Accelerating the future of aerospace

R&D more electric and hydrogen powered aerospace

Royal NLR - Netherlands Aerospace Centre

NLR hydrogen roadmap

- Laboratory (L)H_2 test facilities
- Component design
- Cryo-material research
- H_2 Drone demonstrations
- Safety regulations

- Standardisation & certification
- Ground test facilities
- System design & verification
- H_2 retro-fitted Aircraft
- Flight Demonstrations
- (L)H_2 supply chain developments

Zero-e, ©Airbus

- Airport H_2 infrastructure
- Commercial H_2 Aircraft Operations

SUSTAINABLE AVIATION: MORE ELECTRIC AND HYDROGEN POWERED AEROSPACE

Hydrogen as a fuel is considered to be an important route towards future sustainable aviation. For aviation applications, hydrogen offers several key advantages: it allows for the elimination of carbon emissions in flight and along the entire life cycle. Its usage in fuel cells enables the elimination of NOx and particles. When burnt in a turbine engine, very low particle emissions can be expected, as well as reduced NOx emissions, provided that the combustion system is optimised. However, water vapour emissions need to be carefully managed. Overall, the use of hydrogen in thermal (combustion) engines is also expected to yield significant benefits in comparison to non-CO_2 emissions (high altitude phenomena) that result from conventional kerosene-fuelled aircraft.

Although hydrogen has been employed widely in other industries for many years, the introduction of hydrogen on board aircraft is a major technical challenge, combined with a tremendous certification effort. It has a significant impact on the aircraft architecture, powertrain components and operations, as well as on the ground infrastructure and logistics.

To scale hydrogen-powered aircraft for application in commercial aviation, several technological breakthroughs are necessary to unlock hydrogen's full potential. Parallel technology developments are needed to increase the maturity of the key building blocks. While the aerospace industry is collaborating to develop the necessary on-board technologies, the widespread availability of green hydrogen aviation fuel and the required infrastructure are critical to the overall success of this approach.

Royal Netherlands Aerospace Centre

New technologies developed in several projects that NLR is involved in will contribute to the technical and economic feasibility, safety, and public acceptance of hydrogen systems on board aircraft and at airports. This will be achieved through the gradual adoption of hydrogen-based propulsion in aircraft of increasing size, from small 2-seater general aviation aircraft to large regional aircraft and 200+ passenger airliners. As these hydrogen-powered aircraft grow in size, they will make an increasingly significant contribution to reducing global aviation emissions. The ultimate goal is emission-free aviation from 2050 onwards. Currently (2025), many of the projects NLR is involved with are directly or indirectly linked to hydrogen, building on the success of initial strategic hydrogen research projects. Some examples of these projects are presented in this booklet.

R&D cases

HEROPS

Hydrogen-Electric ZeRo EmissiOn Propulsion System

HEROPS aims to introduce climate-neutral propulsion into regional aircraft by developing MTU's Flying Fuel Cell (FFC) propulsion system concept for entry into service in 2035. This disruptive hydrogen-electric propulsion system uses fuel cells as its sole power source and a liquid hydrogen fuel tank, without the need for high-power batteries. Integrating both the fuel cell system and the electric propulsion unit into a compact engine nacelle will ensure an efficient system at a high power-to-weight ratio.

THE CHALLENGE

HEROPS is targeting demonstration of a 1.2MW propulsion system based on a scalable 600kW core module at TRL4 (Technology Readiness Level). The core module and all further subsystems will be validated up to TRL5. Scalability up to the 2 to 4MW power level will be confirmed, complemented by simulation and electrical network testing of the overall modularised system. The certification programme will build upon ongoing certification activities, enabling timely maturation of the aviation-native HEROPS technology in line with relevant certification requirements.

WHAT WE ARE DOING

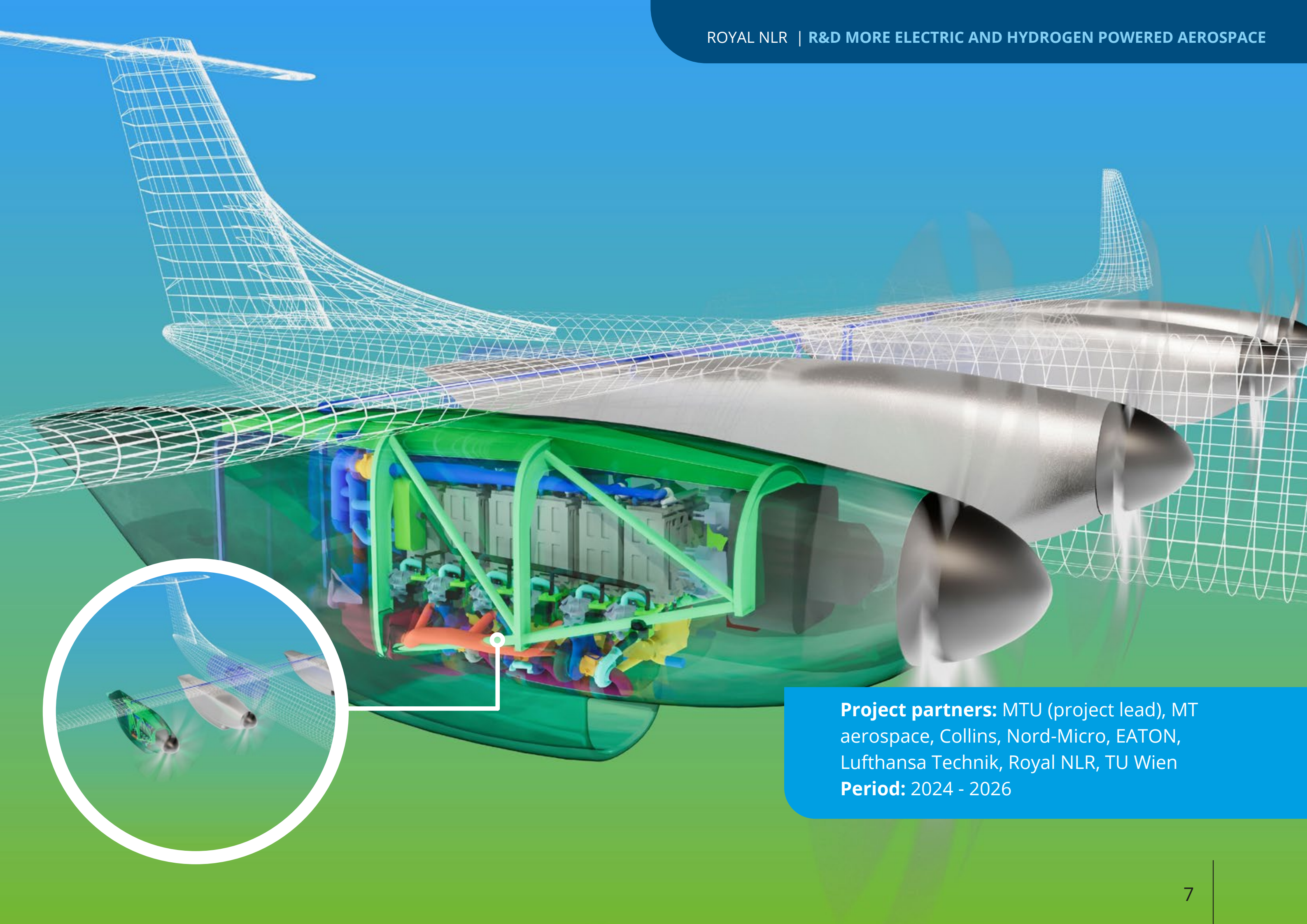
The two-phased approach of the overall programme – including extensive development, test and validation cycles at each stage – is expected to advance the FFC concept to TRL6 for integration and demonstration on a regional aircraft by 2028. It will pave the way for commercial prototyping and entry into service by 2035, delivering a propulsion technology that will be key for achieving the European Green Deal's objective of climate-neutral aviation by 2050 with 100% avoidance of CO_2 and NOx emissions and up to 80% reduction of the climate impact from contrails and contrail cirrus.

THE SOLUTION

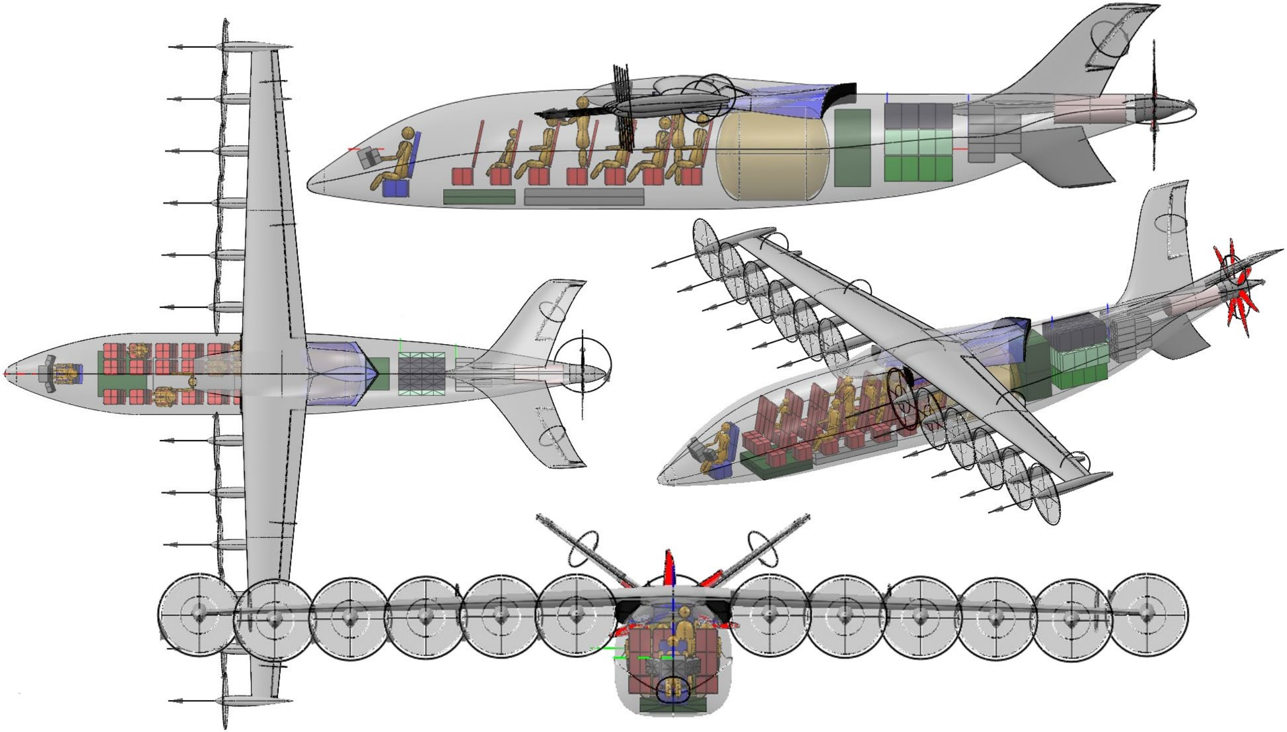
The HEROPS project will meet this challenge with a European consortium of aircraft propulsion system integrators, electrical system experts, key tier-one suppliers and leading researchers in stack technology, mechanics and propulsion, leveraging relevant and effective synergies between European and national programmes.

