

Research Field Aeronautics,  
Space and Transport

Proposal for a Helmholtz  
Research Program

# **Aeronautics**

2009 - 2013



|                                     |                                                                                                                                                                                                                                                  |
|-------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
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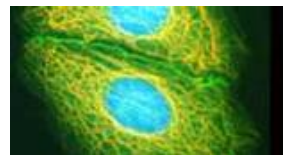
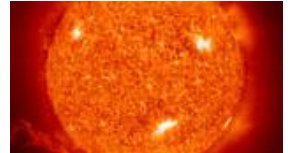
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# Mission of the Helmholtz Association

We contribute to solving grand challenges which face society, science and industry by performing top-rate research in strategic programs in the fields of Energy, Earth and Environment, Health, Key Technologies, Structure of Matter, Aeronautics, Space and Transport.

We research systems of great complexity with our large-scale facilities and scientific infrastructure, cooperating closely with national and international partners.

We contribute to shaping our future by combining research and technology development with perspectives for innovative applications and provisions for tomorrow's world.







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**DLR**

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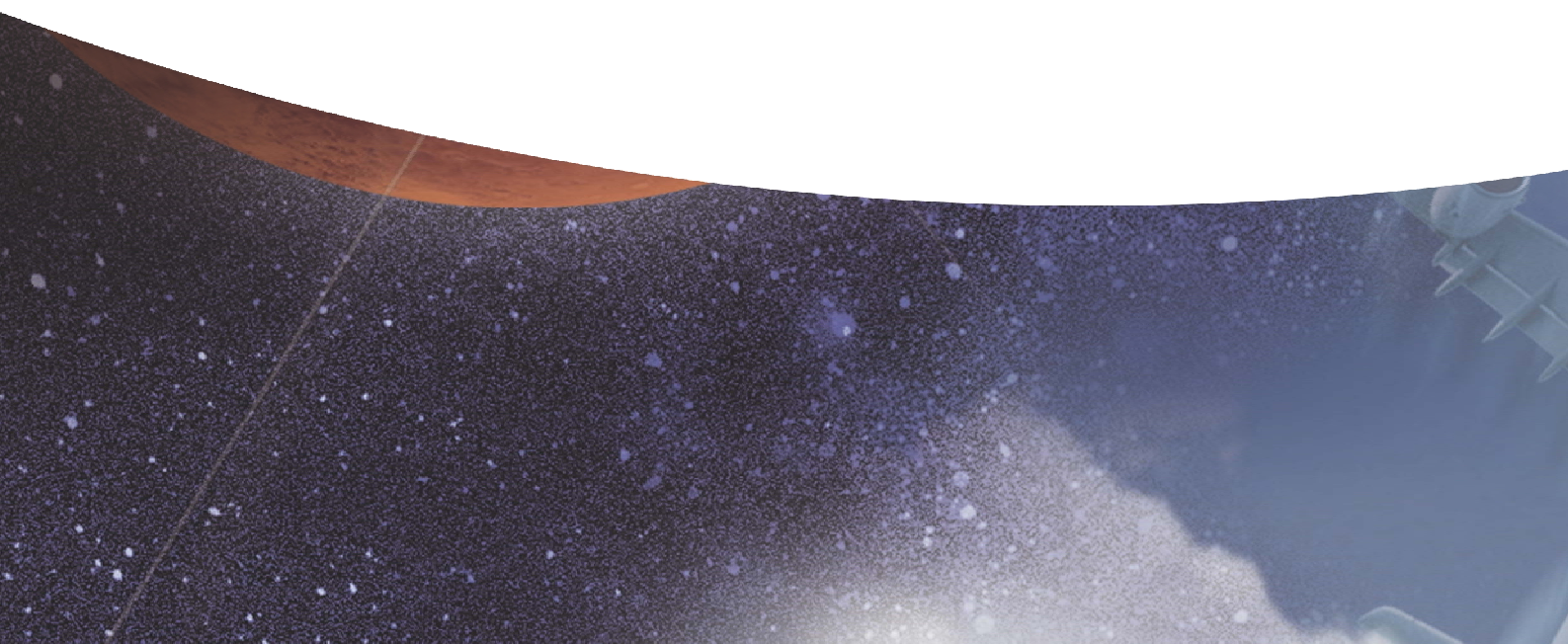
# Global Goals

Mobility, information, communication, resource management as well as the environment and safety: The quality of these factors is decisive for the economic, ecologic and social development of a modern economy and therefore of the highest strategic relevance. Effective concepts and technological system solutions are developed in the research field Aeronautics, Space and Transport for permanently satisfying these requirements. Due to their enormous technology and innovation potential, the activities of these three programs contribute in reinforcing and making Germany's role as a research and innovation location more visible internationally.

DLR occupies a nationally unique key position by assuming a bridging function between fundamental research and innovative applications as well as the transfer of knowledge and research results in industry and politics. DLR is therefore ideally suited to assume management and architectural functions at a national, European and international level. The resulting participation in developmental panels and platforms is maintained and reinforced especially at the European level. It is also important to better interlink national and European programs for research and technological development. Efficient coordination processes are being established for this. The networking and cooperation with universities, scientific organizations, departmental research facilities of the Federal Ministry of Economics and Technology (BMWi) and the Board of Academic Advisers to the Federal Minister of Transport, Building and Urban Affairs (BMVBS) as well as the industrial research facilities will be expanded further.

Joint appointments and chairs, the involvement in collaborative research centers and the promotion of young talents continue to be important starting points for the cooperation with universities. The inclusion of small and medium-sized companies is of increasing significance for the cooperation with industry. Synergies are used in research networks with science and industry via division of labor and cost sharing and innovation processes are accelerated. Its technical and scientific expertise enables DLR to support the dialog between politics, industry and society. This also includes the public's great information demand about the activities of the research field, which is fulfilled by suitable forms of communication via various media.

The application relevance of the topics treated by DLR is particularly reflected in the extremely high volume of external funding. External funding should be maintained at this level, in order to enable the DLR to perform all planned activities to their full extent. In addition, it is planned to further increase the share of acquired funds from industry as well as national and EU programs for research and technological development.



DLR actively supports young scientists in a forward-looking manner. Beginning with sponsoring students, DLR provides support for interns, a structured education of undergraduates and doctoral candidates and even the further education of postdoctoral scholars. Both, the academic as well as the industrial career are kept in perspective here.

The pursuit of prevention research results from our responsibility for the future. The programs of the research field include significant contributions to the topics of sustainability and environmental protection as a supplement to the application-related research work. DLR also has special multi-disciplinary capabilities in the areas of security and defense research. These are included in the respective programs of the Federal Ministry of Education and Research (BMBF) and the Federal Ministry of Defense (BMVg).

In order to exploit dual use potentials, interests of the Federal Ministry of Defense are included in suitable technology fields in a manner corresponding with the extent of the financial contribution. A mutual stimulation and supplementation of civil and defense research is achieved by interlinking these spheres of competence.





# Goals and Strategies of the Programs

Synergies are optimally exhausted by pooling the three programs of Transport, Aeronautics and Space under the roof of the DLR. These activities, however, are still also directly and variably interlinked with the German research community as this also ideally occurs in other research fields. This is supported by the large number of DLR sites in various Federal states – DLR is the only center of the Helmholtz Association with that many sites.

The intensive interlinkage specifically applies to the up-and-coming Transport program, in which specific expert knowledge of transport is also used to acquire know-how from the areas of aeronautics and space as well as energy for transport use. This symbiosis that is unique in Germany ensures problem-oriented research results by using innovative high-technology. In addition, outstanding synergy effects are achieved in the research areas of navigation, communication, structure and materials, aerodynamics and remote sensing. Problem solutions and applications are also combined in the future European satellite navigation system GALILEO through all programs of the research field. Comprehensive program results are also implemented in the field of material research.

DLR is expanding its previously successful cooperation with other centers of the Helmholtz Association for suitable research and development activities. The interaction in the multi-disciplinary Earth Observation System (EOS) and the research with the High Altitude and Long Range Research Aircraft (HALO) specifically serve as successful models for working on common topics with other research fields. Within the Helmholtz Association, there are also links to the research fields for Energy, Health and Key Technologies. However, the relationships to national and international scientific and industrial partners outside the Helmholtz Association dominate overall due to the mentioned characteristics.

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Zukunft gestalten

## Aeronautics

The content of the work of the Aeronautics program is targeted to the European Vision 2020 and the strategic research agenda derived thereof and agreed to within the European scope. Precise as well as quantitative and overall very ambitious objectives of the European aeronautical research are defined there for this time frame. The main aims are:

- > Increasing the efficiency of the air transportation system
- > Increasing the cost-effectiveness of development and operation
- > Reducing aircraft noise and harmful emissions
- > Increasing the quality of air transportation for passengers
- > Increasing safety in the face of growth and external danger

The essential characteristic of this research agenda is the overall observation of the air transportation system as a deciding condition for achieving the objectives. The DLR, with its technical depth in the field of aeronautical research, which is unique in Europe, must continue to specifically embrace this aspect in its research processes. A continuous further development of the program is therefore not only required for all components of its aircraft research (fixed-wing aircraft and rotary-wing aircraft, including propulsion technologies) as well as for air traffic control and traffic management in the air and at the airport, but also for the comprehensive interlinkage.

The interdisciplinary approach to precise questions concerning the efficiency of air transportation, climate and environmental compatibility as well as safety should be the focus here. However, at the same time, there must be room for promoting scientific/technical top-rate performances in individual disciplines.

The following aspects will be addressed in detail in the current Aeronautics program:

- > Expansion of the capability to analyze and evaluate the overall air transportation system, which includes air traffic, airports and flight guidance, taking weather and environmental aspects into account
- > Development of simulation procedures to support design, evaluation and certification programs in aeronautics
- > Further development of experimental techniques, equipment and systems for validating technologies and simulation tools in ground and flight tests
- > Work for the man-machine interaction in the areas of the cockpit, cabin and air traffic control work areas, taking psychological and medical aspects into account
- > Research work for a better understanding of the climate impact of air transportation and especially for suitable reduction measures in all areas of the air transportation system.

The program should combine high scientific demands with adequate application relevance. Future requirements of the aviation industry and the air transportation economy in Germany should therefore be especially accommodated. The latter also applies to the availability and demand-based further development of the comprehensive large-scale testing facilities of the DLR. Especially the start of the flight operations with the new research aircraft HALO and A320 ATRA clearly offers significantly expanded opportunities for science- and industry-related research, which must be built up and supported for the long-term.





The progressing process of the European integration of the aviation industry was also set in motion in the research community in the nineties. In the Aeronautics program, this process is already reflected today in form of an increasing interlinkage with the operations of the European partner organizations within EREA. This development must be pushed forward. The main focus during the coming years will be on the areas of transport aircraft and helicopters in a joint venture with ONERA, flight guidance technology in cooperation with NLR and the further development of the wind tunnel association of the DLR, NLR and ONERA.

## Space

50 years after the launch of the first artificial earth satellite, space flight is still a synonym for high-technology and cutting-edge research. While some space applications such as weather observation, navigation and telecommunications have become an indispensable part of everyday life, missions, which explore our solar system and universe - and particularly human space missions - still hold an enormous fascination. Space flight drastically expands the picture of the world beyond our planet. How did our solar system evolve and our earth in it? Is there life beyond earth? Space flight offers new and unique technical possibilities to answer these questions.

Over the next years, Europe will achieve a major milestone for science and technology with its COLUMBUS module on the International Space Station: this multi-disciplinary research lab opens the door to a variety of new opportunities for the examination of life-scientific and material-scientific processes.

Innovative space research makes indispensable contributions to the economy and is of enormous social relevance. Space flight is essentially a high-tech infrastructure, which should be understood as "enabling technology" and which generates new value creation chains. Investments in space technologies open the door for commercial markets in the areas of end devices and services.

The Space program, which is a vital part of the integrated German space program, will mainly focus on the following objectives for the next few years:

DLR aims to strengthen its leading position in the area of remote sensing of the earth with radar but also with optical systems and, particularly, with regard to new requirements from application and research, further develop this position. DLR's work will also focus on the development of evaluation methods and geo-information products so that it can respond to urgent questions in the areas of environment exploration, atmosphere and climate research as well as the protection of citizens.

In order to purposefully advance the economic implementation of innovative communications and navigation technologies further, research and development as well as support services for the Galileo industry and Galileo users must be provided.

The internationally leading role of DLR in planetary research and the development of scientific instruments must be expanded and incorporated into the Cosmic Vision program of the ESA. DLR specifically wants to advance the research of the interaction between life and the planetary formation and the discovery of extrasolar planets.

DLR wants to advance the further development of unmanned landing systems, robotic methods and innovative mobility concepts for the on-site research of planetary bodies. Habitat developments as well as environmental simulations to prepare for astronautical missions should form additional focal points.

The scientific excellent use of the International Space Station in material and life sciences is the top objective of research under space conditions.

Securing access to space is a strategic objective of special significance for Europe. In order to guarantee the international competitiveness of the European carrier with increasing requirements for reliability and flexibility, DLR researches and develops key technologies for launch systems.

DLR will begin with the development and instrumentation of its own national compact satellite line for various scientific goals and therefore specifically demonstrate the suitability of small, cost-effective satellite systems for dedicated application purposes.

In order to improve the worldwide competitiveness of the German industry for space technology tasks and markets, the development and application of innovative technologies, systems, components and operating processes must occur. Robots research services, innovative operating technologies, and the development and qualification of up-to-date satellite components are the main focus.

DLR is capable to operate all infrastructures required for the spectrum of these tasks. The orientation of the content is based on the national and international environment, which is essentially determined by ESA and the EC.



## Transport

Quick, reliable, safe and secure traffic connections are essential for the development and prosperity of a modern economy. They are a necessary requirement for growth and employment in Germany. For many years, this has been reflected in a significant increase of passenger and freight transport services. The desire for unlimited mobility by an individual, however, is in a continuous tense relationship with the chronic congestion of the transport system, the effects of traffic on man and the environment as well as the high number of accident victims. Furthermore, the continuously increasing transport demand cannot be managed either by building new infrastructures nor by liberalizing the transport markets. It is therefore important to design a modern transport system that is sustainable for the long-term under economic as well as social and ecological aspects.

In order to achieve the apparent "quadrature of the circle", strategic objectives were defined at the national and European level during the past years in cooperation with DLR. Their implementation will influence transport research and transport policy considerably over the next decade. These objectives, among others, include:

- > More efficient use of existing transport infrastructures,
- > Shifting traffic to environmentally friendlier modes,
- > Implementation of intermodality,
- > Expansion of the trans-European transport network, especially the rail network,
- > Reduction of transport-induced impact on man and the environment,
- > Increase of safety.

The transport program already focused on these higher-ranking goals during its development phase. It has taken these goals into account when it decided about the direction of the three new transport research institutes of the DLR and the basic programmatic concept of the research focal points. In addition, the program will be consistently further developed by a reinforced industry-affine research orientation. The success of this customer-oriented approach has already been proven by the increase of industrial external funds, as well as through the interest based on reputation in strategic cooperations by various industrial partners.

With a content-related focus on the program topics

- > Terrestrial Vehicles,
- > Traffic Management and
- > Transport System

the chosen path is dynamically continued. In particular, transport-specific expert knowledge is still used to obtain know-how from the areas of aeronautics and space as well as energy for transport applications. This symbiosis that is unique in Germany ensures problem-oriented research results by using innovative high-technology.

Focal points of research are set for the development of innovative, environmentally-friendly and safety-promoting vehicle concepts for road and rail. Approaches for more effective and efficient organization of management are thoroughly pursued in the road, rail and airport areas. Beyond these research areas with a direct industrial relevance, the transport program also provides essential contributions for prevention research and political consultation. This includes examinations on the interdependencies between transport and the environment. Another focus is the development of traffic management for major events and catastrophes. Furthermore, the clearing house for traffic data is operated as a service offer for the national and European Community.

The advantages of a multi-disciplinary infrastructure and interdisciplinary teams within DLR are exhausted to accomplish the challenging research tasks. The use and expansion of transport-specific large-scale facilities and scientific infrastructures are of primary significance.





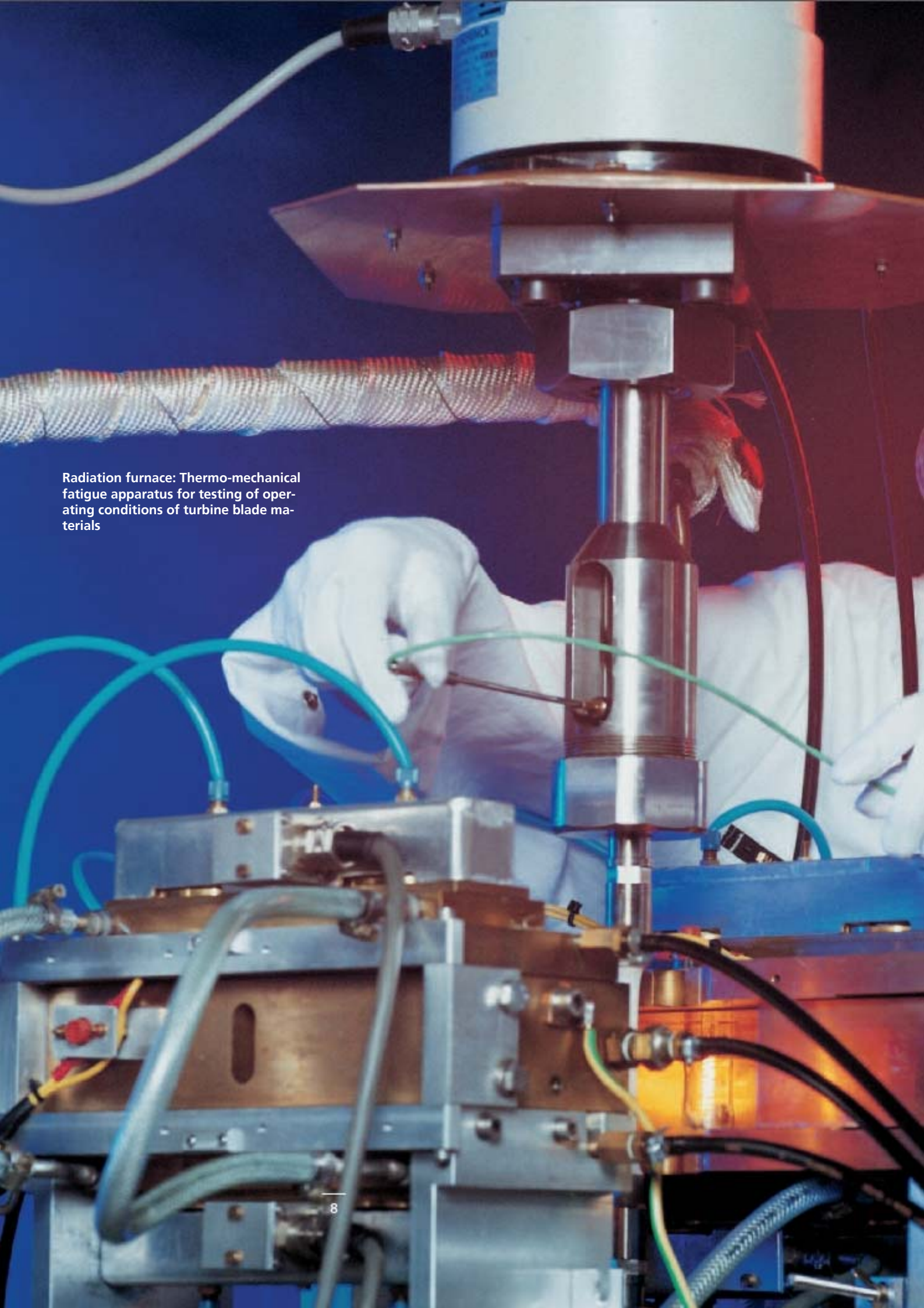
# Planned Costs

Planned costs funded by Helmholtz for the research field 2009

| DLR                          | Million €      |
|------------------------------|----------------|
| Aeronautics                  | 66.936         |
| Space *                      | 90.670         |
| Transport                    | 20.619         |
| Non-program bound research * | 44.556         |
| <b>Total</b>                 | <b>222.781</b> |

\*) including the Institute of Space Systems, Bremen





Radiation furnace: Thermo-mechanical fatigue apparatus for testing of operating conditions of turbine blade materials





# Program Aeronautics

# Challenges



A380

A significant growth in global air traffic is expected for the foreseeable future, despite recent repeated disruptions including severe incidents like that of September 11, 2001. The major aircraft manufacturers estimate that annual passenger travel will increase by 5% and air freight rates by 6% worldwide during the next 10 to 15 years. ICAO is expecting a doubling of flights offered on new and existing routes within 20 years. This growth is expected to take place mainly in Europe and Asia. This will require airport and ATM capacities to be extended significantly.

In the view of the European Union, traffic growth is a prerequisite for reaching the Lisbon goal of making the European economy the most competitive knowledge based economy in the world by 2010. A major consideration in this process will be to balance traffic expansion with environmental protection. To this end, a more efficient use of the airspace will be needed as well as a modernization of total airport management in conjunction with an overall reduction of emissions. European Commission is increasingly shaping European aeronautics strategy through the selection of framework programs for research.

ACARE, the Advisory Committee for Aeronautical Research in Europe, has issued the "Strategic Research Agenda" (SRA). It is guided by two main goals: to achieve global leadership in aeronautics for Europe and to meet society's needs in terms of mobility and environmental protection. This requires air traffic to become more affordable, cleaner and safer. Accordingly, five main challenges have been identified:

- > quality and affordability
- > environment
- > efficiency of the air transport system
- > safety
- > security

In 2001, concrete goals were set for technology development within the "Vision 2020". These goals included, amongst others, a general cost reduction for air travel by 30%, facilitation of 16 million flights annually within the European air transport system, a reduction of per-passenger CO<sub>2</sub> emissions by 50% and of NO<sub>x</sub> emissions by 80%. These goals, to be met while also reducing the accident rate by a factor of 5, have created a broad resonance since their inception. For the DLR's research work, they have become major orientation points.

Environmental aspects, already seriously considered in the Vision 2020, have attracted even more interest in political discussions in the course of current investigations in climate change. Early in 2007, a report of the IPCC (Intergovernmental Panel of Climate Change) confirmed that a global warming of 0.7° C can be observed for the last 100 years and that human activities probably account for the majority of this.

The contribution of air traffic to the total human influence on climate change is small. Nevertheless, aviation must give environmental protection a high priority. About 2.2% of global anthropogenic CO<sub>2</sub> emissions can be traced back to air traffic. However nitrogen oxides, particles and contrails emitted during cruise in the upper atmosphere also have a climate effect. It is estimated that, in total, global air traffic has contributed to global warming by roughly 3% so far. Taking into account current uncertainties about the effect of contrails and particles in the development of cirrus clouds, the contribution might be even higher. Furthermore, due to the high growth rate of air traffic, compared to that of the world economy (currently at 2.6% annually), public attention to this sector will probably increase in the future.



Approach to Heathrow

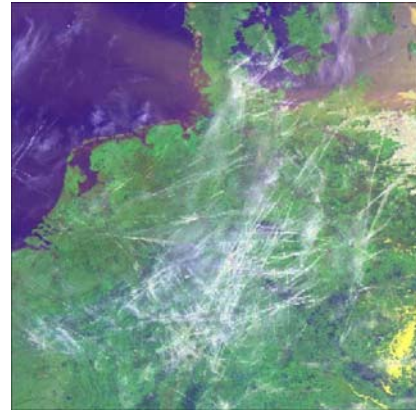
Reducing specific air traffic related climate impacts will therefore be of major importance. The development of new cost factors to the air traffic industry is exemplified by current discussions about an inclusion of air traffic into emissions trade, and discussions of the effect of noise emissions.

Critical advances towards reaching the ACARE goals require contributions from all sectors of the air transport system. The ACARE process, as a coordinated attempt by all industrial sectors and relevant applied research establishments, explicitly takes this into account for the first time. The DLR has taken a leading part in this process from the beginning, and intends both to continue this support and derive internal strategy from it.

The DLR is the largest aeronautics research establishment within the EU with a unique spectrum of expertise in aeronautical research. It is in particular the DLR which faces the challenge of increasingly combining the results of various disciplines in such a way that technological potentials can be identified and evaluated with respect to their impact on the air transport system.

The need to efficiently cooperate in aeronautical research and technology on both an international and a European basis is unquestioned today. As a national research establishment, however, the DLR also has a duty to concurrently support the further development of the industrial base in Germany. It is in the interest of the country's future capabilities that the DLR's system competence in research and education be preserved even though there is a trend on the side of large manufacturers to split their areas of competence into specific national work shares as part of their consolidation process. In particular smaller enterprises, which must be able to act as independent suppliers on the world market, can probably benefit from this capability if retained at the DLR.

Currently, the aircraft industry has considerable problems in recruiting qualified young engineers in sufficient quantities. This illustrates the relevance of the DLR's emphasis on education and on advanced professional training of engineers and scientists, performed in close cooperation with universities and (in part) also with industry. The DLR, as the most important representative of applied aeronautical research in Germany, fully acknowledges the importance of the traditional combination of research and education.



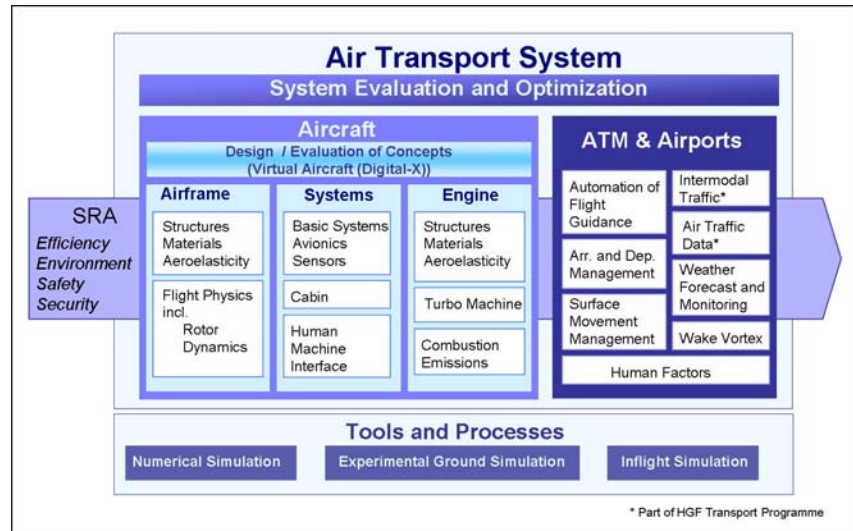
Contrails viewed from a satellite

# Development and Environment

## Previous Work

The DLR has developed a broad portfolio of expertise in the past. Today it forms the basis for the research work in the years to come.

Current research portfolio



While the broad spectrum of research work has always been a DLR specialty, a holistic view of the various disciplines and application fields with the aim of analysing the complete air transport system has been consistently pushed forward only in recent years.

### Air transport concepts and technology evaluation

The experts who conducted the last HGF evaluation asked the DLR to form a working group for virtual aircraft design on the basis of its comprehensive capabilities in the field of numerical modelling and simulation. In consideration of the need for a holistic view of the air transport system, particularly emphasized in ACARE's SRA as a prerequisite for reaching its goals, the DLR not only complied with this suggestion but extended it, aiming at simulations for all levels of the aircraft system. This will allow an evaluation of technological developments with respect to their relevance for practical applications and finally even for further developments of the complete air traffic system.

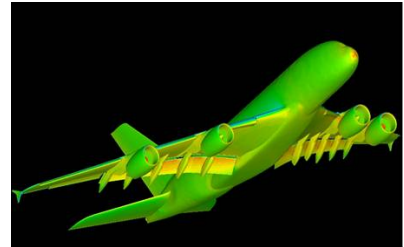
As a first step, a research group for air transport concepts and technology evaluation was established. It coordinates the effort in a close and continuous cooperation with other institutes and takes care of the specification and the development of the necessary simulation infrastructure. Within the limits of a research enterprise without product development and construction, a competence in technology evaluation and sensitivity analysis is to be built up and maintained, using modern methods for simulation and virtual design. For the DLR, this means a considerable competence gain. Compatibility with current industrial processes will allow a close cooperation with its partners. It will also allow the DLR to strengthen its central position in a national research network.

The DLR's focus on numerical simulation and experimental validation is already playing an important role in today's technology portfolio, providing favourable conditions for development. The term "Digital X", addressed in the portfolio as the vision of an air-



craft in the computer, illustrates the potential of pooling the DLR's various advanced numerical simulation methods used in fluid dynamics, structures, engine technologies and many other fields. With its broad spectrum of experimental facilities for ground testing and in-flight testing, the DLR also has unique capabilities for the necessary validation of such numerical methods.

Technology evaluation requires a consistent simulation environment on a pre-design level to be developed by the DLR in order to allow for an integration of all the relevant disciplines. Within the project TIVA (Technology Integration for Virtual Aircraft), involving seven research institutes, initial successful activities in this direction have been accomplished in parallel to the creation of the new research group. This effort is continuing.

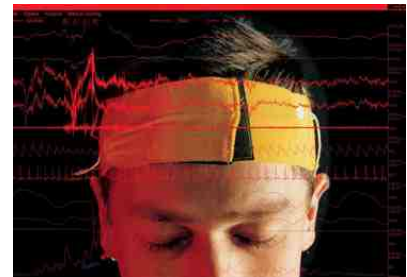


Numerical simulation with the DLR's TAU-Code: Pressure distribution on the A380

## Further examples of research activities in recent years

### 1. Quiet air traffic

Interdisciplinary cooperation as a prerequisite for performing technology evaluations on the system level was increasingly demonstrated in a number of further internal projects in recent years. In the project "Quiet Air Traffic" the noise generation by traffic was investigated. This included investigations into the creation of noise at the source, its atmospheric propagation close to the ground and the effect of noise to the people living in the vicinity of airports. Some concrete proposals for different means of noise reduction were made and also evaluated with respect to their quantitative potential. Disciplines involved included aerodynamics, aero-acoustics, engine technology, flight systems techniques, flight guidance, physics of the atmosphere, and flight medicine. The investigation on sleep disturbances, never before performed with such a broad scope, attracted much attention. Not unexpectedly much discussion of this controversial subject was generated. This research work has already been used in 2006 as a basis for developing a new noise protection concept for the airport Halle-Leipzig. It was later fully accepted by a major German court (Bundesverwaltungsgericht). Only after implementing this new concept, was the construction of the airport in its planned form and with the expected economic benefit for the region possible.



Research on noise effects to human beings

### 2. Design of a quiet engine fan

Engine development has been particularly affected by the requirement of a significant reduction of aircraft noise. One of the current responses concerns fans with a considerably increased bypass ratio.

Within the EU project Silencer, the DLR, together with its project partners SNECMA (France) and COMOTI (Romania), has designed a new slowly rotating fan with a bypass ratio  $BPR = 12$ , which is to be driven by a fast-rotating low-pressure turbine via a reduction gear. Major goals of this work were a reduction of engine noise by about 6 dB and an increased propulsion efficiency.

By means of a 10% increase of the mass flow density at the inlet, compared to today's fans, significant increases in the outer radius, and engine mass could be avoided, as could a severe wing-fan interaction. As a result, the axial Mach number in the outer half of the duct in front of the fan blades is 0.7, an unusually high value not previously achieved for civil aviation engines.

Fulfilment of all performance parameters required for take-off, cruise and maximum climb was possible only by means of a three dimensional design of the rotor blade. This required a close cooperation between the disciplines aerodynamics, construction and



DLR UHBR-Rotor

structural design. The planned noise reduction of at least 6 dB (yet to be verified) is expected to be realized mainly by

- > increasing the bypass ratio together with an enhanced shielding of jet noise from the core engine and
- > reducing the blade tip speed in order to avoid “buzz saw” noise.

### 3. Piloted lean combustion in aero engines

In the national aeronautics research program LuFo 3, a piloted lean combustor was tested in the DLR's single jet sector test stand. This technology is the most promising candidate for fulfilling the ACARE goal of reducing NO<sub>x</sub> emissions. In the test rig, the main flame zone is very close to the observation windows, which have to be cooled. Joint efforts by the DLR and its industrial partner were necessary in order to find an adapted cooling concept which reached a meaningful compromise between sufficient durability of the windows on the one side and a negligible influence of the cooling film on the flame on the other side. Significant new findings about the homogenization of the mixture as a function of the load range will allow the characteristics of emissions measured at high pressure test stands to be better understood.

In the DLR's internal project “Brennkammer 2000” (combustion chamber 2000) the functioning of an internally piloted lean burner was successfully demonstrated. The operational range at partial load was extended by a factor of 2.5 compared with conventional burners. Detailed laser measurements were performed in order to characterize the fluid field. These results contributed significantly to a better understanding of the complex interaction between the pilot and the main combustor. Cooling concepts for WHIPOX ceramic combustion chamber walls were also developed in this project. Ceramic wall elements with these cooling concepts were investigated for the first time on the high pressure cooling test stand under realistic operational conditions. Experimental results and numerical investigations indicate that, with these concepts, cooling air consumption can be reduced by more than 50% compared with conventional cooling concepts.

### 4. Microwave based autoclave processing

The global trend towards an increasing use of carbon fibre reinforced plastics (CFRP) in aeronautics requires new flexible production techniques for higher cost efficiency. Microwave based autoclave processing of CFRP components was proposed by the DLR, using a unique facility at its premises in Braunschweig.

Conventional CFRP components are polymerized under pressure and heat in an autoclave process based on convection. Existing autoclaves are limited in the size of structures which they can successfully cure. For example, internal stresses as well as deformations may be caused by an inhomogeneous temperature distribution during curing. In contrast to conventional curing, processing in a microwave autoclave is volumetric, which means that the material is heated more homogeneously, faster and with fewer inertial effects. The aim is to expedite processing while increasing the quality of the structural components, to reduce energy consumption and thus to reduce production costs.

The reference facility, commissioned at the DLR in 2007, can be used as a conventional oven or as a pressurized autoclave for convection based or microwave based tempering. The maximum length of an object to be cured is 4 m, and maximum diameter about 1.5 m. Thus this microwave autoclave is an ideal research facility for investigating all the technical and scientific problems concerned with the qualification of such a new technology. A first step in this direction will be to process prototype components;



DLR microwave autoclave

for example to manufacture a CFRP fuselage segment or to cure a shell structure with varying wall thicknesses.

