Accelerating the future of aerospace

R&D more electric and hydrogen powered aerospace

Royal NLR - Netherlands Aerospace Centre

NLR hydrogen roadmap

Zero-e, ©Airbus

- Airport H_2 infrastructure
- Commercial H_2 Aircraft Operations

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

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

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 presents several key advantages: it allows for the elimination of carbon emissions in flight and along the entire life cycle. Its usage in fuel cells allows eliminating 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-CO2 emissions (high altitude phenomena) that result from conventional kerosene fuelled aircraft.

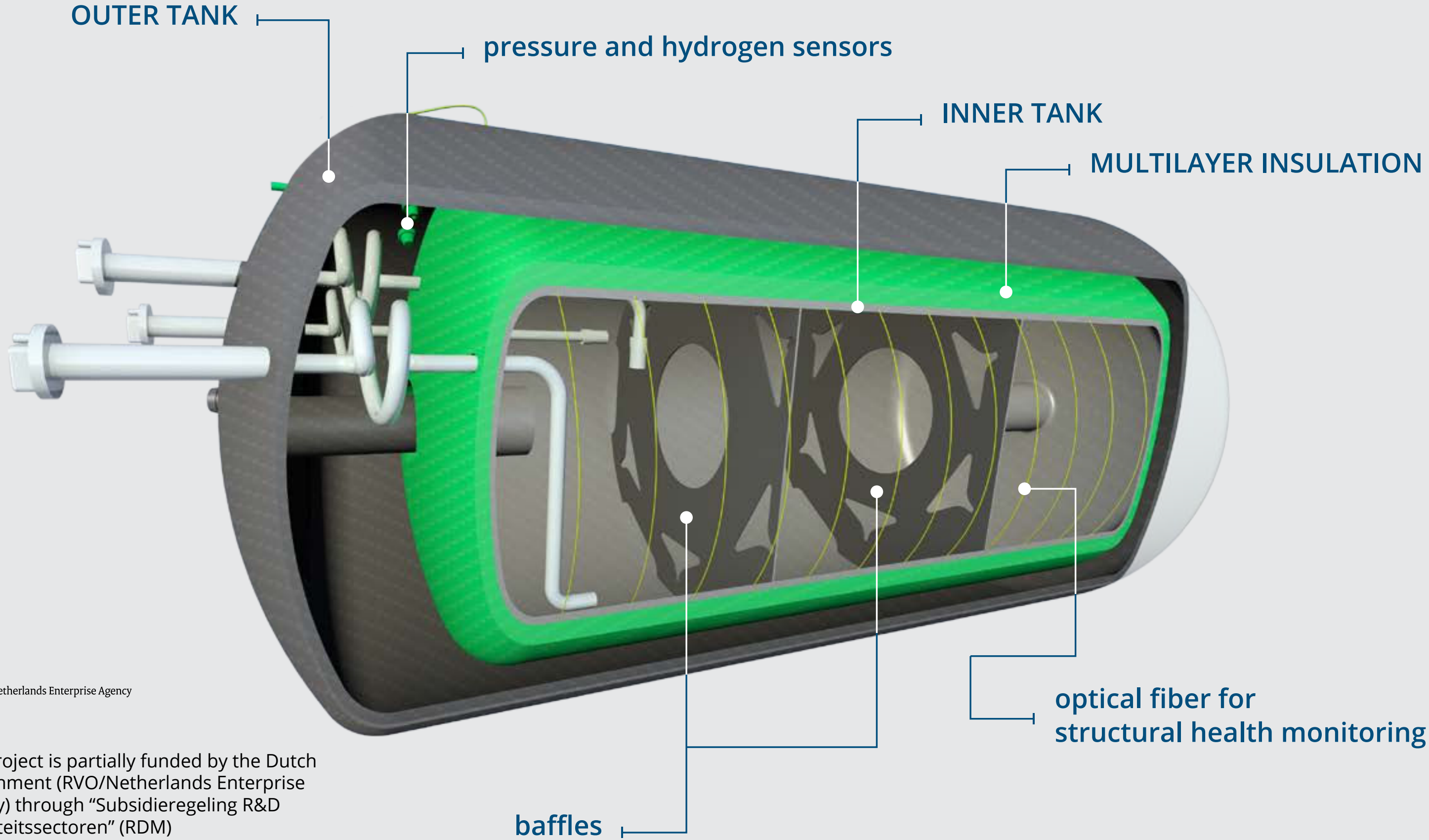
Although hydrogen has been employed widely in other industries for many years, the introduction of hydrogen on board aircraft is a major technical challenge, combined with a tremendous certification effort. It has a significant impact on the aircraft architecture, powertrain components and operations,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

To scale hydrogen-powered aircraft for application in commercial aviation, several technological unlocks need to happen before delivering 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 will be key for the overall success of this approach.

Michel Peters, CEO
Royal Netherlands Aerospace Centre

New technologies developed in several projects that NLR is involved with, will contribute to the technical and economic feasibility, safety and public acceptance of hydrogen systems on board of aircraft and at airports. This is achieved through the gradual adoption of hydrogen based propulsion in aircraft of increasing size, ranging from 2-seater general aviation aircraft up to large regional aircraft and 200+ passenger airliners. At the same time, these increasingly sized hydrogen powered aircraft have an increasing contribution in the reduction of global aviation emissions. The ultimate goal is an emission free aviation from 2050 onwards. Currently (2024), many of the projects NLR is involved with are directly or indirectly linked to hydrogen. Part of the success may be traced back to the initial strategic hydrogen research projects.
To mention a few of which some cases are presented in this booklet.

R&D cases



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, having no electrical signals and minimal heat ingress, that monitor the temperature, pressure, LH2 fuel level, acceleration and leak detection.

Industry (NL): Toray, ADSE, Airborne, Bold Findings, Cryoworld, Fokker Aerostructures, IT'S Engineering, KVE, PhotonFirst, Somni Solutions, Taniq
Research organisations : NLR, SAM XL
Period: 2022 - 2026

COCOLIH2T

Composite Conformal Liquid H2 Tank

The global aviation industry is committed to reducing global net aviation carbon emissions by 50% by the year 2050, with the European Commission pursuing a more ambitious goal of a 75% reduction in CO2 emissions per passenger kilometre. Alternative fuels such as liquid hydrogen (LH2) are seen as playing a central role in a zero-emission future for aviation. To store cryogenic (20 K) liquid hydrogen in an aircraft, the COCOLIH2T carries out research and testing for the design, manufacturing and testing of storage containers for 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.
- Gravity index: > 25%.
- No liner.
- Venting rate: < 2% per day.
- Subsystems for gauging, refuelling and monitoring structural health for safe functioning.