CLEAN AVIATION

Co-funded by the European Union. GA no 101140499



Project partners: MTU (project lead), MT aerospace, Collins, Nord-Micro, EATON, Lufthansa Technik, Royal NLR, TU Wien
Period: 2024 - 2026



Co-funded by the European Union. GA no. 101101998

Project partners: Pipistrel (project lead), Honeywell, Fraunhofer, Royal NLR, Universtity of Stuttgart, Delft University of Technology
Period: 2023 - 2026

HyPoTraDe

Hydrogen Fuel Cell Power Train Demonstrator

The HyPoTraDe objective is to deliver a validated digital twin model based on testing a powertrain demonstrator of a 500 kW fuel cell battery hybrid powertrain that can be scaled up to future MW class aircraft. This involves utilising the fuel cell's waste heat to enhance system efficiency and testing the powertrain under flight-relevant conditions. The project's outcome will contribute to achieving the ambitious goals for regional and short-range hydrogen-powered aircraft with Entry Into Service in 2035, helping to meet the EU's climate neutrality targets by 2050.

THE CHALLENGE

The key impact of HyPoTraDe is a fast-track optimisation of fuel cell powertrain electrical and thermal architectures based on state-of-the-art industrial components. It provides a comprehensive understanding of the operational characteristics of modular, fuel cell-battery hybrid-electric, distributed electric propulsion powertrain configurations for future aircraft. As safety is paramount in aviation, potential failure modes are analysed, and mitigation measures are identified and evaluated during the powertrain demonstrator test campaign.

WHAT WE ARE DOING

NLR is responsible for:

- Coordination of the failure modes studies
- Design of the powertrain demonstrator Thermal Management System design
- Design, modelling and testing of the (liquid) hydrogen distribution system, including a liquid hydrogen heat exchanger and a two-phase heat transfer loop utilising fuel cell waste heat
- Creation of a ground level test environment at NLR Marknesse for flight representative testing of the 500kW powertrain demonstrator (i.e. the Energy to Propulsion Test Facility, page 43)
- Coordination of the subsystems integration and the powertrain demonstrator test activities
- Delivery of a dataset for Digital Twin validation

THE SOLUTION

The project provides a ground level test environment for testing of a 500 kW hydrogen-electric powertrain demonstrator with the aim of validating the Digital Twin model. Flight representative load cases (e.g. taxing, take-off, climb, cruise, descent, and landing) and injected failures are being tested and evaluated. The powertrain demonstrator includes fuel cells, batteries, power distribution system, controls, converters, TMS, hydrogen distribution, liquid hydrogen heat exchanger, propulsor units, non-propulsive load emulation and a large liquid hydrogen storage tank. The validated Digital Twin will enable accurate performance predictions for scaled-up hydrogen-electric powertrains for future aircraft.

ICEFlight

Innovative Cryogenic Electric Flight

The ICEFlight initiative is exploring new technologies to support the development of fuel-cell aircraft, aiming to achieve hydrogen-powered flight. To this end, the consortium partners are investigating the use of liquid hydrogen (LH2) as both a fuel and a cooling source. The project focuses on designing a custom cryogenic cooling and electrical distribution system, providing an ideal environment to develop the skills, competencies, technologies and products needed in the Netherlands to support the next generation of aircraft.

THE CHALLENGE

Making flying sustainable for future generations requires innovative uses of LH2 in aviation, as well as creating new technologies and systems to support this goal. This involves enhancing the performance of next-generation aircraft powertrains through the application of innovative electrical technologies, superconductivity, and hyperconductivity.

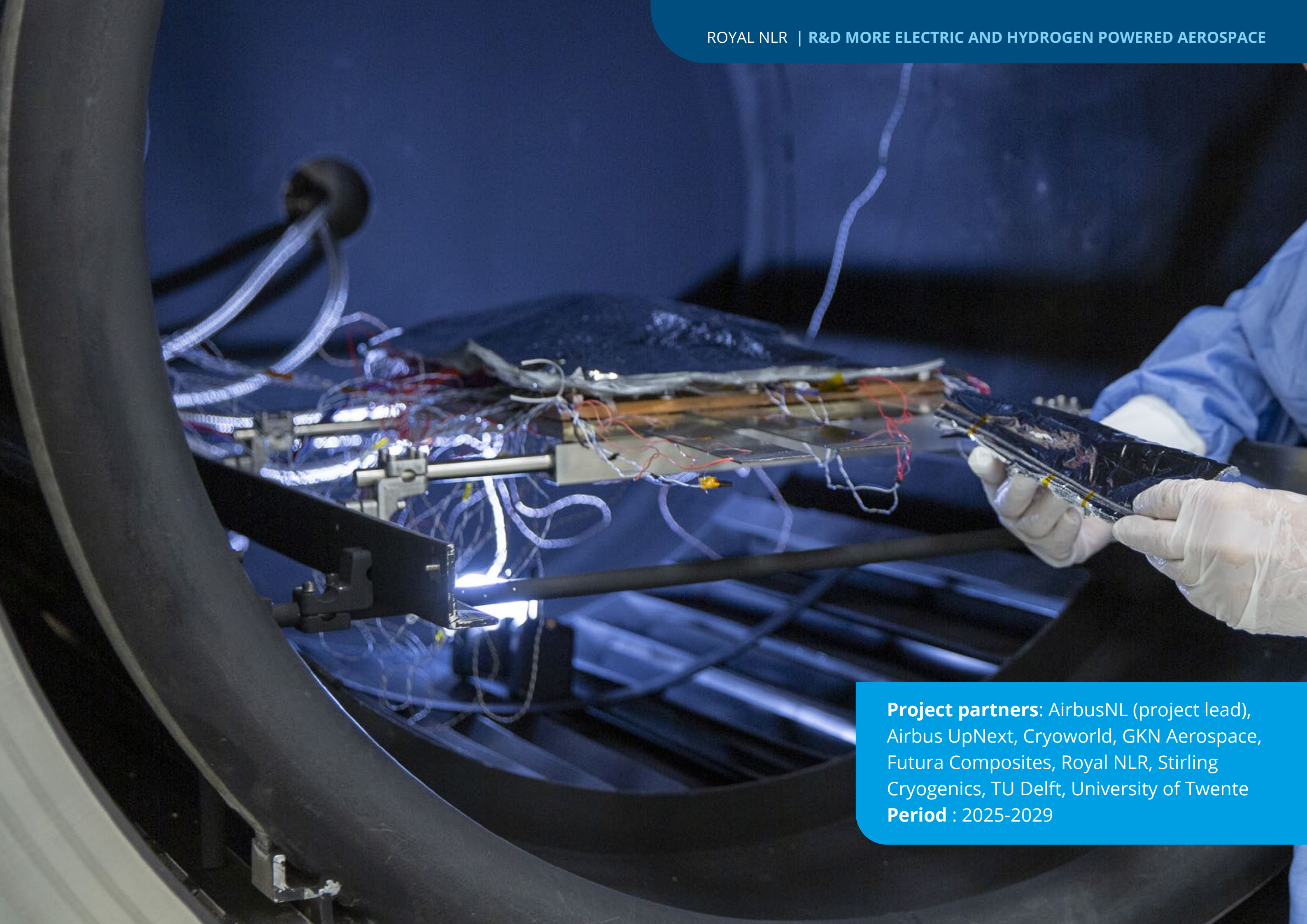
WHAT WE ARE DOING

In ICEFlight, equipment for a cryogenic-electric powertrain is being developed. With the aim of achieving TRL5+, the project requires the development of test capabilities for qualification testing in cryogenic conditions. To achieve this, NLR is leveraging its heritage in qualification testing for aviation and space. This expertise enables us to define testing methodologies and create test benches that meet the requirements for cryogenic equipment qualification testing. A key aspect of the project involves the use of LH2 in the cryogenic cooling system. A dedicated test bench will be designed to verify the concept of using liquid hydrogen as both fuel and cold source in the cryogenic powertrain.

LUCHTVAART in transitie

THE SOLUTION

NLR will contribute to the development of the two key technologies in project ICEFlight by using its expertise in qualification testing for aerospace to define testing methodologies and create specialised test benches. Ultimately, the goal is to improve Dutch global competitiveness and position the Dutch supply chain as a leader in advanced aerospace technologies, paving the way for sustainable aviation.



Project partners: AirbusNL (project lead), Airbus UpNext, Cryoworld, GKN Aerospace, Futura Composites, Royal NLR, Stirling Cryogenics, TU Delft, University of Twente
Period : 2025-2029

Aviation in Transition

Luchtvaart in Transitie

By 2050, aviation must be climate-neutral, and momentum is crucial to achieving this goal. Through Aviation in Transition, the Netherlands strengthens its position as an innovative and resilient leader in aviation.

Within Aviation in Transition, various stakeholders - including universities, knowledge organisations, SMEs, and large enterprises - are united in their efforts. In close collaboration, they work on accelerating the development of breakthrough technologies that make crucial systems, and consequently, future aircraft ultra-efficient and free of CO_2 emissions. The Dutch government supports this mission with essential funding from the National Growth Fund and policies to facilitate the introduction of “new flying”. Between 2023 and 2030, several projects will be undertaken to develop technologies, build sustainable knowledge, and strengthen the aviation ecosystem. As a result, we will have enough trained individuals for the transition to a new aviation system, enabling us to secure a stronger market position within the global chain. The Aviation in Transition programme consists of thirteen projects. NLR contributes to most of them, including the eight projects mentioned here.

Hydrogen Optimisation & Testing (HOT)

Project lead: Fokker NextGen

HOT aims to build validated knowledge and data on hydrogen fuel systems.

Flying Vision Accelerator

Project lead: TU Delft

The goal of Flying Vision is to achieve a 'holistic' collaboration within the aviation ecosystem.

Promising Research

Project lead: Royal NLR

Research to support the manufacturing industry after 2030 by focussing on long term solutions.

Advanced Electrical Wiring

Project lead: Fokker I GKN Aerospace

This project develops advanced high-power wiring systems for increased electrical power in hybrid-electric aircraft and hydrogen fuel cell systems.

LUCHTVAART in transitie

Materials, production technology and structures

Project lead: Fokker I GKN Aerospace

This project develops innovative production technologies for complex thermoplastic composite parts and integrated structures.

Hydrogen Aircraft Powertrain and Storage Systems (HAPSS)

Project lead: Conscious Aerospace

The project develops a hydrogen-electric powertrain for a Dash 8-300 aircraft to achieve emission-free regional flights.

Thermal and Pneumatic Systems (TePS)

Project lead: Aeronamic

For hydrogen-electric powertrains on board low-emission aircraft, new cooling systems and turbo compressors are required.

Dutch Aviation Systems Analysis Lab (DASAL)

Project lead: Royal NLR

This project analyses and monitors the effects of innovations on sustainability, and economic and societal impacts.

Read more

TULIPS

demonsTrating less pollUting soLutions for sustaInable airPorts acrosS Europe

Airports will play a major role in the transition to climate-neutral aviation. Sustainable energy production and use (both airside and landside) as well as a shift towards greener multimodal transport options will reduce greenhouse gas emissions and improve the local air quality around airports.

