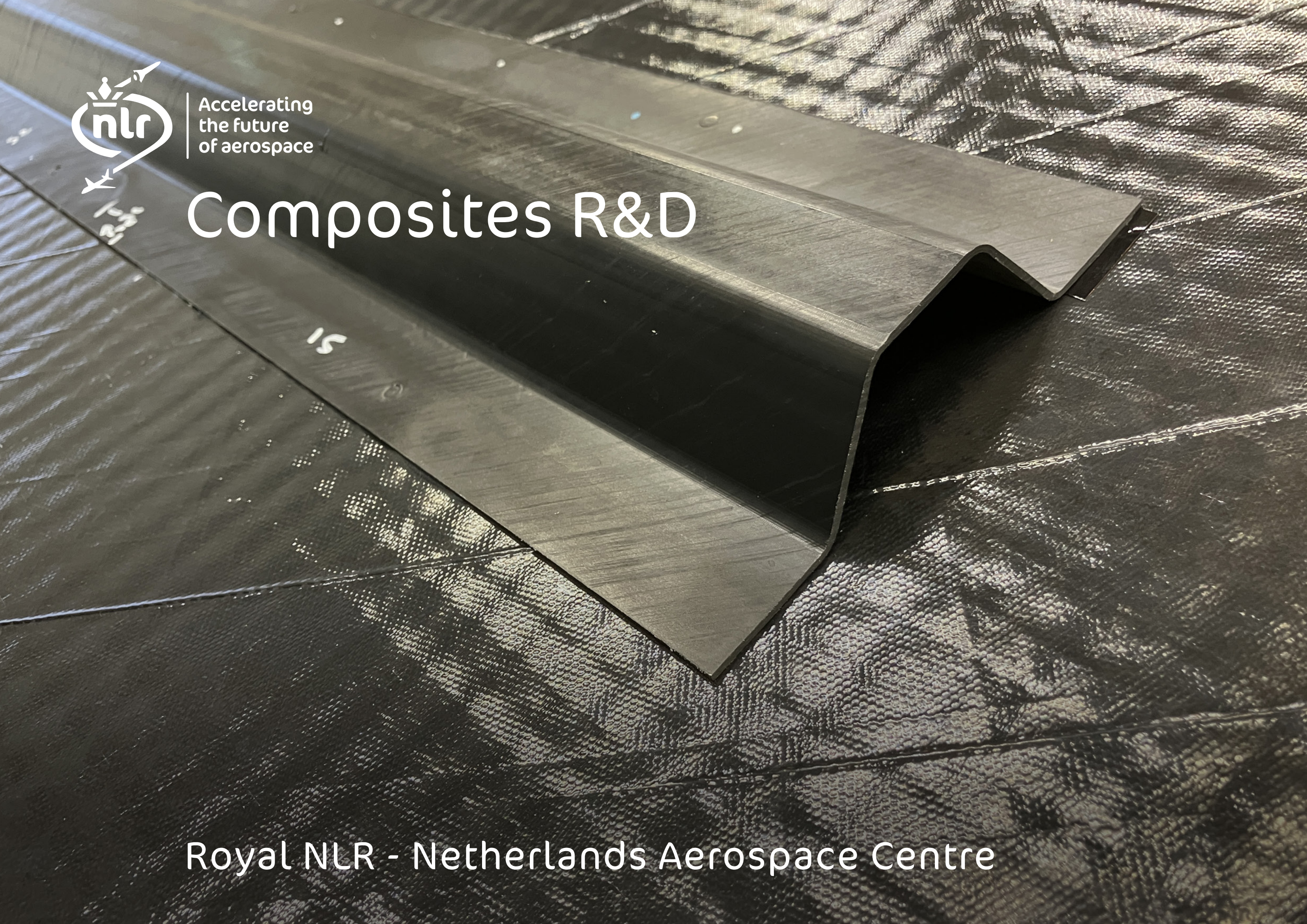


Accelerating the future of aerospace

Composites R&D

Royal NLR - Netherlands Aerospace Centre

From process optimisation to industrialisation

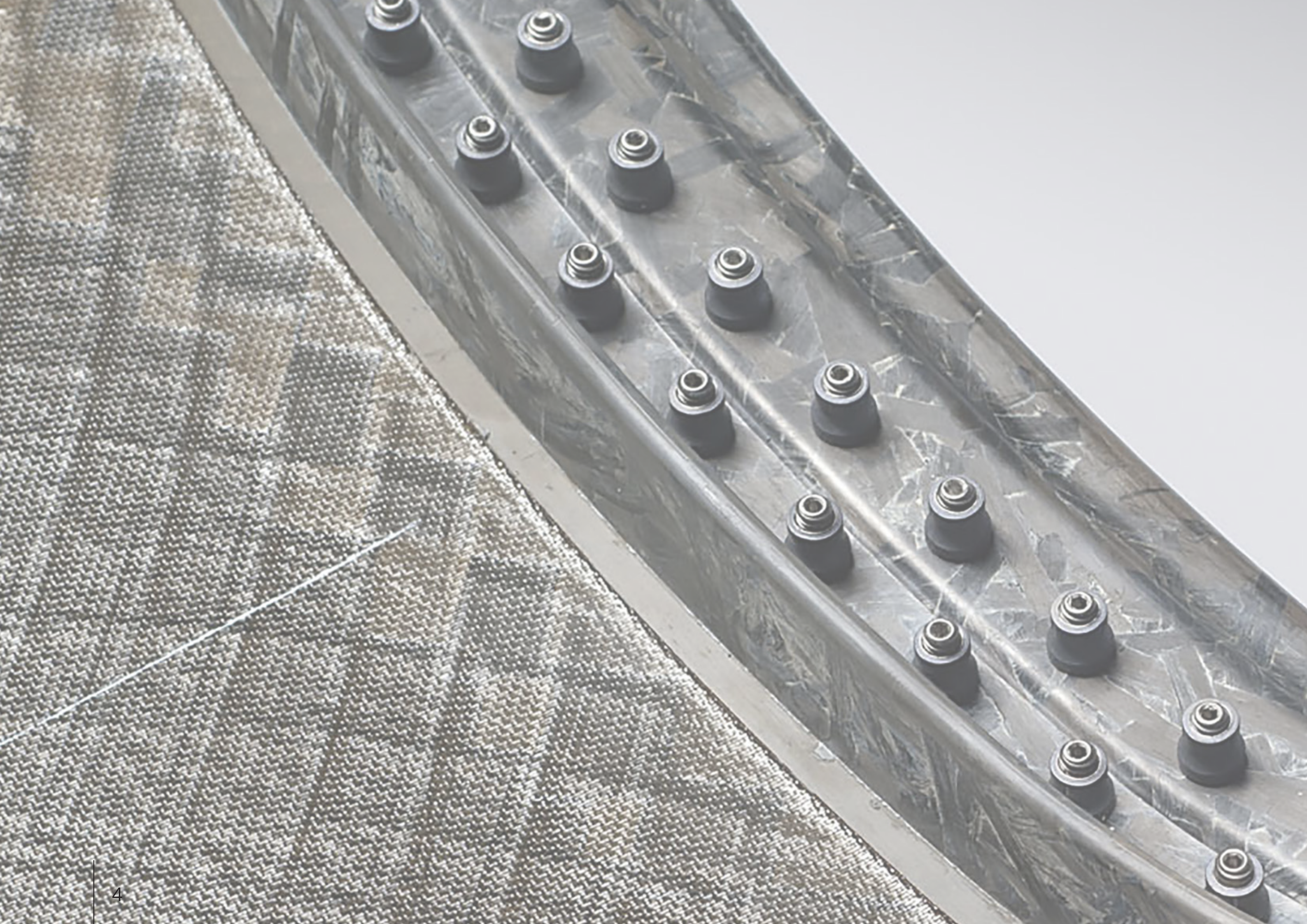
Efficient, durable and automated

A key objective for more efficient and sustainable aircraft is to make lightweight, durable and affordable parts which are designed for ease of maintenance. To be allowed to use parts made of new materials like composite and metal additive printed components in an industry like aviation, all of the materials must be accompanied by the right certification. NLR takes care of the entire process, from calculation and design all the way through to manufacturing, repair and certification. NLR assesses material properties, develops structural concepts and manufacturing technologies, designs components and builds parts up to the level of full scale prototypes. Spanning the entire spectrum of product development is what makes NLR unique.

This booklet gives an overview of the broad spectrum of the knowledge, capabilities and facilities that Royal NLR is applying in the research projects and programs in the Netherlands and worldwide.

We hope you will enjoy reading about our research and welcome you to contact us for more information.

NLR – Royal Netherlands Aerospace Centre



R&D for automated composite manufacturing

AUTOMATED COMPOSITE MANUFACTURING TECHNOLOGY CENTRE (ACM TECHNOLOGY CENTRE)

It starts at the ACM^3 Technology Centre, a facility that addresses research questions at the low to medium Technology Readiness Level (TRL) or levels 3 to 6. In the field of construction technology, NLR develops at almost all TRL levels from 1 to sometimes 8. To be able to implement the processes properly elsewhere, the goal is to work towards generic, flexible systems. A significant portion of the research nowadays takes place virtually using simulations, which speeds up lead time and reduces costs.

AUTOMATED COMPOSITE MANUFACTURING PILOT PLANT (ACM PILOT PLANT)

After the ACM^3 Technology Centre phase, it continues to the ACM^3 Pilot Plant for the development of TRL 6 to 8. Within the ACM^3 Pilot Plant NLR uses state-of-the-art equipment . The end-user must be able to do a copypaste, so to speak, the processes and procedures that were developed and start up production in their own facility.

CERTIFICATION

When developing a new composite part, certification immediately has to be factored in from the start. NLR is deeply involved in materials research so as to gain a better understanding of what happens to various materials, such as composites and printed parts. NLR ranks among the leaders when it comes to knowledge and certification.

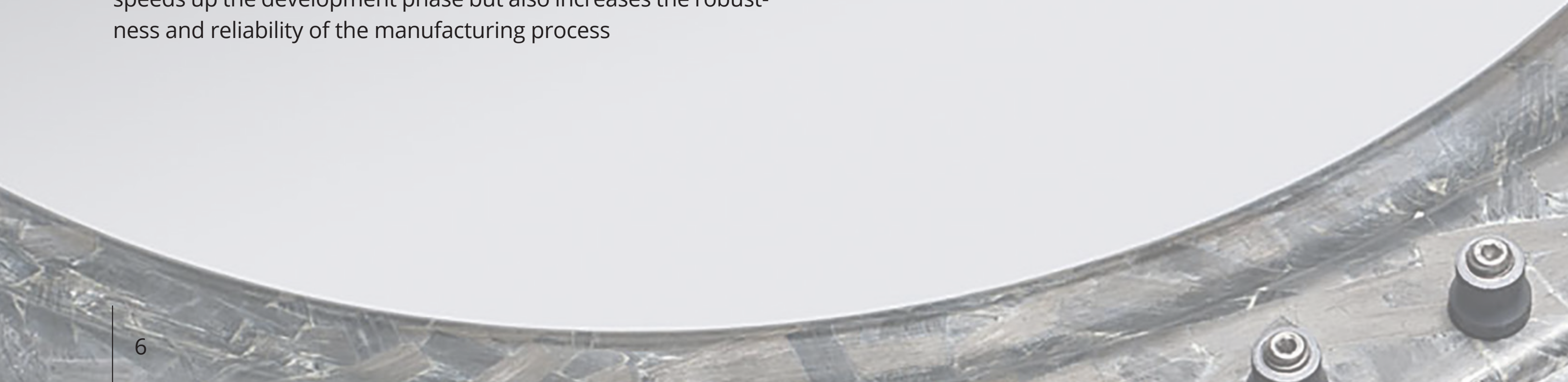
AUTOMATED MANUFACTURING AND DIGITALISATION

