GARTEUR

ANNUAL REPORT 2023

GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE

Front cover image: Participants in the GARTEUR 50th Anniversary event at the Italian Air Force Academy

Back cover image: Moments from GARTEUR 50th Anniversary event at the Italian Air Force Academy

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

Table of Contents

1. Introduction

Dear reader,

In 2023 both the civil and defence sectors of the aeronautics industry have continued to experience a post-pandemic economic resurgence. Likewise, rapidly advancing climate change and the war unleashed by Russia against Ukraine pose new challenges to our community and require to address new paradigms.

The challenges ahead necessarily need to involve the whole aeronautical community, at platform and operations level, in close cooperation with climate scientists, the energy industry and regulatory agencies.

The development and introduction into service of advanced and disruptive technologies to drastically reduce the environmental and climate impact of aviation will need to be done while maintaining Europe's leadership as a global player in aeronautics. There is a clear need to accelerate decarbonisation while maintaining industrial competitiveness amidst growing international competition.

Aeronautical platforms, both in the civil (transport and emergency services) and military domains will have to operate in more extreme conditions than in the past, with the rapid evolution of climate change. Operational safety will have to be guaranteed in challenging environments.

2023 has been a very exciting year for GARTEUR. Whilst continuing our on-going research activities, our community has had a chance to reminisce on the success stories since the creation of GARTEUR in 1973 and to chart the future ahead.

The 50th Anniversary celebration that was held at the Italian Air Force Academy in Pozzuoli on 5-6 October 2023 brought together the GARTEUR community and representatives of major civil and defence stakeholders. It confirmed the effectiveness of GARTEUR's lean operational model with its genuinely «cooperative» approach: minimum burocracy, operational flexibility, own objectives, own funding, bottom-up research, own review. It's particular nature (government-to-government, civil, defence, dual use) among the research-centred organisations allows GARTEUR to rapidly carry out de-risking research activities without the limitations posed by third-party funding.

Nonetheless, it was recognised that there is need to review the mission and to effectively communicate it to the aeronautics community, increasing the cooperation with other organisations, in particular in order to bring new talents to GARTEUR's research initiatives.

As we pass on the chairmanship to Germany for 2024-2025, we are sure that GARTEUR will increase its ambition, strong of its 50-years' experience, and reaffirm that innovation is at the base of GARTEUR's raisons d'être.

Piergiovanni Renzoni

Chairman (2022 - 2023)
GARTEUR Council

Dear GARTEUR Friends,

2022 was a year of transition from the pandemic towards a sort of «normality»: the Italian delegation tried to continue the very good job initiated by the Dutch delegation, during the hardest period of the lock-down, by keeping the GARTEUR community alive and kicking! Meetings in presence started again and the Executive Committee was looking forward organising the event celebrating the 50th anniversary of the Group.

2023 was a very committing year in order to organise at its best the above mentioned event, and the associated conference, at the Italian Air Force Academy in Pozzuoli, Italy on October 5th – 6th. Speakers, coming from academia and industry, also belonging to our Group from a very long time, decided to be part of such conference and also representatives of the military gave their contribution. During those days, the Italian Air Force premises also hosted meetings of Group of Responsables and Action Groups, the beating heart of the work performed in GARTEUR. So, not only the event was the opportunity to have the whole GARTEUR community joined in one place in one moment or to meet a wider research community; it gave the chance to have a shared vision of the results achieved by the Group in the past 50 years of research activities in the aeronautical field and the possibility to chart the future of aeronautical research in the next decade.

Speeches and round-tables provided various observations and suggestions that were welcomed and will be subject of deep discussions to improve the research activities of the Group in the near future!

Vittorio Puoti

Chair XC GARTEUR 2022-2023

2. Executive summary

The GARTEUR Annual Report 2023 provides a summary of the main managerial actions of the Council, and the scientific and technological progress made by the five Groups of Responsables (GoRs). The GoRs constitute the main bodies for establishing research priorities in the technology areas covered by GARTEUR: aerodynamics, structures and materials, rotorcraft, flight mechanics and systems integration, and aviation security.

