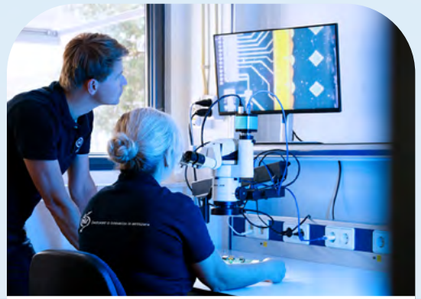
Accelerating the future of aerospace

Impact Report 2025

TURNING KNOWLEDGE INTO VALUE

Royal NLR - Netherlands Aerospace Centre



Reference to Dutch government policy

- Long-term Space Agenda (LTR)
- Aviation Research Agenda
- IKIA for Climate and Energy
- Defence Vision 2035
- Key Technologies

NLR Impact Report 2025

Impact doesn't just happen. Between a good idea and a tangible application, there is a process of research, validation, improvement and collaboration. Because we are an applied research organisation for aerospace, NLR plays a central role in this. Our operations are at the heart of the valorisation process: where knowledge is turned into value. Our goal in this regard is clear: research must lead to applications that make a real difference to society and the economy.

In this edition, just like in previous years, we are showing how that ambition is being put into practice, and how policy and strategic objectives translate into technological and social impact. Proper applied research bridges the gap between fundamental understandings and practical implementation. This enables NLR to contribute directly to enhancing safety, competitiveness, economic growth, and sustainability in the Netherlands and beyond.

The report covers 20 projects that we contributed to in 2025. Collectively, they give a representative picture of the breadth of our field of work: from defence applications to climate-related solutions, and from space research to emerging technologies. Each and every project demonstrates how innovation can be made meaningful.

After all, innovation rarely happens in isolation. Along with our partners in industry and SMEs, we accelerate the development of ideas and bring them to market to benefit society. SMEs bring a unique blend of flexibility and entrepreneurship, while NLR provides the necessary expertise, infrastructure, and facilities. That is why we also focus on the added value of SMEs, particularly deep-tech start-ups and scale-ups.

Finally, we will also a shine spotlight on the people behind the impact, because progress is driven by more than just technology. Above all, it needs dedication, curiosity and skill – which means that our employees are the very heart of our innovative strength.

In this report, we will not only be showing our achievements in 2025, but above all why they matter. I hope you enjoy reading this new edition of the NLR Impact Report.

Martin Nagelsmit,
chief technology officer of NLR

Martin Nagelsmit
CTO NLR

STRATEGIC THEMES

AEROSPACE FOR A SAFE AND SECURE SOCIETY

A technologically advanced military is vitally important.

[read more...]

COMPETITIVE AEROSPACE

New products and markets are emerging to address issues such as the living environment, accessibility and sustainable air transport.

[read more...]

SUSTAINABLE AVIATION

If climate neutral aviation is to become a reality, we need to commit to the development of radical innovations.

[read more ...]

What does ‘impact’ actually mean for central government?

The term ‘impact’ has become more and more of a core concept in publicly funded research. For NLR, this means that research not only needs to be scientifically or technically interesting, but also demonstrably beneficial to the policy objectives of central government.

Every ministry has its own policy priorities, but they could all ask themselves the same key question: what specific changes does applied research yield? The impact of NLR’s activities therefore involves not just the development and transfer of knowledge but also applicability, decision-making and social value.

For the Ministry of Defence, the desired impact is principally in operational effectiveness and strategic autonomy. That applies to all the domains where the Dutch armed forces are active. Research should help improve operational readiness of equipment, reliability of intelligence and operational effectiveness, as well as reducing dependence on foreign technology. From that perspective, the impact becomes manifest once innovations find their way into the actual doctrines (descriptions of the principles defining how the armed forces are deployed), procedures or equipment choices.

“The Ministry of Infrastructure and Water Management recognises how important the innovative research carried out by NLR is for the entire aviation sector. The practical applicability of the results enables data-driven improvements to be implemented, which is extremely valuable.”

Henri van Faassen,
Director of Aviation Strategy and Resilience at the Ministry of Infrastructure and Water Management

At the Ministry of Infrastructure and Water Management, the emphasis is more on civil applications aimed at safety, sustainability and feasibility within the mobility system; aviation plays an obvious role in this. Impact is created here when research findings lead to tangible

improvements in aviation safety, emission reductions, or practical policy tools that can be applied by industry stakeholders. The value of research is thus often assessed in terms of its usefulness in informing regulations and implementation practices.

"NLR enhances the technological capabilities of the Dutch aerospace sector through targeted research and development. By collaborating closely with governmental departments and linking international networks to our national ecosystem, NLR plays a crucial role in our national security, resilience, and economic growth."

Niek Lobé,
Head of Aerospace at the Ministry of Economic Affairs and Climate Policy

The Ministry of Economic Affairs and Climate Policy prioritises economic effects and effects of innovation. In this context, the desired impact means that research must lead to greater earning capacity, new supply chain collaborations or accelerated innovation within Dutch industry. The relevance extends beyond technological advancements to encompass the emergence of new activities, business growth, and increased competitiveness.

In all three cases, this means that NLR and governmental authorities must consider early on in the research process what the project results might lead to. This involves explicitly stating assumptions, identifying potential users and facilitating interaction throughout the research. Most importantly, NLR's impact offers clear justification to funding parties and society at large of its ongoing commitment to solid, relevant research.

"The Dutch armed forces must be agile enough to respond appropriately in any situation. We must be capable of forming a clear picture of a situation or potential threat quickly, so that we can deploy our resources in a targeted and effective way. This applies across all domains we operate in, including space and cyber. Given their interdependent, complex and dynamic nature, it is crucial that we are supported by partners who possess the knowledge, expertise and experience to provide an overview and offer insights. NLR has been one of our key strategic partners in this area for decades"

Robert Adang,
Deputy Commander of the Royal Netherlands Air and Space Force

"Industrial partners often bring advanced technologies to the table"

Accelerating drone innovation for the Ministry of Defence

In May 2025, NLR opened the Quick Response Drone Facility in Marknesse, which aims to accelerate the development, testing and deployment of drones and new drone capabilities. NLR is collaborating closely on this with the Dutch Defence department and various (industrial) partners. This way, field requirements can quickly be translated into practical solutions.

Rapid drone innovation is crucial for Defence. "The war in Ukraine demonstrates that this is essential in order to stay one step ahead of the enemy", says Jorrit van den Eerenbeemt, project manager at NLR. Conventional processes take too long. The Quick Response Drone Facility (QRDF) allows drones or new drone capabilities to be made operational within four to six weeks. Van den Eerenbeemt admits that this is quite a challenge. "It requires a different approach, as well as close cooperation between NLR, its project partners TNO and MARIN, the Defence department and industry."

The facility acts as a fallback for the front line: issues that military personnel in the field cannot repair or adapt immediately are addressed in the Netherlands and rapidly advanced. The project manager says that there is always someone on hand to answer the phone and call in the right specialists immediately. "A system that has failed can be fixed and brought back online in just a short time, for instance."

We work on both hardware and software for drones, depending on the project. That's all done in Marknesse, which is a unique location that offers lots of advantages. The closed airspace and the existing test facilities, such as the Drone Centre and the Automated Composites & Metal Manufacturing and Maintenance Technology Centre, make extensive testing possible.

Impact in multiple areas

The QRDF is making a difference in several areas. "Economically, it helps the Netherlands stay ahead in drone innovation, while strategically, it enables the armed forces to respond more quickly to changes in the field", the project manager explains.

Improving on what we already have

The number of projects completed is now in double figures. One of them made a drone that was creating too much noise significantly quieter. The systems developed at the QRDF generally have a high technology readiness level and are therefore ready for immediate use. "It's usually about improving what's already there. Systems that were developed earlier often only need a minor update to be put to practical use – a small tweak is sometimes all it takes."

Collaboration with industry

NLR and its partners work closely with a blend of startups and larger companies, such as Emergent Swarm Solutions and Smooth Stone Dynamics. Collaborating with industry ensures that innovations get implemented more rapidly, Van den Eerenbeemt explains. "Industrial partners often bring advanced technologies to the table but they don't always understand how to integrate them with a Defence drone. NLR takes care of that conversion: how to put technology to use operationally, or how to test it and implement it quickly. Sometimes the technology still needs further development, and other times it's almost ready to use straight away."

PERIOD
2024 to date
PROJECT PARTNERS
TNO, MARIN, MIND (Defence)
STRATEGIC THEME
Aerospace for a safe and secure society
NLR KNOWLEDGE PROGRAMME
Unmanned and autonomous
GOVERNMENT POLICY
Defence Vision 2035

Laser communication creates fast and secure connections

Currently, communication with satellites largely relies on radio waves. However, as data volumes increase rapidly, alternatives are being explored. Optical communication, which uses laser beams, is a promising innovation. As part of a NXTGEN high-tech project, NLR is researching the satellite electronics required for laser communication, which would allow faster and more secure communication.

"At home, we all switched from landline internet and cable broadband to a fibre-optic connection, and in space too we are now undergoing a similar transition with laser communication", says Sybren de Jong, Principal Space Avionics R&D Engineer at NLR. In the Laser Satellite Communications project, we are working on various applications, such as communication between satellites, with the Earth or with aircraft. Laser communication uses a laser beam consisting of small pulses of light that carry information. "We're working towards a final link with a data rate of around one terabit a second", De Jong states. That's over a hundred times faster than what is currently achievable with radio waves."

The electronics

Along with TNO and partners from industry, NLR is part of a large consortium conducting research into laser satellite communication. "The consortium is developing a complete terminal: a device capable of sending and receiving information using laser beams. At NLR, we're working on the electronics and software for that system", De Jong explains. "It's critical that the transmitter and receiver are aligned properly, given that communication takes place over distances of up to 30,000 kilometres. That is achieved using various movable mirrors and other techniques. Special electronics are needed to control the mirrors properly."

The launch

The Defence department's PAMI-1 satellite, for which laser communication is currently being developed within the consortium, is scheduled for launch in 2028. "We're currently working on a prototype based on more fundamental research, which is the same size and weight as the electronics that will eventually be launched", De Jong says. The initial prototype is expected to be capable of communicating at speeds of up to 2.5 gigabits per second. "We're going to monitor exactly how it behaves

PERIOD

2023 - 2027

PROJECT PARTNERS

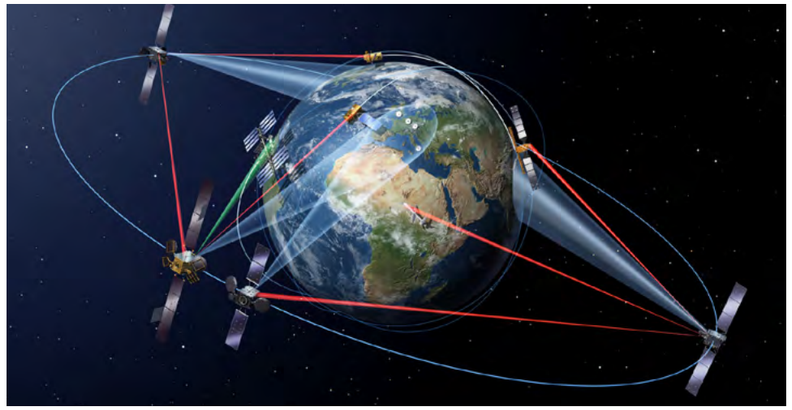
TNO, FSO Instruments (a joint venture of VDL and Demcon), Celestia Tech

STRATEGIC THEME

Aerospace for a safe and secure society

NLR KNOWLEDGE PROGRAMME

Space for defence and society



in space, and we'll use that experience to improve the hardware and software step by step. The next stage is moving to 100 gigabits a second, and ultimately to demonstrate a link at 1 terabit per second in space after 2030."

Crucial communication

There is also a wide range of civilian applications, one of the most important being in-flight Wi-Fi. "Laser communication between space and Earth is tricky because of clouds and particles in the atmosphere, but aeroplanes usually fly above the clouds, which works out favourably." Laser communication is also important for science, for instance in climate research. "More and more measurements are being taken from space, looking at things like air quality and the climate."

De Jong mentions detecting forest fires as an example of an area where laser satellite communication could really make a difference. "Previously, it could take up to an hour for satellite data to reach the end user on the ground. The satellite's orbit always had to pass over a ground station first to let it transmit the data. Laser communication is a key technology for enabling satellites in space to form a network, allowing satellite observations to reach the end user almost instantly. In the event of large forest fires and other natural disasters, this is incredibly important – every minute counts."

The fact that information gets down to the Earth from space more quickly is important to the Ministry of Defence too. “Having data available quickly can be critical in the military sphere”, he says. As well as offering a more stable and faster connection, laser communication has another significant advantage: “It’s more secure than radio waves because the laser beam is much narrower and virtually impossible to eavesdrop on.”

Strong competitive position

Collaboration with industry is crucial if we are to make an impact in space advancements. “At NLR, we contribute by providing expertise and facilities. NLR also has access to various financial resources that enable us to support industry with higher-risk research and technology development.” This applies to established companies, as well as start-ups.

De Jong sees plenty of potential for Dutch industry when it comes to developing and producing laser satellite communication technology. “All the ingredients are in place to make this a success”, he says. This includes both the specialist knowledge available at research institutions and the right industrial partners. “A great deal of research is also being carried out in this area in other parts of the world, so if we’re to maintain our competitive edge and independence, it’s important that we make a major effort together to drive this ground-breaking innovation.”

Achieving space ambitions through united efforts

Rik Bosma is constantly looking for opportunities to make an impact on the world. His guiding principle for life is to “stand out from the crowd”. “Only then can you really be seen and make a mark.” Apart from his ambitions to make a difference, he has had a lifelong fascination with space. This is now coming together in his role as programme leader of NLR’s new knowledge programme Space for Defence and Society.

His career began with studies in industrial automation and computer science. “Two fields that are technically broad, ranging from mechanical to software engineering and from electrical to control engineering. So, they gave me a lot of options to explore.” Early in his career, Rik mainly worked with virtual reality, AI, and the Internet of Things. “I spent most of my time building demonstrators to showcase what was possible, but I wasn’t able to work on many large-scale projects with tangible results.” Looking for a role with more substance, Rik decided to apply for a job at NLR.

read more

Smart and efficient maintenance for a stronger aviation industry

Smart aircraft maintenance helps create a stronger and cleaner aviation industry. The BrightSky research project is exploring ways of improving maintenance using cutting-edge technology such as inspection robots. NLR supports companies in turning research into practice.

Maintenance is often overlooked, but it is an indispensable part of aviation. Quality checks and maintenance work are carried out every day, mostly without passengers even noticing. “As a society, we’re growing more dependent on technology. That makes it all the more important to maintain these aircraft and keep them operational”, says Arjan de Jong, a principal R&D Engineer at NLR and professor of Aerospace Maintenance Technology & Management at the University of Twente.

The BrightSky research project is aimed at improving maintenance in the Dutch aviation sector, while also helping the sector make the transition to sustainability. “Instead of retiring aircraft and parts, we’ll repair them. “That’s a key step towards a circular economy”, De Jong says.

Because aircraft technology is continually evolving, maintenance companies must also innovate. “When new technology is used in an aircraft, maintenance companies need to keep pace because it is ultimately their responsibility to ensure it remains operational”, De Jong adds.

Economic and social significance

There are three cornerstones to BrightSky, namely new technology, social innovation and sustainability. According to De Jong, we can work smarter and more efficiently by leveraging the latest technology, which in turn boosts the economic viability of the aerospace sector. “On top of that, adopting smart and efficient practices can make maintenance and flight operations as a whole more sustainable. The project’s final objective focuses on the workers. Our goal is to make the sector more appealing by using robots to perform tasks that are tedious, dirty, or dangerous.”

