Aircraft, unmanned vehicles and giant wings

Increasing commercial air traffic and ever sophisticated aircraft mean that aeronautics is the subject of intense research today. The impact of these trends on the Earth's environment also needs to be assessed.

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Air traffic is increasing around the world and is forecast to reach more than 8 billion hours per year in 2020. Beside developments in traditional aeronautics, it is also anticipated that the number of vehicles, from very small drones to much larger aeroplanes will increase too. What impact could this proliferation have on the environment? And how could it be possible to make these activities compatible with the growing need to protect the environment and human health?

Norms

Various authorities have tackled this problem and many organizations have produced recommendations and established stricter norms. ACARE (Advisory Council for Aeronautics in Europe) directives on pollutant or noise emissions are mandatory for manufacturers and for aeronautic companies. They are based on norms from the European directive REACH on chemical substances management. Industry has long established plans for the development of future vehicles and CORAC, the French industrial thinking group, proposes guidelines for the coming years(1).

Applied Research

In France, Onera is the main actor in aerospace research and its four branches and 16 scientific departments show how diverse the domains are it covers. These touch on physics, fluid mechanics, materials and structures as well as information and systems management. Scientific challenges involved are addressed in specific research with applications closely linked to those of leaders in the industry and in collaboration with many universities. Many problems are still far from being understood and one of Onera's major roles is to ensure transfer between leading theoretical academic research and industry covering all areas and levels (that is, from theoretical concepts to product and commercialization).

A worldwide centre

Aerospace Valley(2) whose domain extends over both the Midi-Pyrénées and Aquitaine regions is recognized as a worldwide centre for aeronautics, space and embedded systems. The pole is dedicated to innovative industry and training and it supports projects promoting new technology for applications in this sector. Since 2007 a new platform has been created: the thematic network "RTRA STAE" (Thematic Network for Advanced Research in Aerospace Sciences and Technology). That aims to facilitate fundamental research in this domain(3). This network is composed of 27 laboratories in three different sectors: Engineering Sciences, Science and Technology of Information and Communication, and Life, Earth and Planetary Sciences. An important collaboration took place in the framework of this structure and has led to improved knowledge in the field. This was made concrete by setting up 16 multi-disciplinary research projects.

In this group of articles we present some research domains in which the Toulouse laboratories excel and the work being carried here will help to address future aeronautic challenges.

Aircraft design

Among the numerous challenges recognized, some are directly linked to the design of new aircraft. This involves realizing a high fidelity simulation of structures and flows in order to reduce design delays and to refine strategic choices. Improving aerodynamic or aero-acoustical performance aims to use interactive

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methods based upon either continuous deformation of wings and fuselage or upon coupled actuators and sensors for active control. Optimizing the operating conditions can be achieved with appropriate real-time algorithms. Improved motorization with less pollutant emission, use of alternative fuels or even new propulsion modes could also help.

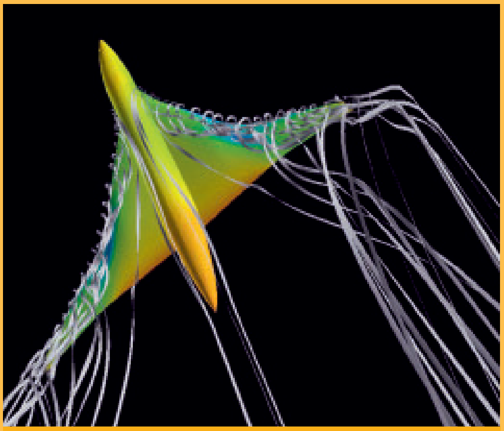
Moreover, much progress is now expected in new materials for aeronautics. Lighter structures that are resistance to ageing, to shocks and to heat are a dream that engineers would like to make reality. Nevertheless if these materials could be "intelligent" too, engineers would enter a new world where so much could become possible.

Avionics

This is another area of study at Toulouse. Command and communication between embedded systems with less and less wired connections is an objective that looks realistic today, not forgetting global management of in-flight energy. Such progress also extends to communications between plane and ground or between plane and other vehicles, as well as man-machine interactions.

Finally, air traffic needs to be managed in a more global context. We also need to better understand how aircraft impact on the environment in urban zones near airports, and inside airports themselves. Such studies should be extended to how air travel affects the worldwide environment in general.

