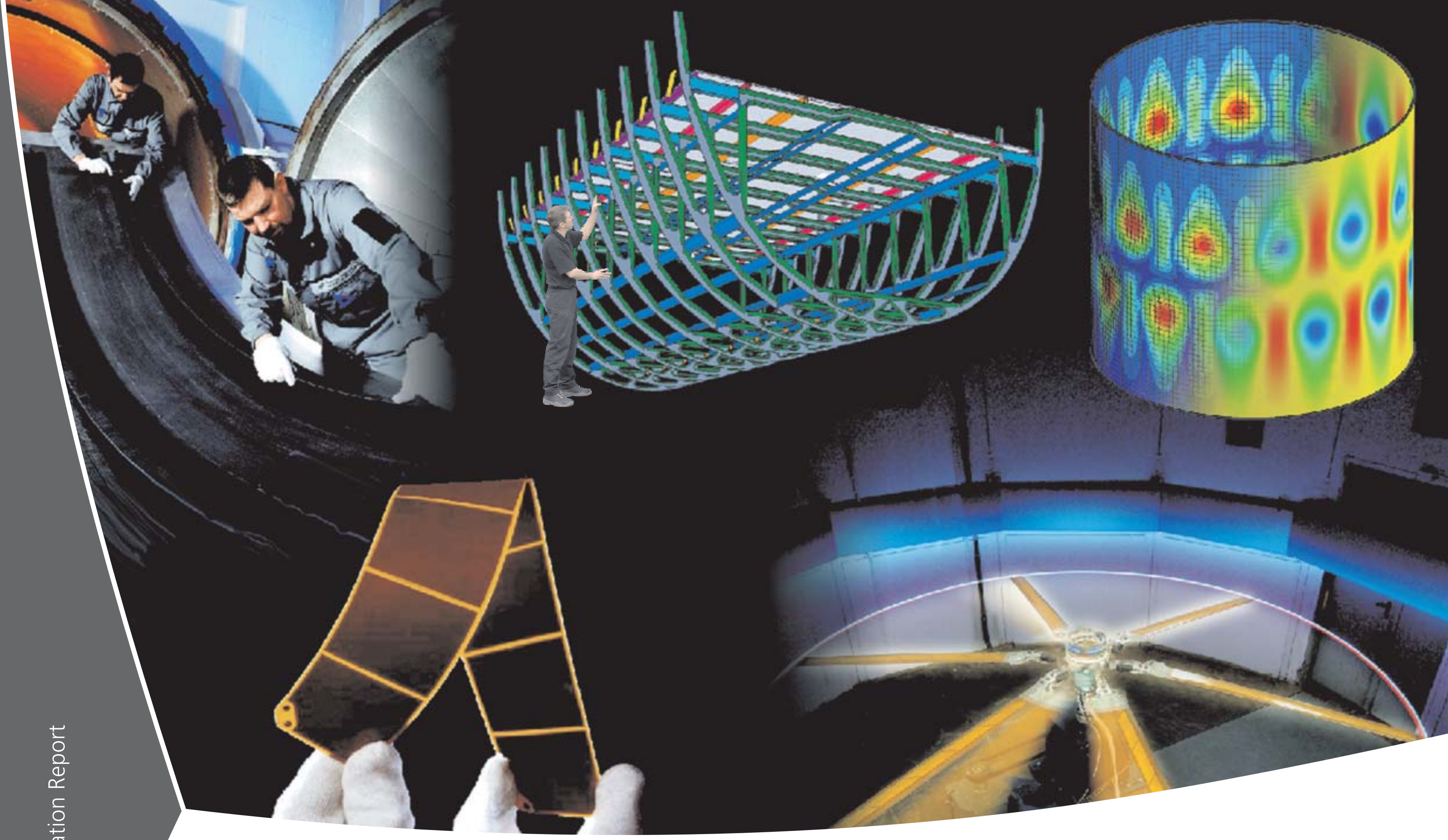


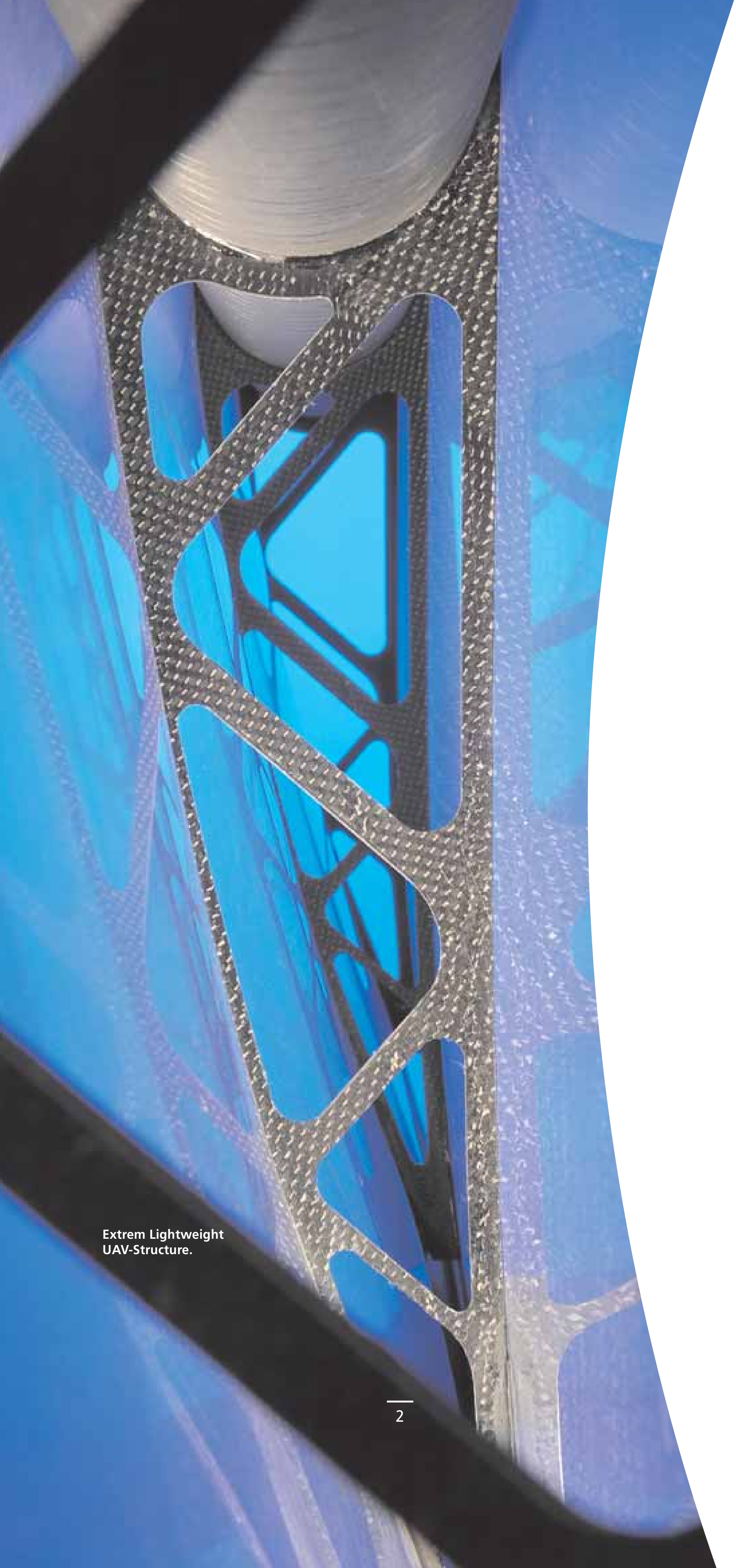
Innovation Report

Innovation Report 2009

Institute of
Composite Structures and
Adaptive Systems

DLR

Contents



Extrem Lightweight UAV-Structure.

Preface

Why has your Institute such a long name? Sometimes we percieve this question when introducing our Institute. However, those working with us understand, the institute name is our scientific conviction: Composite Structures and Adaptive Systems belong together. The economic success of lightweight structures made from carbon composite will become only possible by the functional integration. The cost-intensive production process of carbon fibre reinforced structures can be justified in most cases when the creation of added value takes place, which goes beyond the production of the pure structural component. And thus we have strictly straightened our process chain in the research on the functional integration in the carbon composite structures.

On account of our growth we have restructured the Institute accordingly. Now five departments are working together forming the whole process chain from multifunctional material research to sizing methods and design of multifunctional structures, research in faster and cheaper manufacturing methods and finally to the Adaptronics, which complete the multifunctional system. You will find the profiles of the five research departments at the end of the report emphasizing their competencies.

The next big challenge will be to establish the research on production technologies in industrial scale. We are preparing large research centres in the north and south of Germany (Stade and Augsburg).

Besides the more differentiated and broadened research organisation we have established technical areas addressing main application fields of our research where we have developed most of our solutions for. The reseach field leaders especially coordinate large research projects. A survey on these reseach fields is given on the following pages. You will find there the colleagues responsible for the five research fields.

The Science Day 2009 is devoted to the function integration in lightweight structures for ground transportation applications, a topic, where many changes are expected in the coming years and where new solutions for sustainable growth are required. Producing lightweight structures in a cost-efficient way requires the combination of carbon composite capabilities and adaptive systems. Some examples of potential contributions to new concepts and further improvements in car and railway design are given in this report.

With this fifth Innovation Report we would like to give to our esteemed partners and potential customers a view to the ongoing work of our Institute . We have consciously not focused on special aspects, but show the variety of research that elucidates the width and complexity of the development field of Composite Structures and Adaptive Systems.

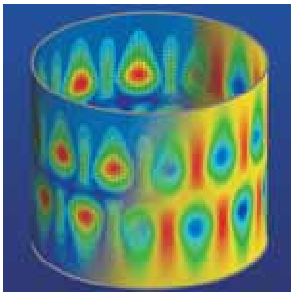
We wish you an inspiring reading of this fifth Innovation Report. With special thanks to all the authors and those who have helped to prepare this report.

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 Research Fields

The departments of a research institute are commonly dedicated to a certain scientific discipline, such as to numerical analysis or to material sciences. However, research as it is practised in the Institute of Composite Structures and Adaptive Systems comprises a lot of projects which are so thematically widespread and interdisciplinary that they cannot be adequately covered by a single department alone. If such projects reach a certain size in terms of manpower, project duration and strategic importance, it makes sense to comprehensively coordinate them from a position bridging the departments involved. The Institute has identified five fields of research for which this situation is particularly true, and appointed a research field leader for each of them. These five research field leaders supervise all projects within their focus in close cooperation with the heads of the participating departments.

CFRP Fuselage

comprises concepts for future aircraft fuselages, mainly based on carbon fibre composites. Special emphasis is placed upon the detailed design of large cut-outs, i.e. for the passenger and cargo doors. The major challenge is to reduce the weight of the primary fuselage structure at same or better safety as the predecessor but at lower costs. Different improved materials, designs and manufacturing processes will be developed, analysed, simulated and tested. The DLR project "CFRP Fuselage Next Generation" brings together all research topics. One demonstrator which is in production now will demonstrate improved impact resistance, integrated fire safety, new 3D stringers, and integral high performance hybrid Steel-CFRP connections. Technologies especially developed for high production rates at low recurring costs like inductive preforming and microwave resin heating will be enhanced. Experts from all Institute departments and partner institutes are working closely together to achieve a safer, more comfortable and highly efficient aircraft.

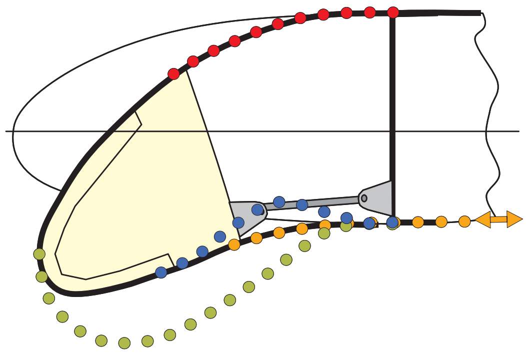
> **Your contact: Dipl.-Ing. T. Ströhlein**

Special Structures

are mainly related to advanced military aircraft applications. The work is especially focussed on unmanned aerial vehicles (UAV), high-flying reconnaissance platforms and other special civil applications. The main objectives of this research field are to provide the technologies, methodologies and materials needed to develop composite structures under the premises of affordability and specialised functionalities. Major areas of interest are antennas integrated in the composite structure, stealth structures which minimize the reflection of radar waves, and the radome design for combat aircraft. The military background of customer requirements, regulations etc. was the main rationale to comprise these projects in a dedicated focus. Special Structures research field dedicates its resources into three areas: "Affordable Fibre Reinforced Plastics", "Multifunctional Structures", and "Structural Design and Simulation Processes". The first area addresses the low cost production, manufacturing and maintenance of fibre reinforced UAV structures. The second area investigates fibre reinforced structures with special electromagnetic requirements e.g. electromagnetic transparency, -absorption or -emission. The third area is dedicated to the virtual development of primary UAV structures.

> **Your contact: Dipl.-Ing. M. Hanke**

High-Lift



is the keyword for technologies dealing with future aircraft providing the required lift at low flight velocities as well as allowing for novel wing designs. Prominent technology examples are the gapless smart droop nose and the adaptive slat for wing leading edge applications as well as various innovative trailing edge devices. Along with structure-system integration aspects of active flow control applications and additional structural wing components for laminar wing technology, the research activities support aircraft manufacturers in their endeavour to substantiate the challenging goals for novel aircraft with improved environmental compatibility (reduction of drag, emissions, and noise). The activities in the High-Lift research field are not just concentrated on the wings leading and trailing edge, but closely involved in developments of future wings. All High-Lift projects are greatly multi-disciplinary such that the Institute's entire scientific expertise is required.

> **Your contact: Dr. O. Heintze**

Space Technologies

are also a "class of its own", and somewhat different from the aeronautical applications. A strong orientation towards ESA, the framework of ECSS standards, and specific technologies make it senseful to deal with the larger space projects of the Institute by means of a coordinating function across the competences of the departments. A primary theme are lander structures for the exploration of the solar system, both for soft landings on comets and asteroids (such as for the Rosetta Lander "Philae") and for semi-hard landings on the Lunar or Martian surface. Another large area of work are so-called gossamer structures, i.e. large ultralight structures which can be stowed in a very small volume during launch and then be deployed or inflated in space to achieve their final size and contour. Future applications will be large antennas, reflectors, or solar sails. The third important topic are hybrid material techniques for the application in next-generation launchers, for instance, for the future version of the Ariane 5 upper stage.

> **Your contact: Prof. Dr. Block**

Transport

has its focus on projects dealing with terrestrial vehicles. Although many technical developments, in particular with respect to lightweight and damage-tolerant structures, can be transferred from aeronautical research, the traffic-related aspects are still so specific that these projects can be more efficiently coordinated within an own focal field of research. Within this research field the Institute of Composite Structures and Adaptive Systems significantly contributes to the subject road vehicles, e.g. novel vehicle structures, and to rail vehicles, e.g. the Next Generation Train project. The main challenge in the transport research area is achieving sustainable mobility balanced between economy, society and ecology, ensuring the mobility of people and goods, protecting the environment and resources, and improving safety. The transport research field is characterised by a systematic approach aiming at concrete prospects for application by using multiple synergies, and by a strategic cooperation with partners from science and commerce.