NLR carries out applied research relating to all three cornerstones. “We’re building a simulator that lets maintenance engineers practise carrying out engine

PERIOD

2021 - 2026

PROJECT PARTNERS

Jet Support, KLM, Schiphol, Amsterdam University of Applied Sciences, Delft University of Technology, T-Hive, S&T, Vanderlande, TNO , DT-Solutions, ILIAS, OneLogistics, SAMXL, Robo House

STRATEGIC THEME

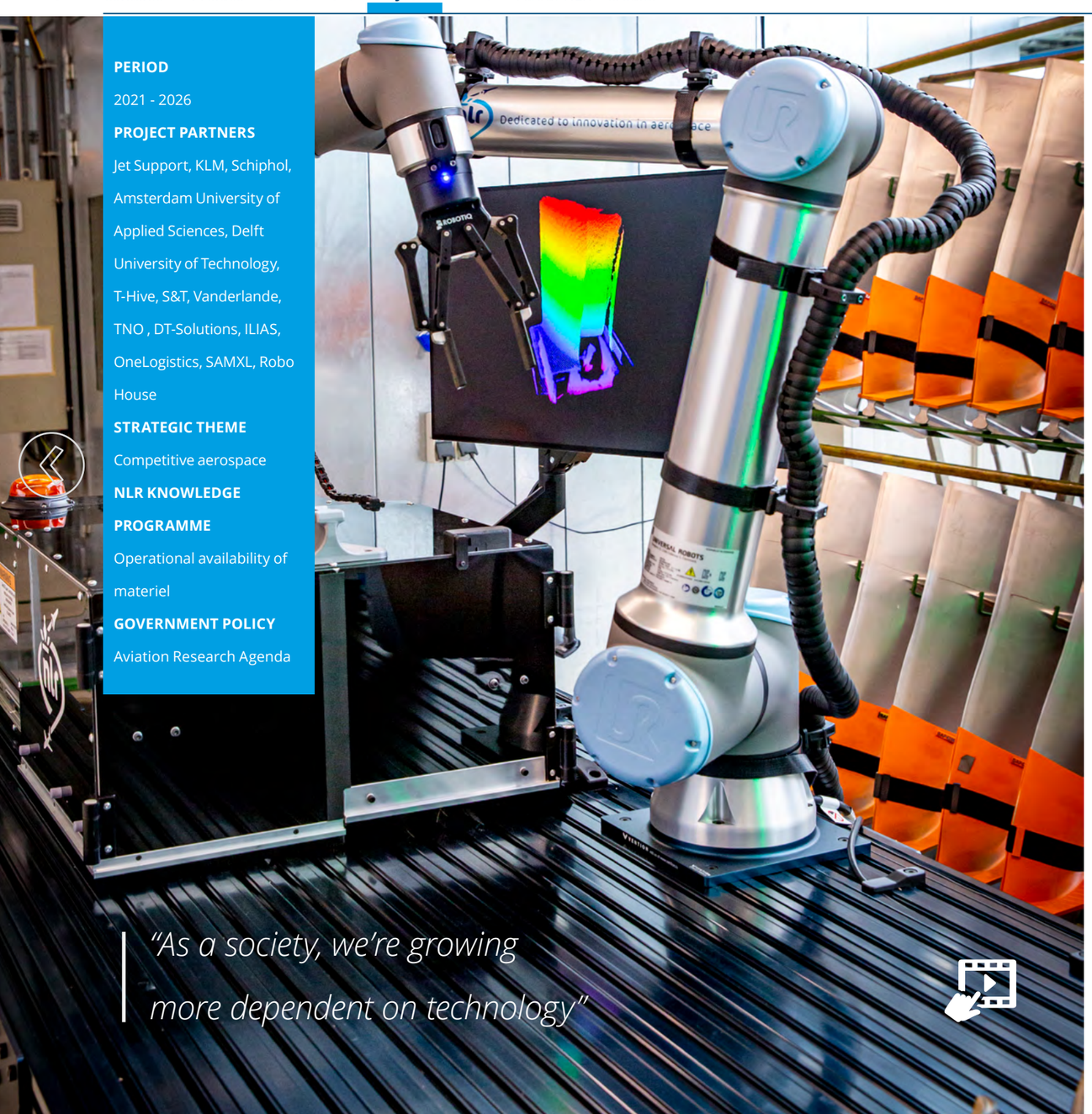
Competitive aerospace

NLR KNOWLEDGE PROGRAMME

Operational availability of materiel

GOVERNMENT POLICY

Aviation Research Agenda



"As a society, we're growing more dependent on technology"

tests that are known as ground runs, which reduces fuel consumption. This not only makes testing more efficient but also cuts the emissions", De Jong explains. The next step will be robots that can help perform inspections of engine components, for instance.

Predictive maintenance

The researchers also use new technology to predict when a part is likely to fail, so that it can be replaced at the right moment. "This enables us to better predict logistics, for example, for shipping parts around the world, and streamline the process." Moreover, robots could take over mundane, dirty, or hazardous tasks in the future, freeing people from these responsibilities.

Additionally, BrightSky has been looking at ways of using cutting-edge technology to monitor work remotely. "It would be incredibly useful if someone wearing smart glasses could observe a colleague's work remotely. You would no longer need to be physically present, which would not only save time but also reduce costs."

Focus on implementation

NLR is aiming to bridge the gap between scientific research and practical uses. "The focus in the maintenance sector is on implementation. Companies are looking for technology that they can put to use relatively quickly", De Jong says.

Implementing new technology is far from easy, though. "The rules are very strict. NLR has a wealth of knowledge in this field and can assist businesses where necessary. That lets us make a real difference."

Engineer and professor

In addition to his role at NLR, Arjan de Jong was appointed Professor of Aerospace Maintenance Technology and Management at the University of Twente in 2024.

"I'm in Twente one day a week, teaching a course on the maintenance of technical systems. That lets me pass on my enthusiasm for aircraft maintenance to a new generation, which is a great addition to my work at NLR."

Laser weapons as the answer to war drones

A laser weapon is a promising innovation in response to the advent of drones in combat situations. It is a quick and relatively inexpensive way of intercepting drones. NLR and TNO are investigating the effectiveness of such a weapon, its safety aspects and its potential applications for the armed forces.

Large numbers of drones are being deployed in conflicts more and more often nowadays. “Current radar systems often fail to detect drones effectively, and large and expensive anti-aircraft defences are used to shoot them down. That’s out of all proportion, for relatively small and inexpensive drones”, one of NLR’s experts says.*

Even large and expensive surface-to-air systems cannot always take out an entire drone swarm, so some of them still reach their target. Laser weapons could be the solution. An airborne object such as a drone can be targeted in a fraction of a second and then destroyed by a powerful, targeted laser beam.

No separate munitions

The expert also points out another major advantage of laser weapons: they do not require separate ammunition. “The logistics involved in supplying munitions – delivering the right numbers to the right locations – is a challenge in wartime. You can’t just drive a truck into a conflict zone. Laser weapons don’t require expensive ammunition: they only need electrical power, supplied from a battery pack or generator.”

Short distances

Laser weapons work best if the target is less than a couple of kilometres away.

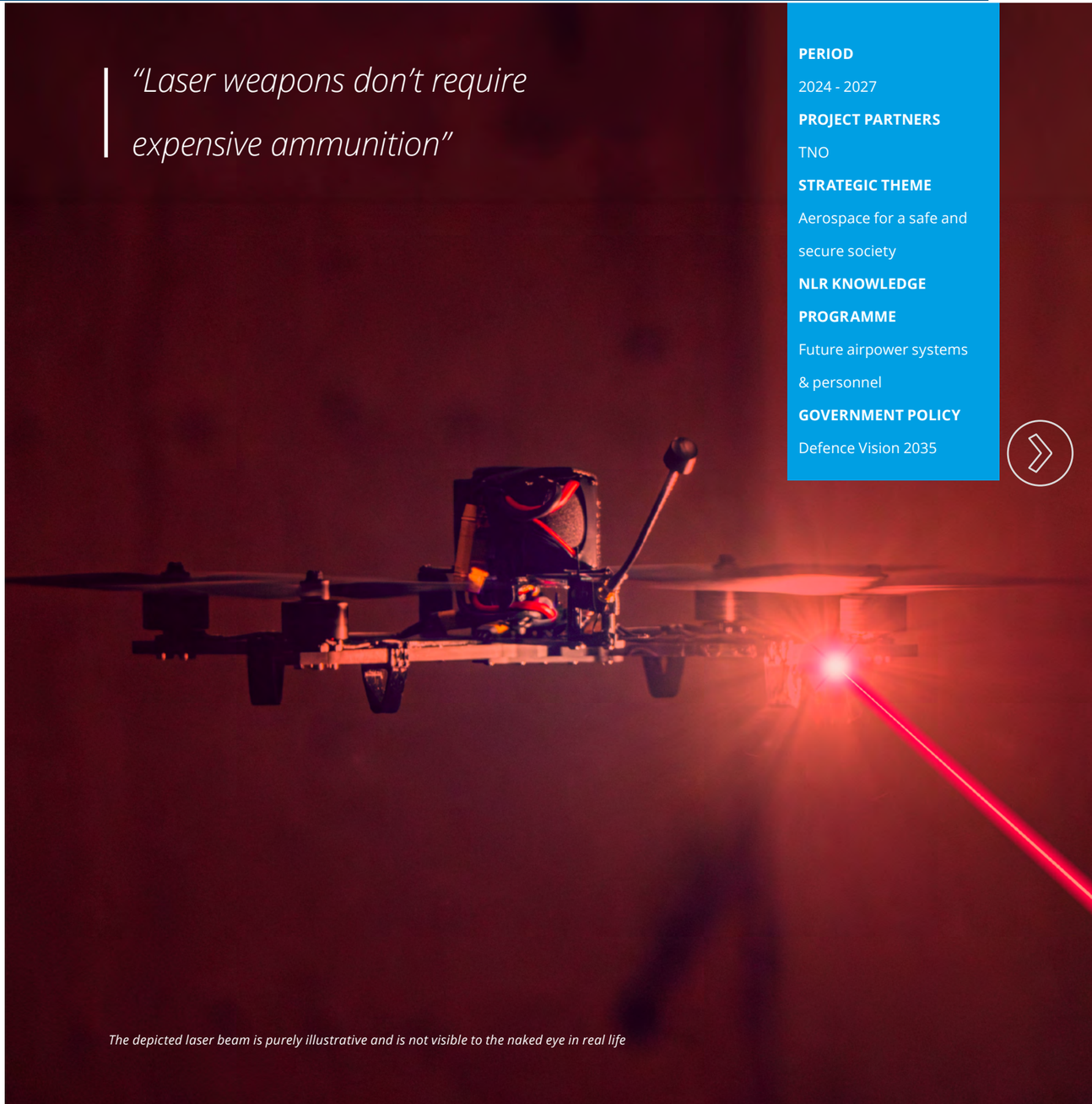
“Over the past year, there’ve been lots of reports of unidentified drones near airports across Europe”, the expert says. “Those are situations where a laser weapon could prove useful in the future.”

Laser weapons are less suitable for longer distances. The beam of light can be disrupted by tiny, invisible particles in the air, known as aerosols. “This means that the laser gets less effective over longer distances.”

The danger of reflections

As with any weapon, there are also disadvantages to using laser weapons, alongside the many advantages. “We may have to cope with reflections of the light beams from reflective surfaces on the target. If the reflections get in someone’s eyes, they could go blind.” That is one area NLR is conducting extensive research into as part of the project. “The study findings so far suggest that the risk posed by reflections appears to be relatively low.”

**The name of the interviewee has been withheld for security and privacy reasons.*



“Laser weapons don’t require expensive ammunition”

PERIOD
2024 - 2027
PROJECT PARTNERS
TNO
STRATEGIC THEME
Aerospace for a safe and secure society
NLR KNOWLEDGE PROGRAMME
Future airpower systems & personnel
GOVERNMENT POLICY
Defence Vision 2035

The depicted laser beam is purely illustrative and is not visible to the naked eye in real life

TESTIMONIAL FROM THE STARTUP PROGRAMME

Emergent is a startup specialising in developing software for autonomous and swarming drones. Their clear vision and strong drive let them develop and innovate their technology. With help from NLR as well as their own determination, they are ready to take the world of drones by storm.

> *"Working with NLR pushes us to deliver within a short timeframe, without compromising on quality. In addition, it provides us with technical validation by a reputable organisation", CEO and co-founder Lennart Bult states.*

read more →

From theory to implementation

NLR has been researching laser weapons on behalf of the Ministry of Defence for over ten years now, aiming to make safe and effective deployment possible.

"We use the knowledge we've acquired to keep advancing the technology. This involves more than just theory - we also gain practical experience through laboratory and field tests. Once it can be implemented safely in practice, it's up to industry to drive further development. We can of course support businesses in this regard, acting as a bridge between the Ministry of Defence and the business sector."

At present, various European countries have built demonstrators for researching the potential of laser weapons. "There is already small-scale deployment of the weapons in operational environments, but it's often still largely experimental." The NLR expert expects that the armed forces will be able to make genuine use of the weapons within a few years.

Larger targets

"Research is also being conducted into the feasibility of using laser weapons to engage larger targets, such as rockets. That would require a much more powerful laser weapon producing roughly ten times the energy output of the current demonstrators. "It will be some time before this technology is ready for deployment."

Quantum tech offers opportunities for safer aviation

Quantum technology has the potential to make aviation more efficient and safer. It could allow vulnerable satellite navigation systems to be partially replaced by mapping based on magnetic fields. As part of its Emerging Technologies programme, NLR studies innovations in aviation and explores the options for implementing them.

Quantum technology promises to change the world. As part of its Emerging Technologies programme, NLR is studying how this technology can benefit the aviation sector. There are currently three subsets of quantum technology: sensors, communication and computing. Quantum sensors are currently at an advanced stage of development and have the potential to make a real difference in the aviation industry.

All conventional measuring instruments – such as thermometers, barometers, anemometers, radio receivers and magnetic field measuring devices – could be replaced by quantum-based variants. "These sensors are generally significantly more accurate than the current versions", says Harmen van der Ven, head of the Emerging Technologies programme.

Safe navigation

Quantum sensors have the potential to make aircraft navigation considerably safer. They are capable of accurately mapping the Earth's magnetic field. The Earth's crust, and in particular the impurities within it, creates local changes in the planet's magnetic field. "You can use that data to create a map", Van der Ven explains. This makes navigation without satellites feasible.

"That is certainly a lot more secure for military aircraft than the current satellite navigation systems, which can be jammed", he adds. "Jamming navigation that is based on the Earth's magnetic field isn't possible. It can make a difference when used in weapons too. After all, we want to be certain that the weapons only hit their intended targets." Given the clear security links, the Ministry of Defence is closely involved in this research.

PERIOD

2022 - 2026

PROJECT PARTNERS

University of Amsterdam, Delft University of Technology, TNO and the Ministry of Defence

NLR KNOWLEDGE PROGRAMME

Emerging technologies

GOVERNMENT POLICY

Key Technologies

Navigation using the Earth's magnetic field will not completely replace traditional navigation; it will complement it to provide additional safety and security. "Analysing the Earth's magnetic field can help determine if you're in a flat area or in mountainous terrain, for example. Street-level navigation, however, is not possible."

Better flight safety

The second area where quantum technology is applied is communication. "This is largely about security and encryption so that enemies can't eavesdrop." The final aspect is quantum computing. Van der Ven emphasises that quantum computers complement classical ones rather than replacing them: "Quantum computers are far more efficient and a lot quicker at performing specific tasks. These are mostly about solving search and optimisation problems – to put it simply, this kind of computer can find a needle in a haystack successfully. And very quickly."

This is interesting for the aviation sector because it can help improve safety. "We already carry out very thorough risk analyses", Van der Ven continues, "and fortunately planes hardly ever crash anymore, but a quantum computer could let us reduce the likelihood of accidents even further."

Implementing what we know

Within the Emerging Technologies programme, we not only conduct research into quantum technology but also other developments such as biotechnology and specific areas of artificial intelligence (AI). In addition to their own fields of expertise, Van der Ven and his team also keep a close eye on technological developments outside the aviation sector. They delve deeper into certain topics by consulting with specialist scientists, for instance. "This allows us to explore the potential implications of new technologies for the aerospace industry", he explains.

> *Quantum sensors make navigation without satellites feasible*

Where there is potential, the team at NLR will continue to experiment with the technology. If it shows promise, they will look at how to place the technology within NLR, for example in a specific department or in collaboration with another organisation.

