Accelerating the future of aerospace

# Enabling safe and seamless drone operations


Royal NLR - Netherlands Aerospace Centre

# Unmanned and autonomous aviation

Drones are a key enabler for innovative solutions to tackle rapidly changing societal, economic and security challenges. NLR is the knowledge partner in this field for industry and government. We offer support in the development, implementation and societal acceptance of unmanned and autonomous aviation, taking into account safety and minimal nuisance. We help with the realisation of safe, sustainable and affordable drone systems and the harnessing of commercial opportunities, and we support the manufacturers in the area of drones and Innovative Air Mobility (IAM).

- Simplifying integration of unmanned aircraft into the airspace as a whole
- Helping industry and the government utilise the effectiveness and added value of Innovative Air Mobility (IAM) both nationally and internationally;
- Taking on a leading role in collaboration on counter-drone solutions to support both government and public partners;
- Mapping out the opportunities for new and existing application domains
- Accelerating the development and realisation of vehicle and system development
- Making communication, navigation and surveillance infrastructure more efficient, more robust and more safely deployable

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

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

NLR – Royal Netherlands Aerospace Centre

UNMANNED AND AUTONOMOUS

The NLR strategic programme Unmanned and Autonomous, helps achieve safe, sustainable and affordable drone systems and make the most of commercial opportunities, as well as assisting companies and organisations in the Netherlands and worldwide, in drones and innovative air mobility.

# R&D cases

- Integration unmanned aircraft into the airspace
- Effectiveness and added value of innovative air mobility and UAM
- Counter-drone solutions
- New and existing application domains
- Development of vehicles and systems
- Communication, navigation and surveillance infrastructure

# ASSURED-UAM: efficient deployment of Urban Air Mobility

**Numerous obstacles preventing common deployment of UAM operations can be identified. There is a lack of rules and standards assuring on the one side safety and reliability of UAM operations, and on the other side guaranteeing the appropriate level of public acceptance, integration and sustainability. The ASSURED-UAM (Acceptance Safety and Sustainability recommendations for Efficient Deployment of UAM) project aims to guarantee outstanding robustness in terms of safety, sustainability and acceptability of UAM. It will promote aviation best practices, standards, recommendations and organisational solutions to the administrative and legislative bodies.**

## THE CHALLENGE

Urban Air Mobility deployment has to be considered as multi-disciplinary complex problem requiring an extra effort towards dedicated preparation and appropriate organisational actions. Due to high uncertainty the process will be considered for three time-horizons (next 5, 10 and 15 years).

## WHAT WE DID

Royal NLR did research on the regulatory framework for UAM deployment. Using this framework, a target level of safety is proposed for UAM operations. Other work, as part of the operational concepts, NLR participated in is the technology readiness review and ConOps definition including several use-cases/ scenarios.

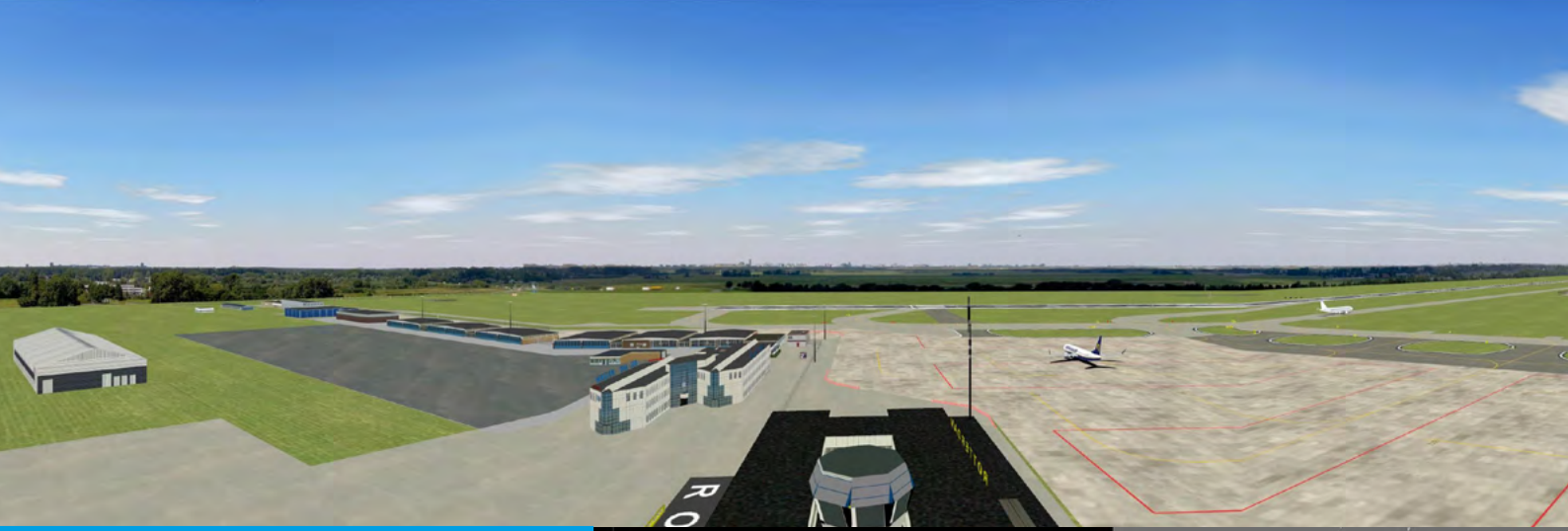
When looking at recommendations and standards definition NLR made an inventory of current standards and regulations and assessed their suitability as means of compliance or guidance for the approval of UAM infrastructure. Finally, NLR contributed to the dissemination of the recommendations and guidelines.

## THE SOLUTION

The project aims to provide authorities, policy makers and urban industry organisations with guidelines for a complete policy definition support in order to implement vertical transport with the horizontal urban space and peri-urban mobility systems. Moreover, the project will carry out the U-Space Air Traffic Management System, so that the introduction of unmanned UAM will be well integrated with organisational and policy framework. ASSURED-UAM is structured around four main areas: Knowledge base development, Foresight scenarios, Standards & recommendations and City projects

Horizon2020
European Union Funding
for Research & Innovation

**Project partners**
ILOT (project leader), CIRA, CEiiA, ISSNOVA, DTA, GZM, Royal NLR
**Funding**: Horizon 2020
**Duration**: 2021 - 2024



**Project partners**
INDRA (project leader), ENAIRE-CRIDA, LFV, NATS, DLR, SINTEF, AIRBUS, EUROCONTROL



# AURA: ATM U-SPACE INTERFACE

**The AURA (ATM U-space InteRfAce) project (SESAR 2020 project PJ34 ) investigated the development of concepts and technologies that are necessary to allow existing ATM systems and future U-space operations to interact in a safe, predictable and seamless way. One of the basic assumptions of the project is that manned and unmanned movements take place in ATM U-space Shared Airspace (AUSA). AUSA can be delegated to be either ATM or U-space controlled. U-space traffic is then segregated by geo-cages around the U-space delegated part of AUSA. Contingencies and emergencies needed to be mitigated by delegating additional AUSA volumes to U-space.**

## THE CHALLENGE

The main goal of the project was to develop and validate interfaces that connect the ATM systems to U-space services. Further, a concept of operations for a mix of manned and unmanned flight operations in controlled airspace areas needed to be developed. NLR contributed to AURA by addressing concept elements for contingency and emergency operations inside U-space with an impact on ATC operations, i.e. scenarios in which a drone malfunction or mission requirement could eventually lead to conflicts with manned aircraft, particularly in the vicinity of airports.