> **Your contact: Dipl.-Ing. J. Nickel**

Door Surround Structures for Next Generation of CFRP Aircraft Fuselages

Fig. 1:
Typical Scuff Plate - A320.

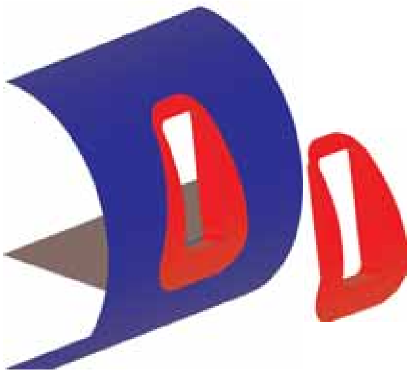


Fig. 2:
Sacrificial Protection Shield with Plug-and-Play Repair Part.

Fig. 3:
Super-Panel:
Integral Hybrid Concept.

Challenges for CFRP Fuselages

For performance reasons, the next generation of airliners will feature a CFRP fuselage. This change of material has a great influence on the design of the overall aircraft. For example, changes are necessary for functional structures like the doors and door surroundings, as the behaviour of the new material is very different to metal.

The most important requirement for these structures is the so called "equivalent safety". This means, that each new aircraft must be as safe as the predecessor. As the composite material has no plasticity, this is a big challenge. Not only the former design allowables and test results must be taken into account, but also real damage and crash scenarios.

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Plug and Play Repair for Crash Elements

The most impact-endangered zones are the areas around the doors. Impacts happen by attaching the passenger bridge for boarding or cargo loading. State-of-the-art airliners feature quickly replaceable scuff plates below the doors (Figure 1). The analysis of repair statistics showed, that also in the area above the scuff plate, impacts are common due to passenger baggage and kitchen trolleys.

For ensuring the safety of the CFRP door surround structure, in one of the first concepts, the load carrying skin and frames are rerouted to the inside, giving space for an additional ultra lightweight sandwich impact absorber structure (Figure 2, red element). This 3D geometry, which is only possible with CFRP material, is self stabilising so that less stiff frames are needed. In case of damage, it can easily be replaced in a few minutes.

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Super-Panel with 100% Integration

The mentioned concept above is highly optimised in respect to in-service costs, but needs further production cost reduction. In order to reduce this, further refinement is necessary. A production analysis of all available CFRP processes and designs showed that instead of a single process a combination of several technologies would lead to a global optimum. Additionally, the assembly of differential parts would increase the costs and also the weight of the structure. For production of the simplified skin, the automated fibre-placement (AFP) prepreg technology offers a very high degree of automation, best performance and high stability at the same time. For the complex doorframes, the advanced draping textile technology offers best performance and highest layup speed.

To achieve the highest benefit of each technology, the DLR has combined the prepreg with the textile technology in one integral one-shot part. To demonstrate the usability, a full-scale demonstrator has been developed and manufactured. Comprehensive tests, analysis and optimisation of the interface zone between the prepreg and the resin for the textile fabrics have been performed to further validate the concept.

Flexible Up-Side-Down Mould Design

For many industries, e.g. automotive industry, the concurrent engineering as well as the computer aided manufacturing (CAM) is already state of the art. In the aviation industry the demand for faster development time and ramp up time forces this development in nowadays as well.

The major problem in CFRP concurrent engineering is, that the structure analysis is highly time consuming, while the results are necessary for a detailed design as well as for manufacturing design. To overcome this, the DLR has developed new concepts for door surround structures, where the analysis as well as detailed and mould design can proceed mostly in parallel. This requires good knowledge of the global design: Areas, which are common for late design changes must firstly be identified and defined. For the door surround structure these are e.g. the skin reinforcements. All other interfaces and reference surfaces can be fixed in an early stage.

The logical result of that assumption is, that the door surround structure as well as the moulds should be designed up-side-down (Figure 4). The new reference surfaces are therefore the inner frame straps as well as the frame web. Therefore, a male mould is used instead of the common female mould. Now, the whole integral door surround geometry can be designed independently while parameterising only the skin interface. In case of a later change of the skin thickness or geometry, only the relatively cheap caul plate must be adapted.

Tolerance Adapted Design

The next milestone to achieve a global cost optimised door surround structure is, to consider all possible uncertainties of the used manufacturing processes. In the shown example, the integral surround structure can be manufactured highly precise, as all functional surfaces will be formed by massive mould parts. The thickness scattering is compensated by flexible- or semi-flexible moulds. For example, in the regions where many layers have run outs, thin flexible silicone caps are used to normalise the thickness scattering (Figure 5).

For solving the tolerance problem at the interface to the skin, a compromise of integral and differential design gives the best overall solution: Most of the main frame, secondary frame, intercostals, sill part and longitudinal beam can be manufactured in a one shot solution (Figure 6), while simple L-profile connectors will be manufactured and assembled separately. For the integral part a thermo-set resin with good impact resistance has been chosen, while for the connectors a thermoplastic PEEK resin gives not only good impact resistance but also the flexibility of hot forming.

> **Dipl.-Ing. Tobias Ströhlein**

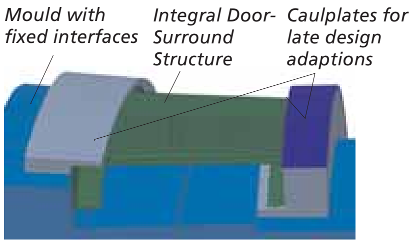


Fig. 4:
Up-side-Down Mould Concept (Shown without cores).

Fig. 5:
Core Conept, with flexible silicone caps to fill highly complex area with undercuts.

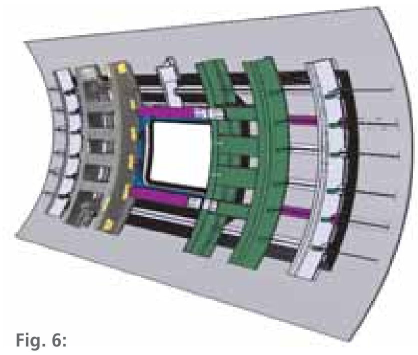


Fig. 6:
Demonstratortestpanel of Door Surround Strucuture: CAD image with built integral structure.

Failure Prediction of Skin-Stiffener Junctions

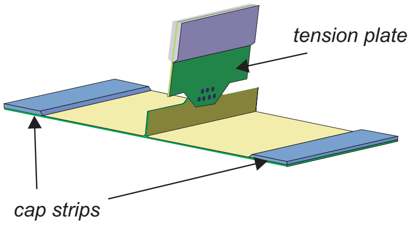


Fig. 1:
T-Pull test specimen of skin-stiffener junction.

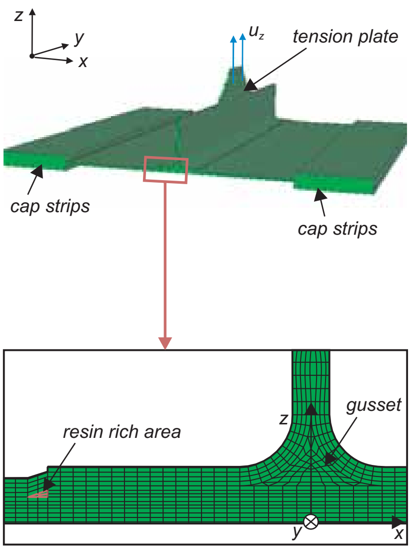


Fig. 2:
FE model of skin-stiffener junction.

High Performance versus Complex Failure Modes

The usage of composite materials within civil aircrafts provides many advantages, such as weight reduction and an excellent strength to density ratio. Challenges arise due to sizing difficulties, because of the complex failure types of composites. Skin-stringer separation is one failure scenario, which can appear within composite structures when reaching sizing limits. The aim of the project Eurocopter Germany is the investigation of several skin-stiffener junctions, which are part of a CFRP door structure. Thereby critical out-of-plane stresses and strains have to be identified and simulated.

Sizing Methods need Test Calibration

During flight the cabin is pressurized, leading to tensile stresses between the stiffener foot and the skin. One sizing criteria is to avoid skin-stringer separation under these special loading conditions. In order to achieve a preliminary design, which will fulfill the requirements, Eurocopter Germany conducted tensile tests of T-Pull test specimen (Figure 1). Several representative skin-stiffener junctions were tested. The specimens were clamped at each side and loaded with predefined displacements u_z=2mm for limit load and u_z=4mm for ultimate load corresponding to limit – and ultimate load. Afterwards the displacement was increased until final failure.

During the tests, strains at several critical points were measured and afterwards used for a cross-correlation of a numerical model. A model generator, based on the software MATLAB, has been developed by DLR in order to create a FE model of each test specimen (Figure 2). All model parameters, such as ply dimensions and material properties can be adjusted individually. For the sake of simplicity primarily only a slice with a width of 1mm is modelled and all displacements in the direction of the stiffener are restrained. Using the results of the ABAQUS simulations, critical stresses and strains are calculated and localized. Besides the criterion that the critical strains shall not exceed the allowable strain, two other design criteria are checked; Puck for matrix failure and Yamada-Sun for fibre failure. Hereby the maximum stresses within the plies are used to calculate the respective reserve factor.

Improved Sizing Method validated

The FE simulations and the experiments reveal, that the analysed structure is able to withstand higher loads than previously predicted with older sizing methods. For higher tensile loads delaminations initiate at the gusset, where the highest out-of-plane stresses and strains occur. This was successfully predicted by the simulations and proven by the experiments. The comparison of the measured strains and the computed values showed a good correlation. This indicates that the test specimens are well represented by the generated FE model and that it is adequate to model only one slice of the respective structure. Summarizing, it can be stated that the developed method, utilizing ABAQUS in conjunction with the created MATLAB mesh generator, provide an efficient approach to model and simulate different skin-stiffener junctions under tensile loading.

> **Dipl.-Ing. Tanja Führer**

Visual Inspection of Composite Structures

An aircraft must remain airworthy despite the possibility of containing subcritical cracks and flaws. Accordingly, continued airworthiness of damage tolerant aircraft strongly depends upon the implementation of inspection programs capable of detecting cracks and flaws prior to reaching their critical size. Over 80 percent of inspections are visual. Visual inspection, then, is the first line of defence for safety-related failures on aircraft and provides the least expensive and fastest method of assessing the condition of an aircraft and its parts. As the use of composite materials in transport aircraft is rapidly expanding, inspection practices for composites need to be standardized. Composites require unique considerations and procedures.

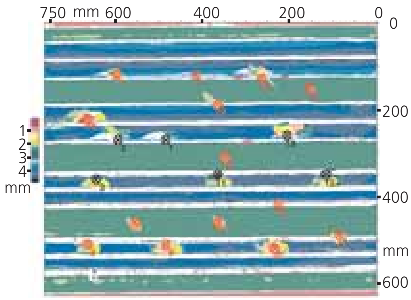


Fig. 1:
Ultrasonic scan of panel 2, visualizing the internal damage of twenty impact locations.

Visual inspection is fast and cheap

The European Aviation Safety Agency (EASA) funded a study on the visual inspection of composite structures relevant for transport airplanes. Composite damage metrics and environment variables that influence damage detection are of special interest, such as colour, finish, lighting conditions, surface cleanliness, and the angle at which the inspection is conducted relative to the surface. The intent was to investigate the basic detectability of damages in composite structures as they may be caused by ground vehicles, tool drop or runway debris. Twenty nominally equal impact damages were introduced into two nominally equal structures (Figure 1). Both structures were exposed to different inspection conditions, thus enabling the determination of influences of single inspection parameters on detectability of damages. Inspection results of ten visual inspections with a total of 112 inspectors were recorded (Figure 2).

Fig. 2:
Visual inspection by DLR personnel.

Influence of inspection conditions

While impacts from small diameter impactors cause a visible dent, which is not difficult to detect by careful visual inspection, the flat, spread out dents from blunt impactors are easily overlooked. Comparing the internal damage of large (blunt) and small diameter impactors as it was detected by ultrasonic scanning, the damage areas caused by the blunt impacts were in the same category as the damage areas caused by 1-inch diameter impactors of the same energy.

The visual inspections showed that variation of a single inspection parameter such as cleanliness, inspection angle and colour / finish combination did not have a large effect on inspection results. Illumination is the parameter with the greatest effect on damage detectability. By evaluating questionnaires filled out by each inspector it was also possible to investigate the influence of certain person-related parameters such as visual capability, age, gender and professional qualification on inspection results. Surprisingly, visual capability did not have a large influence on the performance of an inspector. Professional qualification is an important influence factor, as is the inspector's age.

Fig. 3:
Visual inspection by professional maintenance personnel from Lufthansa Technik.

Illumination is a key for visual inspection

At the end of the study, professional maintenance personnel from Lufthansa Technik demonstrated the effectiveness of visual inspection in combination with the tap test by detecting even smallest damages (Figure 3).

> **Dr.-Ing. Jens Baaran**

Virtual Sensors for Structure Health Monitoring

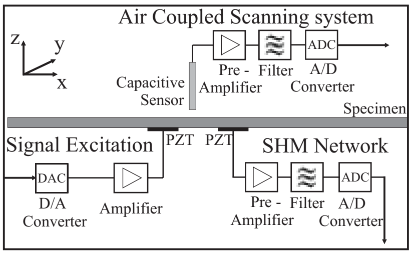


Fig. 1:
System Components for Data Recording.

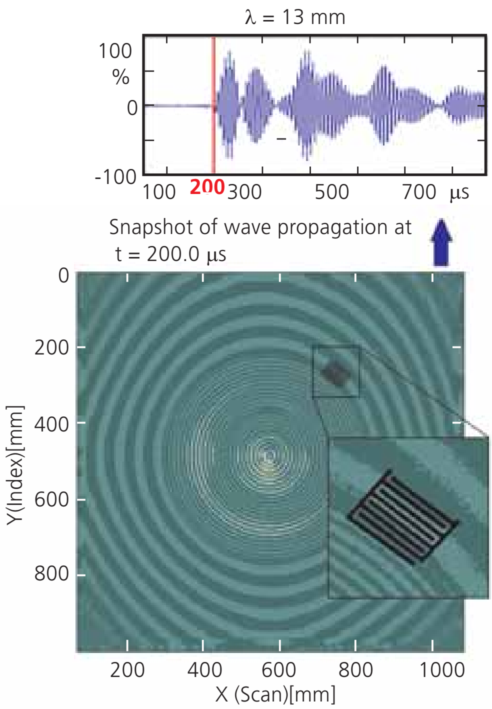


Fig. 2:
Lamb wave propagation in an Aluminium plate with a virtual sensor used for mode separation and the calculated response.

Guided Waves for Health Monitoring

Guided Waves (such as Lamb waves) in principle allow large-area testing of complex composite components in assembled condition. Glued PZT's are typically used for signal excitation and receiving. The waves propagate in the structure and react in case of discontinuities like impacts with reflections respectively mode conversions. The challenge is the signal evaluation due to several influences like dispersion, reflections, or anisotropic materia. Therefore the design of an optimal sensor network for a SHM system for complex structures is a requirement including sensor shape and location.