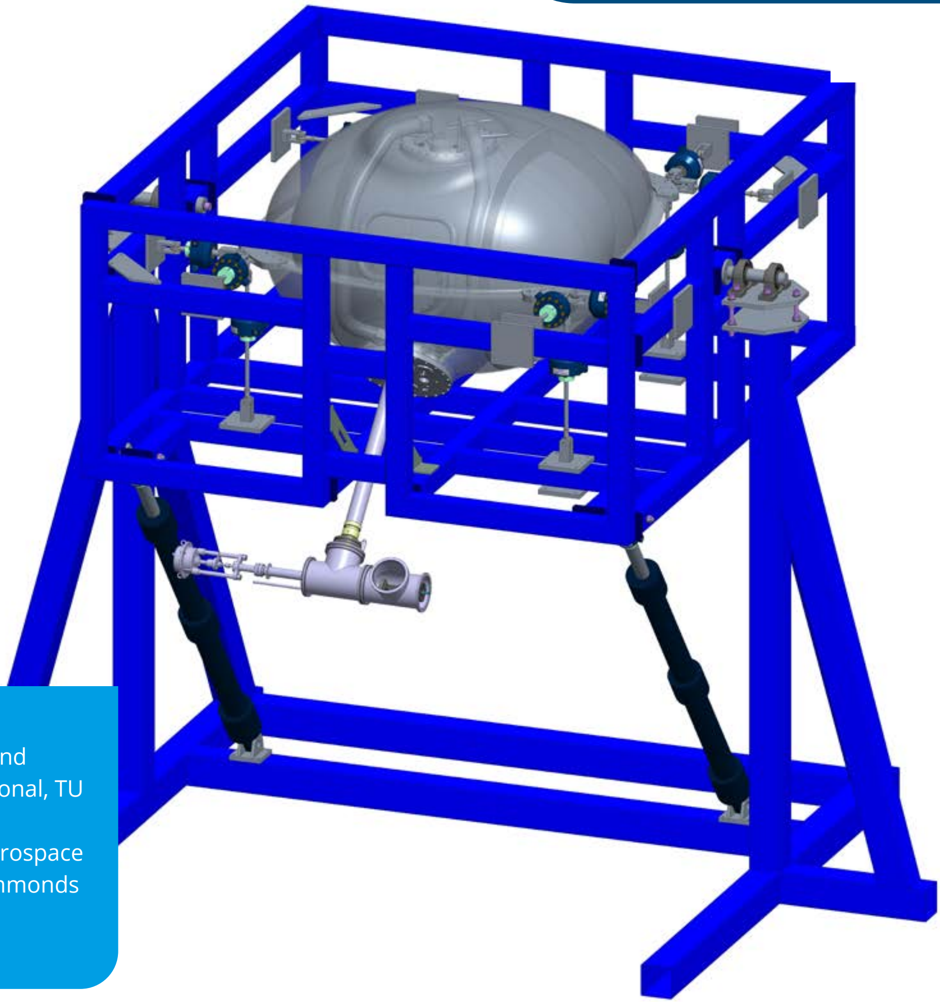
WHAT WE ARE DOING

In collaboration with the project partners, NLR made an initial design of a thermoplastic, composite conformal tank which fits in an ATR-72. To determine static material properties at 20 K, NLR executed a static test campaign in their cryostat. A permeability test was developed and microcracks were investigated. The 2 demonstrators, which will be manufactured by partners in the project, will be tested with large amounts of liquid hydrogen in NLR's newly built Energy to Propulsion Test Facility (EPTF). Test set-ups are being designed and manufactured by NLR to perform the required tests to validate the design and sloshing models. Test and safety procedures are being compiled and reviewed to ensure that the tests are executed safely.

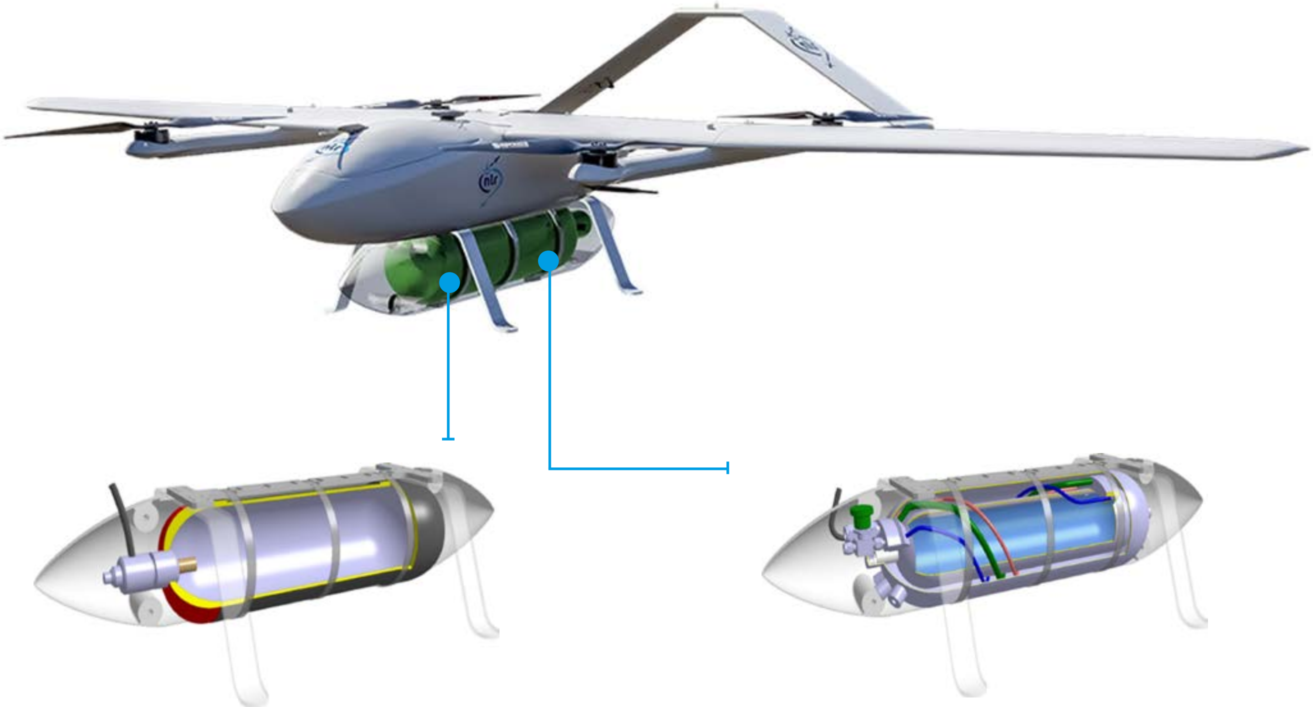
Co-funded by the European Union. GA no 101101961

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 assembly them in 2 demonstrators.
- Test 2 full-scale demonstrators with LH2 to validate the requirements at TRL4.



EU Clean Hydrogen project.
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



GASEOUS HYDROGEN (GH2)

- Composite high pressure tank
- 7.2-liter gaseous hydrogen @ 300 bar
- Hydrogen storage: ca 150 grams
- Gravimetric index: 3.8%
- Expected endurance @ 1000W cruise power: ca 2½ hours

LIQUID HYDROGEN (LH2)

- Aluminium double-walled vacuum-insulated cryotank
- 4-liter liquid hydrogen @ -253°C
- Hydrogen storage: ca 230 grams
- Gravimetric index: > 6%
- Expected endurance @ 1000W cruise power: ca 3½ hours

Hydrogen-powered drones

Drones offer an ideal platform for testing hydrogen technologies safely on a smaller scale and at relatively low cost.

- Hydrogen offers an extended flight duration and distance, beyond what is possible with batteries.
- The HYDRA (Hydrogen Drone Research Aircraft) projects support the standardization and certification of hydrogen systems for commercial applications
- Demonstrator projects for commercial applications such as transporting medicines or cargo, or for first responders or surveying, etc.
- NLR has obtained first-hand experience with both gaseous and liquid hydrogen systems
- Preparing for upscaling for manned aircraft
- First flight of the liquid hydrogen drone: expected in 2024

Drone Type: Fixed Wing Vertical Take-off & Landing

- Weight: 23.5 Kilograms
- Fuel Cells: 2 x 900 Watts
- Expected hydrogen consumption @ 1000Watt cruise power ~ 1 gram/minute
- Storage tank options: ‘G’: gaseous (GH2) or ‘L’ liquid hydrogen (LH2)

Research organisation : NLR

Pipistrel 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 engine and from design to testing and certification. As part of a roadmap and build-up approach, for NLR's electrical 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 cost- and aircraft performance efficient solution for a hydrogen powertrain?
- 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?

