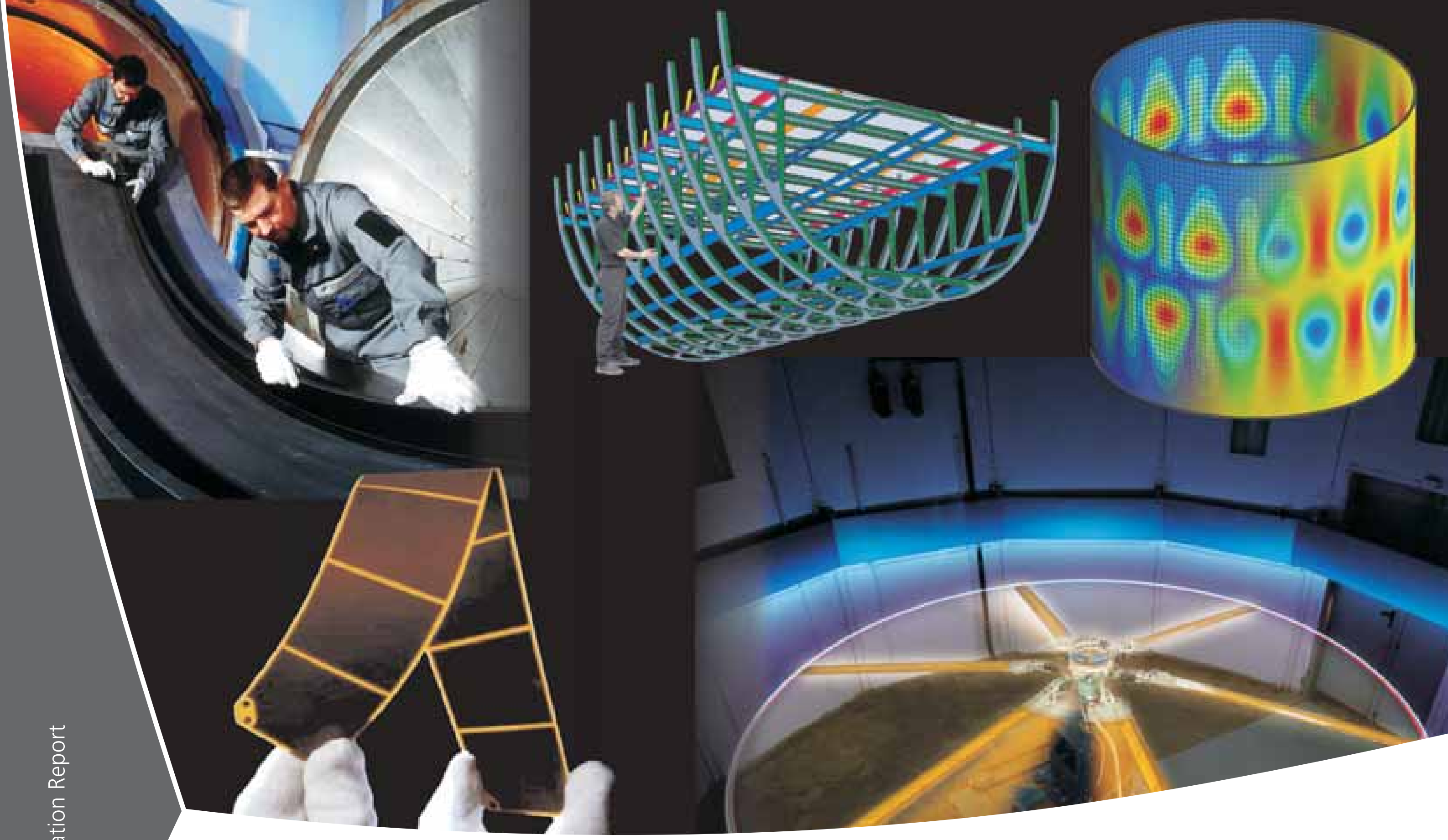
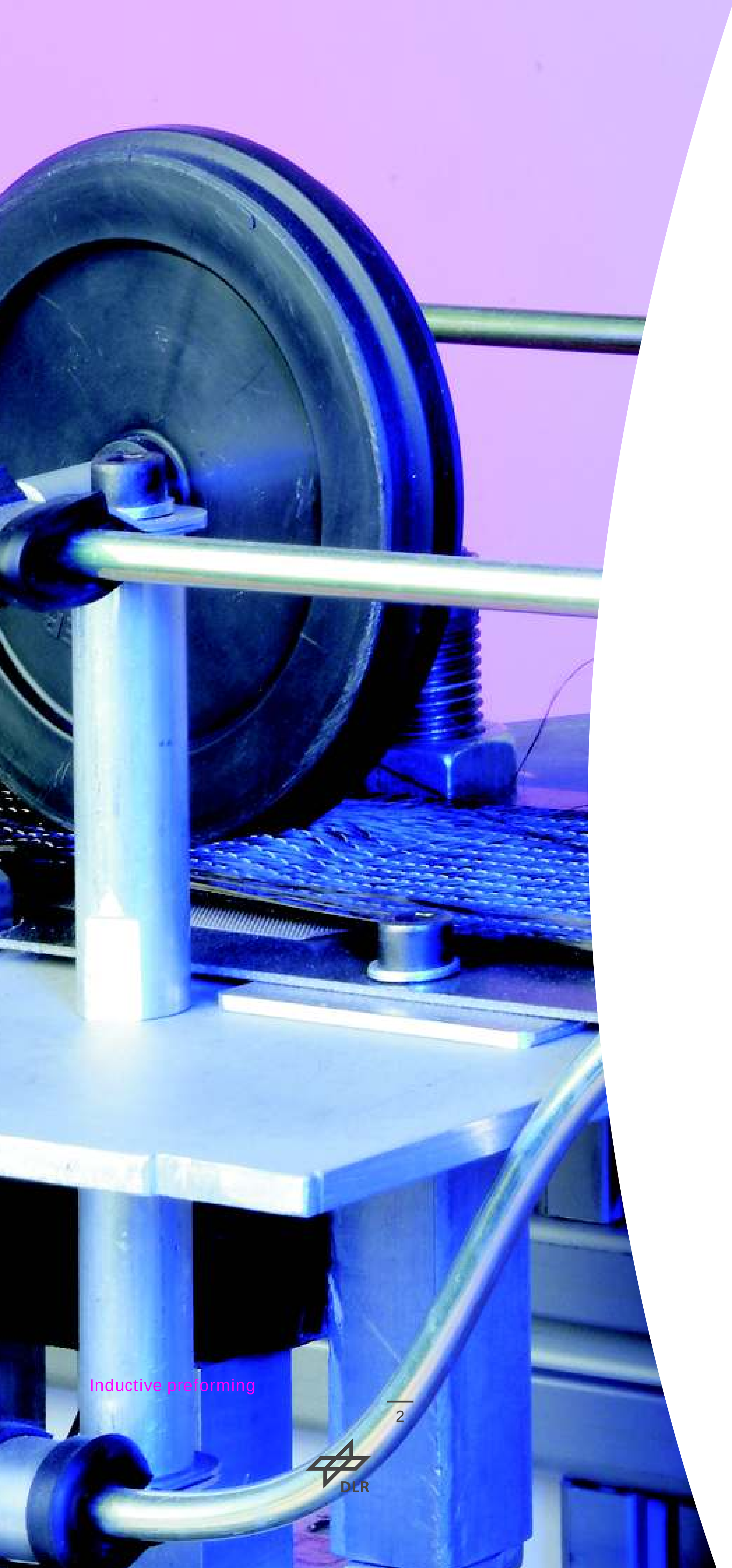


Innovation Report

Innovation Report 2008

Institute of Composite Structures and Adaptive Systems

DLR



Contents

Preface

The Innovation Report 2008 of the Institute of Composite Structures and Adaptive Systems gives an impression of the multifarious scientific issues we are dealing with along the entire process chain of the development of multifunctional lightweigt structures. A selection of new results of our research activities are presented.

In the light of the public discussion on fuel efficiency and environmental protection, the nanotechnology has become increasingly interesting regarding composite structures in order to further improve the performance and to support the automation of manufacturing technologies.

The Science Day 2008 of the Institute is devoted to a topic, the scientific base of which was laid many years ago and which has steadily developed: the nanotechnology in composite structures. This spring, we founded the Virtual Institute Nanotechnology in Polymer Composites directed by our institute and supported by the Helmholtz Association and in cooperation with the technical universities of Lower Saxony. Also this year – for the first time in history – we completed a carbon nanotube (CNT) actuator with solid electrolytes and unambigously demonstrated the CNT actuation effect.

Nanoparticles can improve the curing process of thermoplastic carbon structures effectively by selective inductive heating. The shrinkage of the matrix can be significantly reduced by adding nanoparticles while the strength of the matrix can be significantly increased. Recent research results of carbon nanotubes give reason to believe in the development of extremely efficient multi-functional materials.

Our current research portfolio comprises besides scientific support for aerostructures calculation and production the development of lighter structures for rail vehicles, ultra light space and morphing structures as well as the design of tools for their investigation and evaluation. In this report results are presented concerning new structures, the development of a simplified adaptive controller, and an improved method for calculating the residual strength of damaged structures.

Increased automation of carbon fibre composites production helps to reduce the manufacturing cost and to maximise the quality of components but requires the control of a complex process chain.

With respect to modern lightweight automated production technologies the Institute and DLR will significantly intensify future research activities, a plan that is also reported here.

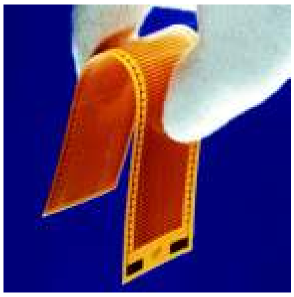
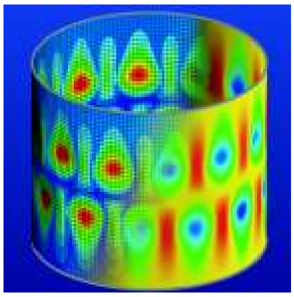
We wish you unflawed pleasure in reading this fourth Innovation Report. With special thanks to all the authors

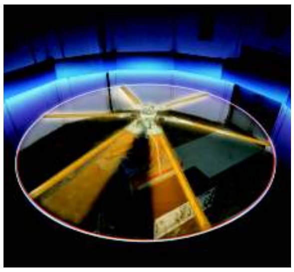
Prof. Dr.-Ing. Martin Wiedemann

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

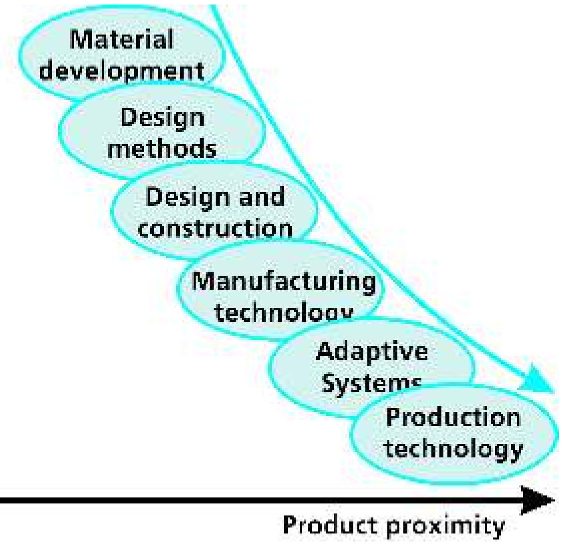
makes it the ideal partner for the industry, the DFG (German Research Foundation), research establishments, ministries and civil aviation authorities in all issues regarding development, design, compuational prediction, manufacturing, experimental testing, and qualification of lightweight structures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



Process Chain of Adaptable, Efficient Manufactured and Tolerant Light Weight Structures

The research activities of the Institute of Composite Structures and Adaptive Systems contribute to the entire process chain of the development of high-performance light-weight structures from the material selection to all relevant topics of the production of lightweight systems.The process chain comprises the material selection and development, fast and reliable design methods, the design and construction of lightweight structures including all questions of assembly, the manufacturing techniques, integration of new functionalities to make the structures adaptable, the topics of automation and reliable, quality assured production.