##### 5. Ground vibration tests on the Airbus A380

In the field of structural dynamics, recent developments of ground vibration test technology allowed the tests on the A380 to be accomplished within a relatively short period of 6 weeks. A joint team of DLR and ONERA personnel was responsible for the test campaign in Toulouse, the first of its kind in Europe on such a large aircraft. Neither partner would have been able to cope with the related technical effort alone. The results of the vibration measurements were required to validate the numerical model of the aircraft structure. During the validation of a model of this type, possible errors are identified and (if necessary) corrected. The structural model was then to be used for basic analyses in the aircraft certification process. In particular the verification of flutter safety relies heavily on simulations performed with the dynamic numerical model.

##### 6. Autonomous flight (ATTAS used as in-flight UAV simulator)

Unmanned aerial vehicles (UAVs) will have to be integrated into air traffic in the foreseeable future. It is unquestioned that such systems will eventually offer new options for a number of civil applications. In the near future, military reconnaissance UAVs will be commissioned in Germany. As a prerequisite for integrating UAVs into the controlled airspace used by civil and military aircraft, adequate ATM methods and rules need to be provided. A comprehensive flight test program, using the DLR's experimental aircraft VFW614 ATTAS as a flying UAV simulator, significantly assisted current efforts to develop and demonstrate new ATM methods. The ATTAS was equipped with a special data link and with the onboard systems necessary to simulate an unmanned aircraft with autonomous capabilities. In the course of a demonstration program in 2004 (with only safety pilots on board), the aircraft was successfully guided from Braunschweig to Manching by ground control stations through controlled airspace without disturbing normal air traffic.

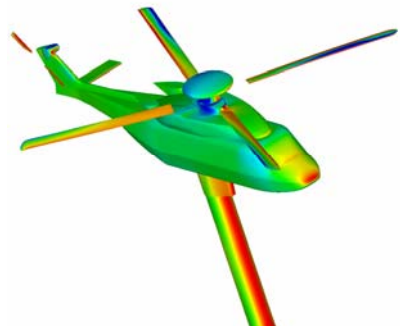


ATTAS

##### 7. Numerical simulation of helicopter aerodynamics

The aerodynamic flow conditions for a flying helicopter are particularly difficult to analyze due to its complex dynamics. In the project CHANCE (Complete Helicopter Advanced Computational Environment), a cooperative DLR ONERA project, also including Eurocopter and the Stuttgart University, a method for the unsteady simulation of the flow around a complete helicopter in various flight attitudes was demonstrated for the first time. Meanwhile, the required software has been integrated into Eurocopter's industrial simulation environment and tested on realistic test cases. As a result of the project, a powerful design tool is now available for the user, which can effectively help to improve helicopter properties with respect to performance, safety, noise, and vibrations.

This project made apparent, however, that the available experimental data were not sufficient for a reliable evaluation of the new method's overall quality. Therefore, the EU project GOAHEAD (Generation of Advanced Helicopter Experimental Aerodynamic Database for CFD Code Validation) was defined together with ONERA, Eurocopter and 12 further European partners. The aim of the ongoing project, which is coordinated by the DLR, is to create a comprehensive set of highly accurate experimental data for a validation of RANS based CFD codes (RANS: Reynolds averaged Navier-Stokes equations). An assembly of main rotor, fuselage and tail rotor will be subject to measurements in various flight attitudes from slow to fast including a turning manoeuvre with high aerodynamic loads. So far the model has been specified and work on modal



Pressure Distribution on the GOAHEAD Wind tunnel model

integration has started. Computational grids have been provided for numerical simulations, which will comprise, among others, fluid structure coupling as well as an approximation of the total helicopter's trim.

#### 8. Climate effects of air traffic

The DLR has long been at the forefront among international research establishments with its contributions to research on climate effects of air traffic and of the complete traffic system. One of the research subjects is nitrogen oxide emissions from both aero engines and natural sources like lightning. For this purpose, measurement campaigns were flown over Europe, as far south as the tropics with the DLR's Falcon aircraft. Significant progress was also achieved in research on the formation of ice particles in the atmosphere. For the first time, ice supersaturated regions in the atmosphere could be predicted. This is a fundamental condition for the prediction and avoidance of contrail development. Using data provided by modern geostationary satellites, cirrus clouds can be detected with a high time resolution and the current contribution of air traffic can be estimated. New climate models allow the evaluation and prediction of climate effects of all types of traffic. As a partner in various EU projects as well as in its own project "PAZI: Partikel und Zirren" (particles and cirrus clouds), the DLR contributed to a new evaluation of the real climate effects of air traffic. This project was initiated due to a 1999 IPCC publication. It was shown that the IPCC had overestimated the direct effect of linear contrails by a factor of about 3, based on an assumption for their optical density that was too high. On the other hand, evidence suggests that contrails may contribute to the development of cirrus clouds in a cold and humid atmosphere. Furthermore, aviation seems also to affect clouds by soot particles resulting from an imperfect combustion in aero engines and by sulphuric acid, developed when burning sulphurous fuels.



Measuring the exhaust of ATTAS from the DLR's Falcon

Research work accomplished so far has confirmed that minimizing CO<sub>2</sub> and NO<sub>x</sub> emissions have to be given top priority. Secondly, contrails as well as soot and sulphur emissions should be reduced. Due to the difference in lifetime, which on average, exceeds 60 years for CO<sub>2</sub> but amounts to only some weeks for other gases and particles, measures to reduce NO<sub>x</sub> emissions and contrails is likely to be especially effective as a short term and low cost contribution of aviation to climate protection.

## Political Framework

This program is based on the research policy requirements of the Federal Ministry of Economics and Technology, providing a basis for planning from a political point of view. In addition to the civil research activities, presented in this HGF program, aeronautical research at the DLR comprises a significant amount of defence related work. This part is funded by the Federal Ministry of Defence and entails a limited amount of third party funding from defence industries.

Although some activities focus on specific defence related tasks, most of them have a distinct dual-use character. This is particularly true of numerical and experimental tool development as well as the operation of test facilities.

The traditional dual-use character of many of the DLR's research activities became even more apparent when, in the wake of the 2001 terror attacks, security aspects attracted much more attention also in Germany and Europe. In Germany, political initiatives for research are currently lead by the Federal Ministry of Education and Research in close coordination with the Ministry of Defence and the Ministry of Internal Affairs. In the future, an even closer link between military and non-military responses to new threats

can be expected, at least in the context of technological developments. The DLR is prepared for this trend. Examples for research topics in this field with relevance for aviation are the protection of all kind of transport aircraft against light anti-aircraft missiles and small arms fire as well as the use of manned and unmanned aircraft for reconnaissance and monitoring tasks.

## Relevant Research Programs

If this HGF program forms the basis for the DLR's research work in civil aeronautics, important complimentary programs can be found particularly within the aeronautics research programs (Luftfahrtforschungsprogramme LuFo) of the Ministry of Economics and Technology and the framework programs for research of the European Commission. Regional research programs are also important complements. In general, such programs aim at creating networks of research capacities within their geographical scope, thus effectively supporting the DLR's concept of entering into co-operations whenever they are deemed beneficial for developing its own expertise or for adequately positioning itself in the research community. The DLR participated in the 6th European framework program more than any other EREA research establishment. The DLR's annual income from the 6<sup>th</sup> European framework exceeded €8m in recent years and comparable results are targeted for the current 7th framework program. In the years to 2012/2013, the European Joint Technology Initiative (JTI) "Clean Sky" and the "SESAR" program (Single European Sky ATM Research) will be of particular importance. Both programs are strongly application-oriented, aiming at a realistic demonstration of technical solutions, especially with regard to the ACARE goals. They will be quite large compared to other European research projects. Together with its EREA partners, especially with ONERA and the NLR, the DLR is currently preparing a significant participation.



The DLR has also been heavily involved in the national €160m research program LuFo 3. As a partner in joint projects or as a subcontractor to industry, the DLR realized a total income of about €20m. A comparable success rate is intended for the current LuFo 4 program. It has to be considered, however, that the LuFo programs primarily address the aeronautical industries and that they clearly focus on research for short or mid-term prospects of application.

For the DLR it is essential to participate in these programs in such a way that the project work is complementary to the activities within the HGF program as far as possible in order to gain a maximum benefit of all projects. Working closely together with the industry in joint European or national projects will give more room for long-term anticipatory research work within the HGF program without putting its basic application-oriented character into question.

## Cooperation and Competition

A high degree of international cooperation is characteristic for the aeronautics industry as well as for related research. The DLR must be able to hold its ground in this environment. The aim is to strengthen the DLR's competitive position in Europe and worldwide. For this purpose it needs a concept for a meaningful cooperation with relevant partners in the national and international fields. The individual approaches for cooperation will allow the DLR to join important networks and to take part in their development, while increasing its own efficiency by sharing efforts and exchanging



expertise with partners. For applied research a continuous link to industrial applications is obviously of major importance. Cooperation with other research establishments and with universities, not least with regard to education and training, has become characteristic of the DLR's activities.

In general, the DLR's concept for cooperation considers the following aspects:

- > avoidance of redundancies in research,
- > use of facilities in a more efficient way,
- > responding to the Europeanization and the consolidation of industry,
- > enhancing political influence,
- > strengthening the position as a partner of industry,
- > complementing the portfolio of expertise and,
- > developing new markets.

### Industry

In the course of industrial consolidation in Europe the aeronautical sector has seen a consolidation to a small number of large companies for aerospace systems. In Germany, there is no longer any major independent aircraft manufacturer. The spectrum of suppliers is characterized by just a few larger companies and a number of relatively small and, in most cases, highly specialized enterprises.

For the DLR, industrial companies may be customers and, at the same time, partners in joint projects. Successful acquisition of third party funding is regarded as an indicator for the relevance of research with regard to practical applications.



The DLR's research helicopter FHS, jointly procured with Eurocopter and the German MoDz

Some of the most important industrial partners of the DLR in civil aeronautics are Airbus, Eurocopter, MTU, Rolls Royce, Liebherr, and Diehl. In addition, there is also a cooperation with the ATM providers DFS and Eurocontrol as well as with some airport operators and airlines. The aim is to become a strategic partner of the most important customers and to cement this position by means of longer term cooperation agreements. In consultation with regional governments, the DLR has also started to establish customer centres at the locations of some major industrial partners.

In addition to internationalization, two trends have been apparent for some time on the industrial side: The first is characterized by a gradual retreat from basic research and, in some cases where partners like the DLR have built up own competences, even from applied research. The second concerns an attempt of the large aircraft manufacturers to shift development and production risks for subsystems to their suppliers. As a result these suppliers are becoming more important as partners of the DLR.

In addition to the aircraft manufacturers, airports, airlines and the providers of services like ATM are important economic powers with a demand for high tech products and services. In total, the European aeronautics industry with its 440,000 jobs achieves a positive foreign trade balance exceeding €22 billion annually. In Germany, the aeronautics industry has about 70,000 high quality jobs, 16,000 of them in research and development. Together with airports, airlines, service providers and other players within this sector, the air traffic economy accounts for about 630,000 jobs in Germany.

## Universities and other research establishments

In Germany, aeronautics research, mainly devoted to basic research, is well established at numerous universities. As a result, a broad spectrum is covered but, the individual activities are widely scattered and funding for building and operating large facilities is generally available on a very limited scale only.

Certain aspects of aeronautical research are covered also by Fraunhofer and Max Planck institutes as well as by some other research establishments in Germany.

Cooperation with universities, but also with other HGF centres, is of major importance for the DLR with respect to both basic research and technology development. It is settled in different ways:

- > The directors of DLR institutes (and occasionally other scientific staff members) are appointed jointly with universities, becoming firmly linked to them by a teaching position. This guarantees a close cooperation in research and education as well as access to junior scientists for the DLR.
- > Participating in collaborative research centres, research training groups and priority programs of the German Research Foundation (Deutsche Forschungsgemeinschaft DFG) provides access to new research topics of the universities.
- > University representatives are regularly involved in the DLR's planning as members of the Senate and as evaluators of institutes and programs in the DLR's periodic evaluation processes.
- > Joint LuFo and EU projects foster cooperation in applied research.
- > New HGF instruments like virtual institutes and Helmholtz university young investigators groups further strengthen the cooperation.

## EREA

Outside Germany, the "Association of European Research Establishments in Aeronautics" (EREA) is the most important partner for cooperation.

Existing nuclei, formed together with the French counterpart ONERA (joint programs for helicopter and civil transport aircraft research) and with the Dutch NLR (joint marketing and operation of DLR and NLR wind tunnels within the DNW foundation) are examples of successful and sustainable cooperation. A new alliance with the NLR in the field of ATM has now been active for about two years as "AT one" and has begun playing a prominent role in Europe.

EREA was founded in 1994. Today's members are CIRA (Italy), DLR (Germany), FOI (Sweden), INTA (Spain), NLR (The Netherlands), ONERA (France), and VZLU (Czech Republic). The long term aim is a harmonization of all aeronautical research activities of these establishments.

EREA members cover all the key aspects of aeronautical research and they are well equipped with related infrastructures and facilities.



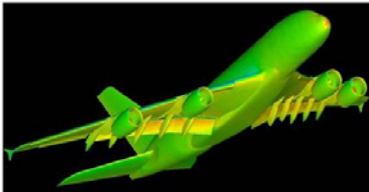
Wind tunnel test at DNW  
(LLF, Nordoostpolder, Niederlande)



EREA members

# Content and Goals

## Program Topics and Integrating Activities



With its broad technology portfolio in conjunction with its focus on applied research, the DLR should be able to act as a competent partner for aircraft and engine manufacturers, for suppliers, airlines, airports and ATM providers. A clear orientation to the relevant technological issues of aircraft industry and air traffic economy is directly reflected in the structure of this program. Four program topics address the major products and services of this economic sector:

- > fixed wing aircraft
- > rotorcraft
- > propulsion systems
- > air traffic management (ATM) and operations

The first three of these topics are related to technology development for aircraft manufacture, the fourth one to aspects of flight operations. The planned technical content of these program topics will be described in detail in one of the following sections.

Within all of these topics, environmental aspects concerning, in particular, a reduction of noise and pollutants will be of major significance. Given the current challenges for aviation as outlined before, there can be no doubt that the importance of environmental problems will increase rather than decrease in the future. In accordance with their interdisciplinary character, these activities will have to involve integration between different program topics.

Another type of cross-disciplinary activity is represented by numerical simulation, which is one of the most promising approaches for faster and more efficient design and development processes. Finite element techniques, complemented by computer aided design (CAD), have already dominated structural development for a long time. Increased computational capabilities together with some significant advances in numerical tool development have also disclosed new options also in other disciplines. Significant advances have been achieved especially in fluid mechanics (Computational Fluid Dynamics, CFD) and in aero acoustics (Computational Aero Acoustics, CAA) in recent years, which suggests that the vision of a computer based process of design, development, qualification and even certification is not unrealistic for the future. Terms like "Common Virtual Bird" at Airbus and "Digital X" at the DLR are used to illustrate respective ambitions. With the centre of competence C<sup>2</sup>A<sup>2</sup>S<sup>2</sup>E, jointly supported by Airbus and the DLR and backed by the federal state of Lower Saxony, the two partners will take decisive steps in this direction. C<sup>2</sup>A<sup>2</sup>S<sup>2</sup>E is described in more detail in the context of the fixed wing program topic. The respective numerical tool development at the DLR is not be restricted to transport aircraft, but covers all areas including propulsion techniques.

A cross-disciplinary approach like this has already been initiated in the predesign domain. Implementing a competence in system evaluation requires fast simulation methods to be available in a consistent simulation environment.

### Virtual integrated products (VIPs)

Evaluating individual technology developments with regard to their relevance for entire systems requires test cases. The DLR as a research establishment, not devoted to hardware development, relies on virtual systems available in form of simulation models only. Whenever aspects of the total air traffic system are to be considered, such test

cases must not be limited to aircraft systems but have to represent air traffic scenarios instead.

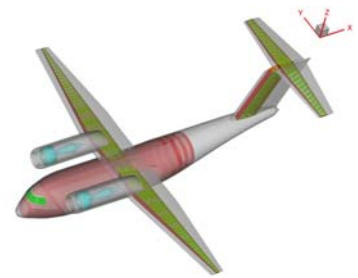
For this purpose, a number of “integrated virtual products” (VIPs) will be specified. They will provide a frame of reference, especially for interdisciplinary projects. Four such VIPs are planned so far:

- > QSTOL            Quiet short take-off and landing, a concept for a transport system mainly for short-haul traffic with future passenger aircraft.
- > ALR              Advanced long range, future aspects of long range traffic including air cargo in a global air transport infrastructure.
- > HELIXX        Low noise, all-weather helicopter operations.
- > Business travel   Technologies for business aircraft as part of commercial air traffic.

The considerations which have led to this selection are as follows:

#### QSTOL

Short-haul air traffic in particular has often to rely on the use of smaller air fields, sometimes situated close to cities. Increasing capacity constraints at larger hubs, but also the attractiveness of flight operations from a larger number of airports close to the customers support this trend in the future. Runway constraints in conjunction with increasing requirements in terms of noise protection for residents are particular challenges for this kind of operation. Technological developments relevant in this context will mainly concern high lift devices optimized for both aerodynamic performance and noise. New aircraft configurations, designed for lower cruise Mach numbers and for new engine concepts (e.g. Propfans), will also be investigated here. In addition, low noise ATM procedures for take-off and approach, supported by suitable means for pilot assistance, will be addressed as well as efficient operation concepts for shorter turn-around times. As airport processes are important to be considered here and will be integrated into the investigation.



#### ALR

More than any other air transport domain, long range traffic including air cargo gives room for the consideration of completely new aircraft configurations. For example, blended-wing-body designs frequently discussed in recent years were nearly exclusively related to this segment. At the same time, flying long distances at high altitude is particularly relevant to air traffic related climate effects. From the passengers’ point of view, cabin comfort is an important issue especially in this context. Finally, cargo transport best offers a realistic chance to seriously consider single pilot or even pilot-less operations in commercial aviation. Airport related technologies have to be considered with regards to the overall efficiency of the air transport system and its processes here as well. Especially for an investigation of long term prospects, methods and tools for a holistic prognosis will be indispensable.



#### HELIXX

Within the air transport system, helicopters will probably play only a minor role in terms of quantity. However, they can be expected to maintain or even expand their position in civil aviation as very flexible transport for special tasks. There is a need for further development to reduce external and internal noise and vibrations, but also with respect to all-weather capabilities, handling and safety aspects. Finally, helicopter performance with respect to speed and operational range should be significantly improved.





#### Business travel

“Business travel” is used here as a shorthand for operations of all kind of smaller aircraft in commercial use. Of special interest is the comparably broad spectrum of potential requirements and of related technologies and applications for configuration and propulsion concepts. This includes concepts for supersonic aircraft. Aspects related to operations from dispersed small airfields and to an integration of this segment into the air traffic infrastructure are serious challenges as overall traffic density grows.

The new research group for air transport concepts and technology evaluations will use these VIPs as references for concrete tasks concerned with technology integration and with studies on a system level. The majority of the DLR’s interdisciplinary research projects will be related to VIPs in order to allow results to be evaluated and sensitivity studies to be performed. The chance to evaluate the results in this way will be an important criterion when specifying project goals.

## Expected Results

From a strategic point of view, the activities aim at supporting and strengthening the DLR’s position as one of the leading research establishments in aeronautics worldwide. The broad spectrum of its technology portfolio combined with the capability for interdisciplinary cooperation (concurrent research) has to be maintained, if the DLR wants to be acknowledged as an authority for technology evaluation, when working with its partners from industry and research. Implementation of this capability, already started in the previous planning period, will lead to the establishment of competences, tools and structures.

Tool development, especially in the field of numerical simulation, will remain a focal point of DLR activities in all areas. With the implementation of C<sup>2</sup>A<sup>2</sup>S<sup>2</sup>E, substantial advances can be expected here. Modern experimental test facilities available at the DLR for validation of the methods developed effectively support this effort.

Applied research will stay as the focus of DLR activities. At the same time, it is indispensable for an establishment with high scientific ambition to keep an adequate scope for more upstream research. Scientific strong points and unique capabilities will be supported in order to further allow top scientific results to be achieved within the individual disciplines. This also means that basic research will always have significance at the DLR.

For all program topics, expected results are presented with concrete figures and milestones in the following sections of this document. Nevertheless, individual focal points may have to be shifted during further planning in order to cope with new challenges and to benefit from emerging chances.

Generally, the goals are oriented with an expectation of the following basic conditions:

- > For the foreseeable future, a clear orientation of civil aeronautical research at the European Strategic Research Agenda (SRA) with its focus on efficiency, environment, safety, and security will be mandatory.
- > Subjects of special relevance for aircraft industries in Germany must be adequately addressed in research.
- > The DLR must be able to develop innovative long-term concepts for air transport.
- > The DLR has to strengthen its leading position within Europe.



Wind tunnel model in the ETW



## Program Prospects

Current efforts to integrate the expertise available in the DLR's various disciplines with the aim of addressing the development of the entire air transport system will support the significance of this research program in the national and international environment, being fully in line with a basic requirement of ACARE. Beyond that, there are options in nearly all of the DLR's research fields for further promising activities, which are currently not in the scope of this program due only to a lack of funding.

In ATM, this concerns for example a more consistent approach to the subject of total airport management, which would require a simulation environment for all major processes at an airport.

In propulsion techniques, providing capabilities for the layout of a series of piloted lean combustors is regarded as particularly demanding. It would be very interesting for the DLR, but cannot be adequately covered within the framework of this program. The same is true for the prospects of alternative fuels. Even if revolutionary developments cannot be expected in this area in a mid term time-scale, anticipatory research should be performed in order to identify prospects and challenges and to give answers to questions of high public interest.

A particularly important technical challenge for a European aircraft industry struggling for competitiveness will be to significantly reduce production costs by further automation. For the future of production lines in Germany, this issue will be crucial. Thus for the DLR it is essential to develop production techniques for lightweight structures, especially for composites. Although this is a new task, a solid basis is available at the DLR in form of the existing DLR Center of Excellence (CoE) for Composite Structures with its expertise in materials research, process development, construction technique, and technical demonstrations on the prototype level.

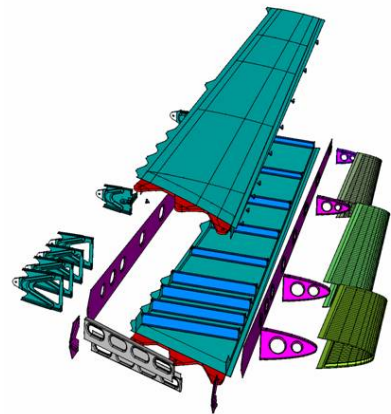
The field of CFRP production techniques can be subdivided into three production areas: large shell-type structures, complex components in large numbers, and production/assembly of components to multifunctional systems.

Content and goals of respective research can be summarized as follows:

- > cost reduction and increase in efficiency,
- > reduction of development risks and of lifecycle costs,
- > shortening of development time,
- > increase in safety and comfort due to
  - k novel design concepts,
  - innovative processes and
  - efficient production techniques.

For large shell-type structures a new generation of automated facilities for shell production will have to be developed. Fuselage and wing shells are examples of target components. For more efficient production of complex components in large numbers, the aim will be automation of the complicated and time-consuming processes in conjunction with an increased quality. Target components in this case are frames and stiffeners. For an integrated production and assembly of a multifunctional system, design concepts adapted to construction methods and novel bonding concepts for a multi material design will be required.

Such a new research topic would be best established in a close coordination with Airbus Stade and with the "CFK-Valley e. V." also in Stade. For the DLR, this is a logical



DLR design study of a new generation vertical tail plane

and consistent add-on to the existing know-how in composites. However, an extension requires a significant new effort. Current resource planning does not cover such an extension, either in terms of personnel or in terms of financial resources.

## External Contributions

As outlined earlier, aeronautical research at the DLR is characterized to a high degree by networking with other partners. Especially the strategic cooperation with ONERA in the fields of fixed wing and rotorcraft research, as well as the cooperation with the NLR in the ATM field result in major achievements being increasingly made in a joint effort.

Networking with external partners is of particular relevance also for research work on environment and climate issues concerned with air traffic. Here it is important to correctly quantify the effects of aviation, which are relevant for climate change, to adequately consider them in global climate models and to evaluate these effects in a context to all anthropogenic factors contributing to climate change. To this end, a close cooperation with meteorologists and climate scientists is indispensable.

## Cross-Program Initiatives



For the DLR, it is a declared objective to make use as far as possible of synergies between its research areas of aeronautics, space, transport, and energy. The majority of its institutes contribute to more than one program with their specific expertise. Furthermore, it is in the interest of the individual programs to harmonize efforts and to cooperate wherever sensible.

From the aeronautics point of view, joint programmatic interests with the space program exist for example in the field of communications and navigation. This concerns a common future demand for broad band communications as well as an interest in the Galileo program with regard to new satellite based ATM tools. With the transport program there is a joint interest in fuel cell systems for mobile applications, but also in noise issues. In particular, the problems of simulating noise propagation in the atmosphere close to the ground and under various weather conditions as well as the effect of traffic noise on human beings are of common interest. The DLR's topics in energy research were selected from the beginning with regard to synergies to aeronautics and space research. Parallel work on aero engines and on stationary gas turbines for power plants illustrates this.

A special role in this context has been assigned to the Institute of Airport Research and Air Traffic. For the previous planning period, the HGF senate had explicitly recommended the establishment of airport research as a new topic and the allocation of sufficient funding within the transport program. The aim is to investigate landside issues of airport layout and operations as well as the issue of integrating airports into a ground traffic system. A direct relationship to aeronautics is apparent, of course, not only in airport research, but also for the subject of air traffic prognoses, covered by the same institute. Therefore, the portfolio of expertise presented earlier is referenced to this know-how as an integral part of the DLR'S overall expertise with respect to the entire air transport system.

In the aeronautics program, the airside of an airport is considered. The interface to the transport program is – somewhat simplified – represented by the gate. An approach towards “total airport management” as currently discussed will obviously require a close programmatic cooperation between aeronautics and transport.

# Infrastructures

Applied research in aeronautics requires a large amount of technical infrastructure to be used. In accordance with its statutes, the DLR builds and operates in particular large test facilities and ground infrastructure for internal and external use. The most important items for aeronautics are wind tunnels (including model workshops), research aircraft, ground simulators, engine test stands, and a broad range of measuring techniques and IT equipment.

## Existing Infrastructure

### Wind tunnels

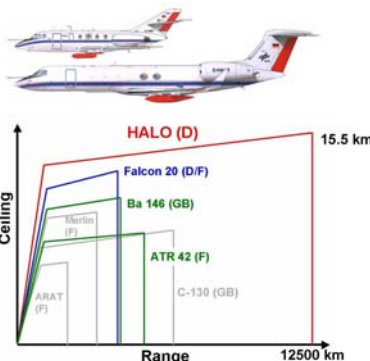


ETW

Wind tunnels are among the most important facilities in aeronautical research. They have traditionally been used for investigating the aerodynamics and acoustics of fixed wing aircraft, helicopters and aero engines. In addition to helping consolidate the knowledge base in fluid mechanics and aero acoustics, the provision of experimental data suitable for validating numerical methods is of primary interest today. The DLR continues developing sophisticated measuring techniques and operates design offices and workshops for wind tunnel models. Nearly all of its wind tunnels used in aeronautics have been integrated into the DNW foundation, together with those of the Dutch NLR. The bilateral enterprise has taken over the responsibility for the joint operation and marketing of these facilities. This process has found a logical continuation in the cooperation of DNW and ONERA in the frame of the Aero Testing Alliance (ATA), recently established to harmonize their respective scientific and commercial activities.

The European Transonic Wind tunnel ETW, unique in its ability to simulate cruise Reynolds numbers, was built as a joint venture of France, Germany, the Netherlands and the United Kingdom in order to support the competitiveness of the European aircraft industry. The DLR is represented on its supervisory board. The ETW supports operations performing aerodynamic research in the field of high Reynolds numbers, developing cryogenic measurement techniques, and integrating CFD methods into test environment. In this way, unique capabilities in aerodynamic analyses are established in Germany in conjunction with the ETW, which is the most advanced facility of its type worldwide.

### Research aircraft



HALO and Falcon

The DLR operates the largest fleet of civil research aircraft in Europe. They are used mainly for internal research, although they can also be made available to other researchers or industrial users. Representing a unique asset within EREA, the fleet is an indispensable element of research capabilities, suitable for validation and demonstration as well as for a broad range of dedicated measurements in atmospheric research. Especially in the field of in-flight simulation, the DLR has developed an expertise which is unique within Europe.

For this task the fixed wing twin jet ATTAS based on a VFW614 and the helicopter FHS based on an EC135 are currently available. ATTAS will be replaced by the A320 ATRA, which was procured in 2007 and will be equipped as a research aircraft by 2008/2009.

The DLR's Falcon twin jet is used for mainly for atmospheric research. This aircraft, well proven in 26 years of operation, will be replaced by the new environmental research aircraft HALO. The HALO project was based on a joint initiative of the DLR and the Max

Planck Society, additionally involving 31 scientific institutes of atmospheric and environmental research in Germany. HALO is based on a Gulfstream G550. With its outstanding performance envelope, it provides a significant increase in capabilities with respect to range, ceiling and payload. The aircraft will enter service in 2008.

The flight operations department of the DLR is supported by its own approved design organisation, which is to assure certification of the aircraft modifications frequently necessary for in-flight experiments.

### Ground simulators/ demonstrators

For development, validation and evaluation of ATM tools, the DLR can use a number of simulators and demonstrators, which can also be applied to training operating personnel. They include facilities for apron and tower simulation, a demonstration cockpit and an airport and control centre simulator. For research related to flight systems, ground simulators are available, which mainly support operations of the in-flight simulators ATTAS and FHS. Cooperation with the NLR further extends the range of simulators available for research in the ATM field. Combining the respective facilities including the aircraft allows a wide range of scenarios to be simulated and entire ATM systems to be evaluated and qualified. With regard to a planned participation in European programs like SESAR, this is a major asset.



Tower simulator

### Propulsion test stands

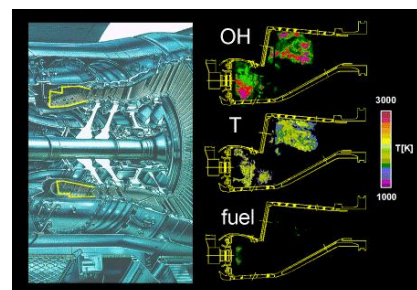
Further development of environmental friendly and efficient aero engines and gas turbines requires large test stands and specialized wind tunnels. Supported by industrial partners like Siemens, MTU and Alstom, the DLR has developed a scientific capability in recent years, which is unique among European research establishments. It combines scientific expertise, modern experimental and numerical tools as well as large test facilities and component test stands for compressors, combustion chambers and turbines. One of the major elements is the high pressure combustion chamber test stand HBK4, originally developed within the frame of a technological alliance with Siemens Power Generation for joint research on advanced gas turbine technologies. Together with other facilities including test stands for basic research and with advanced measuring techniques available in Cologne and Stuttgart it significantly supports the research activities of the DLR and its partners.

### IT

An adequate IT infrastructure is mandatory for efficient research work. The DLR is continuously upgrading its respective equipment including basic software, CAD systems, databases etc., regarding it as a basic prerequisite for achieving its goals in applied research. Internal developments of specialized software and validating them are part of this effort.

### Measurement techniques

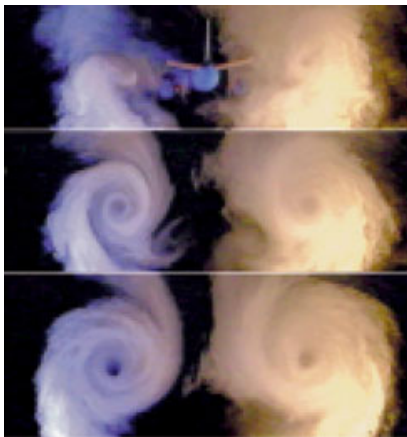
Sophisticated measuring techniques are developed at the DLR for various tasks. They are applied in wind tunnels and all kind of test facilities including research aircraft for internal and external users, representing major elements of the system "experimental simulation". Experimental data including all boundary conditions have to be recorded with a sufficient resolution in terms of time and geometry, especially if they are to be used for validating numerical methods. Experimental tools including related measure-



Laser-Diagnostics at a combustion chamber test stand



ment techniques are the subject of research and development in a number of individual institutes. Once developed, they are available DLR-wide in the interest of competitiveness in all areas. In order to better coordinate the development and application of measuring technique within the DLR a database is currently being established that includes information on all items of measurement equipment available at the DLR.



Measuring wake vortices on models in ONERA's B20 test facility

## External Infrastructure Used

The DLR's numerous cooperative activities, especially those with industry, have always been characterized to a large extent by a joint use of unique test facilities. At the DLR, large scale test facilities like wind tunnels have generally been established with regard to the interest of internal and external users. In special cases, the DLR also operates facilities, which have been procured together with external partners for joint use. The helicopter FHS, procured together with Eurocopter and the Ministry of Defence, and HALO, jointly procured with the HGF and the Max Planck society, are examples for such solutions. The special situation of the DLR's wind tunnels, which have been nearly completely integrated into the bilateral DNW foundation, has already been outlined above. Unlike the DNW facilities, the ETW may be regarded as an external facility from the DLR's point of view, even though it is supported by the DLR.

As a result of the efforts towards networking with other research facilities, the DLR has access to the partners' infrastructures on a case-by-case basis. For the future, one of the goals of networking must be to avoid redundancies in large and expensive infrastructure by means of a coordinated (or joint) investment planning. A general regulation for access to the remaining facilities by external users is necessary.

Coping with numerical models of complex systems, for example in atmospheric research, in aerodynamics or in virtual design requires powerful computers and suitable software packages. In order to be competitive on a global scale, access to world class high performance computing is mandatory, even if the DLR itself does not possess the respective equipment. The DLR currently uses external facilities to a large extent.

## Planned Infrastructure

### Planned infrastructure with costs exceeding € 2.5m

| Planned infrastructure proposals            | Total investment costs |
|---------------------------------------------|------------------------|
| Extension of combustion chamber test stands | 20,000                 |
| Simulation centre                           | 6,000                  |
| Production techniques                       | 43,000                 |

All data in Thousands of Euro

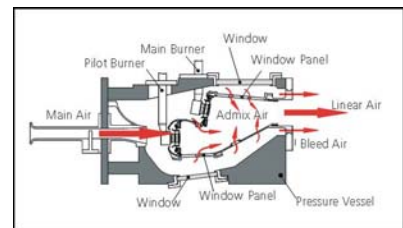
Existing infrastructure is generally subject to periodical upgrades. In the following, some planned investments are sketched, which are beyond the scope of such normal developments. Detailed cost estimations are not yet available for these investments. Furthermore, potential third party participations still have to be checked. Establishment of an infrastructure for production techniques has to be considered under the reservation that funding for the research activities is not yet secured (see section on program

prospects). Any investments here will obviously be meaningful only in a scale adapted to the amount of work that can be really done. On the other hand, without adequate infrastructure, activities like these, which are exceptionally application oriented, cannot reasonably be performed.