## THE SOLUTION

The project consisted of two solutions:

- a technical solution implementing the required services within a common ATM and U-space interface (CISP)
- an operational solution describing the operational environment and the processes for Dynamic Airspace Re-configuration (DAR). With DAR, AUSA was delegated to be either U-space or ATM controlled. NLR introduced the role of a DAR Manager to use prototype

interfaces to negotiate contingency and emergency airspace changes with U-space and ATM actors, and implement them in accordance with the defined DAR processes.

## WHAT WE DID

Royal NLR carried out human-in-the-loop real-time simulations on the NARSIM validation platform with a link to remote pilot station U-FLY of DLR, that carried out drone missions and provided position information. AURA operational and technical requirements were translated into typical drone mission scenarios in order to show that DAR processes are feasible. The DAR Manager was added to the ATC team for Rotterdam (EHRD) and acted as an intermediary between U-space and ATM. Interfaces had to be built for the DAR Manager and the air traffic controllers to be able to negotiate and implement airspace changes in accordance with the DAR processes. Results will be presented in 2023.

sesar JOINT UNDERTAKING *This project has received funding from the SESAR Joint Undertaking (JU) under grant agreement No 101017702.*

# Metropolis 2: a unified approach to airspace design and separation management for U-space

**Urban Air Mobility (UAM) concepts, such as flying taxis and package delivery drones, are increasingly viewed as an essential component of future transportation systems. But before UAM flights can occur on a meaningful scale, several challenges need to be tackled including airspace integration. Recognising the need to address this challenge, several initiatives are underway worldwide to develop the new Unmanned Traffic Management (UTM) services needed to facilitate UAM flights. In this context, the European Commission has initiated the European U-space UTM system. U-space development has been divided into four distinct phases named U1-U4 where the complexity of the resulting operations are gradually increased.**

## THE CHALLENGE

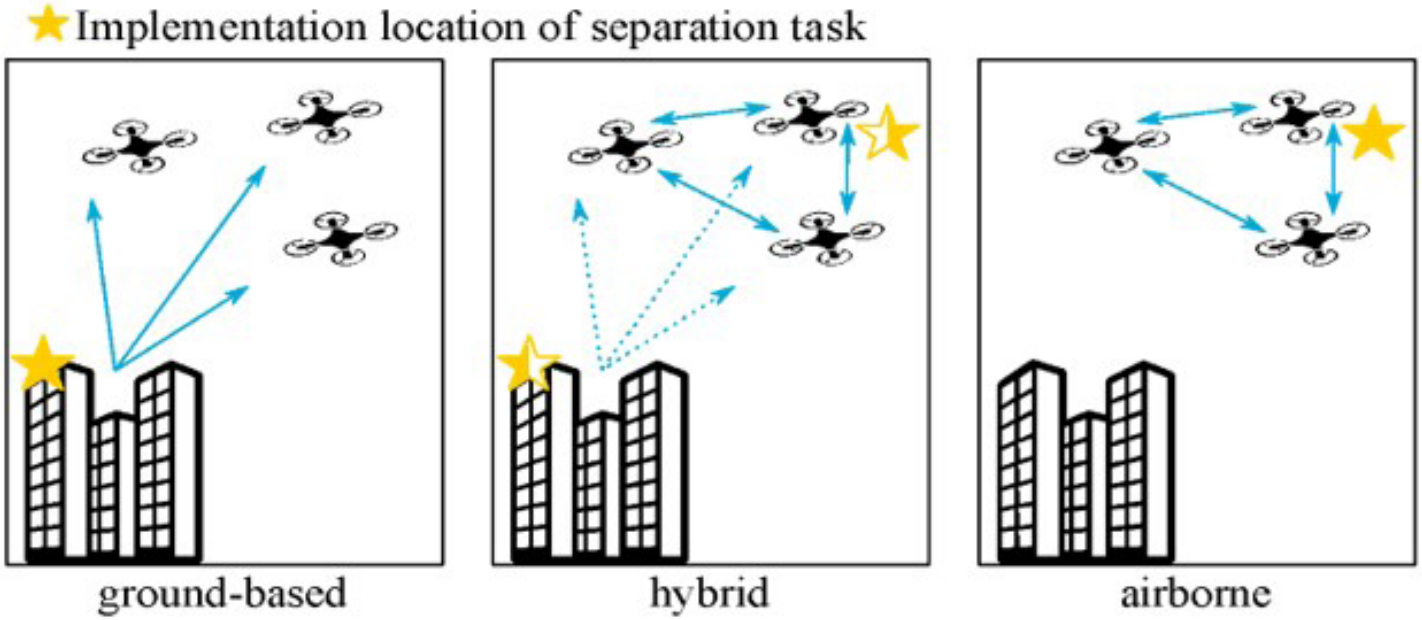
The goal of the Metropolis 2 project was to investigate the separation management architecture that is needed to achieve high density UAM and drone operations in urban areas for a future U-space U3/U4 system. The aim was to develop an architecture that took into account interactions between the following aspects: airspace design, flight planning, strategic deconfliction and tactical deconfliction between drones in U-space airspace.

## THE SOLUTION

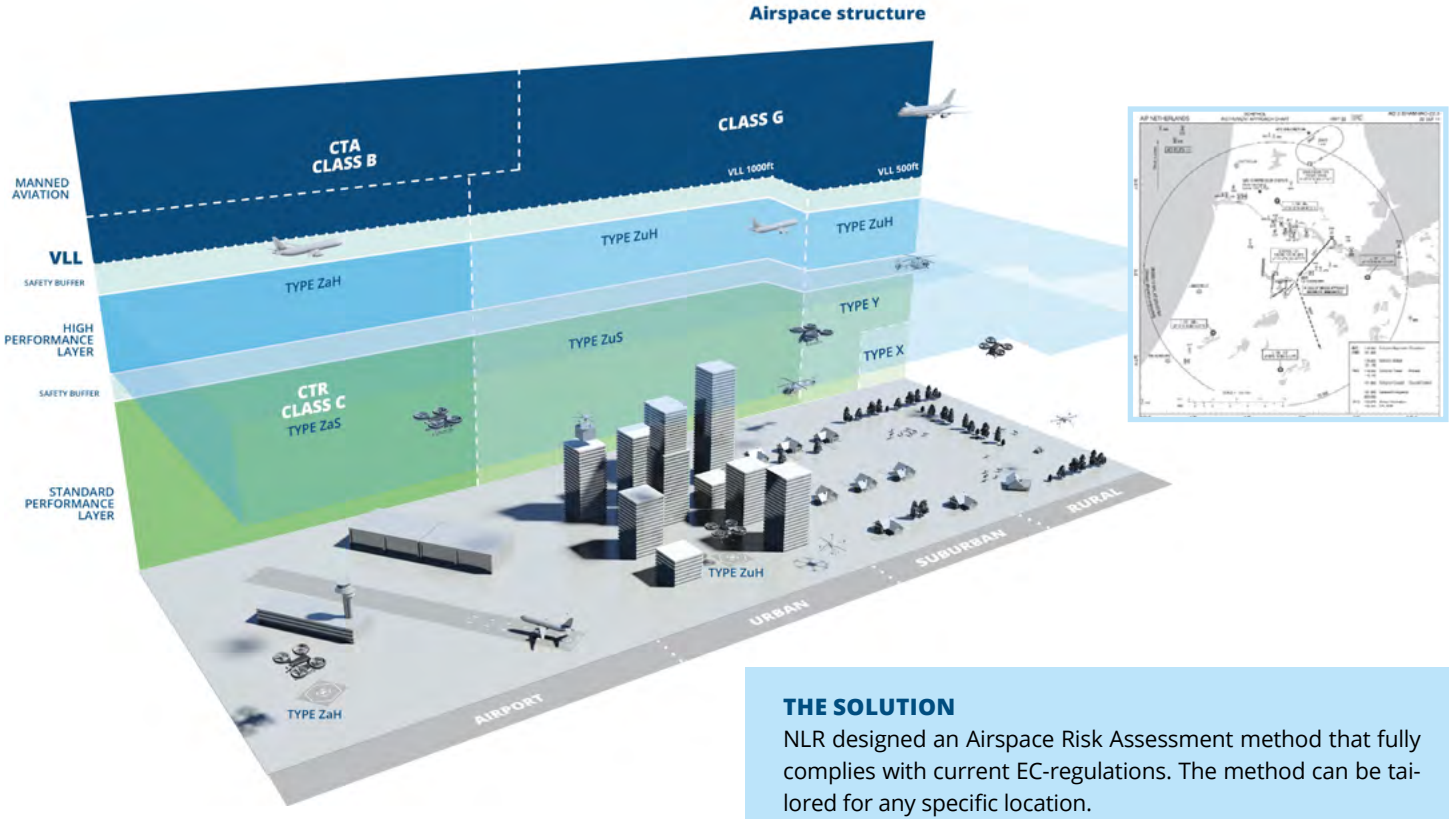
Three different architectures for separation management were tested, a) centralised ground-based, b) decentralised air-based and c) hybrid. The concepts were tested using fast-time simulations for a large number of different traffic volumes for the city of Vienna. This included densities of up to 5000 drones over Vienna over a period of one hour. The simulations were performed using the BlueSky fast-time simulator.

