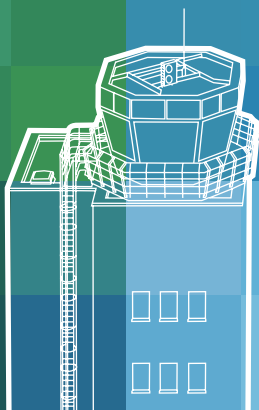
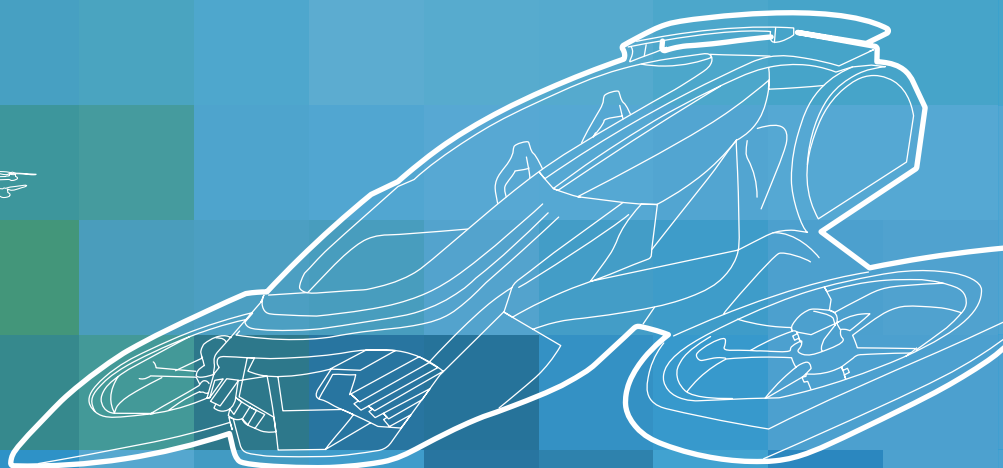
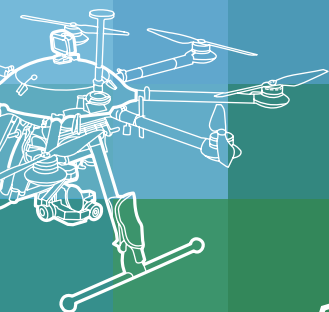


THE NATIONAL EXPERIMENTAL TEST CENTER FOR
UNMANNED AIRCRAFT SYSTEMS
AND UAS RESEARCH AT DLR



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Unmanned flight at DLR

Unmanned flight technology is becoming increasingly important for future mobility. Unmanned Aerial Systems (UAS) are already being used in areas such as disaster relief and the transportation of medicines. The entire unmanned air transport sector is experiencing rapid growth, accompanied by the development of novel concepts and technologies that are giving rise to a whole new industry.

Air-based mobility solutions will become part of future transport planning at local and regional levels. This urban air mobility will present researchers and industry with numerous challenges in the future. In preparation, DLR is driving forward UAS research in an interdisciplinary manner as a strategic focus at many of its institutes.

In the summer of 2019, the DLR Senate approved the establishment of the National Experimental Test Center for Unmanned Aircraft Systems in Cochstedt, which is funded by the German Federal Government and the state of Saxony-Anhalt. The facility is becoming the centre of a highly innovative network for UAS research that is unique in Europe. The airfield offers a full range of technical and scientific capabilities to support joint developments with established industry partners and start-ups, as well as cooperation with authorities for the creation of new regulatory frameworks. With these objectives, DLR is combining all of its expertise and enabling the development and realisation of new technologies in the field of UAS.

In our work, we focus on more than just individual technologies: we consider the system as a whole. We therefore see ourselves as architects, engaging in fundamental research through to the development of applications in close coordination and cooperation with industry, academia and government bodies. The path towards efficient and safe urban air mobility involves a disruptive approach with a high degree of innovation. To this end, the test centre in Cochstedt will facilitate the networking of research, industry and government.



A handwritten signature in blue ink that reads "Anke Kaysser-Pyzalla". The script is fluid and cursive.

Professor Anke Kaysser-Pyzalla, Chair of the DLR Executive Board

Europe's unique testing infrastructure for cutting-edge UAS research

The German Aerospace Center (DLR) has been conducting cutting-edge research into Unmanned Aerial Systems (UAS) for many years through its specialist institutes. This research drives the need for an array of test scenarios and requirements, giving the Test Center a pivotal role as an integrative support function within the UAS landscape. This brochure gives a brief overview of UAS, before going on to introduce the DLR institutes that are focusing on UAS research. It offers insights into various research projects and illustrates the wide range of potential applications for UAS.

The Test Center has been developed and built to reflect these possible applications and usage scenarios, with a view to providing optimal usability and as much support as possible for research, industry and official bodies. We have invested six million euros in the Test Center infrastructure in 2020 alone, four million of which is solely for scientific purposes. Although this brochure presents DLR's work, the Test Center is also available to users and for projects from German and international industry and research institutions.

At this point, it is worth mentioning one particular aspect of the Test Center that is not explicitly addressed elsewhere in this brochure. In addition to creating a UAS testing infrastructure that is unique within Europe, we will also continue to run a 'normal' airport (with reduced capacity) in Cochstedt, in parallel to our UAS operations. This will allow us to acquire knowledge that can be applied to future projects. This is an additional challenge for

DLR and will help create more testing opportunities for research institutions and industry, as well as assisting regulatory authorities and informing processes.

Ongoing discussions with representatives from industry, research institutions and government bodies, as well as with people from the local region, have shown that this site offers enormous potential for the development of UAS technologies. After all, safe yet comprehensive testing options are integral to the validation and certification of new technologies and are instrumental in encouraging wider acceptance of them. We are therefore looking forward to future developments, the start of new partnerships and the consolidation of existing ones, and ultimately the contribution that the Test Center will make towards future air transport.



Jean Daniel Sülberg

Director of the National Experimental Test Center
for Unmanned Aircraft Systems

Unmanned Aerial Systems – a versatile technology for the future

Overview

The air transport industry is set to undergo significant changes due to the emergence of new technologies and business models, against a background of greater environmental awareness among manufacturers and users. The sector will already look very different by the end of the 2020s than it did at the beginning of the millennium. **Unmanned aerial systems** will be a major factor in this development.

The term ‘Unmanned Aerial System’ (UAS) refers to an overall system consisting of an Unmanned Aerial Vehicle (UAV) and the associated control facilities (for example, ground stations for ‘remote control’), data links for communication and navigation purposes and any additional safety systems. The term ‘drone’ was originally used solely to denote UAVs deployed for military purposes, but it has since spread into common usage and often describes commercially available flight systems. When talking about UAS, the term ‘unmanned’ simply refers to the **absence of a pilot** on board the aircraft. This does not preclude the presence of passengers on board a UAS. In addition people on the ground may still be involved in operating the UAS.

Passenger transport is one of the most prominent areas of focus in the development of UAS. The term **‘Urban Air Mobility’** (UAM) is most commonly used for this type of transport within urban areas or on short-haul routes between cities. In the field of UAM, there are two different take-off and landing options for UAS – electric vertical take-off and landing (**eVTOL**) and (hybrid-) electric short take-off and landing (**eSTOL**).

Aside from passenger transport, there are a **variety of other applications for UAS**. One primary application is in the area of **logistics**, especially the use of UAS as ‘delivery drones’ for parcels and all manner of goods, or for the just-in-time supply of replacement parts. Other possible applications in this area include inventory management in large warehouses. A number of companies are already using UAS-based services for **inspection, diagnosis and maintenance tasks**, for example on wind power and solar plants, bridges, buildings and pipelines or railway lines. UAS are also well suited to applications in **agriculture and forestry**. To give one example, UAS-based determination of plant health via hyperspectral analysis will contribute towards a more targeted use of fertilisers and pesticides, thus ensuring better protection of the environment and groundwater. **Emergency services** will also benefit from the use of UAS in the future. By performing initial aerial reconnaissance, conducting radiation measurements and analysing hazardous substances without putting human lives at risk, UAS can provide considerable added value in acquiring situational awareness in the event of a crisis or disaster. They can also be used to search for people or monitor complex emergency services operations. Last but not least, UAS can prove instrumental in **humanitarian aid** by transporting relief supplies to areas that are inaccessible following flooding or other disasters.

New fields of application are constantly emerging due to the broad-based applicability of different UAS. **High-altitude platforms** (HAPs) merit a particular mention here. HAPs tend to be

solar-powered and can therefore achieve very long flight times at high altitudes (above eight kilometres), so they can serve as an alternative to ground- and satellite-based communications systems. They can be used to provide regions that have poorly developed infrastructure with access to communications and information. UAS can also be used in the field of **medical care**, especially in telemedicine, and, looking to the future, for rescue services.

Challenges to the success of UAS

Conventional propulsion systems (those that employ combustion) are being replaced by **new concepts** in the interests of the environmentally friendly, sustainable operation of UAS. Current developments are mainly based on **battery-electric drives**. The energy density currently available from rechargeable batteries is the principal factor limiting the range and scope of applications for UAS. This is proving a particular challenge in the UAM field with eVTOLs and eSTOLs, which require very large amounts of energy during take-off and landing. For this reason, more advanced concepts such as **hybrid-electric propulsion systems** and the use of **fuel cells** are now under investigation.

The absence of a pilot within the aircraft means that at least some degree of **automation** is required in any UAS. Even in the case of flights that are ‘remote controlled’ from the ground, the aircraft must assist the operator on the ground with suitable

sensor systems and control technologies. This is particularly applicable for flying ‘Beyond Visual Line Of Sight’ (BVLOS), the situation upon which most UAS applications are based. In addition, many commercial applications only really become cost-effective if they no longer require control and monitoring from the ground. This means that the ultimate aim is UAS autonomy, which poses a major challenge for sensor systems and control technologies, especially if a large number of UAS are to be used at the same time. UAS operation based on complete **autonomy**, with no human intervention required, calls above all for advances in the field of Artificial Intelligence (AI) and the ability to certify autonomous systems in air transportation.

In addition to the various requirements of vehicle and system technologies, UAS **airspace integration** and new **regulations and laws** in the field of UAS pose further challenges. When it comes to integration into airspace, the emphasis is on areas such as flight and swarm control (including the underlying communications and navigation technologies) and the regulation of lower airspace, which is the purpose of the U-Space concept being developed in Europe.



Institute of Aeroelasticity (AE)

The Institute of Aeroelasticity deals with physical phenomena that occur in nature and engineering, particularly in aircraft. Airplanes must be extremely lightweight in construction, therefore the structures are relatively flexible. Their interaction with aerodynamics is such, that 'aeroelastic' deformations and vibrations can lead to issues that have far-reaching technical consequences in flight. Multidisciplinary research work and industry contracts are carried out at the institute, with the aim of reliably predicting aeroelastic behaviour and demonstrating it during flight tests. In this way new designs can be developed in such a way that they are safe to operate. Numerical analysis and experimental methods for real-time analysis in flight tests are developed and applied for this purpose.

The FLiPASED project

Future aircraft need to be lighter and more fuel efficient, but the possibilities for reducing the weight of aircraft wings using conventional design methods have been practically exhausted. The EU project FLiPASED (the successor to FLEXOP), with partners SZTAKI, TUM, ONERA and DLR, set itself the objective of investigating new possibilities by using a seven-metre wingspan model in a demonstrator.

Two wings were designed using new, weight-optimised design methods and assembled together with a standard wing. Initially, their vibration behaviour was studied in a Ground Vibration Test as part of the FLEXOP project at the DLR Institute of Aeroelasticity in Göttingen, in order to examine the effectiveness of the new wing designs.

The standard wing model is made of carbon fibre. The first innovative wing design, constructed using glass-fibre-reinforced composites, referred to as the 'flutter wing', was created by the Technical University of Munich. A new type of flight control system, designed at the DLR Institute of System Dynamics and Control in Oberpfaffenhofen, is intended to keep the aircraft aeroelastically stable and thus prevent the 'flutter effect' from occurring. A second flight control system was designed by the Institute for Computer and Automation Research of the Hungarian Academy of Sciences (MTA SZTAKI). The use of such a wing would enable the aircraft to transport 20 percent more freight or reduce fuel consumption by 7 percent.

The 'aeroelastic wing' is also currently undergoing testing. This has been jointly developed by the DLR Institute of Aeroelasticity and the University of Delft. It is also made of carbon fibre but has a number of special properties. Not only does the new wing bend under load, it also twists to a significantly greater degree than



Flight test with the FLEXOP demonstrator in Oberpfaffenhofen

present-day wings. This allows the aeroelastic wing essentially to avoid the greatest loads in flight, while proving just as stable as the standard wing despite being 20 percent lighter.

The use of an aeroelastic wing could give an aircraft the ability to transport 20 percent more freight or reduce fuel consumption by seven percent

This is made possible by the specially optimised, unconventional layer structure of the material. This aeroelastic wing and the standard wing were flight tested at the the special airport in Oberpfaffenhofen as part of the FLEXOP project. More tests are planned with the flutter wing in 2021, this time from Cochstedt, to demonstrate its effectiveness.

Director of Institute
Professor Dr.-Ing. Lorenz Tichy

DLR's A320 ATRA research aircraft, equipped with various noise-reducing modifications, flies over acoustic measurement systems at Cochstedt Airport



Institute of Aerodynamics and Flow Technology (AS)

The Institute of Aerodynamics and Flow Technology is a leading research centre in the fields of aircraft aerodynamics, aeroacoustics and space aerothermodynamics. It is based in Braunschweig and Göttingen and also has a department in Cologne. Over 350 personnel conduct theoretical, numerical and experimental investigations on aircraft and spacecraft, with experiments carried out in wind tunnels or during flight tests.

