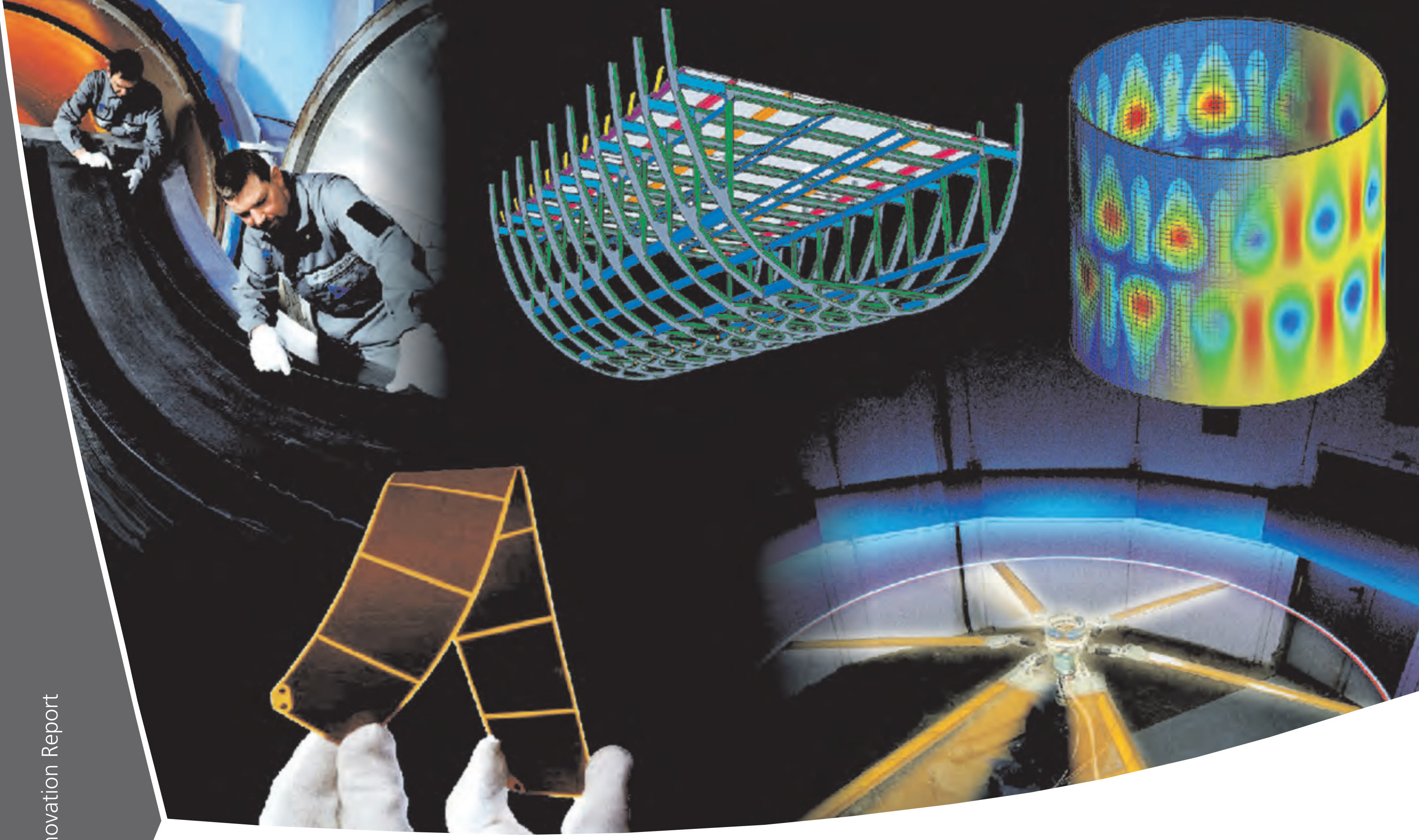


Innovation Report

Innovation Report 2010

Institute of Composite Structures and Adaptive Systems

DLR

CFRP Repair.

Contents

Preface

Growth and sustainability drove our innovations in the last year, which we proudly present in this now sixth innovation report. Our Institute has developed positively indicated by a growth of our staff. More than 25 young scientists joined us. Sustainable mobility increases the attractiveness of our Institutes research in and beyond aviation. The importance of cost-efficient, adaptive light-weight structures made from composites grows for the automotive industry as well as for other businesses like wind energy. However, our main scientific focus remains on aerospace structures. We maintained our cooperation network and especially strengthened it towards the OEMs suppliers. Thus, our network of cooperation is steadily extended which in turn creates novel research challenges.

In order to enable growth we reorganized our Institute in currently 5 departments along the process chain of adaptive, light-weight composite structures. A sixth department delving into the research on sustainable production processes for composite structures will be founded until the end of the year. Details of the department competences are elucidated at the end of this report. Initiated by the reorganization of our Institute was a comprehensive strategic discussion about our long term research agenda in a bottom-up process. The amazing amount of new ideas was condensed to six fields of innovation:

- Nano – Micro – Macro
- Robust Primary Structure
- Compliant Aggregation of Functionalities
- Self-controlled Composite Processing
- Autonomous Composite Structures
- Sustainable Composites Processes

These fields of innovation are explained in more detail on page 6, and they also serve as your guideline through this report. Three exemplary research subjects are chosen for each of the above mentioned fields of innovation.

We have dedicated our Day of Science 2010 to a main scientific focus of our Institute: the investigation of the basics, the concepts and the technologies for multi-functional and adaptive high-lift structures. The question of shape variability of composite structures for high-lift components is the topic of various national and European projects. We currently completed the design and manufacturing of a common test demonstrator in cooperation with EADS (Airbus, EADS-IW and EADS-MAS). You will find a contribution about the related research in this innovation report on page 26.

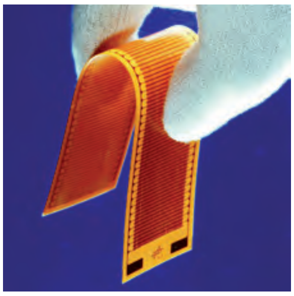
Reorganization and growth for us also mean an actual extension of our working facilities and labs hosted by the novel building, the DLR's Adaptronics and Transportation Systems Centre. Please find brief information in the reports rear section.

Our thanks go to our partners with whom we have achieved the research results described in the following. Special thanks go to the authors of the report, who provided you with the succeeding and inspiring pages. We are looking forward to future cooperation with you in the field of Composite Structures and Adaptive Systems.

Prof. Dr.-Ing. Martin Wiedemann   Prof. Dr.-Ing. Michael Sinapius

Institute of Composite Structures and Adaptive Systems

High-Performance Structures
Adaptable – Efficient – Tolerant



We are experts for the design and realization of innovative lightweight systems.
Our research serves the improvement of:

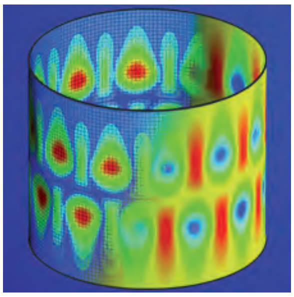
- safety
- cost efficiency
- functionality
- comfort
- environment protection

We bridge the gap between fundamental research and industrial application.

The expertise of the Intitute of Composite Structures and Adaptive Systems in

- multifunctional materials
- structural mechanics
- functional lightweight structures
- composite technology and
- adaptronics

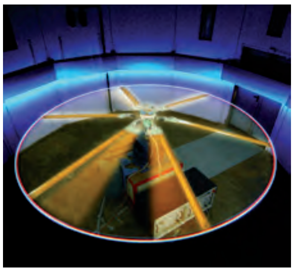
makes it the ideal partner for the industry, the DFG (German Research Foundation), research establishments, ministries and civil aviation authorities in all issues regarding development, design, computational prediction, manufacturing, experimental testing, and qualification of lightweight structures used in aerospace and further applications.



The main objectives of the research and development work on material systems and lightweight structures are

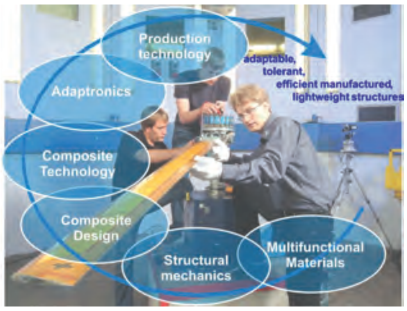
- increase of safety by improving stiffness, strength and durability of lightweight structures with new material systems and improved structural analysis tools
- cost reduction in the production process and by optimizing design and the fabrication procedure in order to strengthen the competitive edge
- increase of functionality of materials, structures and systems to improve their performance; the active structural shape control replaces elaborate and costly actuator systems
- increase of comfort in aerospace and on-ground transportation systems by means of actively reducing noise and vibrations
- reduction of the environmental impact (especially resulting from fuel consumption) and preservation of natural resources particularly due to reduced weight.

In order to deal with strength, stability and thermo-mechanical problems we operate unique experimental facilities like thermo-mechanical test facilities, buckling facilities with the special feature of dynamic loading. Manufacturing facilities like preforming, filament winding, liquid composite moulding or microwave curing enable us to develop novel manufacturing techniques und the realization of innovative composite structures.



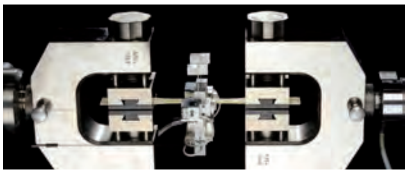
We transfer our scientific and technical expertise in the field of design and manufacture of lightweight composite structures and adaptronics as partners in an international network of research and industry.

Institute of Composite Structures and Adaptive Systems – Our Fields of Innovation

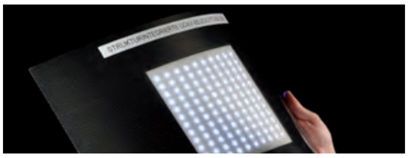


We work along the full process chain in the fields of multifunctional materials, simulation methods, lightweight functional design, production technologies, adaptronics and in the near future up to entire production processes. This consideration of the full process chain is part of our strategy, and it is our conviction that successful research in the field of functional CFRP structures is driven by collaborative work. How can research be organized in such a broad field of scientific work, and how can each scientist preserve attention for the work of the others? Innovation is the total of two steps: invention and diffusion. Invention is where we start with our ideas. Diffusion is where at the end we can present technical solutions to our customers. Innovation covers the full process chain and this is why we have decided to organize six times a year meetings with all scientists of our institute to discuss our long term strategic research topics.

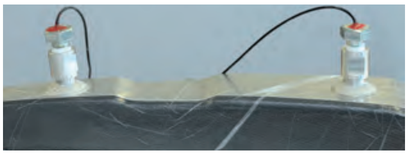
Multi-phase materials like composites require the comprehensive understanding from **Nano – Micro – Macro** -scale of the components interaction. This includes the effect of nano-scaled additives to the resin as will as the effect of manufacturing defects like pores on the mechanical properties of the structure. Moreover, carbon nanotubes exhibit a significant actuation effect in an electrolytic environment. Understanding the path from Nano to Macro means thorough research for our scientists looking for new technical applications.



Reliable design methods for **Robust Primary Structures** are already mandatory, but the challenge to ensure reliability (oder robustness) by adding additional functions into the structure. We strongly believe in the potential of function integration within the composite design, but there is the need to bring all of the elements of such a structure to the same level of reliability. Our scientists keep this in mind while they are making new inventions.



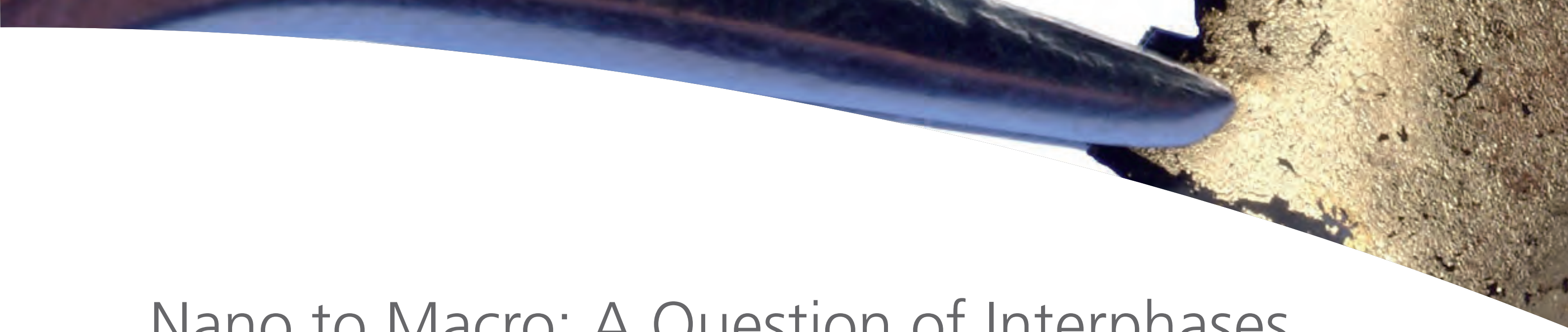
Compliant Aggregation of Functionalities aims for solutions, where integration of additional functions does not degrade the original load carrying function of the structure. To reach this goal the design principles must be adapted to the additional functions. For example the active shape control of a structure may not lead to additional internal loads. Unconventional ideas from many people are required here to find the right solutions.



Self controlled CFRP Processing is one of our most promising concepts for automation in the field of production of carbon fibre reinforced polymer (CFRP) structures, but still in its infancy. With our competencies in ultrasonic NDT, process-simulation and in the field of adaptronics as well as our long lasting experience in CFRP production technologies , our scientists can build on an unique combination of knowledge.

Building **Autonomous CFRP Structures** is our vision of function integration. Any active system today requires external energy for control and actuation at least. The omission of the wiring is one of the conditions for an increasing application of function integration in structures. Our scientists know the vision and are looking for contributions to its realization.

Sustainable Composites Processes will finally become a very important topic in the future for us. Not only the lightweight and multifunctional structure itself shell support the idea of sustainability, but also the way, how this structure is produced. Our scientist know about the need for further cost reduction but very soon this will be also a demand for reduction of consumables in production and minimization of scrap. The development of precise, effective and in-line quality automation along the production processes will be a new research field for us.



