# GARTEUR

ANNUAL REPORT 2022

GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE

Front cover image: Arriving in Frankfurt. Courtesy of the chairman

Back cover image: Italian Air Force HH-101A "CAESAR". Courtesy of the chairman

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# GARTEUR ANNUAL REPORT 2022

GARTEUR aims at stimulating and coordinating cooperation between Research Establishments and Industry in the areas of Aerodynamics, Flight Mechanics, Systems and Integration, Rotorcraft, Structures & Materials and Aviation Security.

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# 1. Introduction

*Dear reader,*

*with the start in 2022 of the Italian chairmanship of GARTEUR, I cannot but express gratitude to the Dutch delegation for having kept the GARTEUR community united throughout the COVID-19 pandemic. Despite all, we are a resilent community and the work went on, planning for the future.*

*As we were seeing the light at the end of the tunnel, on February 24, 2022 Russia launched an invasion of Ukraine, something that our generation never imagined would happen in Europe. We now realise that freedom cannot be taken for granted and that we need to be vigilant.*

*Nonetheless, the European aeronautical community has made significant strides in 2022 and the aviation sector is picking up again. On the civil side we have seen significant efforts from the Clean Aviation and SESAR 3 Joint Undertakings, thus paving the way for climate-neutral aviation and marking a new chapter in modernising European air traffic management (ATM). Likewise, the Horizon Europe framework programme and the Next Generation EU recovery fund promise significant opportunities for the R&D community.*

*On the defence side, we have witnessed the strong commitment of the European Union in responding to EDA's call for Member States, and Europe as a whole, to invest more and better in defense innovation "and to do it together". Launched in 2021, the European Defence Fund promotes cooperation in research and development of state-of-the-art and interoperable defence technology and equipment.*

*With the continuation of the conflict in Ukraine there is concerne that funds witll be diverted to the defence sector thus delaying meeting the objectives of the European Green Deal. From GARTEUR's perspective, being the only framework for both civil and military R&T collaboration in the field of aeronautics in Europe, there is no such contrast but only a commitment to evaluate all research with both domains in mind. The transformation envisioned by the European Green Deal can certainly reduce the threat that Climate Change poses to the defence sector, as addressed in the EU's Climate Change and Defence Roadmap.*

*In 2023 GARTEUR will celebrate its 50th anniversary and it will be a time to rethink what we have achieved and where we wish to go. The ICAS 2022 congress that was held in Stockhom in September 2022 was an excellent opportunity for GARTEUR to meet the wider research community. That experience will continue during our celebrations on 5-6 October 2023 at the Italian Air Force Academy in Pozzuoli, Italy. Join us and be part of our future!*

*Piergiovanni Renzoni*

*Chairman (2022 - 2023)*
*GARTEUR Council*

*Dear GARTEUR Friends,*

*we all hoped that 2022 would have been a better year than the previous one. The first part of 2022 was even worse than 2021 due to the war crisis that obliged most of us to new sacrifices just when we were realising to be at the end of the pandemic. The second part of the year gave us a small flavour of liberty: in fact GARTEUR representatives were able to participate in the ICAS Congress in Stockholm and Council members were able to meet in person in Braunschweig after two-and-a-half years of lockdown.*

*As already mentioned by Harmen last year, keeping the GARTEUR family together was still the greatest challenge also in 2022: the Executive Committee (XC) has continued the monthly meetings with the Group of Responsables (GoR) chairs, which definitely helped the cohesion of GARTEUR and the XC has worked very hard to furtherly improve the level of awareness of our community by organising the event celebrating the 50th anniversary of GARTEUR in Italy, giving a lot of attention to the important work that is done in the GoRs and in their Action Groups.*

*The event, hopefully, will give another push to the GARTEUR community which will keep on contributing, in its own little way, to the technological research in Aeronautics.*

*Vittorio Puoti*

*Chair XC GARTEUR 2022-2023*

## 2. Executive summary

The GARTEUR Annual Report 2022 provides a summary of the main managerial actions of the Council, and the scientific and technological progress made by the five Groups of Responsables (GoRs). The GoRs constitute the main bodies for establishing research priorities in the technology areas covered by GARTEUR: aerodynamics, structures and materials, rotorcraft, flight mechanics and systems integration, and aviation security.

Section 3 of this report provides a summary of the Council activities, including the changes in chairmanship and membership.

Section 4 reports on the European aeronautical R&T environment by highlighting the importance of European Collaborative Programs such as Horizon Europe and Clean Aviation to civil aviation. Great steps have been taken to streamline aeronautical research in Europe, making use of several bodies within the European R&T environment (e.g. EREA and ACARE).

Developments in military aeronautical strategy within Europe are also discussed with information provided on the European Defence Action Plan and Fund and the benefits that may be available to aeronautic development from EU funded defence research. The close involvement of GARTEUR members with ACARE is also described.

The GARTEUR scientific and technical activities are reported in section 5, with each of the five GoRs presenting a summary of their work during 2022.

# 3. GARTEUR Council

## 3.1 Chairmanship and membership

On the 1st of January 2022, Italy succeeded the Netherlands as chair of GARTEUR for a period of two years, ending on the 31st of December 2023.

At the early beginning of 2022, Chairman of the Council was Prof. Guido De Matteis, from the University of Rome “Sapienza” and head of the Italian delegation; then, after a couple of months, Prof. Guido De Matteis left GARTEUR and the position of Head of Delegation was taken by Dr. Piergiovanni Renzoni, from the Italian Aerospace Research Centre (CIRA). From that moment, Dr. Piergiovanni Renzoni was Chairman of the Council with Mr. Vittorio Puoti, also from the Italian Aerospace Research Centre, as Chairman of the Executive Committee. Vittorio Puoti served also as GARTEUR secretary during 2022, as previously done in the first Italian chairmanship of GARTEUR in the period 2006-2007.

## 3.2 GARTEUR Council Meetings

GARTEUR Council meetings occur twice a year, with the main Council meeting being preceded by a meeting of the Executive Committee (XC). During the XC the GoR Chairs and XC members meet to discuss the agenda for the Council meeting, reviewing and proposing outstanding actions, shaping the discussion topics in detail, and preparing proposals to the Council.

The Council meetings consist of representatives from the national delegations with the GoR chairs. These meetings provide a vital opportunity for the GoR chairs to inform the Council on the research being undertaken by their Action Groups and Exploratory Groups and to introduce potential new areas of interest.

The Council meetings also offer the member states an opportunity to provide updates and developments at national level in R&T activities and investments in civil and defence aeronautics. The multidisciplinary nature of the Council meetings provides excellent opportunities for dynamic collaboration and exchange of expertise and varied perspectives.

Meetings:

- XC168 – 18 January 2022, Online
- C72 – 30-31 March 2022, Online
- XC169 – 5 September 2022, Stockholm (Sweden) in connection with the ICAS 2022 Conference
- C73 – 9-10 November 2022, at DLR Braunschweig (Germany)

### 3.2.1 XC168

The first XC meeting of 2022 took place digitally, as consequence of travelling restrictions in place due to the COVID-19 pandemic on the 18th of January. The main topics discussed during this meeting were the communication between Council, XC and GoRs, contact with the PEGASUS consortium. The activities in the field of propulsion were also discussed as well as two new AGs were presented. Participation of researchers as GARTEUR members giving some presentation to the ICAS 2022 conference was also discussed. Attention was given to the possible participation of GARTEUR in SAGAS: a written answer was received by GARTEUR from the advisory group.

### 3.2.2 C72

The first Council meeting of 2022, C72, took place digitally, as consequence of travelling restrictions in place due to the COVID-19 pandemic, on Wednesday 30th and Thursday 31st of March 2022. The main topics discussed during this meeting were the updates from the GoRs and the participation of GARTEUR to the ICAS2022 Congress and the answer sent by SAGAS to GARTEUR. Discussion about the 50th GARTEUR anniversary also took place, see Figure 1.

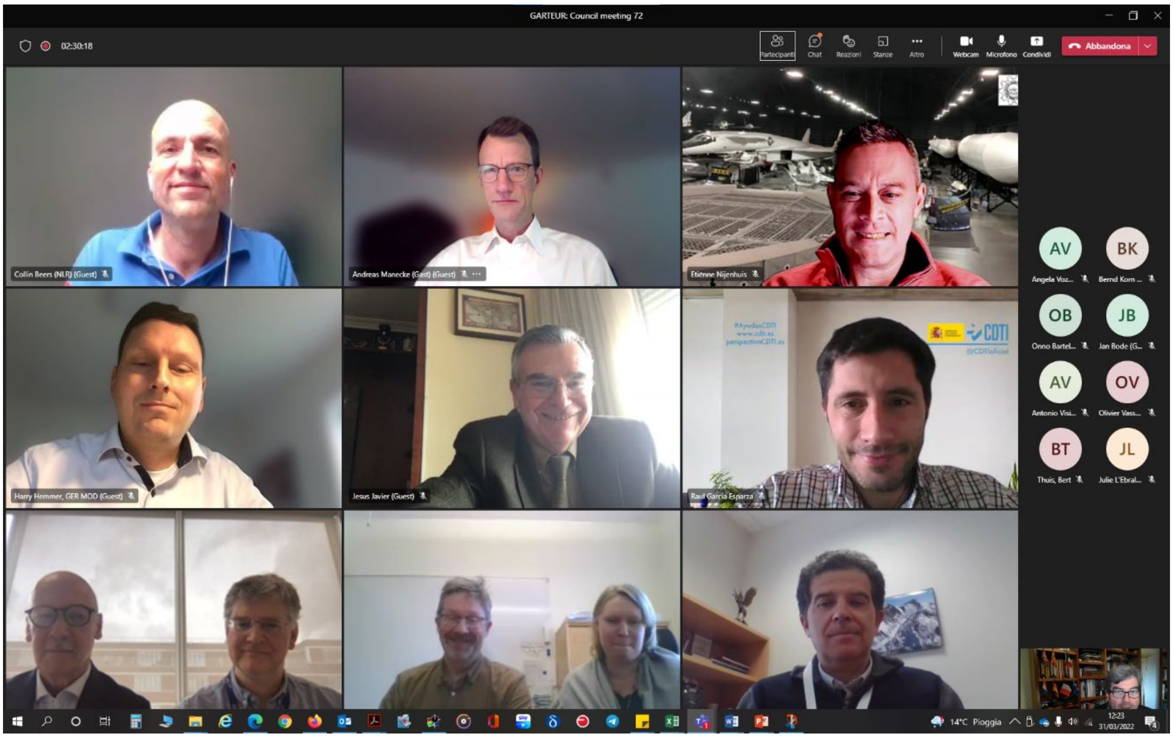



*Figure 1: screenshot of C72 Council meeting held online*

### 3.2.3 XC169

The XC169 meeting took place on 5th September 2022 in Stockholm, Sweden. Location of the meeting, in presence and online, was the Convention Centre of Stockholm where the ICAS 2022 Congress was held. The topics for discussion of XC169 were focused on the communication between Council, XC and GoRs, and the progress on the organisation of the event related to the 50th GARTEUR anniversary.

### 3.2.4 C73

The Council meeting C73 took place on Wednesday 9th November 2022 and Thursday 10th November 2022 at DLR premises in Braunschweig. It was the first meeting in presence after the pandemic. The GARTEUR Award of Excellence for the Netherlands chairmanship period 2020-2021 was physically delivered to AD/AG-55 "Countermeasure Aerodynamics", see Figure 2.

*Figure 2: The Swedish head of delegation, Rian de Rooij, on behalf of the chairman of AD/AG55, receives the award from the Dutch head of delegation, Rickard Stridh.*

Certificates, issued in 2021, are physically handed to national delegations. Focus of the meeting is on communication between Council, XC and GoRs, especially AS-GoR, and the organisation of the GARTEUR event to be held at the end of 2023.

Since the organisation of the event for the celebration of the 50th anniversary of GARTEUR was requiring much more effort than expected, it was a shared thought of the Council members to have many more special meetings in the next weeks. So, the Executive Committee, charged of the organisation task, decided to have extraordinary online meetings in the last part of 2022 and a special session of the next XC meeting focused on the event. The first in presence meeting allowed the delegations to exchange ideas in a very relaxed atmosphere, see Figure 3.

*Figure 3: Council members portrayed at the end of the meeting in Braunschweig*

## 3.3 GARTEUR Website

The GARTEUR website is accessible at www.garteur.org and provides information on the mission, principles and background of GARTEUR, along with access to information and reports from the five GoRs. Contact details and information on how to be involved in GARTEUR research are also provided, along with links to the national strategic documents of the GARTEUR countries. During 2022 the website was updated by the secretary, posting information about the meetings and about the upcoming event celebrating the $50^{th}$ anniversary of GARTEUR.

For the use of the GoRs, DLR has arranged a TeamSites, to be used as a repository for minutes and other documents. Those TeamSites are managed directly by the GoRs.

## 3.4 GARTEUR Certificates

In 2022 certificates were delivered during C73 since, due to the COVID19 crisis, there were no physical meetings before. So, the certificates, issued during 2021, could be delivered to the following GARTEUR members:

- Luigi Paparone (CIRA);
- Kees Wijnberg (NLR);

- Neda Tooloutalaie (SAAB);
- Francisco Muñoz Sanz (INTA);
- Jose Vicente Garcia Calatayud (INTA);
- Lorenzo Notarnicola (CIRA);
- Klausdieter Pahlke (DLR);
- Joost Hakkaart (NLR);
- Mario Verhagen (NLR);
- Aniello Riccio and Andrea Sellitto (Università della Campania "Luigi Vanvitelli");
- Action Groups AD-53, AD-54 and AD-55.

Figure 4 shows the ceremony of delivering some certificates held at CIRA.


*Figure 4: Mr. L. Notarnicola and Mr. L. Paparone have just received GARTEUR certificates from the Council chairman, Dr. Piergiovanni Renzoni.*

# 4. The European aeronautics RTD environment

As a unique forum of aeronautical experts from Academia, Research Establishments and Industry fostering research initiatives for the benefits of all the member countries, GARTEUR actions are aimed to support the European aeronautical community, both in the civil and in the defence domain. Hence, GARTEUR directly or indirectly interacts with other entities or fora, such as the *European Union*, the *Association of European Research Establishments in Aeronautics* (EREA), the *European Defense Agency* (EDA), the *Advisory Council for Aviation Research and Innovation in Europe* (ACARE).

This section provides a brief overview of the European aeronautics RTD environment in both civil aeronautics and military aeronautics.

## 4.1 Participation in the ICAS 2022 Congress

GARTEUR was invited to participate in the 33rd Congress of the International Council of the Aeronautical Sciences (ICAS 2022) that was held in Stockholm, Sweden on September 4-9, 2022.

Two sessions (5.1 and 5.2) were dedicated to GARTEUR allowing to give a general overview of the role it has played over nearly half a century of European collaboration in aeronautics research, its mission, organisation and principles, see Figure 5.


*Figure 5: Council chairman and some GoRs chairmen giving presentation at ICAS 2022 Congress*

A review of current activities in the fields of “Aerodynamics”, “Aviation Security”, “Flight Mechanics, Systems & Integration”, “Rotorcraft” and “Structures & Materials”, and major success stories, were presented by the chairs of the respective Group of Responsable (GoR), see Figure 5 and Figure 6.


*Figure 6: some GoRs chairmen giving presentation at ICAS 2022 Congress*

Details concering the participation in the ICAS 2022 Congress, presentations given in the conference, papers presented in the conference can be easily downloaded from the GARTEUR website.

To the website were uploaded also some interviews given by the Council chairman and some GoR chairmen during coffe-breaks while attending the Congress.

## 4.2 Civil aeronautics

Civil aeronautics research and technology development (RTD) in Europe is centred around collaborative research calls performed within the Framework Programmes for Research and Innovation. The current Framework Programme, Horizon Europe, is the EU’s key funding programme for research and innovation with a budget of €95.5 billion until 2027. It tackles climate change, helps to achieve the UN’s Sustainable Development Goals and boosts the EU’s competitiveness and growth.

The tools available in Horizon Europe are of various types and cover the entire scale of research and the associated degree of technological maturation. The most interesting ones for basic research in the field of aviation are the dedicated calls in Pillar 2 and in particular the specific part of Cluster 5 oriented towards Energy, Climate and Mobility. The reference for the two-year period 2023 - 2024 will be Cluster 5 of the Work Program 2023-2024, made official in December 2022. Although relevant topics for aeronautics can be found in all topics, the most interesting is D5 "Clean and competitive solutions for all transport modes“ and in particular the specific section for Aviation.

Dedicated aviation research programmes have been carried out through long-term Public-Private Partnerships, such as Clean Sky, Clean Sky 2, SESAR, SESAR 2, culminating in the Clean Aviation JU, and SESAR 3 JU, launched at the end of 2021. These initiatives will accelerate the development, integration, and validation of mainly disruptive R&I solutions, for deployment as soon as possible, so as to lead the way toward a climate-neutral aviation system and set new global standards for safe, reliable, affordable and clean air transport.

### 4.2.1 Strategic direction of European R&T

Since 2011, European Commission's Flightpath 2050 document outlines long-term goals associated with meeting society's needs for more efficient and environmentally friendly air transport, as well as maintaining global leadership for the European aerospace industry. It is therefore a crucial reference document for organisations in Europe and served as the basis for the research calls within Horizon 2020 and the research projects that GARTEUR chose to undertake over the last years.

In 2020 the development of the Clean Aviation Joint Undertaking (CAJU) [1] began, entering into force on 30 November 2021 and with the first call being launched in 2022.

Europe needs to accelerate and enhance its efforts to achieve the ambitious goals set out in the Paris Agreement. The European Green Deal has been established as a cornerstone policy of the European Union, including the first European Climate law, which enshrines the 2050 climate neutrality objective in legislation. At the same time, the newly launched Industrial Strategy for Europe lays out in clear terms the importance of industrial leadership in making the transformation to a green and digital Europe fit for the future.

The aviation sector will need to contribute to these priorities and transform. Together with the European Union, European aviation has the power to lead the way toward a climate neutral aviation system and set new global standards for *safe, reliable, affordable and clean air transport*.

The journey to a climate neutral aviation system is well beyond the private sector's capability and capacity to invest alone. Equally, no single country in Europe has the financial, technological and industrial capability to affect the transformation. The European additionality is evident. An Institutionalised European Partnership for Clean Aviation under Horizon Europe constitutes the only approach that can pull together the resources and commitment and adequately reduce the industrial risk for transformative research and innovation. This approach will secure the long-term industrial commitments needed for long innovation cycles. It will ensure that research activities of industry are aligned with the Union's policy priorities. It will build Europe's leadership in innovation and technology, and deliver jobs and economic growth throughout the transition to a climate neutral Europe by 2050. It can offer future generations the promise of continued, affordable and equal access

[1] https://www.clean-aviation.eu/

to air travel, and its social and economic benefits, and contribute to the UN's Sustainable Development Goals.

The new Partnership was built upon the important technological progress that has been made under the Clean Sky and Clean Sky 2 programmes. Support from the EU Institutions and European Member States are essential in creating the conditions for impact, and in enabling synergies with other EU, national and regional research and innovation programmes.

The Clean Aviation Partnership's Strategic Research and Innovation Agenda [SRIA], published in December 2021, sets out the way to achieve the overall vision, in terms of timescales and magnitude of impact. This integrated research roadmap includes the required upstream 'exploratory' research that is essential to finding tomorrow's pathways to mature technologies, ready to be incorporated into further new and disruptive innovations.

The Clean Aviation trajectory defines two clear horizons towards climate neutrality by 2050:

> **2030:** *demonstrating and introducing low-emissions aircraft concepts exploiting the research results of Clean Aviation, making accelerated use of sustainable fuels and optimised 'green' operations, so these innovations can be offered to airlines and operators by 2030 for an entry into service [EIS] in the 2030-2035 timeframe;*
>
> **2050:** *climate neutral aviation, by exploiting future technologies matured beyond the Clean Aviation phase coupled with full deployment of sustainable aviation fuels and alternative energy carriers.*

Following the launch of the first call for proposals in 2022, with an announced value of €654 million in EU grant funding, work began on 20 projects to steer aviation towards a sustainable future. The 20 'daring new projects' that have been selected ensure a broad coverage of the programme's three 'thrusts' and constitute a flying start to the programme:

- Hydrogen-powered aircraft
- Hybrid-electric regional aircraft
- Ultra-efficient short and medium-range aircraft

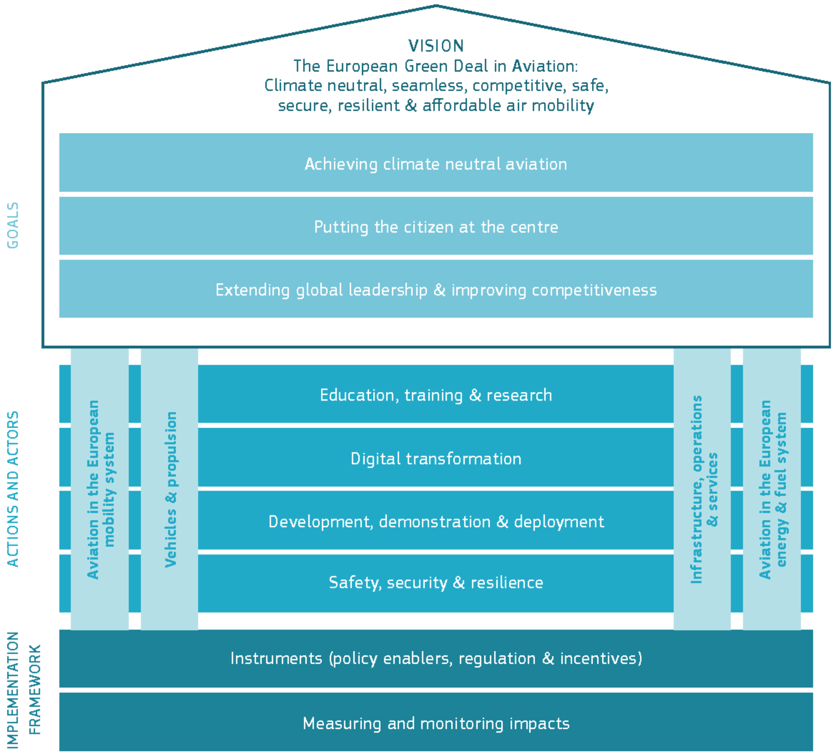
In September 2022, Clean Aviation became a founding member of the *Alliance for Zero-Emission Aviation* (AZEA). This new EU group, formed by the *European Commission's Directorate-General for Defence Industry and Space* (DG DEFIS) brings together public and private stakeholders from across the aeronautical sector to support the roll-out of hydrogen-powered and electric aircraft.

Clean Aviation also signed a Memorandum of Cooperation with the *European Union Aviation Safety Agency* (EASA) in October 2022. This collaboration will help to set new global standards for safe, reliable, affordable and clean air transport, while ensuring a regulatory framework that can support accelerated transformation.

### 4.2.2 GARTEUR and ACARE

In addition to its responsibility for developing the SRIA, the *Advisory Council for Aviation Research and Innovation in Europe* (ACARE)[2] plays an integral role in advancing aviation innovation within Europe by developing policy positions on European aviation initiatives and working closely with European Commission officials to ensure that Horizon 2020 funding calls - as well as calls associated with the Clean Sky 2 and SESAR Joint Undertakings - are closely aligned with the SRIA. This approach is continuing within the Horizon Europe programme.

In June 2022, ACARE, on behalf of all aviation stakeholders throughout Europe, presented the new European aviation vision "Fly the Green Deal" which succeeds the 2011 vision document Flightpath 2050. The new vision presents a single global vision, addressing the three main objectives of the sector: achieving climate-neutral aviation in 2050, putting the citizen at the center and improving leadership and global competitiveness. To ensure that this vision will deliver impact towards its goals, it goes beyond research and includes also topics of new product development, deployment, energy, fuel, infrastructures, digitalisation and the implementation framework and synergies. The Vision and its goals was structured as depicted below.




[2] https://www.acare4europe.org/

Members of the GARTEUR Council are also heavily involved with ACARE and this ensures that GARTEUR's research interests are strategically aligned with the ACARE vision and goals, ensuring that GARTEUR remains focused and committed to the major challenges being addressed by pan-European aerospace research and innovation. GARTEUR's representatives within ACARE have emphasised that the innovation life-cycle needs to have the right mix of projects at all levels; covering the early, critical part of the innovation pipeline as well as the 'market readiness' associated with high TRL projects.

### 4.2.3 GARTEUR and EREA

EREA[3] is the *Association of European Research Establishments in Aeronautics*, whose members are Europe's most outstanding research centres in the field of aeronautics and air transport.

In 2012 EREA proposed a Joint Research Initiative, named Future Sky[4], in which development and integration of aviation technologies is taken to the European level. Future Sky is based on the alignment of national institutional research for aviation by setting up joint research programmes. Future Sky is structured in six themes: Safety, Quiet Air Transport, Energy, Urban Air Mobility, Security for Aviation and Circular Aviation.

In June 2021 the "EREA Vision Study – The Future of Aviation in 2050"[5] was published, updating the previously released "EREA vision for the future –Towards the future generation of Air Transport System" published in 2010. This new study, describing EREA's own vision, has as objectives:

1. to share EREA's vision with external stakeholders to help enhance cooperation;
2. to form the basis for EREA to support policy makers at national and European level;
3. to motivate EREA and its members to work together to common and ambitious goals; and
4. to engage with the general public, particularly on societal needs and sustainability for the aviation sector.

There are many members of the GARTEUR Council that also are members of EREA, and therefore the synergies and complementarities are taken into account in a continuous basis.

## 4.3 Military aeronautics

The European defence industry represents a large collaborative effort from EU members, as well as non-member states, progressing defence technologies and solutions across a variety of industrial fields, such as aeronautics, land and naval systems and electronics. The defence sector is highly innovative and centred on high-end engineering and technologies, with important cross application that extends into the civil market.

[3] https://erea.org/
[4] https://futuresky.eu/
[5] https://erea.org/erea-vision-studies/

### 4.3.1 European Defence Agency

The *European Defence Agency* (EDA)[6] is an intergovernmental agency of the Council of the European Union, comprising all EU members with the exception of Denmark and also including from non-EU member states, Norway, Switzerland, the Republic of Serbia, and Ukraine, through special administrative arrangements. Through close cooperation the EDA seeks to improve European defence by supporting the development of capabilities, and nurturing technology and research to meet future defence requirements, and to promote defence interests in wider EU policies. The EDA operates at ministerial level and connects over 4000 nationally based experts collaborating on defence projects.

