ONERA GEMS

CONTRIBUTIONS TO THE AEROSPACE INDUSTRY IN FRANCE AND EUROPE

Second edition

ONERA

THE FRENCH AEROSPACE LAB

ONERA

THE FRENCH AEROSPACE LAB

In 1946, the French State created ONERA as an instrument of its ambitious policy of excellence for our aerospace industry and national defense. It placed ONERA under the sole authority of the Ministry of Defense. To ensure world-class scientific and technological excellence for France in the fields of civil and military aviation, ONERA was tasked in particular with developing and directing aeronautical research, and with designing, developing and deploying the necessary resources to perform this research and encourage its take-up by industry. Fifteen years later, these missions would be extended to include deterrence and space, working closely with the DMA (now the DGA) and the CNES, created by General de Gaulle. In 2016, ONERA celebrated its 70th anniversary and signed a new objective and performance contract with the State, based on a new scientific strategy plan. These documents confirm our missions and our strategy.

"ONERA inside" gems

ALL the major civil and military programs (fighter and transport aircraft and their equipment, tactical missiles, deterrent missiles, helicopters, unmanned aerial vehicles, launch vehicles, satellites, space surveillance, etc.) that have made our industry, and with it France and Europe too, so economically and technologically strong today, have a very high dose of "ONERA inside".

The first edition of the “gems” enabled readers to discover some of the fruits of the excellence of our teams. In view of their success, and due to the frustration of having had to exclude some very fine achievements, we have decided to add in this second edition some extra gems that have been, are, and will continue to be the pride of our researchers.

Without research, there would be no more programs

The research conducted by ONERA has helped to shape our aerospace industry, both military and civil, and its past and present success. The mission entrusted to it by the State has been well fulfilled and we intend to continue to achieve another 70 years of excellence.

Our industrialists often remind us that programs involve long cycles requiring the necessary technologies to be well prepared and therefore financially supported, and for as long as it takes. They justly point out that "without technology, there would be no more programs", sometimes specifying that it is a matter of moving at the speed of light. I totally agree with this statement, which must however be completed by saying that "without research there is no technology." It is therefore essential that research is also supported.

I now invite you to come and discover, or rediscover, the source of this light, whether it be in the past, the present or hopefully the future, of success and excellence in our industry.

Bruno Sainjon
Chairman and CEO
of ONERA

ONERA GEMS

Table of Contents

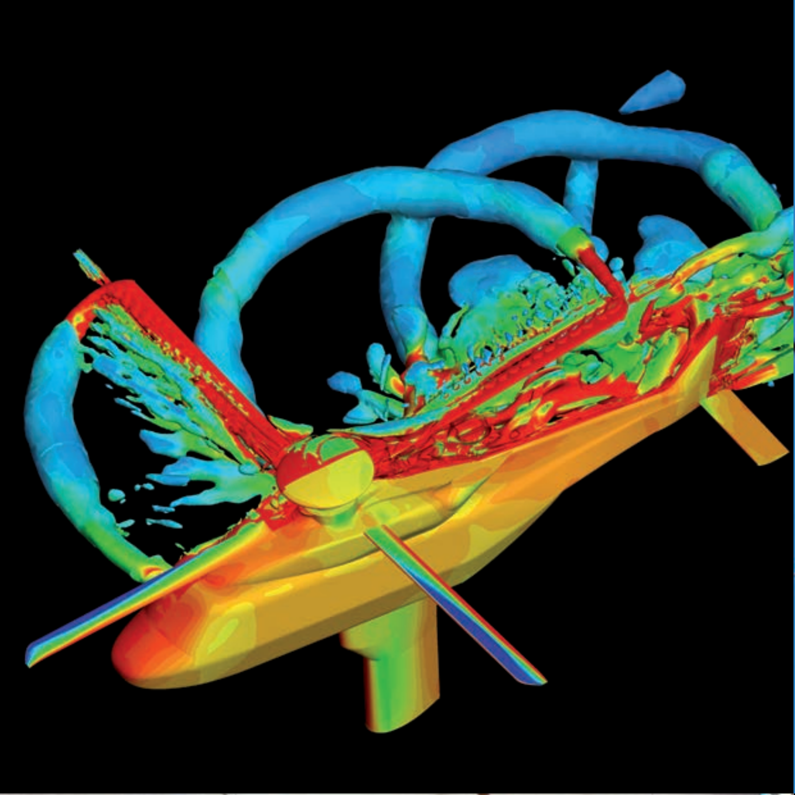
The large wind tunnels, the cradle of French aviation

ONERA has the largest European fleet of large wind tunnels. S1MA, installed in the Alps, is the world's largest sonic wind tunnel: it can blow a wind at almost Mach 1, which is the speed of sound, that is, at about 1200 km/h in a duct with a diameter of 8 m! All aircraft of the Airbus and Dassault Aviation ranges have gone through S1MA, particularly to assess their cruise flight performance.
F1, in the Commune of Mauzac near Toulouse, was designed to simulate flight during take-offs and landings. S2MA and S4MA are particularly used for military aircraft and launch vehicle simulations, with air flows of up to Mach 3 and Mach 12 respectively.
These unconventional means are of course equipped with measuring and viewing instruments.

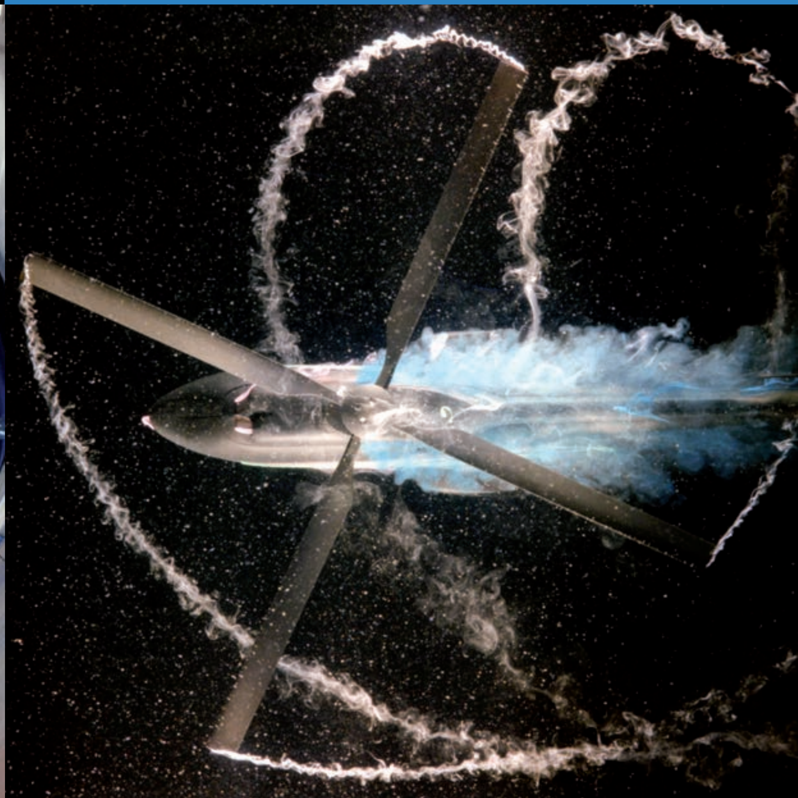
Measuring loads, a matter of balances

The "queen" of all measurements done in wind tunnels is the measurement of loads. There are 6 components: lift, drag (or resistance to motion through the air) which is critical to assess cruising flight performance, the lateral force and three moments (roll, pitch, yaw) that tend to make the aircraft rotate.

These measurements are performed simultaneously by balances, which are instruments that measure the loads by the deformation of gauges (strain measurement). ONERA has extensive expertise in their design, manufacture and calibration, and they are among the best in the world. These balances contribute greatly to the excellence of the measurement accuracy in the tests conducted in ONERA wind tunnels.




F-WOEY

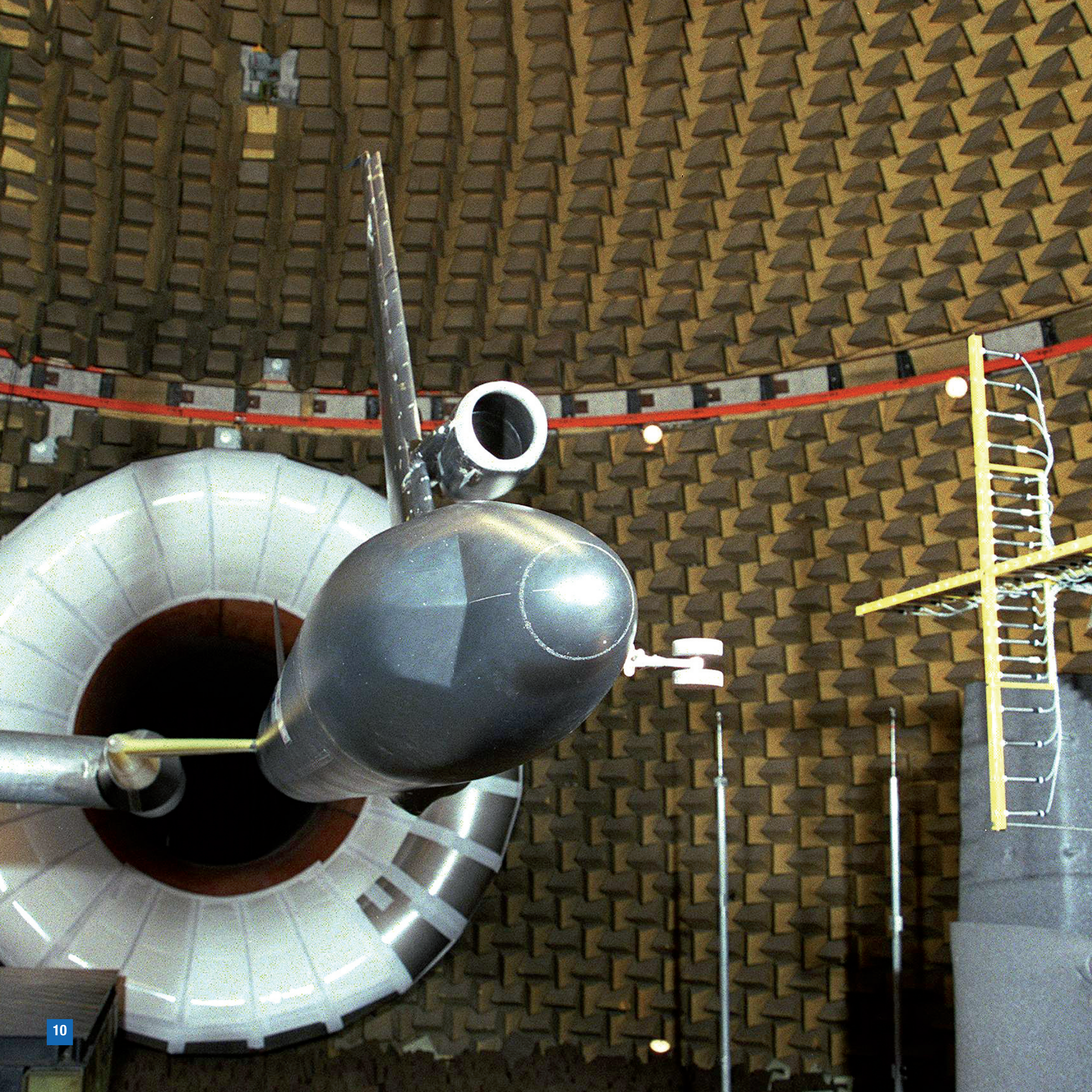


The dream of silent helicopters

The Gazelle, Écureuil, Dauphin, Super-Puma, Tigre and NH90: all helicopter rotors of the Aérospatiale, Eurocopter, Airbus and NHIndustries ranges have blades with profiles that have been defined by ONERA's aerodynamicists. The parabolic tips and the famous "AO" profiles helped the Dauphin to break a world speed record at 371 km/h in 1991. Since 1992, ONERA has engaged in hunting down noise, together with its German counterpart and partner the DLR, developing numerical models and measurements in wind tunnels to achieve a radically new shape, the Erato. Result: the release in 2015 of the H160 by Airbus Helicopters, which reduces noise by half with an aerodynamic performance even greater than that of the previous models. The challenge of the (almost) silent helicopter had been overcome!

A silent revolution at Airbus Helicopters

1994 the DGA notified ONERA of the Erato contract, aimed at developing an acoustically optimised helicopter blade, without any performance deterioration. **1996** ONERA, thanks to the maturity of its numerical models, designed a revolutionary blade exceeding the specifications. The DLR and ONERA tests in wind tunnels confirmed its excellent performance. **2001** After long discussions to convince Eurocopter, a contract was signed with the industrialist and then a joint patent was filed. **2008** Flight tests showed its very good aero-acoustic performance. **2010** Airbus officially unveiled the Blue Edge® blade, which was the result of the collaboration between industry, ONERA and the DLR. **2015** Airbus Helicopters unveiled its new almost silent revolutionary model, the H160.

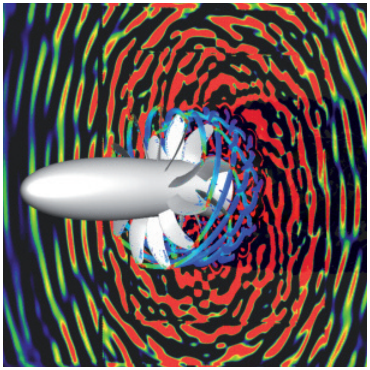


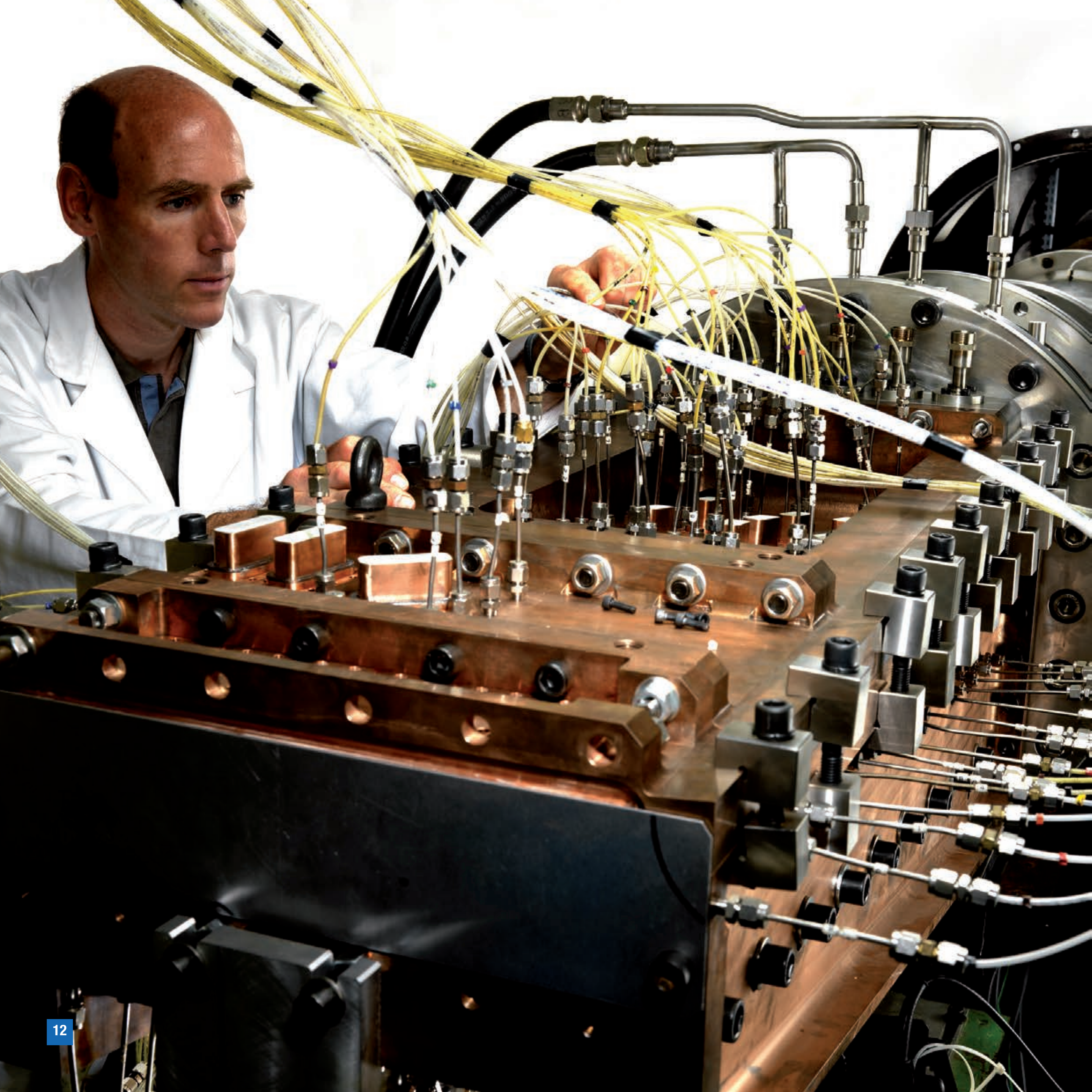
Noise reduction: the other environmental challenge

The need to combat aircraft noise arose with the boom of civilian air transportation in the 60s. Over a period of fifty years, advances in engine technology enabled perceived noise to be reduced to a quarter of the level.
ONERA has been helping engine and aircraft manufacturers for decades by studying the production and propagation of aircraft noise, in order to reduce or change its perception. This war against noise is waged on several fronts: engines (jet engines, fan engines and combustion engines), structures (landing gear, spoilers, slats and flaps) and trajectory management, as well as the perception of those living near airports themselves. ONERA's great software applications (Cedre and Elsa) simulate the sound sources. Specific software applications calculate its propagation. New materials-structures are developed. Traffic simulation is taken into account through the Iesta platform.
The Cepra19 "acoustic" wind tunnel is an experimental facility for low speed noise studies. ONERA's large wind tunnels, such as the S1MA in Modane, are equipped to include this aspect of aviation performance.

Iroqua: all united against noise

In Europe, the Advisory Council for Aeronautical Research ACARE set ambitious environmental objectives in 2001. The Iroqua network was established to unite aircraft noise related efforts in France. Led by ONERA, it includes Airbus, Dassault Aviation, Safran, the CNRS, Air France and Aéroports de Paris, as well as tens of SMEs and research laboratories.
Iroqua, in conjunction with the French CORAC (civil aeronautics research council) has become the reference expertise circle on the impact of aircraft noise.



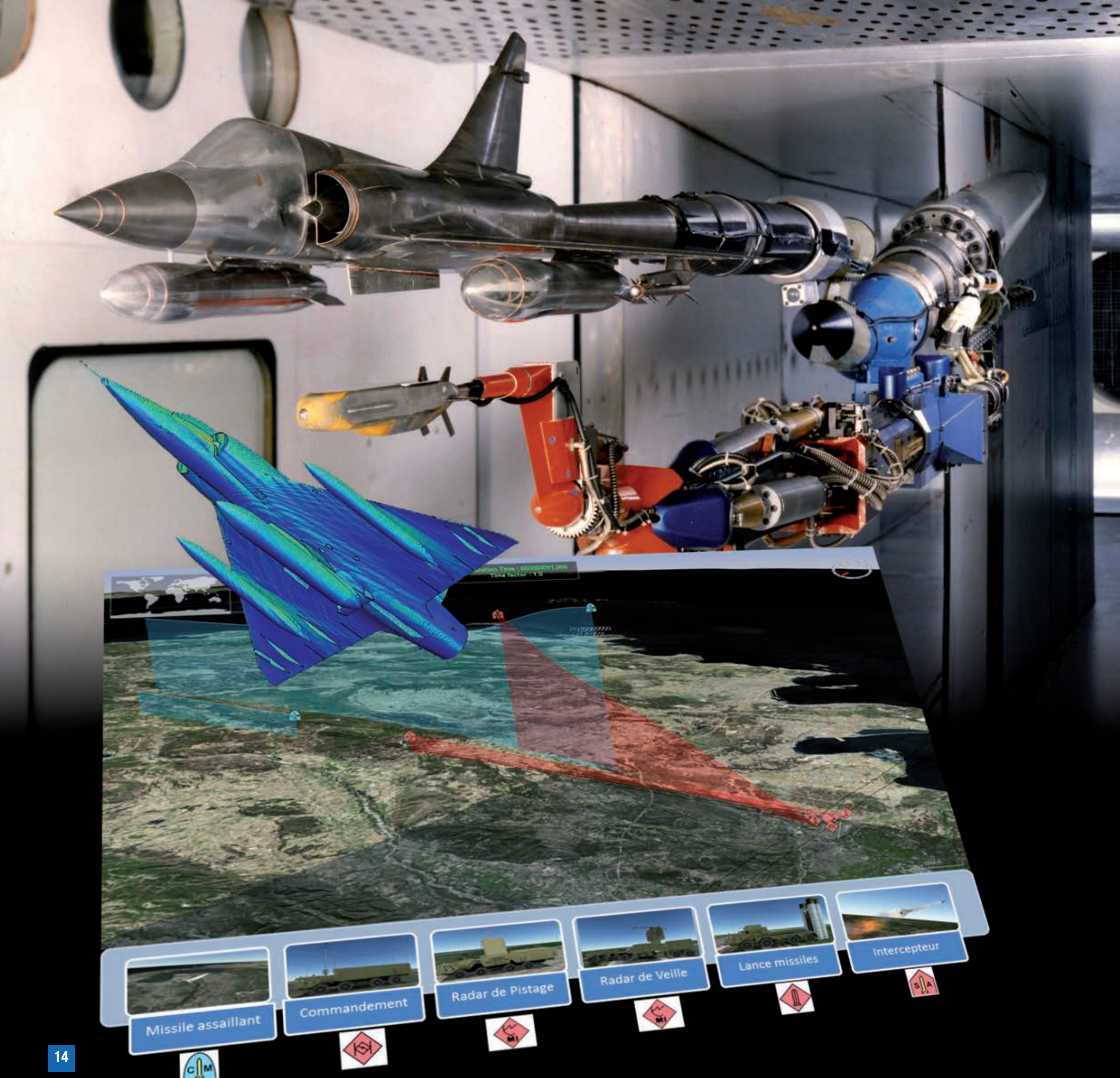


The ramjet (and scramjet) saga

The principle of the ramjet engine is simple: it does not include mobile parts like a jet engine. But it mostly only works well at supersonic speeds. It enables very fast long distance journeys, because it is very light. It in fact only works with kerosene and oxygen from the air once it has been accelerated on start-up, usually by a powder engine.
40 years ago, ramjet technology, already well known at ONERA, was selected to propel the ASMP, the first medium-range air to surface strategic missile (Mach 2 to 3, with a range of up to 300 km). This vector was recently replaced by a modernised version, the ASMPA, for which ONERA has remained the co-contractor of the industrialist MBDA.
Today, ONERA, together with industrialists, prepares for the future with test benches simulating engine propulsion on the ground at speeds of up to Mach 10–12 and, of course, increasingly predictive numerical simulations. At these speeds, we no longer speak of ramjets, but rather of scramjet.

The flame holder, the key of the ASMP's success

The combustion chamber of a ramjet is similar to a pipe where the air passes through at high speed and where the fuel burns. In conventional combustion chamber designs, flame-holders within are used to prevent the combustion from extinguishing. However, the presence of the flame holder requires the powder accelerator to be placed outside of the vehicle, extending it in a way that is not viable (for a total length of around 10m) to be carried by a fighter aircraft.
A stroke of genius from ONERA engineers was the design of lateral air intakes, allowing the injectors to be placed on the wall, without flame holder but with the same efficiency. Suddenly, it became possible to include the indispensable accelerator inside the chamber and to halve the missile length. Carrying it under an aircraft – the Super-Étendard, Mirage IV, Mirage 2000 and later the Rafale – became possible.


