GARTEUR

ANNUAL REPORT 2021

GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE

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GARTEUR ANNUAL REPORT 2021

GARTEUR aims at stimulating and co-ordinating co-operation between Research Establishments and Industry in the areas of Aerodynamics, Flight Mechanics, Systems and Integration, Helicopters and Structures & Materials.

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1. Introduction

Dear reader,

I intended to start this foreword with a more optimistic tone, as countries are at this moment rapidly lifting the restrictions due to Covid 19. Unfortunately, this coincides with the worrying developments in Ukraine. In addition to the tragedy for the local population, we also see unrest on the economic markets and worries about energy reserves. Safety and security again prove to be important conditions for economic stability and growth. When these conditions are met, aviation, tourism and trade can flourish.

Some consider war as a drive for technological development, especially in aviation. With no doubt this was true in the past. WW1 spurred the introduction of the airplane, WW2 saw rapid development of new lightweight materials and the birth of the supersonic age. Since then, developments in military aviation were always closely followed by spin-offs for civilian aviation and more and more vice-versa. We witnessed the end of the cold war and the first space-race, and last years the start of commercial space exploration. Old enemies became allies and new goals are reached by cooperation rather than conflict.

New challenges, like depletion of resources and the stress on the environment, need to be tackled on a global scale. National governments and the EU are at his moment allocating significant R&D resources. For realizing sustainable aviation, we are facing technological challenges on hybrid (hydrogen/electric) propulsion or novel materials to name a few. GARTEUR is one of the organizations where we seek to improve cooperation with this in mind.

As we pass on the chairmanship to Italy, we look back on two years of mainly virtual meetings. Though it saved on travel costs and on environmental impact, this is not the preferred way of working together. Exchanging off topic information and side-line discussions are a few of the benefits of physical meetings. And of course, exchange of culture, stories and bonding by a good glass of wine or beer.

We wish you nice reading of our Annual Report of 2021. Hope that we can meet soon in physical form and good luck for Italy as the new chair 2022-2023.

LCOL Etiënne Nijenhuis

Chair GARTEUR 2020-2021

Dear GARTEUR Friends,

we all hoped that 2021 would have been a better year than the year before. Alas, it proved to be very much the same: the Council meeting scheduled in autumn, initially planned to the first a physical Council meeting in one-and-a-half year, at the last moment had to be switched to (again!) a virtual one because of the outbreak of the delta-variant of Covid-19.

Keeping the GARTEUR family together remained the greatest challenge. The XC continued the monthly meetings with the GoR chairs, which definitely helped the cohesion of GARTEUR. The XC is aware that we provide a framework and that the important work is done in the GoRs and in their Action Groups.

In 2022 the world is now facing a crisis of geo-political nature. It is clear that the western world must be united in the confrontation of this crisis. The GARTEUR community is part of this greater entity and, in its own little way, it contributes to safe-guarding our way of life.

Harmen van der Ven

Acting Chair XC GARTEUR 2021

2. Executive summary

The GARTEUR Annual Report 2021 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, helicopters, flight mechanics and systems integration, and 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 2020 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, the military perspective on the Single European Sky programme 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 2021.

3. GARTEUR Council

3.1 Chairmanship and membership

On the 1st of January 2020, the Netherlands succeeded Spain as chair of GARTEUR for a period of two years, ending on the 31st of December 2021.

During 2021 the Chairman of the Council was Lt. Col. Etienne Nijenhuis, from Directorate Operational Policy and Plans of the Dutch Ministry of Defence, with Kees Wijnberg, head of NLR's Flight Physics and Loads Department, as Chairman of the Executive Committee. After Kees Wijnberg's departure from NLR in September 2021, Harmen van der Ven, acting head of NLR's Flight Physics and Loads Department, acted as Chairman of the Executive Committee, until the end of the year. Ligeia Paletti from NLR served as GARTEUR secretary during 2021.

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:

- XC166 – Online
- C70 – Online
- XC167 – Stockholm (Sweden)
- C71 – Online

3.2.1 XC166

The first XC meeting of 2021 took place digitally, as consequence of travelling restrictions in place due to the COVID-19 pandemic on the 3rd February. The main topics discussed during this meeting were the communication between Council, XC and GoRs, and the possible participation of GARTEUR in SAGAS.

3.2.2 C70

The first Council meeting of 2021, C70, took place digitally, as consequence of travelling restrictions in place due to the COVID-19 pandemic, on Tuesday 9th March 2021 and Wednesday 10th March 2021. The main topics discussed during this meeting were the updates from the GoRs and the possible participation of GARTEUR in SAGAS.

3.2.3 XC167

The XC167 meeting took place on 9th September 2021 in FMV, Stockholm, Sweden. The topics for discussion of XC167 were focused on the communication between Council, XC and GoRs, and the progress on the participation of GARTEUR in SAGAS. Also, the participation of GARTEUR to ICAS conference in September 2022 was discussed.

3.2.4 C71

The Council meeting C71 took place digitally on Wednesday 17th November 2021 and Thursday 18th November 2021. The GARTEUR Award of Excellence for the Netherlands chairmanship period 2020-2021 is awarded to AD/AG-55 Countermeasure Aerodynamics. Harmen van der Ven, as representative of AG-55, gives a presentation about the topic. The award and certificate are virtually handed in to the Sweden delegation, who chaired the AG-55. The physical transfer will be done at the next Council meeting.

During November 2021 the handover for the chairmanship from the Netherlands to Italy was performed. The handover was performed successfully, explaining main operational and administrative aspects. The annual report 2021 was the only action still open to the Netherlands delegation.

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 2021 the website was updated when strictly necessary by the secretary.

For the use of the GoRs, DLR has arranged 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 2021 certificates were issued to:

- Luigi Paparone
- Kees Wijnberg
- Neda Tooloutalaie
- Francisco Muñoz Sanz
- Jose Vicente Garcia Calatayud
- Lorenzo Notarnicola
- Klausdieter Pahlke
- Joost Hakkaart
- Mario Verhagen
- Aniello Riccio and Andrea Sellitto
- Action Groups AD-53, AD-54 and AD-55

4 The European aeronautics RTD environment

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

4.1 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 2020, is the biggest research and innovation programme in Europe and offers almost €80 billion in grants, loans and incentives over seven years (2013-2020) for researchers, engineers and entrepreneurs in addition to private investments the programme attracts.

Horizon 2020 is funding a considerable number of initiatives that will have a positive impact on Europe by unlocking innovation, providing the funds necessary to encourage and enable scientific and technological breakthroughs. Seen as a key driver of economic growth and job creation, Horizon 2020 has the political backing of Europe's leaders and the Members of the European Parliament Aeronautical RTD is funded through a specific Aviation programme within the Transport theme as a Societal Challenge and sets out to tackle some of the main environmental challenges attributed to the aeronautical industry including designing and producing cleaner and quieter aircraft, minimising the impact of transport on the environment. Another key focus of Horizon 2020 is aimed at creating better mobility, less congestion and more safety and security.

Within Horizon 2020, Clean Sky 2 is Europe's dedicated aeronautics research programme with a €4bn budget. Clean Sky 2 represents a Joint Technology Initiative (JTI), a Public-Private Partnership (PPP) that brings together industry (including SMEs), academia and research institutions with the European Commission. Its aim is to develop and demonstrate break-through technologies for the civil aircraft market to cut aircraft emissions and noise whilst securing the future competitiveness of Europe's aeronautics industry.

4.1.1 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 JU began[1].

[1] Clean Aviation (clean-aviation.eu)

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

The new Partnership will build 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 will be 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] 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.*

4.1.2 GARTEUR and ACARE

In addition to its responsibility for developing the SRIA, ACARE 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.

Members of the GARTEUR Council are also heavily involved with ACARE and this ensures that GARTEUR's research interests are strategically aligned with the SRIA, 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.

4.1.3 GARTEUR and EREA

EREA 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.

EREA proposed a Joint Research Initiative, named Future Sky, 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.

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.

4.2 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.

4.2.1 European Defence Agency

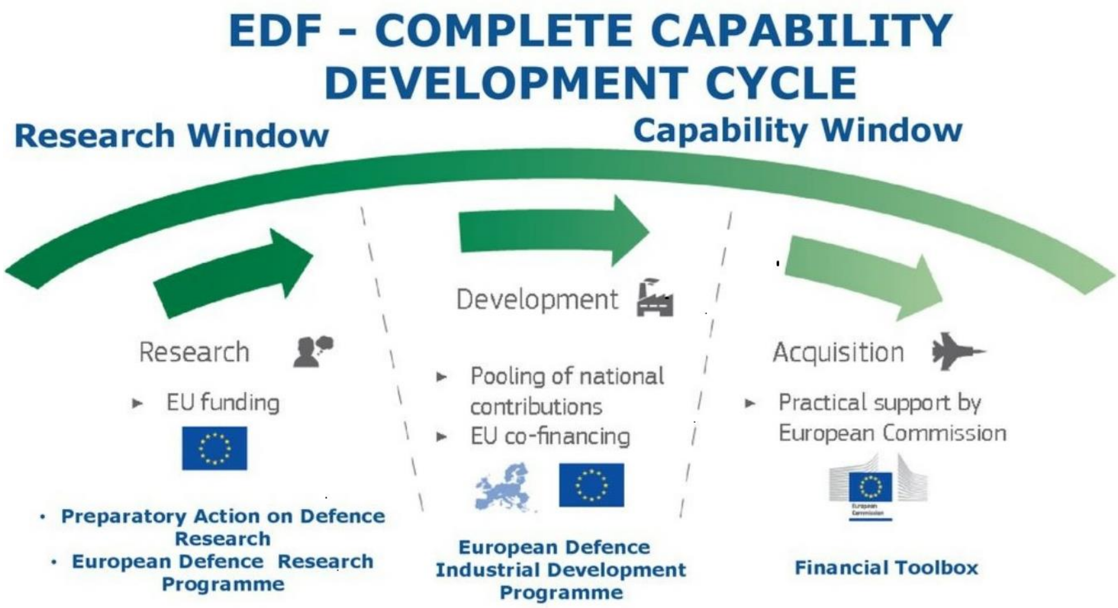
The European Defence Agency (EDA) is an intergovernmental agency of the Council of the European Union, comprising all EU members with the exception of Denmark and also including from non-EU member states, Norway, Switzerland, the Republic of Serbia, and Ukraine, through special administrative arrangements. 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.

4.2.2 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:

- 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 been rewarded a total of 7 Bljrd programme funding by the European Committee.



5 Summary of GARTEUR technical activities

During 2020 the five GARTEUR Groups of Responsables (GoRs) continued to facilitate and deliver 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;
- 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.

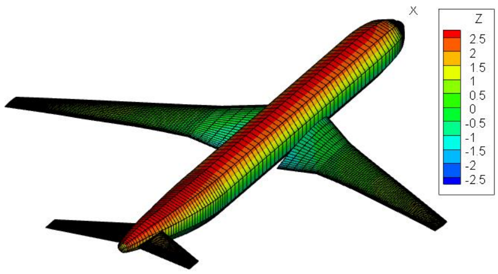
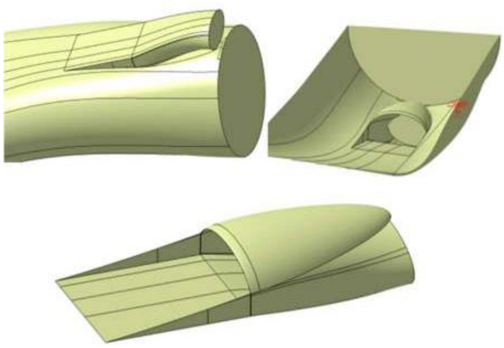
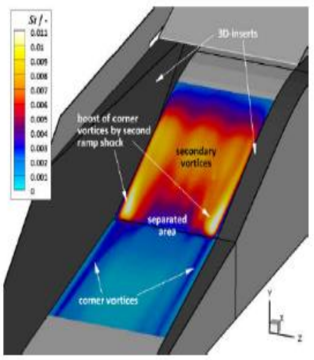
Whilst the majority of the research activities focusses on mono-disciplinary aerodynamics, some of the work also has a significant amount of multi-disciplinary content. This trend is driven by industrial interests, and is likely to increase in the future.

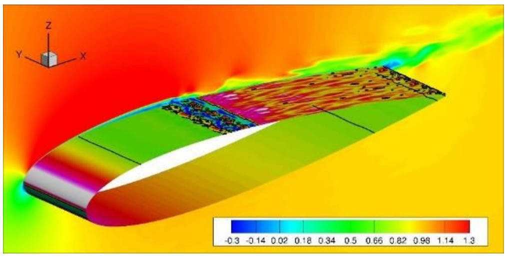
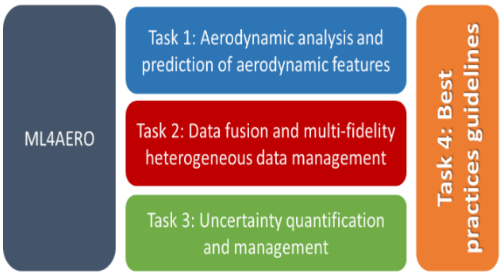
Funding for GARTEUR activities is relatively small and, in general, is insufficient to fully support new research. In most cases therefore the AG activities are combined with activities funded through other routes, such as EU, NATO STO (Science and Technology Organisation) or national aeronautical research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

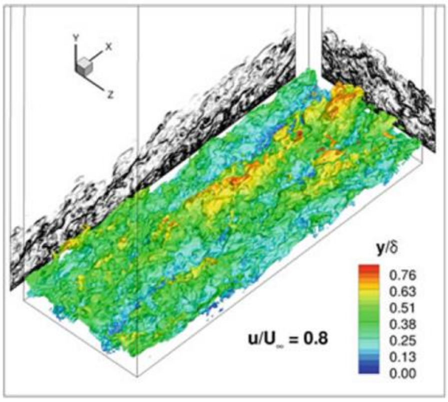
Research initiated in GoR AD programmes sometimes leads to an EU proposal or compliments concurrent EU program content. In addition, the content of GoR AD activities can be cross sectorial in covering both civil and military interests.