### Extension of combustion chamber test stands

Implementing lean combustion in aero engines in order to further reduce emissions of nitrogen oxides requires a systematic development process covering basic experiments, tests of single combustors and, finally, tests of complete ring combustion chambers under realistic operating conditions.

The interaction between combustors, the thermo-acoustics within the entire operational range and the specific conditions of lighting and flame-out can only be verified in such component tests. Large test stands, compressors providing the required air mass flows for engines up to medium size and test and measuring techniques are largely available for these tests at the DLR. For larger engines in a thrust range of more than about 100 kN, maximum mass flow, electric power supply for the compressors, their re-cooling capacity, and the pre-heating capacity, required to achieve adequate air temperature at the intake of the combustion chambers, are not currently sufficient. As realistic testing of combustion chambers with respect to lean stability, thermo-acoustics, lighting characteristics and emissions requires all boundary conditions to be strictly maintained, a substantial extension of the existing infrastructure is mandatory to effectively support European engine suppliers with respect to this class of engines.



Combustion chamber test stand

### Simulation centre

Ground simulators for research on ATM and flight systems are major elements of the DLR's test infrastructure. Continuous support of the new A320 ATRA and the FHS simulators are required, partly replacing older ones. For ATRA, an investment was planned from the beginning as part of the aircraft procurement plan. Current ideas call for an extension to a modular simulator concept, covering both tasks in a more efficient way. Its use will no longer be restricted to supporting flight test operations. Research areas, which will directly benefit from such a system, include

- > handling characteristics of new aircraft configurations,
  - > handling characteristics of degraded configurations due to system failures,
  - > flying into wake vortices or other turbulences,
- and, specifically for helicopters,
- > all-weather capability,
  - > novel (active) controls and,
  - > pilot assistance for safe operations with slung loads.

In general, ground simulation is a meaningful and necessary complement to numerical simulation on the one side and to in-flight simulation on the other side. By means of the planned substantial increase in capacity, in combination with existing facilities for ATM research, a highly capable simulation centre will develop at the research airport Braunschweig.



CFRP shell element in front of an autoclave at the DLR

### Production techniques

Provided that plans to establish an expertise in production techniques can be put into practice, technical infrastructure will be required in a significant scale.

For large shell-type structures a new generation of automated facilities for shell production will be required, characterized by a considerably increased lay-up rate of complex structural parts. This includes flexible facilities for automated fibre placement, hot forming devices, novel autoclaves, and efficient techniques for quality control.

For high precision production of complex parts in large numbers, the main challenge lies in the automation of complex processes and in reducing production times while at the same time increasing quality. Related infrastructure will have to include tools for fixation, discarding, draping and forming as well as resin infusion modules and techniques for process monitoring and quality control.

For an integrated production and assembly of structural components to a multifunctional system, design concepts adapted to production processes as well as novel bonding concepts for a multi material design will be necessary. Development and verification of such concepts require a measuring field for 3D laser measuring, automated tools for machining, bonding, local tempering and positioning as well as devices for analyzing bondings.

# Program Management

**A special feature of the aeronautics program (and of the space program as well) within HGF is that it is exclusively covered by the DLR with no other HGF establishments being directly involved. Therefore, program management can completely rely on the rules for programmatic auditing established at the DLR.**

## Planning and Auditing

For nearly two decades, the DLR has worked in a matrix structure where, below the executive board level, the individual institutes with their scientific expertise meet the program directorates of the four business areas who are responsible for the programmatic orientation of research work. The function of the program directorates is to plan and to audit programmatic activities with regard to agreed strategic objectives for the respective programs. This is achieved by target oriented allocation of resources for personnel and material and by programmatic auditing of processes.

Scientific and technical work is executed in the frame of projects, typically agreed for a duration of three to five years and with clear targets in terms of technical goals, schedules and budgets, or in the frame of one-year schemes (Vorhaben), which generally have to be renewed annually, but which are subject to far less stringent targets. The latter are well suited for basic research and for long term anticipatory applied research. The scientific content and the goals of the individual projects and schemes are jointly agreed by the program directorates and the institutes involved. Execution of project work is organized by project leaders residing in the institutes. In this phase, the program directorates are responsible for auditing from a "customer's" point of view.

The program directorate for aeronautics is organized in a way that an affirmed contact person is available for each program topic (program topic leader). If applicable, the topic leader is also concerned with defence oriented aspects related to the topic.

With respect to third party business, the institutes generally act independently, with the program directorate assuming coordinating and supporting tasks in external relations.

## Cooperation

The DLR's ambition to have a holistic view on the complete air transport system implies a close interdisciplinary cooperation of the various institutes. As already illustrated with some concrete examples, interdisciplinary projects meanwhile make up a large part of programmatic work in aeronautics. This approach is eased by the fact that the program is completely covered by the DLR. Nevertheless, as a secondary effect, practicing project-style activities also fosters professionalism in cooperating with external partners.

## Academic and Pre-academic Training

As the largest scientific and engineering establishment in Germany, the DLR takes advantage of the fascination with air and space in an effort to inspire young people's interest in science and technology. The DLR has a social and public duty to encourage the next generation of young scientists and engineers, and it is for this reason that it offers a wide range of programs for children and young people.



DLR's Bo105



The DLR's Do228



School Lab Göttingen

#### *DLR School Labs*

In the DLR School Labs, secondary and high school pupils can get to grips with the practical side of science and engineering through interesting experiments, motivating them to take these subjects further. Special attention is given to girls in this context.

#### *Girls' Day*

As part of a worldwide community initiative, the DLR is involved in "Girls' Day", providing information about training opportunities, jobs and employment prospects in the aerospace industry. Girls' Day is the opportunity for girls to experience first-hand the everyday work of a technical research establishment. The event is intended to create enthusiasm amongst girls for technical subjects and to show them the wide range of jobs, which exist outside the "traditional" female occupations. Public awareness of the strengths and abilities of girls is encouraged.

#### *Academic training*

The DLR actively encourages young scientists. Every year, about 200 diploma theses and 70 PhD theses are completed at the DLR.

As a partner of academia and industry, the DLR offers a chance to get insight into a wide range of aerospace science and technology from basic research up to industrial applications.

The DLR encourages its staff by means of a comprehensive program for human resources development and advanced training. Amongst others, methods and tools for project management to international standards can be learned here. Preparation of young scientists to take an executive position is supported by means of special qualification modules and by mentoring programs.

In the frame of bilateral projects, the DLR offers secondments abroad and also invites young people from abroad to work at the DLR as visiting scientists.

Sponsorship agreements with industrial companies promote a link between science and industrial application in personnel development. A number of companies, like EADS, Airbus and MTU make use of the offer to participate. Currently, about 40 young scientists are taking advantage of this initiative.

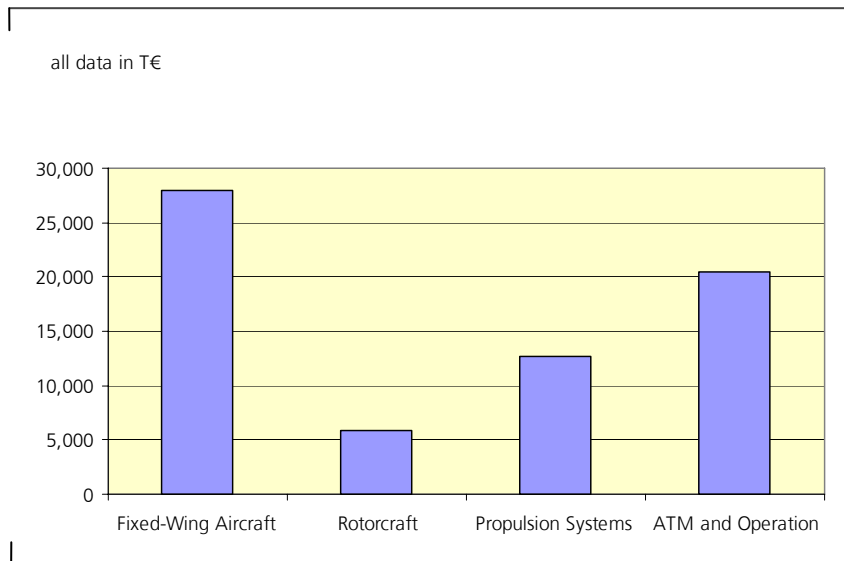
The DLR has been awarded the "Job and Family Audit" certificate. In parallel to a family oriented personnel policy, initiatives for equal opportunities are of high importance. It is a declared objective to increase the percentage of women in science and (in particular) in executive positions.



# Planned Resources

## Planned Costs

Proposed program costs in 2009 by topics



Detailed information on costs in the Annex

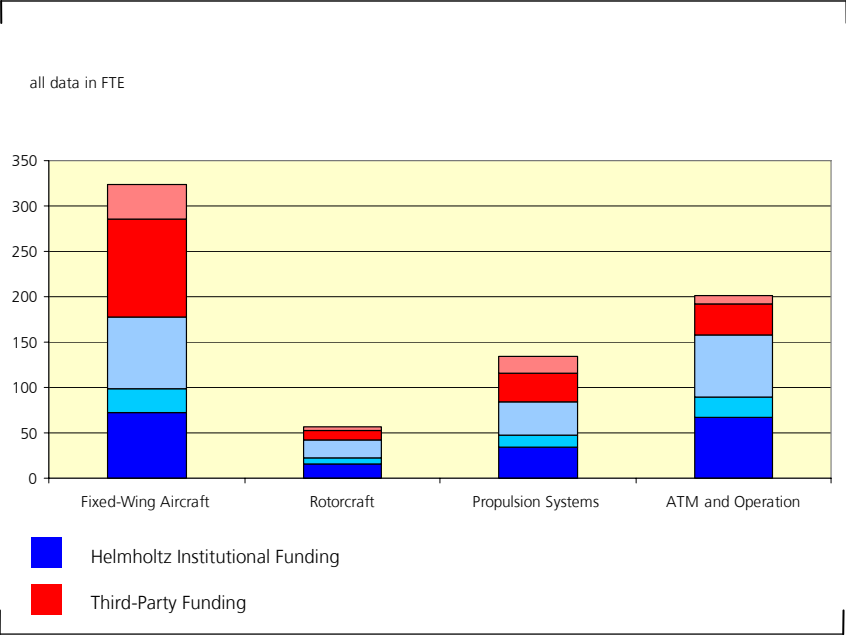
## Additional Resource Information

The allocation of resources and the resulting cost breakdown to program topics reflects realistic options considering the personnel capacities available and the related know-how in the various research areas. At the same time, it is an attempt to adequately take into account the relevance of the individual topics for the aircraft industry and the entire air traffic economy in Germany. As this has always been a formative factor also for the development of capacities, there is no fundamental conflict between the two criteria. For the years to come, planning has to consider that changing priorities can only slowly lead to major reorientations.

It should be remembered also that the complete aeronautics program of the DLR comprises civil and defence related activities. In total, the volume of military part is only about one fourth of the civil part. However, where the dual use character is particularly pronounced (especially in rotorcraft research), the defence related part is an important complement to the resources presented here.

## Planned Human Resources

Planned averaged annual human resources by topics



Personnel category in colour gradation bottom-up: scientists, doctoral students, scientific support personnel  
Detailed information on resources in the Annex

## Planned Large-scale Facilities

Planned infrastructures with costs exceeding € 2.5m

| Planned infrastructure proposals            | Total investment costs |
|---------------------------------------------|------------------------|
| Extension of combustion chamber test stands | 20,000                 |
| Simulation centre                           | 6,000                  |
| Production techniques                       | 43,000                 |

All data in Thousands of Euro

# Program Topics

Fixed-Wing Aircraft

Rotorcraft

Propulsion Systems

ATM and Operation

ATTAS  
cockpit



# Program Topic Fixed-Wing Aircraft

## Challenges

The generally accepted long-term objectives for European Aviation are described in the VISION 2020 and the Strategic Research Agenda 2 (SRA2) of the Advisory Council for Aeronautics in Europe (ACARE). The resulting challenge for passenger aircraft related research is to find solutions to problems related to emissions and resources. Furthermore it is necessary to decrease operational costs, to increase safety and comfort as well as to optimise the design process of aircraft. In the following, these general challenges will be described on the basis of three socially relevant topics.

### Mobility

The predicted growth of the world's air traffic and the increasingly stronger political demand for environmental compatibility and social acceptance are pushing the existing air transport system toward its limits. In order to rapidly obtain results, it is mandatory that new technologies are developed, but also that the basic concepts of aircraft design and the current sequence of operations are optimised. These will then be integrated into a future air transport system. This requires the extension of conceptual design capabilities as well as the simulation and optimisation of the entire air transport system.

The essential challenge in shaping the future air transport system is to increase the air transport capacity by either stagnating or significant lowering emissions. Hence, it is indispensable that all participants shape future air transport concepts. The current situation is characterised by the orientation of activities of aircraft manufacturer, airlines, air traffic organisations, and airports to their own needs. The present potential of an integrated concept, which also takes into account the interaction between individual activities, remains unexploited and sustainable improvements are hard to realise.

The conception, analysis, and evaluation of different scenarios like short-, medium- or long-range transport of passengers or payload requires the development of an integrated design, simulation, and evaluation environment to map air transport concepts in a comprehensive scenario that represents all relevant components in sufficient detail.

The analysis of the entire air transport system opens up the opportunity to derive design targets for the vehicle configurations in question. Together with the results of disciplinary research and technology development it is possible to propose a concept for the improvement of efficiency and the reduction of emissions and to implement those into the definition of new aircraft configurations. The evaluation of the performance of these newly developed configurations has to cover all aspects of conventional concepts to assess their competitiveness. The challenge while establishing such a preliminary aircraft design method is to cover the full range of relevant disciplines and environmental constraints without simulating unnecessary configuration and system technical details at an inappropriately high numerical cost.

The potential of single discipline improvements can only be judged by looking at the aircraft as an integrated system. The necessary prerequisite for such a system examination relies on the ability of multidisciplinary analysis and optimisation. In this way the potential of new technologies for improvement can reliably be tapped and quantified. Such an assessment is based on analysis methods of high quality simulation, which offer a significantly higher accuracy in comparison with conceptual design methods but require a considerably larger simulation effort. Coupling of these exact analysis methods with modern optimisation algorithms opens up the possibility for the improvement of basic shape and structural layout in the preliminary design phase. In the detailed design phase these changes are applied and simultaneously repercussions that might



European flight routes of different airlines

require a new definition of the basic configuration are recognised. The challenges of the implementation of such systems into a multidisciplinary optimisation system lie in the choice of a suitable optimisation strategy and in the combination or coupling of the simulation quality of the participating disciplines. Another substantial element is the continuous description of geometric and structural aircraft parameters to allow a seamless assembly of preliminary and detailed design.

### Environmental Compatibility and Economy

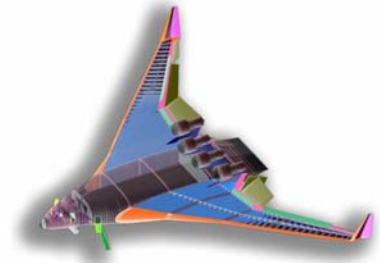
To achieve environmental compatibility and profitability of new aircraft, progress is necessary in flight physics, structures and materials. Flight physics related research is driven by the need to reduce carbon dioxide emissions and to reduce the direct operational costs of aircraft. Flow control technologies can provide major contributions to this. The ability to influence the flow such that wings, tails and nacelles are kept laminar can cut the viscous drag of aircraft components in half. Here, a saving of about 20% of the drag of the entire aircraft is possible. This analogously leads to a reduction in the fuel consumption and a reduction in emissions of carbon dioxide to the same extent. Present gaps in knowledge and experience have to be closed to master the challenges linked to the application of these technologies. Additionally, further technologies of flow control (pneumatic vortex generators, new surface structures, and electro-dynamic actuators) have to be studied regarding their possible contributions to drag reduction and their technical realisation.

The second big environmental challenge of air transport, next to a reduction in climate impact, is the reduction of airframe noise. The challenge for the time period of this application is the development of noise reduction technologies for passenger aircraft that enable a noise level reduction in the order of another  $\approx 5$  dB for propulsion and airframe noise. The reduction of noise at the location of its origin is the most effective measure. It requires a deeper understanding of aerodynamic and aero-acoustic phenomena, to achieve a targeted manipulation of the noise production mechanisms. Wind tunnel experiments coupled with specific numerical investigations provide this knowledge. A further challenge is to transfer knowledge gained by model tests to flight conditions in order to make the developed noise reduction technologies operationally applicable.

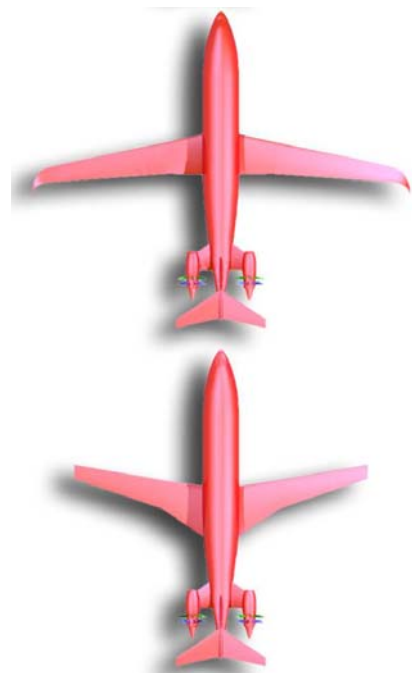
By applying modern, quiet high bypass engines, the slat of the high-lift system is, next to the landing gear, the main noise source of the aircraft during approach. Efficient, modern high-lift systems can reduce the perceived noise of transport aircraft by enabling steeper approaches and climb-outs to and from the airport. Consequently, the challenge lies in the development of an aerodynamically very efficient and quiet high-lift system. Such kinds of systems require the usage of passive and also active flow control.

Wings are designed with increasingly elastic structures to attenuate the quasi-static manoeuvre loads and to reduce the structural weight. This greater elasticity causes a stronger aero-elastic interaction with the flow, which induces additional oscillations of the aircraft. This increases the risk of flutter, increases the dynamic loads due to gusts and reduces the passenger's comfort.

For a high aspect ratio laminar wing, or a forward-swept wing, significant risks exist because of the largely unexplored unsteady aerodynamic influences for these concepts. To make this kind of concept workable, the physical understanding and the prediction methods for these dynamic aero-elastic phenomena have to be further developed in a targeted way, especially towards the flight envelope limits.



Blended wing body configuration

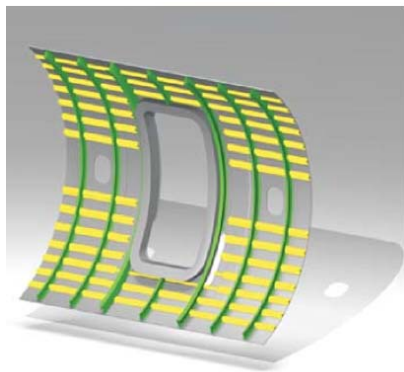


Potential laminar flow aircraft configurations





**Aero-elastic deformation (amplified) of an aircraft in cruise**



**CFRP-fuselage segment with cut-outs**

The flight physical knowledge gained will introduce new structural concepts able to exploit the anisotropy of fibre composites in terms of load and flutter risk reduction. Moreover many of these concepts involve the use of active aero-servo elastic systems to grant a weight-optimised aircraft. Hence, for structures the biggest potential for reaching the ACARE-aims is linked to a significant reduction in weight, mainly by the application of fibre re-enforced plastics.

Structural and production aspects decide the competition within aviation industry today. Therefore, it is the aim to develop the present compromise between profitability, environmental compatibility, passenger comfort, and safety to a new optimum.

The application of the technology of carbon fibre re-enforced plastics (CFRP) on aircraft structures is foreseen to reduce the structural weight by 30% compared to the conventional lightweight metallic construction. This leads to about 5% lower passenger related fuel consumption. At the same time, the manufacturing costs (standard production methods for integral manufacturing) will reduce by 40%, along with the maintenance periods and costs of CFRP-structures (e.g. no corrosion occurrence). The CFRP-type of construction furthermore enables the extremely high-quality surfaces that are necessary for laminar flow. Thus the potential to reduce the aerodynamic drag and to lower emissions and operational costs is clear.

The application of active manoeuvre and gust load reduction systems enable the decrease of these loads and a further reduction in weight. It is a challenge to use this potential because reliability, failure safety, and efficiency place high demands on control systems to be error tolerant and situationally adaptive. Fibre composite structures offer the outstanding opportunity to realise tailored passive properties by using material anisotropy as well as adaptive properties by embedded actuators and sensors to yield a further increase in performance.

Conventional lightweight metallic materials still offer great potential for the reduction of costs and weight. Additionally, they are very advantageous in terms of crash and impact tolerance. New forming and joining technologies for integral fuselage and wing structures promise lower costs in comparison to riveted structures. Components based on aluminium and titanium alloys will be applied as load bearing or safety relevant parts in future aircraft consisting mainly of CFRP-parts. Nevertheless, the challenge is to develop combinations of metal and CFRP into production-ready hybrid structures.

A challenge for the years to come, regarding the competitiveness of the European aviation industry, will be the significant reduction of production costs of CFRP-structures by automatic production. Due to the importance of efficient manufacturing procedures the lightweight manufacturing technique will be anchored as a cross disciplinary task within the DLR. The core of this research is at the DLR Centre of Excellence (CoE) Composite Structures with its competence in material research, development of processes, development of type of construction, and prototype demonstration.

### **Safety and Comfort**

During the development of future flight systems the trend is towards greater automation at simultaneously significantly higher degree of autonomy than previously. This means that flight-dynamic and system-dynamic systems as well as system and parameter identification are required to progressively develop and validate flight mechanical models for existing and new aircraft configurations. Of special interest is the targeted improvement and refinement of models near the safety-relevant limits of the flight envelope (extreme weather, degrading configurations). Modern fly-by-wire flight guidance systems are subject to higher demands concerning performance, robustness, automation, and degree of autonomy. The increasing degree of autonomy requires the

development of present-day procedures for the design of robust error-tolerant flight guidance systems that automatically adapt to the current flight condition. The expansion of the auto-pilot's range of application could bring a paradigm shift about so that at extreme flight conditions the autopilot can be considered as a reliable pilot. It will also be necessary in the future, to evaluate the flight characteristics during the design process and to prove requested flight properties by flight tests e.g. on the new DLR Research Aircraft ATRA (A320). The further development and testing of the required analysis and evaluation tools, mainly for worst-case situations, is a permanent challenge.

The energy supply of the aircraft on-board systems is facing a challenging radical change, which might lead step-by-step to an All Electrical Aircraft (all onboard systems electrically supplied). With such a change, compressed air for air-conditioning and de-icing will no longer be taken from the engine, and central hydraulic systems will no longer be needed. By intelligent multiple usage of the installed generator performance and higher efficiency of electrical systems, energy and fuel can be saved. Additionally, further benefits emerge regarding weight, maintenance, reliability, and availability.

A new efficient method of on-board electricity generation is the usage of fuel cells. They enable efficient and environmentally sound energy generation and can provide reaction water, which can be used for air-conditioning, moistening of air, or sanitary facilities. An efficient on-board hydrogen production facility for the operation of the fuel cell will make additional hydrogen tanks redundant. The concept of partial dehydration of kerosene is a variant of the chemical conversion avoiding the disadvantages of existing reformation techniques. The integration of this concept into future aircraft systems is a considerable challenge.

Due to the increasing competition in civil aviation the importance of the comfort and health of passengers and crew is growing. The quality of on-board climate and cabin noise levels play an important role in the airline's purchase decision for a new passenger aircraft. Increases in comfort are achieved by the reduction of temperature differences, draught, dry air, noise and vibrations inside the cabin and the provision of communication and entertainment options to the passengers. Concurrently the development time for an individual, modular layout of the cabin (to an airline specification) has to be decreased.

At present, climate and noise exposure inside the cabin are evaluated in extensive test series. A significant reduction in today's development and modification time can be gained by the application of numerical methods. Their development is a great challenge due to the geometrical and physical conditions inside the cabin. Especially, acoustics faces new challenges due to the future application of CFRP-light weight structures, as its modified insulation properties require new methods for the realisation of a low-noise and comfortable aircraft cabin.

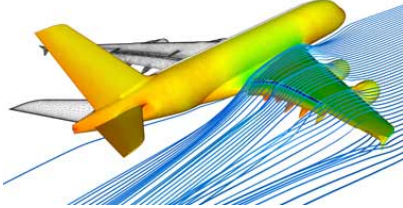
### Shortening of the Design Process

Numerical simulation is a key technology in the aircraft development process. Only by consequent application of numerical methods can future challenges regarding profitability, environmental compatibility and safety be tackled in a shortened design process.

The flow solvers developed by the DLR have meanwhile matured and are applied as standard tools in the aeronautical industry and in research. To exploit the full potential of the numerical simulation in aircraft design, obstacles have to be overcome in the development of procedures, the combination of different aircraft disciplines, the utilization of adequate computer hardware and the introduction of the numerical simula-



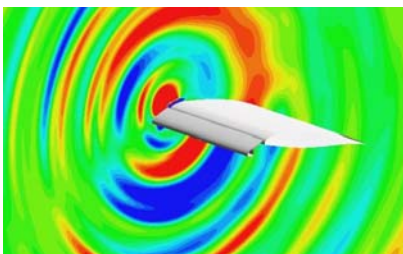
On-board climate measurement installation in an aircraft cabin



Numerical simulation of a configuration in cruise

tion into industrial processes. For this, a concentrated, joint approach of industry and research is required. The challenges the DLR has to accept are the exact determination of performance, loads, structural reserves, and flight properties. This holds for the entire life cycle and the entire flight range of the aircraft, and thus also toward the limits of the flight envelope. Due to the strong interaction of aerodynamics, structure, flight mechanics, and flight control, the multidisciplinary approach is essential. The acceptance of the multidisciplinary approach is documented in two examples. With the support of Airbus and the county of Lower Saxony, a Centre of Excellence C<sup>2</sup>A<sup>2</sup>S<sup>2</sup>E (Centre for Computer Applications in Aerospace Science and Engineering) will be established from mid 2007 for numerical, flight physical simulations. Furthermore, the DLR has the responsibility for the field of “design” within the to-date largest European research project “More Affordable Aircraft through eXtended, Integrated and Mature nUmerical Sizing”, MAAXIMUS, which is concerned with structural topics for the aircraft.

A part of the flight envelope is limited by the danger of flutter occurrence. The solution of such dynamic and aero-elastic problems requires efficient and at the same time high-precision methods due to the great number of different oscillations of the entire aircraft and the large number of flight conditions that have to be investigated. Hence, the complete aero-elastic simulation of the entire aircraft using Navier-Stokes-methods within the time domain has to be reduced to few critical payload and refuelling conditions and a few points within the flight envelope. To identify such cases the process development within aero-elasticity has to provide not only high precision but also highly efficient methods. The challenge lies in providing adequate modelling of non-linear phenomena of aero-structure-interactions for the prediction of aero-elastic processes without modelling unnecessary complexity in the aircraft structure.



Noise generation at a slat

The specific challenge for aero-acoustics in the years to come is to improve the efficiency of the numerical simulation (CAA, Computational Aero Acoustics) for three-dimensional problems such that acoustics can provide input for the aerodynamic design and (eventually) input for the high precision multidisciplinary design process (e.g. high-lift systems). An important capability will be the aero-acoustic calculation of components of any complexity and to consider the effect of absorbing materials in the simulation.

Mandatory for the resilient application of the numerical simulation for the investigation of new technologies and definition of new products is the extensive validation of the methods developed. The quality of the simulation of technologically relevant configurations is based on modelling assumptions. That makes targeted experiments that include all physical processes to capture the phenomenology, validation and assessment of the technologies indispensable. This enables a deeper understanding of e.g. unsteady flows, non-linear deformations, and damaging processes.

The challenges of flow physical experiment lie in the further development of suitable measurement techniques, when possible for flight Reynolds-numbers, in the simulation of manoeuvres in the subsonic and transonic regime, and in aero-elastic investigations close to the limits of the flight envelope. Aero-acoustics requires a considerable effort during the design and the experimental realisation of validation experiments of air-frame noises caused by turbulence in aero-acoustic wind tunnels.

## Content and Goals

The research challenges of fixed-wing aircraft derived from social needs will be tackled to a wide extent in a close coordination with the ONERA. The DLR focuses on the contents and aim of the planned work on “virtual integrated products”, described previously. The works are structured in five topics and described in detail in the following:

- > Concepts and integration
- > Flight physics
- > Structures and materials
- > Flight systems and cabin
- > Numerical simulation and validation

### Concepts and Integration

The existing air transport system will be pushed to the limits of its capabilities due to the growth of the air traffic. It is to be expected that improvements in single disciplines or components of the system are just not enough to be sufficient for future demands on air transport as a pacemaker for economic growth. Attempts at improvements in single disciplines or components have to be analysed in an integrated way with respect to their effect on the entire transport system. They furthermore need to be evaluated to derive new or alternative concepts for an increased capacity of the air transport. This requires an integrated design, simulation, and evaluation environment to depict the air transport concept in a comprehensive scenario.

For the establishment of such an environment, presently existing simulation tools have to be modified and combined with tools for the layout of aircraft systems, in a first step. An example would be to achieve the total energy use for a new aircraft concept can be analysed for a complete transport mission, especially the interaction of engines and on-board power supply. In a second step this design would be integrated into an air traffic simulation.

The aim of this work until 2012 is the development of an integrated approach for a system design under participation of all disciplines, a coupled simulation of the system and accompanying technical, economic and ecologic evaluation of technologies for the exploitation of the full potential of the entire air transport system.

The flight vehicles in use mainly drive environmental compatibility and profitability of an air transport system. As decisive improvements in ecology and profitability of air vehicles can only be achieved with consideration of the entire aircraft, new aircraft configurations have to be developed and analysed in a multidisciplinary fashion. From the results of disciplinary research new technologies and concepts are gained that contribute to the improvement of efficiency and reduction of emissions and can be implemented into the aircraft configuration. Only with a close link between the disciplines, can their often-conflicting trends while optimising aircraft parameters be modelled realistically, critical parameters of influence identified and the whole system evaluated. Conventional and unconventional configurations will be developed and optimised. Afterwards, the performance will be evaluated in comparison to conventional aircraft to determine the improvement.

Alternative configurations like flying wings offer the prospect of jumps in performance. With the usage of a span-wise multi-flap-array the aerodynamic performance, flight



DLRs research aircraft



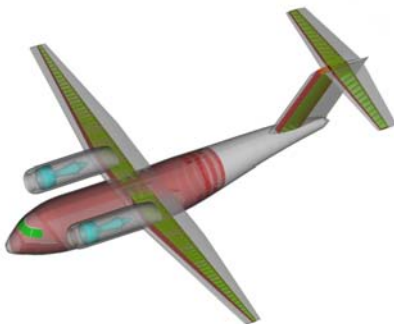
Simulation scenario

guidance, and load distribution can be ideally coupled. The advantages of such multi-flap-arrays like optimal flight performance or redundancy can also be achieved with conventional configurations.

The preliminary design provides suggestions for alternative configurations and the application of new technologies. In order to identify their real potential and to make these technologies ready for application, the multidisciplinary design methods for the detailed design have to have a significantly higher precision than those used for the preliminary design. To achieve this accuracy, high precision numerical analysis methods are combined with numerical optimisation tools to “Multidisciplinary Optimisation” (MDO) procedures, to utilize efficient methods.

For the optimisation of passenger aircraft configurations, disciplines like aerodynamics, structures, aero-elasticity, propulsion, aero-acoustics and flight mechanics are the primary focuses. Due to large expenditures of resources during the application of numerical simulations it is impractical to consider all disciplines at the same high simulation quality. With respect to a given design problem it is much more effective to choose the most suitable combination of simulation quality of the disciplines. Hence, an optimisation environment has to be developed that grants a reliable combination of single disciplines and also permits the choice of different simulation accuracy levels. Another vital element is the continuous description of geometric and structural aircraft parameters that grant the seamless combination of preliminary and detailed design. Research is especially required regarding the definition of criteria to choose suitable optimisation strategies, to guarantee the efficiency and robustness of the optimisation process and the correct choice of the simulation quality (Mixed Fidelity Approach) of the participating disciplines.

The development of a progressive optimisation environment follows an incremental path. The MDO-application combining aerodynamics and structural modelling, that has already proven its superiority in pilot studies, has to be implemented into a suitable optimisation environment that allows sustainable application during, for example the wing design process. Already the combination of these two disciplines within numerical optimisation shows a considerable demand for research with respect to efficient and robust optimisation scenarios. The integration of the other disciplines: aero-elasticity, propulsion, aero-acoustics, and flight mechanics also has to be conducted at a sufficiently high simulation quality. Research and development activities aim to gradually enlarge the application spectrum of MDO to cover a complete passenger aircraft configuration and its mission with the precise treatment of take-off, landing and cruise flight.



Quiet short take-off and landing configuration

Besides the development of tools and methods, research work on different concepts and air vehicles has to be conducted, which are based on the virtual integrated products. Simultaneously, the integration of technologies of other program topics will be executed.

As an example of the development of alternative concepts for the air transport system, a short-take-off and quiet short-range aircraft is considered. This corresponds to the DLR concept “QSTOL” (Quiet Short Take-Off & Landing), which enables operation close by cities. The challenges of this configuration lie in the contrary requirements of short take-off abilities and low noise emissions, as well as the design of an efficient complete system. The design and the optimisation of this air transport system has to encompass all phases of the transport chain. Hence, also the passengers travelling to and from the airport and checking-in at the terminal have to be considered. The concept would lose its entire meaning if the gain in time due to being close to the city is lost in another part of the transport chain.



Further research work supports the virtual integrated product “Long Range / Freighter”. The freighter would be operated more economically with a reduced crew. Further reductions of the crew including the one-man-cockpit or even the unmanned freighter are foreseeable, but require considerable efforts be realised.

On the way to an unmanned transport aircraft the automated sub-functions have first to be developed. Of fundamental relevance is the integration of manual and automated functions into the whole flight control system. Proposals will be elaborated for the implementation of the system and its demonstration will be conducted.

An important function of an independently operating unmanned transport aircraft is to automatically side step obstacles (mountains, other aircraft). It is the aim to develop the necessary tactical autopilot functions and to suggest a suitable and authorized concept for a system implementation. Furthermore, active measures supporting the pilot during unconventional manoeuvres (steep approach for noise reduction) or flights through extreme atmospheric disturbances (turbulence or wake vortices) will be provided for both new and conventional aircraft configurations.