Nano to Macro: A Question of Interphases

Carbon fibre reinforced plastics (CFRP) manufactured by injection technologies do still not completely reach the performance of prepreg laminates. Beside of fibre ondulation, the matrix causes deficits in the composites being mainly based on low stiffness and high shrinkage of the polymer. Therefore, the Institute investigates comprehensively the reinforcement of the polymer matrices with nanoscaled boehmite particles to increase the performance of injection resins.

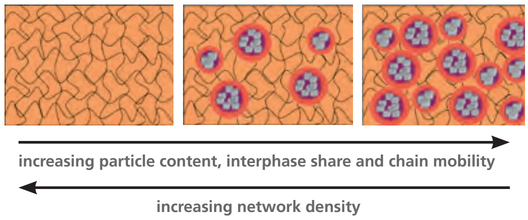


Fig. 1:
Network pattern in dependency of particle content.

Particle-Polymer Interaction

Various types of boehmite nanoparticles have been homogenously dispersed into epoxy resins aiming to achieve best results. After curing, the filled resins were investigated in terms of particle-polymer interaction, polymer network pattern, matrix shrinkage and mechanical properties. Results showed not only an influence of particle size and shape, but also of the surface modification. With a wisely chosen modification not only a stable dispersion and a narrow particle size distribution can be achieved, but also the resin-particle interactions can be adjusted in order to retain the injectability of the resin. The altering of the interface enables the creation of materials with improved properties.

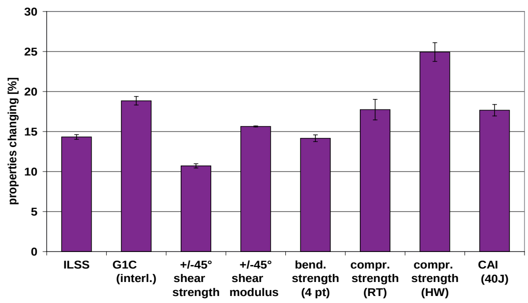


Fig. 2:
Improved material properties of CFRP containing matrices with 15 wt.-% boehmite nanoparticles.

Network Pattern

A dependency of particle content on the mechanical properties can be observed for the cured composites. Low filler contents create materials with a higher strain and lower stiffness compared to the pure resin. With a higher solid fraction the effect is reversed and the composite becomes more brittle. Analytical investigations explain this observation by sterical limitation of the cure by the nanoparticles. This way the tightness of the network pattern decreases and the polymers become more flexible. With increasing boehmite content the particles hinder the chain movement and the composite shows a more ceramic-like character (Fig. 1). Besides the changes in the network pattern, nanoparticles alter the fracture behaviour of the resin. Particularly small particle-particle distances at high particle contents cause very effective crack deflection, -pinning and -bridging.

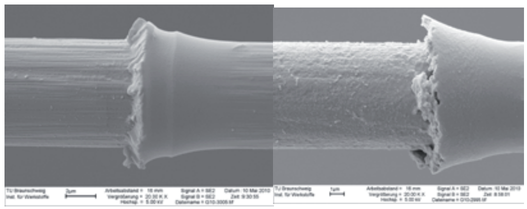
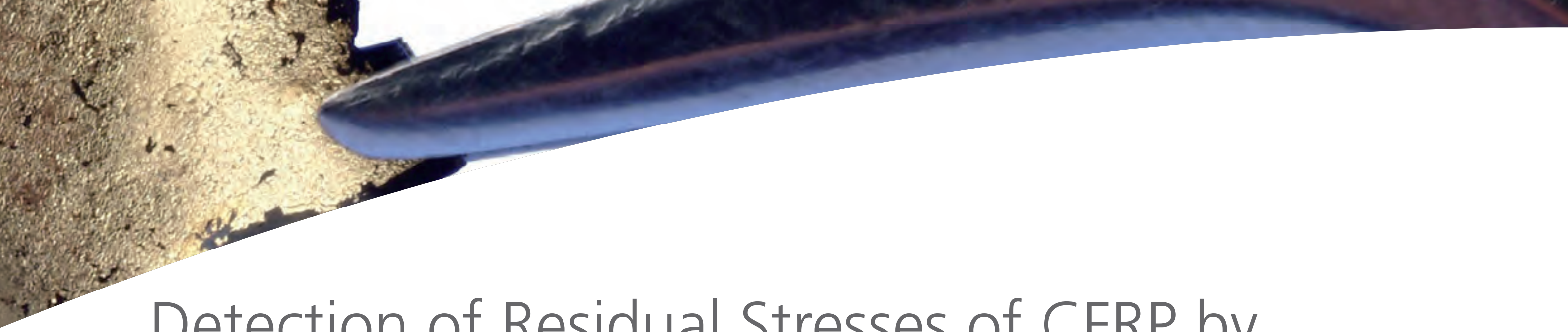


Fig. 3:
Fibres and matrix relics after pull-out test; Left: pure fibre and neat resin; Right: fibre with adherent nanoparticles reinforced resin.

Reinforcing Mechanisms in CFRP

The resulting increased modulus and strength of boehmite nanocomposites can be transferred to enhanced properties of CFRP. Specific matrix dominated characteristics, such as, e.g., the compressive strength, the interlaminar fracture toughness, as well as the resistance against impacts, and the related residual compressive strength were investigated, and considerably upgraded materials have been observed (Fig. 2). Various effects cause these observed improvement that result in a greater overall performance. These are the enhanced mechanical properties, the lower shrinkage and thermal Expansion as well as the higher thermal conductivity of the matrix material lead to less residual stress, a decelerated crack propagation and delamination growth. Furthermore fibre-matrix adhesion is significantly improved (Fig. 3). Our research shows the high ability of nanoparticles to improve the performance of carbon fibre reinforced composites.

> **Dipl.-Ing. Christine Arlt (M.Sc.) (right), Wibke Exner, (M.Sc.) (left)**



Detection of Residual Stresses of CFRP by Using Magnetostrictive Nanoparticles

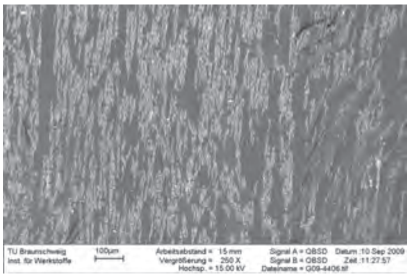


Fig. 1:
SEM image of aligned Terfenol particles (20 wt%) in an epoxy resin.

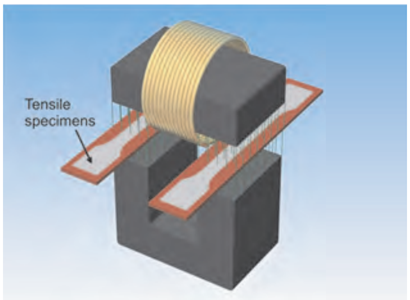


Fig. 2:
Alignment of Terfenol particles in an epoxy resin by the application of a magnetic field.

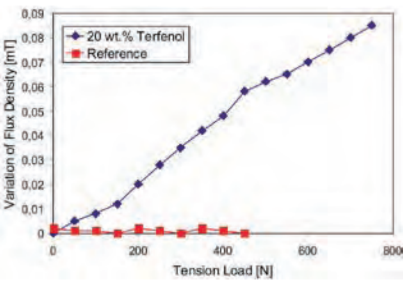


Fig. 3:
Variation of the magnetic flux density for a Terfenol nanocomposite by tension load.


The Innovation

Currently fibre reinforced composites (CFRP) are predominantly manufactured in Prepreg technology. Injection technologies (LRI) have been successfully established in addition as cost efficient manufacturing techniques for CFRP. However, particularly in the case of the LRI residual stresses are induced which have to be attributed to the volume shrinkage of the resin matrix during the curing step and the different coefficient of thermal expansion (CTE) of the components. In consequence these effects lower the maximum performance of the CFRP and reduce the dimensional stability of the CFRP structure. Presently, residual stresses of CFRP can hardly be determined. A novel and innovative way favours a non-destructive quantitative analysis of the residual stresses by means of nanoparticles such as Terfenol. Here the direct magnetostrictive effect of the Terfenol is used, i.e., in the case of any mechanical stress field (e.g. generated by volume shrinkage) the magnetic properties of the nanoparticles vary. The induced differences of the magnetic field (Néel Relaxation) can be three dimensionally detected by a specific test set-up („Magnetic Particle Imaging"). After a preceding calibration, a correlation is sought between the variations of the magnetic field and the internal stress fields. The innovation addresses the following two objectives which should result in better mechanical performance, higher durability and higher dimensional stability of CFRP:

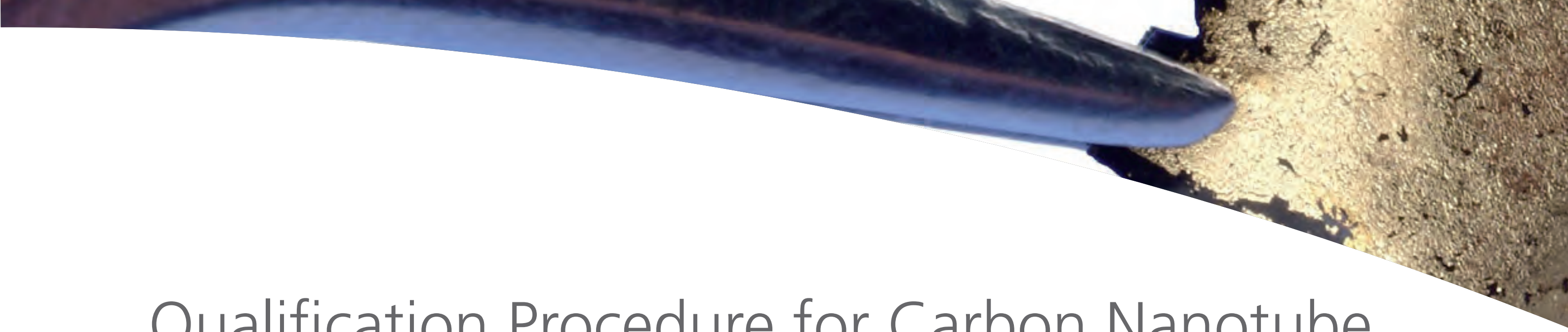
- Determination of correlations between the measured residual stress and the macro scopic material characteristics of the CFRP.
- Identification of beneficial manufacturing parameters for the preparation of stress reduced CFRP by injection technologies.

Initial Experimental Results

Initial experiments with preselected pure resins were successfully performed in order to quantify the local stress condition. Here, Terfenol particles were dispersed in a first step by means of a dissolver (0 - 300 m) and afterwards by a ball mill (20 wt.% Terfenol). This dispersion was cured in an external magnetic field (Fig. 1). Resulting in well aligned domains of Terfenol particles which show improved magnetostrictive properties (Fig. 2). These nanocomposites were observed in a tension test and the variations of the magnetic flux density were measured by means of a Hall probe. This direct magnetostrictive effect is depicted in Fig. 3 and proves unambiguously the sensor effect of the Terfenol particles in the polymeric matrix.

The detection of residual stresses in polymer matrices by means of magnetostrictive nanoparticles has to be verified in subsequent experiments. In particular the impact of the particle size and the particle concentration has to be analysed. Hence, the entire process chain i.e. the production of suitable particle sizes, the dispersing technology as well as the development of suitable dispersing agents and of a practical measurement technology must be considered. The novel knowledge will be applied to CFRP and thoroughly investigated thereafter.

> **Dipl.-Ing. Alexandra Fischer (l), Dr.rer.nat. Thorsten Mahrholz (r), Prof. Dr.-Ing. Michael Sinapius**



Qualification Procedure for Carbon Nanotube Actuators

What's Special about Carbon Nanotubes?

Carbon Nanotubes (CNTs) are cylinder-like furled monolayers of Graphene-sheets. They have extraordinary properties, such as high stiffness and strength in combination with a low density. Therefore they are already qualified as a future structural material. Numerous research activities are ongoing to incorporate them into composites. Beside that it was demonstrated that Carbon Nanotube structures, like CNT-mats (also called Bucky-paper), can be actuated within an electric field and the presence of free ions. The actuation principle is able to generate high strains of nearly 1 % at low frequencies, i.e. < 1 Hz, and low activation voltage (typically ± 3 V). These properties qualify Carbon Nanotubes to become a material with great potential for adaptive systems.

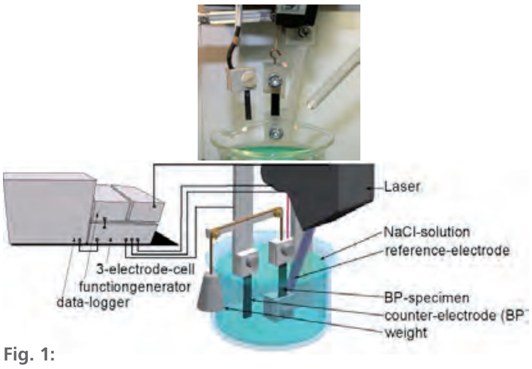


Fig. 1:
In-plain test-rig for free-deflection-measuring.

How to Manufacture a Carbon Nanotube Actuator (CNA)?

Our research covers the whole process chain from the CNT-powder to the manufacturing and assembly of CNAs as well as comprehensive test procedures to measure relevant properties. At the moment the work is focused on the optimization of two main components of the CNAs, i.e. the microscopic structure of CNT materials and the required electrolyte. In general CNT-based materials can be distinguished into two structural classes. On the one hand mats of randomly oriented CNTs, consisting of commercially available CNT-powders, which are processed using a high-pressure filtration. Here it was possible to introduce materials with improved electro-mechanical characteristics resulting in mats with higher conductivity and stiffness (Fig. 2). On the other hand so called CNT-arrays are investigated. This configuration allows a more efficient exploitation of the tube-deflection due to its anisotropic structure. CNT-arrays are processed to flat slides of horizontally aligned CNTs with a clear main orientation. SEM-micrographs and conductivity-tests confirm the alignment of the CNTs (Fig. 3). The CNT-arrays are tested in an in-plain test-rig using a liquid electrolyte (NaCl-solution) to identify the active potential of different materials in a symmetric actuator-build-up (Fig. 1). The results confirm theoretical models of the actuation behaviour, which are based on an electronic constant-phase-element. The work is carried out by the Institute of Composite Structures and Adaptive Systems in cooperation with the Technical University of Hamburg-Harburg, Institute of Polymer Composites and the Swiss Federal Institute of Technology (ETH Zürich).

