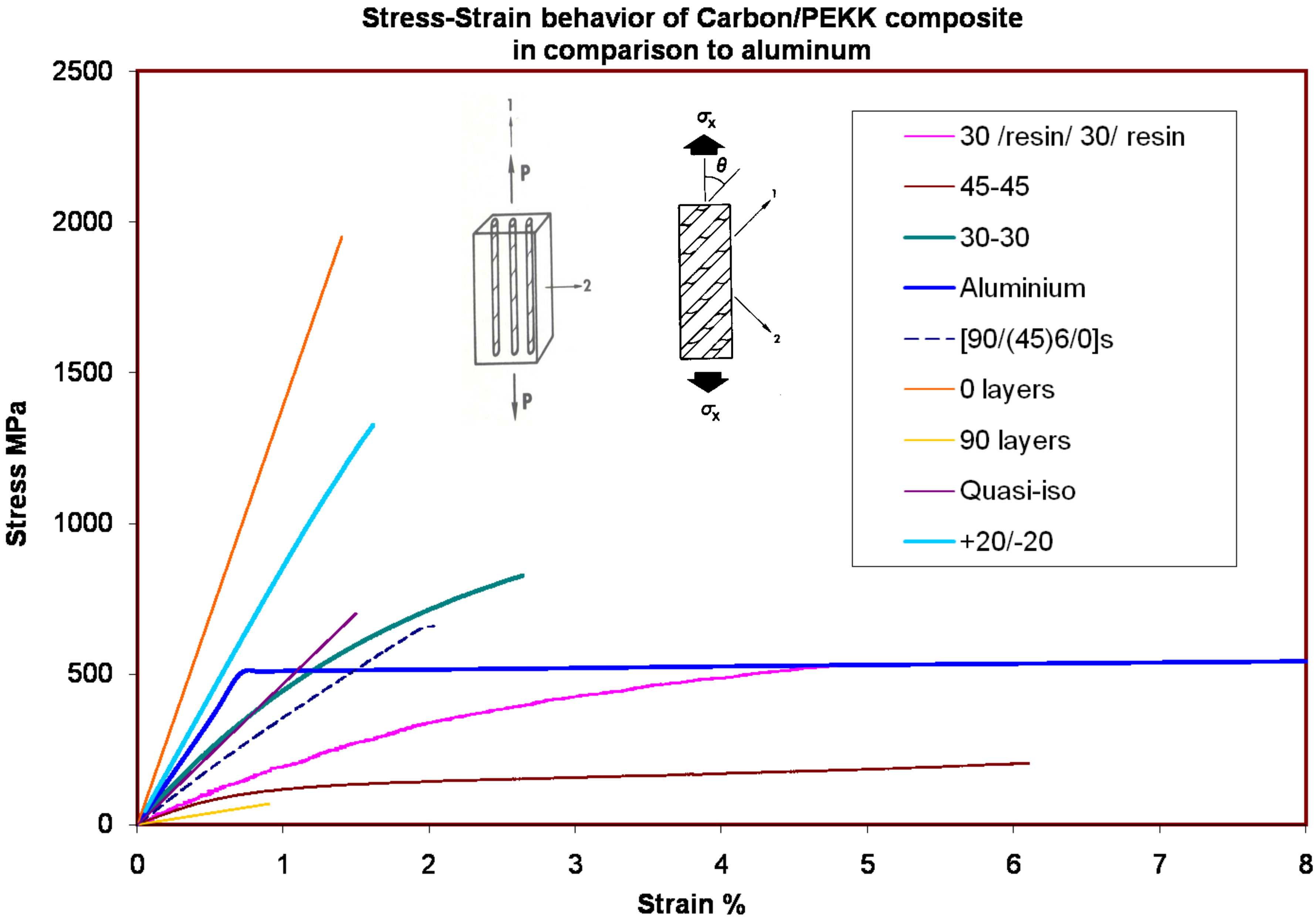
Assuming the same performance, the composite tailboom would be **12.9%** lighter than the aluminum counterpart

Thermoplastic composite landing gear*



* Derisi B. Development of thermoplastic composite tubes for large deformation. PhD thesis, Concordia University; 2008.