LUCHTVAART in transitie

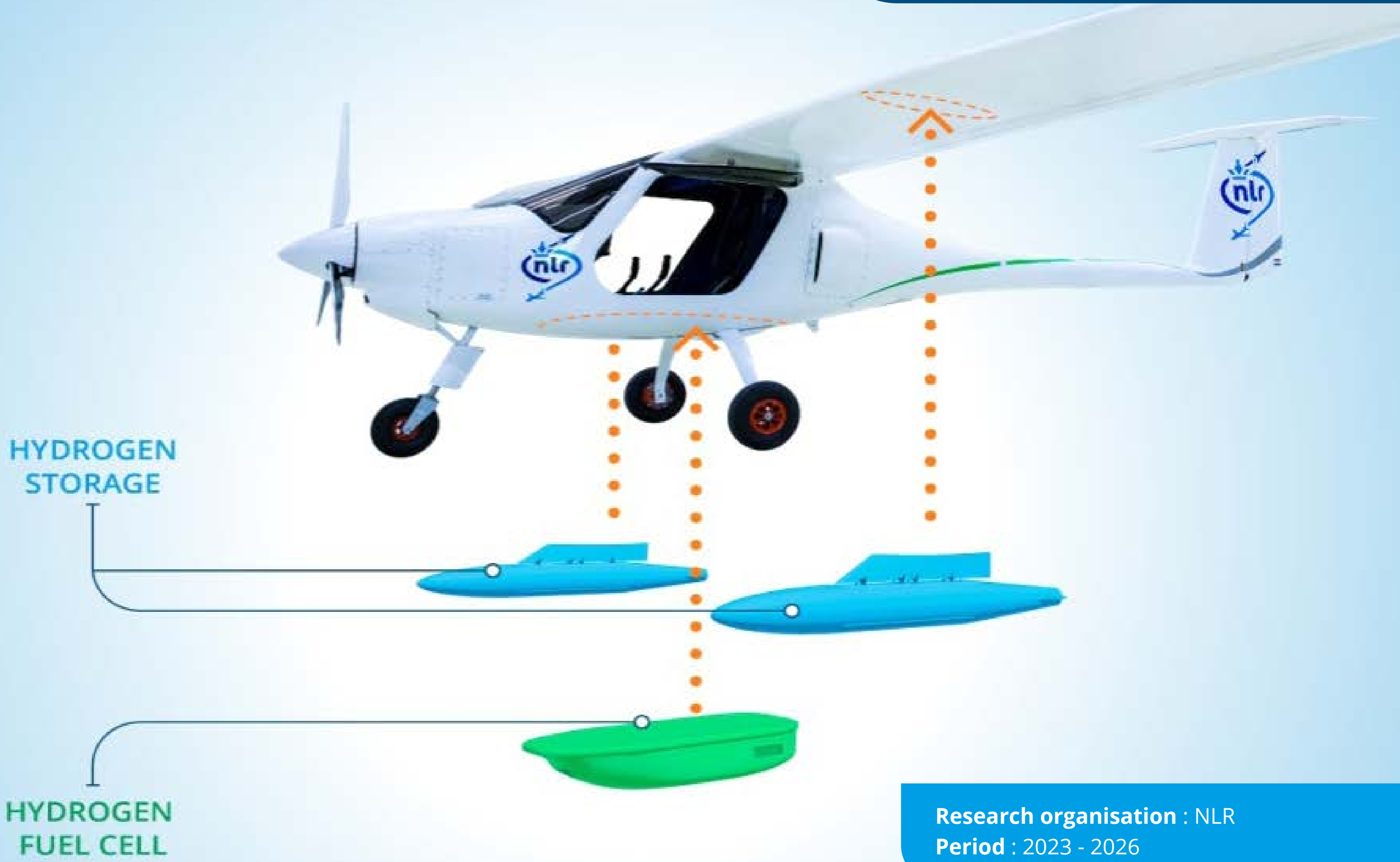
This research is partly conducted within the research and innovation programme Luchtvaart in Transitie, which is co-funded by the Netherlands National Growth Fund.

WHAT WE ARE DOING

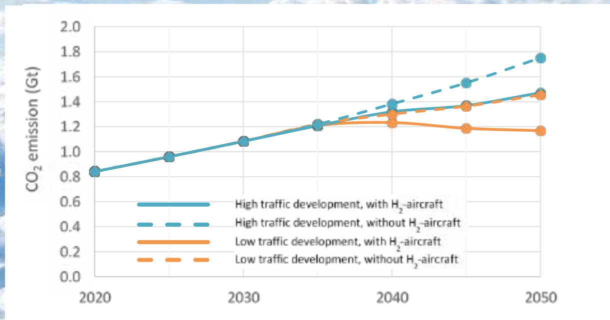
Currently in the requirements capture- and conceptual design phase, trade offs are being assessed to realise a demonstration flight in 2026. Regarding the hydrogen powertrain the existing market and technologies are being explored. In addition the aircraft modification- and integration aspects are being assessed.

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. Thereby independence can be maximised and risk can 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 significant next step in realising the goals.



Research organisation : NLR
Period : 2023 - 2026



Project partners: NLR, Delft University of Technology
Period: 2019 - 2022

Co-funded by the European Union.
GA no. 864089

TRANSCEND

Technology Review of Alternative and Novel Sources of Clean Energy with Next-generation Drivetrains

The Clean Sky 2 Coordination and Support Action TRANSCEND identifies what alternative energy sources for aviation and novel aircraft propulsion methods can help mitigate climate change and achieve the environmental goals for 2050. Additionally, as we progress towards 2050 roadmaps and strategic recommendations for alternative energy sources and novel propulsion techniques have been developed to ensure that the potential contributions become reality.

THE CHALLENGE

Global air travel is expected to increase significantly in the coming decades. At the same time, becoming climate-neutral by 2050 is a key objective that aviation will have to play its part in. Reducing greenhouse gas emissions is therefore one of the main challenges when developing future commercial aircraft. One of the research objectives of TRANSCEND is to estimate the effect of introducing hydrogen (H2) powered aircraft on global greenhouse gas emissions by 2050.

WHAT WE DID

The potential of H2-based aircraft propulsion was studied at both the aircraft level and the fleet level. H2-powered configurations (with future entry into service) were conceptually dimensioned and assessed in terms of mission energy consumption and emissions for three different ICAO seat classes in the 20 to 300-seat range: a regional turboprop configuration, a single-aisle turbofan configuration and a twin-aisle turbofan configuration.

The aircraft modelling results were applied in a global fleet-level analysis (for the period 2020–2050) with varying traffic development scenarios (differing primarily in terms of traffic growth, designated low and high).

THE SOLUTION

In our simulations, the relative number of flights with H2-powered aircraft increases from 2035 to 2050: by up to 38% in the low traffic scenario and up to 35% in the high traffic scenario. This leads to fleet level reductions of 20% (low traffic scenario) and 16% (high traffic scenario) in global gross CO2 emissions by 2050 compared to the case in which no H2-powered aircraft are introduced. On the other hand, global gross energy consumption and NOx emissions increased slightly and H2O emissions increased significantly.

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. It explores utilising the fuel cell's waste heat to enhance system efficiency and tests the powertrain under flight-relevant conditions. The outcome of the project contributes to fulfilling the ambitious goals for regional and short-range hydrogen-powered aircraft with Entry Into Service in 2035 to meet 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-off-the-art industrial components. It provides for a comprehensive understanding of the operational characteristics of modular, fuel cell - battery hybrid-electric, distributed electric propulsion powertrain configurations for future aircraft. While safety is paramount in aviation, potential failure modes are analysed and identified mitigation measures are evaluated during the powertrain demonstrator test campaign.

