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THE FRENCH AEROSPACE LAB

return on innovation

www.onera.fr

Rotorcraft Aerodynamic and Aerocoustic Research at Onera

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CEAA- September 2014 – Svetlogorsk-Russia

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This Document has been approved for release to CEAA Workshop Participants

24-27 September 2014

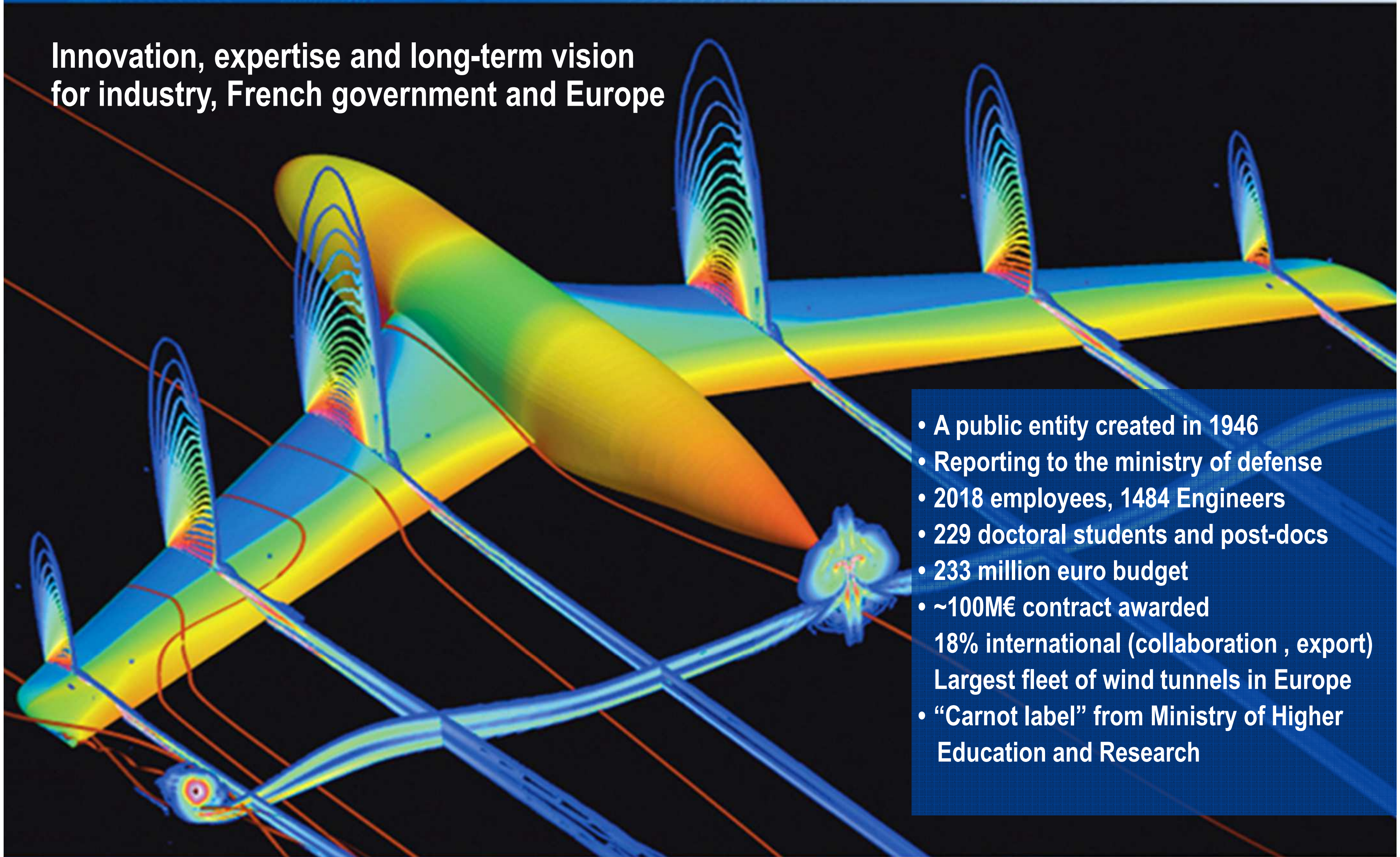
Svetlogorsk Russia

Outlook

- Onera's Identity and Missions
- How Onera is working for Rotorcraft benefit
- Rotorcraft aero-acoustic physical phenomena
- Numerical simulation tools at Onera:
  - Comprehensive codes developed
  - CFD,
  - Aeroacoustic chain
  - Experimental data bases and validation
- Example of innovative solutions
- Internal noise, description, models and solutions
- How to go further.

The French Aerospace Lab

Innovation, expertise and long-term vision for industry, French government and Europe



- A public entity created in 1946
- Reporting to the ministry of defense
- 2018 employees, 1484 Engineers
- 229 doctoral students and post-docs
- 233 million euro budget
- ~100M€ contract awarded
  18% international (collaboration , export)
  Largest fleet of wind tunnels in Europe
- “Carnot label” from Ministry of Higher Education and Research

Expanding the knowledge envelope — a strategic partner

Shaping the future

Expert advisor to the government

Innovative solutions for industry

Onera missions :

- Built the knowledge basis by fundamental research
- Prepare and demonstrate breakthrough technologies
- New technologies responding to strategic vision of industry and governmental agencies
- Prepare the answer to the 15-20 years future market demands
- Support industry's application of research,
- Provide independent expertise to the government and industry
- Train researchers, foster learning through research

A balanced business portfolio:
- 1/3 civil
- 1/3 defense
- 1/3 dual-use

Funding origin :
Governmental grants and contracts
Industry contracts
European initiatives

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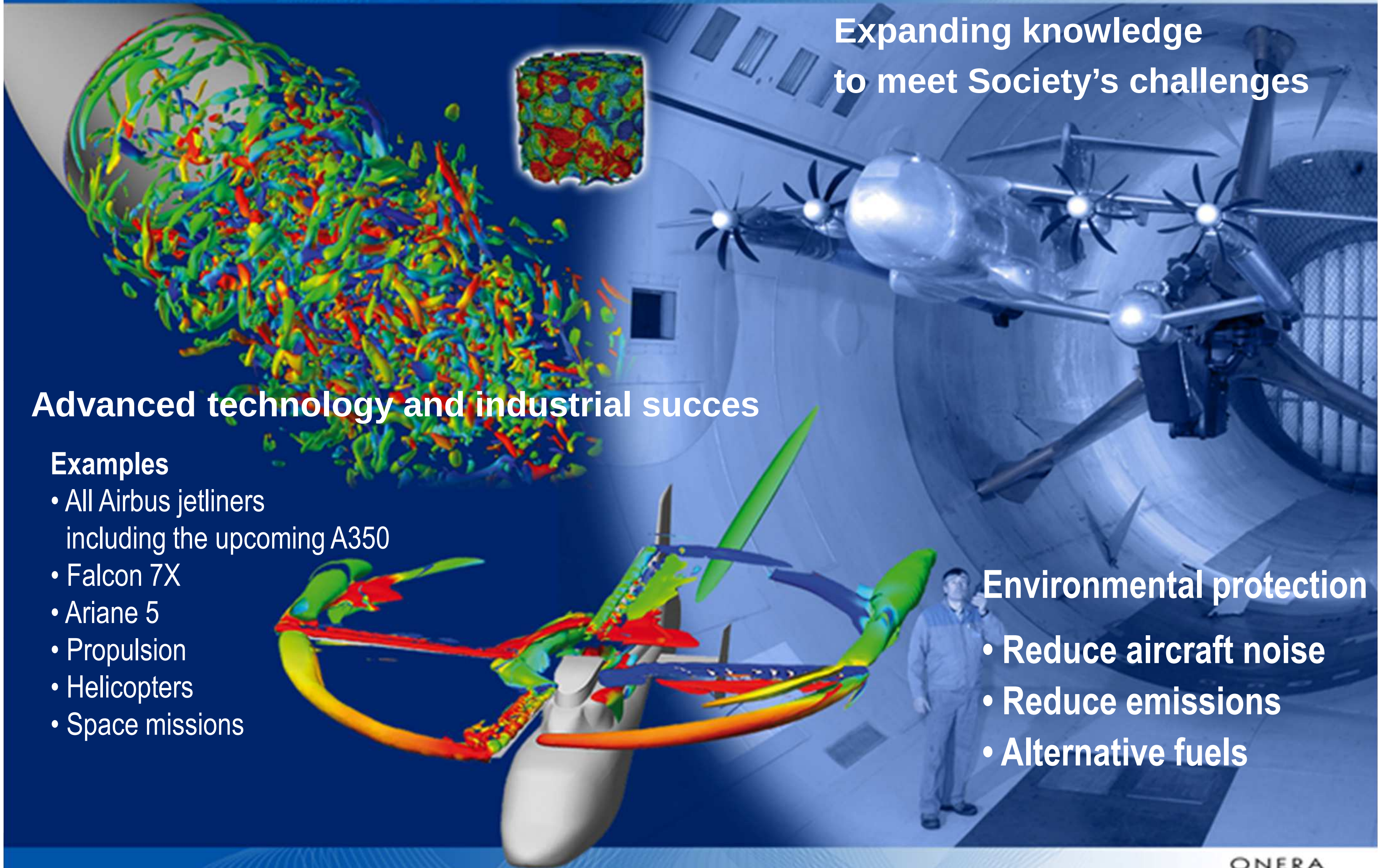
Return on innovation



Expanding knowledge to meet Society's challenges

Advanced technology and industrial succes

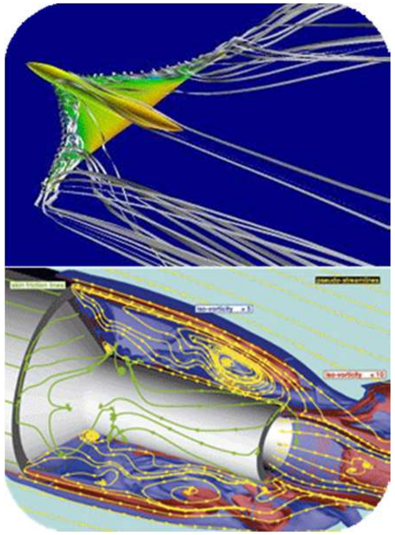
Examples
- All Airbus jetliners including the upcoming A350
- Falcon 7X
- Ariane 5
- Propulsion
- Helicopters
- Space missions

Environmental protection

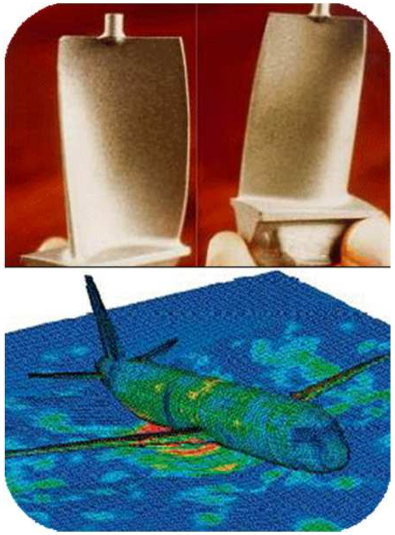
- **Reduce aircraft noise**
- **Reduce emissions**
- **Alternative fuels**