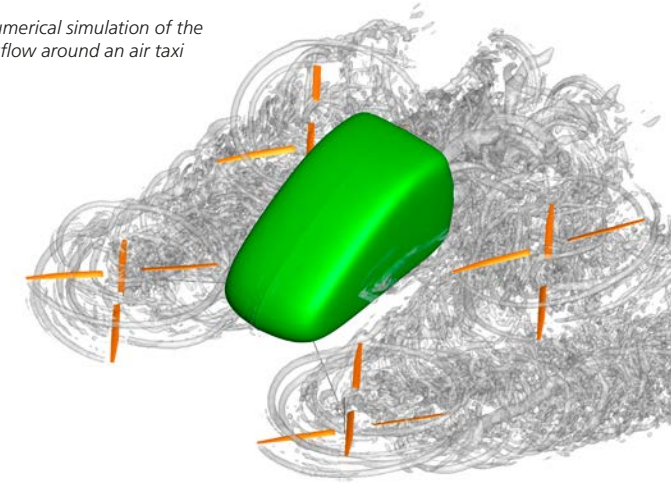
Numerical predictions and experimental measurements for efficient transportation in the future

Environmental policy is playing an increasingly important role in air transport. Accordingly, the DLR Institute of Aerodynamics and Flow Technology is investigating how means of transport can be designed and operated in a manner that is more efficient, environmentally sustainable, convenient, cost-effective and safe. Another of its core areas of expertise is the development of software products for aerodynamic and aeroacoustic simulations.

Contributions to UAS research

UAS need to have capacity for long flight duration and safe operation in all flight and wind conditions, so their aerodynamic design must be optimal. As UAS will be used above populated areas, their noise impact on local residents also needs to be minimised.

*Numerical simulation of the
airflow around an air taxi*



Research into UAS at the institute includes the following:

- Performing numerical flow calculations, predicting flight performance and characteristics, optimising aerodynamic design
- Providing numerical predictions of sound radiation, implementing noise reduction measures, specifying trajectories for minimal noise
- Measurement technologies for aerodynamic and acoustic flight tests and wind tunnel experiments.

The institute is looking at the aerodynamics and sound radiation of drones and air taxis with a view to their future use for the unmanned transportation of goods or UAM as part of the ongoing AACID, CHASER and UrbanRescue projects. Key areas of focus in the research are wind tunnel tests to obtain aerodynamic and acoustic reference data, and the development of numerical prediction methods. The findings will be used to design an air taxi and evaluate the noise impact on local residents.

Head of the Braunschweig site:
Professor Cord-Christian Rossow

Head of the Göttingen/Cologne sites:
Professor Andreas Dillmann



Institute of Structures and Design (BT)

High-performance structures for aerospace, vehicle construction and energy technology are a key focus at the Institute of Structures and Design.

The research conducted at the Stuttgart site ranges from the development and optimisation of materials and their associated process and joining technologies to new design approaches and the construction of full-scale demonstrators and their testing and validation in dedicated facilities or through in-flight tests. The development of new multidisciplinary design tools and digital models serves as the basis for design and component development.

Researchers at the Augsburg site are examining the industrialisation potential of lightweight production. The work focuses on new technologies geared towards the robot-based, automated production of lightweight structures and process-integrated quality assurance and the way in which this feeds back into structural technology and design. The main strategic thrust is research throughout entire process chains, full-scale capability for validation and the consistent digital integration of all elements in the process chain for Industry 4.0.

Interdisciplinary structural design of UAS

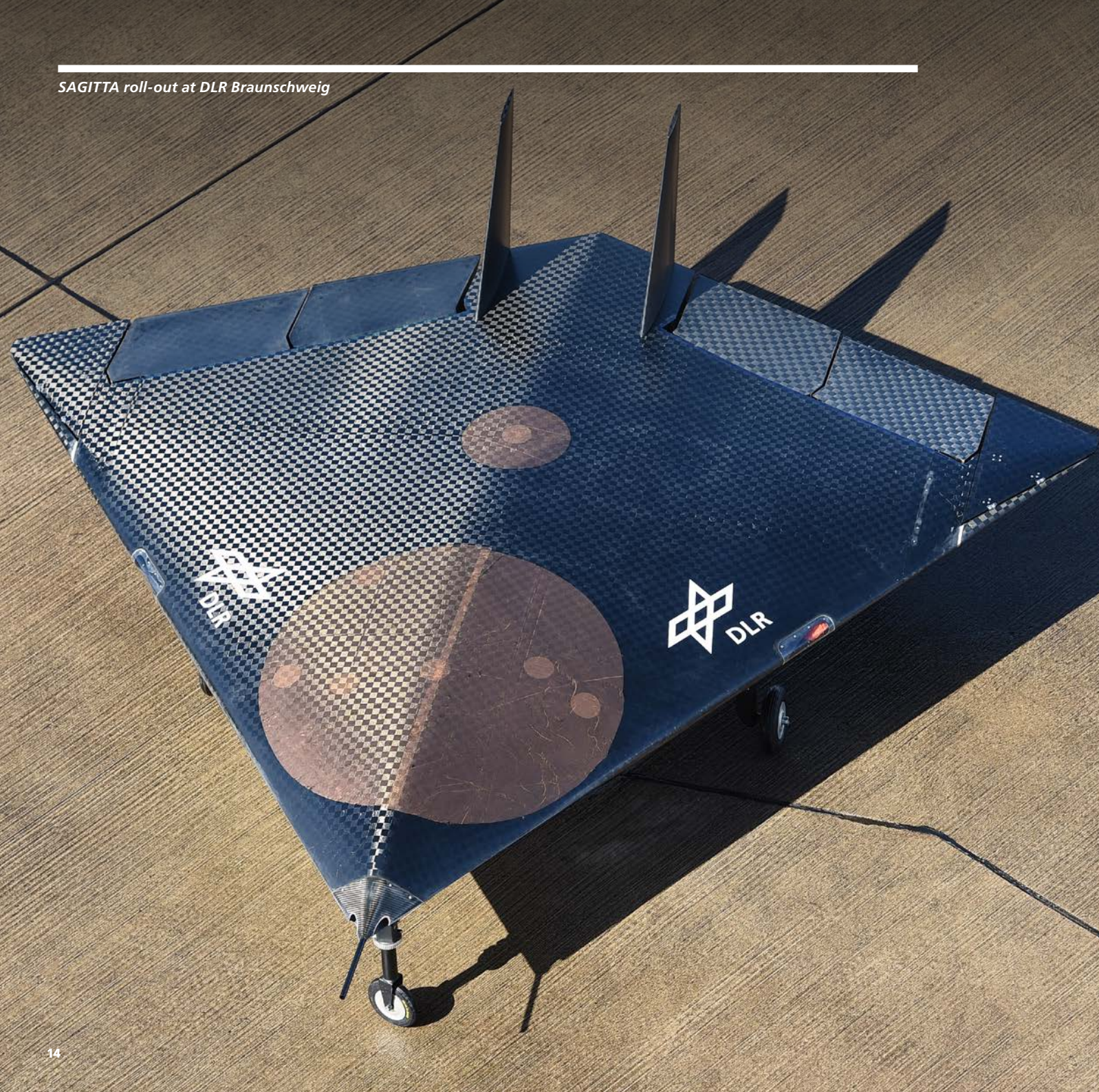
The conceptual design and development of UAS results in a large number of novel overall configurations, which facilitates innovative structural concepts and approaches aimed at optimising structure design. The Institute of Structures and Design brings its expertise in structures to bear on processes related to UAS development across a range of projects. The institute is also contributing its efforts as part of the UrbanRescue project and

developing targeted interdisciplinary structural designs. These can be applied to any UAS configuration and are aimed at achieving an overall optimum through the close linking of standard disciplines such as design and statics with those that joined the design cycle at a later stage, namely dynamic crash design, and manufacturing and production design.

*From design to production –
safe structures to protect the UAS
and its passengers*

An examination of different combinations of materials and construction methods also facilitates the development of UAS structures that can be implemented efficiently, quickly, cost-effectively and sustainably. In addition to harnessing the potential of lightweight construction in the conventional manner, integrated consideration of crash design ensures optimal protection for both systems and passengers, thereby fulfilling the stringent requirements for the approval of urban UAS. Taking production requirements into consideration by implementing the design-to-manufacture philosophy ensures the trouble-free manufacture of future UAS structures. The methodical development of interdisciplinary design thus goes hand in hand with the investigation and validation of full-scale components and application-oriented production processes at the Institute of Structures and Design.

Director of Institute
Professor Heinz Voggenreiter



Institute of Composite Structures and Adaptive Systems (FA)

The Institute of Composite Structures and Adaptive Systems has long-standing expertise in the manufacture of delicate, ultra-light structures made of fibre-reinforced composite materials. The institute is currently researching more efficient means of production and operation for lightweight structures for use in aerospace. The aim is to integrate a range of different functions into the structures in order to increase environmental sustainability by reducing weight and saving resources. The Institute's creative scientists bridge the gap between pure research and industrial applications at the Braunschweig and Stade sites.

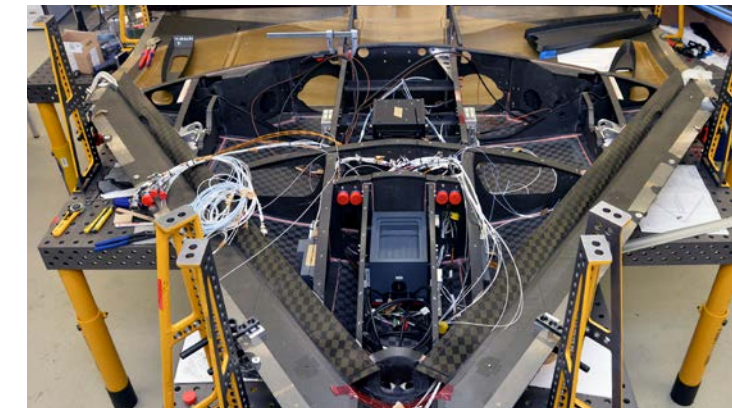
The institute bridges the gap between pure research and industrial applications

SAGITTA project

The construction of the primary structure for the open-innovation SAGITTA testbed is an excellent example of our work. This technology test facility for unmanned flight was developed by Airbus, in conjunction with DLR and institutes at the technical universities of Munich and Chemnitz, the German Armed Forces University in Munich and the Technical University of Ingolstadt.

The design criteria called for a high level of autonomy, a changeable mission design and low visibility in flight. SAGITTA meets these demands with its diamond-shaped flying wing and a propulsion system consisting of two 300-newton turbines. Given that the take-off weight is 150 kilograms, the 29-kilogram primary structure makes up only a fifth of the total weight. SAGITTA has a three-metre wingspan and has sufficient internal space to accommodate flight systems and a number of research instruments.

Designing a lightweight structure of this kind with optimal load transfer meant that the components, made of wafer-thin layers of carbon-fibre-reinforced polymers (referred to as thin plies), had to be cleanly designed, meticulously manufactured and bonded together with extreme precision. The thickness and quality of the adhesive layer are of crucial importance in achieving the necessary strength; the thicker the adhesive layer, the poorer the bond. As such, care was taken to ensure that the components were sparingly and evenly glued.



Integration tasks at the laboratory in Braunschweig

The system was constructed and integrated in a specially prepared laboratory at the Braunschweig site. SAGITTA left its place of assembly for the first time in March 2015. Preparations for its maiden flight then got under way. Countless tests were conducted to ensure the safety and success of the flight. The day finally came in July 2017, and SAGITTA successfully flew its first route over South Africa.

DLR institutes involved: Institute of Flight Systems, Institute of System Dynamics and Control.

Director of Institute
Professor Martin Wiedemann



Institute of Flight Guidance (FL)

The Institute of Flight Guidance develops new concepts for a safe, efficient, environmentally friendly and reliable air transport system. The institute handles the complex issues involved in air transport across its five departments, which cover a broad range of focus areas. The departments are working together on new support functions for the on-board and ground operations, researching whole-system approaches to the optimisation of comprehensive processes at airports, developing new air traffic management procedures and concepts, and evaluating their effects. One particular area of focus for the institute is the integration of new airspace users within general air traffic, from UAS to air taxis and suborbital as well as orbital spacecraft.

New airspace users to air traffic necessitate new concepts and technology for managing airspace

Integrating UAS into airspace

Detect and avoid capability is vitally important if certifiable UAS are to be integrated seamlessly into controlled airspace. If this capability is insufficient, it must be compensated for by greater separation distances and specialised management processes. The institute is therefore conducting research into procedures and processes for stepwise airspace and airport integration, while developing and validating algorithms for collision avoidance. Current UAS vary in size, performance and equipment due to their different mission requirements and purposes. The particular challenge, therefore, is safely managing and monitoring UAS with such different capabilities, together with other users of airspace (for example, helicopters, gliders and paragliders). The Institute of Flight Guidance has devised a density-based air traffic management concept for that purpose, which has been published as the 'DLR U-Space Blueprint'.

Optimised mission planning and implementation

Key research areas include the optimised mission management of one or more UAS (especially for deployment in the event of disasters), the design of ground control stations, and the issue of how best to assist operators in their work and interactions with partially or entirely autonomous systems. Operational safety is always at the fore. Another component of research is planning and controlling unmanned aircraft in swarms. Tasks must be optimally allocated between individual UAS for efficient swarm management, while data that are pertinent to planning must be exchanged promptly by the different units.