We provide our services to customers and partners in five research areas:

1. Multifunctional materials
- Development and exploration of novel injection resins
- Investigation of new textile semifinished products
- Influence of nanoscaled additives on material systems
- Integration of new functionalities into materials
- Piezo composites
- Nanotechnology in polymer composites
- Structural health monitoring (SHM)
- Non-destructive testing methods (NDT)
- Novel inspection methods
- Material modelling
- Material characterization and qualification
- Exploration of special materials

2. Structural mechanics
- Global design
- Fast and reliable methods for stability analysis
- Methods for impact analysis, fatigue, and residual strength
- Thermal analysis
- Multi scale analysis
- Macroscopic material modelling
- Probabilistic methods for material parameters
- Structural dynamics
- Weight optimization and mass estimation
- process simulation

3. Functional lightweight structures
- Multifunctional design
- Design rules for aircraft
- Design and construction of aerospace structures
- Shape variable structures, kinematic mechanisms
- Deployable structures
- Probabilistic methods for tolerance management
- Hybrid concepts
- Bionics
- Space structures

4. Composite Technology

- Novel manufacturing technologies
- Hybrid manufacturing
- Manufacturing with carbon nanotubes
- Composite repair
- Assembly
- Process automation
- Energy management in manufacturing processes
- Qualitiy assurance in composite manufacturing
- Realization of prototype structures
- Realization of partly flexible structures

5. Adaptronics

- Active vibration control
- Active noise control
- Active shape control
- Active structural acoustic control
- Simulation of adaptive systems
- Minaturization of hardware for adaptive systems
- Adaptive control methods
- Energy harvesting
- Vibroacoustics
- Adaptive composites
- Cost assessment for adaptive systems

More than 100 scientific, technical and administrative personnel of the Institute work in these research fields. The Institutes annual turnover is about 11 M€, more than 40 % of which originate from third party funding from industrial partners and national and international competitive research programmes.

The Institute is relevantly engaged in the 4th national aeronautical research programme. We coordinate SMARTLED, a project investigating adaptive high lift systems. Within the 6th and 7th European Research Frame Programme we are engaged in the Integrated Projects (IP) FRIENDCOPTER, NACRE, ALCAS, and MAAXIMUS. We contribute to numerous Level 2 projects like AISHA, COCOMAT, IMAC-PRO, MUSCA or MOJO. We coordinate SADE, the European Project for smart high lift devices for next generation wings.

SEVENTH FRAMEWORK PROGRAMME

We cooperate with Universities in several projects within the research programme of the German Research Foundation (Deutschen Forschungsgemeinschaft (DFG)), e.g. the Collaborative Research Project SFB 562 of the Technical University of Braunschweig "Robotic Systems for Handling and Assembly" and the research project "Structural Health Montoring through guided Lambwaves" with the Otto-von-Guericke University of Magdeburg and Helmut-Schmidt-University of Hamburg. We coordinate the Virtual Institute "Nanotechnology in Polymer Composites", a consortium of Institutes from the Universities of Braunschweig, Clausthal and Hannover.

Virtual Institute "Nanotechnology" in Polymer Composites"

We educate and train young people. 6 professors and 7 lecturers of the Institute support 6 universities with lectures in composite technology, structural mechanics and adaptronis. We supervise annually about 25 Diploma and Master Thesis and numerous practical trainings of students. More than 25 PhD students work with us.

Please contact:
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The "Spring-In" Effect - High Precision Manufacturing of CFRP Components

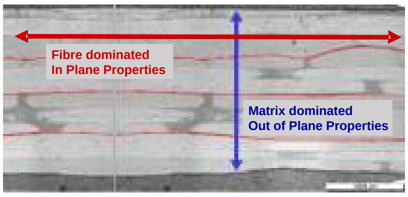


Fig. 1:
In-plane and out-of-plane laminate properties.

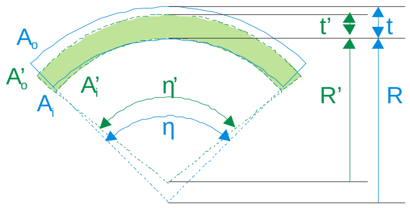


Fig. 2:
"Spring-In" effect on curved laminates.

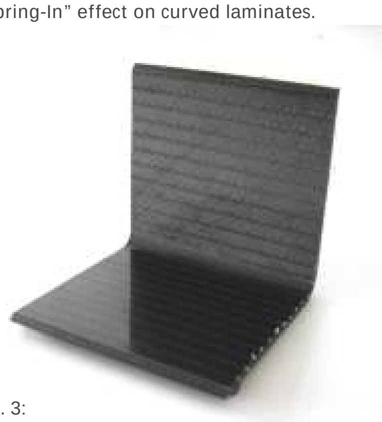


Fig. 3:
L-shaped coupons to determine "Spring-In" dependency on process parameters.

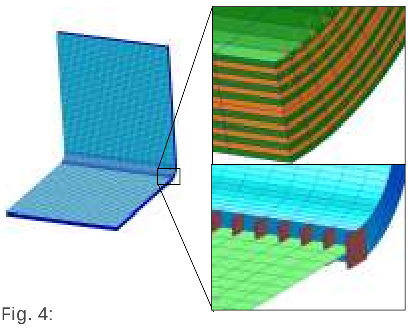


Fig. 4:
L-shaped coupon with 2D and 3D elements.

Motivation

High precision manufacturing of composite components is one of the major challenges for future composite applications. Geometrical component accuracy is a crucial cost driver because a lack of component accuracy leads to increased shimming effort or an expensive and time consuming mould redesign.

The "Spring-In" Effect

Apart from process and material irregularities there is a special, composite laminate specific effect called "Spring-In" that causes significant component distortions at curved composite elements. One of the major "Spring-In" effects is either caused by the different coefficients of thermal expansion (CTE) between in-plane and out-of-plane laminate directions or by resin cure shrinkage. It has been reported that laminate thickness and radius, laminate imperfections, moisture content, and mould-part-interaction do also affect the "Spring-In" effect but the order of magnitude is difficult to quantify. At curved profiles like frame segments e.g. a significant, "Spring-In" dependent, global distortion has been found in addition to the well known deformation of the profile cross section.

Counteractive Measures

A counter measure against "Spring-In" related problems is a "Spring-In" compensating manufacturing mould where all distortions are considered which, in turn, requires the prediction of the deformation behaviour of the composite component.

The problem is, that the deformation behaviour is dependent on several process and laminate parameters and is therefore to some extended unique for each manufacturing approach. It has been found that especially the fibre volume content (FVC) of the laminate and the gelation temperature are important variables.

To solve this problem a combined approach based on experimental investigations with L-shaped coupons and linear thermoelastic Finite Element analysis has been developed and validated at the DLR Institute of Composite Structures and Adaptive Systems. The experimental investigation with a special laminate set-up, a special resin system and the desired process parameters lead to the related laminate properties like out-of-plane laminate shrinkage and out-of-plane coefficient of thermal expansion (CTE). These parameters in turn are used to perform detailed FEM analysis of highly complex frame segments.

The simulation of the structural behaviour of a typical curved cross section requires the implementation of 3D elements in the curved section. In the planar area it sufficient to use 2D elements. Three layers of 3D elements per single ply are necessary to get reproducible and reliable results for the inner stress state.

The method extracing the laminate parameters from simple coupon tests and using 2D/3D Hybrid elements for analysis is now available and validated for the simple L-shaped coupons and for highly complex and curved parts like integral frame segments.

Experimental Analysis

A steel based mould material (Ni36) with a compatible CTE is used in the Institute of Composite Structures and Adaptive Systems for the manufacturing of the L-shaped coupons in order to avoid any secondary “Spring-In” effect. The coupons are manufactured by a Resin Transfer Moulding (RTM) process based on a low viscosity resin system and a dry fibre preform. The utilized closed mould has five different gap distances in the moulding area in order to analyse the effect of different Fibre Volume Contents (FVC) on the “Spring-In” effect . This enables the simultaneuous production of five L-shaped coupons with different FVC. The dwell time on the infusion temperature level has been varied between 180 °C and 110 °C in order to analyse the effect of different gelation temeratures.

As depicted in Figure 5, an increasing “Spring-In” effect has been discovered for reduced FVCs and increased gelation temperatures. Furthermore a linear dependency between the “Spring-In” effect and the FVC can be observed especially below 65 % FVC. Although gelation at low temperature leads to low “Spring-In” deformations, it has to be taken into account that a dwell time of more than 10 hours is required for gelation temperatures below 110 °C. At gelation temperatures of 180 °C only 10 to 20 minutes are required.

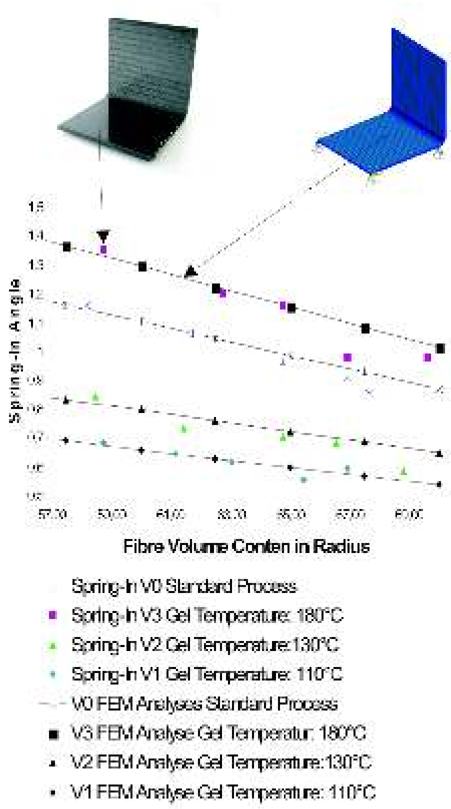


Fig 5:
“Spring-In” dependency on fibre volume content and cure temperature.

Numerical Analysis

Different fuselage frame configurations have been analysed based on the derived out-of-plane laminate properties. The results demonstrate that the simulation of local deformations of the frame cross section (e.g. flange angle) is very accurate. Furthermore, the global fuselage frame deformation (radius of the fuselage) depends on the local deformation of the cross section and on the distribution of unidirectional fibre reinforcements in the middle and inner straps as well. For some configurations the global radius increases and for other configurations the global radius decreases. The order of magnitude for the global radius variation related to “Spring-In”may be more than 10 mm for a fuselage radius of 2 m. If this deformation is not compensated in the mould it may cause severe assembly problems. A low gelation temperature may be used to reduce the “Spring-In” deformation by 50 %. However, the extended process cycle times are inefficient from a cost point of view and are therefore not acceptable.

Conclusion

The “Spring-In” behaviour of complex, curved structures like e.g. fuselage frame segments can be simulated with high accuracy by combining experimental investigations with linear thermoelastic FEM calculations.

These simulations can be used to design “Spring-In” compensating moulds suitable to manufacture high precision composite components.

> Dipl.-Ing. Markus Kleineberg (photo), Dipl.-Ing. Tom Spröwitz

Inductive Heating for CFRP Production

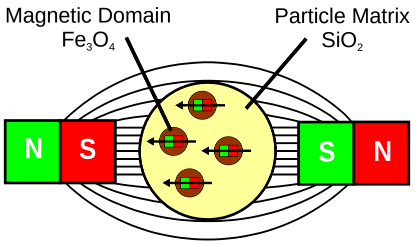


Fig. 1:
Principles of inductive heating: Thermoplastic matrix with embedded ferrite nanoparticles.

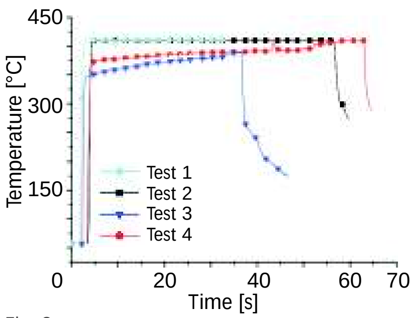


Fig. 2:
Heating Rates of ferrite nanoparticles.

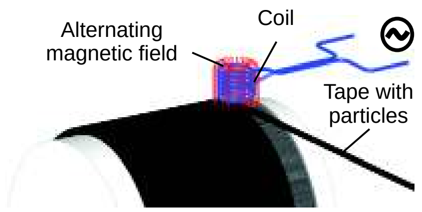


Fig. 3:
Principle of inductive winding technique.

In the near future the range of thermoplastic CFRP applications in aircraft and automotive industries will increase significantly. Especially in comparison to thermosetting matrices the thermoplastic matrix offers many advantages like higher damage tolerance (impact resistance), good repair properties and faster processing speed which is important for higher production rates. On the other hand, thermoplastic matrices with the same thermal stability as thermosetting ones requires much higher processing temperatures. The maximum processing speed of most continuous processes is therefore limited by the heat energy, that can be transferred at a given process speed. Inductive heating offers the potential to reach transferable energy levels far beyond conventional heating rates. Additionally, the well controlled energy input reduces the degree of oxidative degradation reactions in the matrix. Depending on the kind of the fibre semifinished products, two mechanisms for the inductive heating process can be distinguished:

1. Fabrics with thermoplastic matrix: The electrical energy can be transferred into a fabric preform due to Joule losses (contact resistance) as the fibres in different orientation are in contact to each other and entails Eddy currents. This process corresponds to an indirect heat transfer, i.e. from the fibres to the thermosetting matrix and is controlled by the heat conductivity of the components.

2. UD tapes or filaments with thermoplastic matrix: Inductive heating is inefficient if the fibres are electrically isolated by the matrix, which is the case by processing thermoplastic CFRP UD tapes or filaments. The solution is the embedding of ferromagnetic nanoparticles into the thermoplastic matrix. By applying an AC magnetic field the nanoparticles change their orientation which entails a direct energy input and very high heating ramps for the thermoplastic CFRP (see Figures 1 and 2).