ONERA

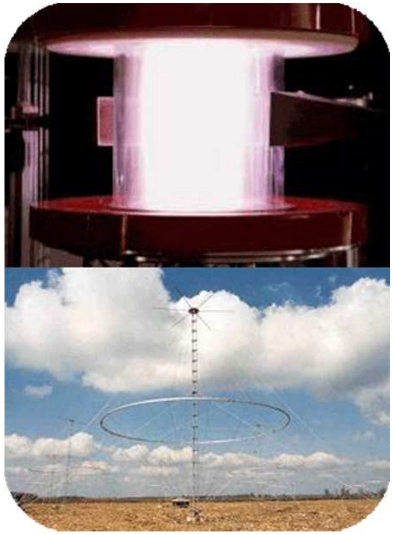
17 departments in 4 scientific divisions



Fluid Mechanics and Energetics



Materials and Structures



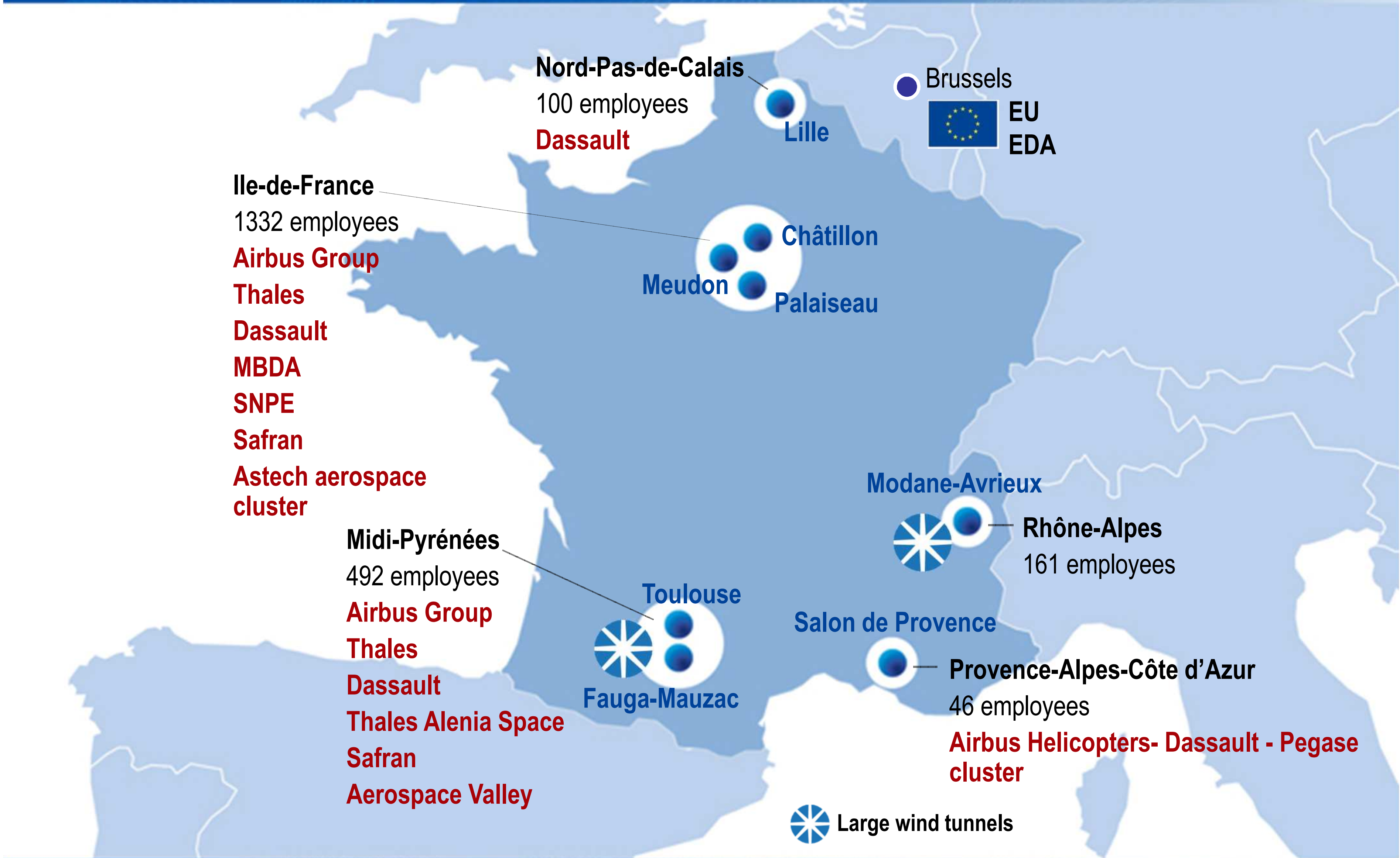
Physics

Information Processing and Systems

Test facilities

In each Branch, fundamental and applied activity

Onera: close to our industrial partners



Major player of the French Scientific Research

- Multidisciplinary Competencies

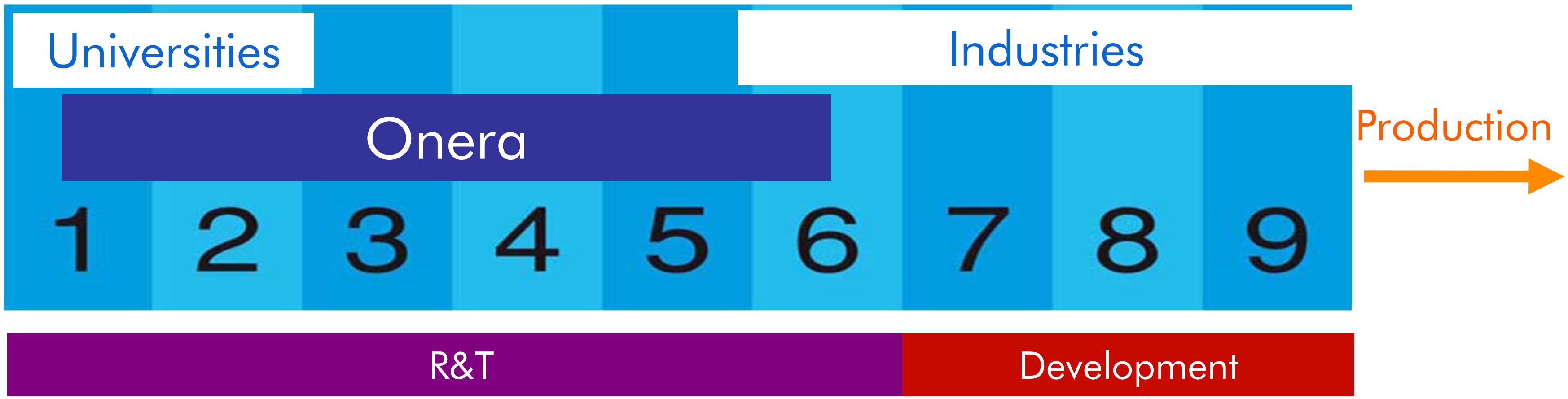
- Large Scientific Basis : 1400+ Researchers and Engineers
  400+ Technicians
  230 PhD / post-doc, ~75 Thèses

  amongs these

  220 Professors Researchers

  260 yearly Articles in Reviewed Journals

  660 yearly Communications in Intl Forums



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Links with EUROPEAN RESEARCH CENTERS

DLR: -Common programme for Rotorcraft from 2000

- bilateral cooperation in

Transport Aircraft,

Measurement Techniques,

Ground Vibration Tests.

Close links with EU RCs through EREA

(European Research Establishments in Aeronautics).

Members : CEIIA (Portugal), CIRA(Italie), CSEM (Swiss), DLR(Germany), FOI (Sweden), ILOT (Poland), INCAS (Romania), INTA (Spain), NLR (Netherlands), ONERA (France), VKI (Belgium), VZLU (Czech Rep.)

plus partnerships with TsAGI (Russia) and AIT (Austria).

Bilateral Agreements with National Research Centers :

NASA, USArmy, AFRL (USA), Tsagi (Russia), JAXA (Japan), CAE (China), DSO (Singapour) and DSTO (Australia)

IFAR: International Forum for Aviation Research

AAD-KTN (UK), IAE/CTA (Brazil), VZLU (Czech Rep.), Budapest UoT (Hungary), TsAGI (Russia), CIRA (Italy), CAE (China), CSIRO (Australia), CSRI-NAL (India), Onera (France), DLR (Germany), NRC (Canada), JAXA (Japan), KARI (Korea), METU (Turkey), NASA (USA), NLR (NL), INCAs (Romania), INTA (Spain), ILOT (Poland), FOI (Sweden), TU Vienna (Austria), VTT (Finland), VKI (Belgium).

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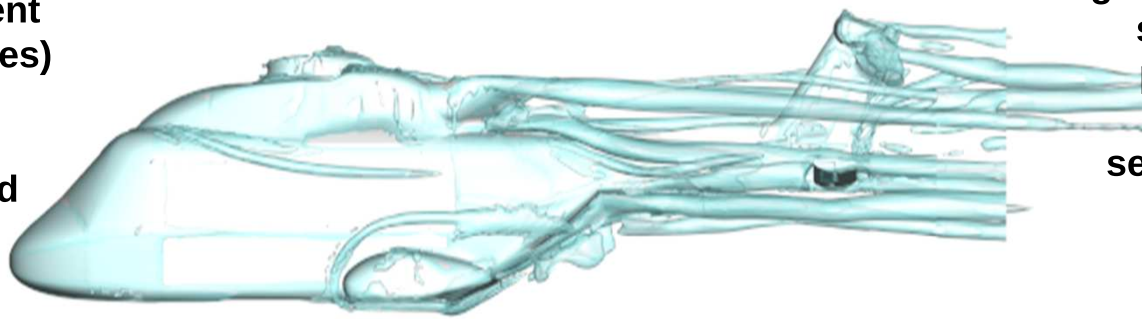
Segmentation of the Onera DLR Common Research Programme

The Virtual Aerodynamic Rotorcraft:
CFD, WTT, aerodynamics, interactional aerodynamics, calculation tools

Noise and dynamics:
External & internal noise (codes and control, noise abatement flight procedures)
Dyn/vibrations (simulation, measures and control

Flight systems; missions systems:
Flight Mechs, HQ, flight simulation tools, pilot assistance, UAVs systems, sensors and Human factors

