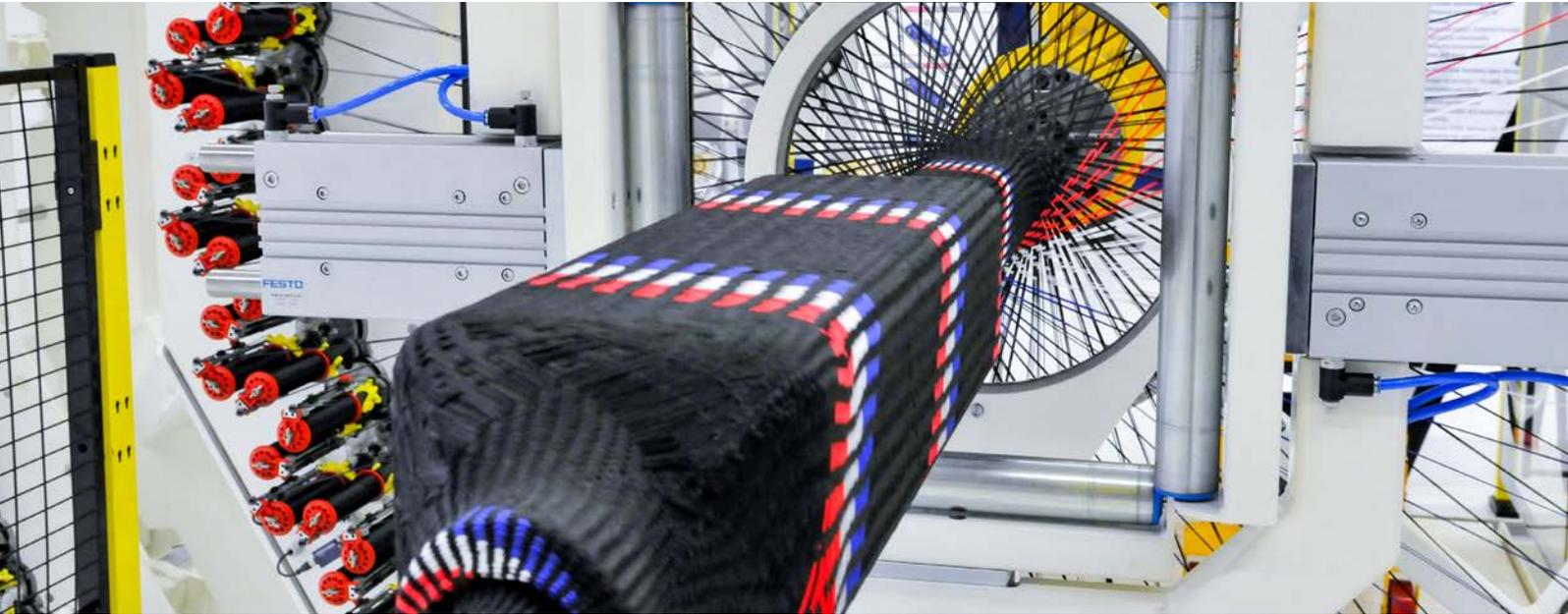




Dedicated to innovation in aerospace

Composites R&D

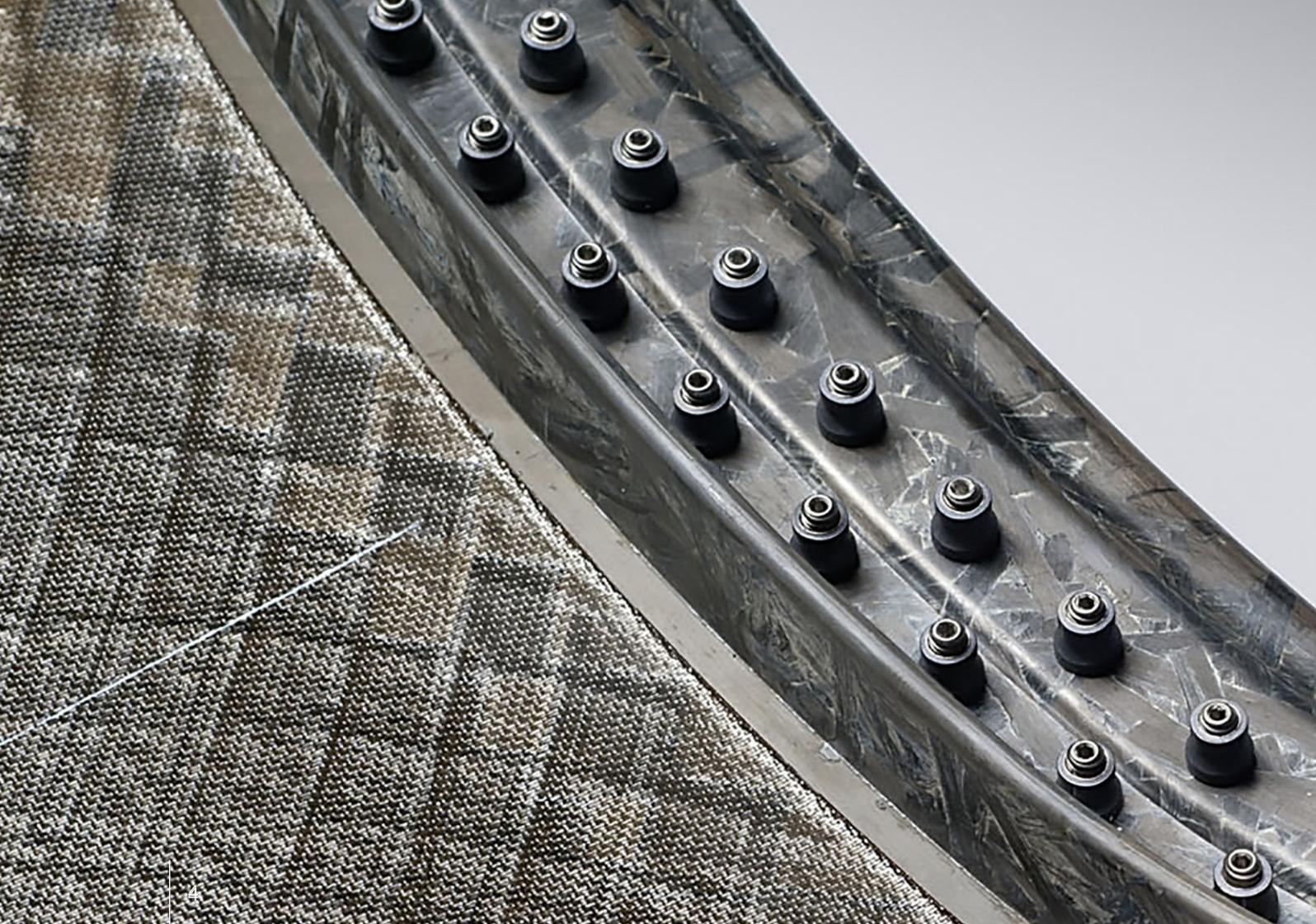


NLR - Royal Netherlands Aerospace Centre

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.



R&D for automated composite manufacturing

Automated Composite Manufacturing Technology Centre (ACM Technology Centre)

It starts at the ACM Technology Centre, a facility that addresses research questions at the low to medium Technology Readiness Level (TRL) or levels 3 to 6. 