Applications

In contrast to conventional heating the inductive heating process of thermoplastic CFRP modified by ferromagnetic nanoparticles offers many advantages like

- up to 1000 times faster than convective heating
- volumetric (especial for CFRP) and selective
- better energy control => better quality

Because of the fact that this process presupposes the usage of UD tape the most important applications are seen in the field of CFRP structures manufactured by filament winding, pultrusion and tape/fibre placement techniques (see Figure 3)

Prospects

The next step will focus on the development of the inductive winding technique to investigate the principles and most important process parameters. Furthermore the CFRP quality will be analysed in comparison to well known thermoplastic prepregs manufactured by conventional press technique.

> Dr. rer. nat. Thorsten Mahrholz (photo right), Dipl.-Ing. J. Mosch (photo left), Dipl.-Ing. T. Wurl, Dipl.-Ing. T. Ströhlein, Dipl.-Ing. M. Kleineberg

Automated Preforming of Composites

Economic aspects are of increasing importance in the CFRP manufacturing processes especially for parts with high production rates. Components, which were manufactured previously in costly manual work with prepreg technology, will be replaced by cheaper components produced in LCM-technology (Liquid Composite Moulding). Here manual work represents the substantial cost factor. For economic production it is important to minimize this factor. One option is to increase the level of automation. In order to demonstrate this potential by examples, the Institute of Composite Structures and Adaptive Systems has established the automated manufacturing of flat test plates with in average 30 % lay-up time reduction.

Fig. 1:
Robot with end-effector.

Main Task and Procedure

The task aims at using dry fabric material, cut by a computer controlled cutter to the size of 300 mm x 300 mm and adequately preformed, being automatically extracted out of a magazine and inserted in a corresponding tool by a robot avoiding any contamination and excessive material deformation. There are three main types of end-effectors which are used in industry to handle semi-finished fibre products:

- Needle grippers
- Adhesive grippers
- Vacuum grippers

Fig. 2:
End-effector with floating suction pads.

The use of effectors with air suction devices generating an air flow and hence a low pressure between the effector and the top surface of the pre-formed fabric has been deemed most suitable. Conventional suction cups excite an air-flow through the air-permeable fabric which results in an undesired simultaneous fixing of multiple fabric pieces, while needle and adhesive grippers lead to unacceptable fibre damage and fabric contamination respectively.

Another approach is the sensory optimization of robotic equipment. In this context, the robot identifies in a self-contained way by an optical system the fiber cutouts and accordingly the robot generates the lay-up by a defined position in the tool. For quality control the sensor will check via camera the fibre orientation and ondulation, so that the fabrication tolerances of the material can be compensated.

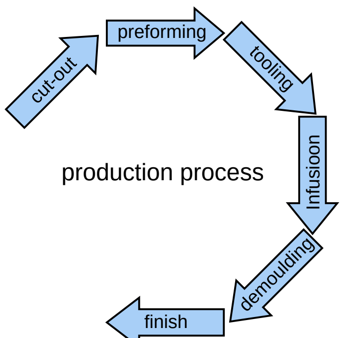


Fig. 3:
Production cycles.

Prospects

When considering the manufacturing process (see Figure 3) for composite structures it is obvious that even complex shaped components for cutting, removal and finishing have to be realized in a fully automated way. Tooling and infusion or injection procedures are semi-automated, but preforming is yet not an efficient automated process. For simple geometries the Institute of Composite Structures and Adaptive Systems has already developed manufacturing techniques to optimize preforming.

We also work at the parallel development of end-effectors for gripping semi-finished fiber products for the production of preforms. The challenge is the precise lay-up and consolidation of the fibre material and the subsequent processing of the preform on final contour. With this automized lay-up technique the complex reworking of the resin consolidated component is avoided and production cost can be further minimized.

> Dipl.-Ing. Heiko Assing (photo), Dipl.-Ing. Michael Hanke

Nanoparticle Reinforced Fibre Composites

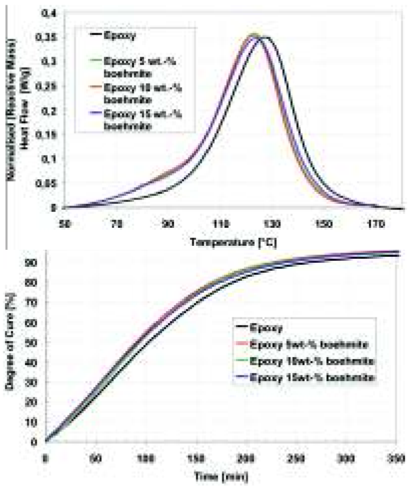


Fig. 1:
Reaction enthalpy and degree of cure (isothermal 80°C) of neat epoxy resin compared to nanoparticle filled resin (various filler contents).

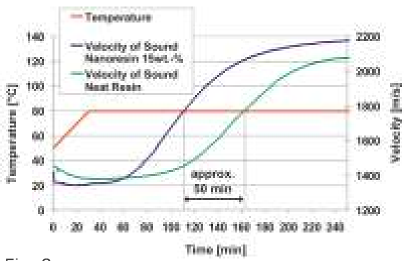


Fig. 2:
Ultrasound velocity signal of neat epoxy compared to the faster cured nanoparticle reinforced resin.

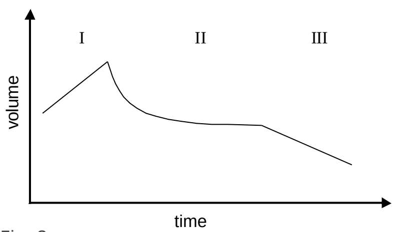


Fig. 3:
The three intervals of shrinkage during the manufacturing process.

Background

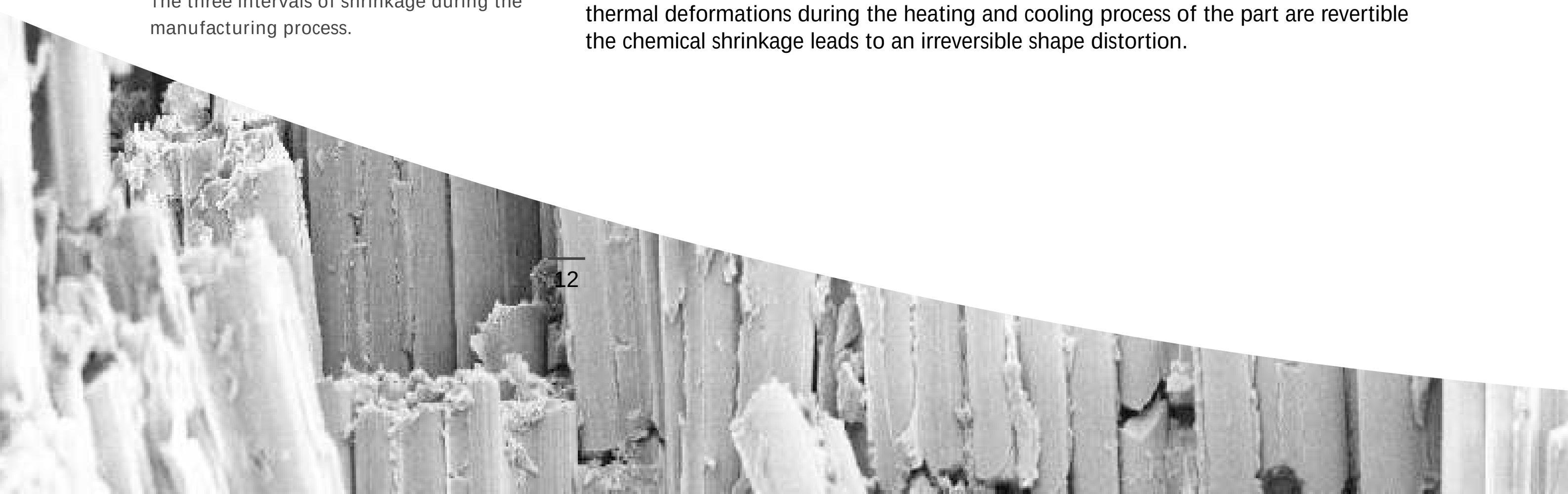
The material performance of carbon composites, especially the compression properties, manufactured by resin infusion technique does not completely reach the one, which is attained by prepreg processing. That deficit is mainly based on lower stiffness and higher shrinkage of the polymer system and therefore on higher residual stress in the laminate. Nanoscaled particles used as fillers promise to compensatethese deficits while retaining the resins injectability. At the same time the distinguishing coefficients of thermal expansion (CTE) are adjusted. By adding surface modified nanoparticles to the resin the goal of a stable dispersion and a narrow particle size distribution can be achieved. Depending on the average particle size remarkable improvements of the mechanical and thermal properties of the polymer are obtained. Hence, residual stress and compressive strength of the composites are exceedingly improved.

Particles and Curing Behaviour

Boehmite nanoparticles, differing in size, shape, and density have been analysed regarding their reaction kinetics and thermal and mechanical properties. Especially the influence of the surface modification (aminosulfonic acid) of the nanoparticles on the reaction kinetics and the degree of cure are investigated. Nanoparticles in general provoke an earlier starting reaction and higher degree of cure compared to the neat epoxy resin. The intensity of these effects depends on the crystallite shape of the nanoparticles as well as on their surface modification. In consequence, their density and heat conductivity change (Figure 1). For the investigation of the effects ultra-sound technique is utilized to observe the rubber to glass transition, i.e. the vitrification of the polymer. The inflection point of the sound velocity occurs obviously earlier for the nano doped resin than for neat resin. This phenomenon can be ascribed to superposing effects: the higher viscosity and the faster curing. The latter is attributed to the higher heat conductivity of the nanoparticles compared to the polymer. In consequence, the nano epoxy system is faster cross-linked. Moreover, the higher end level of the sound velocity points out the higher stiffness of the nanoresin (Figure 2).

Intervals of Matrix Shrinkage

The shrinkage of a reactive resin system indicates the volume reduction of a part. The volume reduction consists of three intervals (Figure 3) and is accompanied by a change of density. After the volume expansion of the liquid resin in the heating period (I) the chemical shrinkage (II) occurs. This includes the timespan of the whole hardening reaction starting at curing temperature, passing gel time and vitrification and ending with the maximum degree of cure at the chosen process temperature. The gel point hereby marks the end of pot life and the expiration of processability of the resin. Cooling shrinkage (III) is devoted to the temperature diminishment from curing to room-temperature. This behaviour is caused by the CTE of the cured resin. While thermal deformations during the heating and cooling process of the part are revertible the chemical shrinkage leads to an irreversible shape distortion.



The volume reduction before the gel point can be compensated by the replenishment of further resin compound. The chemical shrinkage after gel time is crucial. It is accompanied by the occurance of stresses, which negatively affect the mechanical properties of the final structure. For characterisation a measurement method is necessary, which records the volume diminution relevant for the manufacturing process and which enables the differentiation of chemical and thermal shrinkage. The required measurement method has to allow for a precise processing of the resin sample without significant interaction between sample and measurement system.

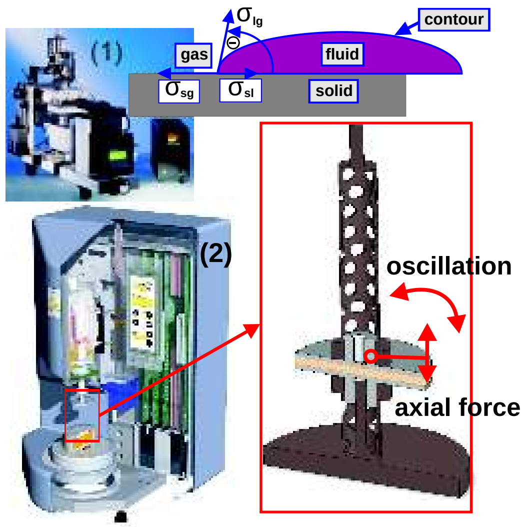


Fig. 4:
Measuring techniques: contact angle measuring device (1) and rotational plate rheometer (2).

An Advanced Analysis Method

The rotational plate rheometer (Figure 4(2))is identified as an appropriate measuring system. The axial force of the active plate can be kept constant during the measurement by controlling the distance between the plates. Thus the volume change of the sample can be recorded by tracking this distance starting at the gel time. It also allows the determination of the resin processing time period. The rheometrical shrinkage measurement is performed in the oszillation mode. The latter allows the analysis of both phases during the process, i.e. the liquid as well as solid resin. The marginal deformation of the oszillation allows the recording of the viscosity while hardly affecting the resin curing. The normal force between the plates is measured by a force transducer. The adjustment of the contraction force is realised by tracking the upper plate in vertical direction. The recorded curve reveals the characteristic intervals of the curing process. Both, the total shrinkage as well as its fractions, i.e. the chemical and thermal shrinkage can be determined.

An additional option is given by the contact angle measuring device (Figure 4(1)). Hereby a continuous video recording of the drop shape verifies the accuracy by excluding any possible distortions caused by the interaction between the measuring system and the sample. The visualisation of the shrinkage qualitatively verifies the data recorded by the rheometrical measurement. The combination of both methods comprises the possibility to extend the range of shrinkage measurement by the fraction of chemical shrinkage occuring before the gel point. Thus it is possible to characterise the influence of process parameters and matrix modifications to the overall shrinkage of the system.