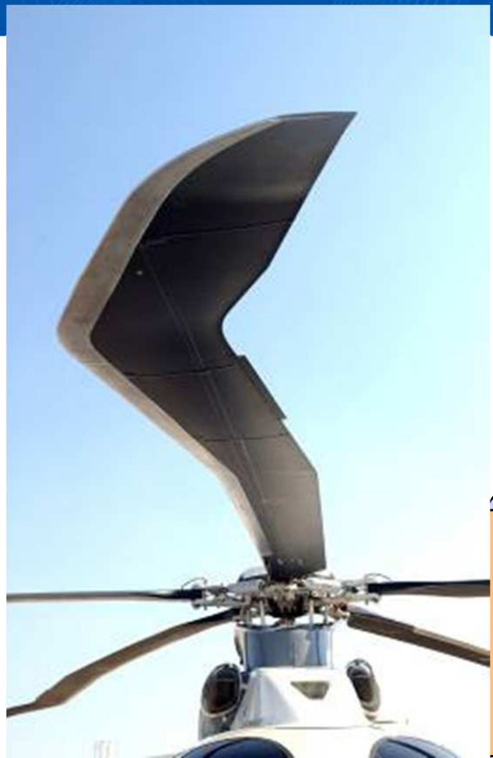


InnovationClassical rotorcraft and new concepts
Active blades, new concepts for rotorcraft, tiltrotor

Safety and all weather caapbilities:
Crash, High Velocity Impact, FOD, all weather studies (icing)

Material and Manufacturing
Composite manufacturing, high temperature structures, welding, processes

From Idea to Innovative Technologies: From TRL1 to TRL6

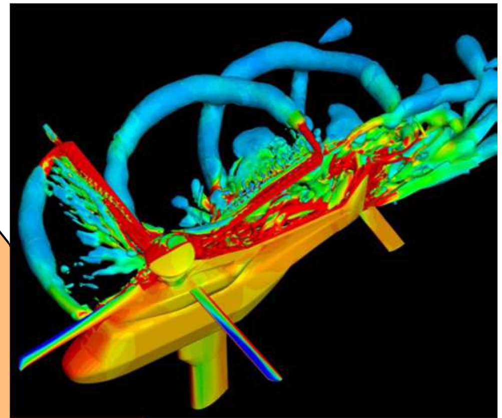


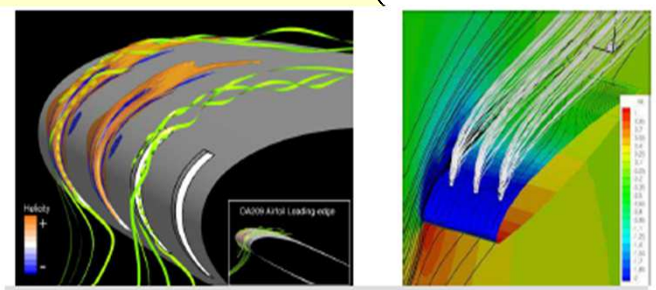
Innovation

Validation:
Wind tunnel
Flight Test

New Blade Shapes
Optimisation
Noise,Vibration, Perf

Idea + numerical simulation, CFD
codes elsA, Dynamics, Acoustics,
Interactional Phenomena





URANS simulation of DVGs (left) and air jets (right)

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Talking about Rotorcraft Noise ?

Rotorcraft Noise is one of the key for Public Acceptance , with Environmental Impact and Flight Security

Noise is also a contributor for increasing comfort (internal noise)

And reducing crew stress.

But to fix ideas:

If you are living in the 7th level of a building, on the street below, the truck is 72 dB noisy as a motorbike is 73dB

To be compared to a single engine helicopter flying over at 500 m above your flat, which is only 68 dB

A modern rotorcraft such as EC145 is 6 dB under the ICAO limit

Rotor Wake and Aerodynamics Interactions

Tremendous influence of wakes in helicopter aerodynamics

- Rotating blades interact with their wakes
  - At the source of induced power in hover
  - Lead to Blade-Vortex Interaction noise in low-speed descent flight
  - Responsible for the Vortex Ring State phenomenon

Low speed: rotor wake remains close to airframe components

- Large Rotor-Fuselage Interactions
- Strong influence on the flight dynamics of the helicopter

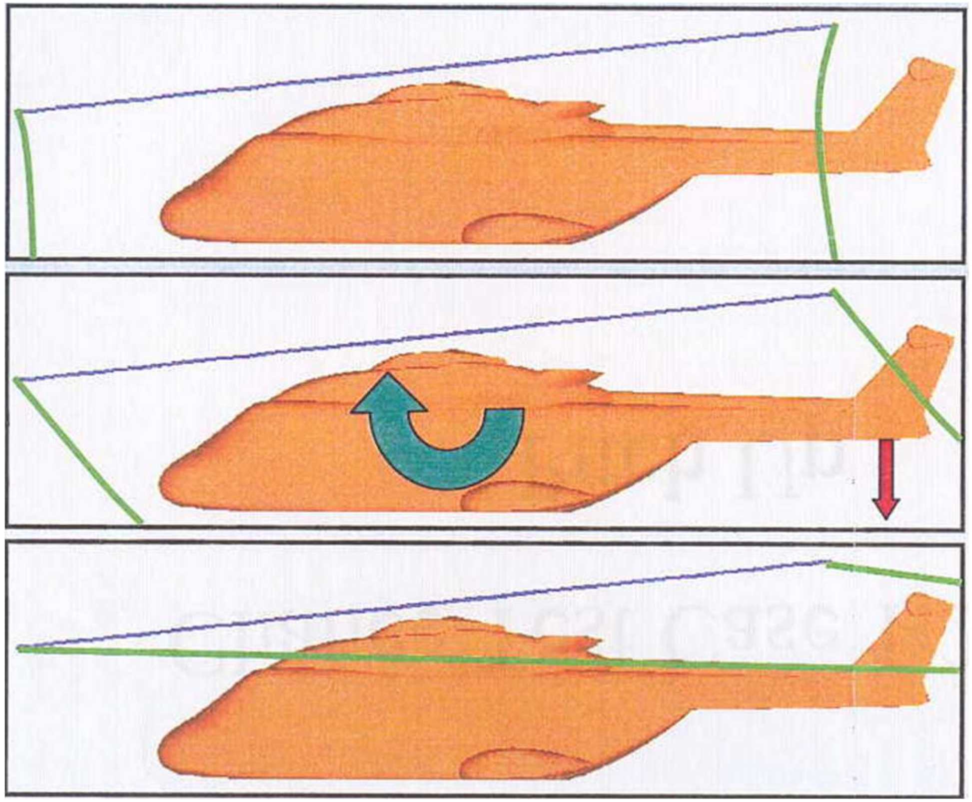
- Other vortical flows play an important role
  - Dynamic stall
  - Tail shake

External noise sources on a helicopter

Noise is depending on flight phases:

- Descent, landing : BVI
- Climb : Blade Wake interactions BWI
- Cruise at high speed : BVI

Main Rotor and Fuselage Interactions



Low Speed (μ<0,2) (hover)

Moderate Speed (0,2 <μ <0,3): horizontal stabilizer impact

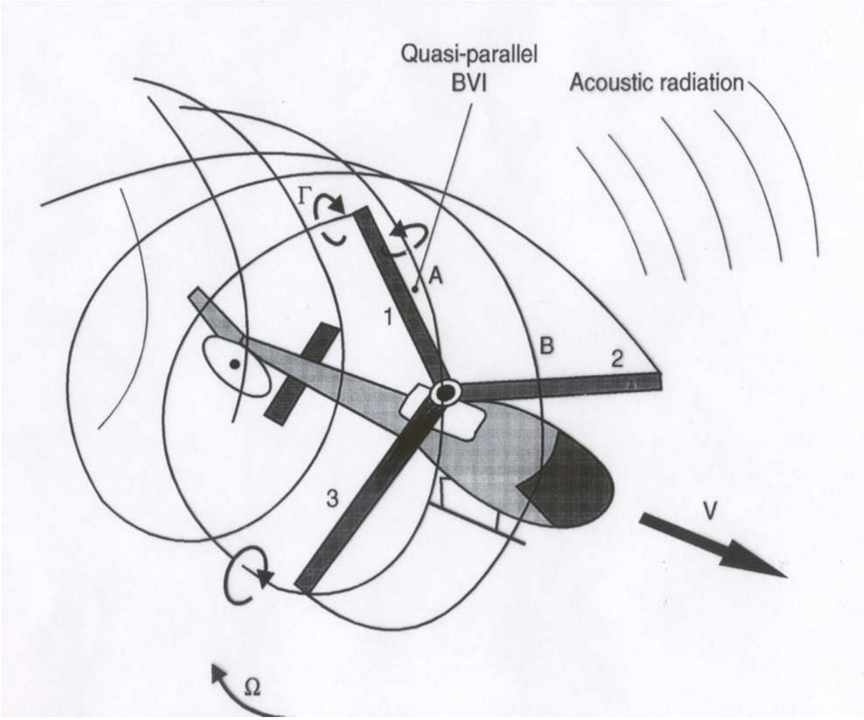
→ pitch-up

Cruise / High Speed (μ 0,4 and +): interaction of the hub wake with rear parts

→ tail-shake (vibrations, fatigue)

$\mu = M_{infinite}/M_{Tip}$

Physical phenomena to understand and simulate



This brings need for understanding:

- aerodynamics interactions
- blade vortex
- rotor wake

And simulation tools with different levels of models:

- comprehensive codes
- CFD
- Simplified model for flight mechs

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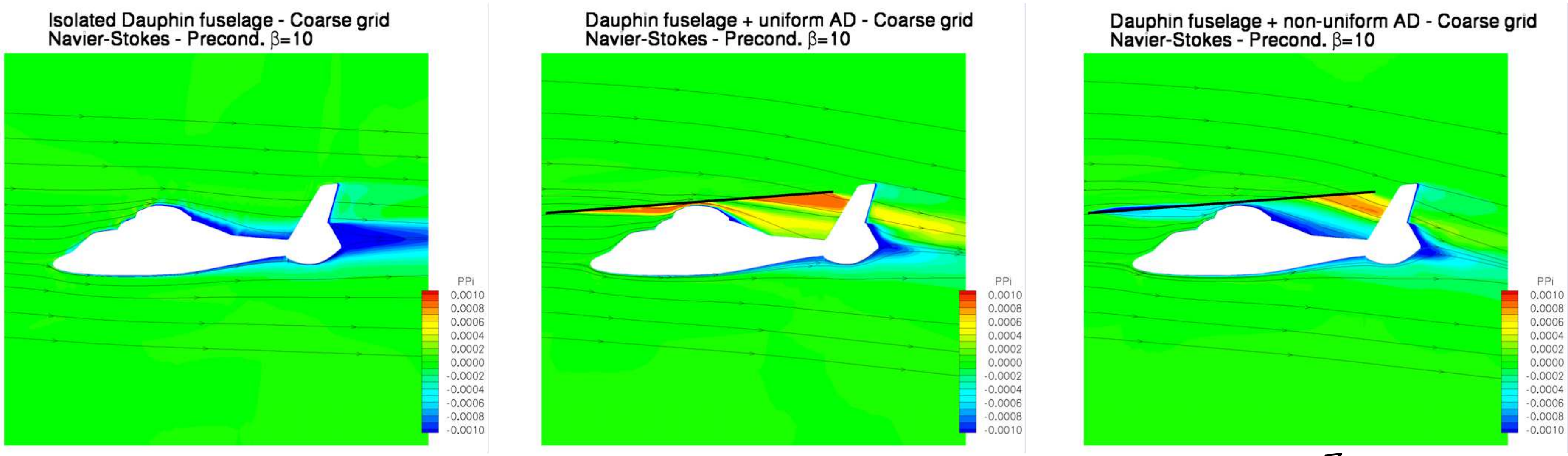
Numerical Approach Steady: CFD with actuator disk (AD)

