The Group of Responsables Aerodynamics (GoR AD)
An Overview of activities and Success Stories

G. Mingione[1], E. Coustols[2], F. Monge[3], H. van der Ven[4], K. Richter[5],
M. Tormalm[6], L. R. Calavera[7], B. Stefes[7], D. Pagan[8], P. Eliasson[9], M. Mallet[10],
R. Gemma[11]

[1]CIRA, [2]ONERA, [3]INTA, [4]NLR, [5]DLR, [6]FOI,[7]AIRBUS, [8]MBDA, [9]SAAB, [10]DASSAULT,[11]LEONARDO

What is GARTEUR: story and mission

- ✓ The Group for Aeronautical Research and Technology in EURope (GARTEUR) is an organization for research collaboration in Europe in the field of aeronautics;

- ✓ It was created in 1973 by 3 nations, while 7 are involved today in GARTEUR: France, Germany, Italy, the Netherlands, Spain, Sweden and the United Kingdom;

- ✓ Industrial, research and academic partners from non-member countries could participate, following a formal procedure;

- ✓ Focuses on collaborative research topics mainly aimed at longer-term R&T that is essential to assure sustained European Aeronautics Industry competitiveness;

- ✓ Subjects of interest within GARTEUR Programme not restricted by application, whether defense, dual use or civil.

What is GARTEUR: story and mission

Main areas of interest are:

- ✓ Aerodynamics;
- ✓ Aviation security;
- ✓ Flight mechanics system and integrations;
- ✓ Helicopters;
- ✓ Structures and materials.

For each area a Group of Responsible (GoR) is established with the objective to address and monitor activities (Exploratory Group and Action Group)

Aerodynamics GoR

The Group is active in experimental, theoretical, analytical, as well as in numerical fields of aerodynamics to support the development of methods and procedures.

Work in experimental areas is performed mainly to obtain valuable data for the validation of methods. Measurement techniques are developed and refined to increase accuracy and efficiency of experimental investigations. Numerical studies are performed to give insight in the mechanisms of basic flow phenomena.

The GoR AD initiates and organizes basic and applied aerodynamic research in the field of aeronautics. The current scope of activities cover the following areas:

- ✓ Aerodynamics;
- ✓ Aero-thermodynamics;
- ✓ Aero-acoustics;
- ✓ Aero-(servo-)elasticity;
- ✓ Aerodynamic shape optimization;
- ✓ Aerodynamics coupled to flight mechanics;
- ✓ Aerodynamics systems integration.

- ✓ GARTEUR along the time had a fundamental role in establishing cooperation among European company.
- ✓ When GARTEUR was set-up, in a period where collaborative projects funded from EU where far from arrive, GARTEUR represented a unique possibility of cooperation among European companies and research centre and represented the feed of future European funded collaborative projects.
  - ✓ The first GoR-AD action group is from 1979: AD/AG-01 wing body aerodynamics at transonic speed
  - ✓ At present time we have arrived at AD/AG-61 WMLES and Embedded LES.
  - ✓ Therefore this means that along its life GARTEUR-AD has developed 61 projects on several topics related to aerodynamics

PERFORMED ACTION GROUP (1/2)

