Aviation Working Group

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AVIATION WORKING GROUP

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Fraunhofer Transport Alliance
c/o Fraunhofer-Institut für Materialfluss und Logistik IML
Joseph-von-Fraunhofer-Straße 2-4
44227 Dortmund
Telefon +49 231 / 9743-371
Fax +49 231 / 9743-372
E-Mail: info@verkehr.fraunhofer.de
Homepage: http://www.aviation.fraunhofer.de

Editorial Team:

Dr. Ralf-Maximilian Jungkunz (Fraunhofer IML)
Dr.-Ing. Normen Fuchs (Fraunhofer IGP)
Dr. Jonathan Köhler (Fraunhofer ISI)
Christiane Kraas (Fraunhofer Transport Alliance)

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SPECIAL REPORTS

RESEARCH AND DEVELOPMENT

FOREWORD

Foreword - Fraunhofer-Gesellschaft

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are used by customers and contractual partners in industry, the service sector and public administration.

At present, the Fraunhofer-Gesellschaft comprises 72 institutes and research units. The majority of the more than 25 000 staff are qualified scientists and engineers, who work with an annual research budget of 2.3 billion euros. Of this sum, almost 2 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Around 30 percent is contributed by the German federal and state governments in the form of base funding, enabling the institutes to work on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to reinforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.

FOREWORD

Foreword – Aviation Working Group

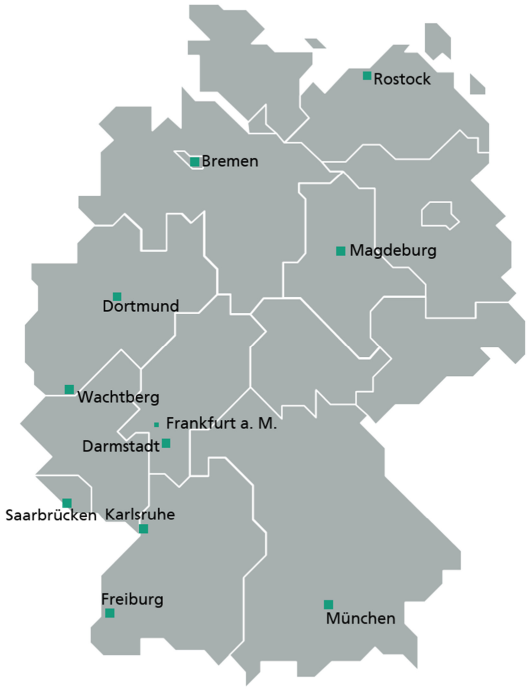
All participants along the aviation value chain face a challenging competitive environment that requires sustainable investments to secure future business success.

However, motivating investment decisions is increasingly difficult for market players. This is e.g. due to the level of external information available about the opportunities and threads of new approaches and technologies such as Industry 4.0, cyber-physical system (CPS) and the Internet of Things (IoT) such as auto-ID technologies and wearables.

In this environment Fraunhofer Aviation Working Group is a competent consultant and successful system supplier and enabler for participants along the aviation value chain in order to enable new business models for clients and to cut costs for established products and services.

Based on our interdisciplinary industry experience in combination with scientific excellence in aviation our customers describe us as the leading experts in industry based research and as a reliable partner for efficient designing, implementing, testing and rollout of complex system solutions that are both innovative and economically successful.

Since we are embedded in the Fraunhofer Gesellschaft with 25.000 colleagues this allows us to successfully combine aviation specific competence with the expertise and industry know-how of other industries. We utilize synergies and transfer successful concepts and technical solutions to aviation.



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CONTEMPORARY TOPICS

ALONG THE PROCESS CHAIN FRAUNHOFER AVIATION IS AN ENABLER AND COMPETENT SYSTEM SUPPLIER FOR FUTURISTIC TOPICS

Digital Transformation

Digital Transformation combines different topics. All members of the aviation process chain consider it as a mega trend and a tool to enable innovative solutions and economic efficiency as well as growth. Aviation -related companies expect quantitative advantages such as an increase in productivity and a reduction of fixed costs as well as qualitative advantages including more flexibility and the possibility to offer each customer unique innovative and affordable products and services. This also includes the development and use of complex sensor systems for non-destructive status detection for every product life phase. The biggest challenge of the Digital Transformation is to manage a systematically shift from the analogue to the digital world. Furthermore, data scientists and experienced employees are needed.

Aviation Next Generation

The development of passenger and freight demand has a decisive influence on the economic success of the future of aviation and producers of machinery and equipment, infrastructure managers and service providers. Drones, working as caps, are supposed to relieve increasing urbanization and traffic load in conurbations and safe lifetime. In order to safe costs as well as to improve process flexibility, airfreight shipments are supposed to find their way to their destination autonomously in the future. Furthermore, there are opportunities to improve the life cycle assessment and to reduce cost.

Safety and Security

Improving civil security is one of the main goals in ensuring quality of life and value creation in Germany. This implies that citizens, companies and authorities have to be protected from natural disasters and threats including hacker attacks or terrorist attacks. Living in a complex and interconnected environment makes this task difficult. This applies to improved prevention as well as to efficient solutions for security conflicts.

Safety and Security have always been important for air traffic (passengers, luggage and freight). Here the parties concerned are especially sensitive to this topic, which makes it complicated and expensive; 91% of all airlines decided to invest in cyber security programs within the next three years and the Airports Council International calculated that the air traffic makes up 4,1% of the European gross domestic product and about 12 millions of jobs.
The rapidly changing global security situation, a high process complexity and high inventions and operational costs, challenge infrastructure operators like airports as well as providers of security solutions. Innovation in new technologies and technologies that can be integrated in the current infrastructure have to be developed to maximize safety and security (risk simulation, risk prevention, damage repair). This does not only apply to a safe end-to-end-transport of passengers, luggage and freight (physical safety and security) but also to a safe transport and use of critical data (Cyber Security).

Sustainability

It is not possible to stop the demographic change and the importance of including disabled people is increasing in society. Products and services, which support the demographic change, are often seen as a tool to raise employment and lead to a structural entrepreneurial change. Environmental protection and sustainable use of energy will determine our future. This also leads to financial and technological risks for all members of aviation’s process chain. An efficient andeco-friendly process chain could be decisive. Aviation’s biggest challenge is to develop while considering ecology, economy and social aspects.

SPECIAL REPORTS

RESEARCH AND DEVELOPMENT

SR - Structural health monitoring of a carbon fiber aircraft fuselage section

Due to the increasing use of carbon fiber reinforced plastic parts in the aviation sector to reduce aircraft weight, it is becoming more and more important to demonstrate their operational reliability in flight. Fraunhofer LBF, in cooperation with two other Fraunhofer institutes, has undertaken to provide this demonstration based on a structural health monitoring system for a carbon fiber reinforced plastic (CFRP) aircraft fuselage.

Measuring in the right places: aircraft fuselage in load test

As part of the European large-scale research project Clean Sky, a team of researchers from Fraunhofer LBF monitored the fuselage structure of an aircraft using a special measuring setup to investigate the behavior of large-scale CFRP structures in aircraft during flight. For this purpose, the aircraft fuselage was subjected to a cyclic internal pressure load in a ground test. This repeated pressurising of the closed fuselage simulates the expansion of the structure at high altitudes.

The aim of the measurements was to obtain robust data which could be compared to the theoretical calculations of aircraft manufacturers on the behavior of large-scale CFRP structures, thus making it possible to design such components more efficiently in future.

With the sensor monitoring network of optical measuring fibers for monitoring strain and stress mounted on a large surface area of the aircraft fuselage and the piezo-based structural health monitoring system for identifying changes in the structure and material, it is possible to analyze and monitor the behavior of a complete aircraft fuselage and to reliably record changes in the structure.

The researchers attached the optical measuring fibers on the side facing the aircraft interior and on the outer skin of the fuselage. The thin, elongated glass fibers are well suited to indicating even very slight changes in larger components. In addition, a piezo-based network for structural health monitoring was applied to the underside of the fuselage.

The tests are part of Clean Sky, a joint research project of the European Commission and the European aviation industry. The aim is to design CFRP components which are even lighter than current designs, thus saving unnecessary material and therefore fuel, to increase the service life and to achieve significant savings in maintenance and replacement, thus making aircraft more cost-effective and environmentally friendly. With a system such as this it would be possible to monitor the structure for its condition on the ground and during flight. A medium-range model for approximately 70 passengers was used as the test aircraft.

Figure 1: Ground test in the laboratory: A special measurement setup detects the cyclic internal pressure load on an aircraft fuselage simulated by inflation. Photo: Leonardo

SPECIAL REPORTS

RESEARCH AND DEVELOPMENT

Customer Benefits

It is possible, using the measurements carried out at Fraunhofer LBF, to detect and display deformation of the carbon fiber aircraft structure very accurately. This knowledge can be used in future to produce lighter, optimized components which will lead to weight reduction and therefore fuel savings. This structural health monitoring can also be used to significantly prolong the operating times of the components thus reducing costs and increasing operational reliability.

Figure 2: The high-precision measurement setup from Fraunhofer LBF can detect and display the deformations to carbon fiber structures very accurately

Summary

To investigate the behavior of a carbon fiber aircraft structure under internal pressure load during flight, scientists at Fraunhofer LBF developed a measurement concept as part of the European aviation research project Clean Sky which was subsequently installed and used in an aircraft fuselage. With these measurements based on optical measuring fibers and piezo-based sensors, it was possible to determine the real loads at high altitude and to monitor the structure. Based on these results, it is now possible to optimize components and thus save weight. As a result of structural health monitoring, these components can also remain in service longer before needing to be replaced.

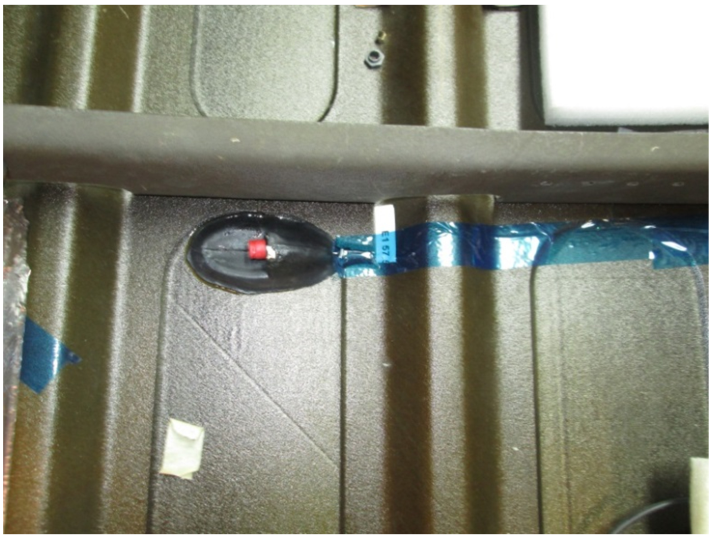


Figure 3: Fraunhofer LBF connector hub for integrated sensors in composite structures.