NLR led the project subteam that developed and simulated the Hybrid concept. The results of the simulations indicated that the Hybrid architecture resulted in the highest safety and capacity. It is recommended that U-space implementations for urban areas adopt such a hybrid architecture that containts both ground-based centralised control for flight planning and air-based tactical control for dealing with conflicts as a result of uncertainties such as wind. The airspace design needs to compatible with the actions of the preceeding safety layers. The results have been published in the SESAR Innovation Days conference in Budapest in December 2022.

sesar JOINT UNDERTAKING *This project has received funding from the SESAR Joint Undertaking (JU) under grant agreement No 101017702.*




**Research Organizations:** NLR
**Universities:** TU Delft, ENAC, Linköpink University, University of Patras
**Industry**: NTT Data, Unifly
**Funding**: SESAR




## THE SOLUTION

NLR designed an Airspace Risk Assessment method that fully complies with current EC-regulations. The method can be tailored for any specific location.

- provide the airspace risk assessment
- visualize and simulate airspace operations
- assess how U-space can help to mitigate hazards
- establish requirements for U-space Airspace
- define advanced U-space services
- define a concept of operations for the U-space Airspace to be established

# U-space Airspace Risk Assessment

**U-space, the air traffic control system for drones, is a set of new services relying on a high level of automation. It offers great potential to fly drones simultaneously in complex environments and is regarded as an enabler for Urban Air Mobility. U-space will provide safe integration with manned traffic. Before the establishment of U-space, EC regulation requires the airspace to be designated as "U-space Airspace" and an airspace risk assessment is required.**

## THE CHALLENGE

Before assigning part of the airspace as U-space Airspace, a good risk assessment will need to take place for the identification of hazards and mitigation of risks. These risks are air and ground related. In the air, other traffic, manned and unmanned, might intervene with the drone operations. On ground, hazards are related to population or infrastructure, causing risk to the people on the ground. Buildings or existing radio signals might interfere with a the signal to and from the drones.

The airspace assessment considers both air and ground risks by first describing the current operations of manned and unmanned traffic. A forecast of future operations must be given as 'reference scenarios' a number of use cases.

The starting point of a thorough U-space airspace risk assessment is a thorough description that identifies relevant details such as population, public buildings, schools, or high risk industries.

## WHAT ARE WE DOING

NLR has set up a method for the performance of an airspace assessment, in line with the EC regulation and accompanying guidance from EASA. The method follows a structured approach towards setting up a full airspace risk assessment for any area that is requesting the use of U-space.

NLR supports organisations, like municipalities, harbors, industry areas and ANSPs, that have plans to operate U-space. NLR performs the airspace risk assessment compliant with EC regulation 2021/664.

**Project partners**
Government: Dutch Ministry of Infrastructure and Water infrastructure
Research organisation: Royal NLR

# Integration of MALE RPAS into European Airspace

**In addition to supporting defense operations, Medium Altitude Long Endurance (MALE) Remotely Piloted Aircraft Systems (RPAS) have numerous civilian applications ranging from infrastructure inspection to search and rescue. However, the current regulatory environment in Europe inhibit such applications as they only permit MALE RPAS operations in segregated airspace. Furthermore, each MALE RPAS flight requires numerous permissions from national aviation authorities, and this process can be very time consuming.**

## THE CHALLENGE

To overcome these issues, and regularise MALE RPAS operations in Europe, it is necessary to develop and validate a comprehensive Concept of Operations (CONOPS) to enable the safe and efficient integration of MALE RPAS into controlled and uncontrolled European airspace.

1. Develop and test CONOPS to integrate MALE RPAS into European airspace, taking into account both nominal and non-nominal conditions
2. Provide empirical evidence to convince all relevant stakeholders that MALE RPAS operations are safe and efficient to fly in European airspace