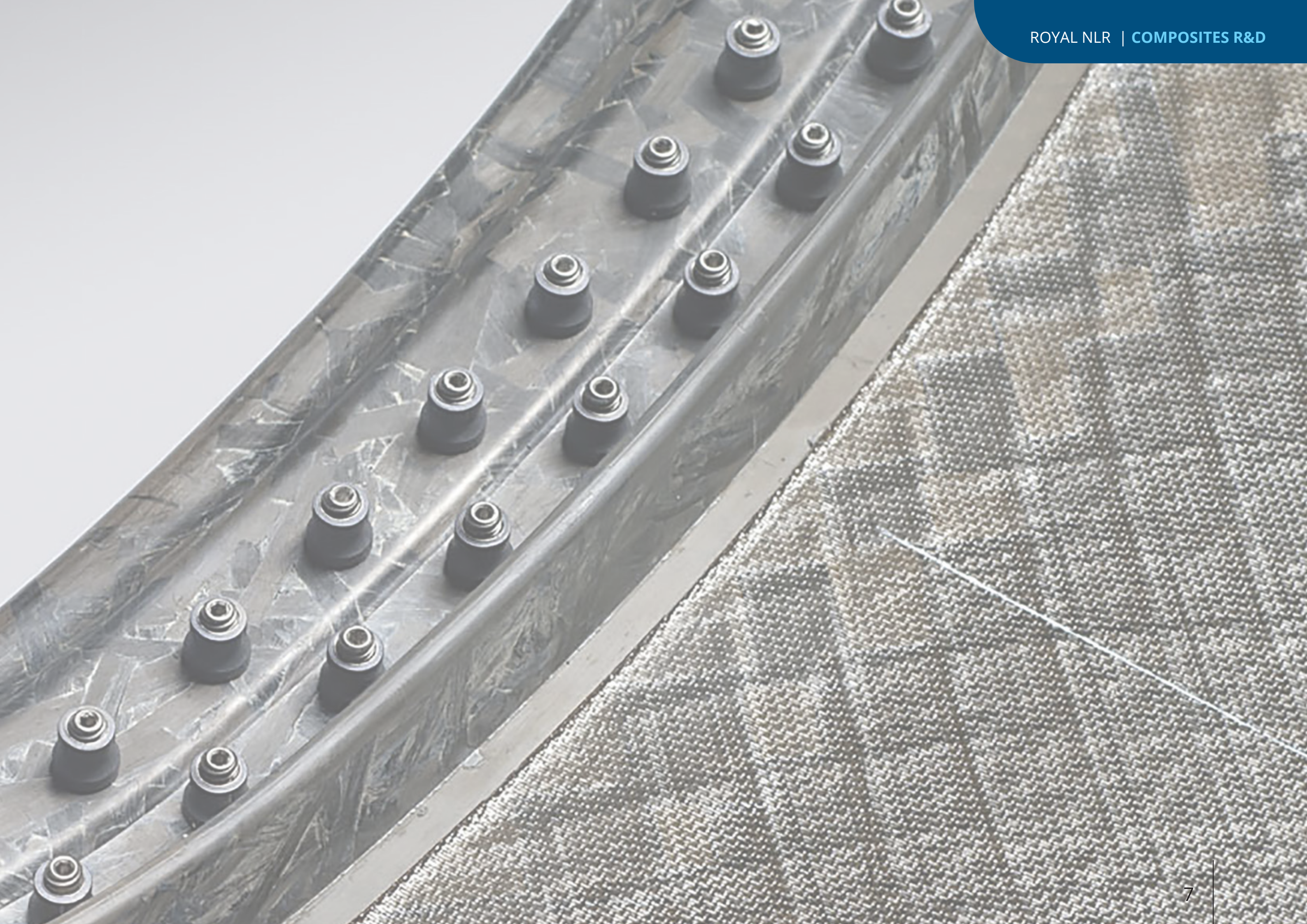
With the increasing penetration of robots in the production process, NLR also meets the demand for automation. The ACM^3 Technology Centre develops a robot-based process for producing composite components. The actual robots are always 'off-the-shelf' models to which various end effectors can be fitted. If necessary, NLR develops its own end effector, frequently in cooperation with the robot manufacturer. NLR knows the requirements a certain robot end effector must meet, such as the pressure that must be exerted, its flexibility and so on. This is an important element in the cooperation with SMEs. NLR has the fundamental knowledge and understanding of materials, the manufacturing process and the final products.

Beside automation of manufacturing processes ACM^3 is also active in the field of digitalisation of manufacturing processes (Digital Twin technology). The Digital Twin technology not only speeds up the development phase but also increases the robustness and reliability of the manufacturing process

DETECTING AND REPAIRING DAMAGE OF COMPOSITE PARTS

Besides the manufacturing industry, NLR is also active for MRO (Maintenance, Repair and Overhaul). There is a lot of MRO work that has to be done because, compared with metals, composites behave differently in the event of damage and maintenance. Knowledge of ageing and repair is becoming increasingly important, particularly with the growing number of composite aircraft parts. The most important question in the aerospace industry is whether it is possible to continue flying after damage has occurred. With an aircraft made of metal there will be a dent, but in composite material you probably won't see anything, although the part could be damaged all the same. NLR has the equipment and the know-how to inspect such an aircraft and to determine whether the damage has to be repaired immediately or whether it is possible to continue flying.





Technology Readiness Level of R&D projects

TRL stands for Technology Readiness Level, a method of estimating technology maturity of Critical Technology Elements (CTE) of a program (hardware, components, peripherals, etc) to integrate this technology into an operational system or subsystem. TRL 1 is the lowest level, where scientific research begins to be translated into applied research and development (R&D). For NLR, TRL 8 is the highest level, where the actual system is completed and qualified through test and demonstration. TRL 9 is the highest TRL level. In close collaboration with industry, NLR elaborates ideas that are not yet viable or for which the business case is not yet clear, but which have the potential to become really big. Focus of the research is related to high performance fibre reinforced composites (thermoset and thermoplastics) and metal additive manufacturing. Key topics that are being addressed are development of new design, manufacturing and assembly concepts and automation and digitalisation of manufacturing and assembly. NLR does this in a research environment where we can also develop the hardware ourselves.

R&D cases

Lightweight structures
Automated (robot) based manufacturing
Welding of thermoplastics
Press forming
Out-of-autoclave processing
Digital twin concepts for manufacturing units
Large scale additive manufacturing

JEC WORLD INNOVATION AWARDS WINNER 2025

THE SOLUTION

As part of the MFFD development, the STUNNING project developed, manufactured and delivered the 180° full scale lower half of the multi-functional integrated thermoplastic fuselage, including cabin and cargo floor structure and relevant main interior and system elements. The STUNNING team applied advanced design principles, innovative system architecture and advanced materials and processes.

Watch the making of the thermoplasic fuselage

This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme EU

STUNNING:

the world's largest known thermoplastic aircraft structures

The Clean Sky 2 Multifunctional Fuselage Demonstrator (MFFD) with its 8.5 meter long composite-made fuselage section with an approx. 4 meter diameter gives a glimpse of what a next-generation aircraft could be. This typical section of a single aisle aircraft fuselage is completely produced from thermoplastic. Now, Royal NLR's STUNNING project is turning heads as the MFFD's largest component, the 8.5 meter long lower fuselage skin, has been manufactured and delivered to the project partners.

THE CHALLENGE

As part of the EU's Clean Sky 2 initiative, the aerospace industry is looking for flight path to sustainability. To deliver a double-digit fuel burn reduction for the Large Passenger Aircraft (LPA) segment next generation fuselage structure concepts are needed in which cabin, cargo and physical system elements are integrated. Its three main and for STUNNING overarching objectives for future Single Aisle Aircraft fuselages compared to the state of the art are:

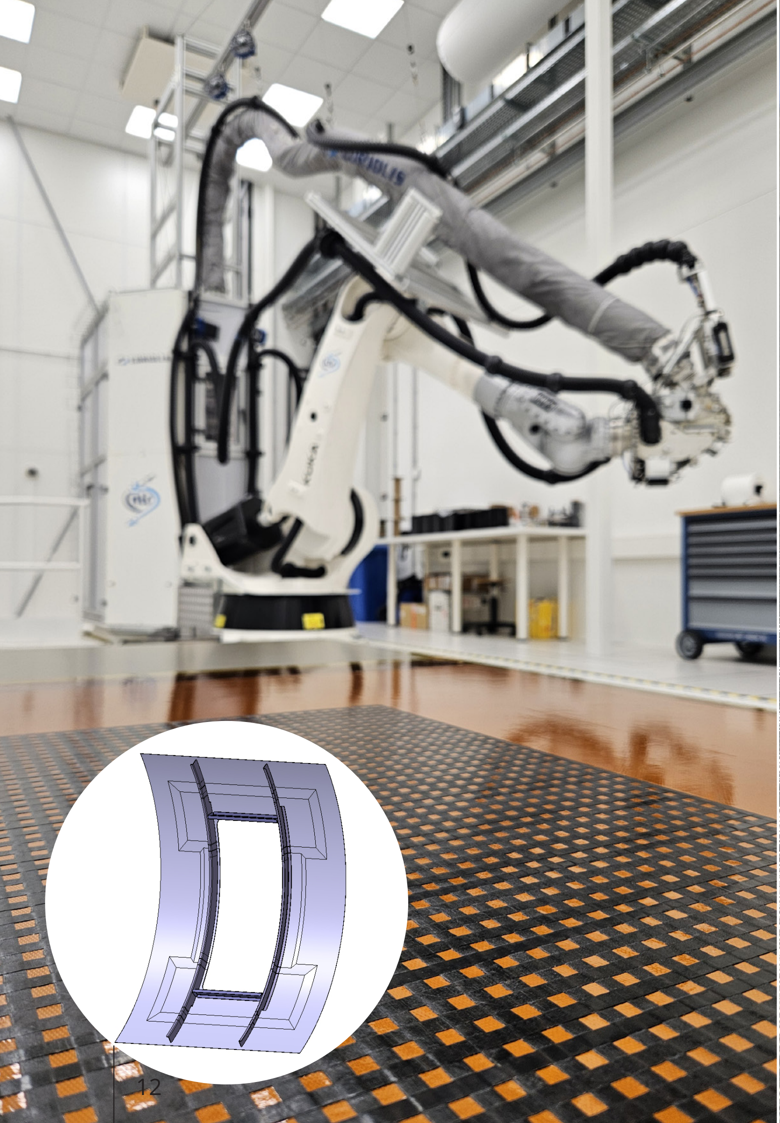
- Reduce weight
- Reduce recurring cost
- Enable a High Rate Production (HRP) of 60-100 shipsets per month

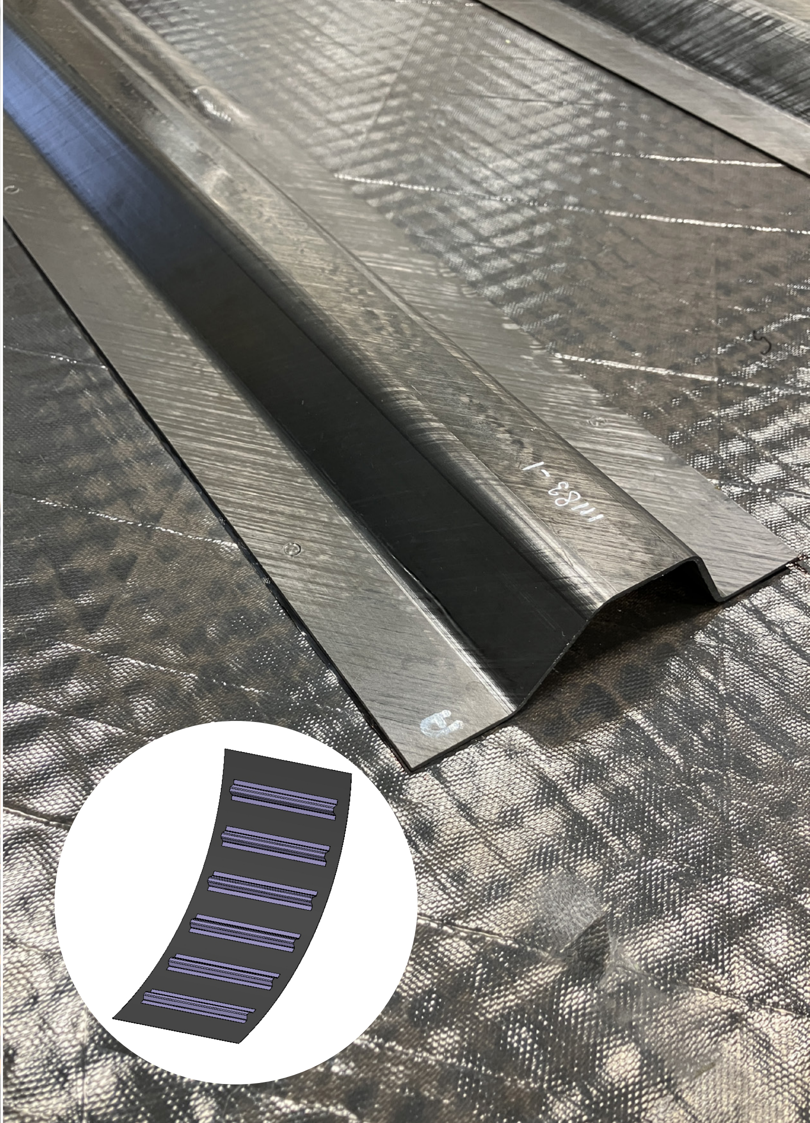
Project partners:
Industry (NL) : Fokker Aerostructures
Industry (EU) : Diehl
Research organisations : NLR
Universities : TUDelft, SAM|XL

WHAT DID WE DO

NLR developed and applied a competitive manufacturing process using fast AFP layup of two 90° fuselage segments out of thermoplastic Cetex® TC1225 LMPAEK/T700 uni-directional carbon fibre material on a layup tool at room temperature. The part was consolidated by the NLR team in an innovative consolidation mould (EMOTION CfP) using the research autoclave at the German Aerospace Centre (DLR) in Stade, Germany. The consolidated 180° fuselage skin was inspected at NLR using Thermography and delivered to the STUNNING partners for the integration of structures, interior and systems installation.