5.1.2 GoR-AD Activities

Five Action Groups and one Exploratory Group were active in 2021. In November 2021, the Exploratory Group was approved by the Council to become Action Group AD/AG-61.

AD/AG-56	Coupled Fluid Dynamics and Flight Mechanics Simulation of Very Flexible Aircraft Configurations
	Very flexible aircraft are light-weight constructions that require multi-disciplinary design tools. Main objectives of AD/AG-56 are to enhance the partners' capabilities in aeroelastic simulations to more accurately predict aerodynamic loads and structural deformations for manoeuvre and disturbance conditions, and to allow for the benchmarking of inhouse tools amongst the partners through the use of a common research model. In 2021, partners have run trim simulations using their methods with either rigid aircraft models or the flexible aircraft model. The chairperson is Richard van Enkhuizen (NLR).
AD/AG-57	Secondary Inlets and Outlets for Ventilation
	Aircraft require a variety of secondary air inlets and outlets mostly for environmental control systems, APU operation, ventilation and cooling purposes. Main objectives of AD/AG-57 are to analyse and improve the efficiency of conventional secondary air inlets for different applications on fuselage and wing, and to explore the feasibility of new low-observable concepts hidden within the main engine intake. In 2021, the scientific activities came to the end and the final report has been written. The chairperson is Jose Angel Hernanz-Manrique (Airbus Operations).
AD/AG-58	Supersonic Air Intakes
	Supersonic air intakes are of foremost importance in the design of supersonic air-breathing vehicles. Main objectives of AD/AG-58 are to gather a database of relevant flow features on representative test cases and to validate CFD codes on these specific topics. Investigations include the control of cowl oblique shock / boundary layer interactions, internal bleed flows, and effects of intake diffusers and scramjet isolators. In 2021, extensive RANS and ZDES simulations have been performed for different test cases. The duration of the working group was extended by one year. The chairperson is Christophe Nottin (MBDA).

AD/AG-59	Improving the Simulation of Laminar Separation Bubbles
	Laminar separation bubbles are one of the main critical aspects of flows at low Reynolds number, of order of magnitude 10^4 to 10^5, which are relevant for small aircraft such as UAV. Main objectives of AD/AG-59 are advancements in the understanding of the evolution of laminar separation bubbles and their effect on airfoil flows, and the improvement of the numerical prediction of flows with laminar separation bubbles. In 2021, activities comprised the analysis of wind tunnel experiments in WP 1 and numerical investigations for various test cases in WP 1 to WP 4. A new transition model has been developed. The chairperson is Pietro Catalano (CIRA).
AD/AG-60	Machine Learning and Data-Driven Approaches for Aerodynamic Analysis and Uncertainty Quantification
	Aerodynamic analysis and uncertainty quantification are key capabilities used in aircraft design. Main objectives of AD/AG-60 are the improvement of machine learning (ML) capabilities and valuable knowledge of the selected data-driven techniques in aerodynamic analysis and uncertainty quantification. Through the proposed activities it is expected that best practice guidelines will be concluded and the use of ML methods is facilitated in the aeronautical industry. The AG started in 2021. An XRF1 database has been provided by AIRBUS. The work focuses on the assessment of different ML techniques for the prediction of the Cp using the XRF1 aerodynamic data. The chairperson is Esther Andrés (INTA).

AD/EG-78	Hybrid RANS/LES methods for WMLES and Embedded LES
	For future aircraft design and certification, wall-bounded turbulence-resolving hybrid RANS/LES methods are of particular interest for the prediction of flow phenomena related to aeroacoustics, unsteady loads, mild flow separations or boundary layers undergoing strong adverse pressure gradients. A work programme is developed in order to enhance the capabilities of wall-modelled LES and embedded LES. In 2021, the AG proposal has been finalized and was approved by the Council. AD/AG-61 will start in the beginning of 2022. The chairperson is Nicolas Renard (ONERA).

5.1.3 GoR-AD Membership

The membership of GoR-AD in 2021 is presented in the table below.

Chairperson		
Kai Richter	DLR	Germany
Members		
Giuseppe Mingione	CIRA	Italy
Eric Coustols	ONERA	France
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
Luis P. Ruiz-Calavera	AIRBUS D&S	Spain

5.2 Group of Responsables – Aviation Security (AS)

5.2.1 GoR-AS Overview

In 2021, 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 performed the activities within ASPRID Project together with the industrial stakeholders to plan tasks and activities.

Specifically:

- ENAIRE, the Spanish Air Navigation Service Provider
- Aena, the first airport operator company in the world by number of passengers.
- Two Italian companies providers of counter drone solutions:
  SoulSoftware SRL
  Aerospace Laboratory for Innovative components (ALI Scarl)

The project ASPRID- Airport System Protection from Intruding Drones - belongs to Horizon 2020 Call: H2020-SESAR-2019-2 (SESAR 2020 EXPLORATORY RESEARCH) Topic: SESAR-ER4-13-2019 Type of action: SESAR-RIA.

It represents a good chance for GoR/AS as it matches the theme identified as interesting for AS action group.

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 interests, which have been properly analysed and the importance of multi-disciplinary work is likely to increase in the future.

The approach in 2021 has aimed at keeping links with other running initiatives like ES4AWG, Optics2 project, ACARE WG4.

Furthermore, the chairperson has attended the SAGAS meeting systematically during the year.

The main actions in 2021 were:

1. To further develop and share ideas among the active members (CIRA, ONERA, INTA, NLR) to identify research challenges and collaboration approaches.
2. To support existing initiatives in aviation security at European level in order to promote harmonization among them and with Garteur.
3. To monitor current funded initiatives to apply for with a collaborative approach involving other key players (the exploration of needs has driven to the definition of a conceptual framework to perform testing activities for security).

5.2.2 GoR-AS Activities

From the previous Council the suggestions for 2021 was:

- 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 on it

Both the suggestions have been implemented.

A meeting (webex) was held among the AS GOR in March 2021.

During this meeting information was shared to assess the interest of the different GoRs on security for aviation research.

Specifically, the following interests were communicated:

INTA: countermeasures, activities for defence, RPAS, electrooptics, safety and security.

DLR: Artificial Intelligence, Cybersecurity, counteruas technology, safety & security

ONERA: safety and security assessment, safety assessment for drones, cybersecurity assessment.

NLR: cybersecurity of aviation assets, artificial intelligence.

CIRA: cybersecurity for aviation assets, artificial intelligence security, security by artificial intelligence, security for drone swarms

DLR has proposed the possibility to reanimate the topic of CBRN detection in the GoR-AS. We discussed CBRN within GARTEUR a few years ago, but it fell asleep.

Request issued by a colleague working at the Institute for Technical Physics at DLR, who is working with his French colleagues from the Physics Instrumentation Environment Space Department at ONERA The French colleagues could also imagine contributing to GARTEUR. the AS GoR chairperson is waiting for a description of the concept by DLR.

Some updates from The project ASPRID:

- EASA has shown interest in ASPRID results
- A publication has received the best paper award and Garteur is named in it

  2021 13th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)
  "Historical Data Analysis and Modelling for Drone Intrusions in Airports

  The approach in 2021 has aimed at keeping links with other running initiatives like ES4AWG which has "joined" Garteur intent the chairperson has attended the SAGAS Stakeholders' Advisory Group on Aviation Security meetings.

For the last part of 2021 the approach has consisted in:

1. Top down: identifying key topics in Horizon Europe
2. Bottom Up: identifying common topics to work upon
3. Vote topics in the intersection of a and b.
4. Start with an EG on the chosen topic.
5. Discuss with industrial and other relevant stakeholders in aviation security (e.g.LEAs).

The First call topic to be considered has been:

HORIZON-CL3-2021-CS-01-03: AI for cybersecurity reinforcement

Due to deadline too close and limited availability of participants due to other priorities it was decided to give up the proposal preparation under this topic.

Then going on analysing potential interests matching HE topics, the focus was put on:

- HORIZON-CL5-2022-D5-01-13 -*Digital aviation technologies for new aviation business models, services, emerging global threats and industrial competitiveness*

2 meetings were dedicated in the last months of 2021 to define a common concept around this topic.

5.2.3 GoR-AS Membership

The membership of this GOR in 2021 is made by :

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 2021 have been limited to writing a pilot paper and exploring the down selected topics from 2020, AI for fault detection and control allocation using distributed propulsion. On both topics a pilot paper was initiated. Furthermore, the following two topics are under consideration for a pilot paper:

- Flexible aircraft control
- Guidelines on certification

The following Exploratory Groups were active or decided to start in 2021:

FM/EG-30	*AI for fault detection* 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.

5.3.3 GoR-FM Membership

The membership of GoR-FM in 2021 is presented in the table below.

Chairperson		
Marinus Johannus van Enkhuizen	NLR	The Netherlands
Members		
Bernd Korn	DLR	Germany
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.

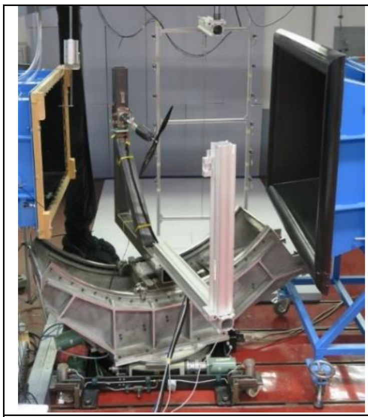
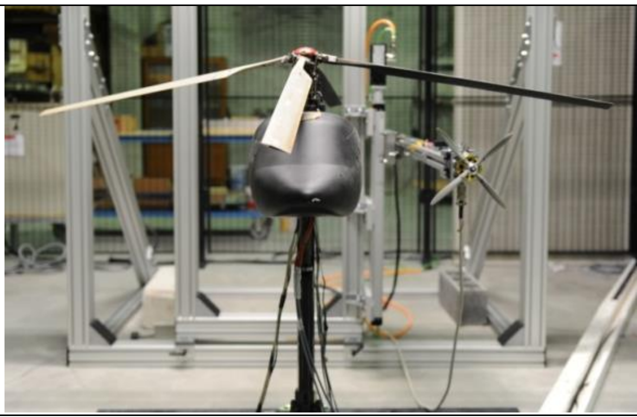
The GoR-RC initiates, organises and monitors basic and applied, computational and experimental multidisciplinary research in the following areas and in the context of application to rotorcraft vehicles (helicopters and VTOL aircraft such as: tilt rotors; compounds and multi-copters) and systems technology.

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 and safety:
    - Security studies, UAVs, 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
    - 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.

	
Preliminary test of isolated rotor in 1m-tunnel at DLR Göttingen (HC/AG-25)	*Generic Main Rotor/Propeller Configuration (ONERA) (HC/AG-25)*

5.4.2 GoR-RC Activities

In 2021, GoR-RC monitored the following Action Groups:

HC/AG-25	*Rotor-Rotor-Interaction* 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.

The following Exploratory Groups were active or decided to start in January 2021:

RC/EG-38	*Verification & Validation: Metrics for the Qualification of Simulation Quality* To define metrics for the qualification of the quality of rotorcraft simulations, as a contribution to the Verification and Validation (V&V) process of numerical codes. The progress in this EG was limited and the workshop in 2019 did not bring the expected clarity for the next steps. As the topic is very relevant, RC GoR is still supporting the key ideas of this EG. It is to be considered that the EU CS2 Project RoCS (Rotorcraft Certification by Simulation) is covering very similar topics. Due to limited resources in the relevant organizations it was first decided to put this EG on hold until the end of the RoCS project. However, due to effects of the Covid 19 pandemic, and since an extension of RoCS project until May 2023 can be expected, it was finally decided to stop this EG and re-propose it as a New Idea to be re-considered in the near future.

RC/EG-39	*Testing and modelling procedures for Turbulent Boundary layer noise* To identify ways how to reduce the flow-induced noise in rotorcraft. The chairman was in 2020 a visiting scientist at NASA working on other topics and took up the EG-lead after his return in Sept. 2020. The first meeting took place in December 2020. During the year 2021 no updates have been received from the EG coordinator. An action was decided during the last RC-GoR meeting in October 2021 in order to verify the will of the coordinator to continue this EG.
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 therefore 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. However, during the year 2021 no meeting was organized and therefore an action was decided during the last RC-GoR meeting in October 2021 in order to verify the will of the coordinator to continue this EG.
RC/EG-41	*Noise Radiation and Propagation for Multirotor System Configurations* The objective is to investigate noise radiation and propagation (installation effect) of multirotor systems. 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 list of interested parties was established in 2020. During the year 2021 this EG proceeded at a good pace, the interest on the topic was confirmed to be high and a wide partnership was identified. The EG kick-off meeting was held on March 2021. A draft version of the ToR was submitted and some amendments were requested by the RC GoR members before the official delivery of the document. Furthermore, all RC GoR members agreed to promote this EG to an Action Group, RC/AG-26, for a possible start in January 2022, provided the approval from the GARTEUR XC.
RC/EG-42	*Analysis and Decomposition of the Aerodynamic Force Acting on Rotary Wings* 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 allocable 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. A draft version of the ToR was prepared and will be discussed among the identified partners in January 2022.

New topics under consideration are:

Modelling of electric systems for e-VTOLS (pre-design)

To provide simple relations for considering the electric system of eVTOLs in predesign.

Drone impact on Helicopters (rotating parts)

To gain insight in the severity level of drone rotor blade interactions.

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 pressure and temperature sensitive paint in rotorcraft wind tunnel tests.

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. For these reasons, the RC GoR members proposed to investigate at national level the possibility to organize a GARTEUR workshop about these topics.

5.4.3 GoR-RC Membership

The membership of GoR-RC in 2021 is presented in the table below.

Chairperson		
Joost Hakkaart (01/01/21– 30/06/21)	NLR	The Netherlands
Antonio Visingardi (01/07/21 –)	CIRA	Italy
Members		
Barbara Ohlenforst (01/07/21 –)	NLR	The Netherlands
Mark White	Uni. of Liverpool	United Kingdom
Arnaud Le Pape	ONERA	France
Klausdieter Pahlke	DLR	Germany
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 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, only a few new ideas were proposed and explored during the year 2021.