Author's quote:

"A significant contribution was made to advancing cost-effective aircraft construction in respect of safe and environmentally-sound air travel by developing a comprehensive monitoring system for recording loads and changes in the structure and testing it successfully under real operating conditions."

Acknowledgements:

Research leading to these results has received funding from the European Union (FP7/2007-2013) for the Clean Sky Joint Technology Initiative under relevant grant agreement Plus EU Flag and CS logo as for 2015

SPECIAL REPORTS

RESEARCH AND DEVELOPMENT

Contact:

Fraunhofer Institute for Structural Durability and System Reliability LBF
Oliver Schwarzhaupt, M. Eng. Conchin Contell Asins
Phone: +49 6151 705 – 490
Mail: oliver.schwarzhaupt@lbf.fraunhofer.de
Phone: +49 6151 705 – 8462
Mail: conchin.contell.asins@lbf.fraunhofer.de
Web: https://www.lbf.fraunhofer.de/

RESEARCH AND DEVELOPMENT

SR - Precise demonstration of CFRP parts deformed during a flight

On board: no passengers, not even rows of seats. The lining of the interior walls is missing. Instead cables, sensors, measuring devices bolted firmly to the floor. The aircraft's fuselage is not made of aluminum as usual. A component made of carbon fiber reinforced plastic (CFRP) forms the upper outer skin from the cockpit to the wings. There's no doubt that it will withstand the loads of the test flight. But how far will it deform during different flight maneuvers? Until recently no exact values were available.

Figure 1: LBF scientists on the aircraft.

LFB measuring technology clearly records flight stresses

CFRP structures behave differently to aluminum during a flight. A team of researchers from Fraunhofer LBF found out exactly how differently with a special test setup during test flights. The aim of the measurement flights was to obtain robust data which could be compared to the theoretical calculations available on the flight behavior of CFRP. Aircraft manufacturers need the real data to build components precisely so that they can withstand the loads arising. The test flights have shown that the test setup can be used to assign a clear CFRP deformation to each individual flight maneuver. The scientists spread out all the measurement hardware in the aircraft for the test flight and evaluated the data. The test flights are part of Clean Sky, a joint research project of the European Commission and the European aviation industry. The aircraft manufacturer will now evaluate the results. Aircraft manufacturers want to build even lighter CFRP components to save unnecessary material and therefore fuel.

With this system it is also possible to monitor the structure during the flight for its condition. This means components can therefore remain in service for significantly longer, resulting in significant savings.

A medium-range model for approximately 70 passengers was used as the test aircraft. For the flights, part of the upper fuselage was replaced with a CFRP component measuring around eight meters long by three meters wide. This area represents the component exposed to the highest loads during a flight. The researchers attached the optical measuring fibers on the side facing the aircraft interior. The thin, elongated glass fibers are well suited to indicating even very slight changes in larger components.

Measuring points which were then attached to the fibers were defined for this purpose. An opto-electrical measuring unit recorded the measuring signals. The black box provided additional information on altitude, flight speed or flight maneuvers. Both data pools – strain measurement and flight data – were then correlated. As a result, it was possible to demonstrate exactly how the flight had impacted the CFRP component. To attach the strain sensors in the right places, the researchers had to know where loads usually occur during flight maneuvers. Here, Fraunhofer LBF was able to contribute its expertise on the behavior of CFRP: The scientists had calculated the places with the highest loads beforehand and attached the measuring points precisely there.

Figure 2: To investigate the behavior of a carbon fiber aircraft structure during flight, scientists at the Fraunhofer LBF developed a measurement concept. Photo: Alenia.

Customer Benefits

It is possible to measure and illustrate the deformation of the carbon fiber aircraft structure very accurately due to the measurements carried out by Fraunhofer. This knowledge can be used in future to produce lighter and optimized components which will lead to weight reduction and therefore fuel savings. This structure monitoring can also be used to significantly extend the operating times of the components and thus reduce costs.

Summary

To investigate the behavior of a carbon fiber aircraft structure during flight, scientists at the Fraunhofer LBF developed a measurement concept as part of the European aviation research project CLEAN SKY which was subsequently installed and used in the aircraft. With these measurements based on optical measuring fibers, it was possible to determine the real loads on the structure in flight and to monitor the structure. Based on these results, it is now possible to optimize components and thus save weight. As a result of structure monitoring, these components can also remain in service longer before they need to be replaced.

Figure 3: Optical sensors illustrate the deformation of the carbon fiber aircraft structure very accurately.
Photo Fraunhofer LBF

Contact:

Fraunhofer Institute for Structural Durability and System Reliability LBF
Oliver Schwarzhaupt, M. Eng. Conchin Contell Asins
Phone: +49 6151 705 – 490
Mail: oliver.schwarzhaupt@lbf.fraunhofer.de
Phone: +49 6151 705 – 8462
Mail: conchin.contell.asins@lbf.fraunhofer.de
Web: https://www.lbf.fraunhofer.de/

SPECIAL REPORTS

RESEARCH AND DEVELOPMENT

SR - Technology development for future aircraft wings

As part of the aviation project Clean Sky – Green Regional Aircraft, Fraunhofer LBF, together with the Fraunhofer IBP and ENAS institutes, investigated an approximately 3-meter wide wing in a climatic wind tunnel test. Prior to this, the wing structure was developed and built at the institute and several innovative technologies were integrated.

New challenges – new solutions

In the European Clean Sky project, pioneering technologies have been in development for future aircraft since 2008. In connection with this, Fraunhofer developed the 1:1 Droop Nose Demonstrator, which was constructed at Fraunhofer LBF and then tested in a climatic wind tunnel test. Based on aerodynamic specifications, kinematics were developed for lowering of the wing's leading edge. The special feature of this highlift device in the leading edge region is that it prevents gaps due to co-deformation of the skin. This is particularly important for future laminar wings as they can only be realized with smooth surfaces. Another advantage is a reduction in noise emissions during landing as a result of preventing gaps. Extensive stretching of the skin, however, which is in evidence during every operation, necessitates adequate structural durability.

An electromechanical actuator causes the skin to deform. It additionally uses several shape-memory alloy actuators provided by Fraunhofer IBP. Fraunhofer LBF is developing a process for reconstructing the wing geometry based on sensor signals so that in future it will be possible to control the kinematics during flight. Among other things, almost 50 fiber-optic strain sensors were integrated in the skin of the movable leading edge for this purpose, and routed to the outside via a structurally integrated connector concept developed by Fraunhofer LBF.

Fraunhofer ENAS provided synthetic jet actuators for the "Wing" technology platform. They are able to exert a positive effect on the airstream. The behavior of this technology under icing conditions was to be tested in the climatic wind tunnel test.

Figure 1: Wing structure with flexible droop nose.

For the first time, a thermal anti-icing protection system was also integrated in a highly elongated wing leading edge. An anti-icing protection system is an important requirement for safe operation. The extensive stretching of the skin, however, previously made it impossible to solve this design concept satisfactorily. During the Clean Sky project, Fraunhofer LBF was able to develop a flexible heating system based on carbon nano tubes (CNT). Thermal sensors were integrated in the model for temperature control.

During initial testing of the model, there was already good conformity in the wing deformations between the results of the FE simulations and the manufactured model. As a result, the demonstrator was tested in a climatic wind tunnel test.

The structure and the various technologies functioned well as expected, and it is possible to demonstrate the technology's maturity level as a result of the successful test in the wind tunnel. Development of the technologies is not yet complete and the plan is to continue it in future projects.

Customer Benefits

At Fraunhofer LBF even complex R&D with prototypes are possible. In this project, the timeframe for the last project phase was six months for design, manufacturing and testing.

Summary

In the context of the Clean Sky Project a 3-meter wide full-scale wind tunnel model of a possible future wing was developed and manufactured at Fraunhofer LBF; several potential future technologies have been integrated. This demonstrator has been conceived as a technology platform: A flexible ("morphing") Droop Nose with a measuring and control system, the novel integration of a variable ice protection system, integration and testing of shape-memory alloy-based actuators and synthetic jet actuators are an important step in enhancing the technology readiness level.

Figure 2: Use of a smoke lance in the climatic wind tunnel.

Research leading to these results has received funding from the European Union (FPJ /2007-2013) for the Clean Sky Joint Technology Initiative under relevant grant agreement.

Contact:

Fraunhofer Institute for Structural Durability and System Reliability LBF
Oliver Schwarzhaupt, M. Eng. Conchin Contell Asins
Phone: +49 6151 705 – 490
Mail: oliver.schwarzhaupt@lbf.fraunhofer.de
Phone: +49 6151 705 – 8462
Mail: conchin.contell.asins@lbf.fraunhofer.de
Web: https://www.lbf.fraunhofer.de/

SPECIAL REPORTS

RESEARCH AND DEVELOPMENT

SR - Radar for navigation support from autonomous flying drones

Radar sensors for navigation support of drones are valuable components in the implementation of autonomous flying drones: they function as obstacle detectors to prevent collisions. Radar sensors also operate reliably in restricted visibility, e.g. in foggy or dusty conditions. Due to their ability to measure distances with high precision, the radar sensors can also be used as altimeters when other sources of information such as barometers or GPS are not available or cannot operate optimally.

Compact and energy efficient

Drones play an increasingly important role in the area of logistics and services. Well-known logistic companies place great hope in these compact, aerial vehicles for the transport of parcels – the aim is to progress from remotely controlled drones to autonomous parcel-supplying drones. Service providers use drones for the maintenance and inspection of plant facilities or for the provision of totally new services such as airborne mapping.

Fraunhofer FHR has developed two compact radar sensors for use on drones: a monostatic radar at 80 GHz for simple applications with short distances (up to 80 meters) and a bistatic radar at 94 GHz for much longer distances. Both sensors have an operating voltage of 5 V, which is provided either by the drone's power pack or a standard power bank. Thanks to the USB interface, the system can be commissioned very easily and integrated into existing drones, whereby the radar is controlled by a low-cost, universally obtainable micro PC (e.g. Raspberry Pi).

Attachable to existing hardware

The radar data is currently transferred via an internal radio channel. An interface to transfer the radar data with the telemetry via the flight controller is still under development.

Figure 1: With the ACoRad-94 on an octocopter, flight altitudes and distances can be measured down to the last centimeter at any time.

After implementing this interface successfully, the information that is collected by the radar can be displayed with existing hard- and software (e.g. apps for drone control and monitoring). When used, for example, as an altimeter, warnings can be issued when the maximum admissible flight altitude of 100 m is exceeded.