View of calculation in median plan (in Total Pressure p_i)



W/O rotor

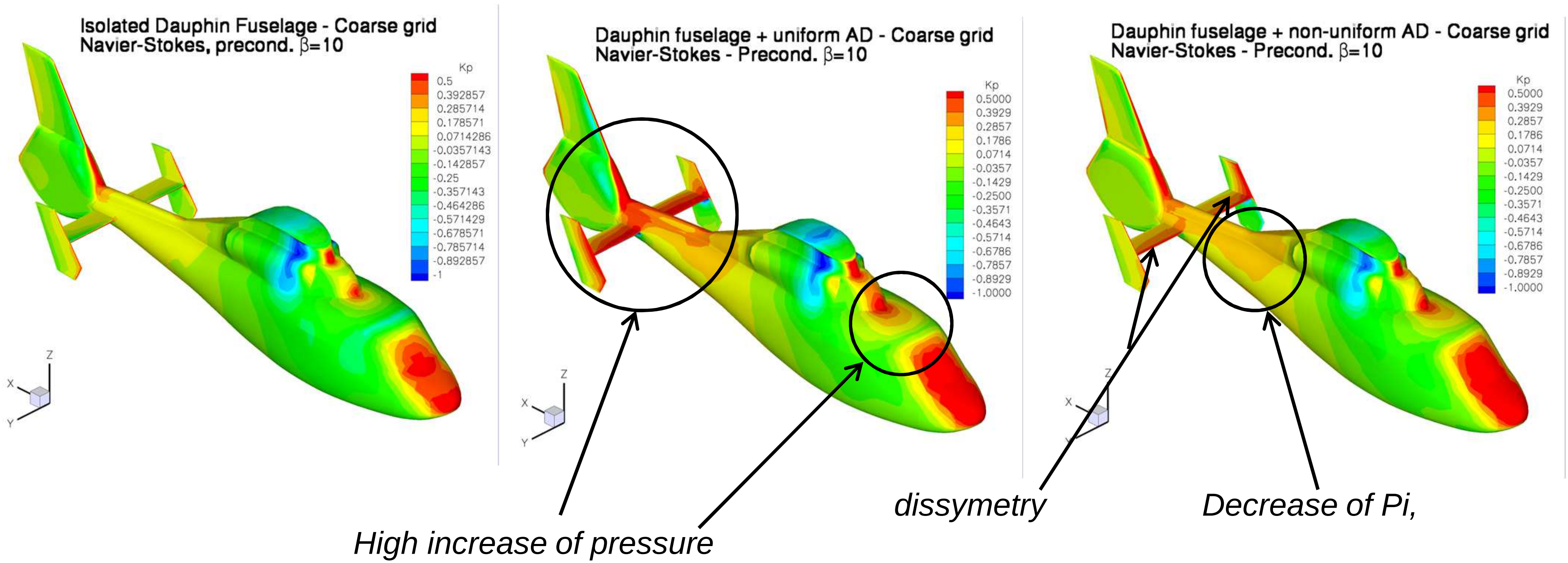
With AD : flow impact on rear parts

There a non negligeable delta between Uniform and Non Uniform Actuator Disc:

- the interaction effect is under estimated on the beam (p_i increase)
- with Non Uniform AD: interaction effects increase on the beam(p_i decrease)

Numerical Approach Steady: CFD with actuator disk

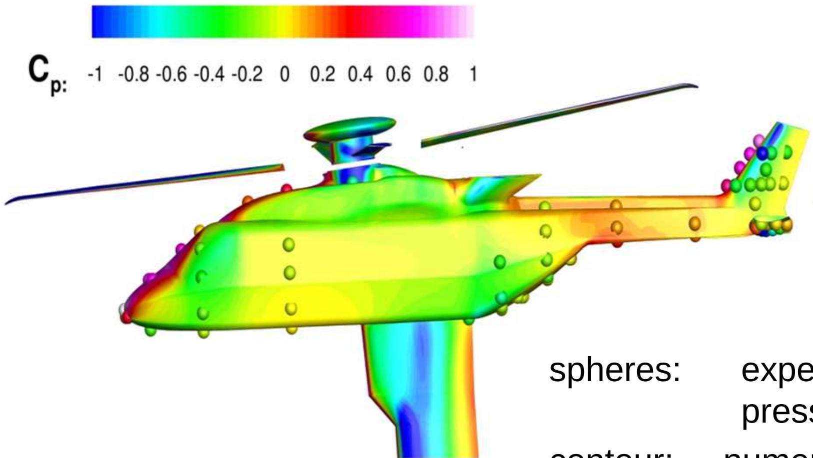
Pressure on the fuselage



EU project GOAHEAD (Generation of Advanced Helicopter Experimental Aerodynamic Database for CFD Code Validation)

- Completion of post-test complete helicopter simulations with correct model geometry and test conditions
- Comparison with unsteady experimental data
- Figure shows results of the cruise test case ($M_\infty = 0.204$, $\Theta_{fuselage} = -2.5°$) at main rotor azimuth $\psi = 90°$

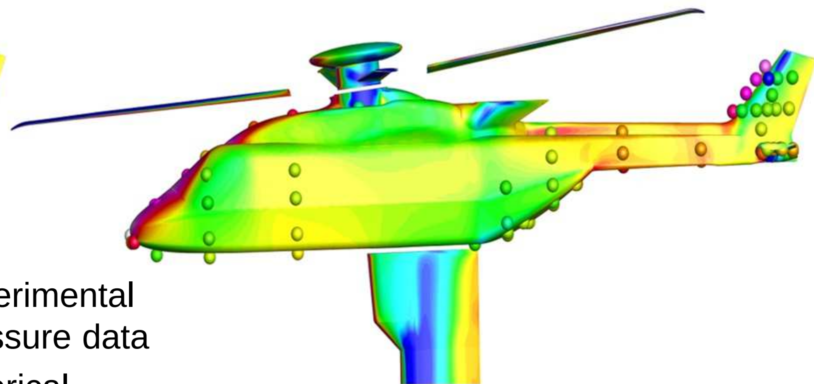

WT model in DNW



DLR results
(FLOWer computation)

spheres: experimental pressure data

contour: numerical pressure distributions

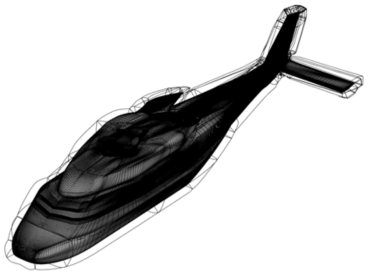


ONERA results
(*elsA* computation)

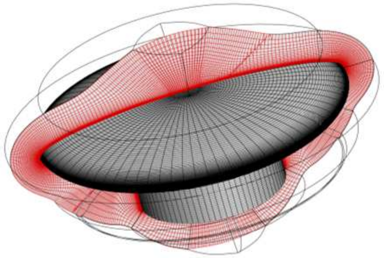
Unsteady Approach: GoAhead configuration

- Intermeshing : « Chimera »