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:

- Fatigue and damage tolerance assessment of hybrid structures
- Damage repair with composites in composite and metallic structures
- 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
- Additive Layer Manufacturing
- Structural health monitoring for hydrogen aircraft tanks

5.5.2 GoR-SM Activities

In 2021, GoR/SM monitored the following Action Groups:

SM/AG-34	**Damage repair with composites** This Action Group started in the second half of 2012 and originated from SM/EG-40. The main objective of the work consists in the definition of effective repair techniques both for civil and military aircraft structures through the development of numerical/experimental methodologies. There has been no activity in the past two years but the work was almost completed. The final version of the final report was issued in November 2021 and approved at the Council Meeting C71 on November 17, 2021. The Group is closed.
SM/AG-35	**Fatigue and Damage Tolerance Assessment of Hybrid Structures** This Action Group started in March 2012 and is a result from SM/EG-38. The final report is ready and still have to be transferred under the GARTEUR format.

The following Exploratory Groups are running:

SM/EG-44	**Characterization of composites with polymer matrix at high temperatures** 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. An Action Group will probably be launched in continuation of the still running EU-project SuCoHS, delayed mid-2022.
SM/EG-45	**Characterization and modelling of CMC submitted to severe thermo-mechanical loading** The main 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 (>1000°C).
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 damping 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 Work program for an Action Group focused on “Characterization and optimization of shock absorbers for industrial applications” is almost finalised.
SM/EG-47	**Additive Layer Manufacturing** The Work program for an Action Group (SM/AG-36) to be launched beginning of 2022 is ready. It deals with new Novel aluminium alloys 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 alloy will be investigated in Laser Powder Bed Fusion (L-PBF) and Directed Energy Deposition (DED).
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.

5.5.3 GoR-SM Membership

The membership of GoR-SM in 2020 is presented in the table below.

Chairperson		
Florence Roudolff	ONERA	France
Members		
Bert Thuis	NLR	Netherlands
Aniello Riccio	SUN	Italy
Javier San Millan	INTA	Spain
Peter Wierach	DLR	Germany
Thomas Ireman	SAAB	Sweden
Mats Dalenbring	FOI	Sweden
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 18th November 2021

GARTEUR Chair Country 2020-2021: Netherlands
Council Chair: Mr. E. Nijenhuis

XC Chair: Mr. Harmen van der Ven
Secretary: Ms. Ligeia Paletti

GARTEUR COUNCIL							
Function	**France**	**Germany**	**Italy**	**Netherlands**	**Spain**	**Sweden**	**United Kingdom**
Head of Delegation	J. L'Ebraly	T. Rüggeberg	G. De Matteis	E. Nijenhuis	R. Gonzalez Armengod	R. Stridh	P. Griffiths
XC Member	O. Vasseur	J. Bode	P. Renzoni	H. van der Ven	A. Coronel Granado	A. Wahlström	M. Scott
Other Members of Delegation	P. Beaumier	H. Hemmer A. Manecke		C. Beers L. Paletti	J.F. Reyes-Sánchez R. Garcia	M.O. Olsson D. Faria	N. Bhadasia S. Weeks 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**	
K. Richter	DE	**A. Vozella**	IT	**R. van Enkhuizen**	NL	**A. Visingardi**	IT	**F. Roudolff**	FR
G. Mingione	IT	E. Oliva	SP	C. Doll	FR	M. White	UK	B. Thuis	NL
F. Monge	SP	J.C. Dauer	DE	B. Korn	DE	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						
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								

Appendix A: Annex GoR-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 2021 five Action Groups (AD/AG-56, AD/AG-57, AD/AG-58, AD/AG-59, AD/AG-60) and one Exploratory Group (AD/EG-78) were active. Details about these groups can be found below.

Another task of the GoR is the interaction with the other GoRs by promoting interdisciplinary topics. An example of such a topic are the aero-servo-elastic simulations conducted in AD/AG-56. The chairs of the different GoRs interact during the Council meetings or meet in specific sessions dedicated to new multi-disciplinary topics.

New ideas for research may be formulated by GoR members or arise within the 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.

In 2021, several ideas for possible new groups were on the table. Among those that have not yet resulted in an EG are: Morphing for Load Control of High Aspect Ratio Wings, Immersed Boundary Simulations, Hypersonic Flows, Thermal Management for Electric Propulsion, Corner Flows, Human Droplet Dispersion, and Virtual Certification.

Activities in 2021 were affected by the worldwide COVID-19 pandemic and the progress of most AGs and EGs has slowed down due to these circumstances. Some of the working groups needed to be extended. Since the pandemic continues in 2022, further delays and extensions of AGs and EGs may be necessary.

Management

Four meetings have been held in 2021. Due to the COVID-19 pandemic, all meetings were held online:

1) AD/A-106 Meeting on 22nd of January 2021
2) AD/A-107 Meeting on 7th of April 2021
3) AD/A-108 Meeting on 1st of July 2021
4) AD/A-109 Meeting on 26th of October 2021

An average of nine GoR members were able to attend these meetings, with three of them from industry. In addition, an average of two AG/EG chairpersons attended each meeting in order to give a technical update about the current status of the working groups.

For the period 2020 – 2021 the chairs are:

Chair: Kai Richter, DLR
Vice-Chair: Giuseppe Mingione, CIRA

The industry representatives of Leonardo Aircraft (ITA) and SAAB (SWE) left the GoR due to retirement. The new points of contact are Peter Eliasson (SAAB) and Riccardo Gemma (Leonardo Aircraft). There is still no

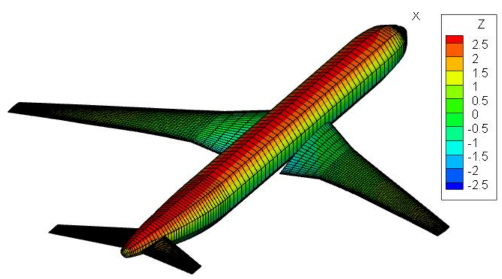
British representation in the GoR. This is a point of concern, as British input in both the GoR and the Action Groups is valuable and has always been much appreciated.
Future meetings in 2022 are envisaged as two full-day physical meetings and two half-day online meetings for the time being. However, the realization of physical face-to-face meetings of course depends on the future development of the COVID-19 pandemic. The first physical meeting is planned for the 16th/17th of March 2022 in Stockholm (Meeting AD/A-110).

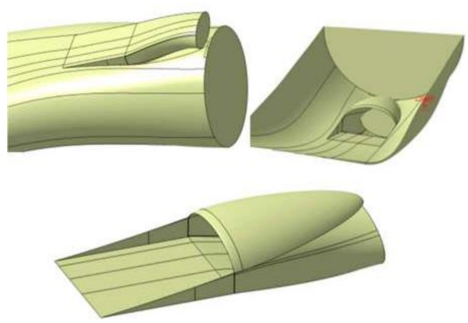
Dissemination of GARTEUR activities and results

The final report of AD/AG-54 “RANS-LES Interfacing for Hybrid and Embedded LES Approaches” has been published in 2021.

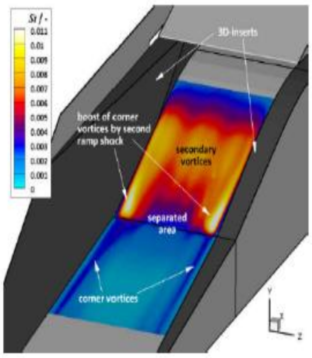
Status of Action Groups and Exploratory Groups

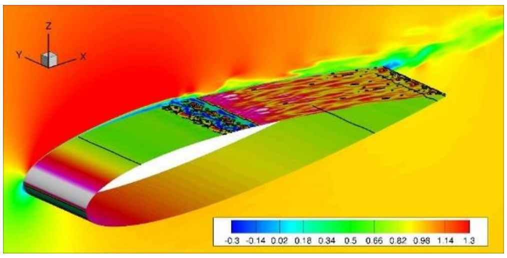
Five Action Groups and one Exploratory Group were active in 2021. In November 2021, the Exploratory Group was approved by the Council to become Action Group AD/AG-61.

AD/AG-56	Coupled Fluid Dynamics and Flight Mechanics Simulation of Very Flexible Aircraft Configurations
	Very flexible aircraft are light-weight constructions that require multi-disciplinary design tools. Main objectives of AD/AG-56 are to enhance the partners’ capabilities in aeroelastic simulations to more accurately predict aerodynamic loads and structural deformations for manoeuvre and disturbance conditions, and to allow for the benchmarking of inhouse tools amongst the partners through the use of a common research model. In 2021, partners have run trim simulations using their methods with either rigid aircraft models or the flexible aircraft model. The chairperson is Richard van Enkhuizen (NLR).

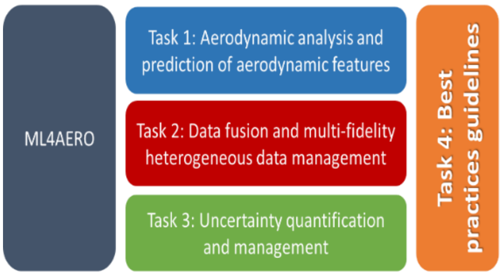
AD/AG-57	Secondary Inlets and Outlets for Ventilation
	Aircraft require a variety of secondary air inlets and outlets mostly for environmental control systems, APU operation, ventilation and cooling purposes. Main objectives of AD/AG-57 are to analyse and improve the efficiency of conventional secondary air inlets for different applications on fuselage and wing, and to explore the feasibility of new low-observable concepts hidden within the main engine intake. In 2021, the scientific activities came to the end and the final report has been written.

	The chairperson is Jose Angel Hernanz-Manrique (Airbus Operations).

AD/AG-58	Supersonic Air Intakes
	Supersonic air intakes are of foremost importance in the design of supersonic air-breathing vehicles. Main objectives of AD/AG-58 are to gather a database of relevant flow features on representative test cases and to validate CFD codes on these specific topics. Investigations include the control of cowl oblique shock / boundary layer interactions, internal bleed flows, and effects of intake diffusers and scramjet isolators. In 2021, extensive RANS and ZDES simulations have been performed for different test cases. The duration of the working group was extended by one year. The chairperson is Christophe Nottin (MBDA).

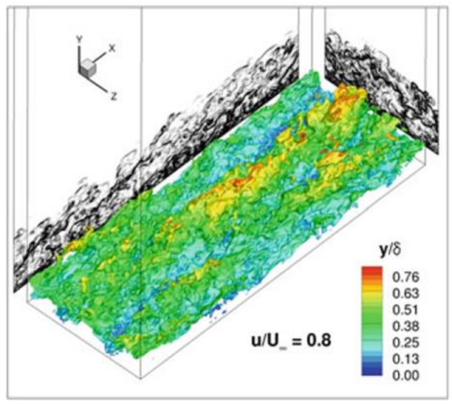
AD/AG-59	Improving the Simulation of Laminar Separation Bubbles
	Laminar separation bubbles are one of the main critical aspects of flows at low Reynolds number, of order of magnitude 10^4 to 10^5, which are relevant for small aircraft such as UAV. Main objectives of AD/AG-59 are advancements in the understanding of the evolution of laminar separation bubbles and their effect on airfoil flows, and the improvement of the numerical prediction of flows with laminar separation bubbles. In 2021, activities comprised the analysis of wind tunnel experiments in WP 1 and numerical investigations for various test cases in WP 1 to WP 4. A new transition model has been developed. The chairperson is Pietro Catalano (CIRA).

AD/AG-60	Machine Learning and Data-Driven Approaches for Aerodynamic Analysis and Uncertainty Quantification
	Aerodynamic analysis and uncertainty quantification are key capabilities used in aircraft design. Main objectives of AD/AG-60 are the improvement of machine learning (ML) capabilities and valuable knowledge of the selected data-driven techniques in aerodynamic analysis and uncertainty quantification.



Through the proposed activities it is expected that best practice guidelines will be concluded and the use of ML methods is facilitated in the aeronautical industry. The AG started in 2021. An XRF1 database has been provided by AIRBUS. The work focuses on the assessment of different ML techniques for the prediction of the Cp using the XRF1 aerodynamic data. The chairperson is Esther Andrés (INTA).

AD/EG-78	Hybrid RANS/LES methods for WMLES and Embedded LES



For future aircraft design and certification, wall-bounded turbulence-resolving hybrid RANS/LES methods are of particular interest for the prediction of flow phenomena related to aeroacoustics, unsteady loads, mild flow separations or boundary layers undergoing strong adverse pressure gradients. A work programme is developed in order to enhance the capabilities of wall-modelled LES and embedded LES. In 2021, the AG proposal has been finalized and was approved by the Council. AD/AG-61 will start in the beginning of 2022.
The chairperson is Nicolas Renard (ONERA).

Rolling plan

No.	Topic	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
AD/AG-54	RANS-LES Interfacing Hybrid RANS-LES and Embedded LES Approaches										
AD/AG-55	Countermeasures Aerodynamics										
AD/AG-56	Coupled Fluid Dynamics and Flight Mechanics Simulation for Very Flexible Aircraft			EG-72 →							
AD/AG-57	Secondary Inlets and Outlets for Ventilation			EG-73 →							
AD/AG-58	Supersonic Air Intakes				EG-75 →						
AD/AG-59	Improving the Simulation of Laminar Separation Bubbles				EG-76 →						
AD/AG-60	Machine Learning and Data-Driven Approaches for AO and UQ						EG-77 →				
AD/EG-78 AD/AG-61	Hybrid RANS/LES methods for WMLES and Embedded LES						EG-78 →				

GoR membership

Chairperson		
Kai Richter	DLR	Germany
Vice-Chairperson		
Giuseppe Mingione	CIRA	Italy
Members		
Eric Coustols	ONERA	France
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
Luis P. Ruiz-Calavera	AIRBUS D&S	Spain

Table of participating organizations

	AG-56	AG-57	AG-58	AG-59	AG-60	EG-78
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					☐	

Total yearly costs of AG research programmes

AG	2018		2019		2020		2021	
	pm	k€	pm	k€	pm	k€	pm	k€
54	12	50						
55	4	5						
56	14	7	12	14	12	14	12	14
57	21	29	22	29	22	29	22	29
58			13		13		13	
59			16	9	21	13	21	13
60							13	11
TOTAL	55	94	63	53	69	56	69	56

Action Group Reports

AD/AG-56	**Coupled fluid dynamics and flight mechanics simulation of very flexible aircraft configurations**
Monitoring Responsable:	H. Van der Ven NLR
Chairman:	M.J. van Enkhuizen 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 fig. 1). For the FEM model, wing elasticity has been modified for increased tip deflections; aiming for 10 percent tip deflection in 1g flight (see fig. 2). 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 fig. 3).