The researchers are also using universally applicable mounting options to ensure that the system can be easily mounted on the drone. Optionally, the detection range of the radar sensor can be enlarged through oscillation motion (e.g. through the utilization of compatible gimbals) so that surveillance area below can be monitored using greater angular ranges.

One system, various applications

In addition to being deployed as an obstacle detector in the area of autonomous flight or as an altimeter, other applications are also conceivable for the radar. It could, for example, be used as part of a multi-sensor suite to enhance situational awareness in the event of a major disaster. Alternatively, it could be used to determine the biomass or ripeness of arable crops, to detect unwanted foreign objects in cultivation areas or to inspect boiler systems, silos or wind turbines.

Author's quote:

"Our radar systems can play a major role for the safe operation of drones due to their large measurement range combined with small size and low power consumption."

Figure 2: Whether at night, in rainy or in foggy conditions, the ACoRad sensors function even in the most adverse conditions.

Contact:

Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR
Dipl.-Ing (FH) Gunnar Briese
Phone: +49 228 9435 - 787
Mail: gunnar.briese@fhr.fraunhofer.de
Web: https://www.fhr.fraunhofer.de/

SPECIAL REPORTS

RESEARCH AND DEVELOPMENT

SR - Contactless radome inspection

Non-destructive testing with terahertz imaging techniques has proven to be highly successful for inspections of glass-fiber reinforced composite structures both in production environments and field use. Such structures are used, for example, in aircraft radomes, in order to protect sensitive radar equipment and other electronic components. Therefore,, assurance of the structural integrity of the composite is essential. Here, terahertz technology can provide contactless inspection of radomes in service as well as during the manufacturing process.

New challenges – new solutions

Aircraft radomes protecting sensitive radar, navigational, and communications equipment are strongly exposed to harsh environmental and weather conditions and have to withstand potential impacts of, e.g., ice, dust and sand particles as well insects and birds. Modern composite structures, in particular in aircraft construction, are therefore highly optimized, layered compounds of various materials.

Besides their significance to the structural integrity of the radomes, it is often crucial to optimize the composite structures for best possible radio performance. Hence, there exists a significant interest in non-destructive testing techniques, which can be used for defect inspection of radomes in service as well as for quality inspection during the manufacturing process. Contactless terahertz imaging techniques can address both application scenarios with millimeter resolution [1].

The technology allows for the contactless visual inspection of a radome's inner structure, while also providing depth information. In addition, automatic defect or feature recognition can be applied. However, depending on the exact materials and the thicknesses of the composite structures under test, a trade-off between spatial resolution and penetration depth with respect to terahertz inspection systems must be considered. Terahertz systems, which take advantage of the frequency modulation continuous wave (FMCW) method, allow for the reconstruction of depth information of transparent samples under test with the depth resolution being inversely proportional to the modulation bandwidth. While many different terahertz imaging schemes have been developed, the relations between object size, wavelength, and required resolution often lead to a need for custom-designed solutions.

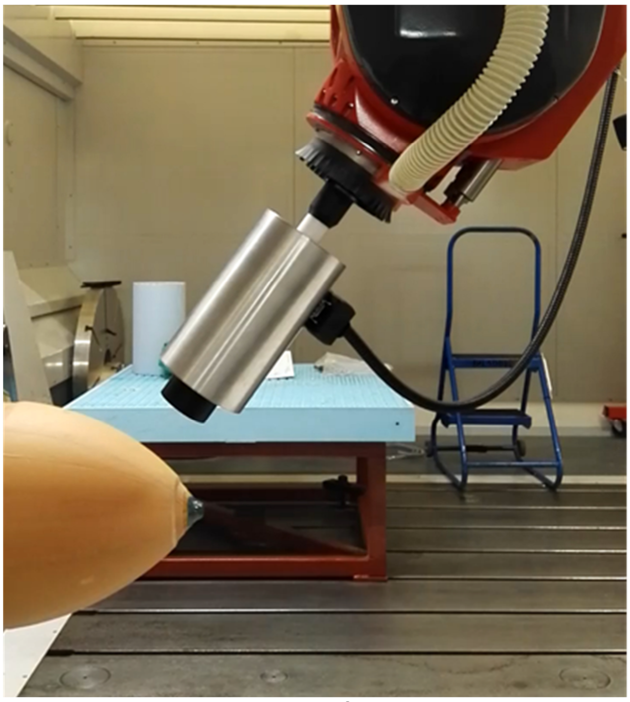


Figure 4: Terahertz inspection of a small radome test structure with the sensor attached to the tool holder of a machining center for radome manufacturing.

Fraunhofer ITWM developed an industrial three-dimensional terahertz imaging system for radome inspection. In order to provide a certain flexibility in terms of resolution and penetration depth, the system comprises two sensors, which operate in adjacent frequency ranges, within a single sensor unit. The measurement data can be evaluated in the form of A-, B- or C-scans.

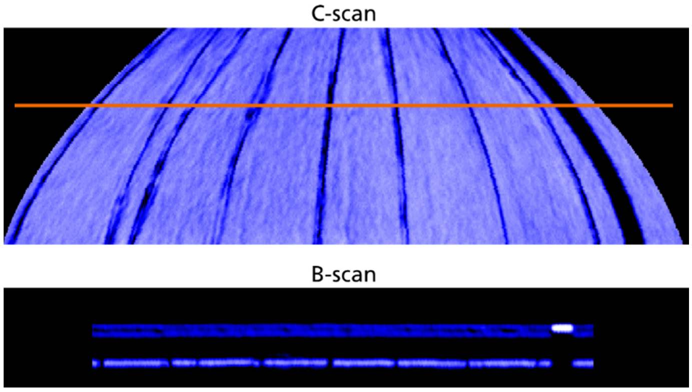


Figure 5: The C-scan shows the backside wall of a radome test structure, which is composed of several glass-fiber reinforced plastic panels. The orange marker indicates the position of the B-scan image below. The strong feature in the upper right of the B-scan comes from a metal stripe attached to the test sample, which completely reflects the measurement signal.

The sensor unit has been created in a way that it can be easily integrated into a machining center for radome manufacturing. The conventional tool holder of the machining center is used in connection with a typical machine program to guide the sensor and to perform a spiral scan of the radome structure.

Customer Benefits

The terahertz inspection system developed by Fraunhofer ITWM provides a contactless alternative to ultrasound testing and tap tests for radome inspection. It has proven to outperform conventional inspection techniques especially when honeycomb or foam structures are used within glass-fiber reinforced composite structures [2]. The technology can provide detailed images of the inner structure with millimeter resolution.

Summary and Outlook

Fraunhofer ITWM developed a terahertz inspection system for radomes, which allows for the contactless visual inspection of a radome's inner structure in the form of A-, B- and C-scans. The measurement sensor has been designed for easy integration in existing machining environments. Besides technological improvements, development towards standardization of this non-destructive testing (NDT) method in collaboration with the UK National Aeronautical NDT board is currently ongoing.

The content of this article has been partly adapted from [1].

Contact:

Fraunhofer Institute for Industrial Mathematics ITWM
Dr. Fabian Friederich, Dr. Joachim Jonuscheit
Phone: +49 631 31600 - 4908
Mail: fabian.friederich@itwm.fraunhofer.de
Phone: +49 631 31600 - 4911
Mail: joachim.jonuscheit@itwm.fraunhofer.de
Web: https://www.itwm.fraunhofer.de

SPECIAL REPORTS

AIRCRAFT MANUFACTURING AND LOGISTICS

SR - Innovative joining technology in aviation manufacturing

Solid Self-piercing rivets (SPR) are mechanical fasteners which have been successfully used in car manufacturing for several years. Regrettably this technology has its limits due to accessibility or technical reasons in car manufacturing. The full potential has been revealed in several industrial projects between the Fraunhofer Research Institution for Large Structures in Production Engineering and aircraft manufacturer AIRBUS.

The aim of these projects is to reduce the amount of time to join two aircraft sections in longitudinal direction. Nowadays the stringer, the longitudinal reinforcement of the aircraft structure, and the stringer coupling, the link between two stringers in different aircraft sections, are mechanically joined with aluminum solid rivets.

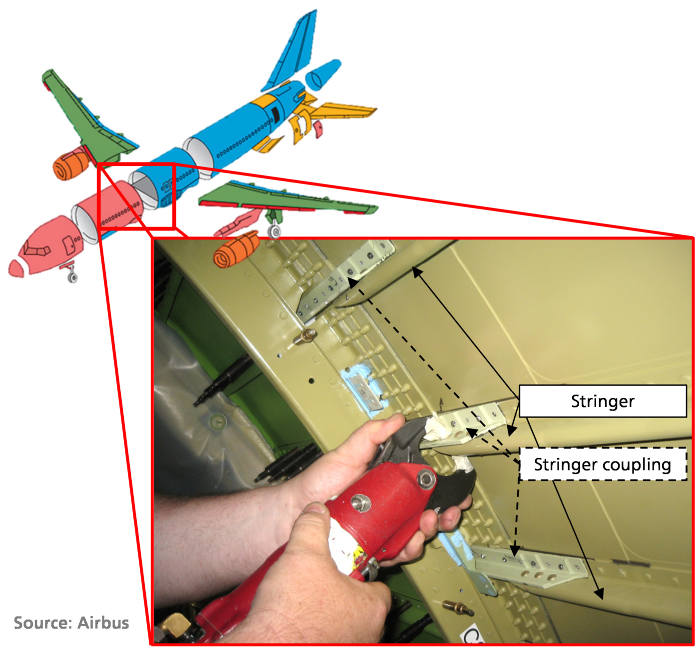


Figure 1: Scope of application

The requirement to mechanically join these elements is to predrill a hole in the stringer and stringer coupling. Due to this multistage drilling process there are several process auxiliary times, e.g. cleaning and positioning of stringer and stringer coupling after each drilling step. This procedure is very time consuming and creates a bottleneck in the manufacturing process. The SPR technology can eliminate this problem due to the drilling process because the rivet itself creates the hole in a stamping process.