Characterization of the material



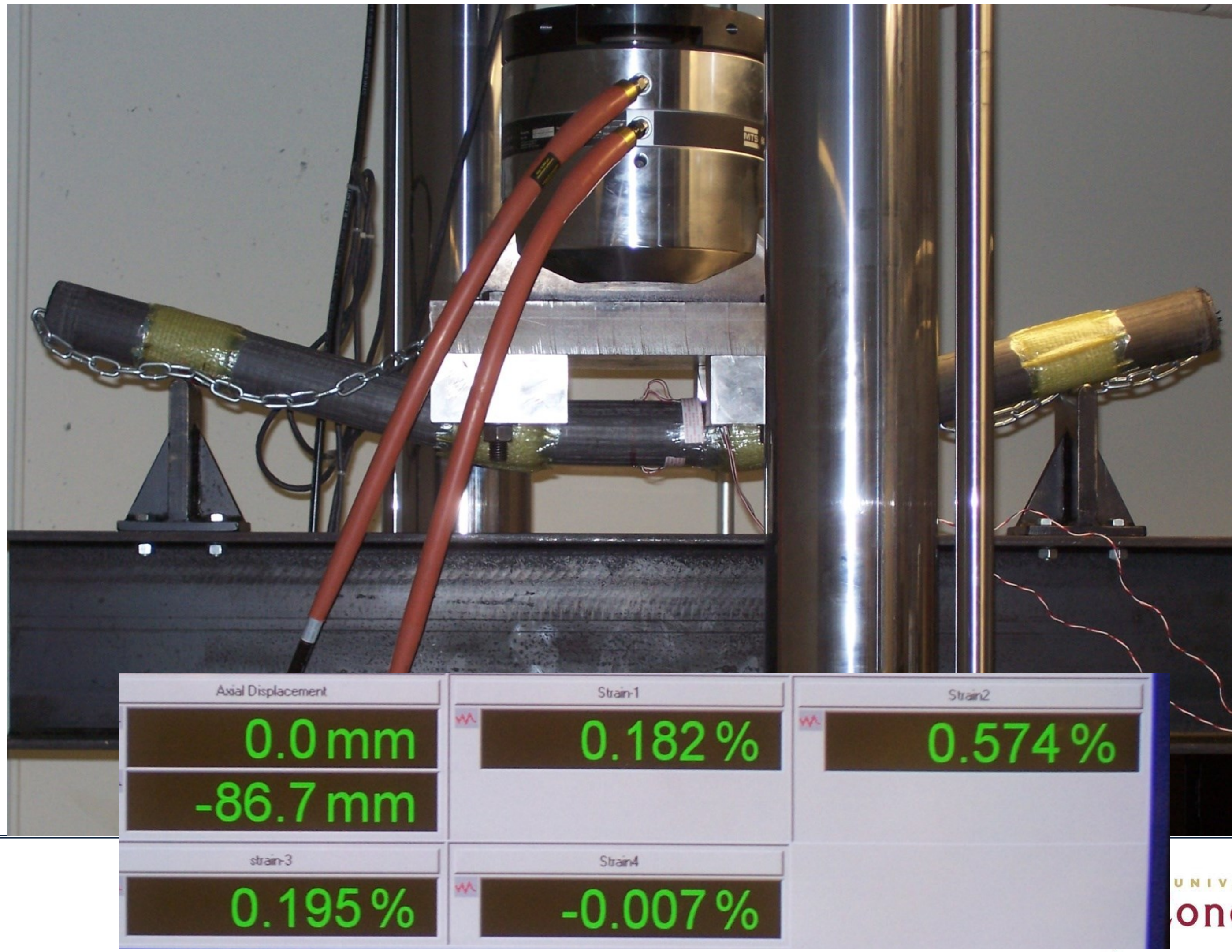
Lessons to learn from material characterization

- As the fiber angle changes from 0° to 45°, the strain limit increases. The +45°/-45° laminates show the best strain limit.
- Adding pure resin layer between the composite layers improves the strain limit. As such, the restriction of adjacent layers on each other must be avoided.
- Coupling layers with high strain limit together with layers of lower strain limit results in layers with lower strain limit being dominant.
- Fiber failure, in low angle fiber laminates, results in very high load transfer to the matrix, which causes abrupt failure of the entire composite laminate.
- Fiber rotation and matrix extension are the sources of large deformation.
- Composite tubes can exhibit large deformation due to the strategic placement of fibers at different orientations across the thickness of the tube.