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

2023 was a very special year for the GARTEUR: in fact GARTEUR celebrated its 50th anniversary! In the Council meeting held in November 2021, it was decided to organise a special event, in conjunction with the Fall Council meeting in 2023, to prepare the future of GARTEUR and to attract people to prepare the future all together. The event is described in Section 4.

Section 5 reports on the European aeronautical R&T environment by highlighting the importance of European Collaborative Programs such as Horizon Europe and Clean Aviation to civil aviation. Great steps have been taken to streamline aeronautical research in Europe, making use of several bodies within the European R&T environment (*e.g.* EREA and ACARE).

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

The GARTEUR scientific and technical activities are reported in section 6, with each of the five GoRs presenting a summary of their work during 2023.

3. GARTEUR Council

3.1 Chairmanship and membership

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

During the second year of the Italian chairmanship of GARTEUR, Dr. Piergiovanni Renzoni, from the Italian Aerospace Research Centre (CIRA) continued to serve as Chairman of the Council as Mr. Vittorio Puoti, also from CIRA, served as Chairman of the Executive Committee and GARTEUR secretary.

A change occurred in the French delegation. Starting 1st of June 2023, Jean-Sébastien Martinez De Castilla from Direction Générale de l'Armement (DGA), will serve as Head of Delegation, replacing Julie L'Ebraly, which provided strong leadership to GARTEUR for the last four and a half years.

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:

- XC170 – 19th – 20th January 2023, both online and in presence, ONERA, Châtillon, Paris;
- C74 – 8th – 9th March 2023, NLR site and National Military Museum, Amsterdam, The Netherlands;
- XC171 – 29th June 2023, online;
- C75 – 5th October 2023, Italian Air Force Academy, Pozzuoli, Italy, in connection with the 50th anniversary GARTEUR event.

3.2.1 XC170

This XC meeting was held at ONERA, Châtillon, Paris on the 19th – 20th January 2023. It was organised both in presence and online for some XC members there were not able to get to Paris. The AS GoR chairman, Angela Vozella, invited to participate in the meeting was present via Teams connection during the morning of the second day, due to previous commitments that could not be cancelled.

This XC meeting lasted over two days since it hosted the first discussion about the organisation of the 50th anniversary GARTEUR Conference: in fact, during the Fall 2022 Council in Braunschweig, Council members had agreed on devoting a full day of the XC meeting to the discussion about the above-mentioned event whose organisation has gained the highest priority. So, the first day of this XC meeting was entirely devoted to the discussion of the main items related to the event: date of the event, location, agenda, focus of the event, participants to be invited and to be involved, etc. Results of the discussion are contained in a document shared by the Council and XC members and subject to a monthly updating. On the second day, some issues concerning AS GoR chairmanship were discussed with the current chairman, Angela Vozella; then, proposals, provided by the GoRs, for the award were presented and some news concerning the organisation of the UAM workshop were given. The discussion related to the award helped XC members to understand that some updating in the related section of the current version Basic Documents would be crucial.

A very important update concerned the interaction with the PEGASUS consortium: the Council chairman, P. Renzoni, is going to invite PEGASUS vice-chairman, Prof. Emmanuel Zenou, to give a speech during the Council meeting in Amsterdam in March. This should be the first step towards a tighter interaction between the two organisations.

3.2.2 C74

C74 took place on 8th – 9th March 2023 in Amsterdam, precisely at NLR, the first day, and at the National Military Museum, located in Soesterberg, on the second day. The main topics discussed during this meeting were the updates from the GoRs and the organisation of the event celebrating the 50th GARTEUR anniversary, see Figure 1.

Figure 1: Council members portrayed during the C74 meeting at NLR in Amsterdam.

The Italian delegation, charged of the main part of the organisation of the event, informed the Council members that the 50th anniversary would be held in Pozzuoli, at the Air Force Academy on the 5th – 6th of October.

One of the main focuses of the meeting was the presentation of PEGASUS, Partnership of a European Group of Aeronautics and Space Universities, given by Prof. Emmanuel Zenou, vice-chairman of the PEGASUS network, see Figure 2.