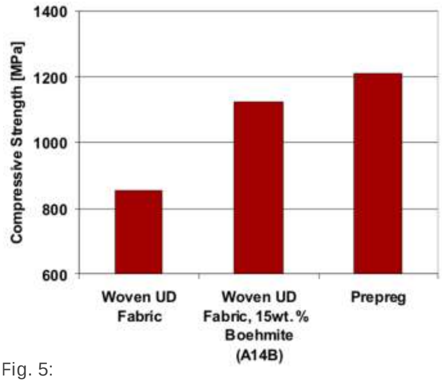


Fig. 5:
Compression Properties of nanoparticle reinforced composites compared to prepreg.

Mechanical Results

Nanoparticle reinforced resins offer a new, more elastic and stiffer matrix with a larger proportional range and a reduced shrinkage for carbon composites. Compared to prepreg, nanoparticle reinforced unidirectional laminates manufactured by injection technology show exceeding good results (Figure 5). Having in mind the ultrasound online monitoring technique, it is now possible to adjust the curing cycles to the respective particle and resin system which will lead to considerably higher performances. Due to these new matrices for fibre reinforced plastics and adapted curing cycles advanced carbon fiber laminates can be generated.

> Dipl.-Ing. Alexandra Fischer, M.Sc. Christine Arlt

Photronics© - Adaptronics with Optomechanical Functional Materials

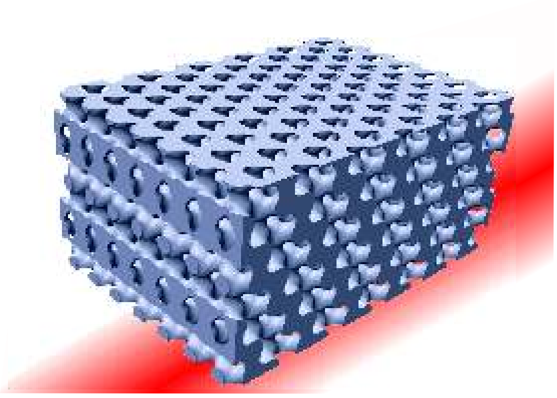


Fig. 1:
Photronic material system for high static and dynamic mechanical loads.

The structural integration of controller units in adaptive systems for active noise and vibration control is a fascinating vision (see also Innovation Report 2006). Using opto-mechanical functional materials, such as photostrictions, in combination with band gap architectures, it is possible to extend the actuating/sensing structural components with logical functions. Therefore in our interest are optically activated actuators and sensors and optical controllers. The concepts and the technologies to realize them are included by DLR´s coinage:

Photronics = Photons + Adaptronics.

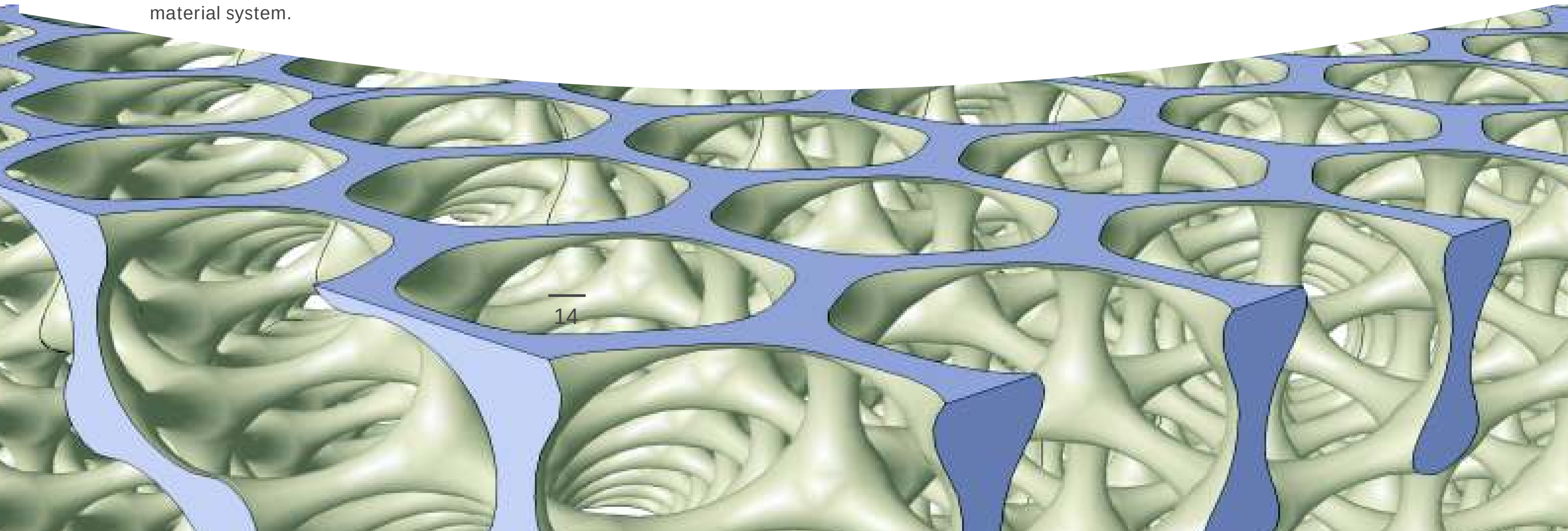
Photostriction is a superposition of the photovoltaic effect, that is based on the inner photoelectric effect, and the inverse piezo effect, that is mostly used in adaptronics for many applications. In photronic material systems (Figure 1) we use both the transversal as well as the longitudinal photo effect. With the increase of laser radiation intensity the actuators dynamic range can be extended. Furthermore photronic material systems have band gap properties such as photonic crystals. Due to their periodically-modulated dielectric constant they are organized into photonic bands which are seperated by gaps where propagating states are forbidden. From there photronic material systems are able to tailor light and the propagation of electromagnetic waves. In order to combine this optical transistor capability with a load carrying capacity the photronic dielectric skeleton corresponds to a diamond lattice (Figure 2). For three-dimensio-nal applications it is the most effective band gap architecture. All thin struts meet with an angle of arccos(-1/3)=109,47°. This arrangement guarantees a perfect three-dimensional load and stress distribution. The strut geometry differs just a little bit from manifold tetroids but break prerequisites of minimal surfaces: the mean curvature of the surface is not any longer zero. The design of the length and thickness of the struts depends on the required static and dynamic properties.

For active vibration control photronic material systems are directly located at the structurally force flow. These forces cause a lattice deformation, that passes the light in those areas where the optomechanical activation of reacting forces should take place.

Photronic components are nonlinear converters because their design considers the dispersion relation (band gap characteristics) such the actuator amplitudes are as large as possible.

> Dr. Jörg Melcher (photo), Eyleen Mund and Daniel Fingerhut together with
Dr. Wolfgang Braue, Dr. Bernd Hildmann, DLR Institute of Materials Research,
Prof. Dr. Jürgen G. Heinrich, Institute of Nonmetallic Materials, TU Clausthal, and
Dr. Jens Günster, CIC Ceramic Institute of Clausthal GmbH

Fig. 2:
Diamond lattice of a photronic material system.



Centre of Lightweight Structure Production

With the increasing demand to reduce fuel consumption, the attractiveness of lightweight structures is further growing. Application especially of composite materials in structural parts is increasing. Boeing advertises the new B787 as aircraft "with unmatched fuel efficiency, resulting in exceptional environmental performance" supported by "as much as 50 percent of the primary structure made of composite materials". Airbus has taken the challenge and prepares the A350 with even slightly more composite parts. Car manufacturers and other mobility branches are searching for more applications of composite materials with a further reinforced need to produce the related structures in cost efficient manner. However, the presently known and proven production techniques are coming to their limits with respect to development cycles, process-speed, cost and reproducible quality. The latter is dominating the mechanical properties, which makes composite materials competitive to metal alloys. The today's limits can be overcome mainly through intensified automation. It is mandatory for the success in composite structures production to completely observe and consider all aspects of the process chain:

- the material components
- the sizing and design compatible with production techniques and assembly needs
- the cost efficient production techniques suitable for the parts
- the automation techniques with integrated quality control
- the assembly and system integration

Therefore the Institute of Composite Structures and Adaptive Systems has set up a scientific initiative for lightweight structure production which will enhance the research portfolio developed since decades by the elements of qualification, serial adaption, automation, and the aspects of assembly and system integration, (Figure 1).

The major challenges for the improved composite structure production technologies will be, to manufacture efficient, fast and with high quality:

- large parts with high level of integration, e.g. fuselage shells or wing panels
- small parts with complex geometries and high production rates
- multifunctional parts, e.g. with active structural acoustic control or EMI-protection

Experiences of the past have shown, that the development of future production technologies must be done close to the scale of real structure parts and under consideration of typical and relevant industrial conditions. To ensure the best transfer of research results into industrial practice the Centre will establish subsidiary branches in Stade and Augsburg, locations, where production of composite structures has already a long history, see Figure 2. The Centre will grow in the next five years with up to 100 scientists and technician. The Centre will be supported within the DLR by the complementary competencies of the Institute of Structures and Design and the Institute of Robotics and Mechatronics. The Centre will be supported by the DLR with own funding, by the industry with project-agreements, it will work in cooperation with related Fraunhofer institutes and with the support of the regional governments in Lower Saxony and Bavaria and the Ministry of Commerce and Industry of Germany. The total budget for the next five years including investments and project work is about 130 M€. With the foundation of the new Centre of Lightweight Structure Production the DLR will support Germany's leading role in the development of high performance carbon structures with low cost and effectively contribute to the successful and wide application of carbon structures in the future.

> Prof. Dr.-Ing. Martin Wiedemann

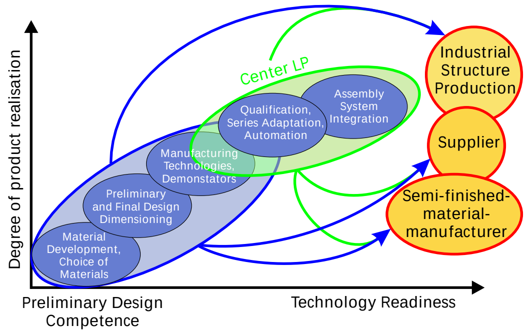


Fig. 1:
The enlarged DLR research portfolio for CFRP structure technologies.

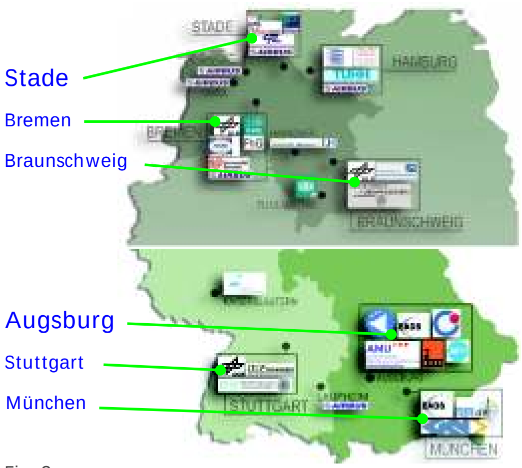


Fig. 2:
Subsidiary branches of the new Centre of Lightweight Structure Production.

Development of a CNT-Based Actuator Using Solid Electrolytes

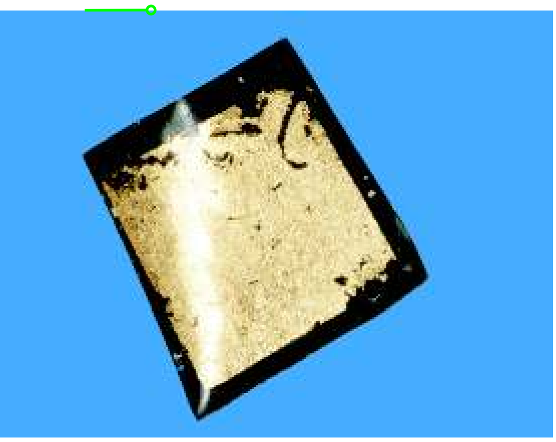


Fig. 1:
Specimen of CNT-based actuator with solid electrolyte.

Objectives

Actuators based on carbon nanotubes (CNT) have the potential to generate high forces at very low voltages. The density of the raw material is just 1.33 g/cm^3, which makes them well applicable for lightweight applications. Moreover, active strains of up to 1% can be achieved - due to the CNTs dimensional changes on charge injection. In combination with the high stiffness of individual tubes the generated stress of such actuators is calculated to be up to two orders of magnitude higher than that of state-of-the-art piezoceramic actuators. In order to work as actuators the nanotubes have to be arranged and electrically wired like electrodes of a capacitor. Fields of potential applications for such actuators are any kind of switches, and shape control in the field of adaptronics. Major research has to be done in the fields of manufacturing of stiff CNT structures and the integration of solid electrolytes into the CNT matrix. In recent years the characteristics of CNT-based actuators has been looked at for liquid electrolytes only. Since those are not suitable for integration into structures, there is a need to investigate the same responses for solid electrolytes. The Institute of Composite Structures and Adaptive Systems recently presented a CNT-based actuator set up which comprises solid electrolytes but still shows the characteristic electrical and electromechanical properties of similar specimen with liquid electrolytes.