AD/AG-01 Wing-body aerodynamics at transonic speed
AD/AG-02 Two dimensional transonic testing methods
AD/AG-03 Theory/Experiment comparison for high lift airfoil (High lift phase I)
AD/AG-04 An experimental and theoretical investigation into the asymmetric vortex flows characteristics of bodies of revolution at high angles of incidence in low speed flow
AD/AG-05 Convergence study for transonic flow for 3D wings
AD/AG-06 Model Support Interference in Large Low-Speed Wind Tunnels
AD/AG-07 Experimental investigation of the turbulent shear layers on swept wing
AD/AG-08 High lift action group (High lift phase I)
AD/AG-09 Flow past missiles afterbody
AD/AG-10 Flow computation for advanced propellers
AD/AG-11 Computations of 2D Navier-Stokes Equations
AD/AG-12 Comparative Investigation of Predictive Capability of Aeroacoustics Methods of Single Rotation Propellers
AD/AG-13 High lift phase III
AD/AG-14 Transition for Airfoils and Wings
AD/AG-15 Validation of Euler codes for supersonic flow (2 parts)
AD/AG-16 Development of Software Package for Graphic Visualization of Flow Simulation
AD/AG-17 Verification of 3D Transonic Euler Methods for Complex Geometries
AD/AG-18 Adaptive wall wind tunnels
AD/AG-19 Particle Image Velocimetry
AD/AG-21 Pressure Sensitive Paint
AD/AG-22 Practical Application of LDV
AD/AG-23 Three Dimensional Turbulent Shear Layer Experiment, Phase 2
AD/AG-24 Navier-Stokes calculations of the supersonic flow about slender configurations
AD/AG-25 Computational Methods for High Lift Flows (High lift phase IV)
AD/AG-26 Navier Stokes Computations of 3D Transonic Flow for a Wing/Fuselage Configuration
AD/AG-27 Transition on airfoils and infinite swept wings with regard to nonlocal instability investigations
AD/AG-28 Transonic Wing/Body Code Validation Experiment
AD/AG-29 Three-dimensional turbulent shear layer experiment - Phase 3
AD/AG-30 CFD for Supersonic Civil Transport high-lift evaluation and configuration development
AD/AG-31 Analysis of a Supersonic Transport Configuration with and without foreplan using a Navier Stokes solver
AD/AG-32 Prediction of performance degradation due to icing for 2D configurations
AD/AG-33 Ice accretion prediction on aircraft components

PERFORMED ACTION GROUP (2/2)

AD/AG-34 AERODYNAMICS OF SUPERSONIC INTAKES
AD/AG-35 Application of Transition Criteria in Navier Stokes Computations
AD/AG-36 3D High Lift Computations
AD/AG-37 Pressure sensitive paint, Phase II
AD/AG-38 Time Accurate Methods
AD/AG-39 Transonic Wing/Body Calculations, Phase II
AD/AG-40 Ice shapes effects on the aerodynamic performance of airfoils, Phase II
AD/AG-41 Ice Accretion Prediction, Phase II
AD/AG-42 Navier-Stokes Calculations of the Transonic Flow Over Slender Configurations
AD/AG-43 Application of CFD to High Offset Intake Diffusers
AD/AG-44 Application of Transition Criteria in NS-Computations, Phase II
AD/AG-45 Application of CFD to predict high “G” loads
AD/AG-46 Highly Integrated Subsonic Air Intakes
AD/AG-47 Coupling of CFD with Flight Mechanics
AD/AG-48 Lateral Jet Interactions at Supersonic Speeds
AD/AG-49 Scrutinizing Hybrid RANS-LES Methods for Aerodynamic Applications
AD/AG-50 Effect of Wind Tunnel Shear Layers on Aero-acoustics Measurements
AD/AG-51 Transition and Turbulence in Hypersonic flows
AD/AG-52 Surrogate Modelling in Aeronautical Design and Optimization
AD/AG-53 Receptivity and Transition
AD/AG-54 RANS-LES Interfacing Hybrid for Hybrid RANS-LES and embedded LES approaches
AD/AG-55 Countermeasures Aerodynamics
AD/AG-56 Coupled fluid dynamics and Flight Mechanics
AD/AG-57 Secondary inlets and outlets for ventilation
AD/AG-58 Supersonic air intakes
AD/AG-59 Laminar separation bubbles
AD/AG-60 Machine learning and data-driven approaches for aerodynamic optimization and uncertainty quantification
AD/AG-61 WMLES and Embedded LES

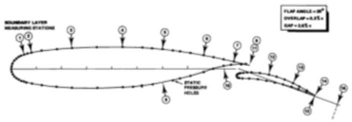
- ✓ A long this period several radical revolutions have happened in fluid-dynamics.
- ✓ Development and availability of increasing computational resources
- ✓ Interest and development of transonic aircraft
- ✓ High lift improvements
- ✓ Studies on second generation high speed transportation
- ✓ Reduction of environmental impact

- ✓ The first one is of course the development of computer and, as consequence in parallel the development of Computational Fluid Dynamics.
- ✓ In parallel with increase of computer resource more and more accurate tools for aerodynamics simulation have been developed.
  - ✓ Euler solver
  - ✓ RANS solver
  - ✓ Grid generation
  - ✓ LES and hybrid methods
- ✓ It is not by chance that the first action group was dedicated to numerical/experimental comparison.