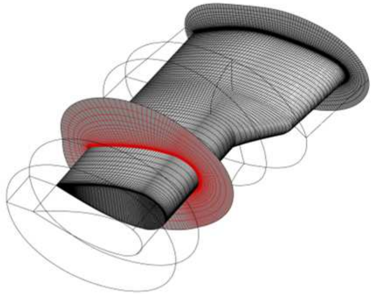
Fuselage 7,4M



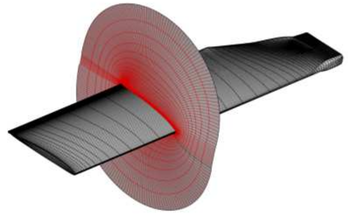
Hub 1,1M



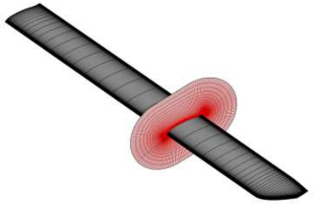
Strut 1,3M

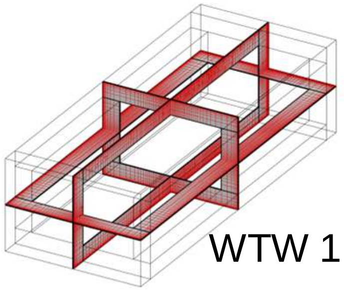


TR 2x0,65M

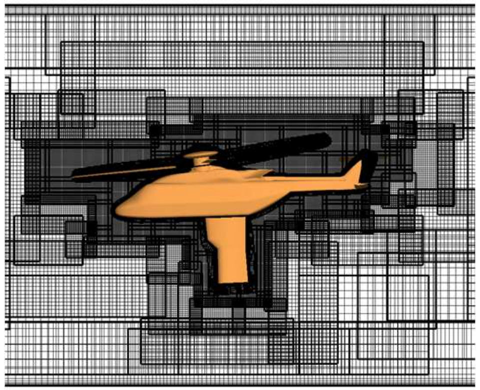


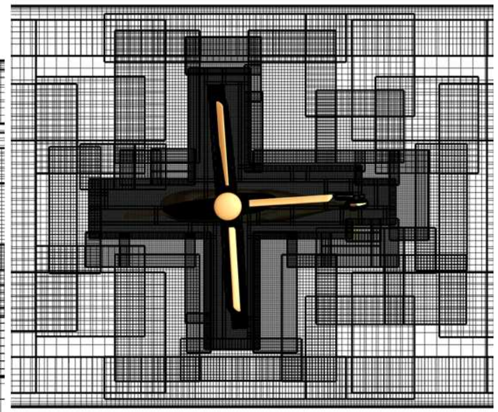
MR 4x1,1M





WTW 1,4M





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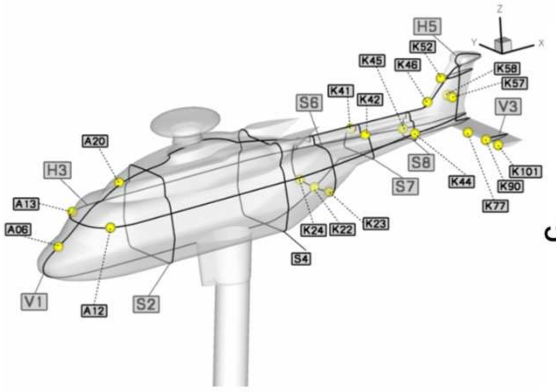
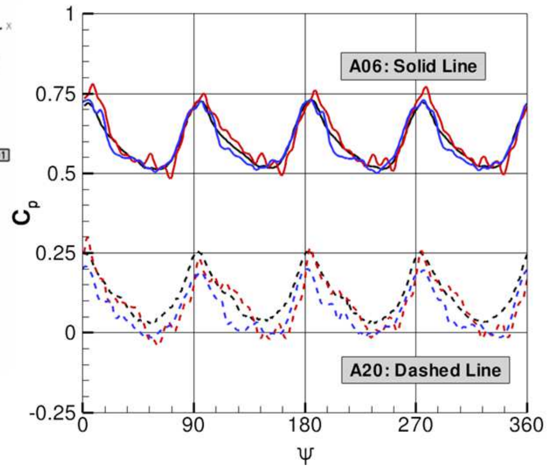
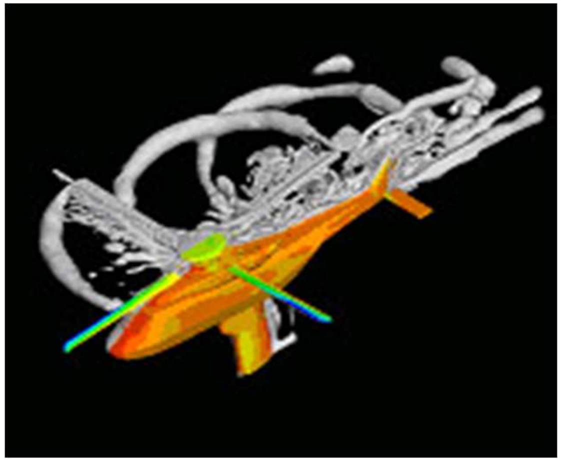
Unsteady Approach: GoAhead

- Complete helicopter simulation by CFD





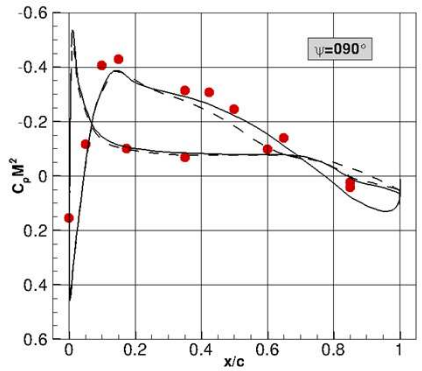


- Good expe/calculation agreement for the blade unsteady effect

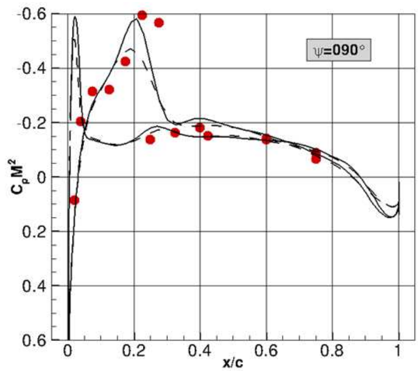
-- main rotor / rear rotor interaction well captured.

-- Pressure variation behind rotor hub not good representativity

r/R=0,7



r/R=0,915

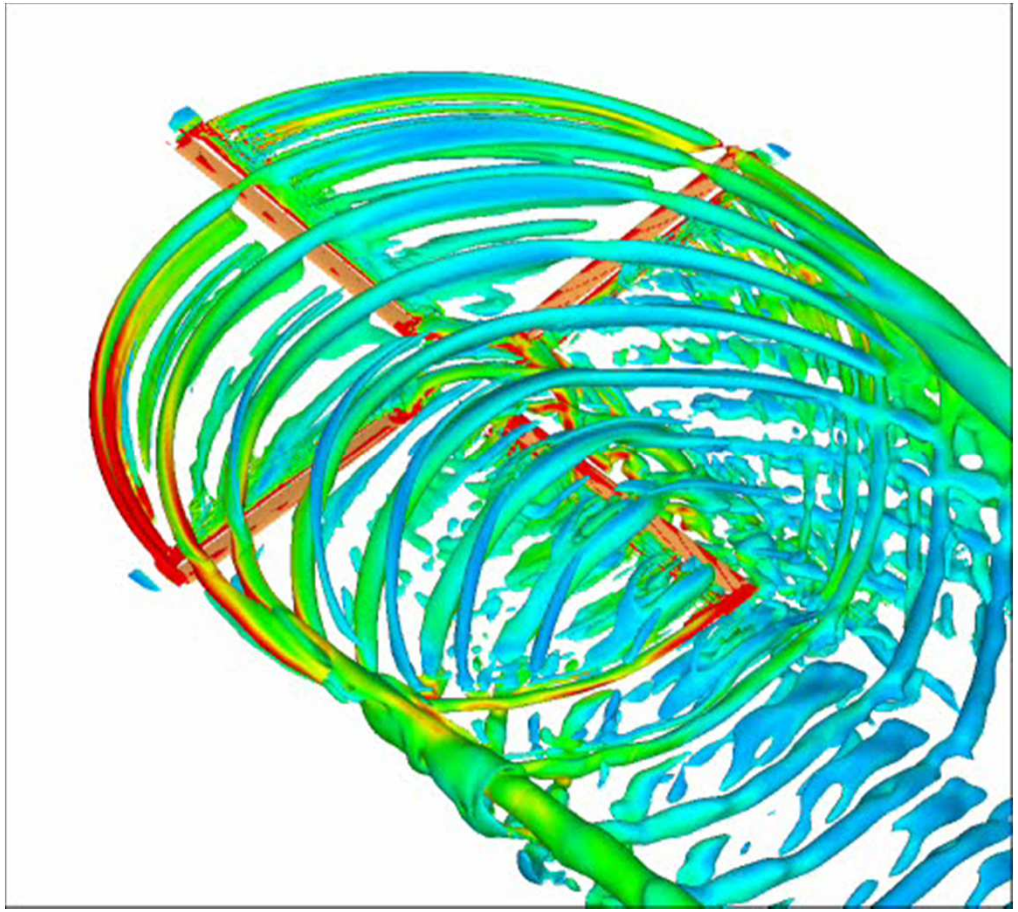


T. Renaud, M. Costes, S. Péron,
Computation of GOAHEAD configurations with Chimera assembly. 36th European Rotorcraft Forum,
7-9 September, 2010 - Paris, France

Blade pressure in two sections.

Dotted line: pre-tests prediction. Full line: post-tests prediction.

Onera’s Numerical tool: *elsA* Structured code



Isolated Rotor Wake and BVI (elsA)

T. Renaud, G. Perez, C. Benoit, G. Jeanfaivre, S. Péron, *Blade-Vortex Interaction Capture by CFD*. 34th European Rotorcraft Forum, 16-19 September, 2008 - Liverpool, UK

Numerical Methods in the *elsA* CFD Code

elsA

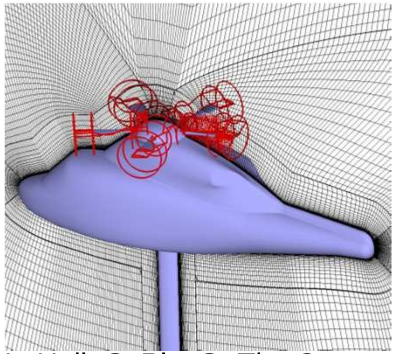
- Finite Volume Solver for Multi-Block Structured Grids
- Centered Discretisation with Jameson Artificial Viscosity
- Implicit Resolution in Time with Newton Iterations

Classical method

Chimera body grids

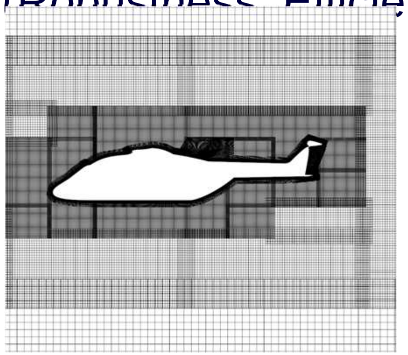
Non-coincident matching boundaries in Cartesian background grid

Same numerical parameters/scheme in the whole mesh



Cartesian adapted grid strategy

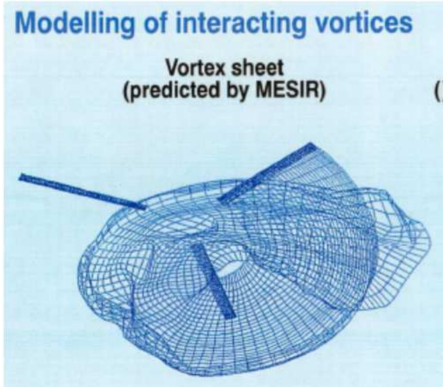
- Chimera body grids
- Automatically generated and adapted Cartesian background grids
- Ability to use different numerical parameters/schemes in Cartesian grids (Robustness, Efficiency)

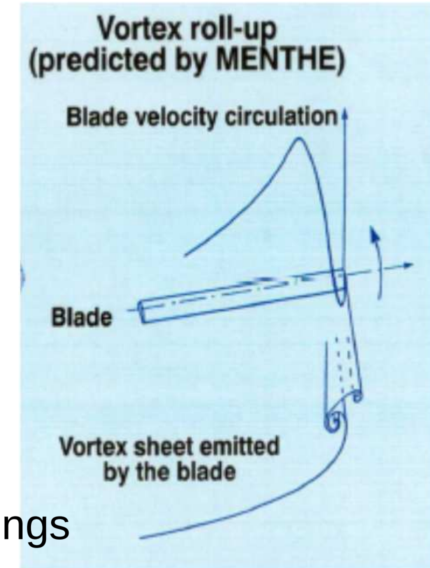


Cambier L, Heib S, Plot S. *The Onera elsA CFDSoftware: Input From Research and Feedback From Industry.* Mechanics & Industry 14, 159–174 (2013).

