Manufacturing of MFFD's lower fuselage skin: World's largest thermoplastics aerospace part

CLEAN AVIATION

AIAA-SCITECH 2022

Johan Kos

Royal Netherlands Aerospace Centre NLR

Co-funded by the European Union

FIRST VIEWS AND MANUFACTURING PROCESS

Thermoplastic carbon-fibre reinforced lower fuselage skin for MFFD

Manufacturing lead: NLR

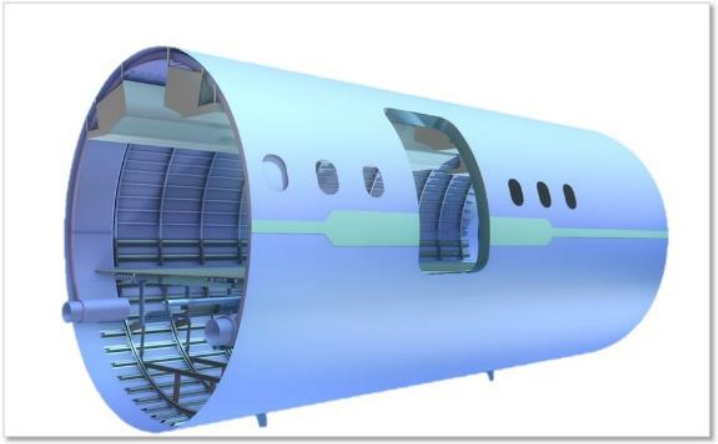
1. Manufacturing engineering, including trials on smaller size (NLR)
2. Automated fibre placement of the preforms in female mould at NLR
3. (in parallel to 1. and 2.)
   Development of innovative female consolidation mould by EMOTION consortium (TUM, Ostseestaal, Alpex) (CS2 CfP project)
4. Consolidation of the preform in EMOTION mould in DLR's research autoclave BALU (NLR & DLR)
5. Finalisation and inspection by NLR
6. Transport in between moulds (NLR) and locations

Shortly after consolidation

Length: 8.5 m; Ø 4 m

Co-funded by the European Union

MAIN DRIVERS / MAIN DESIGN FEATURES



Main drivers:

- Industrialisation
  - Quality of the skin
  - Time needed for production
  - Cost
  - Sustainability of the manufacturing process
- Affordable demonstrator of innovation
- Skin is to be part of the MFFD:
  - First-time-right
  - Timely delivery

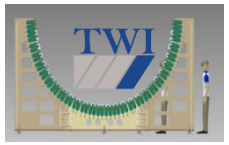
Main lower skin design features:

- Thermoplastics, carbon-fibre re-inforced
- Large size, 50 m^2
- Varying thickness (~2-10 mm) with local reinforcements (e.g., around doors):
  - Ramps with different slopes
  - Ply drop-offs
- Longitudinal interfaces for welding with upper skin (stepped interfaces)
- Interfaces with stringers
- Door cut-outs (passenger and cargo)
- Lightning strike protection (outer layer)