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. NLR does this in a research environment where we can also develop the hardware ourselves.

Automated manufacturing

With the increasing penetration of robots in the production process, NLR also meets the demand for automation. The ACM 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.

Automated Composite Manufacturing Pilot Plant (ACM Pilot Plant)

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

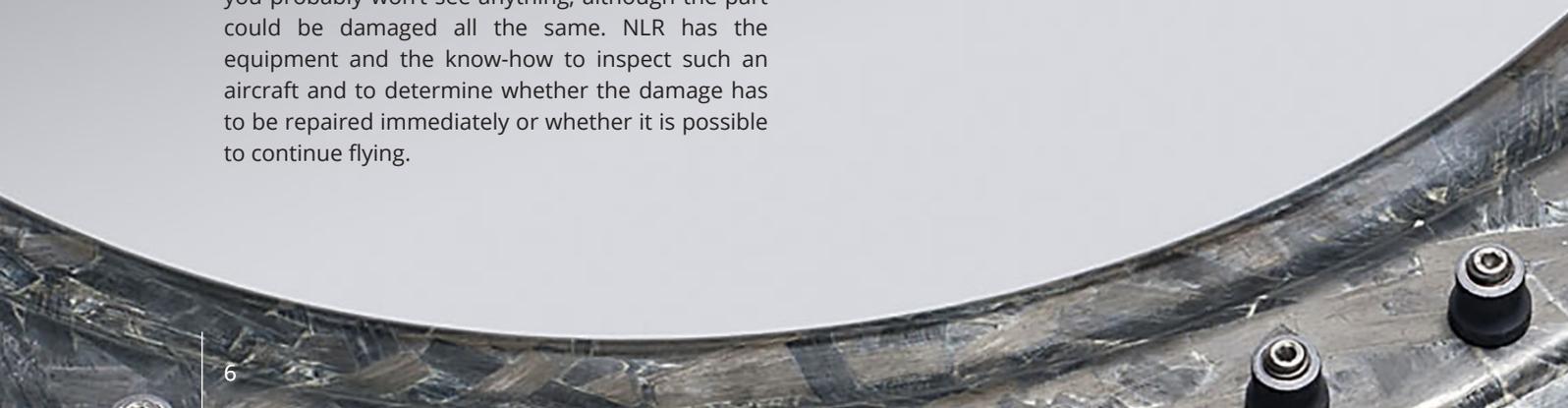
Detecting and repairing damage of composite parts