BVI noise numerical prediction method (HMMAP)

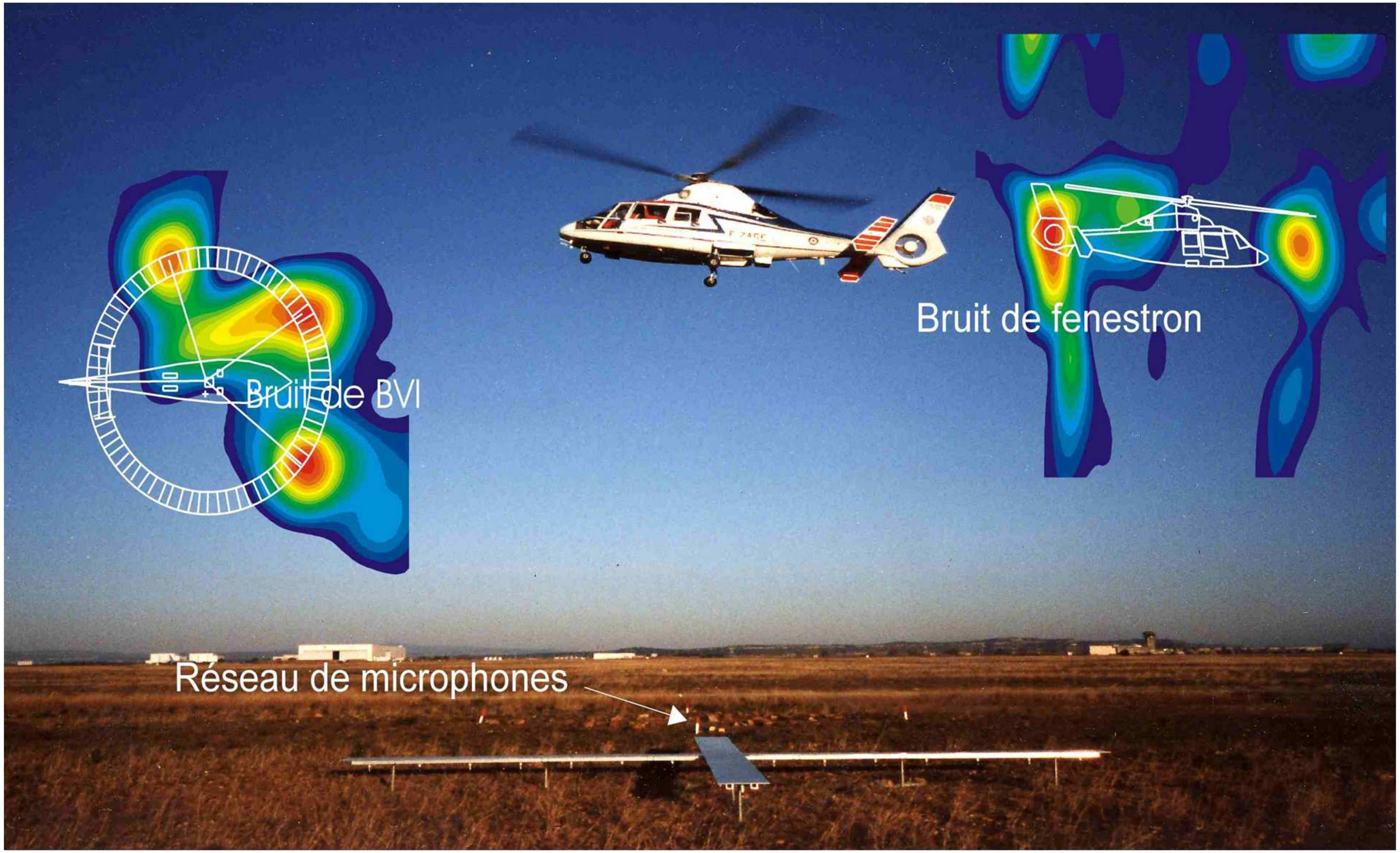
Flight Mech Code *trim+dynamics*	Aeroelastic calculation (lift. line theory, prescribed wake)
MESIR *free wake*	Free wake vortex lattice method, lifting line theory
MENTHE *vortex roll-up*	Model of the vortex sheet roll-up
ARHIS *blade pressures*	2D by slices calculation, singularity method, cloud vortex model option for close BVI
PARIS *noise*	Thickness and loading noise calculation based on FfowcsWilliams-Hawkings equation, identification of BVI source locations





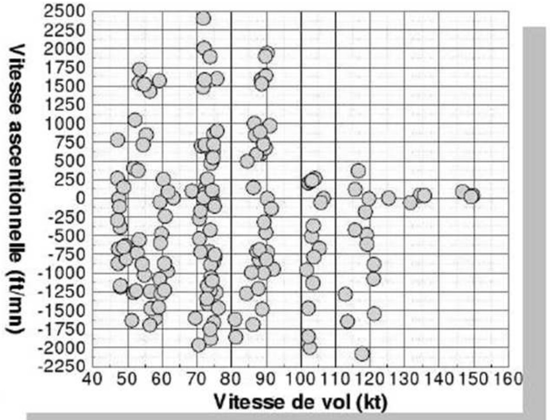
P. Beaumier, Y. Delrieux, *Description and Validation of the ONERA Computational Method for the Prediction of Blade-Vortex Interaction Noise*. 29th European Rotorcraft Forum,16-18 September, 2010 - Friedrichshafen, Germany

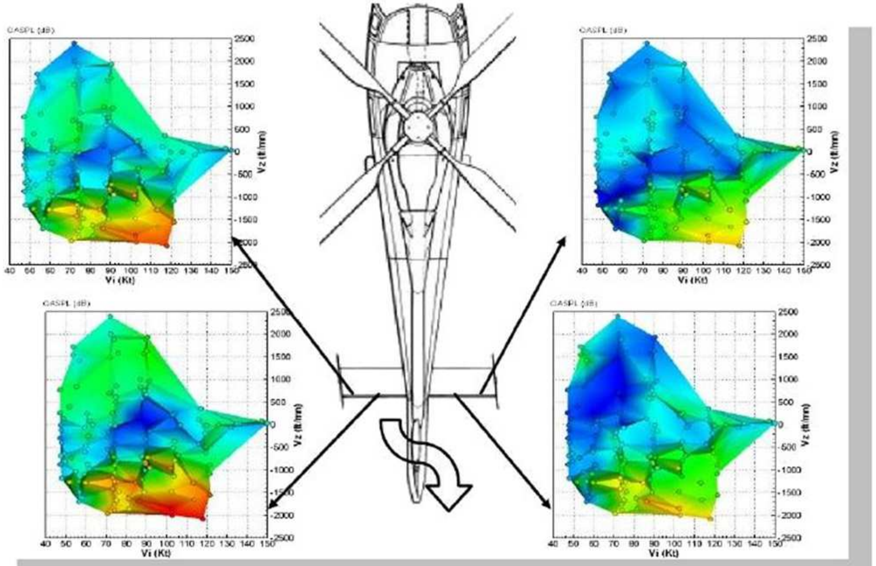
Noise source identification - Flight Tests Dauphin 6075

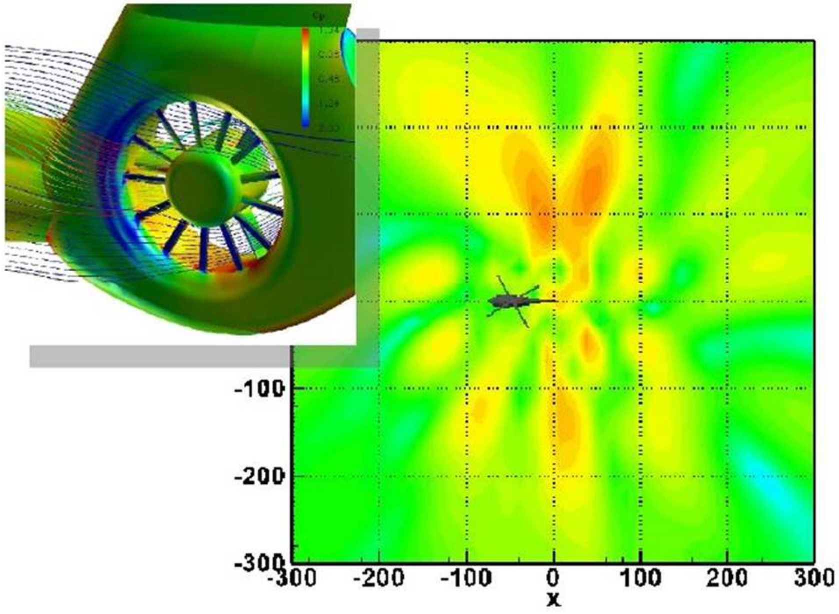


performed at Istres Flight Test Center (Blacodon et al, 2004)

Experimental and numerical study of the noise radiated by a Fenestron in real flight conditions (DTP Fenestron)







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How to reduce the noise ?

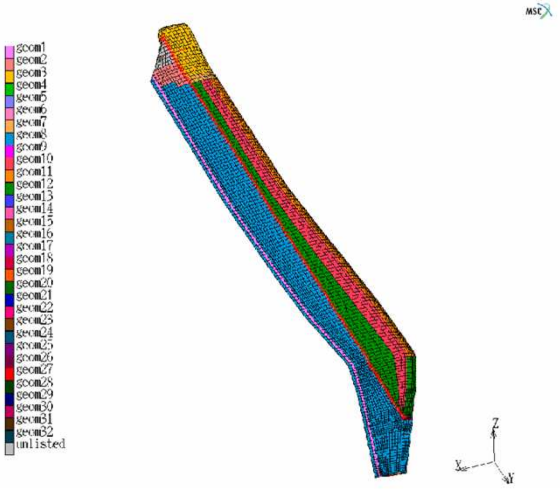
Main rotor:

- Blade Shape: ERATO blade
- Active blade: with actuators or flaps

Rear Rotor:

Fenestron with uneven spaced bladed

Low noise flight procedures studied in Clean Sky GRC.

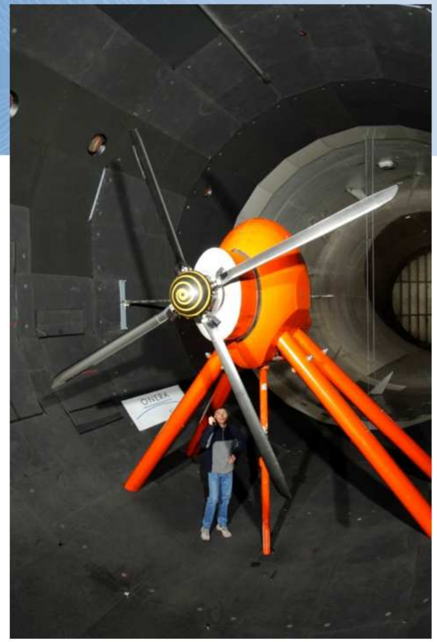


Pale ERATO

Engine noise reduction :

Not considered in this paper.