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 will continue their work to calculate the trimmed 1g flight using the flexible aeroplane for the two flight conditions of interest. Results will be compared, after which the disturbance and control deflection conditions will be performed for rigid and aeroelastic models. Simultaneously panel code simulations will be performed.

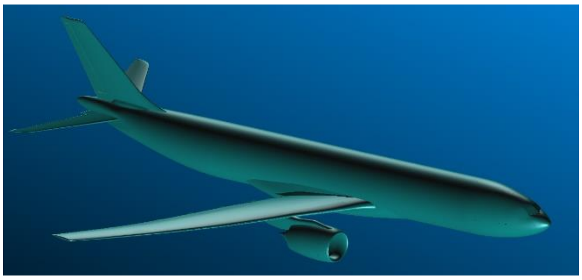


Fig. 1 The CAD geometry of the XRF-1.

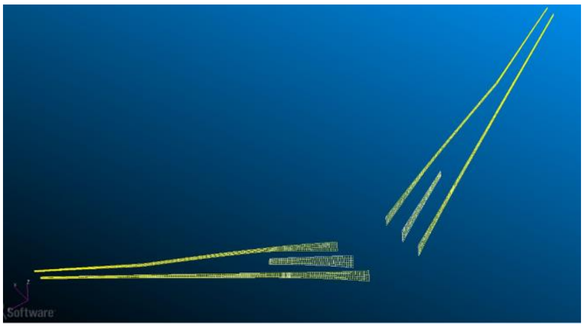


Fig. 2 Depiction of the wing structure in the FEM model. The elasticity of the front and rear spar is tuned for 10 percent tip deflection in 1g flight.

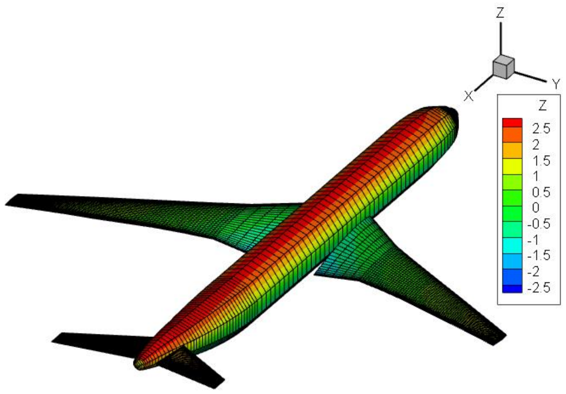


Fig. 3 Panel model used to tune the wing structure for 10% tip deflection for worst-case gust.

- **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.

- **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**

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MJ. van Enkhuizen	NLR	richard.van.enkhuizen@nlr.nl
Cédric Liauzin	ONERA	cedric.liauzun@onera.fr

- **Resources**

Resources		Year					Total
		2018	2019	2020	2021	2022	
Person-months	Actual/ Planned	14 14	8 12	1 12	8	8	38
Other costs (in K€)	Actual/ Planned	7 7	7 14	1 14	10.5	10.5	36

- **Progress/Completion of milestones**

Mile stone	Actual
MS 1: Access to common research model	Completed
MS 2: Completion of CAD model for CFD mesh generation	Completed
MS 3: Completion of FEM model for simulations	Completed
MS 4: Panel code lower fidelity free-free simulations (disturbance)	
MS 5: Initial CFD 1g static aerodynamic analyses around flight shape	
MS 6: Rigid structure CFD simulations (manoeuvre + disturbance)	
MS 7: Aeroelastic CFD simulations with linear structure (manoeuvre + disturbance)	
MS 8: Aeroelastic CFD simulations with non-linear structure (manoeuvre + disturbance)	
MS 9: Generation of MDO optimized linear XRF-1 aircraft model	
MS 10: Aeroelastic CFD simulations with MDO optimized linear structure (disturbance)	
MS 11: Cross-plotting and analysis of all results	
MS 12: Final report	

AD/AG-57	**Secondary Air Inlets and Outlets**
Monitoring Responsable:	G. Mingione CIRA
Chairman:	A.Carozza CIRA

- **Background**

Aircraft capture outside air for the purpose of air conditioning, ventilation and cooling. This is achieved by means of secondary air inlets. Their shapes differ widely depending on integration possibilities, performance requirements and minimization of interference effects (including drag). In case of transport aircraft (civil and military), it is expected that the capabilities of secondary air inlets have to increase considering the tendency to replace bleed air from the main engines by the acquisition of outside air for air-conditioning purposes. This tendency is also driven by the requirement to prevent fumes from entering the cabin as well as to create a possibility to utilise engine bleed air for active flow control purposes.
In case of combat aircraft, the significant use of composite materials for structural parts and their inability to convect/dissipate heat in combination with increasing energy consumption of on-board equipment generates a novel cooling challenge. Here, the integration of secondary air inlets that provide an increased mass flow is predominantly determined by low-observable aspects, since these inlets are critical components for advanced combat aircraft with high requirements for reduced radar signature. The hidden integration of secondary inlets points towards an installation inside the main engine air intake. Such a configuration would considerably reduce the radar cross section of the aircraft on the one hand, but requires additional attention to the quality of the intake flow field and to engine/intake-compatibility on the other hand.

- **Objectives**

Analyse the efficiency of a submerged NACA type air intake for multiple flight envelopes using state-of-the-art CFD and performance evaluation methods. Investigate whether such an air intake can comply with novel requirements for air-conditioning for large transport aircraft (civil and military).
Analyse the feasibility of a low-observable secondary inlet integrated in the main air intake duct of a combat aircraft and assess the impact on the intake duct flow field and on engine/intake-compatibility. Investigate different types of secondary inlets, shapes, locations, and sizes with respect to advantages regarding radar cross section and aerodynamic performance.

- **Approach**

The focus is placed on the methods based on the Reynolds Averaged Navier Stokes (RANS) equations. The capabilities of secondary air inlets for transport aircraft (civil and military) and combat aircraft will be investigated in terms of mass flow rates for a wide range of flow conditions.
Different methodologies both for drag computation and geometries design will be also considered.

- **Management issues**

The kick-off meeting was held at Manching, Munich, Germany in Airbus Defence and Space Factory on May 16th and 20th 2018. The first annual progress meeting has been held on-line on September 2018. The next progress meeting has been held in Amsterdam at NLR on May 9th to 10th May 2019. The last online review meeting has been held on September 2019. In 2020, the chairman Jose Hernanz Manrique form Airbus (Madrid, Spain) left the group and has been replaced by Antonio Carozza from CIRA (Italy) with the support by Alvaro Rodriguez from Airbus as a vice-chairman. Because of the COVID-19 pandemic all the activities have been stopped up to the early 2021. In 2021, there was a series of bimonthly progress meetings to collect material useful to write the final report regarding the activities from each partner.

- **Expected results/benefits**

A code to code comparison has been done in order to investigate and establish the best approach to analyse the performance of secondary inlets and outlets for both military and civil aircrafts.
The final report has been completed and now is under review.

- **AD/AG-57 membership**

Member	Organi-sation	E-mail
A.Carozza	CIRA	a.carozza@cira.it
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A.J.H. Rodriguez	Airbus	alvaro-joaquin.al.rodriguez-hidalgo@airbus.com
R. Ehrmayr	Airbus	robert.ehrmayr@airbus.com
U. Krause	Airbus	udo.krause@airbus.com
H. Maseland	NLR	Hans.Maseland@nlr.nl
J. Himisch	DLR	Jan.Himisch@dlr.de

- **Resources**

	Year				Total
Resources planned	2018	2019	2020	2021	
Person-months	3	3	3	3	12
Other costs	1	1	1	1	4

AD/AG-58	**Supersonic Air Intakes Aerodynamics**	
Monitoring Responsable:		D. Pagan MBDA
Chairman:		C. Nottin 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. The final report is now expected in February 2023. 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 1.
Several RANS computations were performed by ONERA. Inlet flow profiles are now available to all partners, see Figure 2. 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, …).

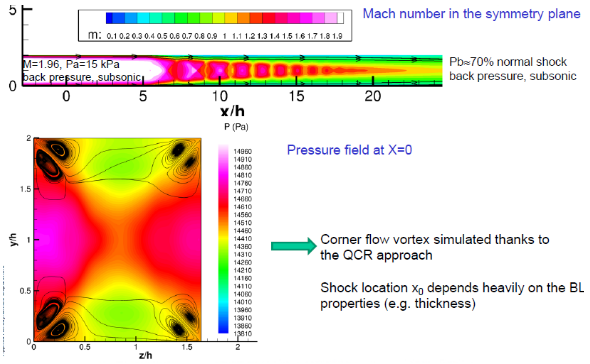

Fig. 1 Shock train in a rectangular cross-section channel. ONERA test-case.

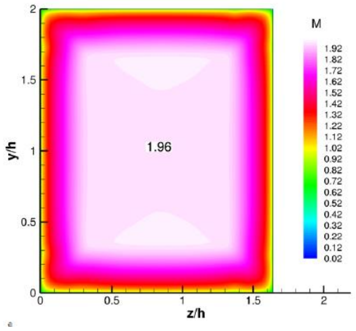

Fig. 2 Common inlet flow field proposed by ONERA for shock train case computations.

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 Boussinesq 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 τ_{ij} are the turbulent stresses computed from the Boussinesq relation, and O_{ik} is an antisymmetric normalized rotation tensor, defined by:

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

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

Fig. 3 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 (cf. Fig. 3).

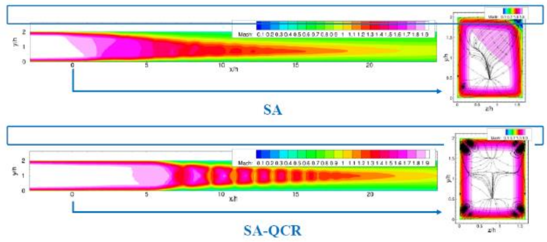

Fig. 3 Effects of QCR closure with the Spalart Allmaras model on corner flows and shock train development for WP2 test-case (ONERA).

Comparisons of CFD predictions with available pressure measurements and published DNS results show local improvements with the non-linear closure of the turbulence model (cf. Fig. 4 and Fig.5).

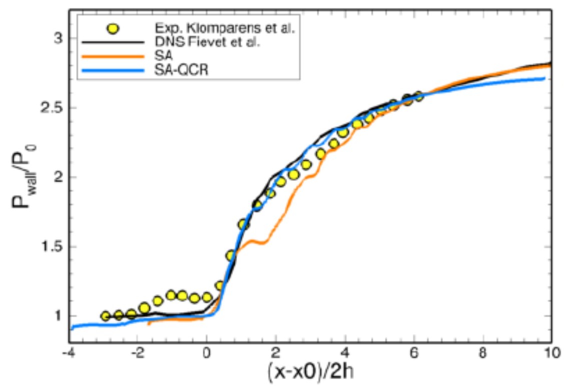

Fig. 4 Effects of QCR closure with the Spalart Allmaras model and comparison with wall pressure measurements (ONERA).

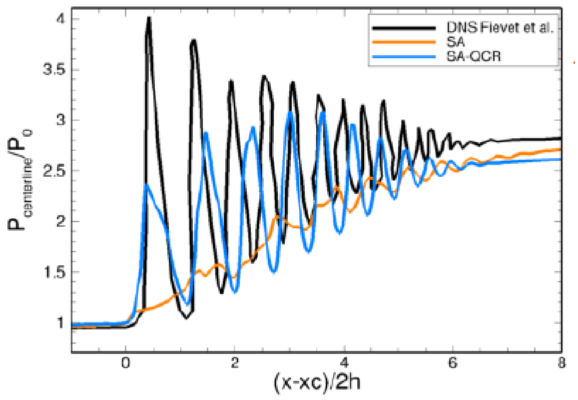

Fig. 5 Effects of QCR closure with the Spalart Allmaras model and comparison with axial pressure computations from DNS published by Fiévet et al. (ONERA).

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

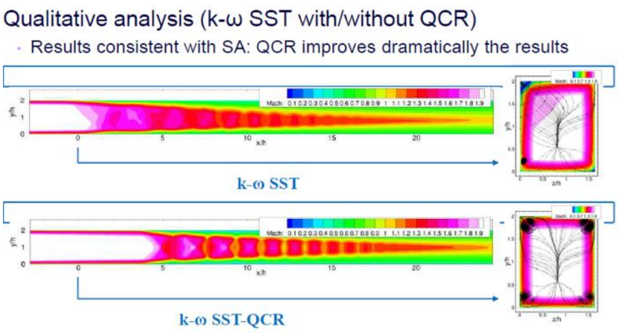

Fig.6 Effects of QCR closure with the k-omega SST model on corner flows and shock train development for WP2 test-case

These results (see fig.6) confirm the trends from previous results obtained with SA model. QCR correction leads to strong improvement regarding corner flow effects (see fig.7)

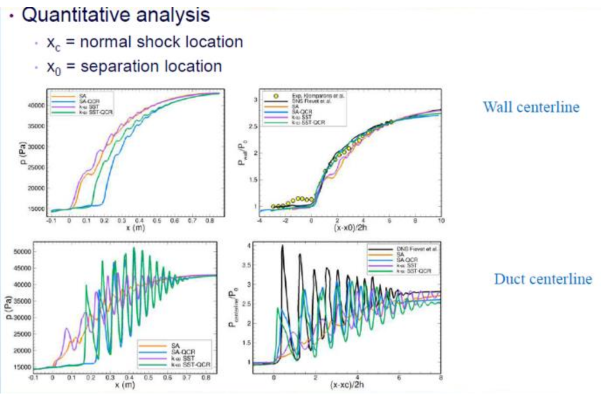

Fig. 7 Effects of QCR closure with the k-omega SST model and comparison with wall pressure measurements and SA/SA-QCR results.