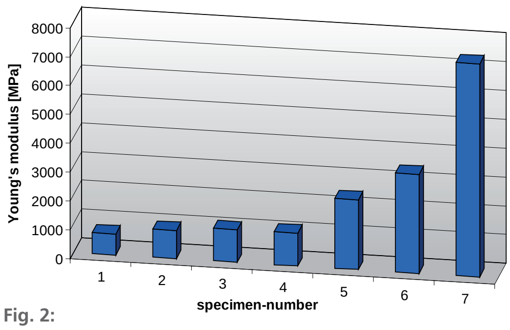


Fig. 2:
Process-induced optimisation of the mechanical BP-characteristics.

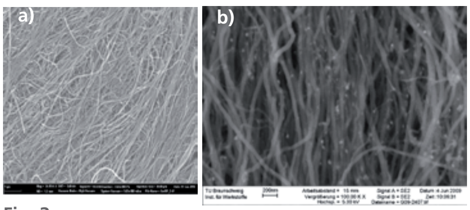


Fig. 3:
SEM-micrographs of Bucky Papers:
a): SEM-micrograph of a randomly oriented BP
b): SEM-micrograph of an aligned BP.

Next Steps towards Application

Some further steps are to be taken on the way from basic research into practical application:

- Improving the electro-mechanical characteristics of aligned CNT-structures.
- Investigations on the crucial CNT-actuation-mechanisms for CNA-optimisation.
- Identification of a time-stable solid electrolyte.

> **Dipl.-Ing. Sebastian Geier**

Testing and Analysis of Composite Stringer De-Bonding

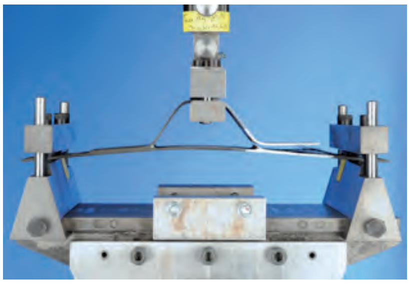


Fig. 1:
Test setup to analyse the stringer-skin-interface.

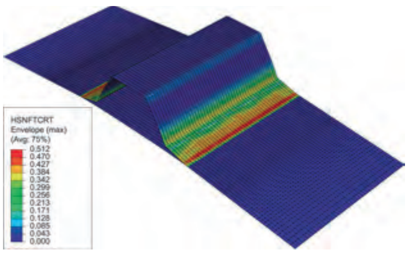


Fig. 2:
FE-Model to determine the progressive damage between stringer and skin.

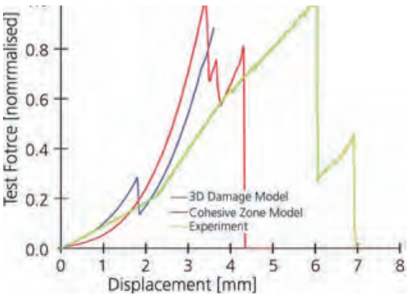
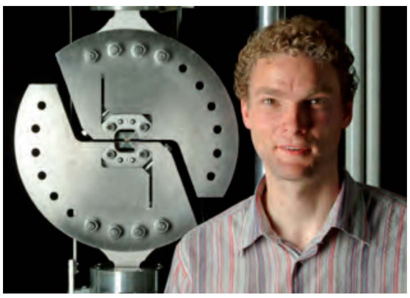


Fig. 3:
Load displacement curves from test and FE-analyses.



Lightweight structures of airplanes are built with frames, stringers and skins. Stringers are attached to the skin to mainly prevent the skin from instability failure and destruction of structural integrity. Especially, the hat or omega stringer geometries became popular for modern CFRP-fuselage structures in recent years and provide improved weight to load carrying capabilities. In order to investigate the bondline strength of composite stringers, a test setup has been developed at the institute to experimentally analyse the skin-stringer de-bonding. A small bonding interface reduces significantly the structural weight but affects the reliability and robustness of the bonding strength. Furthermore, the manufacturing process of the bonding of components, e.g. integrated co-curing of uncured components or co-bonding of cured and uncured components influences the de-bonding behaviour.

Testing of Stringer De-Bonding

The interface strength between the composite stringer feet and the skin is analysed by pulling off the stringer from the composite skin with the test device shown in Fig. 1. The loading direction of the specimen can vary between 0° and 45° orientations. The behaviour of the stringer de-bonding is driven by different failure phenomena according to the fracture mechanics failure mode I for peel stress and mode II for transversal stress. Tests under 0° loading direction cause mainly peel stresses according to mode I, whereas tests under loading directions between 0° and 45° cause a combination of peel and transversal shear stresses according to mode I and mode II.

Non-Linear Failure Analysis

Finite element analyses (Fig. 2) reveal that the de-bonding is accompanied by different failure processes. The de-bonding failure behaviour is analysed with cohesive zone elements, the virtual crack closure technique and a novel three dimensional continuum damage model for composites. It was found that the fracture mechanics approach, driven by the interface failure, is not sufficient to predict the complete failure behaviour. A complete failure analysis requires both, the accurate description of the damage propagation inside of the adhesive as well as the material damage growth. Although the de-bonding of the interface can be analysed with traditional fracture mechanics approaches, the material degradation requires an advanced material model.

The load displacement curves (Fig. 3) show results of the FE analysis from a cohesive zone elements and the continuum damage model in comparison to the test results. The cohesive zone model needs further improvement to predict reliably the onset of damage, but is suitable to determine the progressive de-bonding behaviour. The 3-D continuum damage approach adequately determines the onset of damage and final failure load.

> **Dr.-Ing. Daniel Hartung**

Innovative Repair Concepts for High Performance CFRP-Structures

The steady increase of CFRP-Structures in modern aircrafts has reached a new dimension by entry into service of the Boeing 787 Dreamliner. A decrease of maintenance costs for the overall aircraft is expected due to an excellent corrosion and fatigue behaviour of CFRP. However, in the future an increased number of composite structures is expected in maintenance requiring new repair methods.

Fig. 1:
Demonstrator of a hybrid RFI-infusionsrepair.

State of the Art Repair of CFRP-Primary Structures

Primary structures are essential for the safe flight. Therefore, special rules are applied in case of repair. The repair has to fully restore the load carrying capability of the original structure by an equivalent level of safety. Two rival technologies exist which are capable of recovering the full mechanical properties, bolted repairs and bonded scarf repair. Nowadays only bolted repairs are certified for primary structures. For a bolted repair the damage is drilled out and a titanium plate is bolted on top. The original load path is bypassed by the bolts and the plate. The main disadvantage of the technology is that the bolts require a minimum structural thickness which is a design and weight driver for about 25 % of the primary structure. This does not apply for bonded repairs. The surrounding healthy material is grinded away at a smooth angle and a cured CFRP-patch is bonded by film adhesive to the structure. It is the key challenge to verify the repair success due to numerous environmental influences on the bond strength, e.g. surface contaminations. Nowadays no non-destructive testing method (NDT) exists which is capable to verify the bond strength or even rule out a slip bond (loss of bond shear strength even though interfaces have contact). This is the reason why no structural bonded repair of a primary structure is yet certified for flight.

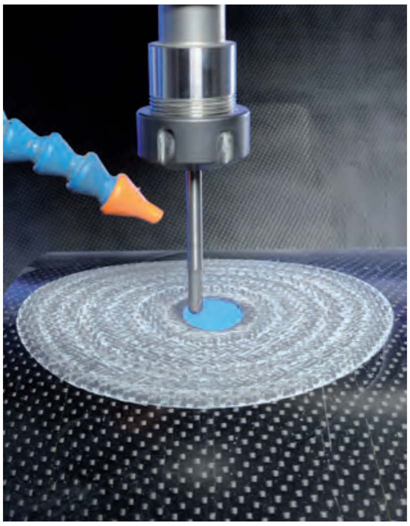


Fig. 2:
Detail of milled repair scarf.

New Repair Concepts

In order to overcome this situation, three concepts are investigated in parallel. A repair process with a high reproducibility ensures the required robustness. Therefore technologies for the automation of the bonded repair process are investigated. The work focuses on replacing the manual grinding by a numerical controlled milling of the scarf. Manual grinding can be imprecise and time consuming for structures with interleaved lay-ups. The automated manufacturing of a repair scarf including an automated repair design is available since the beginning of 2010. The second approach addresses a new Non Destructive Testing method in order to detect slip bonds. Some experimental work demonstrated the sensitivity of bond lines to the specific ultrasonic actuations. With the well established know-how on Structural Health Monitoring (SHM) at the Institute, future work is planned in this field. The third approach is a fail-safe approach. Small steel z-pins in the scarf area are implemented connecting structure and patch in case of a bond line failure. This generates a second load path. Experimental work on tensile probes have been carried out, showing successfully the basic principle of the concept. Long experience on innovative joining technologies of CFRP-structures have been effectively applied to the repair scenario. If one of these three concepts can be applied it will be possible to overcome the philosophy of designing a primary structure for bolted repair.

> **Dipl.-Ing. Dirk Holzhüter (right)**

Pushing the Limits of Parallel Robots for Handling and Assembly

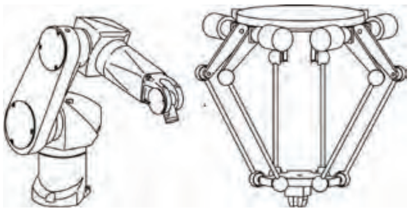


Fig. 1:
Comparison of serial and parallel robots.

Parallel robots offer potential for improving the productivity in handling and assembly. Due to lower moved masses compared to serial robots and higher stiffness, higher dynamics can be achieved. This opens up the path to short cycle-times which is an essential benchmark in handling and assembly. Fig. 1 illustrates the comparison between serial and parallel robots.
Aiming to research the field of parallel robots in handling and assembly, a DFG-funded Collaborative Research Centre (SFB) "Robotic Systems for Handling and Assembly" is established at TU Braunschweig with participation of DLR.

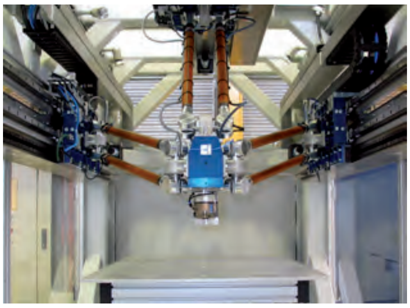


Fig. 2:
Parallel robot TRIGLIDE with active rods based on piezoactuators.

Adaptive Systems for Improved Structural Properties

Trajectories of robots with high accelerations and decelerations induce vibrations into the structure of the robot. This leads to longer cycle-times as can be seen in Fig. 3, where the actual cycle of a robot takes 0.5 seconds (shaded part) while the induced vibration takes 4 seconds to decay as shown by the blue curve in Fig. 3.
Adaptive systems are able to change the structural properties of parallel robots actively, making accessible the dynamic potential of these machines. Adaptive systems usually consist of sensors, actuators or active components and suitable controllers. Proper models of the robot's properties were developed for motion-control of the parallel kinematics, design of active components for vibration suppression and controller design. Typical components for active vibration suppression are active rods as shown in Fig. 2. for the parallel robot TRIGLIDE. These rods are made of carbon fibre reinforced plastics (CFRP) combined with piezo-patch-actuators. The combination of fibre materials with piezo-actuators enables the optimization of actuation authority and the load-bearing capabilities of active rods. The active components are able to induce vibrations and, hence, actively counteract the disturbing vibrations.

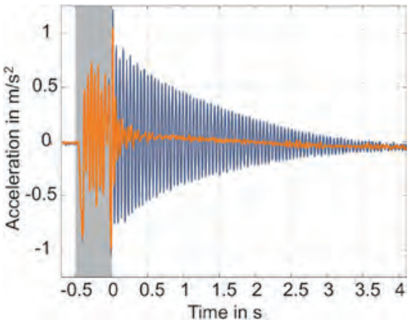
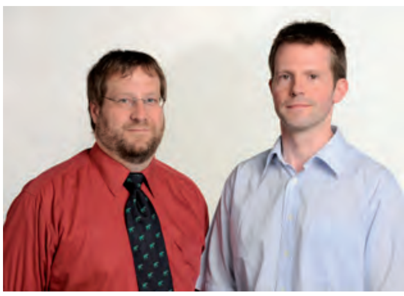


Fig. 3:
Vibration with and without use of an adaptive systems. The gray shading shows the movement in a handling cycle.

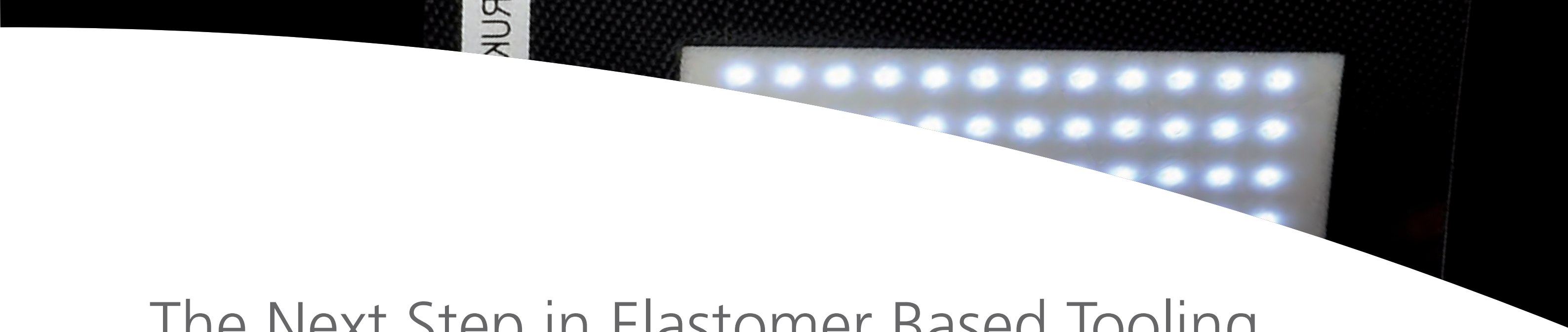
A prerequisite for suitable counteraction is a robust and high-performance control algorithm, which takes the position-dependent structural properties of parallel robots into account. An example of obtainable performance is given in Fig. 3, where the orange curve depicts vibration using an adaptive system resulting in a decay of vibration in less than 0.5 seconds.