Making connections

There are a relatively large number of startups working in quantum technology. "It's a new technology and its first components are only now emerging from the labs. This also creates opportunities to explore its commercial potential." NLR is keen to collaborate with start-ups, combining their technological expertise with NLR's aerospace knowledge. "On top of that, we also have links with organisations such as Defence that are interested in using this technology."

TESTIMONIAL FROM THE STARTUP PROGRAMME

Fermioniq is an ambitious startup that is pushing the boundaries of computing power. While the world waits for the perfect quantum computer, this team is developing software that aims to bring the power of quantum algorithms into practice today. NLR is providing Fermioniq with the opportunity to test its bold technology against current scientific frameworks and validate it in practical applications.

> *"NLR's vision of actively sharing knowledge with startups is truly refreshing. Not only do you gain access to highly detailed technical information, but you also become part of a network that unlocks future opportunities", the Fermioniq team says.*

read more →

PERIOD

2023 - 2025

STRATEGIC THEME

Sustainable aerospace

NLR KNOWLEDGE PROGRAMME

Climate-neutral aviation

GOVERNMENT POLICY

IKIA for Climate and Energy

"Our role is to always stay one step ahead"

New testing facility supports green aviation

As we search for alternatives to fossil fuels, several concepts are being considered. For large aircraft that travel long distances, one crucial question is: what are the implications of flying on hydrogen? "There are plenty of ideas on the table", says Paul Arendsen, head of Structures Testing and Evaluation at NLR. "But we need to turn those ideas into reality - we need to be able to build them."

Following a development period of over two years, the Energy to Propulsion Test Facility (EPTF) was officially opened in November 2025. "Major players such as Airbus and ASML spoke and there was a great deal of interest in the test facility from various European countries", recalls Paul Arendsen, the driving force behind EPTF and head of the Structures Testing and Evaluation department at NLR.

There are various options for making aircraft propulsion systems – the set of components that convert fuel into thrust – more sustainable. Batteries are suitable for short distances but for longer distances, hydrogen could be a solution. "Gaseous hydrogen is lightweight but voluminous, which makes it difficult to transport. You can compress the gas but that requires a very strong tank, making it too heavy. So, the only viable option is to use it in its liquid form", Arendsen explains. This involves some challenges of its own, though, such as keeping the hydrogen liquid at –253 degrees Celsius.

A unique facility

At present, the EPTF is principally used for carrying out tests on powertrains based on gaseous and liquid hydrogen. The HYPOTRADE project tested the propulsion system of Pipistrel's new aircraft, the Miniliner, for example. "The facility is unique because it lets us test not just the individual components, but the entire powertrain", Arendsen says.

Is too much energy being wasted? Is the whole system getting too hot? How quickly does the fuel cell, which converts hydrogen into electricity, respond to changes? The EPTF can provide answers to these kinds of questions.

The test facility is a hall that can be opened on all sides. “There aren’t any solid walls, just sliding doors”, he says, “so there’s good ventilation, which reduces the explosion risk.” Additionally, it has everything that may be required for a test, such as hydrogen, oxygen, nitrogen and a reliable power supply.

From theory to practice

Organisations of all sizes, both Dutch and international, can contact NLR to use the EPTF. “We believe it’s important to provide opportunities not just for large companies, but also for start-ups and SMEs that want to test their technology. NLR offers technical expertise and helps make sure that the correct safety precautions and permits are in place.”

The first tests of 2026 at the EPTF are already scheduled. “For instance, once the permits and safety documentation are sorted, we’ll be carrying out testing with a bigger liquid hydrogen tank than the one we’ve been using so far”, Arendsen says. NLR is also already thinking one step further ahead. “We’re exploring the potential of superconductivity for aviation. Superconductivity eliminates a large proportion of the electrical resistance, allowing a lot of current to flow through a very thin wire. There are some materials in which superconductivity occurs below approximately –240 degrees Celsius, which means we can use the stored cold in liquid hydrogen as a coolant.” To that end, NLR is involved in a project under the national ‘Aviation in Transition’ programme. “Our role is to always stay one step ahead.”

Three shades of green

Arendsen believes that the impact will ultimately be felt in three areas. He calls it three shades of green. “The first is climate green. We need the facility if we want to be able to build the first aircraft with a more sustainable powertrain by 2035. That will let us achieve climate-neutral aviation on a large scale by 2050.” Moreover, it will bring economic benefits if the Netherlands and Europe take the lead in developing sustainable aircraft and airports. “Dollar green, in other words.” Finally, rapidly implementing the technology gives the Ministry of Defence a tactical advantage. “It makes sure that we are self-sufficient in terms of our energy supply, so that makes it military green.”

This new processor makes satellites more robust

A new type of microprocessor could make a big difference in the space sector. NLR is studying how using this RISC-V processor, also referred to as the brain of a device, can make space technology more reliable. To do so, it must be able to withstand high radiation levels to ensure a long service life.

Research into the RISC-V processor is part of Project TRISTAN, which falls under the European Chips Act. In this project, various countries are working to improve the ecosystem around the RISC-V processor family for a range of applications. The Dutch consortium is working on developing a RISC-V processor for space.

“This type of processor is based on an open standard, which means everything is traceable and you know exactly how the architecture works. That allows us to make modifications to improve robustness and safety, which is vital in space applications. Many off-the-shelf processors fall short in that regard”, says Sybren de Jong, Principal Space Avionics R&D Engineer at NLR.

Resistant to radiation

Not all processors are suitable for satellites. “In space, everything is exposed to a radiation environment that’s much more intense than on Earth, so the electronics must be able to withstand it”, De Jong explains.

Earth’s atmosphere and magnetosphere block most of the radiation, but that protection is absent in space. The Dutch company Technolution has developed a RISC-V processor for space and NLR is studying it to see if it is robust enough to withstand a high-radiation environment.

In space, there is a combination of ever-present weak background radiation plus periods when there are vast numbers of charged particles, originating from the sun, among other things. “We can protect electronics from low-level background radiation using a layer of aluminium, for example, but the high-energy particles can pass right through a satellite’s structure. This can cause a bit to flip, preventing it from functioning properly, or even causing a short circuit”, De Jong says.

PERIOD

2023 - 2026

PROJECT PARTNERS

An EU consortium, with a Dutch team comprising Technolution, Irdeto, University of Twente

Visit: tristan-project.eu

STRATEGIC THEME

Competitive aerospace

NLR KNOWLEDGE PROGRAMME

Space for defence and society

GOVERNMENT POLICY

Long-term Space Agenda

Thorough testing

NLR has built a prototype around the processor that includes all the necessary hardware and software. “This enabled us to test various versions of the RISC-V processor, running representative satellite workloads”, he continues. The tests took place at the Holland PTC research facility in Delft, where NLR’s electronics were exposed to proton radiation to assess their resilience.

In addition to the proton tests, the study also examined the effects of heavy-ion radiation. These tests were done at the CERN research institute in Switzerland. Satellites in space are exposed to both types of radiation. “Based on the results, we will assess what measures we can take to mitigate the negative effects”, De Jong says.

Reliable satellites

The application of RISC-V processors has significant implications. “It allows for reliable space technology and, consequently, extends the lifespan of satellites”, De Jong states. “This is crucial as we become increasingly dependent on space infrastructure. With longer-lasting satellites, we can reduce the frequency of launches, which in itself helps mitigate the environmental damage caused by satellites burning up in the atmosphere at the end of their life cycle. It’s essential that we prioritise developing technology that lasts longer.”

> *“High-energy particles can pass right through a satellite’s structure”*

Moreover, it contributes to European autonomy in space. “Developing this technology ourselves makes us less reliant on American companies.” As De Jong sees it, space has become the fourth domain of the Defence sector, alongside air, land and sea. “Better satellites can enhance our security. That is why we’re seeing that the Ministry of Defence is following these developments closely.”

NLR aims to become the Dutch centre of excellence for radiation effects. “There aren’t many organisations working on this and it’s an incredibly important aspect of space technology research”, according to De Jong. The Netherlands can play a major role in developing these new chips. “We’re already active in space technology in the Netherlands, and it would be beneficial to strengthen our ecosystem in this area, allowing us to maintain a competitive edge in Europe.”

Understanding human behaviour improves pilot training

New technology may be changing how we wage war, but human beings remain indispensable. As part of the COMO project, NLR is researching how to understand human behaviour better during training for pilots and air traffic controllers, for example. Incorporating factors such as stress into simulations teaches training programme participants to deal with complex situations more effectively. The result: safer and more effective missions.

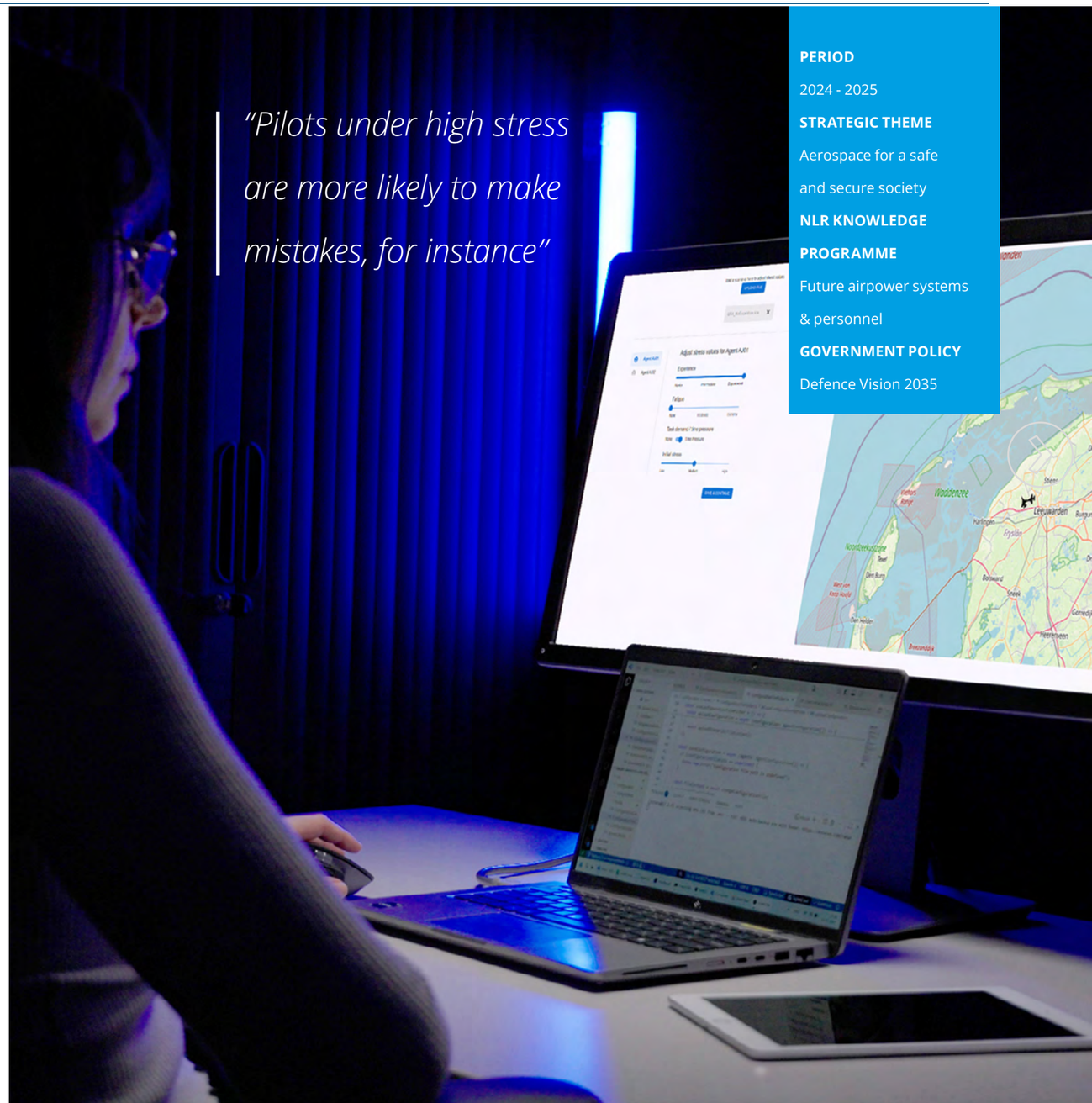
"With the advent of new technology in contemporary warfare, it is important to gain an understanding of human behaviour", says Emmy Gabriel, a training & simulation R&D engineer at NLR. "That's why we are also focusing more on the cognitive aspect in our training courses." We apply this approach to the training of various aviation professionals, from pilots to air traffic controllers.

Simulating stress

Simulations are playing an increasingly crucial role in training people because they are cheaper and more environmentally friendly than actual flights. "To enhance the effectiveness of training courses, we want to integrate the cognitive aspect into the simulators better", Gabriel says.

The researchers in the Cognitive Effects on Military Operations project (COMO) are focusing primarily on stress. Gabriel elaborates: What factors influence stress? How can we incorporate stress into the simulations used in the training sessions? "To answer these questions, our research combined literature reviews with experimental approaches."

It was quite a challenge, given that stress is not easily quantified in common variables. "How stress becomes manifest is very much dependent on the situation and the individual", Gabriel says. That is why several key factors that influence stress have been identified for this project. These include fatigue, experience in the field and time pressure. "Additionally, there's a baseline stress level to consider. "If you're already highly stressed before a mission begins, it can affect the outcome", she adds.



PERIOD

2024 - 2025

STRATEGIC THEME

Aerospace for a safe and secure society

NLR KNOWLEDGE PROGRAMME

Future airpower systems & personnel

GOVERNMENT POLICY

Defence Vision 2035

Demonstrator with a stress meter

A training simulation demonstrator has been built using this approach. It focuses on a specific situation: the quick reaction alert scenario, a common scenario within the Defence department. “There are two fighter aircraft on standby at all times in case anything happens”, she explains. “In this particular scenario, an unidentified aircraft enters the airspace. The fighters then have to scramble and investigate.”

While the simulated pilots carry out the operation in the simulator, their stress levels are displayed on a stress meter. The experience, fatigue and other variables can be set individually for both simulated pilots. “This combination of factors determines the level of stress they experience during the mission, and influence how they react to certain stressful simulations. Pilots under high stress are more likely to make mistakes, for instance”, Gabriel notes. Ultimately, the aim is to get more insight into fighter pilots’ cognitive processes, starting with a demonstrator and eventually using a fully operational simulator.

Processing information

On top of that, military pilots, aircrew and other personnel also need to learn to cope with the enormous flow of information generated by new technology. “Nowadays, pilots aren’t just flying the plane. They also have to process all sorts of information during the flight, such as data provided by drones after they’ve inspected a particular location. They have to make decisions quickly based on that information. These skills are becoming an ever more important aspect of a pilot’s training.”

And there are many more ways of improving the simulations. “By giving hostiles a cognitive dimension – human behaviour – in simulations, we can make them much more unpredictable. After all, in real life, you don’t know how well your opponent has slept or what stressful situations they’ve just experienced. That could increase the training value”, Gabriel comments.

More effective missions

The project aims to produce pilots who are better trained, can handle the technology effectively and are aware of the situation around them. “This will ultimately enable us to improve safety”, she says. “It will lead to safer operations in conflict situations, more effective missions and more effective use of resources.”

In November 2025, NLR presented a showcase to stakeholders, including the Ministry of Defence and research institutions, demonstrating the potential of the technology. “The findings are interesting to them as well, which is why we’re now exploring opportunities for collaborating on the next phase of this research”, Gabriel concludes.

Aviation through the eyes of society

Aviation connects the world together, making long-distance travel possible and bringing economic prosperity. But there is a downside too. Aircraft produce harmful emissions and cause noise pollution. As part of its ‘Impact on People and Society’ research programme, NLR investigates the effects aviation has on people.

“How does aviation technology affect people and what effects does it have on their lives? Those questions are what we aim to answer in this programme”, remarks Rui Roosien, head of the Impact on People and Society programme. This relates in particular to external aviation-related factors at the local level, such as environmental impacts, safety, air quality and noise pollution. “We are looking at the issues faced by people who work or live at or near an airport.”

Accessible for all

NLR carries out research on behalf of the government and for companies such as airlines, as well as conducting its own research to accumulate knowledge.
“We believe that we also have a social responsibility to fulfil, which is why we want to make our research findings accessible to everyone”, Roosien says. He likes to devote extra time and attention to this aspect.