The development of a suitable design method of the sensor network can either be experimentally or being based on the evaluation of virtual sensor signals taken from ultrasonic propagation data. The latter are derived from a combination of an excitation through piezoelectric patchactuators with scanning of the structural surface with an air coupled ultra-sonic sensor. A schematic scetch of both testing circuits is shown in Figure 1. The recorded 3D file of a 1x1m² large laminate with a scanning grid of 2 x 2 mm delivers A-scans of 250.000 measuring points with a dynamic range up to 80 dB (file-sizes about 12 GBytes). "Classic" images like B-, C-, and D-scans as well as video animations of the wave propagation can be calculated.

Signal Processing for Sensor Design

The 3-dimensional data are analysed in order to derive the anticipated time response of a virtually designed sensor. Established methods for visualization are combined with new algorithms for signal processing. The implementation of additional analysis methods allows a systematic evaluation of particular peculiarities of the excited signal, like automatic mode separation or referencing of local interactions with discontinuities. The algorithms deliver satisfactory results even at very complex components. The main focus of the software is the virtual development and evaluation of sensors for SHM networks. A combination of propagation measurements out of 3D data files with an adjustment of different scanning techniques allows the calculation of different sensor layouts and their assumed signals at any position. The signal of the designed sensors can be calculated before bonding a real sensor to the structure. This allows an optimization of the test signals, the sensors themselves in layout and position, and data processing for damage detection with higher time- and cost efficiency. Out of this comprehension a demand-oriented construction of SHM systems can be accomplished.

Virtual sensors can be defined with a Graphical User Interface of the analysis software. After placing the virtual sensor at a position within a propagation snapshot, the software calculates the anticipated signal of an equivalent sensor by analysing the volume data file. Arbitrary sensor layouts can be simulated. The software considers different coupling techniques and sensor layouts. Figure 2 shows an example for simulated sensor with an interdigital transducer layout for mode separation, based on wavelength selection. A circular PZT with a radius of 10 mm is bonded onto the centre of a 1x1 m² Aluminium plate and works as actuator at 120 kHz. The excited Lamb wave modes propagate with wavelengths of 49 mm and 13 mm in the plate. The snapshot of wave propagation is taken from a 3D data file. The virtual sensor with a width of 60 mm is adjusted to a wavelength of 13 mm. The calculated signal shows a high sensitivity for the aligned wave mode at the time of arriving at the sensor position.

> **Dipl.-Ing. Artur Szewieczek**

Evaluation Standard for Quality and Processability of Dry Carbon Textiles

The use of dry carbon fiber non-crimp fabrics (NCF) for the production of composite structures can provide cost advantages,as well as the realization of complex 3D-curved shapes or increasingly integral design. However, the processing behaviour of NCF in complex part manufacturing as well as their mechanical properties can exhibit significant differences. While certain laminate characteristics have been found in previous works to be the most critical in defining the mechanical properties, two questions arise: What features of the dry textile are responsible for these laminate structures and how can they be quantified? Similarly, what are the textile characteristics defining the manufacturing processability and how can they be evaluated?

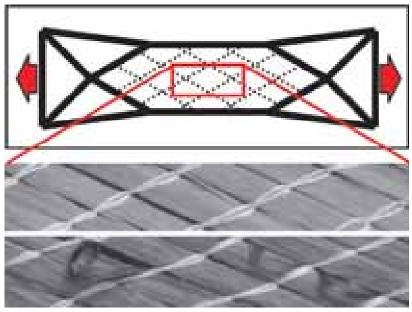


Fig. 1:
Bias extension test schematic, examples for effects of shear deformation on quality of different NCF textiles.

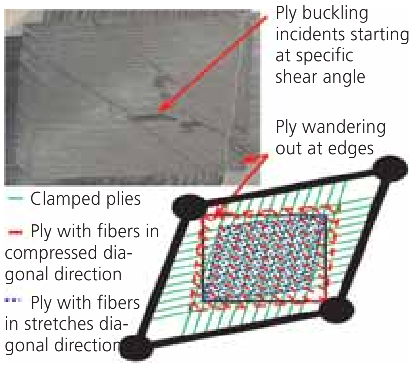


Fig. 2:
Shematic of large area picture frame test with quadraxial NCF and two free moving plies.

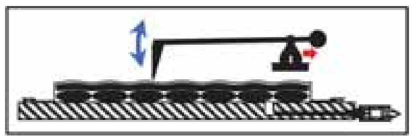


Fig. 3:
Schematic of dry textile waviness measurement.

A new assessment methodology

To make a quick assessment of NCFs possible, a system of characterization methods has been established to obtain comparable results for both processability and material quality aspects.

In terms of processability a focus is laid on drape behaviour, i.e. the ability of the textile to being formed to complex double curved surfaces, and on compaction / preforming characteristics. Two methods are applied for drape testing. First, bias extension tests have been established mainly for biaxial NCF by means of a new evaluation method based on digital image analysis that allows also to analyse degradation of material quality over the deformation process (Fig.1). Second, an approach for deriving parameters for the material deformability has been developed based on an approximation function to the force-shear angle progression. Special picture frame shear tests have been developed for tri- and quadraxial NCF, with a novel specimen geometry to allow clamping of specific plies while other plies have the ability to move freely (Fig.2). In combination with a large test area of up to 420mm edge length, it is possible to investigate the size-dependency of certain fibre buckling mechanisms in plies compressed during the deformation process. This enables the comparison of different materials. The so-called bulk factor has been introduced to characterize the thickness compaction and preforming properties during different process steps. The factor is defined by actual textile thickness divided by the nominal cured ply thickness. Together with a defined set-up the method is ready for standardization.

Material quality is broken down into three aspects. First and second the standard deviations of fiber orientation in plane and out of plane caused by ply waviness (Fig.3) is characterised. Third, the geometries of the pattern of knitting induced distortions characterized by their length, width, distance in- and vertical to the fibre direction are essential parameters. The focus is on developing methods to determine all these values from the dry textile without the need for coupon manufacturing. Comparative studies have been conducted in order to investigate the relation between dry textile characteristics and cured laminate. Finally, the influence of the three textile quality aspects on the laminate compression properties can be assessed via different existing finite element calculation models. This assessment methodology allows the testing of various materials differing in textile technology, knitting pattern, areal weight, spreading methods etc.. Moreover, an increased understanding of the relevant parameters is gained on the material behaviour and properties enabling a more focused and quick optimisation as well as quality assurance.

> **Dipl.-Ing. Julian Kuntz (Photo), Prof. Dr.-Ing. Michael Sinapius**

How Do the Matrix Properties Influence the Impact Tolerance of NCF-Composites?

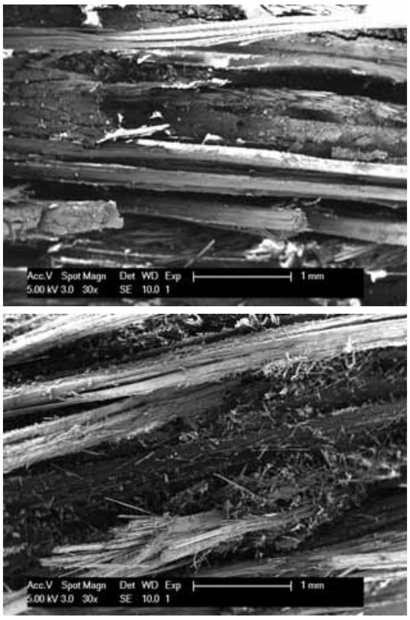


Fig. 1: Micrographs of good (upper) and insufficient (lower) fibre-resin system adhesion.

Non-crimp fabric (NCF) is the preferred type of dry reinforcement, laying down larger areal weight (quantity) of carbon fibre than unidirectional prepreg tape (UDPT) and demonstrating better in-plane mechanical properties than woven fabric. Nevertheless, the main drawback of NCF and liquid resin systems versus unidirectional prepreg tape is their poor tolerance to low velocity impact (compression strength after impact (CSAI) for the same indentation depth). A comprehensive study revealed the influence of the matrix properties (resin system and interlaminar toughening) on the impact tolerance of quasi-isotropic laminate manufactured with biaxial non-crimp fabric.

The study demonstrates, that for current aerospace qualified materials the CSAI of biaxial NCF with liquid resin systems is about 40% lower than unidirectional prepreg tape at 0.5 mm indentation depth. Moreover, the impact tolerance of NCF impregnated with the same resin film used for UDPT is still about 25% lower than UDPT. The resin system was identified causing about 15% of the drawback. In consequence, seven different aerospace qualifiable liquid resin systems and two interlaminar toughening concepts were studied to improve the impact tolerance of NCF-laminate. The neat resin system properties were characterised using flexural and fracture toughness tests. The presence of additives and in some cases the variation of the curing agent can double the neat fracture toughness of epoxy systems. Epoxy resin systems formulated with different components (epoxy resin, curing agent) also allow larger failure strain and strength to be achieved. The benzoxazine system considered shows a stiffer and more brittle behaviour than epoxy systems. The experimental results on laminate demonstrate that an increase in neat fracture toughness does not guarantee an improvement in damage resistance and tolerance. The stress-strain behaviour (modulus, strength and strain) also needs to be considered to determine if the neat resin properties would translate into the laminate properties. None of the considered resin systems originally developed to improve the impact properties of carbon fibre dry reinforcement increases the impact tolerance of the NCF-laminate. For one resin system, very poor damage resistance was observed due to the low fibre-resin system adhesion. The micrographs on Figure 1 show the difference between a good and low fibre-resin system adhesion. The use of a similar fibre but with another surface treatment allows recovering this insufficient adhesion.

In fact, the impact tolerance of UDPT can only be achieved by reducing the most critical impact failure mechanism: delamination. One way to limit this failure is to introduce an interlaminar toughening material in form of a veil, which is placed between each fibrous layer. This material allows retarding delamination creation and limits their propagation as well.

> **Dipl.-Ing. Anatole Gilliot (photo), Prof.Dr.-Ing. Michael Sinapius**

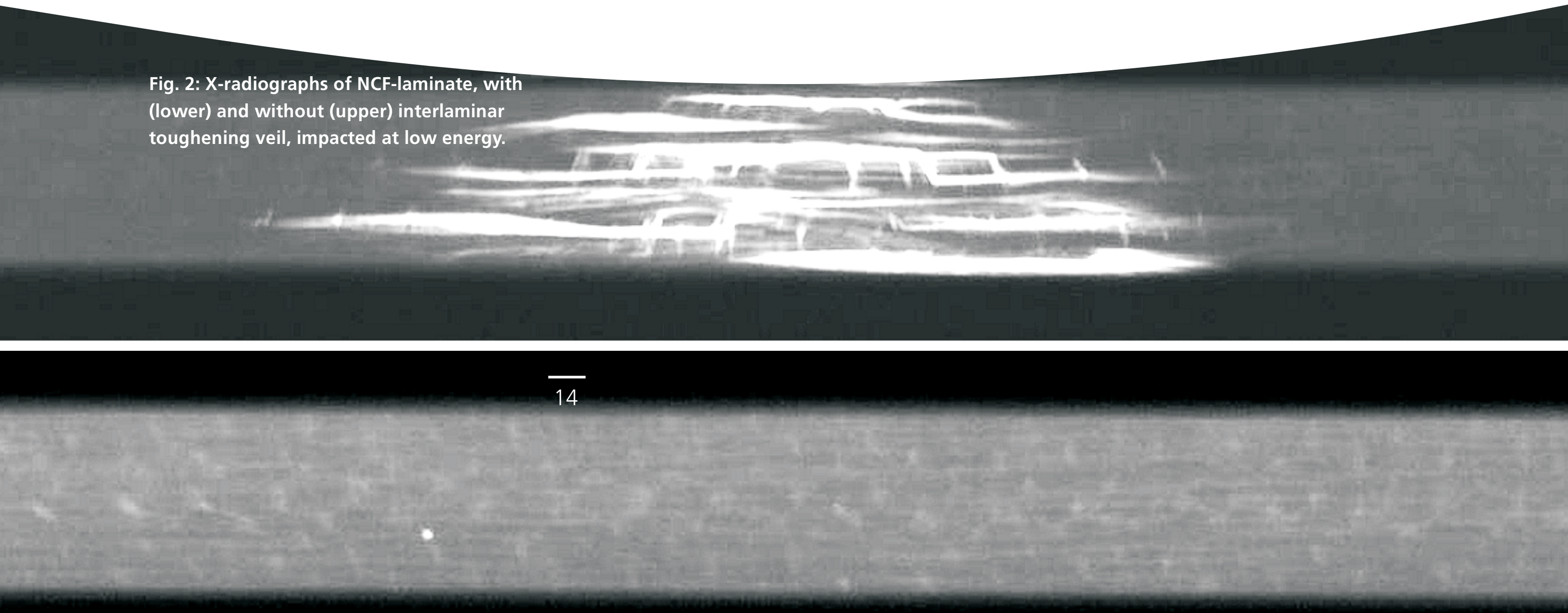


Fig. 2: X-radiographs of NCF-laminate, with (lower) and without (upper) interlaminar toughening veil, impacted at low energy.

Composite Damage Tolerance Analysis

An impact from tool drop, hailstones or runway debris can cause delaminations in CFRP panels, which split the laminate locally into several sublaminates. While the tensile load bearing capability is not substantially affected, the sublaminates can buckle under compressive or shear loading, causing a local reduction of compressive and bending stiffness. Such a soft inclusion leads to load redistribution and stress concentrations, which can cause premature failure of the structure.

Since the mid 1990s the DLR composite damage tolerance software CODAC has been continuously improved. CODAC includes a Finite-Element (FE) solver with special elements for monolithic and sandwich structures along with several modules allowing the efficient prediction of low-velocity impact behaviour and the post-impact residual strength of composite structures. One of these modules is the sublaminate buckling analysis, which provides stiffness reduction factors for finite shell elements, depending on the geometry and position of the stacked delaminations.

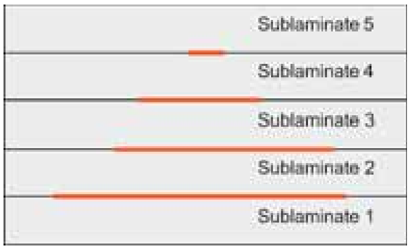


Fig. 1:
Cross section of a damaged laminate: Four stacked delaminations (red lines) split the laminate into five sublaminates.

CODAC provides stiffness reduction factors

A sublaminate, which is susceptible to buckling, always starts at one surface of the laminate and contains all plies between that surface and one of the delaminations inside the laminate. Therefore, there are twice as many such sublaminates as there are delaminations. For each delaminated interface, buckling load and buckling strain of the upper and the lower sublaminate are computed by a Ritz procedure, assuming an elliptical buckling shape. The smallest of these buckling strains is selected, the corresponding sublaminate is removed from the laminate and the buckling analysis is repeated for the remaining laminate until all sublaminates have been assigned a buckling strain and a buckling load. The stiffness reduction factors for the sublaminates are determined depending on their respective buckling loads.