Further investigations will be made on Reynolds Stress Model (RSM) and final issue regarding ZDES computations are on-going work at ONERA (see fig. 8)

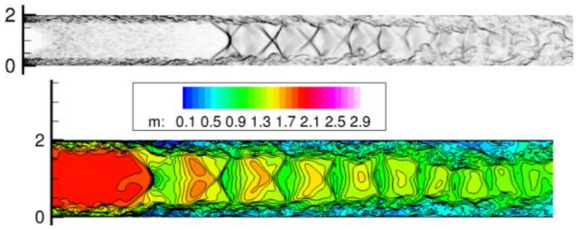

Fig. 8 Ongoing ZDES simulations on WP2.

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 8.

- Two-dimensional ramjet inlet for use in air-to-air missile (similar to Meteor)
- Design point of baseline configuration: Mach 3
- Modular design for configurations from 3 ≤ Ma ≤ 4.5 in steps of ΔMa = 0.5
  - Achieved by exchanging ramp and cowl components
- Self-startable, self-start Mach number Ma = 2.1
- Contraction limit at Ma = 3 is 21.8%
- Contraction ratio about 10%
- Angle of attack: -6° ≤ α ≤ +6°

General dimensions

Ma [-]	# of ramps	δ_1 [°]	L_1 [mm]	δ_2 [°]	L_2 [mm]	δ_3 [°]	L_3 [mm]	L_{total} [mm]
3.0	2	9.0	49.9	15.1°	72.5	-	-	430.2
3.5	2	11.0	56.9	15.9	72.5	-	-	488.8
4.0	3	11.0	56.9	13.1	13.0	15.2	72.5	498.9
4.5	3	11.0	56.9	11.2	25.4	18.1	72.5	543.1

Mach 3 geometry

component	starting point		end point	
	x [mm]	y [mm]	x [mm]	y [mm]
1st ramp	0.0	0.0	49.32	7.81
2nd ramp	49.32	7.81	119.32	26.72
1st transition circle	119.31	26.72	159.92	32.11
2nd transition circle	159.91	32.11	177.32	31.05
diffusor	117.31	31.05	430.18	0.0

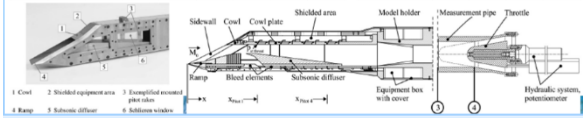

Fig. 8 DLR experimental model for the Mach 3 ramjet intake.

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).

- T_{t0} = 290 K, p_{t0} = 5.8 bar, $Re_\infty = 40.8 \cdot 10^6$ 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 (cf. Fig. 9):

- Schlieren images
- Wall pressure measurements
  - 34 pressure ports along centreline of ramp, cowl and diffuser
  - Static pressure measurements with 8400 PSI System by Pressure Systems
  - 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.

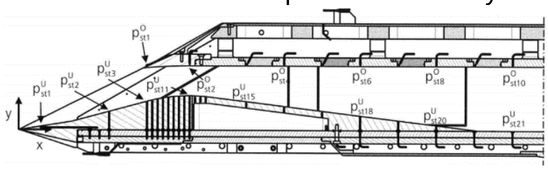

Fig. 9 DLR experiments with measurements and rakes location.

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

Table 4 Measurement uncertainties of throttle device

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 Fig. 10.

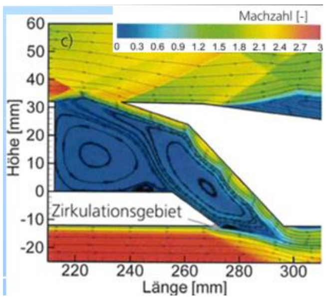

Fig. 10 Illustration of Mach number of the internal flow inside the bleed (DLR).

The 3D CAD file, ready to mesh, has been provided to all members (see. Fig. 11)

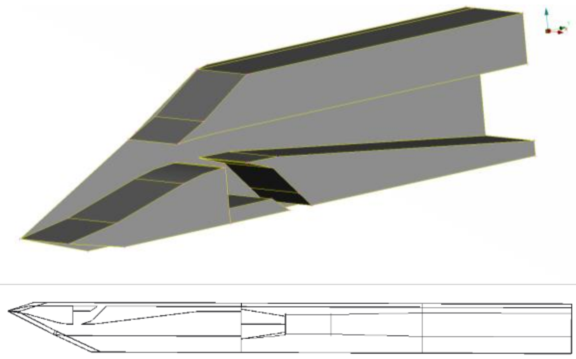

Fig. 11 CAD provided by DLR for the WP3 computation (open bleed case).

The CAD extension down to the throttling device (plug) has been provided as an option so that throttling 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.

WP4 : Mach 7.5 scramjet intake

The proposed test-case is illustrated on the Figure 12.

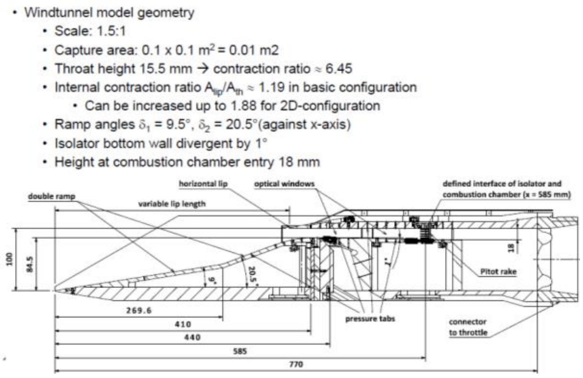

Fig. 12 DLR experimental model for the scramjet Mach 7.5 intake

One topic for WP4 will be the aerothermal fluxes prediction and effects of sidewalls compression, see some examples of experimental results on Figure 13. 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).

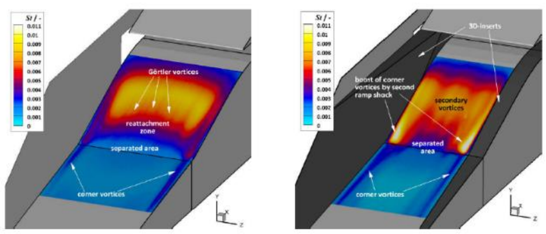

Fig. 13 DLR experiments on the scramjet intakes, with IR thermography. Effect of sidewalls compression on heat fluxes and corner flow.

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.

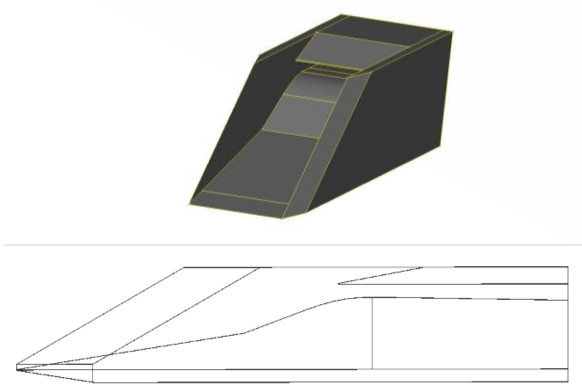

Fig. 14 CAD provided by DLR for the WP4 computation (closed bleed case).

- **Expected results/benefits**

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

- **AD/AG-58 membership**

Member	Organisation	e-mail
Patrick Gruhn	DLR	patrick.gruhn@dlr.de
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- **Progress/Completion of milestones**

Milestones	Planned		Actual
	Initially (end of …)	Currently (updated)	
WP1: Kick-off meeting	Q4 2018	February 2019	Done
WP1: 2020 Meeting	Q1 2020	January 2020	Done
WP1: 2021 1st Meeting	Q1 2021	April 2021	Done
WP1: 2021 2nd Meeting	Q4 2021	Q4 2021	Postponed
WP1: 2022 1st Meeting	Q1 2022	Q1 2022	Not started
WP1: 2022 2nd Meeting	Q3 2022	Q3 2022	Not started
WP1: Final report and meeting	February 2022	February 2023	Not started
WP2: Definition of a numerical case for shock train computations	Q1 2019	Q1 2019	Done
WP2: Each member to prepare his grid and obtain RANS computations	Q4 2019	Q2 2022	In progress
WP2: DES computations	Q3 2020	Q3 2022	In progress
WP3: Fix experimental conditions and provide CAD file	Q3 2019	January 2020	Done
WP3: Each member to prepare his grid and obtain preliminary computations	Q4 2020	Q2 2022	In progress
WP3: Final computations	Q3 2021	Q4 2022	Not started
WP4: Fix experimental conditions and provide CAD file	Q4 2019	January 2020	Done
WP4: Each member to prepare his grid and obtain preliminary computations	Q4 2020	Q2 2022	Not started
WP4: Final computations	Q3 2021	Q4 2022	Not started

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

- **Background**

The laminar separation bubble is one of the main critical aspects of flows at Reynolds number of order of magnitude 10^4-10^5. 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 CO_2 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 f^{tr} 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=6.0x10^4 and α=4°, NACA0015 airfoil at Re=1.8x10^5 and α=5° and 10°, and the Eppler 387 at Re=3.0x10^5 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=3x10^3 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=6.0x10^4 and α=4° over the NACA 0015 airfoil at Re=1.8x10^5 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**

A review meeting has been held on-line on July 9th 2021 Univerisy of Napoli "Federico II", Technical University of Marche, CNR-INM and Imperial College were not able to participate, but all the other partners have presented an update of their activiries.

University of Napoli "Federico II" and ONERA do not have man-power for the project.

The test case TM1 (NACA 0012 airfoil) has been cancelled and replaced with more activities for the TC O1c (NACA 0015 airfoil)

- **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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S. Hein	DLR	stefan.hein@dlr.de
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R: Tognaccini	University of Napoli	rtogna@unina.it
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Yannick Hourau	University of Strasbourg	hoarau@unistra.fr

- **Resources**

	Year			Total
Resources planned	2019	2020	2021	
Person-months	16	21	21	58
Other costs	9.3	12.5	14	35.8

- **Progress/Completion of milestones**

Milestone	Planned	Actual
MS 1: first assessment of models)	T0+36 (new planning)	75%
MS 2: Results for optional test cases of WP 1	T0 + 27	Achieved
MS 3: Results for test cases of WP 2	T0 + 29	Achieved for TC M2b. TC M2a has been deleted
MS 4: Results for mandatory test cases of WP 1	T0 + 30	Achieved for TC M0 and deleted for TC M1
MS 5: Results for 2D test cases of WP 3	T0 + 21	Deleted
MS 6. Results for 3D test case of WP 3	T0 + 27	Achieved

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

- **OBJECTIVES**

The objective of this Action Group is to investigate the potential application of machine learning and data-driven approaches for aerodynamic analysis and uncertainty quantification.

- **MAIN ACHIEVEMENTS**

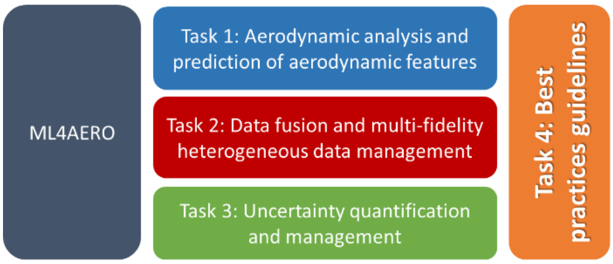
The AD/AG60 took off in February 2021

Eleven members participate in this Action Group: eight research establishments and universities (CIRA, NLR, INTA, DLR, FOI, ONERA, IRT, and INRIA), and three from industry (AIRBUS-Military, AIRBUS and OPTIMAD).

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.

The activities of this AG have been structured in four main tasks, according to the three defined objectives:



The AIRBUS XRF1 configuration is used as the common test case for methods comparison.

Two databases will be 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.

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.

The methods to be 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 modelling 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

Current status:

- All partners have now access to the XRF1 data
- DB1 has been delivered in May by AIRBUS.
- An intermediate report “CFD and WTT database of XRF1” has been delivered in May.
- An AG60 meeting is expected in February 2022.

Next steps:

- Partners are currently working on task 1 & task 2.
- Comparative studies will be conducted for machine learning models evaluation, and proper error measurement.
- A MS on this topic is being organised at ECCOMAS 2022.

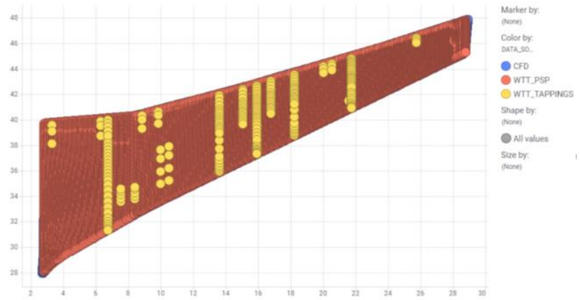


Figure 1: XRF1 dataset (CFD and WTT data)

- **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**

- U. Twente left the project (“the requests on Airbus side are not complying with the university internal rules”).
- DB1 has been delivered but it is not complete. AIRBUS is working in adding simulation points to the database.
- DB2 generation is still in progress (it is delayed).

- **MEETINGS**
  - AG Kick-off: webex meeting, 9th February 2021
  - Database webex meeting, 11st May 2021
  - Task 3 meeting, 16th June 2021
  - AG Follow-up meeting: 14th October 2021
  - Next webex meeting will take place on the 24th of February 2022.