A significant weight reduction resulting from this integrated approach, based on advanced thermoplastic assembly principles like welding, will contribute to the environmental goals. Manufacturing costs and assembly times will be reduced and high production rates can be realized. To achieve the overall goals, 'beyond state of the art' technologies are developed and verified in dedicated tests up to TRL5.





Oven consolidated thermoplastic skin with induction welded press formed stringers

THE CHALLENGE

Thermoplastic composites can lead to more efficient production methods and better recyclability. But new materials will only find their way into future structures if the manufacturing processes are efficient and environmentally friendly. Within two Dutch programmes; Luchtvaart in Transition and NXTGEN Hightech, both funded by the National Growth Fund, the possibilities, necessary equipment and production processes are investigated. Composite aircraft fuselage panels for example are cured in large expensive autoclaves and stiffeners and door surroundings are often bolted to the skins using an immense number of fasteners. The challenge lies in increasing production rates while decreasing societal impact.

WHAT DID WE DO

Fast automated fibre placement (AFP) of fuselage panels, in combination with faster and more energy efficient consolidation steps, is investigated with LMPAEKTM material of Toray. To minimise manual labour hours, fibre placement is also used for the copper lightning strike protection (LSP) layer on the outside of the panel, in this case the first ply on the AFP mould. Instead of using an autoclave, an oven or press is used after AFP for the consolidation. The oven consolidation is optimised for thick panels with local pad ups. Induction welding of thick composites is more challenging, especially in combination with copper layers on the outside. Several fibre placement strategies for the copper layer are investigated in the programmes, to find the best solutions for the induction welding of stringers and door surroundings afterwards. Energy consumption is monitored and the use of auxiliary materials is tracked and compared.

THE SOLUTION

Induction welding of stringers and door surroundings can be a solution to minimise the number of fasteners. The door surroundings can be efficiently produced in thermoplastic materials by using fast AFP to produce flat blanks followed by press forming to create the C-shaped products. Induction welding with copper LSP layers is possible if the correct cooling methods are used during the process. This in combination with the best fibre placement strategy for the copper LSP layer will lead to more efficient fuselage panels.

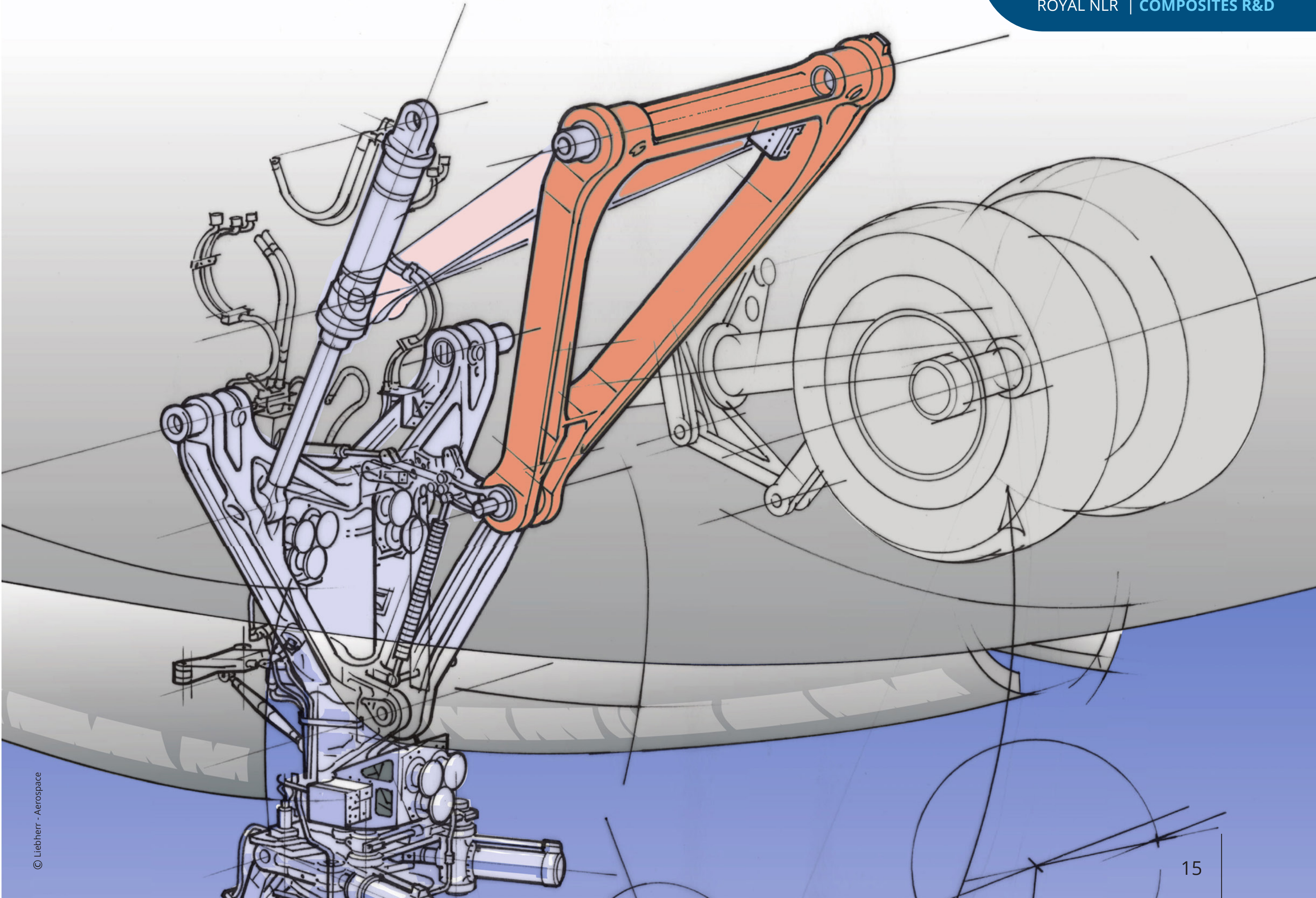
Acknowledgement: This research is conducted within the research and innovation programmes Luchtvaart in Transitie and NXGEN Hightech, which are co-funded by National Growth Fund of the Netherlands.

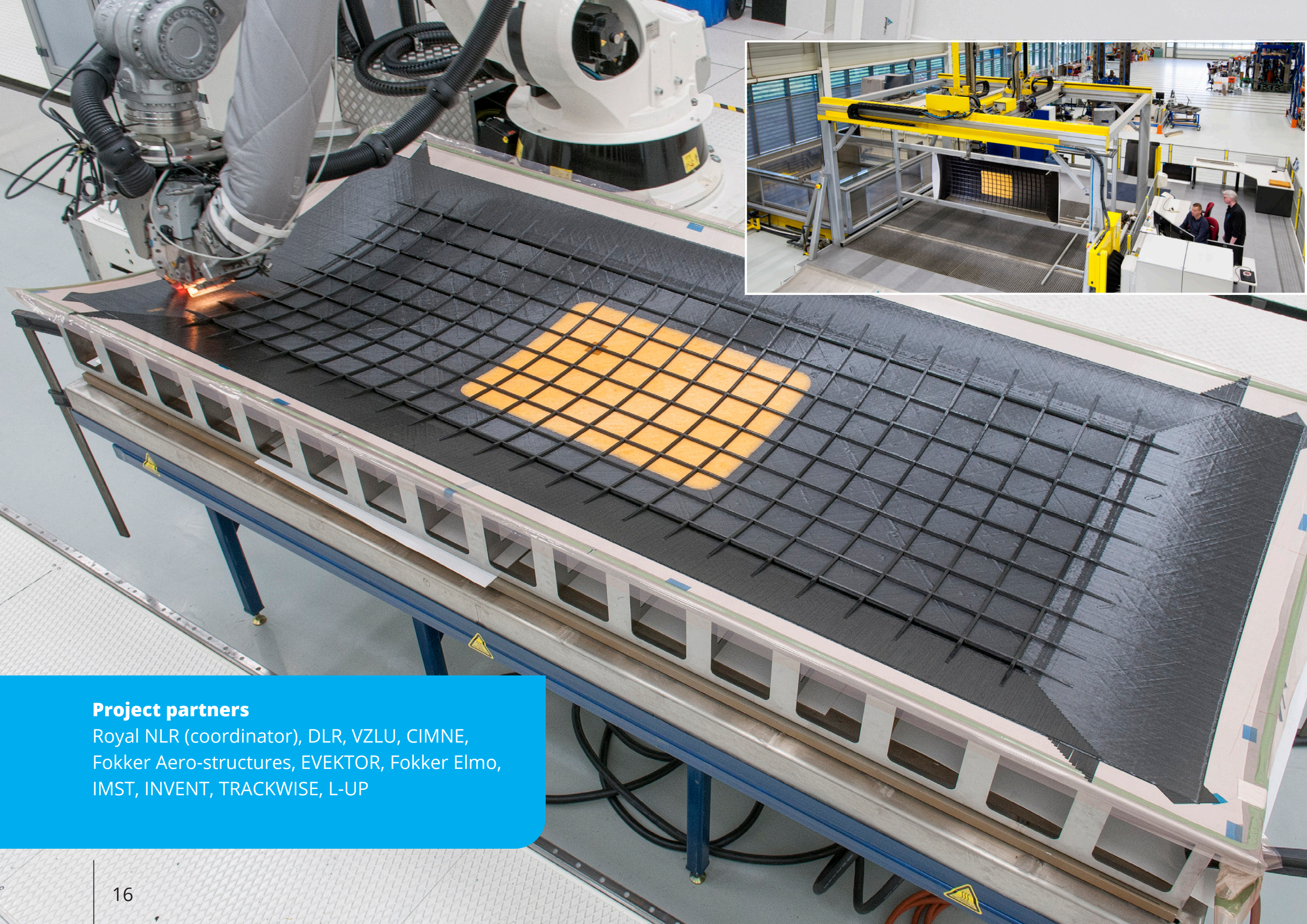
Development of composite drag stay for Airbus A350-1000

Within the CS2 Systems ITD a CFRP drag stay for the A350-1000 is being developed in the Core-Partner project HECOLAG. The goals for the CFRP structure are a weight saving of over 30% at recurring cost similar to the current aluminium drag stay as manufactured by Liebherr-Aerospace. The CFRP drag stay is designed by Fokker Landing Gear (part of GKN Aerospace) in cooperation with NLR, to requirements set by Liebherr Aerospace. Within the project NLR has focused on automated manufacture of preforms for these types of complex geometries. The present design is optimized for automated preform manufacturing and offers a weight saving of approximately 40%. The tooling for prototype manufacturing is designed and built by Compose Tooling. Functional prototypes are being manufactured by NLR and are tested by Fokker Landing Gear.

Project: HECOLAG
Customer: Liebherr Aerospace
Project partners: Royal NLR, Fokker Landing Gear, Compose

Horizon 2020
European Union Funding
for Research & Innovation





Project partners
Royal NLR (coordinator), DLR, VZLU, CIMNE, Fokker Aero-structures, EVEKTOR, Fokker Elmo, IMST, INVENT, TRACKWISE, L-UP

ACASIAS: Advanced Concepts for Aero-Structures with Integrated Antennas and Sensors

THE CHALLENGE

Aircraft drag reduction is an important issue for cleaner air transport. Up to now, satellite antennas are positioned on top of the aircraft in large protruding radomes. Within the European ACASIAS project, Royal NLR is investigating the possibilities to integrate antennas in the structure to create smoother outer surfaces.