Defence must continue to innovate as technological progress reshapes warfare. EDA offers ways to bring together expertise, drawing on start-ups, universities, industry, and national experts. EDA serves as the hub for European defence innovation, known as HEDI.

As of 2022 GARTEUR has carried out regular discussions with EDA, in particular CapTech Air, with the objective to identify where GARTEUR can contribute on research in the Defence domain without duplicating other initiatives. This is fully in line with the strategy of EDA which seeks synergies with various communities to carry out research focused on responding to cabability/operational gaps/needs of the MoD and to assess the various projects contributing to the CapTech Air Strategic Research Agenda and associated TBB roadmaps on the basis of their attractiveness (mainly from MoD), achievability (mainly from industry) and detailed analysis of short-listed projects (MoD, industry, academia).

GARTEUR intends to strengthen its cooperation with EDA, harmonising its activities in the defence domain with the CapTech Air Strategic Research Agenda (SRA). This cooperation is facilitated by the very nature of GARTEUR, an MoU between Governments of 7 European countries.

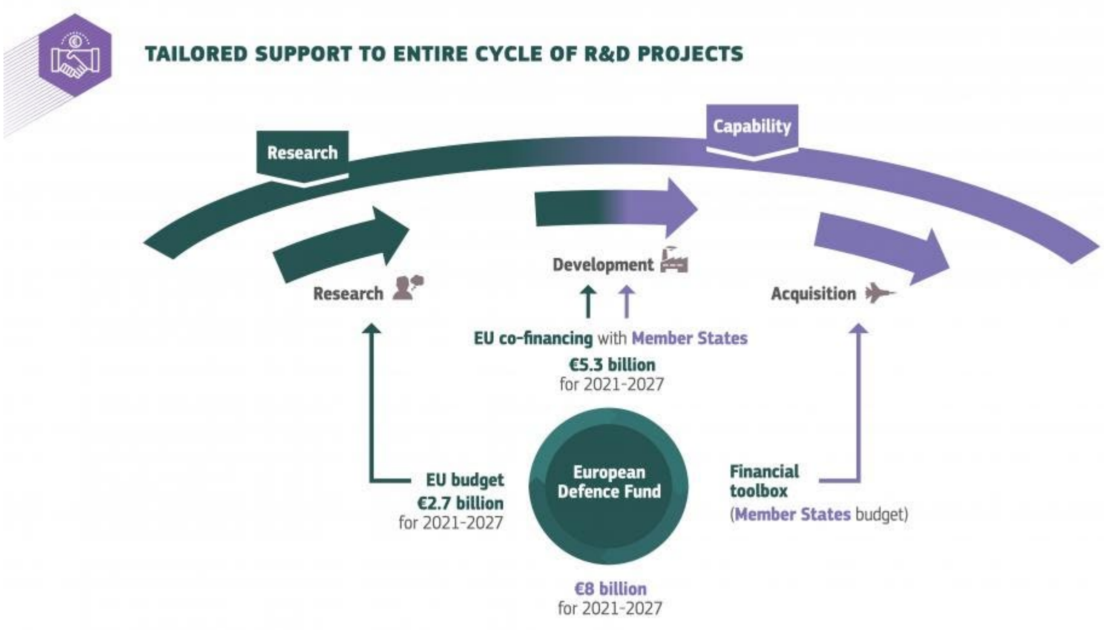
### 4.3.2 European Union-funded defence research

The European Defence Fund (EDF) supports the cross-border cooperation between EU countries and between enterprises, research centres, national administrations, international organisations and universities. This applies to the research phase and in the development phase of defence products and technologies. It has 2 strands. Under the research strand, the EU budget will provide funding for collaborative defence research projects. Under the capability strand, the EU will create incentives for companies and EU countries to collaborate on the joint development of defence products and technologies through co-financing from the EU budget.

The European defence fund supports collaborative defence research and development through consecutively programmes with limited duration and budget:

[6] https://eda.europa.eu/

- The preparatory action on defence research (PADR, 2017-2019. The preparatory action on defence research provided grants for collaborative defence research with a budget of €90 million;
- The European defence industrial development programme (EDIDP, 2019-2020). The European defence industrial development programme offered co-financing for collaborative defence development projects with a budget of €345 million;
- The European Defence Fund (EDF, 2021-2027) has a budget of close to €8 billion for 2021-2027, of which €2.7 billion to fund collaborative defence research.




The first EDF call was launched in 2021 with a total budget of almost 1.2 billion euros. Of this the largest share went to the military aircraft sector, for an amount of nearly 200 million euros divided between three major projects: 40 million euros for research on technologies for the new generation of the rotary wing, and 150 million euros divided development of "enhanced pilot environment for air combat" and "European interoperability standard for collaborative air combat", always with a view to increasing interoperability.

The 2022 EDF calls for proposals, covering 33 topics, with a total budget of about €924 million, closed in November 2022. In June 2023, the Commission announced the results of the 2022 calls for proposals amounting to €832 million of EU funding in support of 41 joint defence research and development projects across the EU.

# 5. Summary of GARTEUR technical activities

During 2022 the five GARTEUR Groups of Responsables (GoRs) continued facilitating and delivering vital research in the field of aeronautics. The GoRs are responsible for monitoring and encouraging the progress of Action Groups (AGs) and Exploratory Groups (EGs). These groups are collaborations of researchers from national aerospace institutes, universities and industry. Although GARTEUR is not a source of funding, the GoRs constitute a powerful network and provide a unique forum for aeronautical research in Europe. The GoRs aid potential research consortia by critically reviewing their proposed research objectives and methodologies.

Without the constraints of financial accountability, the GoRs guide early stage research projects consistent with the GARTEUR roadmap, which in turn is in line with European aeronautical strategy, while also allowing scope for innovative research and the development of low TRL disruptive technologies. The GoR chairs also encourage multidisciplinary research across the GoRs, with the biannual Council meetings providing excellent opportunities for the exchange of ideas and identification of dynamic partnerships.

The primary task of the GoR is to monitor Action Groups, encourage Exploratory Groups and instigate new ideas. The secondary task of each GoR is interaction with the other GoRs to promote interdisciplinary topics.

New ideas for research may be formulated by GoR members or arise within GARTEUR organisations. As GARTEUR does not offer funding, it is essential that the research is supported by the organisations themselves. Therefore, the GoR critically reviews the research objectives and methodology, but does not select particular topics over others.

## 5.1 Group of Responsables – Aerodynamics (AD)

### 5.1.1 GoR-AD Overview

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

- aerodynamics;
- aerothermodynamics;
- aeroacoustics;
- 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 Organisation) or national aeronautical research programmes.

Research initiated in GoR AD programmes 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.

### 5.1.2 GoR-AD Activities

Five Action Groups and one Exploratory Group have been running throughout 2022.

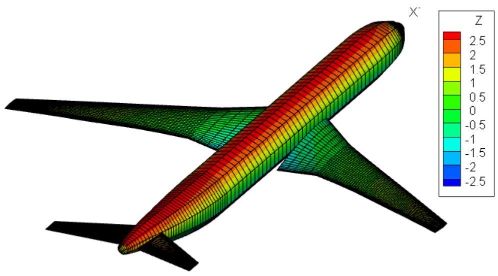
Even if only one Exploratory group is active, there are several topics under discussion that could generate new Exploratory goups in the next future: Morphing, thermal management, corner flows, virtual certification, hydrogen engine combustion fluid dynamics …

***Action groups (AG)***

The following Action Groups were active throughout 2022:

AD/AG-56

*Coupled Fluid Dynamics and Flight Mechanics Simulation of Very Flexible Aircraft Configurations*




The goals of 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 of AG-56 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:

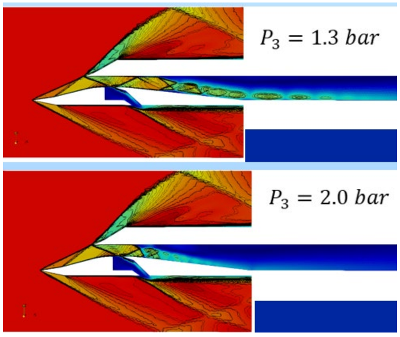
- a flight mechanics model for flexible structures,
- CFD methods with robust grid handling technique capable of modelling a combination of large rigid body motion and large flexible motion,
- fluid-structure interaction procedures that are capable of modelling large translations and finite rotations.

The chairperson is Richard van Enkhuizen (NLR).

AD/AG-58

*Supersonic Air Intakes*

The main objective for the AG-58 is to gather a database of relevant flow features on representative test cases and validate CFD codes on these specific topics. The following investigation themes are proposed:



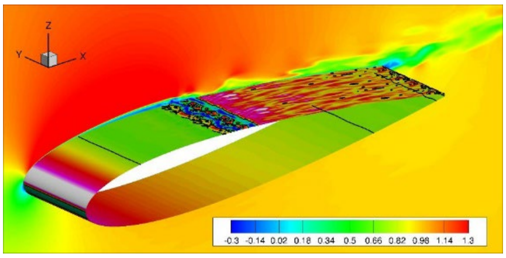

- cowl oblique shock / boundary layer / mixing layer interactions;
- internal bleed flows;
- supersonic air intake diffusers and scramjet isolators including corner flows description.

It is expected to support each theme with recent and detailed experimental data as well as CFD modelling and/or validation.

Due to COVID crisis that complicated organisation and priorites in 2020 for many companies, the collaborative work planned last year has been postponed for a year. Some other priorities in 2022 have lead to other delays. It has been proposed to retart the collaboration by summer 2023 and to prepare the final report in December 2024. An updated list of milestones is proposed.

The chairperson is Christophe Nottin (MBDA).

AD/AG-59



*Improving the Simulation of Laminar Separation Bubbles*

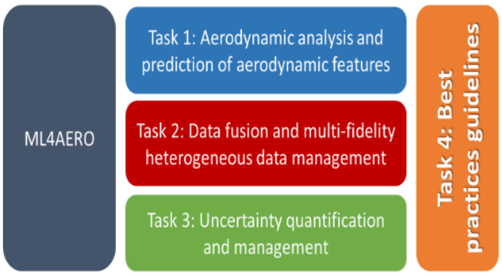
The main objective is to improve the modelling of the numerical methods used in the reproduction of the laminar separation bubbles and the consequent effects on flow instability. The main issues to be addressed are:

- the determination of the transition location and of 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.

The chairperson is Pietro Catalano (CIRA).

AD/AG-60

*Machine Learning and Data-Driven Approaches for Aerodynamic Analysis and Uncertainty Quantification*




The objectives of the Action Group are:

- extensive comparison of deep learning, surrogate models and machine learning techniques for aerodynamic analysis and prediction;
- exploitation of the potential of data fusion (Multi-fidelity) within surrogate modelling by efficient management of heterogeneous data from different sources (CFD with different precision, wind-tunnel, flight test data, etc.);
- exploration of the potential of machine-learning and data-driven

techniques for uncertainty quantification and management.

The chairperson is Esther Andrés (INTA).

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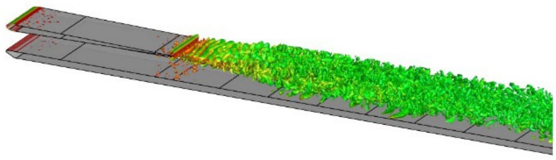
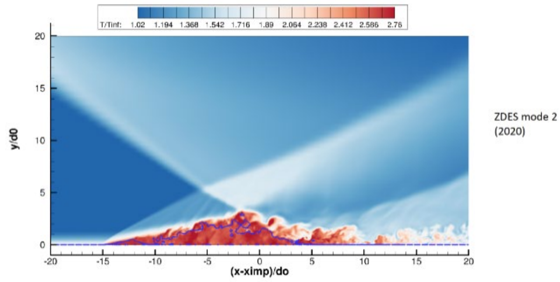
AD/AG-61

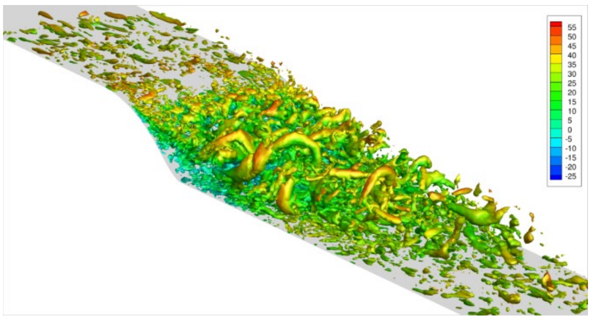
*WMLES and Embedded LES*



*TC1 MIXING CO-FLOW (CIRA)*




*TC2 shock / BL (ONERA)*



*TC3 shallow separation (DLR)*

RANS CFD has shown many merits but fails to model turbulence in adverse-pressure-gradient boundary layers and in separated flows. Turbulent scale-resolving simulations are needed, but DNS and wall resolved LES are not affordable yet for industrial daily needs.

Thus, this group investigates the hybrid RANS-LES strategies. In order to extend previous activities (see AD/AG-54 for instance), family II strategies are of interest (where only the inner part of the attached boundary layer is modelled in RANS whereas the outer region of the boundary layer is resolved by LES). Such strategies belong to the more general Wall-Modeled LES approaches. A substantial cost reduction is gained (over wall resolved LES) and improved turbulent dynamics is simulated (over DES-like, or family I simulations where the attached boundary layer is treated fully in RANS). The use of LES can thus be restricted to the regions of interest in a so called embedded LES strategy.

The activities of the group aim at facilitating the introduction of family II in industry. The several turbulent relative topics are investigated through 4 test cases.

The chairperson is Nicolas Renard (ONERA).

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## *Exploratory Groups (EG)*

The following Exploratory Groups were active throughout 2022:

| | |
|---|---|
| AD/EG-79 | *Hypersonics*<br><br>Partners of the EG are: DLR, University of Munich, CIRA, DLR, TU Munich, NLR, FOI, VKI. After some preliminary meetings there have been no additional activities.<br><br>Even if only one Exploratory group is active, there are several topics under discussion that could generate new Exploratory goups in the next future: Morphing, thermal management, corner flows, virtual certification, corner flows… |

New topics under consideration are:

| |
|---|
| *Cartesian methods / Immersed boundary methods*<br><br>Use of non conventional CFD methods such as immersed boundary tools |
| *Morphing for load control of high aspect ratio wings*<br><br>Use of morphing technologies for aerodynamics improvements |
| *Hypersonic flows*<br><br>Fluid mechanics studies for hypersonic flows |
| *Thermal management for electric propulsion*<br><br>Electrical hybrid aircraft cooling simulation |
| *Corner flows for turbulence model development*<br><br>Detailed flow modelling for corner flows |
| *Virtual certification*<br><br>Methods to decrease certification efforts |
| *Human droplet dispersion*<br><br>Simulation of water droplets originating from human breathing within an aircraft cabin |

### 5.1.3 GoR-AD Membership

The membership of GoR-AD in 2022 is presented in the table below.

| | | |
|---|---|---|
| **Chairperson** | | |
| Giuseppe Mingione | CIRA | Italy |
| **Vice-Chairperson** | | |
| Eric Coustols | ONERA | France |
| **Members** | | |
| Kai Richter | DLR | Germany |
| Fernando Monge | INTA | Spain |
| Bruno Stefes | Airbus Operations | Germany |
| Magnus Tormalm | FOI | Sweden |
| Harmen van der Ven | NLR | The Netherlands |
| Peter Eliasson | SAAB | Sweden |
| **Industrial Points of Contact** | | |
| Riccardo Gemma | Leonardo Company | Italy |
| Michel Mallet | Dassault Aviation | France |
| Didier Pagan | MBDA | France |
| Luiz P. Ruiz-Calavera | AIRBUS D&S | Spain |

## 5.2 Group of Responsables – Aviation Security (AS)

### 5.2.1 GoR-AS Overview

The GoR-AS supports the advancement of civil and defence related security technology in European research establishments, universities, industries and other relevant European Entities (e.g. National Civil Aviation Authority, MoD, Military entities,..) involved in security for aviation through collaborative research activities, and through identification of future projects for collaborative research.

The GoR-AS initiates, organises and performs multidisciplinary research in the following areas: on board software, artificial intelligence, risk assessment, cybersecurity, airport operations, image recognition, Data analytics, decision making tools, RAMS analysis, FMECA, Fault Tree, event tree analysis, HMI, CONOPS.

The main aim is to Increase security, safety and operation performance for critical assets in the aviation domain.

### 5.2.2 GoR-AS Activities

In 2022, working for the action group, by developing approaches to protect critical infrastructures by intruder's attacks, GoR/AS has also monitored the external funded initiatives on the topics of interest.

ONERA, INTA and CIRA have completed the activities within ASPRID Project - Airport System Protection from Intruding Drones - belonging to Horizon 2020 Call: H2020-SESAR-2019-2 (SESAR 2020 EXPLORATORY RESEARCH ) Topic: SESAR-ER4-13-2019 Type of action: SESAR-RIA ended in December 2022.

Efforts have been dedicated to analyse other external sources of information and assess current initiatives on aviation security with the aim to get awareness on the state of the art and build within Garteur a coherent harmonised approach with the external initiatives. This trend is driven by industrial and MoD interests, which have been properly analysed and the importance of multi-disciplinary work is likely to increase in the future.

Another proposal in SESAR3 has been submitted, exploiting ASPRID and AS GoR outcomes.

The approach in 2022 has aimed at keeping links with other running initiatives like ES4AWG, IFAR, ACARE WG4 and maintaining and extending such a valuable networking.

A publication on a journal has been finalized and it names Garteur( on AEROSPACE MDPI Open Access, https://www.mdpi.com/2226-4310/9/12/747).

The AG on malevolent use of RPAS is officially closed.

The resources dedicated to the new EG and information about it and actions will be detailed by the new AS GoR.

### 5.2.3 GoR-AS Membership

The membership of this GOR in 2022 is presented in the table below:

| | | |
|---|---|---|
| **Chairperson** | | |
| Angela Vozella | CIRA | Italy |
| | | |
| **Vice-Chairperson** | | |
| Emilio Oliva | INTA | Spain |
| | | |
| **Members** | | |
| Pierre Bieber | ONERA | France |
| Rene Wiegers | NLR | Netherlands |
| Andreas Bierig | DLR | Germany |
| Hans-Albert Eckel | DLR | Germany |
| Johann C. Dauer | DLR | Germany |
| Clive Goodchild | BAE Systems | UK |

## 5.3 Group of Responsables – Flight Mechanics, Systems and Integration (FM)

### 5.3.1 GoR-FM Overview

The Group of Responsables for Flight Mechanics, Systems and Integration is active in the field of flight systems technology in general.

The GoR-FM is responsible for all research and development subjects concerning a chain starting from the air vehicles and their flight mechanics, concerning embedded sensors, actuators, systems and information technology, cockpits, ground control and human integration issues, with reference to automation for both inhabited and uninhabited aircraft, including, but not limited to:

- aircraft multidisciplinary design aspects;
- flight performance, stability, control and guidance;
- aircraft navigation and mission management;
- air traffic management and control;
- integration of remotely piloted systems in the air spaces;
- safety critical avionics functions and embedded systems;
- scientific and technical expertise for air systems certification and regulatory aspects.

Noticeably, GoR-FM is not active in the rotary wing domain, where the GARTEUR Helicopters GoR leads.

### 5.3.2 GoR-FM Activities

The activities in 2022 have been focused to establishing the EG30 “AI for fault detection”, exploring the down selected topics from 2021, and contributing to the GARTEUR session during the ICAS 2022 Congress in Sweden. This contribution gives an overview of the activities of the Group of Responsables for Flight Mechanics, Systems and Integration (GoR FM) over nearly half a century of European collaboration. It presents the research fields, some very successful highlights and gives an outlook on future activities.

***Exploratory Groups (EG)***

The following Exploratory Group was kicked-off in 2022:

| | |
|---|---|
| FM/EG-30 | *AI for fault detection*<br><br>The idea is to investigate the feasibility AI technics for fault detection on-board aerospace vehicles. The current state of practice generally implies a dedicated |

algorithm (a.k.a. monitoring) to detect a specific fault, and does not rely on AI technics. A more precise objective of the PP is to investigate AI technics that allow to identify the nominal domain of a specific sensor and so to detect any abnormal behaviour once the sensor measurement goes outside its nominal region. The GoR-FM members are currently looking for experts in their organisations to work on this topic and serve as POC for the chairman of this Exploratory Group.

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### 5.3.3 GoR-FM Membership

The membership of GoR-FM in 2022 is presented in the table below.

| | | |
|---|---|---|
| **Chairperson** | | |
| Bernd Korn | DLR | Germany |
| | | |
| **Members** | | |
| Marinus Johannus van Enkhuizen | NLR | The Netherlands |
| Antonio Vitale | CIRA | Italy |
| Carsten Doll | ONERA | France |
| Martin Hagström | FOI | Sweden |
| Andrew Rae | University of the Highlands and Islands in Scotland | UK |
| **Industrial Points of Contact** | | |
| Laurent Goerig | Dassault | France |
| Philippe Goupil | Airbus | France |
| Martin Hanel | Airbus Defence and Space | Germany |
| Peter Rosander | Saab | Sweden |

## 5.4 Group of Responsables – Rotorcraft (RC)

### 5.4.1 GoR-RC Overview

The GoR-RC supports the advancement of civil and defence related rotorcraft technology in European research establishments, universities and industries through collaborative research activities, and through identification of future projects for collaborative research.

The GoR-RC initiates, organises and monitors basic and applied, computational and experimental multidisciplinary research in the context of application to rotorcraft vehicles (helicopters and VTOL aircraft such as: tilt rotors; compounds and multi-copters) and systems technology.

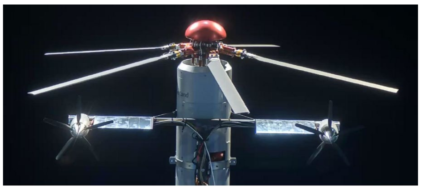
The field for exploration, analysis and definition requirements is wide. It covers knowledge of basic phenomena of the whole rotorcraft platform in order to:

- decrease costs (development and operation) through Virtual Engineering using numerical tools based on low/medium-order (analytical, BEM) to high-order (CFD) methods, validated with relevant tests campaigns;
- increase operational efficiency (improve speed, range, payload, all-weather capability, highly efficient engines, more electric rotorcraft, ...);
- increase security, safety;
    - security studies, UAVs, UAM e VTOLs, advanced technologies for surveillance, rescue and recovery;
    - flight mechanics, flight procedures, human factors, new commands and control technologies;
    - increase crashworthiness, ballistic protection, …;
- better integrate rotorcraft into the air traffic (ATM, external noise, flight procedures, requirements/regulations);
- tackle environmental issues:
    - greening, pollution;
    - visual pollution (for UAM applications);
    - noise (external, internal);
- progress in pioneering: breakthrough capabilities.

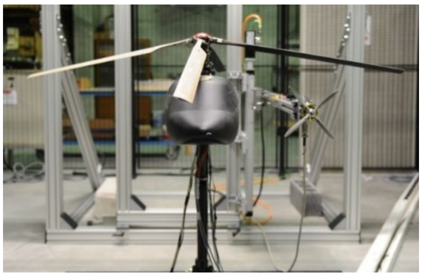
Technical disciplines include, but are not limited to, aerodynamics, aeroelasticity including stability, structural dynamics and vibration, flight mechanics, control and handling qualities, vehicle design synthesis and optimisation, crew station and human factors, internal and external acoustics and environmental impact, flight testing, and simulation techniques and facilities for ground-based testing and simulation specific to rotorcraft.

A characteristic of helicopter, tilt rotor, compound and multi-copter aircraft is the need for a multidisciplinary approach due to the high level of interaction between the various technical disciplines for tackling the various issues for rotorcraft improvement.

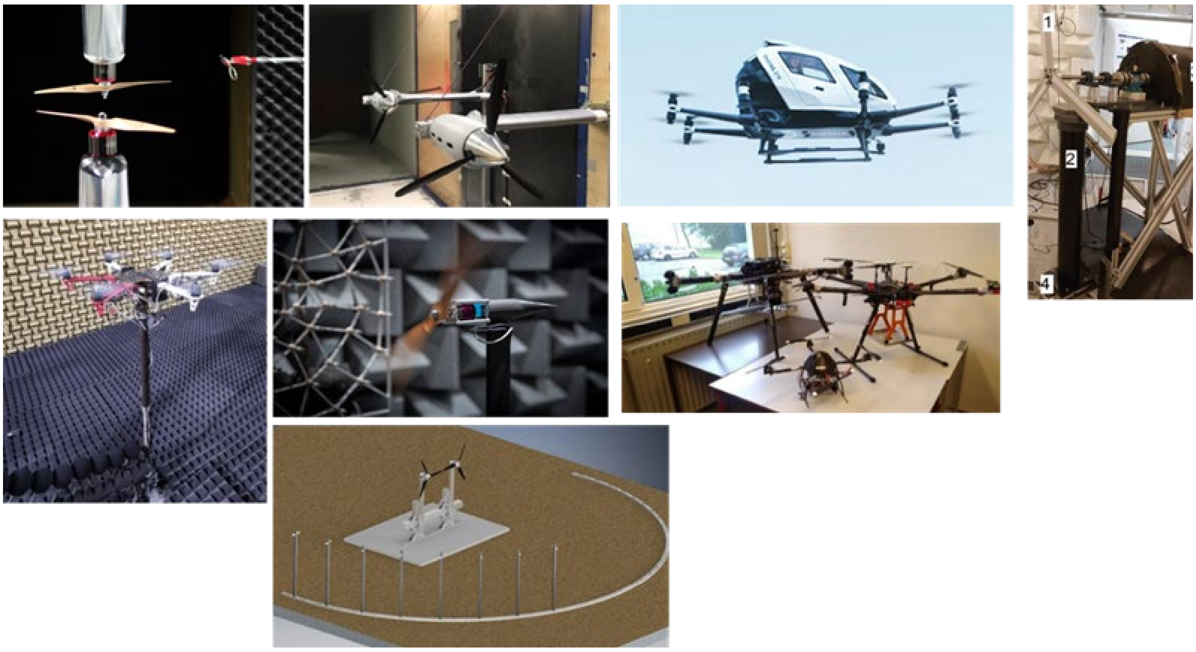
*Multicopter experiment in RTG at DLR Göttingen (HC/AG-25)*



*Main rotor/Propellers configuration in PoliMi wind tunnel (HC/AG-25)*



*Generic Main Rotor/Propeller Configuration (ONERA) (HC/AG-25)*



*Overview of experimental activities in RC/AG-26*

### 5.4.2 GoR-RC Activities

Two Action Groups and two Exploratory Groups have been running throughout 2022.