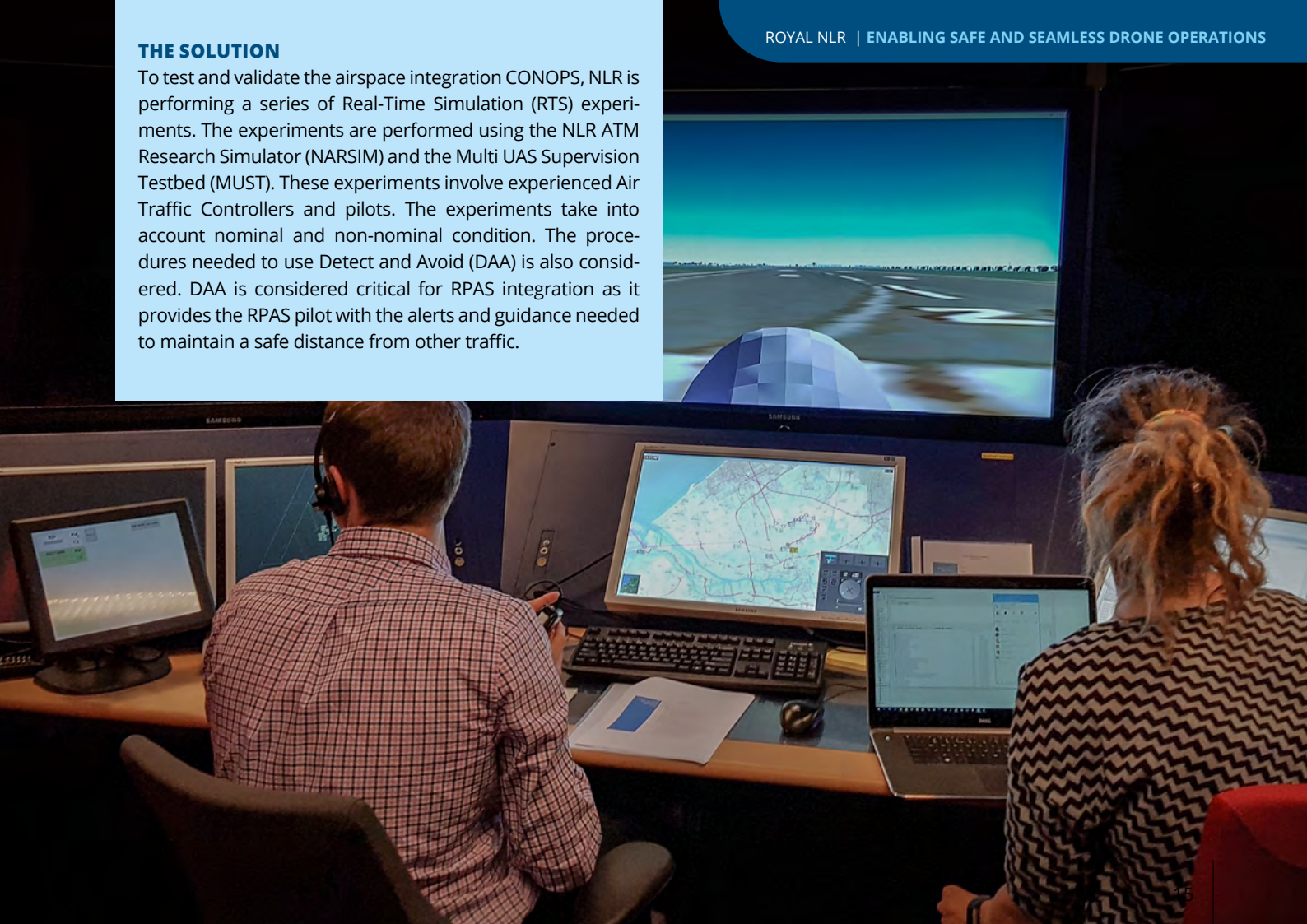
## WHAT DID WE DO

An iterative, step-by-step, approach has been adopted. The first phase of the project focused on setting up the basic simulation infrastructure needed to perform the required experiments. The resulting simulators were used to perform a number of experiments to study the procedures needed to cope with RPAS contingencies, such as Command and Control (C2) link failure, i.e. failure of the digital link between the RPAS pilot on the ground and his/her aircraft in the air. The project is currently in its second phase which is focusing on operations with DAA. To this end, the NLR simulators have been connected to the GA-ASI Conflict Prediction and Display System (CPDS) to provide pilots with DAA alerts and guidance.

**Project partners**
Industry: General Atomics Aeronautical Systems (GA-ASI) & Information Systems Delft (ISD)
Research organisations: Royal NLR

## THE SOLUTION

To test and validate the airspace integration CONOPS, NLR is performing a series of Real-Time Simulation (RTS) experiments. The experiments are performed using the NLR ATM Research Simulator (NARSIM) and the Multi UAS Supervision Testbed (MUST). These experiments involve experienced Air Traffic Controllers and pilots. The experiments take into account nominal and non-nominal condition. The procedures needed to use Detect and Avoid (DAA) is also considered. DAA is considered critical for RPAS integration as it provides the RPAS pilot with the alerts and guidance needed to maintain a safe distance from other traffic.



**Project partners**

Industry: NTT  Data (overall project lead), Boeing, Jeppesen, CATEC, Airbus, EHang, AirHub, Space53, Altitude Angel

Research organisations: Royal NLR (demonstrations project lead), ITG, Enaire, Tecnalia, Ineco, ANRA, Cranfield University.

# AMU-LED: Urban Air Mobility – Large Experimentation Demonstrations

**Urban Air Mobility (UAM) promises to be the next mobility revolution, enabling faster, more efficient and sustainable transport solutions (such as flying taxis and other large drones) throughout urban areas. But there are a number of challenges that need to be overcome for UAM to become a reality. These include the organisation of the lower-level airspace, the scale-up of operations in a safe way, integration with ATM, the development of an architecture that can support operations and public acceptance.**

## THE CHALLENGE

AMU-LED looked into the capabilities of U-space to enable UAM by answering questions related to the maturity of concepts and technology, the challenges, and what needs to be done to implement this new form of mobility in cities. AMU-LED had UAM stakeholders specify various use cases applicable to logistics and the urban transport of passengers, to integrate the UAM environment, to demonstrate the UAS ground and air-borne platforms and finally, to assess safety, security, sustainability and public acceptance.

## THE SOLUTION

AMU-LED performed real-life UAM demonstrations and flights using U-space and deploying several types of drones to showcase different scenarios, use cases and applications (e.g. air taxis, emergency services, delivery of goods, surveys etc.) to demonstrate and investigate the research questions. To this end, several major flight demonstrations took place in the second half of 2022 in the UK, Spain and The Netherlands.

## WHAT WE DID

The project is carried out in a consortium with companies in The Netherlands, Spain and the U.K. Together, an extensive state-of-the-art research was set up where all relevant aspects were considered. Use cases include taxi flights from the city to an airport and last-mile drone delivery. Special attention was given to emergency flights for police, ambulance and fire fighters.
Within the city of Amsterdam, NLR investigated the link with air traffic control of Schiphol and the link with other air traffic on arrival routes to the airport. and demonstrated that U-space, the traffic control services for drones, can help to fly in situations where the pilot does not see the drone anymore. Also public acceptance of drones will be investigated.

sesar JOINT UNDERTAKING *This project has received funding from the SESAR Joint Undertaking (JU) under grant agreement No 101017702.*

# SymAware: Symbolic logic framework for situational awareness in mixed autonomy

**There will be a large increase in the number of aerial and ground vehicles that can operate fully autonomously or with a high level of automation requiring human intervention only in special conditions. In increasingly autonomous operations, the situation awareness, risk awareness and experience of human operators that have played such vital roles until now can no longer be counted upon.**

## THE CHALLENGE

SymAware addresses the fundamental need for a new conceptual framework for awareness in multi-agent systems that is compatible with the internal models and specifications of robotic agents and that enables safe simultaneous operation of collaborating autonomous agents and humans. The goal of SymAware is to provide a comprehensive framework for situational awareness to support sustainable autonomy via agents that actively perceive risks and collaborate with other robots and humans to improve their awareness and understanding, while fulfilling complex and dynamically changing tasks.

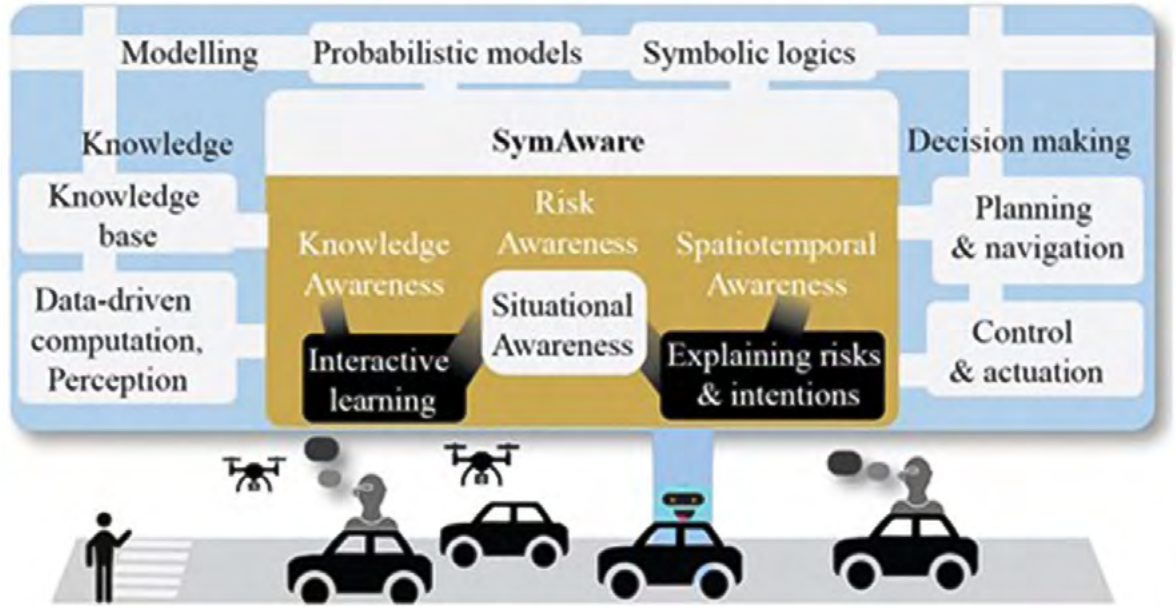
## WHAT ARE DOING

The SymAware approach for awareness engineering will be implemented and validated in use cases. Royal NLR will develop a use case for modelling, simulation and risk assessment of unmanned aircraft systems traffic management of drone operations in an urban environment, including disturbances and hazards during operations. The computational framework building on compositional logic, symbolic computations, formal reasoning, and uncertainty quantification will allow for addressing risks and safety explicitly and in a quantifiable manner.