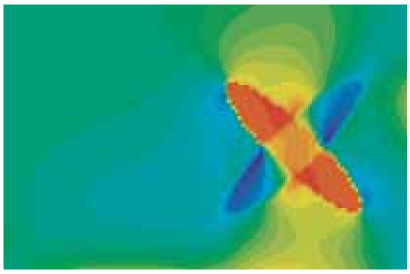


Fig. 2:
Stress in fibre direction in the middle of the topmost ply of a damaged composite laminate. The laminate is loaded compressively in vertical direction. The elliptical shape of two delaminations is clearly reflected in the stress distribution.

MCODAC improves accuracy

This analysis can be used together with CODAC s residual strength prediction, but since this is a linear analysis, global stability effects are disregarded. Furthermore, CODAC s built-in pre- and postprocessing capabilities lack the flexibility of commercial FE-software. Therefore, the sublaminate buckling module has been made available in separate software in a project funded by Airbus Deutschland. Besides providing the degradation factors for delamination damage, the software modifies an existing ABAQUS mesh to account for the stiffness reduction in the damage area. A subsequent non-linear ABAQUS simulation can then take global stability effects into account.

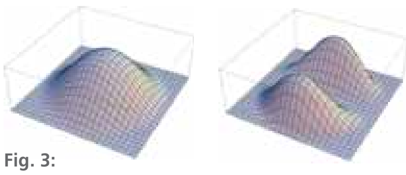


Fig. 3:
Two of the six basic buckling modes used for the approximation of the sublaminate buckling shape (Ritz approach).

From NDE to stress analysis

This effort is part of a larger scale strategy to link CODAC s damage tolerance modules to commercial FE software. The new tool framework is called Modular CODAC (MCODAC) and includes an SQL damage database with interfaces to non-destructive damage evaluation (NDE) and to commercial FE software.

> **Dr.-Ing. Jens Baaran**

Cost Efficient Carbon Composite Structures for Unmanned Air Vehicles (U(C)AV)

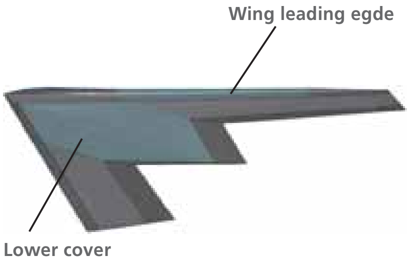


Fig. 1:
Model of proposed UCAV configuration.

Fig. 2:
FAST-RTM UCAV material screening process.

Motivation: Advanced human security

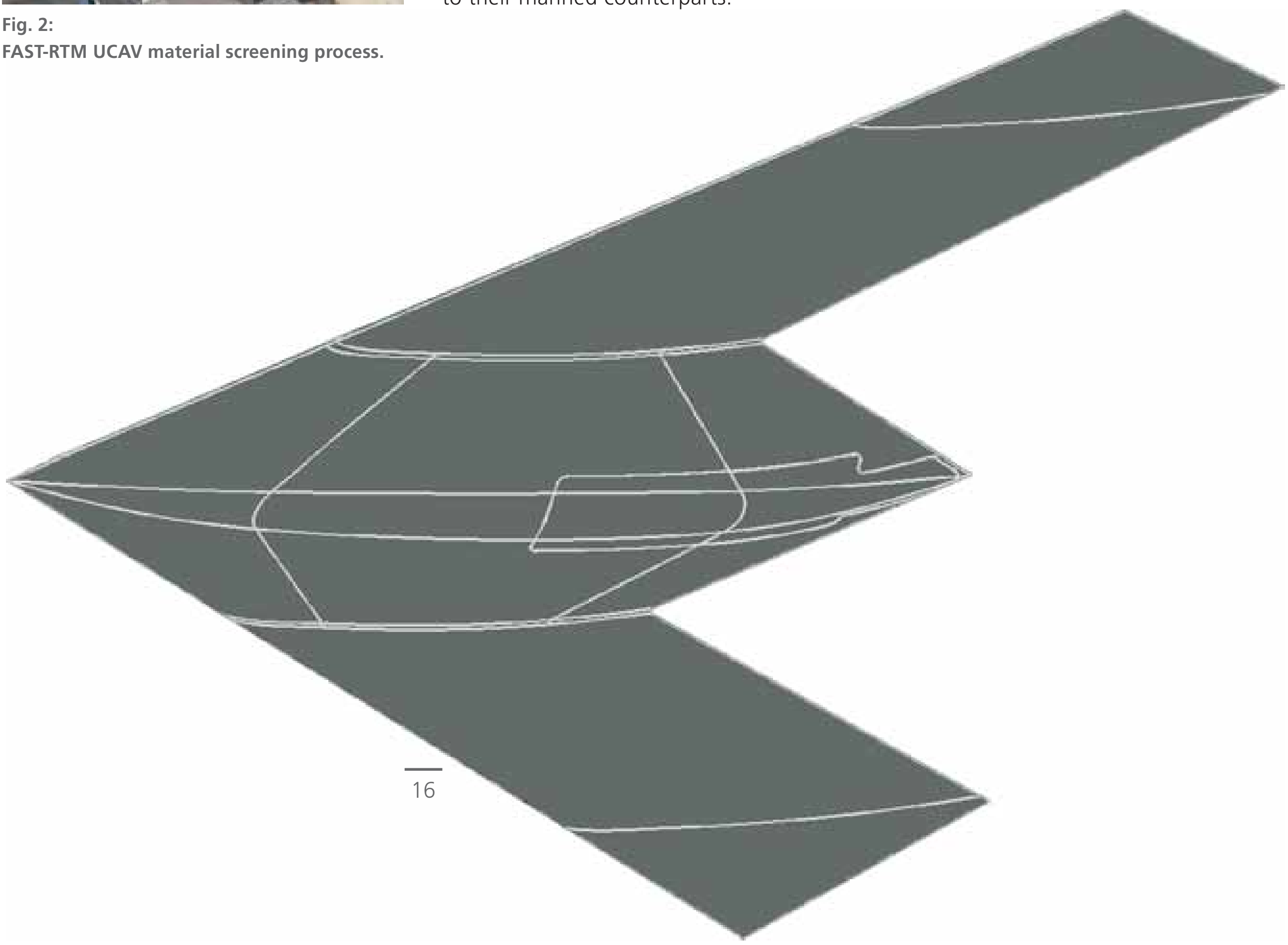
Military air missions always include a safety risk for the crew. Nowadays aerial ISTAR-missions (Intelligence, Surveillance, Target Acquisition an Reconnaissance) are essential for the security of ground forces. Current military as well as civil research initiatives focus on unmanned platforms (UAV, UCAV) to minimize the threat for human life.

The development of aircraft structures for manned aeroplanes is based on well known technologies, structural designs and simulation methods. UAV's are not restricted to these designs because of a complentary mission spectrum. The loitering time (time on station) or the payload e.g. may be increased due to the absence of a life support system.

The performance of unmanned air vehicles can significantly be increased by the use of composite materials. The application of integral manufacturing methods and adapted design concepts will reduce the number of production steps associated with the assembly of complex structural components.

One way of strengthening the reconnaissance abilities of UAV's is to minimize the radar cross section by using special geometries, radar absorbing structures (RAS), and innovative antenna apertures. The derived designs raise the needs of new or adapted technologies.

Only fibre reinforced plastics match the requirements of modern lightweight designs and the flexibility to integrate new functionalities. Reduced production rates for UAV's as well as the smaller dimensions allow shorter cycles to include innovations compared to their manned counterparts.



Advanced affordability and specialised functionalities

The main objectives of the DLR-project UCAV-Structures II are to provide the technologies, methodologies and materials necessary to develop U(C)AV structures under the premises of affordability and specialised functionalities. The project dedicates its resources into three research areas:

- Affordable Fibre Reinforced Structures for U(C)AVs
- Multifunctional Structures for U(C)AVs
- Structural Design and Simulation Processes for U(C)AVs

The first area addresses the low cost production, manufacturing and maintenance of fibre reinforced UCAV structures. The second area investigates the fibre reinforced structures with special electromagnetic requirements e.g. EM-transparency, EM-absorption or EM-emission. The third field is dedicated to the virtual development of primary U(C)AV structures under consideration of their special characteristics.

Fig. 3:
Development of automated plain preforming for the integration into the FAST-RTM process chain.

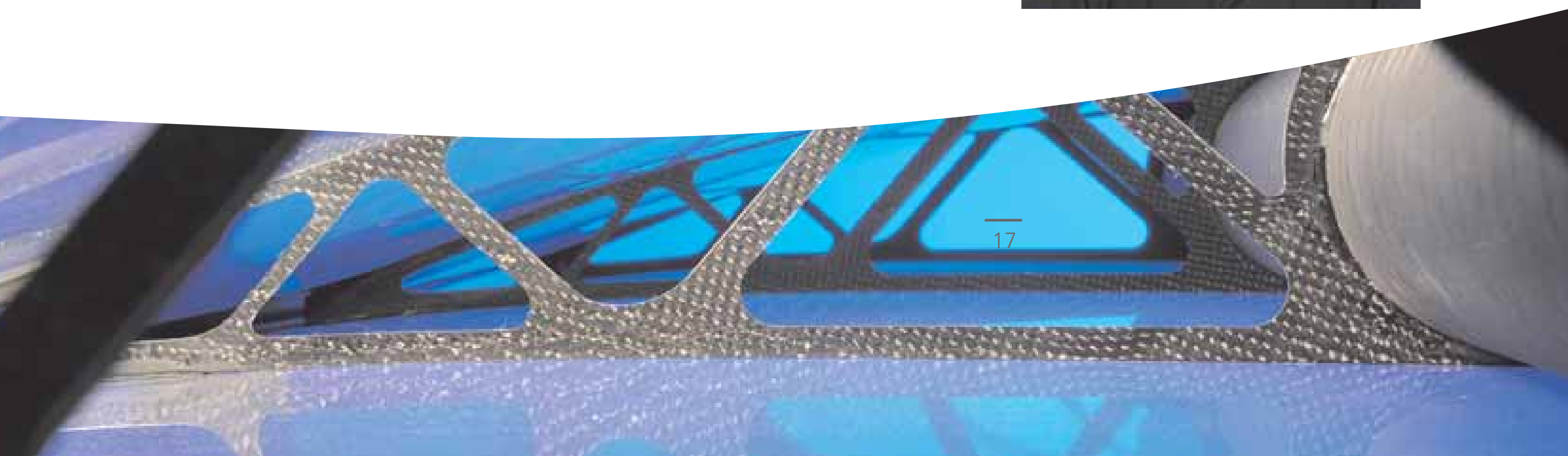
Cost efficient U(C)AV structures

DLR has developed new design principles for conformal antenna apertures and new integration technologies. Nowadays active phased array antennas are integrated into an aircraft by cut outs of the structure. A modern combat aircraft has more than sixty antenna systems. The required cut outs in the surfaces result in parasitic weights and a local reduction of strength. This disadvantage can be eliminated with conformal antennas with electrical beam steering and a complete integration of the aperture into the load carrying structure.

DLR cooperates with EADS-Military Air Systems as industrial partner. The new design of a broadband radome is validated in the cooperation by manufacturing of a high precision demonstrator. The hypothesis of a high precision layered design is proven and the feasibility demonstrated. Electromagnetic testing of the demonstrator revealed extraordinary transmission rates which are not reached by state of the art radomes.

Fig. 4:
Demonstration of cost efficient manufacturing technologies for omega stiffened UCAV panels.

> **Dipl.-Ing. Michael Hanke (photo), Dipl.-Ing. Dirk Holzhüter,**
Dipl.-Ing. Michael Kühn, Dipl.-Ing. Axel Fink, Dipl.-Ing. Jürgen Mosch,
Dipl.-Ing. Andreas Schröder, Dipl.-Ing. Heiko Assing,
Dipl.-Ing. Christoph Dienel, Prof. Dr.-Ing. Richard Degenhardt



New natural fiber reinforced plastics (NFRP) for aviation and traffic

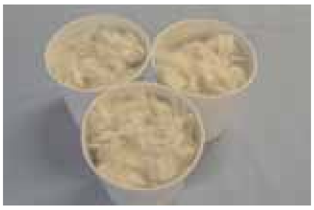


Fig. 1:
Cutted natural fibers.

NFRP can subsitute GFRP

Renewable resources like the bast fibers flax, hemp and jute offer very good opportunities to substitute glassfibers in fiber reinforced plastics (GFRP) ecologically and economically. In spite of the lower absolute strength and stiffness of natural fibers, their low specific weight of 1,5g/cm³ in comparison to glassfibers with 2,5g/cm³, provides considerable weight savings for fibre reinforced plastics. A life cycle assessment carried out by DaimlerChrysler compared the energy consumption for the production of semi-finished parts from glassfibers and natural fibers. For natural fibers a decrease in energy consumption of approximately 80% has been evaluated.

Fig. 2:
Suspended natural fibers with binder.

Natural fibers in aviation?

Previous applications for natural fiber reinforced plastics were limited to less ambitious areas, i.e. secondary structures like automotive linings or back shelfs in the interior. A new challenge is the application of natural fiber reinforced plastics in aviation. The substitution of the combination of glassfiber and phenolic resin in sandwich design for interior parts is in the focus of the research of the Institute FA. Besides the investigation of improved fire retardants in compliance with the fire-smoke-toxicity requirements of the aircraft industry, the selection of suitable natural fibers and semi-finished products is an essential factor for success. Important criterea for natural fiber semi-finished products are a grammage below 200 g/m², a sufficient tensile strength in dry condition, and a good drapability. The question of the needed degree of exposure respectively the fineness of the natural fibers must be determined. Besides the required improvement of mechanical parameters and fire properties, a consistent quality of the natural fiber is very important for high performance applications. Methods to reach these qualities like an enhanced bleaching process are under examination with our partners. The fibers must be less vulnerable to water absorption, swelling, fungal affliction, durability and formation of odour. Alternative resin systems with better environmental behaviour (less volatile organic compounds) and at least the same FST-properties than with phenolic resins will be analysed with natural fibers.

Fig. 3:
Nonwoven produced by the new lab-scale method.

New methods for NF-nonwovens

A fast and efficient lab process has been developed to produce nonwovens from natural fibers for the investigation of the interaction of treated fibers and new resin systems. Cutted natural fibers are suspended for this purpose with a dissolved binder and discarded on a metal wire to obtain a nonwoven. The quality, e.g. the homogeneity of the fiber distribution, of the produced non-wovens can be optically assessed supported by a developed software. The method opens new possibilities for the application of natural fibers in aviation, traffic and automotive.

Fig. 4:
Lay-up of nonwovens in a test-plate tool.

> **Dr. U. Riedel, Dipl-Ing. J. Bachmann** **(photo p. 19)**

Natural Fiber Pultrusion

Possibilities of Pultrusion

Beside the press technology, pultrusion technique is a cost-efficient production process for fiber reinforced plastics and increasingly gains relevance. FRP-profiles are produced in a continual process including the steps fiber supply, impregnation with resin, curing in a die and cutting to a desired length. The shape of the cross-section can be chosen freely in a wide range, but is fixed and cannot be changed within the process.