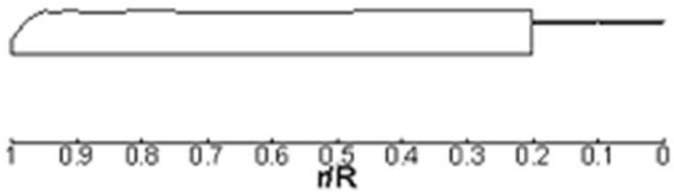
ERATO Blade

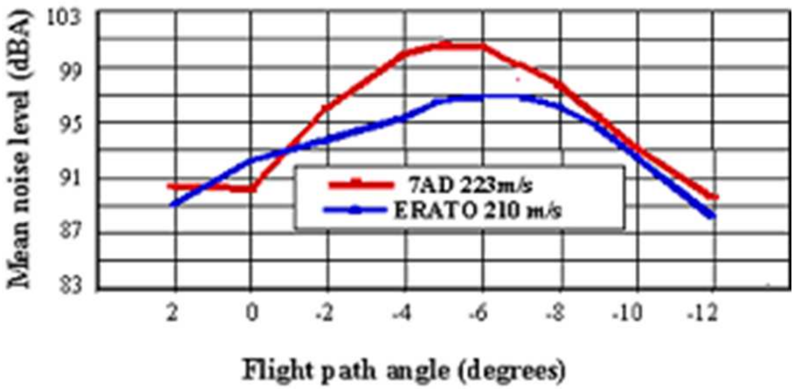


S1 Modane Isolated RotorTest rig:
model rotor up to 4.2 m diameter;
Performances, acoustics , blade deformation, steady and unsteady pressure measurements

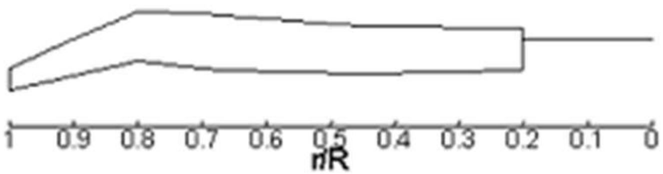
Tested in DNW: acoustic measurements

7AD Blade (reference rotor)





ERATO

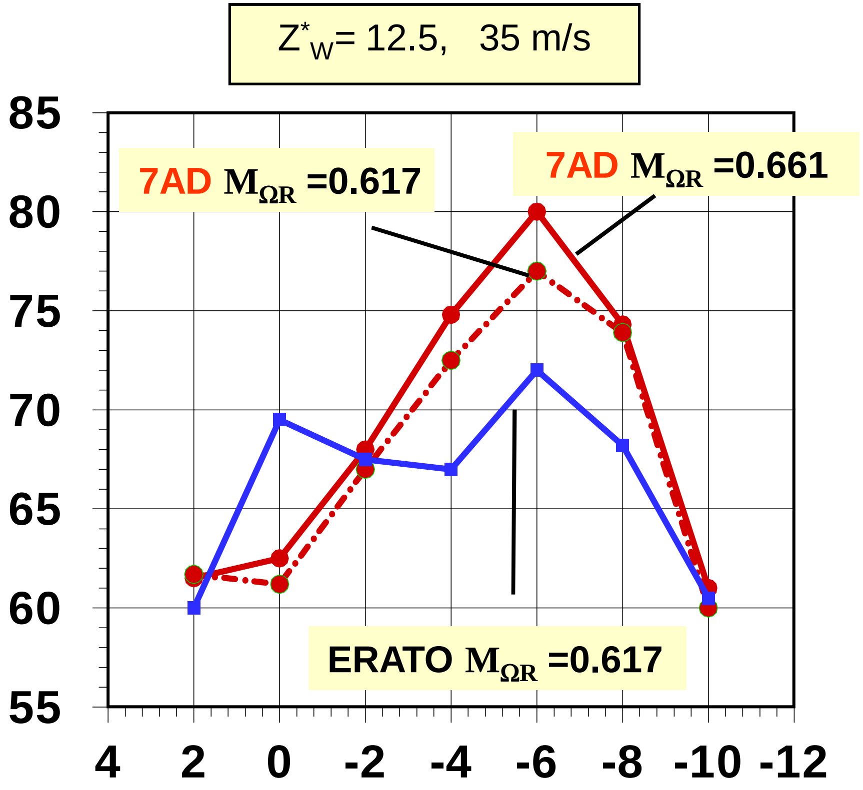


V = 125 km/h and Zb = 12.5
Experimental results in DNW wind tunnel

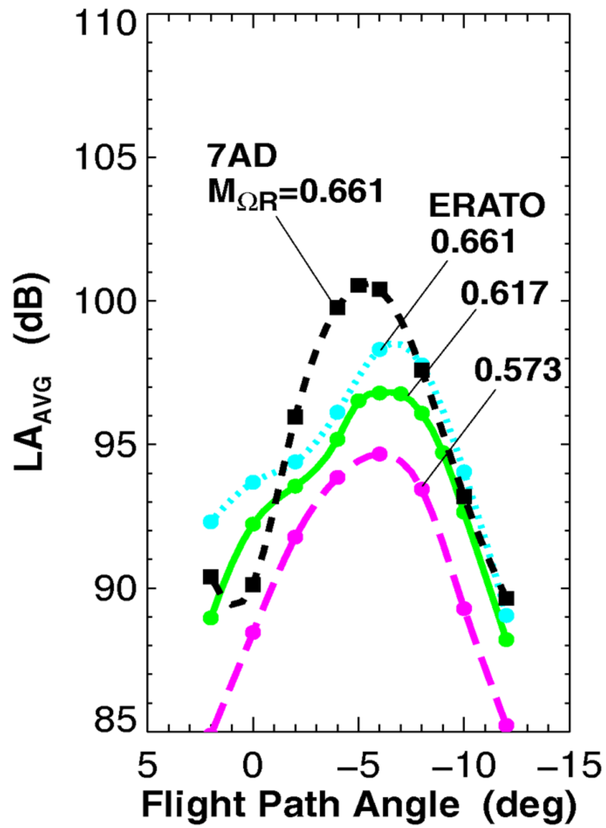
ERATO Blade

Prediction

(Full scale simulation)



DNW measurements



Delrieux, Y., Prieur, J., Costes, M., Gardarein, P., Beaumier, P., Mercier des Rochettes, H., Leconte, P., Crozier, P., Splettstoesser, W.R., van der Wall, B., Junker, B., Schultz, K.-J., Mercker, E., Pengel, K., Philippe, J-J., Gmelin B.: *The Onera-DLR Aeroacoustic Rotor Optimisation Programme ERATO: Methodology and Achievements*, AHS-Aerodynamics, Acoustics, and Test and Evaluation Technical Specialists Meeting, San Francisco, January 2002

From Research to Industry:
From ERATO to BLUE EDGE ™

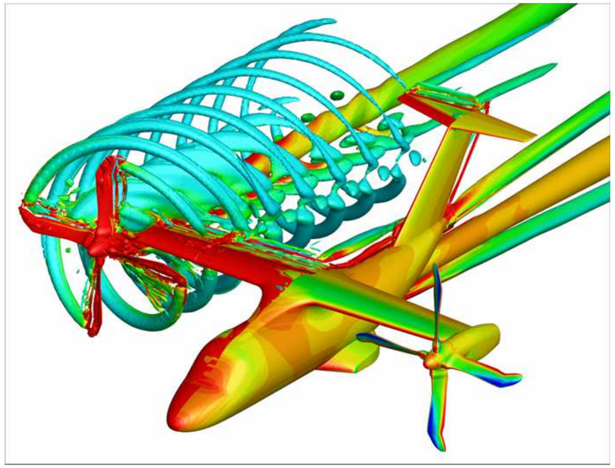
ERATO Blade: Common patent by DLR and Onera (1997)
TRL2 to 3

ERATO noise & performances demonstrated in WT (S1MA and DNW LLF) TRL 4

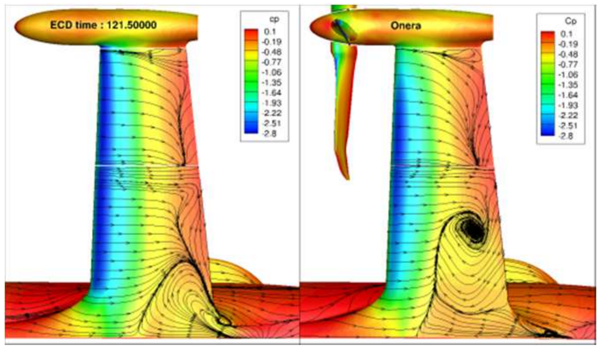
2001 - 2008 : BLADE 2005 – Scale 1 definition and Eurocopter Flight Tests
TRL 6
TRL 7 to 9 running in Industry

New Rotorcraft Configurations

Tilt rotor NICETRIP EU Project (ending in 2014)



Simulation numérique elsA



CFD configuration studies

WTT at S1 MA (high speed)

…and Compound (X3)

ONERA
THE FRENCH AEROSPACE LAB

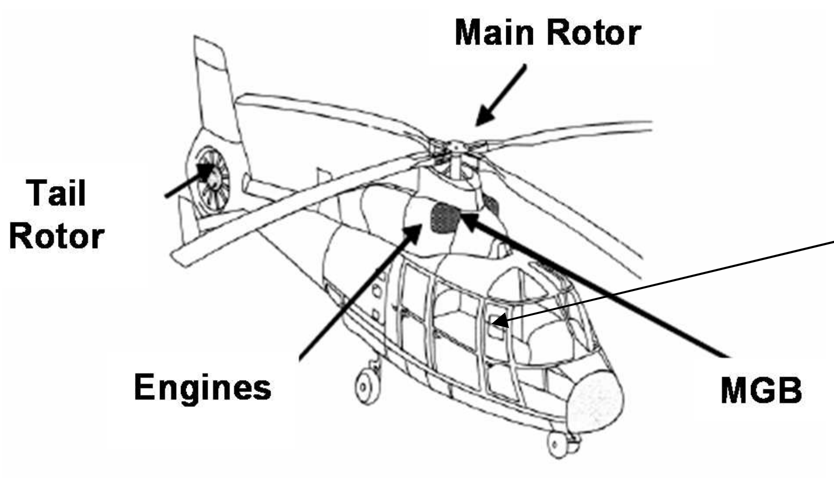
Outlook

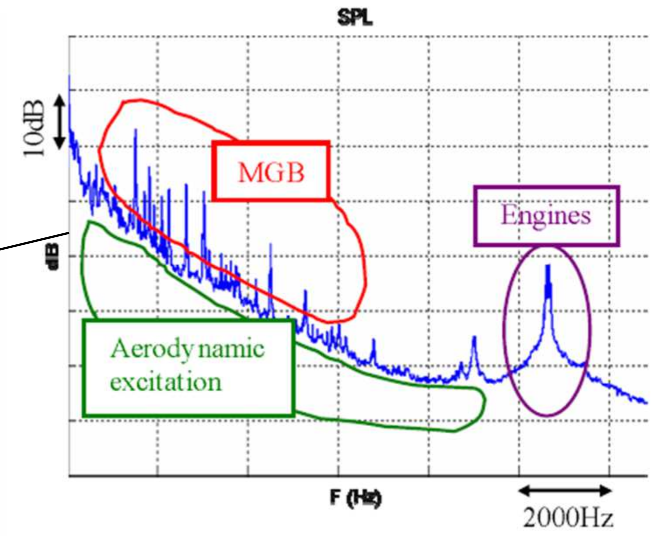
- Onera’s Identity and Missions
- How Onera is working for Rotorcraft benefit
- Rotorcraft aero-acoustic physical phenomena
- Numerical simulation tools at Onera:
  - Comprehensive codes developed
  - CFD,
  - Aeroacoustic chain
  - Experimental data bases and validation
- Example of innovative solutions
- Internal noise, description, models and solutions
- How to go further.