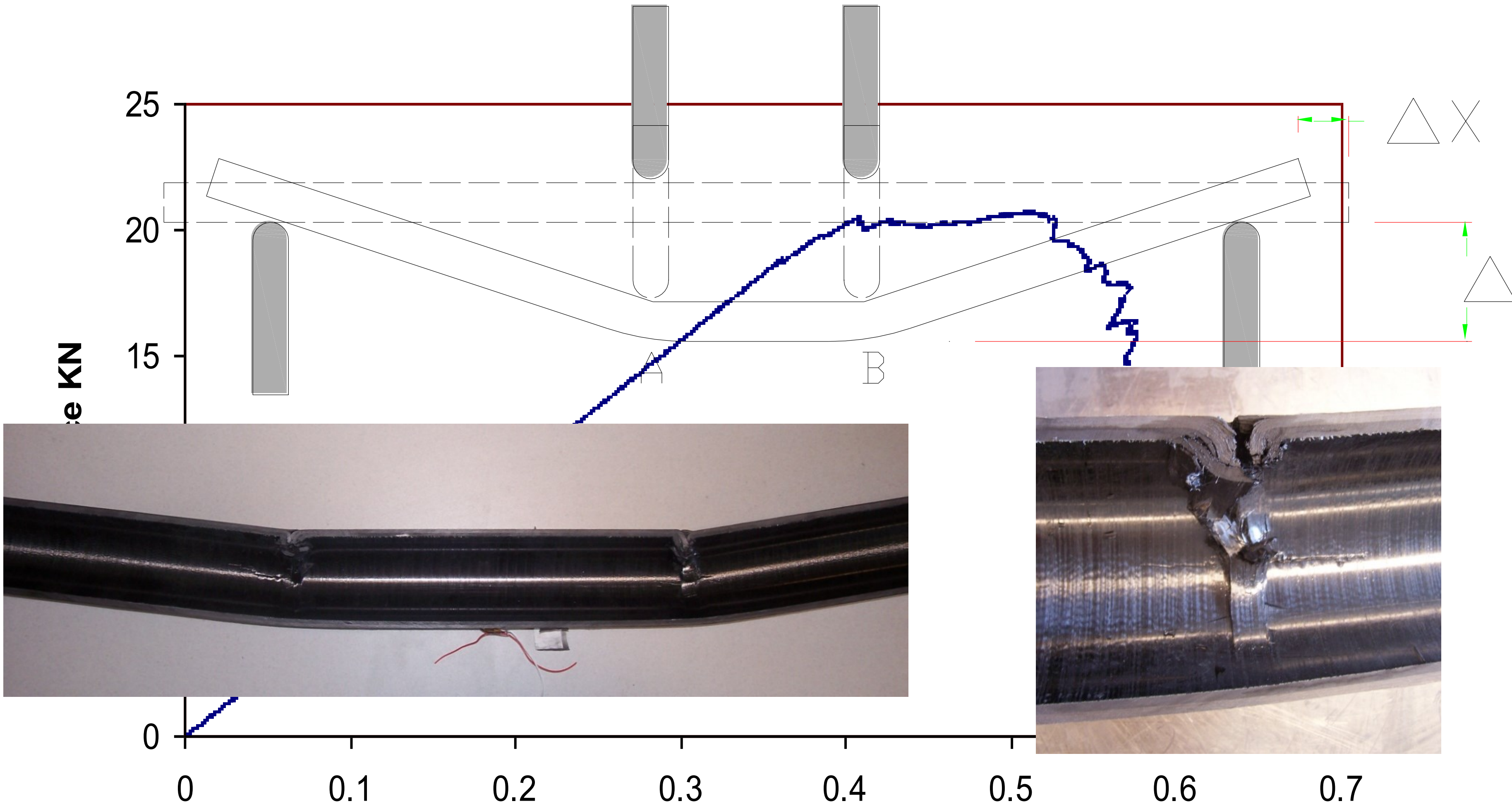
Manufacturing using Automated Fiber Placement

Testing the first composite tube

[90°$_{20}$/0°$_{20}$] layup
ID 56mm, OD64mm, 40 layers



First composite tube



Brittle fracture of the first composite tube

Deformation of the tube is mostly due to the rigid body motion.