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.

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 Composite Manufacturing Pilot Plant

The NLR automated composites pilot plant, ACM3Field Lab ('ACM Cubic'), 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, 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.



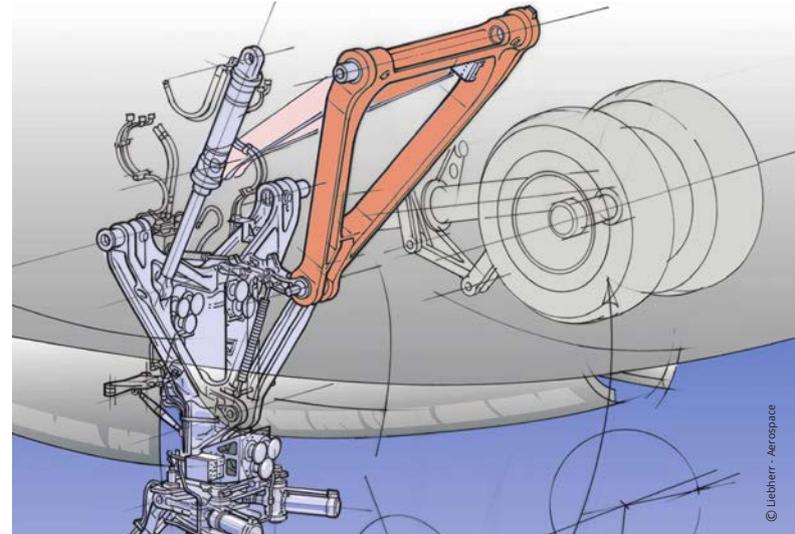
This enables costly capital investments being postponed until there are sufficient prospects of product sales, avoiding the much-feared 'Valley of Death' that affects many companies (particularly SMEs). One recent achievement illustrating the potential of ACM3 is the successful development of

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.

Showcases

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 will be tested in 2019 by Fokker Landing Gear.



© Liebherr - Aerospace

Project: HECOLAG

Customer: Liebherr Aerospace

Project partners: Royal NLR, Fokker Landing Gear, Compose



Horizon 2020
European Union Funding
for Research & Innovation



Project partners

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

Start: 2011

Duration: 2016

ESPOSA:

Efficient Systems and Propulsion for Small Aircraft

WHY?

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%

HOW?

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

WHAT?

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.



EU credits

ESPOSA is a EU funded project.
This message doesn't necessarily
reflect the views of the EU.

STUNNING:

Smart Multi-Functional and Integrated TP Fuselage

WHY?

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 fully equipped Single Aisle Aircraft fuselages compared to the state of the art are:

- Enable a High Rate Production (HRP) of minimum 60 shipsets per month
- Reduce weight by 1tonne
- Reduce recurring cost by 1M€

Project partners

Industry (NL) : Fokker Aerostructures

Industry (EU) : Diehl

Research organisations : NLR, (DLR, Fraunhofer)