Social debate

Roosien and his team strive to make research results accessible to a wider audience. He also aims to contribute to relevant topics in the public and political debate, as well as maintain an online presence to answer questions from the public. “I maintain contact with government departments, for example, as well as campaign groups. I put a lot of time into building relationships with them early on, so now they know exactly where to find us, for instance if they need clarification about specific data”, Roosien elaborates.

Through the programme, Roosien is working towards making a lasting difference in various aspects of society. To achieve this, NLR endeavours to provide people with access to truthful and nuanced information on a wide range of topics. “It’s an intangible kind of impact”, he remarks. Meanwhile, the focus of public debate shifts regularly and the focal points of the programme shift with it. “At times, the emphasis is stronger on climate issues, while at other times, environmental factors like noise pollution take centre stage.”

PERIOD

2022 - 2026

STRATEGIC THEME

Sustainable aerospace

NLR KNOWLEDGE PROGRAMME

Impact on people and society

GOVERNMENT POLICY

Aviation Research Agenda

"We have no vested interest in any particular outcome"

From fundamental to practical

NLR always conducts its research independently, focusing on achieving objective results. "We have no vested interest in any particular outcome, which makes our position in the sector unique", Roosien says. In some cases, this involves applied research that can be put into practice quickly, while at other times it's about acquiring new and fundamental knowledge.

"Practical studies may for instance include noise measurements to see if certain new aircraft are genuinely quieter, as the manufacturer claims, when local residents are questioning those claims. In this particular example, the measurements showed that the aircraft were indeed quieter as a whole, but that there was actually more noise in certain situations. Moreover, specific tonal differences in the sounds can be perceived as irritating. Insights like these can shift a debate from a simple binary discussion to a more informed dialogue about potential improvements."

More fundamental knowledge is being obtained through other paths too, such as a European research programme. "For instance, we looked at the impact of completely new aircraft designs on an airport", he says. "The implementation may still be a long way off, but it's important to make a start right now on gathering knowledge about the new aircraft and all the processes involved."

Feeling more connected

The aviation sector is currently facing a range of social challenges, but according to Roosien, the biggest question is: "How can we keep the Netherlands connected?" This is not just about social cohesion between people, which acts as a counterweight to polarisation, but also about connectivity in the literal sense, through Schiphol in particular.

"You want to protect the environment and give people a pleasant living environment. But at the same time, you want to maintain economic vitality, and aviation – with Schiphol as a key hub – plays a vital role in that regard. Not only for the aviation sector itself, but also for related sectors that depend on international collaboration", Roosien notes.

These two aspects are often at odds with one another. "The debate about whether there should be more or less aviation is very black and white right now, but I'd like to work towards a system in which we use aviation more selectively. Figuring out exactly how we prioritise things is still a complex issue that needs further exploration. Personally, I hope that I'll be able to hop on a plane again in future without feeling self-conscious."

Aircraft maintenance gets a digital upgrade

Digitalising aircraft maintenance processes is a significant step towards future-proofing the aerospace industry. In the NXTGEN HighTech project, NLR and SPECTO Aerospace developed a data-driven approach that automatically records aircraft damage using image recognition and smart algorithms. This digital approach enables the aviation industry to save time and money, and make recurring issues more apparent.

Hailstorms, bird collisions, lightning strikes and even minor parking accidents are common causes of aircraft damage. The current damage inspection process is manual and labour-intensive: an expert inspects the surface and marks any damaged areas with a pen or stickers. The specialist then draws up a repair plan, which is in turn used for preparing a quote that sets out the estimated repair costs.

In NXTGEN HighTech, experts have been looking for a way to digitalise this process within a 3D environment. As part of this project, NLR worked with SPECTO Aerospace, a highly technical, specialist repair company. The company has workshops at Lelystad Airport and Woensdrecht Airbase, where they repair aircraft and helicopter components ranging from the nose cones on private planes to the large control surfaces on big commercial aircraft.

"We helped SPECTO in exploring various techniques for digitalising their repair processes efficiently and effectively, aligning with their proprietary systems," says Julian de Marchi, a project manager and high-tech product developer at NLR.

The impact of going digital

Digitalising maintenance goes beyond simply saving time. Repairs can no longer get lost in the archives – and digitally documenting the damage makes recurring patterns easier to identify than before. "Does a particular type of aircraft often suffer damage? Or does flying in desert regions cause specific wear and tear? New techniques allow us to answer those questions better. These kinds of insights are valuable to aircraft manufacturers, and SPECTO takes an active role in this through its approach."

PERIOD

2022 - 2025

PROJECT PARTNERS

SPECTO Aerospace

STRATEGIC THEME

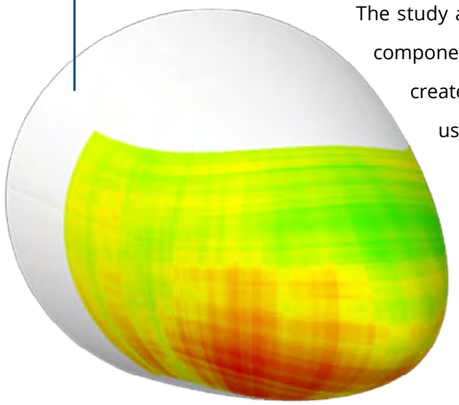
Aerospace for a safe and secure society

NLR KNOWLEDGE PROGRAMME

Future airpower systems & personnel

GOVERNMENT POLICY

Aviation Research Agenda



3D animation showing damage to an aircraft nose cone

The project also offers a solution for the tight labour market. Where previously years of experience were needed to assess damage accurately, a junior staff member can now carry out the inspection using digital tools. An expert is only needed to review the results.

> *"Cameras capture images of the damage to an aircraft component"*

Cameras and smart algorithms

Various conceptual ideas were developed and explored as part of the project. The team studied automatic damage detection and how it might work for SPECTO's customers. De Marchi explains the process: "Cameras capture images of the damage to an aircraft component. Smart algorithms subsequently analyse the images and automatically assess the extent of the damage, followed by validation from a specialist. All the information is then presented clearly in a web portal, where the customer can view the details for each outsourced aircraft component. This includes things like links to maintenance data, material consumption, tooling used and/or man-hours. Aside from that, the repair process itself is also easier to track."

The study also investigated whether it is possible to do a walk-round of an aircraft component that needs repairing, using a standard smartphone to automatically create a 3D model of the damage with sufficient accuracy. "We've tested this and used a working demonstrator to show that it is indeed possible."

Future plans

The project is now completed. De Marchi is satisfied with the final results. "We've shown that these applications are technically feasible. SPECTO has already started integrating the new techniques and methods into its repair processes."

PERIOD

2024 - 2026

PROJECT PARTNERS

MTU (project lead), MT aerospace, Collins, Nord-Micro, EATON, Lufthansa Technik, TU Wien, University of Naples

STRATEGIC THEME

Sustainable aerospace

NLR KNOWLEDGE PROGRAMME

Climate-neutral aviation

GOVERNMENT POLICY

IKIA for Climate and Energy

Zero-emission aviation using liquid hydrogen

As part of its drive towards zero-emission aviation, NLR is developing a hydrogen-electric propulsion system for an aircraft. The system comprises a hydrogen tank in the tail of the aircraft, fuel cells that generate 1.2 megawatts of power, a cooling system beneath the wings featuring four heat exchangers, plus a newly designed propeller. The project is also assessing the climate and environmental impacts of hydrogen-powered aircraft.

NLR is working on virtually emission-free aviation powered by hydrogen as part of the EU-funded HEROPS research project (standing for Hydrogen-Electric Zero-Emission Propulsion System). NLR and its partners are developing the components of the entire propulsion system, from the fuel tank to the propeller. The individual components have all been designed and will be tested in 2026. The results will pave the way for a test flight in a future project.

Completely green

“There are two ways to make an aircraft fly on hydrogen”, says Thomas Dumoulin, R&D engineer and project coordinator for NLR within HEROPS. “One way is by burning gaseous hydrogen in a gas turbine.” This is comparable to burning kerosene in a conventional aircraft engine. The advantage of this method is that very little needs to be changed in the aircraft’s existing propulsion system. “The drawback, however, is that burning hydrogen produces nitrogen oxides as a by-product.”

The other approach uses a chemical process in which a fuel cell combines hydrogen with oxygen from the air and converts it into electricity. That in turn powers an electric motor, which drives a propeller. Dumoulin explains that this process only produces water vapour, making the propulsion system almost climate-neutral. “At high altitudes, water vapour does have a greenhouse effect, but the climate impact is many times smaller than the effect of the nitrogen oxides generated when hydrogen is combusted.”

Tank in the tail

“The challenge is making sure the temperature of the hydrogen remains low enough: –253 degrees Celsius, about twenty degrees above absolute zero.” A vacuum-insulated tank therefore had to be developed for storing liquid hydrogen. It is a double-walled tank in which the air between the outer and inner tanks has been completely evacuated. This means that there is virtually no heat transfer, according to Dumoulin.

Hydrogen's lower energy density compared to kerosene means it requires a much larger volume to store the same amount of energy. As a result, finding a suitable location for the tank was a key part of the research. In the wings – where the existing kerosene tanks are currently located – was not an option. "So far, it seems that the best solution is to place a cylindrical tank in the aircraft's tail", Dumoulin states.

Dripper system

In Dumoulin's opinion, the biggest challenge was the heat exchanger. "We're generating 1.2 megawatts of electricity, which produces a large amount of heat that needs to be dissipated." The heat output is highest during take-off. "On the ground, the air is warm and the aircraft is at full throttle. Because the aircraft hasn't picked up speed yet, there is no incoming airflow to cool the engine. That is why take-off is the most critical phase for the cooling system. Once airborne, the throttle can be reduced, less heat is generated and there is plenty of cold air flowing past, which makes the cooling process easier." But an aircraft must be able to take off anywhere in the world, Dumoulin remarks, "even in the Sahara".

NLR developed a dripper system for the heat exchanger to address this issue. "The system nebulises a small amount of water into the heat exchanger's air intake. That cools the air, which increases the heat exchanger's cooling capacity."

Multifaceted

Additionally, Dumoulin's team is examining the climate and environmental impacts of hydrogen-powered aircraft. "The propellers make a different kind of noise, so we're going to perform acoustic tests." Maintenance is also still a topic of research, Dumoulin says. "How long will it last? What are the long-term costs?" Another crucial aspect is the certification of the system. "Current regulatory requirements for aircraft are based on traditional kerosene-powered flight. We are looking into further specifications that need to be added."

Since it involves the entire fuel system, it's essential to ensure that all components are properly aligned with each other, making it a multifaceted project. That cross-disciplinary nature is what makes the project particularly special for Dumoulin. "We're really at the pioneering stage of flying on liquid hydrogen – it's still uncharted territory. We need to collaborate with many different disciplines to make this a reality."

> *"The hydrogen has to be kept at -253 degrees Celsius"*

PERIOD
2025
STRATEGIC THEME
Sustainable aerospace
NLR KNOWLEDGE PROGRAMME
Climate-neutral aviation
GOVERNMENT POLICY
IKIA for Climate and Energy, Aviation Research Agenda

Smart SAF use to reduce global warming

By 2030, six per cent of all aviation fuel in Europe must be sustainable. How can we ensure that the limited supply of sustainable fuel yields the maximum climate benefits? In the SIONIE project, NLR investigated how SAF can be used strategically, for example on flights where contrails are most likely to form. The project bridges the gap between climate modelling and day-to-day flight operations.

Sustainable aviation fuel (SAF) is a renewable alternative to fossil-based kerosene. It is produced from raw materials such as used cooking oil, waste and biomass. SAF reduces the environmental impact of flying in several ways.

David Engler Faleiros, an R&D engineer at NLR, explains: "Using sustainable fuel reduces CO_2 emissions throughout the entire production chain, and minimises the climate impact of contrails, condensation trails that form in the air. This in turn reduces atmospheric warming."

Looking ahead to 2030

By 2030, six per cent of all fuel used on flights departing from European Union countries must be sustainable. This means that six percent SAF is blended into the kerosene. That percentage will increase to 70% by 2050. This European mandate raises an important question: where will this limited amount of SAF have the greatest climate impact?

In the SIONIE project, which was part of NLR's Climate-Neutral Aviation programme, NLR studied the best way of utilising SAF to achieve the greatest climate benefits by 2030, Faleiros says. "The climate impact of contrails, for example, isn't the same everywhere at all times. For some flights, for instance at night, the effect may be greater than others."

An NLR climate model

The researchers used existing data from previous ground-based measurements and flight data, such as data on soot particles that influence how ice crystals form in contrails. They identified correlations between SAF use, soot particles and ice crystals, which they then fed into an NLR model. This allowed them to clearly determine the climate impact of SAF.

Allocating SAF to particular flights

In theory, you could allocate SAF to specific flights that cause the most warming, but all the fuel at airports is blended together in large storage tanks. "So it would be very difficult for an airport or airline to make sure that flight A should get 10 per cent SAF whereas flight B only gets 5 per cent", Faleiros elaborates. The project therefore looked at broader patterns in air traffic, such as prioritising winter flights, as they are more likely to cause warming contrails. Or using SAF for specific airports or routes.

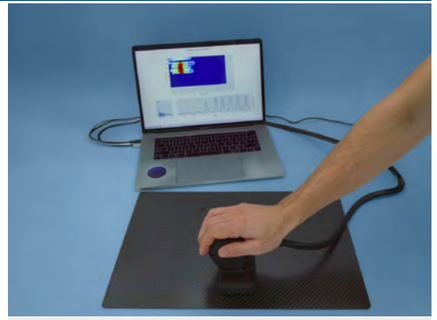
These strategies yield fewer benefits for the climate than targeting specific flights, but they still reduce the overall climate impact. "Many of the strategies we investigated result in a reduction of one to two per cent", Faleiros continues, "which may not sound like much, but in the aviation sector it is significant."

> *"The project bridges the gap between climate modelling and daily operations"*

Another advantage is that these insights can be applied directly within the existing infrastructure and are therefore immediately useful. "The project bridges the gap between climate modelling and daily operations", he adds.

A starting point for policymakers

Faleiros believes that this research could provide a valuable foundation for policymakers. "It shows which strategies are operationally feasible. It's knowledge that could inform more effective policymaking in future, and help the aviation sector become more sustainable, step by step."