Missile assaillant
Commandement
Radar de Pistage
Radar de Veille
Lance missiles
Intercepteur

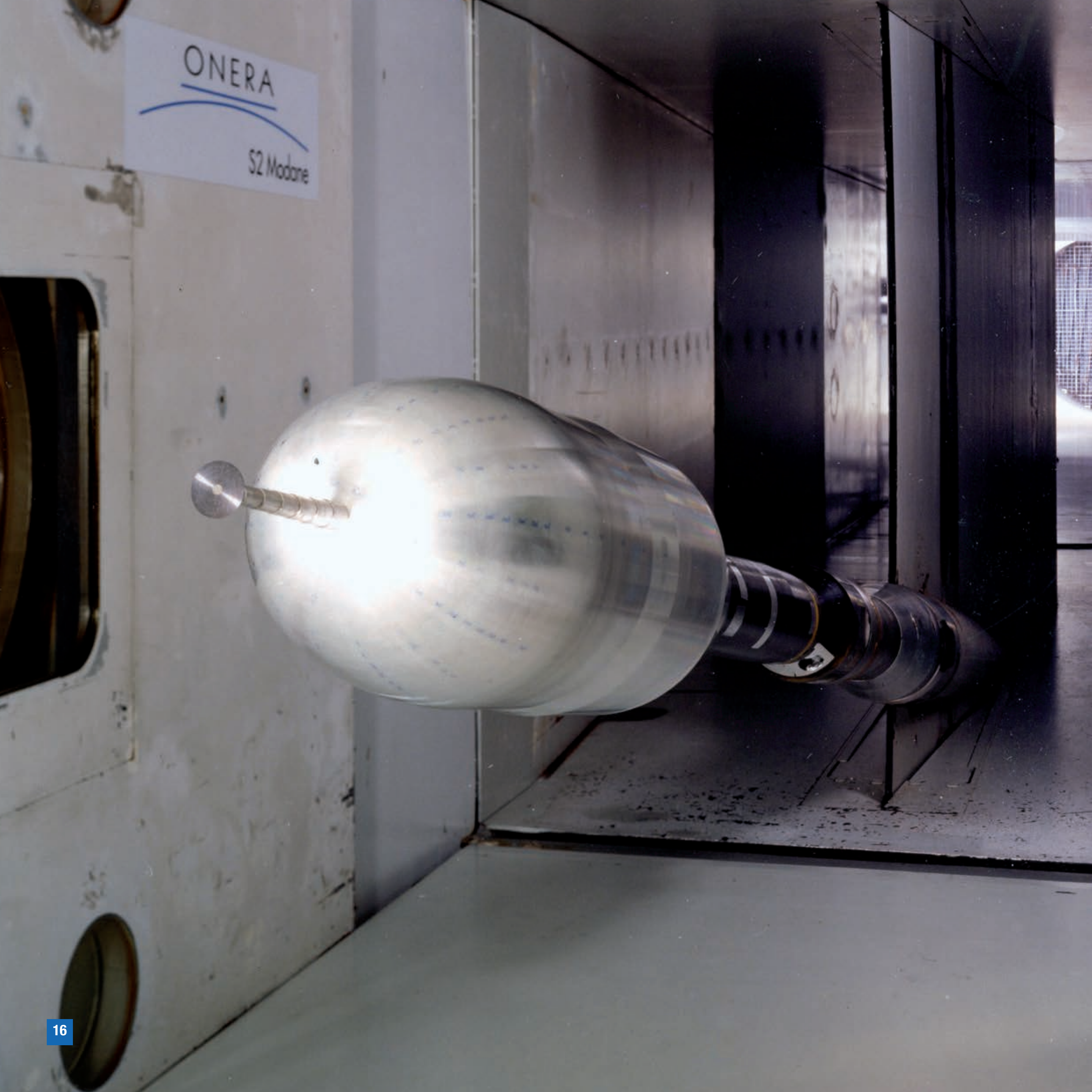
Defence systems: simulation before action

"Physical" simulation, both numerical and experimental, is essential to devise and evaluate future designs and equipment in an environment representative of operational situations. ONERA capitalises on a thorough knowledge of the physics behind phenomena, of technologies and of processes in ONERA's various fields: materials and structures, physics, fluid mechanics and energetics, data processing and systems.
Furthermore, studies and research on the effectiveness of defence means against an opponent, anti-missile defence, battlefield surveillance and UAV systems need a complete and realistic simulation of the players and of their environment. This type of "system" simulation is by nature interdisciplinary and closer to the operational needs of the armed forces.

Blade, ONERA's "battle lab"

ONERA is developing the Blade simulation tool, which assesses system performance in situations, architectures, organisation and use designs. Blade enables ONERA models for sensors, weapons systems, aircraft, satellites, etc., to be included, as well as the processing of information and communications. The IT structure enables 3D simulation and visualisation control.

This tool, which has been completely mastered, is open and fully interoperable through a secure network: operational systems of the three armed forces, NATO, the DGA's technical-operational laboratory and other battlelabs belonging to manufacturers. Applications have already been implemented: penetration of defence systems by missiles and the evolution of the tactical situation on the battlefield.


ONERA
S2 Modane

"The time for deterrence has not been exceeded"

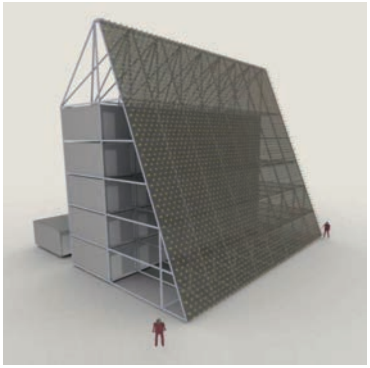
(François Hollande, in a speech on nuclear deterrence in Istres on the 19th of February 2015)

France's nuclear deterrence force includes two components: oceanic deterrence, with the M51 intercontinental ballistic missiles launched from submarines, and airborne deterrence, with the ASMPA medium-range supersonic cruise missiles, which can be dropped from a Mirage 2000 or Rafale in flight. ONERA contributes its expertise on ballistic missiles (M4, M51 and following models) to the DGA, in terms of increasing performance, of solid propulsion, guidance/control and strategic penetration. In the case of airborne missiles (ASMP and following models), ONERA contributes through co-contracting projects with the industrialist MBDA, particularly in terms of aero-ramjet propulsion but also in terms of aerodynamics, stealth, materials, inertial navigation and the penetration of adversary defences.

BMD – ballistic missile defence

BMD or Ballistic Missile Defence is a response to the proliferation of missiles with ranges of several thousand kilometres. It is based on three pillars: the warning device (drones, satellites and radars), the command-control system and the interception-neutralisation means. ONERA contributes its expertise to the DGA, in order to assess and analyse the threat, as well as to respond to any question about France's position in this field (particularly within NATO). An ONERA numerical "battle lab" is part of the means for implementing this expertise.

ONERA is involved in early warning, with the development of on-board infrared sensors and a deployable very long range radar, the TLP (together with Thales and the DGA).

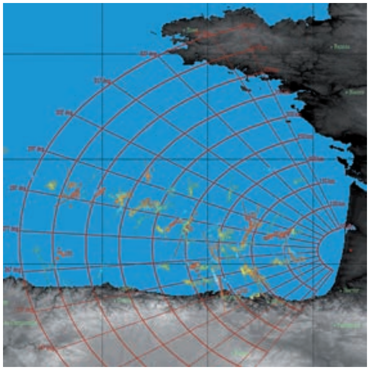


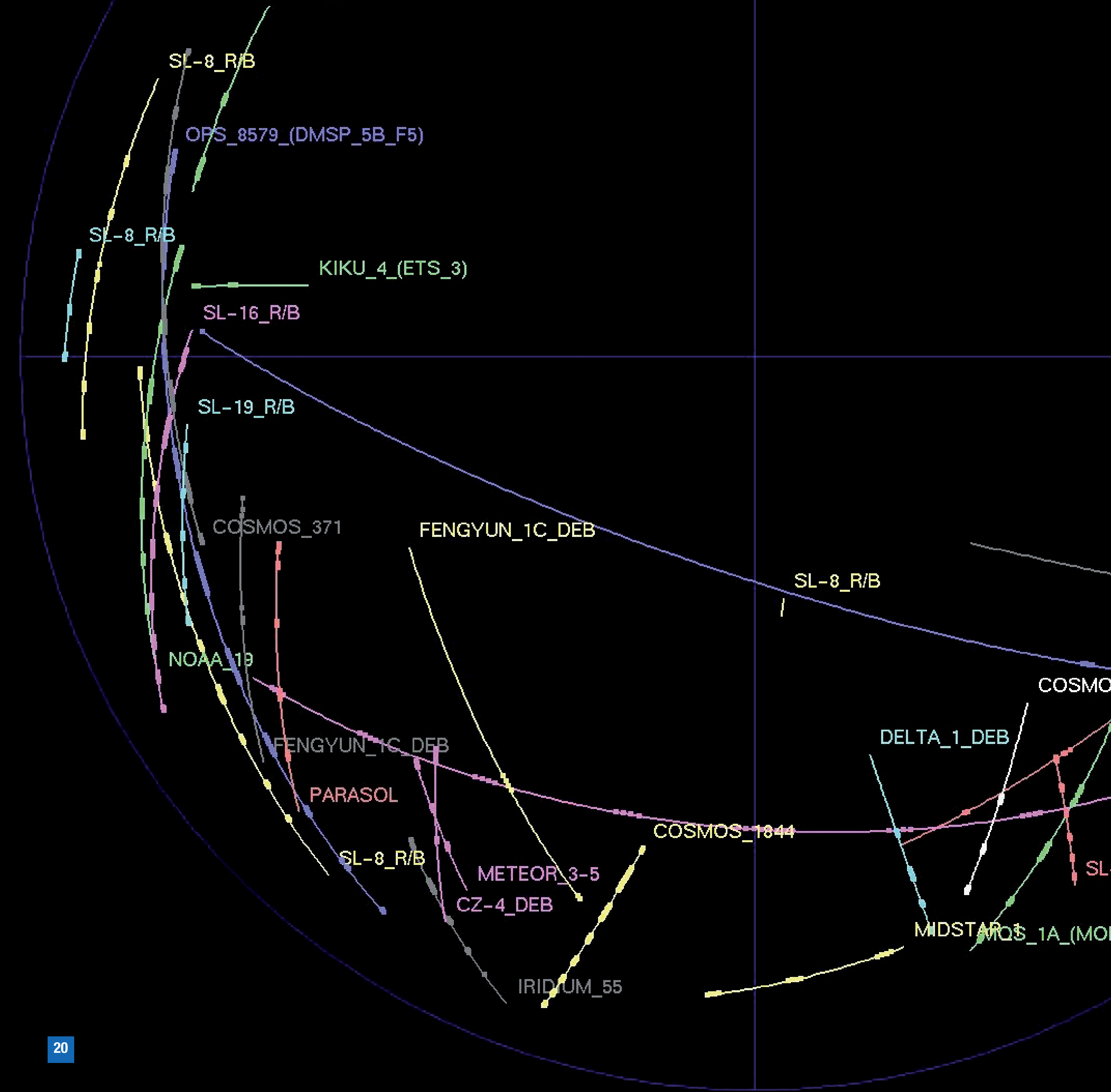
Radars to detect beyond the horizon

ONERA's Nostradamus can see far away. This radar demonstrator is indeed able to view the entire airspace over the Mediterranean from the centre of France. Few countries are exploring OTH (Over The Horizon) means; among these are Australia, the United States and Russia.
Nostradamus uses of powerful long wave antennas to transmit wave trains that are reflected off the ionosphere (the upper atmospheric layer where charged particles circulate) to scan the targeted areas. The return signals are received by the antennas of the Nostradamus platform located near Dreux and processed in real time. The improvement of its performance is already underway.

SWR (surface wave radars) have a maritime use

These radars transmit waves that have the property of propagating over the surface of the sea, well beyond the horizon. SWR technology, transferred to Thales, enables the Exclusive Economic Zones (EEZ, up to 370 km from the coast) to be monitored. Vessel trajectories and speeds can thus be monitored and abnormal behaviours can be detected. A second generation of SWRs enables the detection of small ships at distances of less than 200 km. This innovation will be available for the national program Spationav, intended to renovate the coastal surveillance and security system.
The know-how for these radar applications lies in signal processing numerical algorithms. Their strength lies in what characterises ONERA: a thorough knowledge of physics and the environment.





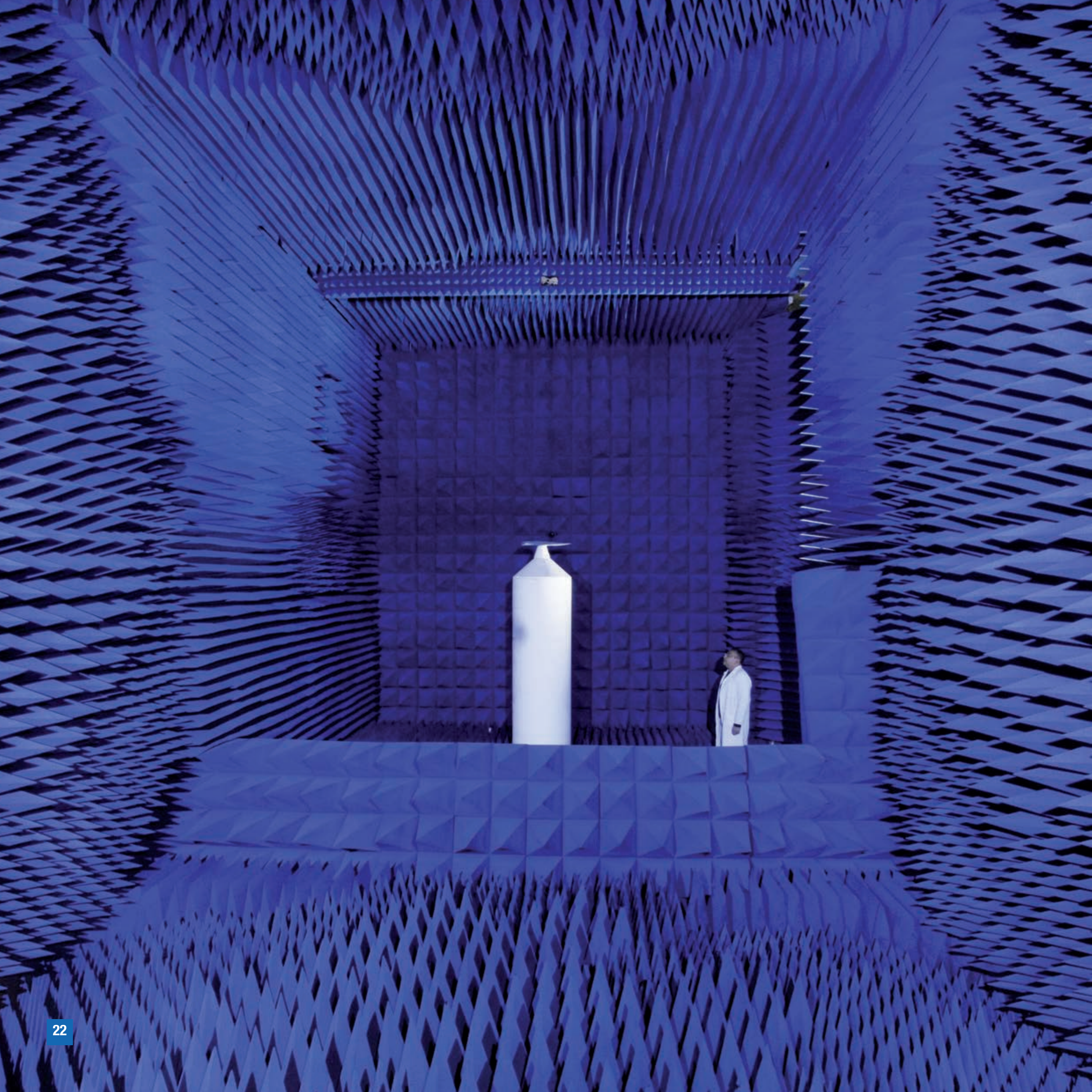
SL-8_R/B
OPS_8579_(DMSP_5B_F5)
SL-8_R/B
KIKU_4_(ETS_3)
SL-16_R/B
SL-19_R/B
COSMOS_371
FENGYUN_1C_DEB
SL-8_R/B
NOAA_19
DELTA_1_DEB
FENGYUN_1C_DEB
PARASOL
COSMOS_1844
SL-8_R/B
METEOR_3-5
CZ-4_DEB
MIDSTAR_1
IRIDIUM_55

The French space watch never sleeps

Why monitor space? Because every day thousands of satellites or objects larger than 10 centimetres orbit the Earth. Among these are spy satellites and debris that poses the risk of collisions. Before the 90s, only the Americans and Russians had a space surveillance system. France, with ONERA, joined this exclusive club as from 2002.
Developed under contract for the Ministry of Defence, the Graves system (Grand Réseau Adapté à la VEille Spatiale, or large network for space surveillance), which comprises a dedicated radar and automated processing, independently ensures the creation and updating of a trajectory database for observed objects. Thanks to its multidisciplinarity – radars, space environment, modelling and orbital analysis – ONERA has designed from A to Z a system that detects, recognises and identifies objects. This is a decisive contribution to the sovereignty of France. Since 2005, Graves, operated by the French Air Force, observes and catalogues thousands of items. Very responsive, the system detects any change in circumstances within 24 hours.

An economic resource that achieves great things

Compared to American systems with budgets on the order of billions of dollars, the French system Graves cost "only" €35 million and it is able to detect most satellites of interest. In addition to an economic design, this ONERA demonstration prototype has been inexpensively converted into an operational system for defence! In addition, Graves can boast of respecting the radioelectric environment, since its single frequency operation creates virtually no wave pollution.
The performance of the Graves system, its optimal cost and its discretion have conquered the military general staffs: ONERA has been commissioned to perpetuate the Graves system and to upgrade it to meet changing defence needs.



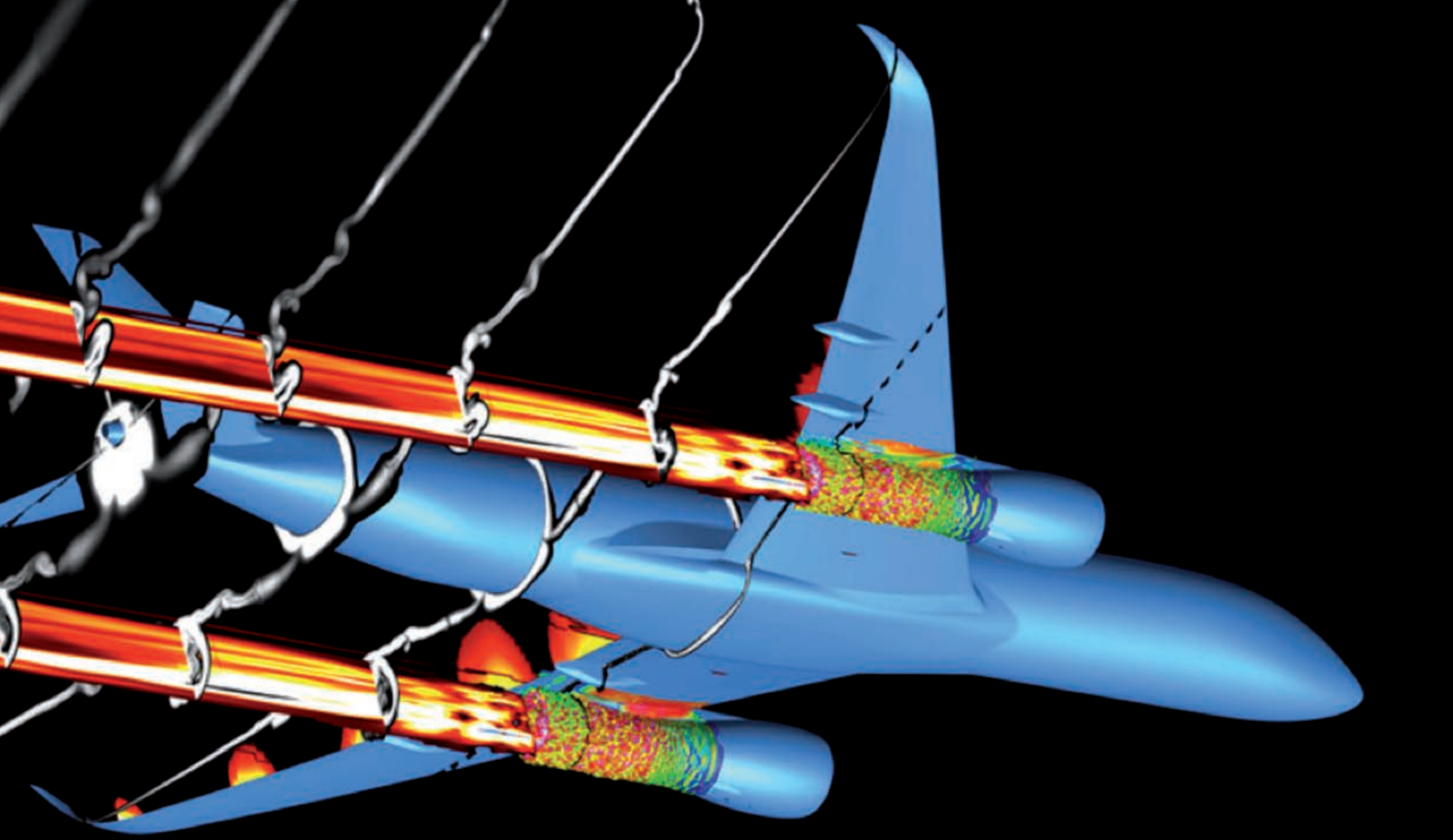
Totally discrete stealth

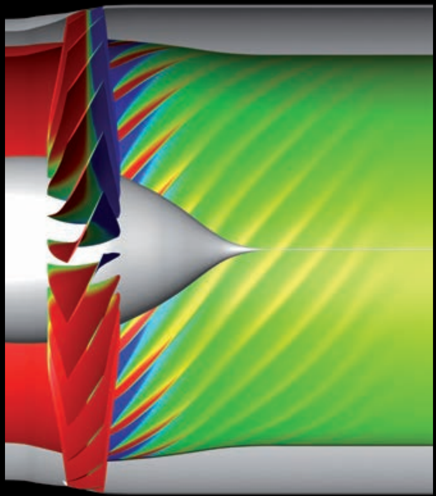
Stealth, that is to say, the fact of being invisible or difficult to identify by radar, is a highly sought quality for military aircraft.
In 1975 ONERA began full-scale research on missiles (cruise missiles, ASMP, etc.). Later, ONERA acquired two anechoic chambers, Camera and Babi, intended to characterise radar echoes with the purpose of reducing aircraft signatures. The databases produced provide a reliable base for the validation of "in-house" simulation software.
These facilities have been used on a succession of missiles, such as ASMP and the Apache-Storm Shadow missiles, helicopters (Gazelle, Tigre), aircraft (Rafale) and drones. ONERA is also the DGA's expert on this subject and participates in the performance of in-flight evaluations of the radar signatures of various aircraft, such as the Neuron recently.