Fig. 1:
Injection device made from transparent acrylic glass.

Injection for fast reacting resins

The method of impregnating the fibers is important for pultrusio. Resins with sufficient long pot life can be filled in an open bath where the fibers are pulled through before they enter the heated die for curing. The surplus resin will be squeezed out at the entry and runs back in the resin bath by a guidance. When using a fast reacting two component resin-system, the fibers should be impregnated just a short time before entering the die. For this purpose a low pressure mixing- and metering device with a wide range of mixing ratios has been developed. It works according the principle of slidable lever arms to adjust the mixing ratio. The injection is realized by a novel injection device for simple laboratory tests. The fibers run through a cylindrical hole and are impregnated under pressure with fresh resin from the metering device by a mandrel with axial drilling holes. The cylindrical hole is tapered at the outlet and can be easily interchanged for other profile cross section areas by changing the outlet diameter. The amount of surplus resin squeezed out at the inlet of the heated die can be minimized by selecting the right outlet diameter of the impregnation device in combination with a correct metering pressure. As a particular highlight, the device is made from transparent acrylic glass enabling the possibility to observe the injection process optically. Successful tests with high reactive polyurethane and natural fibers have validated the concept.

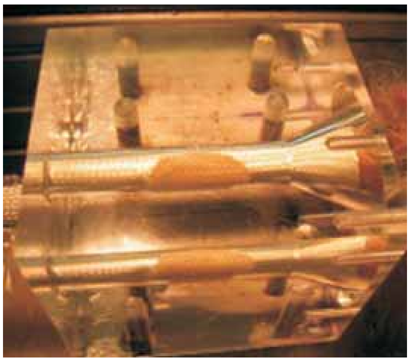
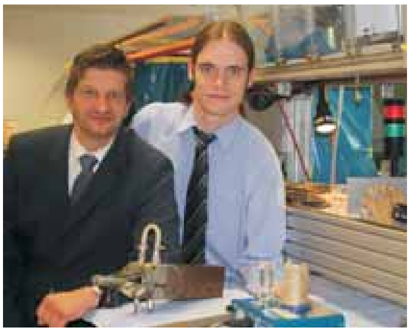


Fig. 2:
Optical observation of the beginning injection process. The resin permeates the natural fibers with glass-weave.

Novel curing technologies

Actually the exploration of new curing methods is important for the pultrusion with natural fibers in comparison with the conventional heating in a steel-die by convection. It is the target to enhance the pulling speed by a faster and more evenly curing reaction to advance the cost efficiency of the pultrusion. These curing-methods require alternative die materials which must be optimized regarding friction, costs of manufacturing, abrasiveness, and temperature resistance. Another application is the drying of natural fibers within the pultrusion process. The moisture content of appox. 10% can lead to porosities, a poor surface quality and decreasing mechanical properties. A method to determine the moisture content before and after the in-line drying device is important.



> **Dr. U. Riedel (photo left), Dipl-Ing. J. Bachmann (photo right)**

Production Line for Continuous Preforming with Variable Web Height Adjustment

Fig. 1:
Automated preform production line.

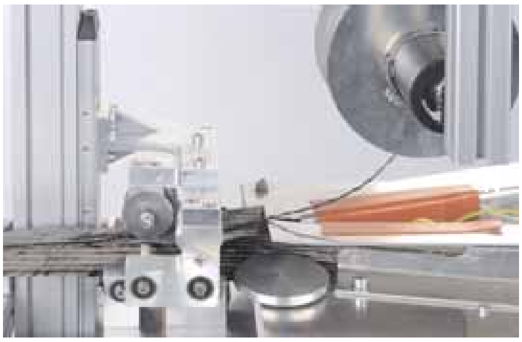


Fig. 2: Vertical linear motion with roller stand.

Preforming is required for complex shaped profiles manufactured in Liquid Composite Moulding (LCM) processes. The stacking is made of dry fibre fabrics, which get infiltrated in a later process-step. The complete stacking is called Preform. The fixing of the textile layers can be realised through stitching- or binder-technology.

The main disadvantage is the immense rate of manual work within the preform process. In consequence, the manufacturing is costly in terms of time accompanied by a high effort for quality control. Automated preforming can reduce the costs by increasing the output and production rate while minimising waste. Preform profiles with variable outlines and non-extrudable sections are of particular interest for the aviation and automotive industry. The DLR Centre of Excellence Composite Structures has developed an innovative device to overcome the previous limitations and fulfil the industrial demands.

Fully Automated Preforming

The novel continuous preform production line is able to manufacture I-Beam profiles with variable web height by using high performance Non-Crimp Fabric (NCF). The material storage is integrated in the machine. The NCF is delivered on rollers, which can easily be installed into the production line using a plug-and-play system. Inside and on one outside of the NCF-tapes a binder with thermoplastic behaviour is integrated. Rollers and adjustment units guide two parallel tapes to the forming units. In the first forming step, the material is formed into an L-profile. This forming step is realised by sheet metal guides. These guides are combined with heating units, which warm up the binder inside the tapes. Two contoured rollers on each side perform the consolidation. Afterwards the tapes are formed into C-profiles and guided together. The binder activation is performed by bonded membrane heat elements. In the next step the two C-profiled tapes get connected on their webs with compaction rollers. In this way the I-Beam profiles are manufactured. Afterwards the formed fabric runs into a split roller stand. The upper roller stand is mounted on a vertical linear motion unit. The height of the I-Beam profile can be continuously adjusted by moving the upper roller stand. The height is continuously adjustable from nine to one hundred millimetres. A distraction lance realises the actuation with a clamping device mounted on a horizontal linear axis. An integrated cutting unit assures the preform profile's net-shape quality. The complete manufacturing procedure is computer controlled and monitored. Various kinds of profiles can be stored in a database in the computer system. The realized preform production line offers a Technology Readyness Level 5/6, i.e. the prototype is validated in a relevant environment. The profiles which were already produced, will be assembled in a test device.

Perspectives in Automated Preforming

It is planned to expand the product range with different cross sections e.g, T, F, C and double curved profiles. In addition a combination of the preform production line with a robot is aspired.

> **Dipl.-Ing. Henrik Borgwardt**

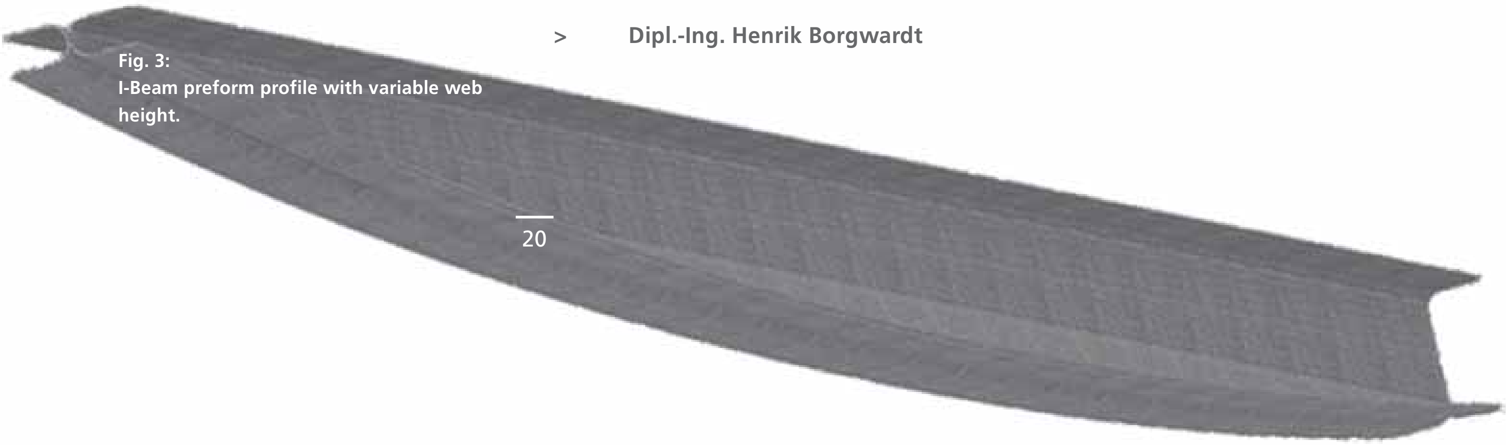


Fig. 3:
I-Beam preform profile with variable web height.

Rapid Flexible Tooling Based on Silicone

Alternative Materials

Economic and temporal aspects are becoming increasingly important in the manufacture of CFRP components. In this context design and manufacturing of appropriate tools represent a major factor. To reduce this factor the Institute of Composite Structures and Adaptive Systems demonstrates the potential of alternative tool concepts and materials. The use of silicones as a construction material allows a wide range of new opportunities in the tooling design. The properties of silicone can be improved by adding appropriate additives. The improvements refer to:

- temperature resistance
- chemical stability
- thermal expansion
- hardness
- self-separating properties

This allows an easy adjustment of the tool properties to the respective manufacturing task.The flexible properties of this material for example allow the implementation of various radii of curvature with one single tool (Figure 1). This and the cost-effective tool manufacturing demonstrates the suitability of this material.

From Concept to Component

The possibility of manufacture complex tools in casting and extrusion processes is the major advantage of tool concepts based on silicone. The use of low cost sheet tools as casting molds and extrusion matrices produced by electric discharge machining allows a reduction of manufacturing time and cost up to 70% as well. For example, the production of the RTM-tool described in Figure 3 needed 2 days, from concept to the finished component 4 days.

Using Properties

When considering the manufacturing process (cutting, preforming, injektion, curing, demolding) for composite structures it is obvious that even complex shaped components have to be realized in a fully automated way. In this regrad the adjustable characteristics of silcone tools offer advantages in the following fields:

- preforming (Figure 2)
- automatic demolding
- automatic vacuum bagging

The demonstration of a fully automated manufacturing process with silicone tooling, the integration of temperature and ultrasonic sensors and out of autoclave processing through the utilization of the thermal expansion are the next steps in the field of rapid flexible tooling based on silicone.

> **Dipl.-Ing.(FH) Michael Kühn**

Fig. 1:
Frame manufacturing.

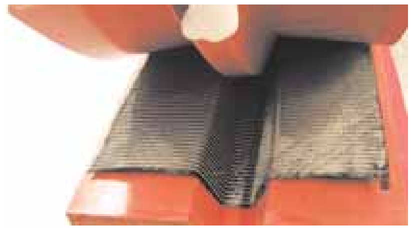


Fig. 2:
Preforming.

Fig. 3:
Silicone RTM-tool with finished component.

A Gapless Droop Nose Device Aims for Its First Ground Demonstration

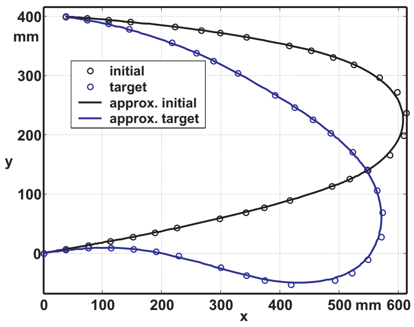


Fig. 1:
Clean and target shape for deployment at a single cross section (about 20° deflection).

Challenging Future High Lift Devices

The high lift systems of nowadays commercial airplanes are highly effective systems providing the required lift during take-off and approach at low flight velocities. State-of-the-art high lift systems consist of movable control surfaces which when deployed increase high lift performance. Typical devices are slats and fowler flaps which consist of rigid parts supported and driven by complex mechanical systems. To achieve the ambitious goals defined in the strategic research agendas provided by the Advisory Council for Aeronautical Research in Europe (ACARE), technologies consequently reducing drag, emissions and airframe noise will be necessary. Especially in this context, innovative high lift systems at the leading edge are of major interest. Slot- and gapless smart droop nose devices as innovative high lift devices at the leading edge (LED: Leading Edge Device) have significant advantages regarding airframe noise and constitute a key technology for drag reduction by natural laminar flow.

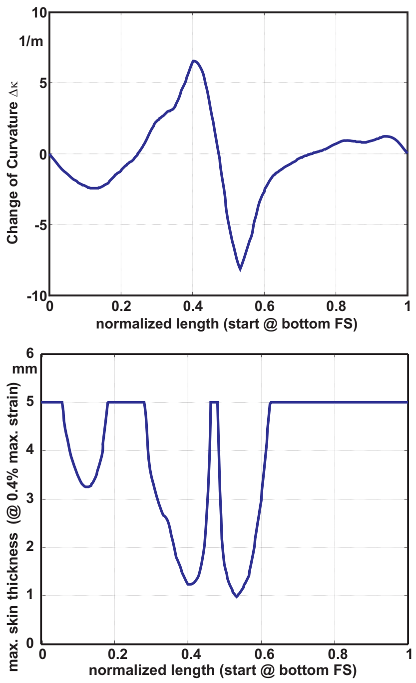


Fig. 2:
Local change in curvature along normalized skin perimeter (a, top); resulting thickness from theoretical analysis (b, bottom).

Morphing Structure for Smart Droop Nose Device

Investigations in the national project SmartLED concentrate on the first assessment of morphing technologies for leading edge high lift devices in a full scale system-structure ground demonstration in cooperation with Airbus and EADS. Motivated by the existing conventional Droop Nose Device (DND) located at the inboard section of the A380 the objective is to check and assess the feasibility of a slotless, smart device for the first time. Compared to the conventional DND, the smart DND aims to reduce the geometrical limitations caused by discrete joints and elements. The approach for a smart DND is to employ continuous flexible panels on the entire surface of the device in order to provide a continuous curvature distribution over the device chord. Furthermore, the high surface quality requirements are considered to support laminar wing technology. Implying this high surface quality, it is expected that the smart DND delivers similar maximum lift performance as a conventional drooped nose device while providing large benefits for take-off (T/O) drag. The underlying NG-wing (Next Generation wing) provides the framework for the droop nose design, which stretches from 20.4% to 23.7% clean chord of the front spar position and, thus, has a length of about 2m.

Monolithic Skin and Omega Stringer

The novel skin concept considered here consists of a continuous end-to-end skin without gaps or steps, support of the thin and flexible skin structure by guiding profiles and a simple drive concept featuring a single main lever arm actuated by a rotary actuator. The most significant challenge in realizing this concept was the union of the contradiction of a continuously flexible morphing skin and stiff load introduction points to attach the inner kinematics framework. A monolithic skin structure only charged by bending loads and, thus, allowing for reasonable maximal strains results from the project work. Omega stringers serve as substructure to connect the kinematics framework, stiffen the leading edge in spanwise direction and permit a smooth outer surface suitable for laminar wing technology. The target shape of the drooped nose is determined by the stiffness design of the skin. Additionally, the overall performance of the system is governed the number and position of actuators and kinematics.