In synchrony with computer development the first action groups were dedicated to CFD code validation and their comparison with experimental data, work was performed step by step along with code developments and computing resources availability increase:

2D CFD tools development and validation

- ✓ AD/AG-02 Two dimensional transonic testing methods
- ✓ AD/AG-03 Theory/Experiment comparison for high lift airfoil
- ✓ AD/AG-11 Computations of 2D Navier-Stokes Equations



3D CFD tools development and validation

- ✓ AD/AG-23 Three Dimensional Turbulent Shear Layer Experiment Phase 2
- ✓ AD/AG-24 Navier-Stokes calculations of the supersonic flow about slender configurations
- ✓ AD/AG-25 Computational Methods for High Lift Flows
- ✓ AD/AG-26 Navier Stokes Computations of 3D Transonic Flow for a Wing/Fuselage Configuration

Transonic flows

- ✓ AD/AG-28 Transonic Wing/Body Code Validation Experiment

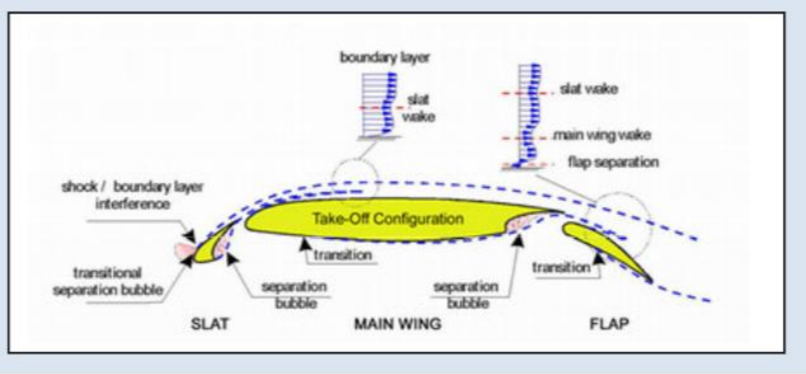
High-Lift

- Large efforts where dedicated to high lift:

- GARTEUR early activities on High Lift Aerodynamics were four Action Groups during 1981-1998:
  - AD/AG-03 1981-1984 High lift, phase I
  - AD/AG-08 1985-1990 High lift, phase II
  - AD/AG-13 1991-1994 High lift, phase III
  - AD/AG-25 1995-1998 High lift, phase IV (maximum lift prediction)

High lift knowledge was improved trough the development of CFD methods and careful experimental investigations in various wind tunnels. These projects were often based on national funding and GARTEUR allowed to share results among involved partners and maximize results.

High lift is still an open issue and more recently AD/AG-36 3D High Lift Computations was performed



In the nineties there was a new interest in supersonic transport, and therefore this interest was caught by GARTEUR that addressed the topics.

- ✓ AD/AG-30 CFD for Supersonic Civil Transport high-lift evaluation and configuration development
- ✓ AD/AG-31 Analysis of a Supersonic Transport Configuration with and without foreplan using a Navier-Stokes solver

Interest on high speed transportation was replaced on interest on environmental impact, therefore, AG regarding fuel consumption reduction (laminarity) and noise have been addressed

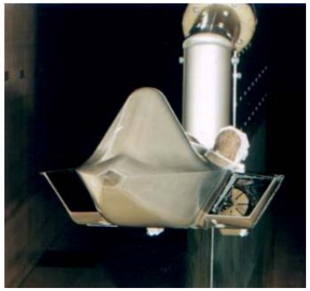
- ✓ AD/AG-27 Transition on airfoils and infinite swept wings with regard to nonlocal instability investigations
- ✓ AD/AG-35 Application of Transition Criteria in Navier-Stokes Computations
- ✓ AD/AG-12 Comparative Investigation of Predictive Capability of Aeroacoustic Methods of Single Rotation Propellers

Flight safety has also been addressed with icing topics

- ✓ AD/AG-32 Prediction of performance degradation due to icing for 2D configurations configurations
- ✓ AD/AG-33 Ice accretion prediction on aircraft components
- ✓ AD/AG-40 Ice shapes effects on the aerodynamic performance of airfoils, phase II
- ✓ AD/AG-41 Ice Accretion Prediction, Phase II

A large amount of work has been performed also for military aircraft problems

- ✓ AD/AG-09 Flow past missiles afterbody
- ✓ AD/AG-34 Aerodynamics of Supersonic Intakes
- ✓ AD/AG-46 Highly Integrated Subsonic Air Intakes
- ✓ AD/AG-48 Lateral Jet Interactions at Supersonic Speeds
- ✓ AD/AG-55 Countermeasures Aerodynamics