Flight campaign with several UAS at the National Experimental Test Center

Testing new concepts

The institute regularly tests and evaluates completely new processes together with users in order to detect conflicts between (unmanned) aircraft in good time and thus counteract critical situations. Initially, this is performed in safe simulation environments at the Institute's own Air Traffic Validation Center. The second step is to conduct flight tests with unmanned flight test vehicles and ground control stations run by DLR or its partners.



City-ATM flight tests around the Köhlbrand Bridge in Hamburg

Flexible integration of new airspace users

DLR’s City-ATM project focuses on the joint use of airspace by unmanned and manned aircraft. It is led by the Institute of Flight Guidance, in conjunction with key stakeholders. The scientists are developing a concept for density-based airspace management for the challenging urban environment. It is intended to integrate the entire range of new airspace users into the future U-space safely and efficiently.

The concept addresses similar efforts elsewhere in Europe and includes adapted flight rules, minimum distance requirements and the different performance characteristics of individual aircraft. In addition, City-ATM provides for a robust communications, navigation and monitoring infrastructure. The concept is being implemented as a simulation and a demonstration platform. This prototype has been tested in a simulated environment and then in real albeit segregated airspaces in the form of comprehensive flight tests, for example around the Köhlbrand Bridge in Hamburg and at Cochstedt Airport.

Exploring urban air mobility

Efficiency, safety, practicability, sustainability and affordability are just some of the aspects addressed in this vision of future urban mobility. The HorizonUAM project is an initial response to this vision. The Institute of Flight Guidance is working with other DLR institutes on the project to investigate urban transport systems that use urban airspace (UAM) and to map and evaluate them in an overall system model. The focus is split between vehicles, infrastructure (including vertiports and operation) and acceptance among society at large. The researchers are drawing upon their expertise and ongoing studies in the fields of propulsion technology, flight systems technology, communications and navigation, in conjunction with their knowledge of modern air traffic control and airport management systems.

HorizonUAM concentrates on inner-city passenger air transport and electric aircraft with vertical take-off capabilities. A range of configurations for vertical take-off and landing are being devised and validated as part of the project. An air traffic management system for urban airspace is also being developed, while a number of future application scenarios are being considered, with an emphasis on their technical feasibility, cost-effectiveness, efficiency and acceptance.

Supporting crisis management

Both natural and human-induced disasters can have unforeseen and often cross-border consequences. Unmanned aircraft can help people respond to crises more quickly and efficiently. The institute is involved in a large number of international disaster management projects.

Real-time imaging by drones can play a significant role in determining the situation in the area of the disaster and thus help with the planning of targeted relief operations. DLR researchers are working together with partners on EU projects such as IN-PREP and DRIVER+ to develop tools for the joint cross-border planning of relief efforts and efficient emergency personnel training. They are bringing together various forms of crisis management technology for disasters and applying them in large-scale Europe-wide demonstrations. The use of entire drone fleets in crisis situations is being examined in the ResponDrone project. Among other things, ResponDrone is investigating a new type of predictive trajectory management that integrates air- and ground-based risks into UAS mission planning and control.

Director of Institute
Professor Dirk Kügler



Institute of Flight Systems (FT)

The research and development work being conducted at the Institute of Flight Systems is aimed at ensuring the safe and straightforward operation of unmanned aircraft under complex conditions – challenging weather, obstructive flight environments and the response of other airspace, water or road users can place great demands on remote pilots. The aim is to minimise the resulting stress by providing unmanned aircraft with a high degree of automation. The situational awareness required of drones is key to the safe operation, versatile usability and integration of drones into the general airspace.

Key areas of focus for research at the Institute of Flight Systems include unmanned cargo flights, the simultaneous operation of manned and unmanned aircraft within a shared airspace, the development of hardware and software components for environmental perception and, in particular, the requisite approval, verification and certification aspects. This will make it possible for drone applications to be put at the service of the general public – perhaps used for medical purposes in cities, for example. Scientists at the institute are also drawing upon their system expertise to develop solutions that prevent the possible misuse of drones. The Institute of Flight Systems operates several unmanned aircraft as test platforms for carrying out research activities. A fleet of unmanned helicopters of different dimensions, automatically controlled fixed-wing aircraft and multicopters are all being used to address current research issues. Meanwhile, an unmanned gyrocopter with a payload of up to 200 kilograms is bridging the gap with manned flight.

*Transporting replacement parts
to any destination flexibly,
safely and cost-effectively*

DLR has been conducting research into automated unmanned air transport at low altitudes since 2016 as part of the Automated Low-Altitude Air Delivery (ALAADy) project. The focus is on economics, technical challenges and potential areas of application for unmanned cargo transport. In the future, humanitarian aid supplies or urgently needed replacement parts could be transported flexibly, safely and cost-effectively to the required destination in this way.



ALAADy demonstrator

The ALAADy demonstrator project focuses on the construction and testing of an unmanned, automatic flight test vehicle. Researchers at the Institute of Flight Systems have developed one of the largest unmanned civilian aircraft systems currently available by extensively converting a 450-kilogram gyrocopter into an experimental 'transport drone' with a load platform. DLR has already conducted several successful flight tests with the ALAADy demonstrator at Cochstedt Airport.

Director of Institute
Professor Stefan Levedag



Delivering relief goods in the Dominican Republic

Transporting relief supplies to hard-to-reach areas with an unmanned helicopter was the goal of a two-week disaster simulation organised by the Institute of Flight Systems in the Dominican Republic in 2018. The scientists teamed up with the Dutch company Wings for Aid and the United Nations World Food Programme (WFP) to carry out a number of flights under realistic operating conditions.

As part of the simulation, the unmanned Autonomous Rotorcraft Testbed for Intelligent Systems (superARTIS) helicopter delivered innovative cardboard boxes full of food to otherwise inaccessible places. When these boxes are dropped, their sides open out of their own accord to slow down and stabilise their descent.

The aim of the missions in the Dominican Republic was to demonstrate the feasibility of drone-based drops of relief goods on site. It also provided an opportunity to realistically evaluate acceptance among local people and the authorities responsible for providing emergency relief.

The unmanned helicopter flights took place in different regions affected by flooding. As the highlight of the campaign, the unmanned helicopter crossed the hypersaline Lake Enriquillo, travelling six kilometres beyond line of sight. It was loaded with 20 kilograms of food, including high-energy biscuits, which were dropped safely and undamaged on the opposite shore.

The approval of the missions in the Dominican Republic by the authorities was one of the first practical applications of the Specific Operation Risk Assessment (SORA) process. This procedure, which has since been recommended for use by the European Union Aviation Safety Agency (EASA), assessed the operational risks of each individual drone deployment and identified appropriate measures to ensure the safety of the application.



Ground control station

FALCON: Drone flying in formation with launch vehicles

One suggestion for reducing the cost of future space programmes is to reuse launchers instead of dropping all or part of them into the sea once they have burned out. A promising concept for reusing booster stages involves stabilising the burned-out components during their unpowered descent through the atmosphere and bringing them into steep formation flight with a powerful aircraft. The aircraft would then connect with the rocket stage and subsequently return it to the ground in a controlled manner.



APUS, a research aircraft with a powerful engine for towing

Research and testing of the necessary technologies is inherently risky and dangerous. This makes drones uniquely qualified as a testing tool. Formation flying and catching loads is a demanding task, but one that is easy to automate; moreover, using only unmanned test vehicles can completely eliminate the risk of endangering people.

The Institute of Flight Systems is examining this exact concept, referred to as In-Air Capturing (IAC), as part of the Formation flight for in-Air Launcher 1st stage Capturing demonstration (FALCON) project. As a rocket model from project partner Embention conducts a gliding flight, the unmanned APUS platform joins a formation flight that allows the aircraft to be coupled by a cable. A controllable coupling unit is used here, having been developed by the Department of Unmanned Aircraft for the implementation of air-to-air refuelling operations. This compact, agile coupling unit, also controlled and monitored by drone technology, is intended to implement the highly dynamic coupling process between the somewhat slow-reacting towing vehicle and the rocket stage, which is also not very manoeuvrable.



Institute of Air Transport and Airport Research (FW)

The Institute of Air Transport and Airport Research deals with a wide variety of issues related to air transport. The main focus of its activities is to improve the efficiency, cost-effectiveness, safety and environmental sustainability of air transportation. The air transportation system is always considered as a system composed of other networked systems; it is analysed as part of the multi-modal transport system and the ACARE objectives are used to assess its development. Forecasting and scenario techniques are being employed and developed for this purpose. In close collaboration with the partners and institutions involved, scientists at the institute are elaborating concrete policy recommendations for technical and regulatory measures to steer air transport system development and measure their effectiveness.

In addition to their technical and economic benefits and shortcomings in comparison with established competitor technologies, the success of new technologies also depends on the market environment in which they are to be used. In-depth market knowledge is therefore essential for assessing the prospects for the market success of new technologies such as civilian Unmanned Aerial Vehicles (UAVs).

The HorizonUAM project

The Institute of Air Transport and Airport Research is examining factors affecting the market development of various use cases in the field of Urban Air Mobility (UAM) with the help of a systems analysis approach that takes socioeconomic, spatial and technological factors into account. This work forms part of DLR's internal, cross-disciplinary research project HorizonUAM. By determining the influencing factors, scientists are able to make statements about the UAM affinity of global metropolises and megacities. The resulting findings are fed into the development and expansion of a prognosis method and forecasting model, which will allow researchers to draw conclusions about the potential demand for UAM (number of trips), the resulting flight movements and number of aircraft, taking different development scenarios into account.

Urban Air Mobility in the world's metropolises – estimates and predictions of future demand and flight movements

An assessment environment must be created in order to classify the project results in terms of their environmental, economic and social benefits. The possibility of evaluating new technologies should serve to drive developments for the air transport market, formulate recommendations for policy-makers and companies in the aircraft industry, and thus contribute towards a sustainable, climate-friendly air transport system.

DLR institutes involved: Institute of Flight Guidance | Institute of Propulsion Technology | Institute of Flight Systems | Institute of Communications and Navigation | Institute of Air Transportation Systems | Institute of Aerospace Medicine | Institute of Atmospheric Physics | Institute of System Architectures in Aeronautics | National Experimental Test Center for Unmanned Aircraft Systems

Director of Institute
Professor Johannes Reichmuth





Flight Experiments (FX)

The DLR Flight Experiments facility operates Europe's largest fleet of research aircraft with 11 aircraft. These manned aircraft are contributing to Unmanned Aerial Systems (UAS) research by flying in controlled airspace and over long distances in conjunction with UAS. The pilot's ability to take over control in an emergency during these research flights allow new flight testing options and pave the way for later possibilities.

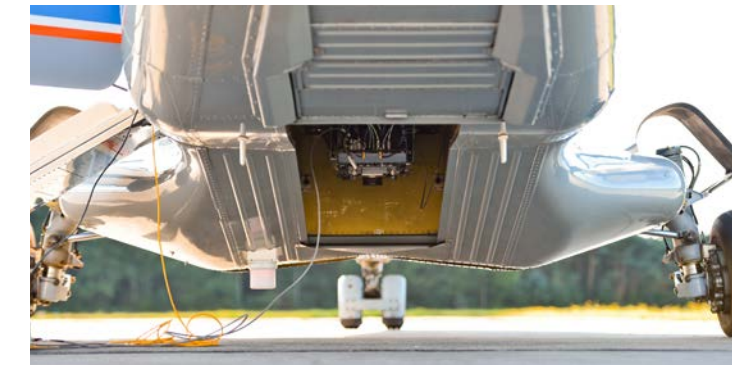
Do 228-101 (D-CODE) – national UAS test bed

The Do 228-101 (D-CODE) operated by the Flight Experiments facility is a manned flying test platform that is integrated into the Air Traffic Validation Center of the DLR Institute of Flight Guidance.

Automatic evasive manoeuvres using the digital autopilot in DLR's Do 228

The Do 228 aircraft is a twin-engine turbine-powered propeller aircraft with short take-off and landing capability (STOL), developed by Dornier as a light transport aircraft with new wing technology. D-CODE has been extensively modified so that the aircraft's functions include a digital autopilot, a power supply for test installations and modifications, a measurement system for recording the required test parameters and precision navigation equipment. D-CODE can be further modified for each new experiment with very little effort. Additionally the Do 228 does not have a pressurised fuselage offering the advantage of enough room in the cabin for 19-inch racks and the operators involved in the tests.

In recent years, one research priority for D-CODE has been the testing of new technologies for the safe operation of Unmanned Aerial Systems (UAS), in particular Remotely Piloted Aircraft Systems (RPAS) in controlled civilian airspace. The digital autopilot allows for the connection of external experimental flight management systems. This data link facilitates remote control analogous to operational RPAS systems and the transmission of sensor data installed for the experiment. D-CODE has developed its capabilities over the course of past projects so that it now supports a wide range of activities in the field of UAS. Various sensor systems can be queried via the data link from the ground station while also allowing D-CODE to be remotely controlled in any airspace via this link.



Do 228-101 (D-CODE) with a bay fitted with instruments – remote controlled via data link and digital autopilot for transmitting image data to a situation centre

In cooperation with project partners, D-CODE can be equipped with sensor system for the safe detection of non-cooperative aircraft (relative heading, altitude, speeds and track difference). Once detected D-CODE can perform evasive manoeuvres automatically. This is possible because the sensor data are processed using proven avoidance algorithms and transmitted to the experimental flight management system, which in turn initiates safe evasive manoeuvre using D-CODE's digital autopilot without DLR test pilot intervention.