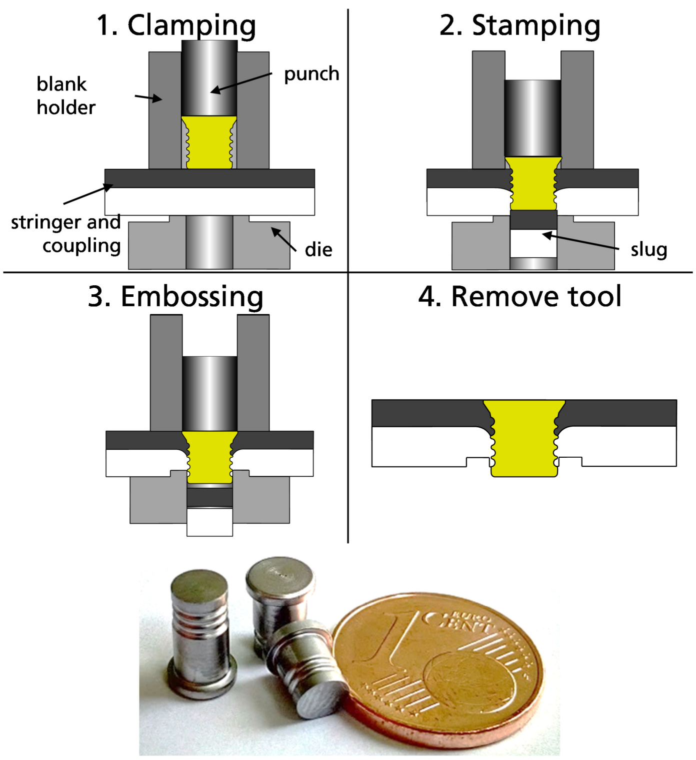


Figure 2: Process steps for a SPR joint (top) and SPRs in comparison to 1 €-cent

In the first process stage the stringer and stringer coupling are fixed between the blankholder and die of the installation tool and the SPR is pushed against the stringer. Afterwards the punch of the tool increases the force on the SPR so that it is pushed thru the stringer and stringer coupling. In this step a slug with a diameter of the rivet is formed and pressed into the die. In the last step the embossing ring of the die is pressed into the material of the stringer which is y yields and fills the circumferential grooves of the SPR. The tool releases the stringer and stringer coupling and is moved to the next joint.

In the aircraft industry the SPR technology is a new application. To integrate such an unknown riveting process, challenges are:

1. Robustness and maturity of joining process
2. Overall lead time reduction
3. Ability/Increase of automation
4. Ergonomic improvements

A comparison has been made between the conventional aluminum rivet and SPR. The results have revealed an improved bearing strength in shear tests of SPR compared to a conventional aluminum rivet. The longitudinal test has shown contrary results. The strength in this load direction is approximately 50 % of today's joining elements. Nevertheless the dominant load direction is shear loading. In this case the SPR technology was approved and further investigations went on to determine the fatigue behavior of SPR.

Lead time reduction is the major argument for using SPR in airplane manufacturing. Investigations at Fraunhofer have shown that the impact of the time saving aspects of this technology is significant. The comparison of today's installation methods to SPR installation process is presented in Figure 4.

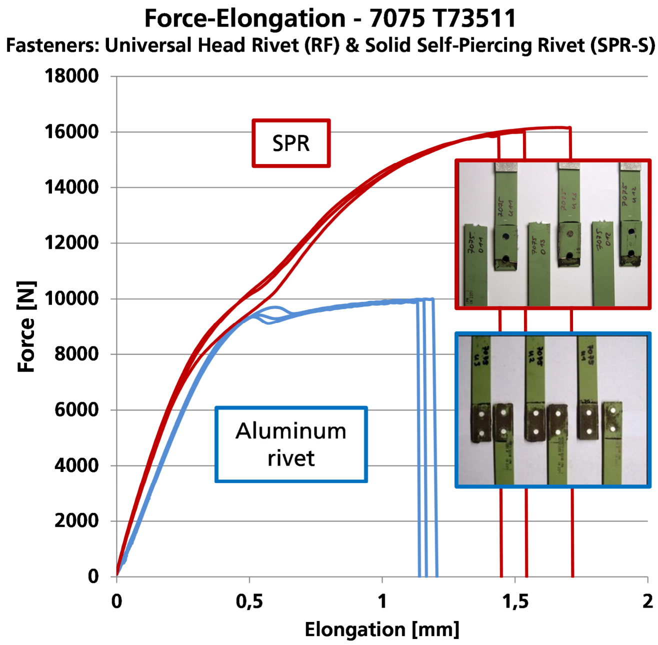


Figure 3: Shear strength of conventional Ø 4,8 mm aluminum rivet compared to Ø 4,0 mm steel SPR

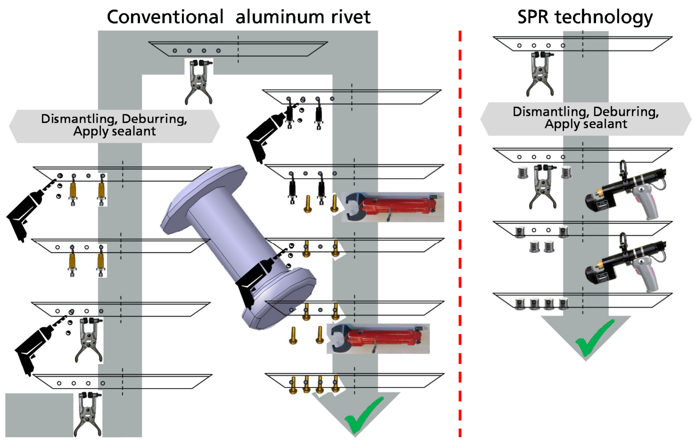


Figure 4: Comparison of the assembly processes

Both multistage processes start with placing the stringer coupling at its final position. Today it is a difficult multistage drilling process until one can finally install a solid aluminum rivet. One can imagine that this process is very time consuming. Due to the unnecessary drilling the SPR reduces the process time by up to 50%.

To implement this fast process one needs an appropriate tool which can reach the installation area in airplane fuselage, provide the power needed in the process, has an automated rivet feed, assists in finding the right place for setting the SPR, is safe as well as reliable and is able to document the installation parameters for each installation point. Such a tool was developed in a close cooperation with TOX Pressotechnik GmbH & Co. KG, a specialist for industrial manufacturing tools for mechanical joining applications.

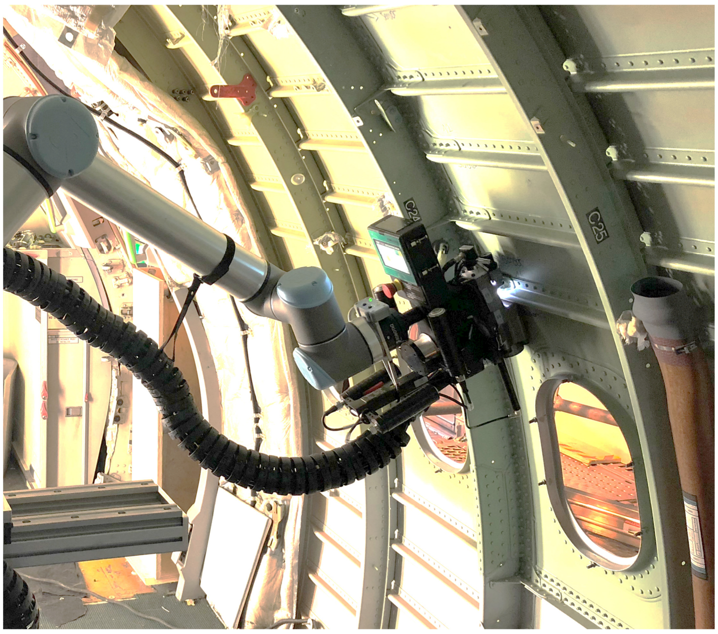


Figure 5: Installation tool at trials in an old airplane

The tool was taken to Airbus to test the whole system under real production conditions. This test has shown that the installation tool works properly and fits the requirements.

Further scopes of application which are of interest are frame couplings. There are about 160 couplings in an aircraft depending on the length and width. Each coupling has about 28 joints to be installed. In replacing the aluminum rivets used today with steel SPR, further major savings in the major component assembly will be possible.

Figure 6: Frame coupling with conventional aluminum rivets

AIRCRAFT MANUFACTURING AND LOGISTICS

In summary it can be said that the use of an innovative joining technology like SPR in aviation manufacturing has a high potential for lowering lead time and costs as well as applying the ideas of "Industry 4.0". Therefore the Fraunhofer Research Institution for Large Structures in Production Engineering and aircraft manufacturer AIRBUS want to expand their collaboration in research to improve the aviation manufacturing process.

Contact:
Fraunhofer-Research Institution for Large Structures in Production Engineering IGP
M.Sc. Thomas Nehls, Dr.-Ing. Normen Fuchs
Phone: +49 (0) 381 49682 -36
Mail: normen.fuchs@igp.fraunhofer.de
Web: https://www.igp.fraunhofer.de

SPECIAL REPORTS

AIRCRAFT MANUFACTURING AN LOGISTICS

SR - Intelligent assistance systems in the manual assembly of aircraft

Final aircraft assembly is characterized by a variety of manual assembly activities. The reasons for this are on the one hand the high number of variant-rich individual parts and assembly tasks, as well as the high flexibility with regard to the size of the assembly object and the associated mobility of employees and work equipment. At the same time, however, the assembly activities often take place under limited working space and unfavorable working positions due to the closed structures. Conventional automation solutions are unworkable or uneconomic under these conditions. Nevertheless, in order to support the employees in the highly flexible manual assembly work and to ensure efficient and economical production with high quality, intelligent assistance systems will be necessary in the future.

The Fraunhofer-IGP is dedicated to these challenges and develops practicable solutions for a flexible aircraft assembly of the future.

The following example provides an insight into how human-robot collaboration, innovative operating concepts and intelligent process monitoring support employees in fulfilling their work task, such as riveting. The application involves the joining of stringers and stringer couplings in the section along the aircraft structure, for which a tool for solid self-piercing riveting (SPR) has been developed at Fraunhofer-IGP.

Assistance through human-robot collaboration

One promising way to help employees do their job is to use assistive lightweight robots that work hand in hand with employees interactively. In particular, tools for the presented Self-Piercing-Rivest (SPR), as they are to be used in the future in aircraft final assembly, lead to high physical stress due to the tool weights and the sometimes unfavorable joining positions for the employees during assembly. Therefore, a hand-held collaborative robot was implemented to actively support the employee. Compared to conventional handling aids such as passive and spring-based balancing systems the robot system opens up more possibilities with regard to their radii of movement and degrees of freedom. By combining different methods of force control of the robot system, the joining tool can be moved quickly and without physical effort to the various positions to be joined. The relatively low weight of the system also allows the location-flexible use of the system. The versatile use of the robot system in the aircraft section is shown in Figure 1, showing different joining positions approached.