WHAT DID WE DO

The complete panel is cured on a female mould in an autoclave at a higher temperature and pressure. To support the stiffeners during this process no labour intensive tools were used. Instead of the common used high number of supporting blocks a silicon bag is developed. The silicon bag has the same pattern as the final panel with stiffeners. In this way, an affordable panel was made with integrated stiffeners. No man-hours are required for cleaning of tool blocks, bonding of stiffeners or the installation of fasteners to connect stiffeners.

THE SOLUTION

As part of the programme, NLR and the ACASIAS partners have developed new beam forming Ku-band antennas, but also new composite structures with integrated Antennas. The ACASIAS fuselage panel is made with a fibre placement machine, using carbon fibre prepreg. Fibre placement machines are often used for large surfaces with local patches. NLR has now optimised the process for the manufacturing of thin stiffeners. In the crossings of the lattice structure, half of the tapes are cut in one direction and half of the tapes are cut in the opposite direction, so no thickness build up occurs. In the middle of the panel, glass fibre prepreg is used to create a transparent skin for the internal antennas.

By doing so, antennas can be placed on the inside instead of on the top of an aircraft, reducing the total drag of the aircraft.

HORIZON 2020

ACASIAS

Digital Twins:

Mastering and optimising highly automated composites manufacturing processes

The aerospace manufacturing and production industries are increasingly challenged to be more competitive, and do more with less. To be able to comply with higher production rates, affordability and constant quality, high levels of automation are required for current-day manufacturing processes. This results in more parts meaning more process data to control and keep track of while the number of operators at the production floor has not grown.

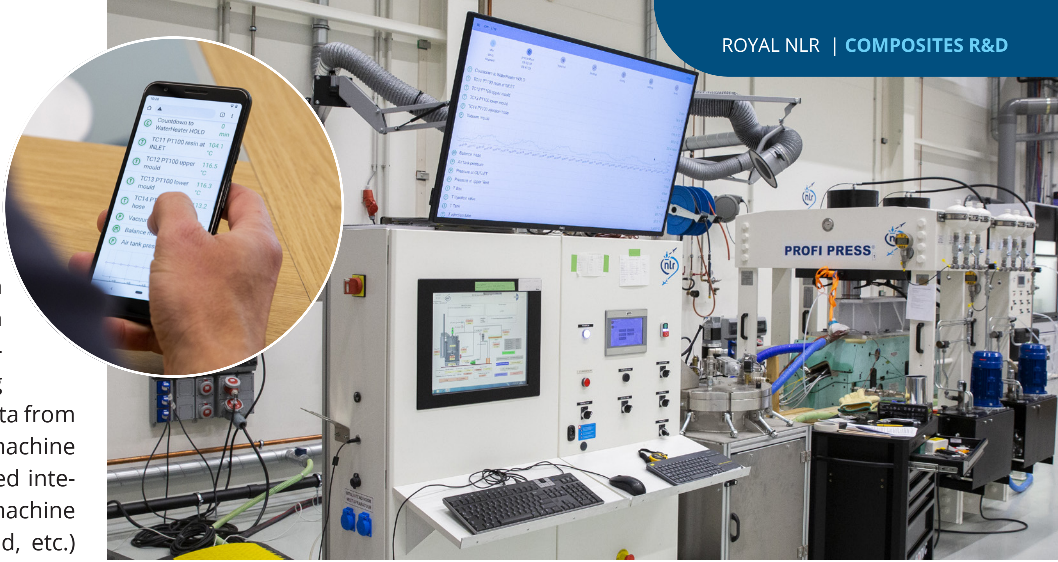
THE CHALLENGE

The challenge is to be able to maintain overview of individual process steps, part quality and status of equipment. Advanced monitoring and inspection of automated processes by a Digital Twin (DT) of the physical manufacturing environment could help an operator to filter all the available data supporting timely detection of production flaws, first-time right production, product quality, and delivery reliability. Additionally, all the collected data can be used for many more purposes:

- Design and optimise the production facilities and manufacturing processes
- Optimise maintenance
- Digital threads, digital product passports, and managing data on behalf of certification

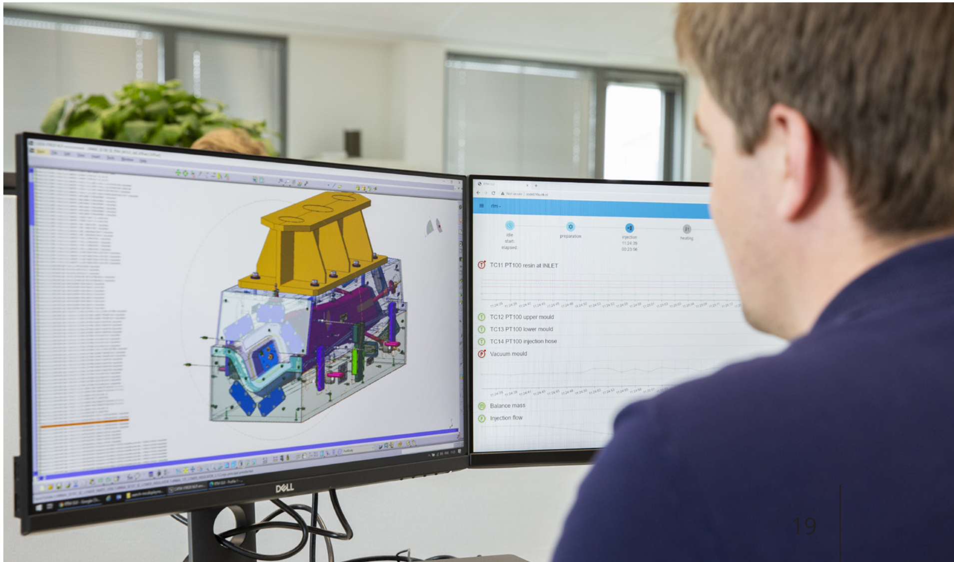
THE SOLUTION

The Digital Twin compares the actual situation, going-on real-time process and product information of the physical manufacturing environment, against the expected and simulated behaviour and properties, thereby signalling deviations beyond thresholds. The DT raises situational awareness through dedicated dashboards and advanced interactive visualisation technology (e.g., VR, AR via handhelds, information projection on PT), enabling and supporting operator and mechanics to monitor, understand, inspect, adjust and repair. A DT can collect and organise data and statistics from processes, detect trends, and analyses data across process runs, to support process optimisation and condition-based predictive maintenance. The Digital Twin facilitates digitals threads and passports of the products and machinery.



WHAT DID WE DO

NLR developed a Digital Twin ecosystem and implemented this as test case on our Resin Transfer Moulding RTM manufacturing environment for validating and testing. By connecting actual live data from the industrial OT/IT technology and machine communication protocols, and a tailored integrated mix of IT technologies (e.g. AI/machine learning, data analytics, big data, cloud, etc.) and data sets, a digital replica (DT) of the physical RTM manufacturing environment was realised. The Graphical User Interface (GUI) of the DT and added handhelds/tablets to the work environment that advises the operator not only when on the production floor but also when the operator is taking a coffee break, have created a powerful “smart assistant”. Besides, the Digital Twin is available in any place over the world remotely, in (near) real-time. It only visualises the relevant data in each phase of the manufacturing process and issues alarms or warnings which are triggered based on defined thresholds and predictions by the Digital Twin.



Enabling interlayer temperature control for Large Scale Additive Manufacturing process

THE CHALLENGE

One of the main challenges of Large Scale 3D printing of high temperature thermoplastics is the control of the interface temperature – which determines the degree of bonding between consecutive layers. When the deposited material has cooled down in excess, poor adhesion is achieved between layers, leading to insufficient strength, delamination, cracking and part failure. If the material has not cooled down sufficiently, it won't support the consecutive layers, therefore leading to print failure. The interface temperature control is especially important when attempting large scale prints and when processing semi-crystalline thermoplastics.

WHAT DID WE DO:

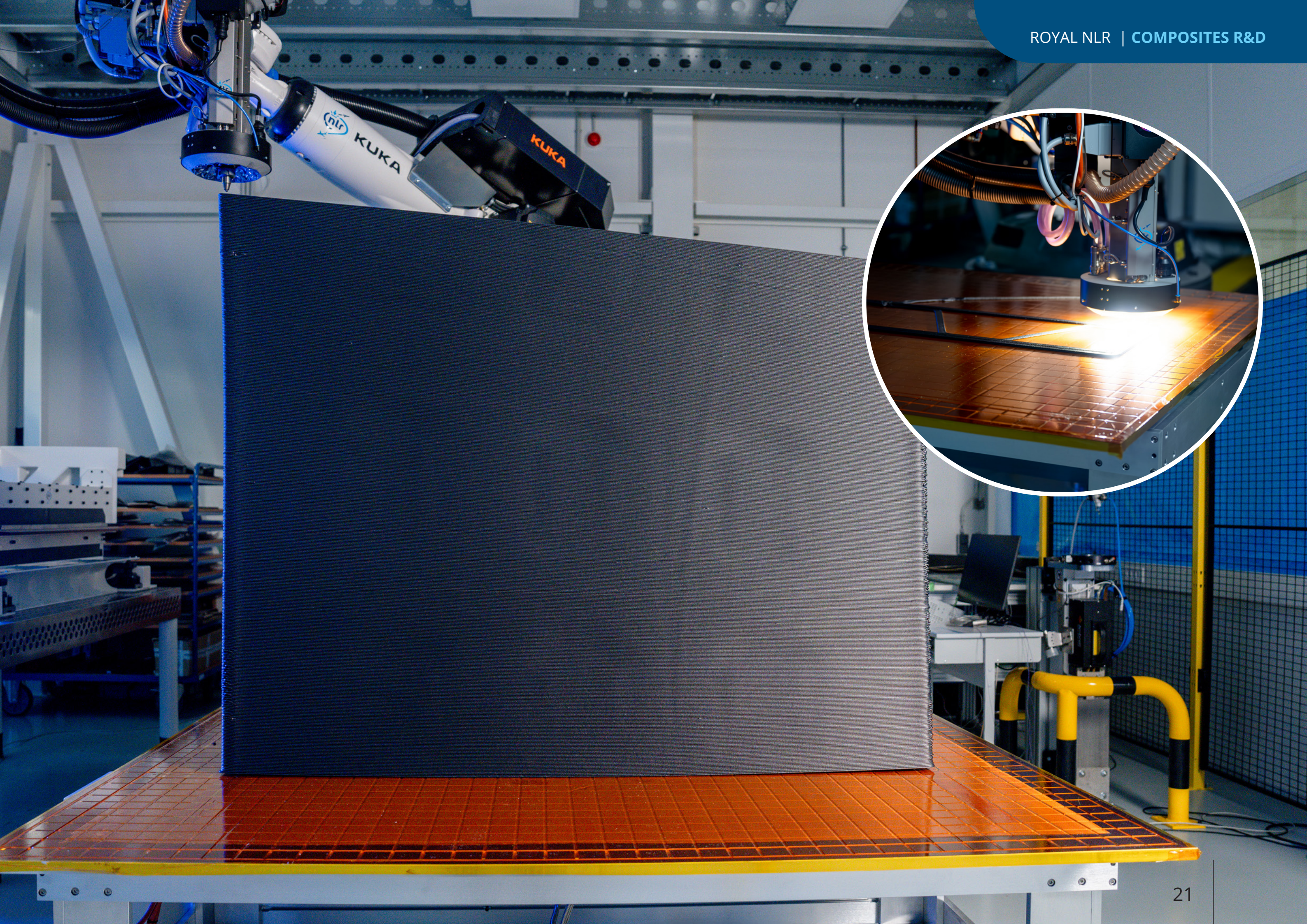
An equipment upgrade was carried out on the NLR LSAM's setup, allowing for better temperature control during the printing process, and the effect on the processed material properties were studied to further understand the optimal interface temperature. To demonstrate the improvement, a large-scale aerospace grade mould is manufactured, achieving five times longer layer length compared to previous experiments, with very high quality and printing stability.

THE SOLUTION:

Upgrading the LSAM equipment with the Directed Energy Material Extrusion (DEMEX) system, developed by LEAM, allowed NLR to control and adjust the interface temperature by means of active heating, cooling or adaptive printing speed. This upgrade also paves the way to further exploring new applications, like overprinting. NLR will investigate how to overprint stiffening elements on a substrate (i.e. composite panels) with the use of LSAM.