Summary

Work in the Collaborative Research Centre leads to a better understanding of many aspects of parallel robot application for handling and assembly. Adaptive systems proved to be a successful path to better structural properties of parallel robots enabling high dynamic trajectories with short cycle-times.



> **Dipl.-Ing. Ralf Keimer (l), Dr.-Ing. Stephan Algermissen (r), Dr. rer. nat. Michael Rose**



The Next Step in Elastomer Based Tooling

State of the art manufacturing of fibre reinforced composites (FRCs) depends for many applications on metal based tools. This tooling is well establish so far, but of course has its weaknesses according to availability, costs and the construction methods required for fibre reinforced composites. Because of this reason, the Institute of Composite Structures and Adaptive Systems developed advanced tooling methods using elastomers. Moulding can be completed within days providing multiple purpose tools by using elastomer materials.

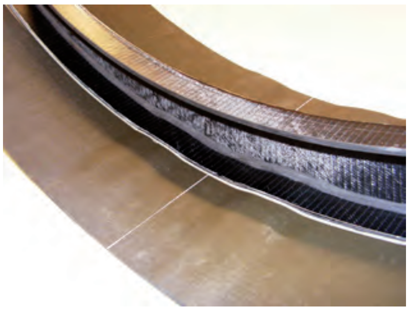


Fig. 1:
Multiple curved frame manufactured by elastomer tooling.

Different Components Manufactured in a Single Mould

The development of tooling concepts requires a high flexibility for a design customisation and short period manufacturing. Metallic tools usually can't fulfil these requirements. Stiffeners for aircraft structures for instance appear with different profiles (I-, T- or Ω-section) and geometry. Both change during the structural dimensioning. By elastomer tooling refitted tools are available in very short time and with significantly less costs. Furthermore, one mould can be used for CFRP (carbon fibre reinforced plastics) parts with different radii of curvature or changing geometric progression in general. A longitudinal stiffener (stringer) and a radial stiffener (frame) with the same cross section are producible in one single mould. Even more complex structures like the multiple curved frame in Fig. 1 can easily be produced in combination with a fitting base and/or additional utilities. Additional benefits are reduced weight, multifunctional usage and simplified handling of the mould. A pressure-sealed design allows manufacturing without typical auxiliaries like sealent tape or vacuum bagging. The pre-process shaping is easier and done in short time, by pre-heating the elastomer mould (Fig. 2).

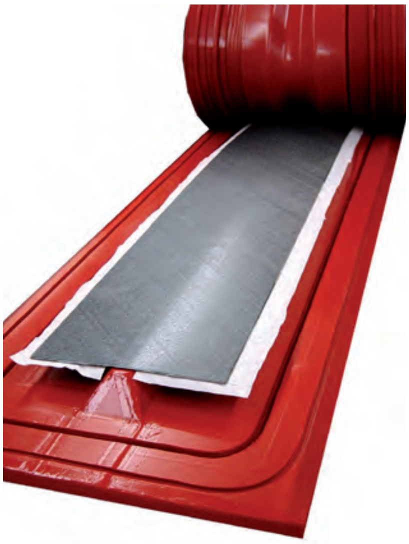


Fig. 2:
Preforming a W-stiffener in a silicone mould.

Matching Future Requirements of Complex Composite Structures

Quality assured manufacturing is of great importance today. Because of this reason mould embedded sensors are a further research topic. Thermal sensors for instance provide an overview over the heat distribution during the curing process which is very important for the excellent mechanical properties of composites. Even more survey and control of the manufacturing cycle will be gained by ultra sonic sensors. Sensors don't need a separate medium to couple the ultra sonic waves into the structure, connected with elastomers. Their implementation is simple. The sensors provide information about the curing degree which leads to optimized processes (time of a curing cycle). The thickness of the structure can be measured as well.

Future manufacturing of complex composite structures will increasingly depend on sensors for process control und shall guide the way into automated process regulation and optimisation. Highly cost efficient production of high-performance CFRP structures is possible by using elestomer tooling.

> **Dipl.-Ing. Michael Kühn, Dipl.-Ing. Sebastian Malzahn, Dipl.-Ing. Michael Hanke (photo f.l.t.r.)**

Upper Wing Cover for Natural Laminar Flow - Ultra-Precise Shape by Process Simulation

Fig. 1:
Global deformation of a wing under aerodynamic loads.

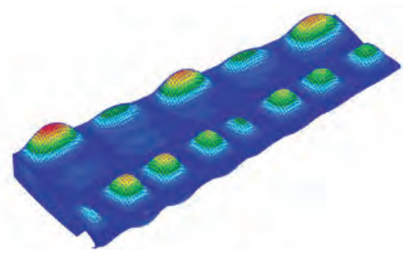


Fig. 2:
Loacal wing deformation.

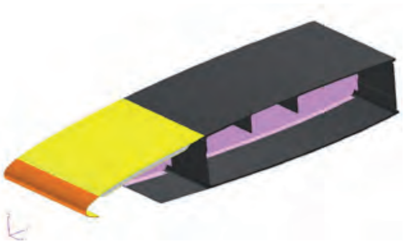


Fig. 3:
Multi-material multi-functional demonstrator.

In the scope of developing efficient future aircraft, fuel saving becomes one of the main issues. The idea of the project LaWiPro – Laminar Wing Production – is to develop and manufacture a part of a wing upper cover fulfilling the aerodynamic requirement of laminar flow.

The surface has to be much smoother compared to current wings. Waviness coming from either manufacturing or load has to be kept in a much smaller tolerance band than at current aircrafts. Also steps and gaps coming from assembly should be disregarded.

Two completely different ways may lead to fulfil these requirements:

- Either by stiffening: The structure can be stiffend until it will be within the requested waviness. This could increase weight and therefore fuel use – for manufacturing as well as travelling
- Or by the shape of the tool: It is adapted by predicting the local deformations caused by the manufacturing process, like spring-in, warpage, and loads

Multi-Material, Multi-Functional Design

A multi-material design is developed to eliminate steps and gaps using monolithic carbon with integrated stiffeners for primary structures, glass sandwich for secondary structures and metal-hybrid for load introduction areas. The multi-functional design provides the opportunity to integrate anti-icing devices or connectors into the same curing process.

Developing innovative process simulation methods gives the possibility to predict the deformations caused by the manufacturing process. The required adaptation of the tooling will be determined first time right, without today's time and cost-consuming iteration loops. The developed methods will be implemented into the Virtual Composite Platform (VCP). Comparing virtual results with real 3D optical measuring from tests ensures the improvement of the methods.

Automation is another key issue to produce a part with acceptable costs and quality for the high production rate of single aisle aircrafts. Based on the first investigations done for spring-in, warpage and pre-deformation, automation concepts will be developed to produce the upper wing panel including part of the nose structure.

At the final stage of the project all ideas will be shown in a demonstrator manufactured automatically at the Institute's facility in Stade (ZLP Nord).

Eventually, the innovative simulation and integration of manufacturing discrepancies and displacements under load on the Virtual Composite Platform might lead to an environmental sensitive design for future aircraft designs.

> **Dipl.-Ing. Jens Bold**

Active Reduction of Turbulent Boundary Layer Induced Noise

The turbulent boundary layer (TBL) is one of the dominant noise sources in high subsonic aircrafts. Especially in modern aircrafts, where common materials for fuselages are currently substituted by carbon-fiber-reinforced-plastics (CFRP), it is essential to avoid a decrease of passenger comfort as a result of an inferior transmission loss of the new materials. Increasing the transmission loss of CFRP panels, they can be equipped with active structural acoustic control (ASAC) systems. These systems consist of a control unit and surface mounted actuators and sensors. Structural vibrations of the panel are measured by the sensors and filtered by the control unit to estimate the radiated sound power in the far field. The transfer path from actuators over the structure to the sensors is called the controlled plant. Based on this information and a mathematical model of the controlled plant, the controller calculates the signals for the actuators in order to reduce the noise radiation.

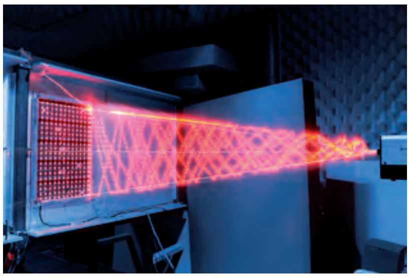


Fig. 1:
Measurement of CFRP panel vibrations using a laser scanning vibrometer.

Wind Tunnel Experiments

The Institute of Composite Structures and Adaptive Systems verified an ASAC system in an experimental study in the aeroacoustic wind tunnel of DLR in Braunschweig. The wind tunnel has an open test section and its nozzle has a cross-section of 1.2 x 0.8 m². The section is enclosed by an anechoic chamber to enable acoustic measurements. For realization of TBL experiments, a closed test section has been designed and built. The active controlled CFRP panel is mounted in the side wall of the section. The TBL is growing steadily over the length of the closed test section until it reaches the CFRP panel with a thickness of approximately 41 mm at Mach 0.16. The panel (500 x 800 x 1.3 mm³) is stiffened with four stringers and equipped with five piezo-ceramic patch actuators and ten accelerometers. Actuator placement was accomplished by an in-house ASAC pre-design tool. Panel fabrication as well as actuator application were made by DLR. Active structural acoustic control has been used to reduce the broadband TBL noise transmission in the bandwidth from 1 to 500 Hz. Robust H-infinity control algorithms were applied in the experiments and showed high performance even in presence of plant uncertainties. The so-called generalized plant framework of robust control is utilized to improve control results. By inclusion of 260 additional surface velocity outputs identified from laser scanning vibrometer (LSV) measurements (Fig. 1), an enhanced global observability has been established.

Fig. 2:
Radiated sound power measured with sound intensity probe.

Broadband Noise Reduction

The experiments proved the possibilities of ASAC systems for thin-walled and stiffened CFRP structures. Though the structural excitation due to the TBL is spatially and temporally weakly correlated, a broadband reduction of the transmitted noise in the bandwidth from 1 to 500 Hz could be demonstrated. In third-octave bands reductions of radiated sound power of up to 6 dB(A) were realized (Fig. 3). Future work will concentrate on the extraction of noise models for the TBL excitation to further improve the control performance.

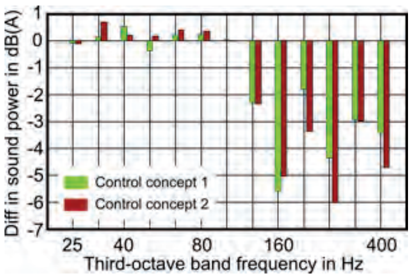


Fig. 3:
Reduction of radiated sound power.

> **Dr.-Ing. Stephan Algermissen (center), M.Sc. Malte Misol (right), Dipl.-Ing. Oliver Unruh (left)**

Smart Process Control for CFRP Production

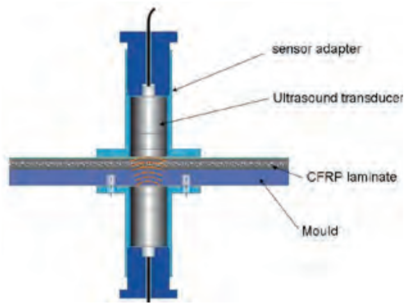


Fig. 1:
Functional principle of ultrasonic thickness measurement.

Fig. 2:
Frame tool with vacuum assembly and integrated sensors.

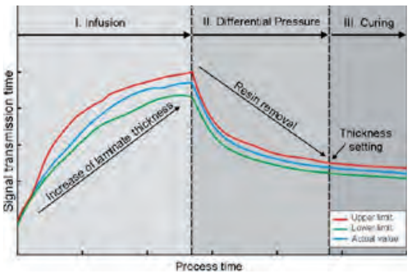


Fig. 3:
Ultrasonic thickness measurement process diagram.

Process Control for a Better Quality at Lower Costs

Today's autoclave and RTM processes for CFRP production strictly follow a given temperature and pressure cycle which is optimized empirically by many iteration loops. The structures quality inspection is performed after the process due to the "black box" character of the autoclave and RTM tool. This makes it hard to perform process parameter optimization and to find failure sources. High safety factors for the cycle duration are used to assure reaching the right tool temperature, complete infiltration and a high degree of cure. This, in turn, leads to excessive process time and costs. New control technologies efficient CFRP production have to be developed to master the challenges for automation. The new approach is to gather all information relevant for the product quality by novel sensor technologies during the whole production process. This information is used to control the process parameters with the support of real time simulation tools. It allows direct control and setting of the desired part quality and optimization of the process cycle duration at the same time.

Sensors for Process Monitoring

Ultrasonic measurement is one of the most important sensor technologies to directly measure the laminate quality during the process. The resins acoustic properties change during curing. Therefore, ultrasonic sensors can be applied into the mould and vacuum bag, enabling degree of cure to monitor the during the process. This allows to look inside the mould and react to the cure progress by applying temperature and pressure, as function of the degree of cure and to demould the part at the optimal time. The ultrasonic signal can also be used to measure the laminate thickness which can be set by applying and adjusting differential pressure during the resin injection process. This technology allows to achieve small laminate thickness tolerances of about 100 µm or respectively to adjust the desired fiber volume content. This has already been tested successfully by manual adjustment of the differential pressure, the next step will be implementing an automatic differential pressure control connected to the ultrasound system. The ultrasonic sensors can also be used to detect the resin injection line as the sound waves can only pass through the laminate when infiltrated by the resin. An advantage is that the sensors can be placed behind the inner surface additional of the mould, so that they do not affect the quality of the structural surface.