Morphing Driven Structural Design

Designing an adaptive high lift system for the leading edge poses many challenges such as structural integrity, target shape, actuation power, aerodynamic loads and weight constraints. The target shape, e.g., is defined by a challenging minimum deflection of about 20° maintaining a smooth surface of high accuracy with respect to the target shape (Fig. 1). For the preliminary optimization of the number and position of support points of the skin structure with respect to optimal surface quality under relevant aerodynamic loads, an estimate of an appropriate skin thickness was derived from the Euler-Bernoulli beam theory due to the pure bending by design. The initial skin thickness distribution results of the local change of curvature (Fig. 2a) between the deformed and undeformed state of the structure assuming a constant common limit strain of 0.4% for fiber reinforced plastics. In Fig. 2b the graph presents the theoretical skin thickness distribution according to the calculated curvature with limiting the maximum skin thickness to 5mm. Obviously, there are three critical areas due to large changes of the curvature of the structure: The s- shaped deformation of the skin at the underside and two major critical parts at the devices tip. In the regions at the tip, a small skin thickness of 1mm is required to keep the strain within the prescribed limit (Fig. 3). Employing a simplex optimization scheme to identify the required actuation forces and locations, the deviation of the deformed droop nose shape from a prescribed target shape has been evaluated and the sought omega stringer positions derived (see Fig. 4).

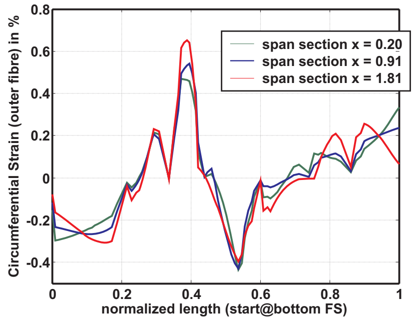


Fig. 3:
Circumferential strain in outer skin layer at three different span sections vs. normalized skin perimeter length.

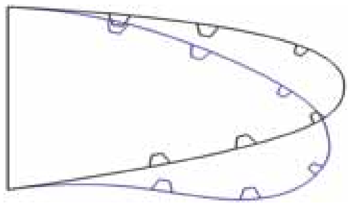


Fig. 4:
Schematic stringer position layout in clean and deployed configuration.

Virtual Proof of Concept

Based on the optimization results, a detailed FE model serving for the virtual proof of concept has been utilized. The skin is completed with four omega stringers for load introduction of the actuator loads at the previously identified positions. Two additional stringers without actuation loads are introduced for stiffening of the skin structure in the spanwise direction to avoid buckling under wing bending loads. The already discussed actuation kinematics were developed in cooperation with EADS and additionally introduced in the model at four discrete locations along the span. The availability of this complete model allowed for the first virtual proof of this innovative concept, where the structural behaviour at maximum deployment angle as well as contour accuracy during cruise flight have been analyzed (see Fig. 5).

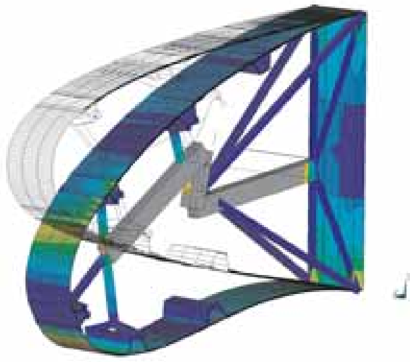


Fig. 5:
Virtual proof of concept by detailed finite-element analysis featuring skin, stringers and driving kinematics.

Upcoming Ground Demonstration

Recent work focuses now on the realization of the droop nose concept aiming for a first time ever structure-system ground demonstration in cooperation with Airbus and EADS. In the upcoming tests in 2010 the modelled full-scale structure equipped with realistic actuation systems will be examined to proof, e.g., structural integrity, contour accuracy and actuation load. As an additional challenge, operation under wing bending is part of the test program. By the time of publishing the Innovation Report 2009, we are excited to manufacture and assemble the first technology demonstrator of this novel high lift device getting one major step closer to make our vision of morphing aircrafts come true.

> **Dipl.-Ing. Markus Kintscher, Dr. Olaf Heintze**

Next Generation Train NGT

Fig. 1:
NGT: High-speed double deck concept.

Mobility: Efficient, Safe, Sustainable

Securing mobility for people and goods, protecting the environment, preserving resources, and improving safety and security without neglecting cost efficiency: These are the challenges and motivation of DLR's transport research activities. The Institute of Composite Structures and Adaptive Systems significantly contributes to the research field 'Terrestrial Vehicles', i.e. 'Road Vehicles' and 'Rail Vehicles'.

NGT: Benchmark of Future Rail Traffic

Consequentially the main objectives within the Next Generation Train project are to increase driving speed by 25 percent to 400 km/h in compliance with existing safety standards as well as reducing the specific energy consumption by 50 percent. Reduction of noise emissions and increase of passenger comfort with regard to cabin pressure, climate control, vibrations and acoustics are further issues (Fig. 1).

Modularisation and improved system integration will allow significantly more cost-effective construction of rail vehicles, similar to road vehicle construction. In addition, there is a considerable potential for increasing the efficiency of development, validation and certification processes. DLR contributes to unlocking this potential by identifying options for integral modelling of the total system and providing specific recommendations on harmonizing requirements and processes in Europe. This will significantly reduce development cycles.

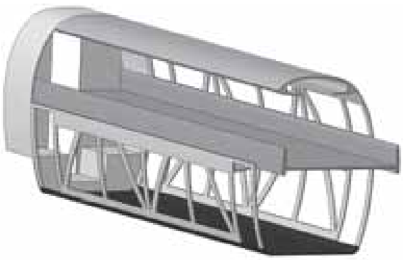


Fig. 2:
Design concept (example).

Scientific issues regarding high-speed railway transportation require a multi-disciplinary approach involving the areas of aerodynamics, structural dynamics, dynamic performance, propulsion technology, and - with significant contributions by the Institute of Composite Structures and Adaptive Systems - acoustics, material sciences, and lightweight construction.

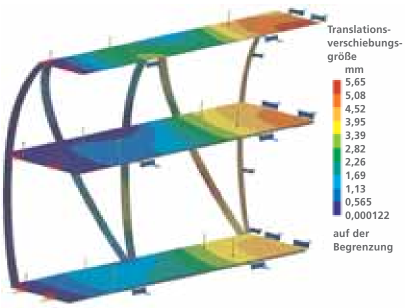


Fig. 3:
FEM validation.

Innovative Composite Car Body Design

High-speed trains with high capacities require innovative lightweight and cost-efficient construction. A key to this is given by reducing the complexity of rail vehicles and their production through platform creation and modularisation as well as weight reduction through lightweight construction and/or function and system integration. In rail vehicle construction, two design and technology priorities have evolved with regard to support structures and vehicle bodies in the course of development. These are firstly differential construction in steel and secondly integral construction in aluminium. In addition to these technologies, hybrid and multi-material design approaches have increasingly been studied in recent years and implemented in semi-structural or non-supporting components.

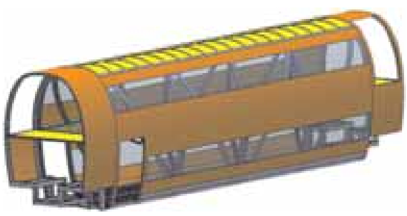


Fig. 4:
Overall design (example).

At the DLR Institute of Composite Structures and Adaptive Systems, (carbon) fibre reinforced composite car body designs are being developed aiming at significant weight and cost savings in railway construction for increased efficiency (Fig. 2, 3, 4, 5). In conjunction with cost-effective construction and production methods, high-performance composite materials or sandwich structures, for example with new types of honeycomb cores, are tailored to the specific requirements of rail vehicle manufacture and appropriate joining technologies are being developed.

Multidisciplinary Approach along The Process Chain of Composites

Apart from the demand for innovative design philosophies and design concepts, the challenges of the Next Generation Train require a multidisciplinary approach in order to achieve the ambitious goals. In other words, there is a strong demand for materials and processes showing a well-balanced profile of properties, regarding e.g. fire protection, cost-efficiency in terms of materials and manufacture, low weight, good damping / acoustic behaviour, repair, sustainability, and integration of additional functionalities (Adaptronics). All these aspects are addressed by current research activities of the Institute of Composite Structures and Adaptive Systems.

Fire protection properties as an essential issue of railway applications can be optimised by adding nanoparticle systems to the matrix materials (Fig. 6). As a decisive factor, other important characteristics, e.g. strength, tenacity etc. will not deteriorate and sometimes can even be improved. The aim is to meet the demands of the recently intensified fire protection standards (from DIN 5510 to EN 45545).

New materials, such as biocomposites using natural reinforcing fibres can replace glass fibre composites in interior applications (Fig. 7). Biocomposites are sustainable materials offering additional options of design in terms of surface, haptics, acoustic properties etc. at 20 % weight reduction on structural level due to lower densities of vegetable fibres compared to glass fibres. Apart from hot pressing further specially adapted production technologies, such as the long fibre injection process (LFI) or the microwave assisted pultrusion technology offer cost-effective manufacturing options for biocomposites and traditional composites as well.

Active Structural Acoustic Control (ASAC) is a promising approach to reduce noise in the interior of a railway vehicle and to improve passenger comfort by increasing the transmission loss by means of adaptronics (Fig. 8). ASAC reduces or changes the vibration distribution of a structure by application of actuators aiming at a reduction of the sound radiation. High efficiency and reliability are essential, i.e. requiring a minimum number and optimal positioning of sensors and actuators, effective control cycles, operating under non-laboratory conditions etc.

In close cooperation with further DLR Institutes, solutions for integrating support structures, crash elements, impact protection, heat and sound insulation, line and cable ducts, optimally adjusted components and modules are currently being explored, developed and designed.

Developing a high-speed train differs conceptually from designs for regional and local transport. With respect to the market share of regional trains, there is a great demand for new concepts and solutions regarding this field of transport. DLR accepts the challenge to transfer the principal procedures of platform and module development to regional and local trains. All this is being performed in close cooperation with industrial partners.

> **Dipl.-Ing. Jörg Nickel**

Fig. 5:
CFRP design concept for sidewall, roof, and intermediate floor of composite car body.

Fig. 6:
Improved fire protection properties by use of nanoparticles (right).

Fig. 7:
Modular composite car body design concept by the Institute FA.

Active Reduction of Car Interior Noise

Fig. 1:
Experimental setup of the active windshield with piezo-electric d_{31}-patches, electrodynamic shaker, accelerometers and laser-scanning grid (reflecting points).

Fig. 2:
Measured operational deflection shape (magnitude) at 116Hz without active control (shaker excitation).

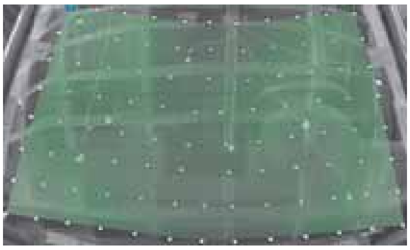


Fig. 3:
Measured operational deflection shape (magnitude) at 116Hz with adaptive feedforward control (shaker excitation).

Increase of driving comfort by means of active structural acoustic control (ASAC)

Active Structural Acoustic Control (ASAC) is an effective measure to reduce the windshield-vibration-induced interior noise in an automobile passenger compartment . The related research of the Institute is based on former work conducted within the framework of the EU-IP InMAR. An existing test-car equipped with an active windshield is used for the investigations. The active windshield consists of the passive structure equipped with optimally placed piezo-electric transducers. The main focus of the subsequent work is the development and evaluation of different control strategies (H2, FxLMS) designed with regard to either local or global performance metrics. Due to the lack of a roller test bench the structural excitation is realized by an electrodynamic shaker located at the roof brace between the A-pillars (cp. Fig. 1). This setup enables the emulation of the broadband structural excitation of the windshield due to rolling and motor force harmonics.

Optimized definition of sensors and actuators improves control performance

The kernel of the real-time system is a dSPACE-DS1005 board used for rapid control prototyping. The signals are conditioned by low-pass filters with a cutoff frequency of 240Hz. Six accelerometers are placed for vibration sensing at heuristically optimized positions on the inner side of the windshield. The sound pressure level (SPL) at different positions in the interior is sensed by a microphone. The reference signal for the adaptive feedforward controller is generated from a force sensor placed in the load path of the shaker near the excitation point at the roof brace. Fig. 1 shows the accelerometer positions (S1 to S6) as well as the selected piezo actuators (1||2, 3||4 and 13||14). The number and positions of sensors are determined heuristically using results from modal analysis of previous investigations and applying the principle of maximum modal observability. The selection process of the control actuators is guided by the evaluation of control-path frequency response functions (FRF). The number of actuator channels was restricted to three in order to achieve a reasonable trade-off between model complexity and control authority. A further increase in control authority is obtained by operating adjacent transducers in parallel.

Efficient System identification and modeling for real-time control

A suitable system model is needed for the design and implementation of a feedback or feedforward controller. A time-discrete state-space-model is calculated for the coarse accelerometer grid (3 control inputs, 1 disturbance input and 6 outputs) from multiple-reference test data. In order to obtain the global system dynamics in terms of a finer grid of 101 points, a subsequent least-squares fit is performed using the obtained state-space model and measurement data from the laser-scanning vibrometer. The final result is an augmented state-space system of the same order, yet with 101 outputs.

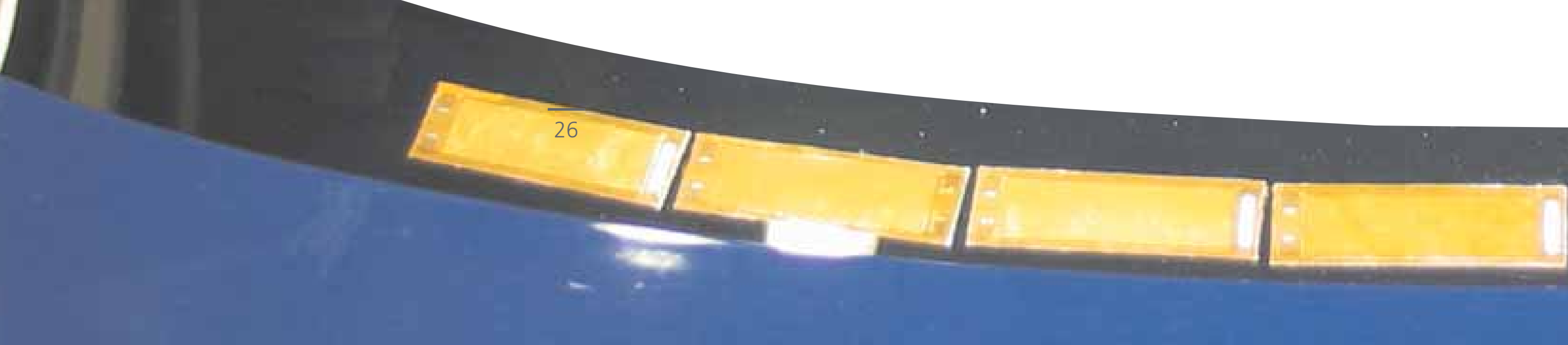


Fig. 4 compares the singular values of the identified system model with measurement data. The comparison confirms, that the use of just 60 states is a numerically efficient and accurate modeling of the 404 transfer paths.

Control of acustically relevant modes

The second eigenfrequency of the windshield is most relevant for low-frequency interior noise which has been proven in previous acoustic investigations performed by our industrial partner Volkswagen AG. The experimental results of the active feedforward control of this mode are presented exemplary.