NXT GEN hightech

Acknowledgement: This project is made possible in part by a contribution from the National Growth Fund program NXTGEN HIGHTECH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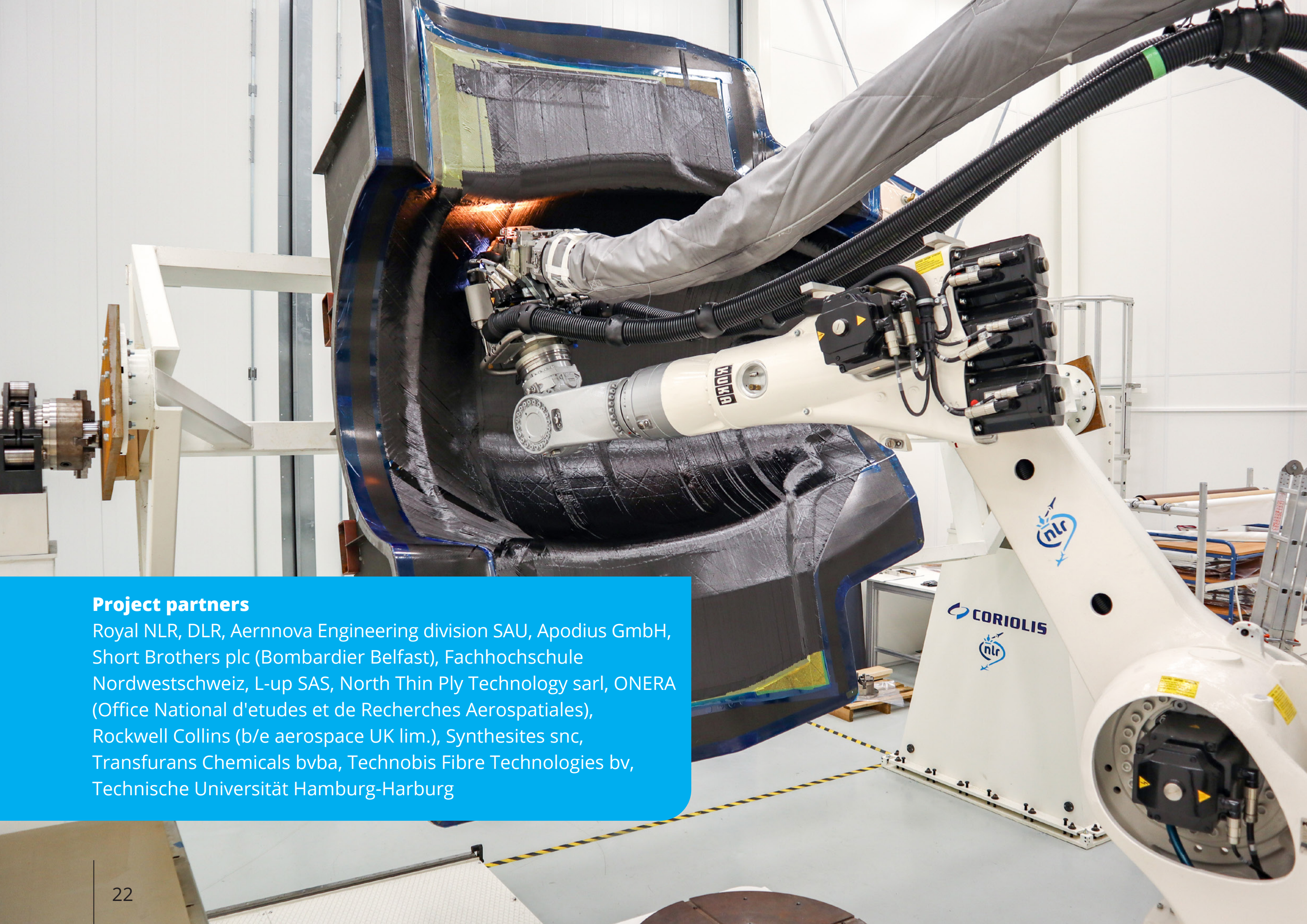


Project partners
Royal NLR, DLR, Aernnova Engineering division SAU, Apodius GmbH, Short Brothers plc (Bombardier Belfast), Fachhochschule Nordwestschweiz, L-up SAS, North Thin Ply Technology sarl, ONERA (Office National d'etudes et de Recherches Aerospatiales), Rockwell Collins (b/e aerospace UK lim.), Synthesites snc, Transfurans Chemicals bvba, Technobis Fibre Technologies bv, Technische Universität Hamburg-Harburg

SuCoHS: Sustainable and Cost Efficient High Performance Composite Structures demanding temperature and fire resistance

The SuCoHS project focusses on new structural concepts with novel multi-material composites to provide high resistivity against thermal, mechanical and fire loading. In order to achieve the project objectives for sustainable and cost-efficient high performance composite structures, the SuCoHS concept focusses on the three main topics: design, manufacturing and operation.

THE CHALLENGE

The main challenge questions for this program are:

- Can we design and develop novel high temperature composite multi-material systems to enable new composite solutions for weight savings up to 15% and costs up to 17%?
- Can we develop new robust sensor systems to increase safety and aircraft availability and to decrease maintenance costs up to 15%?
- Can we demonstrate efficient automated tailored composite manufacturing to reduce time and costs for individual production steps up to 30%?

THE SOLUTION

Develop new materials and efficient manufacturing processes for fire and temperature resistant composites structures. Explore hybrid manufacturing processes, combining different materials and manufacturing technologies as well as sensor- and simulation-based adaptive process and quality control strategies. Perform manufacturing trials and customized material tests to guarantee performance of novel multi-material-systems.

WHAT DID WE DO

New high temperature and fire resistant composites were developed with improved toughness by making use of effects from resin modification, thin ply technologies and woven fabrics. New manufacturing technologies were developed to provide tailored multi-material preforms with specific functionalities (thermal conductors/ barriers, damage resistance, integrated sensors) to enable efficient manufacturing at minimum waste. New manufacturing technologies with integrated process and structural usage monitoring systems were validated and checked on reliability by manufacturing of representative critical details. All developed methods, designs and technology integrations were validated and demonstrated by NLR on thee use-cases: (1) High temperature nacelle component, (2) Composite aircraft interior shell and (3) Tail cone panel substructure.

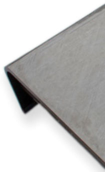
Clean Sky 2

This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme EU (Grant Agreement number: 769178)

Thermoplastic upper spar for an aircraft pylon by Automated Fibre Placement

The challenge: to find out whether thermoplastic materials can be used for really thick and large components, for example in aircraft. Parts of the aircraft engine pylon become very hot during normal use of the aircraft. For that reason, the pylons currently used are commonly made of titanium. Most of the parts, such as ribs and spars in the pylon, are made by forging and milling. A reduction of costs might be achievable if the titanium parts can be replaced by composite materials.

As part of a Dutch innovation programme TAPAS 2 (Thermoplastic Affordable Primary Aircraft Structure 2), NLR examined the manufacturing of a large and thick thermoplastic composite part using Automated Fibre Placement and Cetex® TC1320 AS4D PEKK material of Toray. Within this programme, a preliminary design was made for a pylon upper spar using finite element calculations. Mechanical tests were conducted with the material at higher temperatures and a first prototype was constructed. The prototype was made by fibre placement on a male mould and subsequently consolidated in an autoclave.



Based on developments in this programme, it was concluded that thick components can be made of thermoplastic materials with an automated manufacturing process, thus reducing weight and production costs. The material is usable at higher temperatures. This innovative process has great potential for thick U-shaped products in the aerospace sector. The technique is also usable as a replacement for a wide variety of products like wing spars, stabiliser spars and floor beams.

Customer: Netherlands Enterprise Agency - RVO
R&D: Royal NLR
Partners: GKN Fokker Aerostructures, Toray AC, Airbus

CFRP Vinci Thrust Frame

THE CHALLENGE

The Ariane 6 Launcher will enter a very competitive commercial launcher market. New entrants to this market have reduced the launch price per unit mass payload by half (50%). As a consequence a key requirement for the development of the Ariane 6 is reduced recurring production costs and increased performance. Compared to Ariane 5 the production costs should be reduced by at least 50%. Cost reductions and performance increase (both stiffness and mass) shall be realized in proposed materials, manufacturing technologies, processes, procedures and optimization of the industrial organization.

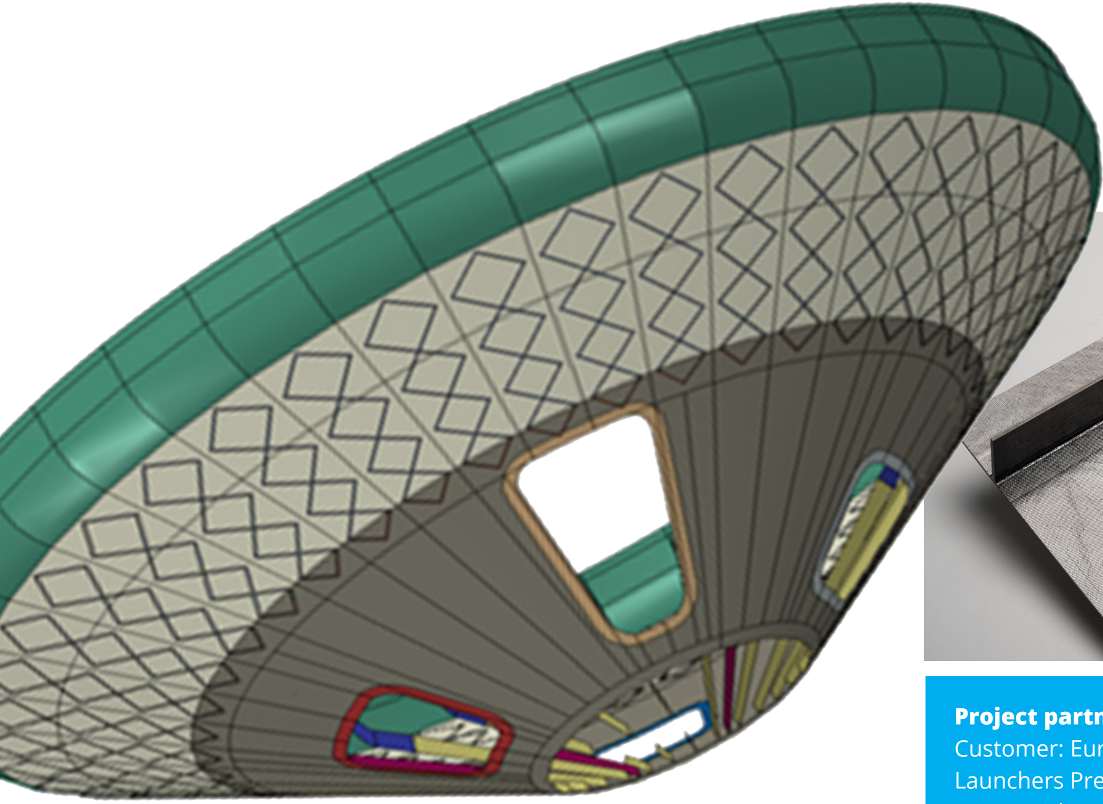
WHAT DID WE DO

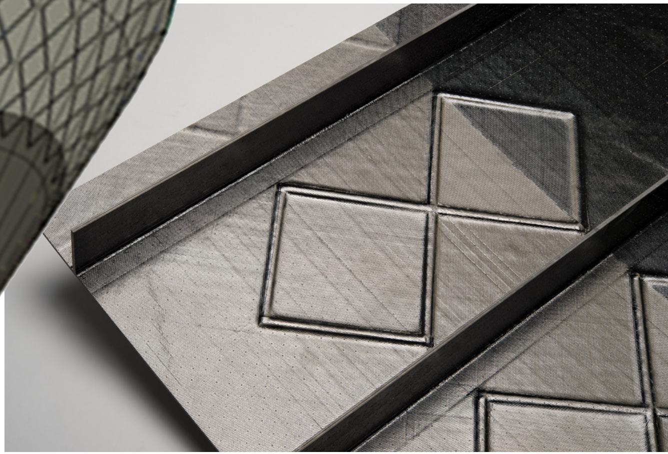
This innovative design in combination with the automated fibre placement technology will lower knock-down factors, reduce weight and minimize scrap material, resulting in reduction of material and energy consumption, processing time and increased payload. Together with application of smart tooling, a snowball effect is created to reduce. A detailed track record of each component will be available in a manufacturing database, containing as-built information.