At present time several Action Group related to different topics are active, most recent groups are:

- ✓ ***AD/AG-49 Scrutinizing Hybrid RANS-LES Methods for Aerodynamic Applications***
- ✓ ***AG-54 RANS-LES interfacing for hybrid RANS-LES and embedded LES approaches***
- ✓ ***AG-55 Countermeasure aerodynamics***
- ✓ ***AG-56 Coupled fluid dynamics and flight mechanics simulation of very flexible aircraft configuration***
- ✓ ***AG-57 Secondary inlets and outlets for ventilation***
- ✓ ***AG-58 Supersonic air intakes***
- ✓ ***AG-59 Improving the modelling of laminar separation bubbles***
- ✓ ***AG-60 Machine learning and data-driven approaches for aerodynamic optimization and uncertainty quantification***
- ✓ ***AG-61 WMLES and Embedded LES***

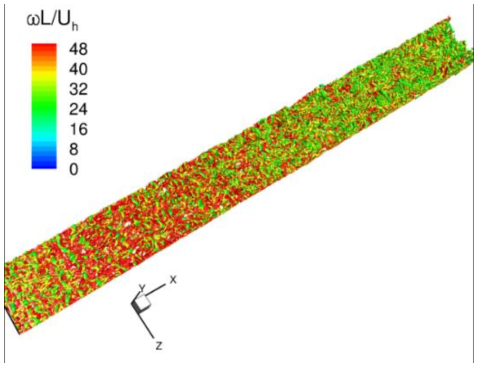
Only one exploratory group: **EG-79** dedicated to aerothermodynamics is at present time active

AD/AG-54: RANS-LES interfacing for hybrid RANS-LES and embedded LES approaches

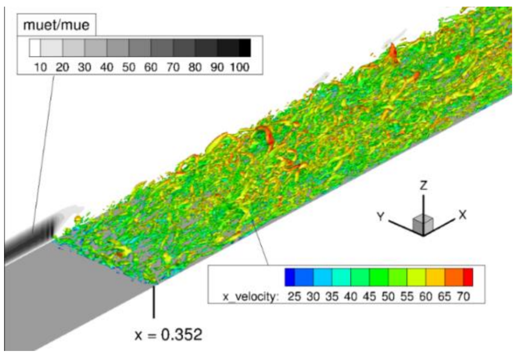
Magnus Tormalm (FOI)

- ✓ Technical tasks
  - ✓ Task 1: RANS-LES coupling for non-zonal modelling approaches
  - ✓ Task 2: RANS-LES coupling for zonal and embedded LES approaches
  - ✓ Task 3: Verification and assessment of methods
- ✓ Modelling improvements developed for “grey area” mitigation (GAM):
  - ✓ None-zonal methods: stochastic backscatter + high-pass filter (HPF) SGS model; vorticity-based LES length scale and Leonard energy-backscatter LES mode
  - ✓ Commutation terms adopted in RANS-LES interface
  - ✓ Zonal methods (incl. ELES): improved synthetic turbulence (divergence free)

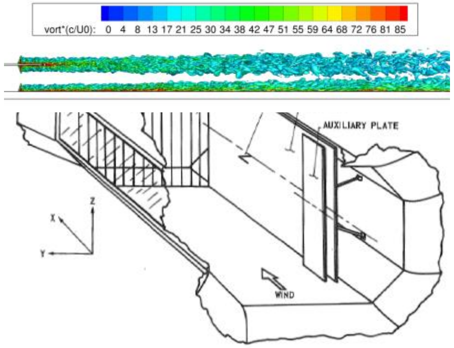
TC1: Shear layer



TC2: Spatially developing B.L.



TC3: Wake/B.L. co-flow



AG-55 Countermeasure aerodynamics - Magnus Tormalm (FOI)

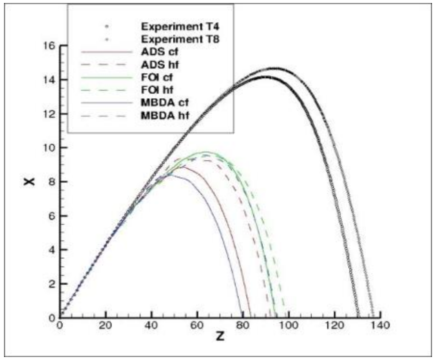
Countermeasures are used to decoy enemy tracking systems. Aerodynamics is crucial for the performance of countermeasures protecting air vehicles.