THE CHALLENGE

One of the challenges addressed in TULIPS is developing a robust facilitating role for airports in accommodating the turnaround of electric, hybrid electric, and hydrogen-powered aircraft. To achieve this, various obstacles in the charging infrastructure and refuelling aircraft with hydrogen need to be tackled.

THE SOLUTION

With its contributions in TULIPS, NLR aims to offer a comprehensive approach to introducing electric, hybrid-electric, and hydrogen-powered aircraft. The completed feasibility study provides a solid foundation, examining the necessary infrastructure, operational procedures, and potential impact on costs and flight schedules. In parallel, NLR has been developing the required safety and operational procedures. Building on this foundation, and following the successful completion of the first demonstration, the focus has now shifted to the remaining demonstrators, which will yield valuable findings and insights.

WHAT WE ARE DOING

NLR leads Work Package 2 of the TULIPS programme, consisting of a feasibility study and three demonstrators. The feasibility study was completed in 2023, followed by the first successful demonstration showcasing unattended charging at Rotterdam The Hague Airport in 2024. The remaining two demonstrations are planned to take place by the end of 2025 and the beginning of 2026, focusing on a modular charging system and an airport-facilitated hydrogen flight, utilising NLR's hydrogen research infrastructure.

Project partners:
Schiphol Nederland NV (project lead), AVINOR, SINTEF, HERMES, Catalink, SAGAT, POLITO, BETA-i, EGIS, EME, Fraunhofer, KLM, KES, MMU, MOBCON, Royal NLR, PIPISTREL, POA, SKYNRG, TNO, TUD, IST-ID, UANTW, BAM, BALLARD, DHL, ZEPP, HyCC, BOS and Middelkoop
Period: 2022 - 2026

Co-funded by the European Union. GA no 101036996

COCOLIH2T

Composite Conformal Liquid H2 Tank

The global aviation industry is committed to reducing net aviation carbon emissions by 50% by the year 2050, while the European Commission has set an even more ambitious target of cutting CO2 emissions per passenger kilometre by 75%. Alternative fuels, such as liquid hydrogen (LH2), are expected to play a crucial role in achieving a zero-emission future for aviation. In this regard, the COCOLIH2T project is therefore investigating the storage of cryogenic (20 K) liquid hydrogen on aircraft, with a focus on designing, manufacturing, and testing storage containers for both new and existing aircraft designs.

THE CHALLENGE

- Design, manufacture and demonstrate a full-scale composite conformal storage tank for liquid hydrogen at TRL4.
- LH2 tank capacity: 57 kg LH2.
- Gravimetric index: > 25%.
- No liner.
- Venting rate: < 2% per day.
- Developing and testing subsystems for gauging, refuelling and monitoring structural health for safe performance.

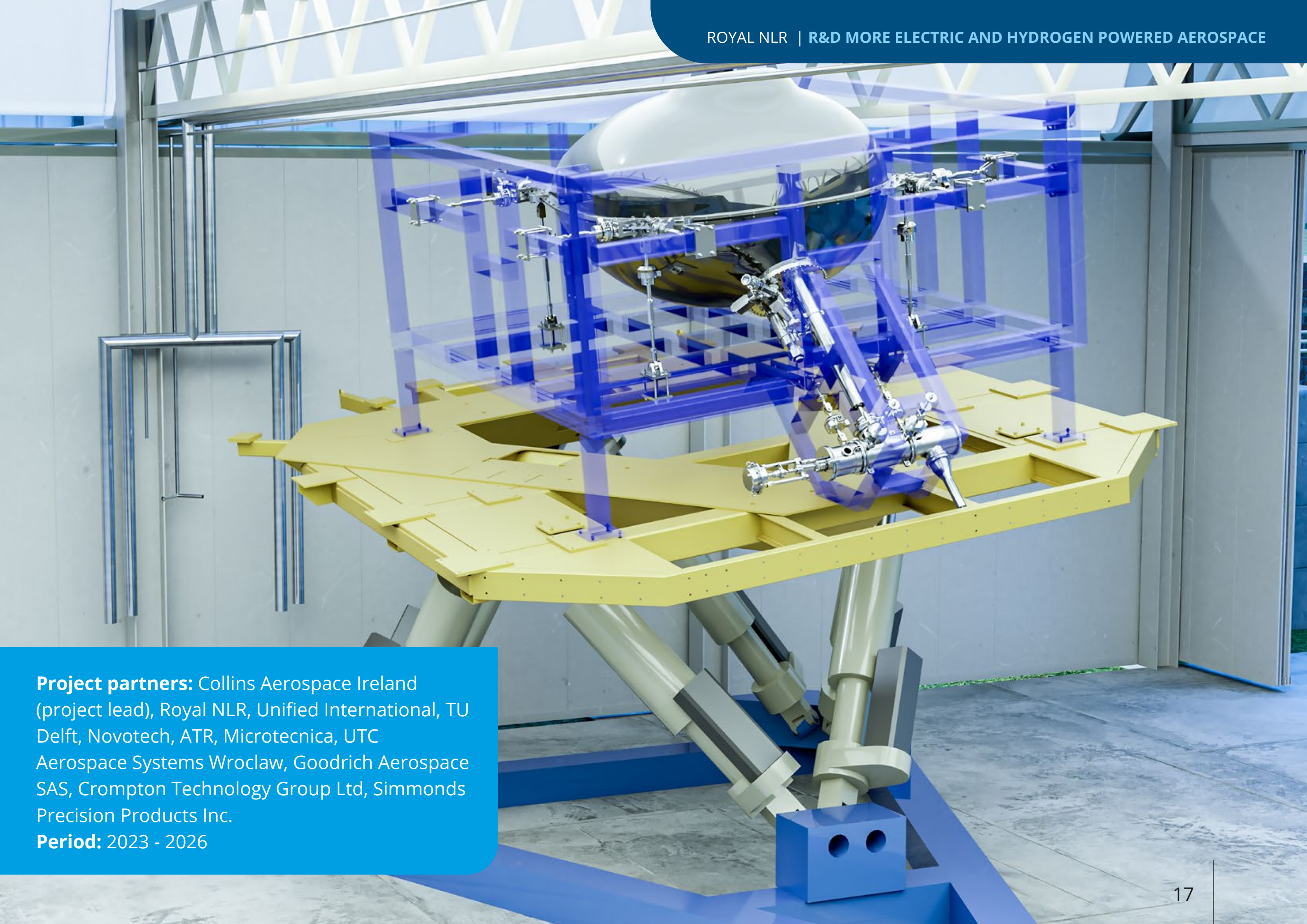
WHAT WE ARE DOING

NLR developed an initial design for a thermoplastic composite conformal tank that fits into an ATR-72 in collaboration with project partners. To determine the static material properties at 20 K, NLR executed a static test campaign using their cryostat facility. As part of this campaign, a permeability test was developed and microcracks were investigated. The two demonstrators, which will be manufactured by project partners, will undergo testing with large quantities of liquid hydrogen at NLR's newly built Energy to Propulsion Test Facility (EPTF). NLR is currently designing and manufacturing test setups to validate the design and sloshing models. Additionally, test and safety procedures are being compiled and reviewed to ensure all tests are conducted safely.

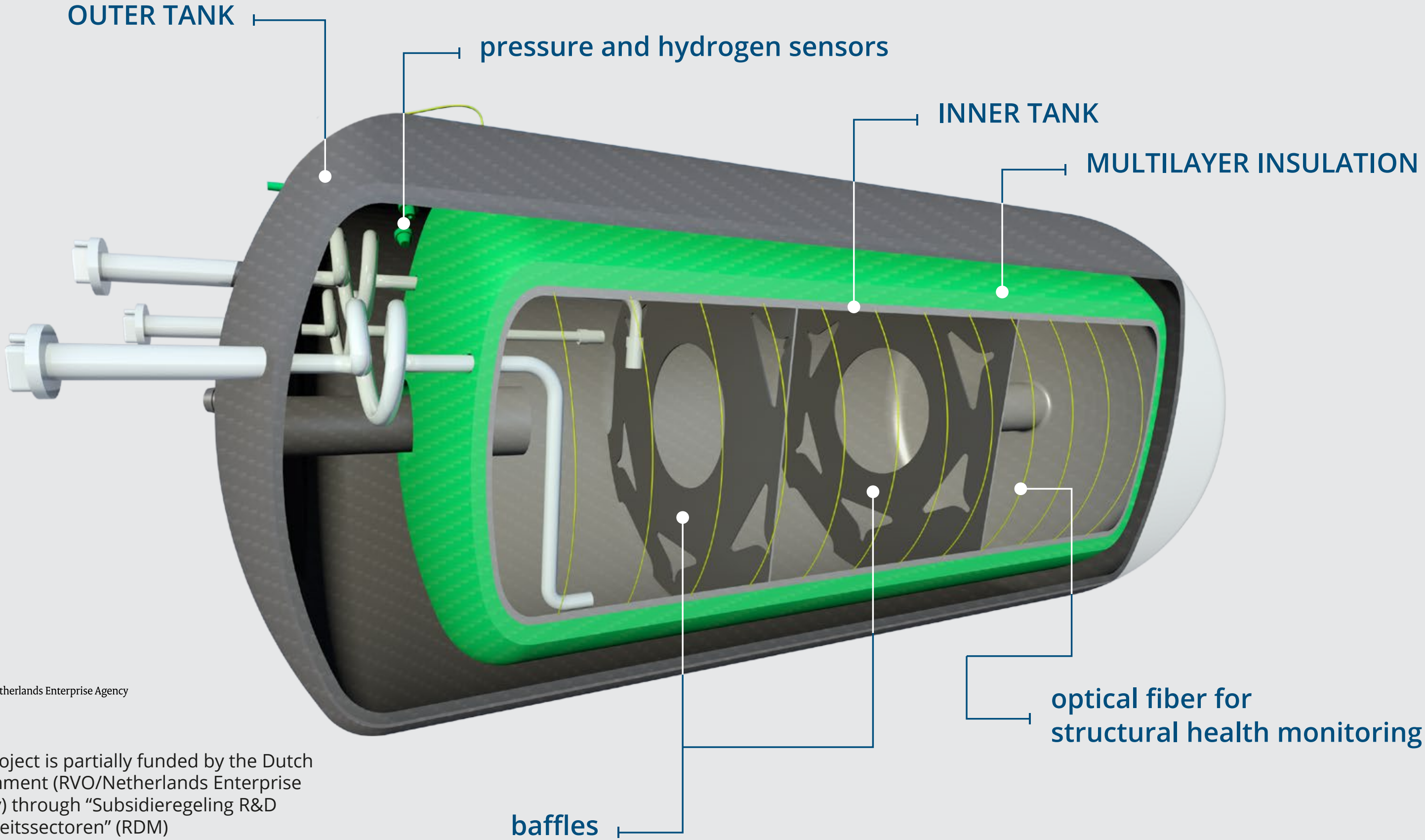
THE SOLUTION

- Perform material testing at 20 K, permeability tests and microcrack investigations to select a suitable composite material.
- Design an inner and outer tank including hoses and valves for safe fuelling and de-fuelling. Designs must be able to absorb internal pressures due to boil off, flight and sloshing loads.
- Design and testing of sensors to monitor LH2 levels, H2 leakage, vacuum and pressure levels.
- Manufacture all individual parts and assemble them in 2 demonstrators.
- Test 2 full-scale demonstrators with LH2 to validate the requirements at TRL4.