***Action groups (AG)***

The following Action Groups were active throughout 2022:

| | |
|---|---|
| HC/AG-25 | *Rotor-Rotor-Interaction*<br><br>The main objective is to investigate, both numerically and experimentally the effect of rotor / rotor and rotor / propeller wakes interactions on high speed rotorcraft operating in low speed conditions with the aim to establish low order models to be used in pre-design phases of advanced rotorcraft vehicles or in comprehensive codes. The AG started in October 2019. |
| RC/AG-26 | *Noise Radiation and Propagation for Multirotor System Configurations*<br><br>The objective is to investigate, both numerically and experimentally, the noise radiation and propagation (installation effect) of multirotor systems and to gain knowledge in the physics of noise generation and near-field noise propagation of multirotor systems under the influence of the installation effects and to establish tools for the noise prediction. Compared to conventional helicopters, the importance of the various noise sources and the influence of noise scattering can be totally different for multi rotor configurations. The AG started in February 2022. Both, a common validation study and a common experiment are foreseen. The common validation study aims at evaluating and improving the prediction accuracy of different simulation methods. |

***Exploratory Groups (EG)***

The following Exploratory Groups were active or decided to start in January 2022:

| | |
|---|---|
| RC/EG-40 | *Gust Resilience of VTOL Aircraft* |

| | |
|---|---|
| | The objective is to set-up a team of researchers able to investigate and test the different approaches that might be employed to achieve gust resilience of multi-rotor vehicles. This EG was identified in 2019 and was expected to be active in 2020. Unfortunately, Cranfield's application for UK funding, to support this activity, was not successful, and for this reason, Cranfield had to withdraw from chairing this EG. Prof. Lovera from Politecnico di Milano accepted to take over the chairmanship from Cranfield Univ. with the aim to restart this EG in 2021. Nevertheless, during the years 2021 and 2022 no meeting was organized and no updates were received from Prof. Lovera. In 2022 the RC-GoR decided to keep this EG active, standing its utmost importance, mainly for UAM applications, and made an effort to identify another chairman willing to lead this EG. |
| RC/EG-42 | *Analysis and Decomposition of the Aerodynamic Force Acting on Rotary Wings*<br><br>The technology for drag analysis of CFD solutions of fixed wing configurations has reached a mature stage. Conversely, applications in rotary wing aerodynamics are still very limited, if not absent. However, recent progresses obtained in unsteady flow analysis are promising for both parasite force calculations, and thrust extraction. The objective of this EG is to study the application to rotary wings of aerodynamic force analysis and decomposition methods. The kick-off meeting of this EG was held on September 2021. During the meeting, Prof. Tognaccini of Univ. Naples Federico II informed the partners about his inability to coordinate the project, due to an unforeseen reduction of allocatable manpower. Fortunately, thanks to the great interest about this topic expressed by the partners, the role of coordinator was taken over by Drew Sanders of Univ. Cranfield, who was in charge for the preparation of the ToR document. The final version of this document and the partners' Letters of Acceptance and Adherence were submitted to and approved by the Council. The new Action Group, |

RC/AG-27 is planned to start the technical activities in 2023.

New topics under consideration are:

*Drone impact on Helicopters (rotating parts)*

To gain insight in the severity level of drone/rotor blade interactions. This topic is important for both civil and military applications.

*Helicopter Icing & De-Icing*

To improve the assessment of performance degradation when flying with rotorcraft in icing conditions, and to identify suitable de-icing systems for rotary wing applications.

*Human Factors issues and Training methods for complex automation in cockpit*

To improve the overall performance of the pilot / rotorcraft system in accomplishing missions

*PSP/TSP for rotors/propellers (drone,e-VTOLS...)*

To assess the potential and the limitations of these pressure and temperature sensitive paint-based measurement techniques in rotorcraft wind tunnel tests applications.

*Perception and public acceptance of UAM and Noise propagation in urban environment (high RPM with high frequency noise)*

These two NIs have much in common. These topics are currently having the biggest attention from the rotorcraft community and investigations about them are of utmost importance.

### 5.4.3 GoR-RC Membership

In June 2022, INTA (Spain) became a member of the RC-GoR.

The membership of GoR-RC in 2022 is presented in the table below.

| | | |
|---|---|---|
| **Chairperson** | | |
| Antonio Visingardi | CIRA | Italy |
| | | |
| **Vice-Chairperson** | | |
| Mark White | Univ. Liverpool | United Kingdom |
| | | |
| **Members** | | |
| Klaus-Dieter Pahlke | DLR | Germany |
| Alicia Verónica Barrios Alfonso | INTA (06/22) | Spain |
| Barbara Ohlenforst | NLR | The Netherlands |
| Arnaud Le Pape | ONERA | France |
| | | |
| **Industrial Points of Contact** | | |
| Rainer Heger | Airbus Helicopters | Germany |
| | | |
| **Observer** | | |
| Richard Markiewicz | Dstl | United Kingdom |

## 5.5 Group of Responsables – Structures and Materials (SM)

### 5.5.1 GoR-SM Overview

The GoR SM is active in initiating and organizing aeronautics oriented research on structures, structural dynamics and materials in general. Materials oriented research is related to material systems primarily for the airframe; it includes specific aspects of polymers, metals and various composite systems. Structural research is devoted to computational mechanics, loads and design methodology. Research on structural dynamics involves more especially response to shock and impact loading.

The group is active in theoretical and experimental fields of structures and materials to strengthen development and improvement of methods and procedures. Of great importance is the mutual simulation of the diverse scientific approaches. Experiments give new insights into the mechanisms of structural behavior that can be included in improved theoretical models. Finally, the theoretical results must be verified and validated by comparison with results from suitable experiments or trials.

Although the specific topics vary over the years, the scientific basis remains largely unchanged. The work is looked upon as an upstream research intended to discover valuable areas of future activity; in this context, many new ideas were proposed and explored during the year 2020.

Activities within the Exploratory and Action Groups cover several aspects of improved conventional and new technologies, new structural concepts and new design and verification criteria. Recent, current and upcoming work is devoted to:

- additive Layer Manufacturing;
- characterization and modelling of Composites with Ceramic Matrix submitted to severe thermo-mechanical loading;
- characterization of composites with polymer matrix at high temperatures;
- characterization and optimization of shock absorbers for civil aircraft fuselages;
- structural health monitoring for hydrogen aircraft tanks.

### 5.5.2 GoR-SM Activities

In 2022, GoR/SM monitored the two Action Groups and four Exploratory Groups:

***Action groups (AG)***

The following Action Groups were active throughout 2022:

| | |
|---|---|
| SM/AG-35 | *Fatigue and Damage Tolerance Assessment of Hybrid Structures*<br><br>This Action Group started in March 2012 and is a result from SM/EG-38. The final report has been finalised and transferred under the GARTEUR format. This final version of the final report was issued in January 2022 and approved at the Council Meeting C72 on March, 2022. The Group is closed. |
| SM/AG-36 | *Additive layer Manufacturing*<br><br>This Action Group started in March 2022 and is a result from SM/EG-47. AG-36 deals with new Novel aluminium alloys (ScanCromal and AlMg1Cr1.5Mo0.5Sc0.5Zr0.25) suitable for processing via metal additive manufacturing techniques. There is an increasing need for high strength aluminium alloys that can be processed with AM for production of applications that require low weight combined with high specific strength. The selected alloys will be investigated in Laser Powder Bed Fusion (L-PBF) and Directed Energy Deposition (DED). |

***Exploratory Groups (EG)***

The following Exploratory Groups were active throughout 2022:

| | |
|---|---|
| SM/EG-44 | *Characterization of composites with polymer matrix at high temperatures*<br><br>The main objective consists in the characterization of the mechanical properties of Composites with Polymer Matrix submitted to high thermal conditions. The work will be mainly experimental with the definition and improvement of experimental methods. The final |

| | |
|---|---|
| | objective would be to provide a test stand for the testing of classical coupons. The topic of high temperature polymer matrix composites was also submitted in a Clean Aviation proposal. The outcome of the Clean Aviation call (expected in September 2022) will determine whether this EG/AG will be continued. |
| SM/EG-45 | *Characterization and modelling of CMC submitted to severe thermo-mechanical loading*<br><br>The main objectives of the EG consist in:<br><br>• understanding of the damage and failure mechanisms under static and fatigue loading at very high temperatures;<br><br>• definition of standard tests to measure mechanical properties (behaviour, damage, failure) at very high temperatures;<br><br>• proposition of damage and failure models to predict behaviour damage, failure and fatigue lifetime of composite materials;<br><br>• testing and simulating CMC composite structures under static or fatigue loading (evaluation of predictive capabilities of models). |
| SM/EG-46 | *Characterization and optimization of shock absorbers for civil aircraft fuselages*<br><br>Commonly adopted shock absorbers and, in general, crashworthy structural components, based on sandwich structural concepts and/or complex dumping mechanisms, are, generally, characterized by high volumes and significant additional mass. The main objective of the proposed work consists in the investigation of the feasibility and effectiveness of novel thin additive manufactured hybrid metal/composite lattice structures as lightweight |

shock absorbing devices for application to structural key components in impact events.

The proposed topics of this EG-46 are:

- Investigation on the key components which require the integration with shock absorber
- Identification and classification of the shock absorbers (material and geometry)
- Material investigation (Alternative materials, Hybridization)
- Integration strategies
- Analytical methods for designing hybrid shock absorber
- Numerical analysis and design
- Unit cell optimization (weight minimization and/or shock absorbing capability maximization)
- Thermal stress analysis
- Experimental tests and validation
- Certification issues
- Definition of guidelines for an effective integration in each scenario.

The Work program for an Action Group focused on “Characterization and optimization of shock absorbers for industrial applications” was finalized and sent to the Garteur secretariat in October 2022 for approval and requesting to open AG-37.

| | |
|---|---|
| SM/EG-48 | *Structural health Monitoring for hydrogen aircraft tanks*<br><br>In order to drastically reduce CO2 emissions, hydrogen is an alternative solution for the production and storage of energy. Regarding the storage, the best option consists in liquefying the hydrogen at a temperature below -253°C. Composite materials are being considered for the cryogenic tank but the issue related to the development of a composite tank is the ability to detect initiation of any damage. Structural Health Monitoring (SHM) methods, consisting of integrating sensors in or on the structure, are then used. However, few studies are dedicated to SHM methods under such temperatures. The objective of the group would be to work on the design of SHM systems dedicated to composite parts under cryogenic temperatures, including the study of the durability of such systems. |

### 5.5.3 GoR-SM Membership

The membership of GoR-SM in 2022 is presented in the table below.

| | | |
|---|---|---|
| **Chairperson** | | |
| Bert Thuis | NLR | Netherlands |
| | | |
| **Vice-Chairperson** | | |
| Javier San Millan | INTA | Spain |
| | | |
| **Members** | | |
| Aniello Riccio | UdC | Italy |
| Robin Olsson | RISE | Sweden |
| Peter Wierach | DLR | Germany |
| Andrew Foreman | QinetiQ | United Kingdom |
| Mats Dalenbring | FOI | Sweden |
| Florence Roudolff | ONERA | France |
| | | |
| **Industrial Points of Contact** | | |
| Roland Lang | Airbus Defence and Space | Germany |
| Mathias Jessrang | Airbus Operations | Germany |
| Robin Olsson | RISE | Sweden |

# 6. List of abbreviations

ACARE: Advisory Council for Aviation Research and Innovation in Europe

AG: Action Group

ATI: Aerospace Technology Institute (UK)

CIRA: Italian Aerospace Research Centre

DLR: German Aerospace Centre

DNS: Direct Numerical Simulation

DSTL: Defence and Science Technology Laboratory (UK)

EASA: European Union Aviation Safety Agency

EDA: European Defence Agency

EG: Exploratory Group

EREA: Association of European Research Establishments in Aeronautics

EU: European Union

FOI: Swedish Defence Research Agency

FP: Framework Programme

GARTEUR: Group for Aeronautical Research and Technology in Europe

GoR: Group of Responsables

AD: Aerodynamics

AS: Aviation Security

FM: Flight Mechanics, Systems & Integration

SM: Structures & Materials

RC: Rotorcraft

IPoC: Industrial Points of Contact

INTA: National Institute of Aerospace Technology (Spain)

JTI: Joint Technology Initiative

JU: Joint Undertaking

LES: Large Eddy Simulation

NATO: North Atlantic Treaty Organization

NLR: Netherlands Aerospace Centre

ONERA: Office National d'Etudes et Recherches Aérospatiales (France)

PADR: Preparatory Action on Defence Research

PPP: Public-Private Partnership

RANS: Reynolds-Average Navier-Stokes

RPAS: Remotely Piloted Aircraft System

R&T: Research & Technology

RTD: Research & Technology Development

SESAR: Single European Sky Air Traffic Management Research

SME: Small and Medium-sized Enterprise

SRIA: Strategic Research & Innovation Agenda

STO: Science and Technology Organisation

TRL: Technology Readiness Level

UAV: Unmanned Air Vehicle

XC: Executive Committee

# 7. Organigram

## GARTEUR ORGANISATION

*Updated 1st October 2022*

**GARTEUR Chair Country 2022-2023: Italy**
**Council Chair: Dr. P. Renzoni**

**XC Chair: Mr. Vittorio Puoti**
**Secretary: Mr. Vittorio Puoti**

| GARTEUR COUNCIL | | | | | | | |
|---|---|---|---|---|---|---|---|
| ***Function*** | **France** | **Germany** | **Italy** | **Netherlands** | **Spain** | **Sweden** | **United Kingdom** |
| ***Head of Delegation*** | J. L'Ebraly | J. Bode | P. Renzoni | C.W. de Rooij | R. Gonzalez Armengod | R. Stridh | P. Griffiths |
| ***XC Member*** | O. Vasseur | A. Lohoff | V. Puoti | O. Bartels | J.J. Fernandez Orio | A. Wahlström | R. Gardner |
| ***Other Members of Delegation*** | P. Beaumier | H. Hemmer<br>A. Manecke | | O. Beers | J.F. Reyes-Sánchez<br>R. Garcia | M.O. Olsson<br>D. Faria | N. Bhadasia<br>S. Weeks<br>S. Pendry |

| GROUPS OF RESPONSABLES | | | | |
|---|---|---|---|---|
| **Aerodynamics (AD)** | **Aviation Security (AS)** | **Flight Mechanics, Systems & Integration (FM)** | **Rotorcraft (RC)** | **Structures & Materials (SM)** |
| **GoR AD members** | **GoR AS members** | **GoR FM members** | **GoR RC members** | **GoR SM members** |
| **G. Mingione** DE | **A. Vozella** IT | **B. Korn** DE | **A. Visingardi** IT | **B. Thuis** NL |
| K. Richter DE | E. Oliva SP | C. Doll FR | M. White UK | F. Roudolff FR |
| F. Monge SP | J.C. Dauer DE | R. van Enkhuizen NL | K. Pahlke DE | T. Ireman SE |
| E. Coustols FR | P. Bieber FR | A. Vitale IT | R.-H. Markiewicz UK | A. Riccio IT |
| M. Tormalm SE | R. Wiegers NL | J. Cabezas SP | A. Le Pape FR | J. Sanmilan ES |
| H. van der Ven NL | A. Bierig DE | A. Rae UK | R. Heger DE | M. Dalenbring SE |
| | H.A. Eckel DE | | B. Ohlenforst NL | P. Wierach DE |
| | S. Schopferer DE | | A. Barrios Alfonso ES | |
| **Industrial Points of Contacts** | **Industrial Points of Contacts** | **Industrial Points of Contacts** | **Industrial Points of Contacts** | **Industrial Points of Contacts** |
| B. Stefes DE | C. Goodchild UK | P. Goupil FR | | R. Lang DE |
| P. Eliasson SE | | L. Goerig FR | RC IPoCs included above | A. Foreman UK |
| R. Gemma IT | | M. Hanel DE | | M. Jessrang DE |
| M. Mallet FR | | P. Rosander SE | | R. Olsson SE |
| D. Pagan FR | | M. Hagstrom SE | | |
| L. P. Ruiz-Calavera ES | | | | |

# APPENDICES


**AND GO TO** https://garteur.org/annual-reports/

# Appendix A: Annex GoR-Aerodynamics (AD)

**ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "AERODYNAMICS"**

## Remit

The GoR AD initiates and organises basic and applied aerodynamic research in the field of aeronautics. The current scope of activities covers 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 Organisation) or national aeronautical research programmes.

Research initiated in GoR AD programmes 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.

## GoR-AD Overview

## GoR Activities

The primary task of the GoR is to monitor Action Groups, encourage Exploratory Groups, and stimulate new ideas. In 2022 five Action Groups (AD/AG-56, AD/AG-58, AD/AG-59, AD/AG-60 and AD/AG61) and one Exploratory Group (AD/EG-79) were active. Details about these groups can be found below.

## Management

After a long period of remote meeting, finally it has been possible to set-up physical meeting. To maximize the participation all the meetings have been mixed: remote and on site. In 2022 two meetings have been held:

- AD/A- 110 Meeting (remote meeting) March 16th 2022;
- AD/A- 111 Meeting at ONERA Meudon, Paris, October 17th, 18th 2022;

For the upcoming year 2023, the first meeting is planned in Spain, March 2nd and 3rd , while the second meeting is planned in Italy in coincidence with the event planned for the 50th anniversary of GARTEUR.

In 2022, it was agreed at GARTEUR level to have a dedicated session to GARTEUR at Stockolm ICAS conference. In this occasion a paper and a presentation dedicated to GoR-AD has been presented.

## Dissemination of GARTEUR activities and results

'The Group of Responsables "Aerodynamics (GoR AD)" An Overview of activities and Success Stories', G. Mingione, E. Coustols, F. Monge, H. van der Ven, K. Richter, M. Tormalm, L. R. Calavera, B. Stefes, D. Pagan, P. Eliasson, M. Mallet, R. Gemma 33th ICAS 22, ICAS2022_0915

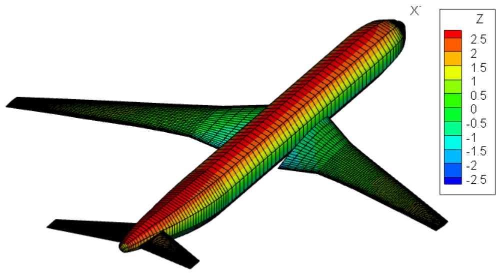
## Status of Action Groups and Exploratory Groups

Five Action Groups and one Exploratory Group have been running throughout 2022.

### *Action groups (AG)*

The following Action Groups were active throughout 2022:

| | |
|---|---|
| AD/AG-56 | *Coupled Fluid Dynamics and Flight Mechanics Simulation of Very Flexible Aircraft Configurations* |




The goals of 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 of AG-56 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:

- 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.

The chairperson is Richard van Enkhuizen (NLR).

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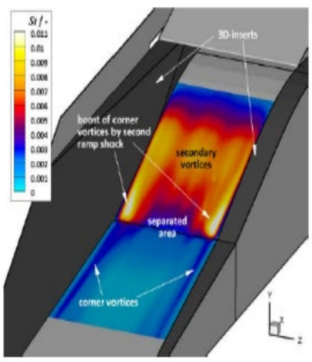
AD/AG-58

*Supersonic Air Intakes*



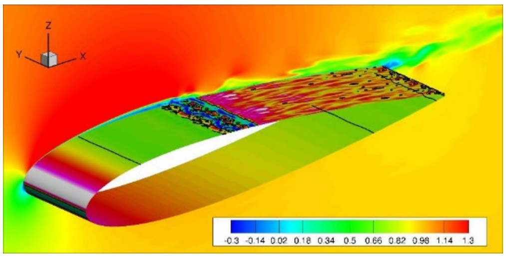

The main objective for the AG-58 is to gather a database of relevant flow features on representative test cases and validate CFD codes on these specific topics. The following investigation themes are proposed:

- cowl oblique shock / boundary layer / mixing layer interactions;
- internal bleed flows;
- supersonic air intake diffusers and scramjet isolators including corner flows description.

It is expected to support each theme with recent and detailed experimental data as well as CFD modelling and/or validation.

Due to COVID crisis that complicated organisation and priorites in 2020 for many companies, the collaborative work planned last year has been postponed for a year.

| | |
|---|---|
| | Some other priorities in 2022 have lead to other delays. It has been proposed to retart the collaboration by summer 2023 and to prepare the final report in December 2024. An updated list of milestones is proposed.<br><br>The chairperson is Christophe Nottin (MBDA). |
| AD/AG-59 | *Improving the Simulation of Laminar Separation Bubbles* |




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:

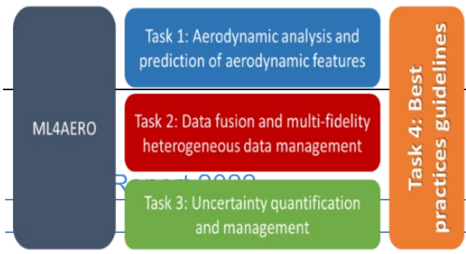
- the determination of the transition location and of transition region;
- the enhancement of the production of the turbulent kinetic energy in the separated flow inside the recirculation region;
- evolution of the bubble with the incidence and with turbulence level;
- possible burst of the bubble at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

The chairperson is Pietro Catalano (CIRA).

| | |
|---|---|
| AD/AG-60 | *Machine Learning and Data-Driven Approaches for Aerodynamic Analysis and Uncertainty Quantification* |

The objectives of the Action Group are:

- extensive comparison of deep learning, surrogate models and machine learning techniques for aerodynamic analysis and prediction;



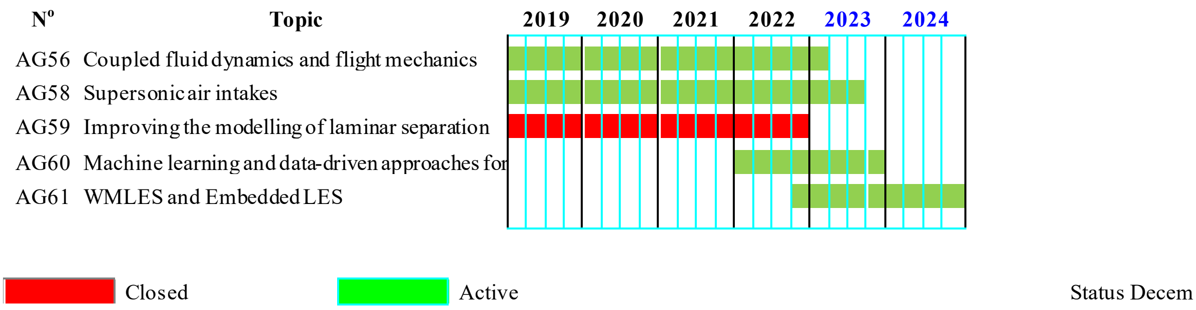
| | |
|---|---|
| | • exploitation of the potential of data fusion (Multi-fidelity) within surrogate modelling by efficient management of heterogeneous data from different sources (CFD with different precision, wind-tunnel, flight test data, etc.);<br>• exploration of the potential of machine-learning and data-driven techniques for uncertainty quantification and management.<br><br>The chairperson is Esther Andrés (INTA). |
| AD/AG-61 | *WMLES and Embedded LES*<br><br>RANS CFD has shown many merits but fails to model turbulence in adverse-pressure-gradient boundary layers and in separated flows. Turbulent scale-resolving simulations are needed, but DNS and wall resolved LES are not affordable yet for industrial daily needs.<br><br>Thus, this group investigates the hybrid RANS-LES strategies. In order to extend previous activities (see AD/AG-54 for instance), family II strategies are of interest (where only the inner part of the attached boundary layer is modelled in RANS whereas the outer region of the boundary layer is resolved by LES). Such strategies belong to the more general Wall-Modeled LES approaches. A substantial cost reduction is gained (over wall resolved LES) and improved turbulent dynamics is simulated (over DES-like, or family I simulations where the attached boundary layer is treated fully in RANS). The use of LES can thus be restricted to the regions of interest in a so called embedded LES strategy.<br><br>The activities of the group aim at facilitating the introduction of family II in industry. The several turbulent relative topics are investigated through 4 test cases. |

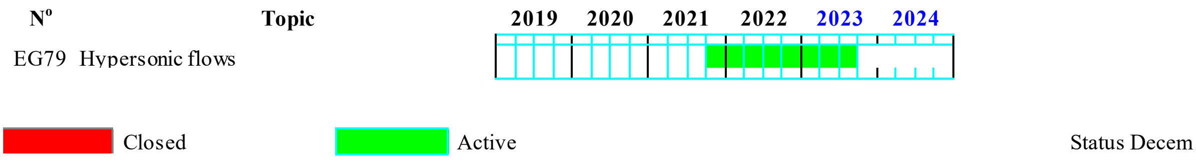
### *Exploratory Groups (EG)*

The following Exploratory Groups were active throughout 2022:

| | |
|---|---|
| AD/EG-79 | *Hypersonics*<br><br>Partners of the EG are: DLR, University of Munich, CIRA, DLR, TU Munich, NLR, FOI, VKI. After some preliminary meetings there have been no additional activities.<br><br>Even if only one Exploratory group is active, there are several topics under discussion that could generate new Exploratory goups in the next future: Morphing, thermal management, corner flows, virtual certification, corner flows… |

## Rolling plan




## GoR membership

This year Italy has chairmanship and ONERA vice-chair. From 2024 France will be GoR-AD chairman and Sweden vice-chairman.

It has to be underlined that Eric Coustols has already announced that he will be retiring next year and will be no more Garteur member.