In this action group, prediction of trajectories for countermeasure objects is addressed.

Two commonly used countermeasures are chaff and flares, which are the main focus of this action group and that have been simulated by using CFD

- ✓ Chaff is radar countermeasure consisting of small pieces or threads of metal or metalized glass fibre.
- ✓ Flares are used against IR-seeking missiles. They are a few decimetres in length and can have built in propulsions systems.

a) Experimental facilities at Lacroix

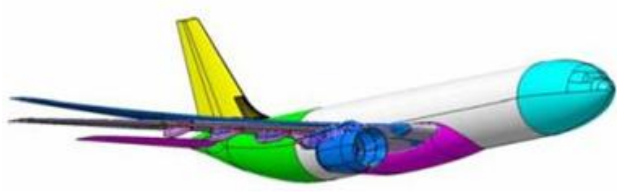


b) Comparison of measurements and simulations

AG-56 Coupled fluid dynamics and flight mechanics simulation of very flexible aircraft configurations Harmen van der Ven (NLR)

The goals of AD/AG-56 are twofold: firstly, this endeavour aims to enhance each partner's capabilities in aeroelastic simulations pertaining to very flexible aircraft. A second aim is to derive a common test case in terms of aircraft and manoeuvre. This will allow the various partners to benchmark their solvers and tools.

This topic poses a challenge due to various requirements inherent to such analyses:



Airbus XRF-1 model

- ✓ A flight mechanics model for flexible structures,
- ✓ CFD methods with robust grid handling technique capable of modelling a combination of large rigid body motion and large flexible motion,
- ✓ Fluid-structure interaction procedures that are capable of modelling large translations and finite rotations.

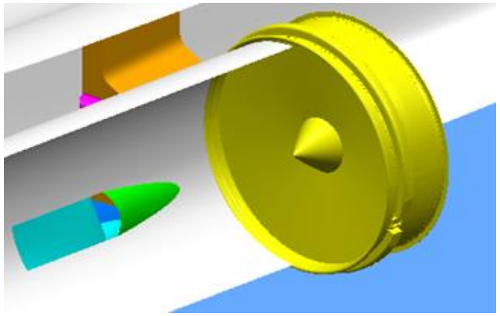
Participants: NLR (coordinator), Airbus, DLR, CIRA, ONERA,

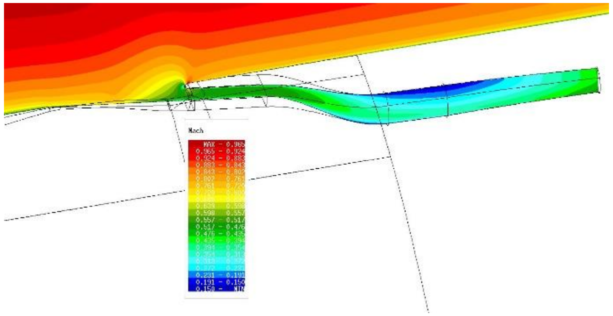
AG-57 Secondary inlets and outlets for ventilation A. Carozza (CIRA)

Analyse the efficiency of a submerged NACA type air intake for multiple flight envelopes using state-of-the-art CFD and performance evaluation methods.

Analyse the feasibility of a low-observable secondary inlet integrated in the main air intake duct of a combat aircraft and assess the impact on the intake duct flow field and on engine/intake-compatibility.

Investigate different types of secondary inlets, shapes, locations, and sizes with respect to advantages regarding radar cross section and aerodynamic performance.