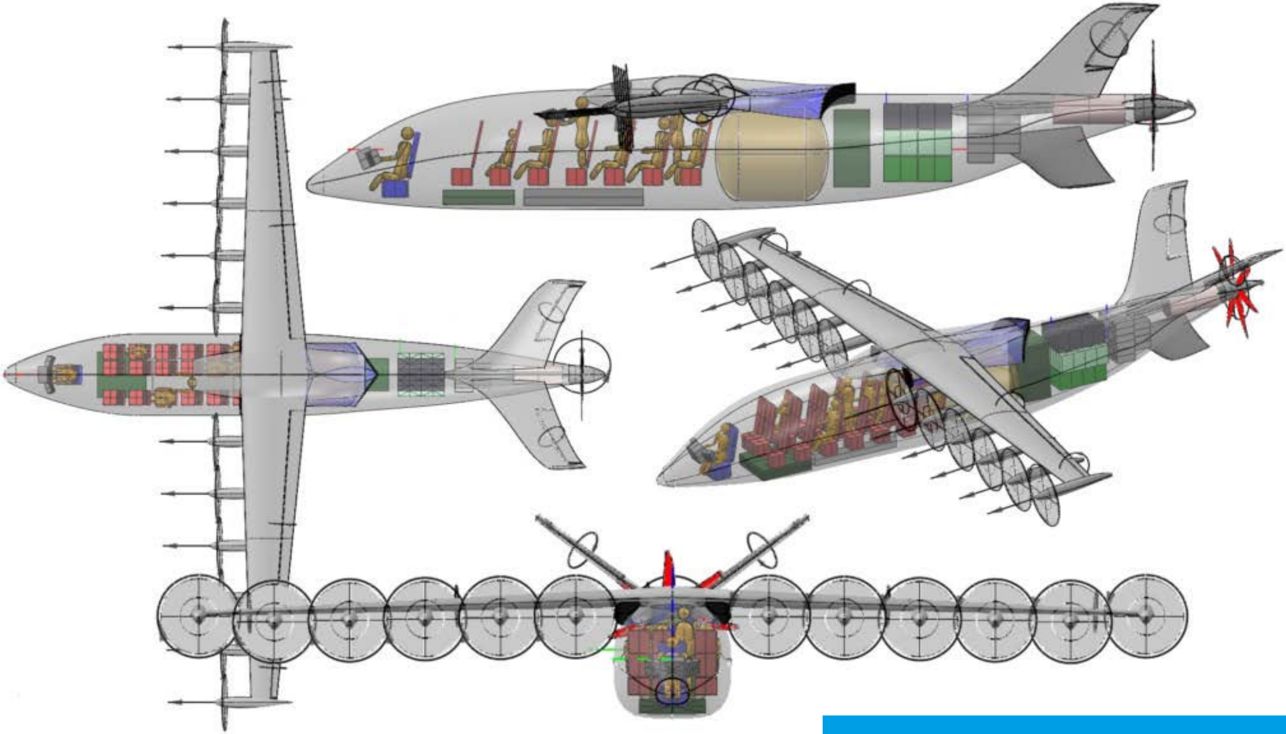
WHAT WE DID/WHAT WE ARE DOING

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 ground level test environment at NLR Marknesse for flight representative testing of the 500kW powertrain demonstrator
- Coordination of the subsystems integration and the powertrain demonstrator test activities
- Delivery of a dataset for Digital Twin validation

THE SOLUTION

The project provides for a ground level test environment for testing of a 500 kW hydrogen-electric powertrain demonstrator with the aim to validate the Digital Twin model. Flight representative mission profiles are being tested and evaluated. The powertrain demonstrator includes fuel cells, batteries, power distribution system, controls, convertors, 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.



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

Industry: Pipistrel (project lead), Honeywell
Research organisations: Fraunhofer, NLR
Universities: Universtity of Stuttgart,
Delft University of Technology
Period: 2023 - 2025

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

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 system, 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-phase 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 NO_x 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

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 the 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.

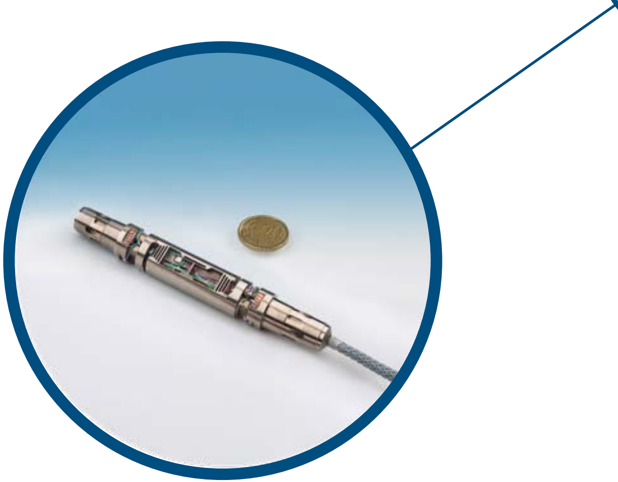
CLEAN AVIATION

Co-funded by the European Union. GA no 101102011

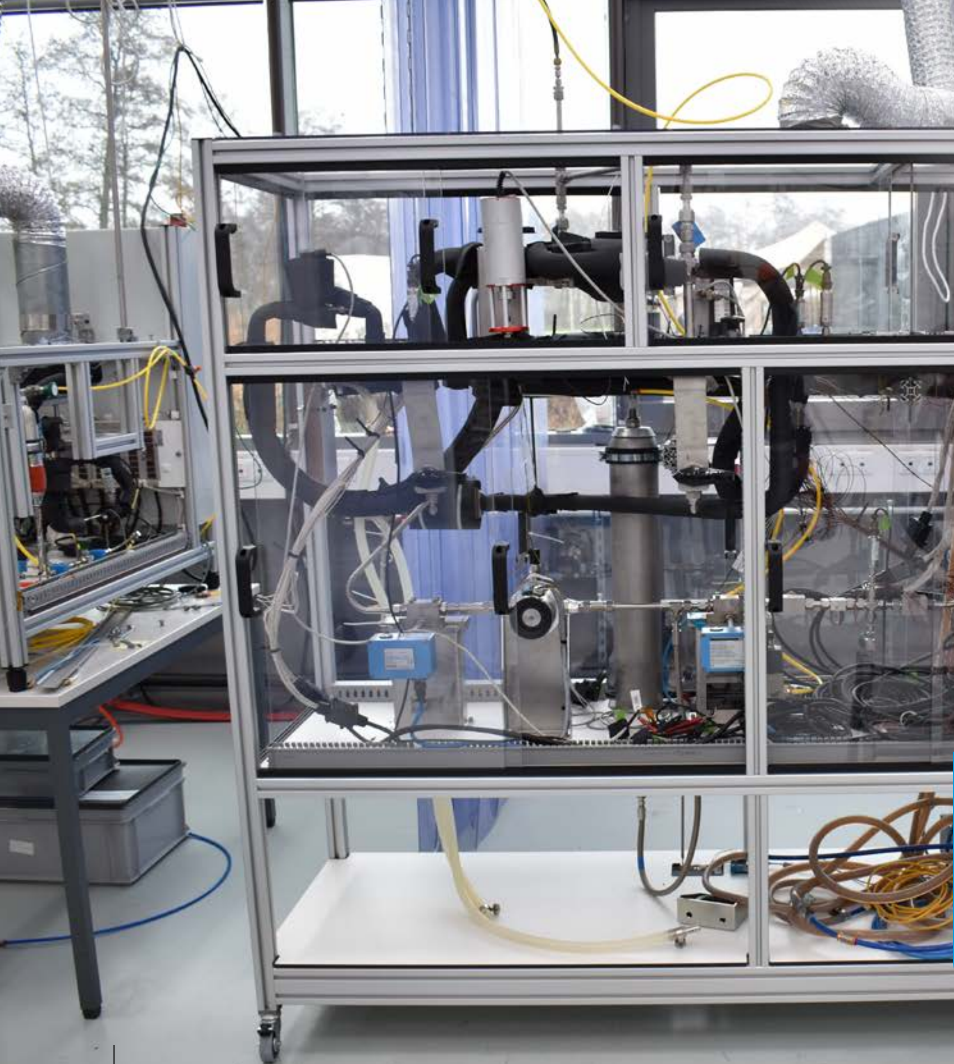
THE SOLUTION

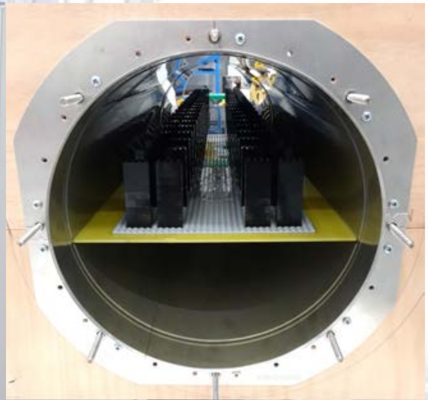
In synergy with national programs, OFELIA will focus on full scale demonstration for the engine architecture and on the development of key enablers for the Open Fan, including innovative turbomachinery technical solutions.
OFELIA will perform a large-scale Open Fan engine ground test campaign, deliver flightworthy propulsive system definition and prepare an in-flight demonstration for the phase 2 of Clean Aviation. The compatibility of the Open Fan to hydrogen is investigated as well.