COCOLIH2T Clean Hydrogen Partnership Co-funded by the European Union. GA no 101101961



Project partners: Collins Aerospace Ireland (project lead), Royal NLR, Unified International, TU Delft, Novotech, ATR, Microtecnica, UTC Aerospace Systems Wroclaw, Goodrich Aerospace SAS, Crompton Technology Group Ltd, Simmonds Precision Products Inc.
Period: 2023 - 2026



Netherlands Enterprise Agency

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

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 (LH2) composite tank will achieve weight savings that enable the advancement of liquid hydrogen as a sustainable fuel 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 achieved 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.

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 will be developed with contributions of all consortium members. The tank will be equipped with fluid level sensors and sensors for safety systems. During the design phase, digital design strategies will be used to minimise thermal stress and optimise utilisation of automated manufacturing technologies.

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 is selected for the inner tank and characterised regarding engineering properties at 20 Kelvin. For the outer tank a thermoset composite material is selected. With these materials a composite tank will be designed, manufactured and tested. The health and safety of the tank will be monitored with various fibre optic sensors. Because of their minimal heat ingress, fibre optic sensors are also used to monitor the temperature, pressure, LH2 fuel level and leak detection.

Project partners: Toray, ADSE, Airborne, Bold Findings, Cryoworld, Fokker Aerostructures, IT'S Engineering, KVE, PhotonFirst, Somni Solutions, Taniq, Royal NLR, SAM XL, TU Delft
Period: 2022 - 2026

PHYREX

Pipistrel Hydrogen Range Extender

Hydrogen-powered aircraft is one of the most promising novel aircraft technologies to contribute to a sustainable future for aviation. NLR is involved in various areas related to hydrogen knowledge and capability development, ranging from tanks to engines and from design to testing and certification. As part of a roadmap and phased approach for NLR's electric research aircraft, the Pipistrel Velis Electro, a hydrogen-based range extender will be developed and demonstrated in flight.

THE CHALLENGE

As hydrogen propulsion is a new technology in aerospace, the following questions need to be answered:

- Is it possible to develop a hydrogen powertrain solution that is both cost-efficient and optimised for aircraft performance?
- Can compliance demonstration of a hydrogen powertrain with the – yet to be defined – safety requirements be achieved?
- How does the hydrogen powertrain compete with other conventional and novel technologies?

WHAT WE ARE DOING

NLR is collaborating with Zepp.solutions and Cryoworld to design and develop a hydrogen powertrain for the Pipistrel. The main considerations include:

- Volume and weight constraints of the existing Pipistrel configuration
- Development and aircraft integration of novel hydrogen technologies
- Safety requirements & limited availability of regulatory frameworks

The primary focus for 2026 is on the manufacturing of all subsystems and extensive testing, concluding with a demonstration flight.

THE SOLUTION

The Pipistrel Velis Electro will be retrofitted with a liquid hydrogen tank and a belly fairing to accommodate the hydrogen powertrain, which will interface with the existing electrical system. This will enable independence to be maximised and risks to be mitigated as a first step towards fully hydrogen-based solutions. Following a design period and extensive ground testing, the flight demonstration will be a major milestone in achieving our goals towards more sustainable aviation.

LUCHTVAART in transitie

This research is partly conducted within the research and innovation programme Luchtvaart in Transitie, which is co-funded by the Netherlands National Growth Fund.

Project partners: Royal NLR, Zepp.solutions, Cryoworld
Period : 2023 - 2026

Research organisation: Royal NLR (knowledge development project)
Period: 2020 - 2025

HYDRA II

Hydrogen Drone Research Aircraft II

Drones offer an ideal platform for safely testing hydrogen technologies on a smaller scale and at a relatively low cost. In 2019, Royal NLR was the first to fly a drone powered by gaseous hydrogen in Dutch airspace as part of the HYDRA I project. Building on this success, the follow-up project, HYDRA II, marked a Dutch premiere by flying a liquid hydrogen-powered drone in August 2025. This milestone provides additional insights into the research and development of alternative fuels and paves the way for sustainable aviation.

THE CHALLENGE

As hydrogen offers extended flight duration and distance, beyond what is possible with batteries alone, flying on liquid hydrogen is crucial to achieving the necessary range to be considered a viable alternative fuel in sustainable aviation. Gaining practical experience in enabling and conducting such flights is essential to effectively support its real-world application in drones and its scalability to crewed aircraft.

THE SOLUTION

The HYDRA II project contributes to the standardisation and certification of hydrogen systems for commercial applications. As part of this effort, handling and operational safety procedures were developed, which can be adopted by other (drone) operators and used by regulatory authorities as a benchmark. This will ultimately facilitate the scalability of these systems to crewed aircraft. Additionally, the findings from the analysis of the electrical architecture and thermal management system required to store hydrogen at -253°C/20K can inform fuel cell and tank manufacturers.

WHAT WE DID

NLR developed the liquid hydrogen (LH2) infrastructure and designed a hydrogen-propulsion conditioning system in preparation of flying the HYDRA II drone on LH2. To achieve this, our initially electrically powered drone was equipped with a powertrain comprising a fuel cell, cryotank, and heat exchanger. Additionally, we conducted safety analyses (EVD, HAZOPs, SORA), test procedures, gained practical experience with these systems, and refined our internal processes, all of which were crucial steps within this project.

GREENPOINT

Reversible fuel cells are promising devices that can both create and use fuels to store energy and power electronic devices. However, traditional PEM hydrogen fuel cells are notorious for their degradation mechanisms and often require costly precious metals. Therefore, there is a need for next generation fuel cells that combine affordability, durability and performance. Furthermore, health monitoring tools are required to identify degradation mechanisms, predict lifetime and optimise performance.

THE CHALLENGE

Many challenges were faced during the development of next generation fuel cell systems and health monitoring tool, such as:

1. Traditional PEM fuel cells require costly precious metals such as platinum and iridium.
2. Fuel cells are notorious for their degradation mechanisms.
3. Fuel cells typically perform poorly in electrolysis mode and *vice versa.*
4. Health monitoring requires fundamental knowledge on material science and electrochemistry.

WHAT WE DID

NLR has designed a test environment for health monitoring of fuel cells. The developed catalyst materials were validated on a larger scale to prove their feasibility for future industrial use. Long-term stability of the AEM catalyst was confirmed by monitoring the health over an extended period. Health monitoring tools were used to ensure adequate cell assembly.

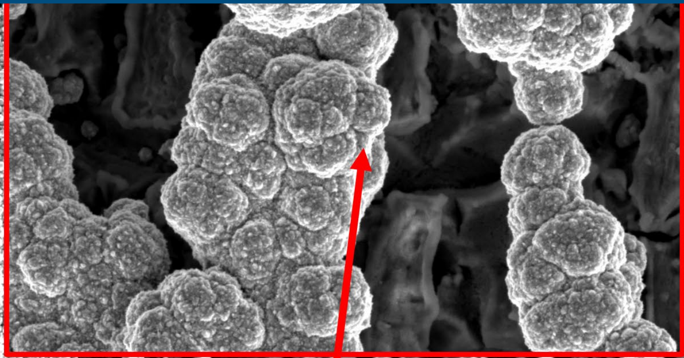
Accelerated stress tests were performed on electrolyser cells to stimulate degradation, after which recovery techniques were used to restore original cell performance and extend the lifetime.

THE SOLUTION

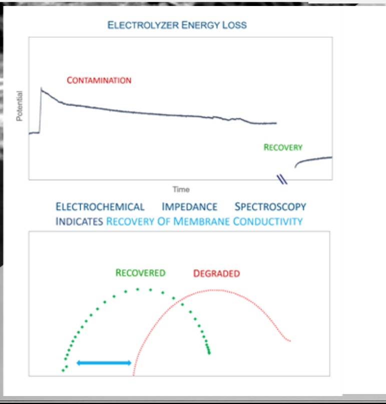
GREENPOINT has developed novel catalyst materials for the next generation AEM electrolysers and fuel cells to achieve low cost, high performance and durable systems. AEM technology paves the way for non-precious metals to be used in fuel cells. Materials such as iron, nickel, carbides and nitrides were prepared to achieve high performance in both fuel cell and electrolysis mode using common materials. Health monitoring tools were used to quantify and optimise performance by identifying critical health indicators. Recovery methodologies were developed using health monitoring tools to rejuvenate degraded electrolyser cells to extend their lifetime.

Nickel and Iron based Catalyst for Reversible Fuel Cells

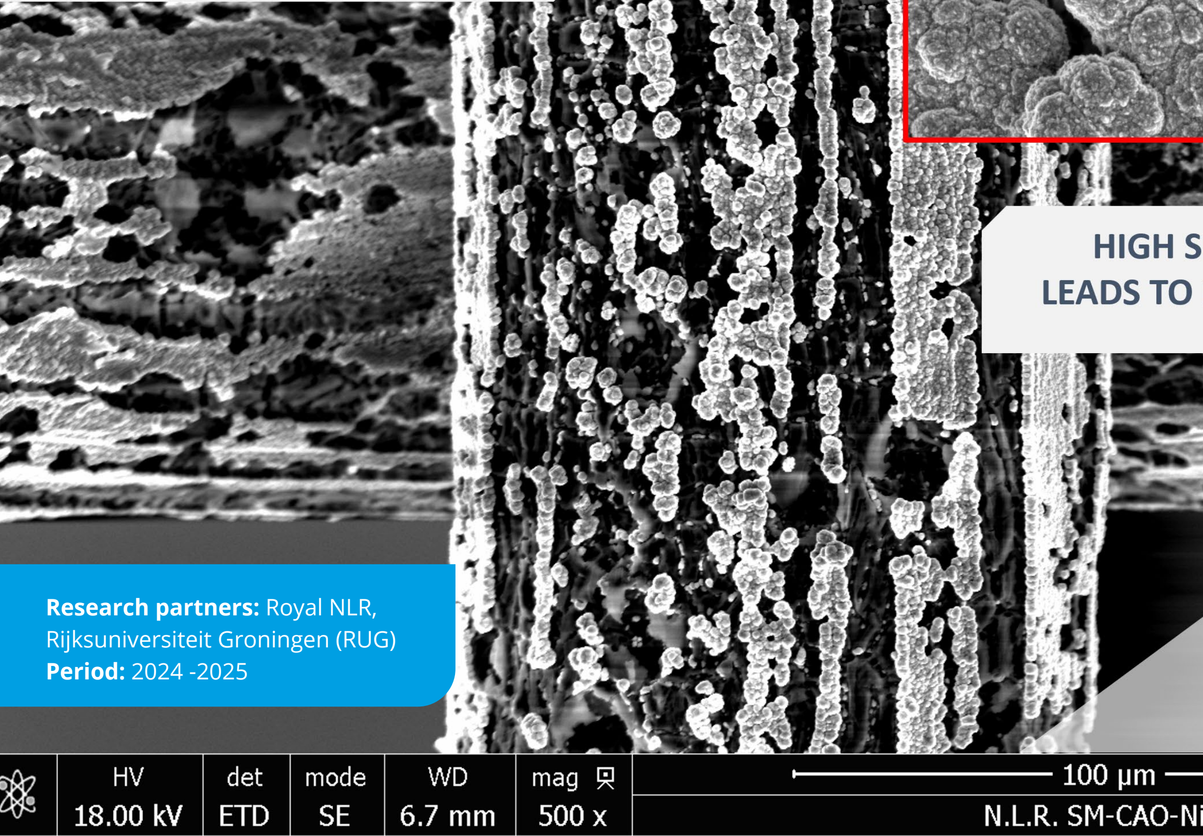
Low Cost
High Stability
Bifunctional



HIGH SURFACE AREA LEADS TO HIGH EFFICIENCY



Research partners: Royal NLR, Rijksuniversiteit Groningen (RUG)
Period: 2024 -2025