Figure 2: Council members portrayed at NLR during video conf with PEGASUS vice-chairman, Prof. Emmanuel Zenou, in Amsterdam.

During the first day meeting, Council members were given the opportunity to visit several research labs hosted at NLR: gratitude and acknowledgement for the time spent goes to all the researchers involved in the visit.

On the second day, the meeting moved to the National Military Museum, located in Soesterberg, where the Council granted the Award for Research for the period 2022-2023 to the action group AD/AG-54, entitled “RaLESin: RANS-LES Interfacing for Hybrid RANS-LES and Embedded LES” for the period 2022-2023. The award would be delivered to the chairman of the AD/AG-54 during next Council, to be held in Italy in the Fall, in conjunction with the event celebrating the 50th anniversary of GARTEUR. The UAM workshop, that would have been held in Amsterdam the day before the Council, was cancelled as deemed not yet mature.

At the end of the meeting, Council members had a tour all around the museum, see Figure 3.

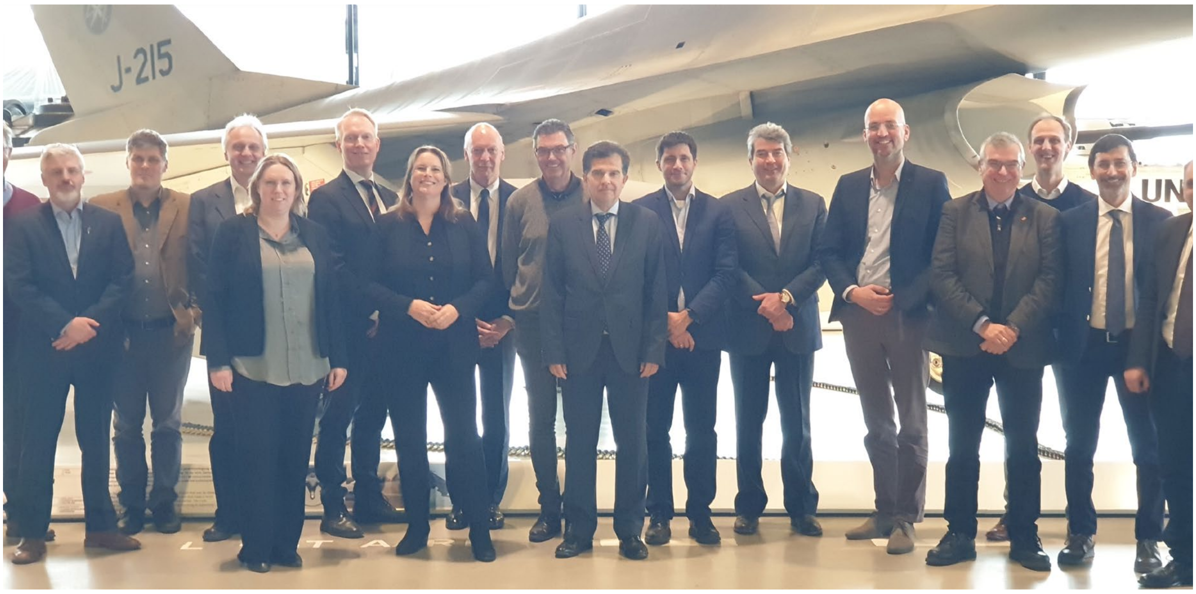


Figure 3: Council members portrayed at the National Military Museum in Soesterberg, NL.

3.2.3 XC171

The XC171 meeting took place on the 29th of June 2023 and was online. XC members decided to have the meeting earlier than usual due to the upcoming event, planned in Pozzuoli at the early beginning of October. Since there were many topics to discuss about and the agenda of the event had to be completed, both in terms of sessions and in terms of participants, XC members agreed that having the meeting in September, as usual, would have been too late.

So, the main topic of the agenda of the meeting was the progress on the organisation of the event related to the 50^{th} GARTEUR anniversary. Anyway, some issues were not solved during this meeting, so several extraordinary meetings were held online in July and September.