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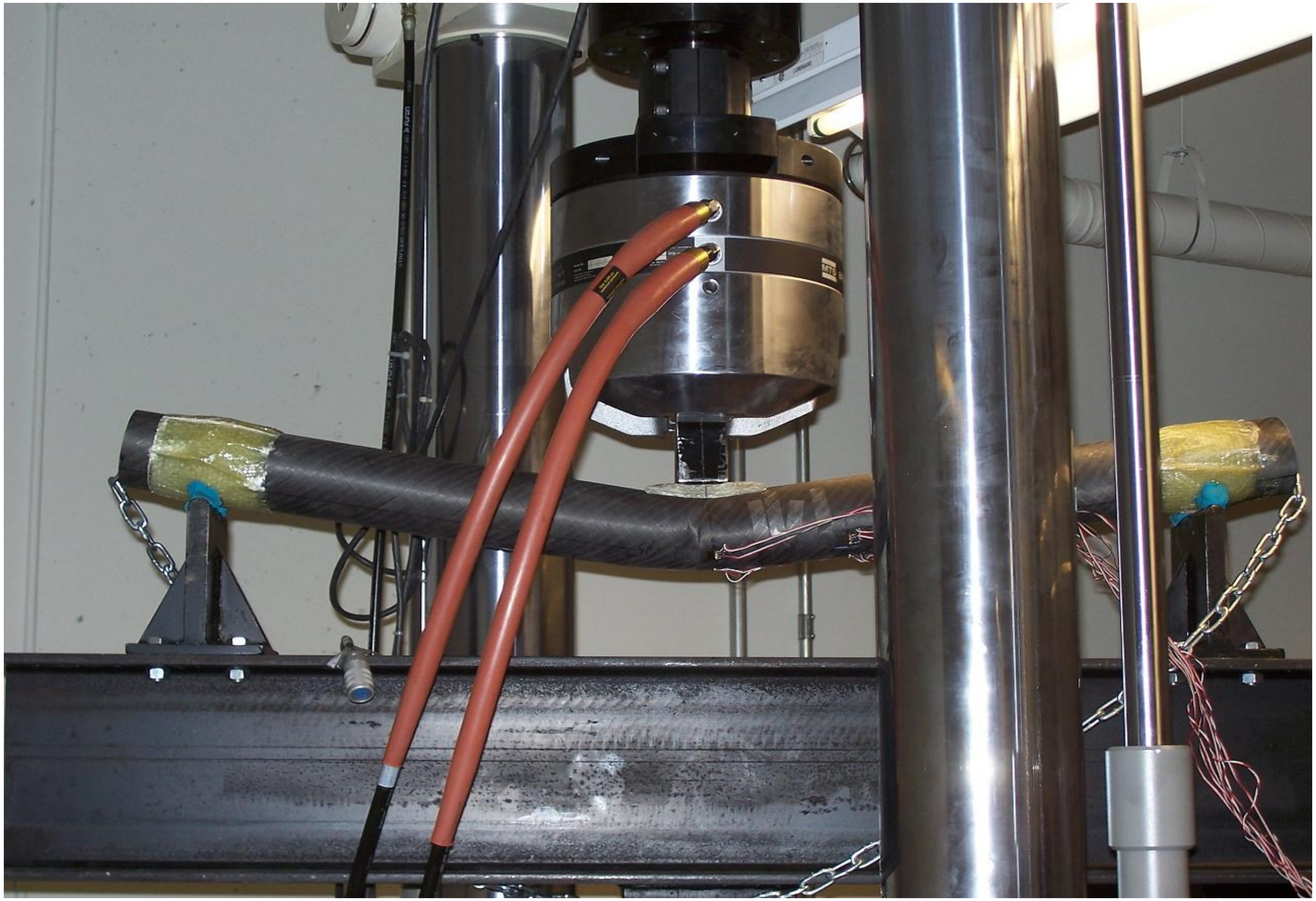