Universities : TUDelft

Start : September 2017

Duration : 6 years

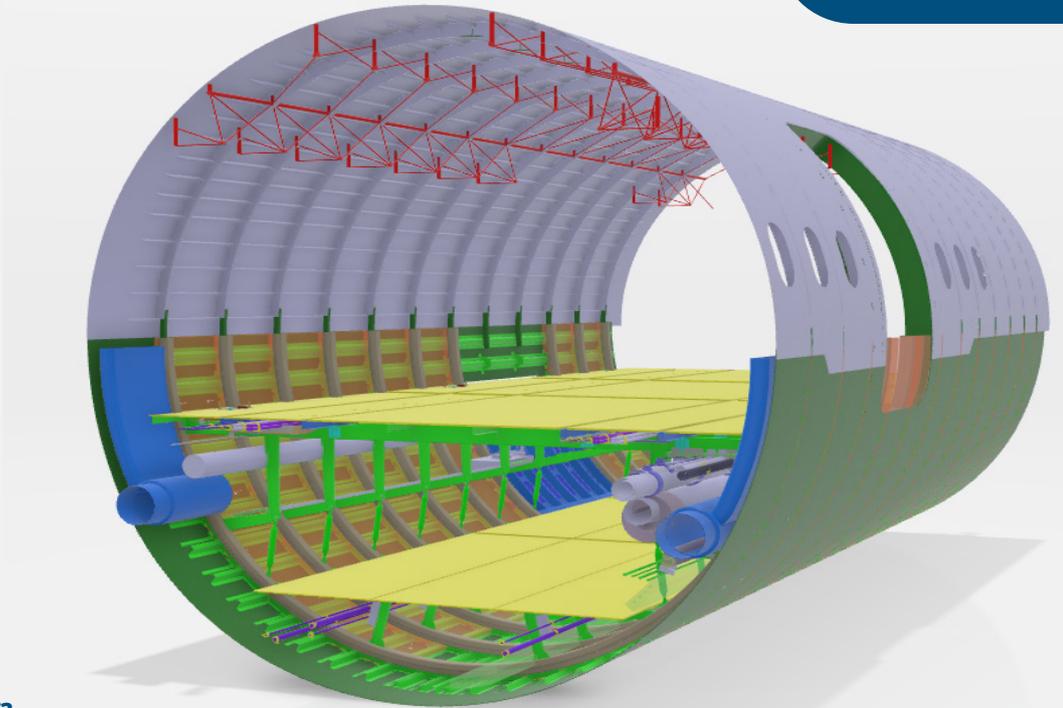
HOW?

The project will develop, manufacture and deliver a 180° full scale multi-functional integrated thermoplastic fuselage shell, incl. cabin and cargo floor structure and relevant main interior and system elements. The STUNNING team will apply advanced design principles, innovative system architecture, advanced materials and processes to generate high potential solutions for next generation fuselages. Addressed topic are:

- A 180° full scale multi-functional and integrated TP fuselage shell
- The potential of TP material and its associated manufacturing processes and welding
- The integration of multiple system functionalities
- Industrial Readiness taking in account the requested HRP of minimum 60 shipsets per year
- Advanced simulation capabilities



STUNNING is a EU funded project.
This message doesn't necessarily reflect the views of the EU.



WHAT?

A significant weight reduction resulting from this integrated approach, based on advanced thermoplastic manufacturing and assembly principles, will contribute to the environmental challenge to reduce the CO₂ and NO_x footprint by 5 to 8% while enhancing the effective space for passengers and cargo.

Manufacturing costs and assembly times will be reduced and production rates will be increased.

To achieve the overall goals, 'beyond state of the art' technologies will be developed and verified in dedicated tests up to TRL6. Several innovative SME's will be involved by outsourcing or CfP's for specific solutions.



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

WHY?

The reduction of the CO₂ 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 tAirplane, ALFA. A way to reduce CO₂ 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.

HOW?

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?

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 advanced fibre placement with respectively dry fibres or 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.

Project partners

Topic manager: Dassault Aerospace

Industry: GKN Aerospace Fokker Aerospace

Research organisation: Royal NLR

Start: September 2018

Duration: 2 years

Thermoplastic automated upper spar for an aircraft pylon by 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 Advanced Fibre Placement and Cetex, TC1320 AS4D PEKK material of TenCate. 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, TenCate, Airbus



Project partners

Royal NLR

Start: September 2018

Duration: 2 years

Composite blades for wind tunnel models: design and manufacturing

WHY?

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? To what extent is the extensive instrumentation influencing the aero-elastic behavior?

HOW?

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.

Coupon tests are also used to validate the modeling 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.

WHAT?

