33RD CONGRESS
OF THE INTERNATIONAL COUNCIL
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

ICAS 2022 SWEDEN

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

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Abstract

The GoR AD is active in initiating and organizing basic and applied research in aerodynamics and aerothermodynamics. Aerothermodynamics is closely related to space operations and flight through the earth's atmosphere at very high speeds.

Aerodynamics is a cornerstone of aeronautics and one of the primary design disciplines to determine the shape of the aircraft. Environmental issues are of great concern in aeronautics for civil aircraft and advanced aerodynamic design will have a significant impact on fuel consumption and the noise of aircraft. For military aircraft, the requirements of stealthy operation require new aircraft shapes to be considered and these shapes must be aerodynamically effective. The GoR AD remit covers aerodynamics, aeroacoustics, and aeroelasticity. The GoR AD is supporting a multi-disciplinary cooperation with the other GARTEUR Groups in areas where a mono-disciplinary approach is not meaningful.

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. Other numerical studies 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.

The activities aim to advance the collaborative aerodynamic research in Europe, combining both numerical and experimental research. Dedicated experiments are carried out using advanced experimental techniques and measurements methods in order to generate valuable data needed for the further understanding of basic flow physics, for the investigation of specific aerodynamic problems, and for the validation of numerical simulation tools in a number of areas. The computational activities comprise the further development of simulation and prediction tools of different classes of fidelity, the tool validation using experimental data, and also the application of these tools for the investigation of specific problems arising in aeronautical applications. The close collaboration of experimental and numerical activities is of great benefit and enables enhanced progress in aeronautical research.

Whilst the majority of the research activities focusses on mono-disciplinary aerodynamics, some of the work also has a significant amount of multi-disciplinary content. This trend is driven by industrial interests, and is likely to increase in the future.

Funding for GARTEUR activities is relatively small and, in general, is insufficient to fully support new research. In most cases therefore the AG activities are combined with activities funded through other routes, such as EU, NATO STO (Science and Technology Organization) or national aeronautical research programs.

Research initiated in GoR AD programs sometimes leads to an EU proposal or compliments concurrent EU program content. In addition, the content of GoR AD activities can be cross sectorial in covering both civil and military interests. Therefore, as climate change is a reality we are all confronted with, *"the importance of such cooperation and above all, partnership across borders, is the only way to achieve our objective of decarbonisation and climate neutrality by 2050"*, as it has been pointed out during the Clean Aviation Forum @ Brussels (March 22-23, 2022).

This contribution will give an overview about GoR AD research activities, will highlight some very successful highlights and give an outlook on future activities.

1. GoR-AD Hystory

GARTEUR along the time had a fundamental role in establishing cooperation among European company. One 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 center and represented the feed of future European funded collaborative projects.

The first Gor-AD action group is from 1979: TP-001: AD/AG-01 "Report on a combined experimental and theoretical investigation of the aerofoil CAST 7". At present time we have arrived at 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

A long trajectory along which several radical revolutions have happened in fluid-dynamics. 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. It is not for Hazard that the first action group was dedicated at numerical/experimental comparison.

The Action Group of that ages where 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: first 2 dimensional airfoil where addressed, than three dimensional cases, and following technological development first Euler solver where addressed and in a second phase RANS solver. AD/AG-25 "Navier Stokes Computations of 3D Transonic Flow for a Wing/Fuselage Configuration"

The first topics of interest was transonic flows, but of course, high lift phenomena covered an important role “AD-AG 36 3D High Lift Computations”

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 15 “Validation of Euler codes for supersonic flow (2 parts)” AD/AG-31 “Analysis of a Supersonic Transport Configuration with and without foreplan using a Navier Stokes solver”

In the following phase, while the interest in supersonic transportation decreased the new interest was toward more efficient and less noisy aircraft, and of course also in this case the topic was addressed by GARTEUR: AD/AG-27 “Transition on airfoils and infinite swept wings with regard to nonlocal instability investigations” and a series of Action Group dedicated to laminarity.

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 continue 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.