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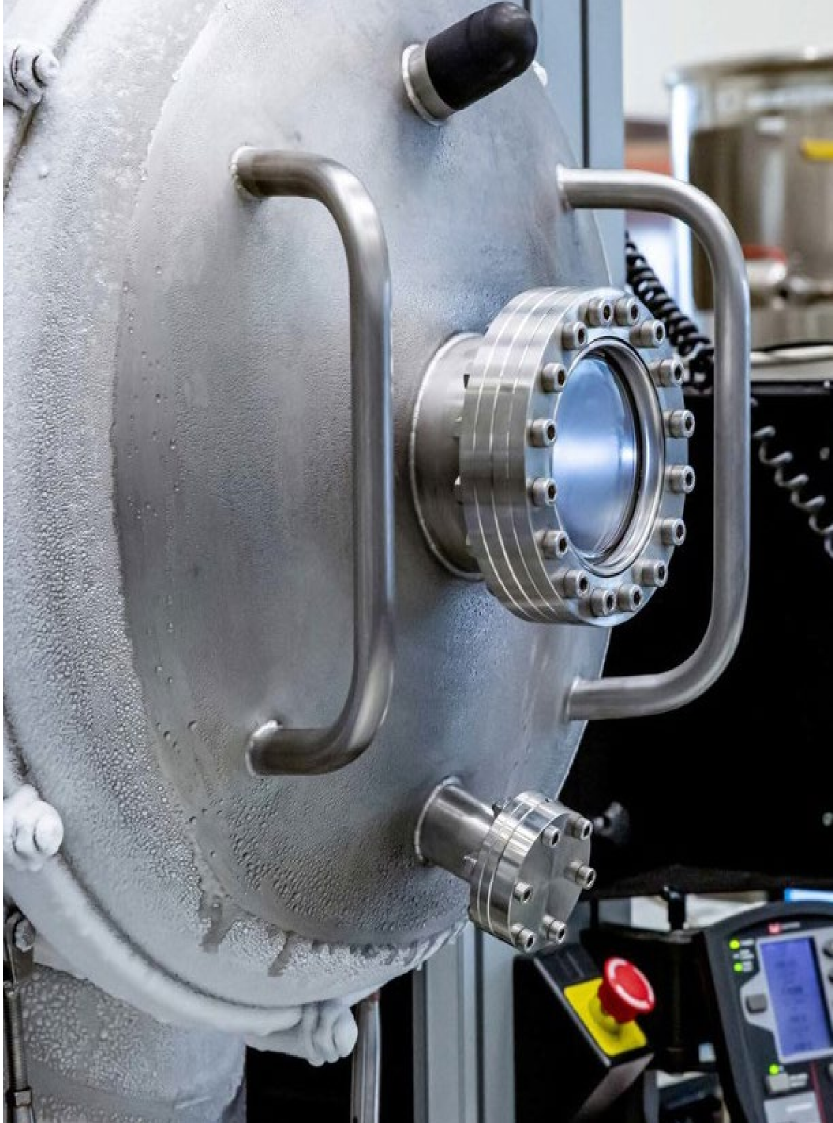


MATPRO@20K

Material properties at 20 Kelvin

The goal of project MatPro@20K is to conduct a feasibility study that explores the possibilities and requirements for dynamic testing at extremely low temperatures – down to -253 °C or 20 K. By identifying the technical, thermal, and mechanical challenges involved, the project aims to lay the groundwork for future development of a dynamic cryostat. The ultimate goal is to develop cutting-edge applications for liquid hydrogen storage and superconducting systems.

THE CHALLENGE

While static tests allow us to characterise strength and deformation under steady loads, real-world applications often involve cyclic or fluctuating forces. Tackling dynamic testing presents a whole new set of challenges: long term effects, thermal gradients, vibration control, precise load application, and material fatigue behaviour at cryogenic temperatures. Overcoming these hurdles will be crucial to qualifying components for demanding, real-use environments.

THE SOLUTION

The solution is a test setup designed to facilitate dynamic testing under cryogenic conditions, while still being safe and efficient. Initially, the setup will utilise helium as the cryogenic coolant in a closed circuit, with plans to transition to liquid hydrogen in the future.

The MatPro@20K project has the potential to revolutionise the field of materials testing, enabling the development of new materials and technologies capable of withstanding extreme conditions.

WHAT WE ARE DOING

The study aims to identify the technical, thermal, and mechanical challenges associated with dynamic testing at 20 K, with a focus on three key areas:

- the load train, which transfers the external applied mechanical load to the test sample
- the interface between moving and non-moving parts, where fatigue may occur
- designing and prototyping the required equipment for dynamic testing

Project partners: Royal NLR, ASML, VDL-etg, HHT Materials
Period: 2024 - 2025

CONCERTO

Construction Of Novel CERTification methOds and means of compliance for disruptive technologies

CONCERTO is aiming to develop a comprehensive set of regulations for aircraft certification, together with a preliminary description of the Methods of Compliance (MoCs) that will apply to the three main thrusts of clean aviation: Hybrid-electric regional aircraft, Ultra-efficient short and short-medium range aircraft disruptive technologies for enabling hydrogen-powered aircraft. Furthermore, it aims to assess the feasibility of a digital certification framework that will help collaboration and model-based certification.

THE CHALLENGE

Certification is expected to improve safety while also shortening the time taken to get new and safe products onto the market and into service, as well as maintaining European leadership and competitiveness. The results are expected to be transferable and scalable to other product lines and aviation segments such as general aviation, rotorcraft, business jets and commercial medium-long range, affecting the entire fleet.

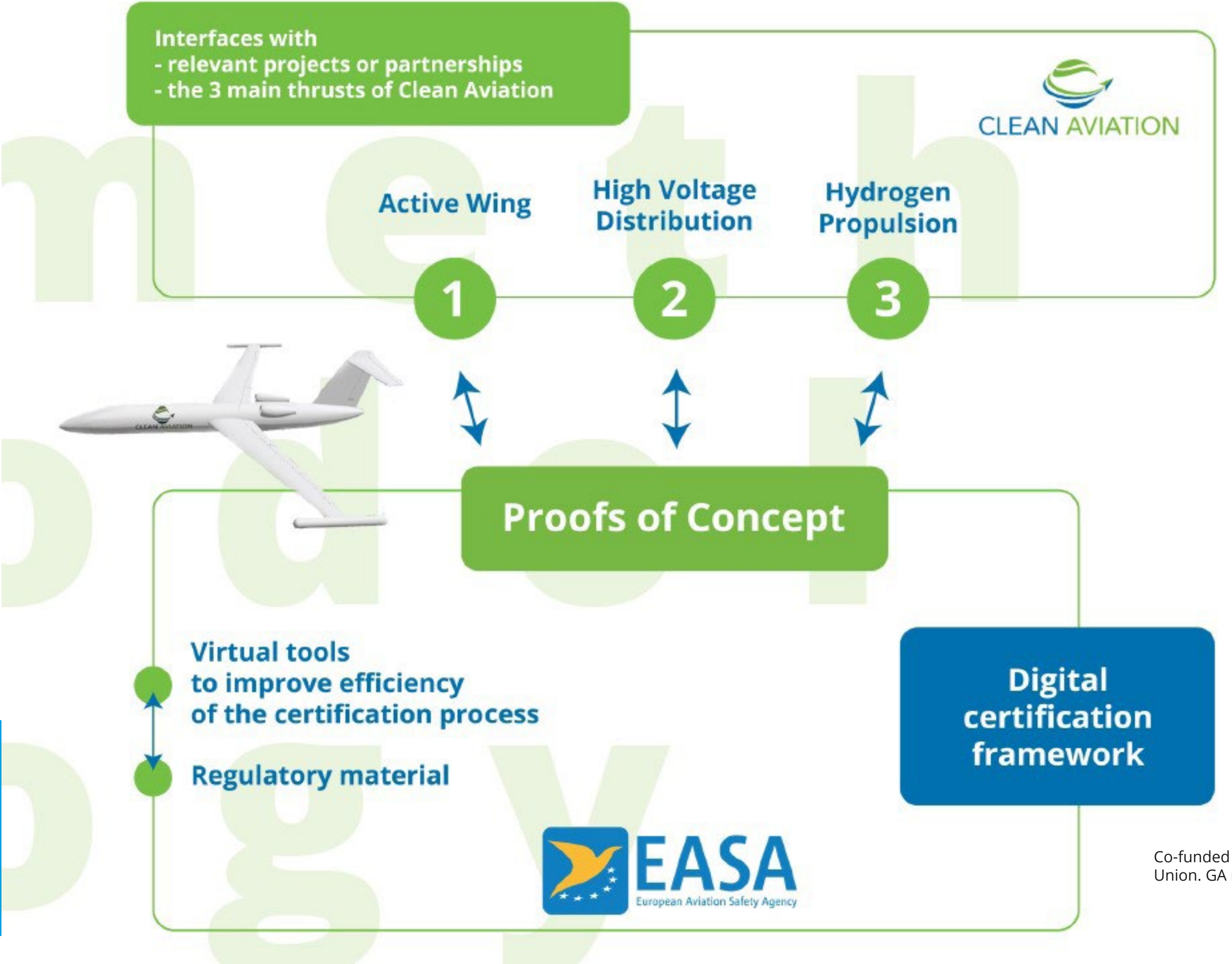
WHAT WE ARE DOING

- Defining safety objectives to develop rules & regulations
- Identifying critical areas and regulatory gaps
- Identifying "gap fillers" for rules & regulations
- Tackling challenges created by the disruptive new technologies
- Proposing new regulatory material and rules

THE SOLUTION

The certification framework can be a key enabler for reducing emissions and achieving the target of climate neutrality by 2050. The new methods and processes for certification will significantly reduce development time and the cost of introducing new products to the market. The initiative is working on creating an ecosystem by encouraging networking throughout the aviation community, sharing common goals and developing synergies with other industries.