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. This research will improve accuracy of the predicted aero-elastic behaviour and improves quality of the manufactured composite blades. 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

10% weight reduction, high stiffness and cost effective manufacturing



The challenge: to design and manufacture a composite forward pressure bulkhead that is 10% lighter than the original aluminium bulkhead, while still meeting bird impact and stiffness requirements. An obvious job for NLR and partner Airborne, commissioned for Clean Sky Green Regional Aircraft ITD.

Two concepts were evaluated: a stiffened solid panel and a sandwich concept.

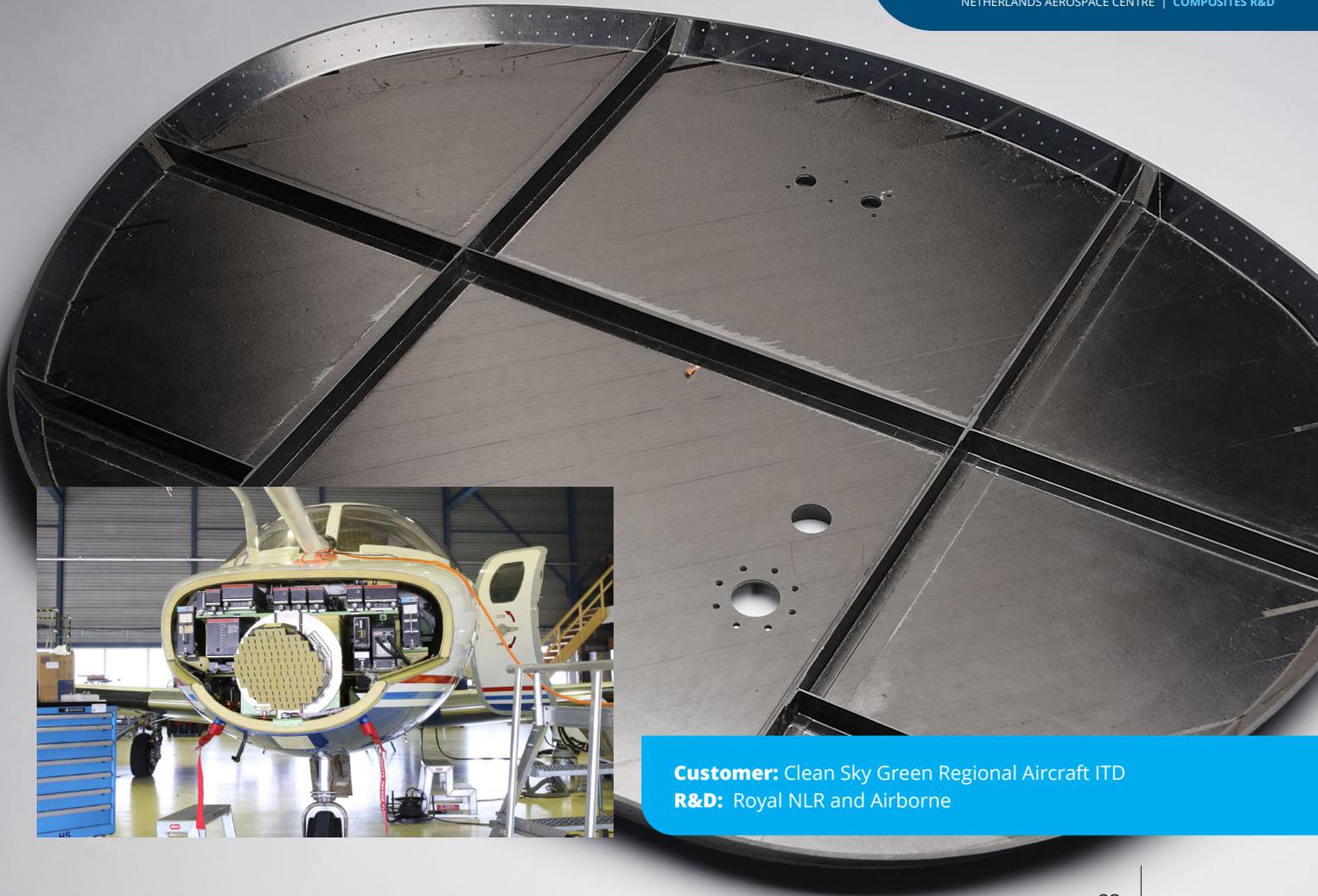
Solid or sandwich composite panels

It was found that the solid panel did not meet the high stiffness requirements without compromising on weight. While the sandwich concept could easily meet the stiffness and strength requirements, the bird impact analysis revealed that the concept failed to meet the requirements. Therefore, a Dyneema plate was added on top of the sandwich to protect the bulkhead from bird impact damage.