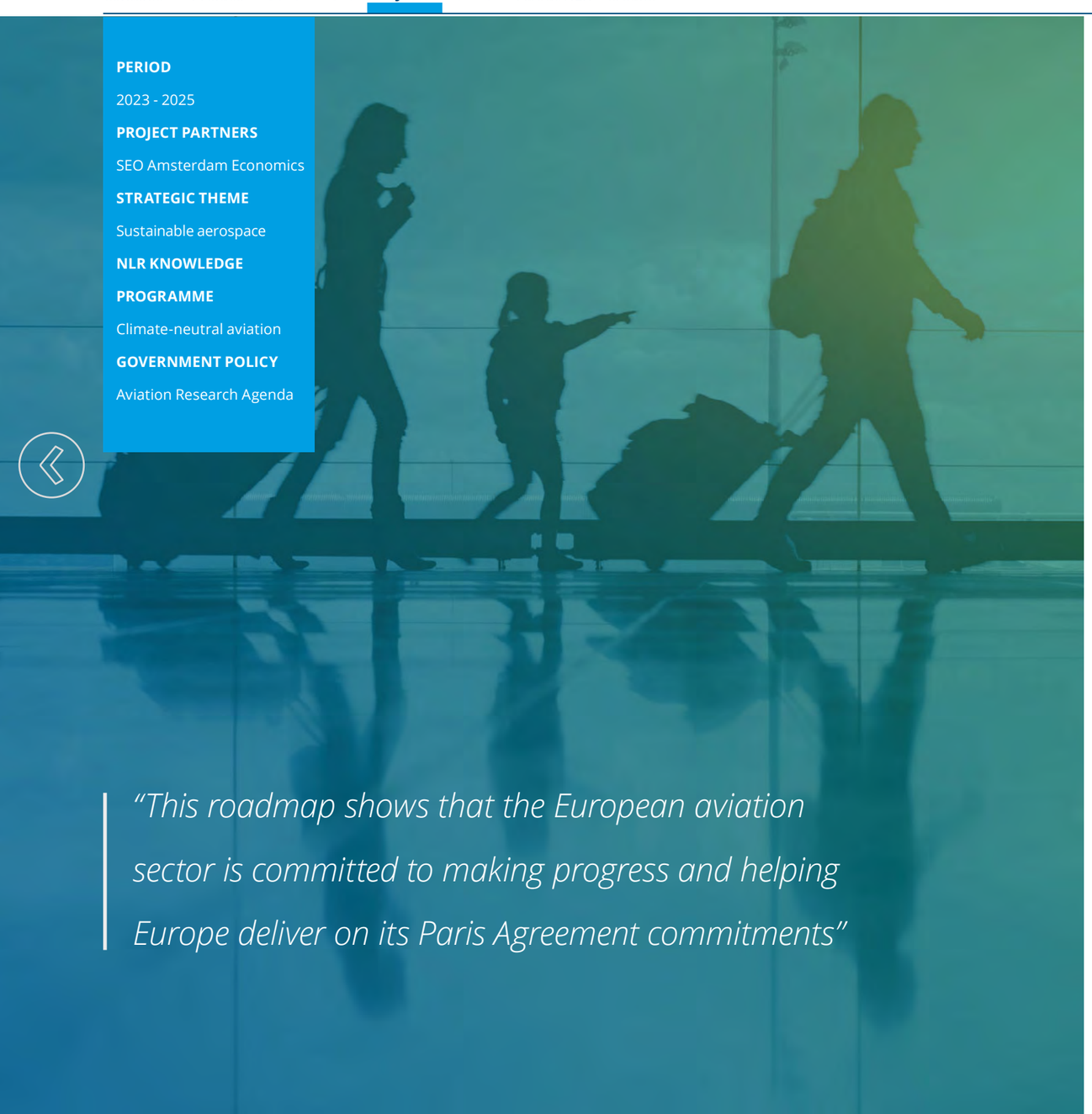


TESTIMONIAL FROM THE STARTUP PROGRAMME

Eddytec is an innovative startup tackling the often time-consuming, complex and expensive process of testing carbon composites. The company uses its technology to make this process faster, more efficient, and better integrated. With support from NLR, the startup is taking important steps towards technical validation and market application.

> *"NLR provided us with valuable expertise on testing processes, documentation, and certification. This knowledge is essential for us to understand how the sector works and what is needed to ultimately achieve certification", says Dr Alina Chanaewa, CEO and founder of Eddytec.*

read more →



PERIOD

2023 - 2025

PROJECT PARTNERS

SEO Amsterdam Economics

STRATEGIC THEME

Sustainable aerospace

NLR KNOWLEDGE PROGRAMME

Climate-neutral aviation

GOVERNMENT POLICY

Aviation Research Agenda

"This roadmap shows that the European aviation sector is committed to making progress and helping Europe deliver on its Paris Agreement commitments"

CO_2-neutral aviation: SAF seems indispensable

Carbon-neutral flying by 2050: how can we achieve it? NLR has created a roadmap for the European aviation sector to work towards this goal step by step. Sustainable fuels seem to be crucial for flying with lower CO_2 emissions. The key message from the report is that we have no time to lose.

"We have drawn up a roadmap for achieving carbon-neutral aviation by 2050. It's a strategy the sector can adhere to, underpinned by data and analyses", says Elisabeth van der Sman, consultant and team leader for sustainable aviation at NLR. European aviation industry associations – including those representing airports, airlines, the manufacturing sector and air traffic controllers – jointly approached NLR and SEO Amsterdam Economics to develop the roadmap. "We work independently and use scientific knowledge to provide an objective overview. This roadmap will let each party move forward in its own way."

New aircraft

The roadmap, called Destination 2050, sets out specific measures that need to be taken to achieve CO_2-neutral aviation within 25 years. The report addresses three technological cornerstones. The first is the technology used in aircraft and engines. NLR has investigated which aircraft can be replaced in the short term and what new aircraft are anticipated in the longer term. New and more fuel-efficient aircraft are expected to enter the market from 2035 onwards.

Efficient operations and sustainable fuels

The second cornerstone concerns air traffic management and operations. "The focus here has predominantly been on reducing CO_2 emissions through improved airspace efficiency management, for example by adjusting flight paths", Van der Sman explains. The final cornerstone centres around alternative fuels. This covers the use of sustainable fuels, such as sustainable aviation fuel (SAF), as well as the potential of hydrogen as an energy carrier in aviation.

"SAF is one of the most promising solutions available at the moment, but further development is needed before it can be implemented on a large scale." Van der Sman points out that only a few factories are currently producing SAF, for example. "It often involves

a production process that produces kerosene from used cooking oil or other waste streams. And those are only available in limited quantities, of course, so we need to look at other forms of sustainable fuel as well."

According to Van der Sman, the ReFuelEU Aviation mandate on using sustainable fuels is essential to achieving these goals. It has now been stated that 70% of aviation fuel must be SAF by 2050. A further 10% needs to be added to this to meet the Destination 2050 targets. "If fuel consumption increases, production capacity needs to be scaled up too. Ultimately, producing sustainable fuels – including synthetic aviation fuel – on a large scale will require substantial amounts of renewable electricity. To achieve that, the aviation sector will have to collaborate with the energy sector."

Economic aspects

In addition to technology, the roadmap also addresses the economic implications. NLR partnered with research agency SEO for this aspect. "They've developed a model that can quantify both the benefits and costs of the proposed measures." Van der Sman uses sustainable fuels as an example: "Sustainable fuel is likely to remain more expensive than conventional fossil kerosene, which will inevitably drive up the cost of flights."

"Now or never"

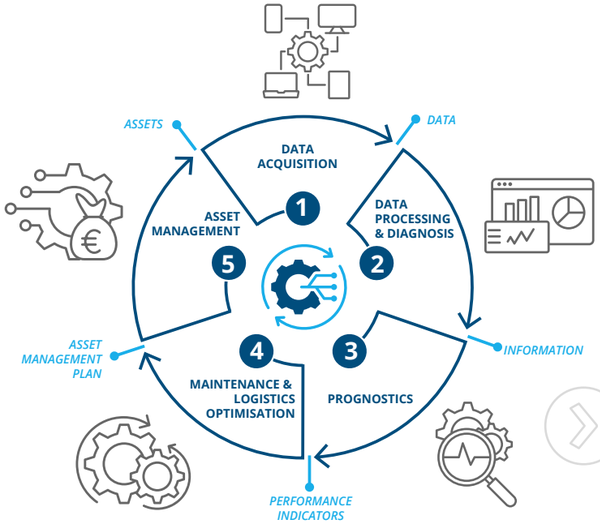
This plan is consistent with a CO_2 budget for 1.7 degrees of global warming and is therefore aligned with the Paris Agreement's objective of keeping global warming well below 2 degrees. "Action is needed quickly, however", Van der Sman states. "It's now or never. If we don't make progress over the next few years, we will have emitted so much carbon dioxide in the meantime that it will be extremely challenging to stay within the carbon budget and still meet the set targets."

The roadmap was finalised and published in 2025. This version is an update of an earlier roadmap published in 2021. "Developments are progressing rapidly. That is why we've reviewed the previous plan to see what is still feasible", Van der Sman says. This covered not only the technical viability of innovations but also external factors such as policy changes.

And the biggest change? "Hydrogen is now playing less of a role in making aviation more sustainable. Progress has been slower than we anticipated in the first version of the roadmap." She emphasises that this means SAF has become a more critical cornerstone. Moreover, the updated report also outlines strategies for tackling non-CO_2-impacts of aviation, such as contrails and nitrogen oxides.

Aircraft maintenance at the right time

How do you know exactly when an aircraft requires maintenance? In the NWO (Netherlands Organisation for Scientific Research) project PrimaVera, NLR worked with universities and companies on predictive maintenance. Sensors and data analysis enable better predictions of damage to aircraft structures, leading to lower costs.



At present, companies still plan their maintenance schedules using a fixed timetable. "In aviation, for instance, an aircraft component is typically inspected every 500 flying hours", NLR's project leader, Frank Grooteman says. However, sensors and models can provide more accurate predictions of how damage evolves and how much longer a structure will last. "By leveraging smart technology, you can carry out maintenance exactly when it's needed." This results in reduced downtime for aircraft and cost savings.

In PrimaVera, several PhD students from Radboud University, Eindhoven University of Technology and the University of Twente worked on developing algorithms for predictive maintenance. NLR helped in advancing this technology and preparing it for practical application.

Lifespan and impact damage

Using sensors that measure load fluctuations, combined with data analysis, allows various parameters to be calculated. Firstly: how much of a component's service lifespan has already been 'used up', which is particularly relevant for metal components. Additionally, these sensors can detect impact damage, such as in a hailstorm or a collision with a luggage cart. "The signals transmitted by the sensors let us pinpoint the location of the impact and determine the energy involved. That's important because aircraft structures can withstand a certain amount of energy without sustaining damage.

PERIOD

2020 - 2025

PROJECT PARTNERS

View all partners on:

primavera-project.com/project-partners

STRATEGIC THEME

Competitive aerospace

NLR KNOWLEDGE PROGRAMME

Operational availability of materiel

GOVERNMENT POLICY

Aviation Research Agenda

If the impact is more severe, we know that an inspection is necessary and where it needs to be carried out", Grooteman explains. Many modern aircraft are made largely of composite materials. They are lightweight and strong, but also prone to impacts. The problem is that damage to these materials can be very difficult to detect visually. "Some damage is barely visible to the naked eye on the outside, but we can locate them using sensors", Grooteman adds.

Experimenting with materials

As part of the project, NLR and the University of Twente conducted a series of tests on composite components. To that end, several experiments were carried out: sensors were attached to the materials, which were then subjected to controlled impacts. The data collected was subsequently used to develop a model for predicting impact energy.

A toolbox for companies

In addition, a platform was developed, enabling participating companies to create their own custom maintenance tools. It also includes the algorithms created by the PhD students. "Think of it as a set of building blocks that companies can use to build their own systems", Grooteman remarks.

Collecting data is a challenge

One of the major challenges in predictive maintenance is collecting the necessary data. That information is often scattered across various parties: manufacturers (OEMs) prefer to have full access, while operators are sometimes unable or not permitted to share everything. This includes various data types: design details, test results for the original components, operational data and repair histories. For reliable predictions, all these data sources have to be combined. Bringing all this information together is therefore the biggest challenge for practical applications of predictive maintenance.

The first steps have been taken in the PrimaVera project and valuable data has been gathered. According to Grooteman, though, it will be several years before systems like these are widely adopted, as even more data is needed. "Companies really should start working on this now. Once all the data has finally been integrated, the maintenance process will become much more efficient."

INTERVIEW

Smart adaptive antennas for safe and more sustainable aviation

As a teenager, Jaco Verpoorte regularly visited the electronics shop where his mother worked. This is where he saw a radio amateur using his equipment to communicate over long distances without the need for wires for the first time. "These were the seventies. The Internet did not yet exist, wireless communication was in its infancy. I thought it was fantastic!"

The interest endures. He even set up his own radio station from his attic and enrolled in the Electrical Engineering course, specialising in telecommunications and EMC (electromagnetic compatibility) at Eindhoven University of Technology. Jaco completed his graduate internship at Fokker Aircraft, where he discovered that his interests in electromagnetic waves and aviation proved to be a fascinating combination.

He used to mix his own music and send it out into the ether, now he leads the electromagnetic technology group at NLR as principal engineer.

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Open-source AI models improve flight safety

AI models can make aviation safer by providing rapid and accurate incident analyses and through training for air traffic controllers. In collaboration with Air Traffic Control Netherlands (LVNL) and students from Delft University of Technology (TU Delft), R&D engineers from NLR explored how open-source AI models can be trained for air traffic communications. Their focus was on achieving this quickly and easily using the minimum amount of data.

“We set out to investigate whether we could adapt an open-source model to suit air traffic communications, using as little data as possible”, says Vincent de Vries, an R&D engineer for flight operations at NLR. “Generating data is labour-intensive, which makes it expensive to develop a model. We wondered whether we could use an open-source AI model instead. We asked ourselves: what if we could use an open-source AI model instead? Could we train a model to communicate in the unique way that’s characteristic of this niche market?”

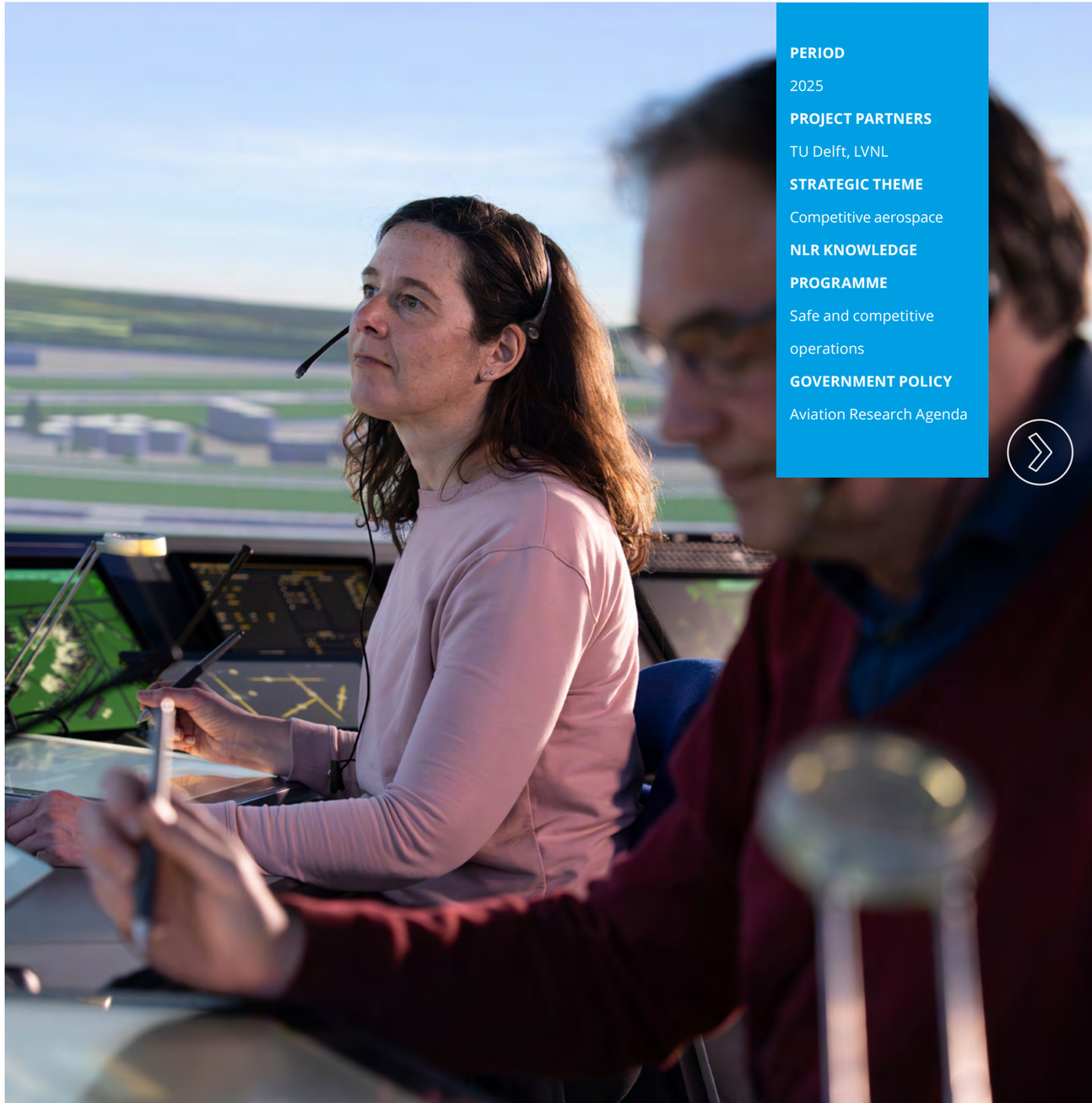
Specific communication

A blog post about a new open-source speech model that had been trained on thousands of hours of publicly available data got De Vries and his colleagues thinking. Could that model also be effective for communication that requires the same level of precision as that between air traffic control and pilots?