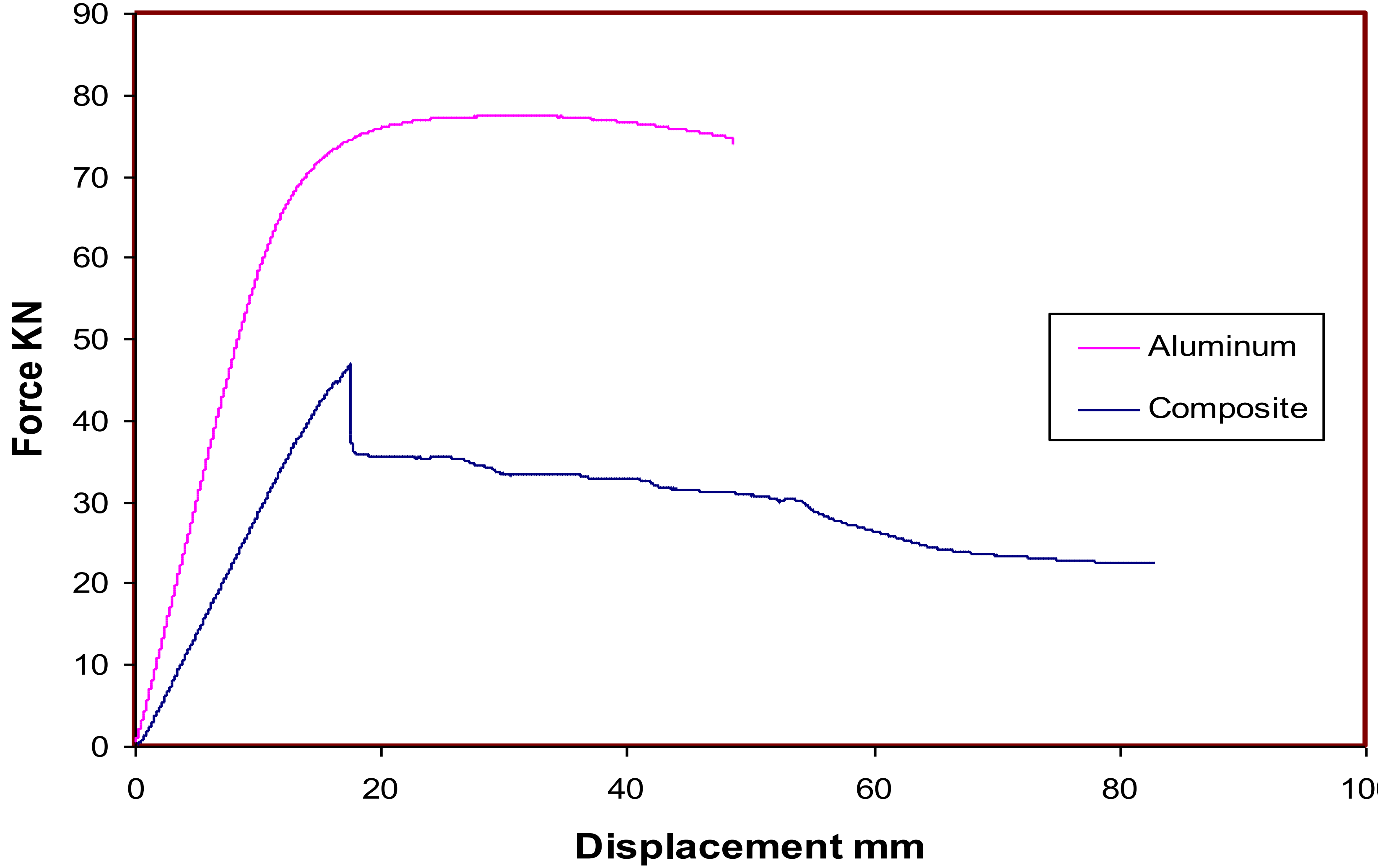
Testing the second composite tube