Figure 1: Riveting using human-robot collaboration

Intuitive operating concepts

A particular focus here was on the implementation of an intuitive operating concept for the entire system, whereby functional, practical as well as safety-relevant aspects of the riveting tool and the robot had to be considered. In order to guarantee the acceptance of the system, the operation was designed in a slim and user-friendly way despite the multiple functions. For this purpose, a mobile user control in the form of a mobile device was implemented, as shown in Figure 2. It allows the employee to record the state of the entire system at any time and also to control functions directly. This increases the safety of the employees, accelerates the work process and improves the cooperation between man and machine.

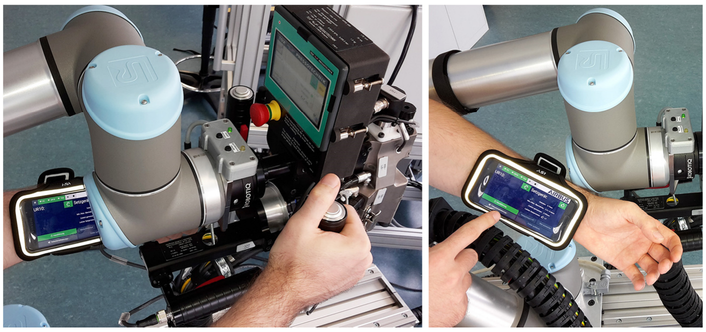


Figure 2: Use of the mobile device

Networking and intelligent process monitoring

A further advantage resulting from the use of the robot system and the combined control is the possibility of sensory linkage of all subsystems involved in the joining process. As a result, in addition to an intuitive control of the overall system, significantly improved process documentation, reproducibility and transparency in the manual joining processes are ensured. This is served by the user interface as shown in Figure 3, which not only helps the operator during the assembly process, but also provides long-term quality assurance. By networking systems and sensors, all recorded production data can be evaluated in real time using intelligent algorithms and processes can be flexibly adapted as needed.

The application developed by Fraunhofer-IGP shows how intelligent assistance systems using lightweight robots can already reduce stress in production processes work today. The built-in robot technology enables a future-proof solution in the sense of Industry 4.0. The use of a mobile device and the development of an individual application enables integrated operation and the flexible extension o other assembly processes.

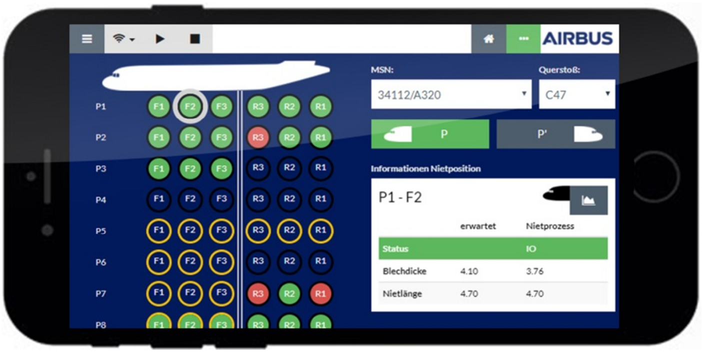


Figure 3: User interface of the process documentation

Contact:

Fraunhofer – Research Institution for Large Structures in Production Engineering IGP
Dipl.-Wirt. Ing. Jan Sender
Phone: +49 (0) 381 / 496 82 -55
Mail: jan.sender@igp.fraunhofer.de
Web: https://www.igp.fraunhofer.de

SPECIAL REPORTS

PICTURE OF THE FUTURE AIRPORT

SR - Picture of the future airport

In future artificial intelligent systems will continuously develop and adapt their capabilities for reducing workloads, allowing people to concentrate on system control functions and strategic decisions. Man-Machine collaboration will become part of new 'digital realities'.

In this manner, technical innovations and successful concepts initially developed to support other industry processes will enable the future airport to successfully combine aviation specific requirements with established industry solutions. Therefore, the future airport will benefit from synergies and the transfer of successful concepts and technical solutions such as Automated Guided Vehicles (AGV).

In future AGV will transport baggage and air cargo between external pick-up/drop-off-points and the future airports. According to the flight plan baggage and air cargo will be buffered or directly used for ULD build-up. Smart devices will help operators to receive remote information about critical process KPI's and process defects e.g. from material handling and community systems in order to instantly intervene if required. Augmented Reality (AR) applications will even allow operators with little experience to quickly build-up ULDs with an optimal packing density and weight balance.

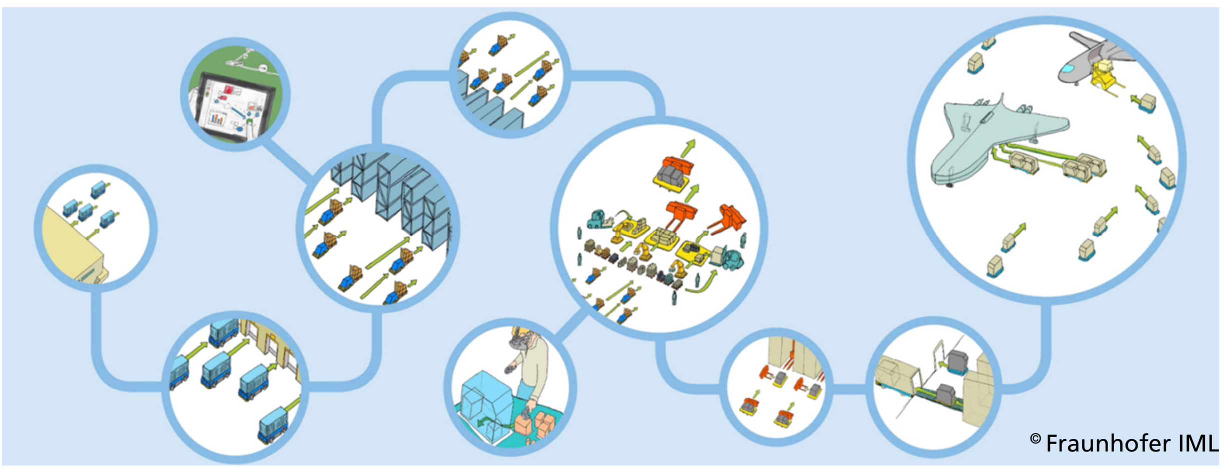
Supportive Man-Machine robots (co-robots) will then use this digital reality data. Autonomous freighters with classic main bodies will become the bottleneck of future air cargo transport and will be slowly substituted by aircraft with a highly flexible center fuselage.

In the future, market participants will cooperate in highly networked ad-hoc corporations g or increasingly offer their services as a single source. Data will control the overall processes and requires a simple to access data network of legally independent companies.

An already visible trend to shift classical value-added processes (e.g. build-up/break down) away from the airport will increasingly lead to space and growth potentials for higher-value infrastructure at airports. Therefore, the space demand for this classic value added processes outside the airport as well as for decentralized pick-up/drop-off-points for air cargo and baggage has to be integrated into business plans and marketing decisions.

Contact:

Fraunhofer Institute for Material Flow and Logistics (IML)
Bessie-Coleman-Straße 7, D-60549 Frankfurt, Germany
Dr.-Ing. Ralf-Maximilian Jungkunz
Phone: +49 (0) 69 / 668118 -356
Mail: ralf-maximilian.jungkunz@iml.fraunhofer.de
Web: www.iml.fraunhofer.de



SPECIAL REPORTS

MAINTENANCE, REPAIR AND OPERATION

SR - Developing the new Cargo Terminal CT02 at Doha Airport, Qatar

The air carrier Qatar Airways (QR) at Hamad International Airport (HIA) in Doha, Qatar, has recently grown significantly in both passengers and cargo volume. QR is running a typical one hub strategy network from HIA as its home base. To meet the current needs and the projected increase in airfreight as well as cargo handling volumes, HIA has awarded a consortium led by F&M Ingegneria an Italian Architectural Consultancy company the contract to develop, design and construct an additional cargo handling facility adjacent to the current cargo terminal.

Main elements such as warehousing, handling spaces and office spaces, as well as roads and other common infrastructures are currently being developed together with BNP (USA) and Fraunhofer IML aviation logistics experts. The new building setup will be able to provide the means for operating QR's single operating major hub strategy at HIA leading to an improved global network. The development plan will consider the planned increase in number of flights, maximising an utmost performance with the shortest possible transfer times. As the core clients of QR, forwarders are being brought into focus, by improving processes and maintaining reliability, supported by offering dedicated processes. It is expected that after completion, the capacity of the new terminal will be among the highest in the world.

Figure 1: © Photo Hamad International Airport

Contact:

Fraunhofer Institute for Material Flow and Logistics (IML)
Dr. Ralf-Maximilian Jungkunz | Dr. Heinrich Frye | Dr. Harald Sieke
Phone: +49 (0) 69 / 668118 -356
Mail: ralf-maximilian.jungkunz@iml.fraunhofer.de
Web: www.iml.fraunhofer.de

SPECIAL REPORTS

MAINTENANCE, REPAIR AND OPERATION

SR - Smart Air Cargo Trailer – AGV based air cargo transport services between forwarders and handling agents

Shipments are usually transported between air freight forwarding hubs located at airports or close to airports and various handling agents by trucks. Due to the volatile aircargo volume and the high degree of labor division between stakeholders, mixed with contradictory optimization efforts for services offered and cost minimization, inefficiencies occur. These comprises for example low utilization of transport resources or long waiting times for truck handling.

Due to frequent failures of data transmission data transmission and interruptions in the information flow, cargo volume and handling peaks occur quite frequently. These unnecessarily limit handling capacities of handling agents and lead to long, incalculable waiting times at the ramps. Consequently, freight forwarders order truck transports, with low load factors. This in turn burdens the transport system, by demanding additional handling resources.

The aim of "Smart Air Cargo Trailer" is therefore, in the sense of the "Internet of Things" (IoT), a better use of resources and an increase in efficiency through process control using object-immanent data and information of the logistics objects. These data will be stored within the process chain both directly at the individual shipments and on standard or swap trailers, used for transport. In addition, a prototype demonstrator of entirely digital and autonomous vehicles within an airport operating area, side by side with mixed traffic, is planned to be achieved.

These autonomous vehicles are requested independently and on demand within the airport premises. The autonomous tractors pick up the trailer and bring it to the appropriate destination resp. ramp at a forwarder or handling agent terminal. This leads to the decoupling of the ramp and handling processes of the handling agents from the transport processes, thus both can be optimized independently by each party.

Acknowledgements

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Contact:

Fraunhofer Institute for Material Flow and Logistics (IML)
Dr. Ralf-Maximilian Jungkunz | Dr. Heinrich Frye | Dr. Harald Sieke
Phone: +49 (0) 69 / 668118 -356
Mail: ralf-maximilian.jungkunz@iml.fraunhofer.de
Web: www.iml.fraunhofer.de

SPECIAL REPORTS

MAINTENANCE, REPAIR AND OPERATION

SR - In-Line Inspection of Assemblies

Introduction

The desire for customization in our society is also confronting industrial assembly with new challenges. Rising demand for customized products is concomitant with steadily decreasing lot sizes, short product life cycles and a large variety of models. Advanced assembly processes in industrial manufacturing as well as quality assurance in assembly have to meet the associated challenges. This requires high flexibility without increasing labor for work preparation or diminishing quality.