(c) Safran



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





Industry (NL): GKN Fokker Elmo (project lead)
Industry (EU): Collins Aerospace Ireland, Evektor, plc-tec ADSE, Synano
Research organisation : NLR
Universities: Eindhoven University of Technology
Period: 2021 - 2024

ADENEAS

Advanced Data and power Electrical NEtwork Architectures and Systems

The More Electric and Connected Aircraft (MECA) concept is one of the most promising enablers for achieving the goals of Flightpath 2050. However, MECA implies more electrical systems exchanging more data – that can be safety-critical – and higher electrical power consumption, leading to higher thermal dissipation.

THE CHALLENGE

For the on-board power and data network, the increased number of electrical systems implies higher complexity, weight and risk to intended or unintended electromagnetic interference. To mitigate these challenges, new communication, power distribution and cooling technologies are required for optimising the power and data networks in future aircraft. ADENEAS is developing these new technologies and paving the way for a safe, lightweight, self-configuring, autonomous and modular power and data distribution network that is scalable to all aircraft sizes.

WHAT WE DID

NLR analysed the propagation of wireless communication inside the aircraft environment, as well as the risk wireless signals may pose through interference with other aircraft systems, in particular the radio altimeter. Samples of shielded windows were tested to analyse their effectiveness in protecting this critical system. NLR has also performed electromagnetic compatibility tests to evaluate the robustness of powerline communication and modelled crosstalk between PLC modems. NLR's thermal team has designed an optimised two-phase cooling system to deal with thermal management of on-board power electronics, and demonstrated the flexibility and modularity of such a system. Taken together, the ADENEAS technologies that enable an optimised power and data network can yield a 456 kg weight reduction, leading to a 334 kg reduction in CO_2 emissions for a single flight of about 4,000km.

Co-funded by the European Union. GA no 101006728

THE SOLUTION

ADENEAS developed enablers for a hybrid data network in which parts of the conventional wiring can be replaced by powerline communication or wireless communication. Modular power electronics were developed for decentralised power network design, targeting dynamic power delivery to consumers. Moreover, a two-phase cooling system for the thermal management of power electronics was developed. Nanofeatures were investigated for further improvement of the system's heat transfer. Finally, supporting architectures, design optimisation and standardisation have all been integral parts of ADENEAS.

EASIER

Electric Aircraft System Integration EnableR

To reduce the impact of aviation on the climate, the aviation industry needs to develop solutions that drastically reduce emissions of greenhouse gases. Hybrid electric flight is one of the cornerstones of our progress towards sustainable aviation. However, the significantly increased electric power levels associated with having electric propulsion on board yield both thermal and electromagnetic challenges.

THE CHALLENGE

Increased currents and voltages caused by the higher electrical power levels on board hybrid electric aircraft introduce two main challenges:

1. The thermal challenge: increased heat dissipation in power electronics and power feeders needs to be managed.
2. The electromagnetic compatibility (EMC) challenge: increased currents may bring the risk of interference with other on-board equipment, e.g. through conducted and radiated emission. Mitigation measures need to be taken throughout the power train.

WHAT WE DID

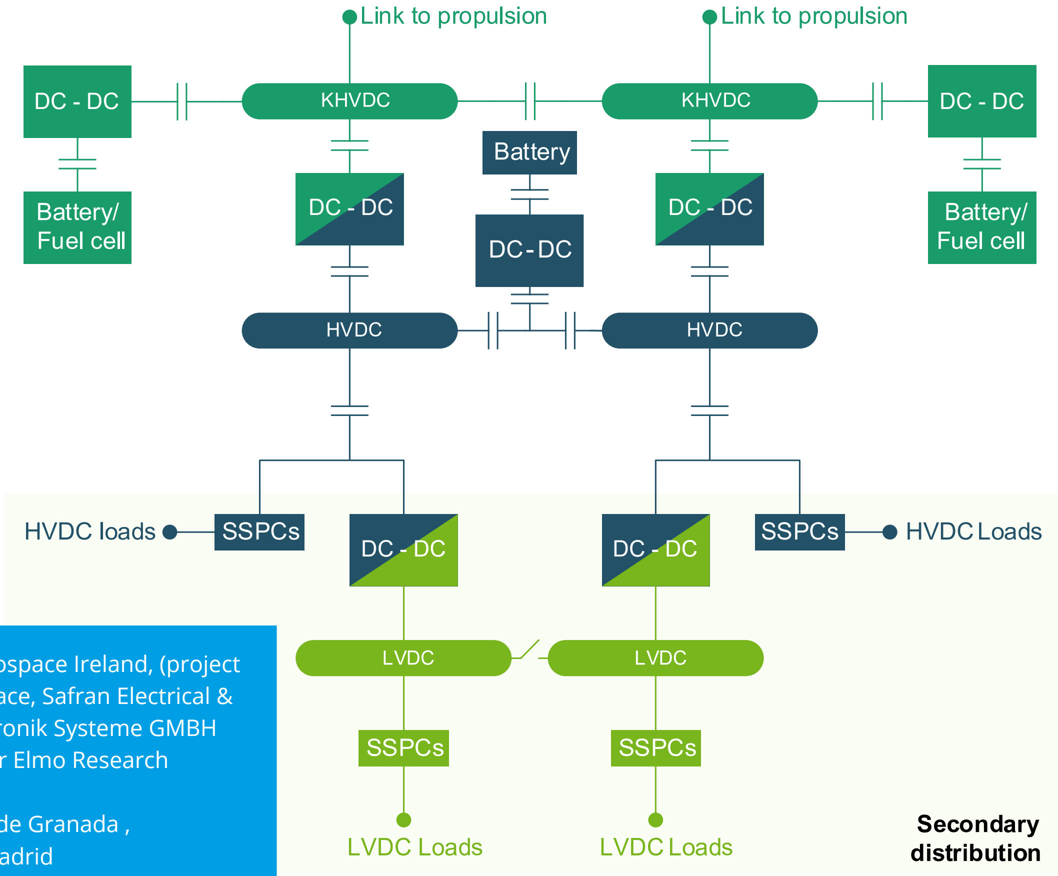
EASIER has developed EMC solutions for power EWIS, power electronics and filtering to mitigate the electromagnetic emission issues. Two-phase cooling systems have been developed to handle the increased heat dissipation. Thermal modelling and validation of power feeder designs has led to less voluminous and lighter power feeders for hybrid electric aircraft. Finally, system trade-offs have been made to optimise the performance and weight of the integrated solutions.

THE SOLUTION

EASIER has developed EMC solutions for power EWIS, power electronics and filtering to mitigate the electromagnetic emission issues. Two-phase cooling systems have been developed to handle the increased heat dissipation. Thermal modelling and validation of power feeder designs has led to less voluminous and lighter power feeders for hybrid electric aircraft. Finally, system trade-offs have been made to optimise the performance and weight of the integrated solutions.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no.875504.

Project partners: GKN Fokker Elmo, Collins Aerospace Ireland, Evektor, EMAG, Raytheon, ARTTIC, University of Twente
Period: 2020 - 2023



Industry (EU) : Collins Aerospace Ireland, (project lead), Airbus Defence & Space, Safran Electrical & Power, Leonardo, HS Elektronik Systeme GMBH
Industry (NL) : GKN Fokker Elmo Research
Organisation : NLR
Universities: Universidad de Granada , Universidad Carlos III de Madrid
Period: 2023 - 2025

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.

Co-funded by the European Union. GA no 101101961

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.

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.