Internal Noise: main sources

Main sources in helicopter cabin :

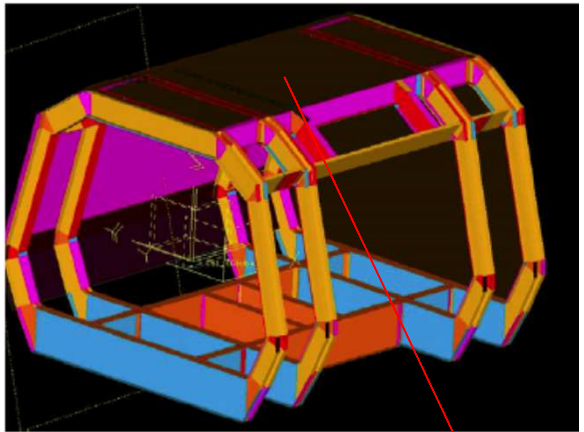
main and tail rotors, engines, main gearbox (tonal noise) and aerodynamic turbulence (broadband noise)





Main sources with frequency ranges

Onera cabin mock-up with structural energy paths

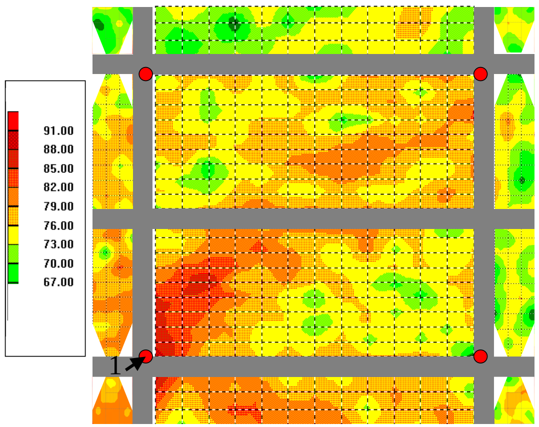


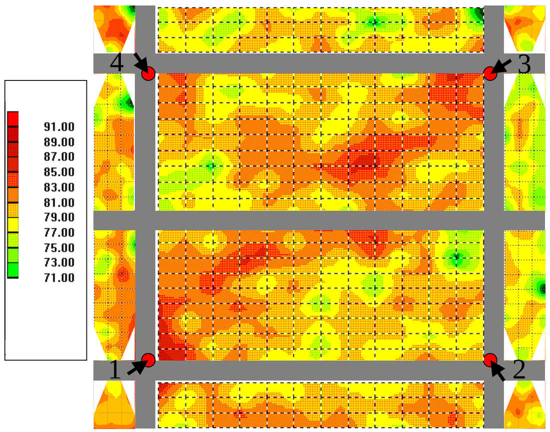
Strong frames of cabin mock-up

Cabin mock up

- VASCO : mock-up of NH90 cabin with carbon frames and Nomex honeycomb sandwich panels placed between fibre-glass and carbon laminates

- Equipped with 4 shakers fixed on mechanical deck to simulate the vibration sources generated by gear-box





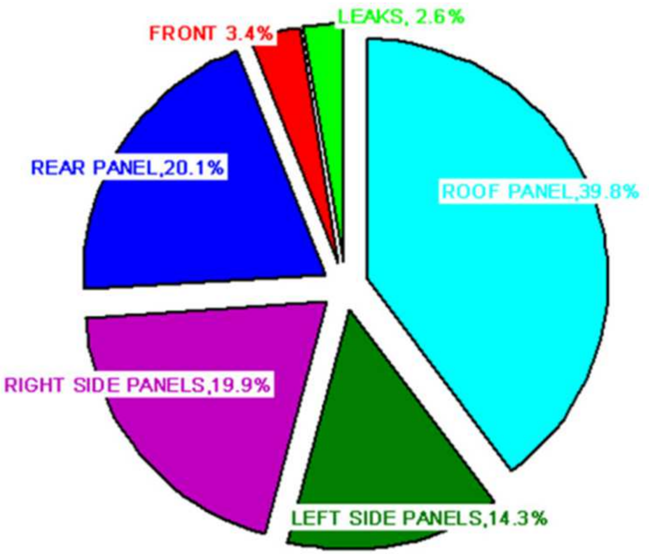
- Energies propagated mainly towards the middle of the mechanical deck from the excited source(s)

- Decreasing of magnitude along the propagation path due to high structural damping and the modal coupling

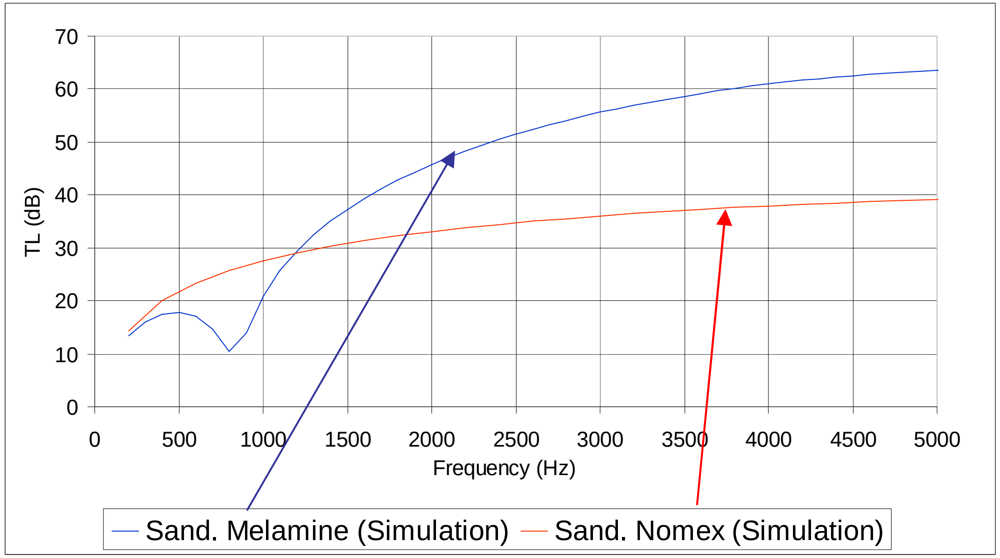
Structural intensity field on the mechanical deck for 500-3000 Hz frequency band

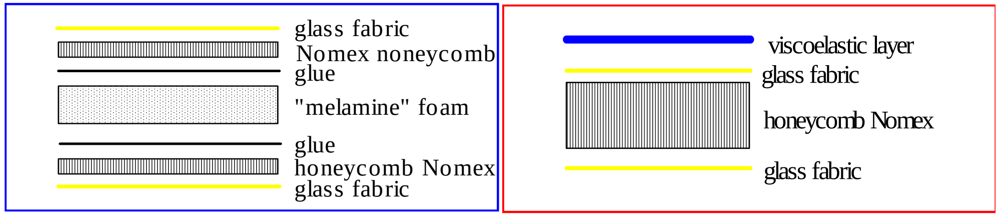
F. Simon, S. Pauzin, Acta Acustica, Vol. 92(2), 2006.

Helicopter cabin noise



Acoustic Transmission Loss (dB) of trim panels (PIAMCO)





Optimised trim panel

Classical trim panel

Average contribution in the EC155 cabin dB SIL4

** J. Caillet et al., "Comprehensive approach for noise reduction in helicopter cabins", Aerospace Science and Technology 23, 17–25, 2012.*

- High acoustic Transmission Loss due to dilatation effect of foam
- Satisfying static bending stiffness due to honeycombs
- Onera Concept approved by Airbus helicopter

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Open Technical Challenges

Breakthrough technologies needed for increasing safety, expanding the flight domain in adverse conditions and addressing environment requirements

To extend rotorcraft use, key issues are :

Increase capability of All Weather Operations for safety in rescue or offshore operations (DVE, sensors, pilot assistance)

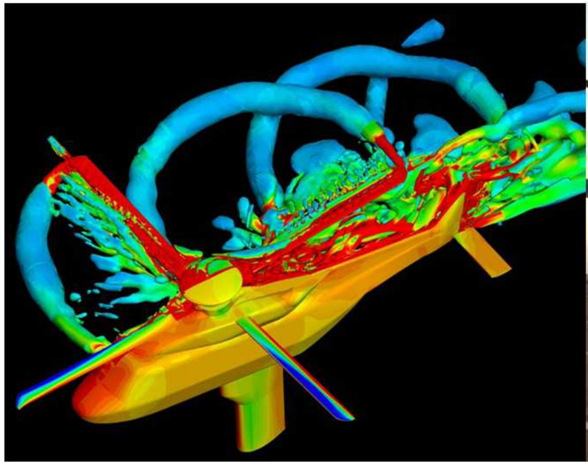
Prepare the future with “Greening” : reducing emission (act on aerodynamic drag and engine efficiency), decreasing noise, vibration, respect environmental regulations for materials

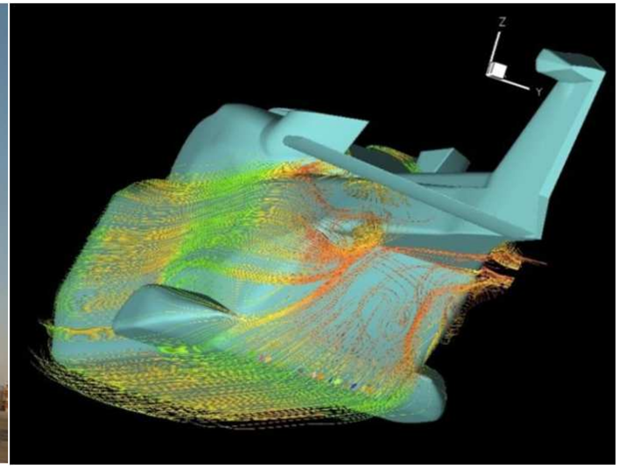
Increase safety : Crash demonstration, passenger protection, flight domain limits alert or controls

New concepts:

On “classical” helicopters by primary control w/o swashplate,

With new concepts: compound (X3, X2), evaluation tools….





Colored view of the flow solution around the GOAHEAD configuration (pressure coefficient on wall surfaces and wakes represented by isosurface of Q criteria (elsA structured CFD solver)

Simulation of passive flow control for drag reduction

Recommendation : pls go to www.onera.fr, the AerospaceLab Journal Issue June 2014

Overview of Acoustics Studies at Onera

Thank you for your attention

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Y. Delrieux (Onera), AerospaceLab Journal- Issue 7- June 2014 (www.onera.fr)

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