Flexibility through Digital Models

A model-based approach can render such inspection systems flexible, i.e. cost effective to use even when the variety of models is large and lot sizes are as low as one. Digital geometry and physical function models of every interacting component and function modules are also employed. A function module can be used, for instance, to inspect the digital 3D CAD models of an inspected part and the probe itself as well as a physical function model of the probe in order to simulate inspection. This serves as the basis for executing steps such as planning tests and providing specified conditions fully automatically and, thus, efficiently (even for a quantity of one).

Standard inspection systems based on a golden sample or learning-driven approaches cannot do this efficiently. Continuous changes to inspection tasks would entail constant manual teaching of the underlying specifications with undue labor.

Model-Based Optical Assembly Inspection

Optical assembly inspection encompasses the inspection of different stages of a single part's assembly in relation to a complete assembly. Typical inspected stages of assembly are presence (i.e. the presence of some part at a targeted position), correctness (i.e. the presence of a specified part at a targeted position), and location (i.e. the part position and orientation within a tolerance range).

A 3D CAD model defines the targeted stage of assembly. Optical sensors scan the actual stage of assembly. Systems that measure three-dimensions, e.g. stereoscopic imaging, light sectioning or structured-light 3D scanning, are also employed. The resulting 3D point cloud can be compared with the 3D CAD model and delivers information on the specific stage of assembly. Since cameras are usually employed in such optical sensor systems, oriented image data is also available for a variation analysis. Synthetic inspection data (synthetic images and synthetic 3D point clouds) is computed to ascertain the required reference data based on model data on the part (3D CAD model with contextual information) and on the inspection system's measuring function (mathematical and physical computational model).

Assembly Inspection in Aircraft Manufacturing with a Robotic Inspection System

Airliners such as the Airbus A380 are custom-made and, thus, hardly different from other capital goods such as custom machines or equipment. Every airline desires a custom interior and has aircraft modified for its specific needs. Whereas one airline installs as many rows of seats as possible, another stresses comfort and gives passengers more legroom. This is much the same with monitors, overhead bins and ventilation systems. All of these demands result in custom manufacturing with thousands of small and miniature parts that have to be positioned and mounted on the respective large parts time after time. This complicates assembly and subsequent quality control considerably. Workers get the specifications for this from paper documents and crosscheck every piece manually. The number of parts inspected in an aircraft such as an A380 is huge. Up to 40,000

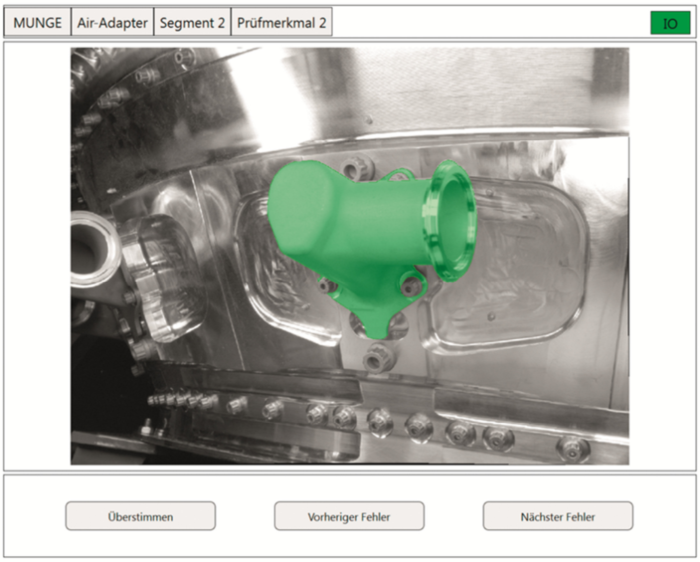
MAINTENANCE, REPAIR AND OPERATION

rivets hold each of an airplane's twenty fuselage sections together. In addition, the correctness and correct positioning of each of up to 2,500 attached parts have to be verified. Error detection is complex, and subsequent correction extremely expensive at times.

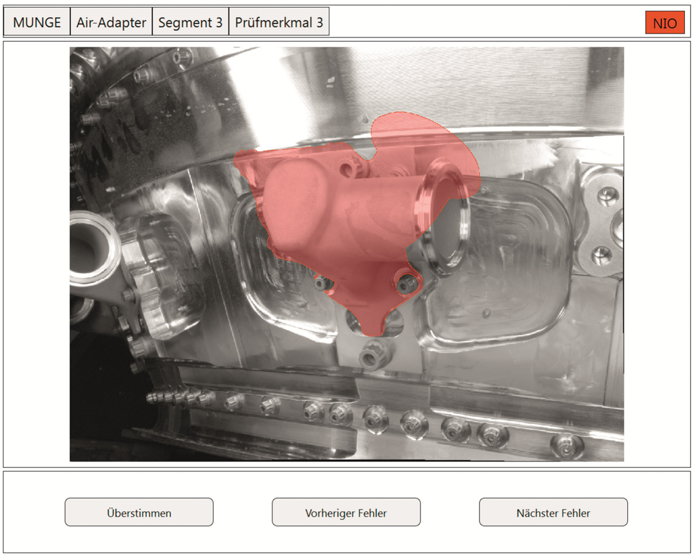
A pilot system based on model-based assembly inspection was developed and in integrated in current production. It autonomously inspects every attached part and joint on fuselage sections. The system consists of a six-axis industrial robot on a linear axis, which has a specially developed sensor head. The head is equipped with image sensors and 3D sensors and automatically scans several thousand test positions on the fuselage section and, thus, every inspected feature (see Ill. 1).

Ill. 1: Fuselage section assembly inspection system (Fraunhofer IFF)

It generates high-resolution measured data on a real attached part's stage of assembly reliably from every position. The system extracts the requisite information from the 3D CAD data available for the fuselage section. They specify the intended outcome and contain all of the test positions' coordinates. The system also generates virtual measured data of inspected features from this data, specifically in the form of synthetic images and 3D point clouds. Every joint and every



Ill. 2: Inspection and test result: attached part and joints correct, some missing joints and missing boreholes (Fraunhofer IFF)



Ill. 3: Inspection and test result: skewed attached part, correct joints (Fraunhofer IFF)

single attached part is represented exactly.

During inspection, the system overlays the real measured data with the virtual specification. It automatically factors in image section and camera angle. When the real and synthetic data match up, i.e. the imaged parts have been mounted correctly, the system marks correct parts in the test report green (Ill. 2).

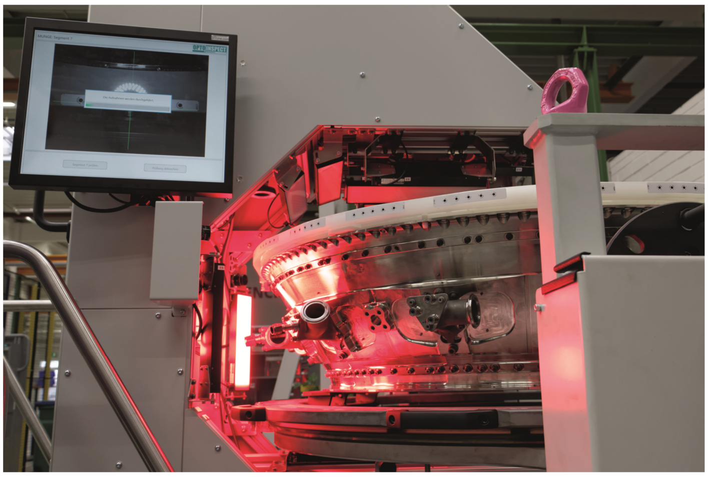
It marks discrepancies rot (Ill. 3), and ambiguities yellow. The user can view different interactive evaluations in the test report. The system delivers not only photos of the parts but also coordinates to locate the part concerned quickly for rework.

Assembly Inspection in Engine Manufacturing with a Manually Operated Inspection System

Early detection of defects is extremely important not only for the manufacture of fuselage sections but also for parts for aircraft turbines. Turbine center frames (TCF) are inspected based on similar principles of model-based optical assembly inspection. Once they are fully assembled, the tapered TCFs with diameters of approximately 1.40 m are packed in containers and shipped to customers that install them in engines. Assembly errors are intolerable for such a safety-related part and must be prevented.

Unlike assembly inspection in aircraft manufacturing, a manually guided inspection assistant was developed for this (see Ill. 4).

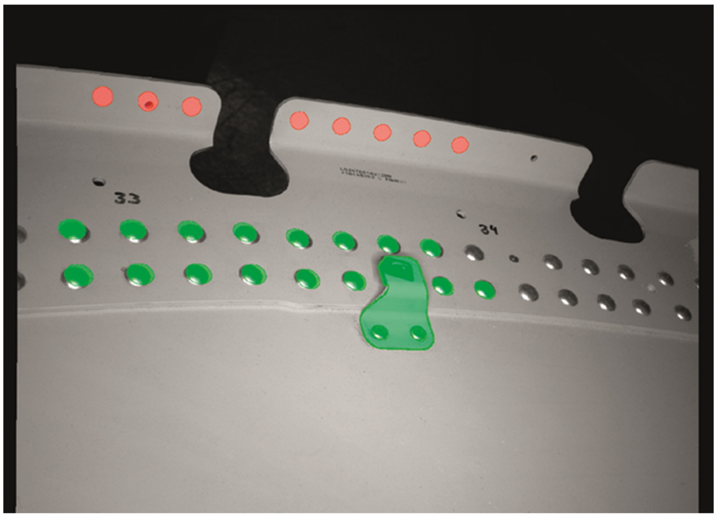
It makes a motorized handling system and an external reference measurement system unnecessary. The worker positions a C-shaped inspection system on rollers at an initial position above the TCF module so that it “looks” into the tapered TCF module above and below a bit. Based on the measuring principle of structured-light 3D scanning, fourteen cameras and two 3D sensor systems capture images and 3D measured data of the attached parts from different perspectives and compare them with the inspection data generated synthetically from CAD model data. Measured data acquisition lasts approximately five seconds, the evaluation another five seconds per position. Once the initial position has been completed, the worker rotates the TCF module in the inspection system to the next specified position and the procedure begins anew. An entire TCF has been inspected after approximately five minutes and twelve positions.