Activities performed within GARTEUR are divided between Action Group and Exploratory Group. Exploratory Gropu represet working group where the subject is addressed and a workplan and objectives are defined. Action Group represent working gropu where activities are implemented.

At present time several Action Group related to different topics are active:
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 [ends 12/2022]
AG-61 WMLES and Embedded LES

Only one exploratory group: **EG79** dedicated to aerothermodynamics has been recently promoted to Action Group: **AG61**

To provide an idea of activities performed within GoR-AD, in the following a focus on two action groups: AG55 and AG 60 is reported.

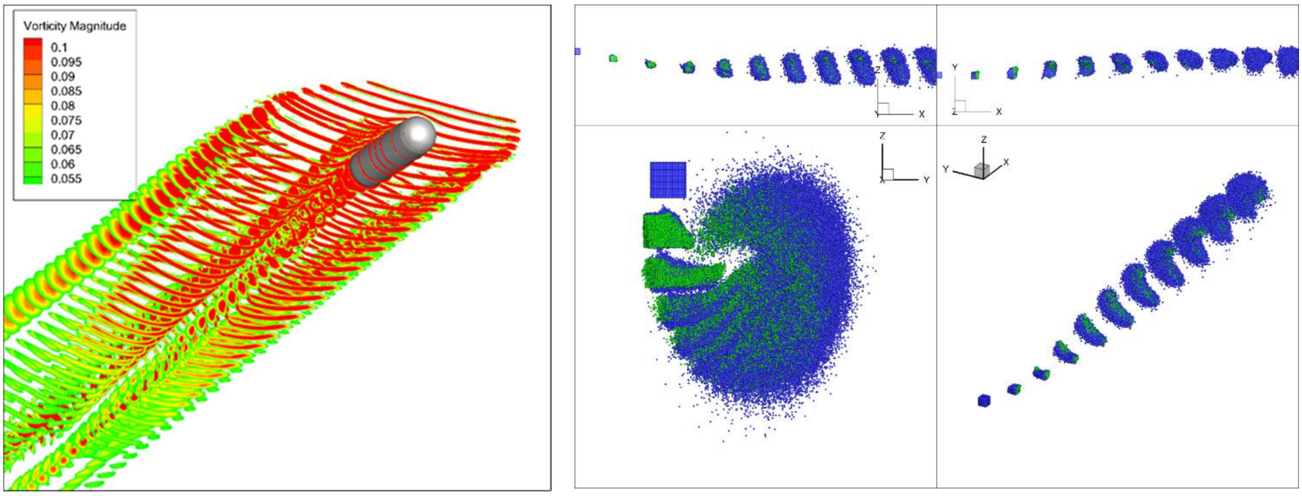
2. AG-55 Countermeasure aerodynamics - Harmen van der Ven – NLR [1]

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. Accurate simulation methods enables studies of the impact of threat situation, manoeuvre and release position. In addition, results and data from numerical simulations can be used for education of pilots.

Two commonly used countermeasures are chaff and flares, which are the main focuses of this action group. 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. In numerical simulation of the movement of counter measure objects, the mechanical computations are decoupled from the aerodynamics i.e., the impact of the objects on the main aerodynamic flow field is neglected. This is true if the countermeasure objects are small compared to flow gradients. The aerodynamic database is computed by CFD, prior to the trajectory simulations that are computed with 6DoF simulations.

The trajectories of chaff are significantly affected by the surrounding air. Different methods to compute propagation of chaff clouds are compared. Chaff dispended from a generic helicopter is chosen as test case. The chaff propagates through the wake with the motion induced by trailing vortices. When simulating chaff dispersion it is therefore of major importance to have a good resolution of flow in the wake. Since the aerodynamics is based on RANS computations, the turbulent vortices do not appear explicitly. In order to take the dispersion due to turbulence into account, special procedures have been developed to estimate a stochastic force due to turbulence on the chaff. The orientation of the chaff is modelled in order to enable a more accurate analysis of the radar signature. The radar signature as such is not a part of this work.