Fig. 2:
Test setup for the characterization of CNT based actuators with solid electrolytes.

Specimen with Solid Electrolyte

The CNT specimen that were tested are so called Bucky-Paper, which are produced eather by vacuum filtration or by casting of a dispersion. In order to increase the amount of available ions some phosphoric acid was added to the CNTs. Nafion was used as solid electrolyte. Special coating techniques allow to build a composite of CNTs and Nafion. On top of this Nafion layer a gold layer is placed, which acts as counter electrode. Similar to actuators with liquid electrolytes, such a composite has two electrodes, where just one of them is made of CNTs and only this layer is expanding on charge injection.

Such a composite can be investigated either as bimorph bender using the in-plain strain generation of the CNT layer in combination with the bending coupling or as actuator working in thickness direction of the composite. In the latter case the displacements that are generated are much smaller, whereas the effect of expansion can be measured directly without utilizing any coupling. In order to do so a special test rig has been installed, which features a displacement sensor with a measuring range of just 80 µm. This test setup makes sure, that the measured effects are not disturbed by other effects like volume change due to mass transport within the solid electrolyte.

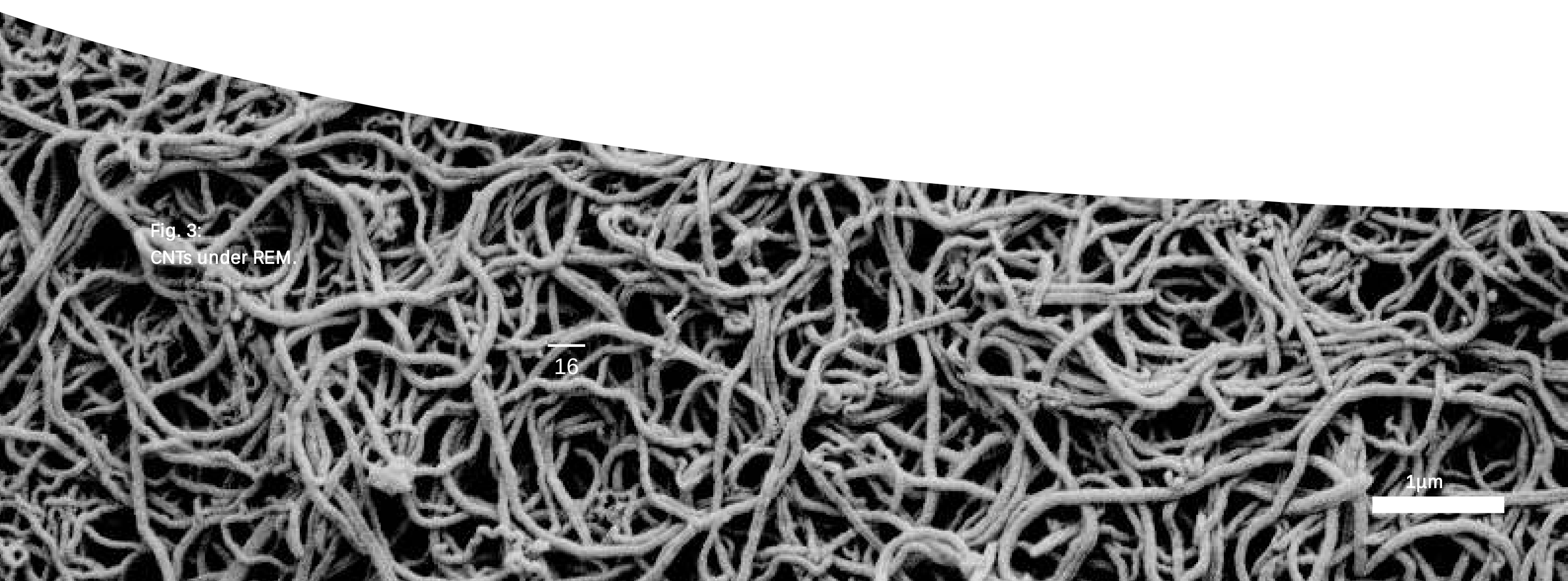


Fig. 3:
CNTs under REM.

Testing Procedure

Several tests are required for the complete characterization of CNT-based actuators in general. The test procedure includes the measurement of electrical as well as electromechanical system responses on different excitations. Due to the non linear behavior of CNT-based actuators there is a need for step responses at different voltages. Positive and negative steps result in a positive displacement. Also the electrical response is of importance. A major capacitive component in the system behavior has to be proven. Otherwise the effect may be due to thermal expansion, which is not the type of actuation we are looking for. This analysis can be done either by the admittance or the step response of the current on a voltage step.

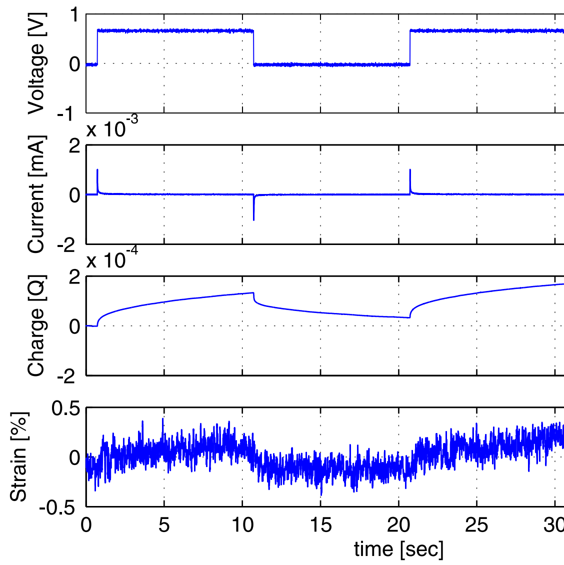


Fig. 4:
System response of CNT-based actuator with solid electrolyte.

Experimental Results

Specimen that were manufactured by slightly different methods were tested. The major challenge is the manufacturing of a composite, with a desired interface between CNTs and electrolyte.

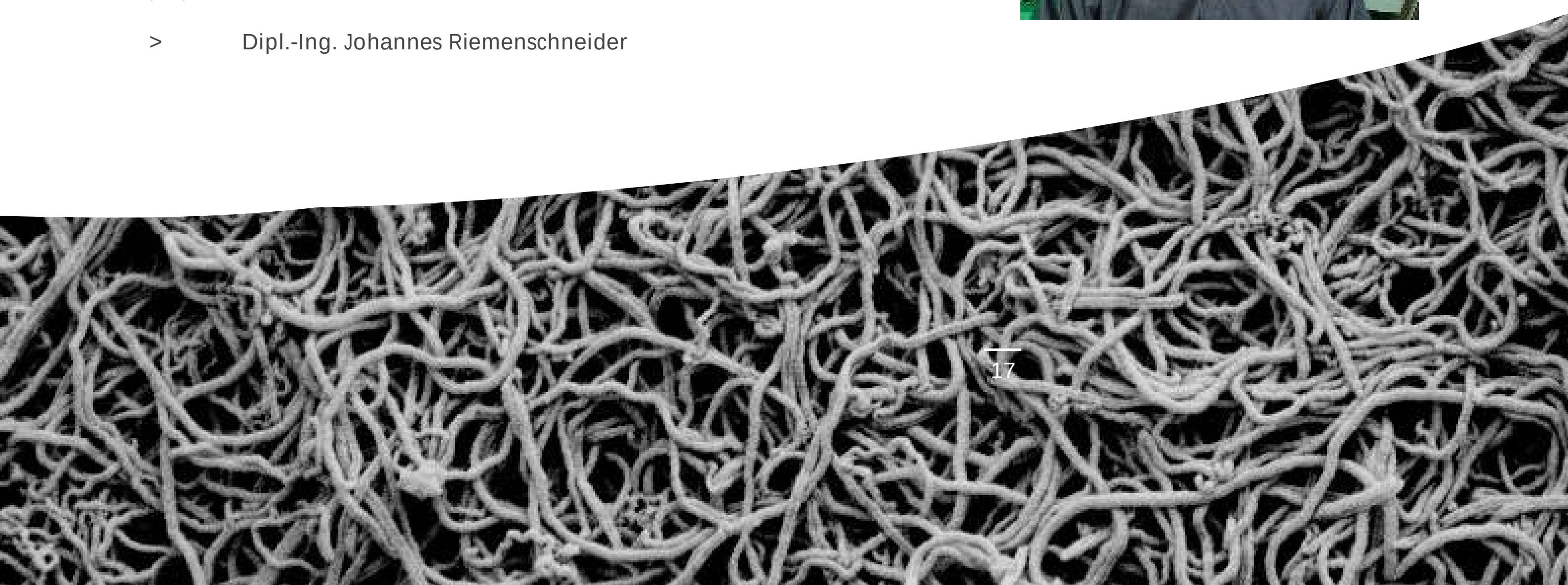
Finally, several specimens showed the expected characteristics: Starting from a voltage in the range of zero any change in the voltage results in an expansion of the nano-tubes. This could be shown in the step responses and the phase shift for excitations at different voltage bias. Also the desired response of the electrical part of the system could be proven. The step responses of the current show decreases looking like an exponential function, the admittance is showing a linear increase in the double logarithmic scale, whereas the phase is close to 90 degrees. This is the characteristic capacitive behavior.

Outlook

Looking at these promising experimental results it is important to collect more data of similar specimens and to show more dependencies - e.g. by an R-curve. The transient dynamics of the system looks somewhat different than it was known from the systems with liquid electrolytes: The electrical response seems to be much quicker than the mechanical response. The additional data will help to adapt the model, which was set up for liquid electrolytes.

Besides these activities it is very important to work - together with partners - in building macroscopic structures, that consist of CNTs, but still show the outstanding properties, which have been demonstrated and calculated for individual tubes.

> Dipl.-Ing. Johannes Riemenschneider



Smart Leading Edge Device

Fig. 1:
State-of-the-art high lift system in deployed position (A320).

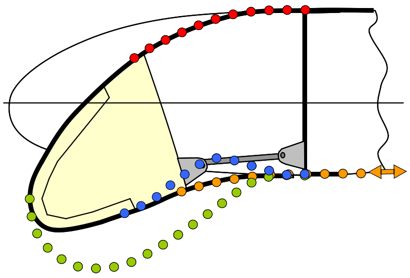


Fig. 2:
Schematic view of various concepts for realization of a Smart Leading Edge Device.

Commercial airplanes need to adapt their wings in flight to meet different requirements such as high lift performance during take-off and efficiency during cruise flight. State-of-the-art high lift systems consist of movable control surfaces which increase high lift performance in their deployed position. Typical devices are slats and fowler flaps which are supported and driven by complex mechanical systems. This concept offers the required aerodynamic performance and relies on proven technology. Figure 1 shows the state-of-the-art high lift system of the Airbus A320.

Innovative High-Lift Concepts for Next Generation Wings

To meet the ambitious goals defined in the VISION 2020, technologies to consequently reduce drag will be necessary. Most experts agree that laminarisation is the only technology which has the potential for step changes in drag reduction within a suitable timeframe. Thus it is probable that the next generation of wings will employ high aspect-ratios with slender profiles like already investigated e.g. within the project NACRE under the acronym HARLS (High Aspect-Ratio Low Sweep). But conventional high lift devices do not provide the high quality continuous surfaces that laminar flow requires. Seamless and gapless high lift devices especially at the wing leading edge are a mandatory enabler for future wings of significantly increased aerodynamic efficiency. Additionally, the construction space in the next generation wings is limited due to the employment of slender profiles. Therefore high lift systems based on conventional concepts will require even more complex and compact mechanics which will lead to severe weight penalties.

The Challenge for the Structural Design

Smart structures technology offers the potential to both, reduce complexity and to fullfill the surface requirements. However, the challenge for the structural design of smart structures is the combination of the conflicting requirements of lightweight design and shape control under aerodynamic loads . Due to the required deformability of smart structures in terms of compliant mechanisms, traditional design rules for conventional lightweight design are no longer applicable. Regarding the enormous amount of design parameters provided by composite materials, advanced optimization strategies are necessary.

Presently the smart leading edge is in the focus of investigations in the corresponding projects SADE and SmartLED. While well-known concepts for shape control of a wings cross-section rely on elastic skins supported by complex kinematics, the innovation of a new Smart Leading Edge approach is a more load carrying skin structure. Selective deformable substructures like fold cores provide corresponding elasticity for effective activation and stiffness to keep the desired contour. The more load carrying skin leads to load reduction of the actuation and kinematics which in most concepts replace the conventional rib. The development of simple, lightweight kinematics in terms of compliant mechanisms as well as skin materials with controllable stiffness will be a key issue in order to deform the smart skin in the desired manner.