THE SOLUTION

Currently, Engine Thrust Frames for launchers are made from metal. Previous programs showed that cost and weight can significantly be reduced by application of carbon fibre reinforced polymers in tailored ply architectures, processed by the automated fibre placement technology. Based on a reference finite element model provided by Airbus DS NL, NLR developed optimisation to reduce the amount of manufacturing steps and tooling and to create vector fields for the steered plies.

Dedicated local reinforcements are composed by smart overlapping in order to improve the buckling behaviour between the reduced amount of blade stiffeners. This innovative optimisation method in combination with the automated fibre placement technology will lower knock-down factors, reduce weight and minimize scrap material, resulting in reduction of material consumption and processing time in order to save manufacturing costs and increase the payload. In addition, fibre detection methods are integrated by Infactory Solutions into the automated fibre placement technology. Possible material defects like gaps, overlaps or twists are detected, analysed and written to a database. Corrections are applied in order to support first time right production for further cost reductions.





Project partners
Customer: European Space Agency – Future Launchers Preparatory Programme (FLPP)
Prime: Airbus Defence and Space Netherlands
Subs: NLR, Infactory Solutions

Project partners
Industry: (EU): PBS, MERL/ELEMENT, Piaggio, Grob, Evektor
Research organisations: Royal NLR, CIRA, ILOT, VZLU, INCAS

ESPOSA: Efficient Systems and Propulsion for Small Aircraft

THE CHALLENGE

Composites offer several advantages over metals to consider them for components in an aircraft nacelle design. The advantages: lower density, higher specific strength and stiffness, better corrosion resistance, better sound absorption characteristics and the possibility to reduce part count by moulding and curing of integrated structures. These advantages have led to increasing application of composites in jet engines over the last decades. However, this involved military and large civil aircraft engines. ESPOSA aimed at small aircraft composite nacelle development targeting:

- Cost reduction by 15%
- Part and weight reduction by 20%

WHAT DID WE DO

Royal NLR in association with project partner CIRA and resin supplier Raptor Resins successfully employed a new vacuum resin injection method using the Bismaleimide (BMI) resin system. With project partners Piaggio, MERL, CIRA and GROB, NLR developed and manufactured a Carbon-BMI nacelle for the Piaggio P180 exceeding the targets for cost, part and weight reduction.

THE SOLUTION

Development of new design approaches aimed at the realisation of advanced, higher temperature capability composite nacelle structures for small aircraft and leading to a cost effective manufacturing solution suitable for this class of aircraft. The advanced composites are to be used for nacelle components which traditionally could only be made using metals requiring significant thermal insulation resulting in a weight and cost penalty.

To achieve this goal several composite technologies were investigated in order to exploit the potential expressed by the most promising emerging materials and processes. Addressed topics:

- Composite materials and processes for high temperature nacelles
- Design engineering approach satisfying design and manufacturing constraints
- Test and validation high temperature performance

ESPOSA is a EU funded project (Grant agreement number: 284859)

Leading edge manufacturing by fibre placement with dry fibres and with prepregs

THE CHALLENGE

The reduction of the CO_2 emission is an important challenge for all industry and transportation sectors. To create a sustainable aerospace, several European research programmes are initiated within the Clean SKY 2 call. One of these programmes is titled Advanced Laminar Flow tAilplane, ALFA. A way to reduce CO_2 emissions of aircraft is to lower the drag (the aerodynamic force that opposes an aircraft's motion through the air). This can be obtained by creating a laminar flow over the wing. A very smooth surface is required for a laminar flow.

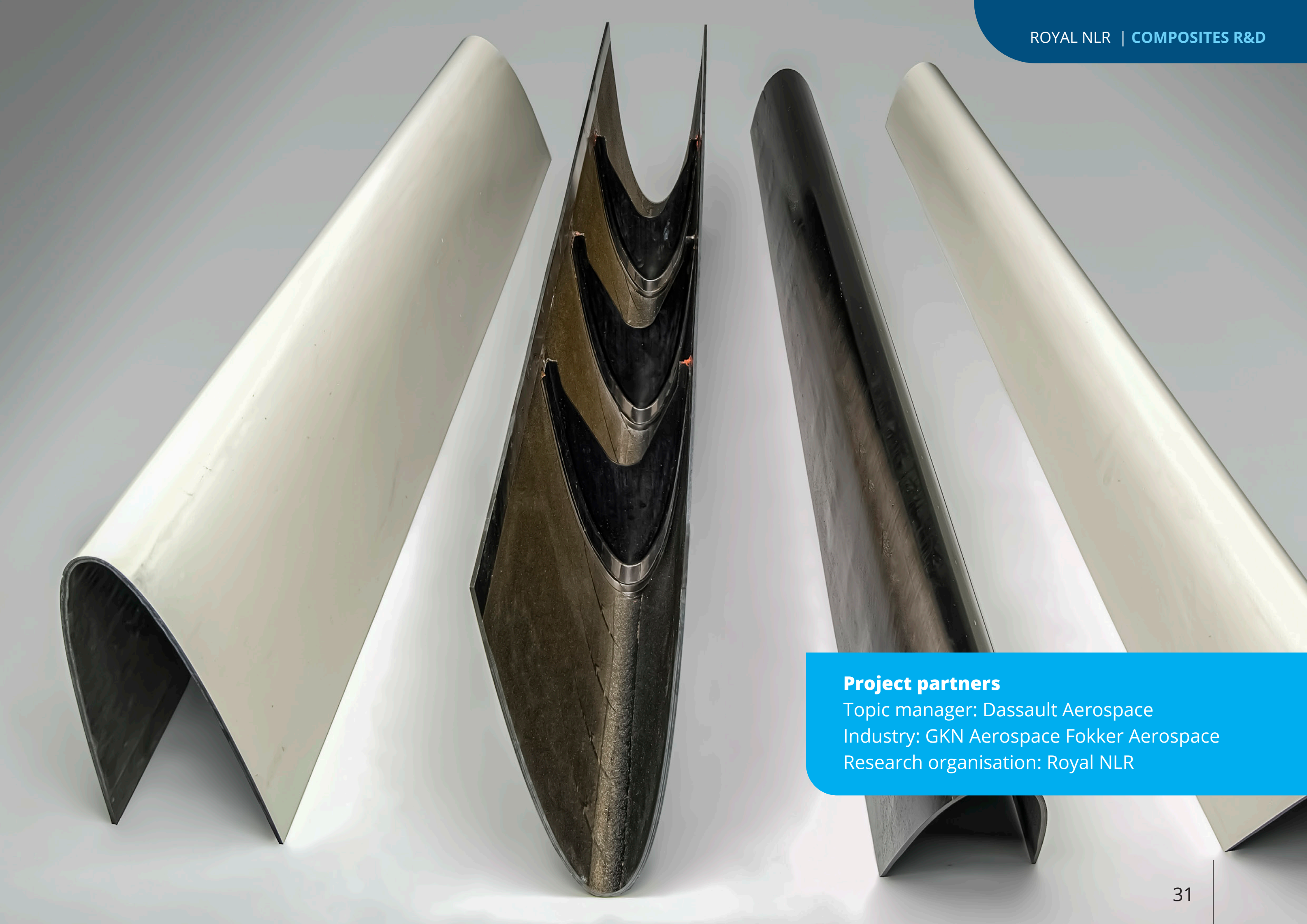
THE SOLUTION

Within the ALFA programme Royal NLR is investigating different manufacturing techniques to create a leading edge without fasteners. One concept could be to bond the ribs to the leading edge skin. However, a fully bonded connection with fasteners is difficult to certify.

WHAT DID WE DO

Two alternative concepts were developed: a one shot vacuum assistant resin transfer moulding VARTM process and a prepreg autoclave curing process with integrated ribs. For both processes, the preforms were made by automated fibre placement with respectively dry fibres of prepreg tapes. The ribs were preformed from flat blanks and vacuum press moulded to the desired 3D configuration. To create an anti-abrasive layer at the front of the leading edges, research was done together with Fichtner & Schicht for pre-treatments and electro plating of Nickel Cobalt layers.

This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme EU (Grant Agreement number: 714479)



Project partners
Topic manager: Dassault Aerospace
Industry: GKN Aerospace Fokker Aerospace
Research organisation: Royal NLR

Project partners
Royal NLR

Composite blades for wind tunnel models: design and manufacturing

THE CHALLENGE

Composite materials have proven to be ideal for wind tunnel model blades. It allows to mitigate potential fatigue loading problems and enables extensive instrumentation. Furthermore, composite materials offer the possibility for aero-elastic tailoring, i.e. the structural design can be optimized in such a way that for example blade deformation and blade frequencies are tuned as desired. For rotating systems, it is essential that this aero-elastic behaviour is well understood prior to wind tunnel entry. Advanced FEM models of composite wind tunnel model blades and a good understanding of the complete manufacture process is important in this. How accurate can blade deformation and blade frequencies be predicted?

WHAT DID WE DO

The test elements and prototypes are subjected to a variety of inspections and typically these inspections are tailored for wind tunnel blades. Geometry inspection, frequency measurement, deformation measurement and structural integrity check are standard procedure.

More extensive instrumentation can be integrated in the blades, like:

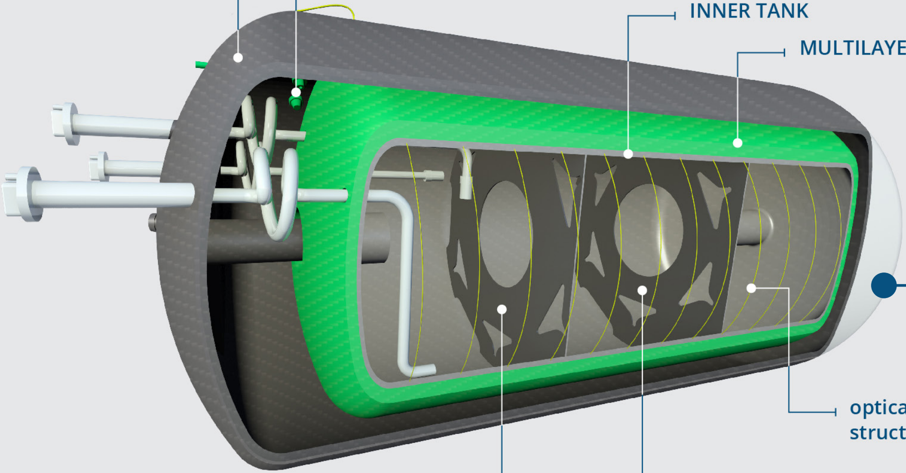
- Integrated strain gauges, especially for load monitoring
- Flush mounted embedded pressure sensors, for aerodynamic and acoustic measurements
- Flush mounted LED's, for blade deformation measurement during rotation
- Integrated heating system, for laminar-turbulent flow transition measurement

THE SOLUTION

Further insight in design and manufacture of composite wind tunnel model blades is developed via NLR and European funded research projects. Material and coupon tests are being performed to validate the basic material properties for the specific manufacturing process used to manufacture the final blades. Predictable tight manufacturing accuracies up to 0.1° twist were achieved. High-cycle-fatigue (HCF) tests are performed to better understand the blade performance under dynamic loading.

Coupon tests are also used to validate the modelling method and material models in an early stage of the design process. In parallel, prototype composite wind tunnel model blades are made with extensive instrumentation included.

LH2 Tank System



This project is partially funded by the Dutch Government (RVO/Netherlands Enterprise Agency) through "Subsidieregeling R&D Mobiliteitssectoren" (RDM)

Project partners
Research organisations: Royal NLR, SAM|XL
Industry (NL): Toray (project lead), ADSE, Airborne, Bold Findings, Cryoworld, Fokker Aerostructures, IT'S Engineering, KVE, PhotonFirst, Somni Solutions, TANIQ
Universities : TU Delft

Liquid hydrogen composite tanks for civil aviation

Hydrogen has been identified as a key priority to achieve the European Green Deal for a sustainable economy. By converting the construction of the hydrogen tank from existing metallic solutions to composites, the liquid hydrogen (LH_2) composite tank will achieve weight savings that enable the advancement of liquid hydrogen as a sustainable fuel source for civil aviation. This will lower the carbon footprint of air travel and extend the flight range of aircraft by reducing construction weight and cost.