$[(90°_{10}/0°_{10})_3 /\pm 45°_{25}]$ layup

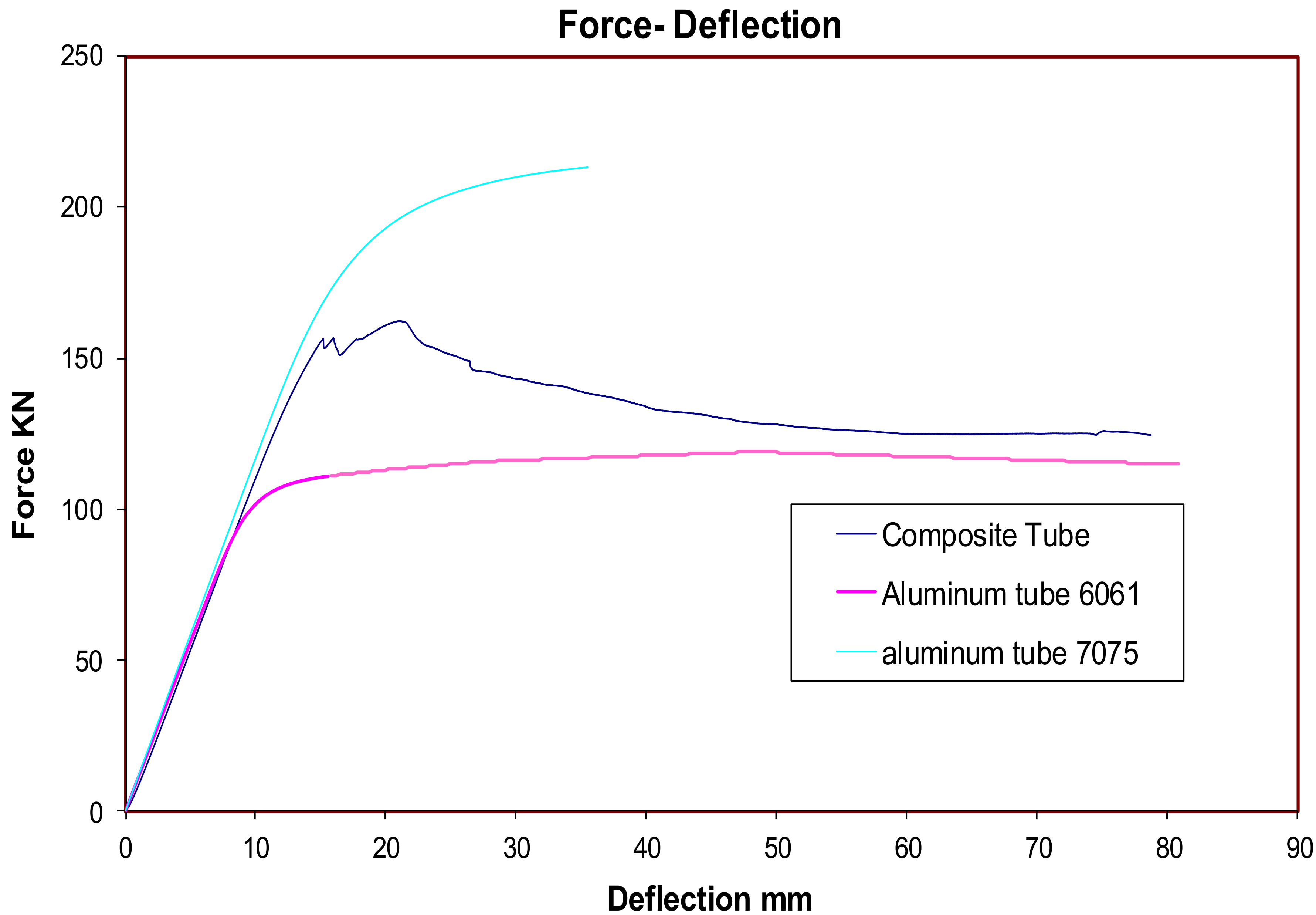
ID = 56 mm OD = 77.6 mm, 110 layers



Second composite tube



Testing the third composite tube



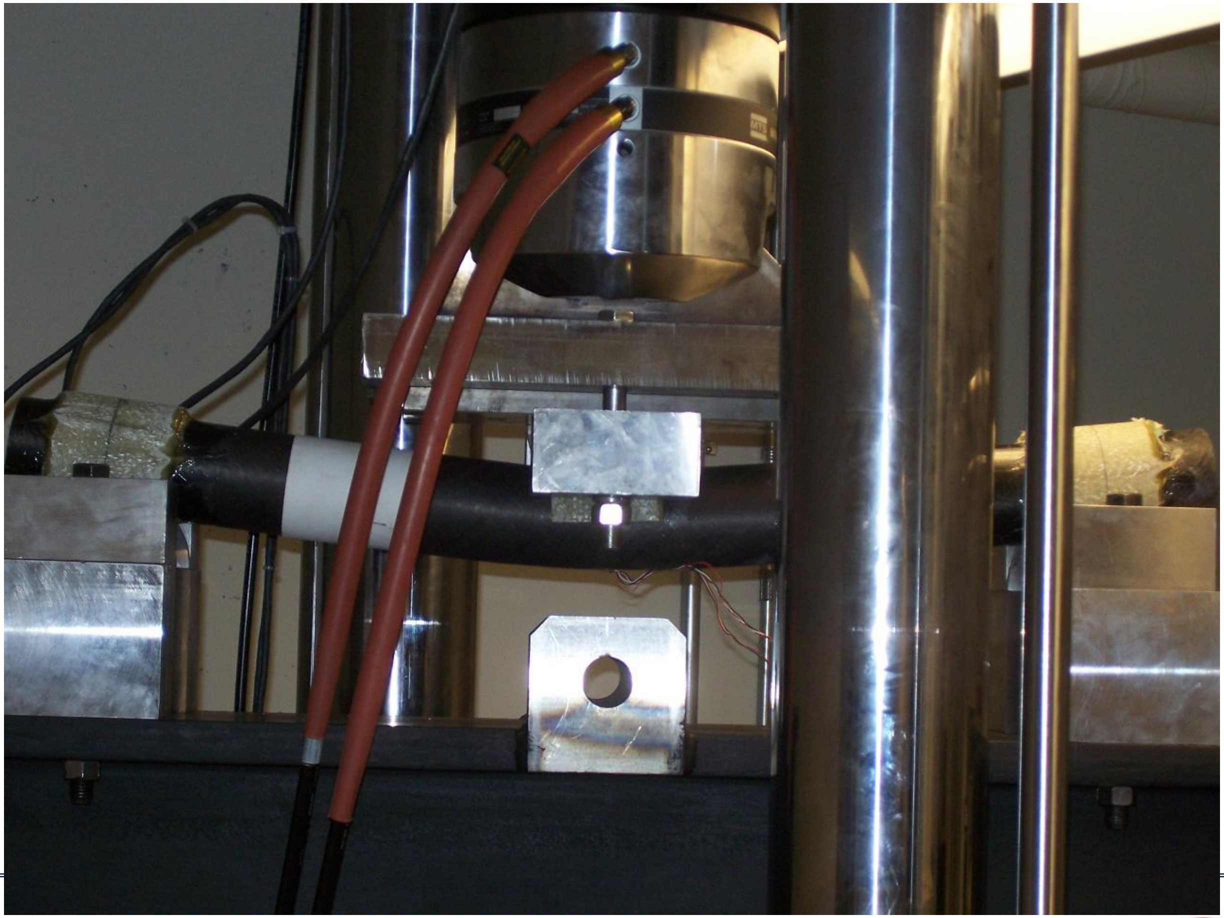
Testing the forth composite tube

Fourth tube to match aluminum tube 7075-T6

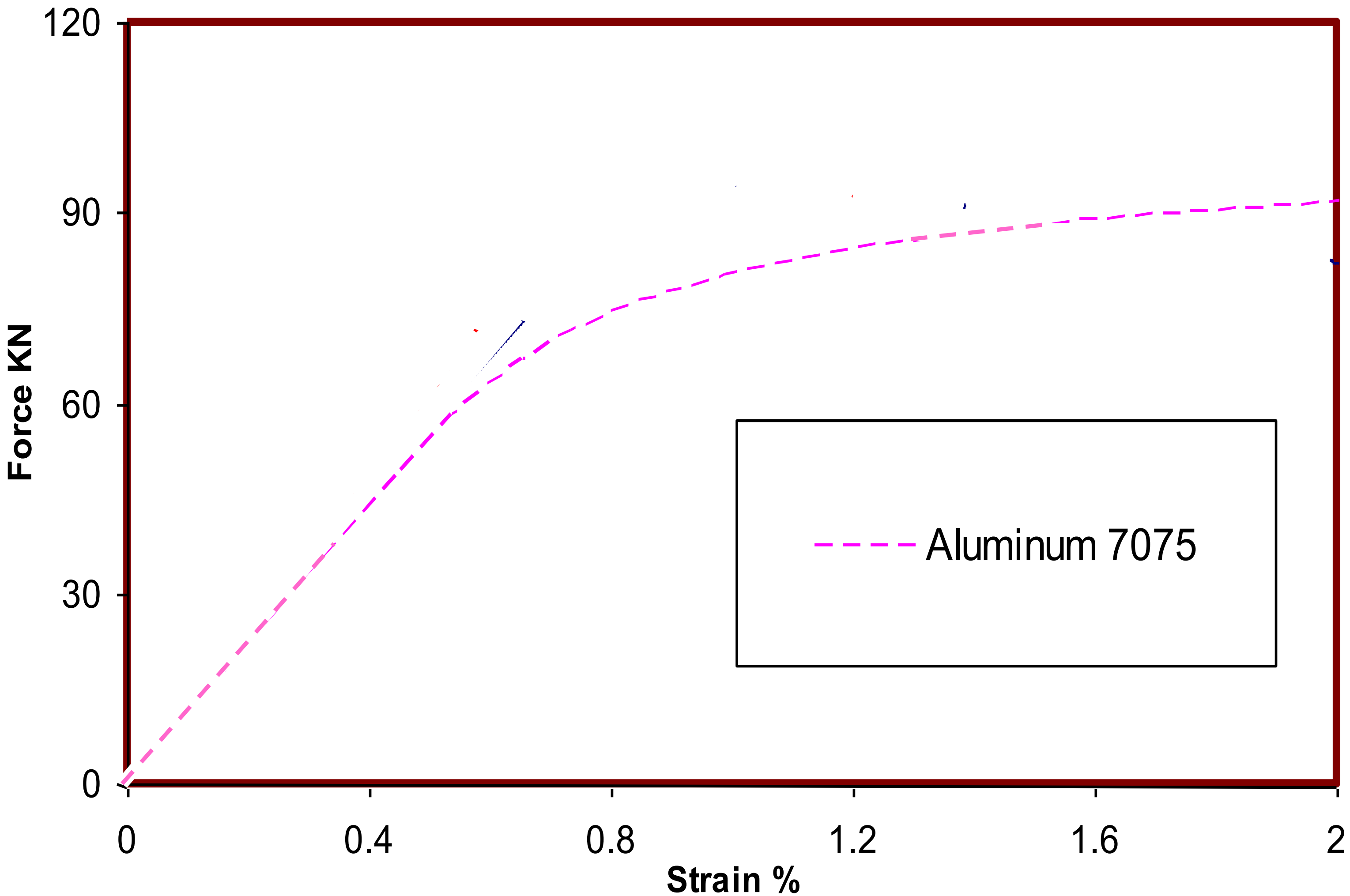
ID = 56 mm, t = 16 mm OD=76 mm- 5.6 kg

$[90°_{20} / \pm 25°_{20} / 90°_{5} / \pm 30°_{25} / 90°_{5} / \pm 45°_{10}]$

140 layers, ID = 56 mm, OD =78 mm – 3.9 kg



Forth composite tube