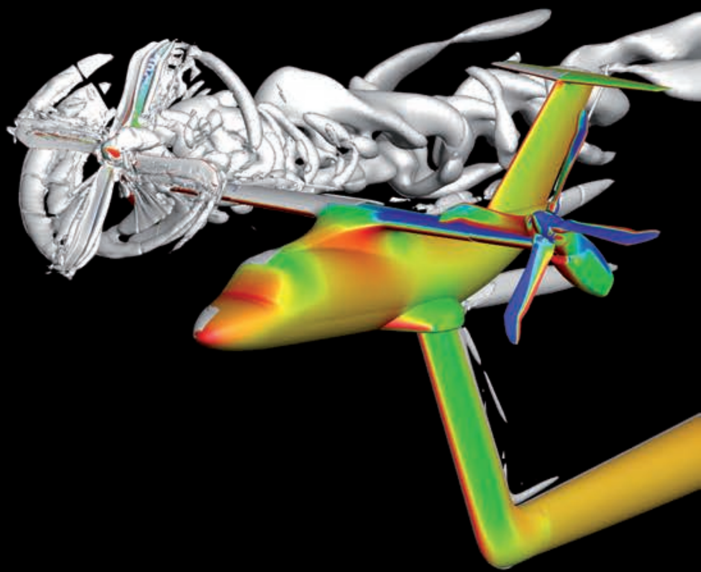
Wind turbines vs. radar: the civilian impact of stealth

Wind farms are flourishing throughout the country and studying them offers many advantages. Depending on their implementation, new installations can disrupt existing meteorological, aeronautical, civil or military radars. Building permits may thus be refused, without a real objective basis. And the courts are often resorted to!

In addition, the DGA has asked ONERA, its signature and stealth expert, to develop the Dempere simulation software, which enables radar operators to objectively decide on future implementations, according to the wind turbine discretion to radar.
ONERA also provides its expertise to wind turbine manufacturers, by adapting their blades to make them "stealthy".





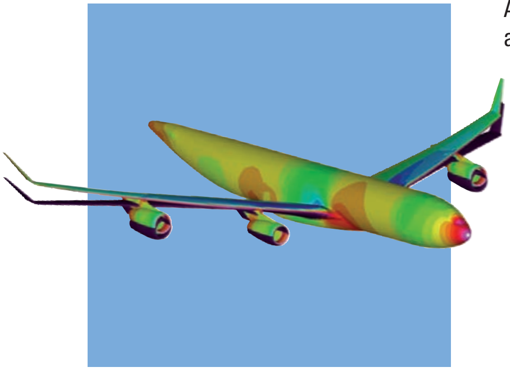


Elsa performs the entire aerodynamics

Elsa is not only ONERA's great fluid mechanics software platform, but also that of the French aerospace industry. A cooperation agreement between ONERA, Airbus and Safran was signed in 2015 to provide the most favourable environment for the development of this strategic software.
The secret behind Elsa's performance: the inclusion of the most appropriate numerical methods, based on research by ONERA and its academic partners. Elsa simulates flows over the most varied configurations, both in terms of external and internal aerodynamics: complete aircraft, complete helicopter, propellers, turbines and compressors (ducted or not), landing gear, etc. Elsa also simulates aeroelasticity and provides the input data for aeroacoustic propagation software.
This ability to model the most complex configurations is particularly due to the experimental facts offered by ONERA's very rich wind tunnel test databases, as well as on the attentiveness of the industrial sector.

Aeroelasticity, the science of fluid-structure interaction

Aeronautical structures, which are always more or less flexible, vibrate and become deformed when they are subjected to aerodynamic forces. The Elsa software offers the possibility of extending the aerodynamic calculations to these phenomena through "high-fidelity" aeroelastic simulations, through coupling between the aerodynamical model and the structural model.
Aeroelastic simulations improve the prediction of aircraft performance, taking into account deformation while in flight. They ensure the integrity of the structure by checking that no catastrophic phenomena (flutter) have occurred and enable the behaviour to be predicted in some situations, such as a gust of wind.




ONERA

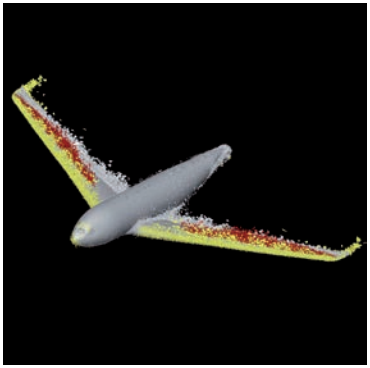
The war on drag never ends

In cruising flight, engine thrust is exactly equal and opposite to the drag, the combination of all aerodynamic forces that oppose its forward motion. In addition, any measures that reduce this drag result in lower fuel consumption, which is both more economical for the operator and more environmentally friendly.

Drag reduction has motivated generations of researchers at ONERA. The simplest and most efficient aircraft in the world are the best reward for their success. After the work carried out on the shape (elongation, winglets) and then on the surface condition (riblets, "shark skin"), that carried out today on the flow control (to prevent the flow from becoming turbulent, to deflect it, to prevent it from separating from the wall, etc.) offers the most attractive perspectives.

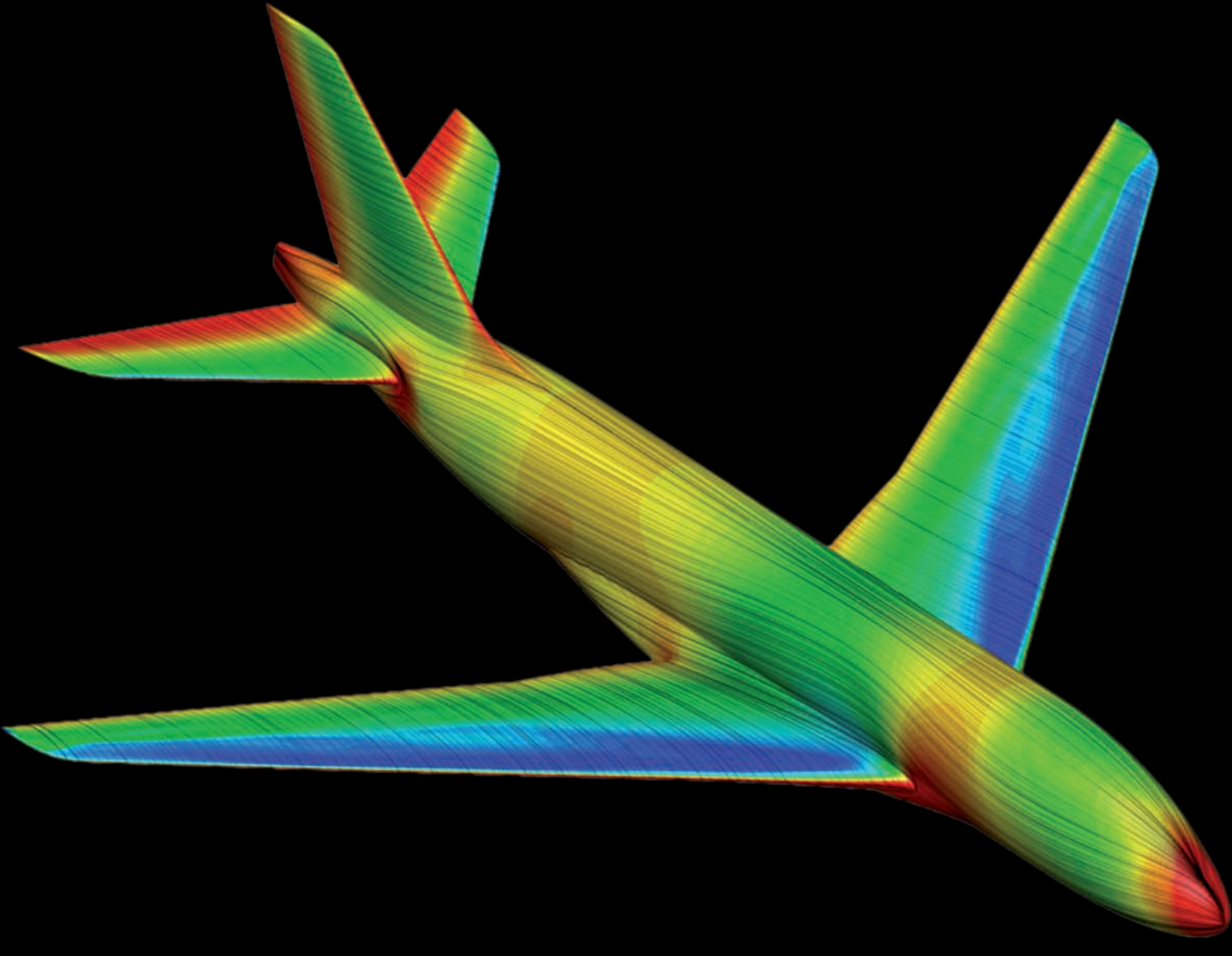
FFD or the smart extraction of drag

The drag on an aircraft results from several phenomena creating resistance to the forward motion: the effect of the wing shape and of the lift distribution (induced drag), viscosity effects (friction, pressure, etc.), compressibility effects (for speeds close to that of sound).



The FFD (Far Field Drag) software operates on the flow field around an aircraft obtained by a numerical simulation like Elsa's. It calculates the various drag components from the effects of the aircraft on the fluid. The decomposition obtained has a real physical sense and is very useful for shape designers. It also enables local sources of drag to be identified.

The FFD software family is commonly used by the manufacturers Airbus and Dassault Aviation.



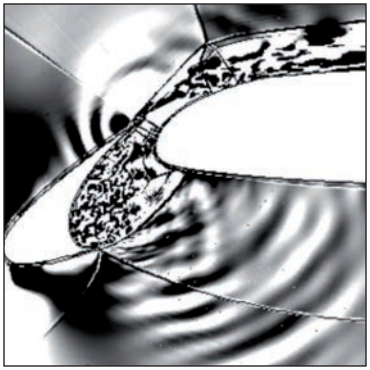
Turbulence and transition, the delicacies of aerodynamics

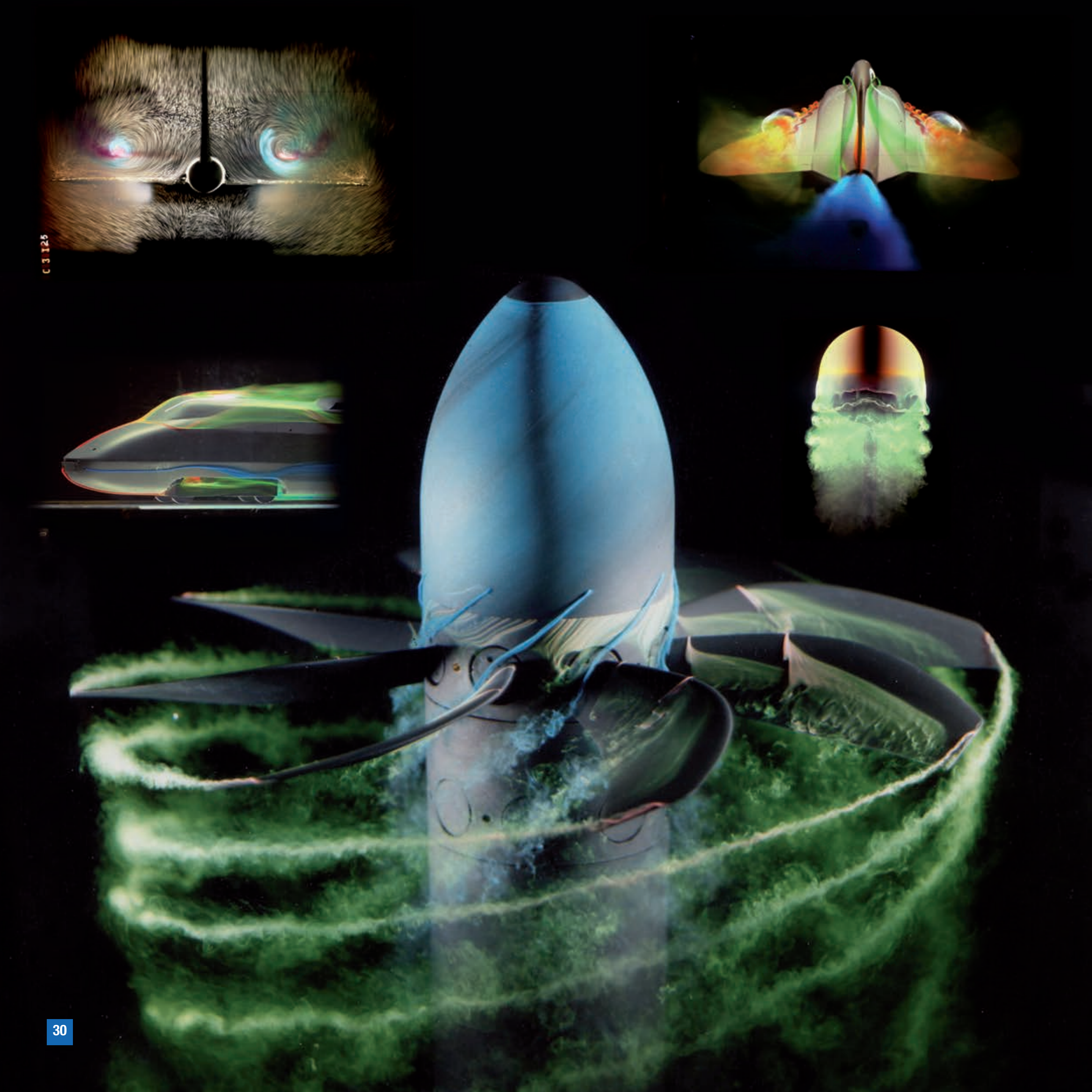
A thin "boundary layer" is formed on the surface of an aircraft in flight, in which the air slows down. Its thickness ranges from a few millimetres to a few tens of centimetres. Early in its formation, this layer is very calm, it is called laminar. Then the air streams begin to oscillate – this is the transition before they become much disrupted and mix – it is turbulence. The state of the boundary layer must be known precisely, because it determines the friction laws of air on surfaces. This wall friction contributes to about half of the drag on the aircraft.
ONERA is recognised worldwide for its theoretical developments to predict transition and turbulent mixing in the boundary layer. These models are included in the ONERA software applications Elsa and Cedre, enabling manufacturers to use them to characterise the flow around complex configurations (full aircraft, etc.) taking into account the "delicate" physics of the boundary layer, without however calculating slight temporal fluctuations in the turbulence exactly (which is not viable for a complete configuration).

ZDES: a model for each zone

Predicting the aeroacoustic sources responsible for noise pollution is an example of a case in which precise knowledge of the fluctuating field in a turbulent flow is required. Such a level of precision is not viable for a complete aircraft, due to the number of points and calculation times.

To meet this challenge, ONERA has developed a method called multi-resolution ZDES (Zonal Detached Eddy Simulation). This method allows an inexpensive time-averaged model and a more advanced model for solving turbulent fluctuations to coexist in the same simulation. This means that the most effective model is used only when it is really necessary, enabling simulation times that are compatible with the existing IT resources.





Looking in the water to understand what happens in the air

The photo library manager is categorical: the most recurrent requests are authorization requests from all over the world to reproduce in publications on fluid mechanics visualizations captured in ONERA's hydrodynamic tunnels. The dissemination of these visualizations have contributed to ONERA's international renown, long after the production of these images ceased (in the 1980s). Visualizations were produced using colored liquid tracers, air bubbles or hydrogen in a vertical glass tunnel, where water flowed uniformly. Under these conditions, low-speed hydrodynamic flows replicated aerodynamic fields efficiently, especially detachment and vortices, making it possible to visually comprehend many of the complex aspects of aerodynamics, and to roughly outline concepts at the pre-project stage. Today, computer simulation and wind tunnel visualization methods such as Particle Image Velocimetry (PIV) have made the use of the hydrodynamic tunnel obsolete.

Submarines and ONERA's wind tunnels

Although the visual experience in the hydrodynamic tunnel is more explicit than in air, it is interesting to measure the performance of submarines in a wind tunnel, to study their maneuvering behavior there. Models of most nuclear-powered attack submarines (SNA), including the Barracuda, and of nuclear-powered ballistic missile launching submarines (SNLE) have thus passed through the Meudon, Saclay and Lille facilities.

With air, it is possible to generate a flow that is quite representative of a realistic water flow for a submarine. Wind tunnels therefore offer many advantages compared to naval traction tanks and hydrodynamic tunnels: the benefit of aerodynamic instrumentation, such as pressure, laser and smoke devices, 6-component balance, etc., without the problem of having to ensure a watertight seal; and, especially, the complete dynamic characterization of a submarine can be carried out in a few days, rather than over several months.

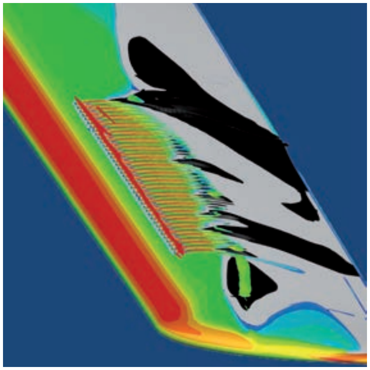

AIRBUS

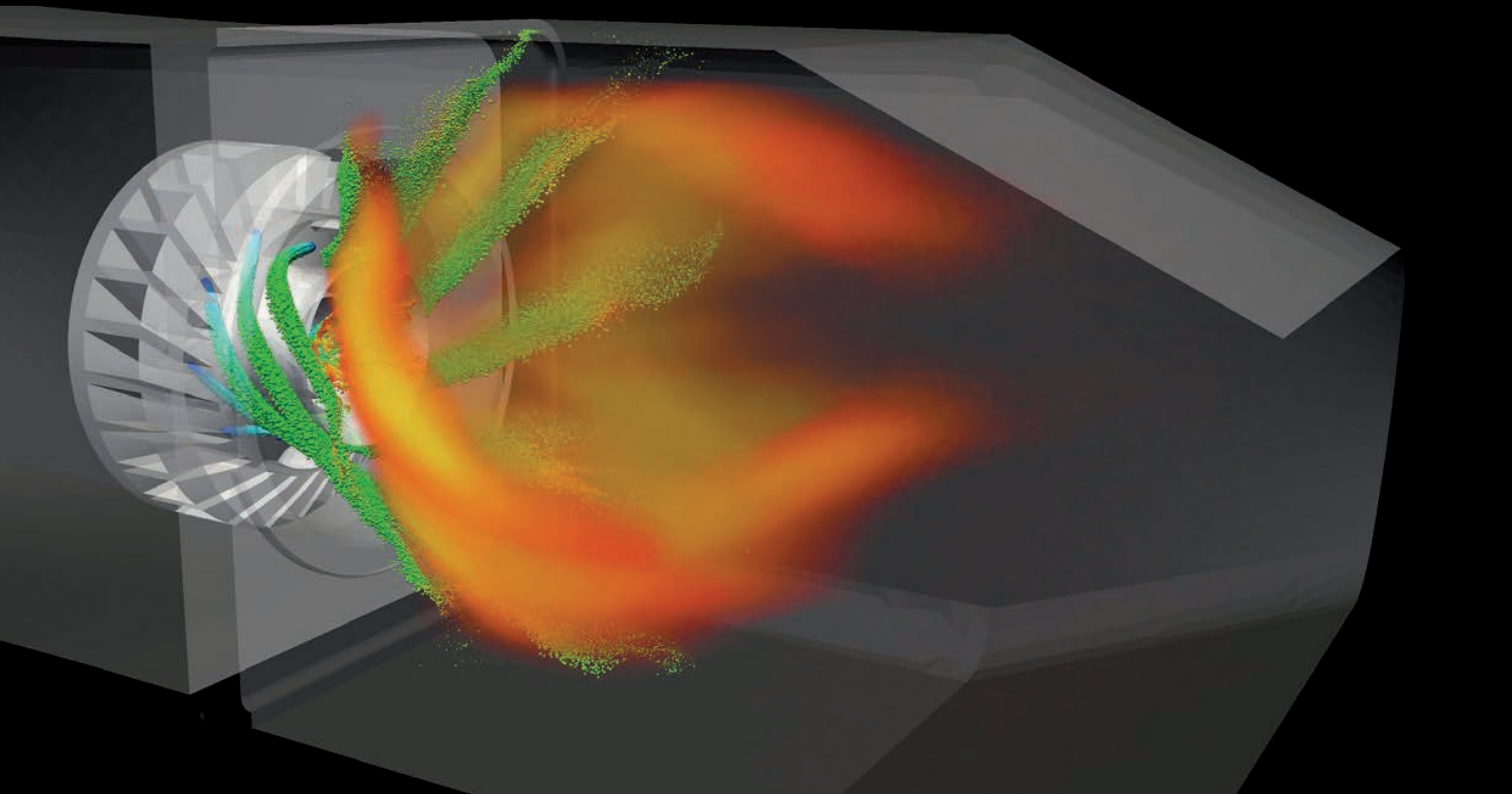
The new CFD, an ally of wind tunnel tests

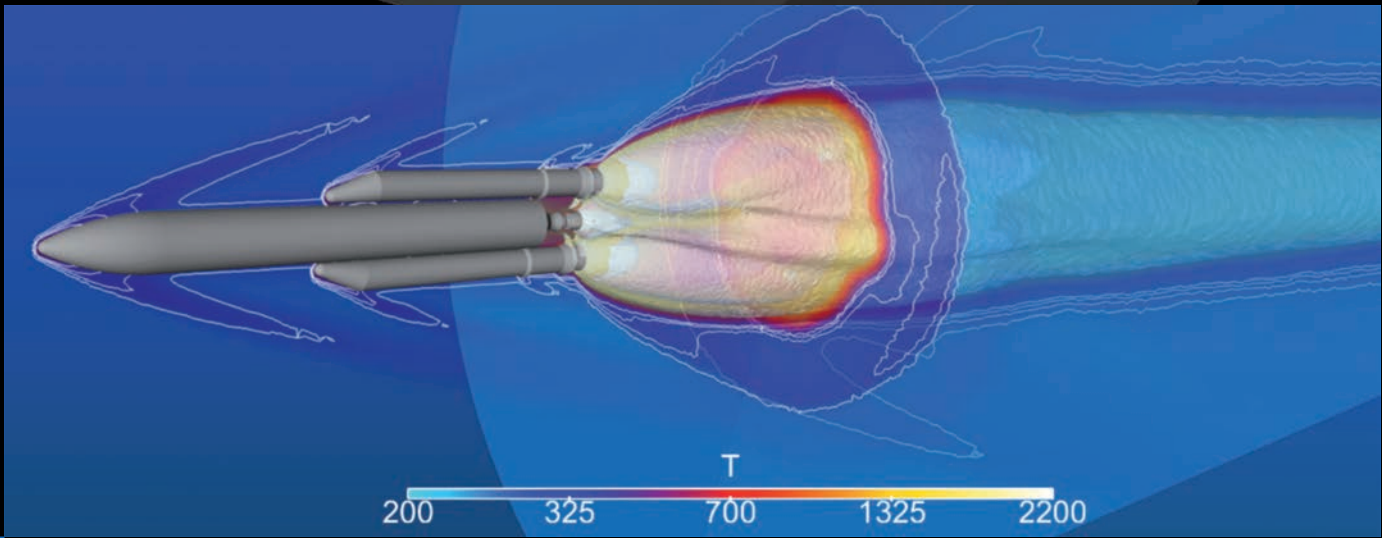
Far from being the demise of wind tunnel tests, CFD (Computational Fluid Dynamics) gives them a new dimension.
The future indeed lies in the joint use of CFD and testing. This association will overcome the difficulties faced by theory. For calculations and tests carried out on a same configuration, "fusion assimilation" helps theory to improve – or regulate – its models, creating the missing link where calculations are uncertain or models are oversimplified.
Conversely, CFD helps test engineers to provide better results. Indeed, where the wind tunnel results are biased due to the presence of the walls and supports (dart, masts), the calculations of the flow around the model installed in the wind tunnel, compared to those for the model alone in an ideal environment, can improve the implementation of the wind tunnel results for flight.