- **AD/AG-60 MEMBERSHIP**

Country	Organization	PoC
THE NETHERLANDS	NLR	Robert Maas
FRANCE	ONERA	Jacques Peter
	IRT	Anne Gazaix
		Matthias De Lozzo
	INRIA	Angelo Iollo
ITALY	CIRA	Domenico Quagliarella
		Pietro Catalano
		Mattia Barbarino
	OPTIMAD	Haysam Telib
		Alessandro Alaia
		Angela Scardigli
GERMANY	DLR	Philipp Bekemeyer
SWEDEN	FOI	Olivier Amoignon
		Boban Pavlovic
SPAIN	AIRBUS-Military	Sergio de Lucas Bodas
		Daniel González
	AIRBUS	Daniel Redondo Marta Gonzalez Blanca Martinez
	INTA	Esther Andrés

- **RESOURCES**

Resources	Year		Total
	2021	2022	
Person-months	24	24	58
their costs (in K€)	62	62	124

AD/EG-78	**Hybrid RANS/LES methods for WMLES and Embedded LES**
Monitoring Responsable:	E. Coustols (ONERA)
Chairpersons:	N. Renard (ONERA) S.-H. Peng (FOI)

The GARTEUR AD/EG78 was established to make progress towards the industrial use of hybrid RANS/LES and embedded LES methods for turbulence modelling where the fluctuations in the outer region of attached boundary layers are LES-resolved rather than RANS-modelled, unlike the former AD/EG54 which focused more on RANS representations of attached boundary layers. The approaches considered here may be seen as Wall-Modelled Large Eddy Simulation strategies (the model is the RANS near-wall region) compatible with the RANS treatment of other regions of the flow, which is key to obtain a computationally affordable and simple-to-use scale-resolving approach.

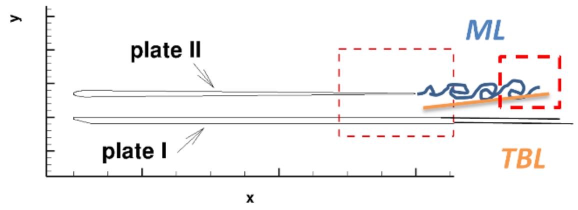
- **Objectives**

The long-term objective of the proposed Action Group is to facilitate the introduction in the industry of hybrid RANS/LES methods resolving wall-bounded turbulence for design and certification processes, which is needed for the prevision of phenomena such as aeroacoustics, unsteady loads, mild flow separations or boundary layers undergoing strong adverse pressure gradients. Several elements must be improved to reach this objective:

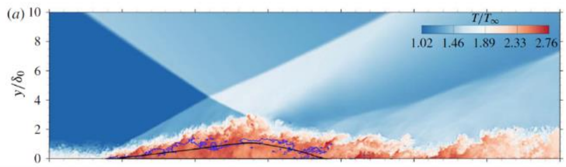
- Resolved turbulence injection near the upstream boundary of (WM)LES domains
- Prediction of mild flow separation on a smooth surface
- Interaction between resolved wall-bounded turbulence and a shock wave
- Prediction of wall pressure fluctuations
- Applicability to multi-domain curvilinear geometries
- Interaction between modelled and resolved turbulence, mitigation of the *log layer mismatch*

The activities of this AG have been structured in two work packages, one for the project management, communication and reporting, the second one for the test cases. The above elements are addressed by means of the following four test cases :

TC1: Mixing co-flow of wake and Boundary Layer

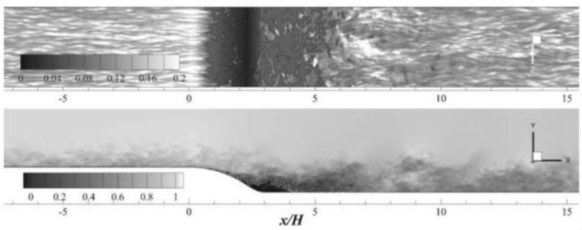


TC2: Shock Wave-Boundary Layer Interaction



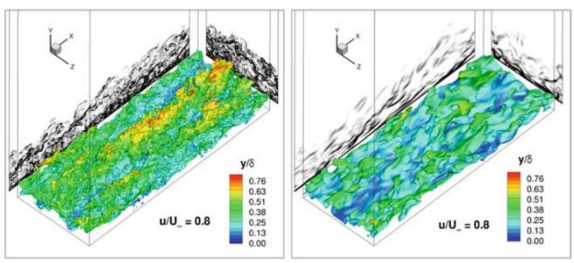
PASQUARIELLO ET AL. (JFM 2017)

TC3: Shallow flow separation from a smooth surface



BENTALEB ET AL., JOT 2012

TC4: Fundamental WMLES test case – ZPG flat-plate boundary layer



- **Progress**

An Exploratory Group first meeting took place in Stockholm on the 28/29th of November 2018, followed by email interactions with the sanitary crisis causing some delay to finalize the process. As a result of the Exploratory Group, a proposal for the establishment of an Action Group (AD/AG-61) has been prepared and approved on the 18th of November 2021. The (virtual) kick-off meeting of AD/AG-61 will take place on the 12th of April, 2022. The initial duration of the project is three years and a half.

- **Benefits**

This AG is expected to contribute to the introduction of hybrid RANS/LES and embedded LES methods with wall-bounded turbulence resolution into the industry thanks to progress made on the key elements identified above. Beyond the final report of the AG, publications both in conferences and in peer-reviewed journals may also be expected.

- **AG/EG-78 membership**

The action group consists of eight partners, including seven research establishments (ONERA, FOI, CIRA, DLR, NLR, University of Manchester, Université de Strasbourg) and one industrial partner (SAAB).

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FRANCE	ONERA	Nicolas Renard Sébastien Deck	nicolas.renard@onera.fr sebastien.deck@onera.fr
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UK	University of Manchester	Alistair Revell	alistair.revell@manchester.ac.uk

- **Resources planned**

Resources	Year			Total
	2022	2023	2024	
Person-months	17.5	19	17	53.5
Other costs (incl. CPU) (in k€)	84	84	77	245

Appendix B: Annex GoR-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 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-AS Overview

During 2020 work has been done by the active members (CIRA, ONERA, INTA) on the following research theme:

Malevolent use of RPAS

The approach in 2020 has aimed at keeping links with other running initiatives like ES4AWG, Optics2 project, ACARE WG4.

Furthermore, the chairperson has started to attend 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 start the work in the funded project and to work on a proposal preparation. The investigated topics have been kept:

- in line with FlightPath 2050;
- further dealt in the ACARE SRIA update and its dedicated Challenge on Aviation Safety & Security;
- fitting with the PADR (Preparatory Action for defence research) in Horizon 2020 and FP9;
- aligned with EREA Security for Aviation initiative;
- a priority for Europe.

The main actions in 2020 were:

1. To further develop and share ideas among the active members (CIRA, ONERA, INTA) to identify research challenges and collaboration approaches involving ONERA and DLR in a project proposal to set up an experimental network.
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), Soulsoftware, ALISCARL, Leonardo.
3. To contact the Italian Armed Forces Italian Joint C-UAS Centre of Excellence and currently defining a MoU to collaborate with them.
4. 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.
5. To write a paper for ESREL 2020 conference.
6. To monitor current funded initiatives to apply for with a collaborative approach involving other key players

ID	ACTION	RESPONSIBLE	DUE DATE	DELIVERABLE
1	Finalize the choice of the common topic	GoR-AS chairperson	May	Contribution to pilot paper
2	Definition of a research concept for C-UAS	GoR-AS chairperson + ONERA, NLR, DLR	July	Pilot paper
2	Identify the objectives and involve partners	GoR-AS chairperson + All	September	Pilot Paper
3	Prepare and Finalize the Consortium agreement and Grant Agreement	CIRA, ONERA, INTA + other partners	October	
4	Start-up of ASPRID project	INTA, CIRA, ONERA + other partners	November	Plan for GoR-AS activities
5	Monitor Progress and organize webexes	GoR-AS chairperson	November, December	Scheduling and agenda
6	Present the paper at ESREL 2020	GoR-AS chairperson	November	

GoR Activities

The GoR-AS involved the other colleagues by email to organize remote meetings.

During these meetings information was shared about the current activities in each involved institution to finalize the action group decision.

A survey among GoR-AS participants was performed to assess the interest to participate in a proposal which seemed relevant to the GoR-AS perimeter of topics.

The call was under **H2020-**Funding Scheme: **ISFP-AG**, to enhance European coordination in the testing of different UAS countermeasures solutions in order to provide Member States with a generic methodology and baseline understanding of the effectiveness of commercially available C-UAS solutions for the detection, tracking and identification (DTI) of drones that may be a security threat. An exploratory group, partially outside GARTEUR, made by ONERA, NLR, CIRA and DLR, has dedicated focus to such a theme and a project proposal led by NLR has been submitted, though the instrument was not specifically oriented to research establishments. The proposal was not funded.

Nevertheless, such a topic can be partially integrated in EREA Security for aviation working group and represents hints for exploratory and future action groups, provided the GoR-AS will receive the necessary commitment by the represented organizations.

In Italy contacts with the following stakeholders increased awareness about their interests.

Leonardo: Hostile Drone Interception , Drone Identification, Drone Localization & Tracking and related challenges.

ONERA, INTA and CIRA started the activities within ASPRID Project:

Horizon 2020 Call: H2020-SESAR-2019-2 (SESAR 2020 EXPLORATORY RESEARCH) **Topic: SESAR-ER4-13-2019 Type of action: SESAR-RIA,** Airport System Protection from Intruding Drones.

It represents a good chance for GoR-AS as it matches the theme we identified as interesting for our action group, together with the other participants:

- ENAIRE, the Spanish Air Navigation Service Provider;
- Aena, the first airport operator company in the world by number of passengers;
- Two Italian companies, providers of counter drone solutions:
    - SoulSoftware SRL
    - Aerospace Laboratory for Innovative components (ALI Scarl)

Management

A remote meeting was held in May to assess the related activities and other remote meetings were performed during Autumn 2020.

Dissemination of GARTEUR activities and results

The dissemination events during 2020 are represented by the following:

Publication in ESREL 2020 PSAM 15 The 30th European Safety and Reliability Conference - T45-09 Solution Set-Up For Airport Protection From Intruder Drones Angela Vozella, Francisco Munoz Sanz, Mario Antonio Solazzo, Pierre Bieber, Giancarlo Ferrara (Eurocontrol), Edgar Martinavarro Armengol

(it is a paper collecting the concept developed in GoR-AS in 2018-2019 among: CIRA, INTA, ONERA…).

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

Status of Action Group

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

<u>There are the following criticalities</u>:

1. INTA has to involve another team member for GoR-AS.
2. DLR has to confirm the members.
3. NLR has to verify interest.

GoR membership

The membership of this GOR in 2021 is made by :

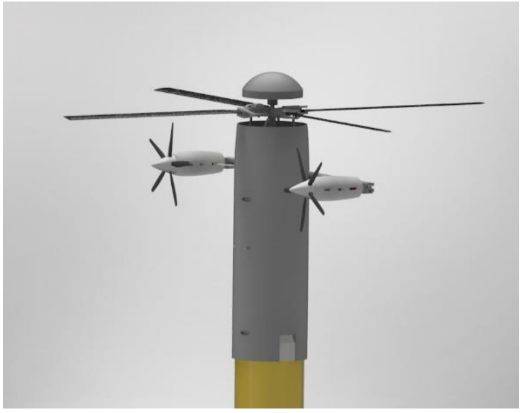
Chairperson		
Angela Vozella	CIRA	Italy
Vice-Chairperson		
Emilio Oliva	INTA	Spain
Members		
Pierre Bieber	ONERA	France
Rene Wiegers	NLR	Netherlands
Andreas Bierig	DLR	Germany
Hans-Albert Eckel	DLR	Germany
Johann C. Dauer	DLR	Germany
Clive Goodchild	BAE Systems	UK

Total yearly costs of EG research programmes

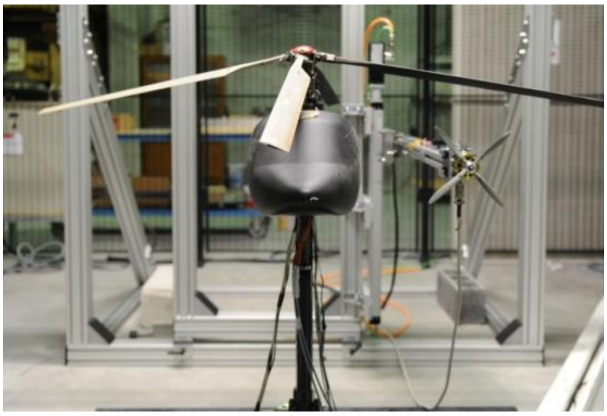
	<2017>	<2018>	<2019>	<2020>
Person-month	2	3	4	3
Other costs (k€)	1	1	1	1

Appendix C: Annex GoR-RC

ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "ROTORCRAFT"



Design of POLIMI Test Rig (HC/AG-25)



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

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 following areas and 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:
  - o Security studies, UAVs, advanced technologies for surveillance, rescue and recovery,
  - o 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 issues:
   - Greening, pollution,
   - 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 2021 was held by Joost Hakkart (NLR) from 01/01/21 to 30/06/21 and by Antonio Visingardi (CIRA) from 01/07/21 onward. Vice Chairman was Antonio Visingardi (CIRA) from 01/01/21 to 30/06/21 and Mark White (Univ. Liverpool) from 01/07/21 onward.

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:

- 83rd GoR Meeting: 17th – 18th February 2021, Teams virtual meeting.

- 84th GoR Meeting: 7th – 8th October 2021, 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 2021 the activities in the RC-AGs were at a low level, also because of the problems caused by the COVID19 pandemic. The year 2021 formally started with one active Action Group and five Exploratory Groups, two of them proceeded at good pace, thus promising to become AGs in 2022.

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.