Figure 1 shows the flow field in which the chaff is released and the so-called blooming of the chaff. Starting position of the chaff is a cube near the rotor disk. This is not a realistic scenario, but chosen not to complicate the verification process by adding the dynamics of ejection from a cartridge. Figure 1b clearly shows that the chaff is dragged into the vortex wake system. Both partners in the group show comparable results. Unfortunately, validation of the chaff blooming is not possible due to lack of experimental data.



a) Vorticity field around generic helicopter

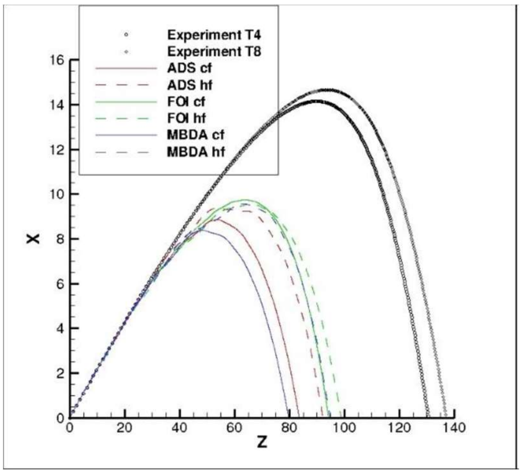
b) Comparison at ten different time steps of the chaff blooming (blue: NLR; green: FOI)

Figure 1 Comparison of chaff blooming in the wake of a generic helicopter

Flares are ejected to divert IR-missiles from their goal. Protection of air vehicles implies that it must cover all directions, also from the front. Certification of flare ejection must guarantee that they don't hit the air vehicle. A key question is how accurately you must model the flare movement: can you model it as a point mass or do you have to simulate 6-DoF dynamics, do you have to take changes in shape and exhaust gases into account?

The group has performed both measurements and computations. The flares in the experiment are ejected vertically from a carriage moving horizontally on a rail (see Figure 2a). For the trajectory computations an aerodynamic database is built for four flare geometries: over time, when the flare burns itself, the shape changes and the volume reduces. Comparison with the experimental trajectories are shown in Figure 2b. There is a significant difference in both range and height of the trajectories. Since the computed trajectories agree fairly well between themselves it is natural to expect that some phenomena is missing in the computational model. Different theories have been pursued but the main candidate is that the combustion behind the flare, which is not included in the computations, contributes with a force in the forward direction.

In conclusion, the most important result of AD/AG-55 is the setup of test cases for chaff and flare computations, a research field with relatively few publications. This will enable future researchers to check their methods against results from the AD/AG-55 action group.



a) Experimental facilities at Lacroix

b) Comparison of measurements and simulations

Figure 2 Experiments and simulations for the flare trajectories

3. 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 architectures and advances in experimental measurement capabilities. Over the past decade, many techniques were developed to handle data of fluid flows, ranging from advanced algorithms for data processing and compression, to databases of turbulent flow fields [2, 3]. However, the analysis of fluid dynamics data has relied to a large extent on domain expertise, statistical analysis, and heuristic algorithms. Massive amounts of data is today widespread across scientific disciplines, and gaining insight and actionable information from them has become a new mode of scientific inquiry as well as a commercial opportunity. There is currently an unprecedented confluence of 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, and 5) significant and ongoing investment by industry. These advances have, in turn, fueled renewed interest and progress in the field of machine learning (ML) to extract information from this data. Machine learning algorithms (categorized as supervised, semi-supervised, and unsupervised learning) are rapidly making inroads in fluid mechanics. Machine learning provides a modular and agile modelling framework that can be tailored to address many challenges in fluid mechanics, such as reduced-order modelling, experimental data processing, shape optimization, turbulence closure modelling, uncertainty quantification and control [4, 5].

The main purpose of the AG60 is to perform an extensive comparison of deep learning, 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). Partners are currenly working on the developments of differente machine learning models applied to the industrial XRF1 configuration [6]. XRF1 is an Airbus-provided industrial standard multi-disciplinary research test case representing a typical configuration for a long-range wide body aircraft. The XRF1 research test/case is used by Airbus to engage with external partners on development and demonstration of relevant capabilities / technologies. 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 [7]. Geometry variations of the initial XRF1 geometry have been also provided in the dataset.