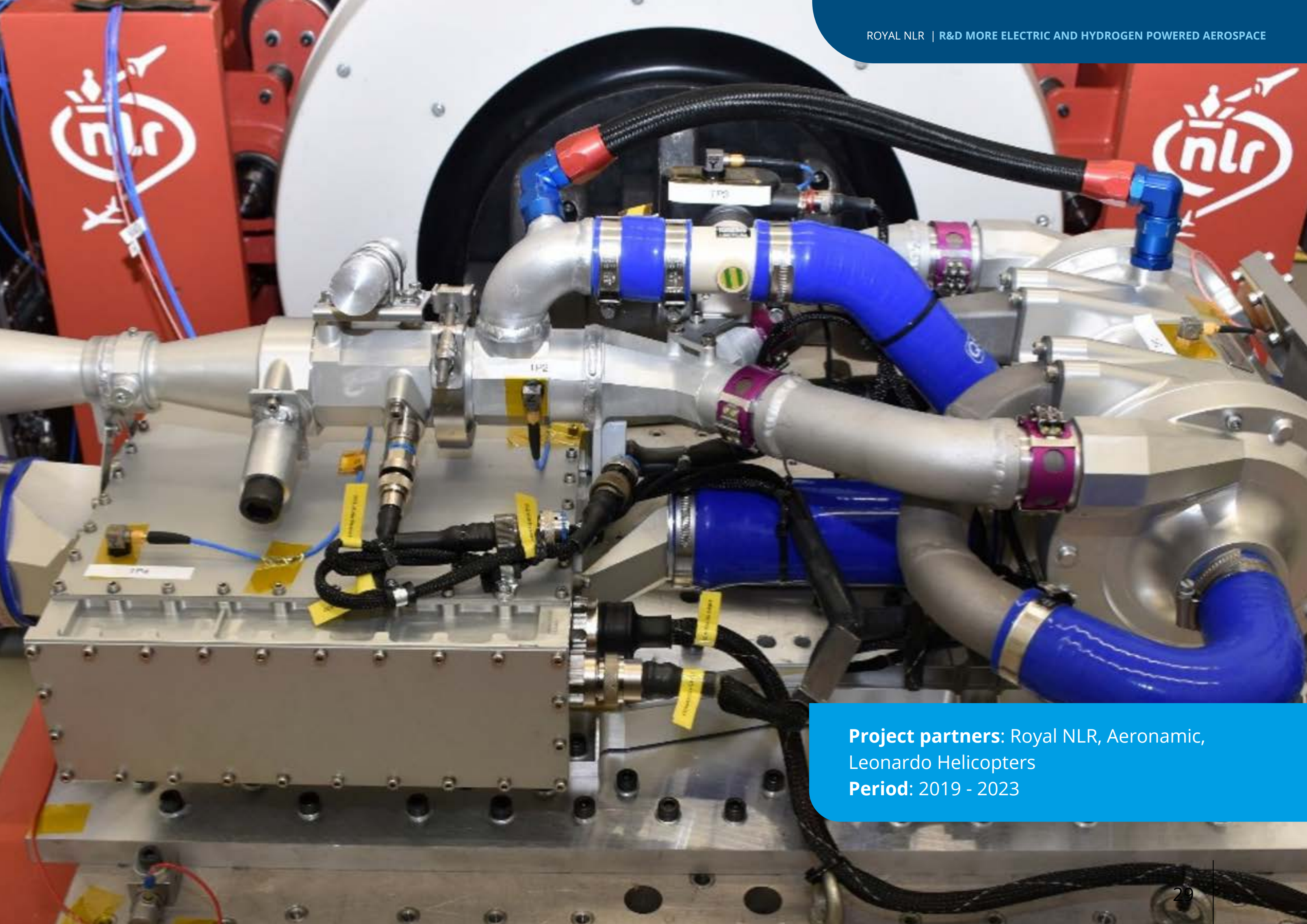
WHAT WE DID

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 developed, the air compressor pack system hardware was developed by the project partner Aeronamic. NLR developed the system test bench that allowed the requirements to be verified and the test results to be fed back to the system models for high-fidelity model updates. The pack hardware was also tested at NLR environmental test facilities including electromagnetic compatibility and vibration resistance, in preparation for flight-testing the equipment aboard the next generation of tilt-rotor test demonstrator aircraft.

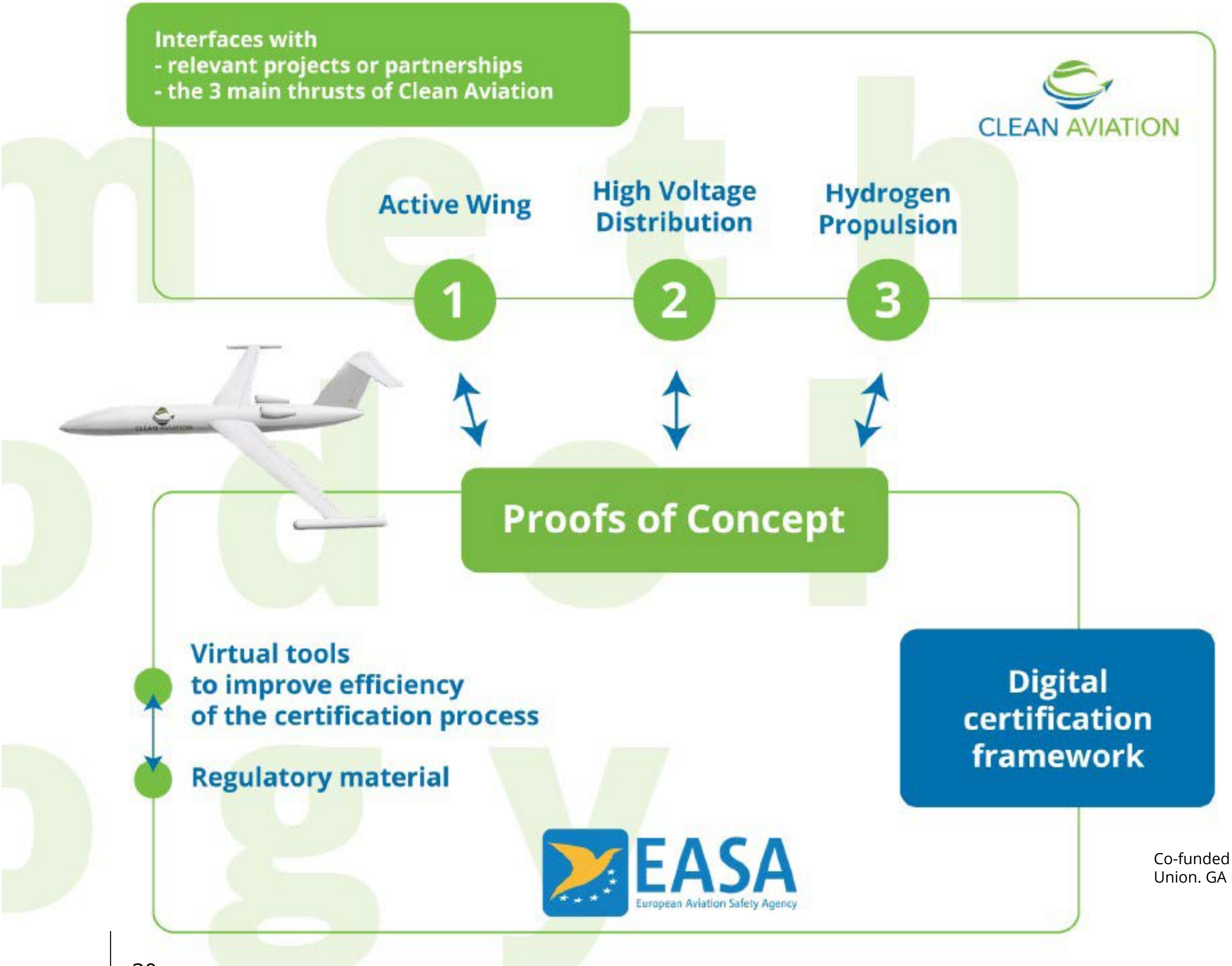
Co-funded by the European Union. GA no 831999

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.