## THE SOLUTION

The SymAware framework founded on compositional logic, symbolic computations, formal reasoning, and uncertainty quantification will characterise and support situational awareness of multi-agent systems by formally modelling and specifying awareness in its various dimensions, sustaining awareness by learning in social contexts, quantifying risks based on limited knowledge, and formulating risk-aware negotiation of task distributions.

Horizon2020
European Union Funding
for Research & Innovation




**Project partners**
MPI-SWS, TU/e, KTH, UU, NLR, Siemens
**Funding**: EU Horizon EIC 2021 Pathfinder Challenges
**Duration**: 2022 - 2025




**THE SOLUTION**

- Miniaturisation of the DAA system suitable to be integrated onboard of small and mid-sized unmanned aircraft
- Sensor suite advancement to include a direction finder to measure the azimuth such that the relative position to the intruders is known
- Information from ADS-B (manned intruder aircraft) will be used to further increase detection of current airspace users

# Detect And Avoid system ADACORSA

**To enable safe airspace integration of unmanned aircraft, a Detect And Avoid (DAA) system is required to evade other (manned) aircraft. One solution is to use a Cooperative Traffic Sensor based on transponder signals. Such a sensor is not yet available with a small form factor suitable for unmanned aircraft. Within the Airborne Data Collection on Resilient System Architectures (ADACORSA) project, such a sensor will be developed and tested in cooperation with the partners.**

## THE CHALLENGE

The main challenges of the project are

- The form factor and power requirements of current DAA systems are not suitable for small and mid-sized unmanned aircraft.
- Due to frequency saturation of the manned aircraft transponder frequencies, drones cannot be equipped with ADS-B transponders.
- Manned aircraft with both Mode-S and ADS-B transponders need to be detected.

**Project partners**
Industry: Anywi, Celestia Technology Group, Embraer, ESC Aerospace, ISEP, etc.
Research organisations: Royal NLR, TUDelft

## WHAT DID WE DO

NLR develops a Direction Finder for the Cooperative Traffic Sensor (CTS) and integrates this with a Mode-S interrogator, developed by project partner Celestia Technology Group. The DAA system uses algorithms developed by NLR for semi-automatic avoidance of other aircraft. These algorithms feature both Remain Well Clear (RWC) and Collision Avoidance (CA) functionalities. The RWC functionality takes into account the rules-of-the-air to calculate a new route for the unmanned aircraft. The calculation is performed onboard to be independent of a data link and allows a fully autonomous system in the future. The DAA system will be integrated and flight tested in the DAA Flying Testbed at the NLR Drone Flight Test Centre. Finally, the developed system will be demonstrated in a logistic support use case.

# Small and silent drones for mission landing zone reconnaissance

**Selecting a good landing zone in an uninhabited area requires a good and extensive exploration of the terrain by specialists. This is a time-consuming activity that sometimes has to be done in silence. Possible locations are identified using digital maps and satellite data, but that data can be outdated and is usually not very detailed. That is why an initial check of the location is needed with current, up-to-date and more accurate recordings. 'Pathfinders' are sent ahead by parachute to explore the area with small drones that fit in a backpack, in addition to their survival gear and weapons. In the Mission Landing Zones (MILZ) project, the partner CGI developed software that can automatically identify possible landing zones based on operational criteria and data from maps and satellites. A quick on-site reconnaissance of the possible landing zone is preferred for updating and refining the data.**

### THE CHALLENGE

The reconnaissance must be carried out not only quickly and silently but also with a high degree of accuracy. Good sensors let a drone achieve the required accuracy. The drone has to have a large flight radius. The specialists land by parachute; the drone has to be carried in a backpack and must therefore be small and lightweight. These are challenging requirements. Can ditches and pits in the terrain be detected by a sensor in a small and silent drone?

### WHAT DID WE DO

In this feasibility study, NLR analysed the client's operational requirements and the software requirements for achieving the accuracy needed, resulting in a set of requirements for an operational drone and sensor. Using this set of requirements, a selection was made for the drone demonstrator. The assignment was not to design a new operational drone but to investigate its feasibility, focusing on (a) selecting a sensor with the required accuracy, the overlap in photos and (b) investigating if the sensor can be installed in a quiet and lightweight drone that fits in a backpack. A cheap and commercially available fuselage with wings was fitted with a motor, propeller and flight controller. An existing sensor has been selected and fitted; additional preview software allows the overlap to be determined immediately after the drone's reconnaissance flight.