As far as the collaboration with PEGASUS is concerned, Prof. Zenou, vice-chairman of the consortium, informed us that he could not be present in Pozzuoli, due to previous commitments, and would be replaced by the local representative, Prof. Francesco Franco, from the University of Naples "Federico II".

A slight modification to the Basic Documents was also proposed in order to avoid misunderstandings in the award process. The modification would be approved at the C75 meeting.

The members agreed to have the next Council meeting, in Pozzuoli, compressed in the morning of the 5th of October, dropping also the Pre-Council session, so that the rest of the day will be available for the event.

3.2.4 C75

The Council meeting C75 took place in the morning of Thursday 5th October 2023, as decided in the last XC meeting held online, hosted, as the upcoming event, by the Italian Air Force Academy. Actually, the premises of the Italian Air Force Academy hosted also other GARTEUR meetings in the same days, such as:

- GoR Rotorcraft 88th Meeting: October 4th – 5th, 2023;
- GoR Aerodynamics 113th Meeting, October 4th – 5th, 2023;
- GoR Rotorcraft: AG27 "*Analysis & Decomposition of the Aerodynamic Force Acting on Rotary Wings*", 1st Technical Meeting, October 4th, 2023;
- GoR Rotorcraft: AG26 "*Noise Radiation and Propagation for Multirotor System Configurations*", 3rd Technical Meeting", October 4th, 2023.

For three days, the Italian Air Force premises hosted one of the main European groups working to chart the future directions of GARTEUR!

The C75 meeting started with the welcome of the Commander of the Italian Air Force Academy, Major General Luigi Casali (see Figure 4) and the presentation, given by the responsible of the Safety Group in the Air Force Academy: in that period, unfortunately, small earthquakes were very frequent in this area due to the phenomenon of bradyseism, so people had to be informed about the emergency procedures in case of an earthquake. Anyway, the Council meeting and the following event were not bothered by this type of natural problems.

One of the main results of the meeting was the slight modification to the Basic Documents: in order to avoid misunderstandings in the future and clearly identify eligible AGs for the award, the section GARTEUR award and Certificates, paragraph 2 was slightly changed.

As already decided, the delivery of the traditional Award of Excellence was moved to the evening during the Gala Dinner in conjunction with the delivery of the special GARTEUR award assigned for the 50th anniversary.

C75 also fixed the changeover of the GARTEUR chairmanship between Italy and Germany: Germany will chair GARTEUR for the period 2024-2025.

Figure 4: Council members portrayed during the welcome given by Major General Luigi Casali, Commander of the Italian Air Force Academy, located in Pozzuoli, IT.

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 2023 the website was updated by the secretary, posting information about the meetings and about the event celebrating the 50th anniversary of GARTEUR.

Due to the huge amount of documents produced and to the importance of the above mentioned event, a brand new section of the website was created by the secretary in order to archive material produced and distributed during the conference for the 50th anniversary of GARTEUR. Agenda, presentations are downloadable as well as *curricula* of the speakers. Many pictures taken during the conference, the dinner and awards ceremony were uploaded to the website.

For the use of the GoRs, DLR has arranged a TeamSite, to be used as a repository for minutes and other documents. That TeamSite is accessible directly by the GoRs and its members.

3.4 GARTEUR Certificates

In 2023 certificates were delivered during C74 to the following GARTEUR members that ended their service in GARTEUR:

- Eric Coustols (ONERA) – Aerodynamics GoR;
- Etiënne Nijenhuis (Dutch MoD) – Council Chairman 2020-2021.

4. The event: 50th GARTEUR anniversary

In 2023 GARTEUR celebrated its 50th birthday: in the Council meeting held in November 2021, it was decided to organise a special event, in conjunction with the Fall Council meeting in 2023, to prepare the future of GARTEUR and to attract people to prepare the future all together.

The discussion among participants in the Council meeting held in November 2022 in Braunschweig, in the XC meeting held in Paris and in many other online meetings provided many ideas that were summarised in a single document depicting a scenario of the event and then implemented in the event itself.