> Dipl.-Ing. Markus Kintscher

Process Simulation of Composite Resin Curing

State-of-the-art technologies of carbon composite curing does not provide features for online monitoring of the polymeric reaction within the component, therefore strong exothermic reactions of the resin as well as energy losses by massive tools may lead to quality loss. In order to reduce residual stresses and deformations, a homogeneous tempering of the component is often ensured by slow heating and cooling cycles. This in turn leads to long process times, high energy consumption and processing costs.

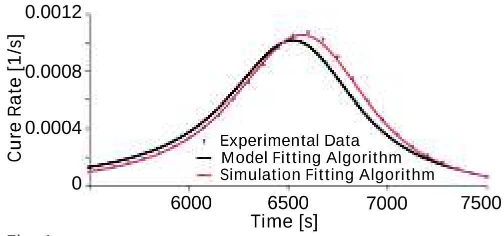


Fig. 1:
Estimation of cure model parameters by different fitting algorithms for dynamical DSC measurement.

Quality Assurance by Process Simulation

Process simulation is very promising to predict the component properties for a given cure cycle. Moreover, it provides a basis for a comprehensive process optimization to minimize cycle times while obtaining similar or less residual curing stresses and deformations. In order to provide numerical models for curing simulation and make them ready for industrial application, research is conducted in different fields.

In a first step, the reaction kinetics of thermoset materials is characterized. On the one hand standard Differential Scanning Calorimetry and Rheometer measurement systems are used to determine the glass transition temperature and viscosity of the resin as a function of curing temperature and degree of cure. On the other hand, the given measurement data are studied for an extended interpretation as well, e.g. to estimate the gelation point. Thereupon common kinetic models are enhanced for selected resin systems, and techniques are developed to derive their associated parameters (Figure 1).

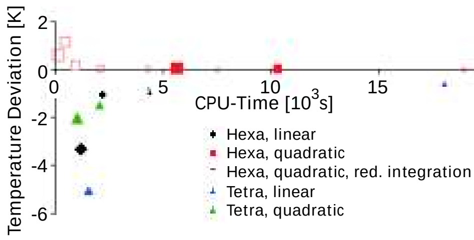


Fig. 2:
Convergence study of thermo-kinetic models (resulting CPU-time and model precision for varying finite element type and size).

Secondly, these curing models are implemented into commercial finite element software via subroutines. After verifying the simulation of the reaction kinetics against analytical solutions, modelling guidelines are derived for the coupled thermo-kinetic simulation of the pure resin with respect to the appropriate element type, degree of discretization as well as the required integration method and time step size (Figure 2).

Applying this simulation method, the influence of relevant boundary conditions, such as the temperature distribution within RTM moulding tools, can be investigated by analyzing the computed temperature fields and fields of degree of cure (see resin block example in Figure 3). In order to optimize the tool shape and energy distribution for relevant components, optimization procedures can be applied to reach minimum process time while avoiding overheating as well as assuring uniform distributions of temperature and degree of cure.

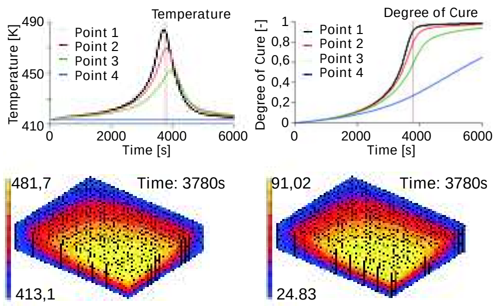
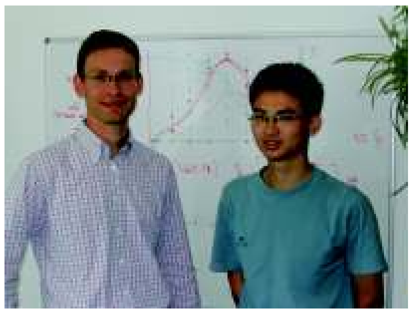


Fig. 3:
Simulated temperatures (left) and degree of cure (right) for a resin block sample.

A Comprehensive Prediction Method

Further research will focus on the determination of cure shrinkage and mechanical properties, which are functions of temperature and degree of cure. After considering these parameters within a coupled thermo-kinetic-mechanical simulation, the computed results – residual stresses and deformations – are to be validated against experimental results. Within this context investigations on appropriate methods for stress measurement are a great challenge. Finally, the process simulation shall provide a comprehensive method to predict the degree of cure, shrinkage, spring-in and residual stresses and therefore support the design process as well as the prediction of composite properties due to their curing process.



> Dipl.-Ing. Tobias Wille (photo left), M.Eng. Xiaohui Yang (photo right), BAMTRI Beijing, Dipl.-Ing. Alexandra Fischer

Deployable Membrane Antennas

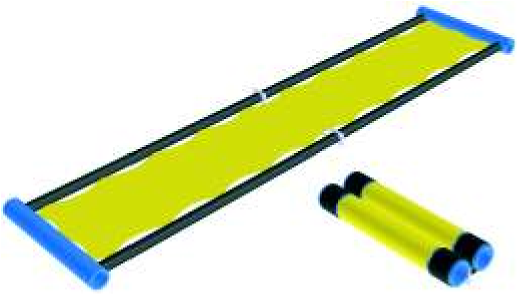
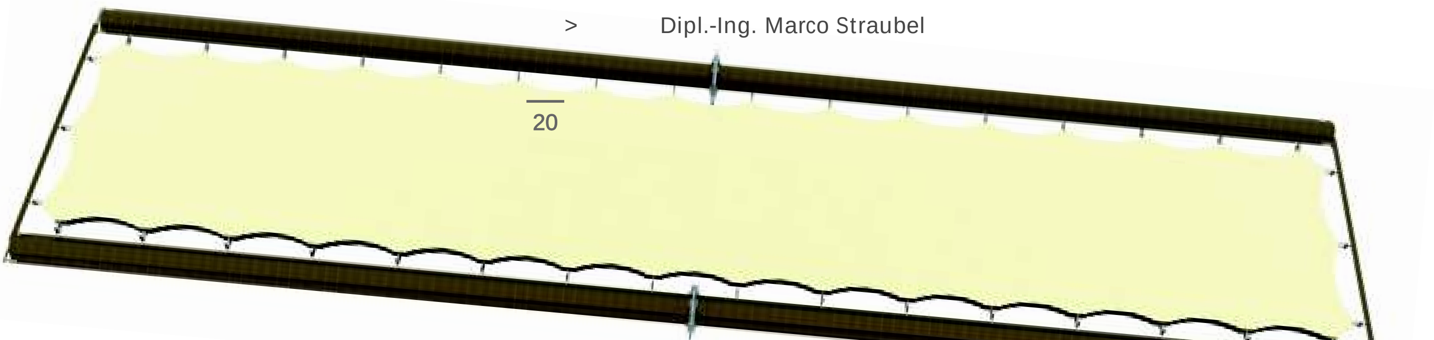


Fig. 1:
Proposed membrane antenna in deployed and stowed configuration .

Fig. 2:
Boom to spacecraft interface in closed and opened configuration.

Fig. 3:
Prototype of a hybrid inflatable/deployable CFRP boom for deployable space structures.

Fig. 4:
CAD model of the planed sub scale breadboard construction.



Huge Antennas for Low Frequency Bands

Current discussions on climate change and its direct and indirect consequences create a new demand for low-cost earth observation systems for monitoring indicators of global change. Space borne, low frequency radar systems are promising for the observation of the entire earth. Since low radar frequencies can partly penetrate the observed surface, thickness measurements of ice shields, monitoring of tectonic activities, or even of ocean currents, are possible.

Huge antenna areas of more than 40 m² are required to provide a sufficient performance for low frequency bands. Such antennas would weight several hundred kilograms if state of the art technology was applied. However, the launch weight of a satellite has a dominant impact on the overall mission costs. Thus, the development of a new lightweight antenna design with competitive accuracy and robustness is required.

Concept and Design

Flat array antennas are a proven concept for space borne radar missions. In contrast to parabolic antennas, the needed flat surface can be simply provided by tensioned membranes with surrounding frames. The use of membranes instead of hard panels leads to a massive reduction of mass and to a simpler storage of the antenna: Rolling or folding is possible. To comply with these membrane capabilities a rollable lightweight frame has been designed. Figure 1 illustrates the intended design and deployment concept. The frame consists mainly of two hybrid inflatable/ deployable booms (Figure 2) and two hollow cores. The design of the deployable booms includes two new aspects: Deployment inhibiting velcro tapes that suppress the self deployment tendency of the boom, and an internal bladder than can be inflated to deploy the boom in a controllable manner. Additionally, the cores are necessary to support the coiled booms and the membrane in stowed configuration. In deployed configuration they act as part of the structure and interconnect the deployable booms to each other.

The design of the interfaces between the morphing booms and the spacecraft is driven by the deployment functionality of the antenna. As the deployable booms change their cross section during deployment, an interface is required that can follow this deployment but can also transfer the load from the antenna to the spacecraft. Figure 3 shows the design of the morphing bearing that is designated for the current concept.

Prototype

A deployable sub scale prototype will validate the concept. Although downscaled to a 1:3 scale, the dimension of this breadboard will still be 6 m x 1.4 m (see Figure 4).

Manufacturing and assembly will be completed by the end of this year. In addition to deployment tests, static surface measurements and dynamic tests will be performed to identify the potentials of this concept.

> Dipl.-Ing. Marco Straubel

ESA Technology Reference Study GEOSAIL - Solar Sail Demonstrator

GEOSAIL Mission

Recently, an industrial team funded by the European Space Agency (ESA) elaborated the future potential of the solar sail propulsion technology. Solar sails work propellant-less. They are therefore very attractive candidates for energetically demanding missions such as Solar Polar Orbiter or Interstellar Heliopause Probe.

The overall purpose of ESA Technology Reference Studies (TRS) is to focus the development of strategically important technologies that are of likely relevance to potential future science missions. The ESA TRS-study GEOSAIL aims at the survey of Earth's magnetosphere; it became selected as a cost-efficient precursor demonstration to pave the way for future deep space solar sailing missions (Figure 1). Here, solar propulsion is established to keep the scientific payload permanently located within a non-Keplerian orbit. The ultimate goal of the study is to identify the minimum nearterm technologies, and to provide requirements of these technologies in a 5 year time frame.

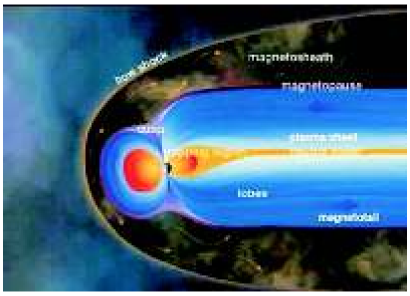


Fig. 1:
Schematic of Earth magnetosphere (source: ESA) and artist's impression of a GEOSAIL square configuration.

Solar Sail Technology

Since solar sails utilise the tiny impulse of solar photons for propulsion, very large and extremely light membrane structures are required to develop a significant momentum. For GEOSAIL, a 50 m x 50 m square configuration was proposed as a baseline concept to provide a characteristic acceleration of approximately 0.1 mm/s².

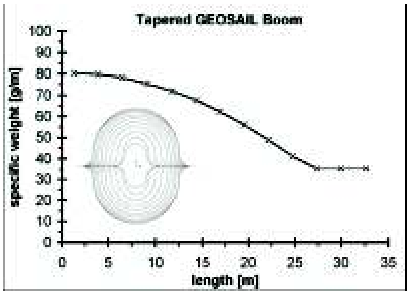


Fig. 2:
Exploration of mass saving potentials by a tapered boom design.

Based on past achievements, the major contributions of the DLR Institute of Composite Structures and Adaptive Systems were dedicated to the exploration of mass saving potentials for the sail assembly module, especially for reelable composite booms and very thin sail films. Figure 2 gives an impression of the results of the boom weight optimizations. Due to the GEOSAIL concept, an assembly of four 35 m long deployable booms is required to span the sail segments. In contrast to a constant cross-section design, which was estimated at a specific weight of 102 g/m, a tapered boom design was identified to spare a significant -18 % contribution of the boom assembly mass budget. The development of attitude and orbit control systems (AOCS) is another important aspect for solar sails that was covered within the GEOSAIL study. Figure 3 depicts the results of a computation to get information on the first mode of vibration and the first natural frequency of the sailcraft. Both are relevant information for the control system design. As can be seen from the analysis results, the booms together with the sail segments oscillate in a cantilever bending mode. The related eigenfrequency amounts less than 0.06 Hz.

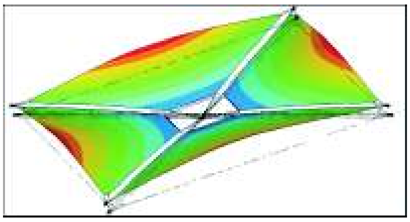


Fig. 3:
Modal analysis of the GEOSAIL.

Outlook

The GEOSAIL TRS made clear that the selected mission profile is technologically feasible. As a conclusion of the study the deployable composite boom concept of the DLR institute was finally ranked at a Technology Readiness Level of 3 to 4, which is fully in line with the strategic interests of European solar sail developments. However, further developments are under preparation to comply with a potential mission launch date in the next decade.