Finally, as since a long time, there are no UK members in the GoR-AD.

| | | |
|---|---|---|
| **Chairperson** | | |
| Giuseppe Mingione | CIRA | Italy |
| **Vice-Chairperson** | | |
| Eric Coustols | ONERA | France |
| **Members** | | |

| | | |
|---|---|---|
| Kai Richter | DLR | Germany |
| Fernando Monge | INTA | Spain |
| Bruno Stefes | Airbus Operations | Germany |
| Magnus Tormalm | FOI | Sweden |
| Harmen van der Ven | NLR | Netherlands |
| Peter Eliasson | SAAB | Sweden |

| **Industrial Points of Contact** | | |
|---|---|---|
| Riccardo Gemma | Leonardo Company | Italy |
| Michel Mallet | Dassault Aviation | France |
| Didier Pagan | MBDA | France |
| Luiz P. Ruiz-Calavera | AIRBUS D&S | Spain |

## Table of participating organizations

| | AG-56 | AG-58 | AG-59 | AG-60 | AG-61 |
|---|---|---|---|---|---|
| **Research Establishments** | | | | | |
| CIRA | □ | | ■ | □ | □ |
| DLR | □ | □ | □ | □ | □ |
| FOI | | □ | | □ | □ |
| INTA | | | | ■ | |
| NLR | ■ | | | □ | □ |
| ONERA | □ | □ | □ | □ | ■ |
| **Industry** | | | | | |
| Airbus Defence & Space | □ | | | □ | |
| Airbus Operations GmbH | □ | | | □ | |
| Airbus Operations S.A.S. | | | | | |
| Leonardo Company | | | | | |
| Dassault Aviation | | | | | |
| MBDA-F | | ■ | | | |
| MBDA-D | | □ | | | |
| SAAB | | □ | | | □ |
| OPTIMAD | | | | □ | |
| **Academic Institutions** | | | | | |
| Imperial College | | | □ | | |
| Technical Univ. Munich | | | | | □ |
| University of Manchester | | | | | □ |
| Zurich Univ. of Applied Sciences | | | | | □ |

| | | | | | |
|---|---|---|---|---|---|
| Univ. of Napoli "Federico II" | | | ☐ | | |
| Marche Polytechnic University | | | ☐ | | |
| Univ. of Strasbourg | | | ☐ | | |
| Univ. of Southampton | | | ☐ | | |
| Institute of Marine Engineering (INMCNR) | | | ☐ | | |
| Nat. Institute for Research in Digit. Science and Technology | | | | ☐ | |
| University of Twente | | | | ☐ | |

## Action Group Reports

| | |
|---|---|
| **AD/AG-56** | **Coupled fluid dynamics and flight mechanics simulation of very flexible aircraft configurations** |
| **Monitoring Responsable:** | H. Van der Ven<br>NLR |
| **Chairman:** | M.J. van Enkhuizen<br>NLR |

- **Background**

With the increasing importance of environmental issues, various technologies are being developed to create more efficient aircraft designs, reducing fuel burn. In terms of airframe enhancements, these include utilizing lighter structures and higher aspect ratio wings, leading to very flexible configurations. By more actively accounting for the large structural deformations in very flexible configurations, greater weight savings and larger aspect ratios can be realized.
To allow for better optimization of such flexible configurations, studies are carried out in bringing closer the various disciplines supporting aircraft design, especially taking into account the large structural deflections in flight mechanics analyses. Building upon GARTEUR (FM) AG-19 where use has been made of simplified aerodynamic models, AG-56 makes use of high-fidelity aerodynamic models coupled with structural models for such very flexible aircraft. Within AG-56, capabilities will be developed to perform aeroelastic simulations of very flexible aircraft. These capabilities will be assessed and benchmarked by performing simulations with varying degrees of fidelity.

- **Objectives**

The goals of AG-56 are twofold: firstly, this endeavour aims to enhance each partner's capabilities in aeroelastic simulations pertaining to very flexible aircraft. This entails more accurately predicting aerodynamic loads and structural deformations for manoeuvre and disturbance conditions. A second aim of AG-56 is to define and develop 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:

- 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.

- **Approach**

Analyses will be performed using the Airbus XRF-1 benchmark model which has been modified to accommodate for more wing flexibility. The baseline XRF-1 model has been made available by AI-O.
Four scenarios will be considered; two gust disturbance conditions and two manoeuvres. The manoeuvre conditions are a 2.5g pull-up and an elevator deflection. Aeroelastic simulations with six degrees of freedom will be performed in a CFD environment. To achieve this, the complexity of the simulations will be increased step-by-step, starting with a purely aerodynamic (assuming a rigid aircraft) simulation, subsequently followed by an aeroelastic simulation without motion, and finally the 6-DOF aeroelastic simulation. Results will be compared to lower fidelity aeroelastic simulations that do not consider a CFD environment. This is done in the NASTRAN and ZAERO environments by means of aeropanels. As stated earlier, the underlying goal of more accurate aeroelastic analyses for very flexible aircraft is to impose less stringent stiffness criteria, allowing for fuel burn reductions with lighter structures and higher aspect ratios. As such, a final analysis will consider an MDO optimized aircraft. This will provide insight in the potential gains and aeroelastic behaviour when optimizing very flexible aircraft wings.

- **Main achievements**

Due to challenges in obtaining the XRF-1 FEM and CAD models, work in the first year was limited. The main achievement was to obtain the model from Airbus with all associated legal requirements. Additionally, the disturbance and manoeuvre conditions have been defined. In the second year, the generic FEM and CAD models have been modified for AG-56 purposes. For the CAD geometry, modifications included geometry clean-up for CFD (un)structured mesh generation and the inclusion of an elevator surface (see Figure 6). For the FEM model, wing elasticity has been modified for increased tip deflections; aiming for 10 percent tip deflection in 1g flight (see Figure 7). This has been done for a worst-case mass condition. The front and rear spar have been tuned to attain the desired tip

deflection; iterating for the gust condition of interest in a panel code environment (see Figure 8).
Due to the world-wide pandemic in 2020, Covid-19, very limited progress is achieved in 2020. Some progress is achieved to setup first simulations, but simulation results have not been achieved in the year 2020.
In the year 2021, partners have run trim simulations using their methods with either rigid models or the flexible model. As shown in Table 1 and Table 2, the results are reasonably close together even though there are known differences between the models of the partners. Some of these differences are investigated further at the beginning of 2022. DLR decided to run the simulation only with the very flexible aeroplane and has reported issues with their approach to run the very flexible model of AG-56. Hence, no trim results of this model are available yet.

*Table 1: Preliminary trim results for rigid aeroplane with engine thrust unless stated otherwise*

| | Case M 0.5 | | | Case M 0.86 | |
|---|---|---|---|---|---|
| | AoA | HTP angle | | AoA | HTP angle |
| **Zaero-Nastran NLR No engine thrust** | 1.30 | -2.74 | | 0.21 | -2.65 |
| **CFD based NLR No engine thrust** | 1.67 | -2.18 | | 0.16 | -2.05 |
| **Zaero-Nastran NLR** | - | - | | - | - |
| **CFD based NLR** | 1.39 | -1.62 | | 0.22 | -1.93 |
| **CIRA** | 1.75 | -2.44 | | 0.43 | -2.6 |
| **DLR** | - | - | | - | - |
| **Onera** | - | - | | - | - |
| **Airbus** | - | - | | - | - |

*Table 2: Preliminary trim results for flexible aeroplane with engine thrust unless stated otherwise*

| | Case M 0.5 | | Case M 0.86 | |
|---|---|---|---|---|
| | AoA | HTP angle | AoA | HTP angle |
| **Zaero-Nastran NLR No engine thrust** | 2.69 | -2.96 | 1.77 | -2.96 |
| **CFD based NLR No engine thrust** | - | - | - | - |
| **CFD based CIRA** | - | - | - | - |
| **CFD based DLR** | - | - | - | - |
| **CFD based Onera** | - | - | - | - |
| **Airbus** | - | - | - | - |

In 2022, partners have finished their work to calculate trimmed 1g flight using the flexible aeroplane for the two flight conditions of interest. Subsequently partners have analysed two disturbance conditions and two manoeuvre conditions. Due to remaining issues with the chosen approach of DLR, the group has decided at the beginning of 2023 that DLR will not contribute to the end report. It is decided to write the end report of AG-56 in the year 2023, using the simulation results available.

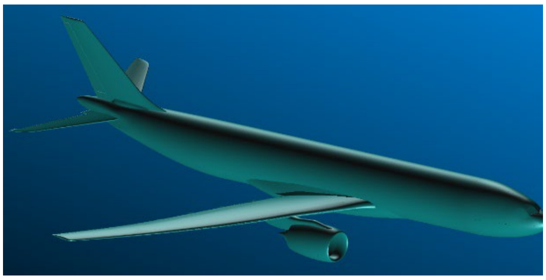


*Figure 7: CAD geometry of the XRF-1.*

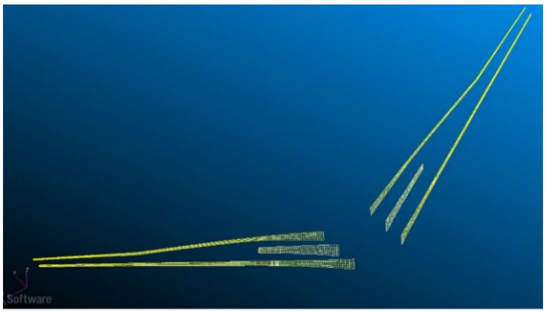


*Figure 8: Depiction of the wing structure in the FEM model. The elasticity of the front and rear spar is tuned for 10 percent tip deflection in 1g flight.*

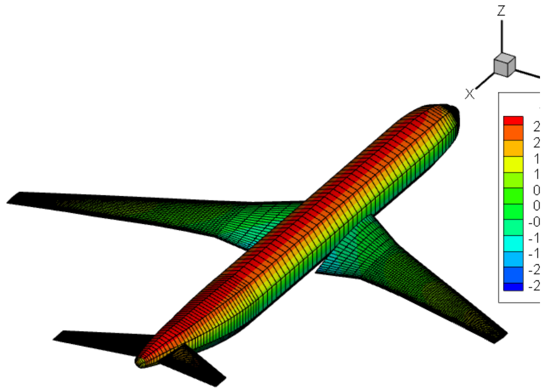



*Figure 9: Panel model used to tune the wing structure for 10% tip deflection for worst-case gust.*

- **Project management**

It has been decided to have alternating physical and teleconference meetings every 3 months. The kick-off meeting took place on the 9th of March 2018 in Amsterdam, hosted by NLR. Two teleconference progress meetings have been held on the 25th of October 2018 and the 25th of March 2019, as well as a physical meeting in Manching, hosted by Airbus Defence and Space on January 24th, 2019. July 4th 2019, a teleconference meeting pertaining to model updates, while various teleconferences have been held between partners pertaining to model generation.
In autumn 2020 the chairmanship has been transferred to M.J. van Enkhuizen.
During the year 2021, preliminary results of the trim simulations are discussed on the four meetings that were organised by NLR on January 25th, April 9th, June 18th, October 27th. Additionally, during the fall 2021 meeting the manoeuvre and disturbance conditions are discussed to further specify the required input to perform the simulations.
During the year 2022, preliminary results of the disturbance and manoeuvre conditions are discussed on the four meetings that were organised by NLR on January 12th, June 21th, October 24th, November 29th.

- **Expected results/benefits**

The various simulations in this project are expected to enhance the understanding, tools and capabilities of partners in the nonlinear aeroelastic domain. Secondly, this project will allow for benchmarking of inhouse tools amongst the partners through the use of a common research model.

- **AD/AG-56 membership**

| Member | Organisation | E-mail |
|---|---|---|
| K. Elssel | Airbus D&S | kolja.elssel@airbus.com |
| H. Bleecke | Airbus O | hans.bleecke@airbus.com |
| P. Vitagliano | CIRA | p.vitagliano@cira.it |
| M. Ritter | DLR | markus.ritter@dlr.de |
| MJ. van Enkhuizen | NLR | richard.van.enkhuizen@nlr.nl |
| Cédric Liauzin | ONERA | cedric.liauzun@onera.fr |

| | |
|---|---|
| **AD/AG-58** | **Supersonic Air Intakes Aerodynamics** |
| **Monitoring Responsable:** | D. Pagan<br>MBDA |
| **Chairman:** | C. Nottin<br>MBDA |

- **Background**

Supersonic air intakes are of foremost importance in the design of a supersonic air-breathing vehicle, whether the propulsion system is a turbojet, a ramjet or a scramjet. They are critical in the performance (thrust, drag, consumption) but also in the mass budget, the general architecture and the radar signature. They need to be accurately designed very early in the development phase. Currently their design heavily relies on numerical simulations (CFD).
An Action Group on supersonic air intakes was completed in 2007 (AG34). It was focused on shock / boundary layer interactions and the modelling of porous walls and bumps. It is proposed to build on the results of this AG and to launch a new research activity in this domain which is of primary interest for military aircrafts and missiles.

- **Objectives**

The main objective for the AG-58 is to gather a database of relevant flow features on representative test cases and validate CFD codes on these specific topics. The following investigation themes are proposed:

- Cowl oblique shock / boundary layer / mixing layer interactions
- Internal bleed flows
- Supersonic air intake diffusers and scramjet isolators including corner flows description.

It is expected to support each theme with recent and detailed experimental data as well as CFD modelling and/or validation.

The main conclusions of the activities carried out during the proposed Action Group should cover the following specific issues:

- Clarify the benefit of new CFD methods (unsteady ZDES approach) and HPC capacities in comparison with the last AG34 for example,
- Assess RANS methodology (including turbulence modelling, grid mesh refinement) to tackle the proposed research topic, and
- Estimate the CPU cost of the comparative methodologies.

- **Main achievements**

**WP1 : Management**
Due to COVID crisis that complicated organisation and priorites in 2020 for many companies, the collaborative work planned last year has been postponed for a year. Some other priorities in 2022 have lead to other delays. It is proposed to restart the collaboration by summer 2023 and to prepare the final report in December 2024. An updated list of milestones is proposed.

**WP2 : Supersonic diffusers flows**
The case proposed in WP2 involves shock trains prediction.
The main challenges are:

- prediction of shock / boundary layer interactions;
- prediction of corner flow separations which distort the flow and affect the aerodynamic losses in a diffusor.

The classical turbulence models based on linear closures generally fail to reproduce accurately these flows. More advanced models may be required based on RANS with non linear closures or LES/DES techniques.
A 3D test case with thick BLs $Re\delta 2 \approx 6000$ and strong effect of corner flows from Fiévet et al (AIAA J, 2017) was identified by ONERA but the paper seems not self-sufficient to be used as a test-case.
ONERA proposed to design a test-case similar for AG58 but with well-known flow conditions at boundaries, see Figure 9.
Several RANS computations were performed by ONERA. Inlet flow profiles are now available to all partners, see Figure 10. Outlet condition is a prescribed back pressure. ONERA will perform a DES mode 3 calculation that can be used as a reference to compare with RANS models. Members will perform DES and/or RANS calculations

including non linear closure turbulence models (SAQCR, RMS, …).

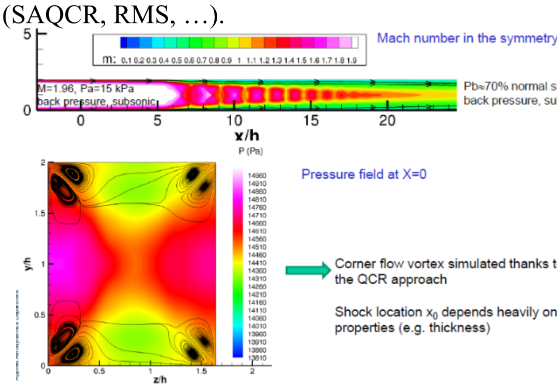



*Figure 10: shock train in a rectangular cross-section channel. ONERA test-case.*

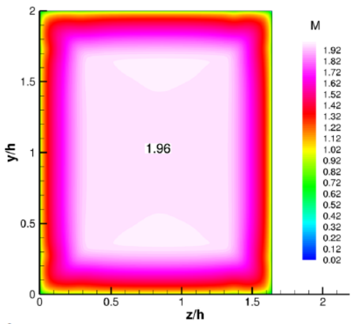



*Figure 11: common inlet flow field proposed by ONERA for shock train case computations.*

RANS computations were performed by ONERA and also MBDA using Spalart Allamaras (SA) and a non-linear closure variant (SA-QCR).

QCR generic formulation are detailed below.

With the Quadratic Constitutive Relation (QCR) correction, instead of the traditional linear Bou relation, the following form for the turbulent stress is used:

$$\tau_{ij,QCR} = \tau_{ij} - C_{cr1}\left[O_{ik}\,\tau_{jk} + O_{jk}\,\tau_{ik}\right]$$

where $\tau_{ij}$ are the turbulent stresses computed from the Boussinesq relation, and $O_{ik}$ is an antisy normalized rotation tensor, defined by:

$$O_{ik} = 2W_{ik}\Big/\sqrt{\frac{\partial u_m}{\partial x_n}\frac{\partial u_m}{\partial x_n}} = 2W_{ik}\Big/\sqrt{u_x^2 + u_y^2 + u_z^2 + v_x^2 + v_y^2 + v_z^2 + w_x^2 + w_y^2 + w$$

$$W_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} - \frac{\partial u_j}{\partial x_i}\right)$$

*Figure 12: principle of QCR non-linear closure for turbulence models.*

Results obtained with SA-QCR model are quite different compared to those obtained with the standard SA model. The prediction of the corner flows is strongly modified resulting in a non-symmetric development of the shock train inside the duct for the SA and a symmetric one for the SA-QCR (see Figure 11).

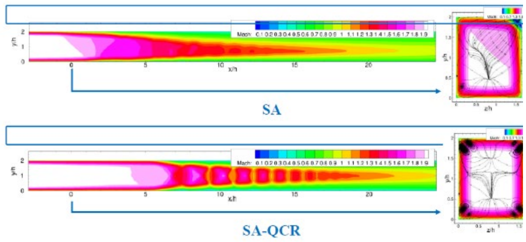



*Figure 13: effects of QCR closure with the Spalart Allmaras model on corner flows and shock train development for WP2 test-case (ONERA).*

Comparisons of CFD predictions with available pressure measurements and published DNS results show local improvements with the non-linear closure of the turbulence model (see Figure 13 and Figure 14).

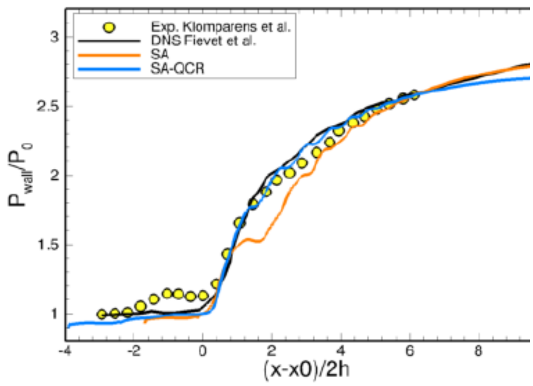



*Figure 14: effects of QCR closure with the Spalart Allmaras model and comparison with wall pressure measurements (ONERA).*

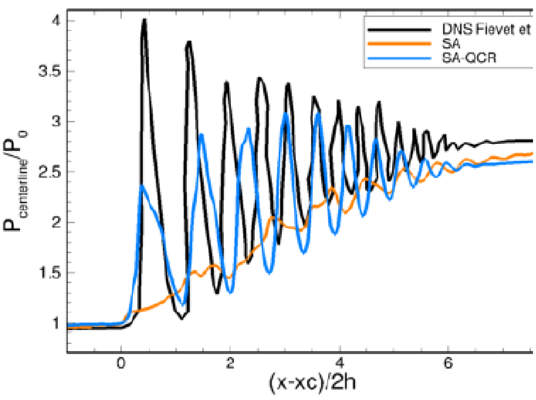



*Figure 15: effects of QCR closure with the Spalart Allmaras model and comparison with axial pressure computations from DNS published by Fiévet et al. (ONERA).*

Further investigations were performed by ONERA and MBDA on QCR correction applied to k-omega SST model.

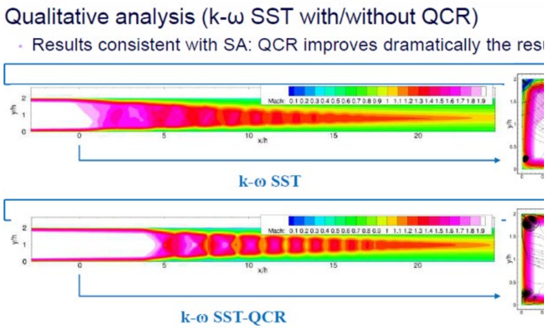



*Figure 16: effects of QCR closure with the k-omega SST model on corner flows and shock train development for WP2 test-case*

These results (see Figure 15) confirm the trends from previous results obtained with SA model. QCR correction leads to strong improvement regarding corner flow effects (see Figure 16).

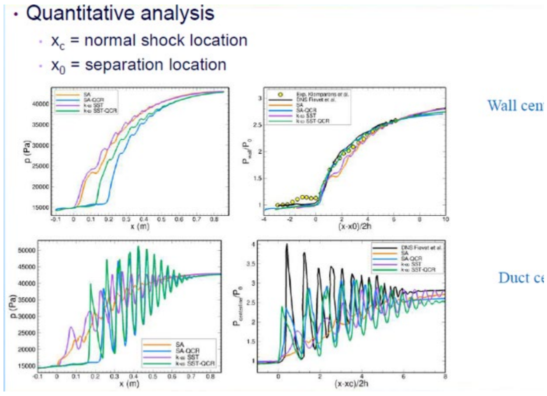



*Figure 17: Effects of QCR closure with the k-omega SST model and comparison with wall pressure measurements and SA/SA-QCR results.*

Further investigations will be made on Reynolds Stress Model (RSM) and final issue regarding ZDES computations are on-going work at ONERA (see Figure 17).

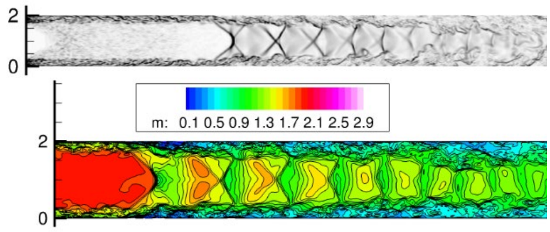



*Figure 18: ongoing ZDES simulations on WP2.*

**WP3 : Mach 3 ramjet intake**

DLR has described in detail experimental results obtained in several existing wind-tunnel test campaigns for a ramjet intake design for Mach 3, see Figure 18.

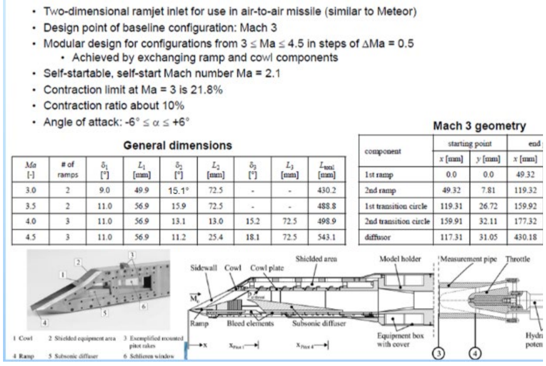



*Figure 19: DLR experimental model for the Mach 3 ramjet intake.*

This large existing database includes several effects:

- internal bleed geometry, open or closed;
- flow conditions such as Mach number (on and off design conditions) and angle of attack;
- geometry of the ramps and cowl.

It was decided to focus GARTEUR activities on bleed prediction effects in design and off-design Mach number conditions.

The members agreed to select the following experimental conditions:

- no bleed versus bleed 22/22 (bleed entrance length/bleed exit length in mm);
- effect of Mach number : Mach 3.0 (on-design condition, shocks on cowl lip) and Mach 3.5 (off-design conditions, shocks from ramps interact inside the duct on the internal cowl);
- Tt0 = 290 K, pt0 = 5.8 bar, Re∞ = 40.8 · 106 m-1;
- no Angle of attack and no sideslip;
- throttling effects at downstream sonic throat condition (throat section can be changed using a translating plug).

The available experimental data contain (see Figure 19):

- Schlieren images;
- wall pressure measurements
    - o 34 pressure ports along centreline of ramp, cowl and diffuser;
    - o static pressure measurements with 8400 PSI System by Pressure Systems;
    - o instationary pressure measurements with XCL-100 Kulite sensors for frequency analysis of inlet buzzing;
- six Pitot rakes with different lengths available

  - can be integrated in four different axial locations in the diffuser section;
  - 2 additional Pitot rakes for exterior flow above and below the model;
- mass flow measurements by conical throttle;
- pressure measurements in throttle used for determination of pressure recovery.

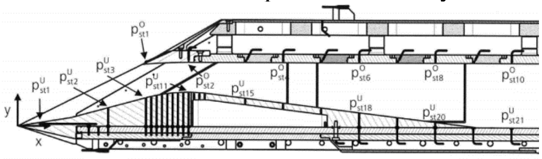


*Figure 20: DLR experiments with measurements and rakes location.*

Accuracy on the air intake performances provided by DLR are presented below.

**Table 4 Measurement uncertainties of throttle devic**

| $M_0$ | $\Delta(\dot{m}_3/\dot{m}_0)/(\dot{m}_3/\dot{m}_0)$, % | $\Delta p_{st3}/p_{st3}$, % | $\Delta A_3/A_3$, % | $\Delta(p_{t3}/p_{t0})/(p_{t3}/p_{t0})$, |
|---|---|---|---|---|
| 2.5 | 1.70 | 0.03 | 0.03 | 0.09 |
| 3.0 | 1.90 | 0.03 | 0.03 | 0.09 |
| 3.5 | 2.06 | 0.03 | 0.03 | 0.09 |

After a detailed investigation of the model and the boundary conditions needed for the calculations, DLR prepared and shared the CAD files with the fixed modifications commonly agreed at last teleconference meeting.
Regarding boundary conditions, DLR will assess by 2D computations the potential effect of wind-tunnel walls on the bleed mass flow rate, as the internal bleed has no sonic outlet as illustrated by Figure 20.