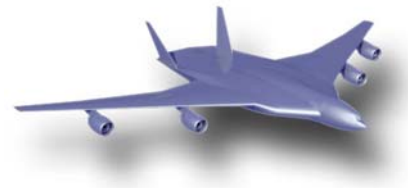
In general, it is the task of transport aircraft to carry passengers and pay-load in a certain time to a certain place. The missions of a special class of transport aircraft also have to cover specific civil tasks e.g. supply of disaster areas. These kinds of tasks have a number of additional requirements: navigation in unknown terrain without infrastructure, precise airdrop, formation flight, and landing on unprepared runways. The scientific findings can be exploited for civil and military purposes (multi-body aerodynamics, landing gear dynamics, flight performance evaluation, etc.). Here, it is the aim, to develop evaluation methods and methods to investigate such transport aircraft and their missions and to make them available.

In order to reach the ACARE-aim of Vision 2020, engine technologies play a decisive role. A reduction of the specific fuel consumption by around 20% can be achieved by propfans. The integration of these engines into the airframe has yet not been investigated to a sufficient extent that statements concerning the efficiency factor of an aircraft equipped with such an engine can be given reliably. Furthermore, the effect of engine noise being emitted outwards as well as inwards is not sufficiently known. Relying on preliminary design and multi-disciplinary analysis and optimisation the combination of highly efficient propulsion concepts with engine integration requirements posed by the rear fuselage and acceptable noise emission levels will be investigated. Besides the aerodynamic and structural integration, concepts of acoustic shadowing and passive and active source reduction will also play a decisive role. For these investigations turbofan engines with a high bypass-ratio (12-17) will be evaluated as an alternative to propfans because it is not certain that problems related to noise and safety of the propfans can be mastered. This requires close collaboration with the program topic Propulsion Systems.

### Flight Physics

The most efficient aerodynamic drag reduction technology is to keep the flow around the aircraft laminar (delaying transition). To enable the profitable usage of delaying transition on passenger aircraft, multi-disciplinary preliminary design studies have to be conducted, which consider not only cruise flight but also take-off and landing.

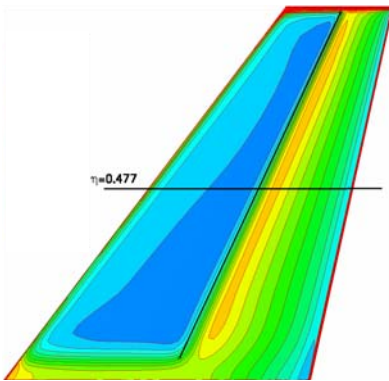
Delaying the transition can be achieved by two technologies. Passive delay of transition is obtained passively by shaping the wing (Natural Laminar Flow, NLF) and actively by partial suction of the boundary layer (Hybrid Laminar Flow, HLF). So far, laminar flow control could not prevail due to high demands on system complexity and surface qual-



**Configuration for maximal transport performance**



**Integration of new propulsion concepts at the rear fuselage**



Drag reduction due to laminar flow



Winglet on a business jet

ity. The increased costs of fuel and the social pressure to reduce the effect of air traffic on climate change have increased the desirability of a laminar flow wing.

Natural laminar flow already offers a considerable potential for drag reduction, without requiring the extra effort of a suction system. Hence, this technology is currently favoured by industry. The potential advantages are opposed by disadvantages like reduced cruise speed and structural complexity due to the high aspect ratio of the wing. The currently achievable performance will therefore be determined by multi-disciplinary design studies relying on high fidelity design methods. By using progressive design methods, the cruise Mach number will be increased above current values. The forward swept wing will be included in these studies, as it is optimal for laminar flow and provides advantages regarding the cruise speed achievable.

Enforcing laminar flow by suction offers more freedom in the design of wings and tail units. This enables the retention of the high flight velocities that have become common. The vertical tail of the DLR Research Aircraft ATRA will be equipped with this technology. This will be achieved with consideration of the results of European research programs. As all necessary systems will be integrated in this component, the effectiveness of laminar flow control with minimal system complexity will also be proven during operation.

The pressure distribution of a laminar wing is characterised by a relatively strong shock. Its greater tendency to generate separations can be reduced by target addition of impulses using pneumatic vortex generators or electro-dynamics actuators. This can support the exploitation of the laminar wing potential to an even greater extent.

To date it is unknown, how the actual physical process of transition from a laminar to a turbulent boundary layer occurs in the large local supersonic regions of passenger aircraft. The knowledge of this process is an inevitable prerequisite for all kinds of active flow control. Flight tests with a specially equipped surface panel on the DLR Research Aircraft ATRA will close this knowledge gap.

Further drag reduction potential lies in the special design of the wing shape, especially the wing tips ("winglets", about 5%). Despite long-term research the true performance potential of different wing shapes has not yet been fully determined, as the interaction of flow and structure is still inadequately considered. The performance potential will be reliably determined with the application of high fidelity design techniques from aerodynamics and structural mechanics. A new wing tip for the DLR ATRA will be designed as an example of how to exploit this potential. In this design study the possibilities of active deformation will be investigated to achieve performance gains for cruise flight as well as for take-off and landing.

Avoiding or delaying separation can achieve drag reductions in the turbulent flow around the fuselage. Here measures that reduce the turbulent skin friction by suitable surface structures are of interest. Hence, their mechanisms and effectiveness have to be investigated numerically and experimentally.

The reduction of the perceived noise is of significant importance for the social acceptance of the increasing air traffic. Within the timeframe of this HGF application new noise reduction concepts will reduce the noise level of propulsion and airframe noise by another 5 dB. This means that the ability to perform coupled aerodynamic/aero-acoustic design has to be developed in a way that verifiably combines the aerodynamic performance with a noise avoiding shape. Additionally, active and passive measures to reduce the sound source levels of high-lift systems and landing gear have to be investigated and developed to an appropriate technology readiness level.

To reduce the perceived noise of aircraft close to the ground two concepts will be investigated:

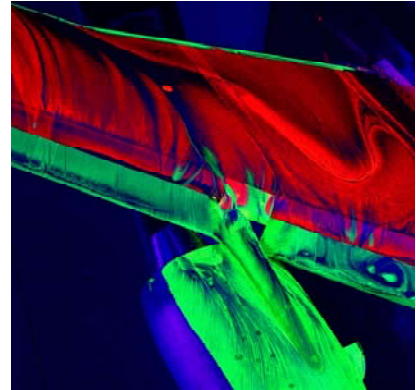
- (I) Design of new high-lift systems of high aerodynamic performance for improved climb capability or steeper approaches respectively, aiming at higher fly-over altitudes to reduce the perceived noise near airports.
- (II) Development and application of noise reducing measures without aerodynamic disadvantages as a reduced fly-over altitude would negate the noise reduction effort.

For new high-lift systems it is desirable to completely avoid the slat as this is the biggest noise source. A solution concept can be area actuated, form variable leading edges (Smart Leading Edges), which probably have to be combined with measures of active flow control to increase the performance. In order to enable steep descent during the approach phase without significant lift loss, the function of the high-lift system has to be expanded towards controlled drag generation. Therefore, brake flap concepts with gap adaptation are to be investigated as trailing edge flaps as well as spoilers on the fuselage. This is to be realised with the simplest possible mechanism and lowest system weight. For the investigation and design of such systems, analysis and design methods are necessary, which reliably capture the high complexity of the flow on the deployed high-lift system for all flight conditions. This requires the coupling of fluid dynamics and structural simulations in order to consider the static wing deformation and the estimation of the flight trajectory while simulating manoeuvres.

During the development of passive noise reduction technologies, the application of special aerodynamically neutral materials, consisting of porous surfaces, which are sound absorbing and able to balance pressures in a selected direction, will be investigated. Concepts of noise reducing control of turbulence via conditioned surfaces have to be tested. Measures that adapt impedance on lee- and windward sides have to be optimised (e.g. brushes, slots etc.). Active noise reduction technologies will experience increasing relevance due to their ability to exceed the efficiency limits of passive measures. A major part of such noise reduction concepts requires further intensive experimental investigations in sufficiently large aero-acoustic wind tunnels of excellent quality to avoid problematic scaling effects. Successful concepts found this way have to be demonstrated in fly-over tests. Numerical simulation will demonstrate the aerodynamic optimisation of a high-lift system weighted according to acoustic criteria. This will be obtained by coupling fluid dynamic and acoustic simulations (CFD & CAA) and by flight test validation.

The application of highly elastic aircraft structures offers the potential to reduce manoeuvre loads and thus structural weight. Also, systems will be investigated that actively reduce gust and wake turbulence loads. The dimensioning of the structure will be determined by considering real loads and the necessary safety factors. In order to exploit the potential of elastic structures, the whole structural design process has to be optimised including the consideration of gust and manoeuvre loads. This includes knowledge of the load spectra actually occurring during operation and the layout of the structure on the basis of realistic loads instead of standardised assumptions. Another point is the precise knowledge of non-linear flow effects and their associated aerodynamic loads occurring during flight in non-uniform flow. These conditions will be modelled by applying coupled high-fidelity numerical CFD and structural simulation methods.

Flight tests will encompass a growing part of the experimental aero-elastic investigations. Active and passive aero-elastic concepts can be tested under real conditions in flight and oscillating structures (components or the whole aircraft) can be identified. With this knowledge, the duration of the ground vibration test, relevant for authorisation and usually taking place shortly before the first flight of an aircraft, can be re-



Complex flow topology on a deployed high-lift system

duced as can the subsequent adaptation of the simulation model of the whole aircraft structure.

### Structures and Materials

The DLR aims at developing lightweight construction concepts for fuselage and wing structures with an optimal cost to performance ratio that will contribute to the competitiveness of future German and European aircraft.

The basic and applied research concerning materials, structures, light weight concepts, and manufacturing technologies will contribute to six main topics: new generation CFRP-fuselage, economical metal fuselage of integral construction, adaptive and hybrid high-lift systems, damage susceptibility of the aircraft, CFRP-structure and manufacturing technology in connection with hybrid material and structure technology.

These main topics represent the whole chain of the total technical design from material development via construction concepts, simulation and computation methods, and manufacturing technologies up to the production of functional samples and prototype components. A prerequisite for the transfer of new structure technologies into new applications is to support the development of accompanying demonstration methods for certification.

The topic "New Generation CFRP-Fuselage" builds on the successful work of the HGF-project "Black Fuselage", which resulted in a demonstrator for the developed fuselage-concepts, technologies, and methods. In the timeframe of this application the DLR will, in co-operation with Airbus, pursue the aims of achieving a weight and cost reduction of 30% by the increase of material (nano particle modified resin systems) and component quality (process engineering ready for production, e.g. micro wave hardening), and of improving production techniques as well as CFRP-specific light weight construction concepts for optimised material structures (fibre orientation, anisotropy). The establishment and evaluation of technology demonstrators will prove the achieved technology progress.

The "Economic Metal Fuselage" in integrated construction will be achieved by the use of new aluminium-alloys in connection with new process engineering, compound technologies, and construction concepts. In co-operation with Airbus and national as well as European suppliers, concepts will be established for the integral fuselage structure elements in multi-material design with the aim of local usage of load-optimised Al-alloy qualities. Composites will be manufactured consisting of aluminium-titanium, aluminium-magnesium, as well as re-enforced and non-re-enforced Al-alloys by friction stir welding. Furthermore, design elements will be tested for the reduction of crack progression in integral Al-structures. This will be done by experimental and numerical fracture mechanics methods and by a static and dynamic bi-axial check of integral skin fields. The bonding zones of compound composites are investigated with high-resolution ultra-sound analysis techniques and inadequate areas will be improved. In this way, the lifetime of the fuselage will be increased by optimised crack progression behaviour.

To use synergies between the HGF-programs relevant partial results will be shared with the main topics "New Vehicle Structures" and "Next Generation Train" of the Transport program.

The topic "Adaptive and Hybrid High-Lift Systems" includes research into a new adaptive structural design that yields the control of the load path in the skin through anisotropic stiffness and elasticity. It is the aim to find a material distribution that effectively combines strength and deformation requirements. Furthermore a hybrid structural



Concept of a CFRP fuselage segment structure

design for slats and landing flaps will be developed that connects lightweight construction and impact tolerance. New CFRP/CFRP- and CFRP-titanium-hybrid structures, respectively, will be developed that fulfil these complex requirements. This encompasses the research of manufacturing and joining technologies to be matured for production. To support and complete the process chain (life cycle) of an adaptive high-lift system, integrated monitoring concepts for components (structure and system side), and corresponding repair and maintenance concepts are required. Due to the exposure of these structures to hail, foreign object damage (take-off and landing), and collision with vehicles on the ground, an “automated” non-destructive test method, suitable for non-accessible areas and being adapted to the life-cycle, is an important element for uncompromised acceptance in terms of cost and maintenance intervals. The topics to be investigated are:

- (I) Adaptive structural technologies by form-variable mechanisms in light weight construction, and highly elastic skins that keep their contour and load bearing properties.
- (II) Hybrid light weight construction by impact-tolerant thermoplastic or CFRP/Titanium hybrid-structures.
- (III) Coupled design methods that consider the interaction of flow and structure especially under by delaying transition of the wing boundary layer.
- (IV) Optimised design methods for the impact behaviour of slats and flaps, and the life-cycle assessment of CFRP/Titanium-laminates.
- (V) Manufacturing technologies for adaptive structural systems with highly elastic skins and integrated actuators and sensors. Additionally, construction concepts of high-lift structures that integrate multi-functional system requirements (de-icing, anti-icing, lightning protection, bird strike).

The proof and the test of technologies will be conducted by establishing and evaluating technology demonstrators, and by performing flight tests on the DLR Technology Research Aircraft ATRA.

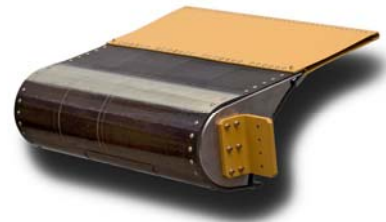
Furthermore, it is the aim to establish an even safer airframe. For this purpose, the crash and impact specific simulation methods will be improved, and crash and impact tolerant CFRP- and hybrid construction concepts will be investigated. Structural Health Monitoring (SHM) systems as well as destructive and non-destructive test and measurement techniques offer considerable potential to increase the operational safety.

In order to achieve the maximum specific energy absorption for light weight structures, the usage of light and affordable hybrid-materials and construction concepts (composites, hybrids) is advised. At the same time, crash and high velocity impact simulation methods based on high velocity material testing and bombardment experiments have to be improved as well as computational tools for low-velocity impact, large damage, and remaining strength.

Highly effective structural protection systems for humans and sensitive control elements within the flight vehicle have to be investigated. Here, simulation methods for massive short-time shock impact (bombardment, hydraulic ram, ditching, and explosion) will be applied.

The evaluation of CFRP-materials and primary structures with respect to vulnerability, damage tolerance, residual load bearing, and in the end “Get you Home“-ability, will be supported by virtual testing (“what-if-scenarios”) and certification.

Certification on basis of virtual tests requires numerical procedures which have a close link to accepted evaluation methods and aircraft-specific simulation platforms. These



Concept of an adaptive slat



numerical procedures are validated against only a few physical experiments. Thus, a number of investigations relevant for certification are replaced by simulation. The cost of stability tests on sectional hulls including the manufacturing of the required parts can easily run as high as 8 to 14 times the cost of the simulation.

### Flight System and Cabin

The automation of flight control is of increasing importance for air safety. Using new, modern control technologies and procedures, flight control systems with new control laws tailored to a specific flight vehicle, or even control routines that adapt automatically and continually by the properties of the flight vehicles will be feasible in the future. Also new kinds of control (e.g. Mini-TEDs, thrust vector control) have to be considered in the flight control design for future modern aircraft configurations that might deviate from today's configurations. It is a great challenge to cope with the regulation technologies caused by major, unintentional changes of the configuration e.g. damage or strong icing.

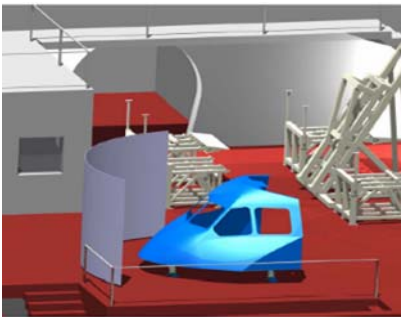
Flight control algorithms have to be developed that also allow safe flight in extreme weather (Clear Air Turbulence, shear winds, wake turbulence, icing conditions). Re-configuration concepts will be investigated that use the flight control redundancy existing on any aircraft. Basic research will be performed to develop comprehensive automated protection systems that avoid the aircraft getting into a critical condition in the first place. The investigations and implementation of a new kind of sensors (e.g. on-board LIDAR) and actuators (Mini-TEDs) within the flight control systems play an important role during the determination of extreme weather conditions and the application of safety relevant situations.

Air rescue and humanitarian tasks have a high social relevance and require specialised flight vehicles. An aircraft developed for such mission scenarios has to have outstanding short take-off and landing-capabilities and has to be able to operate on un-sealed runways in any weather and under any visibility conditions. This will only be possible with a partial automation of the flight control system. Hence, the feasibility of new primary control systems of small aircraft has to be investigated including their possible automation.

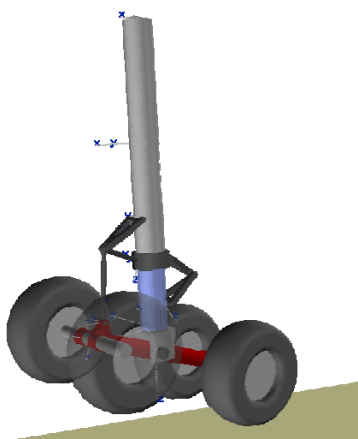
This would consist of active measures, supporting the pilot during his flight through extreme atmospheric disturbances (turbulence or wake turbulence) or measures that enable unconventional flight paths (steep approach, also for noise reduction).

In the future, the development of robust autopilot functions with increased mission requirements and, increasingly, autonomous flight capabilities will come into focus. This is a result of increased mission requirements for new and conventional aircraft configurations. For unmanned flight vehicles (traffic observation etc.) autonomous flight within the controlled airspace is a necessary requirement. Therefore, even under the most difficult conditions automated take-off, manoeuvring, landing, and holding the given or generated flight path has to be enabled. This task, together with the development of system concepts and simulation models for the partial autonomous flight control system architecture has been partially addressed, but it has to be extended.

At take-off and landing, whether automatically or controlled by the pilot, the landing gear has to sustain high loads, and oscillations can be triggered. New investigation methods for the landing gear will be developed. Landing-gear oscillations, like safety critical torsion oscillations of the lever of the nose landing gear or the interaction of braking dynamics and structural oscillations, have to be precisely predicted in an early development stage to be able to avoid unwanted resonance effects and instabilities.



Assessment of flight control systems in the simulator



Model of a main landing gear

The resulting investigations will increase safety and have positive effects on the comfort of passengers and crew.

The landing gear will be considered under the aspect of system integration. New actuator concepts, e.g. the replacement of hydraulic actuators by electrical ones, will be virtually tested and evaluated. It is the aim to both reduce weight, and the required energy. New sources of energy like fuel cells enable the independent and eco-friendly rolling of the aircraft by electric motors in the landing gear.

Methods and integrated tools for modelling, analysis, and synthesis as well as multidisciplinary optimisation have to be continually developed further for a systematic design process of flight control systems. New topics like methods of error tolerant, adaptive regulation have to be evaluated and improved. Future developments of flight control systems require the further enhancement of existing flight dynamic models, and the integration of detailed physical system models (actuators, hydraulic and electrical systems etc.) to also enable the simulation of flight behaviour including malfunction. The derived integrated multipurpose control system design also includes consideration of the flight properties, passenger safety, and comfort as well as manoeuvre and gust loads.

The further automation of passenger aircraft will finally be incorporating the “One-Man-Cockpit”, which is desirable to reduce costs. This automation requires a new specification of the pilot’s role as part of the highly automated flight system, which has to be validated by dedicated experiments in the simulator.

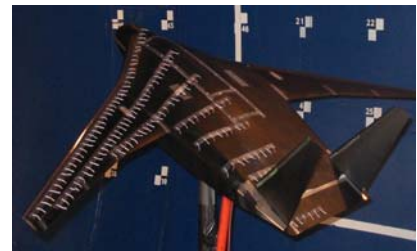
New aircraft configurations like e.g. Blended Wing Bodies, whose properties can be determined by numerical simulation, have to be evaluated at an early stage for the pilot. There is a special need for research with respect to the flyability after the failure of single control surfaces. The envisaged system evaluation requires the pilot’s acceptance of the flight simulation. This puts high demands on the simulation quality to be fulfilled by the flight simulation.

The flight simulation is the scientific bridge between numerical simulation and flight-testing. This brings humans, with their cognitive abilities, back into the centre of research on flight tests. However, the physical load-bearing capacity of humans is limited. Border zones of the flight envelope, which cannot be reached due to this limitation, may be assessed by ‘moving-seat’ simulations. These are a very important tool for the high quality evaluation of the dynamic interaction between human and aircraft. Actual flight accidents have shown that the fine-tuning of the motion simulation with respect to the evaluation task is critical, hence basic research is required.

New supporting functions and their evaluation by the pilots are necessary to enhance flight safety in a disturbed atmosphere. New control algorithms for the automatic compensation for aircraft reactions to disturbance phenomena (e.g. flight into wake turbulence) will be evaluated, firstly in the motion simulator, then in ATRA flight tests.

Further research aims concentrate on the aircraft cabin. In order to promote the Power-by-Wire technology for the “All electric aircraft” within the European aircraft industry, further effort is necessary on the aircraft, system, and equipment level. Error cases require a higher level of observation as these have a strong influence on the dimensioning of components and energy supply systems. The layout of aircraft system architecture integrated over the boundaries of systems requires the complete consideration of snowball effects. For example, thermal interactions have to be analysed. In order to provide this, simulation and optimisation tools have to be extended.

On the system level (e.g. air-conditioning-system, flight control system etc.) new design tools will be developed that support the Power-by-Wire approach and enable compatibility with the tools on the aircraft level. New Power-by-Wire standard supporting



Blended wing body in a wind tunnel

devices have to fulfil strict requirements in terms of electrical properties, weight, and reliability. Improved and unified development processes and the accompanying design tools will be provided for the suppliers.

The use of fuel cells for the electric on-board power generation is a new, efficient path to provide electric energy and simultaneously coverage of a new function in new aircraft architecture.

Currently, a fuel cell system to replace the ram-air-turbine is being flight tested on the ATRA. Further development and testing is planned towards the target of a multifunctional fuel cell system. Together with the electric energy supply, water production and inertisation of tanks is to be demonstrated during flight tests. In parallel, the multifunctional performance capability of fuel cell systems and their basic functions are to be investigated in a laboratory environment. Further developments and optimisations of the fuel cell systems are necessary, as they have to be technically tested in flight.

For the operation of fuel cells, hydrogen is indirectly available on-board the aircraft as part of the kerosene. The drawback of on-board hydrogen-generation is the requirement of strong sulphur resistant catalysts and high temperatures for the conversion. The approach of partial dehydration offers considerable advantages as the low-sulphur fraction of kerosene dehydrates at 300 to 400°C when using an upstream process buffer stage. This concept is to be realised in the 1kW-scale and finally, components and systems will be tested during flight.

In the research field cabin, the aim is to improve the thermal and acoustic comfort inside the aircraft. This requires computer-aided methods for the prediction of air flow, noise transmission, and dispersion inside the aircraft cabin, flow and noise generation in the ventilation system and other supply systems. These models have to be validated by experiments.



Test vehicle Do 728

A high pressure wind tunnel (HDG) is available for validation and feasibility studies, in which the small scale room climate can be modelled realistically. Additionally available are a full-scale cabin model (Airbus A380), the Technology Research Aircraft Do 728, and the ATRA for flight tests.

New, comfort increasing air-conditioning concepts, illumination techniques and measures for noise reduction are to be developed, tested, and optimised. This is to be done on the small scale model under high pressure conditions, as well as on the full scale model and in flight tests. Further, flow, noise dispersion and noise transmission predictions of the numerical methods THETA and PIANO are to be validated with measurements. This requires the development of suitable measurement and simulation procedures. In order to enhance the acoustic comfort inside the cabin, active adaptronic measures for the broad range damping of external noise contributions transmitted via the fuselage structure into the cabin have to be developed and especially designed for new materials.

Structural dynamic oscillations in the audible frequency range are an important aspect of cabin comfort. Methods of aero-elastic experiments are to be applied in vibro-acoustic investigations. Vibro-acoustics is the intersection of aero-elastics and aero-acoustics.

### Numerical Simulation and Validation

Besides theory and experiment, numerical simulation has become a "third pillar" in science and research, and is thus penetrating the industrial design process. Hence, numerical research and development activities of the DLR are dedicated to the simulation of the flying aircraft (in real-time) and its life cycle with high quality simulation

methods. This encompasses the numerical determination of loads on the aircraft in the whole flight regime as well as the numerical prediction of flight performance and handling qualities. The research activities are based on the flow solver TAU, the damage-resistance and damage-tolerance program package M-CODAC and other computational modules for the consideration of further non-linear and multidisciplinary influences. The long-term aims of numerical simulation are virtual flight-testing and certification (Digital-X). In order to achieve optimal exploitation of resources for the consideration of combined non-linearities (flow separation, buckling behaviour, damaging processes), the simulation methods have to fulfil special requirements with respect to stability and numerical convergence.

The reliability of numerical methods available today is insufficient at the limits of the flight envelope, and hence expensive and time consuming wind tunnel and destructive structural bulk tests may be required during the design process. Future work concentrates on the development and systematic validation of higher quality approaches for modelling of structure, turbulence, and transition. It is the aim to predict highly separated, unsteady flows within a given range of uncertainty, the determination of structural reserves, and the simulation of all relevant loads and processes of the structural life cycle.

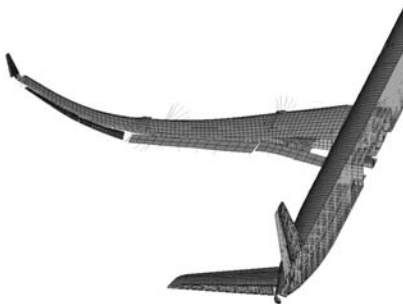
For the definition of the aircraft structure and the determination of the resulting weight, accurate knowledge of the actual aerodynamic loads for all critical flight conditions is required. Furthermore, the design of the flight control system needs reliable data of aerodynamic properties of the aircraft for the whole flight range. Currently, load determination is performed mainly by wind tunnel testing on the basis of certain assumptions. Due to the necessary safety margins, a potential for product improvement remains unused. For future aircraft developments, the aerodynamic loads and derivatives need to be provided in a higher quality, faster, and considerably earlier in the development process than before. Due to the strong interaction of aerodynamics, structure, flight mechanics, and flight control, the multidisciplinary approach is unavoidable. The evaluation of handling qualities and rudder effectiveness at the limits of the flight envelope with higher quality numerical methods requires a coupling of the corresponding disciplines in the time domain. As a consequence, the requirements for computation power are so high that despite the expected increase in hardware-development, further improvements in the numerical algorithms and software techniques are necessary. Otherwise, such simulation scenarios of industrially relevant problems will not be feasible. Hence, research will be dedicated towards algorithms accelerating convergence, exploiting special topologies of computational grids, and efficiently utilising the capacity of hardware architectures, which will finally be integrated into an industrially relevant simulation system. Another focus of research will be the identification, quantification, and minimisation of uncertainties, which are inherently coupled with numerical simulation.

Due to the relevance of numerical simulation as a key technology, and with the support of Airbus and the German state of Lower Saxony, the DLR established the competence centre C<sup>2</sup>A<sup>2</sup>S<sup>2</sup>E for numerical flight physical simulations of aircraft in mid 2007, whose activities are oriented around these aims.

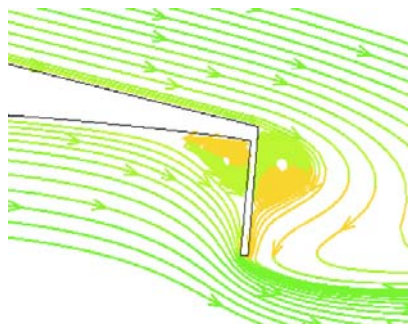
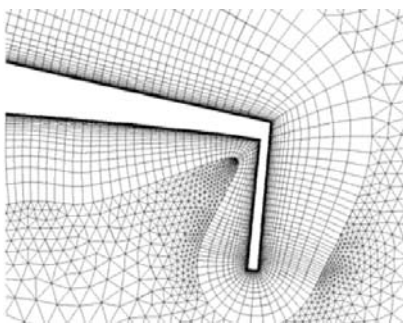
In a special approach, based on high-fidelity methods ("first time right"), multi-level and multi-criteria optimisation for accelerated structural design are envisaged. Here, reliable, multidisciplinary and multiscale simulations of coupled non-linearities (geometric, material-based), and the whole life cycle are of relevance. High-performance test and measurement techniques will be at the users' disposal according to the requirements of model building for the validation of simulation methods. The implementation of existing procedures for the simulation of oscillation behaviour of structures and the consideration of component tests within the frame of certification processes is pro-



High performance computer



Aero-elastic oscillation mode for an aircraft in cruise



Discretisation and flow topology of a Gurney flap at a wing trailing edge

posed. Hence, the validation of aircraft prototypes is shifted into the development and manufacturing phase on the basis of such virtual tests and simultaneous conduction of component tests on parts of the aircraft structure (e.g. wings). This requires significantly higher quality measurement data, but it reduces the cost of the whole certification process.

During the computational treatment of aero-elastic problems (e.g. the determination of the flutter limits), fast and effective and high precision but computationally intensive methods are applied. The fast procedures for transonic flows are supported by a limited number of highly precise computations. One focus of the work on fast numerical procedures is on the development and the comparison of different methods to correct subsonic panel methods by the application of results of highly accurate CFD-methods.

Further work on fast unsteady aerodynamic methods concerns the modelling of viscous effects, and a boundary layer code will be coupled with the TAU Code. Furthermore, a linearised, TAU compatible Navier-Stokes-code is to be developed which provides unsteady aerodynamic forces for the computation of flutter in the frequency domain. Additionally, for rudder and buffet aerodynamic forces, reduced modelling is to be developed.

The highly accurate numerical methods concentrate on the aero-elastic work of physically correct modelling of complex aero-elastic and unsteady aerodynamic systems. The important physical phenomena encompass buffeting (shock induced in transonic flow as well as wing-induced tail buffeting), and non-linear limit cycle oscillations for transonic and separated flow. For the correct simulation, the influence of modelling viscous effects on flutter and buffet behaviour has to be determined. The inclusion of rudders, empennages, adaptive elements like Gurney Flaps, as well as engine thrust vectors and gyroscopic forces will significantly improve the precision of flutter prediction of the entire aircraft.

Also in the field of structural dynamics further developments are required. The improvement of modelling structural non-linearities is necessary to gain information about the aero-elastic behaviour of e.g. systems with play, non-linear material properties, and structure variant behaviour (limited deflection). Another approach is the usage of probabilistic analysis methods ("Uncertainty Analysis"), which aids in the consideration of the influence of unknown parameters e.g. rudder connection stiffness of manually controlled aircraft.

The challenges of the aero-acoustic research will be tackled from three "sides". In order to investigate geometrically complex configurations aero-acoustically, the DLR's numerically high-resolution computational aero-acoustics code (CAA) PIANO has to be enhanced to a hybrid simulation procedure that is able to work on structured and unstructured grids. For the evaluation of noise shielding properties of aircraft configurations, the existing noise ray procedure SHADOW has to be extended to cover the influence of flow field effects.

Thus, the physical modelling has to be extended within the next years. In the foreseeable future, turbulent noise sources will not be able to be directly simulated for noise prediction in the time frame of the design process (for flight Reynolds numbers at acceptable computation times). The corresponding scales are so small that the numerical effort required far exceeds the computational resources available today. The DLR successfully developed a turbulence model for aero-acoustics (Random Particle Method; RPM) analogous to turbulence modelling in fluid mechanics. Experience from applications with this model gained from high-lift systems or pipe systems of air-conditioning systems will be translated into technical improvements. The aero-acoustic turbulence model has to be further developed for noise predictions at fully separated, (i.e. not re-attaching) turbulent, flows. Furthermore, broadband sound absorbing



surfaces and component volumes have to be modelled as boundary conditions for CAA-simulations.

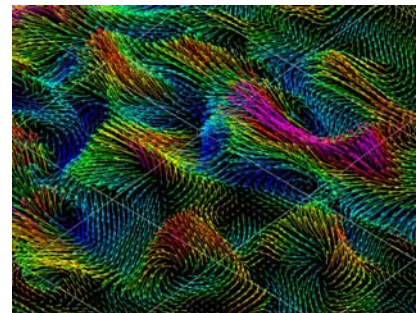
Comprehensive validation of the developed methods is a necessary prerequisite for the sustained application of numerical simulation for research into new technologies and for definition of new products. On the one hand, the simulation of viscous flows of technological relevant configurations still requires assumptions for turbulence modelling. On the other hand, influences of the discretisation error due to non-adapted computational grids or insufficient resolution due to restricted computer resources cannot be reliably separated from the occurrence of physical phenomena. Especially unsteady flow phenomena and the development of noise are not entirely accessible to numerical methods, whereas the interaction with the structure further aggravates these uncertainties. Hence, the physical understanding necessary for modelling has to be gained from well-documented experimental investigations. This provides the basis for all validation databases that record physical effects.

This requires the continuous further development of measurement techniques, since numerical methods are applied to increasingly more complex problems, and hence recording of all relevant data becomes more and more challenging. Also, for the same reason, the complexity of the validation experiments to be conducted is increasing so that models, devices, and measurement facilities require an increasingly sophisticated equipment effort. Finally, planning of the experiments that are necessary for the provision of modelling and validation data is also subject to research.

Recently imaging procedures have increasingly been applied in flow measurement techniques, supported by the fast technological progress in the fields of laser, video, camera, and computer techniques, as well as the development of high performance analysis algorithms. Imaging measurement systems are well suited to the measurement of instantaneous velocity fields (Particle Image Velocimetry, PIV), pressure distributions on model surfaces (Pressure Sensitive Paint, PSP), determination of transition points (Temperature Sensitive Paint, TSP), location and measurement of deformation of moving or deforming models (Image Pattern Correlation Technique, IPCT), measurement of density fields (Background Oriented Schlieren Method, BOS), noise source location (Microphone Array Technique, MAT) and others. They are developed and intensively applied as mobile measurement systems for application in industrial wind tunnels at DNW, ETW, and AIRBUS etc. for the low velocity and transonic range.