Co-funded by the European Union

LOWER FUSELAGE MANUFACTURING AND ASSEMBLY BY STUNNING CONSORTIUM

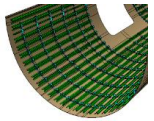
✓ Skin consolidated & delivered

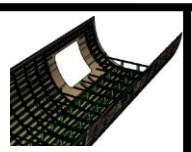


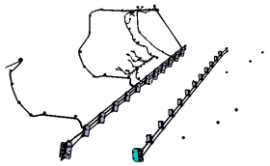
✓ Delivered & installed

Stringer CW

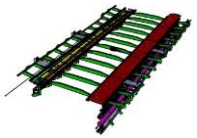
Clip USW



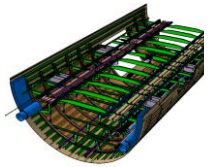




❑ Systems



❑ Systems integrated in sub-assy



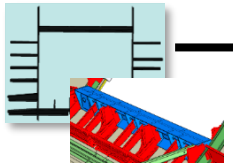
❑ Delivery to FhG/Stade

✓ Parts for Jig delivered

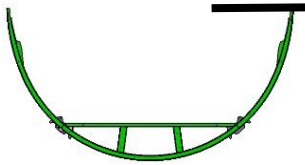
✓ Weld tool delivered

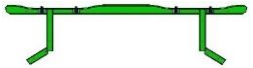
❑ Clips

CDSS



installation





❑ Interior installation at ZAL

Co-funded by the European Union

FIRST VIEWS AND MANUFACTURING PROCESS

Thermoplastic carbon-fibre reinforced lower fuselage skin for MFFD

Manufacturing lead: NLR

1. Manufacturing engineering, including trials on smaller size (NLR)
2. Automated fibre placement of the preforms in female mould at NLR
3. (in parallel to 1. and 2.)
   Development of innovative female consolidation mould by EMOTION consortium (TUM, Ostseestaal, Alpex) (CS2 CfP project)
4. Consolidation of the preform in EMOTION mould in DLR's research autoclave BALU (NLR & DLR)
5. Finalisation and inspection by NLR
6. Transport in between moulds (NLR) and locations

Shortly after consolidation:
Beyond the most challenging phase

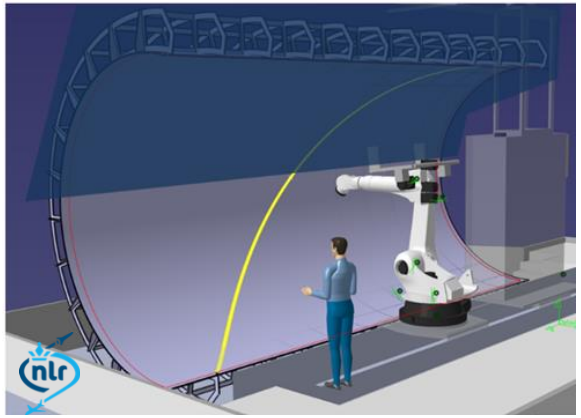
Length: 8.5 m; Ø 4 m

Co-funded by the European Union

AUTOMATED FIBRE PLACEMENT

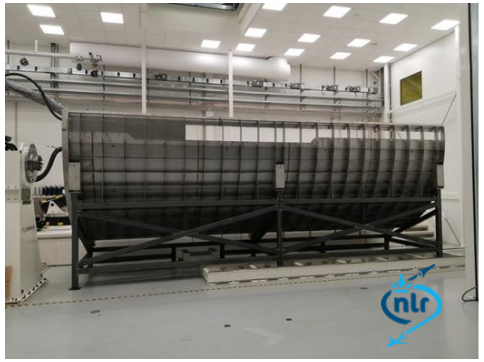
Equipment:

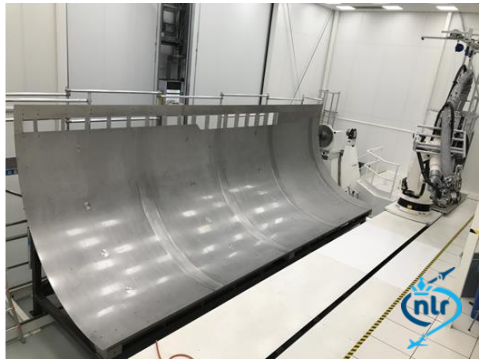
- NLR's AFP machine: Coriolis C1
  - 6 kW laser heating
  - 8 tows of ¼" with individual tow control
  - 9 meter linear track
- Skin laid in 2x 90° segment
- Cheap steel layup mould, moderate accuracy

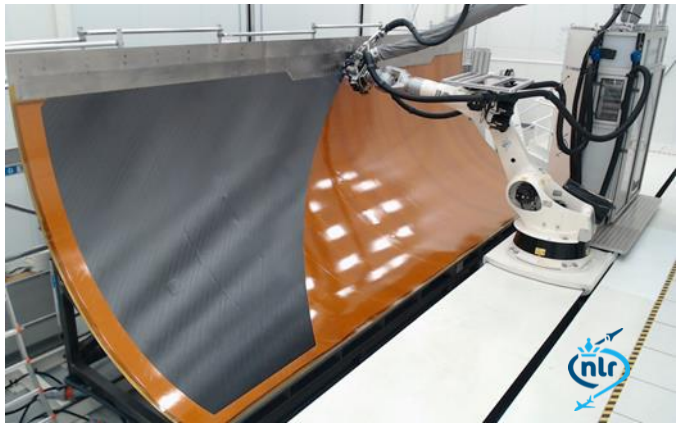


Process specifications:

- Material used is TORAY TC1225 PAEK T700
- Medium/fast AFP layup (500mm/s) at room temperature
- Process window for AFP around 340-360 degrees Celsius (Tm=305°C)
- First layer challenges with TP materials (not sticky at RT)

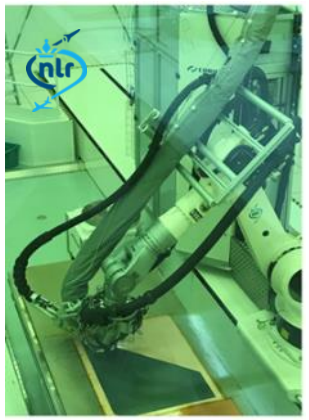


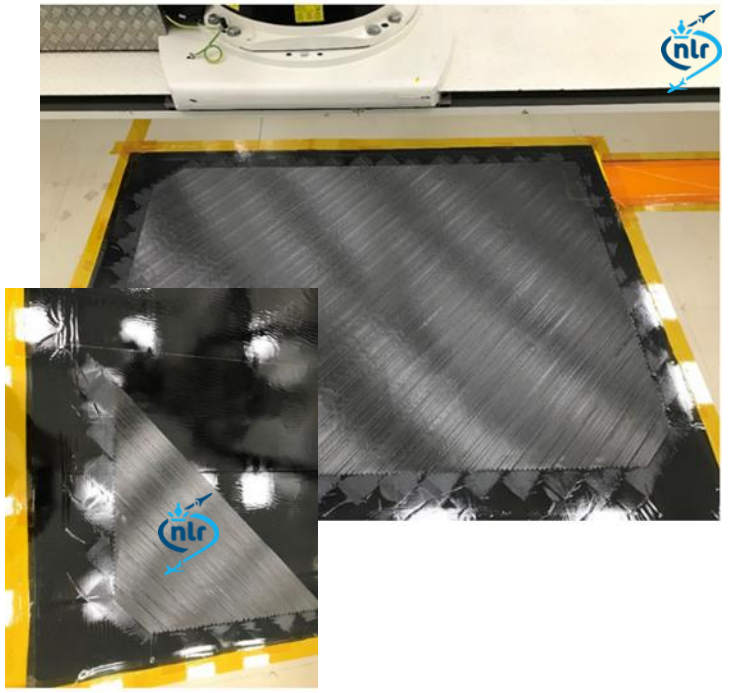




Co-funded by the European Union

AFP: FURTHER DEVELOPMENTS AND OPPORTUNITIES FOR INDUSTRIAL SETTING





Lightning strike protection:

- Can be done as first layer for AFP
- Proven by small size tests
- Not available when AFP of the MFFD skin started
- LSP has been added later, see later slide

Speed: AFP output [kg/hour]. Potential improvement in industrial setting:

- Faster machines exist than NLR's AFP machine (500 mm/s), e.g.
  - Coriolis C solo layup speeds of 1000 mm/s;
  - Elektroimpact/Victrex claim even higher speeds (1700 mm/s)
- These machines may also lay down more and/or wider tows, increasing the output even more

Cost & sustainability:

AFP has low buy-to-fly ratio (gross weight /net weight):

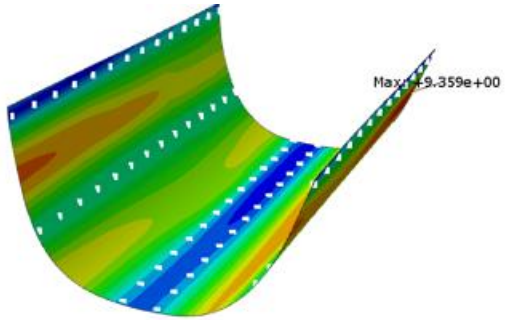
- 1.118, achieved for MFFD
- 1.035, if door areas kept open (opportunity for industrial setting)