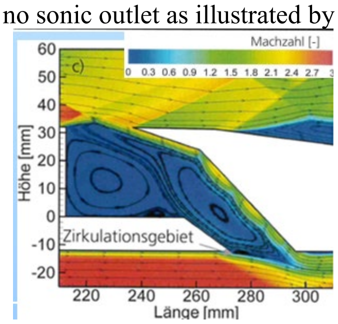



*Figure 21: illustration of Mach number of the internal flow inside the bleed (DLR).*

The 3D CAD file, ready to mesh, has been provided to all members (see. Figure 21).

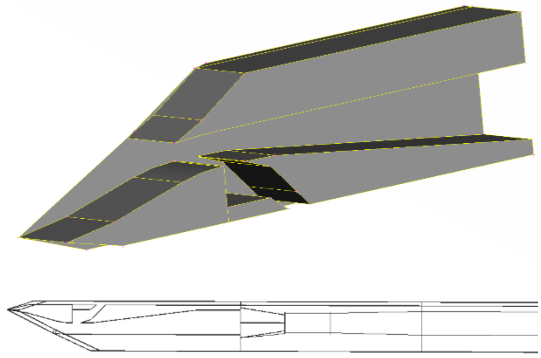


*Figure 22: CAD provided by DLR for the WP3 computation (open bleed case).*

The CAD extension down to the throttling device (plug) has been provided as an option so that throattling effect can be computed either using back pressure on short domain or by modifying the sonic throat on the full domain in the computational process. This could have an effect in case unsteady computations of surging regime is planned (this is not a priority of the WP3).
The experimental measurements will be provided shortly by DLR to all members.
Computations efforts will be focused on RANS approach with same turbulence models effects as those proposed in WP2 as well assessing adaptive grid refinement improvements.

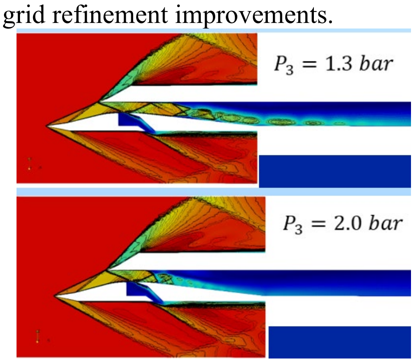



*Figure 23: caracteristic curves at Mach 3.0 using CEDRE code.*

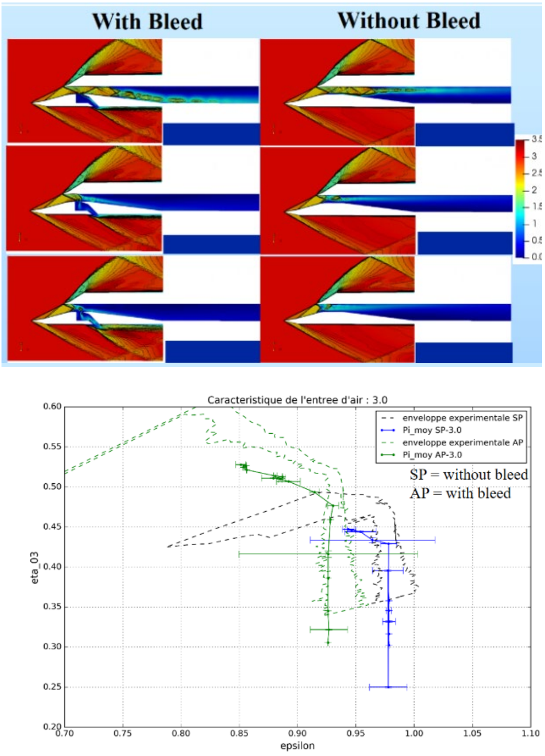



*Figure 24: preliminary investigation of internal bleed effect at Mach 3.0, using CEDRE code with k-omega SST turbulence model.*

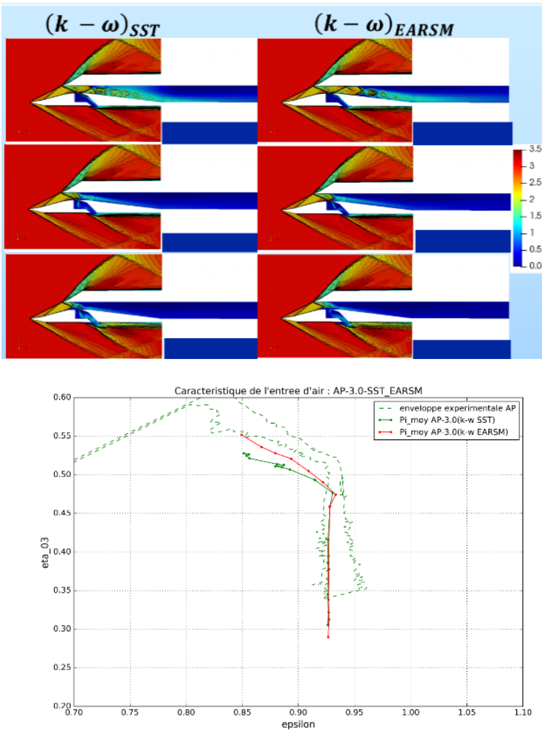



*Figure 25: preliminary investigation of turbulence model effect at Mach 3.0, using CEDRE code with k-omega SST turbulence model vs EARSM*

## WP4 : Mach 7.5 scramjet intake

The proposed test-case is illustrated in Figure 25.

- Windtunnel model geometry
  - Scale: 1.5:1
  - Capture area: 0.1 x 0.1 m$^2$ = 0.01 m2
  - Throat height 15.5 mm → contraction ratio ≈ 6.45
  - Internal contraction ratio $A_{lip}/A_{th}$ ≈ 1.19 in basic configuration
    - Can be increased up to 1.88 for 2D-configuration
  - Ramp angles $\delta_1$ = 9.5°, $\delta_2$ = 20.5°(against x-axis)
  - Isolator bottom wall divergent by 1°
  - Height at combustion chamber entry 18 mm

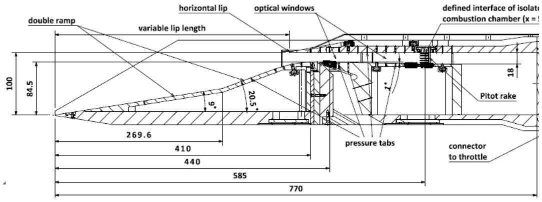



*Figure 26: DLR experimental model for the scramjet Mach 7.5 intake*

One topic for WP4 will be the aerothermal fluxes prediction and effects of sidewalls compression, see some examples of experimental results in Figure 23. It was decided to compute the closed bleed configuration in supercritical conditions with a downstream extension sufficient to include the Pitot rake available in the experiments.

The experimental conditions for CFD validation of heat fluxes still need to be fixed for future calculations as experimental tests were performed with different conditions depending on area of interest (pressure measurement inside the isolator or infrared measurements on the ramps for the heat fluxes).

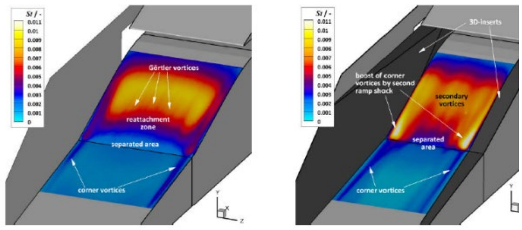


*Figure 27: DLR experiments on the scramjet intakes, with IR thermography. Effect of sidewalls compression on heat fluxes and corner flow.*

The CAD, ready to mesh, provided by DLR is presented on the Figure 14. The exit plan is located downstream the isolator Pitot rake.

Computations efforts will be focused on RANS approach with same turbulence models effects as those proposed in WP2.

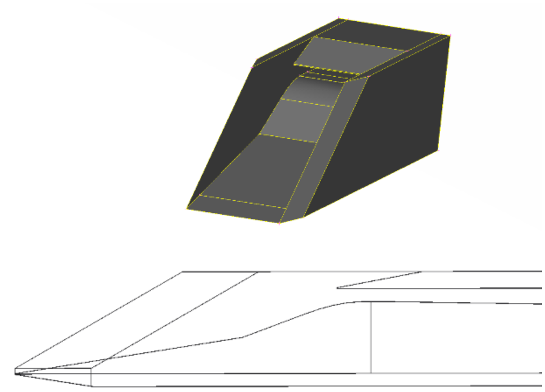


*Figure 28: CAD provided by DLR for the WP4 computation (closed bleed case).*

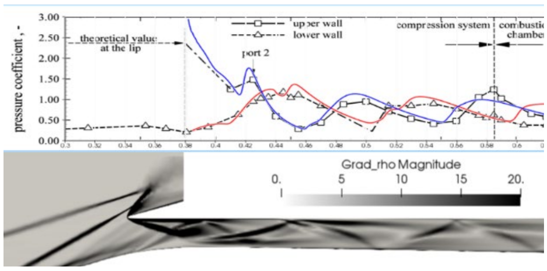



*Figure 29: preliminary compuation, using CEDRE code*

- **Expected results/benefits**

The project is expected to yield increased understanding of turbulence modelling issues for complex internal flows in supersonic and hypersonic intakes as well as adaptive grid improvements. A natural outcome is also that the partners obtain improved best practices for intake flow computations.

- **AD/AG-58 membership**

| Member | Organisation | e-mail |
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| Christophe Nottin | MBDA France | christophe.nottin@mbda-systems.com |
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| Sébastien Deck | ONERA | sebastien.deck@onera.fr |
| Neil Sandham | University of Southampton | n.sandham@soton.ac.uk |

| | | |
|---|---|---|
| **AD/AG-59** | **Improving the simulation of laminar separation bubbles** | |
| **Monitoring Responsable:** | | G. Mingione<br>CIRA |
| **Chairman:** | | P.Catalano<br>CIRA |

- **Background**

The laminar separation bubble is one of the main critical aspects of flows at Reynolds number of order of magnitude 104-105. However, the reproduction of this phenomenon results to be crucial also for flows at higher Reynolds number. In fact, very tiny laminar separation bubbles are present in airfoil used for turbine applications operating at Reynolds number of the order of magnitude of $10^6$.
An interest is growing towards the employment of rotary wing aircraft as valid technological means for a rapid and efficient exploration of planet Mars. The challenge of this new technological solution lies entirely in the specific environmental conditions these aircraft will be required to operate in. Mars atmosphere is 95% constituted by CO2 and the force of gravity is about 1/3 than the Earth's. The reduced atmospheric pressure and density, together with the low temperatures, produce flight conditions characterised by very low Reynolds numbers, about 2% of those on the Earth, in combination with high Mach numbers, 1.5 times higher than the terrestrial ones. The evaluation of the aerodynamic characteristics of airfoils and wings in such particular conditions, scarcely investigated so far, is becoming increasingly more important for the understanding of the feasibility of such technological solution.

- **Objectives**

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 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.

- **Approach**

The focus is placed on the methods based on the Reynolds Averaged Navier Stokes (RANS) equations and on the hybrid RANS-LES methods. Boundary layer instability analysis tools will also be used and compared with the RANS results to ascertain deficiencies of the turbulent onset point; moreover, the RANS embedded turbulence/transition models will also provide significant insight into the efficacy of the boundary-layer instability and hence transition criteria.

- **Main achievements**

A new model has been developed by CIRA and University of Napoli "Federico II". The model couples the Menter κ-ω-γ and the Bernardos κ-ω LSTT models. This new model employs the γ function to evaluate the transition and the ftr function from Bernardos's model to enhance the production of the turbulent kinetic energy in the turbulent region of the bubble. Interesting results have been achieved for the SD 7003 (TC O1a), and NACA 0015 aifoils (TC O1c).

Some LES have been performed by CIRA for the SD 7003 airfoil at Re=6.0x104 and α=4°, NACA0015 airfoil at Re=1.8x105 and α=5° and 10°, and the Eppler 387 at Re=3.0x105 and α=7°. CIRA has also ultimate the test case TCM2b, the flow over a flat plate subject to an adverse pressure gradient. The flow around the triangular airfoil placed in a wind tunnel (TC M3a) has been simulated at M=0.50 and Re=3x103 by time-accurate URANS simulations.

ONERA has reported on the wind tunnel campaign over the NACA 0012 airfoil (TC M1) and on the numerical simulations performed at some flow conditions. A disagreement between numerical and experimental data due to the influence of the WT walls has been highlighted. There is a clear influence of the WT walls on the results and there is no way to correct the experimental data. Therefore, this test case has been cancelled because the numerical reproduction of the flow in free-air is very problematic. The numerical activities planned for the NACA 0012 test case have been replaced with new simulations for the flow around the NACA 0015 airfoil.

Technical University of Marche has computed the flow around the NACA 0015 airfoil by applying different models.

DLR has performed the stability analysis of the laminar separation bubbles over the SD7003 airfoil at Re=6.0x104 and α=4° over the NACA 0015 airfoil at Re=1.8x105 and α=3°, 5° and 10°. The analyses have been performed by considering a geometry made of the actual airfoil where the flow is attached and the dividing streamline of the bubble where the flow is separated. Stability curves, similar to those achieved for an attached boundary layer, have been achieved.

- **Management issues**

The technical activities are over. Some partners declared to have finished the man-power even before the scheduled end of the project.

The writing of the final report is in progress. Almost all the required contributions have been sent to the coordinator.

Imperial College has actually left the project.

- **Expected results/benefits**

The project is expected to yield increased understanding of modelling of laminar separation bubbles. A natural outcome is also that the partners obtain improved simulation tools. Experimental data for the flow at low Reynolds number around the NACA 0015 airfoil are available for the AG59 members.

- **AD/AG-59 membership**

| Member | Organisation | E-mail |
|---|---|---|
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## AD/AG-60 Machine learning and data-driven approaches for aerodynamic analysis and uncertainty quantification (ML4AERO)

**Monitoring Responsable:** F. Monge INTA

**Chairpersons:** E. Andrés INTA
D. Quagliarella CIRA

- **Background**

In the field of aerodynamics, the simulations of complex steady flows have reached a sufficient maturity. Nowadays, they are intensively used in the industrial context and are usually based on Computational Fluid Dynamics (CFD). A specific branch consists in the integration of the Navier-Stokes equations on meshes counting millions of degrees of freedom with the help of high performance computing. Therefore, the aerodynamic simulations of systems such as wings or even aircraft can be computationally expensive. Moreover, several parameters can vary such as the inflow conditions or the shape, leading to an exploration of the input parameter space requiring more than thousands of CFD evaluations and becoming intractable. Taking benefit of the regularity of the outputs of interest (forces and moments) with respect to these numerous inputs, the CFD solver can be substituted by a surrogate model, in order to reduce the computational costs generated by the predictions of the quantities of interest over the parameter space. This substitution is achieved at the expense of model precision and the principal priority in surrogate modelling is the trade-off between the modelling fidelity and computational costs.

- **Objectives**

The objectives of the proposed Action Group are:

- **Objective 1**: Extensive comparison of deep learning, surrogate models and machine learning techniques for aerodynamic analysis and prediction;
- **Objective 2:** Exploitation of the potential of data fusion (Multi-fidelity) within surrogate modelling by efficient management of heterogeneous data from different sources (CFD with different precision, wind-tunnel, flight test data, etc.);
- **Objective 3:** Exploration of the potential of machine-learning and data-driven techniques for uncertainty quantification and management.

- **Approach**

Current work focuses on the assessment of different machine learning techniques for the prediction of the Cp using the XRF1 aerodynamic data provided by AIRBUS.

Two databases are used in this group:

- DB1: XRF1 geometry + CFD + wind tunnel data + Excel file with convergence information.
- DB2: Large database of approx. 7000 aircraft points (simulated with RapidCFD, including geometry variations). Design parameters are: Span ratio, Thickness ratio, Delta Sweep, Front fuselage extension, Rear fuselage extension, Aileron position.

The methods that are tested by partners are displayed in the following table:

| | Task 1: Aerodynamic analysis | Task 2: Data fusion | Task 3: Uncertainty quantification |
|---|---|---|---|
| INTA | SVRs, MLP, DecisionTrees | SVRs, MLP, DecisionTrees | - |
| CIRA | KPLS, Surrogate models Mixture of Experts (MOE) to predict aero-data | Additive and multiplicative variable-fidelity model, multi-fidelity Kriging and Co-Kriging | PCA + Kriging surrogate for predicting the statistical moments and risk measures of the full model outputs |
| NLR | ML/DL autoencoders with neural networks | - | Bayesian methods combined with ML/DL |
| ONERA | From basic machine-learning surrogates to deep learning neural networks for approximation of aerodynamic data | - | Polynomial chaos & compressed sensing to efficiently predict statistical moments |
| IRT | Mixtures Of Experts based on Kriging and/or Polynomial Chaos Expansion | - | Statistical moments and risk measures estimated by PCA + Polynomial |

| | | | |
|---|---|---|---|
| | | | Chaos Expansion |
| INRIA | Geometric analysis of high dimensional data: distributions. Metric, topology, barycentre, sampling, interpolation | | Ab initio modeling for the quantification of uncertainties in direct and inverse models. |
| AIRBUS | Generation of the DB2 database | - | Generation of the DB2 database |
| AIRBUS-Military | Surrogate model based on HOSVD, POD, Kriging to predict aerodynamic features | Research on HOSVD to exploit and manage multifidelity, Kriging and Co-Kriging | - |
| FOI | Auto-encoder + GPR vs POD+GPR for aerodata prediction | - | PCE (Polynomial Chaos Expansions) |
| OPTIMAD | sparse sampling, geometrical autoencoders, POD | Multi-fidelity data fusion by geometrical correlations | - |
| DLR | Surrogates based on GP, POD, ISOMAP, Regression techniques and NN-based approaches including Autoencoders and Deep GPs for aero-data prediction | Kriging, hierarchical Kriging and multifidelity Kriging, kernelized Gappy POD, Bayesian regression | Bayesian methods combined with ML/DL and surrogate-based UQ |

- **Main achievements / current status**

- Different machine learning models have been generated by each of the partners (Isomap+DNN, GPR, HOSVD, GappyPOD, GNSR, amongst others);
- results show a good ability to predict the Cp;
- geometric parameters have been also considered in the prediction, making these model capable to be used within an aerodynamic optimization loop;
- intermediate reports have been generated: (GARTEUR_AD_AG60_Report_DDBB_1.pdf,GARTEUR_AD_AG60_Report_ValidationCases_database_1.pdf);
- a template has been sent for sharing the results of task 1 (April 2022).

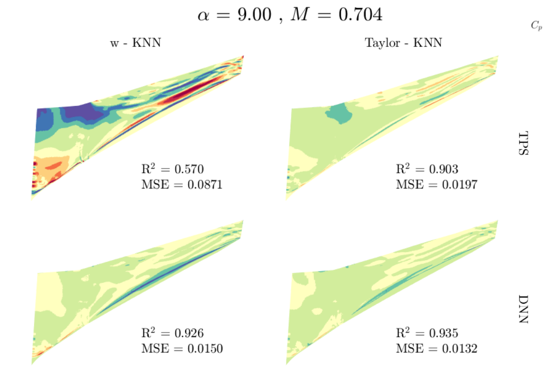



*Figure 30: INTA results, cp prediction using Isomap+DNN*

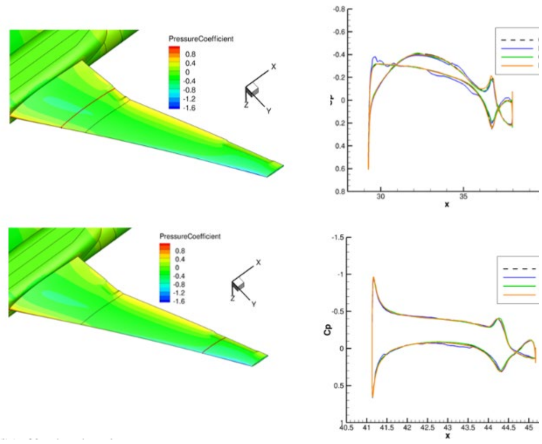



*Figure 31: DLR results, cp prediction comparison of PODi, GNSR and DNNN methods*

- **Next steps**

- Partners are now working on the group tasks. Individual progress has been achieved by each partner. However, there are difficulties in providing a joint approach (risk);
- comparative studies will be conducted for machine learning models evaluation, and proper error measurement;
- a MS on this topic is being organised at EUROGEN 2023.

- **Expected results / benefits**

This AG is expected to yield better understanding of machine learning techniques and their application to aerodynamic analysis and uncertainty quantification. Through the proposed activities, it is expected that some “best practice” guidelines will be concluded and, consequently, facilitating the use of machine learning methods in aeronautic industries. It is also foreseen that the AG will lead to publications, either as conference or journal articles.

- **Management issues**

- UC3M joined the project during 2022. They will contribute to the application of machine learning techiques and dimensionality reduction approaches together with INTA.
- NDAs to access the XRF1 data are signed and must be extended by AIRBUS until the end of 2023 (the NDAs of some partners (i.e. NLR finishes in March). The extension is on going.

- **Meetings**

- Follow-up virtual meeting (overall progress): 24th February, 2022
- Follow-up virtual meeting (overall progress): 9th May, 2022
- Face-to-face follow-up meeting (overall progress): 5&6 October 2022

- **AD/AG-60 MEMBERSHIP**

| Member | Organisation | E-mail |
|---|---|---|
| Robert Maas | NLR | |
| Jacques Peter | ONERA | |
| Matthias De Lozzo | IRT | |
| Anne Gazaix | IRT | |
| Angelo Iollo | INRIA | |
| Domenico Quagliarella | CIRA | |
| Pietro Catalano | CIRA | |
| Mattia Barbarino | CIRA | |
| Haysam Telib | OPTIMAD | |
| Alessandro Alaia | OPTIMAD | |
| Angela Scardigli | OPTIMAD | |
| Philipp Bekemeyer | DLR | |
| Olivier Amoignon | FOI | |
| Boban Pavlovic | FOI | |
| Sergio de Lucas Bodas | Airbus Military | |
| Daniel González | Airbus Miltary | |
| Daniel Redondo | AIRBUS | |
| Marta Gonzalez | AIRBUS | |
| Blanca Martinez | AIRBUS | |
| Esther Andrés | INTA | |
| Andrea Ianiro | UCM3M | |
| Stefano Discetti | UCM3M | |

## AD/AG-61 Hybrid RANS/LES methods for WMLES and Embedded LES

**Monitoring Responsable:** J.-L. Hantrais-Gervois ONERA

**Chairpersons:** N. Renard ONERA

- **Objectives**

RANS CFD has shown many merits but fails to model turbulence in adverse-pressure-gradient boundary layers and in separated flows. Turbulent scale-resolving simulations are needed, but DNS and wall resolved LES are not affordable yet for industrial daily needs.
Thus, this group investigates the hybrid RANS-LES strategies. In order to extend previous activities (see AD/AG-54 for instance), family II strategies are of interest (where only the inner part of the attached boundary layer is modelled in RANS whereas the outer region of the boundary layer is resolved by LES). Such strategies belong to the more general Wall-Modeled LES approaches. A substantial cost reduction is gained (over wall resolved LES) and improved turbulent dynamics is simulated (over DES-like, or family I simulations where the attached boundary layer is treated fully in RANS). The use of LES can thus be restricted to the regions of interest in a so called embedded LES strategy.
The activities of the group aims at facilitating the introduction of family II in industry. The several turbulent relative topics are investigated through 4 test cases.

- **Main achievements**

The following four test cases serve the modelling development and validation objectives:

- Test case 1: Mixing co-flow of wake and Boundary Layer;
- Test case 2: Shock Wave-Boundary Layer Interaction;
- Test case 3: Shallow flow separation from a smooth surface;
- Test case 4: Fundamental WMLES test case – ZPG flat-plate boundary layer.

The launch of the group has been delayed because of the COVID crisis. Nevertheless, the activities have been launched in April 2022.

During its first active year, the group was able to define all 4 cases and some partners could already provide some simulations on the test cases.

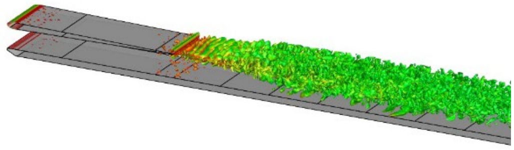


*Figure 32: TC1 mixing co-flow (CIRA)*

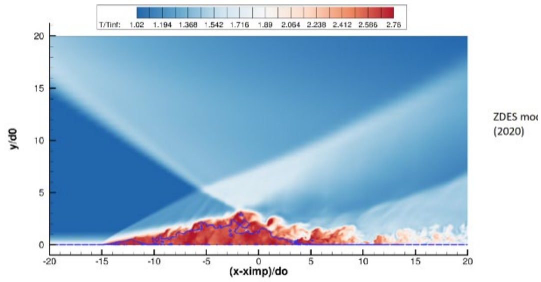



*Figure 33: TC2 shock / BL (ONERA)*

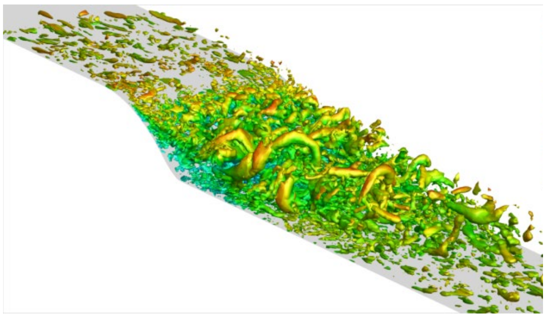


*Figure 34: TC3 shallow separation (DLR)*

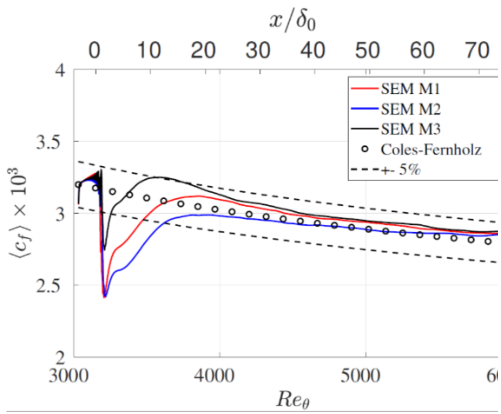



*Figure 35: TC4 flat plat (SAAB)*

- **Management issues**

The group is active since April 2022 (kick off) and a progress meeting has been held in February 2023. Some initial results are already available and the group is well organised to work actively.
Due to the COVID crisis, the kick-off foreseen in 2021 has been delayed to 2022. A delay in the end date is thus requested. The end date was initially planned at the end of 2024 and a 1-year extension to end 2025 is requested (at constant budget).