Documentation issued

Reports

- HC/AG25: Boisard, R. “HC/AG-25 Mid-term Report,” May 2021

Publications

- HC/AG-24: Yin, J., Rossignol, K-S., Reboul, G., Mortain, F., Vigevano, L., Zanotti, A., Gibertini, G., Barbarino, M., Testa, C., Bernardini, G., Brouwer, H., “Evaluation of Acoustic Shielding Effects from a Generic GARTEUR Helicopter Configuration,” presented at the 47th European Rotorcraft Forum organized by the Royal Aeronautical Society, virtually, Sept. 7th - 9th 2021;
- HC/AG-24: Yin, J., Rossignol, K-S., “Experimental and Numerical Study on Helicopter Acoustic Scattering”, Part of the Notes on Numerical Fluid Mechanics and Multidisciplinary Design book series (NNFM, volume 151), 2021;
- HC/AG-24: Bernardini, G., Poggi, C. et al. (2021). “Study of Velocity-Potential Integral Formulations for Sound Scattered by Moving Bodies”. In: AIAA Journal 59.3, pp. 1008-1019;
- HC/AG-25: Boisard, R., and Lim J.W., “Aerodynamic Analysis of Rotor/Propeller Wakes Interactions on High Speed Compound Helicopter,” presented at the 47th European Rotorcraft Forum, organized by the Royal Aeronautical Society, virtually, Sept. 7th - 9th 2021.

Status of Action Groups and Exploratory Groups

Action groups (AG)

The following Action Group was active throughout 2021:

HC/AG-25	*Rotor-Rotor-Interaction* 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.

Exploratory groups (EG)

The following Exploratory Groups were active throughout 2021:

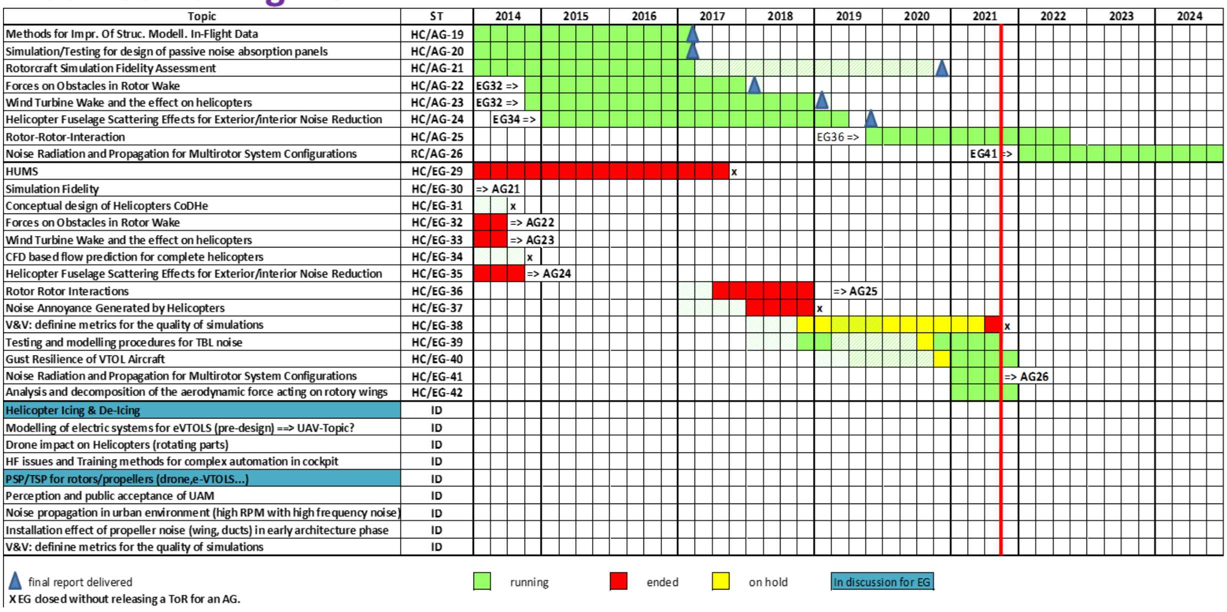
RC/EG-38	*Verification & Validation: Metrics for the Qualification of Simulation Quality* To define metrics for the qualification of the quality of rotorcraft simulations, as a contribution to the Verification and Validation (V&V) process of numerical codes. The progress in this EG was limited and the workshop in 2019 did not bring the expected clarity for the next steps. As the topic is very relevant, RC GoR is still supporting the key ideas of this EG. It is to be considered that the EU CS2 Project RoCS (Rotorcraft Certification by Simulation) is covering very similar topics. Due to limited resources in the relevant organizations it was first decided to put this EG on hold until the end of the RoCS project. However, due to effects of the Covid 19 pandemic, and since an extension of RoCS project until May 2023 can be expected, it was finally decided to stop this EG and re-propose it as a New Idea to be re-considered in the near future.
RC/EG-39	*Testing and modelling procedures for Turbulent Boundary layer noise* To identify ways how to reduce the flow-induced noise in rotorcraft. The chairman was in 2020 a visiting scientist at NASA working on other topics and took up the EG-lead after his return in Sept. 2020. The first meeting took place in December 2020. During the year 2021 no updates have been received from the EG coordinator. An action was decided during the last RC-GoR meeting in October 2021 in order to verify the will of the coordinator to continue this EG.
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 therefore 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. However, during the year 2021 no meeting was organized and therefore an action was decided during

	the last RC-GoR meeting in October 2021 in order to verify the will of the coordinator to continue this EG.
RC/EG-41	*Noise Radiation and Propagation for Multirotor System Configurations* The objective is to investigate noise radiation and propagation (installation effect) of multirotor systems. 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 list of interested parties was established in 2020. During the year 2021 this EG proceeded at a good pace, the interest on the topic was confirmed to be high and a wide partnership was identified. The EG kick-off meeting was held on March 2021. A draft version of the ToR was submitted and some amendments were requested by the RC GoR members before the official delivery of the document. Furthermore, all RC GoR members agreed to promote this EG to an Action Group, RC/AG-26, for a possible start in January 2022, provided the approval from the GARTEUR XC.
RC/EG-42	*Analysis and Decomposition of the Aerodynamic Force Acting on Rotary Wings* 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 allocable 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. A draft version of the ToR was prepared and will be discussed among the identified partners in January 2022.

Rolling plan

The 3–5-year planning will continue to be implemented over the years. This list is implemented with new topics according to the GoR discussions.
During the GoR meetings, several topics of mutual interest have been discussed and their potential for GARTEUR collaborative programmes has been examined.

AGs EGs Rolling Plan



GoR membership

Chairperson		
Joost Hakkart (01/01/21– 30/06/21)	NLR	The Netherlands
Antonio Visingardi (01/07/21 –)	CIRA	Italy

Members		
Barbara Ohlenforst (01/07/21 –)	NLR	The Netherlands
Mark White	Uni. of Liverpool	United Kingdom
Arnaud Le Pape	ONERA	France
Klausdieter Pahlke	DLR	Germany

Industrial Points of Contact		
Rainer Heger	Airbus Helicopters	Germany

Observer		
Richard Markiewicz	Dstl	United Kingdom

Table of participating organisations

	AG25	EG38	EG39	EG40	EG41	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

Total yearly costs of AG research programmes

	2014	2015	2016	2017	2018	2019	2020	2021	TOTAL
Person-Month	44.40	88.70	79.50	55.00	26.50	10.00	26.00	42.00	372.10
Other Costs (k€)	38.00	103.10	102.90	54.00	20.00	27.00	33.00	30.50	408.50

Action Group Reports

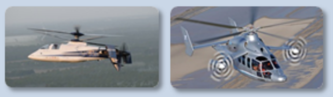
GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE
FRANCE GERMANY ITALY THE NETHERLANDS SPAIN SWEDEN UNITED KINGDOM

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:

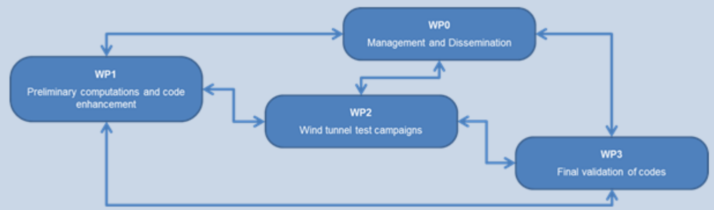
- WP0 – Management & Dissemination: is aimed at the fulfilment of all the obligations concerning the project management and the dissemination of the results.
- WP1 – Preliminary Computations & Code Enhancements: deals with a preparation phase during which partners are involved in literature review and 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

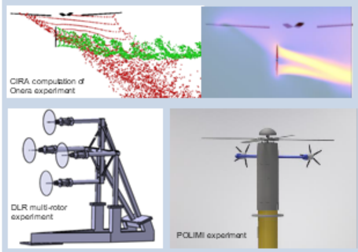
The action group started its activities on 1st of October 2019.

Most partners have performed calculations of the isolated and installed configuration from Onera experiment for different wind speed. Results outline some scattering between the different numerical methods and experiments on isolated configuration but acceptable results on installation effect..

Numerical simulation of DLR experiment has start and shows good comparison between experiment and computations on isolated propeller

All experimental activities are on the way with sometimes some delay:

- Onera experiment has ended in 2021 with PIV campaign.
- DLR isolated rotor experiment was conducted on 11 different setup, and multi-rotor experiment is scheduled in 2022.
- POLIMI experiment is scheduled in April / May 2022.



University of Stuttgart
Institute of Aerodynamics and Gas Dynamics

Centro Italiano Ricerche Aerospaziali

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.

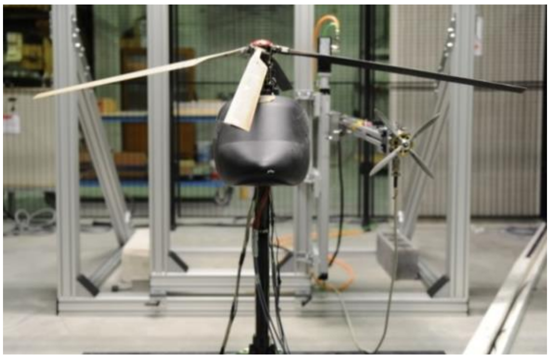
WP1 – Preliminary Computations & Code Enhancements:
The main goal here is literature review and computational actions aimed at providing necessary and useful inputs to the two following work packages where experimental databases are produced (WP2) and the modelling capabilities of the applied numerical 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.

- **HC/AG-25 membership**

Member	Organisation	e-mail
R. Boisard (Chair)	ONERA	ronan.boisard@onera.fr
Q. Gallas	ONERA	quentin.gallas@onera.fr
A. Le Pape	ONERA	Arnaud.Lepape@onera.fr
A. Visingardi	CIRA	A.Visingardi@cira.it
T. Gardner	DLR	Tony.Gardner@dlr.de
T. Schwarz	DLR	Thorsten.Schwarz@dlr.de
M. Raffel	DLR	markus.raffel@dlr.de
V. Riziotis	NTUA	vasilis@fluid.mech.ntua.gr
S. Voutsinas	NTUA	spyros@fluid.mech.ntua.gr
A. Zanotti	POLIMI	alex.zanotti@polimi.it
G. Gibertini	POLIMI	giuseppe.gibertini@polimi.it
G. Barakos	UoG	George.Barakos@glasgow.ac.uk
R. Green	UoG	Richard.Green@glasgow.ac.uk
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

Appendix D: Annex GoR-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 only a few new ideas were proposed and explored during the year 2021.

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:

- Fatigue and damage tolerance assessment of hybrid structures
- Damage repair with composites in composite and metallic structures
- 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
- Additive Layer Manufacturing
- 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. Past works are devoted to the following topics:

- Fatigue and damage tolerance assessment of hybrid structures;

- Damage repair in composite and metal structures.

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 structure of aircraft in service will obtain various types of damage e.g. from impact loading. It is therefore important to have effective repair methods. Damages caused by impact are in general much more severe in composite structures than in metals structures. Reparability of such damage is an important consideration in the selection of composites for aircraft applications. Repair techniques both for civil and military aircraft structures are defined through the development of numerical/experimental methodologies. The following issues are addressed: repair criteria, design of patches and repair strategies, analysis of the repair, manufacturing and test, repair strategies and technology, effective repair methods. The effective outcomes can be summarized in minimizing down-time of the aircraft for repair operations; minimizing costs for repair; promoting the repair of components instead of their substitution; reducing the costs and time for certification of repaired structures.

The technical work in the Actions groups has been completed.

As an important future technology, the topic of additive manufacturing will continue to be prioritized within the scope of an Exploratory Group. 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 the new Exploratory Group 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 alloys.

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 2021, due to the health crisis, only one meeting was held in March by videoconference and the second one, initially foreseen in October was postponed to January 2022. Six members and three IPoC's attended the first meeting on March 4.

The measures taken in the past two years to revitalize the Structures and Materials group were confirmed. Action Group 34 was finalized and Action Group 35 should be finalized soon. Amongst the Exploratory Groups launched at the end of 2020, EG47 submitted a proposal end of 2021 and an Action Group should start beginning of 2022 (AG36). EG46 almost finalized a work program and an Action Group should also be launched in 2022. A new EG dealing with SHM for hydrogen aircraft tanks was also launched in 2021. Due to avaibilities issues, it was decided at first, and accepted by the Council, to only organize meetings between specialists.

Dissemination of GARTEUR activities and results

No new publications were published in the past reporting period.

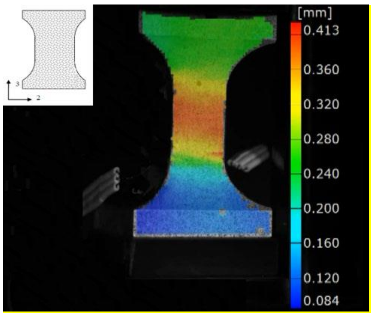
Reports issued

The final report for SM/AG-34 has been issued in November 2021. The final report for SM/AG-35 is ready and still has to be transferred under the GARTEUR format. It should be issued soon.

Status of Action Groups and Exploratory Groups

Two action groups were formally active in 2021. Both action groups have finished their technical activities. AG-34 was closed at the end of 2021 and AG-35 should be closed beginning of 2022 when the final version of report will be delivered.
Four Exploratory Groups (EG-44, EG-45, EG-46, EG-47) were running in 2021. Two of them (EG46, EG47) should lead to Actions Groups beginning of 2022. An Exploratory Group (EG48) was launched in 2022.