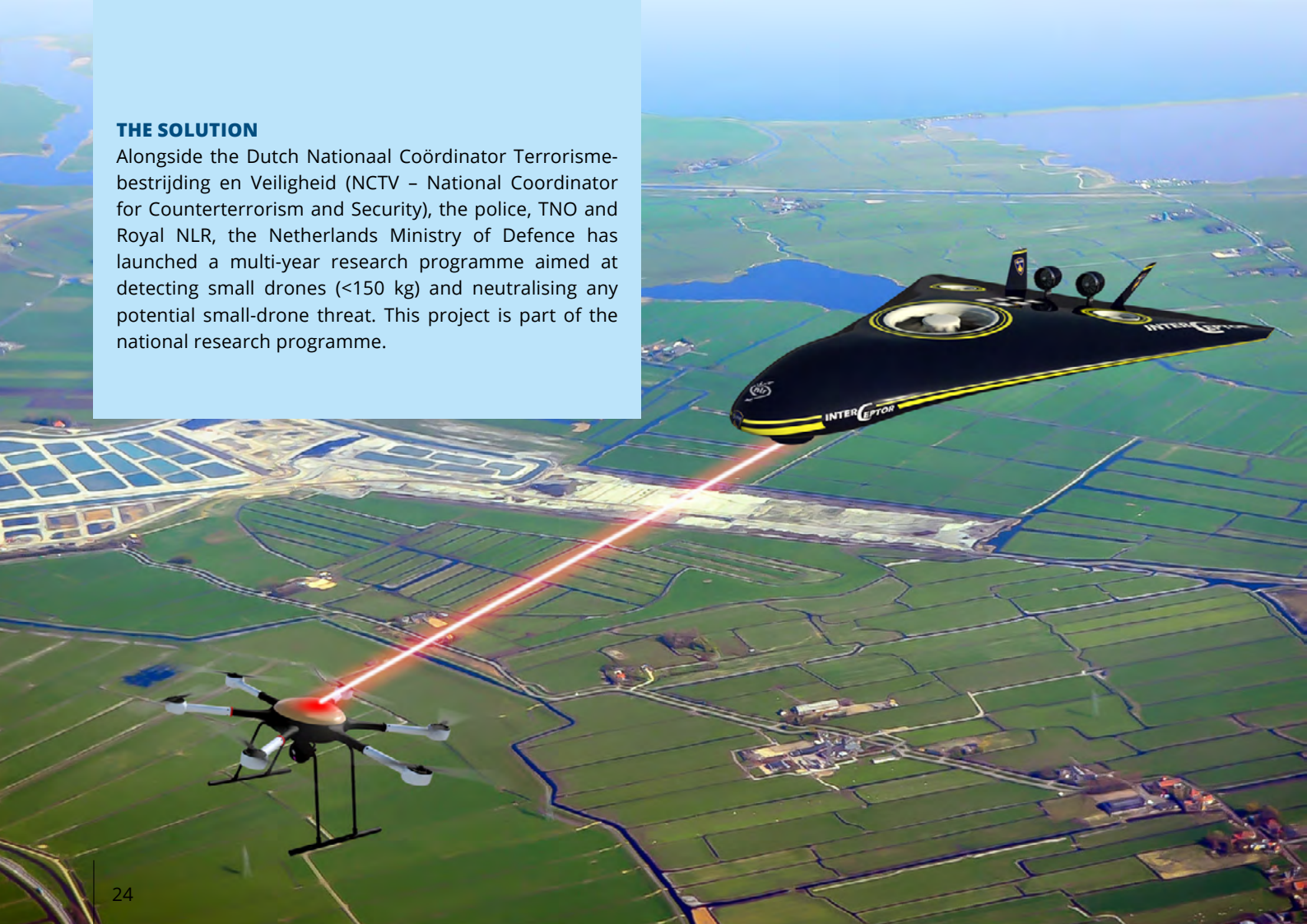
## THE SOLUTION

Taking several overlapping sets of pictures from the drone allows height differences in the terrain to be determined. The software that identified the possible landing zones can perform a new analysis based on the height differences derived from the pictures. The pictures also show the current situation on the ground. Overlap is required both along the flight direction and crosswise to it, necessitating numerous overlapping tracks over the area. This requires a small, silent and energy-efficient drone with a suitable and accurate sensor with specific software.

**Project partners**
Government: Ministry of Defence
Industry: CGI
Research organisations: Royal NLR

## THE SOLUTION

Alongside the Dutch Nationaal Coördinator Terrorisme-bestrijding en Veiligheid (NCTV – National Coordinator for Counterterrorism and Security), the police, TNO and Royal NLR, the Netherlands Ministry of Defence has launched a multi-year research programme aimed at detecting small drones (<150 kg) and neutralising any potential small-drone threat. This project is part of the national research programme.



# Counter Unmanned Aircraft Systems (C-UAS)

**UAS systems are increasingly becoming part of our society and are usually easy to obtain. Continuous and rapid technological developments mean these systems are becoming more advanced and can easily be adapted to the user's wishes. This also gives rise to applications for violent use against both civil and military systems and persons.**

## THE CHALLENGE

Measures against UAS are often still technologically immature, scarce and expensive. This means research is required on effective and affordable countermeasures for both military and civilian applications. With the Counter-UAS programme, the Netherlands wants to advance the technological ways of stopping a possible drone threat. Countermeasures must consist of layered possibilities for fast (real-time) detection, identification, tracking and neutralisation of hostile UAS, where collateral damage is minimised.

## WHAT WE ARE DOING

This NLR research programme builds up innovative knowledge, expertise and infrastructure to support the National Police, the Netherlands Armed Forces, NCTV and other (semi-) governmental organisations in the development of effective measures against UAS. This includes both the sub-aspects relating to threat characteristics, the detection of these threats, the techniques and methods to counter the threats, and the technical integration. These aspects require innovative solutions because of their technological complexity.

**Project partners**
Government: Ministry of Defence, Ministry of Justice & Security, NCTV (all NL) and NATO
Research organisations: Royal NLR, TNO

# AIRTuB: Automated Inspection and Repair of Turbine Blades

**Offshore wind energy plays a major role in the transition to green energy. The wind turbine blades require periodic inspection. The inspection and repairs are carried out by specialists who descend along the blade on a cable. This is very labour-intensive and an even greater challenge offshore. The AIRTuB consortium developed systems that are mounted on a drone and that can automatically inspect the wind turbine blade and carry out repairs if necessary. Regular inspection allows repairs to be planned in a windless period which prevents loss of production.**

## THE CHALLENGE

Flying offshore, close to a wind turbine blade at 100 metres high with a lot of turbulence, requires high demands from the drone vehicle. When inspecting the leading edge of the blade, the drone must follow a flight path very accurately and within 2 metres of the blade. During the inspection, the drone must land on the wind turbine blade and be able to drop off and pick up a crawler with sensors.

## THE SOLUTION

Within AIRTUB1 a dedicated drone, inspection sensors and a crawler have been developed. The drone has an advanced flight controller and a positioning system that determines position and orientation of the drone relative to the blade. A drone has been built in which these systems will be integrated and that can carry out the inspection safely with the sensors and crawler, and follow the planned flight path very accurately in such a turbulent environment. In the first phase the drone will be flown from a ship, subsequently the drone will be resided on the wind farm.

By gaining experience with these systems, it is expected that a new version of systems can become lighter, which will also make the crawler and drone lighter.

## WHAT DID WE DO

NLR has built the drone, 60kg MTOM, that can transport the inspection systems and perform the inspection of the turbine blades. The drone is suitable for the hostile offshore environment and equipped with safety systems. NLR also developed a sensor for inspecting the construction. The drone has already flown with the crawler and leading edge inspection sensor. In addition, a special undercarriage has been developed with which the drone can land on the curved (composite) blade and attach itself to the blade. The drone is ready to install the advanced flight controller and the positioning system.

AIRTuB

**project partners:** WCM, Demcon, TNO, TU-Delft, Hogeschool Zeeland, Stork, Eneco, LM Wind Power, Fusion, Stork, DCMC , Saxion, QLayers, Dutch Terahertz, InHolland
**Subsidy provider:** RVO


FREESPACE

# Performing ILS inspection on airports with drones

**Instrument Landing Systems (ILS) at airports are periodically calibrated using an aircraft equipped with a Flight Inspection System, such as the NLR Citation II research aircraft. If the ILS works well, and the transmission is free from disturbances, some periodic measurements can be carried out from or near the ground. This comprises Reduced Flight Inspection (ReFI). The main benefits of ReFI are 65% lower calibration cost, 90% less environmental impact (noise, emissions), and higher runway availability. The ground measurements can be carried out via Drone Flight Inspection (DFI). Therefore, NLR started developing DFI.**

## THE CHALLENGE

To reduce the impact of periodic ILS flight inspections on airport operations and the nearby community. The goal is to apply Drone Flight Inspection (DFI) and to achieve approximately 90% less flight inspection runs, and 65% less ILS calibration cost.

## THE SOLUTION

Royal NLR is developing a NLR-DFI system to apply ReFI with DFI, based on an RPAS equipped with the capability for accurate positioning, ILS signal reception, and data processing and communication.

## WHAT ARE DOING

In order to minimise development cost, NLR acquired a robust industrial drone, an industrial ILS analyser, and an industrial RTK GPS navigation solution. NLR designed dedicated ILS antennas and industry manufactured these. We developed in-house DFI processing and control software, reusing as much as possible Open Source code. The DFI for ILS signal reception was optimised by using synthetic materials where possible (e.g. propellers, undercarriage). All DFI runs have been designed and verified in-house. All DFI runs can be flown in automated flight mode, ensuring repeatability of the results. The testing of the DFI system and preparation for the validation took place in 2023, the operational level demonstrations will be carried out end 2023-2024.

# DELMO: multirotor payload drone with separate propellers for lift and control

**NLR has developed the DELMO drone (DEdicated Lifting MOtors). An innovative concept for a multirotor drone with two different sets of propellers to optimise the performance, energy consumption and noise impact.**

Multirotor drones are controlled by means of variations in revolutions per minute (RPM). Greater RPM means more power, which is used for stability and control. RPM variations of a large propeller cost a lot of extra force and therefore generate higher peak currents. Peak currents are risky for electrical and electronic components, because they often reach the maximum current the systems can handle. This can cause these components to break down sooner, which reduces operational safety and shortens maintenance intervals. The challenge is how to reduce peak currents in a multirotor drone.