Cost-effective manufacturing

Another project challenge was the use of a cost-effective manufacturing concept. The Liquid Resin Infusion process was selected, using a cost-effective tooling concept. A semi-flexible caul plate was used to achieve the required tolerance and surface roughness on the perimeter flange. The caul plate was made of a non-silicone tooling rubber, locally stiffened with a CFRP prepreg.

The injection strategy included injecting the resin in the centre of the blade stiffeners and using runners on top of the blade stiffeners and the perimeter flange to distribute the resin, after which the resin flowed up the perimeter flange to end at a membrane on top of the product.



Customer: Clean Sky Green Regional Aircraft ITD
R&D: Royal NLR and Airborne



Project partners

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

Start: June 2017

Duration: November 2020

ACASIAS:

Advanced Concepts for Aero-Structures with Integrated Antennas and Sensors

WHY?

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.

HOW?

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.

WHAT?

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.



CFRP Vinci Thrust Frame

WHY?

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.

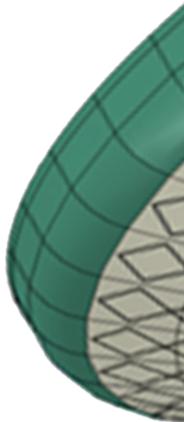
HOW?

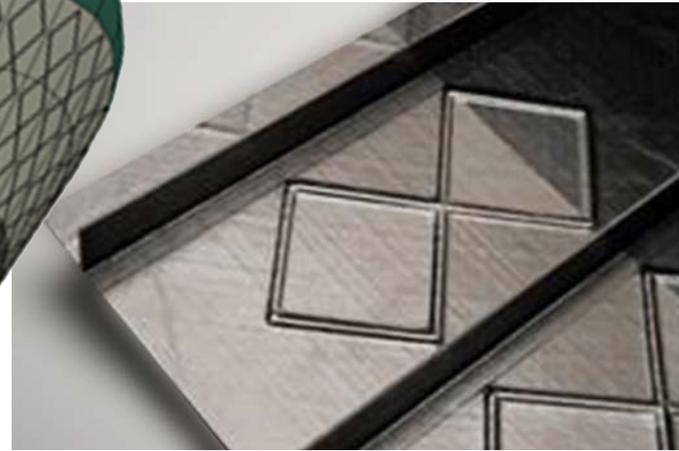
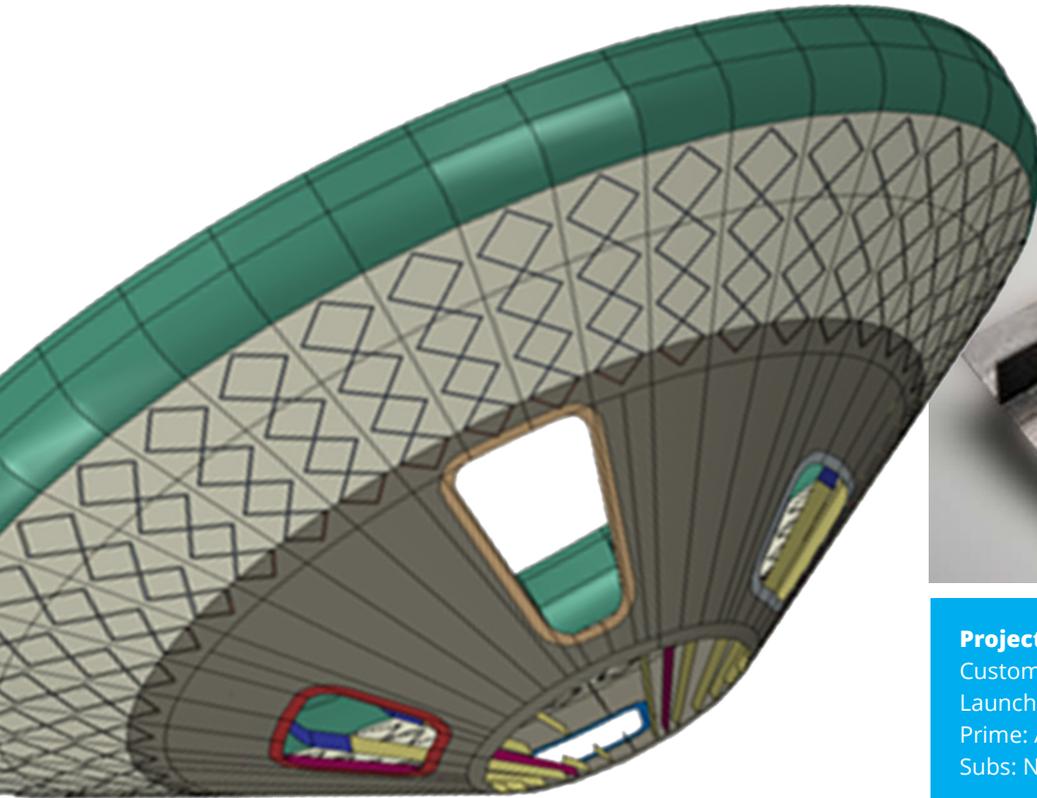
Currently, Engine Thrust Frames for launchers are made from metal. Previous programs showed that cost and weight can significantly be reduced by application of carbon fibre reinforced polymers in tailored ply architectures, processed by the automated fibre placement technology. Based on a reference finite 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.