A favourable environment for active control

ONERA is one of the few research institutions in the world to possess such high-level and close skills in experimental and numerical aerodynamics.
This proximity is an advantage for developing and refining innovations in terms of active control, one of the great promising principles of aerodynamics whose goal may be for example drag reduction or vibration control. Active control is based on measurements made by sensors and flow control through actuators. CFD is very useful to simulate, optimise and understand phenomena and to design devices that will be validated and refined under the actual flow of the wind tunnel.





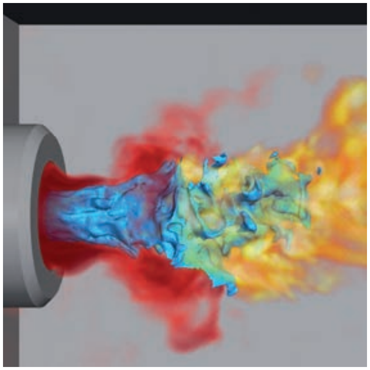

T
200
325
700
1325
2200

Cedre forgets no physics

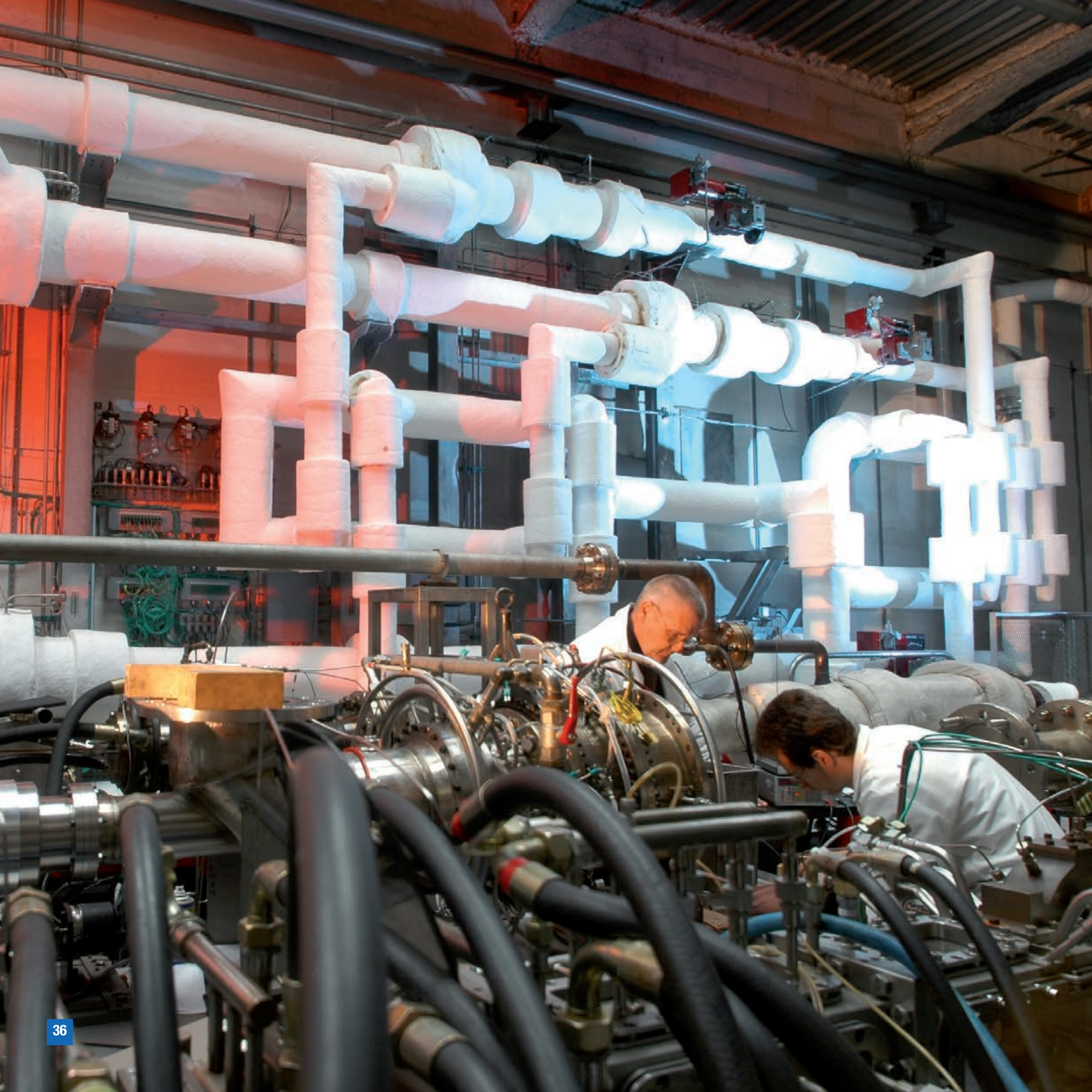
In 2002, the DGA, the CNES and ONERA decided to establish a national unifying calculation software capable of handling all energetics and aerospace propulsion problems. Given its features and its potential, ONERA's new calculation tool Cedre was selected. Today, Cedre's development continues through both ONERA and national programmes. Its multi-physics capabilities make it a popular tool for many national, European and international research and industrial projects. The software is distributed between Safran (Snecma, Herakles, etc.), MBDA, the CNES, Airbus Defence and Space, etc.
Cedre capitalises on decades of expertise in experimentation and multi-physics modelling for all kinds of applications: missiles, ramjets, launchers, civil and military aircraft, space probes, etc.

What is multiphysics?

Energetics is the science of energy under transformation. During the combustion process (simplified), energy arrives in a chemical form, concentrated in the fuel (kerosene, ergol propellant, or propergol propellant), to be converted into heat (thermal energy) and finally to be transformed into thrust (mechanical energy).



Cedre models describe the physics of chemistry, thermodynamics and aerodynamics. Interaction models are also needed: thermochemistry, aero-thermodynamics, liquid-gas interactions, radiative transfer, etc. Cedre, endowed with specialised "solvers", takes into account all of these fields of physics and their interactions. Furthermore, Cedre can be coupled to other more remote physics software applications: solid mechanics, acoustics, etc. Reality is by nature multi-physical...

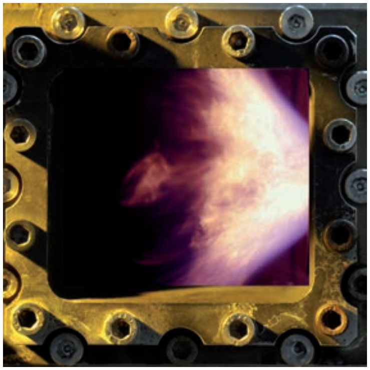


Pollutants are tracked down with combustion test benches

ONERA's test benches are not intended to test engines before their first flight! They are means to test the environmental and economic performance of innovative combustion chamber designs, on demonstrator models.
These research tools simulate realistic engine operating conditions: cruising flight, take-off, restart, etc. ONERA particularly implements one of its specialties in them: combustion laser metrology, which enables vaporised kerosene, OH radicals (flame markers), pollutants, soot concentrations, etc., to be visualised. The data from these experiments are valuable: they allows designs to be certified and offer a basis for the validation of combustion numerical models. These models, integrated into software applications like Cedre, can further improve the design of future engines.

Tosca: a low NOx architecture undergoing tests

NOx, or nitrogen oxides, are a major source of air pollution. The EU has required that the NOx emitted by engines be reduced by 90% by 2050 (based on that of the year 2000).
Safran Aircraft Engines designed Tosca, a combustion chamber architecture aimed at meeting part of this challenge. Tosca has two concentric flame zones: the main zone, which is poor and a weak producer of NOx, and a central zone that is rich but that has a lower flow rate, stabilising the combustion of the main zone.
ONERA tested this chamber on the M1 bench and was able to propose architectural optimisations to the engine manufacturer. Overall result: a 60% gain over the NOx, while retaining all operability and safety qualities, including re-ignition at a high altitude.



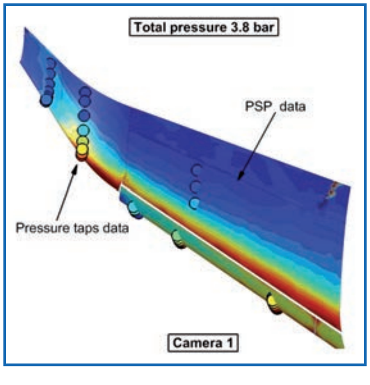

ONERA

The parietal art of wind tunnels

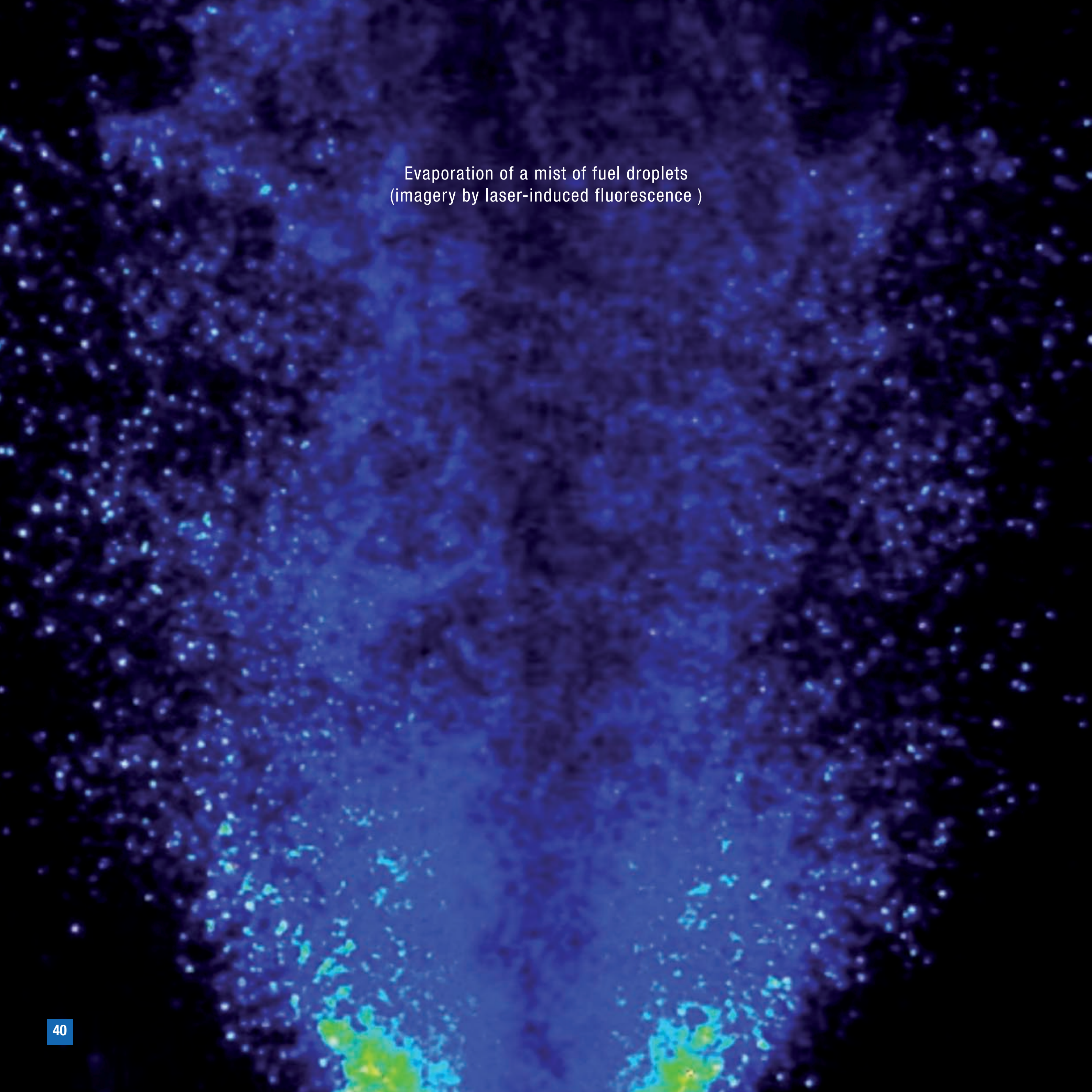
In the 1990s, ONERA acquired, through the TsAGI (ONERA's Russian counterpart), pressure sensitive paint that enables the analysis of aerodynamic flows on the surface of models tested in a wind tunnel. ONERA very quickly decided to develop its own paint, so as to have end-to-end control of this technique. As early as 1995, ONERA's large wind tunnels adopted this new means of pressure measurement and adapted it to the requirements of industrial testing. It offers genuine advantages, with precise mapping of the pressures over the entire surface of a model, making it possible to explore areas of the model that could not be equipped for that purpose before. The precision achieved with PSP paint makes it possible to recalculate the forces on some load-bearing components, providing a real advantage for manufacturers.

ONERA at the cutting-edge of PSP

With the support of the CSEM (Swiss Research and Development Center), ONERA has developed a new type of paint called uPSP (for "unsteady" PSP). This new nano-porous paint allows the measurement of unsteady phenomena, i.e.: phenomena that are variable over time up to 5,000 Hz. This is a major innovation that allows other areas of aerodynamics to be explored, such as instabilities and turbulence.



These new testing resources have prompted ONERA to develop its metrology capabilities. Significant developments have been achieved with regard to the processing of images, because although the nano-porous paint allows very high acquisition rates, it also involves processing thousands of images, and this processing is made possible by the use of massively-parallel computers (GPU clusters).



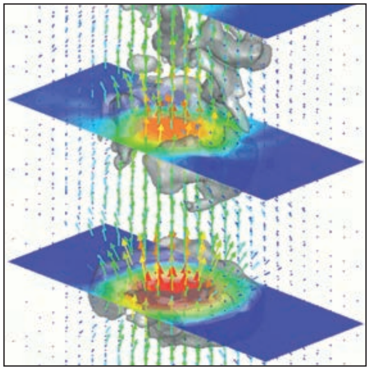
Evaporation of a mist of fuel droplets
(imagery by laser-induced fluorescence)

Champions of non-intrusive measurement

Performing non-intrusive measurements in a flow is doubly interesting: equipment does not need to be placed in a potentially hostile environment (very hot, hyper-swift) and the flow is not disrupted. The laser indeed behaves like a light sensor that comes to encounter molecules or particles: it sends information regarding to a detector, such as speed, temperature, species concentration, etc.
Laser measurement techniques have been developed at ONERA for over 30 years. There is a wide range of effective methods available (LDV, CARS, LIF, FFE, PIV, etc.) that are well suited to all kinds of environments. ONERA often achieves world premieres, to the benefit of its researchers in physics, energetics and aerodynamics. Some spectacular measurements: the determination of the gas species emitted by an aeronautical combustion chamber, the temperature of a flame at 60 bar in liquid oxygen undergoing combustion, the measurement of the atom flux at the outlet of a satellite engine, etc.

PIV3D and BOS3D: computer assisted measurements

In imaging metrology, PIV (Particle Image Velocimetry) provides the velocity field of a fluid and the BOS (Background Oriented Schlieren) is sensitive to the density variations of a compressible flow. These methods are commonly used for visualising plane sections of a flow.



The use of new laser illumination techniques, multi-camera acquisition systems and especially the use of computers now make it possible to measure volumes, that is to say, to obtain instantaneous 3D numerical representations of the structures of a flow.
ONERA is at the forefront of technology in terms of PIV3D and BOS3D techniques, with unique experiments and efficient numerical methods implemented on massively parallel calculators, such as GPUs (Graphical Processing Units).

Are alternative fuels aero-compatible?

Biofuels are derived from biomass (wood, some plants, microalgae, etc.). They complete a fossil fuel (Jet A-1 kerosene, used worldwide in civil aviation). They are renewable, which results in a very advantageous overall CO_2 balance. They are also an asset for the survival of the sector at a time when oil resources are scarce. Biofuels must adapt to aircraft engines, and not the other way around: they must be "drop in", ready for use in existing engines. ONERA chemists are exploring the behaviour of the reference fuel throughout its operation chain and are implementing tools to ensure the compliance of new ones. Examples of constraints: remaining liquid at -47°C, not being too thick or too acid and having an energy density comparable to that of Jet A-1.

Military aircraft must also pass

ONERA is the DGA's expert for checking and preparing an upcoming engine certification (Safran Aircraft Engines) for the Mirage 2000 and Rafale aircraft (Dassault Aviation) using alternative fuels.
Indeed, during exercises or joint operations with the United States, these devices could be required to refuel with fuel already containing a high proportion of alternative fuels. This will require the engines and aircraft to be properly certified to be used in such an interoperability context.


ONERA
S2 Modane

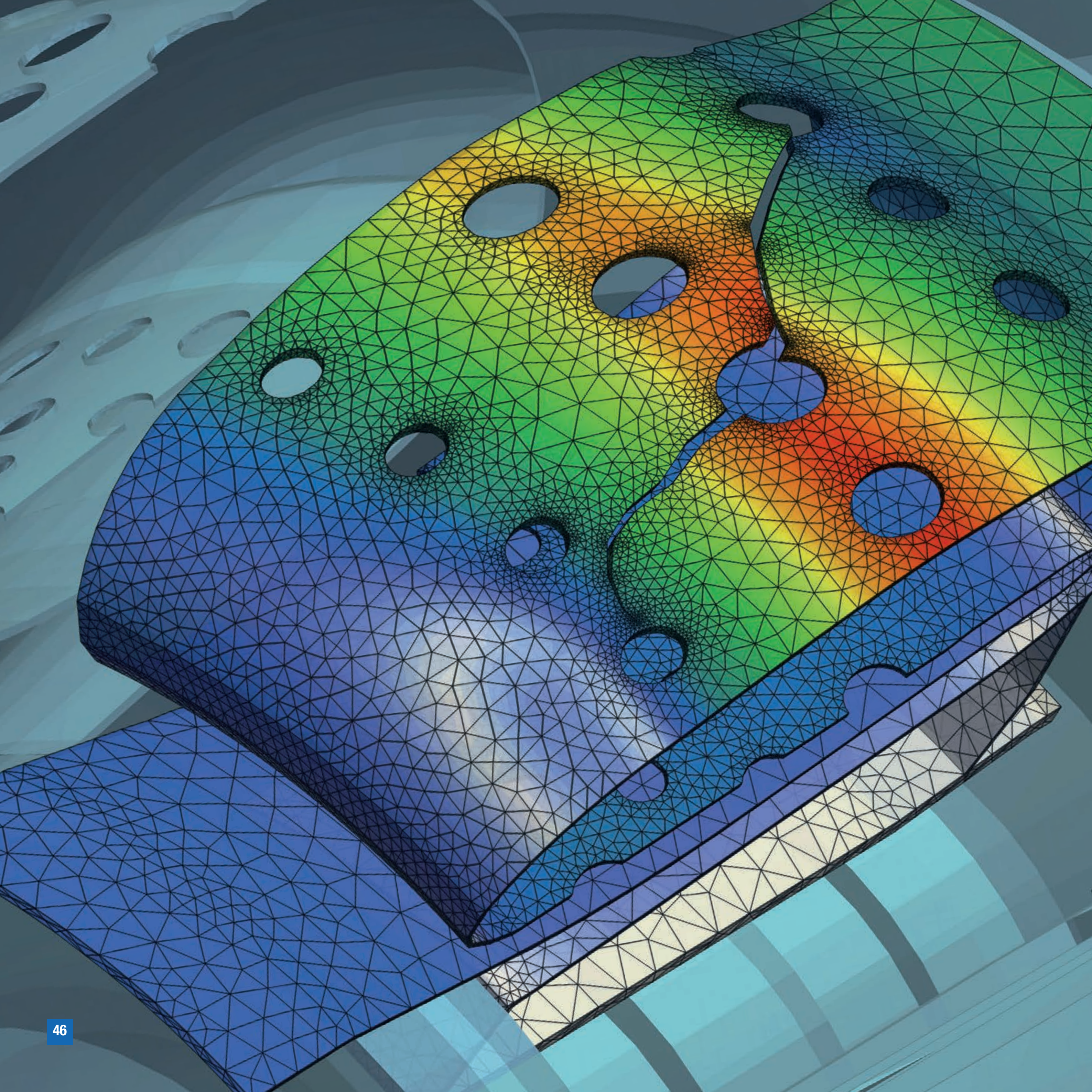
Flutter: prevention is better than curing

In 1946, French aeronautics were reborn. New aircraft with unprecedented performance soared in flight. Some were damaged or even destroyed in flight. ONERA was called in to address the problem. The culprit was often found to be flutter, a wing or tail surface vibration phenomenon, of aerodynamic origin, which amplifies and can deform the structure until it is ruined. ONERA has learned to predict, on each new aircraft, the conditions under which flutter occurs, in order to define a safe flight envelope, or even to change the structure.
Today, ONERA has Airbus' trust with regard to this critical subject: calculations and wind tunnel testing during the design phase and vibration tests on the ground before the first flight. ONERA also provides the identification procedures and the analysis tools for the behaviour of aircraft subjected to flight envelope opening and certification tests.

Vibration tests on the ground: last tests before flight

An important event in the life of a transport aircraft is the one just before its maiden flight: Ground Vibration Testing (GVT). For the Airbus range, these tests are carried out by an ONERA team, together with a team from its German counterpart the DLR.

For this veritable structural check-up, the plane is shaken in all directions with actuators in ways that make it vibrate. Hundreds of sensors (accelerometers) measure responses to the various excitations. Gigabytes of data are analysed on-site and transmitted to the aircraft manufacturer, which can then readjust its numerical model and check by means of simulations that the airplane is actually ready to fly safely.



Zset-Zebulon, the material mechanics crack

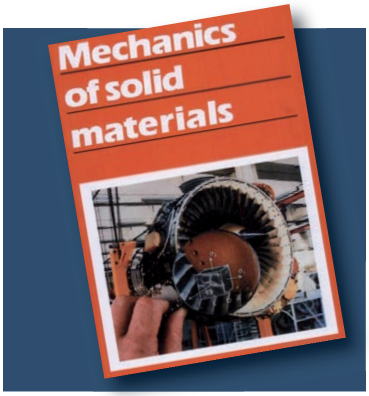
In an aircraft engine, there are highly stressed parts at very high temperatures (some turbine blades rotate at more than 20,000 rev/min at 1,200°C). As from the design, it is important for the manufacturer to have a good idea of the life of these critical components.

Zset-Zebulon is the tool for this prediction. The result of over 30 years of collaboration with the École des Mines de Paris, this software package capitalises on a number of behaviour patterns enabling their use in structure calculations. It can be coupled with fluid mechanics software (such as Elsa or Cedre) as a comprehensive multi-physics approach.

The Zset suite is marketed. Key long-time customers belong to the aerospace (Safran), automobile (Renault, PSA, GM, etc.), energy (CEA, EDF, Areva) and materials (Saint-Gobain, 3M, ArcelorMittal) Industries.

The French School of Material Mechanics

Have you heard of Chaboche models? If you're a material mechanics engineer, teacher or student it is likely that you have. In 1985, together with his teacher Jean Lemaître, this ONERA researcher published "Mechanics of solid materials", a unanimous reference text in lecture halls and design offices worldwide. These two specialists were the initiators of a quest for excellence, a true French "school" of material and damage mechanics.



The work of Jean-Louis Chaboche and his colleagues have produced crucial publications, as well as many Zset-Zebulon models (non-linear changes, fatigue, damage, cracking, etc.). In 2014, they were awarded the Erea Prize (Association of European Aeronautics Research Centres).