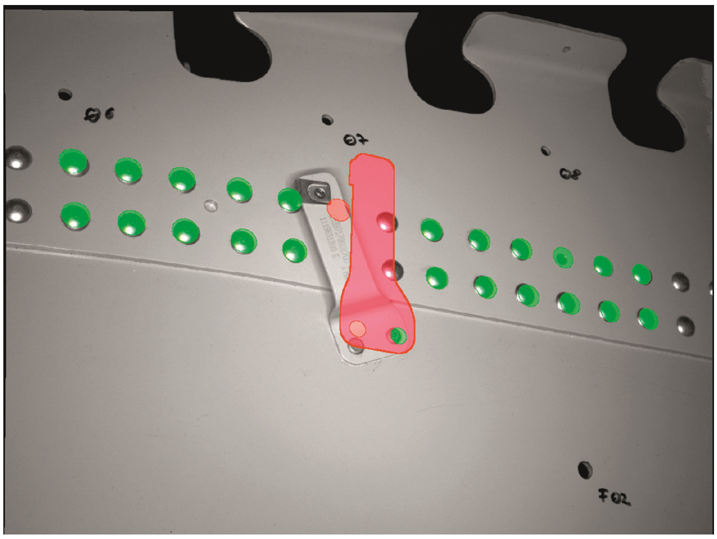
Ill. 4: Assistant for TCF module assembly inspection (Fraunhofer IFF).

The optical system verifies the presence, correctness and location of attached parts, e.g. connectors, the correct assembly of joints, and the correct assembly of bolted connections and lockwires. More than 500 different parts are inspected per TCF module. Defects are usually hidden in the many specific details of the outwardly virtually axisymmetric part and some are hard to detect in a visual inspection. The inspection system detects them reliably, though. The test report shows the worker at a glance whether and, if so, where rework is still required (see Ill. 5 and Ill. 6).

MAINTENANCE, REPAIR AND OPERATION



Ill. 5: inspection and test result: correct assembly (Fraunhofer IFF)



Ill. 6: Inspection and test result: faulty assembly (Fraunhofer IFF).

Conclusion

Resource efficiency and flexibility are demands relevant to competitive industrial manufacturing. Model-based technology modules use integrated digital process chains to make optical inspection systems highly flexible. New specifications for a manufactured product are documented as changes in the CAD model, for instance. This model data is the basis for all other steps in the preparation and execution of optical inspection. This automates the generation of inspection and test programs, the supply of reference data and the performance of a variation analysis. Changes in the CAD model automatically result in an adaptation of the inspection and test process. Another benefit is the elimination of the need to teach specified conditions, as is often common for inspection technologies in mass production. This makes it possible to use inspection technologies cost effectively even for small lot sizes.

Contact:

Fraunhofer Institute for Factory Operation and Automation IFF
Dr.-Ing. Dirk Berndt / Erik Trostmann
Phone: +49 391 4090-224
Mail: Dirk.Berndt@iff.fraunhofer.de
Web www.iff.fraunhofer.de/mpt

SPECIAL REPORTS

MAINTENANCE, REPAIR AND OPERATION

SR - Lightweight Airborne Profiler LAP

Due to the rapid technical progress, unmanned aerial vehicles (UAVs) are becoming more and more attractive for the civil sector. Measurement systems carried by UAVs capture large areas and complex structures. Such areas and structures also occur at airports.

Fast and efficient: 3D detection via UAV

The Lightweight Airborne Profiler LAP was developed by Fraunhofer IPM for application on airborne platforms. Local orientation of the LAP is based on a combination of IMU (inertial measurement unit) and GNSS (global navigation satellite system). In case of shaded and complex structures with poor or no GNSS reception, cameras are used for this purpose, ensuring the functioning of the orientation even under these conditions. The precision achieved depends on the system's respective components and typically lies in the range of a few centimeters.

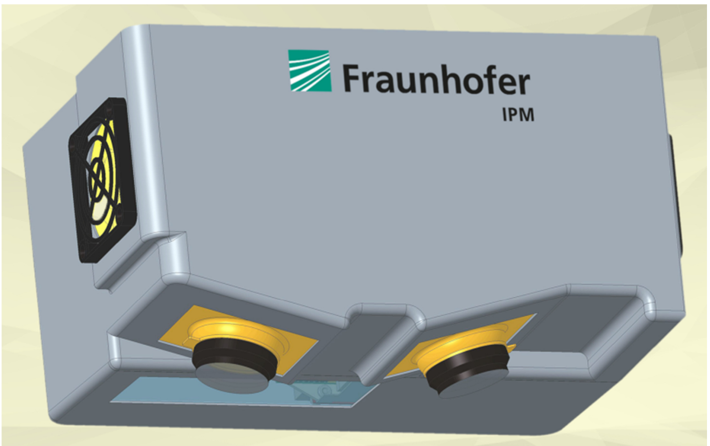
Eye-safe laser scanner detects up to 1,000 measurement points per profile

The system's core component is a laser scanner with a working range of 300m. The lower operating range is fixed at 2.5m. Relative accuracy of the laser scanner is 15mm at a resolution of 1mm for a single scan, at averaging over 16 scans relative accuracy is about 4 mm. The scanning angle can be changed to any value up to 90°. The angular resolution is at about 0.09°, so that with each profile, up to 1,000 points can be detected. In one second, 32 profiles can be recorded. By using pulsed time-of-flight measurement, several measurement echoes can be detected. This allows individual object layers, even when hidden one behind the other, to be discriminated. A laser classified class 1 with a wavelength of 905 nm is used. Hence, the system is absolutely eye-safe. Since the divergence of the laser beam in horizontal direction roughly corresponds to the angle of aperture, the field of view is scanned completely. The laser footprint has a size of 2.8cm × 5.6cm at a distance of 40m.

Combination of cameras in a special set-up

The system's two cameras provide image information in addition to the data acquired by the laser scanner. The cameras with a resolution of 9 MP each are positioned on a slant, inclined towards each other, capturing the measurement area with a small overlap. The image data (RGB) is combined with the scan data, which allows generating so-called depth images (RGBD). Employing two cameras results in a combined aperture angle of 45°. A resolution of 1.1 cm per pixel is achieved at a flight altitude of 80 m.

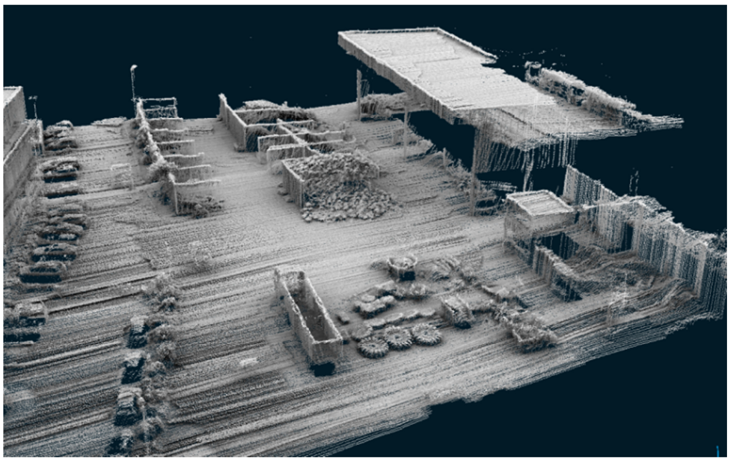
Processing unit



To guarantee synchronous data acquisition and recording, the measuring system comprises a fast processing unit, a removable storage module and features comprehensive connectivity. Power consumption of the integrated system is below 30 Watt. This makes LAP perfectly adaptable to existing UAV systems. Upon request, Fraunhofer IPM designs the integration together with the UAV manufacturer and puts the system into operation in close cooperation with the final user.

Open interfaces

All LAP sensors create data in open data formats (such as LAS). Additionally, all software interfaces can be adjusted individually, so that fast and easy-to-handle control of all components with proprietary programs is guaranteed. This makes LAP the ideal basis for application in research and development.



Contact:

Fraunhofer Institute for Physical Measurement Techniques (IPM)
Dr. Markus Leidinger
Phone: +49 761 8857-413
Mail: Markus.Leidinger@ipm.fraunhofer.de
Web: www.ipm.fraunhofer.de

SPECIAL REPORTS

MAINTENANCE, REPAIR AND OPERATION

SR - 3D-Data Automated Interpretation

Today, infrastructure is surveyed using high performance cameras or laser scanners, which deliver high-resolution images and very accurate, georeferenced measurement data. The data acquired is generally evaluated manually. Fraunhofer IPM has developed a »Deep Learning Framework« which automates this process.

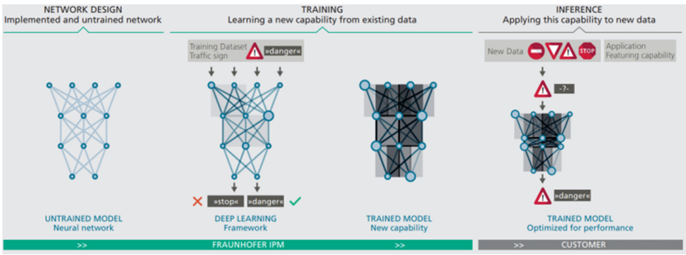


Figure 1: Process chain in a Fraunhofer IPM deep learning framework: Network design, training and application

Artificial neural networks

In order to evaluate 3D data, scientists are turning to complex learning algorithms based on the concept of deep learning using artificial neural networks (ANNs). This approach has been shown to be superior to traditional methods of object recognition. Only a few years ago, training such algorithms took weeks, if not months. A process that has shrunk to a few hours thanks to massive parallelization. Data interpretation with the help of a trained ANN is actually carried out in real-time. In ANNs, the information provided passes through a large number of interconnected artificial neurons, where it is processed and transmitted to other neurons. ANNs learn the output patterns which correspond to specific input patterns with the help of manually annotated training data. On the basis of this »experience«, new types of input data can then be analyzed in real-time. ANNs have proven to be very robust when confronted with variations on characteristic colors, edges and shapes.

Scanner data and camera images

The more detailed the information in the data set, the more successfully objects can be recognized and classified. Camera and /or scanner data or merged scanner and camera data form a suitable data basis for automated object recognition. The Fraunhofer IPM framework transfers the georeferenced scanner data points to a grid format containing depth information before linking them with RGB camera data. This pixel-based RGB-D(epth) data set contains a corresponding depth image for each RGB camera image, which makes it the ideal input format for ANNs. High-resolution scanner data is processed directly within the framework without the detour via generation of RGB-D data. It is the respective task and the kind of data set available, which determine the appropriate method.