> Dipl.-Ing. Christoph Sickinger

Signal Analysis for Degradation Testing of Thick Composites

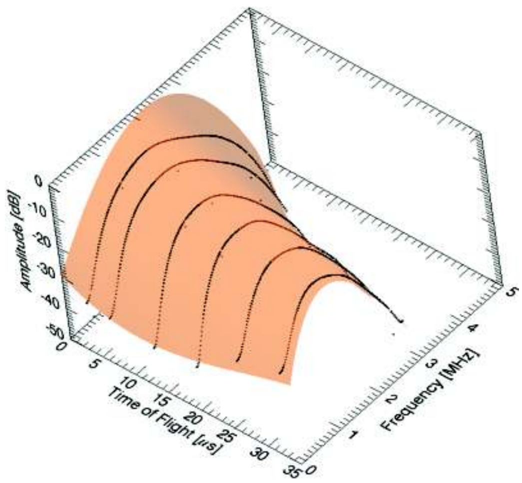


Fig. 1:
Spectral loss over thickness (time of flight).

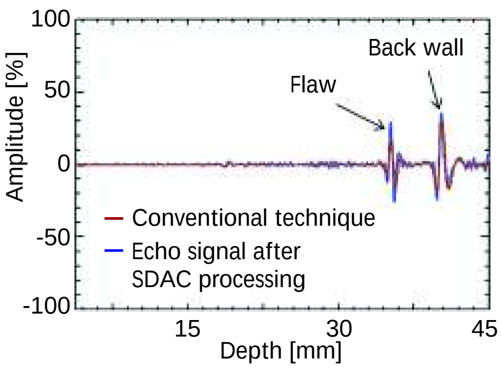


Fig. 2:
Comparison of different A-Scan techniques

Ultrasonic inspection is widely used for non-destructive testing of Carbon Fibre Reinforced Plastics (CFRP). However, the heterogeneous build-up of composites severely affects the sound propagation. Low frequencies have a good penetration. However, the closer the ultrasound wavelength comes to the specimen's typical grain size, the more is lost. Additional variable amplification (Distance Amplitude Correction, DAC) usually compensates only for the general loss of sound pressure the order of 1 dB/mm. However, it neglects the spectral shift towards low frequencies after long sound paths. Figure 1 shows, that after a time of flight of 30 µs (approx. 45 mm in pulse-echo), the centre frequency dropped from 2.5 MHz to below 1.5 MHz). Thus, detection of small flaws is limited, because they require high frequency ultrasonic signal. Consequently, small and deep defects (near to the back wall) are underestimated in conventional ultrasonic testing, compared to flaws close to the upper surface.

In order to compare and evaluate two echoes from different reflectors both in signal amplitude and also in signal shape, it is therefore desirable to counterbalance the spectral deviation at every depth.

Spectral Compensation of Sound Attenuation

To compensate for this effect, a method called Spectral Distance Amplitude Correction (SDAC) has been developed, accounting for the disproportionately strong attenuation at high frequencies along the sound path. The approach of SDAC is to adjust the signal shape of deep echoes (long sound path) to a reference echo from a shallow reflector. SDAC is based on digital signal processing algorithms and consists of a signal analysis module and a signal processing module. The analysis provides the typical sound attenuation characteristics of a specific material in relation to frequency and time of flight. Based on that, the compensation algorithm in the signal processing module recovers the lost spectral signal components in each A-scan in the time-frequency domain. From each pulse-echo A-scan (Fig. 2) a spectrogram is calculated by using Short Term Fourier Transformation (STFT). After applying the correction algorithm, we gather the corrected A-scan (Fig. 3) by inverse STFT.

Recovering Deep Small Defects

Figures 2 represent A-Scans of a thick (40 mm) CFRP monolith with a small reflector (3 mm flat bottom hole) close to the back wall. The red marked signal was recorded with conventional technique, i.e. with standard DAC. Compared to this, the back wall of the SDAC processed echo (blue marked signal) is similar in amplitude, but narrower in shape; the flaw echo is both larger in amplitude and narrower in shape. Thus, flaw echoes now can be directly compared with each other, widely independent of the flaw's depth and its size. SDAC compensates any sound attenuation in A-scans.

Both the higher detection capability of small defects and the increased feasibility of comparing flaws from different depths make SDAC a valuable tool for high-resolution ultrasonic imaging, especially in thick CFRP monoliths. The algorithm has proved to be stable and reliable once an appropriate reference had been recorded. The calculation time is feasible and the algorithm can easily be included into existing imaging systems.

> Dipl.-Phys. Uwe Pfeiffer

Causes of NCF Material's Compression Strength Deficit

It has been frequently observed that non-crimp fabric (NCF) based carbon composites which promise to be less expensive have lower strength properties than comparable prepreg systems, especially in terms of compression strength. Consequently, an effort is necessary to improve the mechanical performance of NCF-based composites which requires a comprehensive answer to the question: Which are the NCF material's characteristics causing its compression strength deficit?

A Novel Micro-Meso-Mechanical Model

In order to provide an answer, a novel modelling approach has been developed for predicting the compression strength of such composites. It is based on a detailed fibre buckling analysis on a microscopic scale (Figure 1), simultaneously recognizing the effects of mesoscopic features of a composite laminate (Figure 2). The microsopic model consists of two steps for describing fiber microbuckling as the underlying mechanism of com-pression failure in fibrous composite materials, with the goal of obtaining a prediction for the compression strength of a single unidirectional (UD) ply as a function of various material characteristics: First, the microbuckling stress of a small portion of the com-posite is analyzed as a function of the local misalignment angle. The result is the imperfection sensitivity function, which is valid for the small material portion where, according to the assumed idealized microscopic material morphology, the fibers are all misaligned by the same local misalignment angle. In a second step, in order to obtain a prediction for the compression strength, the imperfection sensitivity function is combined with the stochastic distribution of misalignment angles of a UD ply using a continuum damage model.The objective of the mesoscopic model is to obtain two pieces of information, a prediction for the ply instability stress and an estimation of the stresses inside the ply induced by its waviness, needed later on for analyzing their influence on the microbuckling failure initiation.

More comprehensively than previously proposed models the approach covers a wide range of material characteristics (fibre properties and volume content, non-linear matrix properties, interface properties, residual strains, fiber misalignment, ply waviness, and interlaminar properties) that may have an influence on the compression strength. The validity of the model for these materials has been demonstrated theoretically and experimentally. Therefore, the model - along with the quantification of input material characteristics - is suitable for distinguishing the effect of the various influencing factors on the composite compression strength in an unprecedentedly holistic approach. As the principal result of the analyses, it has been found that the degree of ply waviness of NCF-based laminates, being high compared to prepreg-based laminates, is the most decisive factor for explaining the performance difference in compression; other factors of strong influence have been identified and quantified (mainly the microscopic fiber alignment and the matrix modulus). In contrast, fibre properties, matrix plasticity and strength, interface properties, residual strains, and interlaminar shear properties turned out to be less relevant. The identified failure initiation mode is always microbuckling (with subsequent kink band initiation), never ply buckling and interlaminar shear failure. These principal findings will be useful for material developers or material users who want to improve today's NCF materials: they reveal the weak points and show the way forward for new developments. In this context, the question about the mechanisms controlling ply waviness and microscopic fibre alignment arises. This problem will have to be addressed in future works.

> Dr.-Ing. Simon Pansart (photo), Prof. Dr.-Ing. Michael Sinapius

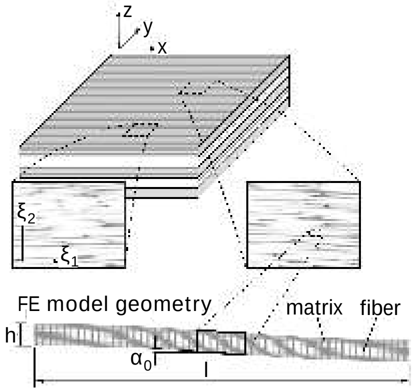


Fig. 1:
Idealization of the composites microstructure, the geometrical features are in the order of 10^{-3} mm (app. fibre diameter).

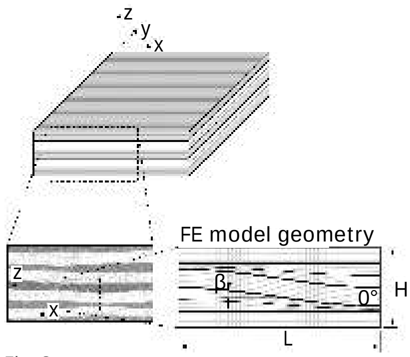


Fig. 2:
Idealization of the composites mesostructure, the geometrical features are in the order of 10^{-1} mm (app. ply thickness).

Efficient Residual Strength Prediction of Impacted Composite Structures

Fig. 1:
Increased dent during compression test.

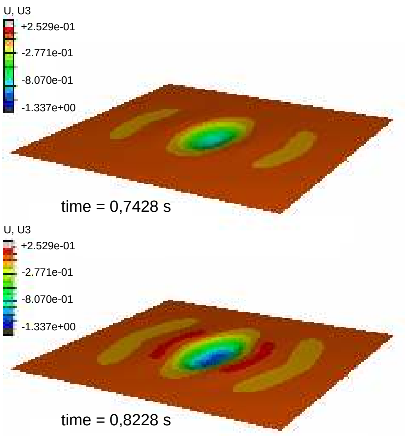


Fig. 2:
Increased dent during simulation.

Objectives

Several factors inhibit the use of sandwich structures, especially for primary structures in aeronautic industry. One major problem is their susceptibility to damage. Non or barely visible damage (NVID/BVID) of a sandwich face sheet may be accompanied by substantial core damage. Such damage can significantly reduce residual stiffness and strength. The proof of structural integrity after damage is difficult, because of the interaction of many damage modes in core and face sheets. At present, overconservative design is necessary to meet aerospace damage tolerance requirements. In order to find ligthweight but safe designs, new methods are necessary for the exact prediction of the damage tolerance. The aim of this work is to provide an efficient simulation methodology for impact damaged sandwich structures under in-plane compression.

Experimental Tests and Simulation Methods

For developing the simulation methods uniaxial in-plane compression tests of impact damaged unsymmetrical sandwich coupons were conducted. The specimens were made of two CFRP face sheets of different thickness and an embedded honeycomb core. Low velocity impacts from 1 J up to 15 J caused varying amounts of core and face sheet damage beside a dent in the impacted face sheet. In the residual strength tests, the dent grew in depth and transverse to the loading direction (Figure 1) until final failure of the impacted face sheet occurred. This phenomenological observation is reproduced well in computational simulations (Figure 2). The simulations use either an efficient finite element model or a semi-analytical Ritz approach including non-linear displacement-strain relations and progressive damage growth in the core. For the latter stress-based failure criteria and stiffness degradation models are applied. The non-linear system of equations is solved by either the Newton method or an incremental arc-length method. Depending on the numerical solver several criteria are developed in order to identify the residual strength.

Achievements

The comparison of simulation and test results demonstrates that the developed methods are able to predict the damage tolerance of unsymmetrical sandwich structures. For both the finite element model and the semi-analytical model it was possible to increase the computational efficiency at the cost of approximating the transverse displacement as a linear function over the core thickness. This was compensated by neglecting the transverse shear stiffness of the core. To keep the computational time low, the semi-analytical model should be only used for impacts with negligible face sheet damage. For damages caused by higher impact energies the simulations show that the face sheet damage has to be included in the model. In the FE model a constant stiffness reduction factor accounts for the face sheet damage. The FE model has a high potential for further explorations.

> Dipl. -Ing. Anja Wetzel

Improved Design of Composite Aircraft Structures - The COCOMAT Project

The EU project COCOMAT (Improved MATerial Exploitation at Safe Design of COmposite Airframe Structures by Accurate Simulation of COllapse) started 2004 and ends in October 2008. It aims to exploit considerable reserves in the capacities of composite panels by accurate simulation of collapse. The main objective is a future design scenario for stiffened CFRP panels for aircraft structures (cf. Figure 1). The project results comprise an experimental data base, improved slow certification tools, fast design tools as well as design guidelines. The COCOMAT project is coordinated by the DLR Institute of Composite Structures and Adaptive Systems.

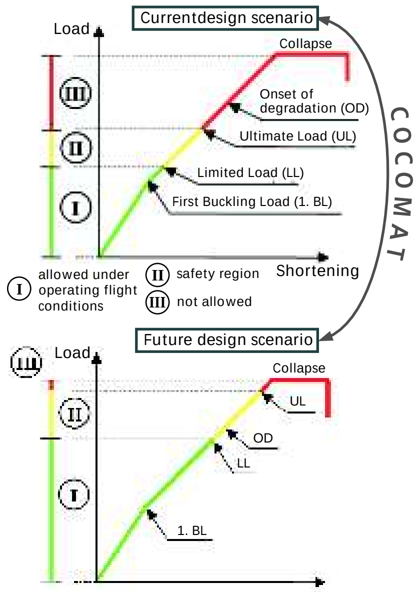


Fig. 1:
Current and future design scenarios for typical stringer stiffened composite panels.