CHARGE MAXI
700 daN

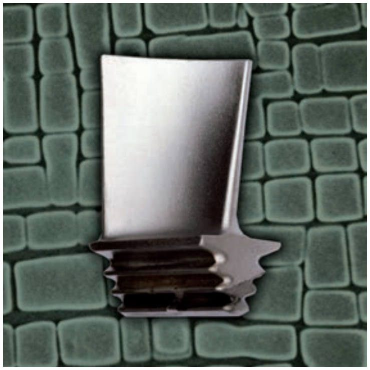
Superstar superalloys

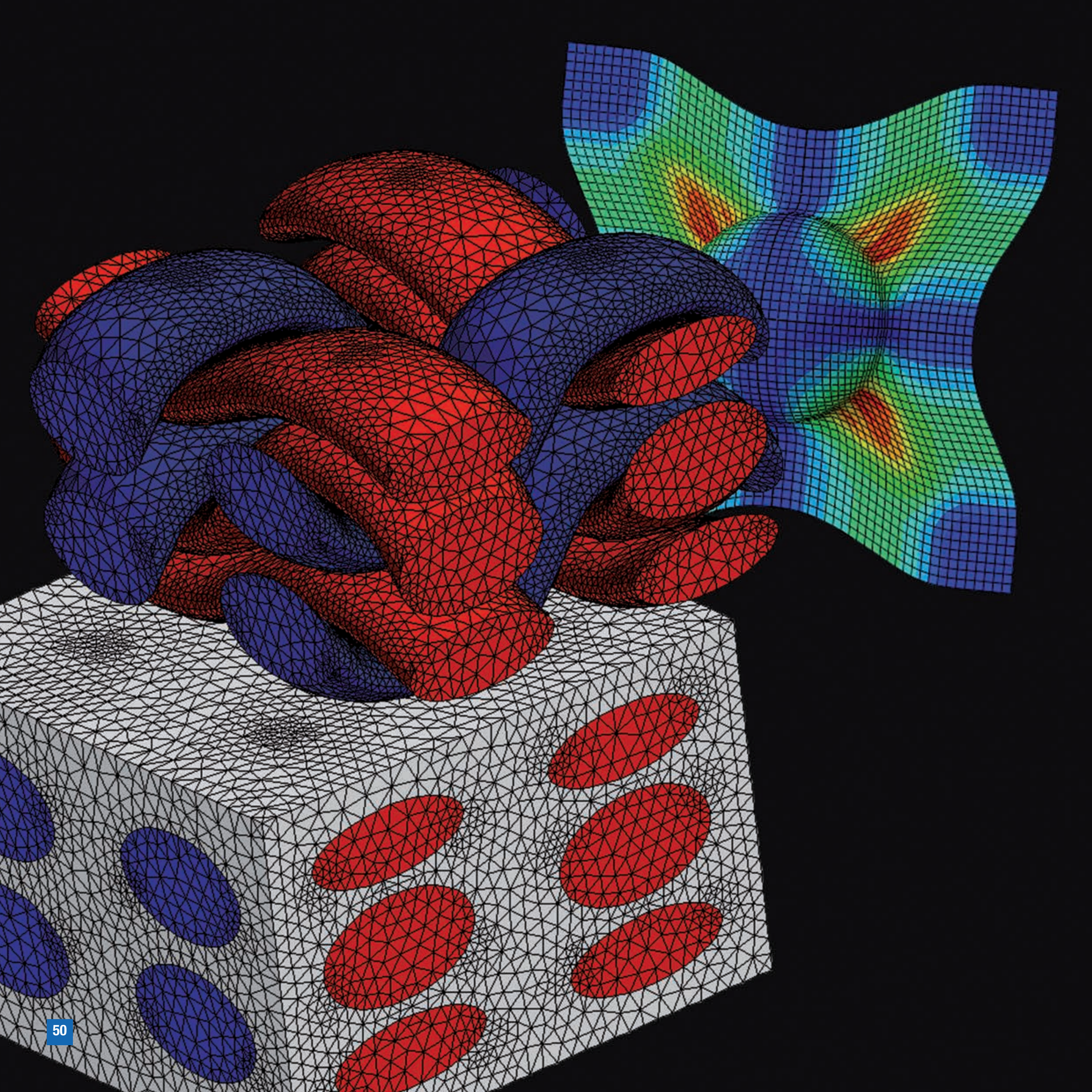
Aircraft engines components are made of metal alloys. Some are subjected to extreme temperatures (up to 1200°C) and can compromise the engine, or even the entire aircraft, if they break. Superalloys, alloys with exceptional properties obtained through the precipitation of hardening components, are highly resistant to heat, as well as to corrosion and deformation.

Since the 70s, ONERA, which has patented new compositions, has comprehensive expertise: in chemistry, with regard to the design of the alloy; mechanical, with regard to the modelling of the life of the component; and metallurgical, with regard to the understanding of the microstructure. Thus, ONERA is the partner of the Safran Group engine manufacturers, always seeking to develop engines with ever improved yields.

ONERA's superalloys are in the air

ONERA's patented (or co-patented) superalloys are used by the engine manufacturers Safran Aircraft Engines and Safran Helicopter Engines. The turbine blades and disks of the Rafale M88-2 engine are respectively made from the materials AM1 and N18. The blades of the TP400 (A400M), SaM146 (Sukhoi Superjet 100) and Silvercrest (Citation Longitude and Dassault Falcon 5X) engines are made of AM1. The Arrius 2 and Arriel 2 turbines that power the helicopters of Airbus Helicopters, Agusta and Bell, etc., contain ONERA's superalloys MC2 and AM3. Under development: the N19, along the lines of the N18, which is aimed at extending the life as regards fatigue.





Composites, one of the keys of sustainable air transport

A composite material is an assembly of at least two integral components whose properties are complementary. Aeronautical composites – often based on carbon fibres and resin, are light weight, resistant to corrosion, easy to shape and offer durability over time. While they meet current challenges (environment, cost), they are more susceptible than metal alloys to external aggressions (hail, lightning, slight impacts).
Who has been able to develop innovative methods for testing these materials? Who has the necessary perspective to take into account technical and industrial problems? Who has understood that it wasn't merely a case of "an additional material" but really a new field deserving its own methods from design up to certification? ONERA.
With 40 years of experience and maintaining a permanent dialogue between numerical analysts and experimenters, ONERA is one of the most expert laboratories in the world as regards composites.

ONERA's expertise, a lever for innovation in the automotive industry

ONERA, as a technical partner of the Centre Technique des Industries Mécaniques (technical centre for mechanical industries) has designed and tested an "all composite" suspension triangle for PSA Peugeot-Citroen, which is a world first. The automotive sector became interested in our research to benefit from our aerospace expertise, in order to reduce the mass and produce less CO_2, while developing "automobile" productivity industrial processes.

In order to predict the behaviour of the component once in place, ONERA implemented its numerical models, as well as the experimental facilities necessary for their evaluation. This ONERA "composite" expertise, unique, is increasingly sought outside the field of aerospace, such as in transport (PSA, Renault, Valeo, etc.) and energy (CEA, Areva, Technip, etc.).

Extreme materials for well-targeted applications

Ceramic Matrix Composites (CMC) have a future in high temperature applications: aeronautical engines (turbo-machines), or structures heated by speed, while Organic Matrix Composites (OMC) are commonly used for structures (wings, fuselage, etc.).
For the rear structure of engines, ONERA is developing oxide-oxide CMCs, in partnership with an SME. They are less heavy and are better resistant to temperature than the titanium usually used (1200°C vs. 650°C), and they are also much less expensive to manufacture.
Another low-cost material, a ceramic based on polymers designed by MBDA for hyper-swift missile warheads (Mach > 5) and able to withstand a temperature of 1200°C for a few minutes.
Finally, ONERA is developing "eutectic" composites for manufacturing turbine blades without cooling channels. They have very good mechanical properties and are able to withstand temperatures of 1600°C. This is a longer term R&D challenge.

High temperature, very strong… and transparent!

ONERA is developing very transparent ceramics with excellent thermomechanical properties, from alumina (Al_2O_3) and spinel ($MgAl_2O_4$) powders hot-pressed (to densify the material and reduce the porosity to the maximum). Defence applications range from missile windows transparent to visible and infrared light, to armoured glass (for combat helicopters, for example). These transparent ceramics offer, with three times less thickness, shielding equivalent to that of a conventional bullet-proof glazing.
ONERA also produces crystals for infrared tunable lasers (OPO) used for counter-measure applications, which are highly stressed thermally and mechanically. ONERA is the only one in Europe that is making this strategic material.

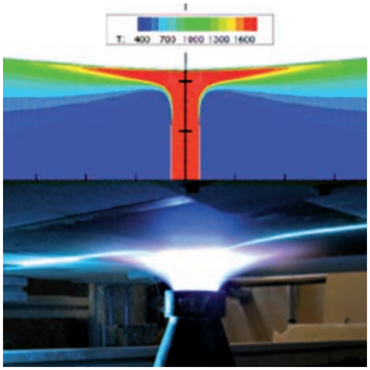

ONERA

Crashes, impacts, fire: a survivability objective

Studying crashes in the field of structures, does not consist in simply addressing the strength of the fuselage, wings or engines to impacts, such as birds, hailstones or debris, etc. It is also consists in increasing survivability; that is to say, a passenger's chances of survival under the harsh conditions of a forced landing, with the risk of fire or immersion.
International authorities (FAA, EASA) have set safety objectives for manufacturers. ONERA, together with the DGA and the DGAC, helps European industry to meet these in the most technically and economically efficient way. ONERA is studying the external dynamic loads from the finest material scale up to structure (wing, fuselage) qualification. Numerical tools such as Abaqus and Radioss, used by international players in the field, are standards that ONERA is helping to improve. The research is leading to software development, for example with the CEA and the Joint Research Centre of the European Commission (JRC Ispra).

Fire, the number one cause of death in the event of a crash

One of the major challenges related to the design of aeronautical structures is the behaviour of materials in fires. The increasing use of composite materials involves taking into account combined aerodynamic, thermal, chemical and mechanical effects.



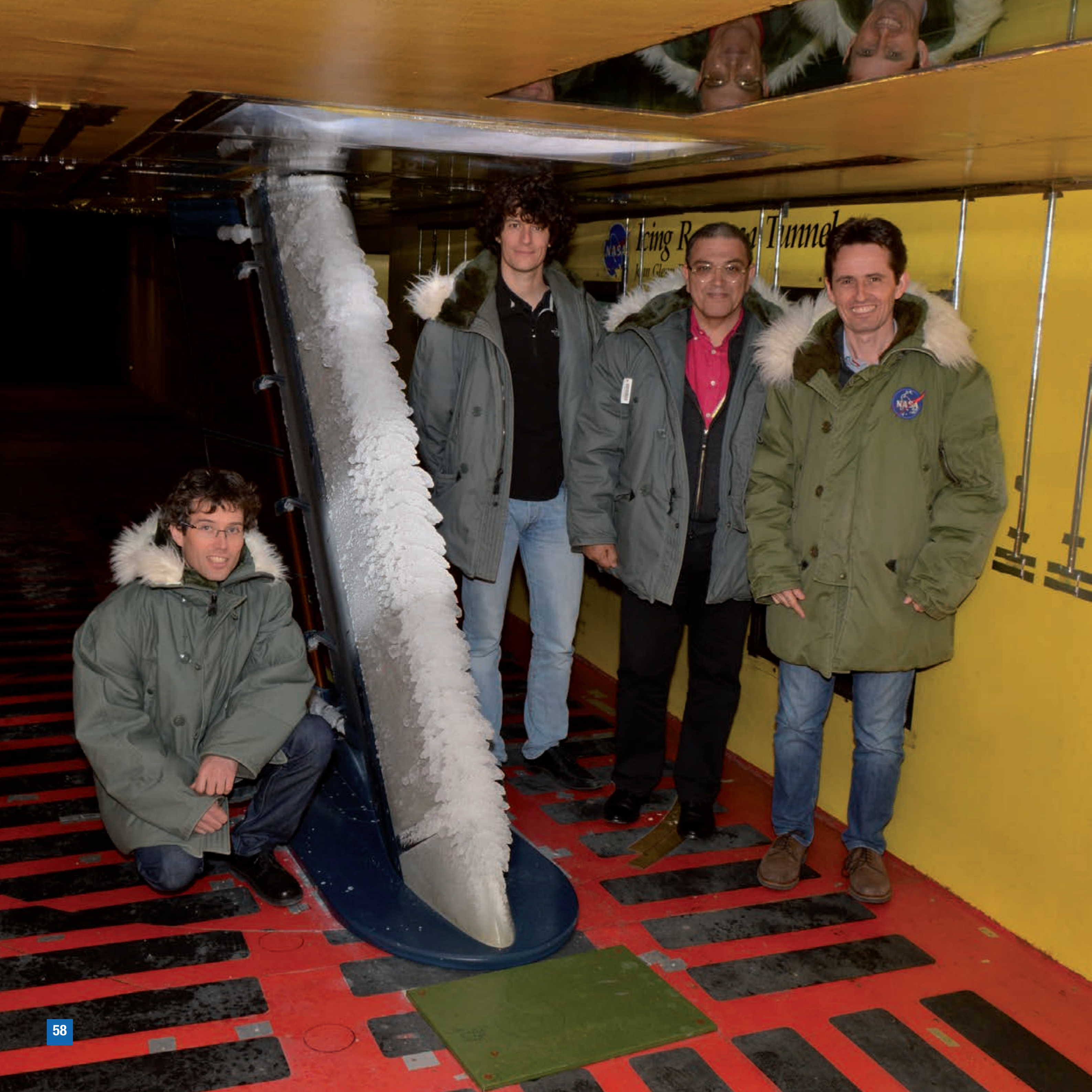
While the fire certification of these materials is established experimentally through standard fire testing (ISO and FAR standards), ONERA is conducting research aimed at understanding the physical phenomena involved, at ensuring better management of the safety margins and at anticipating new problems. ONERA is in particular developing numerical models integrating industrial constraints, without neglecting the confrontation with experiments on a laboratory scale.

Knowing lightning well prevents disasters

Lightning and its consequences, are a globally recognised ONERA expertise, a competence nurtured for 40 years with experiments in the laboratory and in flight, as well as with theoretical developments and with discussions with aircraft industrialists and operators.
In the 70s, lightning in the clouds was observed by launching rockets connected to the ground by a metal wire. Today, industrialists come to ONERA to seek the best expertise in the design of composite structures and electronic equipment that are not vulnerable. Researchers cause lightning "in silico" (through computer simulations) and observe virtual damage. The experiment bench can be reset for a complex physics, to obtain increasingly accurate and reliable models.

In Kourou, lightning does not strike launchers

ONERA EMC specialists have contributed to the definition and optimisation of a lightning protection system for the Ariane, Soyuz and Vega launch sites.
Using their models, they computationally simulated the magnetic fields and currents following a lightning strike on one of the four interconnected towers protecting the launch tower.
Their expertise has gone beyond this: by injecting strong currents representative of those caused by lightning, they have revealed anomalies and poorly protected areas on site, thus contributing to the compliance of the protection system.

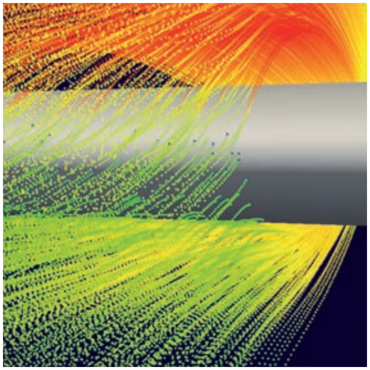


Acting against icing

Icing is the most dangerous weather phenomenon for air transport. ONERA has always studied the phenomenon on aircraft and engines: first through the "natural" conditions of its alpine wind tunnels (Mont Lachat and then the S1 Modane). Since the 80s, ONERA has addressed the issue through modelling and numerical simulation. Its software is used by all French industrialists in the sector. Since 2000, ONERA is considered to be the European reference for modelling icing.
Today, certification requirements have become stricter; protection against icing must be energetically optimised in parallel. ONERA is at work, particularly within the context of the DGAC Physice Agreement to develop second generation numerical tools and on-board measurement systems. Objective: to characterise icing conditions and prevent the formation and consequences of icing within a safer regulatory framework.

A NASA-ONERA collaboration able to face the challenges

The new international regulations are leading aircraft and engine manufacturers to review the compliance procedures. They must prove that icing cannot bring down the plane in any case. Given the diversity of situations, the use of numerical simulations has become inevitable, with increasingly refined software.



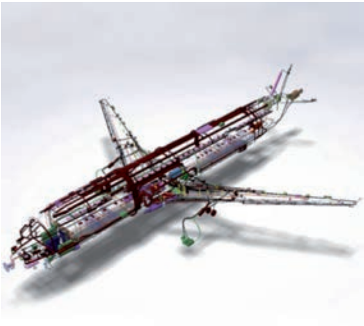
The ONERA-NASA agreements Sunset-1 (2006) and Sunset-2 (2013) are impelling the work decisively. NASA simulates the formation of ice on a wing in an icing wind tunnel. A 3D scanner enables the shape to be digitalised, in order to manufacture resin moulds and to study the deterioration of aerodynamic performance in the ONERA F1 wind tunnel, one of the world's best in its class, and to create data to validate the software. However, the issues raised are daunting. For example: what degree of detail in the shapes is suitable for representing the physical reality satisfactorily?

Safer, more reliable aircraft. Who should we thank?

Achieving high performance and ensuring safe behaviours of complex systems such as aircraft, launchers, satellites, etc., despite uncertainties and failures, in a potentially disrupting environment, that is the challenge.
It is now about 20 years since ONERA researchers, unanimously recognised by their peers, have been developing high-level mathematical tools and have been capitalising on them to make them usable by industry and research centres around the world (in the form of Matlab® functions). It is a matter of robust control and a systematic method for the estimation, analysis and validation of control laws and optimisation.
The expertise extends as far as demonstrating the value of control techniques to the certification authorities.
In terms of safety and reliability, aircraft manufacturers and passengers can say thank you to ONERA!

Certification of critical software

ONERA develops methods and tools for implementing critical functions, such as flight control laws, in the on-board computer systems. The objective is to obtain software without bugs, with controlled development and checking costs. ONERA is currently working on computer architectures that will use a new generation of processors – "manycore processors".
In the field of aeronautics, software must be certified to be able to be included on-board. ONERA has extensive expertise in the field of certification and has participated in the writing of standards within the field (DO-178C and DO-333).

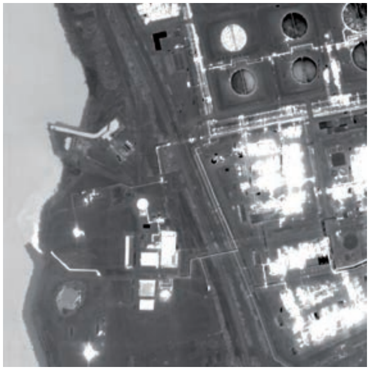


Pod Reco-NG: a real gem under the Rafale

The performance of the Reco-NG pod (aka the Aeros nacelle) has been a major asset for French tactical intelligence, since its adoption by the Armed Forces in 2011. The aircraft performs visible and infrared photographic reconnaissance at both very low and high altitude, over both short and medium range, and at both high and very high speeds. The optical sensors can rotate through 180°, can target a zone and be oriented at several angles, regardless of the aircraft's mission profile, while respecting the parameters predefined by the interpreters. Lastly, high-resolution digital images can be transmitted in real time via a dedicated link. In 2017, Reco-NG remains state-of-the-art.
Back in 1996, ONERA aided the DGA in the definition of the specifications. In 2000, the DGA placed an order with Thales, qualifying the nacelle in 2009, which is still supported by ONERA. Over this period, more than 20 ONERA staff members have been involved.

A complex system, brimming with brilliant science

Everything to please ONERA's research engineers! Specialists in optronics and image processing have naturally been involved in the pod's chain of intelligence. ONERA's airborne multispectral imaging laboratory, Timbre-Poste, designed for satellite imagery, was in great demand to simulate future images, in close relation with the interpreters.
Radar technicians have proposed SAR imagery in the pod. This has not been adopted at this stage (due to the lack of technological maturity).
Lastly, aerodynamics technicians have used wind tunnels and computer simulations to determine a nose shape for the pod, generating the fewest possible aero-optical effects.

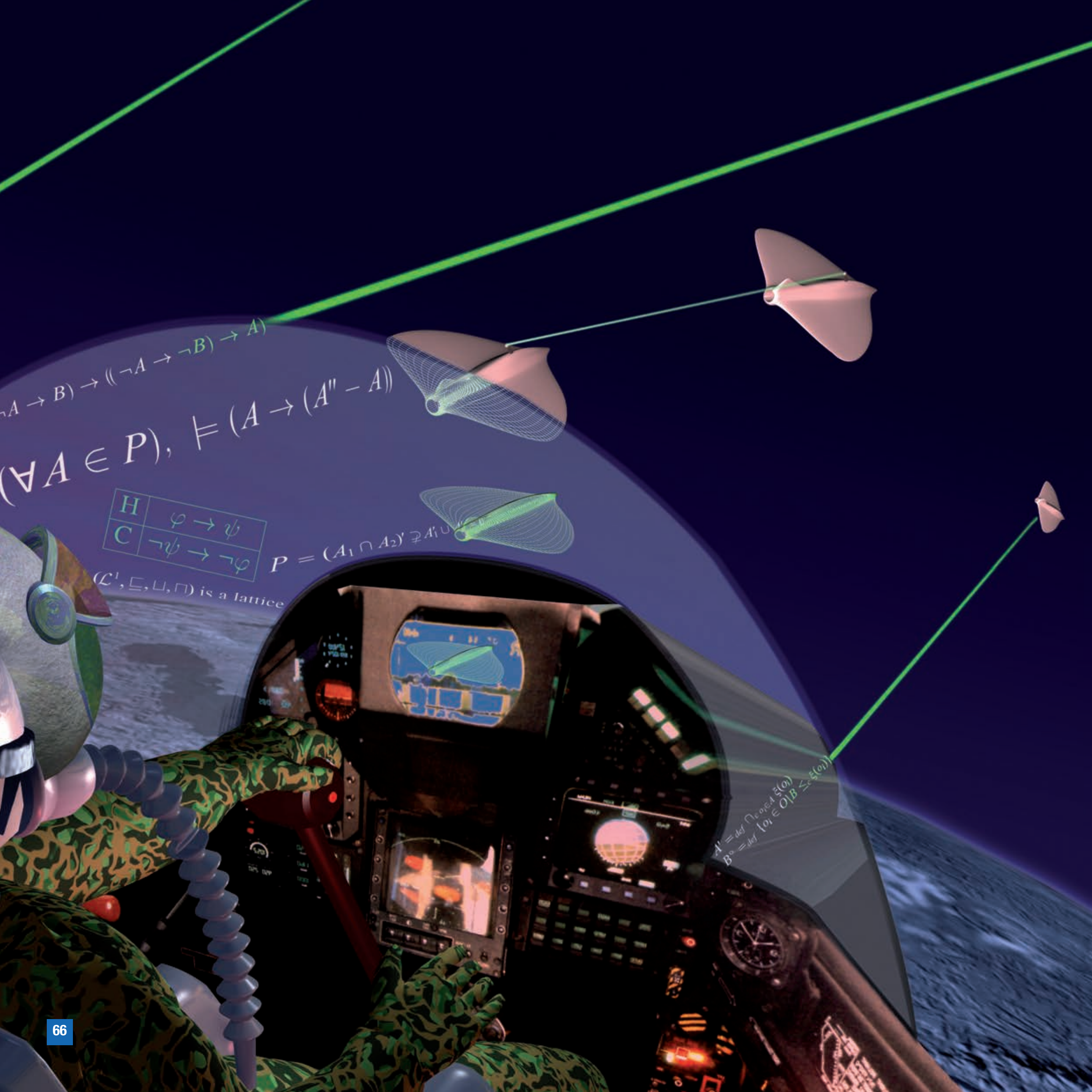


Autonomy means the ability to make decisions

Swarms of combat drones, satellite constellations, or cooperating sets of drones manoeuvring in various environments must perform their missions with a high level of autonomy. For this purpose, they must be equipped with a set of connections – a "brain" and a distributed artificial intelligence that can enable them to achieve their goals while ensuring operational safety.
The autonomy of such systems involves having decision capabilities when faced with information from multiple sources which may be incomplete or inaccurate. The work developed thus lead to the development of uncertainty models and to the implementation of algorithms... All using on-board systems able to implement their decision method in real-time, in coordination with other autonomous entities.