The homogenous tool heating is a key factor for high quality parts since temperature is one of the most important parameters for resin injection and curing . Especially large and complex tools need a refined heating strategy. This can be accomplished by simulation to localize critical points where additional heating elements are employed. Especially for single moulds an interesting alternative to thermocouples is the thermal imaging technology, where the temperature field of the part surface can be measured. Therefore a protective housing is being developed to install a thermographic camera in-side the autoclave which will be used to control the heat elements. This new approach for CFRP process control allows short, flexible and efficient production cycles at a high level of automation leading to low cost and significant reduction of scrap, which is an important step towards a completely automated volume production of composites.

> **Dipl.-Ing. Nico Liebers**

Adapted Moulds for Microwave Curing

Microwave driven dielectric heating of composites is evaluated to be a promising method for curing polymers. To date, conventional metallic moulds are used in combination with microwave driven heating, which does not allow for full capability of the method.

Significant improvements can be achieved by using moulds adapted specifically to needs and requirements of dielectric heating. Fig. 1 shows the energy balance of a convective (right) and a dielectric (left) heating process. While the convective heating demands moulds with a high thermal conductivity, the microwave driven dielectric heating requires tool materials with a low thermal conductivity and a high transparency for high-frequent fields. Recently material screening took place in order to identify suitable materials with good insulating properties and high transparency for microwave fields. Especially ceramic materials and plastic foams seem to be very promising for mould manufacturing. Additionally to their good thermal and electro-magnetic properties, the machining and shaping of such materials is user-friendly. However, new materials require innovative mould design, first iteration of which is shown in Fig. 2.

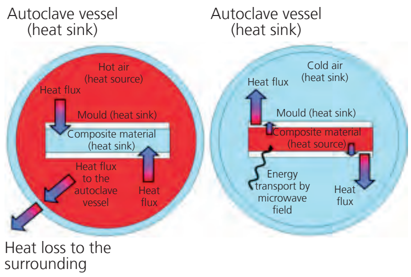


Fig. 1:
Energy balance during convective and microwave driven heating.

Energy Saving is Possible by Using Adapted Moulds

First results show that microwave driven processes allow for high energy efficiency and for locally variable heating. Innovative moulds (Fig. 2) would allow the high-frequent field to penetrate them and therefore double up the energy input into the composite material to be heated. Accordingly to first trials, up to 30 % can be saved by using microwave transparent moulds.

The insulating layer within the mould is dedicated to the reduction of the outward heat flux from the selectively heated composite. It was experimentally proven that by modifying conventional metallic moulds with additionally applied insulating layers made of ceramic wool the energy consumption can be reduced by another 40 %.

As shown in Fig. 2, the energy input by the external microwave field can be adjusted locally by the frame of a microwave-transparent mould. That might help to increase or decrease the temperature at desired regions of the composite part.

Further work will focus on the design principles of microwave transparent moulds, especially for curing of large-scale composite parts and the experimental verification of estimations. Additionally to that, the economical impact of microwave assisted dielectric heating and curing of composites on transparent and insulated moulds will be assessed compared to the state-of-the-art convective heating and curing of composites on conventional tools.

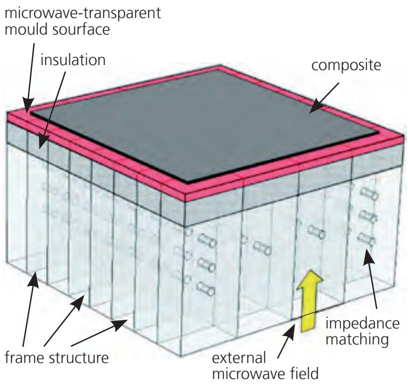


Fig. 2:
Adapted microwave-transparent mould with impedance matching.

> **Dipl.-Ing. Maksim Danilov**

Prediction of Epoxy Curing Kinetics

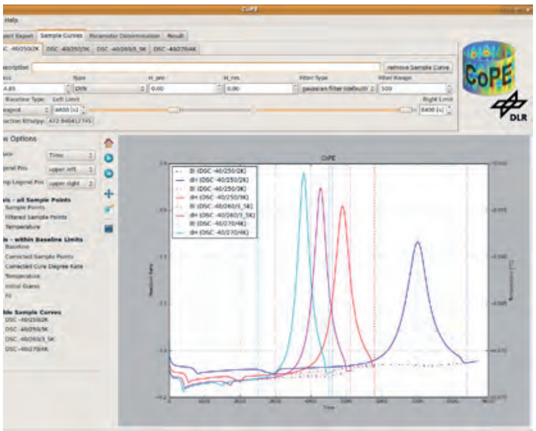


Fig. 1:
Graphical user interface of CoPE.

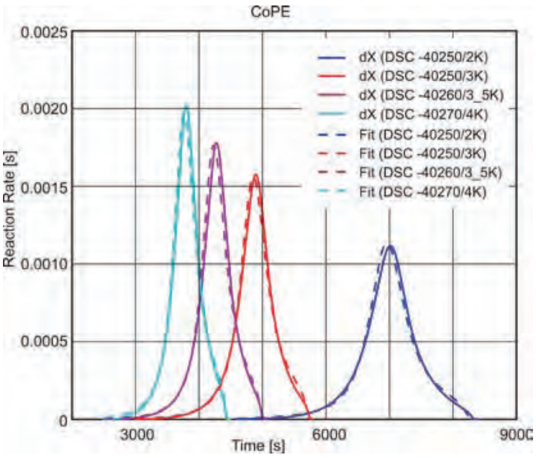


Fig. 2:
Monitoring the sample data (continuous lines) compared to the best fit (dashed lines) during the parameter estimation.

One key challenge within the production process of carbon fiber reinforced plastics (CFRP) is the reduction of residual stresses and deformations due to chemical and thermal shrinkage during the curing process. Other goals are the reduction of cycle times and energy consumption which is opposing the first target. Finding the optimum between both objectives is a complex task that can be supported by numerical simulation of the curing process. Therefore the curing kinetics of epoxy resins must be investigated properly and empirical curing models need to be determined. Such models describe the curing behavior and contain a set of material parameters which have to be validated with measurements.

Experimentally, the curing behavior of an epoxy resin is obtained using Differential Scanning Calorimetry (DSC) measurements. This method provides the energetic behavior for arbitrary temperature profiles of epoxy resins. The desired heat flow due to the exothermic chemical reaction is included as well as several other thermal influences, e.g. phase transitions and the heat capacity as a function of temperature and degree of cure.

Model Parameter Identification

Supporting tool generation, parameter determination and curing process simulation, the software tool CoPE (Composite Parameter Estimation) was developed. Firstly a noise reduction on the measured data is performed by filters in the time and frequency domain. The heat flow can be extracted by setting a baseline within the region of the characteristic reaction peak to approximate the magnitude of other thermal influences (Fig. 1). Thus the area enclosed by the dashed baselines and continuous drawn sample curves represent the enthalpy of the chemical reaction. For this sample background correction, typical baseline functions are included in CoPE and enable calculating the total reaction enthalpy and the reaction enthalpy rate for every sample point. Those values are the basis for determining the degree of cure used within the curing models defined in CoPE.

The determination of the model parameters is done by a curve fitting method. Hence, the least square error as seen in Fig. 2 between sample data (continuous line) and model function (dashed line) provides the target function value to be minimized. Various population based optimizers are available for this optimization task, ensuring robust convergence towards the global optimum if the parameter space is not well known. In the case that a reliable estimation of the optimum is available, a gradient based optimizer can be chosen to speed up the parameter identification.

Benefits of Curing Simulation

Having found valid curing model parameters, an ABAQUS user subroutine can be generated by CoPE in order to enable simulating the heat generation due to curing and, thus, the transient temperature distribution within a finite element model. This can be used to optimize a curing process with respect to the maximum valid curing temperature of the resin and process time. Additionally, the transient temperature distribution of a structure is essential for simulating chemical and thermal shrinkage of arbitrary geometries.

\> **Dipl.-Ing. Sebastian Freund**

Mode Selective Lamb Wave Actuators for SHM

Structural Health Monitoring

Structural health monitoring (SHM) is a novel technology using permanently attached actuator and sensor networks, data acquisition and data evaluation systems to enable in-service inspection of aerospace structures. The implementation of SHM systems into aerospace applications enhances reliability, safety and maintenance performance as well as economic aspects. In this context Lamb waves, a type of ultrasonic guided waves, are a promising approach primarily because of their ability to propagate over long distances in plate-like structures and their high sensitivity to a variety of structural damages. Lamb waves are excited and received using a network of piezoceramic actuators and sensors. In case of damages, the excited Lamb wave propagation field will be disturbed resulting in reflections, refraction, attenuation or mode conversion. By analyzing the sensor signals this disturbance can be observed and the damages can be detected and located. However, the presence of at least two Lamb wave modes (symmetric, S0, S1, S2,…, and anti-symmetric, A0, A1, A2,…, modes) at any given frequency, their dispersive characteristic and their interference with structural discontinuities produce complex wave propagation fields and sensor signals which are difficult to interpret.

Design of Mode Selective Actuators

In order to reduce the complexity of the Lamb wave propagation field, DLR has developed mode selective actuators, which are able to generate a particular Lamb wave mode. This is achieved by controlling the frequency as well as the wavelength of the desired mode within the excitation. An appropriate technical solution is to use monolithic piezoceramic plates with applied interdigitated electrodes, so-called interdigital transducers (Fig. 1, left). The electrode distance corresponds to the half-wavelength of the desired Lamb mode. The bandwidth and the effectiveness of the actuator regarding mode selectivity can be enhanced by applying a weighting function (apodization) to the electrodes during excitation. This is realized by varying the overlap length of the electrode fingers. A promising alternative to conventional interdigital transducers is to utilize the piezocomposite technology to increase the reliability of brittle piezoceramic actuators (Fig. 1, right). To verify the mode selectivity performance of the actuators experimental tests on quasi-isotropic CFRP plates with a surface bonded piezocomposite actuator, as shown in Fig. 1 (right), were carried out. This actuator is designed to attenuate the S0 mode and thus to amplify the A0 mode at a frequency of 40 kHz. In order to distinguish the S0 from the A0 mode, a collocated pair of circular piezoceramic sensors is bonded on the upper and lower plate surface. In a first setup only the first strip of the actuator was driven by a rectangle burst signal at 40 kHz. The sensor signals in Fig. 2 shows that the A0 and the S0 mode were excited in an amplitude ratio of 100 % to 11 %. In a second setup all strips of the actuator were driven. An apodization of each strip was realized by individual signal adjustment. Fig. 3 shows that the designed actuator can attenuate the amplitude of the S0 mode to 0,2 % compared to the amplitude of the A0 mode of 100 %. In summary, it has been shown that the interdigital transducer design is capable to excite a particular Lamb wave mode in CFRP structures. Further research activities are focused on the development of finite element and analytical models in order to design and optimize mode selective actuators for different Lamb wave modes and excitation frequencies as well as for different lay-ups and fibre orientations of CFRP structures.

> **Dipl. Ing. Daniel Schmidt**

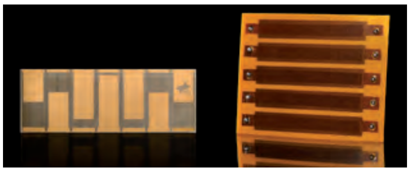


Fig. 1:
Mode selective Lamb wave actuators: (left) interdigital transducer, (right) piezocomposite.

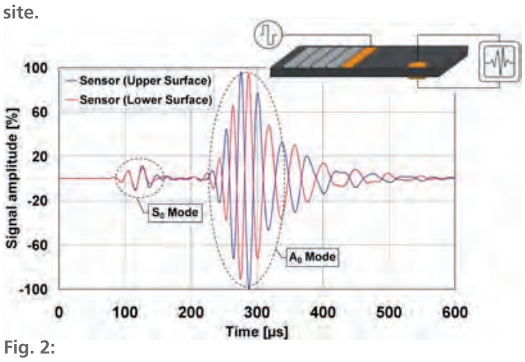


Fig. 2:
Sensor signal by driven the first strip of the actuator (f = 40 kHz).

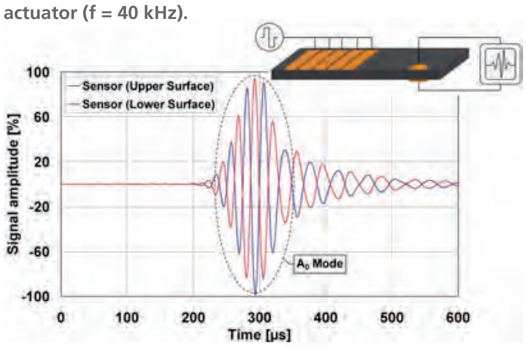
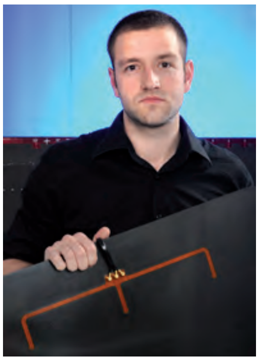


Fig. 3:
Sensor signal by driven all strips of the actuator (f = 40 kHz).



On Realizing High Lift Structures for Green Aircraft Wings

Morphing as Enabler for Less Emissions and Low Noise

Ambitious goals were defined in the well known VISION 2020 stating the need for technologies to consequently reduce drag and airframe noise. The challenging recommendations of the ACARE group for the reduction of emissions per passenger kilometers are CO_2 < 50 %, NO_x < 80 % and noise < 50 % until 2020. Therefore, innovative aircrafts and along with it new concepts for high lift device will have to manage the transition from research into industrial products. Such novel systems have to comply with the next generation aircraft requirements like high wing surface quality and a very strict lightweight design. In conventional high lift configurations of today, devices on leading and trailing edges open slots to achieve the additional lift. However, the slots and especially slat gaps at the leading edge have been identified as the dominant source of airframe noise in approach and are not employable for green laminar aircraft wings. Eliminating these gaps and steps through morphing structures consequently reduces airframe noise, flow resistance during low speed flight and functions as an enabler for a fully laminar wing design. These are the components for green aircraft wings.