- **Expected results/benefits**

Thanks to the simulations and comparisons between the partners, the group aims at achieving progresses in:

- resolved turbulence injection Prediction of mild flow separation;
- improved accuracy in shock wave / boundary layer interaction (for supersonic and transonic flows);
- prediction of wall pressure fluctuations for acoustics (RANS region permeable to fluctuations);
- applicability (and robustness) to multi-domain and curvilinear geometries;
- interaction between modelled and resolved turbulence;
- mitigation of the log layer mismatch.

- **AD/AG-61 membership**

| Member | Organisation | E-mail |
|---|---|---|
| Nicolas Renard | ONERA | nicolas.renard@onera.fr |
| Sébastien Deck | ONERA | sebastien.deck@onera.fr |
| Yannick Hoarau | Université de Strasbourg | hoarau@unistra.fr |
| Shia-Hui Peng (vc) | FOI | shia-hui.peng@foi.se |
| Sebastian Arvidson | SAAB | Sebastian.Arvidson@saabgroup.com |
| Pietro Catalano | CIRA | p.catalano@cira.it |
| Francesco Capizzano | CIRA | f.capizzano@cira.it |
| Axel Probst | DLR | axel.probst@dlr.de |
| Silvia Probst | DLR | silvia.Probst@dlr.de |
| Johan Kok | NLR | johan.kok@nlr.nl |
| Alistair Revell | University of Manchester | alistair.revell@manchester.ac.uk |

# Appendix B: Annex GoR-Aviation Security (AS)

**ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "AVIATION SECURITY"**

## Remit

The GoR-AS supports the advancement of civil and defence related security technology in European research establishments, universities, industries and other relevant European Entities (e.g. National Civil Aviation Authority, MoD, Military entities,..) involved in security for aviation through collaborative research activities, and through identification of future projects for collaborative research.

The GoR-AS initiates, organises and performs multidisciplinary research in the following areas: on board software, artificial intelligence, risk assessment, cybersecurity, airport operations, image recognition, Data analytics, decision making tools, RAMS analysis, FMECA, Fault Tree, event tree analysis, HMI, CONOPS.

The main aim is to Increase security, safety and operation performance for critical assets in the aviation domain.

## GoR-RC Overview

During 2022 work has been done by the following members (CIRA, ONERA, INTA) on the research theme:

**Malevolent use of RPAS**

The approach in 2022 has aimed at keeping links with other running initiatives like ES4AWG, IFAR, ACARE WG4.

Furthermore, the chairperson has attended the SAGAS Stakeholders' Advisory Group on Aviation Security meetings. The role of this group is to advise the Commission in the preparation of legislative proposals and policy initiatives as well as in relation to the implementation of existing legislation. The Group shall be kept informed by the Regulatory Committee on Aviation Security during the entire regulatory process. The Group meets back to back with the Committee approximately six times a year and is open to European representative organisations engaged in, or directly affected by, aviation security.

The action group was dedicated to complete the activities in the funded project ASPRID, to prepare a publication and to work on a proposal preparation. The investigated topics have been kept:

- in line with FlightPath 2050;

- further dealt in the ACARE SRIA, Flying the green deal, update and its dedicated Challenge on Aviation Safety & Security;
- fitting with the EDA Work Programme;
- aligned with EREA Security for Aviation initiative;
- a priority for Europe.

From the previous Council meetings the suggestions for 2022 were:

- on the one hand, to monitor potential external funded initiatives on the topics of interest, starting an exploratory group on such an activity;
- on the other hand, to progress on the concept itself, specifically devoted to prepare a project proposal possibly starting an action group.

Both the suggestions have been implemented.

The main actions in 2022 were:

1. To further develop and share ideas among the active members (CIRA, ONERA, INTA, NLR, DLR) to identify research challenges and collaboration approaches.
2. To involve the industries interested in the chosen topics Eurocontrol, AENA (the first airport operator company in the world by number of passengers), ENAIRE (the Spanish air navigation service provider, ENAC (ECOLE NATIONALE DE L AVIATION CIVILE).
3. To involve ENAC (The Italian aviation Authority) and EASA which are in Asprid advisory board to keep them informed about the approach and to get relevant information from their domains.
4. To complete the activities in ASPRID (including dissemination and exploitation of results).
5. To write a paper.
6. To monitor current funded initiatives to apply for with a collaborative approach involving other key players.

| Id | Action | Responsible/Participant | Due Date | Deliverable |
|---|---|---|---|---|
| 1 | Finalize the choice of the common topic for a project proposal | AS GOR chair-person | Oct | Preparation of the proposal in SESAR 3 |
| 2 | Definition of a research concept for a paper | AS GOR chairperson + ONERA, INTA | Jul | Pilot paper |
| 3 | Prepare and Finalize the paper: | CIRA, ONERA, INTA + Italian Civil Aviation Authority | Oct | A Methodological Framework for the Risk Assessment of Drone Intrusions in Airports<br>on AEROSPACE MDPI Open Access<br>https://www.mdpi.com/2226-4310/9/12/747<br>on AEROSPACE MDPI Open Access |
| 4 | Dissemination of ASPRID project - Workshop with AB in Asprid | INTA, CIRA, ONERA + oth | October 2022 | Future Plan for AS GOR activities driven by ASPRID conclusions. |
| 5 | Monitor Progress and organize webexes | AS GOR chairperson | 3 Meetings (Jan-Feb 2023) | Decision for 2023 |

## GoR Activities

Some Highlights fro ASPRID project (end December 2022):

EASA has shown interest in ASPRID results, while a publication has appeared on AEROSPACE MDPI Open Access, naming GARTEUR in it. https://www.mdpi.com/2226-4310/9/12/747 where also the Italian Civil Aviation Authority has joined.

ASPRID (Airport System Protection from Intruding Drones), is the holistic and operationally oriented response to cope with the question on how to protect airport operations from drone intrusions.

ASPRID work performed is comprised of: identification of the problem, state of art review and regulation assessment, solution requirements definition, the development of a methodological framework for the risk assessment, the development of an operational concept and architecture, the development of validation tools (i.e.: validation plan and demo software) and the definition of roles, responsibilities and procedures. Furthermore, several validation activities have been conducted and recommendations for future regulations and R&D needs have been identified.

ASPRID outcomes can be reflected as an ATM solution, named Drone Intrusion Management that supports and mitigates contingency and restoration actions in case of drone intrusions in the airport environment.

- Validation activities have demonstrated that the solution qualitatively **improves situational awareness, early management and coordination between the key actors** that have an active role in the actual management of the drone incursion or, as defined by EASA, the Drone Incident Management Cell;
- In relation to the ATM Master Plan, main qualitative performance benefits are an increase resilience to drone intrusions, allowing **airport operations continuity in normal or degraded modes** and **reduced degradations in time performance and capacity**, as demonstrated by validation activities.

ASPRID has produced the following key project results applicable to the development of Drone Intrusion Management solutions:

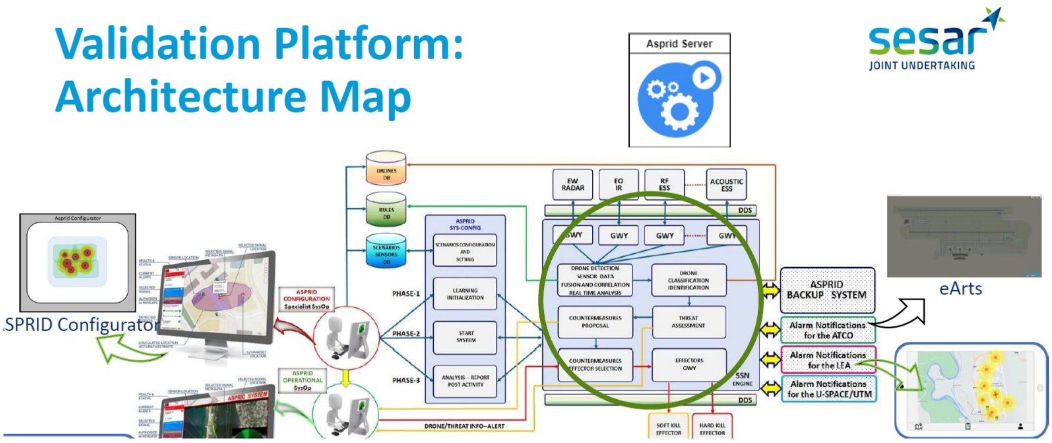
- methodological framework. Set of principles and tools in a detailed workflow that permits the systematic execution of the risk assessment of airport drone intrusions. A particular case example has been developed in regards to Milan Malpensa airport (MXP): unauthorized drone in the departure path of the runway threat scenario;
- requirements elicitation for: (a) system design and project validation of the solution (b) development of multi user digital interfaces for the protection of the airport from drone intrusions;

- a new Operational Concept and Architecture Definition. Validation activities has assured compliance of the proposed SESAR solution architecture with all main requirements. In particular, ASPRID solution cover all EUROCAE ED-286 OSED for Counter-UAS in controlled airspace reference document main requirements;

- ASPRID's HMI, ATCO drone enhanced visualization ASPRID Configurator and ASPRID laboratory simulation environment. ATCO drone enhanced visualization is based on eARTS/Airport ATC commercial software simulator. ASPRID HMI and ATCO drone enhanced visualization, as relevant part of enablers of the solution, have been validated by consortium and ASPRID advisory board experts. Furthermore, recommendations of improvement have been collected;

- a new operational procedure with key actors in airport operations and new roles and responsibilities. This procedure has been validated by means of a gaming exercise;

- regulatory obstacles identification and recommendations in order to solve them.




During last workshop the list of current obstacles to manage intruders at airports has been defined as hints to further progress upon:

Summary of Obstacles:

- confidentiality of Counter-drone regulations;
- complexity of regulations on neutralisation;
- lack of consensus on airport UAS Geographical zones;
- lack of counter-drone performance standards and evaluation methodologies;
- lack of guidance on Counter-drone & ATM interactions;
- uncertainty about guidance on Counter-drone & U-space interactions;

- lack of guidance about trusted AI in counter-drone systems.

SAGAS (SAGAS Stakeholders' Advisory Group on Aviation Security):

The ASGoR chairperson and the representative by DLR (Hans-Albert Eckel) participated in SAGAS on behalf of EREA. During last meeting in 2022 Scientific – Technical info related to GARTEUR AS GoR was about DroneWISE project, entering its final phase, funded by the European Union's Internal Security Fund Call ISFP-2019-AG-PROTECT (Call for proposals on protection in the specific context of counterterrorism aimin at developing a Counter-UAV Command, Control and Coordination Strategy for first responders, supported by Counter-UAV Command Training for all first-responder agencies, including tactical options and decision-making frameworks, underpinned by a CUAV Command Training Handbook and easily accessible via a CUAV Online Training Portal.

Then going on analysing potential interests matching HE topics and studies performed within AS GoR, the focus was put on: Topic: HORIZON-SESAR-2022-DES-ER-01-WA2-4

- meetings were dedicated in the last month of 2022 to define a common concept around this topic which is related to protection against drone intrusion in U-Space environment.

Only CIRA and INTA decided to apply for this topic which received a very high score in the evaluation and it is currently in the reserve list with some possibility to be funded (information on May 2023).

## Management

Four remote meetings were held starting from March 2022 to assess the related activities and other two remote meetings were performed during Autumn 2022. Only remote meetings could be possible, due to some restrictions in travelling.

## Dissemination of GARTEUR activities and results

The dissemination events during 2022 are represented by the following:

1. Publication on AEROSPACE MDPI Open Access
2. Asprid workshop October 2022.

Other meetings and contacts with Italian stakeholders have allowed the collection of information about the initiatives in progress on the chosen topic.

## Documentation issued

### *Reports*

- Minutes of Workshop;
- Power point presentations.

## Status of Action Group

An extended team (made by ASGoR and industrial stakeholders, LEAs and Authorities) has been set up for identifying collaboration opportunities at national and European level.

There are the following criticalities:

The target TRL of the aviation research security topics is quite low and also EREA security for aviation focuses on the same topic. The motivation to contribute is strongly driven by the availability of research funding opportunities.

Furthermore, Security for Aviation represents a complex topic from 2 points of view:

1. there are available funding opportunities, even at low TRL, (as they can be interesting for military, governmental agencies, industrial stakeholders) and People are always more committed to work on funded initiatives, thus they do not comply with Garteur typical activities (not funded).
2. often data and approaches cannot be shared due to restrictions on classified information.

Nevertheless, for the specific topic proposed as action group, AS GoR succeeded with the ASPRID proposal (project end December 2022).

Publications have (also on journal) referenced Garteur, where we involved also the Italian Civil Aviation Authority, as in the previous one.

### Total yearly costs of AG research programmes

| | <2017> | <2018> | <2019> | <2020> | <2021> | <2022> | <Year> |
|---|---|---|---|---|---|---|---|
| Person-month | 2 | 3 | 4 | 3 | 3 | 3 | |
| Other costs (k€) | 1 | 1 | 1 | 1 | - | - | |

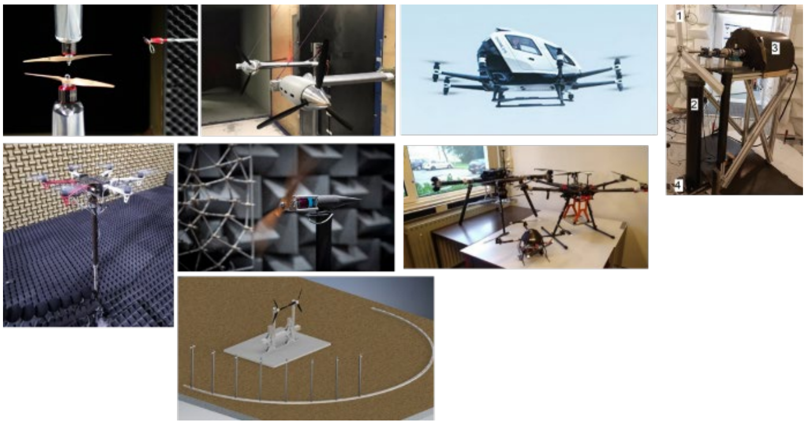
The AG on malevolent use of RPAS is officially closed.

The resources dedicated to the new EG and information about it and actions will be detailed by the new AS GoR.

# Appendix C: Annex GoR-Rotorcraft (RC)

**ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "ROTORCRAFT"**

*Experimental tests in HC/AG-25*



*Experimental tests in RC/AG-26*

## Remit

The GoR-RC supports the advancement of civil and defence related rotorcraft technology in European research establishments, universities and industries through collaborative research activities, and through identification of future projects for collaborative research.

The GoR-RC initiates, organises and monitors basic and applied, computational and experimental multidisciplinary research in the context of application to rotorcraft vehicles (helicopters and VTOL aircraft, such as tilt rotors, compounds and multi-copters) and systems technology.

The field for exploration, analysis and defining requirements is wide. It covers knowledge of basic phenomena of the whole rotorcraft platform in order to:

- decrease costs (development and operation) through Virtual Engineering using numerical tools based on low-order (analytical, BEM) to high-order (CFD) methods, validated with relevant tests campaigns;
- increase operational efficiency (improve speed, range, payload, all weather capability, highly efficient engines, more electric rotorcraft ...);
- increase security, safety;
    - security studies, UAVs, UAM eVTOLs, advanced technologies for surveillance, rescue and recovery;

  - flight mechanics, flight procedures, human factors, new commands and control technologies;
  - increase crashworthiness, ballistic protection, …;
- integrate rotorcraft better into the traffic (ATM, external noise, flight procedures, requirements/regulations);
- tackle environmental and public acceptance issues:
  - greening, pollution;
  - visual pollution (for UAM applications);
  - noise (external, internal);
- progress in pioneering: breakthrough capabilities.

Technical disciplines include, but are not limited to, aerodynamics, aeroelasticity including stability, structural dynamics and vibration, flight mechanics, control and handling qualities, vehicle design synthesis and optimisation, crew station and human factors, internal and external acoustics and environmental impact, flight testing, and simulation techniques and facilities for ground-based testing and simulation specific to rotorcraft.

A characteristic of helicopter, tilt rotor, compound and multi-copter matters is the need for a multidisciplinary approach due to the high level of interaction between the various technical disciplines for tackling the various issues for rotorcraft improvement.

The GoR-RC, wherever practicable, informs, seeks specialist advice and participation where appropriate, and interacts with activities in other GARTEUR Groups of Responsables

## GoR-RC Overview

## GoR Activities

The members of GoR for Rotorcraft represent the major national research centres and helicopter manufacturers in the European Union involved in civil and military rotorcraft related research. Currently, it is noticeable that the two European helicopter manufacturers represent more than 60% of the civil helicopters delivered worldwide.

This membership enables the GoR to act as a highly effective forum in its primary function of promoting collaborative research through Exploratory Groups and Action Groups. It has been successful in establishing collaborative research programmes, at a non-competitive level, to the benefit of the European rotorcraft community, including both governmental and industrial interests. In addition, the GoR represents a unique forum within Europe for the interaction of the research establishments and industry, for the exchange of knowledge and understanding in the field of rotorcraft research and technology. An increasing number of University teams are associated to the activities of the action groups. Since 2011 the University of Liverpool is an active member of the GoR. The Rotorcraft GoR is a kernel for ideas for new research projects and supported the preparation of several EU proposals, even if the number of helicopter dedicated projects within H2020 has significantly been reduced compared to previous framework programmes. The RC GoR is concerned by the fact that rotorcraft topics are not included in the working program for Clean Aviation and that opportunities of a European project dedicated to rotorcraft in Horizon Europe are limited.

A particular area of success in past work has been the development and validation of modelling capabilities for rotor aeromechanics, for rotorcraft flight mechanics and simulation, for vibration prediction and management and crashworthiness, and for acoustics. This modelling capability has underpinned improvements across the field of rotorcraft performance, enhancing both military and civil market competitiveness, as well as safety for all users. There is no question that the availability of high quality, well-validated modelling tools is essential to the effective design and development of competitive rotorcraft and it may fairly be claimed that in supporting the creation of such tools over many years, GARTEUR has significantly contributed to place the European industry in the favourable position that it holds in the world market-place today.

In addition, as rotorcraft require multidisciplinary studies, the AGs discuss and exchange tools with other AGs (for example from FM, AS, AD and SM domains).

The GoR-RC is used as a forum for briefings by members on their organisations' activities and for discussion of new ideas which may be mature for collaboration. The GoR also considers other collaborative initiatives within Europe, bringing mutual understanding and co-ordination and hence contributing to best use of scarce resources. For instance, the GoR is maintaining an awareness of the range of EU Technology Programmes.

## Management

The chairmanship in 2022 was held by Antonio Visingardi (CIRA). Vice Chairman was Mark White (Univ. Liverpool). In June 2022, the member nation Spain appointed Mrs Alicia Verónica Barrios Alfonso from INTA as Spanish representative in the RC-GoR.

Generally speaking, the rotorcraft community in Europe is rather small. In fact, most GoR members are at the same time deeply involved in the preparation of proposals for EU projects so that automatically there are close relations between GARTEUR research activities and EU projects.

In the Clean Sky 2 Joint Technology Initiative and especially for Fast Rotorcraft IADP, the GoR members were active in Calls for Proposals. In the view of the GoR-RC, this aspect is advantageous for all, GARTEUR and EU, industry and research establishments. In practice, the Exploratory Groups are used both for the generation of proposals for continued GARTEUR activity within an Action Group, normally at a relatively low level of effort, to analyse the state of the art for new topics and to define the framework and specification of further common research programmes, including EU proposals. In general, these activities are complementary, with some EU projects based on earlier GARTEUR research, and GARTEUR Action Groups benefiting from the outcome of EU funded activities. This applies in particular by using extensive wind tunnel and flight test databases, as well as any kind of valuable validation data.

During the reporting period, the GoR-RC held two meetings:

- 85th GoR Meeting: 9th – 10th February 2022, Teams virtual meeting.
- 86th GoR Meeting: 1st – 2nd September 2022, Teams virtual meeting.

The main business of the meetings was to discuss further topics and to implement the 3-5 year planning process as well as to present the status of the current AGs and EGs. The GoR meetings were used to harmonize the views and the involvement of members regarding preparations for proposals EU calls, as well as future issues to be considered. Furthermore, the dissemination of GARTEUR results on international conferences like the European Rotorcraft Forum (ERF) and the Annual Forum of the Vertical Flight Society (VFS) (former American Helicopter Society (AHS)) and the Asian/Australian Rotorcraft Forum (ARF) was harmonized and supported.

In 2022 there was a significant recovery of the activities in the RC-AGs after the COVID19 pandemic, but the meetings were still held remotely. The year 2022 formally started with two active Action Group and two Exploratory Groups, one of them completed the procedure to receive the Council's authorization to become an AG in 2023.

## Dissemination of GARTEUR activities and results

Results coming from Action Groups are traditionally prone to publication either in Journals or in Conferences. In the field of Rotorcraft, the two conferences having the greatest impact are the European Rotorcraft Forum and the Annual Forum of the Vertical Flight Society. In addition, in 2022 the International Council of the Aeronautical Sciences organized in Sweden the 33rd congress, ICAS 2022, in which a special session was dedicated to GARTEUR presentations. The RC-GoR presented the paper: "The Group of Responsables "RotorCraft (RC-GoR)": An Overview of Activities and Success Stories," ICAS paper, N. 2022_0917.

## Documentation issued

### *Reports*

- Sanders, D., et alii. "Analysis and Decomposition of the Aerodynamic Force Acting on Rotary Wings - Terms of Reference for the GARTEUR Action Group RC/AG-27 – Vsn. 2," October 2022, (RC/EG-42)

### *Publications*

- L. Lefevre, V. Nowinski, J. Delva, and A. Dazin, "Experimental Evaluation of the Aerodynamic Rotor/Propeller Interactions on High Speed Helicopters, Efforts and Velocity Fields

Measurements," presented at the 78th Vertical Flight Society Forum, Fort Worth – Texas (USA), May 2022; (HC/AG-25);

- L. Lefevre, V. Nowinski, J. Delva, and A. Dazin, "Experimental Velocity Fields Evaluation under the Rotor/Propeller Interactions for High Speed Helicopters for Different Propeller Positions, " in preparation for a publication in Experiments in Fluids (HC/AG-25);
- Andronikos, T., "Hovering helicopter interaction with the ground and bluff bodies: A CFD based investigation," NTUA Ph.D. Thesis, Jan. 2022 (HC/AG-22);
- Andronikos, T., Papadakis, G., Riziotis, V., Prospathopoulos, J.M, Voutsinas, S., "Validation of a cost-effective method for the rotor-obstacle interaction," Aerospace Science and Technology, Volume 113, June 2021, 106698, (HC/AG-22).
- Kostek, A., Braukmann, J.N., Loßle, F., Miesner, S., Visingardi, A., Boisard, R., Keßler, M., Gardner, A.D., "Experimental Investigation of Quadrotor Aerodynamics with Computational Cross-Validation", submitted to The Vertical Flight Society's 79th Annual Forum & Technology Display, 16-18 May 2023, West Palm Beach – Florida, USA. (HC/AG-25);
- T. Zhang, G. N. Barakos, "High-fidelity Numerical Investigations of Rotor-Propeller Aerodynamic Interactions", Aerospace Science and Technology, 124, 107517, DOI: 10.1016/j.ast.2022.107517; (HC/AG-25);
- R. Boisard, "Numerical Analysis of Rotor / Propeller aerodynamic interactions on a high speed compound helicopter", Journal of the American Helicopter Society, Volume 67, Number 1, January 2022, pp. 1-15, DOI: 10.4050/JAHS.67.012005. (HC/AG-25);
- L. Lefevre, J. Delva, V. Nowinski, A. Dazin, "Experimental Evaluation of the Aerodynamic Rotor/Propeller Interactions on High Speed Helicopters, Efforts and Velocity Fields Measurements", 78th VFS Annual Forum, Fort Worth, Texas, USA, May 10-12, 2022. (HC/AG-25);
- F. Lößle, A. A. Kostek, C. Schwarz, R. Schmid, A. D. Gardner, M. Raffel, "Aerodynamics of Small Rotors in Hover and Forward Flight", 48th European Rotorcraft Forum, Winterthur, Switzerland 6-8 September 2022; (HC/AG-25);
- Kostek, F. Lößle, R. Wickersheim, M. Keßler, R. Boisard, G. Reboul, A. Visingardi, M. Barbarino, A. D. Gardner, "Experimental investigation of UAV rotor aeroacoustics and aerodynamics with computational cross-validation", 48th European Rotorcraft Forum, Winterthur, Switzerland, September 6-8 2022 (HC/AG-25);
- R. Boisard, L. Lefevre, T. Zhang, G. Barakos, A. Visingardi, F. Lößle, A. Kostek, T. Andronikos, M. Keßler, R. Wickersheim, A. Colli, G. Gibertini, A. Zanotti, "Rotor / Rotor aerodynamic interactions – A Garteur Action Group", 33rd Congress of the International Council of the Aeronautical Sciences, Stockholm, Sweeden, 4-9 September 2022; (HC/AG-25);

- Visingardi, A., Heger, R., Le Pape, A., Markiewicz, R., Ohlenforst, B., Pahlke, K., White, M., "The Group of Responsables "Rotorcraft (RC-GoR)": An Overview of Activities and Success Stories," 33rd Congress of the International Council of the Aeronautical Sciences, Stockholm, Sweeden, 4-9 September 2022; (RC-GoR);

- Andronikos, T., "Hovering helicopter interaction with the ground and bluff bodies: A CFD based investigation," NTUA Ph.D. Thesis, Jan. 2022 (HC/AG-22).