Heterogeneity strengthens the union

In the Action project, ONERA demonstrates the interest of implementing a team of heterogeneous autonomous drones to optimise the location and global navigation functions of this team involved in complex missions.
These autonomous drones have a generic on-board architecture including elaborate software functions: perception of the environment, situation assessment, decisions regarding what to do and strategies to be implemented in response to new information.
Demonstrations are conducted with unmanned aerial vehicles (ONERA's Ressac), terrestrial robots (together with the systems analysis and architecture laboratory of the CNRS – Laboratoire d'Analyse et d'Architecture des Systèmes) and submarine or surface drones (DGA).


$\neg A \to B) \to ((\neg A \to \neg B) \to A)$
$(\forall A \in P), \models (A \to (A'' - A))$
H | $\varphi \to \psi$
C | $\neg\psi \to \neg\varphi$
$P = (A_1 \cap A_2)' \supseteq A_1' \cup$
$(\mathcal{L}', \sqsubseteq, \sqcup, \sqcap)$ is a lattice

And where is the human aspect in all of this?

Since the advent of electrical controls on airliners (late 80s), the place of humans in the cockpit has changed. The pilot no longer acts, strictly speaking, on the flight controls; he has become a supervisor who manages an increasingly complex and automated system; he nevertheless assumes responsibility together with the other players in the airspace.

The design of interactive systems is now centred on the user and usage. It is enriched with feedback, a topic on which ONERA and NASA are working together with the airlines. Situation assessments enable researchers to develop algorithms and measurement means to characterise patterns of behaviour, analyse the interactions with the system and detect the difficulties encountered and lack of attention. Main objectives: to improve the performance of the systems, particularly enhancing safety, etc., by ensuring that the human can play his part well where it is expected.

Human factors are also important for drones

While the legislation does not yet allow unmanned aircraft to operate in airspace frequented by manned aircraft, ONERA is conducting research on their integration into air traffic.

Like any aircraft pilot, the UAV pilot must ensure the flight safety and in particular "see and avoid". He must be able to apply air traffic control instructions in an informed manner and, when the separation is up to it, the drone must maintain a safe distance from other craft. ONERA is thus working on the role of the pilot and his interactions with partially automated detection and avoidance functions, taking into account the limitations inherent to remote piloting, such as communication times and lack of environmental perception.

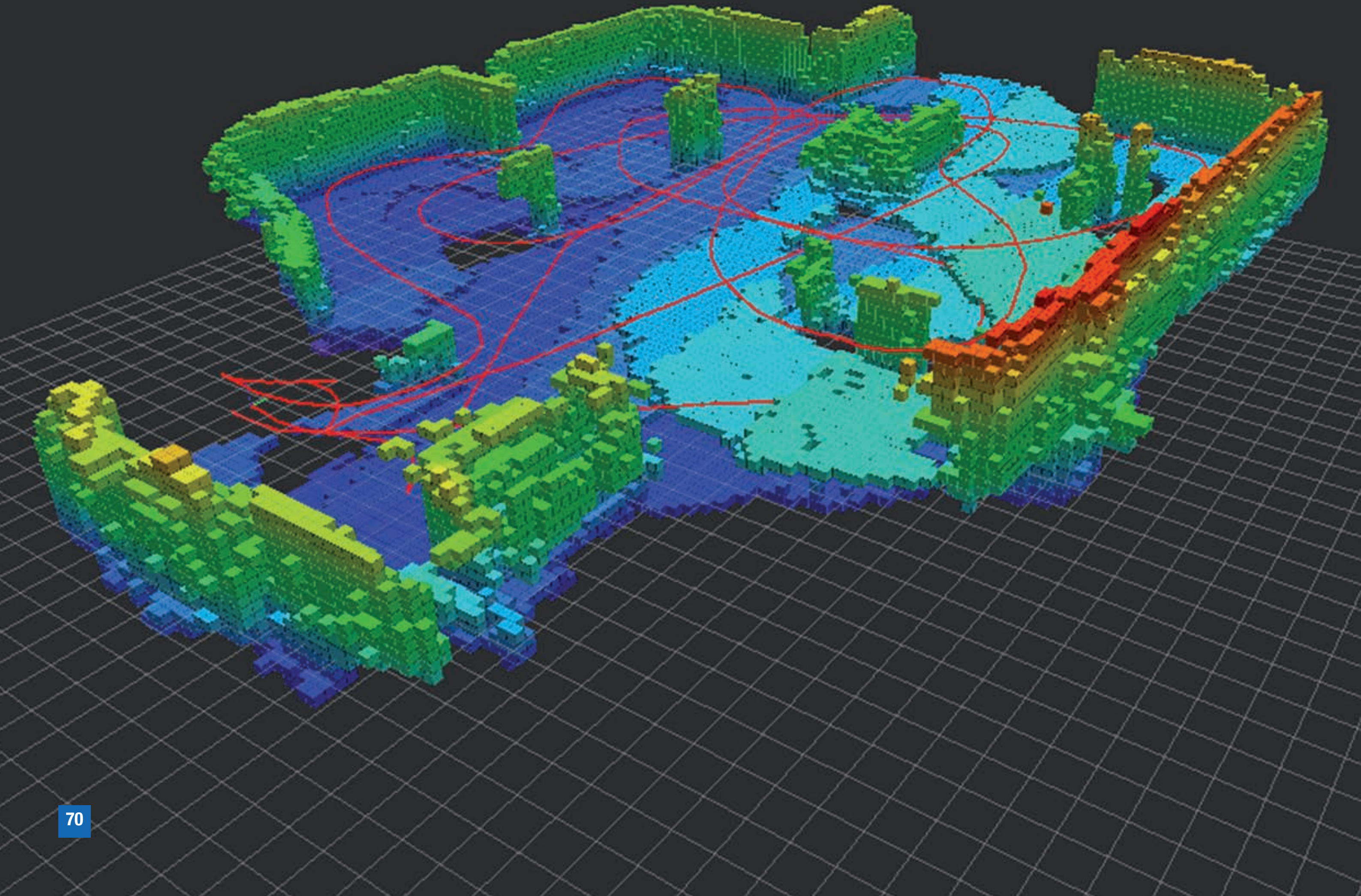
Drone and anti-drone experts

ANGELAS

In 2015, the ANGELAS project (standing for "global analysis and evaluation of anti-UAV technologies and methods"), coordinated by ONERA with six industrial and academic partners, was selected by the National Research Agency (ANR) for the program: "Protecting sensitive zones from UAVs". ANGELAS, which is more oriented towards malicious drone detection and identification techniques, is qualified in several respects. As the only proposal covering long-range detection, this offered the ONERA teams the opportunity to ramp up the maturity of these innovative technologies, such as passive radar operated from the ground or 2D Lidar, which makes it possible to measure flight time and distance using 2D flash laser imaging technology.

For the benefit of the State and of industry

ANGELAS has enabled ONERA to extend its role as a State expert in combating drones for the benefit of the Government Ministries, SGDSN, DGA, gendarmerie, etc. To carry the project through to conclusion, ONERA will have studied many technologies in depth: active radar, acoustic detection, visible or infrared ultra-high resolution camera, 3D Lidar, goniometry, optical glare, data link jamming, etc. ONERA teams and partners will have carried out highly exhaustive work and acquired true expertise with regard to the advantages and limitations of the various emerging technologies. This is an acquired expertise that will be of benefit to the State services and to French industry.



At ONERA, drones navigate by sight

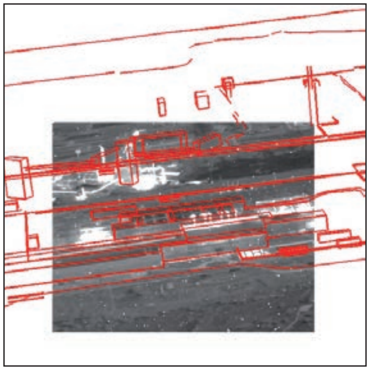
There are two kinds of aerial drones: those operating outdoors according to air traffic rules and those operating indoors or close to buildings. The latter are equipped with a very specific on-board viewing method. A drone equipped with 3D vision and real-time computing capabilities constructs its environment as a 3D model, in which it operates by visually assessing its position there. It can make decisions and make navigation commands itself, according to its mission objectives.

Using components available on the market – a small quad-rotor UAV, miniature cameras and on-board computing resources – ONERA's researchers have engaged in the international race towards the autonomy of aerial robotics and are at the best level worldwide with an expertise primarily focused on software: 3D reconstruction, navigation, control, etc. The areas of application are varied: surveillance and intervention on SNCF railway infrastructures, on EDF transformers, for the military, construction, engineering structures, archaeology, etc.

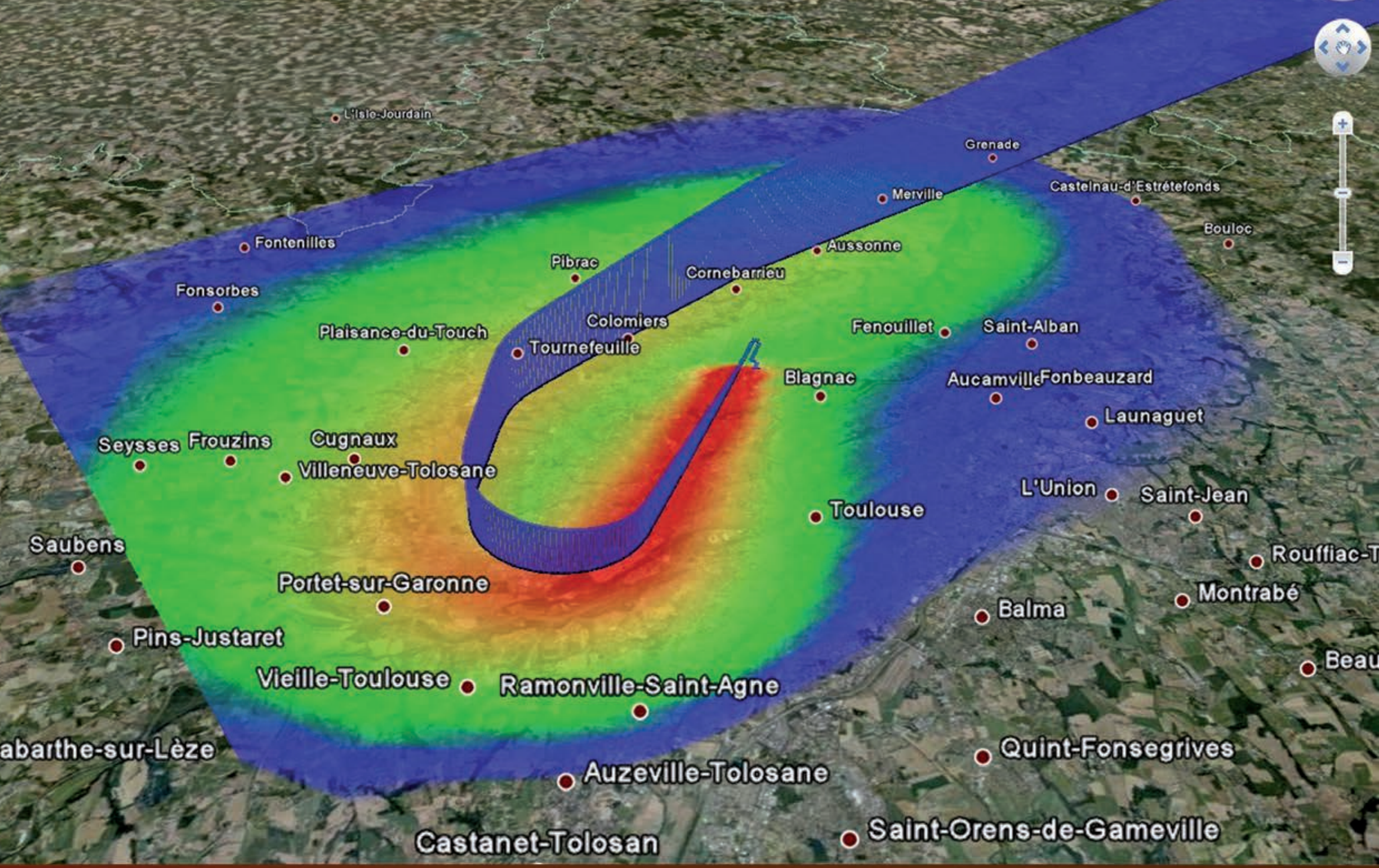
The self-guiding system of the Scalp/Storm Shadow missile

ONERA placed its know-how in image processing and 3D reconstruction at the service of defence, long before the craze for drones that we are experiencing now.

Thus, from 1992 to 2000, ONERA specialists participated, for the DGA and the industrialist MBDA, in the definition, design, simulation and qualification phases of the MBDA Scalp/Storm Shadow missile self-guiding systems.



The precision terminal guidance of this quasi-autonomous cruise missile is based on an intelligent correlation between the images of its infrared camera and a 3D model of the target environment, not constructed in real time, but rather resulting from mission preparation.


L'Isle-Jourdain
Grenade
Merville
Castelnau-d'Estrétefonds
Bouloc
Fontenilles
Pibrac
Aussonne
Cornebarrieu
Fonsorbes
Colomiers
Plaisance-du-Touch
Fenouillet
Saint-Alban
Tournefeuille
Blagnac
Aucamville
Fonbeauzard
Launaguet
Seysses
Frouzins
Cugnaux
Villeneuve-Tolosane
Toulouse
L'Union
Saint-Jean
Saubens
Montrabé
Portet-sur-Garonne
Balma
Pins-Justaret
Vieille-Toulouse
Ramonville-Saint-Agne
Quint-Fonsegrives
Auzeville-Tolosane
Castanet-Tolosan
Saint-Orens-de-Gameville

Testing the air transportation systems of the future

Iesta is ONERA's multidisciplinary numerical assessment platform, which represents the entire complex reality of an air transport system: for example, an airport with its environment, aircraft in the airspace, the monitoring of a procedure, etc.
Iesta's highly realistic virtual space is designed to conveniently assess the introduction into the air traffic of a new aircraft, a new engine and new rules, and to examine the consequences on the environment (noise, fuel consumption, pollutant emissions and quality of the air). Air traffic safety and its capacity are also part of the challenges.
Iesta is particularly used in the major European programmes Clean Sky (development of technologies for innovative and clean aircraft) and Sesar (modernisation of air traffic management).

Iesta, system super-simulator for Sesar

In Europe, even today, each country manages its airspace. However, other organisations are possible. As part of the European programme SESAR (Single European Sky ATM Research), the Iesta platform enables the simulation and evaluation of new flexible and dynamic airspace configuration designs, taking into account the needs of all players involved: air traffic controllers, aircraft, free route, military, etc.
Iesta, by thus testing the innovations upstream and foreseeing the consequences of various scenarios, has proven to be a powerful decision support tool.

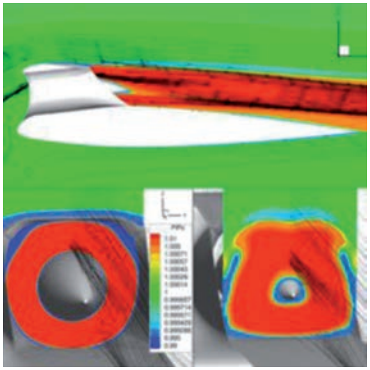

La recherche
CARNOT
pour les entreprises

Ampere or the challenge of distributed electric propulsion

For ONERA, innovating means exploring new solutions in order to offer manufacturers validated and usable technologies. The objective of the Ampere concept is therefore to validate an all-electric aircraft project capable of transporting 4 to 6 people over 500 km in two hours, close to cities. To address this challenge, ONERA proposes distributed electric propulsion: an innovation that has led to completely rethinking the design of the aircraft.
Within the framework of this mission, Ampere is a coherent assembly that allows technologies to be integrated and tested. Aero-propulsion integration has already been the subject of initial computer simulations and validations in a wind tunnel (Lille) that have proven wholly conclusive.
Although 2025 seems to be a realistic goal for the Ampere project, the engineers are already thinking ahead to 2040, with the idea of a regional transport aircraft based on the same principles, offering a capacity of 50 to 80 seats, and a 1000 km flight range: a true energy revolution!

The advantages of distributed propulsion

• Take-off and landing over short distances, the engines having a wing ducting effect, which increase lift at low speeds. A 200 m runway would be sufficient • Participation of the engines in the piloting and stabilization of the aircraft through the management of their unit thrust • Improvement of flight safety thanks to the pooling of functions and the intrinsic redundancy of the propulsion components • Power supply also distributed with 8 fuel cells (defined on components supplied by the CEA) and lithium-ion batteries for transient power needs • Precise sizing of the propulsion thanks to the propulsion system component distribution (fans and energy sources) • No release of pollutants or greenhouse gases in operation • Potential reduction of energy losses due to friction, thanks to the effect of 32 fans located on the upper wing surface, very close to the hull.

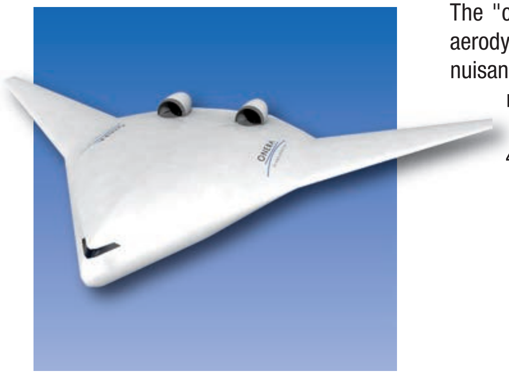


New challenges, new designs

Current environmental awareness obliges manufacturers to perform technological feats to achieve ambitious goals, such as reducing the passenger-km consumption fourfold between 2000 and 2050. Current aircraft with a "conventional appearance" offer no hope of significant gain.
However, there are promising ideas, illustrated by the Nova concept proposed by ONERA. For example, installing the engines behind the wing or fuselage would enable the joint propulsive output of airframe and engine to be improved, since they would then no longer be considered as two separate elements but rather as an assembly.
ONERA is adopting a multidisciplinary approach, capable of orchestrating all of its skills to produce technological advances, while optimizing the requisite qualities: aerodynamics, propulsion, structure, performance, maneuverability, acoustics, etc.

The flying wing, future long-haul?

For a long time, the flying wing has been credited with a potential greater than that of conventional aircraft. However, this has yet to be demonstrated for commercial transport. The reasons for this are the uncertainties that undermine the performance evaluation of this concept, in which all key technologies interact with each other in a much more powerful way than in conventional aircraft. The "continuous" flattened wing-fuselage configuration is a challenge in terms of aerodynamics, structural design, engine embedding, aero-propulsive efficiency, noise nuisance, and piloting due to the absence of a tail fin. This is why ONERA is working on removing these uncertainties; its CICAV (“integrated design of a flying wing configuration”) research project is studying a hybrid flying wing to transport 400 passengers over a distance of 8,000 nautical miles at a speed of Mach 0.85.




ONERA
+24V
Wasp
Motorised Pan
and Tilt Unit
instro
CE

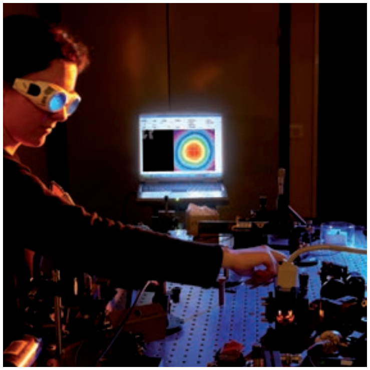
Lidars are replenished for new applications

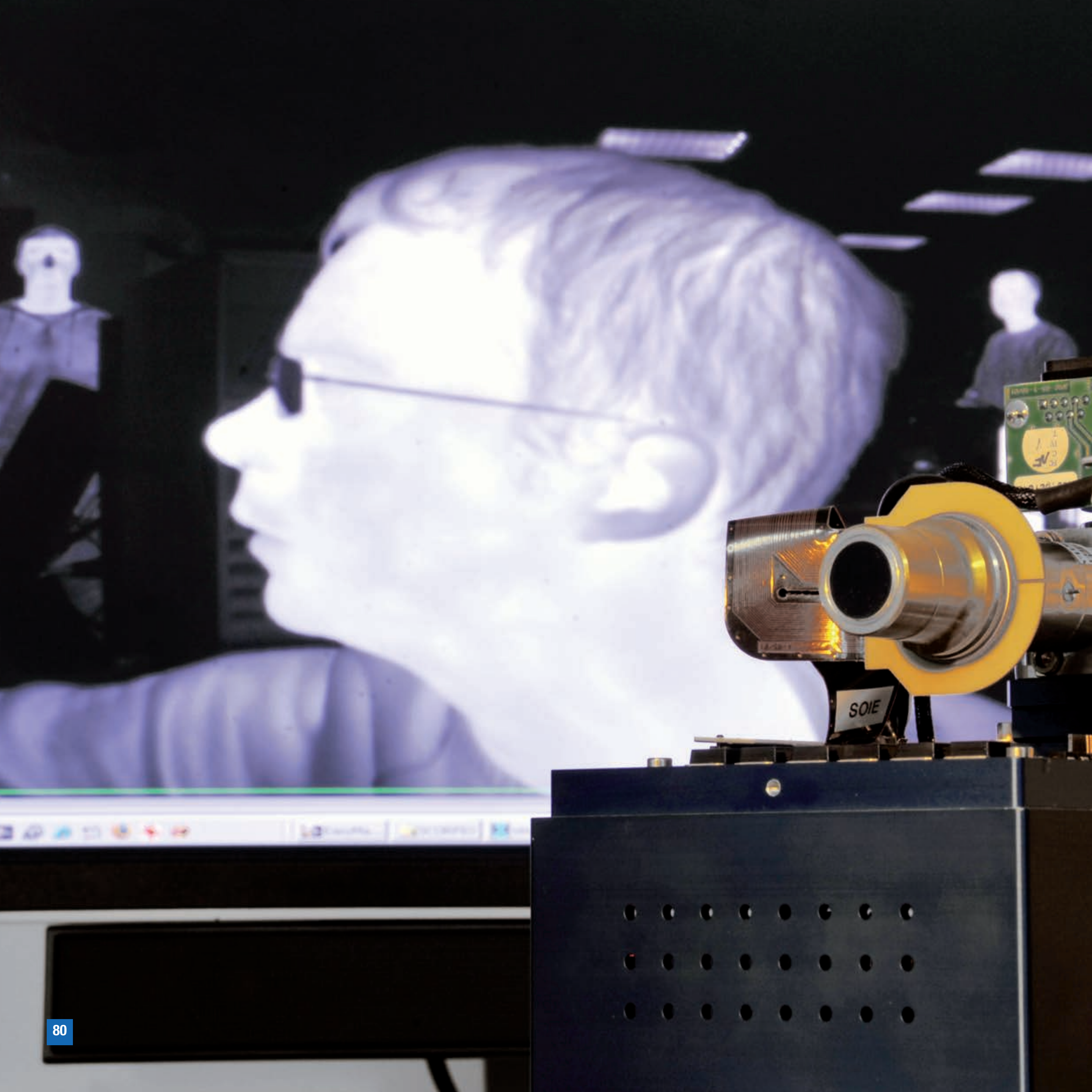
Lidars are devices for analysing the reflected or backscattered light from a laser beam that they emit themselves.
The ONERA is creating and developing new lidars, especially new fibered laser sources that are cheaper and can be installed on-board (fibre optics "doped" with rare earths). These lidar, which analyse the light backscattered by atmospheric aerosols or molecules, are mainly conceived for aviation safety: at the airport (wind and wake mapping) and on-board (turbulence zone detection, anemometry). ONERA's experimental platform Licorne reached the largest span in the world for wind measurement (16 km) in 2015.
These lidars have an enormous potential for defence, the environment and safety: the identification of mobile objects, gas detection, active imaging, measurement of greenhouse gases in the atmosphere from a satellite, etc. ONERA has thus helped the SME Leosphere to become a world leader in environmental observation.