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



Co-funded by the European Union. GA no 101101999

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 the target of becoming climate-neutral by 2050. The new methods and processes for certification will significantly reduce the development time and the cost of introducing new products on 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), 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

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

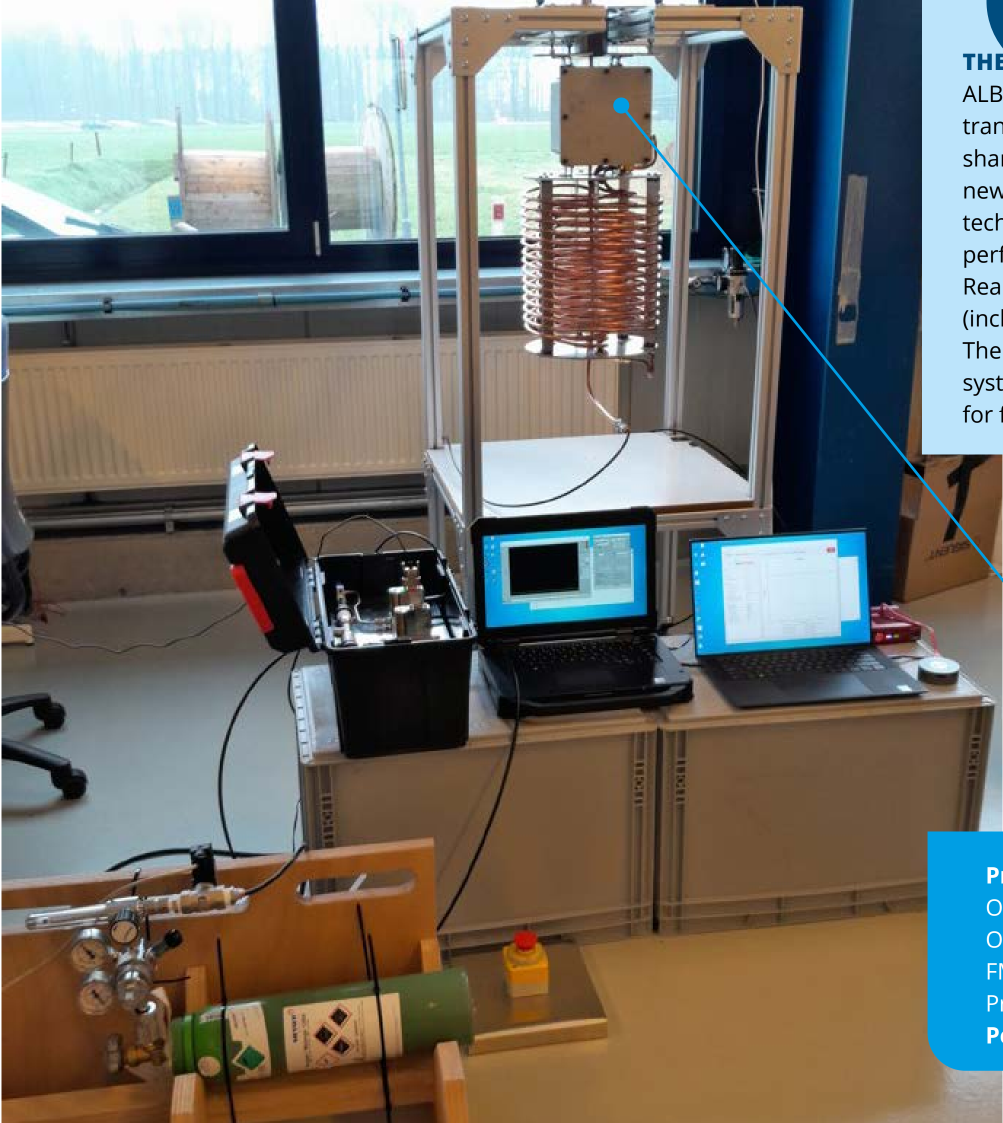
The ALBATROS project aims to revolutionise aviation safety. It addresses diverse challenges, from real-time anomaly detection on runways to weather hazard prediction and crisis management. Improvements in safety procedures, communication and training for aviation stakeholders will let ALBATROS boost 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

The following have been done regarding hydrogen:

An analysis examining the risks linked to new fuels and energy systems, specifically electric and hybrid electric power trains and hydrogen-fuelled aircraft. A detailed report has been generated outlining these risks and mitigation measures. One section focuses on applying hydrogen energy, both on the ground and during flight, proposing monitoring solutions for minimising the risks associated with leaks. This includes enhancing sensitivity and safety through lab tests of the hydrogen FBG sensor. The tests centre on intrinsically safe FBG sensors that monitor hydrogen levels, averting potential explosions or fires due to liquid hydrogen tank leaks. The report concludes by presenting test results, performance evaluations and specifications.



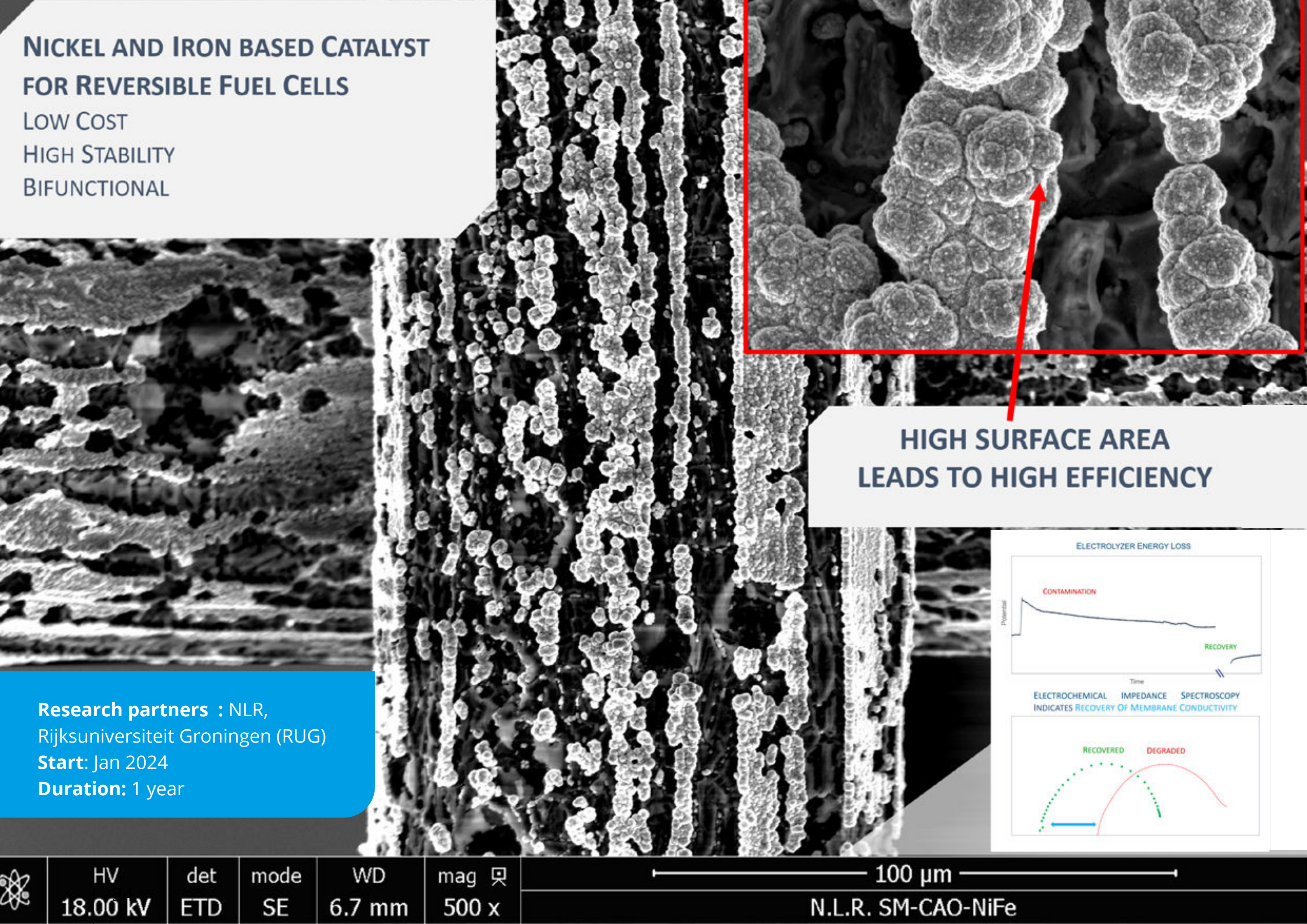
THE S

ALBATROS will deliver a comprehensive safety transformation for aviation. It introduces a novel safety-sharing concept, enriching the Data4Safety platform with new datasets to enhance vulnerability detection. New technologies and training tools will allow human performance during crises to be improved substantially. Real-time weather hazard prediction and risk mitigation (including 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: 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



Nickel and Iron based Catalyst for Reversible Fuel Cells

Low Cost

High Stability

Bifunctional

High Surface Area Leads to High Efficiency

Research partners : NLR, Rijksuniversiteit Groningen (RUG)

Start: Jan 2024

Duration: 1 year

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 in which health monitoring on fuel cells can be performed. The developed catalyst materials are validated on a larger scale to prove their feasibility for future industrial use. Long-term stability of the AEM catalyst is confirmed by monitoring the health over an extended period. Health monitoring tools are used to ensure adequate cell assembly. Accelerated stress tests are performed on electrolyser cells to stimulate degradation, after which recovery techniques are 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.