4.1 Description of the event

The event was hosted in the premises of the Italian Air Force Academy which has been training its pilots and engineers there for more than 60 years. The Academy is located in Pozzuoli, a small city very close to the north of Naples with an ancient harbour and the Flavian Amphitheatre that date back to the Roman empire, see Figure 5.

In accordance with the Italian Air Force Academy and in order to take advantage of the last part of the summer period, it was decided to hold both the Fall Council meeting and the event on the 5th and 6th of October.

During all of 2023 the Council asked to GoR and AG chairmen, when possible, to plan to have their technical meetings at the Italian Air Force premises; doing so, 5th and 6th of October 2023 would be devoted to charting the future directions of GARTEUR!

Figure 5: Aerial view of the Italian Air Force Academy, hosting the 50th GARTEUR anniversary, located in Pozzuoli, IT.

The main aim of the event consisted in spreading across Europe the awareness on GARTEUR and preparing the future of research in aeronautics in Europe. In order to pursue this objective, the event had an agenda customised for this target. There would be presentations given by GARTEUR researchers chosen by each Group of Responsables and, at least, two keynote speakers that would give presentations about the most relevant technologies resulting from GARTEUR studies and a very innovative topics in the research world at the moment. Both presentations would push further GARTEUR knowledge across Europe but have a different aim: the first one was needed to give GARTEUR strong roots in the past whereas the second one provided the GARTEUR community a solid topic useful to demonstrate how GARTEUR can contribute to advance aeronautics developments in the future.

4.2 Schedule of the event

This special event, split over two days, united in one place researchers, scientists, managers of the GARTEUR community and other stakeholders that charted the future of Aeronautical Research in Europe!

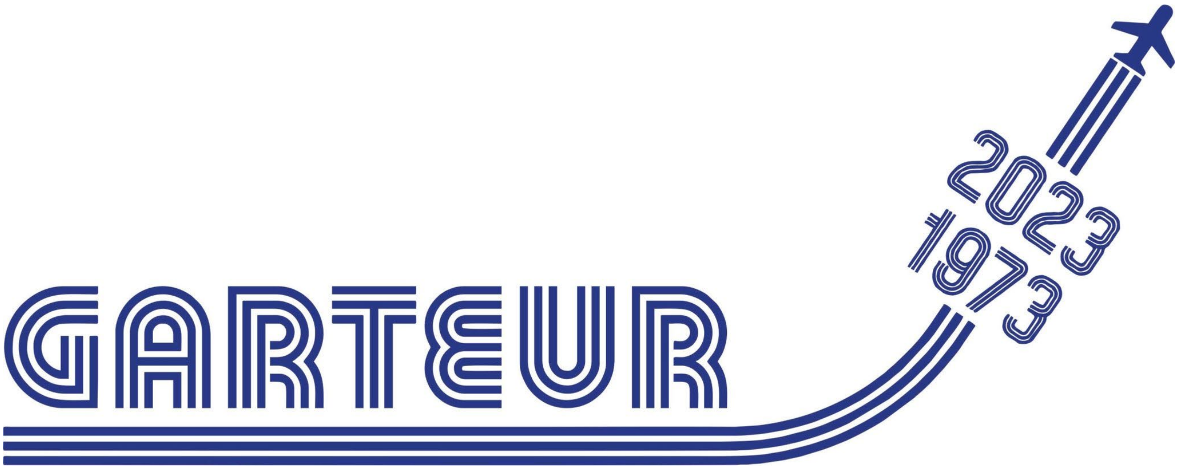


Figure 6: GARTEUR Logo for the 50th anniversary.

In order to have as less modifications as possible to the classical GARTEUR agenda, where the Council meeting is split over two days, the event and the Council meeting took place in two different days, so that:

i. on the morning of the first day, the Council started in the morning and finished with lunch;

ii. in the afternoon of the first day, the event started and finished on the second day at lunchtime;

iii. the morning of the first day was devoted to the classical GARTEUR Council but in a compressed form: the agenda of the meeting took into account the participants' requirements;

iv. the afternoon of the first day was devoted to the presentations of each Group of Responsables with an audience consisting of students and researchers coming from as many GARTEUR countries as possible, including also cadets of the Italian Air Force Academy;

v. the evening of the first day hosted a Gala Dinner with two lectures given by high-level managers of the aerospace sector (public and private, civil and defence), dealing with the most relevant technologies resulting from GARTEUR studies;

vi. during the Gala Dinner, the traditional GARTEUR award, assigned during each chairmanship, and the special GARTEUR award for the 50th anniversary were delivered.