## Status of Action Groups and Exploratory Groups

### *Action groups (AG)*

The following Action Groups were active throughout 2022:

| | |
|---|---|
| HC/AG-25 | *Rotor-Rotor-Interaction*<br><br>The main objective is to investigate, both numerically and experimentally the effect of rotor / rotor and rotor / propeller wakes interactions on high speed rotorcraft operating in low speed conditions with the aim to establish low order models to be used in pre-design phases of advanced rotorcraft vehicles or in comprehensive codes. The AG started in October 2019. |
| RC/AG-26 | *Noise Radiation and Propagation for Multirotor System Configurations*<br><br>The objective is to investigate, both numerically and experimentally, the noise radiation and propagation (installation effect) of multirotor systems and to gain knowledge in the physics of noise generation and near-field noise propagation of multirotor systems under the influence of the installation effects and to establish tools for the noise prediction. Compared to conventional helicopters, the importance of the various noise sources and the influence of noise scattering can be totally different for multi rotor configurations. The AG started in February 2022. Both, a common validation study and a common experiment are foreseen. The common validation study aims at evaluating and improving the prediction accuracy of different simulation methods. |

### *Exploratory groups (EG)*

The following Exploratory Groups were active throughout 2022:

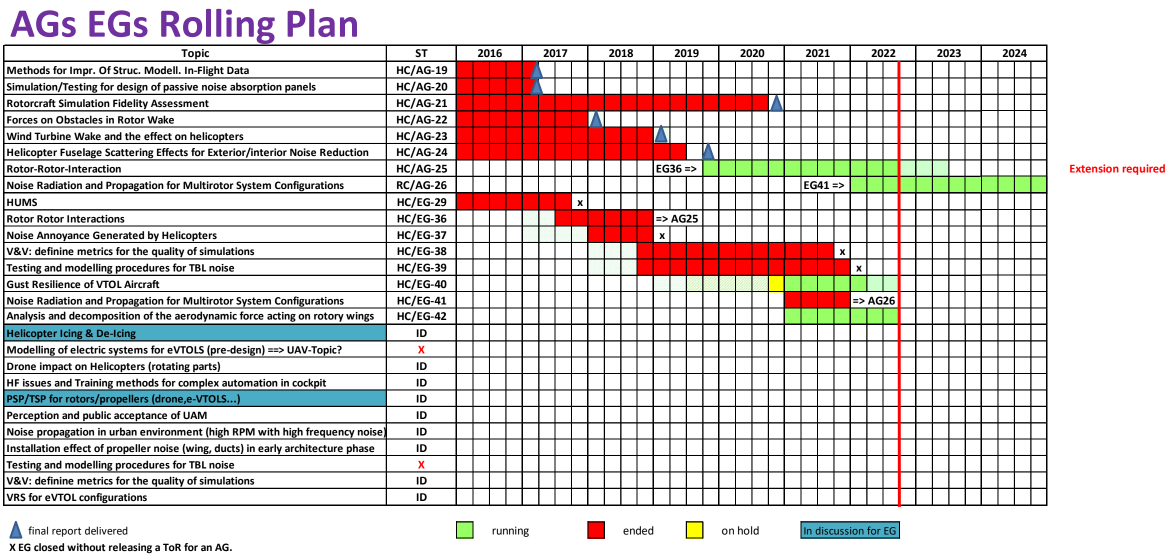
| | |
|---|---|
| RC/EG-40 | *Gust Resilience of VTOL Aircraft*<br><br>The objective is to set-up a team of researchers able to investigate and test the different approaches that might be employed to achieve gust resilience of multi-rotor vehicles. This EG was identified in 2019 and was expected to be active in 2020. Unfortunately, Cranfield's application for UK funding, to support this activity, was not successful, and for this reason, Cranfield had to withdraw from chairing this EG. Prof. Lovera from Politecnico di Milano accepted to take over the chairmanship from Cranfield Univ. with the aim to restart this EG in 2021. Nevertheless, during the years 2021 and 2022 no meeting was organized and no updates were received from Prof. Lovera. In 2022 the RC-GoR decided to keep this EG active, standing its utmost importance, mainly for UAM applications, and made an effort to identify another chairman willing to lead this EG. |
| RC/EG-42 | *Analysis and Decomposition of the Aerodynamic Force Acting on Rotary Wings*<br><br>The technology for drag analysis of CFD solutions of fixed wing configurations has reached a mature stage. Conversely, applications in rotary wing aerodynamics are still very limited, if not absent. However, recent progresses obtained in unsteady flow analysis are promising for both parasite force calculations, and thrust extraction. The objective of this EG is to study the application to rotary wings of aerodynamic force analysis and decomposition methods. The kick-off meeting of this EG was held on September 2021. During the meeting Prof. Tognaccini of Univ. Naples Federico II informed the partners about his inability to coordinate the project, due to an unforeseen reduction of allocatable manpower. Fortunately, thanks to the great interest about this topic expressed by the partners the role of coordinator was taken over by Drew Sanders of Univ. Cranfield, who was in charge for the preparation of the ToR document. The final version of this document and the partners' Letters of Acceptance and Adherence were submitted to and |

| | |
|---|---|
| | approved by the Council. The new Action Group, RC/AG-27 is planned to start the technical activities in 2023. |

## Rolling plan

The 3-to-5 year planning will continue to be implemented over the years. This list is implemented with new topics according to the GoR discussions.

During the 2022 GoR meetings, several topics of mutual interest have been discussed and their potential for GARTEUR collaborative programmes has been examined. Some New Ideas were added, some others were cancelled because of lack of interest or manpower unavailability.




## GoR membership

| **Chairperson** | | |
|---|---|---|
| Antonio Visingardi | CIRA | Italy |
| **Vice-Chairperson** | | |
| Mark White | Univ. Liverpool | United Kingdom |
| **Members** | | |
| Klausdieter Pahlke | DLR | Germany |
| Alicia Verónica Barrios Alfonso | INTA (06/22) | Spain |
| Barbara Ohlenforst | NLR | The Netherlands |
| Arnaud Le Pape | ONERA | France |
| **Industrial Points of Contact** | | |
| Rainer Heger | Airbus Helicopters | Germany |
| **Observer** | | |

| | | |
|---|---|---|
| Richard Markiewicz | Dstl | United Kingdom |

## Total yearly costs of AG research programmes

| | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| **Person-Month** | 44.40 | 88.70 | 79.50 | 55.00 | 26.50 | 10.00 | 22.50 | 42.00 | 78.00 | 446.6 |
| **Other Costs (k€)** | 38.00 | 103.10 | 102.90 | 54.00 | 20.00 | 27.00 | 29.10 | 64.50 | 144.60 | 583.2 |

# Table of participating organisations

| | AG25 | AG26 | EG40 | EG42 |
|---|---|---|---|---|
| RESEARCH ESTABLISHMENTS | | | | |
| CIRA (I) | □ | □ | □ | |
| CNR-INSEAN (I) | | □ | | |
| DLR (D) | □ | ■ | □ | |
| DSTL (UK) | | | | |
| ENSTA Paris (F) | | □ | | |
| NLR (NL) | | □ | □ | |
| ONERA (F) | ■ | □ | | □ |
| INDUSTRIES | | | | |
| Airbus Helicopters, France | | | | |
| Airbus Helicopters, Germany | | | | |
| CAE (UK) | | | | |
| IMA Dresden (D) | | | | |
| Leonardo Helicopters (I, UK) | | | | |
| LMS (B) | | | | |
| MICROFLOWN (NL) | | | | |
| Thales (F) | | | | |
| ZF Luftfarhttechnik GmbH (D) | | | | |
| ACADEMIC INSTITUTES | | | | |
| Institut Superieur de l'Aeronautique et de l'Espace (F) | | | | |
| National Technical University of Athens (GR) | □ | | | |
| Netherland Defence Academy (NL) | | | □ | |
| Politecnico di Milano (I) | □ | □ | ■ | □ |
| Politecnico di Torino (I) | | | □ | □ |
| Technical University of Delft (NL) | | □ | | |
| Technical University of Munich (D) | | □ | | |
| Università Telematica Cusano (I) | | □ | | |
| University of Cranfield (UK) | | | | ■ |
| University of Glasgow (UK) | □ | □ | | |
| University of Liverpool (UK) | | | | |
| University of Magdeburg (D) | | | □ | |
| University of Napoli Federico II (I) | | | | □ |
| University of Roma Tre (I) | | □ | □ | |
| University of Stuttgart IAG (D) | □ | □ | □ | |
| University of Twente (NL) | | | □ | |

■ = Chair □ = Member

GARTEUR GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE
FRANCE GERMANY ITALY THE NETHERLANDS SPAIN SWEDEN UNITED KINGDOM

# HC/AG-25: Rotor – Rotor Wakes Interactions

Action Group Chairman: Ronan Boisard (ronan.boisard@onera.fr)

## Background

Almost all conventional helicopters have several rotors, from the classical helicopter with a main rotor and a tail-rotor, which has an anti-torque function, or the less classical tandem configuration with two side-by-side rotors, or the helicopters with co-axial rotors, or even tilt-rotors. In the context of the development of high speed compound helicopters, the main rotor cannot be used as an efficient propulsive device at high speed and most of the time a propeller has to be added in order to reach high advancing velocities. This multiplicity of rotors is also up-to-date in the field of UAVs, where the lifting function is more and more distributed on several rotors (sometimes more than 4).

The simultaneous use of rotating blades distributed around the airframe with planes of rotations that may differ adds a lot of aeromechanical complexity and can lead to complex unsteady interactions between the wakes emitted by the blades of the rotors or the propellers. It is legitimate to assume that such interactions, of aerodynamic nature, can have a significant impact on vibrations, on radiated noise and on aerodynamic performance, especially but probably not exclusively, in low speed conditions.

An overview of the available literature outline the fact that Rotor / Rotor and Rotor / Propeller wake interactions has been identified since the beginning of compound helicopters as extremely important for aircraft maneuverability and performances and is still an important concern for next generation of VTOL vehicles like multicopters. However, experimental databases are either extremely old or protected by the manufacturers. In such conditions it is almost impossible to improve and validate numerical tools without performing new experiments. Concerning the physical understanding of the interactions, the literature is scarce. Manufactures only focus on the overall aircraft stability, maneuverability and performances, and academic work is almost nonexistent, probably linked to the lack of freely available experiments.

## Programme/Objectives

### Objectives

The principal objective of HC-AG25 is then to promote activities which could contribute to a better understanding and prediction of the aerodynamics of rotor / rotor wake interactions. This will be achieve by:

- Providing to the community extensive experimental databases about different kind of rotor / rotor and rotor / propeller interactions
- Validation and improvement of state of the art computational tools against experiments
- Improvement of low order models to be used in pre-design phases of advanced rotorcraft vehicles or in comprehensive codes

The time frame for this program is three years during which both experiment and numerical simulations will be performed

The work programme is structured in four work packages:

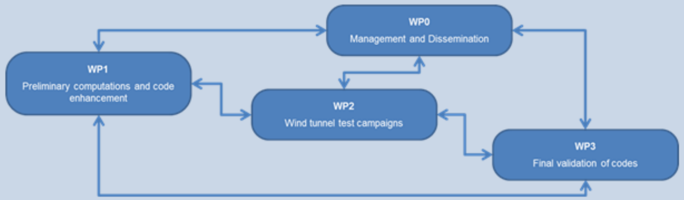
- WP0 – Management & Dissemination: is aimed at the fulfilment of all the obligations concerning the project management and the dissemination of the results.
- WP1 – Preliminary Computations & Code Enhancements: deals with a preparation phase during which partners are involved in literature review and preliminary computational activities
- WP2 – Wind Tunnel Test Campaigns: concerns the performance of the different wind tunnel test campaigns:
  1. Rotor – Propeller Interactions (ONERA)
  2. Mach scaled Rotor – Propeller interactions (PoliMi)
  3. Rotor – Rotor Interactions (DLR)
- WP3 – Final Validation of Codes: is aimed at the final validation of the numerical tools proposed by partners.

**Members of the HC/AG-25 group are:**
**(only contact persons are listed here)**

| | |
|---|---|
| R. Boisard | ONERA (Chairman) |
| A. Visingardi | CIRA (Vice-Chairman) |
| M. Kessler | IAG |
| G. Gibertini | PoliMi |
| T. Schwarz | DLR |
| S. Voutsinas | NTUA |
| G. Barakos | UoG |

**GARTEUR Responsable:**

| | |
|---|---|
| A. Lepape | ONERA |



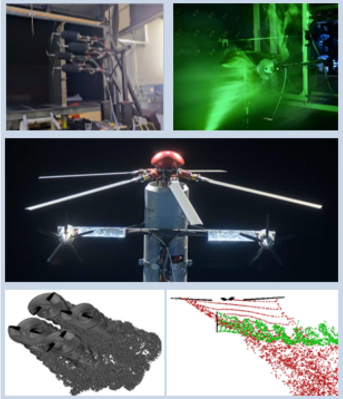

## Results

The action group started its activities on 1st of October 2019 and will end in May 2023.

All the experiments are over and shared between the different partners

Most partners have performed calculations of the three different configurations (Onera and Polimi: Rotor / Propeller interactions, DLR: multicopter)

Some numerical results and comparison between solvers has already been published in conferences. All the results (numerical and experimental) are currently gathered and summarized within different reports, along with some best practices for the numerical simulation of wake interactions.



University of Stuttgart
Institute of Aerodynamics and Gas Dynamics

CIRA Centro Italiano Ricerche Aerospaziali

POLITECNICO MILANO

DLR

University of Glasgow

ONERA
THE FRENCH AEROSPACE LAB

## HC/AG-25 "ROTOR - ROTOR Wake INTERACTIONS"

**Monitoring Responsable:** A. Le Pape, ONERA

**Chairman:** R. Boisard, ONERA

- **Objectives**

If rotor-rotor or rotor-propeller interactions can nowadays be numerically addressed by high order aerodynamic tools (CFD), such approaches are extremely expensive in terms of CPU time due to the difference in terms of rotating speed between the main rotor and the propeller, and also to the fact that the rotor and propeller wake have to be propagated with high accuracy on long distances. Moreover, at low speed, phenomena are highly unsteady and therefore need to be averaged over a long period of time. Therefore, there is a clear need of low order models to be used in pre-design phases of advanced rotorcraft vehicles or in comprehensive codes. Developing such low-order models requires adequate experimental databases, which are moreover mandatory to validate CFD or free-wake models. However, the analysis of the previous work clearly highlights the lack of such experimental databases.
An exploratory group (EG-36) was created with the aim to promote activities which could contribute to fill these gaps. For the purpose, EG36 proposed the creation of the action group HC/AG-25 gathering a team of researchers willing to investigate, both numerically and experimentally the effect of rotor / propeller wakes interactions on high speed rotorcraft operating in low speed conditions.
The time scale for the project is three years during which the following activities are planned:

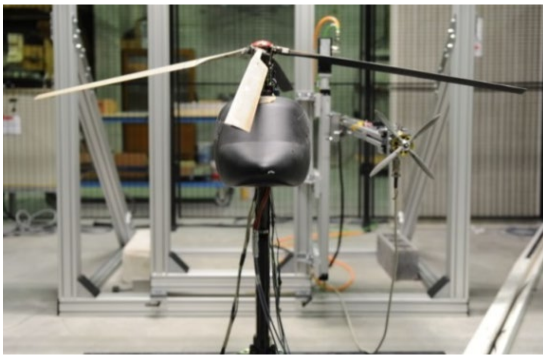
- application and possible improvement of computational tools for the study of rotor / propeller wakes interactions
- setting up some cost-effective wind tunnel test campaigns aiming at producing experimental database for the validation of numerical methodologies
- final validation of the numerical methodologies.

**Activities**

The AG consists of 4 work packages:
WP0 – Management & Dissemination:
This work package aims at the fulfilment of all the obligations concerning the project management and the dissemination of the results. Through it the project interacts with the Group of Responsables (GoR), by receiving inputs and providing the information required, and the scientific community, by collecting the results of the activities of the other three work packages and disseminating them.
WP1 – Preliminary Computations & Code Enhancements:
The main goal here is literature review and computational actions aimed at providing necessary and useful inputs to the two following work packages where experimental databases are produced (WP2) and the modelling capabilities of the applied numerical tools are validated (WP3). It also provides WP0 with all the information required for management and dissemination.
WP2 – Wind Tunnel Test Campaigns:
In this work package all the wind tunnel test campaigns that have been identified by partners as particularly meaningful for the phenomenological understanding of the wake interactions will be performed. The resulting experimental databases will be delivered to WP3 for the final validation of the numerical tools proposed by the partners. It will also provide WP0 with all the information required for management and dissemination.
WP3 – Final Validation of Codes:
In this work package, the final validation of the numerical tools proposed by partners will be performed by comparing the numerical results of the computational activity with the experimental data produced during the wind tunnel test campaigns of the project in the framework of WP2. The work package also provides WP0 with all the information required for management and dissemination.

- **Management Issues**

This AG is planned to run for three years. The kick-off meeting was held at ONERA Lille, France in October 2019.



- **Results/benefits**

The action group started its activities on 1st of October 2019. All the foreseen wind tunnel test campaigns are in a preparation phase. The geometry of the ONERA wind tunnel test was shared and all the partners involved in the numerical activities have started some pre-test computations. On 16th June 2020 a web conference took place for progress monitoring. A second web conference took place in November 2020. In 2020 the preparation of experiments was continued. There was a clear negative effect of the Covid19 pandemic on the test preparation. Due to the need of the physical presence of the technicians and scientists in the labs or test facilities which was partially not allowed because of lockdown regulations in the different partner nations. Furthermore, the procurement of material and sensors etc. was slowed down because many suppliers were also suffering from lockdown regulations. At ONERA, isolated propeller tests, started during Summer 2020, were concluded in 2021 and the data have been delivered to the partners and used for numerical methods and code-to-code comparisons as well as the comparison of experimental and numerical results. Experimental data are also planned to be produced by POLIMI and DLR and related geometrical data have been shared with the partners for numerical simulation. DLR data have been made available in Fall 2021. POLIMI wind-tunnel tests are planned to be conducted in 2022.

This action group will come to an end June 7th 2023. All experiments are over and measurements were made available. Most partners have performed calculations of the three different configurations (Onera and Polimi: Rotor / Propeller interactions, DLR: multicopter). Some numerical results and comparison between solvers has already been published in conferences. All the results (numerical and experimental) are currently gathered and summarized within different reports, along with some best practices for the numerical simulation of wake interactions. Reports should be made available in June 2023.

- **HC/AG-25 membership**

| Member | Organisation | e-mail |
|---|---|---|
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| M. Kessler | IAG | kessler@iag.uni-stuttgart.de |

- **Resources**

Person month resources were confirmed during the kick-off meeting and have been split tentatively in years. The table below provides these numbers and the final numbers for 2020.

| Resources | | Year | | | | Total |
|---|---|---|---|---|---|---|
| | | 2019 | 2020 | 2021 | 2022 | |
| Person-months | Actual/ | 8,3 | 26,0 | 0,0 | 0,0 | 34,3 |
| | Planned | 6,8 | 30,3 | 40,0 | 26,1 | 103,2 |
| Other costs (in k€) | Actual/ | 0,0 | 33,0 | 0,0 | 0,0 | 33,0 |
| | Planned | 9,4 | 64,5 | 43,0 | 28,1 | 145,0 |

GARTEUR GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE
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# HC/AG-26: Noise Radiation and Propagation for Multirotor System Configurations

Action Group Chairman: Jianping Yin (Jianping.yin@dlr.de)

## Background

Multirotor propulsion systems are increasingly applied to lift Vertical Take-Off and Landing (VTOL) configurations as well as to small scale drones used for surveillance, monitoring, search, aerial surveying and photography. In recent years multirotor systems have been scaled up and are today typical designs for person carrying eVTOL configurations for Urban Air Mobility. Many different options exist in designing multirotor systems, for example single or co-axial rotors or rotors with ducts as well as the positioning of the propulsion units relatively to each other.

A major concern with drones, and vehicles for Urban Air Mobility in particular, is their noise emission. In order to be publicly accepted, the noise of Urban Air Vehicles must be barely audible compared to the city's background noise. Therefore, Urban Air Vehicles must be designed from the beginning to meet stringent noise standards

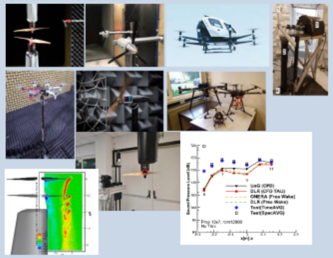
The design of low noise multirotor rotorcraft requires an in depth understanding of the physics related to noise sources, especially multi-interactions and near field sound propagation. Compared to conventional helicopters the importance of the various noise sources and the influence of noise scattering can be totally different. The main noise sources for conventional helicopters are well known, for example blade vortex interaction noise (BVI) in descent flight. But by using distributed single or co-axial rotors, the multiple interactions among rotors and the rotor-wake interactions (Figure 1b) may play an important role in the total noise signal. Ducts, wings or the fuselage may shield or scatter the noise during its propagation. In addition, broadband noise may become a dominant noise source for rotors with low tip Mach number or disturbed rotor inflow.

## Programme/Objectives

### Objectives

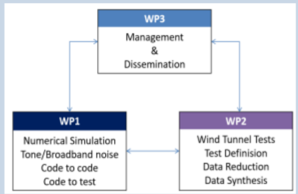
The present research work will investigate noise radiation and propagation (installation effect) of multirotor systems. The objective of the proposed GARTEUR group is therefore to gain knowledge in the physics of noise generation and near-field noise propagation of multirotor systems under the influence of the installation effects and to establish tools for the noise prediction. The focus is put on rotors in steady hover and forward flight but other operating states and configurations could also be considered. The partners will contribute with wind tunnel experiments as well as with numerical simulations. Both, a common validation study and a common experiment are foreseen. The common validation study aims at evaluating and improving the prediction accuracy of different simulation methods.

The data sets for the numerical studies validation will be provided by either existing or new experiments by the partners. The common experiment aims at using the dedicated capabilities of the partner's wind tunnels to improve the validation data base for the simulations and at the same time will validate the experimental accuracy by performing the same experiments in several wind tunnels.



The work programme is structured in three work packages:

- WP 1: Numerical Simulation on the acoustic tone/broadband noise and scattering effect
  - Code adaptation & prediction
  - Code validation & improvement of prediction tools
  - Post-test predictions & code to test comparison
- WP 2: Wind Tunnel Tests & Synthesis
  - Model preparation
  - Test preparation
  - Model setup and installation
  - Test matrix & instrumentation
  - Test conduct
  - Test data compilation & distribution
  - Test data analysis
- WP 3: Management & Dissemination
  - Action group Management
  - Exploitation & Info dissemination




## Results

The duration of action group is 3 years and the AG started the activities since February 2022.

3 meetings including two technical review meetings were conducted since the beginning of the action group. The following results were achieved during this period:

1. Description on existing test data and numerical tools for proposal on common test and numerical simulation in AG, 2022;
2. Existing test cases as well as common test will be used in the code validations;
3. AG26 common simulations with continuing update according to common test program defined and are under going;
4. Common test for CIRA/DLR defined and test matrix established for CIRA/DLR and tests conducted in Nov. 2022 by CIRA/DLR and the analysis of the test data are under going;
5. Common tests by using DLR und Uni-CUSANO setup and rotors are planned among DLR,Ensta-Paris, ONERA and Uni-CUSANO
6. 2 ERF papers with respect to the common simulation and common test between CIRA/DLR are submitted and under preparation;

**Members of the HC/AG-24 group are:**
**(only contact persons are listed here)**

| | | |
|---|---|---|
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| Harry Brouwer | NLR | Harry.Brouwer@nlr.nl |
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| George Barakos | School of Engineering, University of Glasgow (UoG) | George.Barakos@Glasgow.ac.uk |
| Daniele Ragni | TU Delft | D.Ragni@tudelft.nl |
| Claudio Testa | CNR-INM | claudio.testa@cnr.it |

**GARTEUR Responsable:**
K. Pahlke DLR

CIRA Centro Italiano Ricerche Aerospaziali · Marine Technology Research Institute INSEAN · DLR · ENSTA IP PARIS · NLR · ONERA THE FRENCH AEROSPACE LAB · Politecnico di Milano · ROMA TRE UNIVERSITÀ DEGLI STUDI · Technische Universität München TUM · TU Delft · Università Cusano · University of Glasgow · University of Stuttgart Institute of Aerodynamics and Gas Dynamic

**RC/AG-26** **"Noise Radiation and Propagation for Multirotor System Configurations"**

**Monitoring Responsable:** K. Pahlke DLR

**Chairman:** J. Yin DLR

- **Objectives**

The present research work will investigate noise radiation and propagation (installation effect) of multirotor systems. The objective of the proposed GARTEUR group is therefore to gain knowledge in the physics of noise generation and near-field noise propagation of multirotor systems under the influence of the installation effects and to establish tools for the noise prediction. The focus is put on rotors in steady hover and forward flight but other operating states and configurations could also be considered. The partners will contribute with wind tunnel experiments as well as with numerical simulations. Both, a common validation study and a common experiment are foreseen. The common validation study aims at evaluating and improving the prediction accuracy of different simulation methods.

The data sets for the numerical studies validation will be provided by either existing or new experiments by the partners. The common experiment aims at using the dedicated capabilities of the partner's wind tunnels to improve the validation data base for the simulations and at the same time will validate the experimental accuracy by performing the same experiments in several wind tunnels.

The main innovation of the AG comprises:

An experimental data base for multirotor acoustics based on experimental data from the partners

Improved understanding on multirotor noise emissions by analysis of experimental data and numerical simulations considering effects of interaction tone noise installation effects and broadband noise.

Validated prediction tools for multirotor noise including Assessment of different noise modelling approaches.

Validation of the partner's wind tunnels for experimental investigation of multirotor aerodynamics and acoustics by a common experiment.

- **Activities**

The AG consists of 3 work packages:

WP1: Numerical Simulation on the acoustic tone/broadband noise and scattering effect:

This work package deals with the activities to perform a literature survey for possible existing databases for evaluating and improving partner's numerical tools, to collect available test data from all partners, to conduct pre- & post-test predictions & code to code comparison and to validate the improved numerical tools against the experimental data produced or collected during the project wind tunnel test campaigns.

WP2 – Wind Tunnel Tests:

This work package deals with the performance of individual tests done by each partners and common tests where a common (or partly common) test setup can run in a partner's facility. The common test may also include common test teams involving different partners. The individual tests planned by each partner. The resulting experimental databases are used in WP1 for the final validation of the numerical tools proposed by the partners.

WP2 – Wind Tunnel Test Campaigns:

In this work package all the wind tunnel test campaigns that have been identified by partners as particularly meaningful for the phenomenological understanding of the wake interactions will be performed. The resulting experimental databases will be delivered to WP3 for the final validation of the numerical tools proposed by the partners. It will also provide WP0 with all the information required for management and dissemination.