>>> Artist's view of a giant wing for high capacity air transportation. ©Onera



>>> Direct numerical simulation of the flow around the epistle at high angle of attack ©Onera

(1) http://www.acare4europe.org/
http://www.aerorecherchecorac.com/
http://europa.eu/legislation_summaries/institutional_affairs/institutions_bodies_and_agencies/
(2) : http://www.aerospace-valley.com/
(3) : http://www.fondation-stae.net/

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CERFACS: Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique / European center for research and advanced scientific computing.
IMFT: Institut de Mécanique des Fluides de Toulouse/ Toulouse Institute of Fluid Mechanics.
ISAE: Institut Supérieur de l'Aéronautique et de l'Espace / Superior Institute of Aeronautics and Space.
CIRIMAT: Centre Interuniversitaire de Recherche et d'Ingénierie des Matériaux/ Interuniversity Research and Engineering Centre on Materials.
LAAS: Laboratoire d'Analyse et d'Architecture des Systèmes / Laboratory for Analysis and Architecture of Systems.
LAPLACE: Laboratoire Plasma et Conversion d'Energie/Laboratory on Plasma and Conversion of Energy.

Sandwich structures for aeronautics

The speed and performance of aircraft depends on the structure of the materials used to build them. Several laboratories in Toulouse are investigating sandwich structures, made of rigid outers around a light core, that can be modulated depending on the end application.

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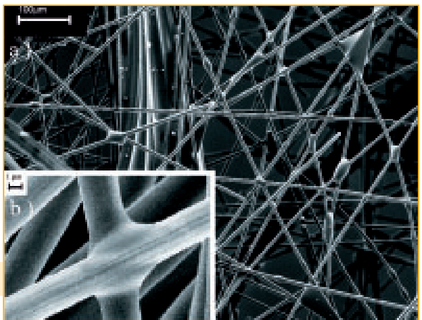
The first aircraft made of metal saw the light of day a century ago, replacing older models that were made of wood and canvas. Since then, aircraft have greatly improved but research into new materials and alloys, such as those made from aluminium that are more resistant to static and dynamic charge, continues. At the same time, composite materials are also being studied thanks to their corrosion resistance and their good rigidity/density.

Rigid outers and light cores

Sandwich structures are used in aeronautic and space applications for which bending rigidity and lightness are required. A sandwich structure is composed of two rigid outer layers (mainly made of a stratified composite or aluminium) glued to a less dense core. Many components, including beams, sheets and helicopter rotors, can be made of such structures. The materials used for the cores of these sheets are important for the sandwich's durability and its performance – for example, during impact and vibration. The strength of the glue used to stick the sheets together is also important.

Metallic or organic honeycomb structures are frequently used as well, such as aluminium or PMI (polymethacrylimide) foam. The behaviour of these materials is strongly related to their internal architecture that can be optimized by juggling with the size of the cells and/or the thickness of the walls. Nevertheless, existing solutions show many disadvantages: the sheets are more likely to fail following low-energy impact, such as when a tool falls on the sheet during maintenance, or when ice impacts the sheet during flight. Water can also condensate on the sheets during flight cruising because the temperature at altitude is much lower than that on the ground.



>>> a) Tangled, reticulated material for sandwich structure core made with carbon fibres, volumic mass 180kg/m^3, b) zoom on an epoxy graft

Matencrash Project

Since 2006, CIRIMAT and the Clément Ader Institute have joined forces to put forward the MATENCRASH project. The idea here is to develop an innovative core material from fibres but above all one than could be modified depending on the type of end application.

The first results obtained from this collaboration spurred us to continue with the study in a co-sponsored thesis during which a new process was developed to make a network from glass fibres, carbon and steel held together by epoxy resin. The amount of fibre used can be increased or decreased to change the mechanical, vibratory, electric and impact-resistant properties of the final sandwich sheets. The use of tangled and reticulated carbon fibres optimizes, for a given mass, the rigidity of the sandwich but this still remains inferior to those made from honeycombed structures. In contrast, impact tests show that the internal architecture of the core and outer layers proposed limit damage during low-energy impact and this advantage is currently being explored by the two laboratories involved.

Tailor-made cores

Another possibility is to use a mix of fibres. It is thus possible, by adding conducting fibres, for example, to obtain a material with enhanced electrical conductivity. Finally, a collaboration with the company Montauban (ATECA) was begun in 2007. Thanks to support from the Midi-Pyrénées region, we have started to make tangled, reticulated fibres around spheres to produce a material with a double internal architecture. For impact applications, zones of temporary contact are often weak points so separating these spheres using a light, shock-absorbing, porous material with a controlled rigidity is a promising approach. This study is the object of a joint patent (1).