Despite the technological achievements there is a considerable demand to further develop the above mentioned measurement techniques. The procedures are to enable higher spatial and temporal resolutions as well as faster data processing (best case on-line). The enlargement of their application range for measurement at flight Reynolds numbers in the wind tunnel requires adaptation to the special conditions of cryogenic flows. There is a further demand to increase the precision of the procedures at low velocities and to define and achieve accepted quality standards.

Knowledge of as many as possible simultaneously recorded physical parameters (pressure, velocity, location and deformation, noise etc.) is required for a comprehensive understanding of unsteady flows, for the evaluation of new technologies, and for the validation of numerical calculations. A digital mock-up will be developed to examine the complex test conditions prior to initiation of the test. This enables the measurement section of the according wind tunnel and the position of the model in the measurement array to be modelled in the computer and verified during measurement. Planning of complex test cases, examination of optical accessibility, size and position of momentary observation areas, calibration and quality assurance can be considerably more cost and time efficient in this way. This contributes to a better communication of



**Stereo PIV measurement of a turbulent boundary-layer**



Instrumentation for air pollution measurements inside a research aircraft



Aero-acoustic measurement on a half wing model

the test planning to the customer and finally to a shortening of development times of aircraft.

Additionally, measurements on the aircraft during flight become important in order to check design predictions or to analyse problems. Imaging measurement procedures will be applied in flight tests with the DLR Technology Research Aircraft ATRA.

On ATRA, another special experiment will be conducted for the validation of numerical procedures on high-lift configurations. For previous validation on such configurations, wind tunnel data had to be used, which did not show the same high-lift behaviour as the final aircraft due to wind tunnel and Reynolds number effects. For a correct validation, flight experiment data are required at maximum achievable lift coefficients and data at typical manoeuvre points during take-off, approach, and landing. Such a test requires the precise and simultaneous recording of all relevant physical data of oncoming flow, the flow around the aircraft, flight parameters, and the actual deformed geometry.

Experimental and aero-elastic investigations have to be synchronized with the numerical activities. Aero-elastic experiments are still essential, as many aero-elastic effects, e.g. structural oscillations caused by strongly detached flow, are not completely amendable to numerical simulation. Also here experimental data bases for the validation of computational schemes are of growing importance. In the field of unsteady aerodynamics, experimental datasets for code validation are of strategic importance, and the DLR is in the position to validate its own simulation methods und their modelling with highest accuracy, which is only possible if planning and conduction of these experiments are within one institution.

Also of great importance is the validation of aero-acoustic simulation methods. Following the first, partly successful validation experiments, considerable efforts have to be made for the design of validation tests in aero-acoustic wind tunnels for flow noise based on turbulence. The complete experimental aero-acoustic assessment of a 2D high-lift system at high Reynolds numbers ( $> 2 \cdot 10^6$ ) is the primary target. At an open measurement section in low-reflection environment a complete record of free stream deflection is necessary to determine the directional effect and the absolute noise pressure level. Additionally to using farfield microphones, farfield microphone arrays have to be applied to be able to separate the sources. A wall array measurement on the same model is necessary with a closed measurement section to determine the effect of the open measurement section on the sources. The validation tests have to be continued stepwise in order to isolate the dependence of the noise on decisive design parameters like wing sweep or shape under well defined conditions for the distinct comparison with numerical simulations. In another study validation tests have to be conducted with passive or active noise reduction technologies to determine the prediction quality of simulation procedures for realistic applications.

## Expected Results and Milestones

| Year | Milestone                                                                                                                                                                        |
|------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2010 | Experimental and numerical registration of combined structural non-linearities is achieved for panels (entire aircraft 2013)                                                     |
| 2010 | Long CFRP-fuselage hull is manufactured using microwave technique                                                                                                                |
| 2011 | Functional sample of an adaptive leading edge wing is available                                                                                                                  |
| 2011 | Development and demonstration of a modern reconfiguration concept for the usage of existing flight control redundancies                                                          |
| 2011 | Validated concept for partly-autonomous flight guidance for small aircraft                                                                                                       |
| 2011 | 3-dimensional noise intensity measurement system applicable for aircraft cabins                                                                                                  |
| 2012 | New air-conditioning concept demonstrated for the improvement of the thermal comforts in aircraft cabins                                                                         |
| 2012 | Experimental proof of a noise reduction technology: new, high-lift system, noise reduced by about 5 dB with unchanged aerodynamic performance                                    |
| 2012 | Simulation and evaluation of a QSTOL-passenger air transport systems for short range application under the focus of climate effects, noise development, and transport efficiency |
| 2012 | Unsteady simulation of a realistically pre-damaged aircraft flying through a gust, by coupling of aerodynamic, structural mechanics, flight mechanics, and flight guidance       |
| 2013 | Numerical noise simulation of a complete high-lift wing with a precision of $\pm 3\text{dB}$                                                                                     |
| 2013 | Test of an integrated system for on-board power generation on the DLR-research aircraft ATRA                                                                                     |

# Planned Resources

Planned resources for the program topic Fixed-Wing Aircraft

|                                      | 2009   | 2010   | 2011   | 2012   | 2013   |
|--------------------------------------|--------|--------|--------|--------|--------|
| Helmholtz Institutional Funding (T€) | 27,911 | 27,911 | 27,911 | 27,911 | 27,911 |
| Human resources (FTE)                | 164    | 159    | 154    | 150    | 145    |

Detailed information on resources in the Annex

# Program Topic Rotorcraft

## Challenges

Modern rotorcraft research is driven by the critical success factors of today's and future designs. In order to achieve high hover performance considerable disadvantages are accepted in other domains of the flight envelope of a helicopter. Therefore, rotorcraft research is targeting an extension of the flight envelope and at the same time a reduction in inherent disadvantages of rotorcraft like noise, vibrations and the low flight speed compared to fixed wing aircraft. The specific risk of flying in close proximity to the ground highlights the importance of crash safety research. The difficult handling requires improvements in handling qualities and flight control. All improvements require a reliable description of the fluid and structural mechanics of the rotor and a simulation of the full rotorcraft system. Such simulations have not yet reached the same level of maturity as for fixed wing aircraft because of the complexity of the physical phenomena involved. Pilot support in all flight segments will direct the efficiency of rotorcraft missions in the future. In this context flight control functionalities are to be investigated together with sensors, displays and flight procedures.

While continuous improvements in classic configurations have led to considerable performance increases, new approaches are required for extensions of the flight envelope. Hybrid concepts like compound helicopters, tilt rotor aircraft or auto gyros have the potential to create their own market segments and require systematic scientific support to fulfil new tasks.

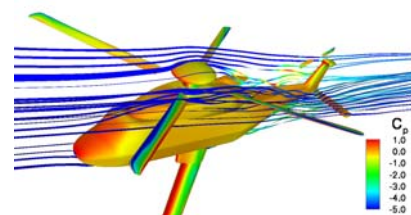
Rotary wing research is primarily an experimentally driven research field because of the very complex rotor phenomena. While the experimental equipment at the DLR with flight test aircraft and rotor test stands for wind tunnel tests in DNW are at a top level in an international scale there is room for improvement in the field of simulation. This holds for increasing the understanding of certain phenomena as well as for assessing given configurations. It is expected that the systematic application of adequate numerical simulation and optimisation methods will allow significant improvements in rotorcraft design ranging from aerodynamics to system layout.

For many years the DLR and ONERA have cooperated closely in the field of rotorcraft research in a complementary way. This cooperation was the first cooperation between the DLR and ONERA to produce a fully harmonised annual research program. The experiences are positive and the coordination will be extended in the future to external activities.

The new heavy transport helicopter HTH will be of high importance to the applied rotorcraft research. HTH will be a lead concept for technology assessment. It is a must that the improvements achieved within the last decade in all fields of rotorcraft research are integrated in the requirements for the new vehicle in order to provide a future oriented high performance rotorcraft to the public customer. Furthermore this will allow the retention and extension of technologically demanding responsibilities within the German industry.



FHS flight test aircraft



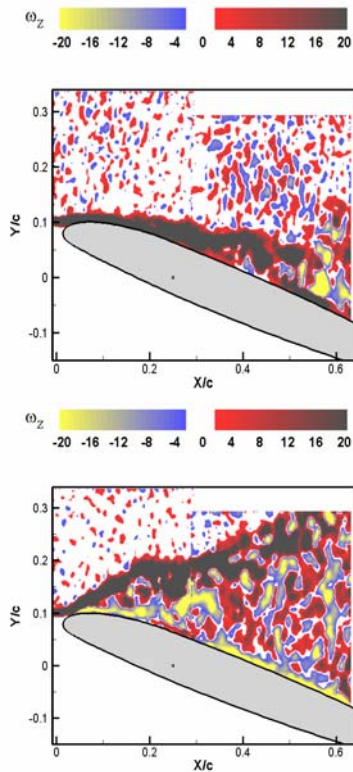
Pressure distribution on GOAHEAD-model

## Content and Goals

In order to address the above challenges the program topic rotorcraft is structured into the following research concepts. The DLR and ONERA cooperate closely in these research concepts.

The Virtual Rotorcraft





**Vorticity computed out of PIV-measurements with (top) and without LeVOGs (bottom) for OA209-airfoil in dynamic stall-conditions**



**FHS-cockpit with integrated active sidestick**

## The Quiet and Comfortable Rotorcraft

### The Smart Rotorcraft

### The Robust Rotorcraft

### The Innovative Rotorcraft

Compared to the previous HGF period this program topic structure is a continuation of the former proven structure with a slightly reduced number of research concepts.

The Virtual Rotorcraft concentrates on the development and validation of methods for analysis and design with a clear focus on CFD methods for the complete rotorcraft.

The RANS solvers which were developed within the previous HGF period in the frame of the CHANCE-cooperation have been successfully integrated into the design process of the German helicopter industry. This includes methods using structured grids for geometrically simplified complete configurations consisting of main rotor-fuselage-tail rotor including fluid-structure-coupling, together with methods using unstructured grids for isolated fuselage cases with all geometrical details. For the generation of the required validation data in wind tunnel tests an EU-project has been successfully proposed (GOAHEAD), which is coordinated by the DLR. For dynamic stall a comprehensive experimental data base for oscillating airfoils was generated.

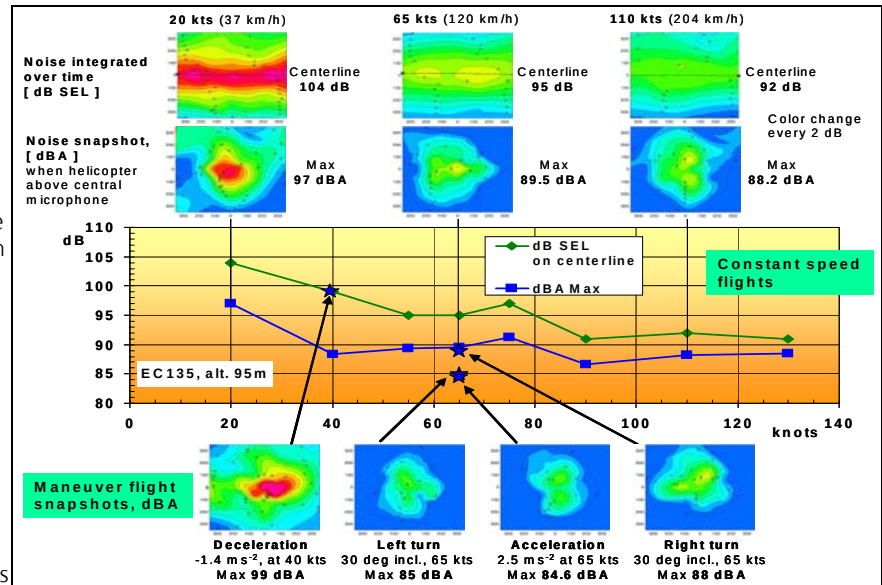
An important result of the coming HGF period will be the extension of the CFD methods to compute the flow around a helicopter including the interactions of the vortical wakes, generated by the main rotor, the fuselage and mounting parts, with each other and with helicopter components. The improved accuracy will allow assessment of the aerodynamic reasons for flight envelope limits and the prediction of noise, vibration and tail shake within design tasks. Furthermore, the methods will be applicable within the next 5 years to the optimisation of airfoils and blade plan forms including unsteady effects (dynamic stall). The developments of CFD methods for rotorcraft are extensions of the basic methods which developed within the program topic Fixed-Wing Aircraft.

One of the main factors restricting the use of rotorcraft in civil and partly in military missions, is the noise emission of these vehicles. Because of the low flight altitude during many missions the noise emitted by rotorcraft is considered annoying by the population. Therefore, The Quiet and Comfortable Rotorcraft concerns itself with the development and validation of methods for the prediction of external and internal (only ONERA) noise and specific solutions for noise reduction. This includes the main and tail rotor/Fenestron noise, as well as the engine noise. Due to the complex interaction of aerodynamic and dynamic phenomena and different helicopter components (main and tail rotor and the interaction between them, engine, gearbox und fuselage) in the process of noise emission only the flight test with detailed noise measurements allows the assessment of a new low noise design, both today and in the near future. Important results of the previous HGF period are the generation of experimental reference data for noise and vibration within the EU-project HELINOVI, the provision of noise prediction methods and first low noise flight procedures. In order to achieve this, a ground noise measurement system was developed, the flight test helicopters were instrumented, numerical methods for the design of low noise flight procedures were developed and first flight tests were carried out. An important goal of the coming phase is the development of low noise flight procedures which are consistent with operational requirements. Moreover the topic of vibrations in the passenger compartment will be dealt with. The simulation capacity is targeted at a full helicopter configuration and investigates the vibration paths and the possibility of reducing vibrations in the cabin by passive or active means.

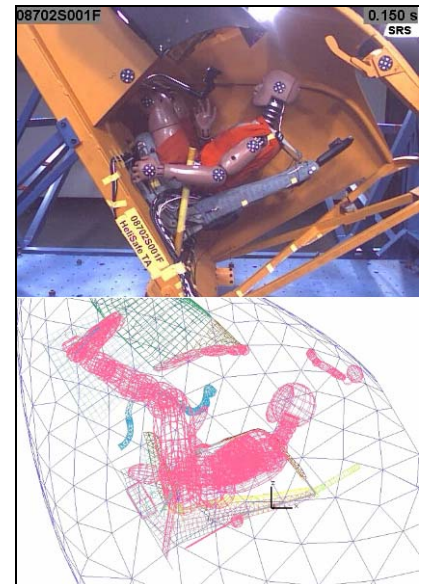
The successful application of helicopters in Emergency Medical Services (EMS), in rescue operations (Search and Rescue: SAR) and in specific military missions is limited by bad weather conditions, especially degraded visual environments and icing conditions. Helicopters are frequently operated in close proximity to the ground at short distances from obstacles (trees, power poles, etc.). The workload of the pilot and the accident risk in such difficult missions is considerably higher than that of a typical fixed wing aircraft. Therefore research is done in The Smart Rotorcraft on flight control, man-machine-interface, sensor development, information display, pilot assistance and navigation systems. At the same time new operational procedures and redundancy concepts for safety and certification aspects will be developed. The DLR and ONERA provide highly qualified solutions in close cooperation with industry and public services. A main activity is the development and validation of prediction methods for the flight dynamics as well as the description and assessment of handling quality criteria. The results achieved with the flight test aircraft Flying Helicopter Simulator (FHS) were of particular importance in the previous HGF period. Since the FHS was integrated into the DLR flight test department in November 2002, a complete test environment has been developed including system identification, real time simulation, ground simulator, model following control system (MFCS), integration of an active sidestick including the required software in the aircraft and the ground simulator. Based on these prerequisites, important progress and outstanding scientific results are expected for the next 5 years. One main milestone is the landing of a manned helicopter in a degraded visual environment on an unprepared landing site.

In order to successfully fly low noise flight procedures (see The Quiet and Comfortable Rotorcraft) a very high degree of automation is required which is enabled by the activities of The Smart Rotorcraft. Concepts for unmanned rotorcraft (UAV) will be investigated with respect to specific military and civil missions. The emphasis for UAV research is on algorithms for autonomous flight (see and avoid algorithms, decision taking, landing on unprepared sites). Manned-unmanned teaming will be addressed together with the FHS for cooperative missions.

The research concept The Robust Rotorcraft treats the following topics: helicopter specific safety and manufacturing technologies, crash behavior, passenger protection and all weather capability (de-icing, lightning protection). This includes the development of methods for crash modeling of composite structures, the generation of the required validation data and the application of such methods for the design of new structures. The crash scenarios considered here range from investigations of isolated components, emergency landing of a complete helicopter including passengers on solid ground or water, up to bird strike and ballistic impact. The generation of test data for complete helicopter crash tests in the previous HGF period was mainly carried out in the framework of EU-projects (e.g. Helisafe TA). New construction and manufacturing technologies for helicopter fuselages have a large potential for reducing production costs. In addition a weight reduction at constant or even improved safety is possible.



Noise carpet of EC135 in horizontal flight (H=95m) for different flight conditions



Cockpit sled test and MADYMO simulation



**TILTAERO tilt rotor model in DNW LLF**

The approaches under investigation are aimed at the acceleration of the manufacturing processes for the sandwich structures which consist mainly of composite material. A weight reduction and at the same time increased safety can be achieved using high performance material in combination with new construction methods. The activities on icing and lightning are carried out by ONERA only.

The Innovative Rotorcraft is concerned with new concepts of rotor control, new rotorcraft concepts like the compound helicopter and tilt rotor aircraft. The background of these activities is the inherent disadvantages of helicopters with respect to flight speed, flight range and also noise and vibrations.

New rotor concepts like active flap or active twist control, but also rotors with controlled lead-lag motion (Derschmidt-Rotor) show significant potential for extending the flight envelope of main rotor-tail rotor configurations without the enormous complexity of a tilt rotor aircraft. This holds true for compound helicopter concepts in which additional components produce lift or propulsive forces for relieving the main rotor. An important result of the previous HGF period was the design, manufacturing and successful test of an active twist rotor blade in the DLR rotor test stand. For the coming 5 years it is planned to manufacture and test a fully instrumented active twist rotor in the wind tunnel in order to assess the maturity of the existing technologies.

The activities with respect to tilt rotor aircraft are almost fully integrated in EU-projects. The large potential of this configuration in terms of flight speed is contrasted by the enormous complexity, the significantly reduced hover efficiency and noise problems. The DLR is active in this field in applying numerical and experimental methods for design and assessment purposes. In the TILTAERO and ADYN projects numerical investigations and the layout of two rotors with the accompanying wind tunnel validation tests were carried out, although it turned out that the quality of the experimental data did not fully achieve the expected level.

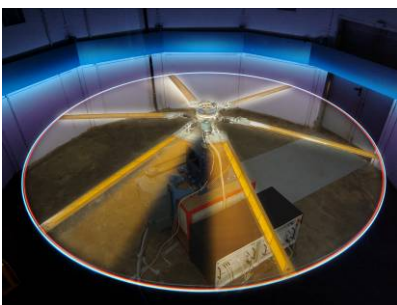
Through a well directed participation in framework programs of the EU, the DLR managed on the one hand to acquire a considerable amount of external funding and on the other hand synergies are exploited through a knowledge exchange with universities and other research centers within Europe. The main part of the expensive wind tunnel campaigns in the DNW LLF was conducted in the framework of EU-projects.

In parallel to the more basic research oriented level 1 projects of the 7FP the DLR will participate together with ONERA as associates in the Green Rotorcraft Platform of the Joint Technology Initiative (JTI) Clean Sky.

In addition to the specific research activities mentioned before it is part of the mission of the DLR and ONERA to develop up-to-date test techniques, large scale test stands and flight test aircraft (DLR: rotor test stand, ground simulators, flight test aircraft: BO105, EC135 FHS) and to make these available as public services. These test environments are used for development and assessment of new technologies and additionally for supporting research projects of the industry.

In its role as the national aeronautical research centre in Germany, the DLR has the task of supporting German ministries and official services. Moreover, the ONERA/DLR Partnership in Rotorcraft Research provides access to the results and experience in both research establishments, and consequently widens the basis and the capabilities for supporting the authorities in both countries.

In the same way the French / German integrated helicopter industry benefits from the combined efforts of the DLR and ONERA in the field of rotorcraft research. In order to better support Eurocopter, the common ONERA/DLR Mid-term Rotorcraft Research Program was jointly harmonised and the largest part is directly connected to the Euro-



**Active rotor blade in rotor test stand**

copter R&T Strategic Plan. These harmonised activities are presented in a common standardised format: the Co-ordinated Action Programs (CAPs).

## Expected Results and Milestones

| Year | Milestone                                                                                                                                                                                                                                                       |
|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2009 | Equipping of FHS with sensors for obstacle recognition and terrain data processing for fully automatic flight.                                                                                                                                                  |
| 2010 | Conduction of a wind tunnel campaign with an active twist rotor. Objective: Efficiency augmentation in hover by 2%, power reduction in high speed flight by 2-3%, 90% vibration reduction, 4-5 dB noise reduction, evaluation of new control laws.              |
| 2011 | Experimental proof of efficiency of fluidic control devices. Objective: reduction of pitching moment peaks in dynamic stall by at least 30%.                                                                                                                    |
| 2012 | Development of low noise flight procedures by combining the rotorcraft simulation platform for the numerical prediction of rotorcraft fly over noise of a complete helicopter with an optimizer. Objective: 4 to 5 dB noise reduction over standard procedures. |
| 2013 | Landing of a manned helicopter (FHS) at reduced/no vision on a non-prepared landing site.                                                                                                                                                                       |



DLR-BO-105 model in DNW LLF

## Planned Resources

### Planned resources for the program topic Rotorcraft

|                                      | 2009  | 2010  | 2011  | 2012  | 2013  |
|--------------------------------------|-------|-------|-------|-------|-------|
| Helmholtz Institutional Funding (T€) | 5,910 | 5,910 | 5,910 | 5,910 | 5,910 |
| Human resources (FTE)                | 39    | 38    | 36    | 35    | 34    |

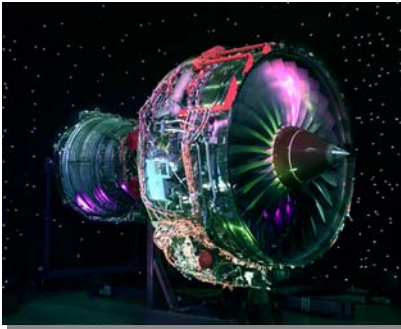
Detailed information on resources in the Annex



Extended primary flight display with additional guidance cues for flying predefined 4D missions



# Program Topic Propulsion Systems



Rolls-Royce Trent 500 3-shaft jet engine

The program topic Propulsion Systems encompasses, particularly in respect to the reduction of specific fuel consumption, pollutants and noise, all research activities at the DLR relating to the improvement of civil aircraft engines. Within the framework of these activities the DLR's, in part unique, experimental facilities are used in the validation of new technologies, and both advanced numerical simulation tools and novel measurement techniques are developed and evaluated.

## Challenges

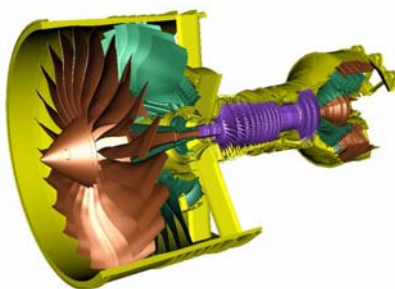
### Efficiency and Environment – Reduction of fuel consumption and CO<sub>2</sub>-emissions

A holistic or integrated approach to aero engine design is important if the ACARE goals VISION are to be realized. These goals target, amongst other objectives, drastic reductions in fuel consumption and nitrogen-oxide emissions. As the further potential of today's propulsion system concepts is limited, the development of new concepts is of increasing importance. In order to achieve better specific fuel consumption propulsion efficiency must be improved. This requires low to medium jet velocities and, for the same thrust requirement, increased mass flow rates and larger bypass ratios. As increasing bypass ratio conventionally increases the engine dimensions and therefore installation weight and drag, new low weight materials and construction techniques, as well as new concepts for engine-aircraft integration, are necessary in order to shift the point of optimal efficiency to larger bypass ratio engines.

Furthermore, it is necessary to raise the thermodynamic efficiency of the engine core. This requires both the turbine inlet temperature and overall pressure ratio be increased. At the same time, the efficiency of the individual components (e.g. fan, compressor and turbine) must be further increased. This requires highly accurate simulation methods more capable of accurately resolving the predominant flow features in the highly viscous secondary flow regions. It is also necessary to consider unsteady flow effects, which result primarily from the relative motion of the adjacent blade rows, in the design process.

Cooling- and secondary-air level requirements must also be reduced to an absolute minimum in order to minimize their negative effect on overall efficiency. To enable cooling efficiency to be raised, unsteady and three-dimensional flow effects, including those due to the interaction between neighbouring blade rows, need to be considered in the design process. Furthermore, new high temperature materials, with better thermal and structural properties than today's nickel-based materials are desirable. A significant temperature reduction in air-cooled components can be achieved through ceramic thermal insulation coatings. The challenges here are to improve the material reliability (flaking and crack formation prevention), reduce thermal conductivity, lower the oxidation rate at higher temperatures, raise allowable temperatures in the bond coat, and increase the coating thickness in highly loaded areas.

In terms of power to weight ratio the compressor remains the critical component. This is because of the limited pressure increases that can be realised per stage without inducing flow separation. In the past power density has been increased through BLISKS (bladed discs) by raising the angular velocity to its mechanical limit. If angular velocity is to be raised further, stronger and lighter materials, such as TMC (Titan-Matrix-Composites), along with new construction (e.g. BLINGS = Bladed Rings) and manufacturing approaches suitable for volume production will be required.



Counter-rotating turboprop engine (Source: GE)



For a given angular velocity, power density can only be increased through the stabilization of critical operating points by employing active or passive flow control strategies such as boundary layer suction, air injection, unsteady triggering or casing treatments.

### Environment – Reduction of noise emissions

As current aircraft development projects, such as that of the Airbus A380, have shown, the issue of aircraft noise continues to increase in significance. Furthermore, as air traffic volumes continue to rise and the sensitivity of the population to aircraft noise increases, it is to be expected that the topics of noise generation and propagation will continue to gain in importance.

Therefore, the aim, in conjunction with higher efficiencies and lower pollutant emission levels, is to realize, particularly during takeoff and landing, the lowest possible noise levels. This will require highly accurate numerical tools for simulating the generation of noise in the main engine components (e.g. Fan, Bypass channel, combustion chamber, low-pressure turbine and mixing nozzle) so that noise can be utilized as a design criterion in the development process. The development of higher performance fans and compressors with lower noise emissions requires fundamental work on the modelling of broadband noise. The progress already achieved in tonal noise prediction needs to be transferred to the design process. Furthermore, engine-aircraft integration effects need detailed consideration, as does the integration between individual engine components.

### Environment – Reduction of pollutant emissions

The reductions in the greenhouse gases  $\text{NO}_x$  targeted in the ACARE goals provides the chance to achieve a level of reduction in the environmental impact of aircraft, comparable to that planned through reductions in  $\text{CO}_2$  emissions, through optimisation of the combustion chamber alone. Compared with the costly development necessary in engine and aircraft technology for the envisaged  $\text{CO}_2$  reductions to be achieved, combustion chamber technology is capable of providing a relatively inexpensive contribution to climate protection.

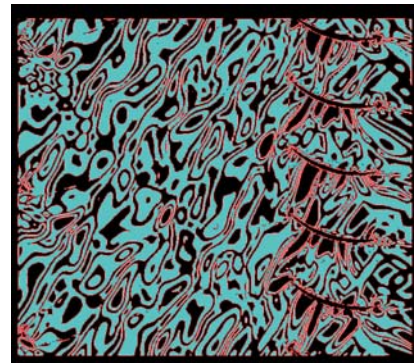
With the lean-burn concept a technology, already demonstrated in laboratory tests, exists with the potential to deliver the required emission reductions. The challenge now lies in trying to eliminate the deficits present in this promising technology within the short time period available. These shortcomings include the reliability of piloted lean-burn combustion chambers and flame tubes in view of the need to simultaneously satisfy the  $\text{NO}_x$  reduction goals at full load, the flame extinction margin necessary at idle and during deceleration, the requirement of oscillation free operation over the entire operating range, and reliable ignition at both ground level and high altitudes.

The demands on combustion chamber cooling systems have grown as combustion chamber entry pressures and temperatures have increased. These demands will rise further with the low-emission lean-burn premixed combustion concept as more air is drawn directly from the compressor into the combustor, leaving less available for cooling. As it seems unlikely that these demands can be met simply through improved cooling concepts, such as impingement effusion cooling, the employment of alternative materials (e.g. WHIPOX) with higher temperature resistance is necessary in combination with tailored cooling and bonding concepts.

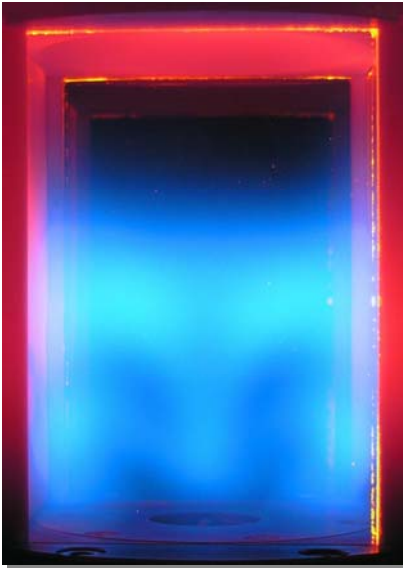
Additionally, although the emission of soot particles from aircraft engines contributes to air pollution, soot formation and oxidation also play an important role in heat transfer within the combustion chamber. A difficulty in dealing with this topic lies in the



The MTU high pressure compressor PW6000



Pseudo-colour image of a TRACE simulation of noise propagation in an engine bypass channel



Lean-burn combustion in the optical test rig

complexity of the soot formation process, starting with the thermal decomposition of the fuel, the formation of polycyclic carbohydrates up to particle formation and growth, and the underlying chemical and physical processes associated with soot formation. Important research goals are therefore to increase our understanding of soot formation in modern engine combustion chambers and attempt to further reduce soot emissions. For this purpose a sectional particle formation model will be integrated into existing numerical simulation tools.

The task of the DLR, in cooperation with industry, is to make available the necessary experimental tools, to carry out relevant experiments and to develop basic design principles for these new technologies.

#### **Competitiveness – Reducing development lead times**

In view of the need to drastically shorten development times without increasing risk in the development process it is necessary to significantly raise the speed and accuracy of the design tools employed, and to reduce, or indeed entirely avoid, time intensive component tests in the development phase. In the near future, all detailed engine component design work will be carried out exclusively using 3D Navier-Stokes methods. At present, steady-state analysis of the flows in entire engine components, or at least component stages, is the state-of-the-art. Highly accurate results are commonly obtained for the design point.

To better understand flow behaviour at critical operating points, for which viscous and unsteady effects are often predominant it must be possible to simulate such flow conditions with sufficient accuracy. In addition, in order to further raise engine component performance it will be necessary to be able to incorporate the modelling of unsteady flow phenomena in the design process. This will require highly efficient algorithms in order to make the integration of such, traditionally time intensive, calculations into the design process feasible.

Furthermore, as pre- and post-processing and the manual analysis and revision of designs are large parts of the design process, their future automation is important, particularly if the simultaneous consideration of multiple operating points is to be included in the design process.

A further improvement in efficiency is to be expected through the adoption of a multi-disciplinary design approach. Once integrated in the design process, the current sequential analysis of the aerodynamic, structural and aeroacoustic aspects of a design could be performed simultaneously to further reduce development time.

#### **Safety – Accident rate reduction**

Despite continually improving engine structural integrity, operating safety remains a contemporary issue. Current certification is contingent upon the blade structure not penetrating the compressor-housing in the event of compressor blade loss. Ideally, this is to be achieved through a minimization of the structural weight. Further measures include endeavouring to raise general safety and extending the containment function of the engine casing to accommodate blade disk failure. Due to weight considerations this is not achievable by simply strengthening the engine casing.



Four-stage transonic compressor of the DLR

## Content and Goals

### Engine

To establish, within the DLR, the competence to evaluate propulsion system concepts an integrated multidisciplinary preliminary design tool needs to be developed using existing DLR know-how and technical expertise. The closely connected individual disciplines dictate an interdisciplinary approach to preliminary design, particular for the analysis of novel engine concepts conceived to exploit synergies.

For the evaluation of individual propulsion concepts, such as the un-shrouded counter-rotating prop fan, it is necessary that, alongside the appraisal of the thermodynamic cycle, the capability to analyse, in detail, the individual engine components exists. This requires not only the evaluation of a component's aerodynamics, but also the consideration of other disciplines, such as materials, manufacturing, combustion, aeroelasticity and aeroacoustics, in order to obtain a meaningful assessment of a particular propulsion system concept. The new preliminary design tool should build upon existing preliminary design capabilities already available within the DLR. The development of new models will, however, also be necessary to bridge existing gaps in the available preliminary design tools and to make truly integrated design analysis possible.

The integrated process chain being developed should be able to perform, at the pre-design level, automatic, multi-disciplinary design iterations. Subsequently, it should be possible to include more detailed design methodologies whose levels of detail can be increased as required. The investigated concepts will be analysed and assessed, and used as a basis for system analysis, technology evaluation and for future advanced combined aircraft-engine optimisation.

In a further step, the observed trends are to be incorporated into simple models for use in preliminary design studies. In this way these import correlations will also be available for use in aircraft mission studies.

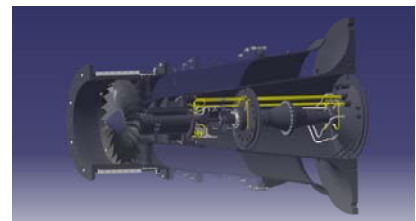
### Fan and Compressor

Within the framework of recent EU projects the structural and aerodynamic design of both a very high bypass ratio (BPR=12) geared fan and a shrouded counter rotating fan have been successfully completed. For this purpose an integrated aerodynamic and structural design process has been developed, validated and tested through application.

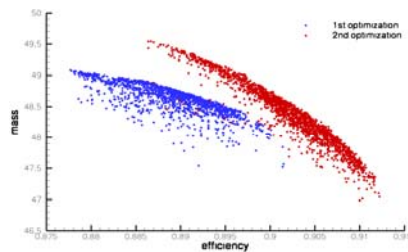
For future research and development projects it is necessary to further extend complete-component design competence in the field of compressor systems. The focus is the development of efficient and quiet fans, highly loaded multi-stage axial compressors and high performance radial compressors.