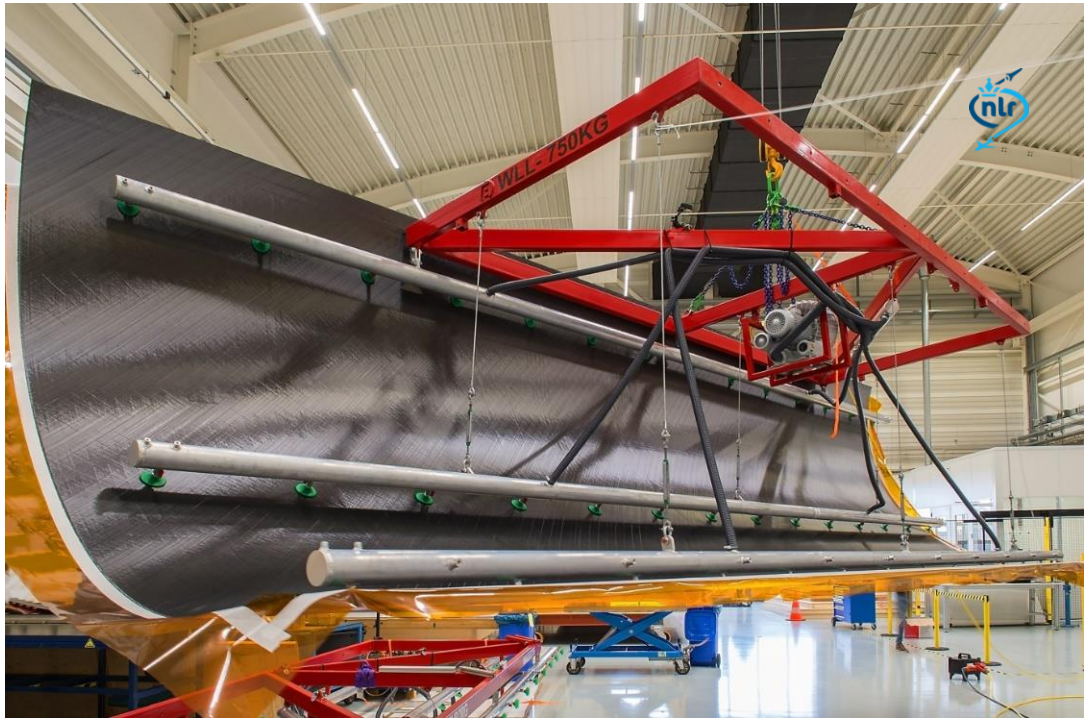
Co-funded by the European Union

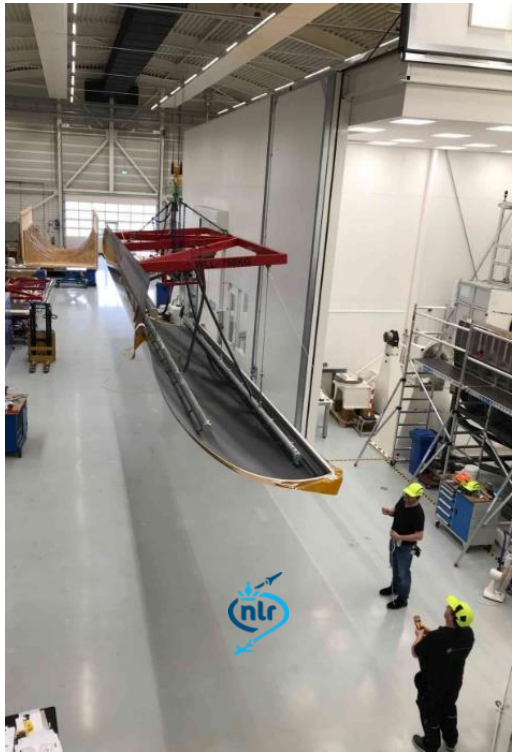
HANDLING TOOL

Dedicated hoisting tool, based on suction cups, designed and developed by NLR for transport of:

- 90° preforms
- 180° consolidated skin (later)







Co-funded by
the European Union

FIRST VIEWS AND MANUFACTURING PROCESS

Thermoplastic carbon-fibre reinforced lower fuselage skin for MFFD

Manufacturing lead: NLR

1. Manufacturing engineering, including trials on smaller size (NLR)
2. Automated fibre placement of the preforms in female mould at NLR
3. (in parallel to 1. and 2.)
   Development of innovative female consolidation mould by EMOTION consortium (TUM, Ostseestaal, Alpex) (CS2 CfP project)
4. Consolidation of the preform in EMOTION mould in DLR's research autoclave BALU (NLR & DLR)
5. Finalisation and inspection by NLR
6. Transport in between moulds (NLR) and locations

Shortly after consolidation:
Beyond the most challenging phase

Length: 8.5 m; Ø 4 m

Co-funded by the European Union

INNOVATIVE CONSOLIDATION MOULD

Developed by **EMOTION** consortium:

- TU Munich, Germany
- Ostseestaal, Germany
- ALPEX, Austria

under separate contract with the Clean Sky 2 JU ((#864474). Technically guided by NLR.

Innovative high temperature consolidation mould

- Floating mould surface
- Dimensions: 8.5 x 5.6 x 3.3 m
- Fit for DLR’s autoclave

Co-funded by the European Union

FIRST VIEWS AND MANUFACTURING PROCESS

Thermoplastic carbon-fibre reinforced lower fuselage skin for MFFD

Manufacturing lead: NLR

1. Manufacturing engineering, including trials on smaller size (NLR)
2. Automated fibre placement of the preforms in female mould at NLR
3. (in parallel to 1. and 2.)
   Development of innovative female consolidation mould by EMOTION consortium (TUM, Ostseestaal, Alpex) (CS2 CfP project)
4. Consolidation of the preform in EMOTION mould in DLR's research autoclave BALU (NLR & DLR)
5. Finalisation and inspection by NLR
6. Transport in between moulds (NLR) and locations

Shortly after consolidation:
Beyond the most challenging phase

Length: 8.5 m; Ø 4 m

Co-funded by the European Union

CONSOLIDATION: CHALLENGES ADDRESSED AND FIRST STEPS

Large size challenges for bagging:

- High temperature foils are less flexible
- Tacky tapes are less tacky
- Foils are not available for this size
- Need to make seams in the high temperature bagging which adds risk for vacuum

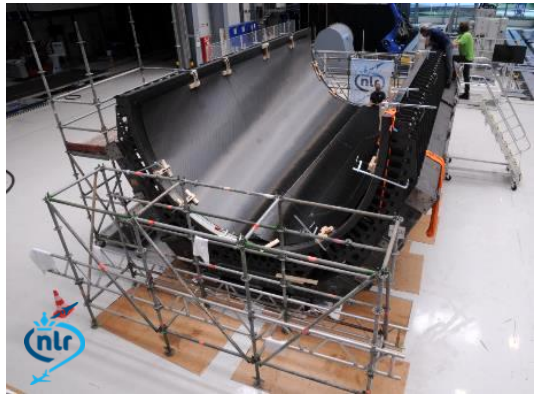
Road transport:

- Consolidation mould
- Preform

LSP material US spot welded to preform

Preform hoisted into consolidation mould

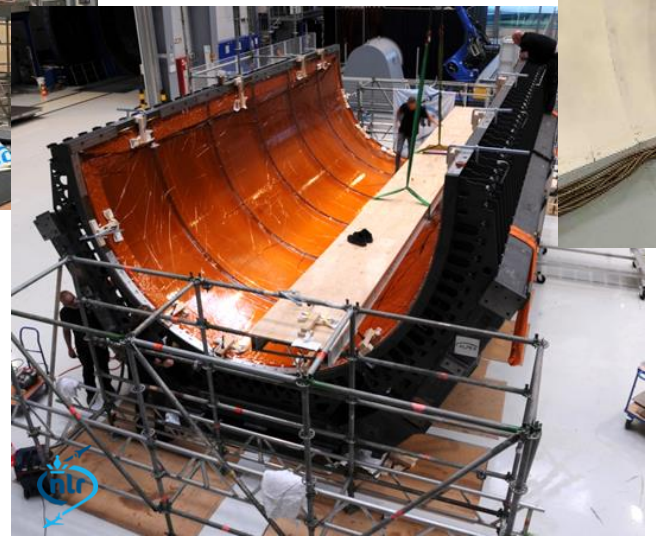
Clamping



High temperature vacuum bag with multiple seams

Co-funded by the European Union

CONSOLIDATION: FINAL STEPS AND RESULT



Autoclave consolidation: 350° C for 30 minutes at 7 bar

Vacuum: remained strong during entire cycle and only dropped to 80% during cooling down below Tg.

Co-funded by the European Union

FIRST VIEWS AND MANUFACTURING PROCESS

Thermoplastic carbon-fibre reinforced lower fuselage skin for MFFD

Manufacturing lead: NLR

1. Manufacturing engineering, including trials on smaller size (NLR)
2. Automated fibre placement of the preforms in female mould at NLR
3. (in parallel to 1. and 2.)
   Development of innovative female consolidation mould by EMOTION consortium (TUM, Ostseestaal, Alpex) (CS2 CfP project)
4. Consolidation of the preform in EMOTION mould in DLR's research autoclave BALU (NLR & DLR)
5. Finalisation and inspection by NLR
6. Transport in between moulds (NLR) and locations