WHAT?

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.





Project partners

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

Start: 2018
Duration: 2 years

A high rate automated manufacturing process for thermoplastic carbon composite bicycle frames

WHY?

Carbon composite bicycle frames are currently manufactured by manual labour. Production in Europe can be more cost competitive compared to cheap labour countries by reducing manual labour as much as possible. An automated production process will lower the recurring cost of the frame production. In addition, the automated production enables a more constant and high quality of the manufactured parts.

Another factor which is influencing the recurring cost is the cycle time of the production process. Traditional thermoset composites take a long time to cure. Thermoplastic material can potentially be processed much faster allowing for high rate production. Furthermore, traditional thermoset composites are quite vulnerable for impacts damages. The newly developed FEATHER material on the other hand offers extreme impact resistance.

HOW?

FEATHER material is a new composite material technology offering extreme impact resistance, which is a revolution in the composites arena. Bicycle frames with FEATHER technology inside increase safety and reliability beyond what is now available.

Adding a certain percentage of steel to the composite eliminates the sudden, brittle fracture behavior.

NLR developed a dedicated press forming production for the FEATHER material, reducing the recurring manufacturing cost. This includes the design of so called tailored blanks to optimize the press forming process and limit the amount of scrap material.

WHAT?

Royal NLR has extensive experience with the development of fast and automated manufacturing processes both for thermoset and thermoplastic composite materials. The press forming process was selected to competitively manufacture bicycle frames in Europe compared to the cheap manual labour production from Asia.

NLR has developed the press forming process and designed the press tooling which is critical for the final product quality. By developing a fully automated production process the manufacturing quality now is at a constant high level. The result of the project is that REIN4ced is now able to realize high rate production of bicycle frames competitively in Europe. Delivery to end customers will start mid 2020.