Essential in this context is the further development and extension of an integrated multi-disciplinary design system with preliminary design tools, the 3D Navier-Stokes solver TRACE, an FEM solver and automatic optimisation strategies.

Recently, in the development of automatic design tools great success has been achieved with regard to increasing the efficiency and power density of fans and compressor stages. These tools, or more precisely the methodologies underlying them, need to be further generalized to encompass as many of the, often conflicting, design parameters and objectives as possible. An intelligent and robust, multi-disciplinary process for complex systems with a nearly unlimited number of free parameters is



Counter-rotating turbofan engine (Source: GE)



**Automatic optimisation of an aero-engine fan**

required. The aims are to meaningfully parameterise complex systems, to develop a suitable approach for selecting free and fixed parameters during process execution, and thereby to automatically generate improved designs at acceptable cost.

With further increases in power density and compressor pressure ratios the physical limits of passive compression systems will soon be reached. Further significant weight reductions will then only be achievable if highly loaded compressors can be developed that remain stable even at extreme operating points. Although various methods for extending the stability boundaries of compressors are known (using steady or unsteady air injection or suction), significant work must still be conducted before they can be applied in industry. This work includes the selection of the most promising passive and active control methods, basic research to improve our understanding of their operation and experimental tests to verify their potential in realistic configurations.

For this purpose it is necessary to extend existing test facilities and furnish them with appropriate cost effective measurement equipment capable of providing the necessary data on the dominant flow phenomena (optical and unsteady measurement techniques).

### Combustion Chamber

The primary goal of future combustor and combustion chamber research is to use focused research projects to advance the low emission lean burn combustion concept to the point of industrial readiness. The main problems at present are maintaining stable operation from idle through to full load with a homogenous fuel mixture distribution and an even temperature distribution, the avoidance of lean blow out through internal piloting and fuel input staging, the avoidance of combustion oscillations, reliable ignition and re-light at high altitudes as well as developing an improved understanding of the complex interactions and the design of new combustion systems. In addition alternative fuels (synthetic or organic fuels) will continue to increase in importance as a supplement, or replacement (beyond 2030), for today's kerosene.

Due to the inherent complexity of combustion, research and development in this field is still dominated by experimentation and complex measurement and analysis methods. To perform research into low emission combustion chambers under realistic boundary conditions (geometry, temperature and pressure) a new combustion chamber test rig furnished with laser measurement equipment is currently being built. The aim is to investigate fuel positioning, mixture and behaviour under partial load in a realistic combustor configuration of real size. By improving our understanding of the interaction between flow and heat release it is expected that a clearer understanding of the emission character of the combustor at full load, known from measurements in conventional test rigs without optical access, will also be achieved. In parallel, in the single nozzle sector, a detailed investigation of spray combustion, including unsteady phenomena, will be carried out in a generic combustor.

Alongside experimental work, extensive research also needs to be carried out to improve numerical methods for the simulation of the combustion process. Substantial efforts will be taken to test these methods, which have been developed at the DLR, in real aircraft engine combustion chambers. For the simulation of spray combustion including spray diffusion and evaporation the DLR numerical simulation tool SPRAYSIM will be applied and further developed. Alongside this work, the development of combustion models for the detailed simulation of reaction mechanisms will continue.

The basic aims in the field of thermo- and combustion chamber-acoustics are the furthering of our understanding of combustion chamber oscillations, passive acoustic damping, active control mechanisms, and direct and indirect combustion chamber



**Combustion chamber and compressor test center in Cologne**



noise. Combustion chamber noise is caused by temperature inhomogeneities at the exit of the combustion chamber and transonic flow conditions in the downstream turbine (entropy noise). To better understand these phenomena existing test rigs will need to be extended and new ones built, acoustic and laser-based measurement technologies further developed and numerical simulation (CAA and CFD calculations) employed.

In addition, the design, construction and experimental investigation of an oxide ceramic sectional combustion chamber incorporating a generic lean-burn combustion model is planned. The aim of this work is to drastically reduce the cooling- and secondary-air required, at a given flame temperature, to obtain higher turbine entry temperatures with lower  $\text{NO}_x$  emission rates.

Based on an analysis of existing methods for manufacturing synthetic fuels (e.g. Fischer-Tropsch synthesis) and known results for kerosene-like model fuel components and mixtures, synthetic fuel mixtures, and the influence of organic components or additives, can be characterised through a comparison with real kerosene. Appropriate variables for comparison at this research stage are enthalpy, ignition-delay-time and laminar flame velocity. For the most part, the data required have been published or are otherwise available. Certain data however still need to be acquired. The aim of these basic investigations is the development of a design process that will enable, on the basis of a yet to be validated reaction mechanism, a mixture of synthetically manufactured fuel components to be described kinetically. With this achieved it would be possible to assess alternative fuels in new or existing combustion chamber concepts. With regard to numerical modelling, previous research on the numerical simulation of the phase-transition in real fuels will be continued for alternative fuels.

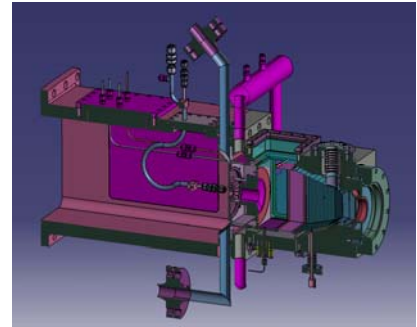
## Turbine

In modern gas turbines the thermal loading of the first stage immediately behind the combustion chamber has greatly increased due to fuller temperature profiles and significant increases in exit temperature. In particular, the blades and blade platforms in this stage are highly thermally loaded regions, whose efficient cooling is critical. Cooling and the improved prediction of thermal loading are therefore important topics of industrial research. This requires highly accurate modelling of the spatially and temporally varying flow including cooling air injection, convective heat transport and heat transfer coefficients.

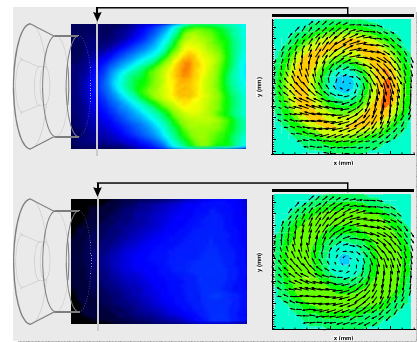
For this purpose more extensive use of the CFD simulation tool TRACE will be made following its validation against the latest experimental data, and, if necessary, further development. In a parallel step, the internal flow through heavily cooled turbine blades will be simulated and validated with detailed experimental data. The challenge here lies in the comparatively low flow velocities, the incompressibility of the flow, the presence of micro-structured surfaces for increasing turbulence and improving heat transfer, as well as stronger viscous effects with flow separation and regions of recirculation. For good simulation to be accomplished improvements in the areas of convergence, stability, turbulence generation, wall treatment and local heat transfer need to be achieved.

To complement this work investigations into the influence of cooling-air and air-leakage in heavily cooled and highly loaded turbine stages are to be carried out. Through the creation of a data pool this will enable both existing cooling system designs to be validated and new methods for devising novel cooling concepts to be developed.

In the coming years component and aero-thermodynamic design competence will be further increased. For this purpose, starting with a relatively simple thermodynamic

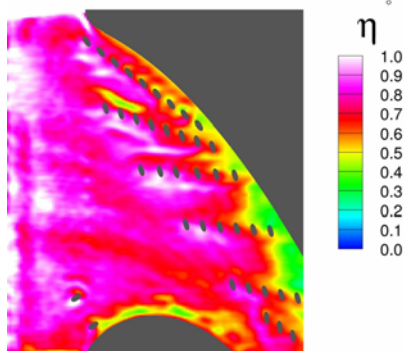


**New combustion chamber test rig for investigating novel lean-burn combustors under realistic operating conditions**



**Visualization of combustion oscillations**





Platform cooling improvement of a turbine stator

approach, the boundary conditions for a turbine will be defined. Then, using a Through-Flow method, stage loading and profile requirements are to be determined so that an aerodynamic design of the blade profiles can be carried out. In the next stage the thermal loading will be estimated and consideration of blade cooling and material properties will be incorporated in the design process.

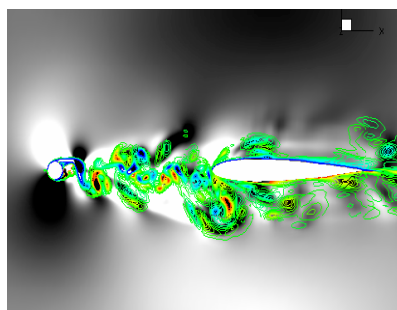
For many years the currently available turbine test rigs have been successfully employed in both industrial and research projects. The development of new turbines has, however, seen challenges emerge that are very difficult, or even impossible, to meet with the available test facilities. The facilities therefore need to be modified and updated in accordance with the latest developments in turbine technology. This will require an increase in the compressor pressure ratio and the power available to the high-speed turbine test facility in order to be able to investigate the next generation of high performance turbines and, over the medium-term, highly loaded two stage (and twin shaft) turbine models. With regard to the linear turbine cascade facility the development of the capability to vary Mach number and Reynolds number independently is of great interest in order to investigate flow phenomena in the flight phase.

### Numerical Methods

In all aspects of modern aero-engine design and development accurate numerical tools for the simulation of steady, viscous and three-dimensional flow phenomena are indispensable.

Shortened development times, as well as numerical design efficiency, require an integrated design process based on a multi-disciplinary design tool. In this context the simulation tool TRACE is being developed into a multi-disciplinary design tool for multi-stage compressor and turbine components. This work includes the development of a frequency domain linearised solver for the efficient analysis of aeroelasticity problems, and the development of an adjoint solver for sensitivity studies that should enable the automatic optimisation of compressor and turbine profiles to be performed significantly faster.

In the future it will be necessary to perform unsteady simulations, at least for selected operating points, of critical components in order to better understand unsteady effects and raise product quality. The aim must therefore be to improve the efficiency of unsteady numerical simulations to enable their integration in the design process. To realise this aim various approaches are being developed. These include: deterministic stress models for the modelling of unsteady effects in steady calculations, unsteady mixing plane models for mixed steady-unsteady calculations of multi-stage compressors and turbines, as well as the phase-lag method for the efficient computation of configurations with arbitrary blade ratios. As a result of this work, and further improvements to the solution algorithm, computational times will fall sufficiently (circa two orders of magnitude) to permit unsteady calculations to be included in the standard design process.



DES-Simulation of a cylinder-aerofoil configuration performed with TRACE

For acoustic phenomena, and in particular the simulation of tonal and broadband noise, numerical methods with low dissipation and dispersion properties need to be developed, validated using a broad variety of components and configurations and subsequently integrated in the design process. These methods provide improved computational efficiency in that, although they have a higher computational overhead, they require far fewer computational cells to resolve a given flow structure, or alternatively can resolve smaller structures than conventional methods on a mesh of a specific density. Together with the further development of scale adaptive DES models these schemes are important in the realization of Design-to-Noise, the design of quiet engine components, and thereby tomorrow's more environmentally friendly engines.

### Validation Methods

In the last ten years of compressor and combustion research Particle Image Velocimetry has provided valuable insight into the basic nature of the central flow phenomena. Nevertheless as PIV only provides data in a two-dimensional plane, complex three-dimensional flow structures in the boundary regions such as tip vortices can not be directly measured. The tomographic PIV method extends conventional PIV in the third dimension through the simultaneous observation of an illuminated measurement volume using multiple (at least three) cameras.

The application of this method to the study of turbomachinery flows will be, in particular due to optical access limitations, complex and challenging. As a first step towards the application of tomographic PIV existing research projects, in which conventional PIV is employed, will be harnessed and adapted to acquire appropriate data, through the use of additional cameras, for tomographic flow field reconstruction. Suitable objects for assessing tomographic PIV would be the diffuser of the DLR's radial compressor and the near wall flow in the DLR's axial compressor rig 250; two facilities in which laser measurement techniques have been successfully applied on multiple occasions. In a second step this measurement technique will be utilized to validate numerical simulations (using the TRACE code) of secondary flow regions in compressor geometries.

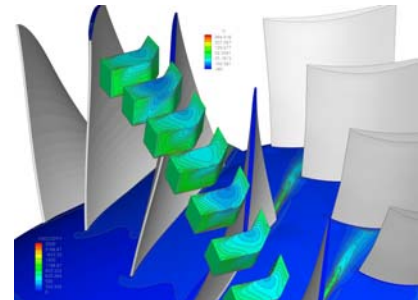
Whilst performed under realistic aero-thermal conditions, most investigations in combustors of the atomisation process downstream of a prefilmer have been carried out under idealized geometric boundary conditions. In such studies the atomisation of diagonally injected kerosene jets or two-dimensional kerosene films is investigated. The typically circularly symmetric geometries of real swirl atomisation nozzles differ from these idealized configurations primarily in the additional shear flow downstream of swirl inducing channels and in the acceleration of the flow.

In the near future flow swirl and acceleration effects in fuel atomisation nozzles will be investigated. Due to the significant optical access restrictions the possibility of using convention optical measurement techniques (such as LDA or PIV) will be limited and either novel solutions will have to be found or the use of alternative methods considered. For the visualization of the atomisation process a recently developed method known as digital in-line holography is an interesting possibility. Alternative visualization or measurement methods include specially adapted PIV, tomographic PIV, shadowgraphy and also Laser-Induced Fluorescence (LIF).

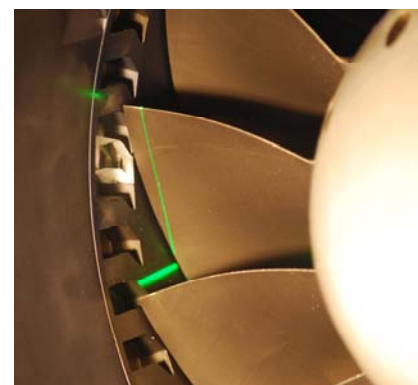
In future effects to further our understanding of turbulent combustion processes, laser measurement methods based on CARS (Coherent Anti-Stokes Raman Scattering) and LIF will continue to play an important role. Important, however, will be the further development of these methods to enable their application in high pressure regions and in particle and droplet laden flames. To determine soot concentration and particle size distributions time-accurate LII (Laser Induced Incandescence) measurements, complemented with probe measurements using SMPS-Analysis (Scanning Mobility Particle Sizing), will be applied. For the investigation of unsteady processes, and in particular engine re-ignition, laboratory scale experimental rigs, with well defined boundary conditions, are required to provide experimental data for model validation.

### Lightweight hybrid materials for the compressors of tomorrow

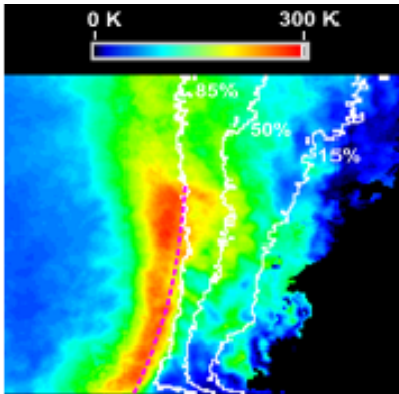
In order to judge the potential benefits of new materials an integral approach, rather than the isolated analysis of individual components, is paramount in structural design. This is motivated on the one side by the strong interaction between components and



Casing treatments for extending the operating range of a transonic compressor



Glass casing treatments facilitating flow field measurements in a transonic compressor



Temperature distribution in a lean-burn premixed combustor

on the other side by the diminishing potential for further optimisation. The development of modern compressors is therefore, for example, closely connected with engine casing development. The containment function required of the engine casing often frustrates the use of weight saving materials in the rotor region. New hybrid materials, comprising combinations of metals, fibre-reinforced metals and fibre-reinforced plastics, therefore aim not only to increase the specific energy absorption of the compressor casing but also to reduce the size of the fragments released through a controlled disintegration mechanism. Through the use of these materials the optimal overall structural weight of the rotor and engine casing can be achieved and / or heightened safety requirements satisfied.

Integral design approaches are also being implemented in a multi-disciplinary manner. Through the coupling of the CFD tool TRACE and the commercial FE code PERMAS a link between the currently separate processes of compressor aerodynamic and structural design will be established.

Within the framework of the DLR project AeroLight, in which several DLR institutes are collaborating in the design of a hybrid compressor rotor, technology validation constitutes the last part of the development chain. The final construction of the rig provides not only the opportunity to verify the chosen materials and basic construction but also the aerodynamic and aeroelastic characteristics of the design. It is expected, in particular from the aeroelastic investigations, that insight will be gained into structure durability that will provide the foundation for improvements in the structural design.

At the DLR, as well as other research institutes throughout the world, new high performance materials with excellent properties have been developed in recent years. Despite significant potential in terms of efficiency and environmental sustainability these new developments have not been introduced because of the very high costs associated with the manufacturing and application of new materials. At the DLR in, for example the Helmholtz young investigator group "Electrolytic Production Routes for Titanium Matrix Composites", new manufacturing concepts have been developed to reduce the manufacturing costs of fibre-reinforced metals and to make the integration of reinforcing elements in structures possible.

Intermetallic alloys, based on titanium and aluminium, are currently viewed within the aeroengine industry as possible replacements for the nickel-based alloys currently used in high- and low-pressure compressors. These materials have the potential to provide weight savings of around 50% in comparison to conventional materials and construction techniques. At the DLR the properties of the latest alloy developments are being investigated and, for the purpose of component dimensioning, data and material models are being developed.

#### Fibre-reinforced ceramic composites for combustion chambers

Thanks to the successful development work conducted in recent years the oxide ceramic fibre-reinforced composite WHIPOX (Wound Highly Porous Oxide Ceramic Matrix Composite) has now reached a maturity sufficient for its application in industry. With its low manufacturing costs, excellent thermal shock resistance, high damage tolerance, intrinsic oxidation stability and high corrosion resistance WHIPOX possesses unique properties in the field of fibre-reinforced ceramics.

Future development work will be primarily focused on modifying the material's properties to meet the requirements of specific components or prototypes. Prototype development is aimed at components for the next generation of aero-engine, combustion chamber components, as well as the evaluation of specific characteristics. In parallel to the development of prototypes a quality assurance system is being developed. In this



Fibre-reinforced engine shaft test specimen

context, methods like thermography, ultrasonic inspection, x-ray analysis and tomography, are being considered for the quality assessment of highly porous ceramic composites. The development of design concepts for components made of fibre-reinforced composites is being carried out on an inter-institute basis. The central themes of this work are the development of fibre-reinforcement and load transfer concepts. For the construction of complex components new joining techniques, such as permanent in-situ joins, are being developed and evaluated using prototypes in terms of technical feasibility, potential and cost effectiveness.

In more fundamental research it is planned through the application of novel characterisation methods to develop a deeper understanding of the micro-structure / property relationships of WHIPOX. With this understanding the manipulation of the pore structures of WHIPOX to realise specific gas permeabilities, for example for transpiration cooling, should be possible. In additional research aspects relating to end production are to be systematically investigated.

In order to make WHIPOX usable in complex components and loading profiles, simulation must first be possible. The modelling of WHIPOX will first build upon the numerical simulations of fibre-reinforced composites. In the next stage micro- and macro-models describing the inhomogeneous and anisotropic construction of the porous fibre-reinforced ceramic composites will be developed. With these models it should then be possible to determine the directional dependence of the required structural design variables and to obtain a deeper understanding of the possible failure mechanisms.

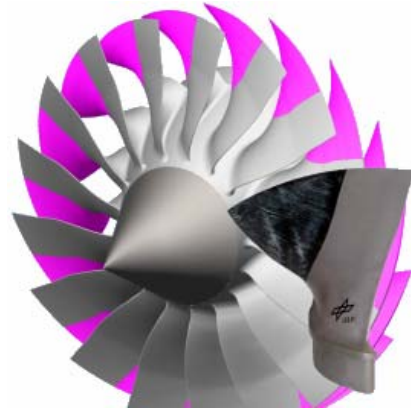
Although oxide ceramics are inherently resistant to oxidation, in the presence of fast flowing exhaust gasses hot gas corrosion can occur through, for example, the formation and mobilization of gaseous hydroxide species. Consequently, for long term high temperature application in gas-turbine combustion chambers, ceramic materials require protection from water-vapour hot gas corrosion. The development and validation of such protective layers is being carried out in connection with DFG projects.

The high temperature stability of fibre-reinforced ceramic composites is primarily dependent on the micro-structural stability of the fibre material employed. As part of the collaboration between research institutes and industry supported by the BMBF, alternative fibre materials are being manufactured, analysed and tested. If higher strength and thermal stability can be demonstrated, suitable matrix-systems will be developed to deliver the next generation of WHIPOX-analogous composite materials.

### Protective and functional coatings for engine components

The research and development work in the field of high temperature and functional coatings is concentrated on those engine components, such as compressor and turbine blades, as well as combustion chambers, with the largest potentials for improvement in the next generation of engine. The most important application areas for coating systems include oxidation and erosion protection of titanium and nickel alloys, thermal insulation as well as sensor and catalyst coatings. In the future the multi-functionality of coating systems will become increasing important, requiring the development of new coating concepts.

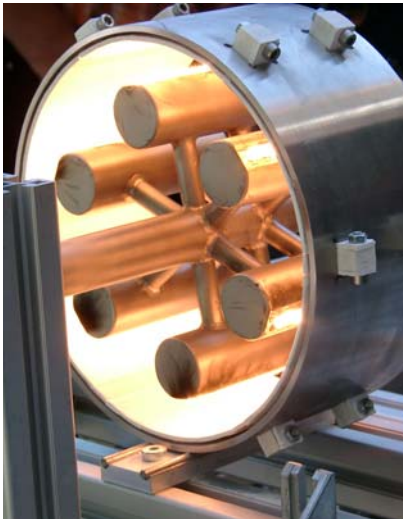
The DLR's new "Center of Excellence SURFACE" as well as the current HGF large investment "Coating Center" (€3.2m) underline its excellent reputation in the coating technology field. The Multiple-Source-Magnetron-Sputtering device (MEGA) makes possible the inexpensive manufacture of protective and functional coatings with novel structures and properties on aero-engine components. The purpose of the integrated



Hybrid construction of a highly loaded transonic compressor (DLR-Project AEROLIGHT)



WHIPOX segment with cooling channels for a model combustion chamber



**Combustion chamber demonstrator with segmented WHIPOX lining**

gas-flux-sputtering system is the rapid coating of geometrically complex compressor and turbine blades with flexible coating architectures.

In cooperation with national and European partners new thermal insulation coating systems with reduced thermal conduction and improved durability have been developed. These coatings raise component durability and enable cooling air requirements to be minimized. Priorities in this work include the optimization of the coating properties and process parameters, achieving an improved understanding of the possible damage mechanisms and the assessment of coatings in terms of their long term stability and turbine blade portability.

#### Experimental and numerical description of material behaviour

The main research topics in the work package “experimental and numerical description of material behaviour” are the development of more accurate material models for high temperature and lightweight materials (thermal insulating coating systems, intermetallics and ceramic fibre-reinforced composites, hybrid metal CFRP systems), the implementation and further development of more efficient simulation methods for the description of damage and failure behaviour through fatigue and time/temperature loading, as well as the further development of experimental validation methods for material behaviour under realistic operating conditions (multi-axial loading, fatigue and ageing).

The aim of the work is to enable the utilization of the material’s potential for lightweight construction and higher turbine entry temperatures and the reduction of lead times between the development of new material systems and their application in industry.



**The DLR’s new coating center MEGA**

## Expected Results and Milestones

| Year        | Milestones                                                                                                                                                                                            |
|-------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>2009</b> | Multi-disciplinary 3D design of a highly loaded compressor stage using automatic optimization                                                                                                         |
| <b>2010</b> | Minimization of the cooling air required in heavily cooled turbine stages through new coating and cooling technologies                                                                                |
| <b>2011</b> | Operational and validated simulation tool for the computation of hybrid materials and structures, and in particular material interfaces                                                               |
| <b>2012</b> | Design, construction and experimental investigation of a hybrid construction high performance compressor stage in the axial compressor test rig                                                       |
| <b>2012</b> | Operational and validated tool for the simulation of aircraft engines                                                                                                                                 |
| <b>2013</b> | Operational concept for a low-emission lean-burn combustion chamber through an improved overall understanding of the operating behaviour of lean-burn combustors under realistic operating conditions |



## Planned Resources

### Planned resources for the program topic Propulsion Systems

|                                      | 2009   | 2010   | 2011   | 2012   | 2013   |
|--------------------------------------|--------|--------|--------|--------|--------|
| Helmholtz Institutional Funding (T€) | 12,691 | 12,691 | 12,691 | 12,691 | 12,691 |
| Human resources (FTE)                | 77     | 75     | 73     | 71     | 68     |

Detailed information on resources in the Annex

# Program Topic ATM and Operation

The subject of this new program topic is the safe and efficient guidance and surveillance of an aircraft as well as its interaction with the human and the environment.

The scientific scope includes psychology, physiology and ergonomics. It considers the future air traffic management including all navigational and communicational aspects and it also considers the interaction of air traffic with the environment taking into account the climate aspects.

This combination of diverse research areas is unique within the aeronautical program. Six DLR institutes are involved in this topic including an intensive usage of DLR research aircraft. The mainly interdisciplinary work is structured in the following five thematic areas:

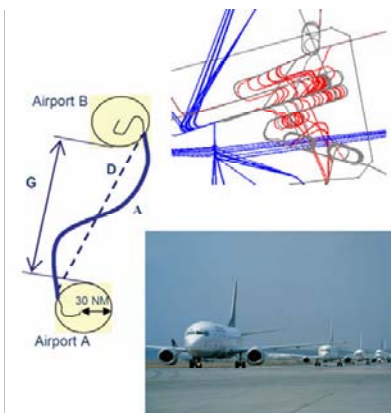
- > **Airport and airport vicinity**
- > **Human factors and safety in aviation**
- > **Climate, weather and environment**
- > **Communication, navigation and surveillance**
- > **Future air traffic management**

## Challenges

This program topic focuses on the challenges of Vision 2020 and the ACARE goals. The significant increase of air transport capacity must be managed with improved punctuality while maintaining at least the same level of air traffic safety. The minimisation of the negative influences of current and future aviation, in particular on people and the climate is no less important. These goals concern both passenger and cargo flights and both short and long-range flights.

Furthermore, the expected increase in the level of automation presents additional challenges and makes high demands not only on the air traffic management (ATM) but also on human operator's ability to perform and adapt.

At European level the initiative SESAR (Single European Sky ATM Research) has already started. Bringing all ATM-stakeholders together, an ATM master plan is currently prepared and will be implemented in the next few years.



Challenges – “Direct Routing” and the avoidance of holding stacks/queue

### Airport and airport vicinity

Airports in the ATM environment are facing a growing demand for transport services as well as an increasing cost pressure. In scenarios of the future, airports and terminal areas have been identified as capacity bottlenecks for the development of traffic within the prospering air transportation system. Many of the studies on this subject that have been carried out so far at the DLR have gained international recognition and acknowledgment. In this field of research, the DLR has attained a leading position worldwide. This position is to be firmly established and extended, as the basis for work on future integration of automation in ATM and at airports.

In airports, the focus is placed on increasing capacity while simultaneously reducing the risk of incidents and accidents. By managing European projects, for example in the area of taxi and ramp management (Advanced Surface Movement Guidance and Control System – A-SMGCS), the DLR has strongly positioned itself at an international level

in this field. In the future, it will be necessary to concentrate further research on the implementation of higher level A-SMGCS functions.

The development of new operational concepts using operator assistance systems to increase capacity while at the same time reducing emissions at the airport and in the terminal area is an important challenge for future research and development.

**Time and performance based ATM:** The ICAO (International Civil Aviation Organization) has listed the main challenges of future commercial aviation under Key Performance Areas – KPAs. These include punctual, predictable, capacity-optimised and environmentally-friendly flight operations. To meet these challenges, it will be necessary to increase flexibility and to overcome the rigid procedures and processes that are currently used.

**Time-based ATM,** which means the planning and controlling of arrival times at certain navigation points, requires new operational concepts and procedures. Time-based sequencing and controlling of arrivals and departures enables an increase in efficiency with regard to both capacity and punctuality. Taking the other performance parameters mentioned above into account, new concepts result which holistically optimise the planning and controlling of flight operations-based performance parameters (Performance Based Airport/Performance Based ATM). To achieve this, new technologies, processes and management procedures need to be developed.

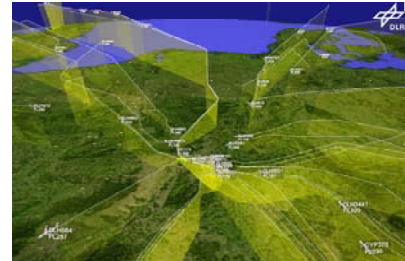
**Continuous trajectory through the airport:** Cost pressure, induced in particular by low cost airlines and to an increasing degree by established airlines, can be partly alleviated by shorter turn-around times. An indication of a change in paradigm is expressed in the move from the concept of “Gate to Gate” to the concept of “En-Route to En-Route”. This new approach is accompanied by the use of a continuous trajectory and one standardised set of information per aircraft from arrival to departure. This requires new planning tools at the airport which enable on-time processing.

**Cooperative ATM:** Reliability is increased through the seamless, plan-based handling of flights, movements, and turn around processes via the exchange of data. More reliable planning is the prerequisite for enhanced punctuality, safety, and efficiency, as required by Vision 2020.

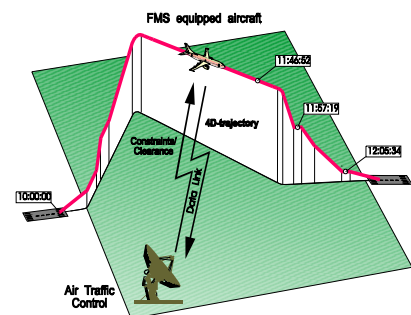
The challenge is in a higher level of flight and resource planning reliability, and in incorporating all related information in this process. The specific interests of the individual stakeholders also need to be taken into account. The prerequisite for this is the agreement of the relevant stakeholders on jointly defined goals in a cooperative process. Intensified research is required for all areas which are essential for implementation of a cooperative ATM system.

**Information management:** The need to supply information to all of the parties involved in air transport (airlines, ATM service providers, airports, dispatchers, etc.) requires a system-wide information management system (SWIM). The exchange of information beyond the currently existing boundaries and interfaces is the key element for success in this process. Each of the stakeholders must be provided with information that is individually tailored while guaranteeing the necessary level of confidentiality.

**Airport systems:** Linking several airports to one airport cluster has certain advantages for traffic handling. This results in improved distribution of traffic load or the ability to react to operational impairments due to external influences or weather conditions. Rules for interaction and cooperation between the involved airports have to be worked out in order to achieve these benefits. Additionally systems have to be developed which support the common management of the traffic distributed over a cooperative airport system.



Arriving and departing traffic at Frankfurt/Main airport



4D trajectory and cooperative ATM

The increasing air traffic is being generated partly by low cost carriers. They often operate from smaller airports, with a low number of flights per day. Cost-efficient operation of these airports could be supported by controlling the aircraft movements from centres located further away. Initial solutions for remotely monitoring airports are already being investigated.

Unmanned Aircraft Systems (UAS) Integration: The integration of unmanned aircraft, both civil and military, into civil airspace is a big challenge. With regard to the operational incorporation of UAS, safety aspects are in particular of vital importance.

### Human factors and safety in aviation



Enhanced vision display for approaches under poor visual conditions

Air safety: Approximately 60-80% of all aviation accidents have human error as their main cause. Despite all the technical developments relevant to safety, this percentage has not altered significantly in the last few decades. Hopes that further automation can significantly reduce the rate of human-factor accidents seem virtually unfounded. Human error even plays a comparable role in accidents involving unmanned aircraft systems (UAS).

The field of human-factor research can therefore make a significant contribution to increasing air safety. This requires fundamental work on man-machine interaction in both the cockpit and in air traffic control.

Hence, when considering human-centred automation, it is necessary to adapt the support systems to humans and not vice versa. In addition, all the desired improvements always have to be accepted by the operators.

New roles for operators: Humans as operators of technical systems will continue to be the key element in aviation both on the ground and in the air. Aviation without the human operator and his creativity, such as in problem-solving, is barely conceivable in the coming years.

In future, operators will take on new roles, e.g. as remote controllers in a virtual tower or in a UAS. Furthermore, discussions on the restructuring of responsibilities between flight controllers and pilots have already begun. Consideration of human abilities and limits will continue to present a challenge in designing innovative new solutions.

Improved situational awareness: The actual design of the human-machine interface (HMI) has a crucial influence on the interaction between man and machine. It is becoming increasingly important to improve the operator's situational awareness. The HMI design is of crucial importance in connection with the perception and processing of information by the human operator.



Assessment of pilots' situational awareness

The challenge here lies in developing these systems to the optimum and at the same time integrating the human operator into his new highly automated work environment. Only then will he be capable of making the correct decision in a critical situation.

Assistance systems: Automation of the working environment will continue to advance in aviation in order to support the operator in fulfilling his increasingly demanding tasks. The growing complexity of the tasks within the aviation system also is a major challenge and calls for the development of increasingly powerful support systems.

In the future these technical systems will even be able to take over higher-level cognitive human functions. With the aid of these assistance systems and the functionalities they contain, it will be possible to achieve a level of interaction between the air traffic controller and pilot that will meet the demand for greater aviation safety.

**Increasing the efficiency of aviation personnel:** Due to the high safety and quality standards required, training aviation personnel is time-consuming and costly. In the past, medical and psychological aptitude diagnostics were able to play a substantial role in increasing efficiency as they guarantee to a large extent that suitable applicants fulfil the high requirements in training and professional work.

One special challenge in the future, apart from adapting existing methods to technical and socioeconomic changes, is the increasing scarcity of applicants. Consequently, the methods used in future will have to yield even more reliable forecasts than has hitherto been the case.

Another challenge is globalization, not only of aviation but also of aviation personnel. Due to national licences, applicants largely used to come from the domestic market. Introduction of the JAR-FCL European licences is now leading to the development of a European and increasingly worldwide market for applicants. This places special demands on the fairness of the test procedure in terms of language and culture.

**Avoidance of health risks:** The environmental parameters of the aircraft cabin have to be designed in such a way as to exclude health risks (e.g. climatic conditions, exposure to radiation). In the event of malfunctions, the emergency measures must achieve a maximum level of efficiency in order to rule out any serious harm to the health of the crew and passengers. The use of telemedicine reduces the health risk on long-haul flights, above all for passengers with a health problem.