THE CHALLENGE

For single-aisle commercial aircraft, the energy density of compressed hydrogen gas is not sufficient to provide the necessary range; this can only be reached with liquid hydrogen, stored at 20 Kelvin/-253 °C. The project aims to develop a linerless long-life lightweight composite tank that can withstand the low temperature of liquid hydrogen and related thermal stress.

WHAT WE ARE DOING

NLR has developed additional facilities for testing composite materials at 20 Kelvin. Several thermoset and semi-crystalline thermoplastic composites (Toray) have been screened regarding their properties at this very low temperature. The materials are also characterised regarding their permeability properties and resistance against thermal cycling down to 20 Kelvin. Together with project partners, a suitable thermoplastic composite material was selected for the inner tank and characterised regarding engineering properties at 20 Kelvin. For the outer tank a thermoset composite material was selected. With these materials a composite tank has been designed and manufactured. The tank will be tested with liquid hydrogen in 2026. The health and safety of the tank will be monitored with various fibre optic sensors. Because of their minimal heat ingress, these sensors are also used to monitor the temperature, pressure, LH2 fuel level and leak detection.

THE SOLUTION

The project will focus on the application of microcrack resistant composite materials with sufficiently low permeability for hydrogen. In order to comply with boil-off and dormancy requirements without adding significant weight and/or volume, a vacuum/MLI insulated tank has been developed with contributions of all consortium members. The tank is equipped with fluid level sensors and sensors for safety systems. During the design phase, digital design strategies were used to minimise thermal stress and optimise utilisation of automated manufacturing technologies.

ATTILA: Advanced Testbed for Tiltrotor Aeroelastics

THE CHALLENGE

Rotor blade designs have to be sufficiently strong for wind tunnel testing and must have dynamic characteristics that resemble the full-scale behaviour. This implies that the blade design should have a closely matching stiffness and mass distribution along its entire span in comparison with the target properties of the aeroelastically scaled blades.

- Stiffness properties along the blade span:
  - Axial, flap and lead-lag bending, and torsion stiffness
  - Location of the neutral axis and shear centre
- Mass properties along the blade span:
  - Mass and mass moments of inertia
  - Centre of gravity position

In addition, the blades have to be instrumented for monitoring the loads and dynamic behaviour of the blades during the wind tunnel test.

WHAT WE DID

Aeroelastically scaled blades were designed and manufactured. The design encompassed everything from conceptual design to detailed stress analysis of the final blade structure. The final blade design has closely matching stiffness and mass distributions, while still satisfying all wind tunnel strength/safety requirements.

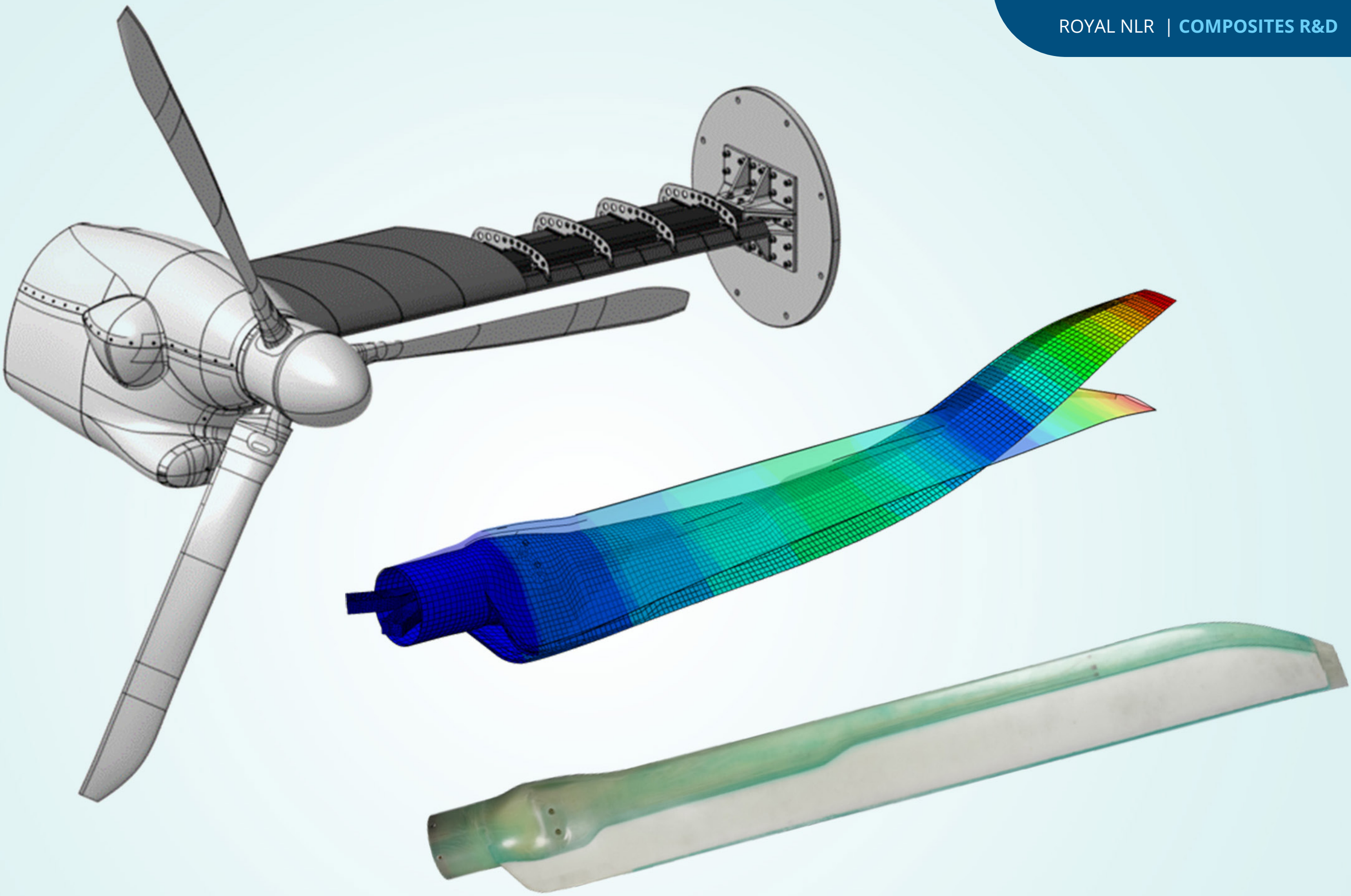
The blades have been instrumented with embedded strain gauges and optic fibres to monitor the flap bending, lead-lag bending and torsion loads at three different cross-sections, and at the same time to monitor the dynamic behaviour of the blades during the wind-tunnel test.

THE SOLUTION

The blade design consists of a load-carrying D-spar and separate (thin) trailing edge. Both are constructed from glass fibre-reinforced laminates supported by an internal foam core. In addition, the D-spar has tungsten bars of varying lengths and diameters; these non-structural masses are used for tuning the mass distribution and CoG position along the span of the blade.

The final design of the blade is based on detailed FEM analyses to determine the cross-sectional stiffness properties along the blade span. These properties were tuned to the required values by varying the lay-up in the different segments (nose, top/bottom skin, web, trailing edge) for each blade cross-section.

It turned out that the blade needs to be very flexible towards the tip. The low required stiffness properties necessitate the application of ultra-thin glass fibre fabric plies (47 gsm). These thin plies also allow accurate tuning of all the different stiffness properties in the rest of the blade.



This project has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No 831969. 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

Project partners
NLR, DLR, Politecnico, DNW, Photonfirst

Thermoplastic Composites for Sustainable Aviation

For future aerospace applications, the goal is to reduce weight, improve circularity and be more cost efficient in terms of manufacturing and operation than the current state of the art. Clean propulsion goals also require lighter and more aerodynamic aircraft. Thermoplastic composites have a great deal of potential in all these areas. As we are also on the threshold of other types of aviation such as Urban Air Mobility (UAM) and Sub-Regional Electric Vehicles (SREV) as well as the traditional types, there is plenty of opportunity to develop, validate and implement new thermoplastic technologies that can than later also be implemented on single aisle and wide-body airliners.

THE CHALLENGE

The research focuses on new lightweight fibre-reinforced thermoplastic materials as well as new and innovative manufacturing and design concepts. As expected volumes for the UAM market are high (thousands per year), a high degree of automation and digitalisation of the manufacturing processes is needed. The main goal is to develop distinctive technologies for fibre reinforced thermoplastic composites and raise its application to the next level in terms of sustainability, costs and circularity.

WHAT WE ARE DOING

Parallel to the thermoplastic material, design and manufacturing development, test components like a tail and door of a UAM are manufactured to characterize and validate the new technologies. Within this project NLR will focus on:

- Continuous fast induction welding of unidirectional (UD) thermoplastic double curved aerospace structures with variable thickness, including the lightning strike protection Not only physical welding activities but also modelling, simulation and qualification are addressed.
- By using a Digital Twin for induction welding, a real-time digital representation combining process, measurement and modeling data, will improve process optimisation while limiting downtime and scrap.
- Research into high temperature thermoplastic sandwich solutions as a sustainable alternative for thermoset sandwich structures. The focus is on both core materials and the process development.
- Using robotic large-scale additive manufacturing (LSAM) as an alternative way of stiffening thermoplastic panels. High-performance aerospace materials in particular, such as LMPAEK, will be used for printing onto curved parts manufactured by automated fibre placement.

The facility for automated composite manufacturing provides NLR the capability required for developing fabrication methods and structural concepts in composite for aircraft and other lightweight structures.

The facility has a total floor area of 1000 m^2 and includes:

- Pilot Plant for pick and place technology, hot drape forming, large heat press and Resin Transfer Moulding
- Automated Fibre Placement of thermoset and thermoplastic materials and dry fibres
- Press forming of thermoset and thermoplastic materials
- Induction welding of thermoplastic materials
- Thermal analysis of composite materials
- Laminating and curing composites using autoclave processing

FACILITIES OF ACM-TC

The core of ACM is the R&D facility for composites manufacturing at NLR. The facility is equipped with a Coriolis fibre placement machine and MTorres machines capable of processing thermoset materials, thermoplastics and dry fibres. Other equipment consists of an automated preform cell for robot based composite manufacturing, automated RTM machine with full process monitoring and control features, a press for thermoplastic processing, apparatus for out-of-autoclave processing, large scale additive manufacturing, an autoclave, a C-scan, clean rooms and a well-equipped test-house to perform material qualification and structural certification programmes.

Composite facilities

Automated Composites Manufacturing
ACM Pilot Plant
Large scale additive manufacturing

STUNNING, MULTIFUNCTIONAL FUSELAGE DEMONSTRATOR

Automated composites manufacturing

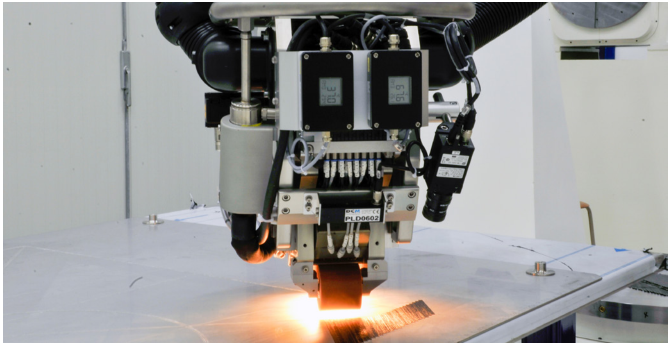
The Automated Composite Manufacturing Technology Centre (ACM-TC) and the Automated Composite Manufacturing Pilot Plant (ACM-PP) were established at NLR in the Netherlands to prepare the way towards automated manufacturing of advanced composite structures, largely in support of the 'composites' industry, but also of enterprises, which are new to this material. The centre brings together the complementary research capabilities of research centres, universities and specialised small enterprises and industries. ACM-TC operates at Technology Readiness levels TRL 3 - TRL 6 where the ACM-PP operates at TRL 6 - TRL 8.
The vision of the ACM is 'to pioneer innovative fabrication technologies for composites with potential for automation' and thereby 'to enhance the competitiveness of its members', by conducting applied research and carry out development programmes up to the level of full scale prototypes.