Also, unlike traditional helicopters, multirotor drones do not have rotors with a constant rotational speed (RPM). This means that the rotors are more difficult to optimise from an aerodynamic point of view, because the airflow conditions are constantly changing. This results in the performance of these "classic" drones is only optimal in a limited range of RPM conditions.

## THE DELMO CONCEPT

The DELMO prototype has two large rotors which carry about 70% of the total weight. The other four smaller rotors are used to produce the remaining thrust and to control (stabilise and move) the drone. In this concept, the large lifting rotors are constantly active and rotate with a constant RPM, which requires a steady current and thus avoids peaks. The four smaller rotors rotate with a variable RPM for the stability and control, while generating less peak currents due to the small size of the rotors. As the majority of the lift is carried by the large lifting rotors at constant RPM, the performance of the drone can be better optimised than "classic" drones. Finally, a constant RPM is also more suited to reduce noise annoyance since the noise pollution from the lifting rotors is not varying. A specific noise frequency can be targeted and noise mitigations specific to a constant frequency incorporated.

The technological solutions experimented in DELMO can aid the implementation of drones as means to transport payload in a variety of applications, from urban settings to defence applications.

*DELMO is a prototype supported by the NLR Living lab, the social and technological disruptive innovation hub within Royal NLR.*


22.71
0.62
0.00
229.86
-0.07
48.60

# Beyond Radio Line Of Sight (BRLOS)

**Drone operations are often performed with a direct telemetry link enabling the pilot to control the drone. This is not possible if the drone is too far away or it disappears behind obstacles; this is called 'Beyond Radio Line of Sight' (BRLOS), where the telemetry link is not direct but occurs through the 4G mobile phone network, for example. This offers a range of new commercial operations, including in the Netherlands. But the mobile phone network is intended for mobile phones on the ground, not for flying drones.**

## THE CHALLENGE

If the network is received somewhere on the ground, that's not to say that it can also be received at flying altitude. And if the connection is occasionally interrupted, that's annoying during a telephone call but is unacceptable if it makes a drone uncontrollable. NLR's ambition is to support the Dutch government and industry in conducting BRLOS operations safely through the mobile phone network. This Moonshot is intended to acquire the basic knowledge for this in the short term, and to build up practical experience.

## THE SOLUTION

An NLR drone was equipped with a 4G telemetry system, and then flown and piloted from NLR Amsterdam using the 4G network, with a safety pilot at the Drone Centre who could take over the controls.

## WHAT ARE WE DOING?

Commercially-available equipment for controlling a drone through 4G was built into a drone. A separate VPN connection had to be set up to meet NLR's security criteria. The drone flew above NLR Marknesse while the pilot was at NLR Amsterdam, controlling the BRLOS drone through the internet and Vodafone's 4G network. The findings have been set out in a report, and follow-up steps are being drawn up.

**Project partners**
Research organisation: Royal NLR

# NOVAIR; Demonstration of Distributed Electric Propulsion on a scaled aircraft

**The NOVAIR (Novel Aircraft Configurations and Scaled Flight Test Instrumentation) project focuses on the potential benefits of hybrid electric propulsion on Large Passenger Aircraft for sustainable aviation. Promising aircraft configurations and technologies have been investigated and the partners have decided to specifically study and demonstrate distributed electric propulsion.**

## THE CHALLENGE

Significant reduction of energy consumptions have been calculated when integrating of distributed propulsion on the aircraft. The investigation and demonstration of this project aims to reduce the risks applying this technology in the aircraft development process. Scaled flight testing has been validated in the Clean Sky 2 programme as a valuable tool in the aircraft development process. Dynamics and control characteristics can be investigated before building a full-scale prototype aircraft, which allows harvesting more benefits of new technologies such as distributed electric propulsion

## WHAT ARE DOING

A 4 meter wing span scaled aircraft with a mass of 160 kg has been designed, built and tested in the wind tunnel. In the wind tunnel, aircraft systems have been operational, moving the control surfaces and powering the propellers. Taxi tests are in progress and will be followed with measurement flights in mid 2023.

During the wind tunnel test and the measurement flights, accurate instrumentation records aircraft and flight parameters. Dynamic manoeuvres will be flown in the flight tests using an autopilot to derive flight characteristics. Modeling the aerodynamics and the flight dynamics is an integral part of the investigation to support the design of the scaled aircraft, to train the flight crew, to develop control algorithms and to support the analysis of results. Analyses will focus on implications for the full-scale aircraft with distributed electric propulsion and a better understanding of how to implement this technology

## THE SOLUTION

A scaled aircraft has been developed and manufactured that is equiped with Distributed Electric Propulsion. Six propellers are installed on the wing. The aerodynamics, dynamics and control of the scaled aircraft are measured in the wind tunnel and in free flight. This provides a wealth of information. Investigations include utilising the wing tip propellers and differential thrust to minimise the energy consumed in a flight. Results will be transposed to implications for the full-scale aircraft.

**Project partners**
Airbus, ONERA, CIRA, TU Delft, Orange Aerospace, Royal NLR
**Funding**: EU Clean Sky 2 Large Passenger Aircraft (LPA) Programme


**Project partners**
Research organisations: Royal NLR
Industry: Avy, CryoWorld
Universities: TUDelft/AeroDelft

# HYDRA-2: Hydrogen Drone Research Aircraft

**Hydrogen as a fuel is considered to be an important alternative for future sustainable aviation. When produced from green energy sources, hydrogen delivers zero $CO_2$ emissions – only water vapour. Hydrogen is a light-weight fuel with a 3-4 times higher energy density than kerosene. It can be stored in tanks both in gaseous and liquid form. It can be burned in conventional combustion engines, as well as transferred highly efficiently into electric power with fuel cells, as an alternative to batteries.**

## THE CHALLENGE

Although the use of hydrogen has been employed widely in other industries for many years, the introduction of hydrogen on board aircraft is a major technical challenge, not to mention the tremendous certification effort that's required. It has a significant impact on the aircraft architecture, powertrain components and operations, as well as on the ground infrastructure.

## THE SOLUTION

Drones offer an ideal platform for testing hydrogen technologies safely on a smaller scale and at relatively low cost. Hydrogen also offers an extended flight duration and distances beyond what's possible with batteries. This is highly relevant for commercial applications like transporting medicines or cargo, or for first responders or surveying.

## WHAT WE ARE DOING

In cooperation with Dutch industry and universities, NLR obtained first-hand experience in designing, selecting, testing and improving hydrogen components (both gaseous and liquid) suitable for drones, as well as extensive safety analysis and test procedures. The HYDRA projects support the standardisation and certification of hydrogen drones for commercial applications, while also preparing for upscaling for large manned aircraft. The first flight of the liquid hydrogen drone is expected to take place in mid 2023.

# ISABELLE : Integrated Steerable Antenna for Beyond Line-of-sight L-band data Exchange

**The market for satellite communications for Unmanned Aerial Vehicles (UAV) is expected to grow significantly over the coming years. The growth of the UAV sector follows from the diversity of potential applications. Among the earliest applications of UAVs for civil use are the so-called dull, dirty or dangerous tasks (e.g. performing oil and gas exploration surveys). To operate a UAV routinely Beyond Visual Line Of Sight (BVLOS), one needs a SATCOM link between the UAV and the Remote Pilot Station (RPS).**

### THE CHALLENGE

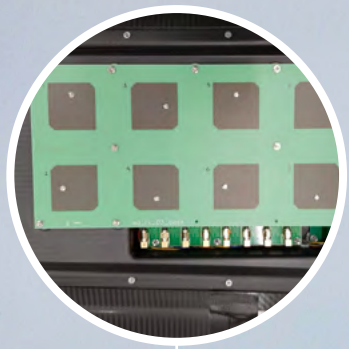
Its dimensions mean accommodating any satellite antenna into small-sized UAVs may be an obstacle. The project has developed an integrated satcom array antenna, taking the electromagnetic, structural and thermal aspects of the antenna integration into account.