Depending on the final applications of the sandwich structure, we can dream of creating cores on-demand and even cores with different architectures in the same structure. Work is continuing on this topic, and the focus will especially be on the vibratory behaviour of these materials, or more precisely the shock-absorbing properties of the cores. Such behaviour is particularly important for helicopter applications.

1 - Patnent n° from FR 08/58211 to 3/12/2008, ATECA, INPT, UPS. Extension PCT/FR2009/052357 from 1st December 2009.

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Human factors and flight safety

What goes on in the brain of human flight operators when faced with danger? Researchers in Toulouse aim to understand just this thanks to brain imaging. Their goal: improve aviation safety.

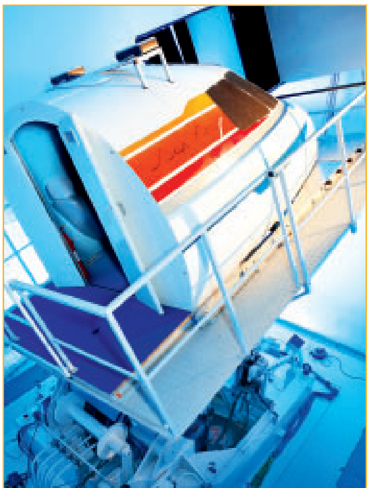

>>> Frédéric DEHAIS, researcher at the Centre aéronautique et spatial (CAS) at ISAE (Institut de l'aéronautique et de l'espace) and Julien CEGARRA, assistant professor at the University of Toulouse Le Mirail (UT2), researchers at the Laboratory of Cognition, langues, langage, ergonomie (CLLE, UT2/CNRS)

Paradox

Technical advances in aeronautics and considerable efforts to improve flight safety mean that flying is the safest means of transport in terms of number of kilometres travelled by passengers (source: European Transport Safety Council). However, the absolute number of aircraft accidents is on the rise because air traffic is increasing year on year. The cause of accidents are many, but when they involve critical operators (such as pilots, air-traffic controllers and maintenance technicians), the main culprits are tiredness, stress, time constraints and information overload. Indeed, the interaction between these various factors are likely to increase stress levels beyond the individual or a group's ability to react in a positive way. These issues are motivating many researchers to understand and measure the effects of stress and workload to improve flight safety

Irrational decisions

Experiments conducted on flight simulators at ISAE in partnership with Onera have shown that stressful situations lead to aircrews making irrational decisions. To better understand these phenomena, we employed techniques such as fMRI (Functional Magnetic Resonance Imaging) at the Brain Imaging and Neurological Disability Laboratory (joint UPS/ INSERM lab) and the Santa Lucia Institute in Rome. Participants were made to perform a simplified landing task in which both the level of uncertainty (the probability of a crash) and the financial costs of the decision (landing or overshoot) were manipulated. The results showed that the financial factor led the participants to make more risky landing-related decisions. These decisions were linked to a shift from the activation of the dorsolateral prefrontal cortex ("rational" brain) to the activation of the cerebral ventromedial prefrontal cortex ("emotional" brain).



>>> Simulator at Isae.

Information overload

The French Air Navigation Services Department (DNSA/DTI) and the Cognition, Language, Ergonomics (CLLE/CNRS) laboratory is studying mental workload management by air traffic controllers when air traffic increases. More precisely, when estimating mental workload (for example, by measuring how long the eye fixes on a certain object, like an aeroplane), it appears that controllers anticipate the situation and do not passively react to changes that occur around them. In order to take such adaptive components of cognition into account, it is necessary to assess the situation as seen by controllers. For instance, they use their episodic memory (which allows human beings to recall past events) to anticipate how a certain situation will evolve. In our study, new indices of how humans use their memory are compared to eye data. Such comparisons allow researchers to re-assess how operators switch between tasks and the errors (delays) associated with this switching.

Researchers at The Toulouse Institute of Computer Science Research (IRIT) and The French Civil Aviation University (ENAC) are also modelling the multiple components of the human-computer interaction in critical systems. Such modelling allows (1) to improve the safety and efficiency of information visualization and data entry (2) to study new design processes for interactive software (ENAC and IRIT) (3) to formally verify and manage critical systems (IRIT).