Project partners: Dassault Aviation (project lead), Royal NLR, DLR, TU Delft, Airbus, ONERA, Pipistrel, EASN, Safran, Collins, Leonardo, Fraunhofer, Thales, IRT Saint Exupery, Aviation Design, Arianegroup, BNAE, University of Stuttgart, University of Girona, INTA
Period: 2023 -2026



Co-funded by the European Union. GA no 101101999

Project partners: 26 partners, including Safran Aircraft Engines (project lead), GE AVIO,GKN, Airbus, Royal NLR, research centres, SMEs, universities
Period: 2022-2025

OFELIA

Open Fan for Environmental Low Impact of Aviation

Decarbonising aviation is the greatest challenge facing the air transport industry. The open fan engine architecture is in line with the Clean Aviation Strategic Research and Innovation Agenda (SRIA), which prioritises the development of technologies that reduce the environmental impact of small-medium range (SMR) aircraft. The engine is essential in this effort.

THE CHALLENGE

The EU-funded OFELIA project will demonstrate the Revolutionary Innovation for Sustainable Engines (RISE) Open Fan architecture for SMR aircraft as a key contributor to the Air Transport Action Group's goals towards carbon neutrality by 2050. The Open Fan engine architecture is the most promising solution in terms of fuel efficiency to both achieve environmental goals (20% emissions reduction versus 2020) and target a rapid Entry into Service, as early as 2035.

WHAT WE ARE DOING

OFELIA is led by Safran Aircraft Engines with 26 partners. The project will also optimize the engine installation and prepare an in-flight demonstration for phase 2 of Clean Aviation with the airframer and supported by European research centers. NLR contributes to the numerical aero-acoustic and aero-elastic evaluation of the RISE Open Fan architecture, using CFD-based analysis. In addition, NLR investigates the feasibility of experimental means and methods to measure the thrust of the Open Fan during the in-flight demonstration. In particular, the transfer of accurate measurement methods known from wind tunnel testing to in-flight testing is investigated.

CLEAN AVIATION

Co-funded by the European Union. GA no 101102011

THE SOLUTION

In synergy with national programmes, OFELIA will focus on full-scale demonstrations of the engine architecture and on developing key enablers for the Open Fan, including innovative turbomachinery technical solutions.

OFELIA will perform a large-scale Open Fan engine ground test campaign, deliver a flightworthy propulsive system definition and prepare an in-flight demonstration for the phase 2 of Clean Aviation. Lastly, the compatibility of the Open Fan with hydrogen will be investigated as well.

HECATE

Hybrid ElectriC regional Aircraft distribution Technologies

HECATE is helping achieve the required reduction of aircraft greenhouse gas emissions down to zero by 2050. This will be done by a move towards electric/hybrid-electric propulsion technologies that will significantly reduce the fuel burn. HECATE is aiming to deliver transformative technologies that will make the electrical distribution in such future hybrid-electric aircraft possible.

THE CHALLENGE

The transition to electric and/or hybrid-electric propulsion implies a significant increase in on-board electrical power, which needs to be distributed appropriately. The HECATE goals for tackling this challenge are:

- developing holistically optimised electrical architecture
- technology brick development to TRL5
- mitigating high-voltage (HV) phenomena and electromagnetic interference (EMI)
- developing digital twins
- achieving a certifiable electrical distribution architecture
- technology roadmap for short and longer term electrical architectures

WHAT WE DID

NLR is helping GKN Fokker Elmo optimise the high-voltage direct current (HVDC) cabling for the secondary power network by modelling and testing thermal and electromagnetic compatibility (EMC) aspects.

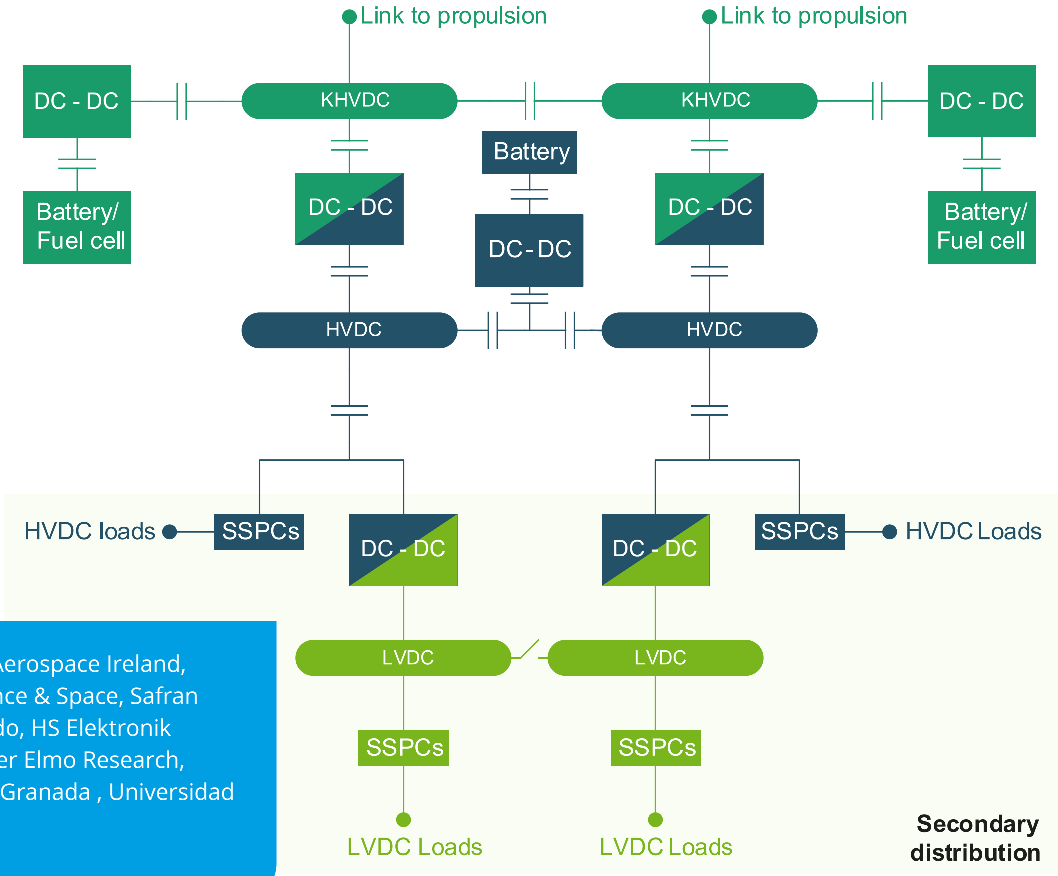
Moreover, NLR is involved in tackling the new EMI/EMC challenges arising from HV power distribution. This includes compatibility of the HV network with existing electrical networks and adverse physical effects such as arcing and lightning protection. Simulation models will be extended further to assist the EMC analysis that is a leitmotif throughout all the technologies developed for HECATE.

THE SOLUTION

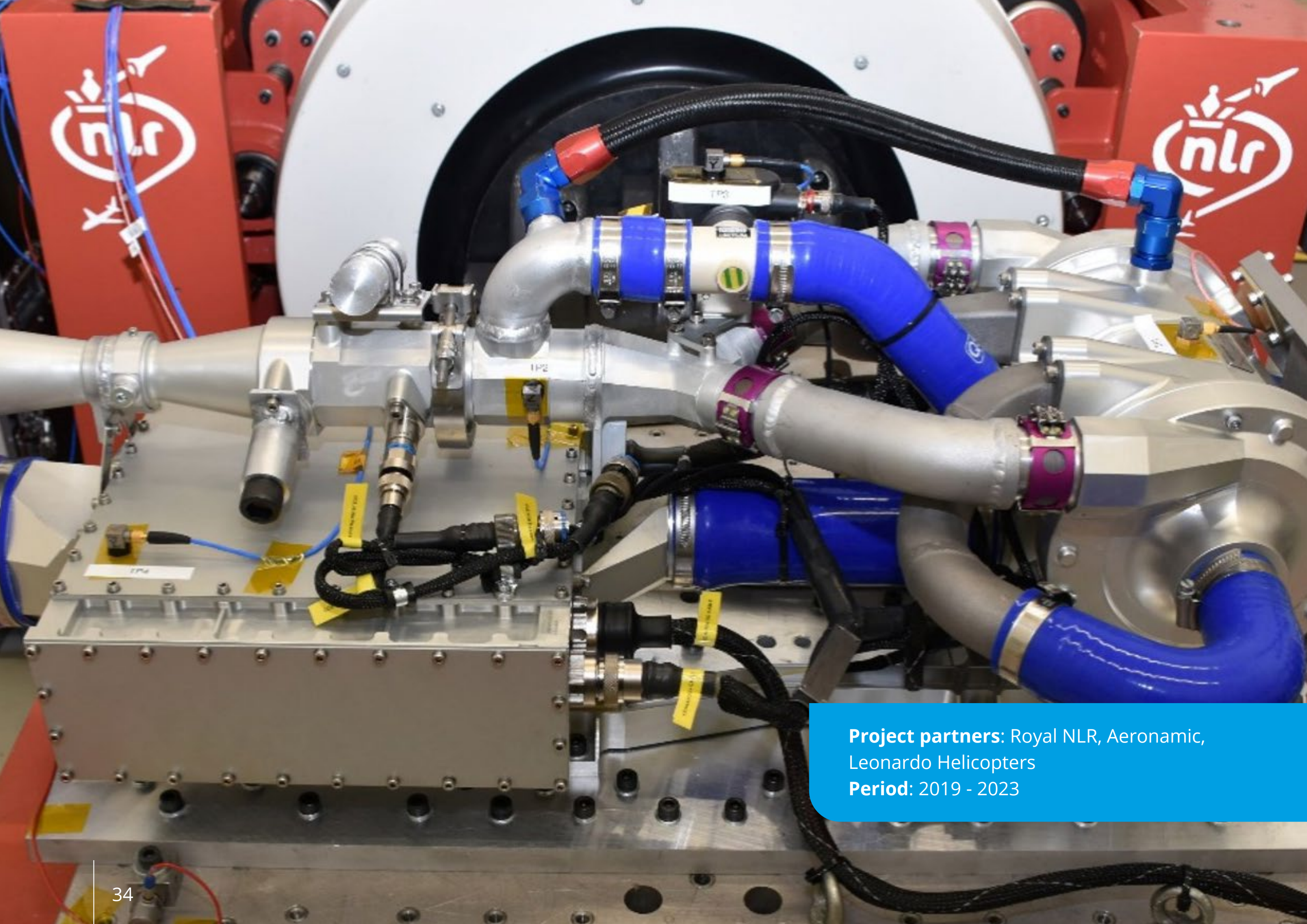
HECATE is developing critical technologies for high-power, high-voltage and certifiable electrical distribution architectures capable of enabling hybrid-electric propulsion for regional platforms, that may also affect other aircraft domains such as Urban Air Mobility and Short and Medium Range aircraft. The architectures will drive the reduction of aircraft greenhouse gases towards the objectives of 30% net GHG emission reduction by 2035 and zero emissions by 2050. The HECATE project will demonstrate a >500 kW architecture in a copper bird test facility in 2025.