4.3 Delivery of the awards

Due to the decision of assigning a special GARTEUR award for the 50th anniversary, the Council decided to deliver both awards during the Gala Dinner, held in the evening of the first day of the event. Unfortunately, due to the absence of the chairman of the AD/AG-54, entitled "RaLESin: RANS-LES Interfacing for Hybrid RANS-LES and Embedded LES", awarded with the GARTEUR Award of Excellence for the Italian chairmanship period 2022-2023, the presentation of the work carried out by the Action Group was given by one of its main members, Dr. Pietro Catalano from CIRA, see Figure 7.

Figure 7: Representative of AD/AG-54 giving the presentation of the results of the awarded Action Group.

For the same reason, the GARTEUR Award of Excellence, was physically delivered at the event to Tomas Mårtensson, representative of FOI, see Figure 8.

Figure 8: The representative of FOI, Tomas Mårtensson, on behalf of the chairman of AD/AG-54, receives the award from the GARTEUR Council Chairman, Piergiovanni Renzoni.

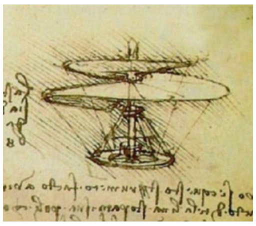
The Council also decided to assign a special award for celebrating its 50th anniversary to "*honour researchers who provided an outstanding contribution to aeronautical science and technology development*". To this aim, a special Committee comprised of Council members and experts coming from civil and defence sector was nominated to select amongst full-time researchers in research organisations and academia who have contributed to past or current GARTEUR GoR activities. On the basis of criteria well identified and shared by the council members, the special Committee decided to assign the special award to the Professor Mark White of the Mechanical and Aerospace Engineering Department at the University of Liverpool, UK.

Unfortunately, due to previous commitments, Prof. Mark White was unable to be physically present in the event but joined the celebrations in remote. The Italian Head of Delegation and chairman of the Council, Piergiovanni Renzoni, presented the Special Award and expressed the gratitude of the GARTEUR community for the significant contributions provided by Prof. White, see Figure 9.

Figure 9: The GARTEUR Council Chairman, Piergiovanni Renzoni, presents the Special GARTEUR award to Prof. Mark White.

At the end of the gala dinner, the Council Chairman, Piergiovanni Renzoni, announced that he had decided "*motu proprio*", as the closing act of his two-year chairmanship, to assign an award based on his personal knowledge to a research scientist that over the years has best embodied the spirit of GARTEUR.

He presented the "Chairman's Award" to Dr. Klausdieter Pahlke (DLR, Head of Rotorcraft Branch) and driving force of the Rotorcraft Group of Responsable. The award was a scaled model of Leonardo da Vinci's concept known as the "vite aerea" (aerial screw)



that was later assembled by Dr. Pahlke, see Figure 10!

Figure 10: Klausdieter Pahlke in his office with the assembled Leonardo Aerial Screw, personal award of the Council Chairman, Piergiovanni Renzoni.

A special thanks went to the local organising committee of the event, see Figure 11.

Figure 11: Local organising committee of the GARTEUR event (from right Piergiovanni Renzoni, Maria Chiara Noviello and Vittorio Puoti).

Figure 12 contains the group picture, taken at the end of the first day, of the participants to the event.

Figure 12: Participants in the event held at the Italian Air Force Academy in Pozzuoli, IT, in front of the iconic F-104 Starfighter.

4.4 The event and the GARTEUR website

The GARTEUR website, accessible at www.garteur.org, has a new section, named the 50th, that collects the most relevant information related to the event. Agenda, presentations given to the conference and curricula of the speakers can be downloaded for your convenience. Pictures taken during the two-day event are available as well.