WP3 – Management & Dissemination:

The nature of a GARTEUR project requires a limited, yet necessary effort for a good project development and successful outcome. This work package is focussed on the fulfilment of all the management obligations and it is mainly performed by DLR, with contributions from all participating partners.

- **Results/benefits**

The duration of action group is 3 years and the AG started the activities since February 2022.

3 meetings including two technical review meetings were conducted since the beginning of the action group. The following results were achieved during this period:

1. Description on existing test data and numerical tools for proposal on common test and numerical simulation in AG, 2022;
2. Existing test cases as well as common test will be used in the code validations;
3. AG26 common simulations with continuing update according to common test program defined and are undergoing;

4. Common test for CIRA/DLR defined and test matrix established for CIRA/DLR and tests conducted in Nov. 2022 by CIRA/DLR and the analysis of the test data are undergoing;
5. Common tests by using DLR und Uni-CUSANO setup and rotors are planned among DLR, Ensta-Paris, ONERA and Uni-CUSANO;
6. 2 ERF papers with respect to the common simulation and common test between CIRA/DLR are submitted and under preparation.

- **RC/AG-26 membership**

| Member | Organisation | e-mail |
|---|---|---|
| F. Petrosino | CIRA | f.petrosino@cira.it |
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| D. Ragni | TU Delft | d.ragni@tudelft.nl |
| C. Testa | CNR-INM | Claudio.testa@cnr.it |

- **Resources**

Person month resources were confirmed per work package, involved in the AG in years.

| Partners | WP1 | WP2 | WP3 | Total |
|---|---|---|---|---|
| CIRA | 6 | 5 | 3 | 14 |
| DLR | 9 | 4 | 2 | 15 |
| Ensta-Paris | 5 | 3 | 1 | 9 |
| NLR | 5 | 5 | 1 | 11 |
| TU Delft | 4 | 6 | 2 | 12 |
| ONERA | 5 | 6 | 1 | 12 |
| Polimi | 7 | 7 | 1 | 15 |
| RomaTre | 9 | 6 | 1 | 16 |
| CNR-INM | 9 | 0 | 1 | 10 |
| TUM-IAD | 3 | 3 | 1 | 7 |
| TUM-SBA | 4 | | | 4 |
| TUS-IAG | 6 | 1 | 0 | 7 |
| UniCusano | 5 | 3 | 1 | 9 |
| UoG | 5 | 2 | 1 | 8 |
| **Total** | 82 | 51 | 16 | 149 |

# Appendix D: Annex GoR-Structures and Materials (SM)

**ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "STRUCTURES AND MATERIALS"**

## Remit

Structural and material research in aeronautics strives to reduce structural weight, improve safety and reliability, keep operation cost low, reduce environmental impact and improve passenger comfort. In many cases, the research tasks are strongly interconnected so that an optimum design can only be reached through balanced improvements in all fields.

The GoR SM is active in initiating and organizing aeronautics oriented research on structures, structural dynamics and materials in general. Materials oriented research is related to material systems primarily for the airframe but also for the landing gear and the engines; it includes specific aspects of polymers, metals and various composite systems. Especially the integration of new functionalities is the key to further enhance the performance of materials. Structural research is devoted to computational mechanics, loads and design methodology. Research on structural dynamics more especially involves response to shock and impact loading.

The group is active in theoretical and experimental fields of structures and materials to strengthen development and improvement of methods and procedures. Of great importance is the mutual stimulation of the diverse scientific approaches. Experiments give new insights into the mechanisms of structural behaviour that can be included in improved theoretical models. Finally, the theoretical results must be verified and validated by comparison with results from suitable experiments or trials.

Although the specific topics vary over the years, the scientific basis remains largely unchanged. The work is looked upon as an upstream research intended to discover valuable areas of future activity; in this context many new ideas were proposed and explored during the year 2020.

Activities within the Exploratory and Action Groups cover several aspects of improved conventional and new technologies, new structural concepts and new design and verification criteria. Recent, current and upcoming work is devoted to:

- Additive Layer Manufacturing;
- Characterization and modelling of Composites with Ceramic Matrix submitted to severe thermo-mechanical loading;

- Characterization of composites with polymer matrix at high temperatures;
- Characterization and optimization of shock absorbers for civil aircraft fuselages;
- Structural health monitoring for hydrogen aircraft tanks.

## GoR-SM Overview

## GoR Activities

The activities within the Action Groups cover several aspects of new technologies, new structural concepts and new design and verification criteria. In 2022 two AG's were active and were devoted to the following topics:

- **Fatigue and damage tolerance assessment of hybrid structures SM/AG-35**

A major challenge in the fatigue analysis and subsequent fatigue testing of hybrid structures originates from the differences in deriving fatigue spectra for metal and composites and incorporation of required environmental load factors for composites. For example, elimination of peak loads in the spectrum for metals is conservative as crack retardation is prevented whereas for composites this is not conservative. In addition, the effect of larger scatter and environmental effects are for composites incorporated by means of a Load Enhancement Factor, thereby applying in the order of 10-20% higher loads, which will result in potential premature failure of metal components in the fatigue test.

The technical work of SM/AG-35 was completed in 2021 and the final report was completed and issued in 2022.

- **Additive layer Manufacturing SM/AG-36**

Additive Manufacturing (AM) with metals is an emerging technology that finds more and more applications in different markets such as orthopaedic implants, dentistry and high-end industry. There is also a lot of interest coming from the Aerospace industry.

Metal AM technology can provide great advantages with respect to conventional metal working techniques, such as significantly lower waste of materials, a larger freedom of design, high potential for weight reduction and the possibility to integrate additional functionality. Specific design guidelines must be taken into account and currently available CAD design tools are considered inadequate for designing for AM. Currently it still is difficult for AM technologies to compete with traditional techniques on reliability and reproducibility because the quality of final products depends very strongly on material and process parameters. Metal AM material qualification and process certification methods are not available yet. Qualification and Certification is essential for high demanding applications for example in aerospace. The goal of SM/AG-36 (which was launched in 2022) is to build up knowledge and skills in the field of metal AM processes and materials in order to support the manufacturing industry and increase its competitiveness. The work will more especially focus on novel Aluminium alloy like Scalmaloy and ScanCromal.

Although the specific topics vary over the years, the scientific basis remains largely unchanged. The work is looked upon as an upstream research intended to discover valuable areas on future activities.

## Management

In 2022, three meetings were held by video conference on 11th of January, the 9th of June and the 29th of September.

The measures taken in the past years to revitalize the Structures and Materials group were confirmed. Action Group 35 was finalized. Amongst the Exploratory Groups launched at the end of 2020, SM/EG47 submitted a proposal end of 2021 and as a result of that Action Group SM/AG-36 was started in the beginning of 2022. EG46 finalized a work program and the Action Group was launched in December 2022. For SM/EG-44, SM/EG-45 and SM/EG48 several meetings were held however due to availability issues little progress was made in bringing these EG's to a potential AG's.

## Dissemination of GARTEUR activities and results

A presentation was given and a paper was submitted for the International Council of the Aeromnautical Sciences (ICAS 2022) on the 5th of September 2022 in Stockholm. In this paper an overview of activities and success stories of the Garteur GoR-SM were presented.

## Reports issued

The final report for SM/AG-35 has been issued in February 2021.

## Status of Action Groups and Exploratory Groups

Two action groups were formally active in 2021. Action group SM/AG-35 finished their technical activities and issues their final report beginning 2022 and was closed. AG-36 started their activities in the beginning of 2022.

Four Exploratory Groups (EG-44, EG-45, EG-46) were running in 2022. An Exploratory Group (EG48) was launched in 2022.

### *Action Groups (AG)*

The following Action Groups were active throughout 2022:

| | |
|---|---|
| SM/AG-35 | *Fatigue and damage tolerance assessment of hybrid structure*<br><br>The objective of the group is to validate the basic assumptions for any applied spectrum manipulation techniques for fatigue test of hybrid structures, to examine the capabilities and benefits of a probabilistic |

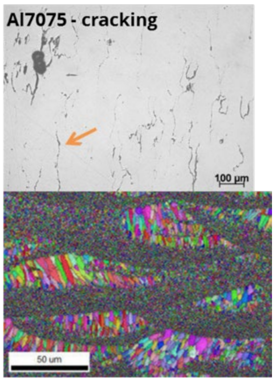
approach, to determine the optimum way to account for thermal loads in a non-thermo test set-up with the goal to find a joint 'best practice' approach for testing of hybrid airframe structural components. The technical activities of this group have finished. The final report was issued in 2021 and still has to be submitted under the GARTEUR format.

The chair was J. Laméris from NLR.

SM/AG-36

*Additive layer manufacturing*

Aluminum and its alloys are widely used in the aerospace sector due to their excellent mechanical performance in combination with their light weight. Their strength and low density are the main advantages of these materials. Fabricating components with complex geometries from high strength aluminum alloys by conventional processing techniques is challenging due to their low formability. In contrast, metal Additive Manufacturing (AM) techniques allow the production of near-net-shape and complex parts, adding value to the use of aluminum alloys in the aerospace sector. Even so, not all aluminum alloys are easy to process by AM.




Currently, there are several novel aluminum alloys being investigated for application in AM. Great advancements are being achieved on laser powder bed fusion (L-PBF) and also on directed energy deposition (DED). One of the focus points is to broaden the materials palette towards higher performance aluminum alloys. On one hand, the high-strength 7000 series has been investigated aiming at avoiding solidification cracking during the AM process. Several works have focused on modifying the composition by additions of Zr, Sc or Si in order to avoid cracking and improve the mechanical properties. On the other hand, casting aluminum alloys have been widely investigated with addition of nano-/micron-sized particles such as TiB2 or TiC aiming at increased fatigue performance. Examples of these modifications have resulted in commercially available aluminum alloys such as A20XTM developed by Aeromet with Cu and TiB2, or

Scalmalloy® developed by Airbus & commercialized by APWorks.

Besides the advancements on alloy development for AM, there is still a big gap w.r.t. commercialisation of these novel alloys. Therefore, great efforts should be done to fully characterise these compositions in order to get a full overview of their mechanical performance in various conditions. In addition, aluminum processing is still a big challenge due to the laser related high reflectivity & unstable melting behaviour of the alloy.

Based on these considerations, a proposal for an Action Group proposal focused on "Additive Manufacturing of novel high strength aluminum alloys" was prepared and should start beginning of 2022.

The chair is Maria Luz Montero from NLR.

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### *Exploratory groups (EG)*

The following Exploratory Groups were active throughout 2022:

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SM/EG-44

*Characterization of composites with polymer matrix at high temperatures*

This topic has first been proposed by ONERA and DLR. Both partners participate to the SuCoHS H2020 project (Sustainable & Cost efficient High-performance composite Structures) which emphasizes the industrial needs of experimental characterization methods for composite properties at high temperature (< 400°C). More detailed objectives consist in:

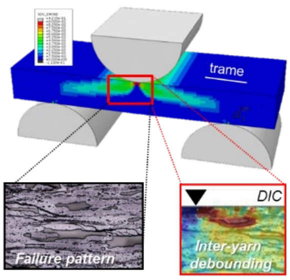
- The definition of experimental methods for mechanical properties for the ply and the interface
- How take into account the thermal degradation in the characterization process

- experimental methods and analysis of DMA results in temperature
- characterization of the thermal expansion coefficient
- analysis of the thermomechanical results by taking into account the thermal strain evolution
- providing a test stand for testing classical coupons

The chair is Tobias Wille.

SM/EG-45

*Characterization and modelling of CMC submitted to severe thermo-mechanical loading*



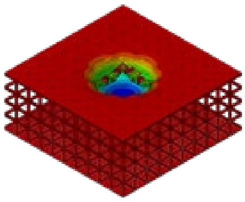

This topic has been proposed by ONERA and DLR. The objective consists in the characterization of the mechanical properties and modelling of Composites with Ceramic Matrix (CMC) submitted to high mechanical loadings and extreme thermal conditions. More detailed objectives consist in the:

- comprehension of the damage and failure mechanisms under static and fatigue loading at very high temperatures;
- definition of standard tests for the measurement of mechanical properties (behaviour, damage, failure) at very high temperatures;
- proposition of damage and failure models to predict behaviour damage, failure and fatigue lifetime of composite materials;
- testing and simulation of CMC composite structures under static or fatigue loading (evaluation of predictive capabilities of models).

The chair is Frédéric Laurin (ONERA).

SM/EG-46

*Characterization and optimization of shock absorbers for civil aircraft fuselages*



Commonly adopted shock absorbers and, in general, crashworthy structural components, based on sandwich structural concepts and/or complex dumping mechanisms, are, generally, characterized by high volumes and significant additional mass. This research activity is focused on the investigation of the feasibility and effectiveness of novel thin additive manufactured hybrid metal/composite lattice structures as lightweight shock absorbing devices for application to structural key components in impact events. These hybrid structures would represent a real step beyond the state of the art of shock absorbers being characterized by an additive manufactured metal lattice core, able to maximize the absorbed energy by plastic deformations and, at the same time, by a composite skin/cohesive coating, fully integrated with the internal metal lattice structure, able to lower the global weight and increase the stiffness and strength of the shock absorber.

The hybrid shock absorbers must be able to reduce the peak acceleration transferred on the main structure, ensuring the integrity of the core structure and, eventually, the safety of the passengers.

Starting from the above considerations, the Exploratory Group SM-EG 46 prepare an Action Group proposal focused on “Characterization and optimization of shock absorbers for industrial applications”. This proposal should be ready mid-2022.

Salvatore Saputo (University Campania in Italy) will assume the chairmanship.

SM/EG-48

*Structural Health Monitoring for hydrogen aircraft tanks*

In order to drastically reduce CO2 emissions, hydrogen is an alternative solution for the production and storage of energy. Regarding the storage, the best option consists in liquefying the hydrogen at a temperature below -253°C. Composite materials are being considered for the cryogenic tank but the issue related to the development of a composite tank is the ability to detect initiation of any damage. Structural Health Monitoring (SHM) methods, consisting of integrating sensors in or on the structure, are then used. However, few studies are dedicated to SHM methods under such temperatures. The objective of the group would be to work on the design of SHM systems dedicated to composite parts under cryogenic temperatures, including the study of the durability of such systems.

The expected chairman is Jean-Michel Roche from ONERA.

## Rolling plans

| Cat | Topic | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|
| SM/AG-35 | Fatigue and damage tolerance accesment of hybrid Structures | | | | |
| SM/AG-36 | Additive Layer Manufacturing | | | | |
| SM/EG-43 | Development of additive layer manufacturing for aerospace applications | | | | |
| SM/EG-44 | Characterization of composites with polymer matrix at high temperatures | | | | |
| SM/EG-45 | Characterization and modelling of CMC submitted to severe thermomechanical loading | | | | |
| SM/EG-46 | Characterization and optimization of shock absorbers for civil aircraft fuselages | | | | |
| SM/EG47 | Additive Layer Manufacturing | | | | SM/AG3 |
| SM/EG-48 | Structural Health Monitoring for hydrogen aircraft tanks | | | | |

| | |
|---|---|
| | Active |
| | Extended |
| | Inactive |
| | Stopped |

## GoR membership

| | | |
|---|---|---|
| **Chairperson** | | |
| Bert Thuis | NLR | The Netherlands |
| | | |
| **Vice-Chairperson** | | |
| Javier Sanmilan | INTA | Spain |
| | | |
| **Members** | | |
| Florence Roudolff | ONERA | France |
| Aniello Riccio | UniCampania | Italy |
| Peter Wierach | DLR | Germany |
| Andrew Foreman | QinetiQ | United Kingdom |
| Robin Olsson | RISE | Sweden |
| Mats Dalenbring | FOI | Sweden |
| | | |
| **Industrial Points of Contact** | | |
| Roland Lang | Airbus Defence and Space | Germany |
| Mathias Jessrang | Airbus Operations | Germany |
| Thomas Ireman | SAAB | Sweden |

## Table of participating organisations

| | AG-35 | AG-36 | EG-44 | EG-45 | EG-46 | EG-48 |
|---|---|---|---|---|---|---|
| **Research Establishments, Universities** | Closed end of 2022 | Started in 2022 | Under definition | Under definition | Under definition | Under definition |
| CIRA | | | | | □ | |
| DLR | □ | | ■ | □ | □ | □ |
| FOI | □ | | | | | |
| INTA | | | | | | |
| NLR | ■ | ■ | | | □ | □ |
| ONERA | | □ | □ | ■ | □ | ■ |
| CNR | | | | | | |
| ICAS | | | | | | □ |
| **Industries** | | | | | | |
| Airbus | | □ | | | | |
| SAAB | | | | | | |
| Fokker | □ | | | | | |
| GKN | | | | | | |
| Leonardo Company | | | | | | |
| RISE/Swerea SICOMP | | | | | | |
| QinetiQ | | | | | | |
| ALENIA | | | | | | |
| Dassault Aviation | | | | | □ | |
| **Academic Institutions** | | | | | | |
| University of Campania | | □ | | | ■ | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Imperial College | | | | | | |
| Lulea University of Technology | | | | | | |
| Norvegian University of Science and Technology (NTNU) | | | | | | |

# Action Groups reports

## SM/AG-35 : Fatigue and damage Tolerance Assessment of Hybrid Structures

Action Group Chairman: Jaap Laméris (jaap.lameris@nlr.nl)

### Background

Hybrid structures, i.e. structures consisting of a metallic and CFRP components, will become more prevalent in aircraft structures in the future. Structural components made out of metal require a different approach with respect to fatigue-analysis and fatigue-testing than components made out of fiber reinforced plastics (composites). A major challenge in the fatigue analysis and subsequent fatigue testing of hybrid structures originates from the differences in deriving fatigue spectra for metal and composites and incorporation of required environmental load factors for composites. Also the joining of metallic components with carbon fiber reinforced polymers will require additional care and attention in terms of design and assembly requirements. In particular the influence of the environment is of importance for hybrid structures. Due to the differences in thermal expansion coefficient between metal and composites thermal stresses may arise and have to be dealt with in the static and fatigue strength substantiation. Another concern is the long-term stability and degradation of bonded joints and fiber-metal laminates (FML) due to environmental influences: the aging of joints in humid environments.

### Programme/Objectives

**Objectives**

The main objectives are listed below. They should lead to a joint "best practice" approach for testing of hybrid airframe structural components.

**Task 1: Loading aspects of full-scale Fatigue and Damage Tolerance tests**

A major challenge in the fatigue analysis and subsequent fatigue testing of hybrid structures originates from the differences in deriving fatigue spectra for metal and composites and incorporation of required environmental load factors for composites. The following aspects can be addressed:

- Composite structure is sensitive to environmental conditions, metal parts usually are not. Relevant aspects of the 'environment' are in this case the temperature and the in-service moisture content, both as environmental history effect during the lifetime of the structure as well as conditions during proof of residual strength. If it is decided not to perform fatigue- or residual strength tests under these conditions, which aspects should be taken into account via environmental factors on the applied loads?
- Material scatter for composites is much larger than for metals. However, to avoid non-linear behaviour of test set-up and too high stress levels in the metal parts a maximum overall load increase should be respected.
- In general, damage growth in composite materials is most sensitive for compression-compression cycles, where metal fatigue initiation and crack growth are more sensitive to tension-compression and tension-tension cycles. A generic process for a load spectrum reduction technique covering both aspects should be discussed.
- Spectrum truncation levels must be different for metals and composites. Where composites experience high damage from high peak loads , metals will experience crack retardation after application of a severe load condition .

**Task 2: Determination of the optimum way to account for thermal loads in a non-thermal test set-up of hybrid airframe structural components**

One of the most important effects of the environment on a hybrid structure, thermally induced interface loads due to the differences in coefficient of elongation between metals and carbon composites (e.g. for attachment areas between a warm fuselage and a cold wing), come in addition to the 'mechanical' loads. In non-thermal fatigue testing, it is a challenge to apply these loads mechanically. As thermal loads will generally build up in all directions throughout an aircraft structure, the combination with 'mechanical' loading can result in either a uni-axial or a bi-axial stress state. It is to be discussed when the thermal loads are significant enough to be considered for the fatigue and damage tolerance justification.

**Task 3: Environmental influences**

One particular focus of this research is on the long-term stability and degradation of bonded joints and fiber-metal laminates (FML) due to environmental influences: the aging of joints in humid environments. Very often the major challenge in adhesive bonding is not the load-carrying performance of the joints, which can typically be realized even with simple surface pretreatment technologies like grit-blasting, but in ensuring that the joints will not fail after a short period due to e.g. the effect of water.

### Results

The AG results in establishing a joint 'best practice' approach for full scale fatigue testing of hybrid airframe structural components.

Task 1: The experimental program for this task was designed to show any differences between a traditional - and widely accepted - approach for the derivation of the test spectrum for a hybrid structure and two new approaches, the Load-Life-Shift (LLS) and Multi- LEF approach respectively.

Task 2: Experimental and numerical studies of static and fatigue bearing failure were conducted in uniaxial and biaxial loading of composite joints at elevated temperature. The experiments were designed to isolate the local phenomena and to represent, in a simplified way, the effect of thermally induced loads on hybrid composite-aluminium assemblages.

Task 3: The bonding and resistance against degradation by water has been studied for different aerospace relevant titanium alloys joint with the thermoplastic PEEK. Morphological details of pretreated metal surfaces, wetting and infiltration by the polymer melt, mechanical and aging behavior have been characterized in order to further the understanding of aging and bonding mechanisms and to derive specific surface pretreatments for reliable high-performance adhesive joints.

## SM/AG-35 Fatigue and Damage Tolerance Assessment of Hybrid Structures

**Monitoring Responsable:** B. Thuis, NLR

**Chairman:** R.P.G. Veul (till 31/08/2013) NLR
J.Laméris (from 01/09/2013) NLR

- **SM/AG-35 membership**

| Member | Organisation | e-mail |
|---|---|---|
| Dr.-Ing Joachim Hausmann till 01/09/14 | DLR | joachim.hausmann@dlr.de |
| Dr Jan Haubrich from 01/09/14 | DLR | jan.haubrich@dlr.de |
| Dr Anders Blom | FOI | anders.blom@foi.se |
| Dr Joakim Schön | FOI | joakim.schon@foi.se |
| Tim Janssen | Fokker Aerostructures | tim.janssen@fokker.com |
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| Dr Jaap Laméris | NLR | jaap.lameris@nlr.nl |
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| Rudy Veul | NLR | rudy.veul@nlr.nl |
| Hans Ansell | SAAB | hans.ansell@saabgroup.com |
| Zlatan Kapidzic | SAAB | zlatan.kapidzic@saabgroup.com |

- **Objectives**

The main objectives are listed below:

- Validation of the basic assumptions for any applied spectrum manipulation techniques;
- Examination of the capabilities and benefits of a probabilistic approach;
- Determination of the optimum way to account for thermal loads in a non-thermo test set-up;
- leading to a joint 'best practice' approach for testing of hybrid airframe structural components.

- **Main achievements**

Tasks accomplished in 2022:
The final report was delivered in 2022 in the GARTEUR format and the group was closed.

- **Expected results/benefits**

Recent developments and papers in the field of fatigue testing of hybrid structures indicate a few problem areas where conflicts between the 'metal'- and the 'composite' side of the test evidence need to be resolved before compliance with the fatigue and damage tolerance requirements for hybrid structures can be shown with one fatigue test article.

## SM/AG-36 Additive Layer Manufacturing

| | |
|---|---|
| **Monitoring Responsable:** | B. Thuis<br>NLR |
| **Chairman:** | M. Montero<br>NLR |

- **Context and challenge:**

Aluminium and its alloys are widely used in the aerospace sector due to their excellent mechanical performance in combination with their light weight. Their strength and low density are the main advantages of these materials. Fabricating components with complex geometries from high strength aluminium alloys by conventional processing techniques is challenging due to their low formability. In contrast, Metal Additive Manufacturing (AM) techniques allow the production of near-net-shape and complex parts, adding value to the use of aluminium alloys in the aerospace sector. Even so, not all aluminium alloys are easy to process by AM.
Currently, there are several novel aluminium alloys being investigated for application in AM. Great advancements are being achieved on laser powder bed fusion (L-PBF) and also on directed energy deposition (DED). One of the focus points is to broaden the materials palette towards higher performance aluminium alloys. On one hand, the high-strength 7000 series has been investigated aiming at avoiding solidification cracking during the AM process. Several works have focused on modifying the composition by additions of Zr, Sc or Si in order to avoid cracking and improve the mechanical properties. On the other hand, casting aluminium alloys have been widely investigated with addition of nano-/micron-sized particles such as TiB2 or TiC aiming at increased fatigue performance. Examples of these modifications have resulted in commercially available aluminium alloys such as A20XTM developed by Aeromet with Cu and TiB2, or Scalmalloy® developed by APWorks.

**Scope:**
The main objective of this proposal is the exploration of new aluminium alloys suitable for processing via metal additive manufacturing techniques, i.e. L-PBF and/or DED. This work will focus on the following steps:

- Alloy selection
- Alloy production (powder production)
- AM process optimisation
- Design values
- Microstructure and mechanical performance
- Feasibility study: demonstrator

- **Expected Impact:**

Development of an AM-process for high-performance novel aluminium alloys opening up the advantages of additive manufacturing for this class of materials, particularly for the aerospace industry, but also elsewhere.
Refinement of the AM process to achieve mechanical performance (static and/or dynamic) for the 3D printed parts that equals or exceeds the current high-performance aluminium alloys allowing the initial steps to be taken towards certification.

- **Main achievements:**

AG-36 started its activities in the beginning of 2022.
In 2022 the alloy composition was selected: AlMg1Cr1.5Mo0.5Sc0.5Zr0.25
Airbus provided Scancromal powder to get familiar with the characterisation techniques.
Powders were analysed and a test matrix was defined. A begin was made with manufacturing of test specimens.

- **SM/AG-36 membership**

| Member | Organisation | e-mail |
|---|---|---|
| M. Montero | NLR | |
| M. de Smit | NLR | |
| A. Pastor | INTA | |
| M. Thomas | ONERA | |
| A. Morel | ONERA | |
| F. Palm | AIRBUS | |
| V. Alcafora | UniCampania | |

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