In the cockpit it also has to be remembered that the human operator's performance is affected by numerous environmental conditions (temperature, humidity, pressure, acceleration, vibration, noise, radiation,...), which on the one hand can be kept within tolerable limits by the systems engineering but, on the other hand, can very rapidly become a threat to health and safety outside of the standard range (e.g. loss of cabin pressure).

Additional factors that reduce performance and which also have to be taken into account are those typical of aviation, such as flights crossing time zones and duty/rest period arrangements and the operation of new aircraft types.

Also important are the effects of air traffic on the residential population. The most serious problem in this context is aircraft noise in the vicinity of the airport. Undisturbed sleep at night, for instance, is of particular importance in recovering from the strains of the day and in maintaining performance and health. The forecast growth in air traffic will not be possible unless the demands of the affected population for protection against nocturnal aircraft noise are met. In order to determine the population's need for protection, it is essential to have the most accurate possible information on the influence of nocturnal aircraft noise on sleep.

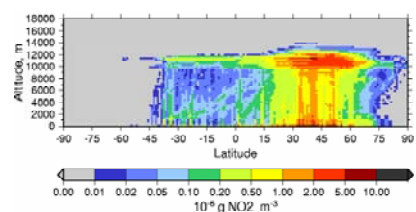
**Increasing subjective passenger comfort:** Customer satisfaction amongst passengers is a decisive criterion for the aircraft manufacturers and airlines. One crucial factor in this is the subjective perception of comfort among passengers, which has yet to be sufficiently investigated and quantified.

### Climate, weather and environment

Continuing rapid growth in air traffic over the coming decades will only be possible if negative impacts on society are reduced to a minimum. These include noise, particle emissions and other effects on air quality in the airport environment, but also increasingly the contribution of emissions from air transport to climate change. In addition to carbon dioxide (CO<sub>2</sub>), these include NO<sub>x</sub> emissions and the generation of contrails, which play a role in long-range air traffic that has not yet been sufficiently studied.



Training and aptitude testing of aviation personnel

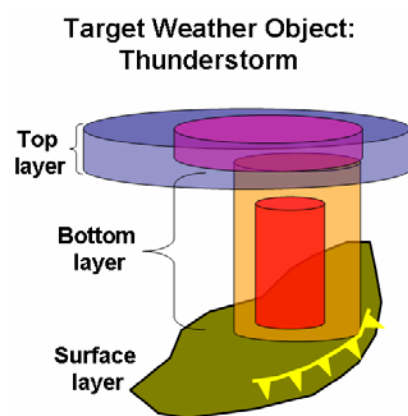


Global vertical distribution of nitrogen oxide emissions from world-wide civil air traffic





Contrails as detected by a satellite west of Spain and northern Africa. An automated algorithm enables the detection of a part of the contrail cloudiness associated with linear structures based on the remotely sensed data. Some of the cirrus clouds nearby have likely been triggered by such line shaped contrails, but this cannot be quantified with this method.



Example of the representation of a thunderstorm cell for pilot information in the cockpit

A reliable assessment of the effects of air traffic on its surroundings, the development of technologies for reducing emissions, and the investigation of methods for reducing potential harmful effects on humans and the environment is therefore becoming important. Emissions will also increasingly become a cost factor in air transport. This is already apparent in the future inclusion of aviation in emissions-trading schemes and increased efforts to define and enact noise- and emission-reducing take-off and landing procedures.

With increasing constraints on the air transport system, the influence of weather on safety and punctuality of air traffic is playing a growing role. Measures to reduce the impact of wake vortices, thunderstorms and winter weather are becoming increasingly urgent.

Climate-optimized Air Traffic: Minimizing the climate impacts of aviation is among the most difficult challenges facing the aviation industry and in particular air traffic management, and requires a reliable assessment of aviation-induced climate change. Substantial scientific uncertainties are currently hampering a targeted reduction of climatic effects. A sound metric is not available that could be used to compare the climate forcings caused by aviation with those from other natural and anthropogenic sources. An acknowledged scientific basis is lacking that would enable appropriate consideration of aviation in the emissions-trading schemes discussed in the European Union.

Global climate change requires measures for reduction of all anthropogenic sources, including those from aviation. Aircraft emit carbon dioxide ( $\text{CO}_2$ ) and nitrogen oxides ( $\text{NO}_x$ ) and therefore contributes to greenhouse gases (e.g. ozone). In contrast to  $\text{CO}_2$ , the climate impact of  $\text{NO}_x$  depends on the emission altitude and atmospheric conditions. In addition, aviation contributes to climate change by the formation of contrails and changes in cloudiness. Long-range traffic has a larger share than short-range traffic. Because air traffic growth rates of about 5% per year are twice as large as global economic growth rates, reductions of  $\text{CO}_2$  and  $\text{NO}_x$  according to the ACARE goals are of high priority. In contrast, contrails cannot be avoided by altering the air frame or engine technology.

Through a wide array of innovative measures, specific fuel consumption (per passenger seat and flown kilometre) has been significantly reduced. Regardless, global emissions continue to grow. Therefore, new directions are to be developed within the coming decades, enabling the reduction of aviation climate impact for given transport scenarios. In particular, the possibility of mitigating climate impact by changes in flight routing should be studied.

The scientific competence gained within the DLR-project "Particles and Cirrus Clouds" and related ongoing research creates "know-how" which enables policy makers and industry partners alike to make sound decisions. This supports the political will of the German government to efficiently limit the consequences of global change.

Weather and Flying: Weather contributes both directly and indirectly to accidents and delays. Vision 2020 sets ambitious goals for increased safety and punctuality in air transport, explicitly stating that these goals must be achieved in all weather conditions. But weather is not a technical problem that can be simply solved.

Predicting weather is by nature difficult and only possible within limits. It is therefore necessary to observe and forecast the changing state of the atmosphere as precisely and as rapidly as possible. This must be followed by a combination of measures for air traffic management and tactical manoeuvring, on the ground and in the aircraft, to minimise the impact of adverse weather conditions. With the DLR internal project "Weather and Flying", the foundations will be laid for increased efficiency in the air transport system.

Aircraft noise prediction: Air traffic is associated with various environmental nuisances, of which noise is the most serious according to the concerned residents near airports. In order to manage the growing air transport volume in an environmentally compatible way, reliable noise predictions and the minimisation of the noise burden are essential goals.

Increasing air traffic requires estimates of the expected impact on health and annoyance. Based on existing know-how, advanced prediction models will be developed which also include the effect of noise on humans. These models will enable the assessment of innovative mitigation measures: technological ones at the source, and operational ones during flight, the latter also as a function of weather.

The research provides the basis for new environmental protection measures and the development of low-noise technologies. It is performed in cooperation with external partners, and an active engagement in the respective national and international committees ensures an efficient transfer of the gained knowledge into the practice.

The research on aircraft noise takes advantage of synergies with the DLR program 'transportation' to promote sustainable development of all traffic modes.

### Communication, navigation and surveillance

Future ATM communications: Due to the continuing growth of air-traffic, current ATC/ATM communications systems are expected to reach their capacity limits before 2020. According to EUROCONTROL, this even holds with full VDL Mode 2 (VHF Digital Link Mode 2) deployment and full conversion of 25 kHz to 8.33 kHz DSB-AM channels for analogue voice communications. Thus, additional communications capacity must be provided to ensure the safety and efficiency of future air-traffic systems.

EUROCONTROL and FAA (Federal Aviation Administration) have correspondingly initiated the development of the Future Communications Infrastructure (FCI) within the framework of ICAO. The FCI is intended to cover the communications needs of all air-traffic partners, like airlines, airports, and ATM service providers.

The transition from analogue voice to digital data link communications is a challenge which not only implies a paradigm shift in ATM procedures but also requires the development of new high-performance data link technologies. These are necessary to make considerably increased communications capacity available as well as future applications to enable the integration of the aircraft into the concepts of SWIM and CDM.

Networking the sky: The FCI addresses both the development of new data link technologies and the design of networking concepts for integrating the different communications technologies into a single aeronautical communications network. This approach is in line with the DLR's vision of "Networking the Sky" which aims at integrating the aircraft as full node into the SWIM network, and thus ensures that all decision-makers have available consistent information which is a prerequisite for CDM. The aeronautical communications network of the future comprises a number of different links, including in particular Air/Ground (A/G), Air/Air (A/A), and satellite. Additionally, it integrates different applications, like ATC, ATM, AOC (Airline Operational Communication), and probably even passenger communications.

Both the development of future ATM communications technologies and the design of aeronautical networking concepts are well reflected within the SESAR work plan. Research in this area is already performed within the DLR Program Aeronautics, but shall be intensified in the future. The DLR aims at a key role in the definition of the concepts for a complementation and substitution of the current aeronautical systems.



Noise effects of air traffic

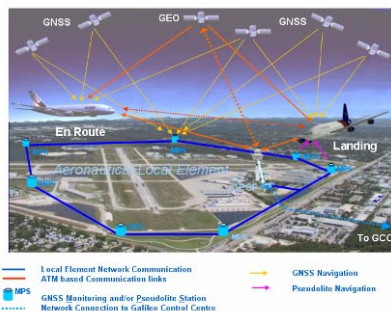


DLR vision „Networking the Sky“

Satellite-based navigation and surveillance: Joint situational awareness strongly depends on the reliable localization of the various aircraft, and must work under all weather conditions. Furthermore this must also be the case in situations that involve some levels of unintentional or intentional jamming. Finally, the capability to automatically process the data is important as well in order to ease the integration with automated control systems.

Ultimately, a combination of satellite and inertial navigation will lead to a replacement of today's Instrument Landing Systems (ILS). The advantages are significant, including the capability to maintain the landing rate under bad weather conditions or the possibility of more complex approach procedures, such as curved approaches. Furthermore, the costs of operating the system can be lowered by having one single installation per airport. The cost reduction also applies to the complete airports, since the clearance margins for buildings can be significantly reduced over those required by ILS. In order to address these potentials, the components of the communication and navigation systems have to be integrated into a unified CNS-System (Communication, Navigation, and Surveillance System).

Precision approach and landing under all weather conditions: The precision approach and landing under CAT III conditions is a special challenge. It requires the highest levels of integrity conceivable (the probability of some misleading information must be smaller than  $10^{-9}$  per approach). This is dictated by the fact that the pilot cannot intervene any more in order to correct any failures or misinterpretations of the system. Errors might be due to failures or to the statistical accumulation of many small errors originating from different sources. The latter must be analyzed statistically, which requires a characterization of all error sources. This characterization, partially derived from models, is generated locally or is provided through augmentation systems, e.g. Ground-Based Augmentation Systems (GBAS). Prediction of future statistics is needed to prevent any unexpected event in a critical flight phase. The fusion of satellite and inertial data is the best candidate for enabling the latter continuity.



Satellite-based navigation and CAT III landing

Adaptive antenna systems are a promising option for mitigating interference and multipath signals. Electronically steered antenna arrays are foreseen on the aircraft, and on the monitoring stations of the augmentation system. The integration of the antenna in the surface of the airplane in order to minimize the drag is another issue addressed in this context.

### Future air traffic management

In order to fulfil the expected capacity demands, ATM concepts need to be designed and validated that closely follow the international, and in particular European, air traffic developments within the framework of SESAR. Analyses show that further improvements which go beyond the concepts and developments of SESAR are necessary for fulfilling the ACARE goals. Within SESAR these improvements are partly tackled and will be elaborated through long-term ATM research also at the European level. The new conceptual approaches are based on a holistic view and evaluation that overcome the limitations of the individual components within the air traffic system and individual interests. Interdisciplinary research combining vehicle technologies and ATM technologies will be increasingly necessary.

As a result of the Single European Sky Initiative the European ATM research will be substantially funded via the SESAR Joint Undertaking (SESAR-JU). As a consequence of increasing competition with other research institutes and industry, the DLR and AT-One (the ATM-research alliance of the DLR and the NLR) have to improve its position by taking part in the SESAR-JU by contributing competitive research approaches and innovative ideas.

**Defragmentation:** Especially in Europe, a significant disadvantage of the current ATM system is the fragmented, nationally based infrastructure. This is characterised by low interoperability, limited data exchange and limited cooperative planning. The current concept is not flexible enough to fulfil the requirements of commercial airspace users. The defragmentation of the European ATM network would result in a significant increase in capacity. At the same time, cost savings and reduced emissions are expected while maintaining or even improving the current level of safety. In order to overcome fragmentation of the European ATM system, operational procedures as well as the institutional framework need to be changed.

**ATM master plan and concepts 2050:** In addition to the changes envisaged in current European research projects that focus on the introduction of these changes until 2020, the research establishments have to work on the next steps for further development of the air traffic system. The effects of technological developments on the planning and implementation of air traffic need to be investigated. Research issues include e.g. concepts for changing the way in which the aircraft is controlled (zero pilot cockpit) and new forms of air traffic management (such as a self-organising ATM). Other issues which affect the air traffic management of the future are, for instance, new propulsion systems, new energy sources and innovative types of air vehicles.

**Validation:** The development of far-reaching concepts puts special demands on the way in which they are investigated and evaluated. A decisive success factor here is the early assessment of the improvements as well as the feasibility and suitability of these concepts. The necessary reorganisation of air traffic control and management structures places significant demands on the validation infrastructures provided in Europe. New concept validation requirements arise from this, in particular the use of analytical tools and fast-time simulations. Overall, the development time should be accelerated by a more efficient validation strategy as well as validation procedures and facilities that can be applied more simply and efficiently. For this reason, high priority is being given to designing a harmonised European validation infrastructure.

Further development in the area of validation tools must be accompanied by investigations into validation methods that are necessary for ensuring the comparability of the evaluation results in an international context.

**Networking:** Emerging developments require highly networked validation facilities from both the DLR internally as well as externally with international partners (e.g. the NLR). Networking is a requirement which is driven by the necessity of having scalable validation systems, in order to investigate criteria for global or local solutions.



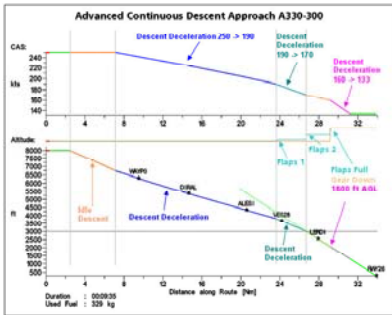
“Super ATM Simulator”

## Content and Goals

### Airport and airport vicinity

To meet the challenges expected from the increasing air traffic, improved cooperation will be necessary between all stakeholders. The systems for supporting the tactical, pre-tactical and strategic tasks must be capable of efficiently supporting the various planning tasks by quickly and precisely capturing the situation while using high performance air-ground communication networks.

The further automation of monitoring and control tasks is a key area of work to increase the performance of ATM, in particular at the airports and its vicinity. To achieve the positive economic effects associated with the high degree of automation, other effects should not be disregarded.



Speed and altitude profile of a CDA for an Airbus A330-300

**Time and performance based ATM:** At the DLR, concepts have already been developed for managing mixed air traffic i.e. aircraft equipped with 4D-FMS (4 dimensional flight management system) and data links in combination with conventional non-equipped aircraft. Based on this research, developments and experimental analyses are carried out in the internal project FAGI (Future Air Ground Integration) in order to fly aircraft as efficiently and environment-friendly as possible, without loss of capacity. User-preferred trajectories and continuous descent approaches (CDA) will result in fuel savings and will reduce pollution while maintaining a high level of capacity.

Transferring the responsibility for maintaining separation during certain flight phases to the pilot (Airborne Separation Assurance System – ASAS) can lead to a further significant reduction of ATM costs. With regard to the balance between the economic interests and minimising pollution, the adjustment or redevelopment of suitable low-noise and low-consumption approach and departure procedures achieves this target. This is accompanied by optimising the layout of the terminal area (TMA). The distribution of tasks between on-board and ground systems for ensuring separation during 4D-flight management needs to be defined and the capabilities of operators and systems must be enhanced.

The current method of coordinating departures, based on an airport's local planning and support system (Departure Manager - DMAN), may become a capacity-limiting factor. Assuming that in future local planning will be insufficient, "Departure Metering", the coordination of departures from neighbouring airports, can offer a solution. The objective is to enable a seamless transition from departure to en-route traffic without causing delays at airports sharing the airspace.

**Airport systems:** The development of concepts for remotely monitoring regional airports is an important issue for reducing costs. Future areas of research for remote airport operation include technical equipment with sensors and control devices, operational procedures and information management.

**Collaborative decision-making:** A cooperative air traffic management system also requires coordination at the airport between the stakeholders involved, as well as the air and ground information exchange. The necessary capturing of the entire process and subsequent evaluation is conducted in an interdisciplinary team. The objective is to overcome the information and process limitations. This will ensure the realisation of optimising concepts for a comprehensive airport management system together with the associated advantages. Concepts for CDM implementation at airports have been developed as part of the DLR internal project FAMOUS (Future Airport Management Operational Utility System) and in cooperation with EUROCONTROL. These concepts need to be further refined and then implemented.

**Total airport management:** Driven by the objective of reducing operational costs and improving punctuality, in cooperation with the EUROCONTROL Experimental Center the basis for an integrated airport management system (Total Airport Management – TAM) was defined. In this concept, the DLR developed a vision of an airport control centre (Airport Operations Control Centre - APOC) in which the stakeholders involved in the airport processes agree a jointly established goal while using supporting systems. In accordance with the agreed goal, the airport processes can be pre-tactically planned and then controlled. The key elements of this comprehensive concept have already been fed into the SESAR ATM master plan. A logical step for optimising the overall traffic system at the airport will also be the integration of the landside processes in the TAM concept.

**Optimisation of airport processes:** In parallel to the strategic and pre-tactical optimisation, tactical control and conflict solving must also be improved. This includes questions of vertical process coordination between air and ground units as well as horizontal process optimisation. On ground, this is carried out by mutually coordinated and inte-



Control centre simulator of DLR in Braunschweig



grated management systems (known under the acronym of X-MAN). With X-MAN technologies, operations will be optimised and tactical decision-making for selecting alternative actions will be supported. Examples of this include developments for linking arrival and departure management, support systems for using one runway in mixed-mode or an optimised taxi and ramp management system at the airport by developing advanced functions for managing surface traffic. The acknowledged expertise of the DLR in the field of A-SMGCS, for example as a result of the EU project EMMA (European Airport Movement Management by A-SMGCS) should be further developed at this high level. The DLR's leading European position in the field of A-SMGCS can thus be maintained and extended.

**System-wide information management:** SWIM forms the basis for a cooperative ATM which will be implemented at a European level in the future. The exchange of reliable information beyond the currently existing limitations is an important criterion for success. The provision of all necessary information to stakeholders involved in a suitable level of quality is achieved through integrating the current distributed data systems. In addition to the technical realisation of the control and management of ATM data via interoperable electronic interfaces, the main goal lies in eliminating the institutional obstacles of the parties involved, along with the operational and procedural implementation.

**UAS integration:** The integration of unmanned aerial vehicles (UAV) in civil airspace places special requirements on airspace organisation and the procedures that are used. Based on demonstrations and investigations carried out at the DLR, procedures need to be developed that allow a safe operation of UAS even after the connection to the ground station has been lost. The main focus lies on the partial or complete on-board autonomous performance of flight manoeuvres.

The on-board flight management systems of a UAS must be enhanced to sense the surrounding traffic and to generate and implement conflict-free management instructions based on this (keyword: "Sense and Avoid"). The procedures and responsibilities associated with a mixed operation of UAS and aircraft need to be developed and investigated in terms of their practical feasibility.

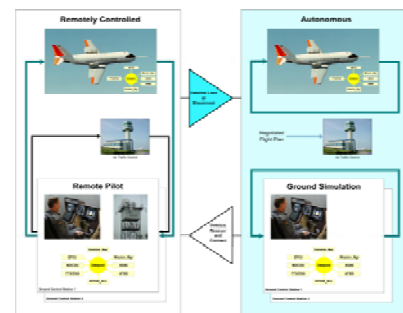
### Human factors and safety in aviation

Apart from the human operators (pilot, air traffic controller) in the air traffic system, studies also include passengers and the population affected by air traffic.

**Future requirements of aviation personnel:** In order to ensure that operators working in aviation fulfil the requirements in the increased air traffic of the future with even higher safety standards if possible, the envisaged requirements of pilots and air traffic controllers should be defined for the next two decades, in cooperation with the airlines and air traffic control organizations.

The internal DLR project "Aviator 2030" (running from 2007-2009) has been initiated for this purpose. This has already received attention from SESAR and is closely coordinated with the SESAR work schedule.

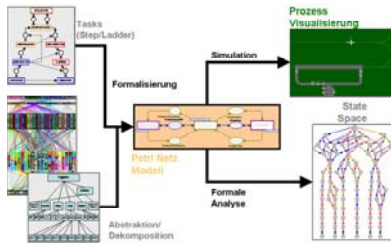
Apart from technical changes, one of the other factors to be considered is that the division of labour between pilots and air traffic controllers could differ in the future. As an exact prediction of future technologies may be partially speculative, various scenarios should be drawn up and examined for any changes in requirements. It will also be necessary to scrutinize the legal provisions in terms of duty and rest periods for aviation personnel.



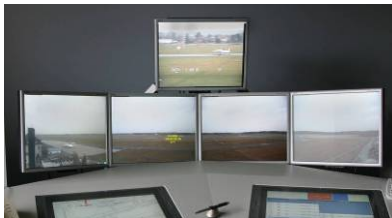
Demonstration platform for processes for integrating UAS in controlled airspace



A Pilot in the flight simulator when filling out questionnaires.



Work analyses of human operators.



Remote Tower Working Position:  
Panorama displays showing the entire airport. Integration of A-SMGCS information and video image of a landing DLR research aircraft.



Selection of future pilots and air traffic controllers

Human-centred automation: New technical equipment and improved operational measures are necessary to cope with the challenges in aviation. The role of the human operator always has to be taken into account here and the effects on the working conditions of the operators have to be determined by means of advanced methods of work analysis.

It is certain that the rising degree of automation and the increasing use of assistance and planning systems will make new kinds of human-machine interaction technologies necessary. Examples of this include virtual reality with working environments generated entirely synthetically as well as with enhanced (augmented) vision, i.e. enhancing natural vision by superimposing additional information.

Modelling and simulation of work systems and decision-making processes:

The need to model human decision-making and behavioural processes is present even in the initial development cycles of technical systems so that development of the systems takes account of user requirements. These user models can be employed in later phases of development, also in modified form as operator models in a validation environment. They considerably reduce the validation costs in human-in-the-loop experiments.

The aim is to develop these models and simulation procedures, to validate them independently and then integrate them meaningfully into a validation environment for advanced ATM work systems.

These studies, commenced in the internal DLR project "RapTOR" (Remote airport Tower Operation, 2006-2008) for an air traffic controller's workstation, are to be continued in a subsequent project. The very promising results from the internal DLR project "ADVISE-PRO" are to be further developed for the cockpit crew.

Single pilot cockpit: In the longer-term view, routine human operating functions will be further substituted by technical systems in air traffic management. More studies will be necessary for a future single-pilot cockpit and for integrating unmanned aircraft systems (UAS) in order to comply with standards of safety and efficiency.

Following the introduction of the two-person cockpit, a continued reduction of cockpit crew will mean flying passenger aircraft with a single-pilot cockpit. The logical consequence of this development will be aircraft operations entirely without a cockpit crew. To achieve this aim, it will be necessary to demonstrate what effects crew reduction will have, what assistance systems can take over the tasks of the crew and how the organization of air space and flight management will change. Which tasks can be performed when and where and with what equipment has yet to be conclusively clarified.

Development and validation of psychological selection methods: Performance and personality tests for selecting aviation personnel will have to be adapted to the changed requirements. One particular difficulty in personality diagnostics is to be seen in the decreasing age of applicants. In this connection it is necessary to develop procedures that allow reliable forecasts even for young applicants whose personality is still developing.

In the international context, test will have to be designed that are as neutral as possible in terms of language and culture. As the training of pilots will undergo considerable changes in the coming years (training for multi-crew pilot licence MPL, in compliance with ICAO standards), it will be interesting to see whether the validities of tests using the new training scheme will change.

In addition to feedback data from flying schools, the test systems should also be validated by criteria data from airlines and air traffic control organizations.

**Health protection:** Apart from the initial examination of pilots in the aero medical centre (AMC), long-term occupational health monitoring by regular follow-up examinations from specific aviation aspects is essential for the medical prognosis as well for the length of service and for retirement.

To protect the crew and passengers in the event of loss of cabin pressure, industry is carrying out further developments on oxygen supply systems, which will have to undergo testing for their physiological effects. Pressure chamber systems of the Institute of Aerospace Medicine will be employed for this purpose.

In order to protect those living near airports from the effects of nocturnal aircraft noise, without unnecessarily overestimating the risks, it is important to determine the relationship between short-term loss of sleep due to noise and long-term adverse effects on health and to obtain information on the influence of aircraft noise on the sleep of sensitive groups within the population. The relationships and possible cumulative effects between road, rail and aircraft noise will also be subject to an interdisciplinary investigation in conjunction with the "Traffic" program.

**Comfort in the aircraft cabin:** Preliminary studies on the subjective perception of passenger comfort have already been completed as part of the internal DLR project "CO-SICAB". These studies will now be continued in the follow-up project "CoSiCab+" (Comfortable and Silent Cabin, running from 2007-2009).

Standardized questionnaires and psychological tools are to be developed to quantify subjective passenger comfort. Refinement of ambulatory diagnostic techniques is also planned in order to make physiological parameters available for assessing comfort.

Subjective experiences of comfort including the physiological reactions are to be investigated experimentally in appropriate simulation facilities at the DLR and will allow forecasts to be made on future new developments and refinements for aircraft cabins. The resultant recommendations for manufacturers and operators are ultimately intended to increase the comfort experienced by passengers.

## Climate, weather and environment

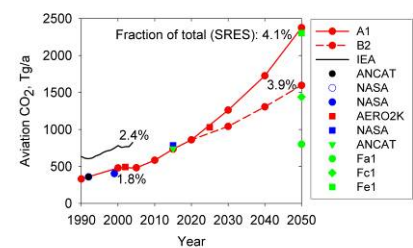
**Climate-optimized Air Traffic:** An important goal is to create a scientific basis for the sustainable development of global aviation and to identify and assess the corresponding technological options. This requires the climatic impact of the entire air transport system to be quantified for given emission scenarios.

To reach this interdisciplinary goal, the DLR-project „Climate-optimized Air Traffic“ (duration 2008-2011) will develop and assess such options for the air transport system for the first time. The focus will be on measures to reduce fuel consumption, but also on ozone production from NO<sub>x</sub> emissions and cloudiness triggered by contrails and soot particles. Among the strategies to be investigated will be whether the contrail climate impact can be mitigated by selecting higher or lower flight levels based on weather prediction, constrained by concomitant effects on ozone and climate via NO<sub>x</sub> emissions. Reducing such short-lived effects potentially reduces the climate impact of aviation more effectively than reducing long-lived CO<sub>2</sub> emissions. Measures that can be effective within about 10 years should be studied with high priority. Therefore, options involving the existing fleet and technology will be studied first. The climate impact of new aircraft and routing concepts are a subject of future studies.

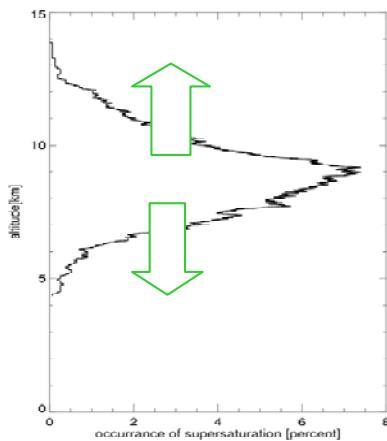
Options to reduce climate impacts will be developed and assessed using scientific criteria. For the first time, the determination of climate impacts will include technical and operational aspects of air frame and air traffic management. Ultimately, the potential of several options thought to be suited to reduce the aviation climate impact will



Oxygen supply systems: further development and tests



Past and future global emissions of carbon dioxide taken from different sources. The relative contribution from aviation increases from about 2% currently to a possible 4% in 50 years according to the most recent scenarios.



**Probability distribution of ice supersaturation as a function of altitude at a meteorological station near Berlin. The arrows indicate the changes in flight altitude required to avoid long-lived contrail cirrus.**

DLR aims at a concept that enables significant reductions of contrail occurrence with small altitude changes, depending on the actual humidity profile.



**Simultaneous measurement of the wake vortices of an A380 and A340 with a Lidar on board the Falcon research aircraft**

be assessed. Studies to bring the best options into practice and targeted investigations leading to reduced uncertainties will follow.

Simulations of air traffic scenarios and their climate impact are at the heart of these studies. New tools to analyze aircraft and their missions will be developed across the programmatic themes and their climatic consequences will be assessed. The assessment of options regarding flight management will initially be based on a conceptual level building on existing knowledge of aircraft and mission planning. Technology factors (e.g., the use of fibre-reinforced composites, alternative propulsion concepts and fuels, energy scenarios, ATM) will be considered in a simplified manner.

At the same time, existing uncertainties in assessing the climate effects of global air traffic or individual missions will be successively reduced with dedicated research. This effort will be based on the results of the DLR-project "Particles and Cirrus Clouds" (ending 2007). Innovative research will be carried out within the HGF alliance (e.g., the junior research group AEROTROP) and with international partners (e.g., the FAA in the USA and in the EU), mainly focussing on cirrus clouds and ozone chemistry. To this end, a combination of model simulations covering many spatial scales, airborne measurements with the DLR research aircraft FALCON and HALO and remote sensing will be employed.

The project integrates groups from 4 DLR institutes and further internal and external partners. With the project, the DLR will investigate the prerequisites for sustainable and environmentally friendly progress in aviation.

**Weather and Flying:** The combined talents of many partners will be required for the development of a new weather information system for airports, including appropriate ATM concepts of operation, while at the same time investigating and developing new sensors, automatic flight controls and adaptive aircraft technologies to minimise weather impacts. This effort builds on the results of the DLR internal project "Wake Vortex" (completed in early 2007), including a wake vortex warning system, sensor development, automatic flight controls, and adaptive wing technologies.

This interdisciplinary challenge will be addressed in the DLR internal project "Weather and Flying" (duration 2008-2011). The goals are  
(a) minimisation of the influence of weather on air traffic through the development of an Integrated Terminal Weather System (ITWS) for air traffic management at Frankfurt and Munich airports, with components for wake vortex, convection and winter weather, providing targeted, timely and customised weather information for the airport environment, and  
(b) the minimisation of the impact of wind gusts, wind shear and wake vortices upon aircraft, through analysis and specification of onboard sensors, development and testing of automatic flight control systems, and the design, evaluation and virtual testing of aircraft configurations.

An ITWS combines all available observations and forecast products in the airport region, merges them into appropriate products for ATM and cockpit, and relays the results in simplified form to controllers, pilots and operations managers. In this way it is assured that all stakeholders receive the same information as a basis for their decisions. An integral part of the project is the development of new Concepts of Operations for the use of the customised weather information. This will allow the prototype ITWS to be trialled at the two busiest airports in Germany (Frankfurt and Munich). Finally the complete tool-chain will be subjected to a technical and economic evaluation.

To support pilot decision-making, an integrated flight control system will be developed, to improve flight characteristics, and reduce loads on pilot, passengers and aircraft in extreme atmospheric motions (IRLIS – Integrated Ride and Loads Improvement System).



A precondition for this development is the deployment of novel forward-looking sensors. Passive measures in aircraft design will also be investigated to determine the extent to which they can contribute to an improved response to disturbances. IRLIS will also generate anticipatory tactical avoidance manoeuvres to enable the pilot to fly around atmospheric hazards.

The successful completion of this program requires the development and validation of precise mathematical models of the relevant physical properties and processes to enable realistic simulations. The techniques and systems developed in the project will be demonstrated in simulations and flight tests and evaluated by pilots. These techniques will also be subjected to a technological evaluation.

Seven DLR institutes will participate in "Weather and Flying". In addition, there will be close cooperation with external partners. The Deutsche Wetterdienst (German National Meteorological Service), together with Frankfurt and Munich airports and the Deutsche Flugsicherung (German air traffic control), will deploy new airport observing systems in a companion project. Other partners include, EADS-CRC, who will develop an airborne gust sensor, ONERA (for Lidar technology), and the NLR through AT-One.

**Aircraft noise prediction:** The quantification of the effects of noise and air pollution on humans and the climate is an interdisciplinary topic of the DLR. All aspects of aircraft noise will be investigated in the program 'aeronautics', while the emissions from other transport modes are dealt with in the program 'transportation'.

A quantification of the effects of aircraft noise requires the definition of appropriate assessment criteria (as part of impact research) and the provision of suitable tools for the prediction of perceived noise levels (as part of noise and emission modelling). The objective is to use these tools to control air traffic such that noise effects are minimised without impairing the economic conditions of airports.

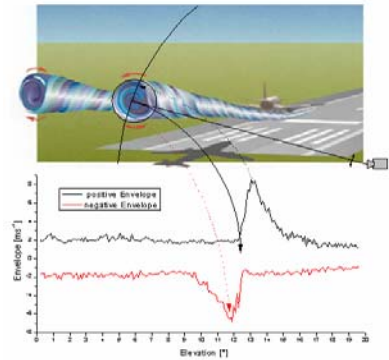
Without short-term measures the growth in air transport would inevitably lead to an increase of the noise burden. Therefore low-noise flight procedures will be optimised, including taking into account the local meteorological situation. These activities will be based upon the experience gained during the completed DLR projects 'Quiet air traffic' and 'Low-noise arrival and departure procedures'.

Reliable modelling and forecasting of aircraft noise require a solid data base of sufficient quality. However, existing data suffer from major deficiencies which must be overcome in cooperation with air transport operators. The work will be embedded in national and international projects. Proposals for EU and LUFO projects aim at noise measurements and the improvement of prediction tools in cooperation with EMPA (Switzerland) and Deutsche Lufthansa (Germany)

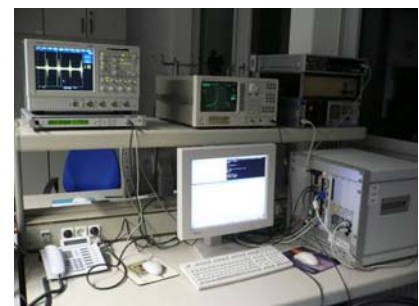
### Communication, navigation and surveillance

**Future ATM communications:** The development of future aeronautical data links comprises A/G communications between controllers and pilots both en-route and within the airport area, satellite links, and direct A/A communications between aircraft. These tasks are performed within the FCI activities of ICAO and are aligned with SESAR.