SM/AG-34 **Damage repair with composites**



The objective of the group is the definition of effective repair techniques both for civil and military aircraft structures through the development of numerical/experimental methodologies. This will lead to minimized down-time of the aircraft for repair operation, minimized costs for repair, reduced certification costs and time for certification and will promote the repair of components instead of their substitution. The technical activities of this group have finished and the final report was delivered. The group was closed end of 2021.

The chair was Aniello Riccio from the University della Campania in Italy

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

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/EG-44 **Characterization of composites with polymer matrix at high temperatures**

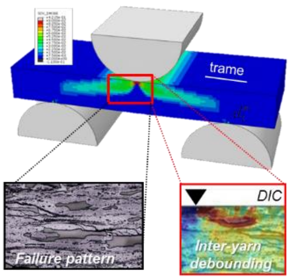
This topic has first been proposed by ONERA and DLR. Both partners participate to the SuCoHS H2020 project (Sustainable & Cost efficient High-performance composite Structures) which emphasizes the industrial needs of experimental characterization methods for composite properties at high temperature (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

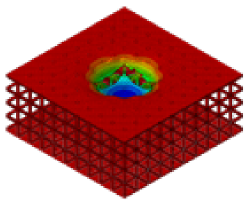


This topic has been proposed by ONERA and DLR. The objective consists in the characterization of the mechanical properties and modelling of Composites with Ceramic Matrix (CMC) submitted to high mechanical loadings and extreme thermal conditions. More detailed objectives consist in the:

- 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**



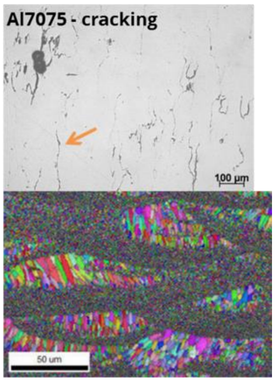
Commonly adopted shock absorbers and, in general, crashworthy structural components, based on sandwich structural concepts and/or complex dumping mechanisms, are, generally, characterized by high volumes and significant additional mass. This research activity is focused on the investigation of the feasibility 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.

Andrea Sellitto (University Campania in Italy) will assume chairmanship.

SM/EG-47 Additive layer manufacturing



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 A20X™ 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, aluminium 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 aluminium alloys” was prepared and should start beginning of 2022.

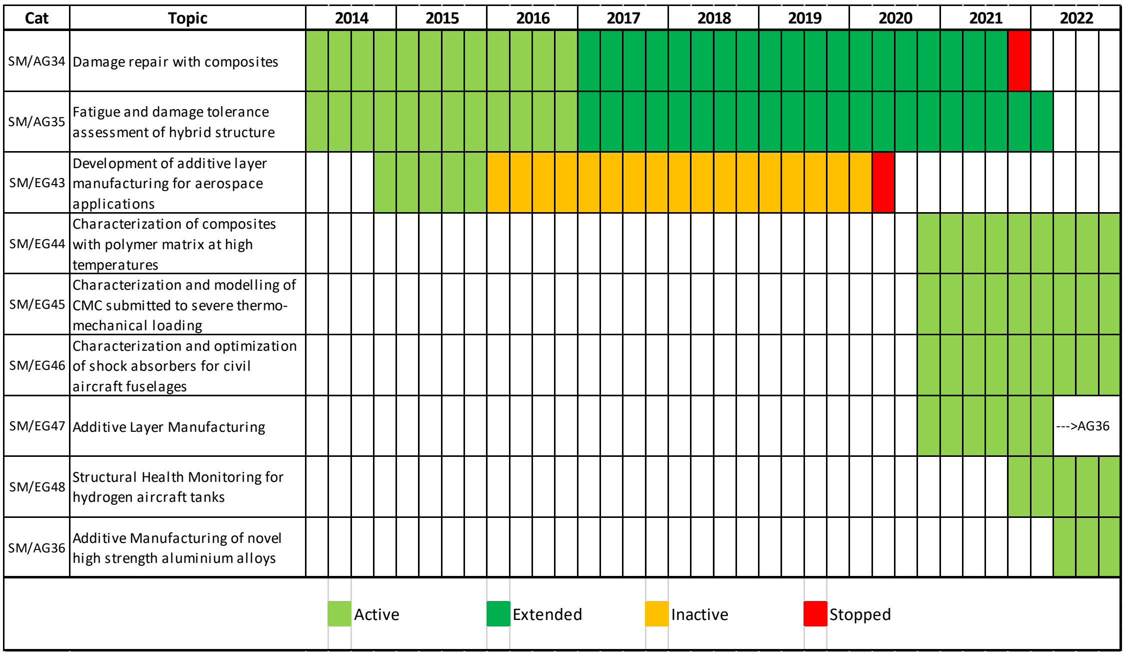
The chair is Maria Luz Montero from NLR

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



GoR membership

Chairperson		
Florence Roudolff	ONERA	France
Vice-Chairperson		
Bert Thuis	NLR	The Netherlands
Members		
Aniello Riccio	SUN	Italy
Javier San Millan	INTA	Spain
Peter Wierach	DLR	Germany
Thomas Ireman	SAAB	Sweden
Mats Dalenbring	FOI	Sweden
Industrial Points of Contact		
Roland Lang	Airbus Defence and Space	Germany
Mathias Jessrang	Airbus Operations	Germany
Robin Olsson	RISE	Sweden

Table of participating organisations

	AG-34	AG-35	EG-44	EG-45	EG-46	EG-47	EG-48
Research Establishments, Universities	Closed end of 2021		Under definition	Under definition	Under definition	Proposal ready	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	☐						
Norwegian University of Science and Technology (NTNU)	☐						

Action Groups reports

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

SM/AG-34 : Damage Repair with Composites

Action Group Chairman: Aniello Riccio (Aniello.RICCIO@unicampania.it)

Background

Composites are much more prone to be damaged in service than metals, for example, by mechanical impact. Reparability of such damage is an important consideration in the selection of composites for aircraft applications. In addition, metal structures can be repaired by using composite patches with great potential benefits such as costs reduction, time saving.

Repair techniques can be considered applicable to a wide range of structures both metallic and composites (laminates or sandwich).

The repair scheme used for structural restoration should be the simplest and least intrusive that can restore structural stiffness and strain capability to the required level and be implemented in the repair environment, without compromising other functions of the component or structure.

It is usually necessary to restore the capability of the structure to withstand a design's ultimate loads and to maintain this capability (or some high percentage of it) for the full service life.

The functions that must be restored include: aerodynamic shape, balance, clearance of moving parts, resistance to lightning strike. The requirement in military to restore the stealth properties of the component may also have to be considered and may influence the type of repair chosen.

The wide spreading use of composite structures but also the need to reduce costs (both for metals and composites) have lead to an increasing interest in repair and especially in repair with composites and in its potential applications.

However, uncertainties remain in the behaviour of repaired structures that generally lead aircraft manufacturer to use repair only for secondary structures, to prefer bolted repair (mechanical fastened repair) to bonded repair (adhesively bonded repair) and to limit the use of bonding only to limited-size damage.

Programme/Objectives

Objectives

In order to meet the needs of strengthening the use of repair in aircraft structures and to overcome the state of the art in repair with composites, the main objective of this Action Group is:

"Definition of effective repair techniques both for aircraft structures through the development of numerical/experimental methodologies"

The objective addresses the following issue:

Repair criteria, design of patches and repair strategies, analysis of the repair, manufacturing and test, repair strategies and technology, effective repair methods

The activities have been split in Work Packages:

WP1 REPAIR CRITERIA (WHEN UNDERTAKING REPAIR)

Task 1-1 – Methodologies for the assessment of residual strength in damaged composite components to decide when repair has to be undertaken

Task 1-2 – Crack growth analysis (static and fatigue)

WP2 DESIGN OF PATCHES AND REPAIR STRATEGIES

WP 3 ANALYSIS OF THE REPAIR

WP4 MANUFACTURING AND TEST

Task 4.1 - Manufacturing and repair procedure issues

Task 4.2 - Experimental tests

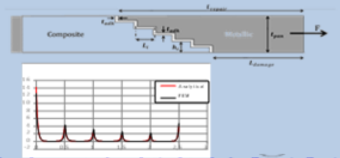
WP5 - EFFECTIVE REPAIR METHODS

Task 5.1 - Optimization of the patching efficiency

Task 5.2 - Certification issues;

Task 5.3 - Technologies for repair;

Task 5.4 - Definition of guidelines for an effective repair of both civil and military aircraft structures



Development of analytical tools for Repair Design

Results

The effective outcomes can be summarised in:

- Minimize down-time of the aircraft for repair operations;
- Minimize costs for repair;
- Promote the repair of components instead of their substitution;
- Reduce certification costs and of the time for certification for repaired structures.

The main challenges addressed consisted in:

Failure mechanisms

When dealing with bonded repair (composite patches) problems are related to the complex behaviour of composite material itself as well as to the many potential failure mechanisms associated with its design and use. It is worth noting that, in this kind of failure mechanisms, both the adhesive behaviour but also manufacturing issues such as the surface treatment play an important role. Indeed, any contamination-be it dust or fluid- between the adhesive and the bonding surface can cause an adhesive failure. The development of failure mechanisms has been extensively simulated in the frame of the project.

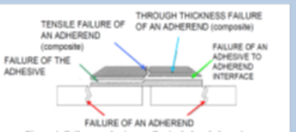


Figure 4: Failure modes in an adhesively bonded repair

Repair design procedures

The design of effective repairs on the structures have been considered. The choice of proper geometry for the repair patch and the correct dimensions for the repaired area have been proven to provide advantage in repair operations.

SM/AG-34 Damage Repair with Composites

Monitoring Responsable: D. Tescione CIRA

Chairman: Dr. A. Riccio UCL

- **Objectives**

Based on of the emerging needs (detailed in the previous section) related to the composites usage in aerospace applications, the main objective of this Action Group is:
- "Definition of effective repair techniques both for civil and military aircraft structures through the development of numerical/experimental methodologies ".
This objective addresses the following issues:
- Repair criteria, design of patches and repair strategies, analysis of the repair, manufacturing and test, repair strategies and technology, effective repair methods.

- **Statement of work**

The detailed description of the activities to be performed under each WP and task is given hereafter.

WP 1 Repair criteria (when undertaking repair)
- Task 1.1: Methodologies for the assessment of residual strength in damaged composite components to decide when repair has to be undertaken:
- Task 1.2: Crack growth analysis (static and fatigue).

WP 2 Design of patches and repair strategies
WP 3 Analysis of the repair
WP 4 Manufacturing and tests
- Task 4.1: Manufacturing and repair procedure issues;
- Task 4.2: Experimental tests.

WP 5 Effective repair methods
- Task 5.1: Optimization of the patching efficiency;
- Task 5.2: Certification issues;
- Task 5.3: Technologies for repair;
- Task 5.4: Definition of guidelines for an effective repair of both civil and military aircraft structures.

- **Main achievements**

Tasks accomplished in 2021:

- The final report was finalized in November 2021 and accepted by the Council on November 17, 2021. The Group is closed

- **Expected results/benefits**

The effective outcomes can be summarized in:
1) Minimize down-time of the aircraft for repair operations;
2) Minimize costs for repair;
3) promote the repair of components instead of their substitution;
4) Reduction of the costs and time for certification of repaired structures.

- **SM/AG-34 membership**

Member	Organisation	e-mail
Aniello Riccio (chairman)	SUN	Aniello.Riccio@unicampania.it
Iñaki Armendariz (Vice Chairman)	INTA	armendarizbi@inta.es
Andrea Sellitto	SUN	Andrea.sellitto@unina2.it
Dimitra Ramantani	SICOMP	dimitra.ramantani@swerea.se
David Mattsson	SICOMP	David.mattsson@swerea.se
Ralf Creemers	NLR	ralf.creemers@nlr.nl
Joakim Schon	FOI	snj@foi.se
Umberto Mercurio	CIRA	u.mercurio@cira.it
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Janis Varna	LULEA UNIVERSITY of TECHNOLOGY	janis.varna@ltu.se
Marcus Henriksson	Saab	marcus.henriksson@saabgroup.com
Andreas Echtermeyer	NTNU	andreas.echtermeyer@ntnu.no
Giovanni Perillo	NTNU	giovanni.perillo@ntnu.no

- **Resources**

Resources		Year									Total
		2012	2013	2014	2015	2016	2017	2018	2019	2020	2012-2016
Person-Months	Act./Plan.	-	50/36	50/30	/0	/0	/0	/0	/0	/0	100/66
Other costs (in k€)	Act./Plan.	-	49/32	20/0	/0	/0	/0	/0	/0	/0	69/32

- **Progress/Completion of milestone**

Work package	Planned		Actual
	Initially (end of...)	Currently (updated)	
WP1 Report	Oct 2014	Oct 2014	Oct 2014
WP2 Report	Apr 2016	Apr 2017	Apr 2020
WP3 Report	Apr 2016	Apr 2017	Apr 2020
WP4 Report	Apr 2016	Apr 2017	Apr 2020
WP5 Report	Oct 2016	Oct 2017	Oct 2020
Final Report	Oct 2016	Oct 2017	March 2021

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.

FOI NLR DLR FOKKER AEROSTRUCTURES SAAB TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

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

- **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 2021

The report was delivered in 2021 under a NLR format. It still has to be transferred under the GARTEUR format before the group is 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-35 membership**

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- **Planned Resources**

Resources		Year									Total
		2012	2013	2014	2015	2016	2017	2018	2019	2020	2012-2016
Person-Months	Act./Plan.	1/1	10.5/11	11/11	/10	/0	/0	/0	/0	/0	22.5/42.5
Other costs (in k€)	Act./Plan.	1/2	16/30	41/41.5	/35	/0	/0	/0	/0	/0	58/128

- **Progress/Completion of milestone**

Work task	Planned		Actual
	Initially (end of...)	Currently (updated)	
Task 1	April 2015	December 2017	December 2017
Task 2	June 2015	December 2017	December 2017
Task 3	June 2015	December 2017	December 2017
Report	October 2015	December 2017	February 2022

For further information about GARTEUR please contact:
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