CLEAN AVIATION

Co-funded by the European Union. GA no 101101961



Project partners: Collins Aerospace Ireland, (project lead), Airbus Defence & Space, Safran Electrical & Power, Leonardo, HS Elektronik Systeme GMBH, GKN Fokker Elmo Research, Royal NLR, Universidad de Granada , Universidad Carlos III de Madrid
Period: 2023 - 2026



Project partners: Royal NLR, Aeronamic, Leonardo Helicopters
Period: 2019 - 2023

ELECTRA

Electric Compressor Pack for Cabin Air Pressurisation

European tilt-rotor aircraft have pressurised cabins for high-altitude flight, which is uncommon in helicopters due to the weight and cost. Traditional pressurisation for large aircraft uses engine bleed air but there are advantages to an electrically driven compressor using fresh outside air. In the Clean Sky 2 ELECTRA project (Efficient and Light Electric Compressor for Tilt-Rotor Aircraft), a high-speed electric compressor pack was developed for cabin pressurisation.

THE CHALLENGE

Conventional cabin pressurisation relies on engine bleed air, sacrificing energy efficiency because the air requires conditioning and because there is an excess air supply. Moreover, oil contamination risks from traditional systems cause discomfort and pose health hazards to crew and passengers.

WHAT WE DID

NLR developed a simulation platform for architectural trade-off analyses, component dimensioning and optimisation, and system performance and stability prediction. Based on the system requirements that were defined, the air compressor pack system hardware was developed by the project partner Aeronamic. NLR developed a system test bench to verify the requirements and enable test results to be fed back into the system models for high-fidelity model updates.

The pack hardware was also tested at NLR's environmental test facilities, including electromagnetic compatibility and vibration resistance tests, in preparation for flight testing the equipment aboard the next generation tilt-rotor test demonstrator aircraft.

Co-funded by the European Union. GA no 831999

THE SOLUTION

The ELECTRA project proposes an electric compressor for cabin pressurisation, enhancing energy efficiency and eliminating oil contamination risks. Key technological features of an electric compressor pack are very high shaft speed, its rotor and bearings (which must be oil-free) and a precisely controlled electric motor, optimally designed impeller and air path, and a built-in air mass flow sensor.

ALBATROS

Advanced systems and solutions for better practices against hazards in the aviation system

Safety and resilience are paramount in European transport systems. The EU has adopted innovative 'safety pillars' that aim to achieve sustainable mobility: technology, regulations and human factors. Air transport is achieving significant emission reductions through new technologies, such as hydrogen-based propulsion, which require robust safety assessments. Climate change is bringing extreme weather risks, affecting aviation operations and Air Traffic Control. Increasing digital connectivity is introducing cyber risks. Despite high safety standards, accidents often result from crew handling technical failures and challenging conditions. Adapting practices and infrastructure is crucial for enhancing safety amid evolving hazards.

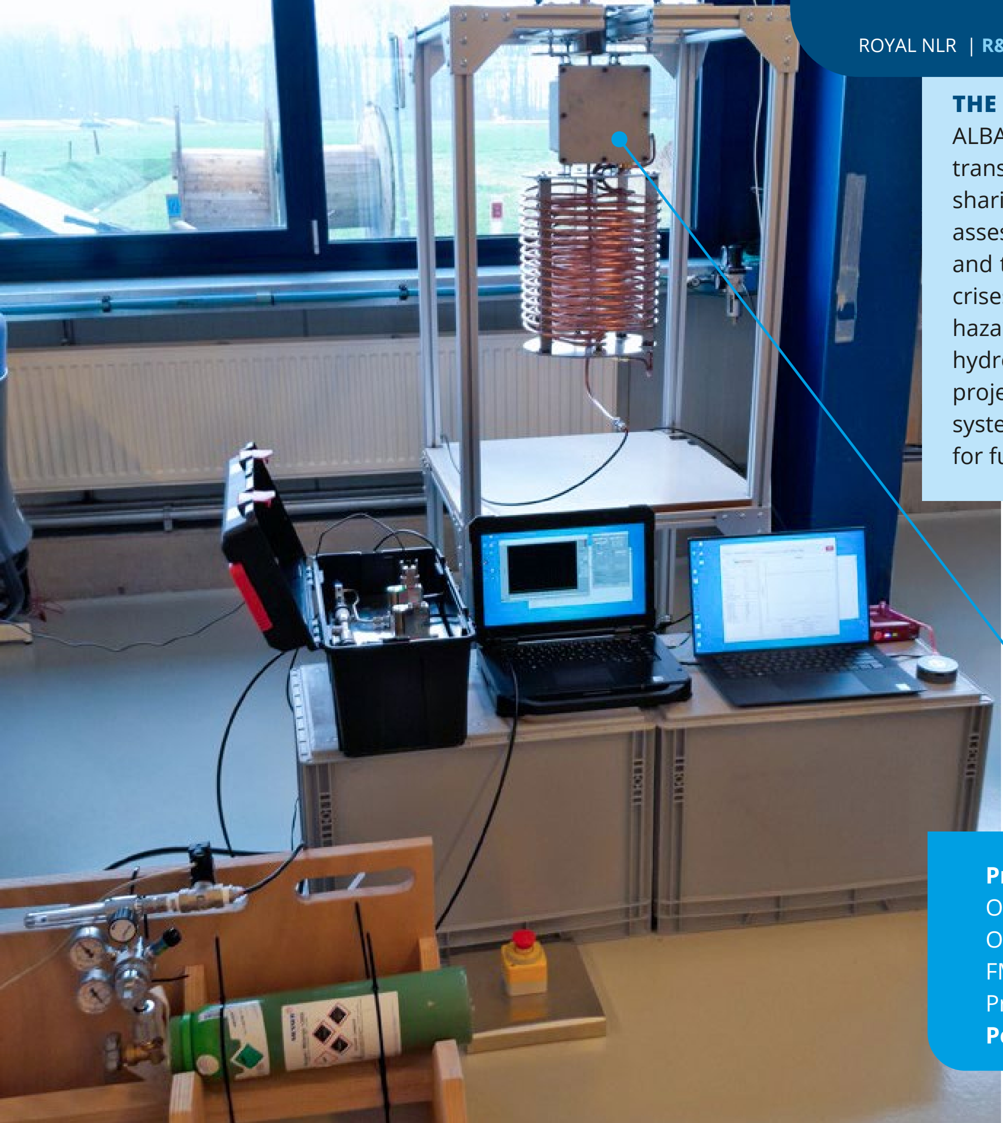
THE CHALLENGE

The ALBATROS project aims to revolutionise aviation safety. It addresses diverse challenges, from real-time anomaly detection on runways to weather hazard prediction and crisis management. Improvements in safety procedures, communication and training for aviation stakeholders will let ALBATROS boost the resilience of the industry. Additionally, the project will assess the risks associated with zero-emission hydrogen-electric aircraft, paving the way for safer, more environmentally friendly aviation. Ultimately, ALBATROS aims to transform safety practices, bolstering passenger and crew survivability and establishing a positive feedback loop of trust and innovation.

Co-funded by the European Union. GA no 101077071

WHAT WE ARE DOING

An analysis has been conducted to examine the risks associated with new fuels and energy systems, specifically electric and hybrid electric powertrains, as well as hydrogen-fuelled aircraft. A section in a detailed report outlines these risks and suggests mitigation measures for the application of hydrogen energy, both on the ground and in flight. To minimise the risks associated with leaks, monitoring solutions have been proposed, including the enhancement of hydrogen FBG sensors through laboratory testing. The tests focus on intrinsically safe FBG sensors that monitor hydrogen levels, thereby reducing the risk of explosions or fires caused by liquid hydrogen tank leaks. Additionally, procedures have been established to guide first responders in handling emergencies involving liquid hydrogen-powered aircraft.



THE SOLUTION

ALBATROS will deliver a comprehensive safety transformation for aviation. It introduces a novel safety sharing concept, providing a robust framework for assessing emerging hazards in aviation. New technologies and training tools will allow human performance during crises to be improved substantially. Real-time weather hazard prediction and risk mitigation (including for hydrogen-powered aircraft) will be promoted. The project will integrate safety measures into current systems and procedures, while also providing inspiration for future safety design in aircraft and airports.

H2 leak detection sensor

Project partners: Royal NLR (project lead), DLR, ONERA, CIRA, RTHA, Schiphol, AIA, ANA, Airbus Operations, Pipistrel, DeepBlue, Ferronats, JAA, FMI, OULU, ENSOSP, SOMNI, AEGEAN, Airbus Protect, EASA, FHNW

Period: 2022 - 2026

Research Infrastructure

NLR HYDROGEN AND ENERGY TRANSITION RESEARCH INFRASTRUCTURE

NLR is strongly involved in technology development to increase the maturity of aircraft systems that are needed for hydrogen propulsion. Our main technology focus areas are: hydrogen fuel cell systems for application in aviation, thermal management systems, hydrogen-electric systems and components, composite liquid hydrogen tanks for large aircraft, systems and material testing at deep cryogenic temperatures, hydrogen technology flight testing and demonstration.

NLR is setting-up a research infrastructure at NLR Marknesse, that supports the research and testing of the new hydrogen expertise and technologies.

Hydrogen energy transition infrastructure

ENERGY SOURCE

- **Sunspace Solar park**
- High voltage grid connection

ENERGY CONVERSION E > H2

- **Hydrogen Production Pilot Plant** (a cooperation with Roger Energy), providing a local supply of (green) gaseous hydrogen, liquid hydrogen and methanol and high TRL validation capabilities.

H2 STORAGE AND (RE)FUELLING

- Commercial storage tank of 40m3 liquid hydrogen (at the Energy to Propulsion Test Facility)
- Co-designed/manufactured local LH2 storage ground vessel: **DEWAR**

ON-BOARD FUEL TANK

- Design, manufacturing and testing of composite LH2 storage solutions for aircraft applications
- Deep cryogenic (20K) material and structures testing: **Cryostat**
- Co-designed/manufactured local LH2 storage flying tank (in the HYDRA II drone)

ENERGY CONVERSION H2 > E

- Advanced power electronics and wiring infrastructure
- Best of class thermal control and cooling solutions: **Energy management**
- Membrane health monitoring and maintenance research: **Membrane Research**
- Fuel cell testing in controlled environment: **THETA I**

AIRCRAFT PROPULSION SYSTEM

- Dedicated airfield and airspace with facilities for operation and testing of GH2/LH2 powered drones: NLR Drone Centre and HYDRA II
- **Energy to Propulsion Test Facility** (EPTF)
  - Powertrain ground testing, currently up to 2MW
    - Electric, hydrogen-electric, and other possible energy carriers
    - Battery, gaseous/liquid hydrogen and e-methanol energy storage solutions
    - Functional component and full system performance testing
    - Ground testing and moving platform testing of full systems
  - Mechanical testing of liquid hydrogen tanks
    - In situ LH2
    - Dynamic loads
    - Slosh testing


Energy Management
Membrane Research
THETA I
Energy to Propulsion Test Facility
2024-2025
HYDRA II
GRACE
Hydrogen Production Pilot Plant
PROPULSION
FIELD LAB
(2026)
ROGER ENERGY
Dewar
LH2
Cryostat
Solar Park
DNW wind tunnels
NLR Drone centre
NLR MARKNESSE


nlr
CRYOVAT
ACCELERATING SUSTAINABLE PROPULSION
nlr
ENERGY TO PROPULSION TEST FACILITY

Energy to Propulsion Test Facility (EPTF)

THE CHALLENGE

The urgent need to achieve emission-free flight by 2050 necessitates the development of sustainable propulsion technologies, with hydrogen-electric flight as a promising candidate. To ensure reliability and safety, comprehensive testing of components and the full powertrain is crucial, which is precisely the purpose of NLR's "Energy to Propulsion Test Facility" (EPTF). By facilitating these tests, the EPTF will help accelerate the development of this groundbreaking technology.