The applicability of adaptive feedforward control depends on the existence of a reference signal that is sufficiently time-advanced and highly correlated with the sensor signals. If these constraints are fulfilled, a very powerful and robust control system can be designed. In contrast to an observer-based state-feedback control scheme, the implemented FxLMS algorithm performs no post-processing of the sensor signals and can thus only process local information based on the coarse sensor grid. The adaptive filtering is performed with 200 FIR-filter taps for each control channel, a leakage factor equal to one and a normalized step size of 0.1% of the theoretical maximum value.

The SPL shown in Fig. 5 was measured at six arbitrarily chosen points about 0.1m from the inner surface of the windshield. These results give a initial impression of the potential sound reduction demonstrating the capability of active methods. The realization of profound intensity or sound power measurements was beyond the scope of these experiments and remains a topic for further investigations.

Significant reduction of interior SPL

Different control strategies for the active reduction of windshield-vibration-induced interior noise are developed, experimentally validated, and now available. The comparison of the vibration levels in open and closed loop show a global reduction of 5dB to 7dB in the acoustically relevant frequency band containing the second and third eigenmode of the windshield system (100Hz to 150Hz). The acoustic effects, though not yet entirely scrutinized, are reflected in a reduction of up to 15dB in SPL at 145Hz. Moreover, the results are obtained in a realistic environment.

These promising results encourage future work on this topic. Possible questions for subsequent research activities concern the implementation of piezo-electric transducers for a structurally integrated sensing and the use of a larger number of low-voltage piezo actuators in order to handle the observed complex operational deflection shapes. Also, a further development of sound power estimation based on structural information or a frequency-selective post-processing of sensor data might be a focus of prospective research activities.

> **M.Sc. Malte Misol**

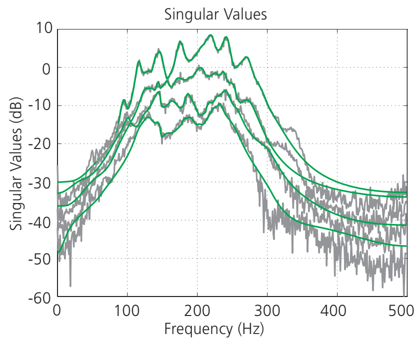


Fig. 4:
Singular values of control- and disturbance-path FRF-matrix. Identified state-space model (green) and measurement data (grey).

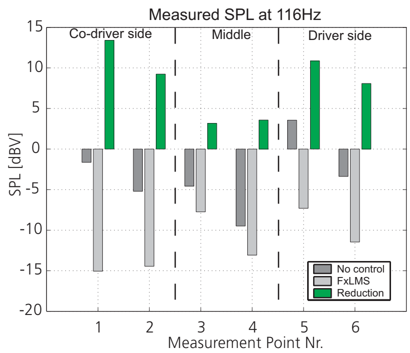
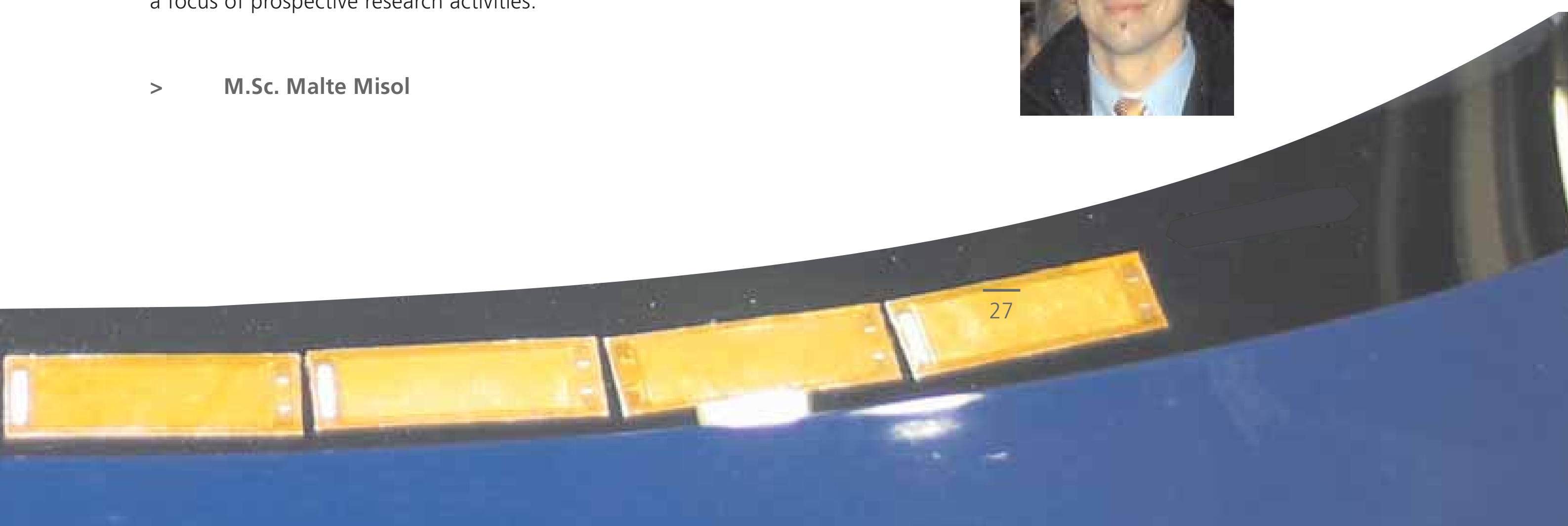


Fig. 5:
Reduction in sound pressure level (SPL) at 116Hz achieved by the adaptive feedforward controller (FxLMS).



Vibration and noise reduction of a circular saw blade through semi-active shunt networks

Fig. 1:
Circular saw blade with piezoelectric elements.

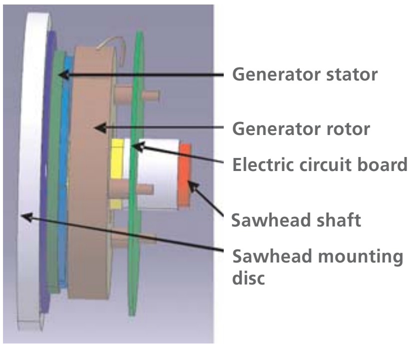


Fig. 2:
Generator and circuit board (CAD Image).

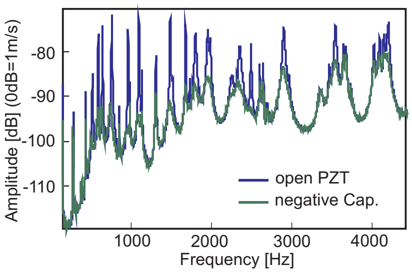


Fig. 3:
Vibration amplitude of saw blade with and without shunt.

Damping by Energy Conversion

Circular saws are widely spread tools for machining wood, metal, plastics or even stone. Common for them is a circular blade with teeth or a diamond dust coating on the outer edge used for cutting material. The contact to the workpiece, caused by the circular blade, leads to severe vibrations with frequencies up to several kilohertz in combination with a large amount of emitted noise. Therefore noise protection is a necessity for saw workers and due to the vibrations, rough and uneven cutting surfaces occur.

Compared to passively damped saw blades, a new approach is investigated at the DLR which is used to damp a circular saw blade. As to be seen in Figure 1, piezoelectric patch actuators are placed on the surface of the saw blade. They are connected to external shunt networks interacting with the structure. The piezoceramic elements are acting as energy transducers to transfer vibration energy from the mechanic system into electrical energy within the shunt networks, where this energy is dissipated. By this, vibration amplitude can be reduced.

As shunt network, a negative capacitance circuit is used. This can be compared to a broadband vibration absorber system. By compensating the capacitive reactance of the piezoceramic patch, the energy transmission rate and by this the coupling factor is increased. This leads to an efficient, wide-frequency damping effect.

Does it work?

To perform real sawing tests at a CNC controlled machine, a saw head tool which contains the shunt networks and an independent power supply, was developed. There, the required electrical energy is produced by a generator using the rotation of the saw blade. The electrical circuits are also placed in the rotating system which makes spinning electrical connections, e.g. sliprings, obsolete. A CAD Image is shown in Figure 2.

Initial tests with a scanning vibrometer in the static system, as can be seen in Figure 3, show the damping efficiency of this configuration. The Vibration amplitude is damped over a wide frequency range with reductions of up to 20dB. Futher tests with the free-running sawblade in the CNC machine also prove the ability of the shunt damping system to reduce noise emission up to 10dB.

Prospects

The next step will be to obtain the reduction of the vibration amplitude also in the spinning system when the saw blade is running in the CNC machine together with the Instutute of Machine Tools and Production Technology at the TU Braunschweig (IWF). Therefore, a measurement procedure and system will be developed and built, where the vibration speed is sensed by a laser-vibrometer beam, which rotates with a special mirror system with the saw blade so that always the same point of the saw blade is spotted. By this, a quantification of vibration reduction of the negative capacitance shunt systems at the saw blade is possible.

> **Dipl. Ing. Martin Pohl (photo), Dr. rer. nat. Michael Rose**

Active Twist Rotor Blade Testing

The active change in twist of helicopter rotor blades is considered to establish a powerful means to reduce helicopter noise and vibrations. To asses the benefits of an active twist rotor, intense numerical as well as experimental investigations are necessary. The experiments are mainly used to create a database that is needed for the validation of the simulation.

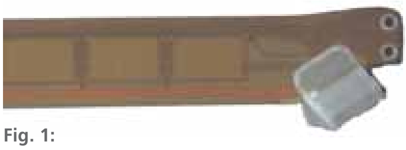


Fig. 1:
Active Twist rotor blade.

How to actuate and instrument a rotor blade?

The twist is generated by piezoceramic macro fiber composite (MFC) actuators that are integrated into the skin of the blade (Fig. 1). These actuators are producing strain in direction of the piezoceramic fibers. Aligning the fibers of the actuators at an angle of 45° with respect to the blade axis, the strain of the MFC's results in a blade twist. Beside the actuators the blades are also equipped with sensors. Strain gauges are used to capture the moments in bending and torsion at different radial positions. Further, two light emitting diodes are integrated into the tip of the rotor blades. which in combination with a high speed camera represent a robust and convenient method to measure the twist and the flap displacement of the blade tip.

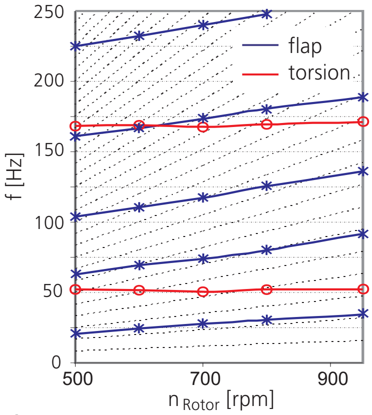


Fig. 2:
Experimental fan plot.

How to capture the blade dynamics?

Within the rotor code the motion of the blade is calculated via a modal synthesis. Hence it is evident that matching the natural frequencies of the blade is of major importance. Due to the centrifugal forces the eigenfrequencies are depending on the rotational speed of the rotor. The diagram showing the natural frequencies of the rotor blade versus the rotational frequency of the rotor is called fan plot (see Fig. 2) and is well suited to check whether the system dynamics are captured by the model. Therefore the fan diagram has to be derived experimentally. Within the tests the blade is excited with a voltage sweep applied to the most inboard actuators. The eigenfrequencies were identified from the frequency response functions of the strain gauges. Looking at the strain gauge data from different radial positions, it is possible to distinguish the different modes by their shape. From the diagram it is obvious that the flap frequencies are rising with the rotor speed while the torsion frequencies are nearly unaffected.

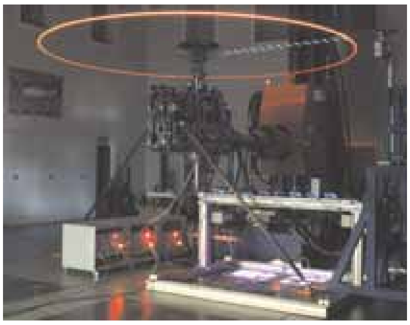
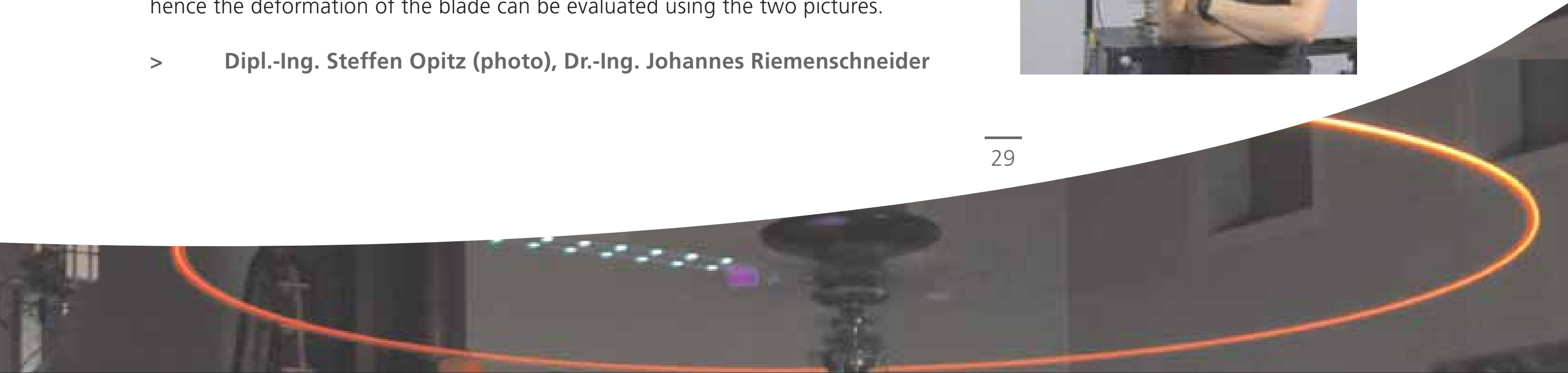


Fig. 3:
SPR measurement setup.

Once the frequencies between model and experiment are matched, the next step is to compare calculated blade deformations with experimental data. In a first stage the blade tip positions measured with LED's and high speed camera can be correlated. The next step is to validate the deformation of the whole blade. As the strain gauges are only measuring the moments at discrete cross sections the data has to be integrated to derive the blade deformation. Due to the relatively big distance between the strain gauge locations this leads to unacceptable big errors. Another possibility to measure the blade deformation is the stereo pattern recognition (SPR). To prepare the blade for the measurements 18 ultraviolet reflecting markers are painted at the leading and trailing edge of the blade. Two cameras are located underneath the rotor disc (Fig 3). When the blade passes by it is illuminated by a flash of ultraviolet light and a picture of the markers is taken by both cameras. Afterwards the position of the markers and hence the deformation of the blade can be evaluated using the two pictures.