OPO – a multi-coloured laser that can be modulated at will

An OPO or Optical Parametric Oscillator is a laser light source whose colour (or, more precisely, the wavelength) can be adjusted at will. OPOs can produce some colours that other laser sources cannot produce and can be of benefit to some applications due to their great "tunability".

ONERA has developed and patented specific OPO sources and conducts research to demonstrate their technological applications. In particular, OPOs enable the simultaneous measurement of multiple compounds. Lidar applications: remote detection of chemical attacks, anti-terrorist surveillance, monitoring of the air quality in public spaces (technology transfer to the Blue Industry and Science company underway) and non-lidar applications: countermeasures to jam missile self-guiding systems.



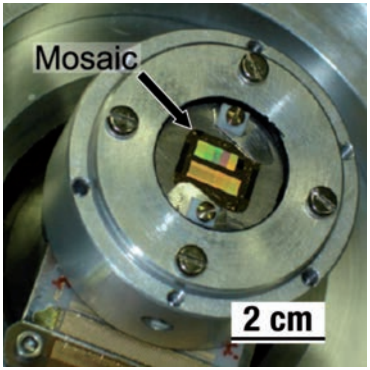

SOIE

Miniature cameras, increased vision

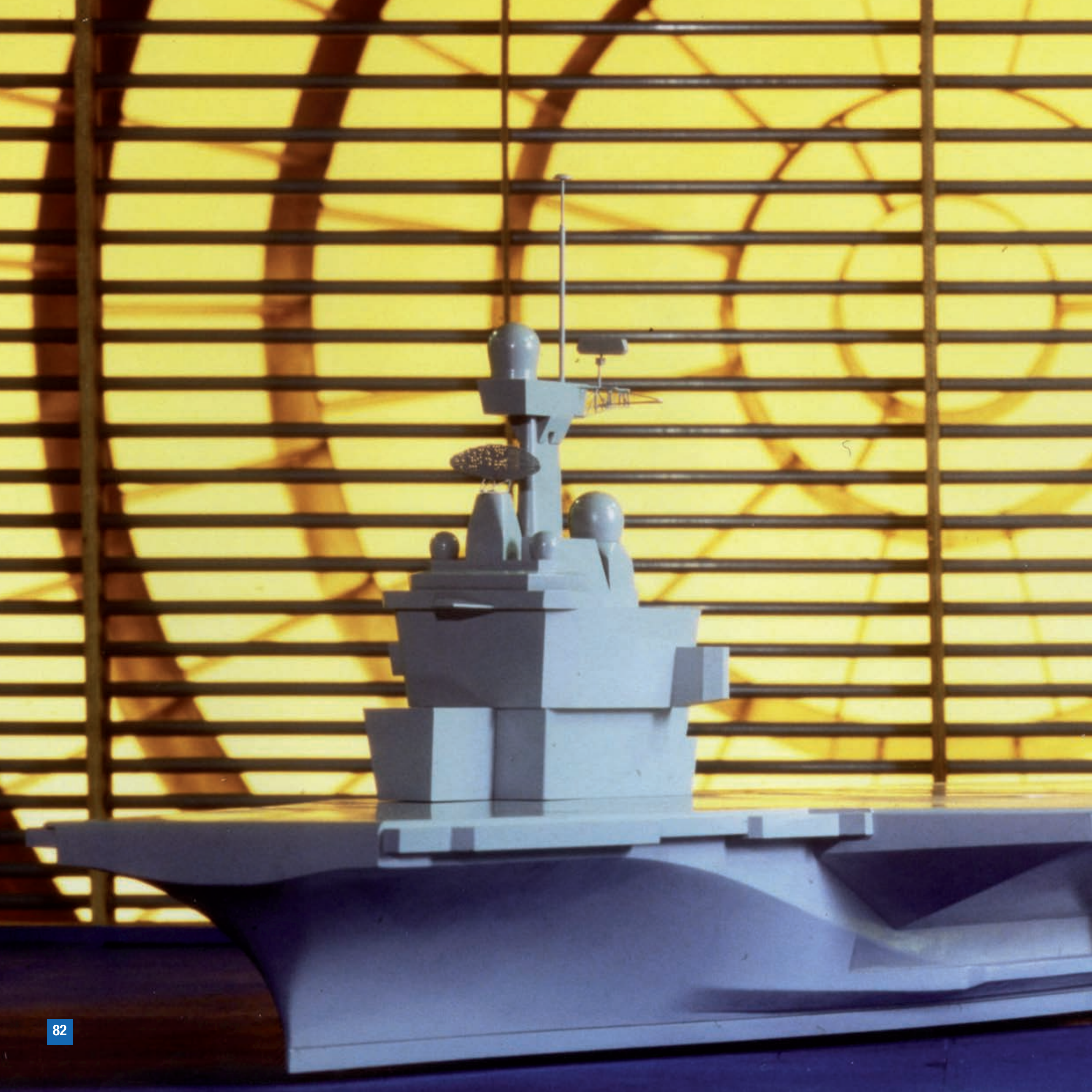
Infrared light is invisible to our eyes, but it can be used for night vision, temperature imaging, gas identification, etc. The infrared detectors that make up IR cameras have been continuously improved and their use is becoming more democratic for civilian applications. Defence applications are still numerous: navigation, piloting, recognition and identification of targets, weapon guiding, etc.
With the support of the DGA, several prototypes were made at ONERA and moved on to the industrial stage, thanks to a partnership with the company Sofradir (since 2013). These include "wide angle" compact cameras imitating the architecture of the human eye dedicated to surveillance or drone control and ultra-compact "chip cameras" that produce many small images of the same scene, whose combination can increase the information perceived – increasing the resolution, 3D vision and multi-spectral imaging (several infrared "colours").

Nanophotonics, optics without optics

ONERA is developing infrared sensing application concepts that are a breakthrough from current technologies. The properties of the devices with respect to the light are not dependent on optical components such as lenses, but rather interact according to structures etched into the material, etc., at the micrometric, or even nanometric, scale.



First prototypes developed: *stained glass* a nano-filter mosaic for multi-spectral imaging; *black gold* to totally absorb several "colours", *photon funneling* to detect very low photon fluxes. Applications: security (motion detection), cameras or pollutant sensors for mini or nano-drones, cryptography, etc.
Fruitful mutual enrichment has been achieved together with the CNRS photonics and nanostructure laboratory – *Laboratoire de Photonique et de Nanostructures.*

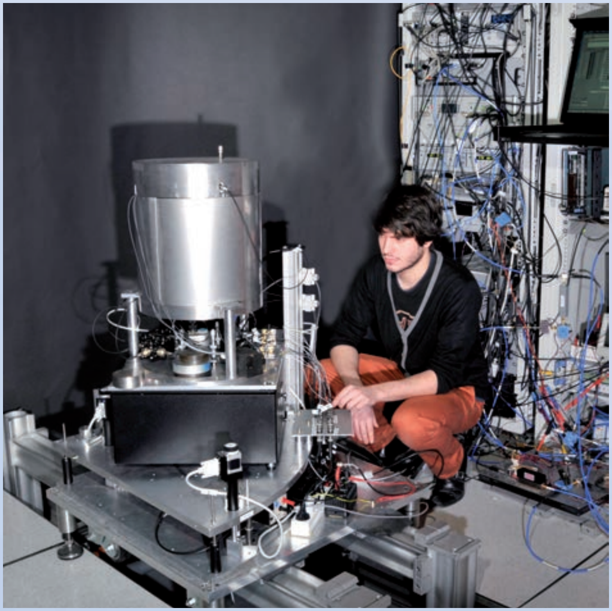


From air to sea

Up until the early 2000s, ONERA was involved in the design and development of the piloting system for the *Charles de Gaulle* aircraft carrier and *La Fayette* type frigates.
Catapulting and safely landing aircraft on aircraft carriers, even in rough seas: this was the challenge faced by Naval Group's engineers in the 1980s, with the help of ONERA's engineers. Predicting in real time certain ship movements in order to better control them was one of the keys to the development of an original piloting and stabilization system for ship movements, called SATRAP. In addition to the classic rudders used to steady the *Charles de Gaulle* and enable the scrambling of aircraft even in heavy weather, a system of 12 transverse mobile masses under the flight deck (22 tons each), dubbed COGITE, makes it possible to limit the lateral inclination of the flight deck. ONERA also conducted wind tunnel tests on models to characterize the wind-induced aerodynamic forces on the hull and superstructures.

On the surface but also under water...

Up until the 2000s, the autopilots of all French submarines were designed at ONERA: those of nuclear-powered craft, SNA and SNLE (from *Le Redoutable* to *Le Terrible*), as well as those of new versions of the *Agosta* and *Scorpene*.
As well as pilots for steering in calm waters, ONERA conducted spectacular developments of piloting techniques, in particular with regard to stabilization in swells with periscope up (and in firing phase for the SNLE). Early studies thus resulted in the removal of the costly and noisy hydro-reactors, to move toward automatic stabilization by water movement. To further reduce acoustic noise and costs, the studies carried out made it possible to optimize the sizing of the installations by optimally distributing the overall force between the diving planes and the ballast tanks.



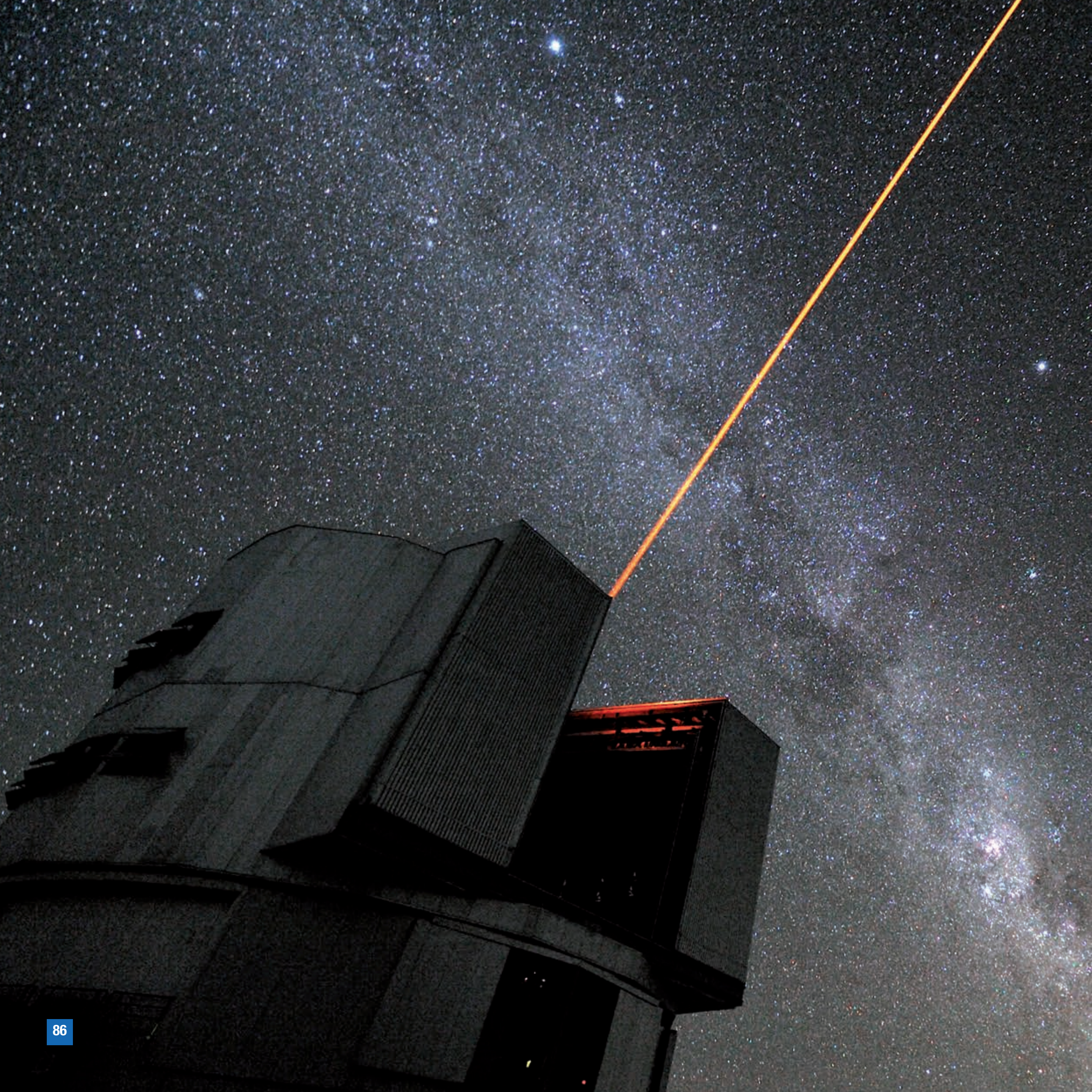

BEAUTEMPS-BEAUPRÉ
A758

ONERA’s cold atoms don’t get seasick

ONERA's physicists have explored "quantum-wave interferometry", a quantum technology that exploits the cooling of atoms by laser, a technique that won the 1997 Nobel Prize in Physics for Claude Cohen-Tannoudji et al.
They proposed to the DGA, in collaboration with the Navy Hydrographic and Oceanographic Service (SHOM), the bold project of constructing a gravimeter based on this principle, placed onboard a ship, and capable of mapping gravity with unprecedented precision and speed. Based on a first successful experiment, ONERA developed a first prototype with a precision of some 10^{-9} g in the laboratory, followed by the Girafe2 instrument – capable of withstanding offshore navigation conditions. In the SHOM scientific building, carrying out tests along the coast of Brest, Girafe2 would improve the known values of the gravity field, despite a swell reaching 6 m! Possible applications: geophysics, gravity field mapping, navigation without GPS, etc.

Girafe in airborne mode: a world first

The same cold-atom gravimeter designed for maritime navigation was used in flight in 2017 around the Vatnajökull glacier in Iceland, a zone of particular interest for the study of melting ice and volcanic activities.
This collaboration with the Technological University of Denmark and ESA was carried out in the context of studies on the effects of global warming. This mission was an excellent opportunity to validate this cold atom technology, which has become one of ONERA’s specialties, for mapping gravity in airborne mode.
Based on fundamental physics experiments carried out in the 2000s, this technique, providing very precise and absolute values (recalibrations are unnecessary), has led to the production of a technological demonstrator that can be used under quasi-operational conditions.



Adaptive five star optics

The flickering that can be seen when observing the stars is due to atmospheric turbulence. Thus, a photograph taken from Earth produces a blurred image, compared to an image taken without turbulence, for example from space.

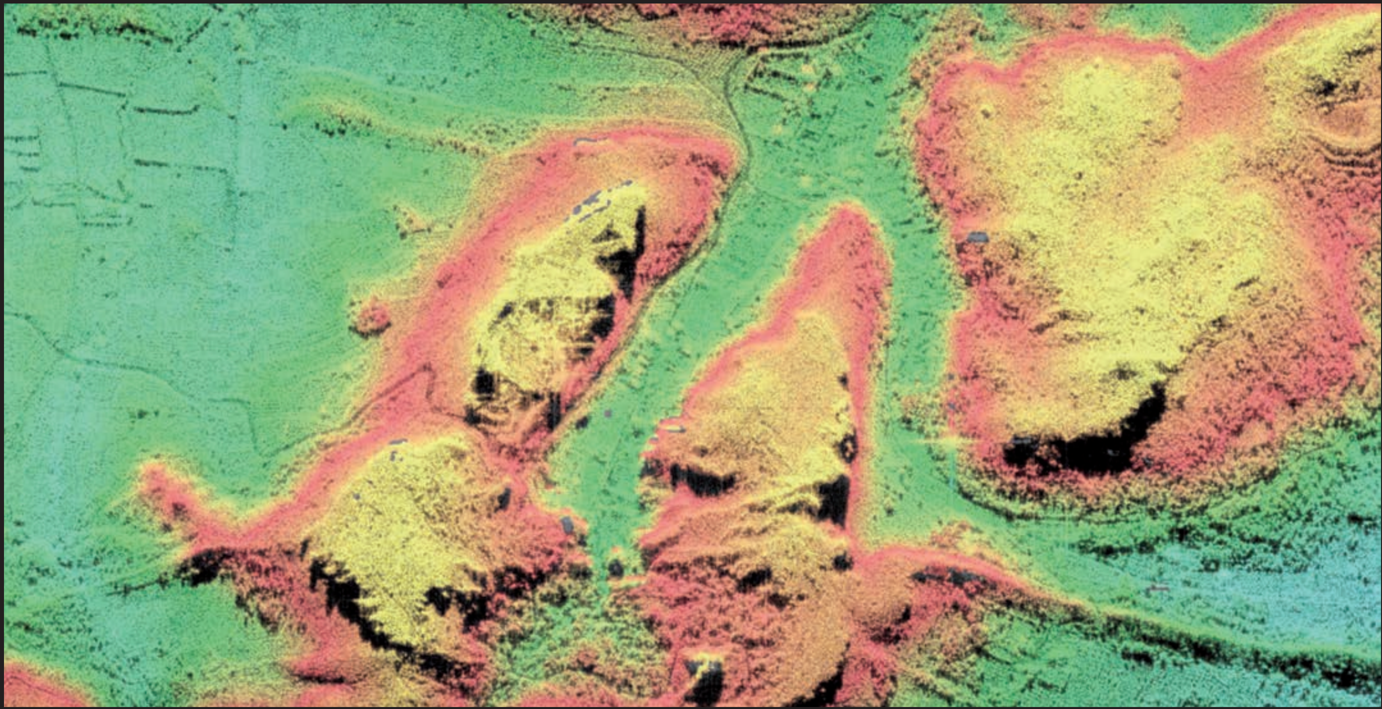
Following the Defence work intended to counter the effects of turbulence on the propagation of laser beams in the atmosphere conducted in the early 1980s, ONERA researchers have become international experts in adaptive optics for astronomy. The technique is based on a deformable mirror that "rectifies" the luminous flux coming from the observed object, according to the instructions provided by an ad hoc analyser. The ESO's Very Large Telescope in Chile was equipped with ONERA's Naos system (2001) on an 8-meter telescope, which led to the first direct observation of exoplanets. Then Saxo (2014) on the VLT's Sphere instrument, a veritable extrasolar planet imager. Next challenge: the adaptive optics (AO) of the European Extremely Large Telescope (eELT), which will have a 39-meter mirror.

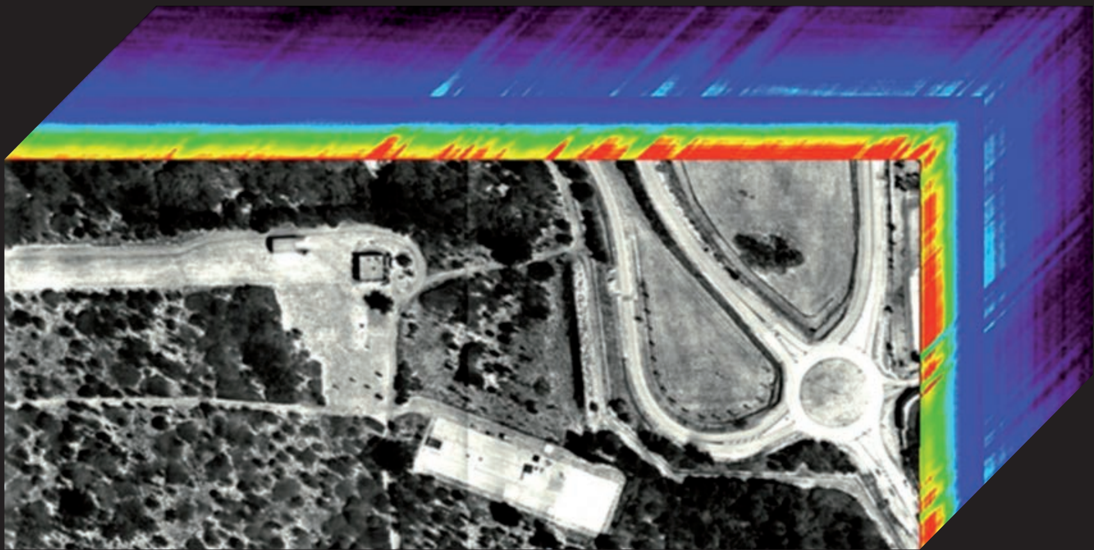
The eye, another preferred medium for AO

As the flagship laboratory for adaptive optics technology worldwide, ONERA is transferring its expertise to ophthalmology. The observation of the eye fundus poses similar problems to those faced by astronomers observing the stars. By correcting optical aberrations due to the crystalline lens and the vitreous body, AO enable the retina to be observed with a very high resolution. These are long awaited advances in medical diagnosis and laser surgery.

Furthermore, as regards biometrics, ONERA is the leader of a project whose objective is to develop a low cost AO iris recognition system. This is a very promising identification technique, because it is much more reliable than facial features or fingerprints.

This is an emblematic example of transferring advanced technology to other sectors. Its use outside of the aerospace industry is one of ONERA's missions.