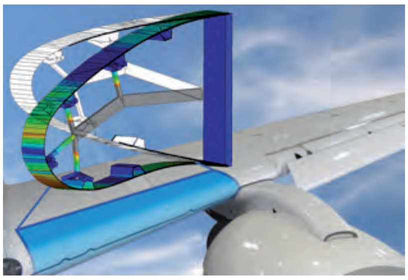


Fig. 1:
Schematic illustration of a smart droop nose concept consisting of an integrated outer skin and internal driving mechanics.

Can a Composite Skin Handle it?

A morphing structure typically consists of a flexible outer skin and an internal driving mechanism (Fig. 1). While many driving mechanisms where patented in the past, flexible skin structures that fulfil industrial requirements are still very scarce. One approach to break through this barrier is to employ composite material systems. They generally allow for tailoring the structural design to various applications and are widely available. Nevertheless, a morphing high lift device in the shape of a seamless droop nose requires a skin that unites contradicting properties of flexibility and sufficient stiffness. From the skin concept featuring a monolithic outer shell and internal spanwise stiffeners result the detailed material requirements. It is desired that the skin is able to withstand 1 % strain and the omega stringers maintain integrity even during a load introduction through the mechanical actuation inside the leading edge. Several structural tests of flight-certified composite material systems have been performed allowing for a selection between carbon and glass fibre based systems. Fig. 2 illustrated carbon and glass fibre specimen after bending tests, where CFRP (carbon fibre reinforced plastics) were not able to provide the desired 1 % strain. The GFRP (glass fibre reinforced plastics) skin on the other hand did not show significant performance degradation below the given strain limit and in addition provided a significant security margin. So, composite material systems are suitable for morphing and in our case GRFP was selected as material system for the smart droop nose structure to be manufactured for testing in the national project SmartLED considering industrial requirements.

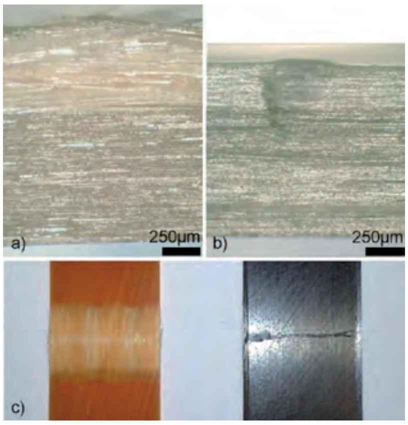


Fig. 2:
Exemplary GFRP (left) and CFRP (right) specimen after bending tests until fracture (top: cross section, bottom: topview).

A Closer Look Inside our Structures

Moving one step forward in the process chain for composite structures, the strength of our omega stringer design (especially its binding to the skin) had to be benchmarked. Numerical analysis and application of upstream damage models allowed for the classification of maximum loading and failure phenomenon.

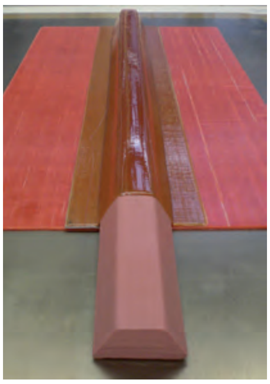


Fig. 3:
Stringer specimen manufacturing for testing employing GFRP pre-preg and silicone tooling.

Therefore, a representative stringer-skin substructure has been modelled and equipped with 3d continuum mechanics damage model to analyze the structures damage at the expected large strains during morphing. The results from these finite-element simulations provided confidence in our design. Nevertheless, we were striving for an experimental validation and manufactured the analyzed substructures. Fig. 3 shows such an omega stringer and morphing skin segment being build integrally employing a silicone tooling and GFRP pre-preg. Its capability to handle morphing requirements was impressively demonstrated (Fig. 4).

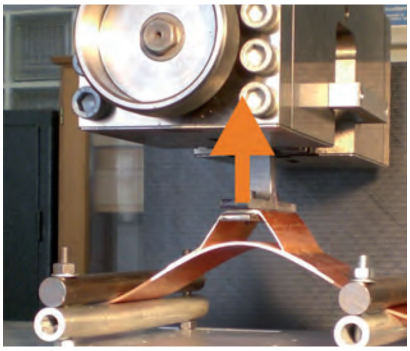


Fig. 4:
Stringer specimen during testing until fracture.

Fully Featured Virtual Testing

In the national project SmartLED, the test of a 2 m smart droop nose segment is being performed in 2010. The smart droop nose segment had to be equipped with integrated kinematics that were developed in cooperation with EADS, where the entire leading edge unit is mounted to a testing front spar suitable for a wing bending simulation. Such large scale tests require detailed preparation and, thus, the finite-element modelling and simulation of the entire test setup was performed. The model in Fig. 5 included the composite morphing structure, the internal driving mechanics and the front spar as well. An important goal for the analysis was to quantify the interaction of the driving kinematics with composite structure and front spar in addition to the fully featured virtual proof of function. We were able to refine the design of the composite leading edge and the test stand. In a next step the test program was planned in detail employing test stand simulation. Mainly three load cases are to be tested, which are the 2.5 g case mimicking an interception manoeuvre, the 2.0 g case as gust load and the 1.15 g case simulating the droop nose behaviour during landing.

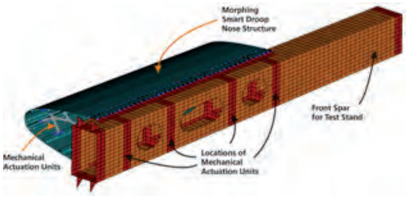


Fig. 5:
Finite-element model of droop nose test stand.

Large Scale Test Hardware

The composite skin of the smart droop nose was manufactured integrally including the omega stringers. Here, the previously selected GRFP pre-preg material has been employed not just due to its proven strength but also to match the designed layup sequence as close as possible and maintain low tooling costs. The tools and the integral manufacturing of the composite skin have been executed in cooperation with the Invent GmbH of Braunschweig. First, a positive core with the contour of the leading edge was milled out of tooling plastics and a CFRP tool was formed on this core such that the resulting tool is able to resist the temperatures occurring during the GFRP curing cycle. The pre-preg layers were positioned in the CFRP-tool and the pre-formed but uncured omega stringers placed and locked in position. The manufacturing of the entire composite structure in the so-called co-curing process allowed for a highly loadable stringer-skin interface. Fig. 6 presents a side view of the resulting composite structure for the smart droop nose to be tested in 2010.The smart droop nose test of the integrated structure-kinematics concept will manifest the successful application of the process chain in the Institute of Composite Structures and Adaptive Systems as well as the institutes close cooperation with external partners. The work to transform ideas into hardware was especially propelled forward by Sebastian Geier, Daniel Hartung, Markus Kintscher und Thomas Wurl.

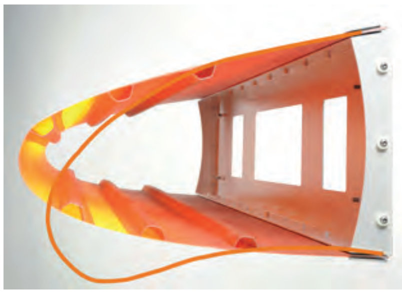
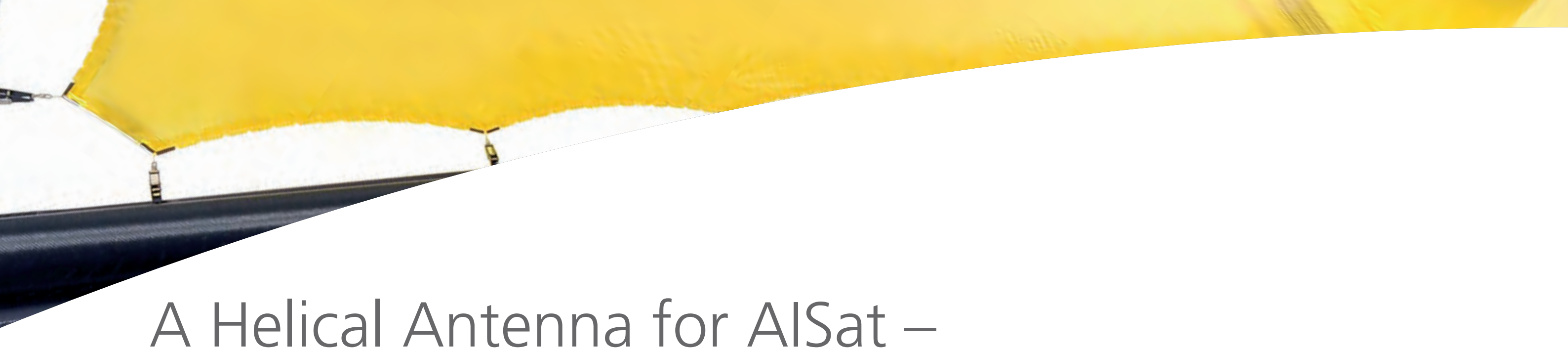


Fig. 6:
Large scale droop nose section (side view) with marked high lift contour.

> **Dr. Olaf Heintze**



A Helical Antenna for AISat – Self-Deploying and Self-Aligning

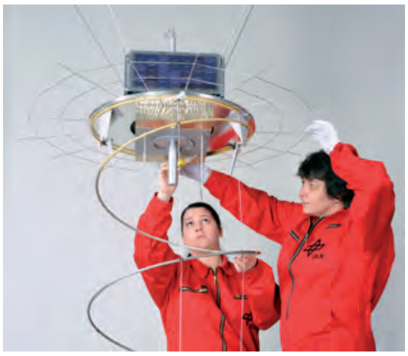


Fig. 1:
Adjusting the antenna.

DLR Nanosatellite to Monitor Maritime Traffic

AISat is a suitcase-sized nanosatellite with a deployable fiber-composite antenna. The antenna is stowed within a small volume for launch, only to extend to its operational dimensions once in orbit. Both the antenna and the AISat project as a whole are ambitious undertakings – the DLR satellite will increase maritime safety and will precisely locate individual ships on busy sea routes. The 'AIS' in the mission name stands for Automatic Identification System – a radio system designed for the exchange of navigation, position and identification data from each and every vessel, to make global maritime traffic safer and easier to control.

Cooperating Partners

Two DLR institutes, the Bremen University of Applied Sciences, and two industrial partners are collaborating on the AISat project. DLR's Institute of Space Systems in Bremen developed the nanosatellite itself and performed the whole system engineering, while the DLR Institute of Composite Structures and Adaptive Systems in Braunschweig took the responsibility for the helical antenna, in particular for its experimental qualification on a parabolic flight. The time schedule of the AISat project is tough, because the maiden flight of the first satellite is already planned for 2011. The satellite will be launched on a Polar Satellite Launch Vehicle from the Satish Dhawan Space Centre on the Island of Sriharikota, India.

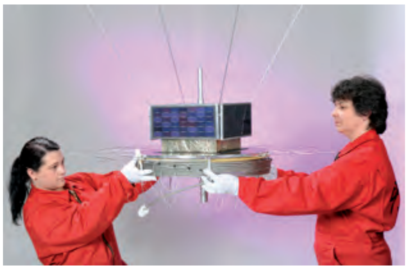


Fig. 2:
Antenna in stowed configuration.

Why a Helical Antenna?

The mission objectives require an antenna with an excellent directionality, i.e. with a comparatively narrow illumination radius. Otherwise, with a too large antenna footprint, the satellite would receive a huge amount of signals from a very large area. Moreover, many interfering signals which are present in adjacent frequency bands would make it almost impossible to trace individual ships. High-gain helical antennas have the required directionality – and they are able to receive not only the Class A VHF signals from commercial shipping, but also Class B signals from non-commercial ships, as well as Search And Rescue (SAR) transmitter signals sent from survival craft or distressed vessels. Thus, the spiral form of the antenna was mandatory.

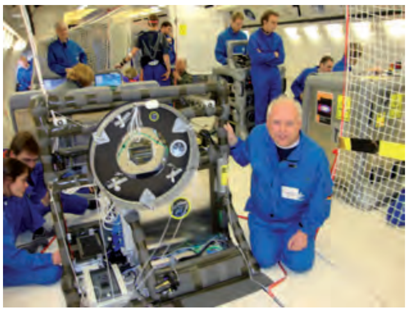


Fig. 3:
Test rack with stowed antenna on board the NOVESPACE Zero-G aircraft.

Acting Like a Spring

For the project team at DLR Braunschweig as well as for its partners at Schütze GmbH & Co at Dorsten the task was to design the antenna core such that it would really expand as a compression spring, once the hold-down mechanisms on the satellite base plate would have been released. Since three hold-down mechanisms were needed (in rotational symmetry, i.e. with an angular distance of 120° between them), the initial friction of the antenna on each of them became a critical parameter with a strong influence on the initial directionality of the expansion, i.e. on the generation of lateral and torsional vibrations. In longitudinal direction the expansion was limited by fine

glass fiber threads, which act against the residual spring stiffness once the antenna has achieved its final configuration. Four different types of fiber cores with varying stiffness were built, containing combinations of carbon, glass, and aramide fibers. These antenna cores were coated with a thin metallic mesh, and only this covering is conductive and acts electromagnetically as antenna. Mechanical and electrical functions of the antenna are thus completely decoupled.

Deployment Tests in Weightlessness

It is obvious that such a slender structure as the 4 m long antenna helix could never be tested on ground. In horizontal attitude the expanding helix would be immediately deflected downwards by its own weight, and in vertical (hanging) position the antenna mass would concentrate itself at the bottom end, leaving the first coils below the satellite under strong stress. Therefore the only chance to realistically prove the deployment behaviour was a verification test under zero-g conditions – on occasion of the 15th DLR Parabolic Flight Campaign in Bordeaux in March 2010. The test results were impressive: The helix extends rapidly and in doing so, it moves the satellite body, which is much smaller. Figuratively speaking, the tail really wags the dog! But soon the vibrations become smaller and smaller; and once the satellite has achieved its final position, the configuration becomes operable. The tests were a large success; the results were encouraging and will now be incorporated into the final design of the first AISat flight unit.

Fig. 4:
Deployment tests on the 15th DLR Parabolic Flight Campaign, March 2010.