Figure 2: RGB data

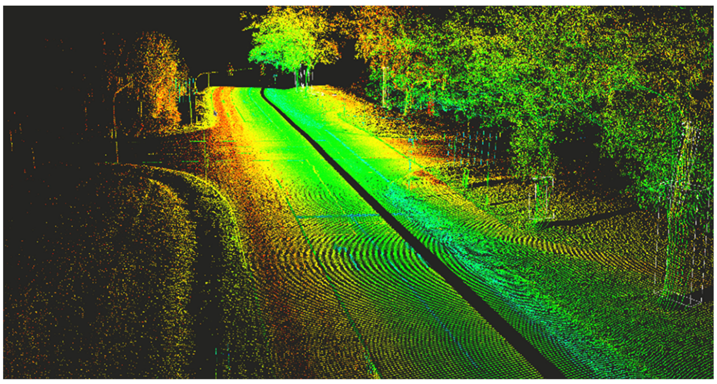


Figure 3: intensity image

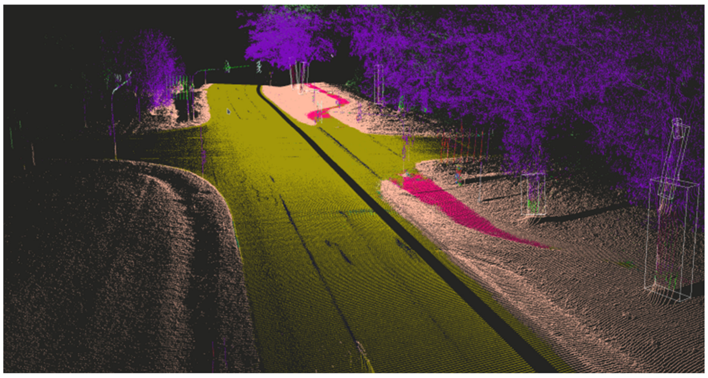


Figure 4: intensity image

Classified objects in 3D

The architecture of the network, in other words the number of network layers and the type of hierarchical links, is adapted to each specific task. Convolutional Neural Networks are of particular interest in 3D data processing. They make use of the fact that the information contained in images or scanner data is mostly local, i.e. confined to a small section of the data set. This allows filters to be applied for data analysis which select small sections of, for instance, 7×7 or 11×11 data points/pixels. Irrespective of the network design, a suitable training data set is generated for training the network. To this end, images are first semantically segmented manually and each pixel or each 3D point is attributed to a specific object class (annotation). Once a network has been trained with this data, it can be expanded to include additional object classes or enhanced at any time with a new training data set. Using the pixel coordinates of the objects identified in the image data, the segmentation can be back-projected into the point cloud. The segmentation can also be carried out directly on the basis of the 3D data. A classified data set can be exported once the segmentation of the point cloud has been completed. Fraunhofer IPM offers a tool for generating training data sets, which allows for a fast and straightforward annotation of the 2D and 3D Data. The trained network is delivered as an executable program for Windows or Linux. Interfaces are adapted according to customers' requirements.

Contact:

Fraunhofer Institute for Physical Measurement Techniques (IPM)
Dr. Markus Leidinger
Phone: +49 761 8857-413
Mail: Markus.Leidinger@ipm.fraunhofer.de
Web: www.ipm.fraunhofer.de

SPECIAL REPORTS

SUSTAINABILITY

SR – Study on technologies and potential for greenhouse gas emissions reductions in civil aviation

Contract for the BMVI as part of the programme of research supporting the BMVI MKS - mobility and fuels strategy.

Aviation activity civil aviation have had a continuing trend of growth over the last 30 years (see figure 1). Although considerable improvements have been made in aircraft technology (see figure 2), the CO_2 emissions from aviation have also increased. Given the global efforts to control greenhouse gas emissions to stabilise the climate, as agreed in the Kyoto Protocol and the Paris Accord, IATA agreed emissions reduction goals for civil aviation. These goals are:

- An average increase in energy efficiency of 1,5 % per year from 2009 to 2020
- Climate neutral growth from 2020 onwards
- An absolute reduction of 50% in CO_2 emissions of 50 %, relative to 2005 by 2050.

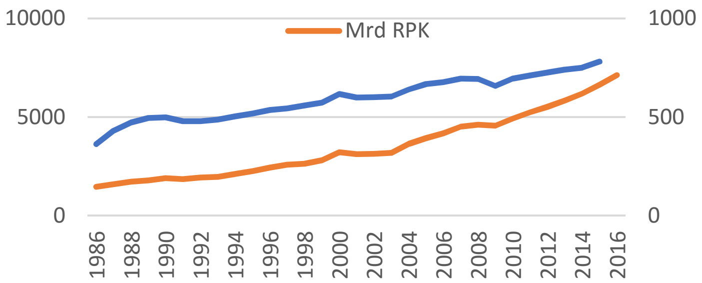


Figure 2: historical revenue passenger kilometers and CO_2 emissions [7], [8]

New aircraft designs now entering the fleet are demonstrating that the first of these targets is being achieved (table 1). These improvements are achieved through new high-bypass ratio engines such as the Pratt & Whitney PurePower PW1000G/ CFM International LEAP-1A, GE9X, Rolls-Royce Trent 7000, winglets and the extended use of composite materials in particular for wings. This trend in efficiency improvement is projected by the industry to continue into the future. However, figure 1 suggests that this will not be enough to deliver absolute emissions reductions in the longer term to 2050.

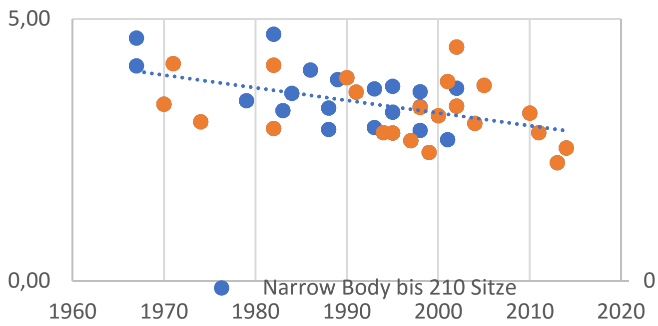


Figure 1: Fuel consumption per passenger (left axis l/100 km, right axis CO_2 emissions kg/100 km) Calculations based on European Emission Agency (2016) [6], [7]

New aircraft designs now entering the fleet are demonstrating that the first of these targets is being achieved (table 1). These improvements are achieved through new high-bypass ratio engines such as the Pratt & Whitney PurePower PW1000G/ CFM International LEAP-1A, GE9X, Rolls-Royce Trent 7000, winglets and the extended use of composite materials in particular for wings. This trend in efficiency improvement is projected by the industry to continue into the future. However, figure 1 suggests that this will not be enough to deliver absolute emissions reductions in the longer term to 2050.

Given the projections of continuing growth in aviation activity and also emissions from aviation, this project has examined the potential for absolute reductions in CO_2 emissions through the development of new aircraft configurations and engine designs.

Table 1: Efficiency improvements in the current generation of new aircraft

Aircraft	Efficiency improvement in fuel / passenger km %	Reference aircraft
320neo/A321neo	15	A320
B737Max	14	B737-800
Embraer E190neo	17	E190
Bombardier CS100, CS300	15	CL900RJ, A319
A350XWB: A350-800, A350-900	25	A330-200, A330-300

The project reviewed the literature and developed the combinations of airframe and engines as shown in table 2. These concepts have been estimated to have the potential to reduce emissions per passenger kilometre by more than 50%. This opens up the possibility of absolute emissions reductions if these aircraft are developed and adopted in civil aviation on a large scale.

The Strut Braced Wing concept employs very high aspect ratio wings, which are supported by struts (figure 3). This has the advantage that a conventional fuselage can be used. Engines can be mounted at the rear of the fuselage, either turbofans or open rotors. The wings can be folded to fit into the standard box dimensions of airport passenger gates. Fuel savings of 39% and up to 63% with a gas - electric hybrid propulsion) in short haul operation have been estimated [3], [4].

The D8-Double bubble concept employs a wide The D8-Double bubble concept employs a wide fuselage that also contributes lift. This enables the wing area to be reduced. The wider fuselage also enables the incorporation of boundary layer ingestion turbofans at the rear of the aircraft (Figure 4). Yutko et al. (2017) estimate the potential savings over current aircraft in the 180-seat class to be up to 60%.

Table 2: Radical aircraft technology concepts

Concept	Size (seats)	Market-entry (year)	Potential Improvement in fuel demand	Reference aircraft
Strut Braced Wing + open rotor	75, 125	2035	54%	B737-800
D8-Double Bubble + rear engine BLI	180	2035	60%	B737-800
Blended Wing Body + turboelectric	255, 350, 450, 550	2040	72%	B777-200LR

Figure 3: D8 Double bubble concept with boundary layer ingestion turbofans [10]

Figure 4: A strut braced wing aircraft (Nasa)

The most radical departure from the current 'tube-and-wing' arrangement is the blended wing body concept, close to a flying wing. There have been a series of concept studies and the NASA N3-X studies have investigated the possibilities for a blended-wing-body with Distributed turbo-electric propulsion. Assuming the use of super-conducting electrical systems, Felder et al. (2011) [5] estimated the potential to be up to 72% efficiency improvement over a Boeing 777-200LR. However, the wide configuration requires new gate arrangements at airports and new evacuation arrangements and regulations for passengers. This requires an increased length of time for development, compared to the other concepts.


Figure 5: NASA N3-X blended wing body concept with distributed turbo-electric propulsion [9]

Summary

The review of technologies for aircraft has identified concepts that have the potential to deliver aircraft with savings in greenhouse gas emissions of more than 50% compared to in-service aircraft.

However, even though the aerodynamic properties and engine developments have been researched, they all require extended development times of 15-20 years. Given the long expected service life of aircraft, the civil aviation fleet in 2035 will require a long time to replace. This will limit the potential for such designs to deliver large scale emissions reductions by 2050.

Contact:

Fraunhofer Institute for Systems and Innovation Research ISI
Dr. Jonathan Köhler
Phone: +49 (0)721 6809 -377
Mail: j.koehler@isi.fraunhofer.de
Web: https://www.isi.fraunhofer.de

APPENDIX

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APPENDIX

AVIATION GROUP

AP – Aviation Working Group

Dr.-Ing. Ralf-Maximilian Jungkunz
Head of Working Group

Fraunhofer-Institut für Materialfluss und Logistik
Bessie-Coleman-Str. 7
60549 Frankfurt am Main

Phone +49 69 668118-356
Fax +49 69 668118-77356
Mail: ralf-maximilian.jungkunz@iml.fraunhofer.de

Christiane Kraas
Head of Office

c/o Fraunhofer-Institut für Materialfluss und Logistik
IML
Joseph-von-Fraunhofer-Straße 2-4
44227 Dortmund

Phone +49 231 / 9743-371
Fax +49 231 / 9743-372
Mail: christiane.kraas@iml.fraunhofer.de