### THE SOLUTION

Available surfaces such as the wing and tail can be used to integrate antenna arrays. The objective of the ISABELLE project was to demonstrate by design, manufacture and testing, the viability of an embedded antenna array with real-time adaptive beam forming, where the antenna is integrated into the wing structure of the UAV.

### WHAT WE ARE DOING

- Provide an overview of the available satellite services and antennas for satellite communication.
- Selection of applications that benefit most of the use of the integration of antennas in the mechanical structure of the UAV.
- Definition of an antenna concept, antenna architecture and antenna requirements.
- Creating a preliminary design of an array antenna integrated in the wing of a UAV.
- Design, manufacturing and testing of a number of the antenna system's critical components.
- Manufacturing of the antenna arrays, the beam formers and the antenna control.
- Measurements to characterise the manufactured components.
- Ground tests, flight tests and a demonstration of the antenna performance during flight



**Project partners**
Client: European Space Agency (ESA)
Partners: Royal NLR, Orange Aerospace, Bernard Microsystems

*ESA Contract N° 4000123386/18/NL/NR*
*'Embedded antenna arrays in small uav wing structures'*


NLR Marknesse
NLR Drone DigiCity
NLR Drone centre
Runway 320 M

# NLR Drone centre

**NLR set up the NLR Drone Centre in 2015. Here, tests and evaluations of (prototype) RPAS and sensor applications are conducted, demonstrations are facilitated, flight inspections are carried out and drone practical training and technical examinations are given.**

The NLR Drone Centre has its own restricted airspace with the necessary authorisations and exemptions to facilitate these activities. It offers developers, manufacturers and business users, both civil and military, the opportunity to carry out test flights needed to take advantage of the economic opportunities offered by RPAS developments. The NLR Drone Centre is located at NLR's premises in Flevoland, and complies with all government requirements.

## RESTRICTED AIRSPACE

Only aircraft and pilots who fulfil all the statutory requirements may fly in Dutch airspace. The NLR Drone Centre has more extensive dispensation: for example, it is permitted to fly prototypes that do not yet meet all the requirements. The airspace above the NLR Drone Centre is closed to other users, and the territory is also a restricted and closed area. Herewith fulfilling a significant need for drone development and the technology it requires, such as detect-and-avoid sensors that prevent drones from coming too close to other air traffic. In this way the centre supports the development and use of drones and integrating drones safely into civil airspace, and acts as a 'one-stop shop' for the drone sector. With its drone expertise, NLR builds on its integrated knowledge of the entire aerospace chain, using its extensive test and research facilities for this purpose.

# NLR Drone DigiCity
# The new test facility for launching UAM

**NLR Drone DigiCity is the new facility at the NLR Drone Centre in Marknesse. Businesses and organisations can experiment and test their drones and UAS systems here in a flexible operational simulated urban environment. To monitor this environment, a measurement system is being developed with a digital infrastructure (such as 5G) plus all kinds of sensors and measurement devices in the city and on the drone. This 'smart city' comprises sixteen shipping containers that can be configured in various ways. Assessing how 'city-proof' the drones are will show what is still needed before they can be used in practice. This will help simplify the licensing process and reduce the time to market.**

### DIGICITY CO-MAKER SPACE

In addition to the outdoor testing facility, there will also be an indoor component. Companies, start-ups and organisations can use a co-creation workspace (workstations and workshop) in the NLR Drone Centre and Drone DigiCity building, where they can prepare and monitor experiments and tests together with NLR's experts. This also includes the technical measurement and analysis rooms and the 'digital twin' (as it is known) of the outdoor test environment.

### TRANSPORT DRONE ON HYDROGEN

Shore is launching customer at NLR Drone DigiCity, collaborating with NLR on the development of a VTOL transport drone fuelled by hydrogen. The aim is for this device to be able to carry a payload of 15 kg and have a flight time of 2 to 3 hours.

NLR's expertise in hydrogen power will let it make a major contribution to the design and execution of the test and demo flights.

### NLR DRONE DIGICITY OFFERS:

- An operational simulated urban environment (16 shipping containers in flexible configurations)
- Technical measurement and analysis rooms and (from the end of 2023) a digital twin of the outdoor test environment
- Closed airspace EHR66 (0 to 1500 ft / 3500 ft) with permanent BVLOS and airport arrangements
- Landing runway of 325 x 15 m
- Co-working space with workstations and a workshop (from mid-2023)
- Access to NLR's unique R&D expertise and facilities in drones and aeronautics



G4P4 Kansen voor West II

NLR Drone DigiCity

NLR Drone DigiCity is being implemented through a grant from Kansen voor West under REACT EU and NLR


SURV
COM
UAS 1
12:30:45

# MUST: Multi-UAS Supervision Testbed

**MUST is NLR's testbed for operating unmanned systems. It provides a workplace for an RPAS crew that can be used for controlling multiple RPAS craft at the same time. MUST offers standard functionalities, while also being fully customisable as required. The MUST architecture supports the control of operational and simulated RPAS; this has also been demonstrated in practice. One aspect making this possible is the STANAG 4586 compatibility.**

MUST is an integrated component of NLR's Airpower Simulation, where all the NLR simulators can be linked flexibly as required for a variety of missions. For example, MUST has connections to Fighter 4-Ship (F4S), Helicopter Pilot Station (HPS) and Virtual Battlespace (VBS). This makes manned-unmanned teaming (MUM-T) concepts possible, for instance.

MUST can also be coupled to NLR's Video Exploitation System (VES), allowing MUST to be utilised as an element of an actual or simulated data-to-decision chain. Moreover, for carrying out tests for the integration of RPAS craft in controlled airspace, MUST is also linked to NARSIM. NARSIM is NLR's simulation environment for radar and ATC towers. This connection offers options for testing new concepts with RPAS, from the perspectives of both the ATC (e.g. in a tower) and the RPAS crew.

# About NLR

## Royal Netherlands Aerospace Centre

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

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

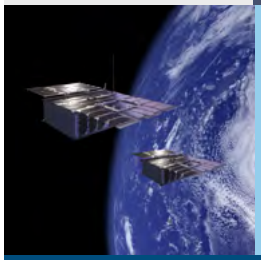
Royal NLR stands for practical and innovative solutions, technical expertise and a long-term design vision, regarding their fixed wing aircraft, helicopter, drones and space exploration projects. This allows NLR's cutting-edge technology to find its way also into successful aerospace programmes of OEMs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

# NLR in brief

AMSTERDAM, MARKNESSE, ROTTERDAM, BRUSSELS

1000+
STAFF

144M
TURNOVER



SINCE
1919

FOR INDUSTRY, GOVERNMENT, CIVIL, DEFENCE AND SPACE

78% DUTCH, 17% EU & 5% WORLDWIDE

GLOBAL PLAYER WITH DUTCH ROOTS ACTIVE IN 24 COUNTRIES

VERY HIGH CUSTOMER SATISFACTION

The development of drones is moving fast in every conceivable field. NLR has been leading the way for years. NLR has been providing theoretical training since 2013 and in 2015 it became the first institute to train drone operators in the Netherlands. It was also the first party authorised to certify drones for use in the Netherlands.

NLR operates as a “centre of drone expertise”. It offers expertise and facilities to provide valuable assistance to companies and governmental authorities, for example in designing, testing and certifying quieter drones that can fly further, as well as in integrating drones into the airspace (including in urban areas). NLR supplies the technology, assists with the operation and provides advice about policy and regulations. Furthermore, NLR can offer support in preparing civilian applications such as medical transport and incident response, and in research into defensive applications, e.g. counter-drones for events or interceptor drones.

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E1830-03 - May 2026