Project partners

Industry: REIN4CED

Research organisation: Royal NLR

Start: 2016

Duration: 2020

Foldable rotor blades and foldable propeller for the PAL-V

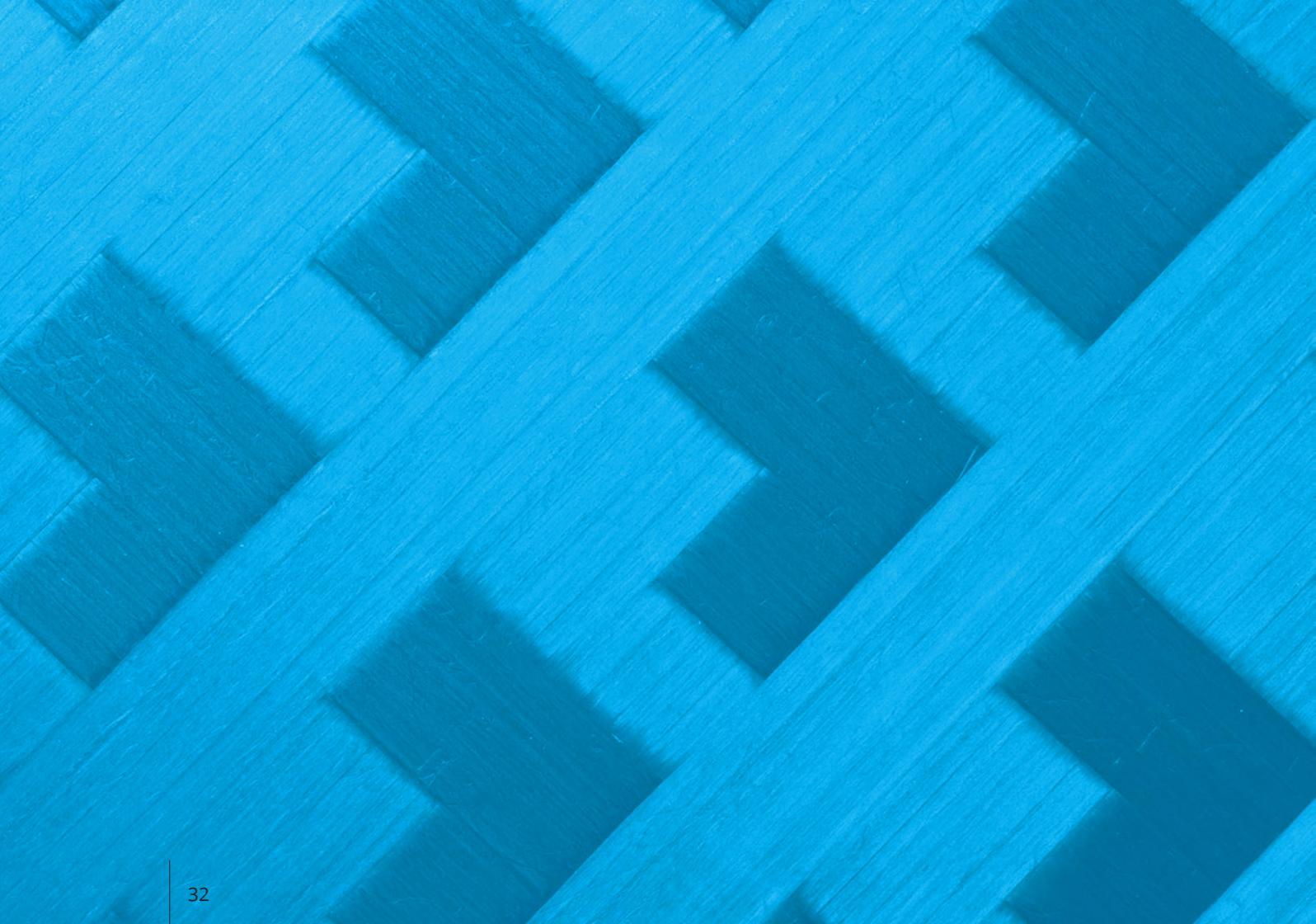


The PAL-V Liberty is a true innovation. This new Personal Air and Land Vehicle is capable of driving on the road at 160 km/hour and of flying at up to 180 km/h. In flying mode, the gyrocopter principles are applied. In drive mode, the rotor and propeller are folded. The foldable rotor blades and foldable propeller have to comply with the EASA CS27 small rotorcraft design principles and airworthiness requirements.

PAL-V and NLR evaluated several conceptual solutions for the foldable rotor blades and propeller. The most promising concepts were developed into a mature design that can meet certification requirements. The main challenges were the reduction of the weight of the rotor system and the integration of a free flappable mid-hinge in the rotor blade. Low-cost manufacturing processes based on press moulding principles were developed. Fully functional prototype rotor blades and propellers have been manufactured and are being tested.



PAL-V Liberty was introduced at the Geneva International Motor Show (8-18 March 2018).



Technology Readiness Level, R&D and industry

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.

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.

NLR in brief



One-stop-shop



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government



For civil and
defence



632 employees



€ 88 M turnover



72% Dutch, 21% EU
and 10% international



Active in 26 countries



Extremely high
client 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.

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.

Some of our partners and clients: PBS, MERL/ELEMENT, Piaggio, Grob, Evektor, CIRA, ILOT, VZLU, INCAS, European Space Agency, Airbus Defence and Space Netherlands, Infactory Solutions, Fokker Aerostructures, Diehl, DLR, Fraunhofer, TU Delft, Dassault Aerospace, GKN Aerospace Fokker Aerospace, Toray, Airbus, REIN4CED, PAL-V.

Some of the programmes NLR is currently involved in: CleanSky (European Union), TAPAS 2 (Thermoplastic Affordable Primary Aircraft Structure 2).

For more information:

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