Shortly after consolidation:
Beyond the most challenging phase

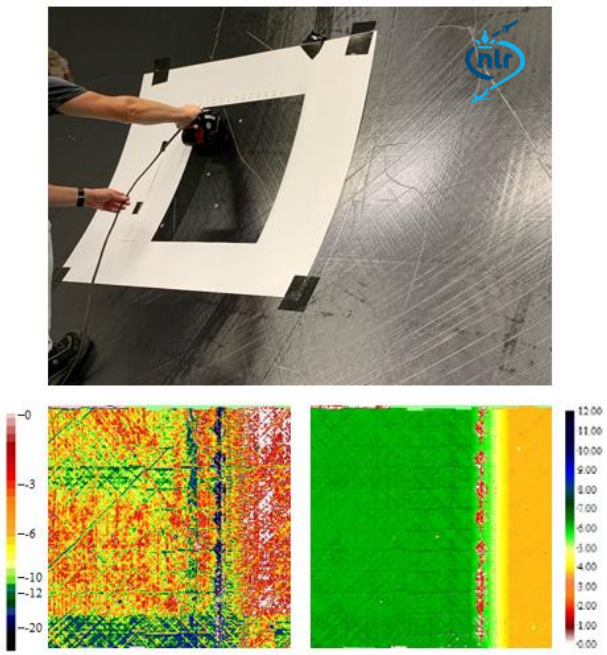
Length: 8.5 m; Ø 4 m

Co-funded by
the European Union

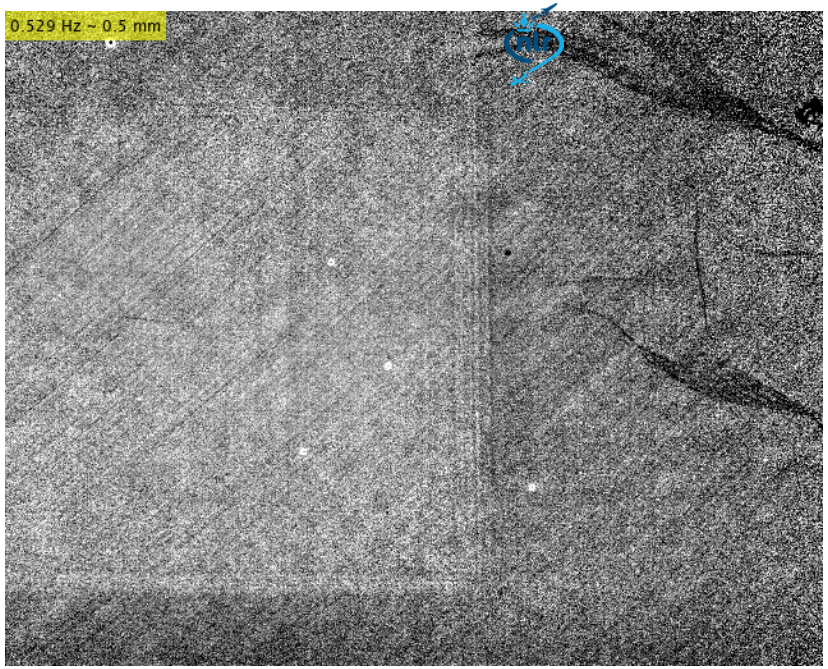
INSPECTION

Inspection methods: complementary and for comparison:

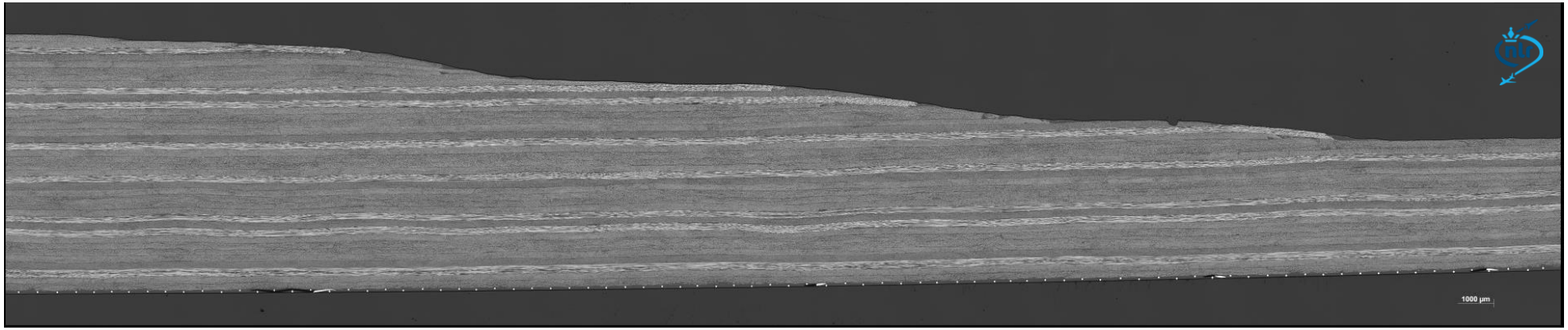
- Geometry measurements
- C-scan of cargo door cut-out
- PAUT roller probe locally
- Thermography globally (fast method)
- Micrographs of cargo door cut-out



PAUT roller probe



Thermography at multiple frequencies



Micrograph

Co-funded by the European Union

CONCLUSIONS

World's largest thermoplastic aerospace part: successful lower fuselage skin manufacturing for the MFFD overall:

- Shiny fuselage skin with excellent quality at outside
- Good laminate quality, very little porosity
- Geometrical steps in the weld areas are well defined
- Robust manufacturing concept demonstrated for such a large TP skin
- Further opportunities for optimization identified towards industrialization
- Delivered for assembly into STUNNING's pre-equipped lower part of the MFFD (GKN Fokker, NLR, TUD, Diehl)
- Looking forward to the integration with the upper shell into the complete MFFD

On-the-way to be used in the assembly the lower fuselage of the MFFD by STUNNING consortium partners GKN Fokker and SAM|XL

Movie: https://www.youtube.com/watch?v=WBGQgHvZc-g

Co-funded by the European Union

CONTACT, ACKNOWLEDGEMENT AND DISCLAIMER

Contact

Johan Kos
johan.kos@nlr.nl
Phone: +31 88 511 3494

Acknowledgement

This project has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No 945583. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Clean Sky 2 JU members other than the Union.

Co-funded by the European Union

CLEAN AVIATION

ENGAGE

with US!

www.clean-aviation.eu

Visit our online stand at
https://cleansky.virtualfair.be/

Co-funded by
the European Union