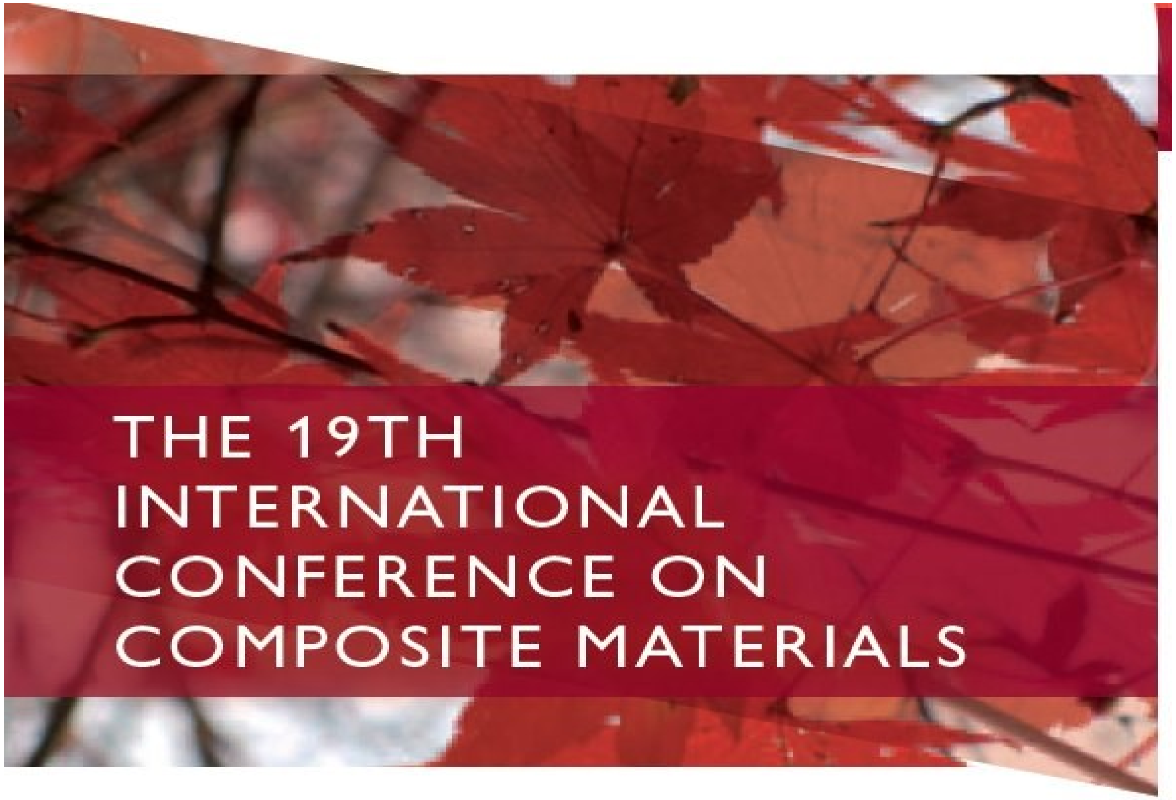
The composite landing gear is **30.4%** lighter than the aluminum counterpart

Design guidelines

- In order to have large deformation, +/- 45 layers should be placed on the outside.
- In order to prevent sudden load drop, gradual reduction of fiber orientation from groups of layers should be used.
- Maximum load depends on prevention of delamination due to local loading, and then on the number of layers.

Conclusions

- Manufacturing of greener aircraft structures has been made possible by using Automated Fiber Placement (AFP) technique and high performance thermoplastic composites.
- Manufacturing of low-cost thermoplastic composite tailboom by in-situ consolidation using AFP technique is feasible.
- Manufacturing of low-cost thermoplastic composite landing gear by in-situ consolidation using AFP technique is feasible and stiffness, deformation and strength of the composite landing gear matches the aluminium counter part



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Thank you for your attention!

Questions?
Suggestions!