The research helicopter EC 135 ACT/FHS (D-HFHS) teams up with unmanned aircraft

The interaction between manned and unmanned aircraft during formation flight in common airspace presents a particular challenge. In this scenario, the unmanned aircraft are guided either from the helicopter accompanying them or automatically. This means that various strategies for automated formation flight must be tested and assessed in terms of pilot expectations and the visibility of the unmanned aircraft. The Flight Experiments facility is therefore focusing on creating a general safety concept for flying a manned and an unmanned aircraft within a common mission airspace, together with evaluating the tested approaches from the perspective of the helicopter pilot. Among other things, the Institute of Flight Systems focuses on upgrading the unmanned research UAS superARTIS, developing the overall software and creating the systems and displays to be integrated into the ACT/FHS. The real teaming flight tests with the DLR research helicopter EC 135 ACT/FHS and the research UAS superARTIS were carried out at Cochstedt Airport.

The Falcon 2000LX ISTAR (D-BDLR) – a UAS test bed

The latest member of the DLR research aircraft fleet, the Dassault Falcon 2000LX, has been used under the name 'ISTAR' (In-Flight Systems and Technologies Airborne Research) since 31 January 2020.



Falcon 2000LX ISTAR

DLR's ISTAR is a flight test aircraft that will allow work with new technologies. The aircraft will gradually be upgraded to an in-flight simulator in further expansion phases. As expansion phases are completed, the ISTAR will be used for initial scientific research projects within the context of UAS research, in order to meeting the needs of the DLR's strategic concept, 'The unmanned air cargo transporter'.

Future UAS-related areas of focus include:

- Autonomous flight control functionality
- Integrating UAS into civilian airspace
- Sense-and-avoid scenarios
- Entire system architecture for a Remotely Piloted Aircraft System (RPAS)

Head of Facility
Dr Burkard Wigger



Small aircraft technology (KF)

This research facility was founded in 2020 and is currently under construction. In recognition of the planned structural reorganisation and the designation of the Rhineland lignite mining area as a 'mobility region of the future', the focus is on General Aviation (GA) and Urban Air Mobility (UAM) as the basis for a new form of mobility. This will be done with a strong emphasis on the overall design, production, sustainable propulsion systems, avionics and increasing automation, all the way through to autonomous new vehicles and systems. In this case, the focus is on fully electric and hybrid-electric small aircraft (aircraft up to the 'Normal' category according to EASA CS-23) with improved take-off and climbing capabilities, which enable socially sustainable operations that are optimised in terms of emissions and noise. In the context of the electrification of air transport, current technological progress opens up appealing options for the implementation of sustainable and automated solutions. Particularly in view of the capabilities in production technology, the focus here will be on production research for complete small aircraft, including maintenance and repair aspects (MRO/lifecycle).

A question of scale

Current aeronautics research at DLR deals with both ends of the spectrum, that is, technologies for commercial, 'classic' air transport (passenger aircraft size) on the one hand, and new technologies and areas of application for unmanned aircraft on the other, with the current focus mainly on small to medium-sized UAS for inspection missions, cargo transport or disaster relief applications.

New aircraft concepts for sustainable urban and regional mobility

Both areas and ends of the spectrum are largely decoupled from one another in terms of the underlying technologies (especially with regard to propulsion systems, system security and more) and with regard to the regulations and certification requirements that currently apply, as they operate on different scales (orders

of magnitude) and scalability (in relation to economics and technology). Research into technology and issues related to GA (small aircraft carrying up to six passengers) and UAM (primarily air taxis) falls in the middle of the spectrum in terms of size. This has the advantage that the underlying technologies can be 'extended' in both directions.



Simulation of the HY4 over an airport

This means that a newly developed technology or process for the field of GA/UAM can potentially be scaled up into the area of commercial aircraft (in other words, expanded with minimal outlay) or scaled down to suit unmanned aircraft that do not carry passengers (simplified with minimal effort). In terms of system complexity, the GA/UAM field is simple enough to offer fast and cost-effective technology development, yet complex enough to overcome various hurdles to transfer and market entry (for example, certification, system design, etc.). This opens it up to new technologies and the possibility of multi-scale capability in testing and certification, which represents a promising approach for new projects across the whole of DLR.

Head of Facility
Dr Christian Eschmann

Institute of Communications and Navigation (KN)

Scientists at the Institute of Communications and Navigation in Oberpfaffenhofen and Neustrelitz are designing new systems and processes for communication and navigation in the aeronautical, maritime and terrestrial domains. Their work ranges from theoretical studies and simulations through to the development of test, validation and demonstration systems. Projects are allocated to specific missions: 'Global Connectivity for People and Machines', 'Global Positioning for Future Applications', 'Autonomy and Cooperation for Critical Systems' and 'Cyber Security for Radio Systems'. These missions have been selected for their considerable benefit to society. Scientific demand and economic viability usually play a major role in the choice of individual projects.

The institute's research work in the field of air transport is integral to all four missions and encompasses aeronautical Communications, Navigation and Surveillance (CNS). The Institute is a world leader in the ongoing global modernisation of Air Traffic Management (ATM) by developing and validating new powerful, cyber-secure and robust CNS technology. This applies to traditional civil aviation and UAS alike. Modified CNS technology is already being developed for Remotely Piloted Aircraft Systems (RPAS), enabling them to be integrated safely into controlled civilian airspace. In addition, CNS technologies are being developed for drones in urban environments in order to support and secure the air traffic management system in lower – uncontrolled – airspace.

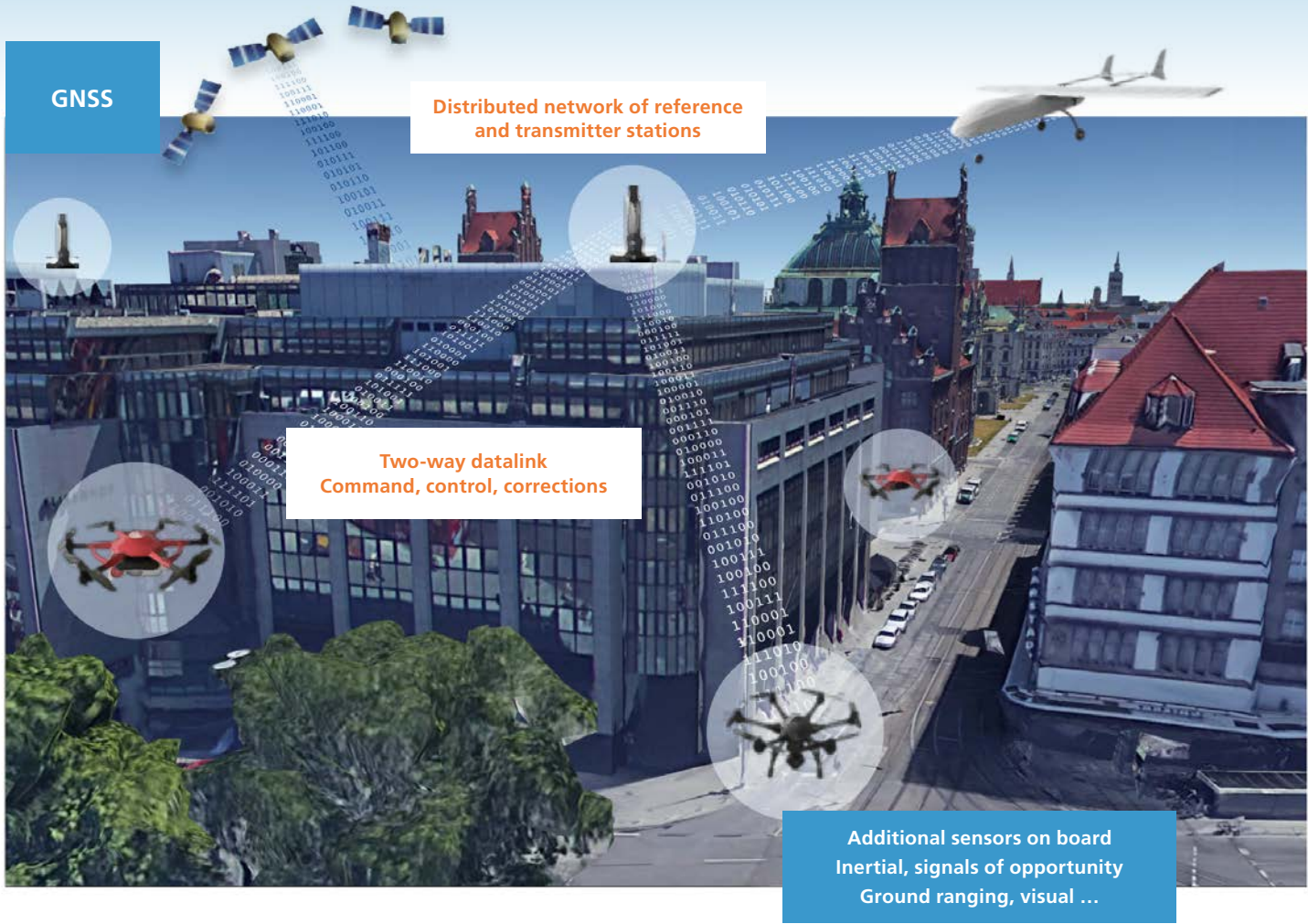
Robust, cyber-secure CNS technology

As a cross-sectoral issue, CNS plays a major role in all of the projects outlined in this brochure and allows information to be acquired and distributed as required. In addition, CNS technologies enable the control and monitoring of drones and RPAS so that they can be managed safely and efficiently. CNS technologies for drones and RPAS must be designed to be cyber-secure and robust so that control information and sensor data cannot be falsified or disrupted in transmission. This is particularly true in the context of the increasing autonomy of unmanned aircraft systems.

The Institute's current CNS research work includes the development and validation of a robust, cyber-secure data link for the control of RPAS, modelling the propagation of electromagnetic signals in urban environments, the design of the security network for drones through a cooperative monitoring system, the development of robust miniaturised navigation receivers and defence against drones.

The targeted rerouting of drones via GNSS spoofing can provide a defence against threat scenarios

The National Experimental Test Center for Unmanned Aircraft Systems in Cochstedt provides optimal infrastructure for validating and assessing the newly developed CNS technologies in detail within a realistic environment.



Dependable navigation

One key research area at the Institute of Communications and Navigation is interference-resistant multi-antenna receivers for satellite navigation. The institute has set itself the objective of miniaturising the necessary receiver hardware so that this powerful technology can be used on UAS. The institute has expertise across the entire signal chain of GNSS receivers – antennas, high-frequency technology, analogue and digital signal processing and the preparation of information for user interfaces.

For the UAS sector, the miniaturised GNSS receivers are equipped with additional sensors, including acceleration and yaw rate sensors, plus a compass and barometer. When used in conjunction with satellite navigation, these sensors can provide more precise and reliable position information (sensor data fusion). For some years now, DLR has been working on Ground-Based Augmentation Systems (GBAS) to support precision landing approaches in civil aviation. For UAS, the institute is looking at the transferability of similar concepts to future drone traffic, especially in challenging urban settings. Satellite navigation supported by local GNSS references, which make it more precise and incorporate greater monitoring of integrity, is a component intended to provide dependable navigation for future UAV applications in multi-sensor navigation systems.

An experimental GBAS will be installed at Cochstedt Airport. It will subsequently be expanded in a modular fashion as part of the model city and can be adapted to UAV applications.