> **Prof. Dr. Joachim Block**

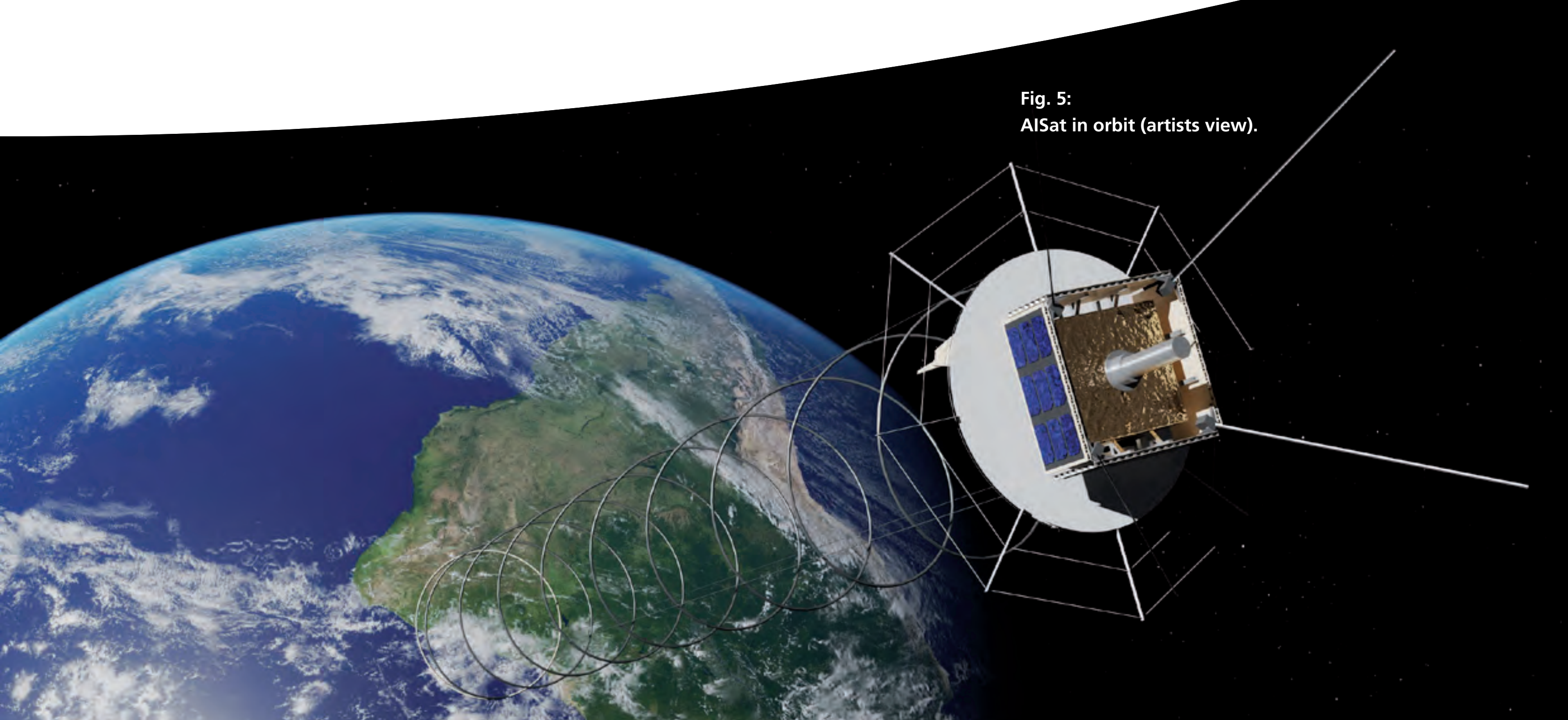


Fig. 5:
AISat in orbit (artists view).

New Sound Transmission Loss Test Facility for Acoustic Evaluation of Smart Lightweight Panels

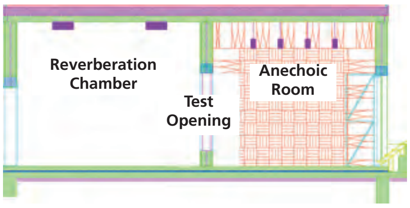
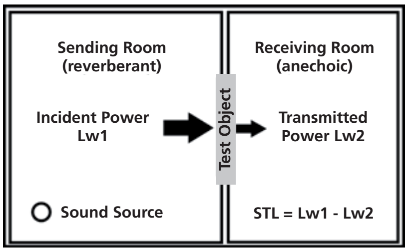


Fig. 2:
Anechoic room of the test facility.



The sound transmission loss (STL) quantifies the propagation of incident acoustic energy through a structure to a neighboring fluid. It is an important measure not only in building acoustics but also in the aircraft, automotive, railway and marine industries as it is directly linked to noise exposure and acoustic comfort of passengers. A low STL permits a high transmission of acoustic energy through the structure resulting in high noise levels, e.g. in the cabin of an aircraft. The growing use of stiff and lightweight structures such as carbon-fiber-reinforced-plastics (CFRP) in the transportation sector poses great acoustic challenges especially in the low-frequency domain (< 500 Hz) where the STL typically drops. The urgent need of lightweight-compliant sound abatement methods promotes the development of smart structures with active structural acoustic control (ASAC). The new sound transmission loss test facility makes it possible to determine the STL of passive and active structures with method precision conforming to the relevant ISO standards.

Characteristics and Functionality of the Test Facility

The sound transmission loss test facility consists of a reverberation chamber and an anechoic room. The rooms are connected by a test opening of 2.5 x 2.5 m^2 which can be used for the integration of flat or curved test structures such as aircraft panels. Additionally, both rooms can be used independently according to DIN EN ISO 3741/3745. The lower cut-off frequency is 100 Hz for both rooms. If necessary, the test opening can be closed by means of a highly sound absorbing double-panel construction with surfaces compliant to each room. The reverberation room is typically used as the sending room for STL measurements, providing a diffuse sound field excitation of the test object. Furthermore, it facilitates quick sound power measurements based on the temporal and spatial average sound pressure level (SPL). The anechoic room is typically used as the receiving room for STL measurements providing semi-free field conditions due to the sound-absorbing walls and ceiling. It moreover provides suitable conditions for sound intensity probe and microphone array measurements, allowing a determination of the sound intensity distribution on the structural surface. Given the need of a directional acoustic excitation of a structure for STL measurements, a sound source can alternatively be placed in the semi-anechoic room. In this case, the transmitted sound power has to be evaluated in the reverberation chamber.

Application for Future Research in Active Structural Acoustic Control

The activities of the Institute of Composite Structures and Adaptive Systems in the field of ASAC are focused on the development of smart lightweight structures with improved acoustic properties, especially in the challenging low-frequency domain. The new test facility will provide the experimental conditions necessary for the investigation and validation of numerically designed and optimized ASAC systems. A future research topic will be to investigate the transmission of sound through double-panel structures such as fuselage parts in order to derive more advanced actuator, sensor and signal processing schemes for ASAC.

> **M.Sc. Malte Misol**

Advanced Automated Fibre Placement (AFP) Technology

The project GroFi develops advanced production processes for large-area, highly integral parts of fibre composite materials by using automated fibre placement technologies. The aim is the development of a production platform of high productivity using both fibre tapes and tows. Due to a simultaneous fibre lay up with coordinated robots a productivity of 150 kg per hour will be possible. Hence, the robots provide a high flexibility for several tasks in the production process by an easy adaption of different tools. Three key factors will increase the productivity of the fibre placement:

- Increasing the placement speed and the number of placement units
- Improving the system dynamics
- Integrating quality control and assurance into the production process

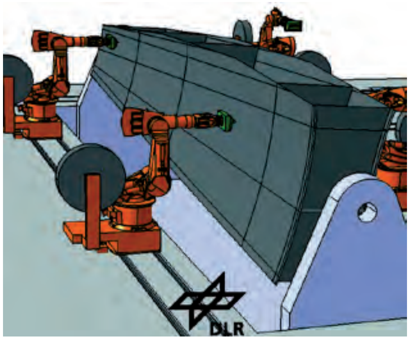


Fig. 1:
Using coordinated robots to produce large area parts.

Specialised Automatic Fibre Placement Heads

Besides the robot platforms, the technology used in the system includes a new generation of tow placement and tape laying heads. New online quality assurance techniques will also be integrated to minimise the time required for downstream, non-destructive testing processes or eliminate its need completely.

This highly flexible automated fibre placement system differs from today's technology by offering the following features:

- Coordinated, simultaneous deployment of several placement units
- Double-side lay up tools
- Integrating quality control and assurance into the production process
- Automating the vacuum evacuation and excavation

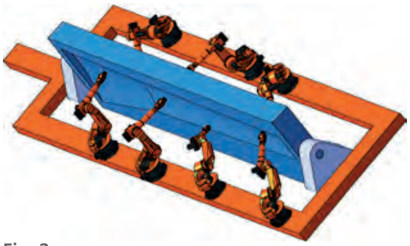


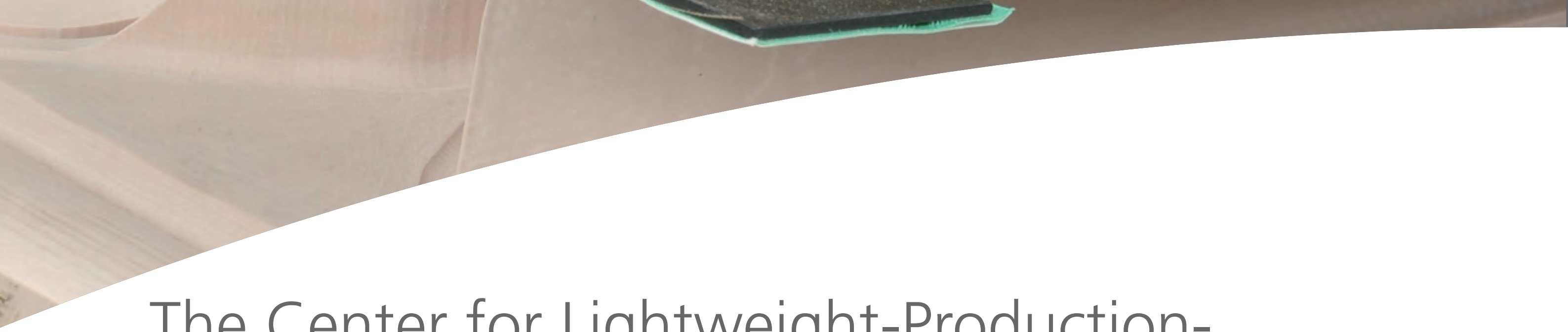
Fig. 2:
Increasing the productivity by performing a double-sided lay up.

High Flexibility, High Efficiency and High Precision

By using independent lay up units on movable platform the facility's flexibility will be increased in terms of the mix between AFP and ATP, a separate maintenance and several lay up heads. Due to that a high productivity will be guaranteed, since the specialised lay up techniques will be easily applied for different part shapes. The maximum lay up rate will be achieved by a continuous lay up, where the lay up units move unidirectional around the tool and provide a double-sided lay up. With a smart data and sensor management an interaction of the units make a high precision possible and production defects will be avoided.

Fig. 3:
Producing different part shapes using moveable platforms on the circular rail system.

> **Dipl.-Ing. Ivonne Bartsch (center left),**
Dipl.-Ing. Matthias Bock, (left)
Dipl.-Ing. Marcus Perner, (right)
Dipl.-Ing. Dirk Röstermundt (center right)



The Center for Lightweight-Production-Technology (ZLP)

The ZLP is a common approach of the Institute for Composite Structures and Adaptive systems and the Institute for Structures and Design with locations in Stade and Augsburg. Its concept was designed to cover the complete process chain for composite parts. ZLP is building upon the Institutes' research portfolio consisting of materials research, design, technology and assembly. With that, ZLP bridges the gap to the industrial application in terms of technology. Close cooperation with industry is key for a successful application. As an output, the technology in Stade has been identified by considering both the interests of industry and research. Such examples include a research autoclave with diameter of 5.8m and the fiber placement facility with a part-length of 20m. Hence, ZLP follows the interests of the manufacturing as well as the machining industry, which is carrying out its know-how for the research platforms. This acknowledges the aim for a quick use of research results within industry.

With the funding by the State of Lower Saxony, DLR has been given the opportunity to do research in the fields of:

- Robot-based Automated Fiber Placement
- High production rates in resin transfer molding technology
- Online Quality Assurance for autoclave processes
- Tooling technologies
- Process simulation

ZLP is integrated in the CFK-Nord complex along with its industry and research partners. The technologies are driven by a future application for fuselages, frames and wing covers. In Stade, DLR will develop three technology projects for robot based fiber placement, high production rates in resin transfer moldings technology and online quality assurance for autoclave processes. The projects are also used to build up the research platforms. Within the project for robot based fiber placement the production of large scale parts is conducted through the development of the AFP-facilities, as well as tooling technologies as described on the previous page 25. The project for online quality assured autoclave processes aims to minimize the process time inside an autoclave. The quality assured production inside the autoclave is based on fundamental process understanding including elements described on page 16. Within the project for high production rates in resin transfer molding technology the core process technology has to be created first. Short cycles, automated handling and material development are the focus of today's demand. The project answers the question on how to produce a high performance part 100.000 times a year. Therefore a multifunctional platform will simulate several methods of application in terms of a fully automated process and the full scale part. Thus, requirements from automotive and aeronautical industry are taken into account. The basis of the technology development is given by the resin-transfer-molding-process with its sub-processes. Within the project the whole process chain is taken into consideration to demonstrate the cooperation between the several sub-technologies.

As demonstrated by the three projects, ZLP in Stade provides the front end of the process chain, which is completed by the approach in Augsburg. To cover a complete process chain on an industrial scale will give a new perspective for applied science in composite technologies.

> **Prof. Dr. Martin Wiedemann (r), Dr.-Ing. Matthias Meyer (l)**

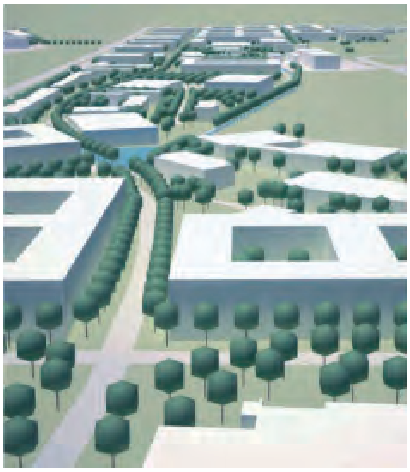
The Development of our Institute

Research results from adaptronics and from the area of transportation systems are enjoying increasing demand from industry, leading to an increase in research activities and scientists working in those fields.