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The impact of air transport on climate

>>> Daniel CARIOLLE, engineer at Météo-France and at CERFACS (SUC team with CNRS) and Olivier EIFF, professor INPT at the IMFT (joint UPS/INP/CNRS lab), coordinators of the ITAAC project.

Air traffic is increasing worldwide, and although aeroplanes are less polluting than before, they still remain one of the biggest emitters of greenhouse gases. Determining their impact on the environment is difficult, however.

Since 1990, air traffic has been increasing by around 5% a year and it looks set to double between now and 2020. Despite technological improvements, particularly in the emissions of CO2 emitted per passenger per kilometre, the fact that air traffic numbers are on the rise means that more greenhouse gases are being emitted. What impact could this increase have on the environment?

Compared to other modes of transport, air travel is unique in that emissions are produced at altitude. Scientists say that a molecule of CO2 emitted high up in the atmosphere has a greenhouse gas effect that is three times greater than that of a molecule emitted at ground level. However, much uncertainty surrounds this factor of three figure.

Production or destruction?

There are two main causes for this uncertainty. Firstly, the interactions between chemical and physical processes in the atmosphere, fluid mechanics and combustion are intrinsically non-linear and produce indirect effects. For example, the chemistry of nitrogen oxides in the gas phase or by heterogeneous reactions at the surface of emitted particles either produce or destroy ozone depending on how dilute the aircraft emissions are. Also, contrails formed by condensation of water vapour onto aircraft exhaust aerosols and soot particles trigger the formation of cirrus clouds that have an important impact on the radiative balance of the atmosphere.

Secondly, we must take into account the enormous disparity in the length scales associated with these processes. In fact, if the emissions are analyzed at the engine exhaust, their impact on atmospheric chemistry and on the radiative balance of the atmosphere continues for several days over areas covering several hundreds of square kilometres. It is a real challenge to model those transformations from the “near field” of the aircraft to much larger, global scales.

From combustion to impact on the climate

We have proposed a new project, financed by the RTRA STAE and which involves six Laboratories in Toulouse, called “impact of air transport on the atmosphere and climate” (ITAAC). Its goal is to study how combustion-related process at the motor level impact on the climate.

The LAPLACE laboratory specializes in modelling radiative transfers; the CERFACS and CNRM in modelling the climate and the chemistry of the atmosphere; and SAFIRE in in-situ airborne measurements.

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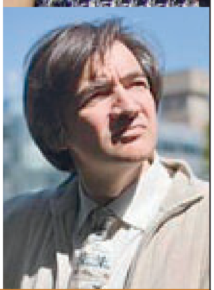
>>> Aeroplane trail with ice particles transported in the vortices created around the wing
Accumulation of trails and cirrus ice cloud formation.

Electroactive Morphing: a new concept for improving aerodynamic performance

Electroactive Morphing is an emerging multi-disciplinary subject covering aerodynamics, aeroelasticity, new smart materials and flight control commands.

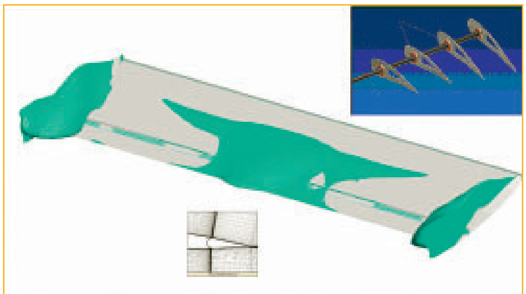


>>> Marianna BRAZA, CNRS senior scientist at the Institut de mécanique de fluides de Toulouse (IMFT, joint CNRS-INPT-UPS lab) Bertrand NOGARÈDE, INPT professor, researcher at the Laboratoire plasma et conversion d'énergie (LAPLACE, joint CNRS-INPT-UPS lab).

Morphing exploits intelligent mini-piezo actuators spread under the 'skin' of a structure that are able to optimize its shape in real time during flight. This concept, an important priority for the European Commission's 7th Framework research Program, can improve flight performance via shape optimization.

On the Toulouse campus, researchers from the IMFT, LAPLACE and ISAE research institutes are collaborating to develop intelligent microdrones and next-generation ailerons (hinged control surfaces attached to the trailing edge of an aircraft's wing) able to change their shape and so attenuate harmful vibrations (EMORPH project). This research is supported by the STAE foundation (research program on Electroactive Morphing for Micro-Airvehicles or EMMAV) financed by the RTRA STAE.