“Air traffic communications involve very specific terminology and abbreviations, and even the sentence structure is different. While open models perform well with everyday language, the probability of errors increases as the language becomes more technical.

Incident analyses

The open-source model was trained further using voice recordings provided by LVNL, partly to enable incidents to be analysed more quickly and accurately. A report is always filed after an incident occurs in airspace, De Vries explains. As part of the process, speech is transcribed manually into text, which is a rather specialised and time-consuming process. “If that process can be automated, we’ve already taken a first step towards greater efficiency.”



PERIOD
2025
PROJECT PARTNERS
TU Delft, LVNL
STRATEGIC THEME
Competitive aerospace
NLR KNOWLEDGE PROGRAMME
Safe and competitive operations
GOVERNMENT POLICY
Aviation Research Agenda

Converting voice messages to text automatically also generates a larger volume of data that can be used to refine existing safety indicators. “More information about what was said by whom and when means that incidents can be interpreted more accurately. The system can then scan the text for incident-related elements and extract the key information. A subsequent application could be a second algorithm that automatically identifies hazards. Although this algorithm may be predictive in future, its current primary function is reactive, such as analysing and identifying contradictory statements during operations.”

Training courses

Another application: using data from voice messages to train air traffic controllers. Various scenarios are simulated during these training sessions and the air traffic controller speaks to a pseudo-pilot – someone sitting at the other end of the line who is pretending to fly.

“It’s difficult to find pseudo-pilots for the training sessions, as they often have jobs as pilots, accumulating actual flight hours. Successfully applying techniques like these may well let the pseudo-pilots work more efficiently in the future. If all the air traffic controller’s spoken communications are converted straight into text, an algorithm can interpret them. Another algorithm can in turn display the actions required in the simulation aircraft on the pseudo-pilot’s radar screen, for instance. This allows the pseudo-pilots to work more efficiently, so fewer are needed.”

The students at TU Delft played a significant role in refining the model. They did a great deal of the practical work such as collecting data, as well as fine-tuning and testing the various models.

Flawless

De Vries was surprised at how well the model recognised the aviation-specific abbreviations and applied them correctly in the text. The model transcribed the NATO alphabet flawlessly – Alfa for A, Bravo for B and so on. The aircraft names and runway designations were also spelled correctly. “It’s great to see that even knowledge of a niche application like aviation is already built into this kind of model.”

On board

The project received a great deal of positive feedback at the innovation day organised in October 2025 by NLR’s Safe and Competitive Operations knowledge programme. Stakeholders from organisations including the Ministry of Infrastructure and Water Management and LVNL provided input and came up with out-of-the-box applications within their own organisations, De Vries says. “We’re also investigating and using this type of speech-to-text model at NLR in other areas, such as for military applications within the Sentinel project.”

What is on the agenda for the near future? “We plan to conduct further research and testing to see how this type of model could be useful on board our research aircraft. This approach can also help us assist the pilots and technical staff on board.”

> *“This allows pseudo-pilots to work more efficiently, so fewer are needed”*

Improving flight safety

NLR contributes to improving flight safety. It conducts research and helps the aviation industry to maintain control of and understand the processes that can affect flight safety. This includes using NLR to investigate the cause of accidents.

Gerard van Es is principal consultant flight operations and flight safety at NLR. “Major aircraft accidents are exceptions, but they have a huge impact and stay with you all your life.” His career is mainly dedicated to preventing such accidents. “Here, we work every day on improving flight safety. We do this by increasing knowledge of the conditions in which aircraft fly through research and innovations. Safety is paramount in aviation. In fact, it is one of the safest forms of transport.”

read more →

Managing risks: ALBATROS is future-proofing aviation

Aviation is on the brink of major changes. New types of aircraft powered by electricity or hydrogen hold the promise of cleaner flight. They also introduce new risks, however. How would you handle a hydrogen leak at an airport, for example? As part of the European research project ALBATROS, NLR is collaborating with twenty partners from various countries to find answers to these kinds of questions. The goal is to have all the necessary procedures in place, alongside the new technologies.

With NLR in the lead, the ALBATROS project is investigating how airport operations can be made safer, more resilient and more sustainable in the future. “New technologies, such as hydrogen-powered and electric aircraft, demand a different approach to safety”, project coordinator, Wouter van Engelen says. “We want to avoid situations where the technology is ready but the procedures and safety precautions are still lagging behind.”

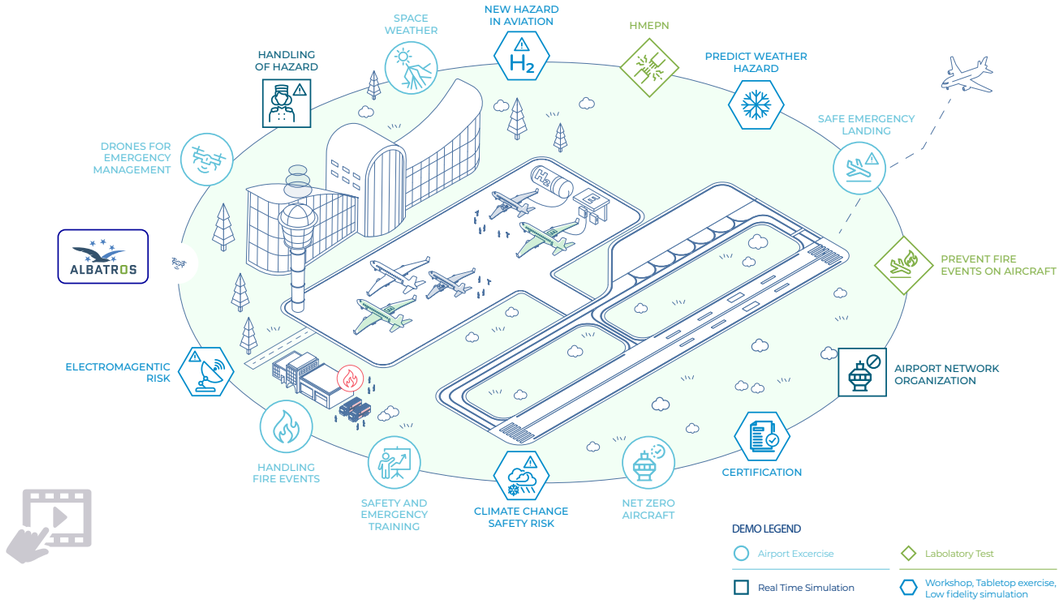
The project, which is funded by Horizon Europe, is focusing on various developments that could radically transform aviation in the next few years. As well as new aircraft technologies, these also include extreme weather – which is becoming more common due to climate change – and digital threats such as cyberattacks, for instance.

“All these factors affect airport safety”, according to Van Engelen. “We’re looking at the entire chain, from pilots and cabin crew to air traffic control and ground-based emergency services.”

ALBATROS is not just studying the technology but also human performance, decision-making and training. The project involves developing data-driven safety models, decision-support tools and training materials to make sure that innovations are not only technically sound but also operationally applicable in real-world settings.

Fifteen demonstrations

Fifteen demonstrations will be carried out as part of the project to validate concepts, technologies and supporting tools in relevant environments across Europe, such as airports, flight simulators and crisis control centres in Portugal, Greece, the Netherlands and elsewhere. Additionally, the project will involve testing at other locations, including experiments with battery packs for electric aircraft.



> *“We’re looking at the entire chain”*

By conducting exercises at multiple sites, researchers can verify whether the developed procedures work in different types of airports, rather than only in one specific environment.

“This will make it possible to implement the results more widely across the European aviation sector later on”, Van Engelen comments.

Demonstration at Rotterdam The Hague Airport

A noteworthy demonstration took place at Rotterdam The Hague Airport in late 2025. As part of a large-scale safety exercise, an emergency scenario was simulated involving an Airbus A320neo operated by Aegean Airlines. The aircraft was used to mimic a fictitious hydrogen-powered aeroplane with a leak in its fuel system. That’s a problem because it poses a fire hazard.

At the forefront of innovations in aviation

After completing her studies in mechanical engineering at the University of Twente, Kylie Knepper immediately started working at NLR, in the Vertical Flight and Aeroacoustics department. This was over ten years ago, and she still learns something new every day.

As an R&D Engineer in aeroacoustics, Kylie is right at the forefront of important innovations in aviation. Aerodynamics and acoustics are closely linked; improving aerodynamics is an effective way to reduce noise from aircraft. "To limit the noise of an aircraft as much as possible, we look at how to make the airflow around the aircraft as efficient as possible", Kylie says. Improvements to aircraft, such as enhancing aerodynamics and reducing weight, contribute to both more sustainable and economically efficient aviation. "For example, consuming less fuel will contribute to reducing both the cost and environmental impact of flights."

read more →

Air traffic control issued an emergency alert, prompting the airport fire brigade to respond. At the same time, an NLR drone took to the air to monitor the incident. The team was able to use a thermal camera mounted on the drone to see where heat was building up at the rear of the aircraft.

"The unusual thing about hydrogen is that the flame is barely visible", Van Engelen explains. "With a traditional fire, you can feel the heat and see the smoke. With hydrogen, the situation is much less obvious. That is why sensors and drones with thermal cameras are crucial for quickly understanding what's happening." The drone feed was shared in real time with the emergency services on the ground, helping them prepare properly for the situation.

The project's results should ultimately ensure that airports, airlines, emergency services and other stakeholders are better prepared for new risks. That is how ALBATROS is helping to link the introduction of new technologies, such as electric and hydrogen-powered flight, to practical procedures, training and collaboration.

PERIOD	2022 - 2026
PROJECT PARTNERS	View all partners on: albatros-horizon.eu
STRATEGIC THEME	Competitive aerospace
NLR KNOWLEDGE PROGRAMME	Unmanned and autonomous
GOVERNMENT POLICY	Aviation Research Agenda, IKIA for Climate and Energy

Using data to put the best team together

Drone operators are faced with a substantial volume of complex information every day, both from the drones themselves and from their surroundings. They need to make the right decisions quickly, based on the information available. But how do they do that? How can they use technology to optimise their performance? NLR is investigating this, together with the Dutch Ministry of Defence, as part of the Team Metrics project.

"While technology offers many possibilities, people need to be able to use them effectively", says Maykel van Miltenburg, a senior scientist in the Human Performance and Safety department at NLR. NLR is working with TNO and the Air Force Research Laboratory (AFRL) in a project called Team Metrics to investigate how smart use of technology can improve human performance. "We need to achieve more with fewer people, so we must optimise our processes", Van Miltenburg continues. "The Ministry of Defence wants to make personnel deployment in the field more flexible and robust by doing so."

This will, for example, let a commander make a more informed judgement beforehand of how ready a team is for a particular operation, according to Van Miltenburg. "Are the team up for it, or is anyone too fatigued? It also provides insights during the operation itself. In the end, it's about combining technology and people in a way that enables teams to keep operating effectively and safely under a variety of circumstances."

Mental state

One part of the research centres on a semi-realistic simulation where multiple drones operate simultaneously. In this simulation, a navigator and a pilot-operator, for example, work closely together. Throughout the process, they are equipped with various measuring instruments that continuously and automatically generate objective data. This data yields valuable information about the mental states of the operators. Van Miltenburg is the project leader for this simulation.

As the flow of information increases or decreases, researchers analyse brain activity, heart rate, eye movements, sweat response and other parameters, as well as facial expressions and intonation. The research team correlates this data to performance metrics, providing an understanding of both individual workloads and team dynamics, such as how team members respond to relevant information and how it impacts their cooperation. "We provide insights into what team

configuration works well in a given environment for a specific task", Van Miltenburg explains. "That used to be based largely on experience, but we can now justify it more objectively using technology."

Array of measurements

The study generated a vast amount of data. The intention is not to use the full array of measuring equipment in practice, Van Miltenburg remarks. "We're refining the monitoring equipment down to a minimum, so it can be used continuously in the field, allowing reactions and performance to be measured as unobtrusively as possible", he adds.

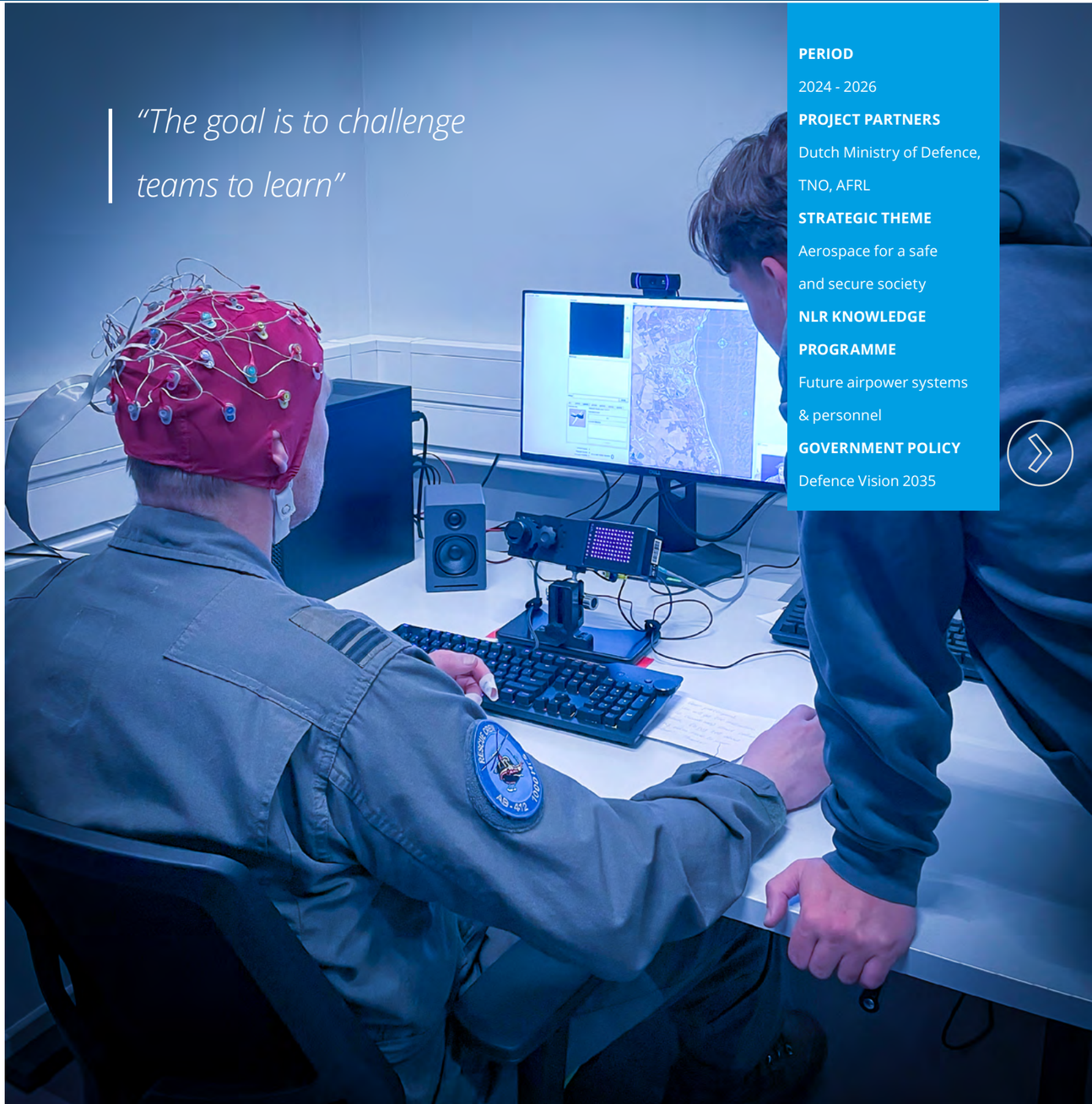
Challenging versus overwhelming

The final dataset has broader applications beyond just team composition. The data can also be used when training new operators. Instructors can, for example, use this information as a tool to help them identify when the workload is becoming too much for a trainee, Van Miltenburg says. This enables instructors to intervene at the right time and tailor the training to meet the needs of both individual trainees and the team as a whole. "The goal is to challenge teams to learn without overwhelming them. As a result, teams can learn more quickly, in a sense."