The DLR in Braunschweig got the chance to enlarge its working facilities supported by a states program recovery program. Therefore we decided to jointly establish together with the Institute of Transportation Systems a new

Adaptronics and Transport Systems Centre

This building will create space for about 100 scientists coming partly from surrounding buildings and partly as new young engineers to work on their PhD thesis in adaptronics and transportation systems.



Together with new laboratories for lecture accompanying exercises and modern conference rooms the Adaptronics and Transportation Systems Centre – worth 9M€ - will be a further step in strengthening the cooperation with the Technical University of Braunschweig.

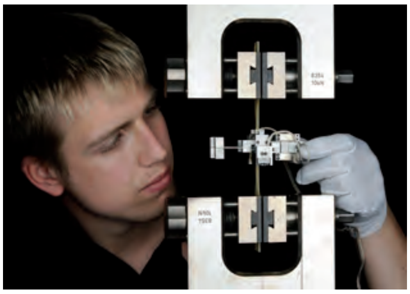
Furthermore we are engaged in the development of the joint organisation Campus Research Airport, where today 13 institutes from DLR, from the Technical University Braunschweig and Leibniz University Hannover are doing coordinated research. A renewal of the five years research strategy is just in development.

DLR and TU Braunschweig together have proposed a development plan for the area surrounding the airport in Braunschweig, where small and medium enterprises together with the research institutes and the university can form an unique combination of education, research and industrial application to find solutions for all the upcoming challenges in the field of sustainable mobility.

As already presented on page 26 of this innovation report, the institute of Composite Structures and Adaptive Systems has recently inaugurated a new research centre for composite structure production processes in Stade, where up to 40 scientists and technicians will work. Together with our customer centre in Bremen housed in the materials and process department of Airbus with today 3 scientists we are developing the institute towards a distributed organisation with offices close to cooperation partners. This is a real challenge for our organisation as we have to find new ways to ensure and maintain the intensive exchange and communication between our scientists.

But with our good, highly motivated and inventive scientists we have a strong foundation for implementation of all our new and future-oriented impulses. We hope that after reading this innovation report you share our vision and our confidence and we look forward to continuing to work with you in Braunschweig, Bremen, Stade, or any other place.

Multifunctional Materials



Mission

From materials to intelligent composites!

The department of Multifunctional Materials is doing research on the development, characterization and qualification of advanced fibre composite materials. New materials with superior properties are a prerequisite for technological innovations. Especially the integration of new functionalities is the key to further enhance the competitiveness and application range of composite materials. The collaborative research on composite materials within interdisciplinary and international teams is focused on the following areas:

- Integration of new functionalities
- Improvement of properties
- Advancement of processability
- Provision of reliable material data
- Qualification of new structural concepts

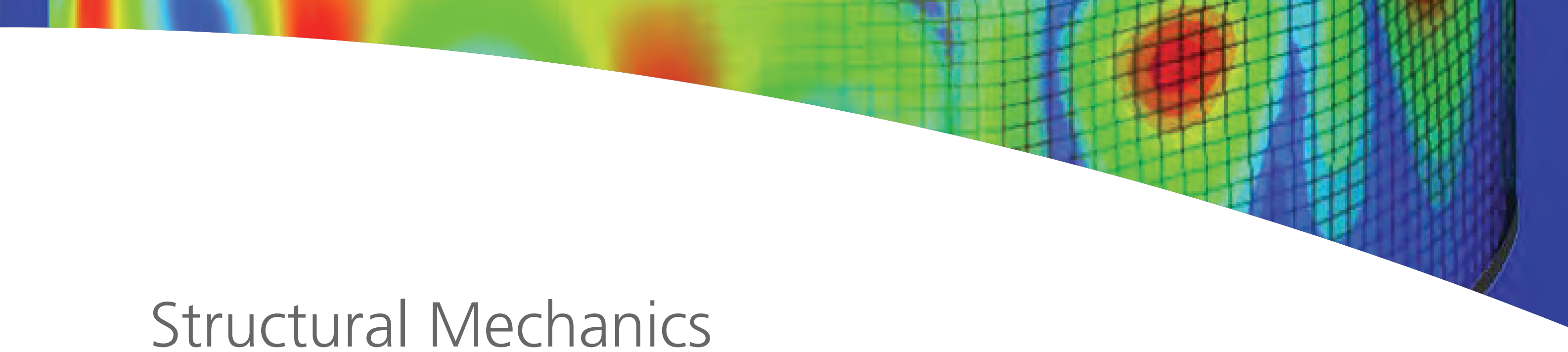
Based on our knowledge and experience in composite materials we explore new possibilities to enhance the properties and functionality of composites in many aspects. By adding nano-scaled particles the mechanical properties, processibility and fire resistance of composite materials are drastically enhanced. New bio-composite are developed and characterized to offer sustainable and environmentally friendly material solutions. Beyond that, new functional materials with sensing and actuation capabilities as components for adaptive structures are investigated. Sensor and actuator networks are embedded in materials to allow a continuous monitoring of fibre composite structures during production and operation.

Competences

The department of Multifunctional Materials operates facilities for static and dynamic testing of materials and structures. In combination with a well equipped thermo- analysis lab and a long experience in non destructive testing with ultrasound, new material systems from coupon level and beyond can be evaluated. Our competence profile comprises:

- Evaluation of new textile semi finished products
- Nano-technology in fibre composite materials (nano composites)
- Development and characterisation of bio composites
- Exploration of smart materials for adaptive structures
- Design and characterization of piezocomposites
- Development of structural health monitoring (SHM) systems
- Non destructive testing with ultrasound (NDT)
- Static and dynamic testing of materials and structures)
- Thermo-analysis and microscopy

> **Dr.-Ing. Peter Wierach**



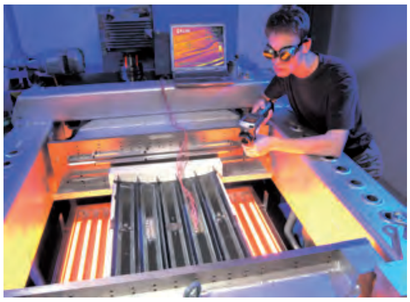
Structural Mechanics

Mission

From the phenomenon via modelling to simulation!

In order to fully exploit the high potentials of composite materials, efficient and qualified structural mechanical methods and tools are increasingly demanded. To cope with this we develop, verify and validate computational and experimental methods integrated in robust development processes from the preliminary design up to the detailed design phase. Within the scope of aerospace, aeronautical, automotive and railway transportation applications our focus is laid upon:

- Fast and accurate design, simulation methods and tools
- Virtual testing for the entire life cycle
- Innovative experimental methods and test facility concepts



Competences

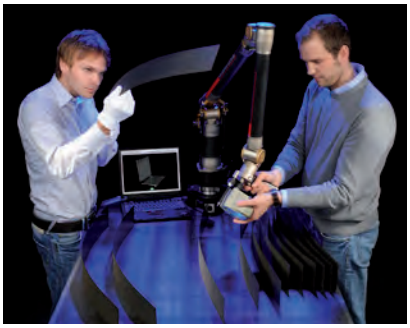
Supported by a highly qualified staff of scientific and technical employees, we bring structural mechanical methods and tools to application for our customers within concurrent/integrated engineering concepts in the following areas:

- Strength Analysis (e.g. 3D reinforced composites, extended 2D methods)
- Structural Stability (e.g. postbuckling, imperfection, dynamic buckling, robust design)
- Damage Tolerance (e.g. failure criteria, impact, residual strength, degradation)
- Effects of Defects (EoD) (e.g. fibre waviness and porosity)
- "As Build/ Manufactured"-analysis (e.g. AFP feedback loop to account for manufacturing deviations)
- Thermo-Mechanics (e.g. extended 2D methods, models for fibre metal laminates)
- Multi-Scale Analysis (e.g. global-local or submodelling concepts)
- Multidisciplinary Simulation (e.g. resin curing, spring-in, piezo-electric-thermal coupling)
- Tool-Integration (e.g. fast, seamless and robust tool-chains for structural analysis and life cycle assessment)
- Methods and tools for global aircraft analyis
- Test Facilities (e.g. strength, thermo-mechanics, structural stability)

An example is our contribution to the European large scale project MAAXIMUS (More Affordable Aircraft structure through eXtended, Integrated, and Mature nUmerical Sizing), where we hold the lead for the sub-project "Design" and give scientific contributions on the topics Effects of Defects (EoD), postbuckling and "As Build"-analysis of advanced fibre placement methods development.

> **Dr.-Ing. Alexander Kling**

Composite Design



Mission

Our design for your structures!

The department Composite Design offers a closed development chain from the first sketch of composite structures, their sizing up to a design for an efficient production:

- Preliminary design: Herein, design concepts, an adequate selection of materials, hybridisation, and further aspects specific to fibre composites are being addressed.
- Sizing: Design concepts are optimized and assessed by using low and high fidelity simulation tools, which also take into account probabilistically distributed material and manufacturing parameters.
- Detailed Design: In the end the detailed design is realized under consideration of tolerance management, quality assurance and appropriate tool concepts.

Particular emphasis is placed on the design of multi-functional structures, which contain additional features like electrical conductivity, acoustic noise absorption, information transmission etc. besides their required structural mechanical properties.

Competences

From requirements via concepts to multi-functional structures

The department Composite Design proves itself as a strong link between research and industrial application in the following topics:

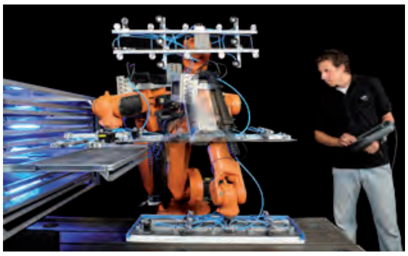
- Door surround structures in future aircraft
- Composite-driven design of airframe structures
- CFRP-metal hybrid structures in aerospace applications
- Design considering relevant manufacturing aspects, e.g. spring-in effects
- Tools and facilities for efficient and economic CFRP-production
- Deployable structures in ultra-lightweight space applications
- Design of multi-functional lightweight terrestrial vehicles

The closed development chain and the design of multi-functional structures are subject of continuous common research work with our partners.

> **Dr.-Ing. Christian Hühne**

Composite Technology

Mission



The experts for the composite process chain!

In To fully exploit the potential of lightweight composite structures it is necessary to have a detailed understanding of all physical and chemical parameters that have an impact on the final component quality. Most of these parameters have to be adjusted during the manufacturing procedure which means that there is a high potential for process optimisation. On the other hand there is a significant risk because inaccurate process parameters will inevitably lead to inacceptable results. To solve this problem our approach is to directly control all crucial production parameters in a way that the outcome of the production process is highly reproducible on the highest possible level. In order to do this different sensors and adequate control strategies for geometrical parameters like e.g. local fibre volume fractions and for structural parameters like e.g. residual stresses are under development to realise smart and mature manufacturing concepts.

Competences

- Development of quality assured process chains for specific production scenarios
- Development of production optimised mould concepts
- Development of production optimised manufacturing equipment
- Manufacturing of demonstrators and test components
- Evaluation of innovative fibre and matrix products under processing conditions
- Realisation of highly integrated multi-functional components
- Cost analyses and trouble shooting for production processes

Even though creating composite components simply means to embed load bearing fibres in a polymer matrix the variety of technical approaches is nearly as multifarious as the field of applications itself. Within the last 30 years all baseline manufacturing processes like filament winding, prepreg lay-up, Liquid Resin Infusion and RTM processing have been considered and further developed in order to meet the demands of the various research and development projects .

To ensure the highest possible productivity in terms of cycle times and reproducibility at acceptable costs the actual focus is on the utilisation of industrial automation equipment for composite manufacturing strategies.

> **Dr.-Ing. Markus Kleineberg**

Adaptronics

Mission

The adaptronics pionieers in Europe!

Since 1989 the department of Adaptronics works as one of the first European research groups on solutions in the field of smart-structures technology. With their experience adaptive systems comprising structural material, distributed actuators and sensors, control strategies and power conditioning electronics across all lines of business can be realised. Applications range from space systems to fixed-wing and rotary-wing aircraft, automotive, optical systems, machine tools, medical systems and infrastructure.

An adaptive system has the capability to respond to changing environmental and operational conditions (such as vibrations and shape change). Microprocessors analyse the responses of the sensors and use integrated control algorithms to command the actuators to apply localized strains/displacements/damping to alter the elasto-mechanical system response.

Within national and international interdisciplinary teams the department of Adaptronics focusses the research on the following areas:

- active attenuation of vibrations (e.g. for parallel robots, antennas)
- active structural acoustic control (e.g. for CFRP fuselages, magnetic resonance tomography)
- morphing structures (e.g. for high lift devices, rotor blades)
- Stand-alone systems (e.g. energy harvesting, shunted systems)

Competences

The department of Adatronics offers its competences to customers and project partners starting from consulting and system analysis up to the design of adaptive systems:

- Experimental methods for structural dynamical and vibro-acoustical system analysis
- Experimental deformation analysis of large structures
- Development of actuator and sensor systems
- Modelling and numerical simulation of complex adaptive systems
- Controller development and implementation
- System integration and validation
- Demonstration of adaptive systems and their components

> **Dr.-Ing. Hans Peter Monner**

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Imprint

Published by **Deutsches Zentrum
für Luft- und Raumfahrt** e.V.

German Aerospace Center

Institute of Composite Structures and Adaptive Systems

Titel Subject Innovation topics of the Institute
of Composite Structures and Adaptive Systems

Adress Lilienthalplatz 7
D-38108 Braunschweig
Tel. +49 531 295 2300

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Printed by Druckerei Thierbach
D-45478 Mühlheim an der Ruhr

on September 2010

www.DLR.de

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