Thanks to electroactive materials, the aerodynamic efficiency of microdrones (their 'figure of merit') is considerably improved. Furthermore, with the help of Shape Memory Alloys (SMA), active ailerons are deformed to make pre-studied optimal shapes that increase lift and decrease drag. We have also developed an efficient high-fidelity modelling approach for fluid-structure interactions. These studies include modelling the structural properties of new materials as well as new concepts in turbulence modelling using CFD (Computational Fluid Dynamics) and CSM (Computational Structural Mechanics) equations.



>>> Negative take off speeds behind a wing with aileron, and morphing schematic.

To achieve high deformation together with high frequencies for dynamic operation, we envisage hybridizing SMA with intelligent mini-piezo-actuators that operate in dynamic regimes (at frequencies on the order of 1KHz). Appropriate flight control commands, studied by ONERA's DCSD department will be applied to ensure that the concept of morphing is operational in real time. Therefore, the Electroactive Morphing concept developed is highly innovative and state-of-the-art and represents a technological breakthrough.

Electroactive Morphing research is based on a triple approach - theoretical, digital (CFDSM coupling) and experimental - to make smart microdrones/ailerons/tails/active wings.

Another important point in the concept is that it is low energy. Indeed, the actuation processes studied allow us to compensate for the energy needed for morphing, thanks to *the intrinsic energy reversibility* properties of electroactive materials. These materials are indeed able to absorb vibrational energy that naturally exists in the system's environment and recompose it for electroactive actuation. Moreover, the *distributed* character of the actuation allows for optimum rheological modification of the material's structural properties that is much more efficient in real time than localized actuation methods to modify structures.

Morphing also introduces new physics that takes into account the behaviour of both the fluid and solid parts of a material. This global approach requires specially-adapted modelling concepts that consider the strong non-linearity of the physics involved.

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Miniaturized communication systems for space and aeronautics

>>> Robert PLANA, professor at Paul Sabatier University and member of the Institut Universitaire of France – head of the research group at LAAS (independent CNRS lab associated with UPS) and Daniela DRAGOMIRESCU, assistant professor at INSA, researchers at LAAS.

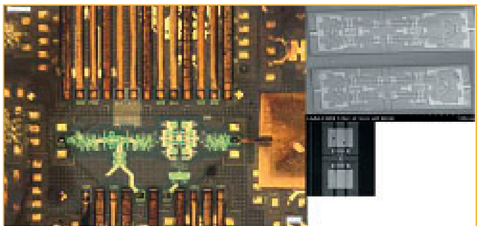
Smaller, more reliable and adaptable on-demand communication systems for aerospace applications are undergoing a revolution and Toulouse researchers are involved.

Communication systems play a crucial role in aeronautics and space systems and their development relies on several scientific and technological domains. We need to improve the reliability of these instruments, make them more secure and protect them from electromagnetic radiation. We also need to reduce the power they consume and miniaturize them.

Circuit dimensions

As part of the SYMIAE project (miniaturized systems for aeronautics and space) funded by the RTRA STAE, three laboratories in Toulouse, the LAAS, CIRIMAT and LAPLACE are looking at how to modify the geometric dimensions of circuits, either to repair a connection in a device or to change certain characteristics, like the frequency band, the central frequency or the power level in a system.

These circuit dimensions are modified by coupling the mechanical and electromagnetic properties of a system. Micro- and nano-technologies now allow us to make miniature electrostatic actuators that can locally modify how energy is spread across a device and consequently modify the properties of a communications instrument.



>>> 3D architecture of reconfigurable millimetre-sized communication system composed of a silicon integrated circuit (developed by the University of Toronto and made by ST Microelectronics), an electromagnetic transducer and a miniaturized antenna.

Researchers in Toulouse have made reliable miniaturized actuators assembled in 3D with nanometric CMOS circuits (just 65 nm in size) to realize reconfigurable communications systems. The figure below shows such a system that works at 150 GHz and which comprises an antenna, a transducer and silicon architecture. CIRIMAT has also been working on piezoelectric materials to improve the performance of actuators while research at LAPLACE has allowed us to better understand failure mechanisms observed in these technologies and so make processes more robust.

Millimetre-scale probes

More recently, a project has been accepted in the context of the “Nano-Innov” plan (Nanocom project), whose goal is to make millimetre-sized probes based on the principles mentioned above. This project has allowed us to make circuits on ultrathin, supple substrates that can thus be integrated onto non-planar surfaces.

The project could continue as part of a new project at the IRT of Toulouse and so address future challenges in aerospace.

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