DLR Achievements

Besides the co-ordination DLR accomplished considerable research contributions within COCOMAT. The efforts were supported by more than 40 years of experience the institute has in the field of analytical, numerical and experimental buckling and post-buckling research. The main achievements the Institute reached through COCOMAT can be summarized into two parts.

The first part is the improvement of the DLR in-house simulation tool IBUCK, which is a fast, semi-analytical buckling and post-buckling tool for typical aerostructure panels and an improvement of ABAQUS taking skin-stringer separation into account. IBUCK was extended for the consideration of composite materials and simplified degradation models. For the simulation of the collapse load IBUCK allows reducing the computational time by an order of magnitude.

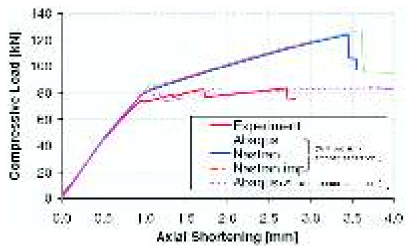


Fig. 2:
Comparison simulation and test of one tested CFRP panel.

The second part comprises buckling tests of 12 panels, axially loaded until collapse. The results are needed for the validation of improved computational tools like IBUCK. Half of the panels were undamaged and the other half were pre-damaged. In order to study the influence of degradation a part of the panels were also loaded repeatedly. The panels were tested in the DLR buckling test facility applying several advanced measurement systems, which have been proven to provide good controllability of the panel behaviour. The high-speed ARAMIS system, which is based on photogrammetry, allows the full scale measurement of the deformations up to 4000 pictures per second. This is needed because the buckling scenario – even under static loading – is a highly dynamic process. The use of thermography allows determining skin-stringer separation already during the experiment. Due to the local deformations, the structure is slightly heated in the damaged areas. As an additional method, piezo patches were placed at different positions of the structure to send and receive Lamb-Waves, the results of which indicate damages. Figures 2 compares load-shortening curves of one stiffened CFRP panel obtained by test and simulation. It demonstrates that the improved ABAQUS simulation, which takes skin-stringer separation into account, is able to obtain a better comparison with test results even after the global buckling point.

The results support a better understanding how far the structural behaviour in the postbuckling region can be exploited as a major step for weight reduction. The partners used the results for the development of improved design guidelines. All project results were presented at the Int. Conference on Buckling and Postbuckling Behaviour of Composite Structures on September 3-5, 2008 organised by DLR. The proceedings can be downloaded from www.cocomat.de.

> Prof. Dr.-Ing. Richard Degenhardt

Implementation and Evaluation of Active Noise Reduction for a Truck Oil Pan

Fig. 1:
Radiation filters numerically computed for truck oil pan (first top left, clockwise increasing order).

Fig. 2:
Truck oil pan equipped with piezoceramic actuators.

Challenging Lightweight Structures

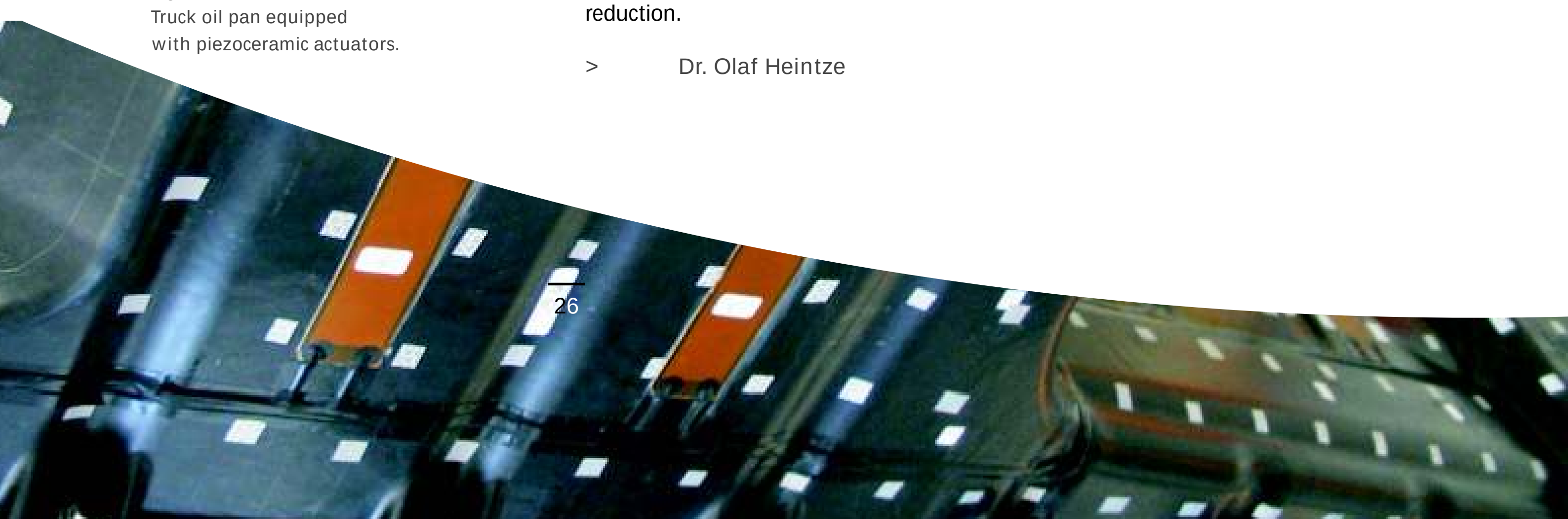
Long-term monitoring of the road traffic in the European Union (EU) revealed a constantly rising traffic noise level. Legislative and technological measures aim to counteract this trend and have resulted already in more silent cars, trucks and busses. Nevertheless, in the case of heavy-duty trucks, nearly half of the entire pass-by noise is caused by its large diesel engine and related components. The passive noise treatment would lead to a very challenging heat management and would be ineffective in the regime of low frequencies. Furthermore, the increasing endeavor to improve the environmental compatibility of future structural systems consequently leads to light-weight designs that are even more prone to vibrations likewise in the challenging low frequency regime. In order to address this challenge, an active structural acoustic control (ASAC) system has been designed and realized such that the vibration of the oil pan is altered in a noise reduction manner. Here, piezoceramic actuator modules are directly applied to the main structure and influence its dynamic behavior through the application of electric power.

Towards Silent Trucks with Significantly Reduced Noise Radiation

The oil pan of a Volvo MD13 engine has been chosen within the European project InMAR in cooperation with Volvo Trucks as the basis for the technology demonstration in a laboratory test stand. The key task is to extract relevant information about the sound radiation simply from measurements of the vibration itself to allow for a real time noise control. A type of radiation estimation is required such that it is suitable for every type of vibration – from narrow band to broadband. DLR applied a method to compute sound radiation filters that allow for the computation of the radiated sound power. Typically, such filters are based on analytical formulations for flat or simply curved panels and, thus, were not be suitable for structures of general shape like the truck oil pan. Therefore, the radiation filters have been computed numerically by a novel in-house tool. The resulting sound power estimation for the oil pan was validated by measurements performed in cooperation with the Physikalisch-Technische Bundesanstalt (PTB) in remarkable agreement.

The application of the previously computed radiation filters allowed for the optimal actuator placement and the prediction of the acoustic efficiency to the ASAC system in the frequency range from 50-500 Hz. For a typical, three-dimensional structural excitation of the truck oil pan, a sound power reduction of 6 dB has been computed. Finally, the hardware implementation of the control was performed in DLR laboratories in a special test stand, where a set of four actuators involved in the control scheme reduced the sound power radiation by 4.3 dB (63 %). Considering measurement and numerical simulation uncertainties, this result agrees well with the previously computed reduction.

> Dr. Olaf Heintze



Smart Structures for Masses: Low-Cost Components for Sensing and Control

For the last decade smart structures technologies emerged as reliable and efficient tools for reduction of vibration and noise. The components that make a structure a “smart” structure are actuators, sensors and control hardware. With knowledge of the structure’s vibration behaviour and the sensor information, complex control algorithms are able to drive the actuators in order to reduce the vibration and noise emission of the structure.
The concept of active structural acoustic control (ASAC) realised and implemented in several applications by the Institute of Composite Structures and Adaptive Systems is an efficient tool for noise reduction. For a satisfying observation of structural mode shapes a multiplicity of sensors, typically accelerometers, is needed. Sensor information is processed by complex control algorithms running on multi-input-multi-output control systems. For setups on a laboratory scale DLR typically uses high-quality equipment like very sensitive accelerometers and high-performance rapid-prototyping control systems. Therefore, costs for a complete laboratory system add up to a considerable amount. Certainly, the cost-intensive hardware is not suitable for series production of ASAC systems. To fill the gap between laboratory and industrial needs and to enable adaptronic to enter mass markets, DLR proved that systems based on low-cost components are able to gain comparable performance. Since piezo patch actuators invented by DLR are already commercially available, attention is drawn to sensors and control systems.

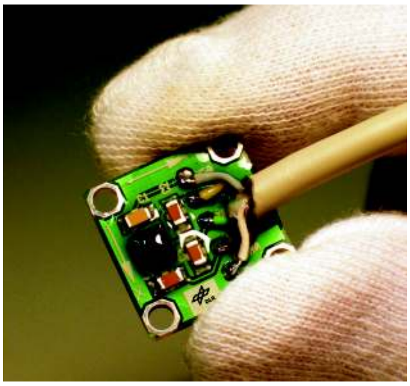


Fig. 1:
Tri-axial MEMS accelerometer on a printed circuit board. Measurement range is ±3 g.

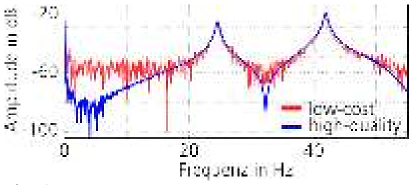


Fig. 2:
Frequency response functions measured with low-cost and high-quality sensor.

Sensors

Accelerometers are common sensors for structural vibrations. High-quality accelerometers for laboratory setups are characterised by large signal-to-noise ratios and excellent signal quality. As alternative, DLR built a printed circuit board that combines an off-the-shelf Micro-Electro-Mechanical System (MEMS) accelerometer and a couple of parts for signal filtering to a low-cost sensor board, see Figure 1. The sensor board has an edge length of only 20 mm and an application or integration onto or into structures is easily possible. Figure 2 compares two frequency response functions measured with a high-quality sensor and the sensor board. Signal quality of the low-cost sensor is worse of course, but quite sufficient for a successful realisation of ASAC systems. The new sensor board proved that a cost reduction by a factor of 100 is possible.

Fig. 3:
PC-based control system cox including
8 input-, 4 output-channels and touch screen.

Control

Complex controllers for ASAC systems require high computing power and have to be easily programmable and tunable. Common rapid-prototyping systems meet this demands, but are very cost intensive and hence not chosen for series production of ASAC systems. With development of cox, see Figure 3, DLR realized a high-performance but low-cost control system for smart structure applications. Cox consists of an off-the-shelf single board PC and a control core that is engineered in DLR. This multi-thread core integrates methods for rapid-prototyping, system identification, signal processing, control synthesis and remote controller tuning. Among applications on a laboratory stage, cox is very suitable for series production due to its self-tuning and remote maintenance features. Compared to common rapid-prototyping systems cox reduces hardware costs by a factor of 20.

> Dipl.-Ing. Stephan Algermissen

Next Generation Train NGT

Objectives

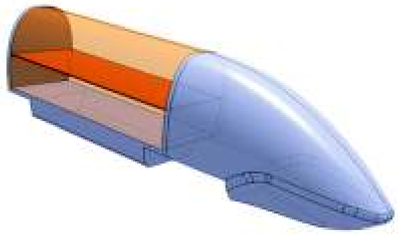


Fig. 1:
NGT concept study. FA-work share (orange):
Composite parts in car body of traction unit.

Behind the DLR concept of the Next Generation Train Project there are scientific issues regarding high speed railway transportation from the areas of aerodynamics, structural dynamics, dynamic performance, propulsion technology, material sciences and light-weight construction. The objective is to increase driving speed by 25 percent in compliance with existing safety standards. At the same time, the specific energy consumption shall be reduced 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. 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.

Cost-Efficient Composite Car Body Design

Fig. 2:
CFRP design concept for sidewall, roof, and
intermediate floor of composite car body.

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.

At the DLR Institute of Composite Structures and Adaptive Systems, fibre reinforced composite car body designs are being developed aiming at significant weight and cost savings in railway construction for increased efficiency of railway transportation. 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. New materials systems, such as natural fibre composite materials, or new production technologies, such as the long fibre Injection process (LFI), could be used in the interior of the train. 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 designed. Developing a high-speed train differs conceptually from designs for regional and local transport. The challenge here is to transfer the principal procedures of platform and module development to regional and local trains also in close cooperation with industrial partners.

> Dipl.-Ing. Jörg Nickel

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