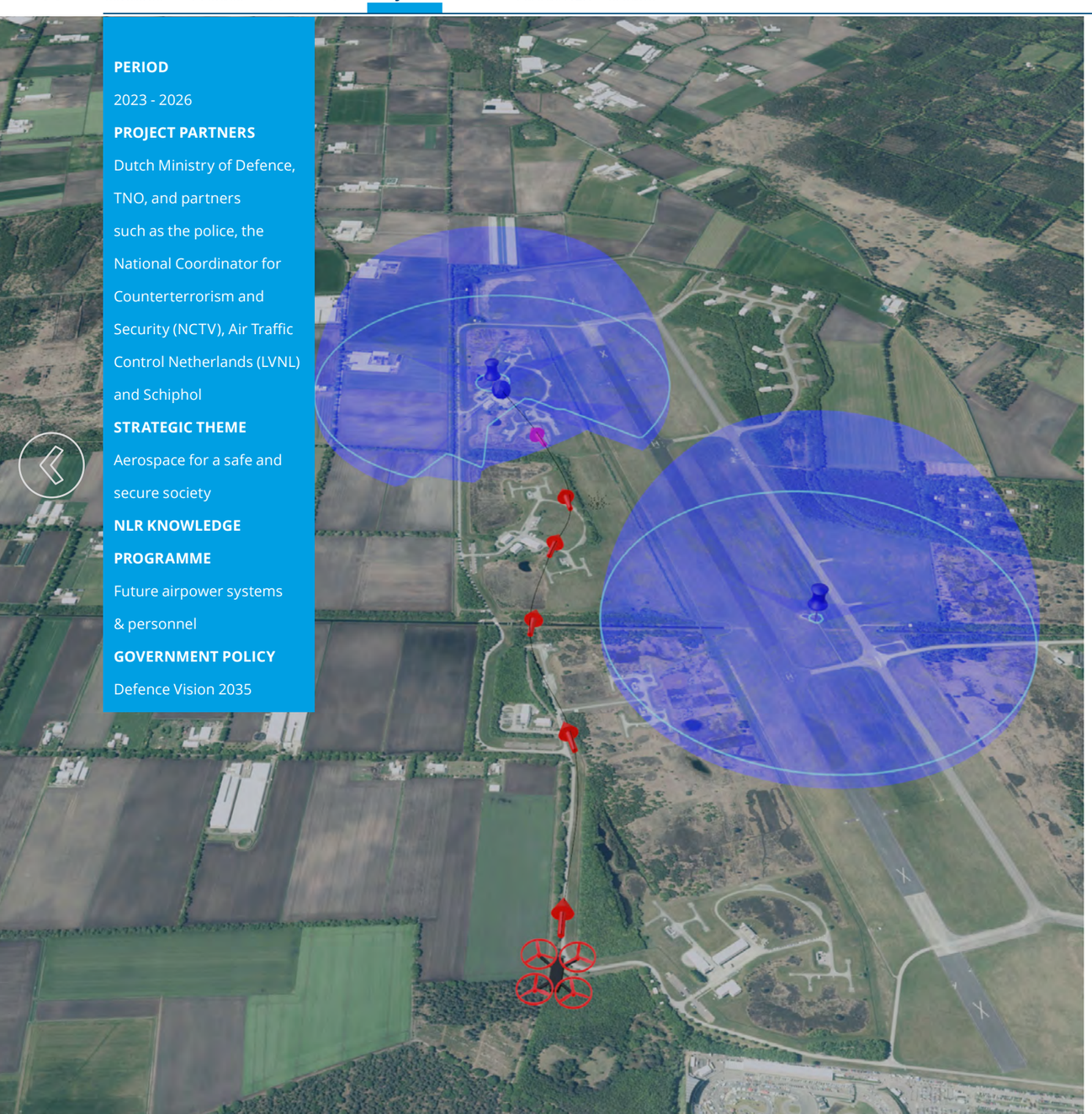
Additionally, the data can provide valuable insights afterwards, Van Miltenburg notes. "During a debriefing, for instance, a team can see when the workload increased and what their attention was focused at that moment. This helps identify patterns so that their actions can be improved in future situations."

Interface

Van Miltenburg is even thinking beyond the current scope. "We're also helping operators determine which tasks can be automated, so that they can focus on the most crucial information. That enhances team effectiveness and resilience: they maintain their performance levels despite changing circumstances and are less susceptible to work overload or errors made by other individuals. At the same time, they become more agile because we understand the team compositions better and the task allocations that work best for specific scenarios." It is always a question of finding the right balance, according to Van Miltenburg. "This project truly explores the interface between humans and technology."



PERIOD
2024 - 2026
PROJECT PARTNERS
Dutch Ministry of Defence, TNO, AFRL
STRATEGIC THEME
Aerospace for a safe and secure society
NLR KNOWLEDGE PROGRAMME
Future airpower systems & personnel
GOVERNMENT POLICY
Defence Vision 2035



PERIOD

2023 - 2026

PROJECT PARTNERS

Dutch Ministry of Defence, TNO, and partners such as the police, the National Coordinator for Counterterrorism and Security (NCTV), Air Traffic Control Netherlands (LVNL) and Schiphol

STRATEGIC THEME

Aerospace for a safe and secure society

NLR KNOWLEDGE PROGRAMME

Future airpower systems & personnel

GOVERNMENT POLICY

Defence Vision 2035

Effective protection against malicious drones

Drones have become a normal part of our daily lives, as well as on the battlefield. These devices offer numerous benefits, but they also have a downside: the risk of misuse. Fortunately, more and more systems are being developed to protect us from malicious drones. Nevertheless, these protective measures are struggling to keep pace due to the rapid evolution of drone technology. In the C-UAS project, NLR is bringing together civilian organisations and the Ministry of Defence in order to accelerate the development and integration of protection systems.

"C-UAS stands for Counter Unmanned Aerial Systems", explains Jacco Dominicus, C-UAS-project leader and principal R&D engineer in the Defence Operations department at NLR. The aim of the C-UAS project is to identify what is effective and what is not, and under what circumstances. The field is evolving rapidly, making it an ongoing endeavour, Dominicus remarks. "It's a complex subject encompassing numerous technical, operational, legal and ethical considerations. And it will remain that way for decades to come." The military police, navy, air force and army are all involved, as are civilian organisations such as the police force, correctional facilities, airports, and seaports..

Smart combinations

Detecting drones effectively requires a combination of methods, Dominicus explains. "Radar is perfectly capable of spotting a drone, but struggles to detect low-flying drones quickly enough. Acoustic sensors detect the drones, but their range is limited. Combining them with radar makes them more effective: an adversary must fly at a higher altitude to evade the acoustic sensor, at which point the drone becomes visible on radar."

Individual systems can, for example, analyse flight patterns, altitude and speed, or intercept control signals and read the identity (known as the remote ID) of the drone or pilot. According to Dominicus, the project aims to combine observations in a smart way and

subsequently validate their accuracy. When an operator detects a drone, they may for instance decide to disrupt the drone's data link signals – this is called jamming.

The process of detection, verification, decision-making, and response is still largely carried out by humans but will in future increasingly be automated, at least in part, Dominicus says. For example, by using AI to detect drones.

Classical air defences

The Ministry of Defence has been exploring various drone applications for several years. Since 2020, there has also been a heavier focus on developing countermeasures against drones that could be used by potential enemies against the Netherlands and its allies. To achieve this, we require additional systems beyond traditional air defence capabilities. "We're looking for systems that are readily available and relatively cheap", Dominicus comments.

Fusion

At NLR's site in Marknesse, the team is working on establishing a new Drone Detection Centre in partnership with the existing NLR Drone Centre. The new centre will feature a range of detection test facilities to enable the industry test its products. Furthermore, the data will be combined in a smart process known as sensor fusion, Dominicus elaborates. "We also use drones that execute pre-programmed scenarios to simulate an opponent."

> *"Detecting drones effectively requires a combination of methods"*

International exercise

The knowledge and experience gained have already been utilised to provide security for events such as the Formula 1 race at Zandvoort and Remembrance Day. The NLR team was also involved for the NATO summit in June 2025. In May 2026, NLR will host a large-scale international exercise that has been held annually since 2020. "There wasn't an international exercise last year as everyone involved in C-UAS was busy with the NATO summit. In 2026, we're organising a large-scale exercise at our Marknesse site. That's new for us. We're looking forward to showing how we can facilitate that type of complex exercise."

Rapidly clearing the airspace in the event of falling space debris

The skies and outer space are becoming increasingly crowded with all sorts of aircraft, satellites and rockets. Gradually, this is also increasing the likelihood of space debris colliding with a flying object. In the Uncontrolled Re-entry project, researchers at NLR have demonstrated that Dutch airspace can be evacuated in a controlled manner within twenty minutes should the need arise.

Discarded satellites and parts of rockets or space shuttles, such as empty rocket stages that have been jettisoned after launch, can re-enter Earth's atmosphere from space in an uncontrolled way. "The maximum risk of casualties from falling space debris as determined by NASA is one in ten thousand", says Wissam Chalabi, an R&D engineer at NLR. "But the risk of these objects hitting an aircraft will be seven times higher by 2035."

Chalabi emphasises that this probability calculation is a mathematical formula. "If it does happen, the likelihood calculated beforehand won't matter. We want to avoid collisions at all costs. A piece of space debris like that can have a major impact. It wouldn't just have catastrophic consequences for the passengers and crew of an aircraft: it also poses a danger for people on the ground when it eventually crashes."

The space in between

Together with his colleagues, Chalabi initiated the Uncontrolled Re-entry project, as part of the larger NearSpace project that NLR launched in 2024, and in which NLR is investigating the region between outer space and the atmosphere. This region, known as near space, begins approximately 20 kilometres above the Earth's surface and stretches up to the Kármán line, which marks the formal boundary of outer space at 100 kilometres altitude. Commercial aircraft typically reach a maximum altitude of around 20 kilometres above the Earth, whereas above 100 kilometres is primarily the domain of spacecraft, satellites and rockets.

"There has been little activity in the space in between for a long time", Chalabi says, "but it's getting busier and busier there as well." Several initiatives are underway for supersonic aircraft that fly just above the current

PERIOD
2025
STRATEGIC THEME
Aerospace for a safe and secure society
NLR KNOWLEDGE PROGRAMME
Safe and competitive operations
GOVERNMENT POLICY
Long-term Space Agenda

airspace, for instance. In addition, the number of data–gathering satellites is also on the rise, for example, for security and environmental reasons. “Until recently, there wasn’t much need for coordination in that area”, Chalabi notes. That coordination is needed now, however, particularly when a piece of space debris crashes to Earth from space. “We are studying the scenario of an uncontrolled re-entry of space debris and how air traffic control can manage the entire airspace safely and efficiently in that event.”

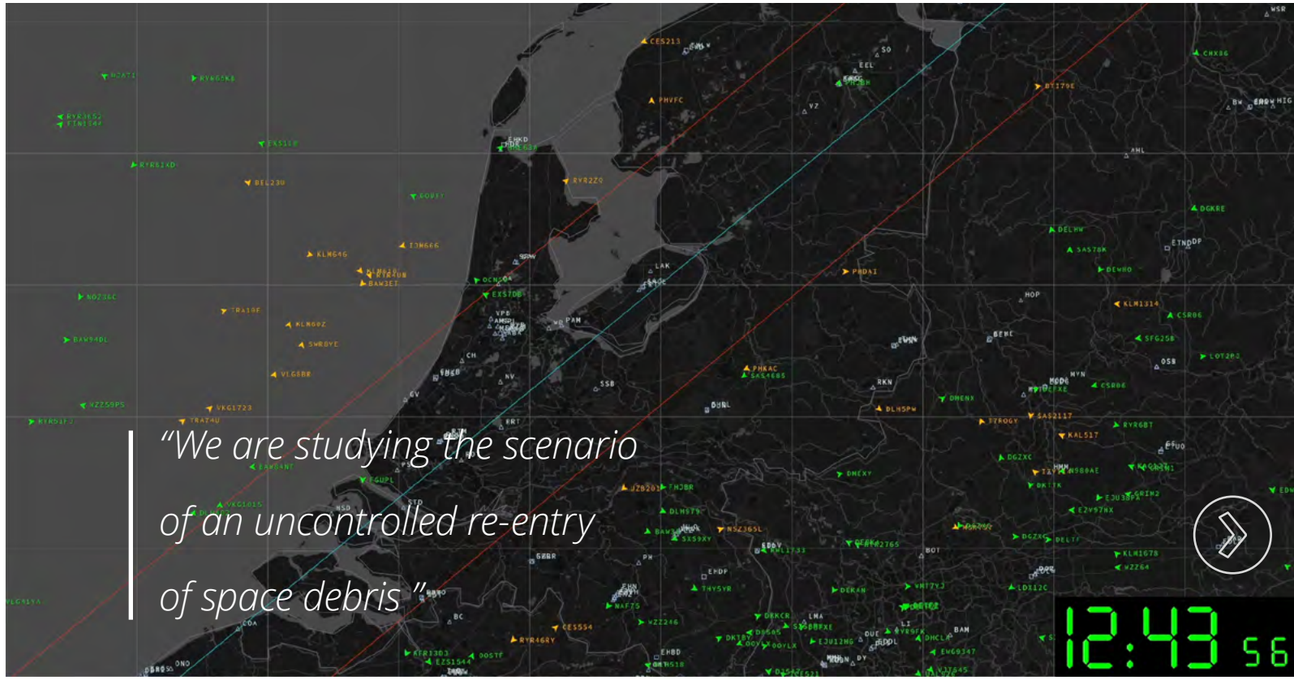
Simulated evacuation

To ensure a smooth evacuation, NLR engineers specialising in air traffic management and space traffic management worked together in the Uncontrolled Re-entry project. Led by Chalabi, they developed a simulation in which evacuation can be achieved efficiently within twenty minutes.

Evacuating that rapidly is only possible if several conditions are met, Chalabi continues. Air traffic controllers and pilots need to have been properly trained, and they must have the right tools to give them access to accurate information. Procedures and regulations also need to be established to facilitate close collaboration between space agencies and air traffic control.

Consensus

According to Chalabi: “Information is crucial in this regard. We need to know as precisely as possible what the falling object is, its expected trajectory, where it will land, and what the timeframe will be when it falls through a particular area.” He refers to a piece of space debris that caused chaos in the airspace in November 2022. Spain closed its airspace for forty minutes, while planes continued to fly over Portugal as normal, and France only partially closed its airspace. The debris ultimately landed in the South Pacific Ocean.



“The fact that countries made such different decisions points to a lack of coordination and consensus when dealing with this sort of incident. We want to improve this coordination, so that we can all be safe in future if a piece of space debris heads our way. Even if the chance of it happening remains slender”, Chalabi says.

Continue working on the preconditions

The Uncontrolled Re-entry project led to recommendations on how air traffic control can prepare for and respond to falling space debris in a coordinated and controlled manner. It also provides insights into what specific information is required from space agencies.

When Chalabi presented the research findings at a conference, attendees were surprised to learn that an airspace evacuation could be carried out in just twenty minutes. “That motivated us to carry on”, he adds. The next step is putting the simulation into practice. “This project was only the beginning. We would now like to invite other parties to play a role in the next phase.”

PERIOD

2021 - 2025

PROJECT PARTNERS

Cryoworld, Rotterdam The Hague Innovation Airport

STRATEGIC THEME

Sustainable aerospace

NLR KNOWLEDGE PROGRAMME

Unmanned and autonomous

GOVERNMENT POLICY

IKIA for Climate and Energy, Aviation Research Agenda

First drone flight on liquid hydrogen

Can you fly a drone on liquid hydrogen? You certainly can! The Hydra-II, NLR's hydrogen-powered drone, made its maiden flight in September 2025. The test flight, which lasted just a few minutes, allowed the researchers to gather technical data and make sure the necessary safety precautions and documentation were in place. This is an important step towards climate-neutral aviation.