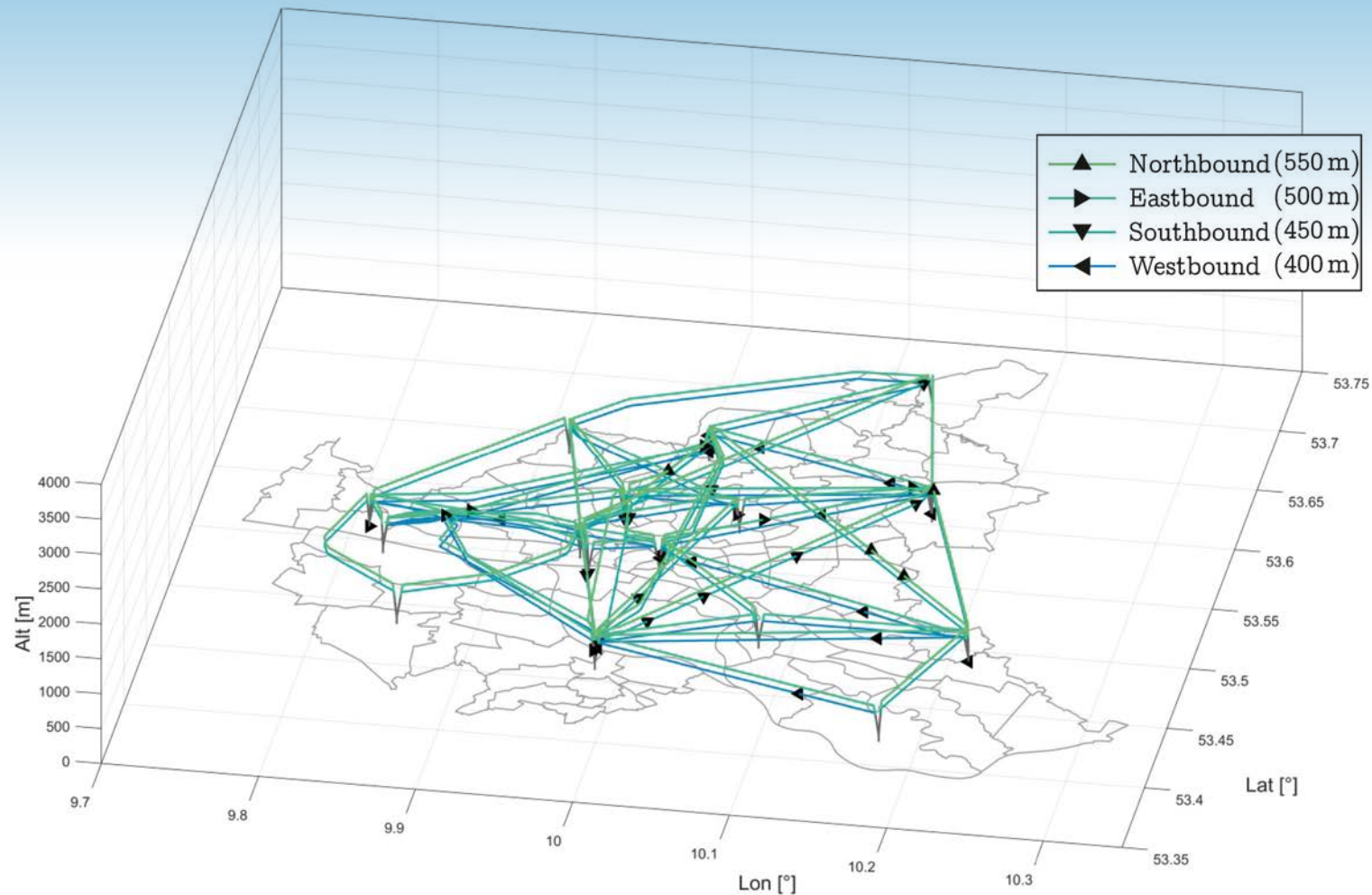
Counter-UAV

The development and use of unmanned aircraft is steadily increasing, opening up many new fields of application and giving rise to new threat scenarios. In response to the latter, the DLR Microwaves and Radar Institute (HR), the DLR Institute of Technical Physics (TP) and the DLR Institute of Communications and Navigation (KN) are developing a new concept (KABUL) for the detection and combating of unmanned aircraft. The concept uses a multi-sensor approach to detect, track and classify the threat, enabling countermeasures to be taken. The Institute of Communications and Navigation has developed a detection and localisation system that detects the WLAN signals emitted by the drone and estimates their direction of arrival.

One promising measure against intruder drones is GNSS spoofing (decoy signal generation), whereby the position measurements of the drone's satellite navigation receiver are manipulated. GNSS spoofing is used as part of KABUL in order to navigate a drone into an area where damage can no longer be caused by the drone payload. The drone can also be safely landed or intercepted in this area as necessary.

Director of Institute
Professor Christoph Günther

Snapshot of a 24-hour traffic simulation across 16 different city districts of Hamburg. The vehicles, represented by triangles, move within a network encompassing 92 routes at different altitudes. This allows 1963 flight movements over the course of the day.



*Simulating and evaluating
the sustainability and economics
of air transport systems*

Air Transportation Systems (LY)

DLR's Air Transportation Systems (LY) facility is dedicated to research and teaching related to the systems that inform the complex interrelationships of air transport. The research includes concepts, preliminary designs and the optimisation of test systems, as well as the simulation and evaluation of entire air transport systems with regard to economic and environmental sustainability.

i-LUM (Innovative Airborne Urban Mobility)

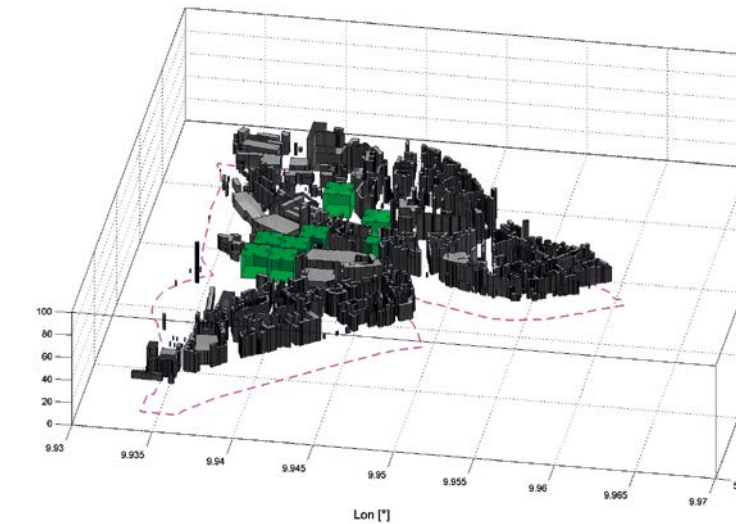
The joint i-LUM project, funded by the Hamburg State Research Foundation, aims to develop and evaluate feasible innovative concepts for Urban Air Mobility (UAM). The integrated architecture of an aerial transport system will be designed by drawing upon a wide range of expertise and using Hamburg as an example. Researchers will identify essential system components in the air and on the ground that need to be integrated into the existing transport system. The resulting overall picture will enable researchers to identify the prerequisites for introducing air taxis and assess the consequences from a technical, urban planning and social perspective.

Interdisciplinary research

The needs of the general population and passengers must be identified and taken into account when designing the system if the forward-looking vision of UAM is to be successfully realised. The issues that emerge relate to a range of different disciplines and are often closely interrelated. Relevant research priorities as part of the i-LUM project therefore deal with the relationships between demand and achievable transport capacity, environmental or ecological costs and the acceptance among wider society in relation to noise.

Hamburg University of Technology (TUHH), HafenCity University (HCU), Helmut Schmidt University (HSU), the Hamburg University of Applied Sciences (HAW) and DLR, including institutes focusing

on logistics, automation technology, public law, urban development and social sciences, are taking part in the project with a view to addressing all necessary areas of expertise. The project is led by the Institute of Air Transportation Systems (ILT) at TUHH.

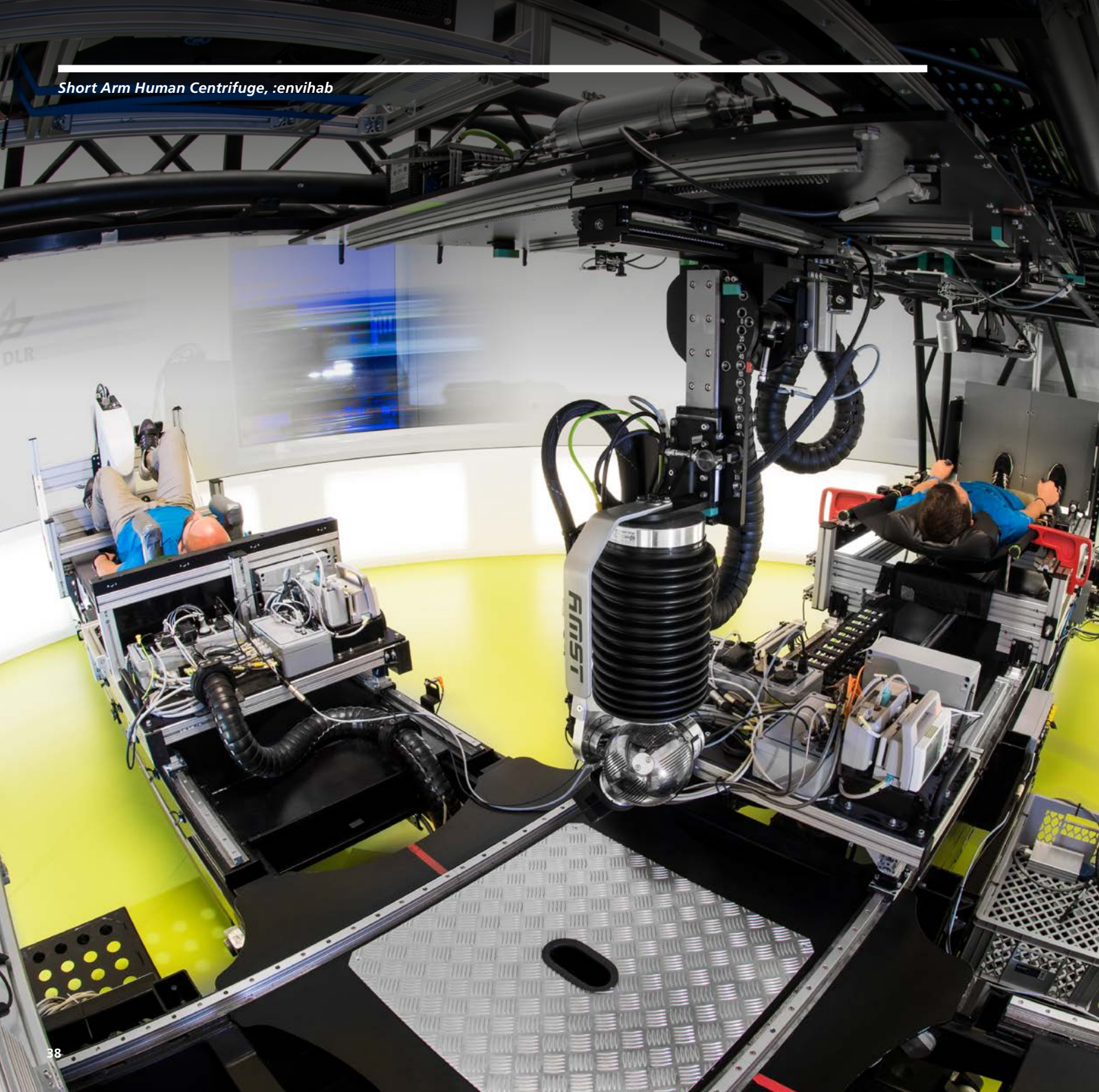


Example distribution of take-off and landing positions in the Hamburg district of Altona, based on an assumed transport demand for needs assessment and actual 3D building data for positioning. The demand can be met by eight vertiports (green rectangles) in a range of sizes.

Overall system evaluation

As an overall system architect and integrator, DLR's Air Transportation Systems facility makes decisive contributions to the development of overall system evaluation capacity from a technical, economic and social perspective. To this end, an interdisciplinary evaluation methodology is being developed to measure new mobility concepts against the performance of current transport systems. This will make it possible to draw comparisons with existing modes of transport and weigh the resulting benefits against the monetary and societal costs.

Head of Facility
Professor Volker Gollnick



Institute of Aerospace Medicine (ME)

The Institute of Aerospace Medicine conducts interdisciplinary, translational research at the interface between medicine, biology, psychology and technology development, with the aim of preserving and improving human health and performance in space, aviation and on Earth. The institute's research is conducted in close cooperation with leading national and international research institutions and industrial companies. The institute creates basic research and develops innovative solutions for aviation, space travel and traffic.

The overall objective of the institute is to preserve and improve human health and performance in space, aviation and on Earth.

*The short-arm human centrifuge
in the aerospace medical research
facility :envihab
("environment" and "habitat")*

Human factors and unmanned aerial systems

Human factors relating to unmanned aircraft systems are being studied at the Department of Aviation and Space Psychology in Hamburg. As part of the DLR's UFO project, for example, workshops on the acceptance of certain operational concepts for controlling unmanned cargo aircraft are being presented by German air traffic controllers. In addition, the department is involved in the conceptual design and evaluation of a nationwide representative study on aspects related to the societal acceptance of civilian drones. Ongoing projects include the definition of psychological capability requirements for operating different types of drones and a scientific comparison of such requirements between pilots of manned and unmanned aircraft.

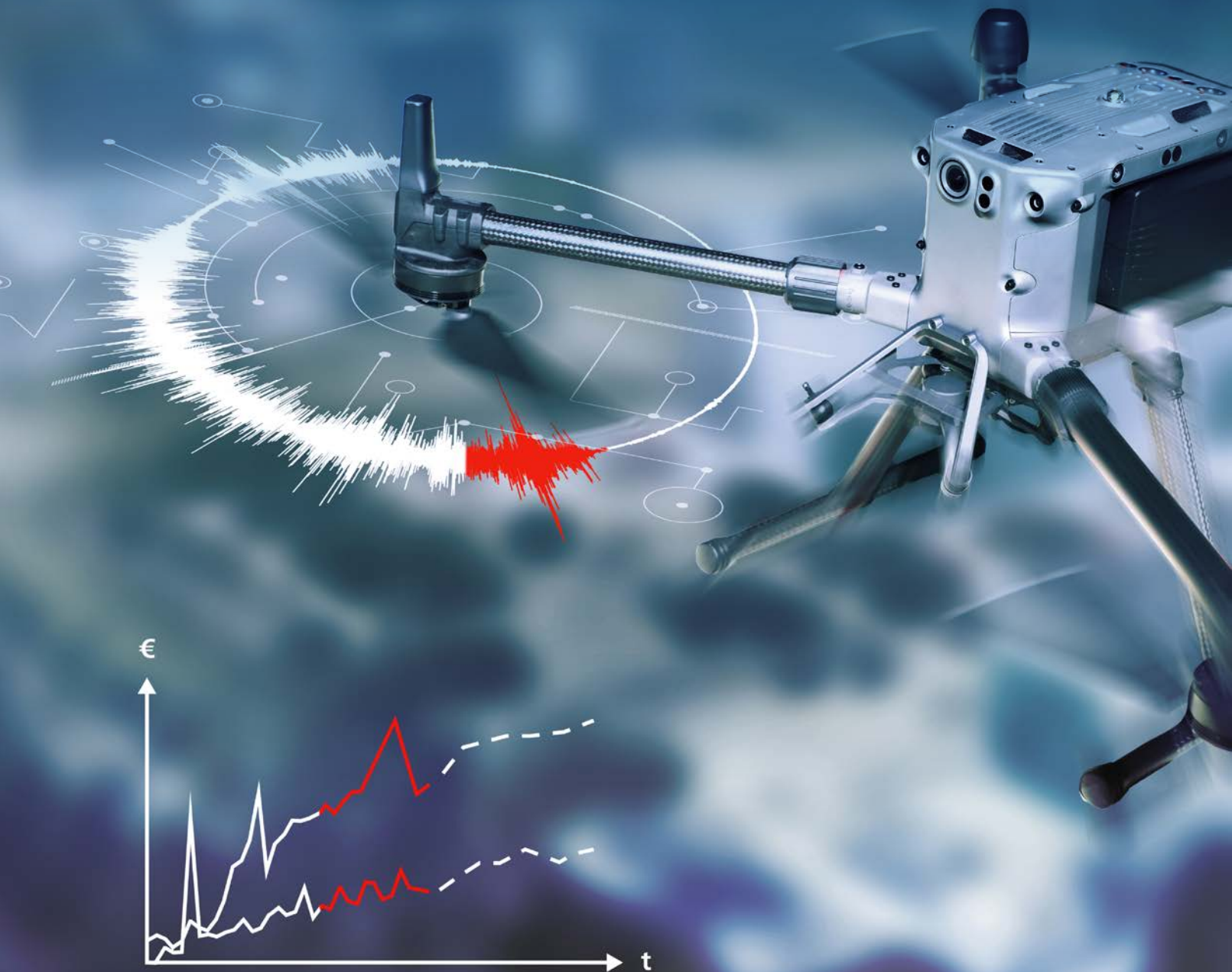
In terms of urban air mobility – specifically, air taxis – factors pivotal to acceptance are being analysed including flight noise, possible countermeasures and aspects of passenger comfort.