MATPRO@20K

Material properties at 20Kelvin

Material properties dictate the world. Functionality, manufacturability, durability, design - everything that defines a product - depend on material properties. In extreme environments, these properties are often unknown, sometimes amazing. In the quest/search for possible answers to big challenges, two application areas focusing on material properties at 20K are addressed in this research project: superconductivity, to be used in electrical drive trains, and energy storage in liquid hydrogen. The research object is a storage vessel for liquid hydrogen.

THE CHALLENGE

The development of a storage vessel for liquid hydrogen starts with establishing material properties, e.g. permeability, strength. The development of super powerful, superconductive systems implies high mechanical forces on structural details, with unknown mechanical properties. Even the methods for deducing these properties at 20K are unknown.Success in achieving these goals will help enable climate neutral aviation by flying on hydrogen. It will also provide a sound basis for the development of superior waver steppers.

WHAT WE DID

The work is divided into a feasibility study and a second part in which the NLR device is upgraded and the material properties desired by NLR, ASML and VDL-etg are established. The feasibility study involves three key items:

- The load train, the structure which transfers the external applied mechanical load to the test sample.
- The interface between moving and non-moving parts of the cryostat, which might be fatigue prone.
- Designing and prototyping the inner cryostat. Its functionality can by proven in the unchanged static cryostat.

The feasibility study ends with the actual design of test items and the definition of the test specifications. The second part will be performed in the follow up of the project.

THE SOLUTION

Starting point for establishing material properties at 20K is the NLR xx testing machine which can perform static tests at 20K. It uses liquid nitrogen and liquid helium for cooling. However, liquid helium is extremely expensive. For static testing, which does not take very much time, this is acceptable. For long duration testing (dynamic testing, wear and tear testing), further improvements are required. The first improvement is the re-use of helium, hence the capture and reliquefication of the helium used for cooling to close the circle. A second improvement is called ‘Matryoshka’, a cryostat in a cryostat.

Project partners: ASML, VDL-etg 2025, HHT Materials
Period: 2023

Aviation in Transition

Luchtvaart in transitie

In 2050, aviation must be climate-neutral. Through Aviation in Transition, the Netherlands strengthens its position as an innovative and resilient leader in aviation. Between 2023 and 2030, a range of 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, and we can secure a stronger market position within the global chain. Within Aviation in Transition, various stakeholders, ranging from universities, knowledge organisations, and SMEs to large enterprises, are united. In close collaboration, they work on the accelerated development of breakthrough technologies that make crucial systems, and consequently, future aircraft ultra-efficient and free of CO2 emissions. The Dutch government contributes to this mission with essential support from the National Growth Fund, as well as supportive policies to facilitate the introduction of "sustainable flying."

Aviation in Transition (Luchtvaart in Transitie) is a groundbreaking eight-year program where the Dutch government and the aviation sector join forces. The goal: to initiate a revolution by accelerating sustainability, with climate-neutral flying from 2050 as the guiding principle. Participating partners in Aviation in Transition aim to achieve this by developing energy-efficient solutions, lighter materials and systems, and even carbon-neutral propulsion systems using hydrogen as a fuel. To achieve this, the Aviation in Transition program will financially invest in and collaborate with over 60 partners to boost the Dutch aerospace sector and, consequently, the economy. The National Growth Fund (Nationaal Groeifonds) supports this programme.

Aviation in Transition will result in:

- Development of three flying demonstration airplanes
- Technology development for a new generation of ultra-efficient aircraft
- Sustainable knowledge development and preservation
- Reinforcement aeronautical networks

LUCHTVAART in transitie

The Aviation in Transition programme consists out of twelve projects. NLR is partner in most of the twelve LiT projects, including the following industry led projects

NLR is furthermore partner in the following projects:

Advanced Electric Wiring

Project lead: Fokker I GKN Aerospace

Project aim: to develop advanced high-power wiring systems for increased electrical power in hybrid-electric aircraft and hydrogen fuel cell systems

Hydrogen Aircarft Powertrain and Storage Systems (HAPSS)

Project lead: Conscious Aerospace

Project aim: by 2027, to have a flying HAPSS zero-emission hydrogen-based demonstrator turboprop aircraft (>36 seats) derived from a large regional turboprop airplane. And to develop products for the other two hydrogen demonstrator aircraft.

Hydrogen Conversion Turbofan (HOT)

Project lead: Fokker NextGen

Project aim: to develop a retrofit modification, enabling existing jet aircraft to be suitable for hydrogen combustion in a hybrid solution. This can still involve the use of kerosene or a greener variant thereof (bio or synthetic).

Lightweight composites and structures

Project lead: Fokker I GKN Aerospace

Project aim: the development of innovative production technologies for complex thermoplastic composite parts and integrated structures. The activities cover the entire spectrum from material development and product design to production, certifiability, repairability, reuse, and sustainability evaluation of thermoplastic composite products.


STOP
PASSERENDE

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 building up a strong facilitating role for airports for accommodating the turnaround of electric, hybrid electric and hydrogen-powered aircraft. To achieve that, various obstacles in the charging infrastructure and in refuelling aircraft with hydrogen will have to be resolved.

WHAT WE ARE DOING

The feasibility study has been completed, now the focus is on preparing demonstrations for unattended charging, a modular charging system and airport-facilitated hydrogen flight, utilising NLR's hydrogen research infrastructure.

THE SOLUTION

NLR is in lead of Work package 2 of the TULIPS programme for a feasibility study looking at the infrastructure required, the operational procedures and the impact on costs and flight schedules of introducing electric, hybrid-electric and hydrogen-powered aircraft. Along with this, it is developing the necessary safety procedures and operational procedures.

TULIPS will demonstrate its resulting innovations for:

- Unattended charging
- Modular charging system
- Airport-facilitated hydrogen flight

Project partners:
Schiphol Nederland NV (project lead), AVINOR, SINTEF, HERMES, Catalink, SAGAT, POLITO, BETA-i, EGIS, EME, Fraunhofer, KLM, KES, MMU, MOBCON, NLR, PIPISTREL, POA, SKYNRG, TNO, TUD, IST-ID, UANTW, BAM, BALLARD, DHL, ZEPP, HyCC, BOS and Middelkoop
Period: 2022 - 2025

Co-funded by the European Union. GA no 101036996

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
NLR research & test facilities (NL)

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: E**nergy 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)
  - Power train ground testing, currently up to 2MW
    - Electric, hydrogen-electric
    - 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
Hydrogen Production Pilot Plant
PROPULSION
FIELD LAB
(2026)
ROGER ENERGY
DEWAR
LH_2
Cryostat
Solar Park
Grid connection
11 kV and 150 kV
DNW wind tunnels
NLR Drone centre
NLR MARKNESSE

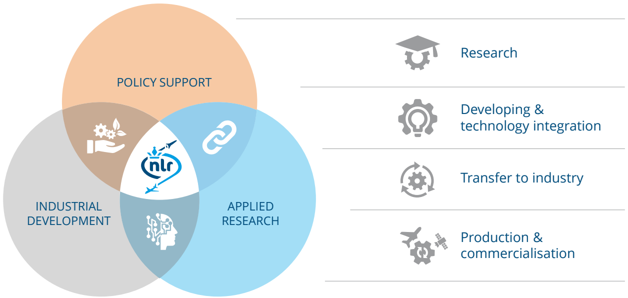
About NLR

Royal Netherlands Aerospace Centre

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

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

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



NLR 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 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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