OUR CAPABILITIES

- Design concepts in composite
- Detailed finite element calculations for composite designs
- Trade studies to evaluate different design concepts
- Cost modelling
- A second opinion on composite designs
- Composite manufacturing
- Full scale prototyping
- Mould design and manufacturing
- Automated Fibre Placement
- Resin Transfer Moulding
- Vacuum assisted Resin transfer moulding
- Automated Composite Manufacturing (e.g. Pick & Place)
- Press forming
- Induction welding
- Large scale additive manufacturing

WHAT WE DELIVER

Extensive experience with, and knowledge of, Polymer Based Composite Materials, manufacturing processes, the mechanical behaviour of composite materials and the structural response of composite structures. We perform activities for the 'High Tech-High Spec' community like aerospace, automotive, maritime, rail, transport and medical.

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Automated Composite Manufacturing Pilot Plant

The NLR automated composites pilot plant, ACM³ Field Lab, aims to attract Small- and Medium-sized Enterprises (SMEs). This well-equipped, state-of-the-art field laboratory makes high-tech equipment available for the development of light-weight products.

The purpose of ACM³ (Field Lab for Automated Composites Manufacturing, Metal Manufacturing and Maintenance) is to support companies in the development of light-weight systems made of composite materials and/or metal. NLR can provide this support in nearly all phases of product development: from concept studies and material screening to preparing detailed designs and creating concepts. Repairs and full-scale prototyping are also carried out in the centre. ACM³ is optimizing accessibility in various ways. For instance, a ‘menu’ of the available equipment has been prepared to provide quick insight into the facilities and their operation. This allows companies to discover at a glance what they can do at ACM³. Users can receive training or hire an NLR operator if the equipment is too complex for unassisted operation. During the production of a pilot run, for instance, users can receive training to ensure that properly qualified personnel is available when actual serial production starts at the customer site.

AFFORDABLE PROTOTYPES

The centre particularly offers benefits for SMEs. Without any requirement for major investments, they can join forces with NLR and use the equipment available at ACM³ to work on the development of new light-weight products and the required manufacturing technologies. This process can start with ‘proof of concepts’ that are eventually developed into full-scale prototypes.

Another benefit is the ability to postpone capital investments until there is more certainty about the commercial potential of the product. The facilities at ACM³ enable companies to delay the ordering of production equipment until there is greater certainty of a successful market introduction. In order to bridge the intervening period and maintain market momentum, companies can use ACM³ equipment to produce the initial pilot runs.

One recent achievement illustrating the potential of ACM³ is the successful development of PAL-V: the world’s first flying car production model, equipped with unique collapsible rotor blades. Designs for the composite rotor blades and propeller were developed and tested in the NLR Field Lab. The required manufacturing method was also developed here.

Equipment for manufacturing composite components

PREFORM CELL

This cell comprises of :

- Zünd cutting machine
- Kuka robot with end effectors for pick and place, preform
- trimming and tool handling
- Global vacuum press with infra-red heating
- Assembly Guidance laser vision system

RESIN TRANSFER MOULDING

The RTM station consists of a dedicated Isojet injection system for one component resin systems with water heaters for resin tank, injection hoses and product moulds. The closing of the moulds can be controlled by multiple presses. Online process monitoring by digital twin.

LARGE SCALE ADDITIVE MANUFACTURING

LSAM, also referred to as FGF (Fused Granulate Fabrication) or BAAM (Big Area Additive Manufacturing), has revolutionised the industry by facilitating the creation of intricate structures on a much larger scale than ever before. In this process, the raw material is initially in the form of granules or pellets. These granules are fed into a heated extruder, where they melt in several stages or heating zones. The molten material is subsequently deposited layer by layer to create the desired object. The extruder is typically mounted on a robotic arm or a gantry system that performs the movements to achieve the 3D shape.

INDUCTION WELDING

The cell with a Kuka robot, induction power generator and welding end effector is used to develop automated welding processes for thermoplastic sheets and stringers. Different set-ups can be positioned in the cell for process optimisation.

Equipment for manufacturing composite components

AUTOMATED FIBRE PLACEMENT MACHINE

A Coriolis fibre placement machine is used to develop structural components in thermoset and thermoplastic composites as well dry fibre preforms. The robot based Coriolis machine is capable of making components with a maximum diameter of 4.0 m and a length of 8.5 m in the horizontal spindle. For processing thermoplastics or dry fibres a 6 kW laser heating is used. For processing thermoset materials an infrared heater is used. In 2026, an MTORRES fibre placement machine will be installed to complement the AFP facilities.

AUTOCLAVE

An autoclave is available equipped with automated data logging of temperatures, pressures and vacuum.

- Working volume 5.5 m^3
- Heat output 70 kW
- Temperature (max) 400 °C
- Pressure 20 / - 1 bar
- Medium Air or nitrogen

VACUUM INFUSION

A dedicated Isojet machine is available for vacuum infusion. Like the RTM machine it is designed for processing one component resins. The maximum resin capacity is 30 litres. The machine is equipped with an electrical heating system both for the resin tank and the tooling.

HEATED PRESSES

Two heated presses are available for press forming and curing with thermoplastic and thermoset materials. A larger press will be installed in the first quarter of 2026. Presses can be used in combination with infrared heaters and automatic/robotic loading systems.

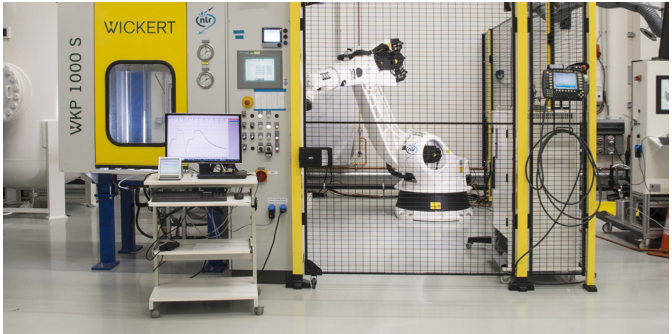
The main characteristics of the presses are:

- Langzauner: 500 x 500 mm, 5/350 kN
- Wickert: 600 x 600 mm, 20/1000 kN
- Langzauner: 2400 x 800 mm, 35/6500 kN (oil heated)
- Temperatures up to 400 °C

LARGE CURING OVEN

A large curing oven is available for curing or consolidating large products

- Internal size 3.4x3.4x8.0 m
- Temperature (max) 400 °C



Equipment for analysis and characterisation

RHEOMETER

With the Anton Paar rheometer MCR302, viscosity measurements can be carried out in the temperature range of -40 °C to 620 °C. In the oscillation mode with plate-plate Ø 40 mm, viscosities between 40 kPa.s and 1 mPa.s can be measured. The maximum heating rate is 60 °C/min.

DIFFERENTIAL SCANNING CALORIMETER (DSC)

The Discovery DSC 2500 with autosampler from TA Instruments is used to study curing, ageing, melting, crystallisation and specific heat (Cp) of thermosets and thermoplastics at temperatures between -90 °C and +725 °C with heating rates up to 200 °C/min and cooling rates up to 100 °C/min. Modulated DSC (MDSC) is possible. Typical sample size is 15 mg. The sensitivity is <10 μW.

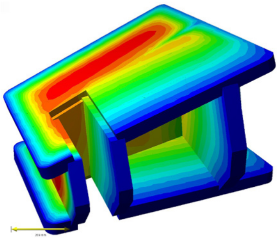
THERMOGRAVIMETRIC ANALYSIS (TGA)

Moisture-, volatile- and resin content are measured with the Pyris 6 TGA from TA Instruments at temperatures from 5 °C up to 1000 °C on test specimens up to 1500 mg. Maximum heating rate is 50 °C.

SUPPORTING SOFTWARE

In support of the composite manufacturing activities, several software applications are available:

- CATIA V5
- CATIA CPD
- CATFiber
- Fibersim
- ESI PAM Composites
- MSC Nastran / Patran
- Abaqus
- AniForm
- Convergent COMPRO and RAVEN



NON DESTRUCTIVE INSPECTION (NDI)

A C-scan facility is available for Non-Destructive Inspection.

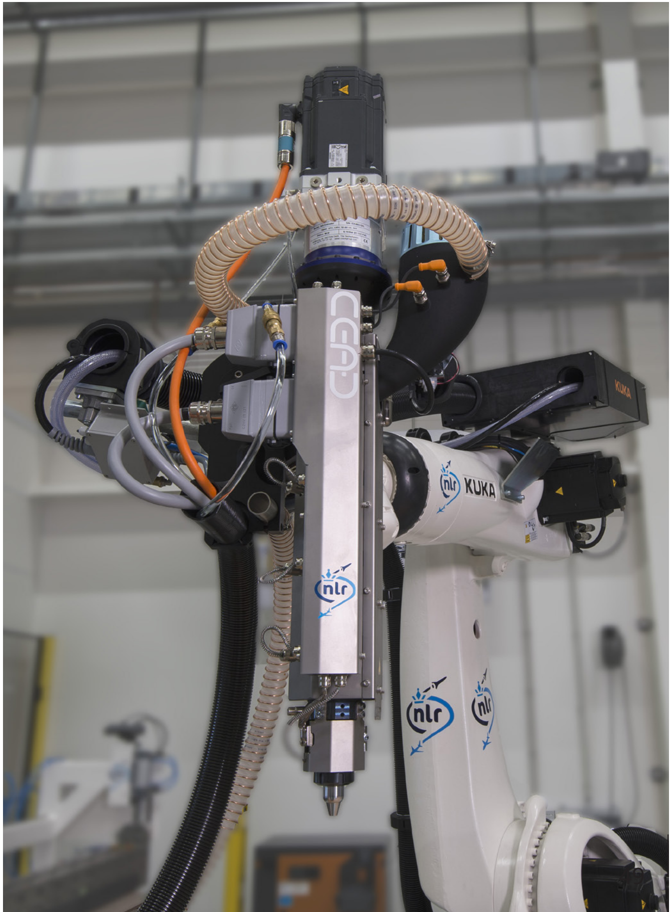
- Scan window of 4.0 x 2.5 x 2.5 m
- Immersion and squirter inspection mode
- Turn table for circular components (max. diameter 1.9 m)
- Scanning pulse echo and through transmission mode simultaneously
- Linear Scanning Array available
- Complex scan geometries generated from CATIA

Large scale additive manufacturing

The CEAD S25 extruder is used to 3D-print short fiber reinforced thermoplastic materials including LMPAEK & PPS. The size of the extruder and its mount within NLRs robot cell opens the possibility for large size 3D printing of parts up to 2 meters in length. The system is equipped with a next generation motor of 2.7 kW which increases manufacturability of highly viscous composite materials. The large scale printing technology is used in applied research for applications such as high temperature tooling & grid stiffened structures on top of composite laminates. Key benefits of the technology include its design freedom, reduced lead time and the possibility to recycle materials and re-use.

The main characteristics of the S25 extruder are:

- Max. material output: 25 kg/h
- Max. material temperature: 400 °C
- Motor power: 2.7 kW
- Nozzle size: 2-18 mm
- Material feedstock: Automatic hopper loader with dryer



NLR in brief

One-stop-shop	Global player with Dutch roots	100+ Since 1919	Amsterdam, Marknesse Rotterdam, Noordwijk, Brussel
Innovative, involved and practical	For industry and governmental	For civil and defence	800+ staff
€ 127 M turnover	78% Dutch, 19% EU and 3% worldwide	Active in 24 countries	Very high customer satisfaction

About NLR

Royal Netherlands Aerospace Centre

NLR is a leading international research centre for aerospace. Its mission is to make air transport safer, more efficient, more effective and more sustainable. Bolstered by its multidisciplinary expertise and unrivalled research facilities, NLR provides innovative and comprehensive solutions to the complex challenges of the aerospace sector.

NLR's activities span the full spectrum of Research, Development, Testing & Evaluation (RDT & E). Given NLR's specialist knowledge and state-of-the-art facilities, companies turn to NLR for validation, verification, qualification, simulation and evaluation. They also turn to NLR because of its deep engagement with the challenges facing our clients. In this way, NLR bridges the gap between research and practical applications, while working for both government and industry at home and abroad.

Royal NLR stands for practical and innovative solutions, technical expertise and a long-term design vision, regarding their fixed wing aircraft, helicopter, drones and space exploration projects. This allows NLR's cutting-edge technology to find its way also into successful aerospace programmes of OEMs like Airbus, Boeing and Embraer.

NLR enjoys working in a challenging and fast-changing field of research every day, assisting a wide range of clients. All of this knowledge benefits companies that are suppliers of large corporations like Airbus and Boeing and SMEs. Much of the knowledge of these new materials is also widely usable in other fields, such as the automotive industry, the maritime sector and the infrastructure, creating numerous spin-offs outside the aerospace industry.

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