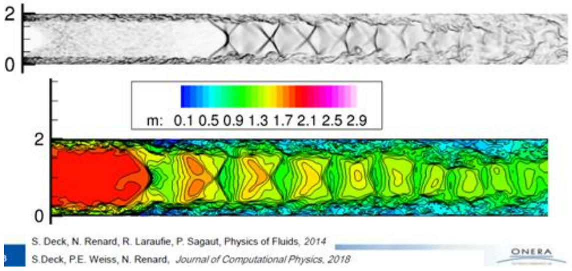


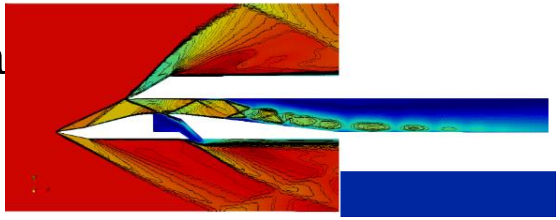
Participants: CIRA (coordinator), Airbus, DLR, NLR

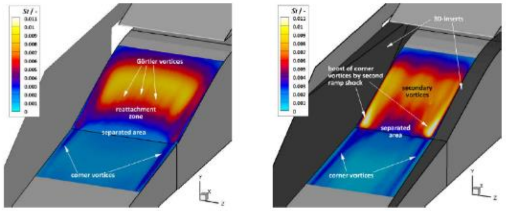
AG-58 Supersonic air intakes – Dider Pagan (MBDA)

The main objective for the AG-58 is to gather a database of relevant flow features for supersonic air intakes and validate CFD codes on these specific topics. Three test cases have been identified:

- A generic supersonic diffuser flow, with focus on non linear closure RANS and LES/DES methods.
- A supersonic Mach 3 ramjet air intake: with support of a detailed experimental database provided by DLR, the group focuses on the validation of RANS approaches.
- An hypersonic Mach 7.5 scramjet air intake: DLR also provided a detailed experimental database and the group focuses on aerothermal fluxes prediction.







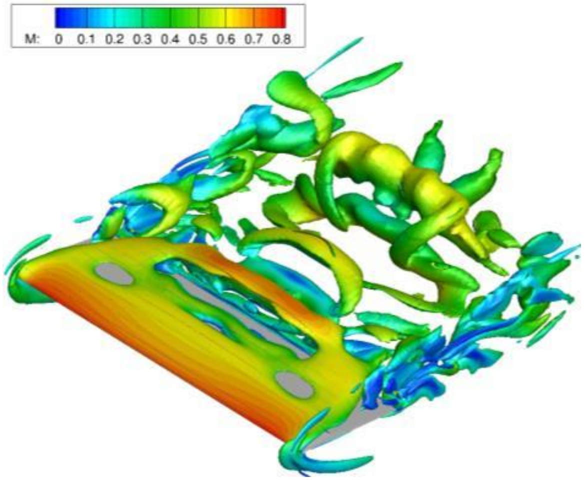
The project is expected to yield increased understanding of turbulence modelling issues for complex internal flows

AG-59 Improving the modelling of laminar separation bubbles P. Catalano (CIRA)

The main objective is to improve the modelling of the numerical methods used in the reproduction of the laminar separation bubbles and the consequent effects on flow instability.

The main issues to be addressed are:

- ✓ The determination of the transition location and of the transition region,
- ✓ The enhancement of the production of the turbulent kinetic energy in the separated flow inside the recirculation region,
- ✓ Evolution of the bubble with the incidence and with turbulence level,
- ✓ Possible burst of the bubble at high incidence and consequences on the stall characteristics,
- ✓ Critical evaluation of the laminar boundary-layer instability analysis methods treatment of laminar separation bubbles.



AG-60 Machine learning and data-driven approaches for aerodynamic optimization and uncertainty quantification – Fernando Monge - INTA

Fluid dynamics has traditionally dealt with massive amounts of data from experiments, field measurements, and large-scale numerical simulations.

Big data has been a reality in fluid mechanics over the last decade due to high-performance computing and advances in experimental measurement capabilities:

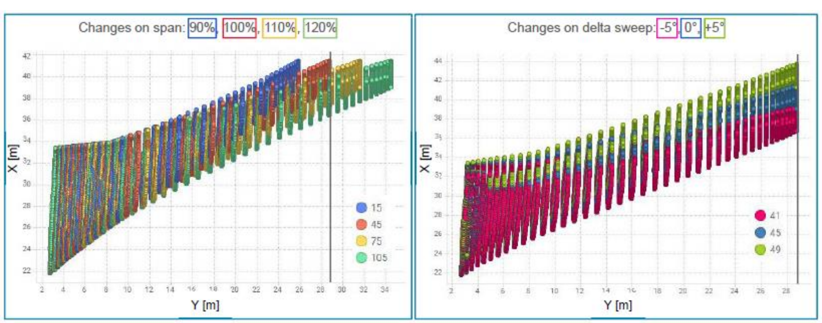
1) Vast and increasing volumes of data
2) Advances in computational hardware and reduced costs for computation, data storage and transfer
3) Sophisticated algorithms
4) An abundance of open source software and benchmark problems
5) Significant and ongoing investment by industry.