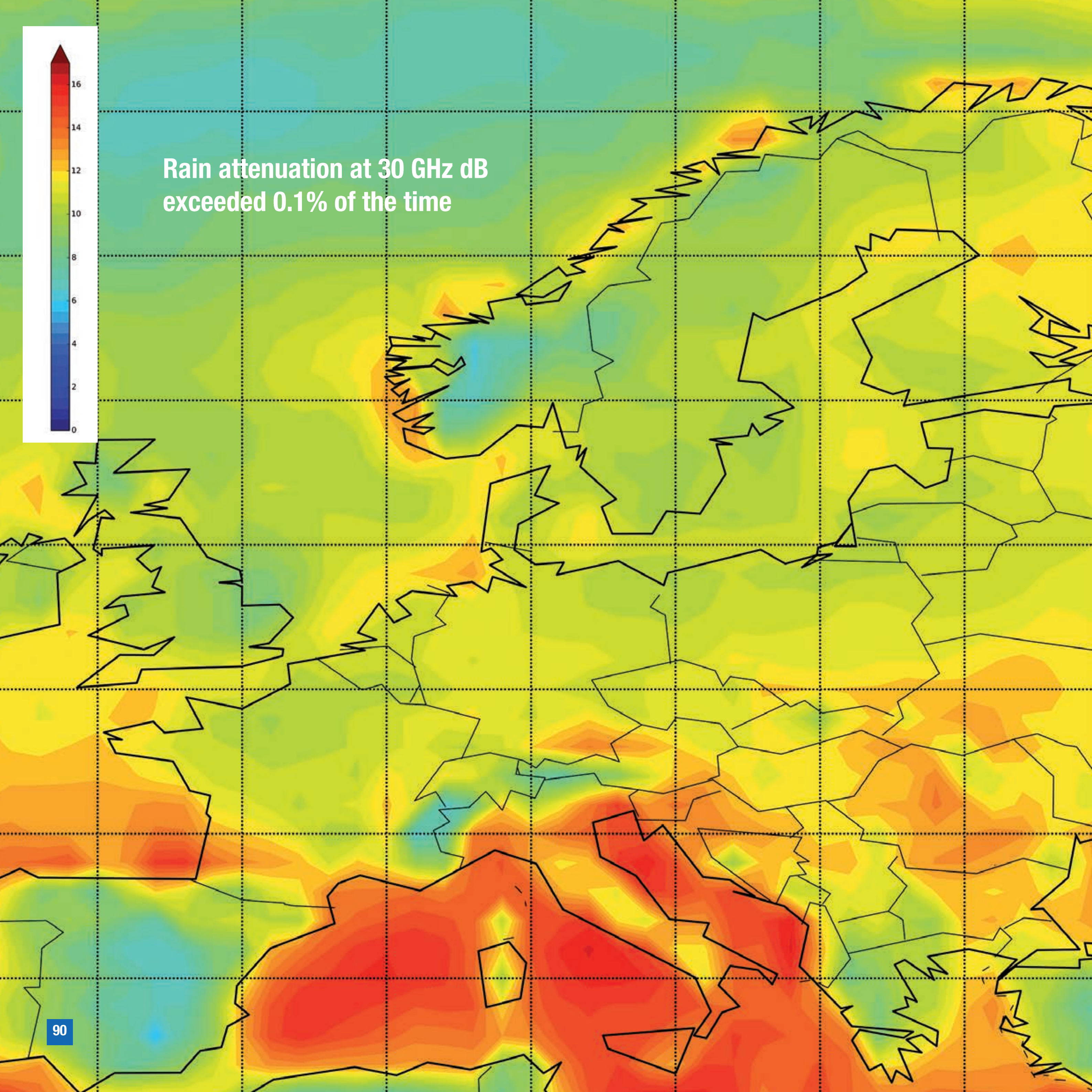
New remote detections, new views of the Earth

The Ramses-NG, Sysiphe: two technological demonstrators to be able to see the invisible on the ground. The SAR radar technology (Synthetic Aperture Radar) of the airborne Ramses-NG uses a compact antenna that takes advantage of aircraft movement to obtain a high resolution image after processing the data. For defence, ONERA is developing this radar that enables mapping by day/night in all-weather, the classification of objects and environments, the achievement of terrain numerical models and the detection of buried objects or objects under cover, etc.
While photography acquires red, green and blue, a hyperspectral camera acquires hundreds of "colours", including infrared, forming a very rich image cube showing the details of the observed area. Sysiphe, a DGA project led by ONERA, is an innovative hyperspectral means that is unique in Europe: it offers an image of the ground with a resolution of 50 cm in more than 500 colour bands, from visible light to the far infrared, which can be used for example for the detection of targets, even camouflaged, for the characterisation of effluents, for the detection of mines, underground, etc.

Lima, airborne imaging open to all

Lima is ONERA's research platform for the development of civilian uses for new airborne imaging technologies – high spatial and spectral resolutions and 3D laser imaging. Here, ONERA offers its partners and customers turnkey airborne campaigns, from the needs to the data used.

One of Lima's main resources is the Sethi pod, an airborne device equipped with SAR and hyperspectral radar capabilities. The fields of application are numerous: agriculture, urban planning, pollution detection and characterisation, forest fires, industrial accidents, floods, site and border surveillance, resource exploration, meteorology, archaeology, etc.


Rain attenuation at 30 GHz dB
exceeded 0.1% of the time
16
14
12
10
8
6
4
2
0

The Ka band experts
(to be pronounced as K-A)

The Ka band is for satellite internet broadcasting what the FM band is for terrestrial radio: a radio frequency range that is particularly suitable for its use. The Ka band has started to be used in Europe and has many advantages, such as broadband access at a cost comparable to terrestrial offerings, smaller antennas, etc. Nevertheless this frequency band is sensitive to atmospheric attenuation: rain, clouds and steam.

ONERA, following the defence work conducted in the 90s, has put its skills at the service of the CNES, the ESA, industry and operators. From propagation measurements and the use of weather data, ONERA has built models able to predict signal weakening and service availability. These models are used, within and outside of Europe, as support tools for the design of future satellite communication systems.

Ka is also satellite altimetry to the nearest cm

The Ka-band has other advantages besides communication. It is for example particularly suitable for SAR imaging to perform environmental measurements with a very good spatial resolution and with heights to the nearest centimetre. ONERA is called in by space agencies to assess and qualify new Ka-band imaging systems. It has the Busard, a motor-glider equipped with a pod capable of carrying such systems. The team of SAR radar imaging specialists around the airborne means, makes ONERA a centre of excellence for this breakthrough technology at the service of the environment.

ONERA thus participated in the preparation of the CNES-NASA SWOT mission, which will measure the dynamics of continental and ocean water levels in a much more precise way than before.

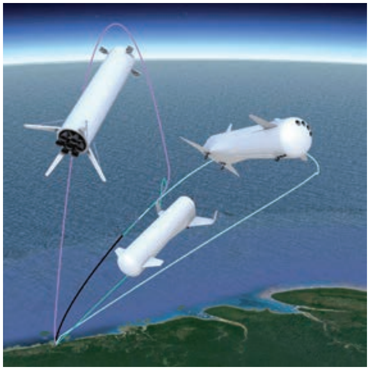

ALTAIR

Reusable launcher: from concept to demonstrator

ONERA has been reflecting over the past twelve years on the concept of a partially reusable launcher for small satellites (up to 150 kg payload). Conducted in partnership with the CNES and with students, Perseus should validate the feasibility of replacing the first stage of a conventional launcher with an automated and reusable aircraft. This study has resulted in a 1/3 scale demonstrator, called Eole, built with Aviation Design, which has flown several test campaigns.
In light of its excellent performance, the project has become European. Altaïr is to study in depth the feasibility of such a concept at reduced cost, also including the ground installations. Having begun in 2015, the Altaïr project is mobilizing 8 European partners, and may potentially result in an industrial program. ONERA is coordinating the project, and contributing its know-how and tools to the optimized multidisciplinary development of this concept. With the strong development of constellations of micro or nano satellites, such as OneWeb, a project like this could well become an industrial and commercial success.

From light to heavy

Having been involved since the start of the Ariane adventure, ONERA, an important partner of ArianeGroup, is contributing its expertise to the Ariane 6 program. Looking towards the future, ONERA is also considering what will come after the Ariane 6. With the working title of Ariane Next, ONERA is studying and discussing with the CNES the feasibility of a European heavy reusable launcher concept. Several avenues are being explored: return to Earth with vertical landing, return by gliding or return by propelled flight with conventional landing, like the space shuttle.



Preparing satellites for a lifetime of aggressions

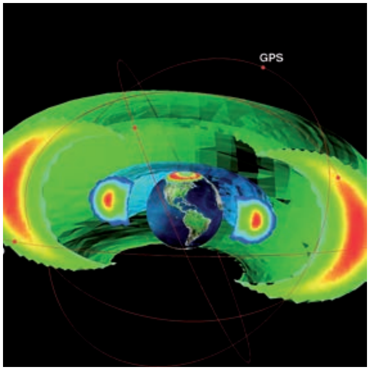
Before designing a satellite (or any other space system), it is essential to predict the phenomena that it may be subjected to in flight. Solar and cosmic radiation, charged particles (protons, electrons and ions) are in fact a real danger for surface materials and especially electronic devices, which are highly vulnerable in space.

ONERA has expertise that enables it to specify tests to be carried out on the ground according to each space mission and has a range of experimental and numerical means to implement them. The idea is to globally characterise environmental effects that threaten satellite integrity, to be taken into account during the design.

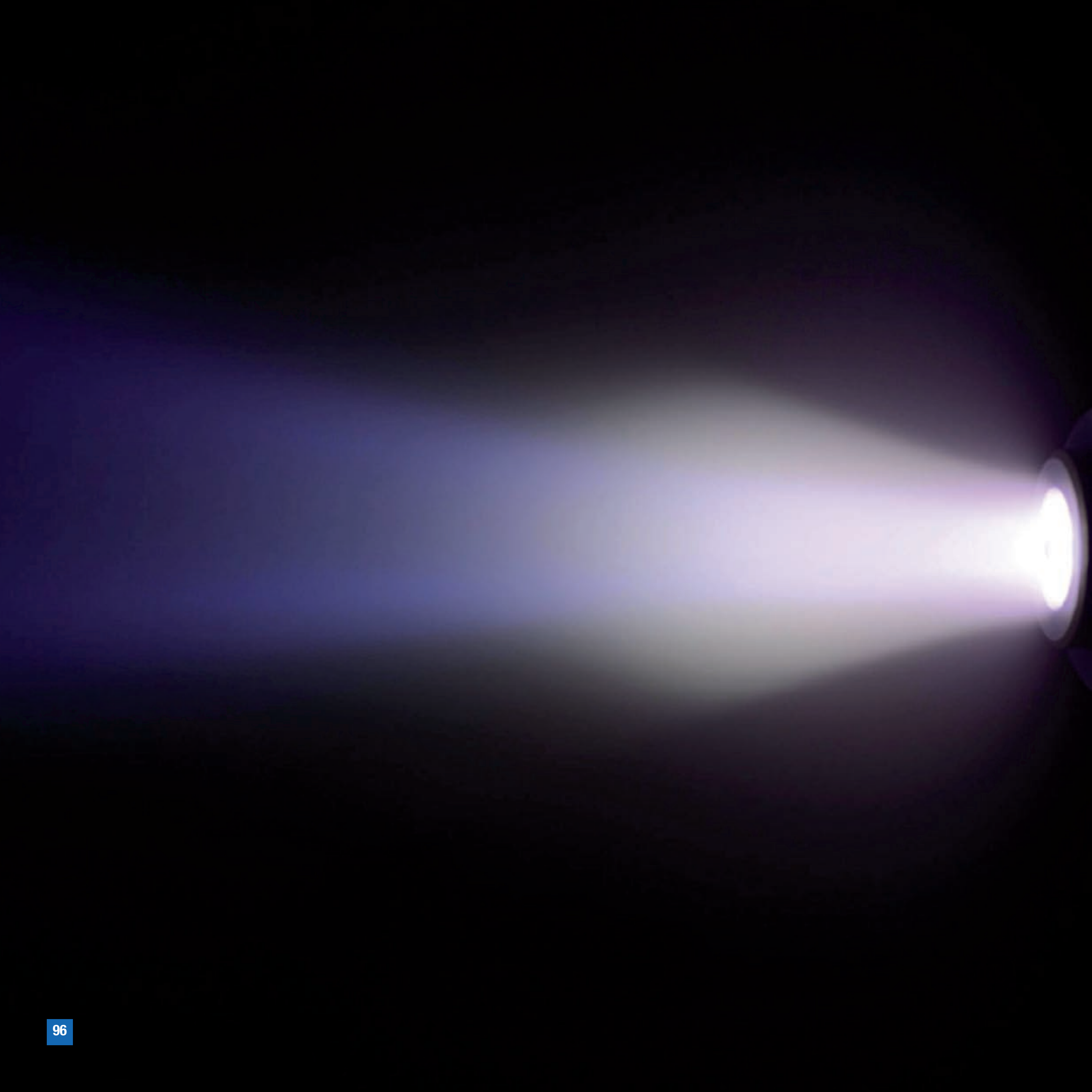
ONERA's expertise in the evaluation of the electrostatic charge of satellites and in the prediction of singular events in the electronic devices is highly recognised worldwide. The space agencies (ESA, CNES, NASA and JAXA, etc.), the satellite industry and many component designers place their trust in it.

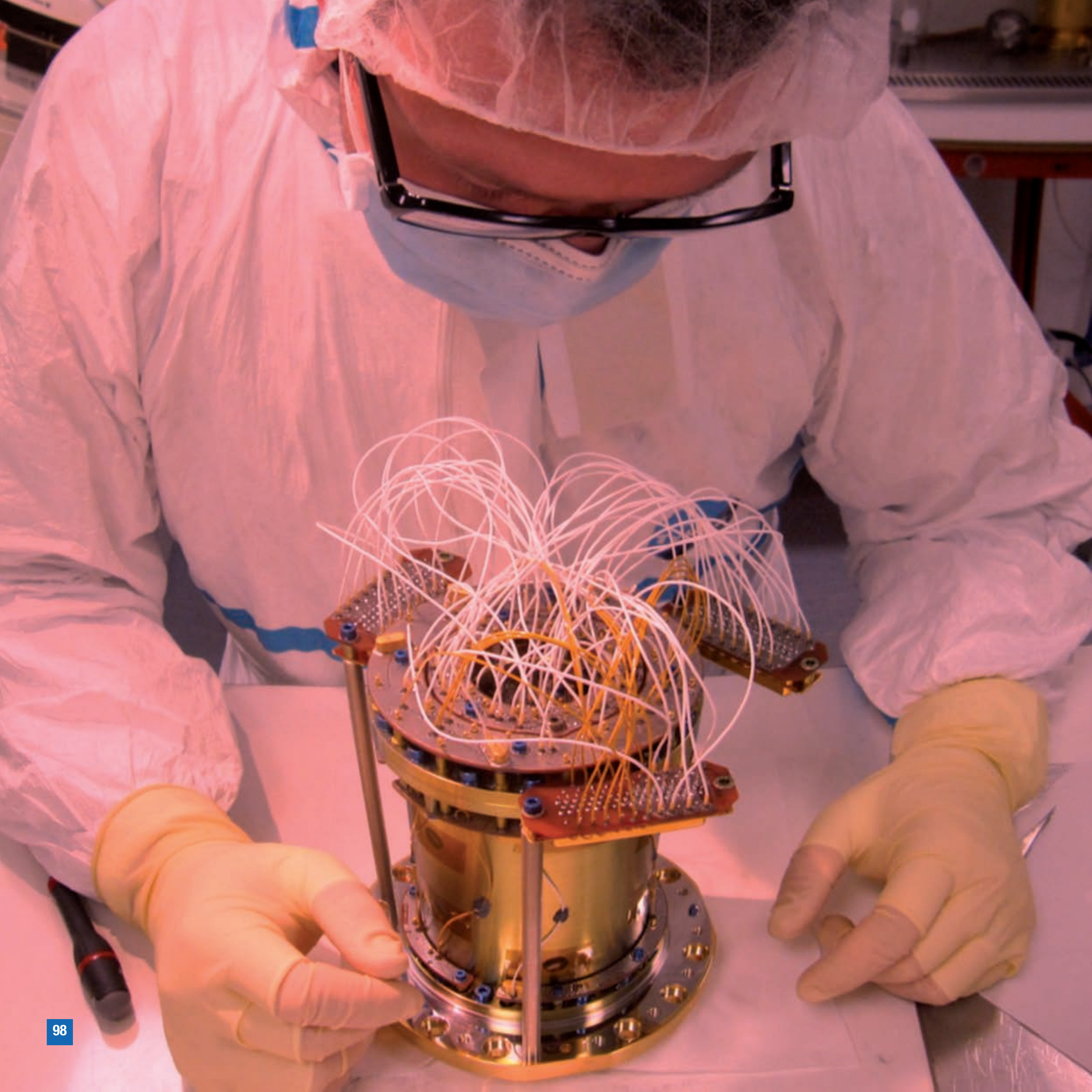
Salammbô, a physical model of the radiation belts

The radiation belts, or Van Allen belts are toroidal areas around the Earth. They contain a very large amount of energy particles from the solar wind and cosmic radiation, trapped by Earth's magnetic field. It is crucial to prepare satellites to face this potentially highly aggressive environment, especially given that the new propulsion method – electric – will increase the transit time.



The physical model Salammbô, which ONERA has been enriching for over 20 years, enables the modelling of all of the phenomena involved in the magnetosphere during geomagnetic storms. It is a space weather tool. Salammbô relies on an in-flight measurement base that is unique in the world. Its fame is worldwide.



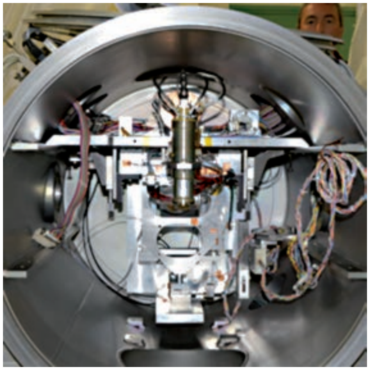


Space propulsion becomes fully electrical

Most satellites use thrusters, either to control of their orientation, their position, or to transition from the transfer orbit to the geostationary orbit.
An electric thruster uses electricity from solar electricity panels to transform gas into plasma and accelerate to a speed of several tens of km/s (that is what creates the thrust). Using solar energy rather than chemical propellant energy can save a large satellite in transit up to 2 tons of fuel, or €20 million at launch. The disadvantage: the transit takes a few more months. France and Europe wish to be in this market where the US already are.
ONERA, supported by the CNES and the ESA, is developing innovative measurement means to test these electrical or plasma thrusters: laser and electrical diagnostics and ultra-precise balances. ONERA is also developing its own technology, patented in 2011: magnetic-nozzle propulsion (ECRA), which promises to further reduce launching costs due to its efficiency.

The best European space thrust balances are at ONERA

ONERA's micronewton balance is extraordinarily precise: it measures thrusts between 0.1 µN and 2 mN. It is the most efficient in Europe (0.1 µN corresponds approximately to the weight of 1 mg on Earth).
It was selected by the CNES and the ESA to perform cold gas precision thruster acceptance tests – during the Gaia (Mapping of the Galaxy, 2013) and Lisa Pathfinder missions (cosmology, 2015). It will also validate the drag compensation microthrusters of the CNES-ONERA Microscope mission (fundamental physics, 2016).



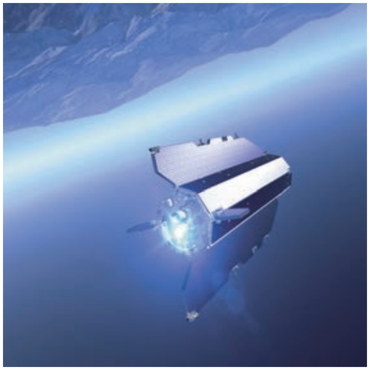
Space accelerometry, world leadership by ONERA

The overall study of ocean currents and melting ice, mapping Earth's gravity, obtaining better knowledge of what is under the earth's crust, checking the most fundamental laws of physics, evaluating satellite position variations, etc. How can all of this be done? With ONERA's space accelerometers!

These instruments, veritable ultrasensitive balances developed by ONERA for over fifty years, enable the measurement of acceleration from the movement of a body levitating in an electrostatic field with a record accuracy of up to 10^{-15} ms^{-2}. NASA, the ESA and the CNES all trust ONERA for Earth science or fundamental physics space missions called Champ, Grace, Grace Follow-On, Goce and Microscope, etc.

At the start, a "false good Idea"

The discovery of accelerometers arose from good intuition by ONERA aerodynamicists. In the early 1960s, they sought a way to suspend models inside wind tunnels without using either a support or a wire. They chose levitation, that is to say, to suspend them in an electromagnetic field. However, levitation is very unstable: the project was abandoned.



The idea was taken up again by physicists: they trapped a ball in a small spherical cage, and kept it levitating in an electric field. The acceleration variations of the whole tend to make this mass move, becoming closer to one of the receptacle walls. A servo causes the electric field to vary, in order to keep this mass centred. These variations in the electric field provide the acceleration measurements.

ONERA
Communication Department
August 2017
Design-editing: Sylvain Gaultier
Writing: Sylvain Gaultier, Guillaume Belan
together with ONERA scientists
Graphic design: Philippe Bernou

Image credits

ONERA
Back cover left, FCAS: Dassault Aviation;
right, Eole launcher: CNES/ONERA/Aviation Design
P. 8, EC155 helicopter: DLR
P. 9, "Blue edge" blade: Eurocopter/Patrick Gertner
P. 13, ASMPA missile: Daniel Bechennec
P. 38, Falcon 7X model: ONERA-Dassault Aviation
P. 43, Rafale aircraft: USAF/Capt. Jason Smith
P. 45, vibration test: DLR
P. 48, M88 engine: Snecma-Safran/Philippe Stroppa
P. 62, Rafale: (French) Armée de l'Air
P. 64, satellites: CNES
P. 84, Beautemps-Beaupré ship: Franck Seurot/Marine Nationale
P. 86, VLT: ESO/G. Hüdepohl (atacamaphoto.com)
P. 99, Goce: ESA-AOES Medialab
Thinkstock

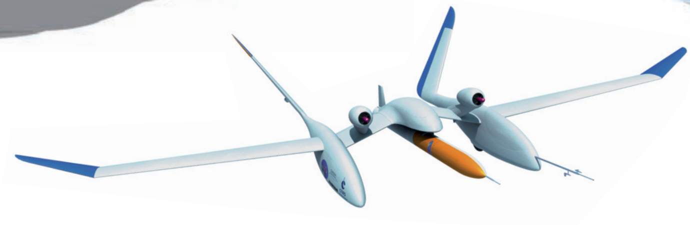
ISBN 13 : 978-2-7257-020-5

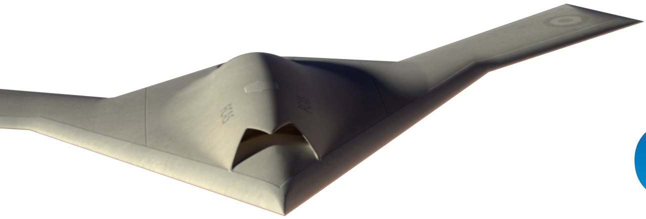
Main abbreviations used

CEA	*Commissariat à l'énergie atomique et aux énergies alternatives* (French Alternative Energies and Atomic Energy Commission)
CNES	*Centre national d'études spatiales* (French Space Agency)
CNRS	*Centre national de la recherche scientifique* (French Center for Scientific Research)
DGA	*Direction générale de l'armement* (French Government Defense procurement and technology agency)
DGAC	*Direction générale de l'aviation civile* (French civil aviation authority)
DLR	*Deutsches Zentrum für Luft- und Raumfahrt* (German aerospace research centre and space agency)
DMA	*Délégation ministérielle pour l'armement* (former name of DGA 1961-1977)
EASA	European Aviation Safety Agency
ESA	European Space Agency
ESO	European Southern Observatory
FAA	Federal Aviation Administration (USA)
JAXA	Japan Aerospace Exploration Agency (JAPAN)
NASA	National Aeronautics and Space Administration (USA)
NATO	North Atlantic Treaty Organisation
SAR	Synthetic Aperture Radar
SGDSN	*Secrétariat général de la défense et de la sécurité nationale*
SHOM	*Service hydrographique et océanographique de la Marine*
UAS	Unmanned Aerial System

ONERA

THE FRENCH AEROSPACE LAB





ONERA GEMS

ONERA

THE FRENCH AEROSPACE LAB

ONERA - BP 80100 - 91123 PALAISEAU CEDEX - Tel: +33 1 80 38 60 60 - Fax: +33 1 80 38 65 10

www.onera.fr