Within the FCI activities, the data link concepts B-VHF (Broadband VHF) and B-AMC (Broadband Aeronautical Multi-Carrier Communications System), which have been developed in EU and EUROCONTROL co-funded projects with essential DLR contributions, have been assessed and selected by EUROCONTROL and FAA as promising candidate technologies for future ATM communications. Based on these concepts, a high-performance data link will be designed which fulfills the requirements for current and future aeronautical services. The resulting improved aircraft-ground integration will

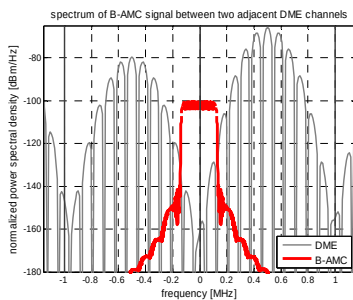


Depiction of the wake vortices, together with Lidar measurements of the maximum vortex wind speed, behind a landing aircraft at Frankfurt airport



Data link demonstrator in DSP-technology





**B-AMC – a future ATM data link deployed as inlay system in L-band. Advanced communications technology ensures coexistence between B-AMC and existing L-band navigation systems, like DME (Distance Measuring Equipment).**



**GBAS-station in Braunschweig.**

enable the aircraft to participate in the future ATM concepts SWIM and CDM. The final goal of this activity is to implement the concept developed in a data link demonstrator and to initiate standardization.

Based on the standard IEEE 802.16e (WiMAX, Worldwide Interoperability for Wireless Access) a data link for the airport surface will be developed as part of the FCI as proposed by EUROCONTROL and FAA. Moreover, a concept for direct A/A communications will be designed based on aeronautical ad-hoc networks.

Satellites are gaining importance for aeronautical communications and are considered an essential component within the FCI. Satellites are of especially high value for the provision of ATM services in remote or oceanic areas and for establishing redundancy. Therefore, data link technologies for ATM over satellite will be designed and concepts for the integration of satellites into the FCI developed.

For both satellite and direct A/A communications, antennas which are capable to form and steer several beams simultaneously are of high interest. These intelligent antennas will be developed and adjusted to aeronautical needs.

Networking the sky: Besides the development of future ATM communications technologies the realization of the DLR's "Networking the Sky" vision is another important goal within the framework of the FCI design. To achieve this goal the necessary IP (Internet Protocol) based networking concepts will be developed taking into account the special requirements, like security, reliability, and high mobility, imposed by aeronautical applications.

The proof of concept for this approach will be performed using theoretical investigations, computer simulations, and demonstrations. These tasks have been conducted within the EU project NEWSKY (Networking the SKY) since February 2007, where the DLR acts as consortium leader.

In parallel to these activities, an aeronautical communications network simulation tool will be developed and implemented within the DLR internal project FACTS (Future Aeronautical Communications Traffic Simulator) which started in 2007 and will continue until 2009. FACTS enables the investigation and optimization of both future ATM communications technologies and networking concepts and, thus, is a very useful complement to the research work performed in aeronautical communications.

Satellite-based navigation and surveillance: Curved approaches, optimized descent profiles, late merging of lateral flight paths, and tighter aircraft separations provide additional degrees of freedom for optimizing noise emissions and airport utilization. The DLR is contributing to the definition of the navigation means that will enable such flight patterns during final approach and ultimately landing, as well as to the guidance of airplanes on the ground. They strongly depend on satellite navigation signals.

With the signals currently available and the techniques developed so far, the levels of integrity required can only be met using GBAS. The developments for CAT-I landing are very well advanced. Minor support is still needed to complete this task. A solid assessment of traveling ionospheric disturbances for Europe will address one of the major threats. Furthermore, experience will be gained in developing the GBAS procedures for CAT II/III through initial lab and flight experiments. This will be done in the context of the internal projects FACTS and FAGI.

The ultimate goal is to support CAT-I operations without ground infrastructure. The additional satellites provided by the Galileo constellation, the greater diversity of signals in the aeronautical navigation bands, and new concepts for receiver autonomous integrity monitoring (RAIM) suggest that this might become possible. The use of several signals allows mitigation of some of the ionospheric impact. The new concept of

relative RAIM promises short alert limits with low missed detection and false alarm probabilities. The augmentation data needed in this concept could be distributed from satellites (e.g. Galileo). This development is just starting.

The new aeronautical signals are unfortunately in a band shared with distance measurement equipments (DME). This requires that appropriate mitigation techniques be developed. One focus is on pure time and frequency methods, basically blanking out affected portions of the time-frequency domain. Other sources of interference will also be addressed in the time and frequency domain. Their impact will be reduced by increasing the dynamics of the receiver and stabilizing the various loops that control the gain, the frequency or the code delay.

Spatial interference suppression techniques will also be developed. They will be realized by adaptive antennas that can be integrated in the surface of aircraft. These systems will be capable of suppressing the interference from arbitrary sources both unintentional and intentional. They typically aim at directing nulls in the beam pattern towards the interferer. Contributions to this are being developed in a number of projects including the EU-Project ANASTASIA (Airborne Communication and Navigation Satellite Technologies and Techniques in a System Integrated Approach).

Precision approach and landing under all weather conditions: Automatic landing under CAT III conditions is clearly the most demanding scenario that can be considered. There is no possibility for any human intervention to mitigate errors or misinterpretations. Fortunately, satellite and inertial navigation complement each other in an ideal manner. The latter cannot be jammed and the former can be made very accurate. The DLR is developing an architecture for integrating the satellite signals, augmentation data, and inertial measurements that will achieve the necessary level of reliability. In parallel, the DLR is developing the algorithms for generating accurate and reliable position information from the satellite signals. In an initial phase they will rely on all Galileo signals in the aeronautical bands. In a second phase the robustness with respect to DME interference will be considered. Next the integration aspects with inertial will be addressed and finally, reduced sets of signals, like L1/L5 GPS, will be considered. Failure modes will be considered throughout the work. The focus at the DLR will be somewhat biased towards extreme ionospheric events. Some of this work has started in projects such as the LuFo IV Project LINA (Local Integrity & Navigation Augmentation).

### Future air traffic management

Within the evaluation period, tools and methods will be developed which allow a consideration of the air transportation system as a whole as well as technology assessment with the main focus on air traffic management. This includes technologies and procedures to increase the capacity not only en-route and in the vicinity of airports but also at the airport itself. The methods associated with technology assessment are to be extended from the established technical and economic evaluation, taking ecological quality offered by new technologies and procedures into account.

The expertise of the DLR in the areas of simulation and validation is based on the successful accomplishment of numerous national and international "Human in the Loop" experiments (e.g. RapTOR; OPTIMAL – Innovative Procedures for Approach and Landing Phases; IFATS – Innovative Future Air Transport System).

Especially cargo airlines demand increasing automation of air transportation with the objective of improving capacity and efficiency. Increasing automation requires development and validation of reliable emergency procedures. Such procedures and systems need to be able to compensate temporary failures in data link systems. In addition they have to be capable of generating collision-free 4D-emergency trajectories. Those ad-



Electronically steerable antenna array for satellite navigation or communication.

vanced systems supporting the flight crew and taking visual flight rules into account will increase flight safety to a considerable degree. To achieve this, research projects will have the task of developing suitable procedures and sensors over the next few years.

For this field of research, DLR institutes have already joined forces with external key partners in Germany, including DFS, FGAN, EADS, Airbus, Diehl and several universities, to develop this segment in the scope of national aviation research. The aim of this research is to develop globally applicable concepts which can be implemented regionally. Thus, cooperation at the European level is being intensified, in particular through the research alliance of AT-One with the NLR, driving forward further research networks.

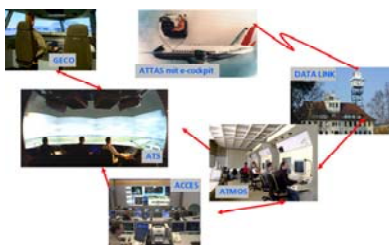
**Defragmentation:** The institutional fragmentation of the air traffic system needs to be eliminated. An accompanying measure will be the consolidation of operational rules between stakeholders. Today, air traffic is mainly handled according to the outdated principle of "first come, first served". Procedures to overcome these rigid requirements need to be developed based on existing approaches to solutions. This includes prioritising flights according to the quality criterion of punctuality. Flights meeting the agreed 4-D-flight path will be given priority over flights not arriving on time at a particular checkpoint.

**ATM master plan and concepts 2050:** Various concepts will be developed based on the aforementioned requirements over the next few years and analysed in terms of their effects on global and local air traffic systems. The research focuses on the aspects of air traffic management concentrating on new guidance procedures of individual aircraft and on innovative holistic approaches for managing air traffic. The aim of this work is to increase the degree of automation for efficient air traffic management.

**ATM validation:** The holistic approach concepts and the increasing complexity of the ATM systems demand a suitable validation infrastructure. Due to reasons of cost and acceptance this should be harmonised at European level. In anticipation of future challenges, AT-One has already started the harmonisation of simulation facilities and systems between the DLR and the NLR in the area of ATM. The successful cooperation within AT-One will be continued in this spirit.

The increasing necessity of incorporating simulators at an early stage of development is one of the main requirements for a modern validation strategy and can be addressed by the DLR. A scalable and highly linked validation infrastructure will form the framework for verifying and validating the DLR's own prototypes, such as What-If probing tools in addition to product-based solutions before industrialisation.

**Super ATM simulator:** AT-One enables the further development of simulation facilities, their databases and scenarios as well as their connection and the provision of a "Super ATM simulator" which includes new development and validation dimensions. Shared databases and scenarios reduce the maintenance expenditure and reaction times of the involved facilities and increase the economic viability of the simulation experiments. The integration of intelligently automated simulation components, to be used as an alternative to human-in-the-loop modules, is a more efficient solution for sub-areas of the linked simulation environment. In addition to real-time functionality, accelerated run times ("Faster-time Simulation") will be required in the pre-tactical planning environment, to then be incorporated into new developments. The linked and scalable simulation facilities will become a unique selling proposition for the DLR and AT-One associated with a good reputation and scientific attractiveness, both in Germany and abroad.



Simulation network comprised of research aircraft, cockpit simulators, tower simulator, ATC simulator and control centre simulator

Operational test environments: Extension of existing field and flight test environments are the logical consequence and accompanying measure for further development of simulation facilities. In combination with industry partners, it will be possible to evaluate product-based prototypes under real-life conditions, for example an Advanced Flight Management System or the development and design of new types of flight guidance displays in conjunction with ground based monitoring and guidance systems. The implementation and expansion of the A-SMGCS and GBAS at the Braunschweig Research Airport is a further target in addition to the suitable equipping of the DLR's research aircraft ATRA (Airbus A320).

The collaboration with Hamburg airport as a test platform and operational partner for testing A-SMGCS and apron control systems will be intensified. Available systems will be technically coordinated in order to use them for the general ATM concept development and evaluation (e.g. of the "Future European Communication Network").

Validation methodology: To support the technological developments, further work is being conducted on developing the validation methodology for the changing ATM environment (TAM, SESAR) and on harmonisation in the international context. The work is being carried out on a European level (European Operational Concept Validation Methodology – E-OCVM) as well as in a transatlantic alliance by means of the EUROCONTROL-FAA Cooperation (Action Plan 5) to create an "Operational Concept Validation Strategy Document" as an accepted worldwide standard.

Integrated assessment of future air transport systems: The holistic improvement of the air transport system in terms of economic, technological and ecological considerations requires the assessment of vehicle and ATM technologies in a joint context due to many interactions. For this purpose, suitable integrated validation environments consisting of ATM and system simulations as well as technology assessment methods need to be developed that enable a comprehensive evaluation of new ATM concepts and new system technologies. This is being conducted as part of interdisciplinary projects encompassing various program topics.

## Expected Results and Milestones

| Year | Milestone                                                                                                                                                                                                                                                                                                                            |
|------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2009 | Development of prototypes for planning and monitoring systems for managing airport processes. Integration of the Total Airport Planner (TOP), TOP clients and airside support systems in the FAMOUS system.                                                                                                                          |
| 2010 | Definition of future requirements of pilots and air traffic controllers available.                                                                                                                                                                                                                                                   |
| 2010 | Development of an IP-based networking concept for aeronautical communications ("Networking the Sky").                                                                                                                                                                                                                                |
| 2011 | Proof of the benefit of a Remote Tower Operations Centre and the completion of a prototype environment for remote-monitoring of smaller airports.                                                                                                                                                                                    |
| 2011 | First investigations finished on dose-response relationships of physical environmental parameters on comfort, performance, strain, and health in aircraft cabin.                                                                                                                                                                     |
| 2012 | Proof of the benefit of low-noise approach and departure procedures (e.g. CDA) and their utilisation under various weather conditions within a high traffic density environment at international airports.                                                                                                                           |
| 2012 | Demonstration of GBAS-based landings of CAT III and of a navigation receiving system employing digital beam forming for the suppression of interferers.                                                                                                                                                                              |
| 2012 | Validation and quantification of the benefit of vertical and horizontal cooperation through linking arrival management systems with modern on-board flight management systems and the use of the 4D trajectory as well as the proof of significant reduction of queues and increase of the throughput for approaches and departures. |
| 2013 | ITWS handover to DWD und airports, and climate parameters with the greatest potential for reduction identified.                                                                                                                                                                                                                      |
| 2013 | Setup of a unique test and demonstration system using high performance CNS systems at the Braunschweig Research Airport for validating new approach and departure procedures, taxiing procedures and airport process management.                                                                                                     |



## Planned Resources

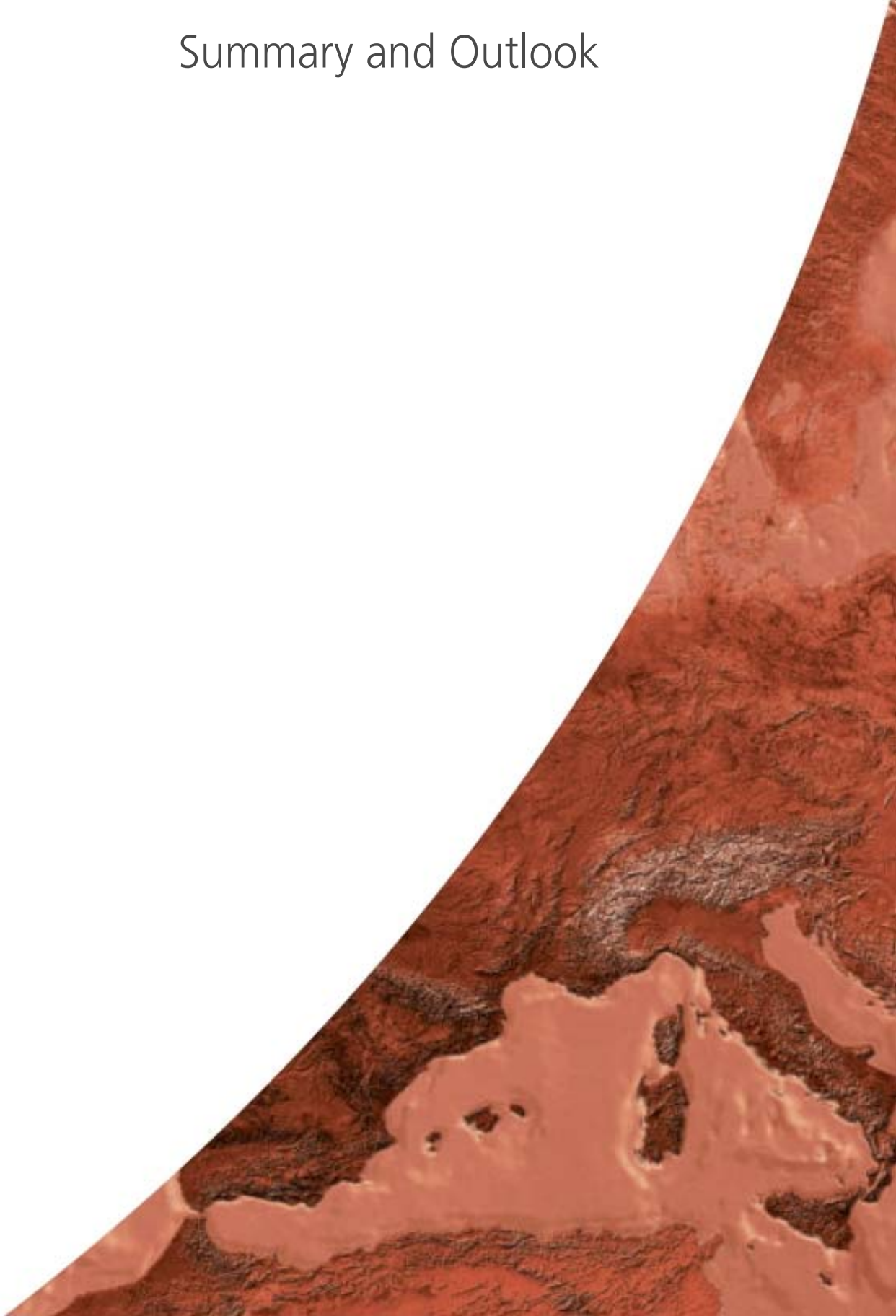
### Planned resources for the program topic ATM and Operation

|                                      | 2009   | 2010   | 2011   | 2012   | 2013   |
|--------------------------------------|--------|--------|--------|--------|--------|
| Helmholtz Institutional Funding (T€) | 20,425 | 20,425 | 20,425 | 20,425 | 20,425 |
| Human Resources (FTE)                | 146    | 142    | 137    | 133    | 129    |

Detailed information on resources in the Annex



## Summary and Outlook



## Summary and Outlook



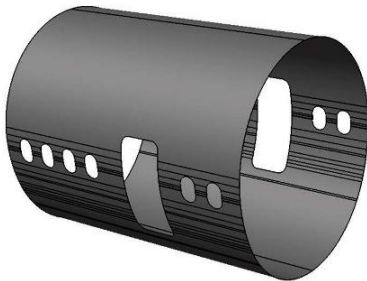
Helicopter UAV ARTIS of DLR

The mid term program presented here represents the status of planning as of the year 2007. In the course of the years to come, individual tasks may change or additional research subjects may have to be added, if new requirements become apparent. Likewise, already in the previous planning period the research area of cabin system technologies was subsequently included. The reason for this was an increasing demand for activities in this field, which is of particular importance for the industry in Germany. Similarly, must preserve its flexibility to react on new chances emerging from scientific and technical advances.

At the same time, it is in DLR's interest to consistently stick to longer term efforts on research subjects regarded promising for the future, even if a direct industrial relevance or a reasonable maturity of the achievements is not yet foreseeable.

All this must include research in areas of application not belonging to actual work shares of the industry in Germany. As the national research establishment in aeronautics, DLR must maintain and further develop its system competence as a central partner of industries and political institutions, but also with the objective to support job training for technical and scientific staff in a reasonably broad scheme

The total amount of activities planned is adapted to the foreseeable frame of resources available. As briefly sketched in the section on program prospects, for nearly all of the major research fields, important subjects can be identified, which cannot or only insufficiently be addressed in this program. As hitherto, DLR is prepared to make use of additional resources from other programs as far as possible. Of course, only specific project funding or start-up financing for certain new initiatives can be expected in such cases. The problem of securing the respective activities for a longer term, poses practical limitations to any such options.

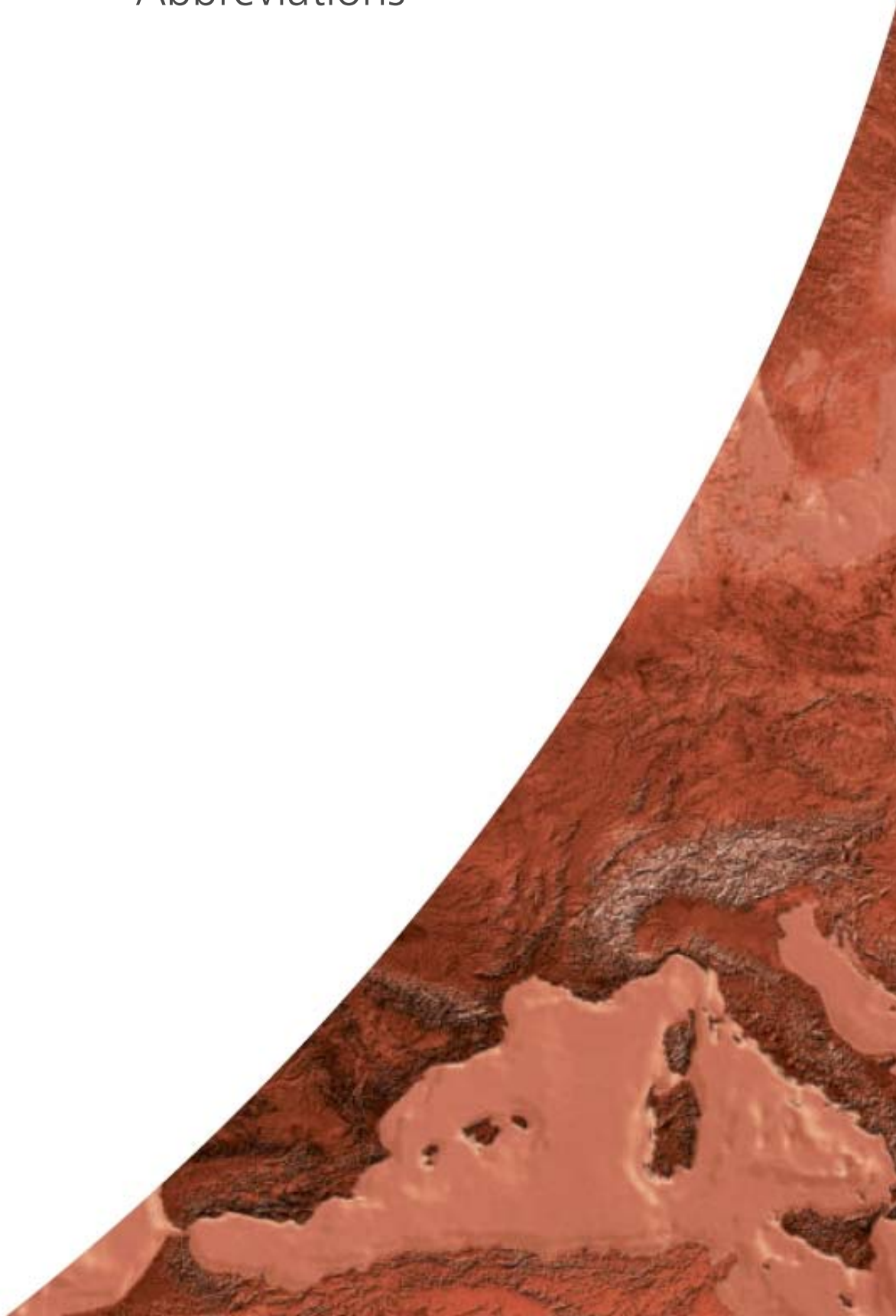


CFRP fuselage barrel,  
design for a planned 1:2 scale functional  
model

At this point, the issue of production techniques for composite structures should be addressed once more. Both Boeing and Airbus currently plan to rely on "black structures" to a dramatically higher degree in the near future. As a result, access to respective production capacities (internal or external) and related costs will become decisive competitive factors. For potential suppliers, the ability to deliver CFRP components in sufficient quantities and at competitive prices will be crucial, as competition will more and more take place in a world wide scope. Accordingly, availability of new, highly automated production techniques for composite structures will be of superior importance.

DLR is ready to address respective issues in the frame of a new research field. However, this cannot be achieved in an adequate way just by reallocating funds. Therefore, all possible means of additional funding are currently scanned.

## Abbreviations





## Abbreviations

|                                                 |                                                                       |
|-------------------------------------------------|-----------------------------------------------------------------------|
| <b>4D-FMS</b>                                   | 4 Dimension Flight Management System                                  |
| <b>ACARE</b>                                    | Advisory Council for Aeronautic Research in Europe                    |
| <b>ADYN</b>                                     | EU Project: Advanced European Tilt Rotor Dynamics and Noise           |
| <b>AI</b>                                       | Aluminum                                                              |
| <b>AMAN</b>                                     | Arrival Manager                                                       |
| <b>AMC</b>                                      | Aero Medical Center                                                   |
| <b>AOC</b>                                      | Airline Operational Communication                                     |
| <b>APOC</b>                                     | Airport Operations Control Center                                     |
| <b>APSIM</b>                                    | Aeroacoustic Prediction and Simulation Tool                           |
| <b>ASAS</b>                                     | Airborne Separation Assurance System                                  |
| <b>A-SMGCS</b>                                  | Advanced Surface Movement Guidance and Control System                 |
| <b>ATA</b>                                      | Aerotesting Alliance                                                  |
| <b>ATC</b>                                      | Air Traffic Control                                                   |
| <b>ATM</b>                                      | Air Traffic Management                                                |
| <b>ATRA</b>                                     | Advanced Technology Research Aircraft                                 |
| <b>ATTAS</b>                                    | Advanced Technologies Transport Aircraft System                       |
| <b>BMBF</b>                                     | German Federal Ministry for Education and Research                    |
| <b>BMWi</b>                                     | German Federal Ministry for Economy                                   |
| <b>BMVg</b>                                     | German Federal Ministry for Defence                                   |
| <b>BOS</b>                                      | Background Oriented Schlieren Method                                  |
| <b>BPR</b>                                      | Bypass Ratio                                                          |
| <b>CAA</b>                                      | Computational Aero-Acoustics                                          |
| <b>CAD</b>                                      | Computer Aided Design                                                 |
| <b>CAP</b>                                      | Co-ordinated Action Programs                                          |
| <b>CARS</b>                                     | Coherent Anti-Stokes Raman Spectroscopy                               |
| <b>C<sup>2</sup>A<sup>2</sup>S<sup>2</sup>E</b> | Center for Computer Applications in AeroSpace Science and Engineering |
| <b>CDA</b>                                      | Continuous Descent Approach                                           |
| <b>CDM</b>                                      | Collaborative Decision Making                                         |
| <b>CFD</b>                                      | Computational Fluid Dynamics                                          |
| <b>CFRP</b>                                     | Carbon Fiber Reinforced Plastic                                       |
| <b>CHANCE</b>                                   | Complete Helicopter Advanced Computational Environment                |
| <b>CIRA</b>                                     | Italian Aerospace Research Centre                                     |
| <b>CNS-System</b>                               | Communication, Navigation, and Surveillance System                    |

|                    |                                                                                                         |
|--------------------|---------------------------------------------------------------------------------------------------------|
| <b>CoE</b>         | Center of Excellence                                                                                    |
| <b>COMOTI</b>      | Romanian Research and Development Institute for Gas Turbines                                            |
| <b>CPU</b>         | Central Processing Unit                                                                                 |
| <b>DES</b>         | Detached-Eddy Simulation                                                                                |
| <b>DFG</b>         | Deutsche Forschungsgemeinschaft (German Research Foundation)                                            |
| <b>DFS</b>         | Deutsche Flugsicherung (German Air Traffic Control)                                                     |
| <b>Digital-X</b>   | Virtual digital experimental aircraft                                                                   |
| <b>DMAN</b>        | Departure Manager                                                                                       |
| <b>DNW</b>         | Duits-Nederlandse Windtunnel / German Dutch Wind Tunnel                                                 |
| <b>DWD</b>         | Deutscher Wetterdienst (Germany's National Meteorological Service)                                      |
| <b>EMS</b>         | Emergency Medical Service                                                                               |
| <b>EnMAP</b>       | Environmental Mapping and Analysis Program                                                              |
| <b>EOS</b>         | Earth Observation System                                                                                |
| <b>EREA</b>        | Association of European Research Establishment in Aeronautics                                           |
| <b>ESA</b>         | European Space Agency                                                                                   |
| <b>ETW</b>         | European Transonic Wind Tunnel                                                                          |
| <b>EU</b>          | European Union                                                                                          |
| <b>FAA</b>         | Federal Aviation Administration                                                                         |
| <b>FCI</b>         | Future Communications Infrastructure                                                                    |
| <b>FE</b>          | Finite Element                                                                                          |
| <b>FEM</b>         | Finite Element Method                                                                                   |
| <b>FHS</b>         | Flying Helicopter Simulator                                                                             |
| <b>FOI</b>         | Swedish Defence Research Agency                                                                         |
| <b>GBAS</b>        | Ground Based Augmentation System                                                                        |
| <b>GNSS</b>        | Global Navigation Satellite System                                                                      |
| <b>GOAHEAD</b>     | EU Project: Generation of Advanced Helicopter Experimental Aerodynamic Database for CFD code validation |
| <b>HALO</b>        | High Altitude and Long Range Research Aircraft                                                          |
| <b>HBK</b>         | High pressure combustion chamber test stand                                                             |
| <b>HDG</b>         | High pressure wind tunnel Göttingen (DNW)                                                               |
| <b>HELINOVI</b>    | EU Project: Helicopter Noise and Vibration                                                              |
| <b>Helisafe TA</b> | EU Project: Helicopter Occupant Safety Technology Applications                                          |

## Abbreviations

|                |                                                                               |
|----------------|-------------------------------------------------------------------------------|
| <b>HGF</b>     | Helmholtz-Gemeinschaft (Helmholtz Association)                                |
| <b>HLF</b>     | Hybrid Laminar Flow                                                           |
| <b>HMI</b>     | Human Machine Interface                                                       |
| <b>HPC</b>     | High-Performance Computing                                                    |
| <b>HTH</b>     | Heavy Transport Helicopter                                                    |
| <b>HVI</b>     | High Velocity Impact                                                          |
| <b>ICAO</b>    | International Civil Aviation Organization                                     |
| <b>ILS</b>     | Instrument Landing System                                                     |
| <b>INTA</b>    | Spanish National Institute for Aerospace Technology                           |
| <b>IPCT</b>    | Image Pattern Correlation Technique                                           |
| <b>IRLIS</b>   | Integrated Ride and Loads Improvement System                                  |
| <b>IT</b>      | Information Technology                                                        |
| <b>ITWS</b>    | Integrated Terminal Weather System                                            |
| <b>JAR-FCL</b> | Joint Aviation Requirement – Flight Crew Licensing                            |
| <b>JTI</b>     | Joint Technology Initiative                                                   |
| <b>LDA</b>     | Laser Doppler Anemometry                                                      |
| <b>LIDAR</b>   | Light Detection and Ranging                                                   |
| <b>LIF</b>     | Laser-Induced Fluorescence                                                    |
| <b>LII</b>     | Laser-Induced Incandescence                                                   |
| <b>LuFo</b>    | Luftfahrtforschungsprogramm (German's National Aeronautical Research Program) |
| <b>MAT</b>     | Microphone Array Technique                                                    |
| <b>MDO</b>     | Multidisciplinary Optimisation                                                |
| <b>MPG</b>     | Max-Planck-Gesellschaft (Max Planck Society)                                  |
| <b>NLF</b>     | Natural Laminar Flow                                                          |
| <b>NLR</b>     | National Aerospace Laboratory of the Netherlands                              |
| <b>ONERA</b>   | Office National d'Études et de Recherches Aéronautiques                       |
| <b>QSTOL</b>   | Quiet Short Take Off and Landing                                              |
| <b>PAZI</b>    | DLR-Projekt: Partikel und Zirren (particles and cirrus clouds)                |
| <b>PIANO</b>   | Perturbation Investigation of Aerodynamic NOise                               |
| <b>PIV</b>     | Particle Image Velocimetry                                                    |
| <b>PSP</b>     | Pressure Sensitive Paint                                                      |
| <b>RANS</b>    | Reynolds Averaged Navier-Stokes Equations                                     |
| <b>R&amp;D</b> | Research and Development                                                      |
| <b>RPM</b>     | Random Particle Method                                                        |

|                 |                                                                      |
|-----------------|----------------------------------------------------------------------|
| <b>SAR</b>      | Search and Rescue                                                    |
| <b>SESAR</b>    | Single European Sky ATM Research                                     |
| <b>SHADOW</b>   | Ray tracing solver for acoustics                                     |
| <b>SHM</b>      | Structural Health Monitoring                                         |
| <b>SMPS</b>     | Scanning Mobility Particle Sizing                                    |
| <b>SNECMA</b>   | Société Nationale d'Etudes et de Constructions de Moteurs d'Aviation |
| <b>SPRAYSIM</b> | DLR numerical tool for spray combustion simulation                   |
| <b>SRA2</b>     | Strategic Research Agenda 2                                          |
| <b>SWIM</b>     | System Wide Information Management                                   |
| <b>TAU</b>      | Triangular Adaptive Upwind Scheme                                    |
| <b>TED</b>      | Trailing Edge Device                                                 |
| <b>THETA</b>    | Thermal Heat Release Extension of TAU                                |
| <b>Ti</b>       | Titanium                                                             |
| <b>TILTAERO</b> | EU Project: Tilt Rotor Interactional Aerodynamics                    |
| <b>TIVA</b>     | DLR Project: Technology Integration for Virtual Aircraft             |
| <b>TMA</b>      | Terminal Control Area                                                |
| <b>TRACE</b>    | DLR-3D-CFD Navier-Stokes solver                                      |
| <b>TSP</b>      | Temperature Sensitive Paint                                          |
| <b>UAS</b>      | Unmanned Aircraft Systems                                            |
| <b>UAV</b>      | Unmanned Aerial Vehicle                                              |
| <b>UPM</b>      | Unsteady Panel Method                                                |
| <b>WHIPOX</b>   | Wound Highly Porous Oxide Composite                                  |





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## DLR at a Glance

DLR is Germany's national research center for aeronautics and space. Its extensive research and development work in Aeronautics, Space, Transportation and Energy is integrated into national and international cooperative ventures. As Germany's space agency, DLR has been given responsibility for the forward planning and the implementation of the German space program by the German federal government as well as for the international representation of German interests. Furthermore, Germany's largest project-management agency is also part of DLR.

Approximately 5,300 people are employed in DLR's 28 institutes and facilities at eight locations in Germany: Koeln-Porz (headquarters), Berlin-Adlershof, Bonn-Oberkassel, Braunschweig, Goettingen, Lampoldshausen, Oberpfaffenhofen, and Stuttgart. DLR also operates offices in Brussels, Paris, and Washington, D.C.

DLR's mission comprises the exploration of the Earth and the Solar System, research for protecting the environment, for environmentally-compatible technologies, and for promoting mobility, communication, and security. DLR's research portfolio ranges from basic research to innovative applications and products of tomorrow. In that way DLR contributes the scientific and technical know-how that it has gained to enhancing Germany's industrial and technological reputation. DLR operates large-scale research facilities for DLR's own projects and as a service provider for its clients and partners. It also promotes the next generation of scientists, provides competent advisory services to government, and is a driving force in the local regions of its field centers.



DLR

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