:envihab

Education, training and licensing, especially for drone users working for the emergency services, complete the range of human sciences issues covered at the institute.

Director of Institute
Professor Jens Jordan



Institute of Maintenance, Repair and Overhaul (MO)

The DLR Institute of Maintenance, Repair and Overhaul in Hamburg is dedicated to the digitalisation of the lifecycle of aircraft and their component as well as their condition monitoring and maintenance.

UAVs represent a special area of application because their manufacturers, operators and maintenance providers are usually closely interlinked. Indeed, one company can take on all three roles. In addition to this, there are considerably fewer official safety requirements compared with passenger aviation, plus higher flexibility in terms of system composition and the already extensive digitalisation and networking of today's UAVs.

Predictive maintenance concept

UAVs thus provide an excellent basis for predictive maintenance based on integrated condition monitoring and cross-system data analysis. The data are not only required for analysis and appraisal of the available system condition, they also open up various options for conducting maintenance in a flexible and optimal way. If UAVs are dismantled after a flight for further transport or converted for the next mission, adjustments in the maintenance scheme do not necessarily constitute significant modifications to the operational procedure.

Machine learning methods are considered key to analysing the recorded data. Although barriers to the installation and approval of sensors for special monitoring tasks are significantly lower than in passenger aviation, their use in practice is subject to stringent technical limitations due to the small size of UAVs and the desire to maximise payloads. Therefore, the research pays particular attention to recording changes in condition by analysing the behaviour of the surrounding components and the way in which they interact.

UAVs as an ideal platform for predictive maintenance scenarios

The implementation of a predictive maintenance concept at fleet level opens up further possibilities. Particularly in the case of an operational concept with a central base from which operations start and where conversions and maintenance procedures are carried out, there are opportunities to implement optimised maintenance at fleet level. This starts with the mission planning. The assignment of operations to individual UAVs in a fleet can take into account the current condition of the individual vehicles and their components if the fleet size is large enough. Not only does this ensure that the available resources are used effectively, it also increases the reliability and availability of the overall system.

Director of Institute
Professor Hans Peter Monner



Institute of Atmospheric Physics (PA)

The Institute of Atmospheric Physics conducts research into the physics and chemistry of Earth's atmosphere from the ground up to an altitude of approximately 120 kilometres through Helmholtz Association (HGF) programmes relating to Aeronautics, Spaceflight, Transport and Energy. It employs a wide range of methods from sensor development, observations on all scales and using different carriers (aircraft, satellite), analysis, theory building and numerical modelling. The interaction between measurement and simulation gives insights into scientific issues and ensures a strong application orientation. The institute is an expert point of contact for all atmosphere-related issues for the rest of DLR, wider society, business and policy-makers.

Drone swarm

The institute is working on the project 'Simultaneous wind field detection with unmanned aircraft in 3D swarms' as part of its Energy programme. Quadcopters are equipped to measure temperature, humidity, wind speed and wind direction simultaneously and at a range of points in the atmosphere close to the ground. By simultaneously using a large number of drones as flexible measuring points, scientists are able to record the spatial structures of small-scale atmospheric flow instantaneously. The drones fly to pre-defined points automatically and remain hovering there. Miniaturised sensors measure the temperature and humidity while the wind speed and direction are calculated on the basis of the avionics data. One example of the small-scale structures in the atmosphere is the wake of wind turbines, the characteristics of which are determined by wind direction and atmospheric stratification. Measurements on masts can only be used in small wind direction zones in order to measure the wind speed deficit and turbulence in the wake. The quadcopter swarm allows the measuring area to be flexibly adapted to the wind field.



10 quadcopters

A swarm of 10 quadcopters was used in the German Meteorological Service's Falkenberg boundary layer measurement field in July 2020 to improve and validate algorithms for wind measurements by aircraft. The National Experimental Test Center for Unmanned Aircraft Systems in Cochstedt will be able to offer logistics and infrastructure to enable tests with 100 quadcopters operating in swarms, as required to measure wind fields in large areas such as wind farms. Testing of intelligent swarm control is conceivable in the future and will enable the recording of meteorological parameters more efficiently and over longer periods of time. For example, the institute is working alongside the

A drone swarm as a meteorological tool – flexible simultaneous measurements for wind power research

Institute of Communications and Navigation to measure gases with miniaturised sensors in a swarm in order to track down the sources of pollutants. Demonstrations are planned under realistic conditions in Cochstedt, with the swarm expected to detect sources of gas independently.

Director of Institute
Professor Markus Rapp

Closed-loop flight test during the ATON project. The image shows a test helicopter with an integrated ATON navigation system over the test field, with georeferenced craters.

Institute for Software Technology (SC)

The Institute for Software Technology focuses on research and development in the field of innovative software technologies. The current main topics are software for distributed and intelligent systems, artificial intelligence, software for embedded systems, scientific visualisation, quantum computing and high-performance computing.

The technologies developed at the institute are used in all of DLR's areas of research, from spaceflight to aeronautics, transport and energy, all the way through to digitalisation and security research. More than 90 per cent of the Institute's products are open source software and can therefore also be used outside DLR without restrictions.

The institute contributes to DLR research on Unmanned Aerial Systems (UAS) primarily through the development of simulations and visualisations.

ATON

An optical navigation system for autonomous landings on celestial bodies has been developed as part of the joint ATON project, which is being led by the Institute of Space Systems. The aim is to use the system for the entire landing approach to the Moon. To demonstrate the functionality and accuracy of the system, flight tests were carried out with unmanned helicopters, in addition to laboratory tests. The lunar surface was simulated with crater images and artificial three-dimensional features. Instead of GPS/GNSS systems, the superARTIS test vehicle specified its position and the landing trajectory using only the crater images. Some of the experiments took place at night to increase the degree of realism. The use of a real flying unmanned aircraft demonstrated the robustness of the process against vibrations, lighting effects and modelling errors.

The Institute for Software Technology provided a simulation environment, integrated system components into the real-time flight software and developed a test infrastructure.

DLR institutes involved: Institute of Space Systems | Institute of Flight Systems | Institute of Optical Sensor Systems | Institute of Robotics and Mechatronics

In another project, a study with simulated drones was carried out under the project management of the Institute of Flight Guidance. The study looked at the social acceptance of the use of drones in cities, given that unmanned aircraft will increasingly be used for transporting goods. Besides the aspects of security and data



Study in the Virtual Reality Laboratory – simulated drones are shown to the test person using HoloLens glasses in a virtual environment.

protection, the scientists examined public perception of visual and acoustic disturbance variables. The perception of individual exposure to these environmental stimuli was analysed in a study involving test subjects in the 360-degree Virtual Reality Laboratory at the DLR Institute of Transportation Systems.

Studies in virtual reality – investigating public acceptance of UAS

The Institute for Software Technology visualised the terrain and the drones in augmented and virtual reality. The area surrounding Braunschweig's main train station was visualised in a VR laboratory, while virtual drones were shown to the test subjects through HoloLens glasses.

Director of Institute
Rolf Hempel



Institute of System Architectures in Aeronautics (SL)

Aeronautics is digitalised, from aircraft design all the way through to production and operations. This end-to-end availability of all data is described as a digital thread. The Institute of System Architectures in Aeronautics is investigating how this comprehensive data can give rise to usable knowledge, with a view to designing safer, more powerful and increasingly efficient aviation products. The digital thread draws large areas of aeronautics into design processes, so that synergies can be harnessed to a greater extent than in the past. The focus is on systems that are made up of many coupled subsystems (referred to as System of Systems Engineering, or SoSE). The combination of subsystems is described as system architecture.

Scaled systems as a key factor in the development of future commercial aircraft

Designing new aircraft for future operational concepts and using new technologies requires optimising the architecture of these coupled systems. The institute is researching design methods that can map the entire process digitally and are able to handle a very large number of heterogeneous models efficiently. This creates new and potentially revolutionary overall concepts, with vehicle, operational and technology options all optimally coordinated.

EXACT

Since early 2020, 45 scientists from 20 DLR institutes have been working together on the Exploration of Electric Aircraft Concepts and Technologies (EXACT) project, led by the Institute of System Architectures in Aeronautics, to develop new technology building blocks for an eco-efficient commercial aircraft.

The overall objective is to have the technologies for such an aircraft, with at least 70 seats and a range of 2,000 kilometres, ready for use by 2040. Various hybrid-electric propulsion concepts and possible aircraft configurations will be examined in the initial step. Interactions with airport infrastructure must also be considered, along with how new propulsion systems affect the atmosphere and thus the climate. DLR's expertise in the various areas of research required for the implementation of a complex study of this nature makes it globally unique.

With the newly opened UAS Test Center in Cochstedt, DLR is expanding its research activities and opening up new opportunities to enter flight testing with innovative aircraft concepts in scale-model form, in order to bring multidisciplinary design methods from the design process – in this case, particularly critical thermal management for electric or hybrid-electric propulsion systems – into the air and validate them on the basis of flight tests.



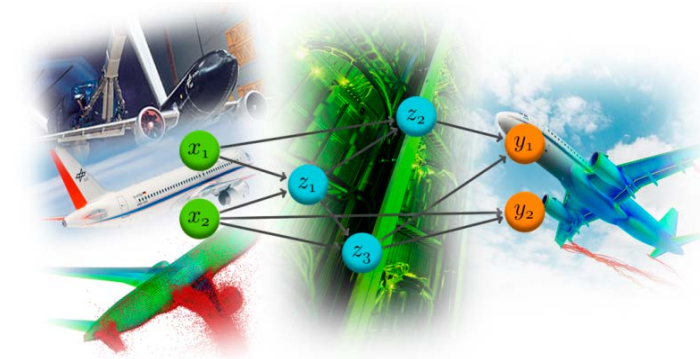
From the digital design process to aircraft system architecture

Director of Institute
Björn Nagel

Institute of Software Methods for Product Virtualization (SP)

*Faster UAS development
times through virtualization*

The Institute of Software Methods for Product Virtualization which was founded in 2017 at DLR's Dresden site, deals with the research and development of IT and software methodologies for describing and implementing DLR's guiding 'Virtual Product' aeronautics concept on the basis of high-quality, multidisciplinary simulation processes. Scientists at the institute are researching high-performance computing, simulation environments and software methodologies. Working in close collaboration with the aeronautics institutes, the scientists aim to combine research expertise in the field of software development for product virtualization and to provide the necessary infrastructure through the operations of the DLR HPC computing cluster. The aim is to make development, certification and maintenance processes faster, more economical, more precise and, above all, safer. Approaches from virtual testing to virtual certification are intended to enable rapid development times, as expected of providers of UAS services in terms of adaptation to customer requirements and external conditions. Examples of this include larger loads or different environmental conditions that mean that UAS services need to be adapted at short notice.



Software methodologies

The Institute is also involved in software development for Digital Twins. For this purpose, a storage and application service hub is being developed and made available as a prototype, through which data from DLR research aircraft is systematically linked with applications or analysis – in the form of services, for example – and can be shared centrally between many stakeholders. The hub consists of a powerful, scalable back-end that can be activated via a Python client or a web front-end.

Director of Institute
Dr Olaf Brodersen

Institute of System Dynamics and Control (SR)

Research at the Institute of System Dynamics and Control focuses on the development and application of efficient system simulations and intelligent control systems for space and robotic systems, aircraft, and road and rail vehicles. The aim of the methodology and tool development is to robustly increase the performance, efficiency, safety and comfort of the controlled systems.

New flight control and aircraft on-board systems

Aeronautics research focuses on the design of innovative flight control and aircraft on-board systems. The aim is to reduce weight by actively reducing aircraft structural loads and improving the partial or completely autonomous operation of manned and unmanned aircraft. Validation of the simulation models and control methods required for this purpose on test benches and in flight tests plays an important role in the research work.