"Our goal was to demonstrate that it is possible to fly on liquid hydrogen", says Jan-Willem van Doorn, a project engineer at NLR and the project leader for Hydra-II. He considers this achievement a major milestone, which underlines the quality of the research organisation. "At NLR, we thoroughly commit to a project, taking it from initial theoretical models all the way to a functional prototype. This provides a solid foundation for other projects, either within NLR or externally, to build upon."

At –253 degrees Celsius

NLR had previously flown a drone powered by gaseous hydrogen in 2019. "Compared to battery power, hydrogen-powered flight is much more energy-efficient", Van Doorn says. "One kilogram of hydrogen contains more energy than one kilogram of batteries. Gaseous hydrogen takes up a great deal of volume, however, which means it has to be stored under high pressure if it is to be carried on board a drone or aircraft. This adds weight to the tank, making it less suitable. Liquid hydrogen, on the other hand, can be carried in larger quantities, enabling longer flights." Developing the liquid hydrogen tank was one of the biggest technological challenges. Van Doorn explains that keeping the hydrogen liquid means it must be at –253 degrees Celsius, just twenty degrees above absolute zero. "Vacuum insulation is the best way of keeping it cold. We make sure there is a vacuum between the inner and outer tank walls." As a result of the insulation, it takes about four hours for the hydrogen to evaporate from the tank. The fuel tank itself – which should allow the drone to fly for four hours – was manufactured by Cryoworld.

Integration

A fuel cell is required to generate electricity from hydrogen. To do this, the liquid hydrogen must be converted back into a gaseous state, "because the fuel cell can't handle liquid hydrogen." A heat exchanger warms the hydrogen to 30 degrees and feeds it into the

fuel cell. A chemical process then ensues in which oxygen and hydrogen are converted into water and electricity. This creates roughly as much heat as electrical energy, and that heat has to be disposed of.

To dissipate that heat, extensive ground tests were conducted to understand the thermal behaviour of the fuel cell within the drone's fuselage, Van Doorn says. "We've managed to integrate all the components so that the drone can fly safely and legally. Procedures were also developed to ensure the safe handling of the hydrogen. The guidelines developed in Hydra-II are now the standard at NLR for working with liquid hydrogen."

Permit

A European regulation on drones has been in force since January 2021. "The new regulations weren't clear about the requirements imposed on hydrogen-powered flight", Van Doorn notes. To allow them to fly legally on hydrogen, Van Doorn and his team worked closely with the Human Environment and Transport Inspectorate to obtain a permit.

The hydrogen drone represents a step towards a manned aircraft powered by liquid hydrogen. Hydra-II serves as the foundation for the PHYREX project, which involves fitting NLR's PH-NLX, an electric two-seater aircraft, with a fuel cell that converts hydrogen into electricity. This involves applying the knowledge acquired through Hydra-II about the design and manufacture of the hydrogen tank. "We took the Hydra-II tank design and adapted it to create a larger version for NLR's electric aircraft," Van Doorn remarks.

A piece in the puzzle

Hydra-II will be followed by the four-year European project TULIPS (Demonstrating lower polluting solutions for sustainable airports across Europe), which is developing innovations for making aviation more sustainable. "We'll be holding a demonstration at Rotterdam Airport in late April 2026 to give a small-scale illustration of what the infrastructure and logistics involve when a hydrogen-powered aircraft takes off from an airport. This includes refuelling and taxiing, for example. As such, Hydra-II represents a key piece in the puzzle of achieving climate-neutral aviation by 2050."

"One kilogram of hydrogen contains more energy than one kilogram of batteries"

Synergy between SMEs and NLR

Dutch SMEs play a crucial role in the innovative capacity of the Dutch aviation and defence sectors. NLR collaborates closely with such companies on technological innovation and risk management and on developing intellectual property. This cooperation takes various forms, allowing NLR to reinforce the Dutch ecosystem and enhance the international standing of SMEs.

Small and medium-sized enterprises (SMEs) in the Netherlands, including deep-tech start-ups and scale-ups, are an important part of the Dutch economy and consequently of the aviation ecosystem. Whereas start-ups are typically still focused on scalability and refining their business model, scale-ups are already at a more advanced stage. They are rapidly growing companies that have proven business models. NLR assists both types of SMEs in developing technological innovations in a variety of ways.

Bilateral contract research

NLR sets up numerous research projects in collaboration with technology-driven SMEs, with the goal of turning concepts into practical applications. These smaller, innovative companies are increasingly finding their way to us through various channels. One is the NLR start-up programme, which offers direct access to knowledge, expertise and facilities that are at the cutting edge in the aerospace sector. Contacts are also made through NLR's advisory committees, at conferences, symposia and events, or through our colleagues' networks.

"Our collaboration with NLR means we have direct access to top-quality expertise, along with state-of-the-art computer models and facilities for analysing and verifying our technology. That makes NLR an indispensable partner in our ecosystem for developing our battery-electric aircraft and its underlying technology. NLR's expertise can be directly applied in the design of our thermal management system, for instance, and in the tail section, including its control surfaces. In the near future, we expect to be able to carry out similar studies with NLR to develop our technology further"

Rob Wolleswinkel,
Co-CEO and CTO of Elysian Aircraft

One specific example is Elysian Aircraft, a company that approached us for collaboration. NLR has assisted this Dutch company (founded in 2023) in conducting a thermal management study and stability and control research for the battery-electric aircraft that Elysian is developing, the E9X. Moreover, NLR and Elysian are collaborating on battery-electric powertrains for defence applications as well.

Government-subsidised clusters

As well as one-to-one collaborations, NLR also works closely with SMEs in several government-funded cluster schemes. This includes participation in National Growth Fund programmes such as *Luchtvaart in Transitie* (LiT, Aviation in Transition), NXTGEN HighTech, *Duurzame MaterialenNL* (Sustainable Materials NL). Furthermore, NLR is involved in projects for Holland High Tech (TKI HTSM), through the *Topsector* High Tech (TSH, High-Tech Top Sector) scheme for the aircraft manufacturing industry and within what are known as Defence Technology Projects (DTP).

On top of that, NLR plays a prominent role in European tenders, programmes and partnerships, such as with ESA for space applications or the Horizon Europe, Clean Aviation and SESAR framework programmes in the aviation sector, as well as the EDF for defence-related initiatives.

NLR and other Dutch organisations are jointly exploring promising opportunities for collaboration in this context. They subsequently discuss which additional parties could be involved in forming a consortium and in what capacities.

The AnDREA project[1] is a prime example of this. This project received funding from the TSH Aircraft Manufacturing Industry programme. It focuses on developing cleaner and more efficient aircraft. Led by the start-up Elysian, a consortium consisting of NLR, DNW and TU Delft is working with industrial and research partners to develop and test design tools. These tools are targeted at new aircraft configurations and integration concepts, with the ultimate goal of making electric propulsion possible.

[1] *https://www.rvo.nl/subsidies-financiering/tsh-vliegtuigmaakindustrie/nieuwe-selectie-projecten-tsh-2025#andrea---aerodynamische-weerstandreductie-voor-elektrische-vliegtuigen*

"T-Minus develops, manufactures and launches rockets for scientific research and defence applications. In that sense, it's very convenient that we can make use of a secure test site at the NLR premises in Marknesse. It gives us the ideal opportunity to strengthen the synergy between the ambitions and developments of NLR and T-Minus"

Hein Olthof,
co-owner of T-Minus Engineering

Industrial participation

The Netherlands has an innovative defence and security industry that supplies its armed forces. However, the market for defence equipment is not a level playing field, particularly in countries that have their own national defence industries; foreign companies are then less likely to win contracts. When the Dutch Ministry of Defence procures military equipment abroad, industrial participation can provide a solution: the Dutch government asks for offset orders from Dutch manufacturers in that case.

This industrial participation and early engagement of the relevant parties lets NLR work closely with SMEs. NLR is actively committed to promoting the Dutch ecosystem and linking it to the supply chains of major international aircraft manufacturers (original equipment manufacturers, OEMs) such as Lockheed Martin, Bell and Boeing. NLR also makes connections between other major international players, including Airbus and Embraer, and the appropriate Dutch high-tech companies.

NLR plays a pivotal role in this regard by putting promising SMEs in touch with aircraft manufacturers, for example, with specific needs that they can meet. One excellent illustration of this is the joint development by NLR and PhotonFirst of an innovative SHUMS (Structural Health and Usage Monitoring System) solution for helicopters[2].

"Our partnership with NLR is essential in converting our optical sensor technologies into certified applications for aviation OEMs worldwide. We're proud to be setting a new benchmark in structural health monitoring together"

Leendert-Jan Nijstad,
CEO of PhotonFirst

"Together with other aviation stakeholders, NLR is playing a significant part in further strengthening the Dutch aviation ecosystem. NLR has, for instance, helped to optimise our website to provide more information about Dutch and European funding opportunities[3]. This makes it easier for organisations to tap into on new opportunities"

Mark Ommert,
Public Affairs & Industry Relations Manager at NAG-LRN

Business development

Turning international opportunities into new prospects for Dutch organisations is by no means always straightforward. Joining forces lets us present a united front. Various supporting organisations such as NAG-LRN, the trade association for the Dutch aviation industry, network organisations such as NIDV (Dutch Industry for Defence and Security) and SpaceNed play a key role in this. NLR is a knowledge and research centre and thereby also part of the ecosystem, so we work closely with these organisations to put the country's sector firmly on the international map.

How do we see SMEs?

Small and medium-sized enterprises or SMEs is a collective name for the business sector that, according to the Netherlands Enterprise Agency (hereinafter "RVO"), comprises three types of ventures.

Size	Number of employees	Annual turnover	Annual balance
Medium-sized	< 250	≤ €50 mln	≤ €43 mln
Small	< 50	≤ €10 mln	≤ €10 mln
Micro	< 10	≤ €2 mln	≤ €2 mln

Source: RVO

Within this group, NLR focuses particularly on so-called deep-tech start-ups and scale-ups. NLR supports both types of companies during development of technological innovations that involve significant technological or financial risks, which would be too great for the companies to bear on their own.

[2] *https://www.nlr.org/newsroom/nieuws/nlr-and-photonfirst-for-real-time-condition-monitoring-of-helicopters/*

[3] *See: https://nag.aero/nag/public-funding-in-aerospace/*

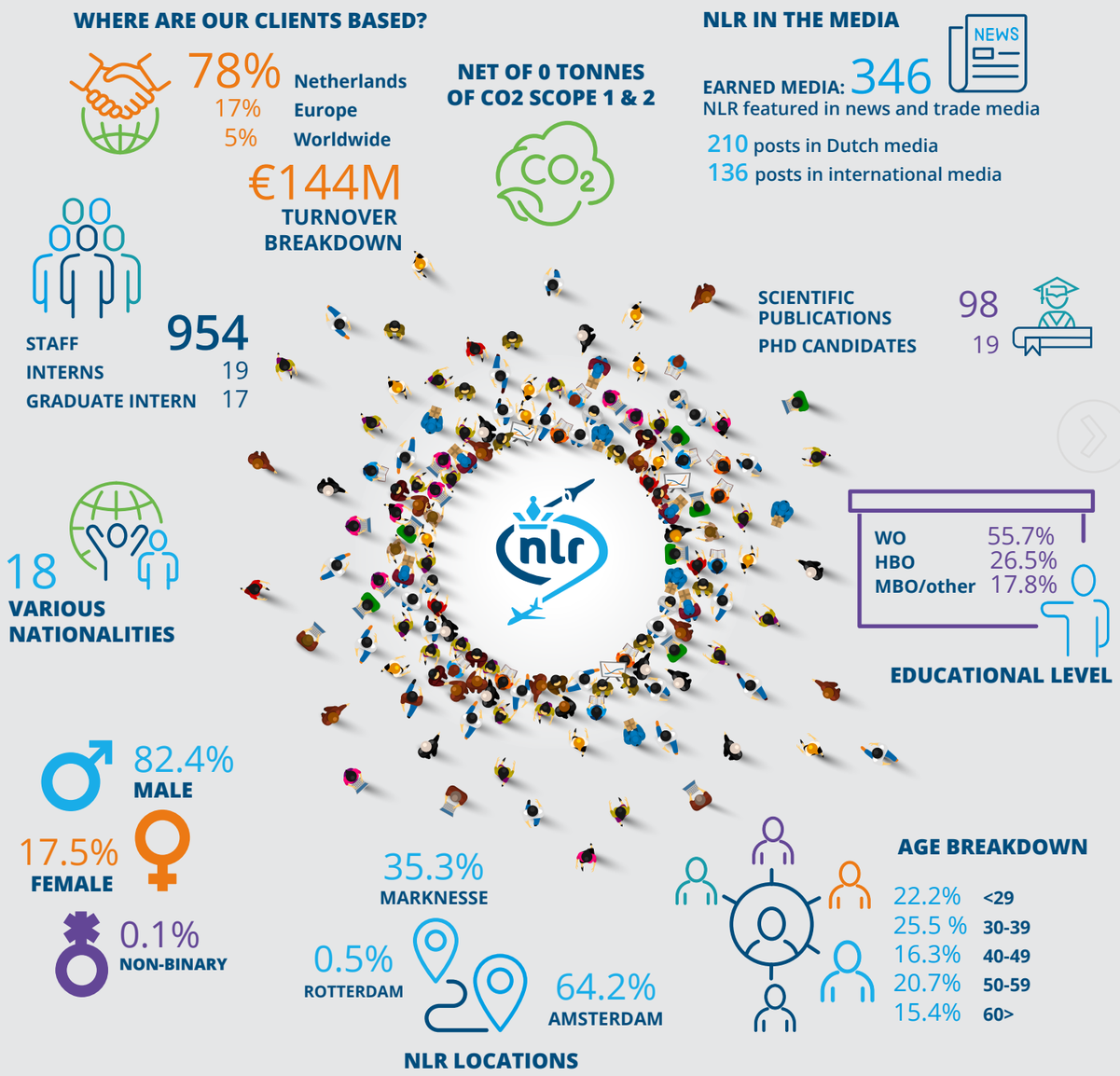
About Royal NLR

For over 100 years, NLR has been an ambitious applied research organisation, driven to keep innovating and improve the sustainability, safety, efficiency, and effectiveness of aerospace. Objectively and independently, we are now laying the foundation for a future meaningful, societal impact.

In a rapidly changing world, mobility and stability needs are constantly evolving. Aware of the social urgency, NLR helps pave the way for promising concepts to quickly become a reality and transform into disruptive solutions or incremental improvements. We do this by combining a deep understanding of customer needs, multidisciplinary expertise and the use of our state-of-the-art research facilities. In doing so, NLR plays a pivotal role between science, industry and government, both domestically and abroad, bridging the gap between fundamental research and practical applications.

NLR is taking a leading role to achieve Dutch and European objectives. Together with our partners, we are working tirelessly to develop a resilient and sustainable mobility system, and we support Dutch Defence in all military domains, where space and cyberspace are playing an increasingly prominent role. From our headquarters in Amsterdam and Marknesse, as well as our satellite location, NLR is contributing to a safer and more sustainable society, and strengthening the competitive position of Dutch industry.

Visit www.nlr.org for more information.



(gegevens op basis van boekjaar 2025)

Credits

The projects mentioned in this impact report have been made possible in part by the following organisations and their members, where applicable. The opinions expressed in the project articles solely reflect the views of the author.

A number of projects have received funding from other parties, Dutch funds, and the European Commission:

- QRDF (p. 9) and Destination 2025 (p. 45) received funding directly through commissioned projects.
- The laser communication project (p. 11) has received funding from the National Growth Fund and NXTGEN-Hightech.
- BrightSky (p. 15) has received funding from the RVO mobility fund.
- The laser weapons project (p. 18), the project within the Emerging Technologies programme (p. 21), Metrics (p. 57), and C-UAS (p. 61) have received funding from the Ministry of Defence.
- TRISTAN (p. 27) has received funding from Horizon Europe Chips JU and the Holland Hightech foundation (TKI HTSM).
- The project with SPECTO (p. 36) has received funding from NXTGEN-Hightech.
- HEROPS (p. 39) has received funding from the Clean Aviation Joint Undertaking.
- PrimaVera (p. 47) has received funding from NWO.
- ALBATROS (p. 54) has received funding from Horizon Europe and the Holland Hightech foundation (TKI HTSM).

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April 2026