One of the activities performed in the group is dedicated to a comparison of different decision-tree based machine learning algorithms and their level of accuracy when using hyperparameters optimization, with or without a previous dimensionality reduction step. The preliminary results of this work are displayed in the following figure:

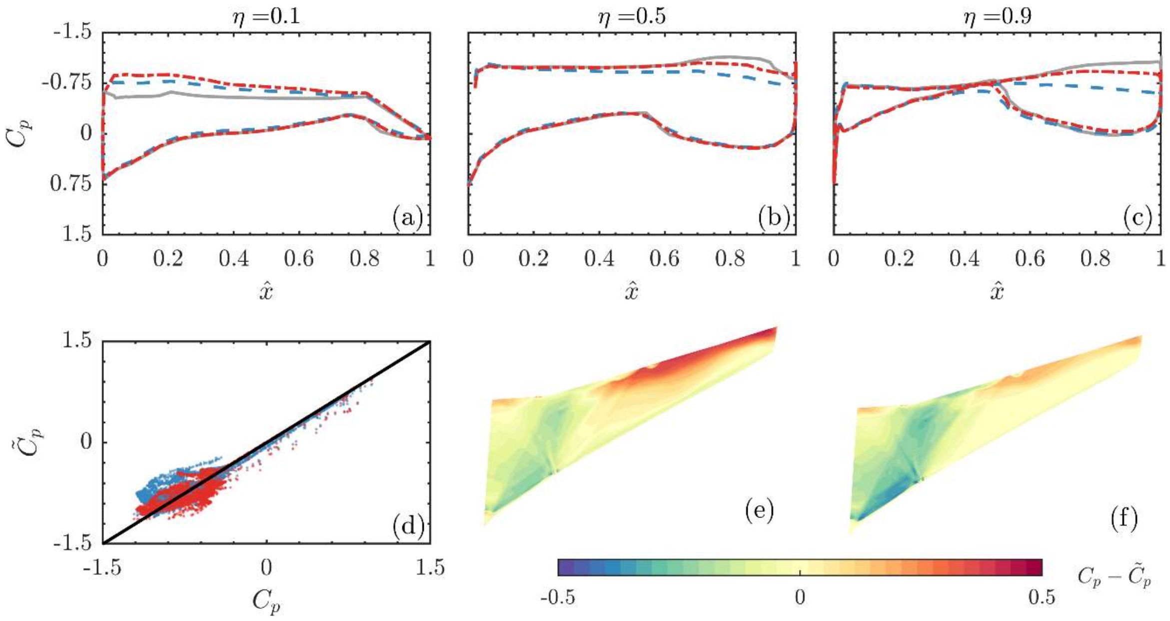


Figure 3: (a-c) Cp distribution for Mach of 0.9440 and Alpha 10 at wing sections 10%, 50% and 90%. Solid grey line for input Cp, short dashed red line for Cp from random forest and long dashed blue line for Cp from the random forest with POD. (d) Error regression representation between Cp's predicted. (e,f) prediction error for the Cp distribution for random forest (e) and random forest with POD (f).

At the end of the group, it is expected to address a deep evaluation and assessment of machine learning and data-driven methods and to define "best practice" guidelines, facilitating the use of these methods for aerodynamic analysis and uncertainty quantification in aeronautic industries and making a step forward towards the use of machine learning techniques as a standard approach.

4. Conclusions

Even if several progresses have been performed in Computational Fluid Dynamics since it beginning, the original dream of using Computational Fluid Dynamics to replace wind tunnel test and flight test has not yet been achieved. GARTEUR Aerodynamics is contributing to this challenge by performing step by step basic studies and trying to improve both numerical computation but also experimental test.

GARTEUR-AD at beginning represented the unique framework allowing European cooperation in fluid-dynamics in Europe and represented the seed for future EU funded cooperation projects. Today cooperation among European partners is well established and instruments provided and funded by EU are well mature. Nevertheless, GARTEUR has not lost is role and has new mission with the role of developing small cooperative projects addressing mainly basic studies that cannot been addressed in classical EU funded projects where often mode mature technologies and methodologies are studied.

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7. Copyright Statement