FLEXOP and FLiPASED

In the FLEXOP (Flutter-Free Flight Envelope eXpansion for eCO-nomical Performance improvement) and FLiPASED (Flight Phase Adaptive Aero-Servo-Elastic Aircraft Design Methods) projects, the Institute of System Dynamics and Control and the Institute of Aeroelastics are working together with EU partners to devise novel technologies that bring the flutter effect under control in new ways and reduce structural loads. These technologies make it possible to construct wings with a lower weight and a higher aspect ratio. The lighter yet still very stable wings generate less drag and are therefore more energy efficient. As part of these projects, an unmanned flying demonstrator has been built to test various wing concepts in flight. The Institute of System Dynamics and Control develops integrated simulation models and flight control algorithms for load reduction and flutter suppression and plays a key role in the development of autopilot functions for the automated flying of test trajectories. A training simulator has also been set up for the safety pilots on the ground.

Project partners: MTA, Airbus, FACC, INASCO, TU Delft, TU Munich, University of Bristol, RWTH Aachen.

SAGITTA

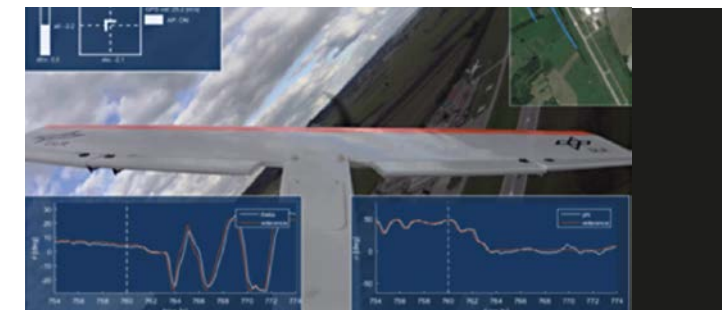
New technologies for future unmanned aircraft have been developed and tested in the SAGITTA open innovation project. The institute was responsible for the planning, construction and operation of simulation and integration testing systems. Project partners: Airbus, TU Munich, TH Ingolstadt, UNIBW München, TU Chemnitz, DLR (FT, FA, SR).

HAP (DLR)

The aim of the unmanned High-Altitude Platform (HAP) cross-sectoral project is to develop comprehensive systems expertise for high-altitude aircraft at DLR. This expertise will make it possible to develop, construct and operate an approved overall system (platform, payload, ground station, operational procedures) for continuous operation. The Institute of System Dynamics and Control is developing the flight control algorithms and autopilot for the platform. The unconventional flight envelope and ultra-light and therefore highly flexible structure of a solar-powered aircraft pose particular challenges.

FASER

The institute uses the FASER UAS to test new flight control techniques. This test vehicle is equipped with a flight control computer developed by the University of Minnesota and enables flight tests to be carried out at low risk and low cost. This is followed by testing with a manned test vehicle. A number of control methods have already been flown for the first time anywhere in the world using FASER, and then successfully made ready for use in manned aircraft.

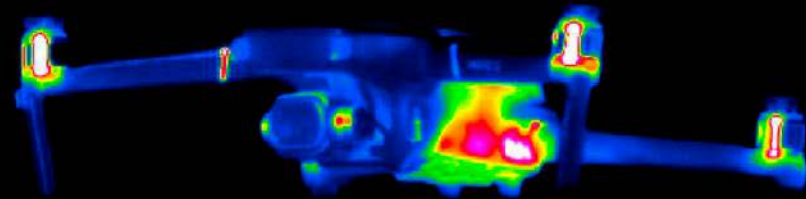


FASER

Director of Institute
Professor Johann Bals

*Control methods and technologies
to increase safety,
comfort and efficiency*

Drone signatures in different spectral ranges (top: visible; middle: thermal image; bottom: infrared).



Institute of Technical Physics (TP)

The Institute of Technical Physics develops laser systems for applications in aerospace, security and defence. Scientists, engineers and technicians are working on interdisciplinary issues from the main subject areas at the Institute's sites in Stuttgart and Lampoldshausen:

- Detection and removal of space debris
- Laser-based remote detection of pollutants and hazardous substances
- Long-range laser effectors
- Laser-based flight instrumentation

Location and identification of UAS using laser-based sensor systems

With its many years of experience in the development and evaluation of high-performance laser systems and technologies for active optical systems, studies of beam propagation over long distances and investigations into laser-matter interactions, the Institute of Technical Physics is a centre of competence for civilian and defence security research.

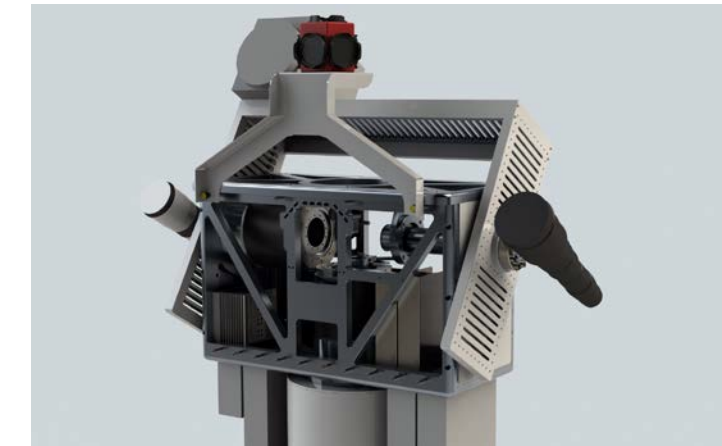
TRAILER research platform

Unmanned Aerial Systems (UAS, drones) are being used increasingly frequently due to rapid technological progress and falling costs. Malfunctions and the accidental or deliberate disregard of rules lead to new threats.

Early detection, precise localisation and clear identification of an unmanned flight system are necessary to enable security authorities to assess dangerous situations. Scientists at the Institute of Technical Physics are developing innovative laser-based electro-optical sensors and evaluation algorithms to meet the requirements of the various tasks safely and reliably. One of our research platforms is the Tracking, Ranging And Identification using Laser Energy on the Road (TRAILER) system.

This is a mobile, trailer-mounted pan/tilt platform used to test new sensors, algorithms and defence systems. In addition to the high payload and the easy integration of additional measurement sensors, it is also possible to incorporate powerful lasers.

The TRAILER platform includes high-speed visible-light cameras, high-resolution infrared detectors and an extremely powerful thermal imaging camera. The high resolution of the imaging sensors enables the clear identification and classification of target objects. In addition, the distance to the flight systems can be determined using a laser ranging system. The highly agile TRAILER system ensures precise alignment with moving objects. In conjunction with powerful laser systems, this could be used to create a targeted and scalable means of defence.



Model of the pan/tilt platform for the identification and precise route tracking of drones

One potential application scenario for the TRAILER system would be the development and evaluation of defence systems to protect against small, unmanned drones at airports or over protected terrestrial or maritime zones.

Director of Institute
Professor Thomas Dekorsy



Institute of Transportation Systems (TS)

Approximately 200 researchers at the Braunschweig and Berlin locations are working in interdisciplinary teams to develop customer-oriented solutions for greater safety and efficiency in road and rail traffic. Their work focuses on road and rail systems, intermodality and local public transport, as well as traffic management and the integration of transport systems.

Through its research, the institute is designing future solutions for public mobility and the transport of goods. It is conducting application-oriented research for the benefit of society and with the aim of strengthening Germany as a location for business. Scientists are implementing integrated tool chains of simulations, laboratories and test fields, and developing methods, technologies and system solutions for coordinated, cooperative transport.

Communication of air and ground traffic for faster rescue operations

Close cooperation within the DLR network enables synergies with aerospace and energy technology to be exploited. In addition, the institute is working with partners from scientific research institutions and industry in an application-oriented manner, bringing its research into line with policy requirements and public needs.

The Air2X project

Together with the DLR institutes of Flight Guidance and Flight Systems, the Institute of Transportation Systems has set itself the goal of demonstrating the potential of communication and cooperation between airborne and ground-based traffic. To that end, it has demonstrated that rescue operations that use helicopters on motorways can be carried out more safely and quickly with the aid of communications with vehicles.

Researchers connected a drone with wireless communication directly to vehicles as part of the project. This allows the drone to automatically transmit its planned landing site and thus inform vehicles that have a corresponding communication interface. A digital barrier prevents these vehicles from entering the desired landing site. As a result, they also create a physical barrier for all of the vehicles following them in their lane. The scenario was examined on the test site as a prototype, with a drone standing in for the helicopter. The technology is currently being implemented on a helicopter.



Instrument display inside a vehicle

This unique communication technology allows air rescue missions to be less dependent on rescue workers on the ground. Time to assistance can also be significantly reduced, while the safety of the helicopter and third parties is ensured.

For a video of the project, go to:
<https://verkehrsforschung.dlr.de/en/projects/air2x>

Director of Institute
Professor Katharina Seifert



Institute of Engineering Thermodynamics (TT)

The Institute of Engineering Thermodynamics has over 180 personnel conducting research in the fields of thermal and chemical energy storage, with a focus on power-to-heat-to-power, hydrogen, batteries and innovative next-generation energy conversion technologies for fuel cells and electrolyzers. Its work ranges from theoretical studies and fundamental laboratory work to the operation of pilot plants.

Alternative propulsion systems for UAVs and more – research into the use of fuel cells in air transport

In addition to its core activities in DLR's 'Energy' research area, the Institute of Engineering Thermodynamics is also investigating fuel cell systems for 'More Electric Aircraft' and 'All Electric Aircraft' to address the 'Aeronautics' research area. Fuel cell systems are being set up at the Hamburg and Stuttgart sites and researched during operational use.

HY4 – the first zero-emissions passenger aircraft

Passenger air travel without noise, soot particles or carbon dioxide emissions. As early as 2008, the Institute of Engineering Thermodynamics was able to put the world's first pilot-controlled Antares DLR-H2 aircraft into the air with a fuel cell propulsion system. Building on this, HY4 – the world's first four-seater passenger aircraft with hydrogen fuel cell technology and an electric propulsion system – was developed, marking a milestone on this journey.



HY4 propulsion system

Electric flight with HY4 is quiet, protects the environment and is better than its predecessors in terms of range and safety. The HY4 flying research platform is currently being converted into a highly redundant hybrid in the EU MAHEPA project, which utilises the long-term energy research activities of the Institute of Engineering Thermodynamics in the fields of batteries, fuel cells and hydrogen technologies.

HY4 is based on technology designed for a four-seater hydrogen fuel cell passenger aircraft. The hybrid is equipped with a powerful PEM fuel cell for long-range travel and a high-performance lithium battery with an output of 80 kW to assist with take-off and changes in altitude. As a result, HY4 can reach a top speed of up to 200 kilometres per hour and has a range of up to 1500 kilometres. HY4, which carries a maximum of four passengers, is the world's first fuel-cell-based passenger aircraft.

This technology is the result of more than 10 years of work by DLR in the field of electric flight and was funded under Germany's National Innovation Programme for Hydrogen and Fuel Cell Technology.

Director of Institute
Professor André Thess

Security Research Programme Coordination (PK-S)

Climate change, future mobility, migration and digitalisation are representative of the current global challenges facing society. These must be defined through a whole-system understanding of the technological, economic and social aspects to their interactions, their changeability and their close links with the issue of security. Security is not only a basic human need, but also represents the basis for a modern, globalised future society.

Interdisciplinary cooperation – at DLR and beyond

DLR combines its security-relevant specialist expertise in the cross-sectoral area of security research. This incorporates the core expertise of established DLR programmes in aeronautics, space-flight, energy and transport. Multidisciplinary and interdisciplinary collaboration creates new synergies and makes it possible to develop innovative security solutions that make peoples' everyday lives noticeably safer.

To be more specific, our expertise in independent analysis and assessment is already helping to maintain and strengthen the ability of public users, especially the German Federal Ministry of Defence (BMVg), to maintain and strengthen their state security assessment capabilities.

MaRPAS project

DLR's motto, 'Knowledge for Tomorrow', does not just refer to the dissemination of knowledge. It is also geared towards practical systems and services that are used today or will be used in the future, based on the knowledge and expertise of DLR personnel. One example is the **Maritime RPAS Operation 2** (MaRPAS 2) project.

For maritime rescue missions or surveillance tasks, the ship-based operation of unmanned aircraft (Remotely Piloted Aircraft Systems, RPAS) could provide highly automated situation images and identify critical situations, enabling responders to act quickly in an emergency. This potential application is the subject of ongoing research as part of the MaRPAS 2 project.

The DLR institutes of Flight Guidance and Flight Systems are developing procedures and technologies to enable an RPAS to land on a moving platform in difficult weather conditions.

The RPAS is guided to a precise point above the ship's platform based on a precision landing procedure for relative navigation using GPS double differencing. A patented cable landing procedure is used for descent from this position. Automatic take-off and landing procedures are being developed for this purpose, while the design of the DLR U-Fly ground control station is being further advanced for use on ships. The superARTIS unmanned helicopter will be used to demonstrate the procedures and technologies that have been developed.

Security Research Programme Coordinator
Dr Dirk Zimmer



The High-Altitude Platform (HAP) cross-sectoral project (HAP – High-Altitude Platform)

DLR has set itself the goal of building up and disseminating its comprehensive expertise in the implementation of high-performance, certified, high-flying solar-powered aircraft. Under the leadership of the Institute of Flight Systems (FT), DLR is pursuing a holistic approach and is developing not only a platform, but also the necessary ground station, payloads to be carried on the platform for earth observation and operational procedures essential for carrying out the corresponding missions. To this end, DLR is combining a wide range of expertise from the fields of aeronautics, spaceflight and security from the 17 institutes involved. The aim is to test promising technologies and construction concepts, as well as demonstrating different application potentials.