HOW CAN WE SUPPORT YOU?

We offer a state-of-the-art testing facility for comprehensive (ground) testing and expert support to help you develop and improve your hydrogen electric propulsion-related products. Whether you're working on:

- advanced (composite) storage tanks for holding liquid hydrogen at 20K
- (3D-printed) heat exchangers to heat gaseous hydrogen
- (lightweight) compressors for fuel cell or fuselage compression
- next-generation structural battery packs
- high-performance (MW) fuel cell systems (without rare earth metals)
- superconducting or hyperconducting converters and electric motors (including advanced cabling)
- cryogenic liquid hydrogen distribution systems
- (silent) propeller systems

MAIN FEATURES

I. Semi-"Open Air" roof design: providing shielded setup and fully ventilated testing conditions
II. Reinforced flooring: enables easy fixture of Equipment Under Test (EUT)
III. Large liquid hydrogen storage: 40,000 l
IV. Abundant supply of gaseous hydrogen
V. Advanced hydrogen handling: large hydrogen evaporation and venting capabilities (including various venting options)
VI. Liquid nitrogen storage: 6,000 l, with evaporation capabilities and ample gaseous nitrogen supply
VII. Electric power capabilities:
    a. 400 kVA bi-directional grid
    b. Bi-directional AC/DC conversion
VIII. Hydraulic and pneumatic power: available for full-scale mechanical testing of components, such as VIP-piping
IX. Hexapod moving platform: for manoeuvring of tanks (sloshing) or entire powertrains
X. Sound wall
XI. Safety and regulatory compliance: permits and safety regulations in place, with appropriate project housing available.

Generic Research Aircraft Component Environment (GRACE)

THE CHALLENGE

A liquid hydrogen tank for aviation needs to be lightweight, double-walled, and vacuum-insulated. The connection between the inner and outer walls needs to be such that heat fluxes are minimal. This means that the relatively low stiffness and strength of these connections are critical design elements. Furthermore, liquid hydrogen tanks are susceptible to boil-off, where the fuel evaporates over time. As a result of sloshing, the boil-off rate increases. Evaluating and improving this boil-off behaviour is therefore an important research topic.

Drones are becoming increasingly important for both civil and military applications. As they are deployed on moving platforms, such as ships or tanks, they need to be able to take off and land safely from a mobile base. To evaluate their performance in these situations requires a testing capability that can mimic the motions of these platforms.

HOW CAN WE SUPPORT YOU?

GRACE is a mobile hexapod that was originally used as the moving platform of a flight simulator. It is capable of moving 7 tons at accelerations of 9g, and can operate in different locations, including inside Hal-8 or outside the EPTF.

The GRACE platform can be used to:

- perform sloshing tests of liquid hydrogen storage tanks
- carry out attitude tests (of parts) of a complete powertrain
- simulate drone landing scenarios on moving platforms
- mimic the movements of various platforms or objects (within its physical limits)
- provide a modular deck with optional sizing (up to 15m x 15m)

MAIN FEATURES

DIRECTION	OPERATIONAL EXCURSIONS		VELOCITY	ACCELERATION	ACC. ONSET
Surge	-0.557 m	0.660 m	0.85 m/s	6.0 m/s²	80 m/s³
Sway	-0.553 m	0.553 m	0.85 m/s	6.0 m/s²	80 m/s³
Heave	-0.414 m	0.446 m	0.61 m/s	8.0 m/s²	80 m/s³
Roll	-17.75°	17.71°	30 °/s	130 °/s²	1000 °/s³
Pitch	-17.25 °	16.60°	30 °/s	130 °/s²	1000 °/s³
Yaw	-22.05 °	22.05°	40 °/s	200 °/s²	1000 °/s³

- Max. payload: 7.356 kg
- Mass without payload: 19.000 kg
- Nominal power: 100 kW


LH2
Liquid Hydrogen
nlr


cryoworld
advanced cryogenics
nlr

NLR's Liquid Hydrogen Dewar

THE CHALLENGE

Due to its extremely high energy density per kilogram (120MJ/kg), hydrogen is a potential contender for alternative aviation fuel. However, hydrogen is a buoyant gas that needs to be compressed into high-pressure tanks (300-700 bar) or stored on board an aircraft in liquid form in a cryotank at an extremely low temperature (-253°C, 1 bar).

HOW CAN WE SUPPORT YOU?

NLR received its very first liquid hydrogen Dewar in 2021. It is a state-of-the-art liquid hydrogen storage system designed with safety and efficiency in mind. Our Dewar can provide clients with a safe and reliable way to store and handle LH2, supporting a range of research, development, and testing activities related to hydrogen technology. Our services:

- Safe storage and handling of LH2
- Support for research and development
- Preparation for drone test flights
- Ground testing of hydrogen systems
- Fueling activities

MAIN FEATURES

- A vacuum-insulated double-walled stainless steel container (weight: 170 kg)
- Storage of 125L liquid hydrogen, LH2 (~7kg @20K)
- Design pressure: 1-4 bar
- Boil-off: 1-2%/day (~70-140 g H2/day)
- Estimated storage time full tank: 50-100 days
- Level indicator (differential pressure measurement indicator)
- High level alarm (Argon gas tube)
- A safety valve and burst disc for added protection
- A vent-relief valve to regulate internal tank pressure
- Multiple connections for safe and easy operation
- A design that allows for natural ventilation of hydrogen leakages and prevents accumulation of hydrogen
- Rubber transport wheels
- Maintained by Cryoworld BV

Cryostat

THE CHALLENGE

NLR has pioneered advanced cooling systems for material and structural testing, on a journey that started at -55°C and eventually reached extreme temperatures, such as -253°C. NLR's future goals include testing of full-scale hydrogen tanks, fuel system components and hydrogen-electric powertrains. Pursuing these goals is vital for achieving net-zero emissions by 2050. The continuous technological advancements and high demands highlight the crucial role of cold testing technology in the aerospace industry.

HOW CAN WE SUPPORT YOU

NLR’s test house has developed modular and specific cooling solutions for material and structures testing, utilising various cryogenics and thermal equipment. NLR’s approach prioritises affordability, maintainability, safety, scalability and accuracy, over a broad operating temperature range. The developed systems are highly autonomous, suitable for continuous 24/7 operation.

Typical testing temperatures include:

Cold -55°C / 218K Standard temperature for aircraft flying at cruise conditions.

- Using liquid nitrogen (LN2) coolant combined with a control loop for the temperature.

Cryogenic -169°C / 104K Temperature for pipe structures transporting LNG (Liquified Natural Gas).

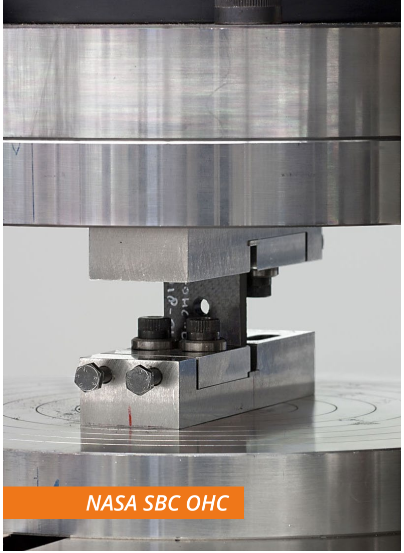
- -180°C / 93K Temperature for specific space structures.
- Using LN2 coolant combined with a control loop for the temperature.

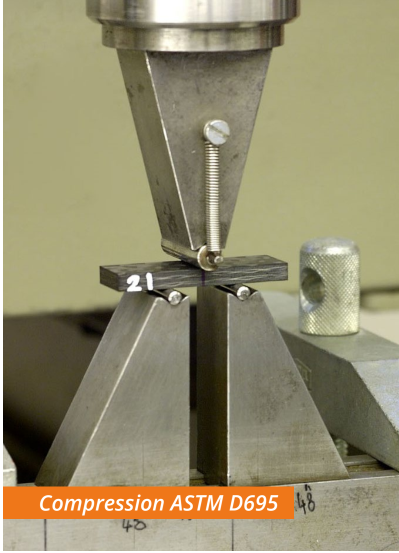
Deep Cryogenic -253°C / 20K Temperature for liquid hydrogen applications (the boiling point of hydrogen).

- Using various cryogenic gases for temperature control.
- Using thermal equipment for cooling efficiency

Mechanical tests can be performed in accordance with:

- ASTM standards
- AITM standards
- ISO standards
- Custom requirements for unique non-standard small-scale specimens


NASA SBC OHC


Compression ASTM D695

MAIN FEATURES

Load capacity:

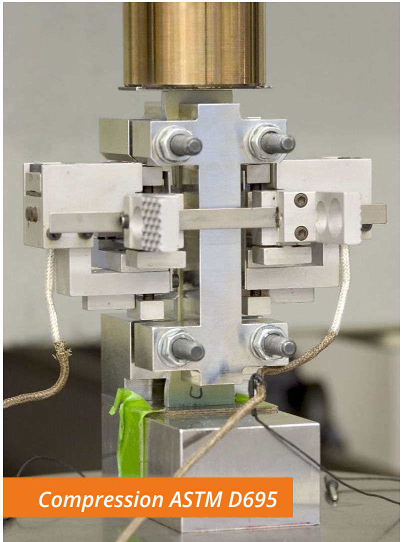
- Tensile capability of up to 100 Kn
- Compression capability of up to 250 kN

Current capabilities:

- Static testing of coupons according to ASTM/AITM/ ISO standards at 20K
- Non-standard small-scale static testing at 20K

Foreseen capabilities:

- Dynamic testing of coupons at 20K & max. frequency of 120 Hz
- Tear & Wear of materials and/or seals at 20K
- Temperature cycling 20K - 77K / 20K - 293K
- Dynamic testing with in-situ H2 atmosphere


Compression ASTM D695


Tensile ASTM D3039

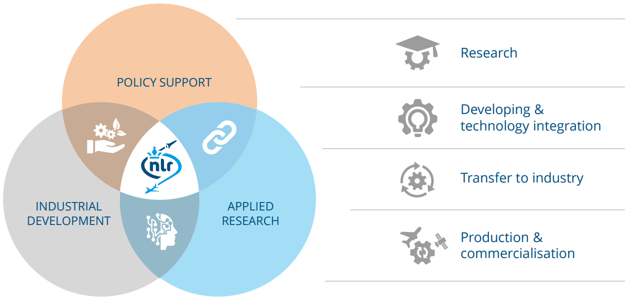
About NLR

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 also find its way into successful aerospace programmes of OEMs like Airbus, Boeing and Embraer.



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

Royal 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 is a founding member of Clean Aviation and linked to Clean Hydrogen as a member of Hydrogen Europe Research. This places NLR at the heart of the European ecosystem that aims to realise the EU's aviation hydrogen strategy through innovation. An indispensable step on the road to climate-neutral aviation.

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