\> **Dipl.-Ing. Steffen Opitz (photo), Dr.-Ing. Johannes Riemenschneider**



Ultralight Deployable Structures – a Big Step Forward

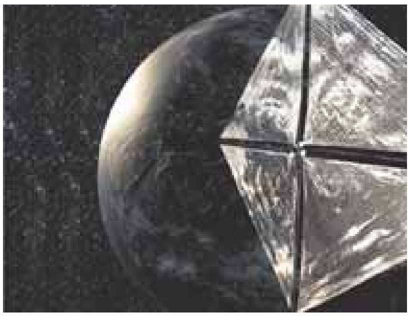


Fig. 1:
Solar sail concept with four booms.

Solar Sails and Other Gossamer Structures

Future solar sail spacecraft which do not need any rocket motors and propellants are a promising option for long-term exploration missions in the solar system, for instance aimed at Mercury, the asteroids, or even the Kuiperbelt. However, they will require ultralight reflective foils and deployable booms which will allow for the unfolding of huge sails. The achievement of an acceptable ratio of reflective sail area and structural mass, which results in a still small, but significant acceleration under the photon pressure of sunlight, is extremely challenging. The same challenging deployment technique is required for the unfolding of very large antennas or reflector membranes in orbit. All these structures are called "Gossamer Structures".

Fig. 2:
Zero-G-verification of the deployment process.

Zero-G Verification

Within the 13th DLR Parabolic Flight Campaign in Bordeaux the Institute had the extraordinary chance to use the experimental aircraft, an Airbus A300, for one day all alone. The whole length of the experimental compartment was used to convincingly demonstrate that the unfolding process is both controllable and reproducible. The tested booms were 14 m long and consisted of two co-bonded omega-shaped carbonfiber half shells with 0.1 mm wall thickness each, resulting in a specific weight of only 62 grams per meter. Once unfolded, the mechanical stresses frozen in these half shells keep the cross-section of the boom stable, but beforehand a suited uncoiling mechanism is required.

Two different uncoiling technologies were tested, one based upon an inflatable 12µm thick polymer hose inside the boom, the other one using an electromechanical uncoiling device at the outward-moving tip of the boom.

Fig. 3:
Ultralight boom section, partially coiled.

The first option allows the central control of the uncoiling process even for the simultaneous deployment of several booms by regulation of the inflation pressure. In the parabolic flight campaign this was achieved by a computer-controlled air inflation pump; while in a real space mission a pressurized gas tank with an actuated valve would be used. In this concept no devices at the boom tip are required, possibly apart from a simple cylindrical hub which flies away in radial direction.

The second option is a true tip-reel concept. The whole electromechanical uncoiling mechanism is moving outward with the boom section which is still on the spool, leaving the already unfolded and rigidized boom section behind it. The root of the boom remains rigidly connected with the central structure of the spacecraft. The main advantage of such "expendable deployment mechanisms" is that their mass does not count any more for the spacecraft mass that needs to be accelerated or actively controlled during the later mission.

Fig. 4:
Tip reel concept.

In the course of the Zero-G test campaign in Bordeaux a comprehensive experimental program with both abovementioned types of mechanisms has been performed. From parabola to parabola, the mechanisms, the boom parameters, and the deployment speed were systematically varied. In case of the inflation option, the boom deployment was also intermediately interrupted in order to verify that it is a fully controlled and not only a triggered process. The performance of the booms was accurately pursued by a number of cameras on both sides of the aircraft cabin, and the records were synchronized with all other test parameters.

Although any kind of uncoiling mechanism is certainly indispensable for the boom deployment in space, the entirely free and uncontrolled unfolding of a coiled boom was also tested. The objective was the validation of the analytical models and simulation tools that had been used throughout the development history of the ultralight carbonfiber booms in the Institute. The respective results are still under evaluation but very encouraging.

Fig. 5: Testrig.

Outlook

The Zero-G test campaign in February 2009 has convincingly demonstrated that the design of the ultralight deployable carbonfiber booms is meanwhile rather mature and ready for real space applications. The same is true for the sail technology which is also a subject of DLR research (at DLR-RY). At present, chances for an in-orbit demonstrator mission are looked for, and studies for advanced applications are being performed. Solar sails for future scientific missions, large antennas, or the utilization of the drag of sails in a low earth orbit as a reliable deorbiting tool are envisaged.

\> **Prof. Dr.-Ing. Joachim Block, Dipl.-Ing Marco Straubel**

Multifunctional Materials

Mission

From materials to intelligent composites!

The department of Multifunctional Materials concentrates 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

By adding nano-scaled particles the fire behaviour, the electrical conductivity and the processability of resins are decisively improved. Beyond that, new functional materials with sensing and actuation capabilities as components for adaptive structures are explored. The research ranges from very basic studies in the area of Carbon Nano Tube (CNT) based actuators to the development of piezocomposites ready for serial production in cooperation with industrial partners. Sensor and actuator networks capable to excite and sense wave propagation are developed to allow a continuous monitoring of fibre composite structures during production and operation.

Competences

The department 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
- Development and improvement of new injection resins
- Nano-technology in fibre composite materials (Nano Composites)
- Natural fibre 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

> **Dipl.-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 over sizing 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

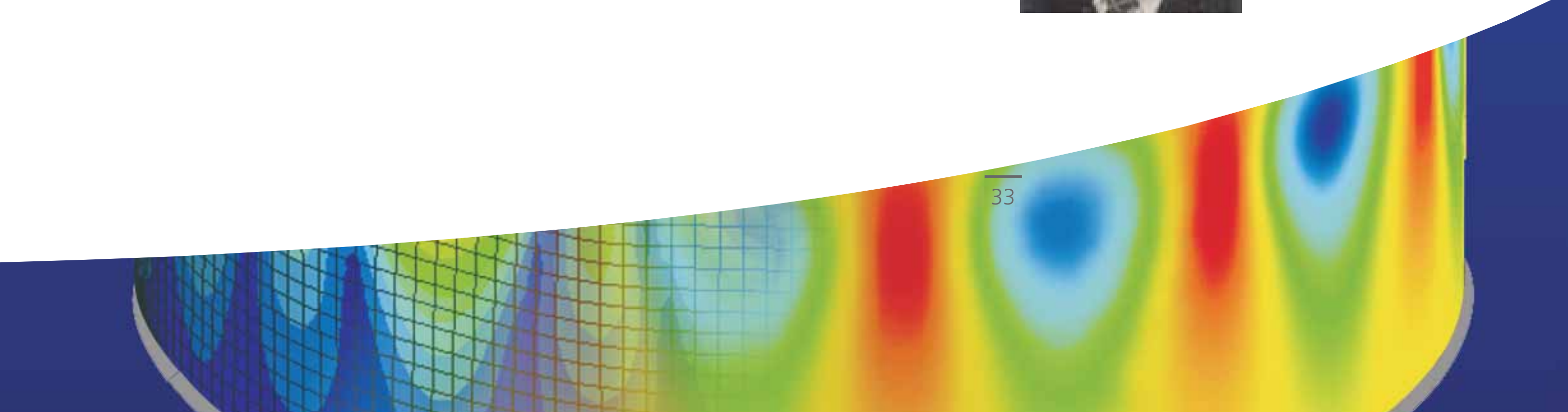
Competences

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, tailored fibre placement)
- Global Design (e.g. tools for design and weight assessment of future structural concepts)
- Multi-Scale Problems (e.g. global-local concepts)
- Structural Stability (e.g. postbuckling, imperfection, dynamic buckling, robust design)
- Damage Tolerance (e.g. failure criteria, impact, residual strength, degradation)
- Multidisciplinary Simulation (e.g. resin curing, spring-in, piezo-electric-thermal coupling)
- Thermo-Mechanics (e.g. extended 2D methods, models for fibre metal laminates)
- Test Facilities (e.g. thermo-mechanics, structural stability)

An actual 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, postbuckling and tailored fibre placement methods development.

> **Dipl.-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 are being addressed an adequate selection of materials, hybridisation, and further aspects specific to fibre composites.
- 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 links 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!

We develop tailored manufacturing strategies and adapted manufacturing equipment for continuous fibre reinforced composite components with outstanding potential for lightweight design approaches. The bandwidth of production scenarios covers highly automated, rate optimised production concepts for automotive applications as well as manufacturing concepts for extremely performance driven aerospace components.

In order to strengthen the competitiveness of composite structures the realisation of components with a high degree of structural integration and extended functionality play a major role. To reach this target research activities are focussed on the following aspects:

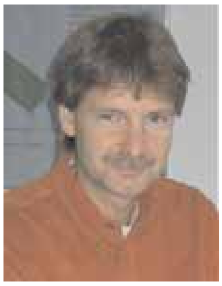
- Complete process chain from semi finished product to a net shape component
- Individual automation strategies
- Evaluation of manufacturing risks and productivity bottlenecks

Competences

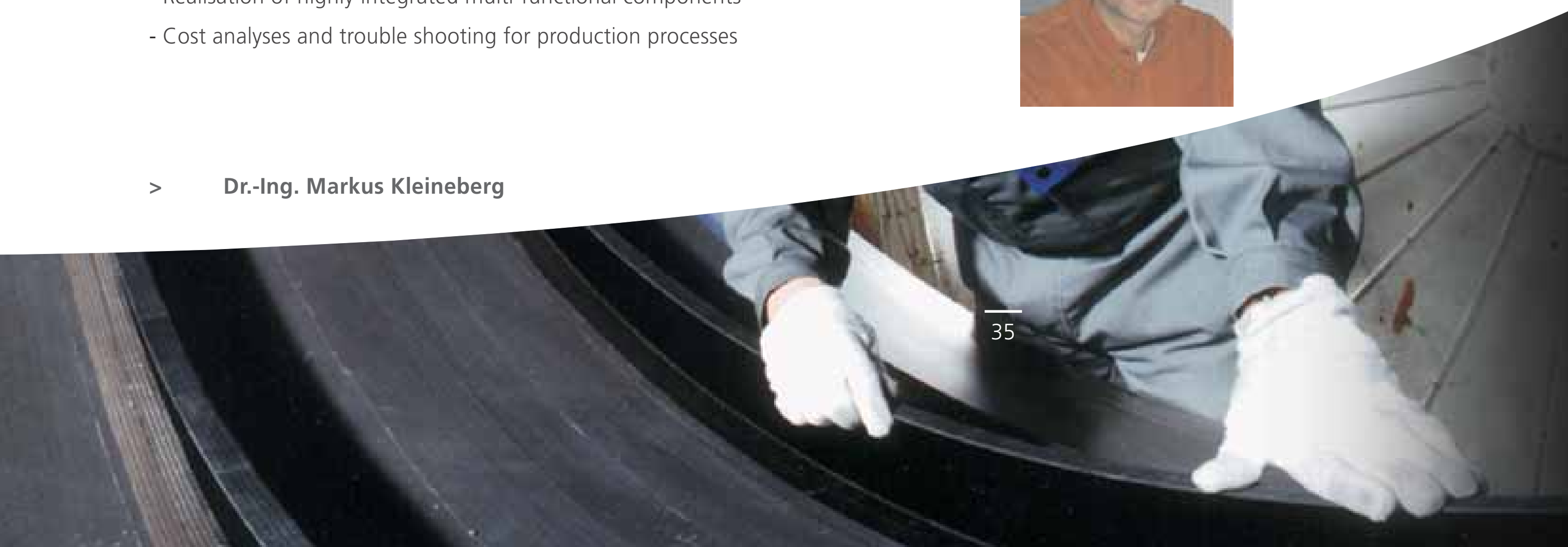
Within the last 30 years a wide variety of production concepts has been developed to address the demands of different boundary conditions. Besides the well known manufacturing approaches like filament winding, prepreg lay-up and RTM processing several innovative processing concepts have been developed to meet specific customer's demands. Promising approaches were based on microwave or induction technologies.

To increase cost efficiency and laminate performance special methods have been developed to reduce cycle times, process related energy consumption, scrap rate and e.g. matrix porosity. Furthermore, mould concepts to realise highly complex components and optimised process parameters for specialised resin and fibre products are typical research activities.

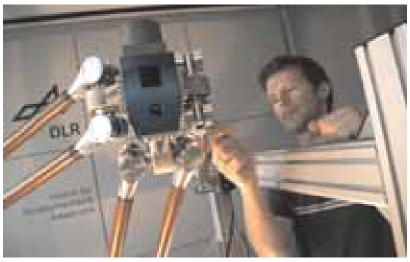
- Development of quality assured process chains for specific production scenarios
- Development of production optimised mould concepts
- Development of production optimised manufacturing equipment
- Manufacturing of demonstrators and test components
- Evaluation of innovative fibre and matrix products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



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



Adaptronics



Mission

The adaptronics pioneers 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 focuses their research on the following areas:

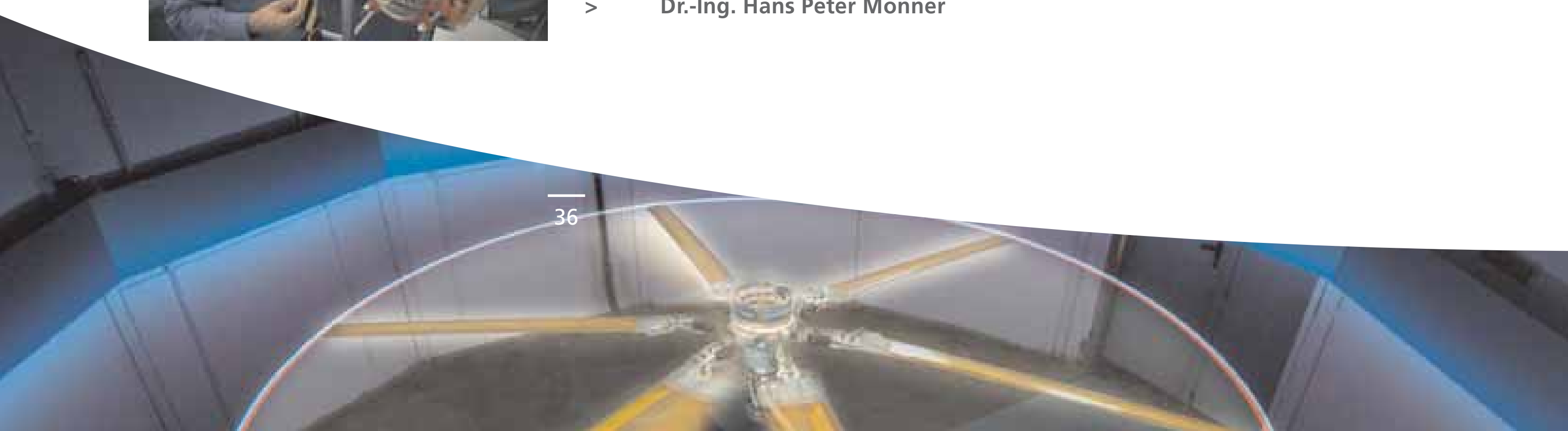
- active attenuation of vibrations (e.g. for parallel robots, antennas)
- active structural acoustic control (e.g. for CFRP fuselages, magnetic resonance tomography)
- Imorphing structures (e.g. for high lift devices, rotor blades)
- Stand-alone systems (e.g. energy harvesting, shunted systems)

Competences

The department of Adaptronics offers their 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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