Development, construction and testing of unmanned, solar-powered stratospheric aircraft

The platform is configured along conventional lines, but is extremely lightweight, with a total weight of 138 kilograms and a wingspan of 27 metres. The sensor systems, including a high-resolution camera and a synthetic aperture radar system, will each weigh less than five kilograms. Numerous Earth observation tasks can be carried out using these sensor systems. This includes surveillance of shipping routes, reconnaissance in the event of flooding and forest fires, and the monitoring of ice surfaces. An aircraft that can be stationed at an altitude of 20 kilometres must achieve wing loads significantly less than five kilograms per square metre, which explains why mass differences of just a few grams are crucially important to the planning and design of the aircraft and its systems.

Both the project itself and the efforts made by industry to date demonstrate that high-altitude, long-duration platforms of this nature, and their lightweight sensor systems, must therefore be developed and built at the very limit of what is technically feasible. Industry is showing a keen interest in the progress of the project.

The project, which began in 2018, will soon undergo its preliminary design review, which will assess the technical feasibility and appropriateness of the initial design. As with the system requirements review conducted in April 2019, this will be overseen by external experts.

The first test flights with the HAP technology demonstrator, called HAP alpha, are planned for 2022, with the first flights initially planned at low altitude at the National Experimental Test Center for Unmanned Aircraft Systems in Cochstedt. Once the aircraft has been sufficiently tested and the procedures for the ground crew have been properly established, HAP alpha will gradually progress to an altitude of up to 20 kilometres. Extensive demonstration flights with payload systems will then be carried out at high altitudes. The team is in talks with suitable flight test facilities around the world that have the necessary extensive restricted ground and air zones up to high altitudes, with a view to executing high-altitude flights.

DLR institutes involved: FT, AE, AS, DFD, FA, FL, HR, KN, MF, OS, PA, RB, RM, SC, SHT, SR, UX, VE

Unmanned Aircraft Systems Coordinator
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Andreas Bierig

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National Experimental Test Center for Unmanned Aircraft Systems

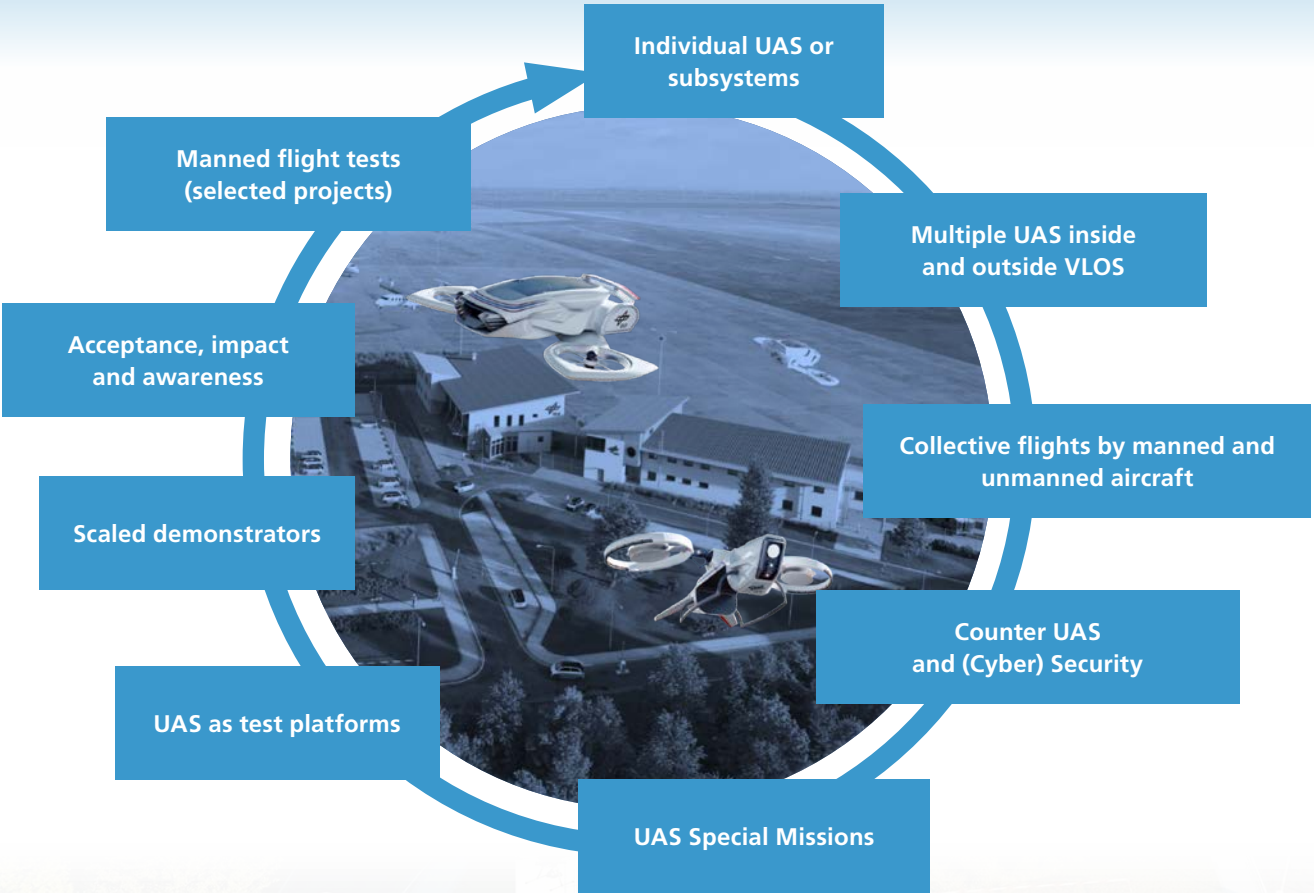
The National Experimental Test Center for Unmanned Aircraft Systems is a test centre that combines skills and expertise for the development of unmanned aircraft systems. The Test Center facilitates the networking of scientific research and industry for the ongoing development of UAS technologies.

Since neither manufacturers, users or the regulatory authorities can investigate and resolve all issues by focusing on UAS alone, involvement in large-scale research and support for such endeavours is becoming increasingly important as a link with both technical and regulatory issues alike. In addressing these challenges, the National Experimental Test Center for Unmanned Aircraft Systems will play a key role as a pioneer for future research and the development of new UAS technologies. The aim is to create a test environment that can be used by any entity, which will provide a basis for technological and regulatory decisions in the future. For certification purposes, new unmanned aircraft systems and their missions will need to be comprehensively tested and qualified under realistic conditions within a controlled environment. Cochstedt Airport is ideal for this due to its location and infrastructure. The test site will be accessible to universities and other scientific research institutions, industrial enterprises

for research purposes, and DLR's own researchers. The Test Center is also particularly beneficial to start-ups and SMEs, which have the opportunity to use a state-of-the-art test centre and build up a network with other participants, without the need for large investments.

Infrastructure, test services and DLR's own research

The Test Center provides the necessary infrastructure for its users (for an overview, see the fold-out graphic at the end). It can help users to plan, apply for and carry out tests. Possible test scenarios range from system or subsystem testing of individual UAS, testing swarm behaviour and airspace integration to defence against UAS (including cybersecurity) and investigating acceptance and the effects of UAS. Moreover, in conjunction with the University of Magdeburg and the DLR institutes in Cochstedt, as part of a UAS centre of excellence founded in 2020 within the National Experimental Test Center, the facility is establishing its own research topics, which are intended to stand alongside existing research. (These are currently being coordinated.)



Scaled technology demonstrators

The development and use of scaled demonstrators have proven to be extremely effective in the past at DLR and is set to grow in future due to challenges and expectations in the field of UAM. Added to this, testing in realistic scenarios will aid the modernisation and automation of air transport in general. In terms of scaled demonstrators, research on the vehicle itself will also include research and testing of the new procedures and processes required for the successful establishment of new UAS technologies. In this case, real processes and procedures are mapped and researched in a scaled-down environment in order to be able to make a rapid statements about their cost effectiveness and feasibility.

Interdisciplinary cooperation, scaling and a place for networking

One example is the (pre-) testing of UAM scenarios and the associated technologies for UAS integration in a ‘miniature city’ before they are rolled out as a real process, at full scale and high cost.

The UAS research platform

UAS research at DLR currently takes place primarily at a local level, at the respective sites (see image inside the cover for an overview). DLR’s Cochstedt site, which is home to the Test Center, is intended to show solutions that advance research in an efficient and effective way for DLR as a whole. This can be achieved through the idea of a ‘UAS research platform’ to combine cross-institute research in Cochstedt. This concept follows the approach whereby the disciplinary topics remain within the remit of their existing locations, while integrative elements are transferred to Cochstedt. In future, this will be of particular interest to larger cross-sectoral DLR projects and external research projects for which relocation to the UAS research platform will allow institutes and project partners greater flexibility. In addition to dedicated research in Cochstedt, all of DLR’s UAS research will be networked in Cochstedt.

HorizonUAM

The National Experimental Test Center for Unmanned Aviation Systems, which is under the project management of the Institute of Flight Guidance in cooperation with eight other DLR institutes, is involved in the DLR’s new UAS flagship project. In addition to the use of existing contacts in industry to benchmark the assumptions on which the project is based, the safety assessment capabilities for planning flight tests and demonstrations will contribute to the success of the project. In addition, UAM test infrastructure in the form of a model city, including a vertiport demonstrator for the validation of processes and technology concepts, is to be developed as part of the project. The conception and the subsequent structure are largely being driven by the Institute of Flight Guidance and the National Experimental Test Center.

Scaled vehicles	
Scaled test infrastructure	
Scaled processes and operations models	

Applications for scaled demonstrators

“The future use of UAS at a commercial level poses new challenges for researchers, manufacturers, operators and legislators alike. In view of the complexity of the challenge, a compartmentalised approach to dealing with individual parts of the overall system is no longer sufficient. Hence, they need to be considered, tested, validated and certified conjointly.”

(Quote from the concept for the Test Center)

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Overview of Experimental Test Center site and infrastructure



Office Building

- Offices and meeting rooms – for researchers
- Work areas for the UAS Research Platform
- Rest areas (with sleeping facilities) for project use



Tower

- Flexible project work areas
- Meeting rooms for project use (incl. video conferencing options)



Urban test infrastructure (planned)

- Model city at different scales
- Flexible building arrangements
- Measurement technology preparations



DLR employees



Airport operations



UAS testing



Service



Projects and research



Main building

- Conference centre
- Laboratories
- Mission control centre



Operations building

- Fire service
- Security technology
- Airport operating company



Communications/navigation systems and data links

- S-band data link
- Telemetry data links (433MHz / 2.4GHz)
- First-person view system
- Experimental GBAS ground station
- LTE, 5G tracking (planned)
- MLAT system
- FLARM
- Visual flight path measurement (cinetheodolites)

Calibration and testing systems

- GPS repeater and simulator in the various test preparation areas
- Mobile hardware-in-the-loop system
- Calibration systems (for aviation technology components, camera systems, GPS, etc.)

Ground station and mission control centres

- Stationary: up to 8 workstations in the main building
- Mobile: up to 4 workstations in the container and van
- Documentation systems (video and camera technology, chase platform)
- Flight termination datalink
- Radio network for test operations
- Security facilities for ground station teams

Airport-specific infrastructure

- Runway and landing strip
- 2.5 km tarmac, 800 m grass
- ATC infrastructure (tower)
- Cat MET 2/3 weather system



UAS workshop

- Parking and hangar areas
- Individual project areas
- Metal and plastics processing
- Electronics workshop
- Meeting room

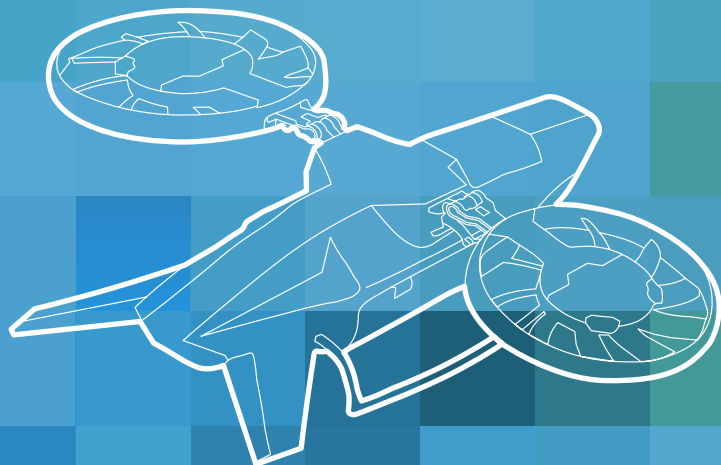


DLR National Experimental Test Center for Unmanned Aircraft Systems

About DLR

DLR is the Federal Republic of Germany's research centre for aeronautics and space. We conduct research and development activities in the fields of aeronautics, space, energy, transport, security and digitalisation. The German Space Agency at DLR plans and implements the national space programme on behalf of the federal government. Two DLR project management agencies oversee funding programmes and support knowledge transfer.

Climate, mobility and technology are changing globally. DLR uses the expertise of its 54 research institutes and facilities to develop solutions to these challenges. Our 10,000 employees share a mission – to explore Earth and space and develop technologies for a sustainable future. In doing so, DLR contributes to strengthening Germany's position as a prime location for research and industry.



**Deutsches Zentrum
für Luft- und Raumfahrt**
German Aerospace Center

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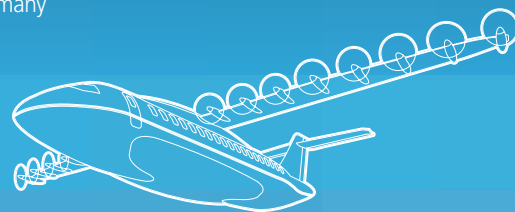
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