The purpose of the AG60 is to perform an extensive comparison of surrogate models and machine learning techniques for aerodynamic analysis and prediction. The action group consists of 11 partners, including eight research establishments (CIRA, NLR, INTA, DLR, FOI, ONERA, IRT and INRIA), two industrial partners (AIRBUS-Military, AIRBUS) and one SME (OPTIMAD).

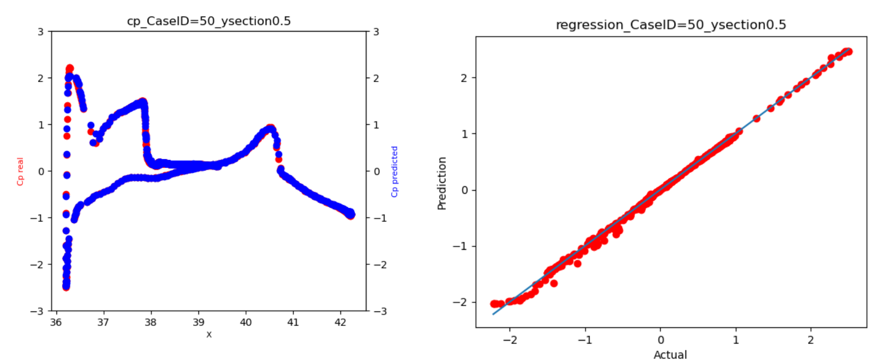
Machine learning models, once properly trained, can predict aerodynamic features in the order of seconds, instead of the order of hours that a CFD solver would take.

The dataset consists of different CFD simulations, which were competed using the TAU solver for two different Reynolds numbers and ($Re = 2.5\times10^{7}$ and 4×10^{7}). The flight condition parameters swept the whole envelope of the proposed aircraft, ranging the values of the Mach number from 0.5 to 0.95, and computing the polar for angles of attack spanning from −12º to 15º . Geometry variations of the initial XRF1 geometry have been also provided in the dataset.

These pictures show the type of geometry variations included in the database and results of the Cp prediction using a model with Random Forest method:



Geometry variations in the database



Cp prediction and regression plot using Random Forest

AG-61 WMLES and Embedded LES - Eric Coustols (ONERA)

The recent needs of the aerospace industry for design and certification processes have issued increasingly difficult challenges for the CFD community. This requires simulations of increased fidelity at an affordable computational cost. An attractive way is the **Hybrid RANS/LES Methods** "HRLM" aiming to treat the regions of interest with LES (Large Eddy Simulations) whereas the rest of the flow is modelled in RANS (Reynolds Averaged Navier-Stokes) approach at a low computational cost (LES is thus embedded).

AG-61 pursues and thus consolidates the work already performed in the frame of EU-funded projects (DESider, ATAAC, Go4Hybrid…) and AG-49 & AG-54 since early 2000s.

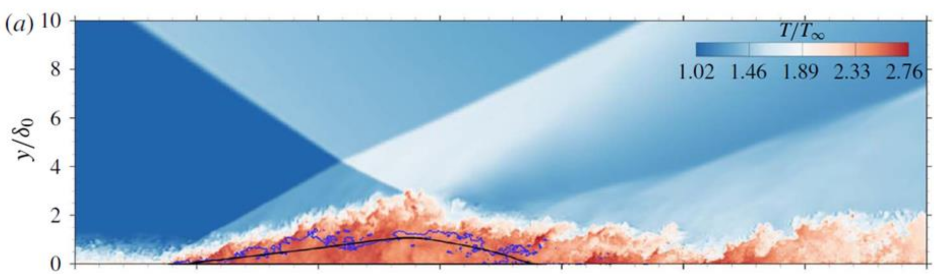
The group focuses on those HRLM methods whereby the outer region of attached boundary layers is LES-resolved, while the inner region of attached boundary layers is treated in RANS. The wall model is provided by the near-wall RANS region. The afore-mentioned modelling approach is usually referred as a "**Wall-Modelled LES** strategy".

The proposed activities will be conducted by means of extensive computations of the following four test cases that will serve the modelling validation and verification.

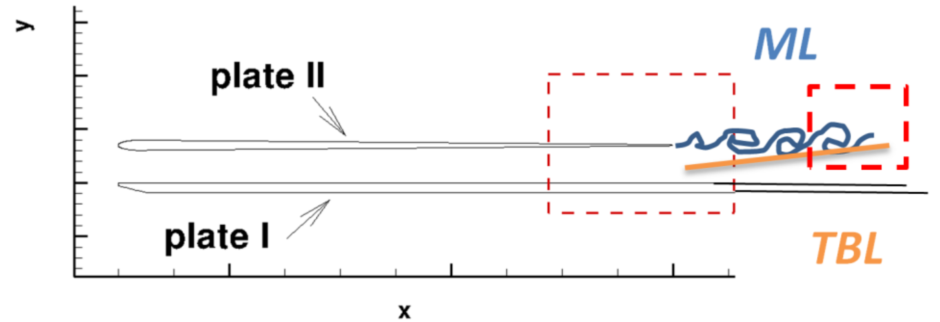
<u>Partners</u>: ONERA (lead), FOI, CIRA, DLR, NLR, SAAB, UNIMAN, UNISTRA

AG-61 WMLES and Embedded LES - Eric Coustols (ONERA)

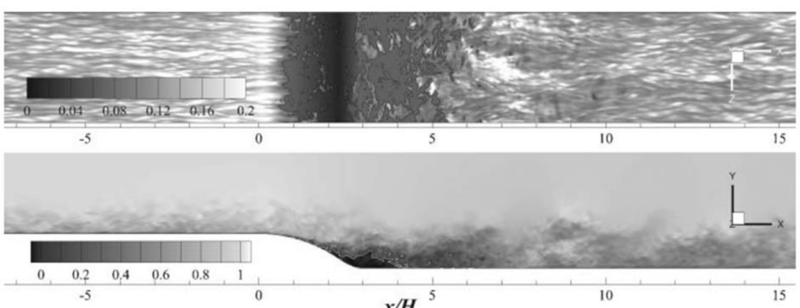
TC 1:
Mixing co-flow of wake & Boundary Layer



Pasquariello et al. (JFM 2017)

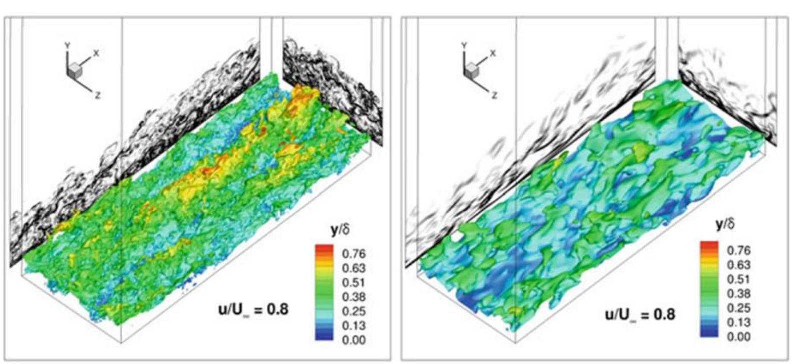


TC 2:
Shock Wave-Boundary Layer Interaction



Bentaleb et al., JoT 2012

TC 3:
Shallow flow separation from a smooth surface (2D-bump)



TC 4: Fundamental WMLES Zero Pressure Gradient flat-plate boundary layer

Even if today is more and more difficult because often GARTEUR projects are self-funded by companies, also experimental activities, such as pressure sensitive paints, or Particle image velocimetry, have been tackled by GARTEUR.

Company self-funding of GARTEUR activities represent at same time a positive and a negative point. Negative of course because without external funding is very difficult to perform activities, especially when experimental work and hardware are required. But self-funding has also a positive side since this automatically produce a selection of topics to be studied and only topics for which there is a string interest are addressed

Today computer codes are quite mature, nevertheless GARTEUR continues his role has vanguard addressing new challenges and new topics that cannot be tackled within frame of European funded where often only mature topics and technologies can be addressed.

GARTEUR Aerodynamics remains one of the unique area where international cooperation on basic aerodynamics research topics can be performed. The new challenges are toward unsteady and multidisciplinarity, use of new accurate CFD methods and finally introducing new technologies such as artificial intelligence.