5. European aeronautics RTD environment

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

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

5.1 GARTEUR and ICAS

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

At the early beginning of 2024, just after the changeover, former GARTEUR secretary was contacted by Axel Probst, ICAS Executive Secretary, in order to try to setup a cooperation between GARTEUR and ICAS[1] since many fields of work of the groups overlap and, sometimes, they include the same persons. Since, at that time, the GARTEUR chairmanship had changed from Italy to Germany, the former Italian secretary Vittorio Puoti forwarded the information to the new German GARTEUR secretary Jutta Frohling in order to stimulate the possible collaboration, provided that another ICAS conference is going to be organised in Italy in September 2024.

5.2 GARTEUR and PEGASUS

The Partnership of a European Group of Aeronautics and Space UniversitieS (PEGASUS[2]) is a network of aeronautical universities in Europe created in order to facilitate student exchanges and collaborative research between universities. It has been originally created by the groupement des écoles aéronautiques françaises (group of French aeronautical grandes écoles) (ENAC, ENSMA and ISAE) in 1998. PEGASUS currently has 31 members, and 3 associate partners, in 13 different European countries and has an organisational structure quite similar to GARTEUR, both characterised by a Council and a rotating Chairman.

In 2023 GARTEUR has contacted the Chairman of PEGASUS in order to start having some interactions to understand whether a collaboration between the two entities was possible or not. GARTEUR Council Chairman, Dr. Piergiovanni Renzoni, invited the PEGASUS Vice-Chairman, Prof. Emmanuel

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[1] https://www.icas.org/

[2] https://www.pegasus-europe.org/

Zenou, to the Council in Amsterdam. There a presentation of the PEGASUS Consortium was given to the Council members and a very interesting and fruitful discussion started.

The PEGASUS representative in Italy, Prof. Francesco Franco from the University of Naples "Federico II", was then invited to participate in the event in Pozzuoli in order to have a closer look at the GARTEUR research activities.

Dott. Michele Mazzola, Director of Office III (Internationalization of Research) of the Italian Ministry of University and Research, during the 50th anniversary event pointed out how the membership of Italian universities in PEGASUS is crucial because this partnership aims to offer highly relevant educational and research programmes, thereby attracting the best students and scientists. He emphasised how achieving these goals will require coordinated changes, staff and student exchanges and innovation.

Contacts with PEGASUS will continue in 2024 in order to check the conditions for a more stable collaboration on themes of mutual interest.

5.3 Civil aeronautics

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

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

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

5.3.1 Strategic direction of European R&T

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

In 2020 the development of the Clean Aviation Joint Undertaking (CAJU) [3] began, entering into force on 30 November 2021 and with the first call being launched in 2022.

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

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

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

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

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

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

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

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

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

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

In 2023 eight innovative projects were added to the portfolio through a second call for proposals, with an overall amount of activities for €380 million, including €152 million in EU funding. The projects target novel aircraft concepts, innovative propulsion architectures, and new fuselage and wing designs, complementing those funded under Clean Aviation's first call for proposals and preparing all the necessary elements for ground and flight test activities starting in 2026.

Work on the 20 projects selected in the first call is advancing well to develop cutting-edge innovations including electric propulsion systems, hydrogen and hybrid gas turbine designs and the next generation of high-power fuel cells. Funded with €806 million, the 28 projects in total bring together close to 300 entities from 24 different countries. It is expected that new aircraft integrating Clean Aviation's technologies will be introduced within the programme's lifetime for an entry-into-service by 2035.

Achieving climate neutral aviation by 2050 is a massive challenge and can only be achieved by joining forces at EU, national and regional levels. Therefore, maximising synergies with programmes and initiatives across Europe contributing to sustainable aviation remains a core priority of Clean Aviation.

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

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

On March 2023 a Memorandum of Understanding was signed between the Clean Aviation and the Clean Hydrogen JU to establish a strategic cooperation on research and innovation in hydrogen-powered aviation, with the objective to maximise synergies, strengthen cooperation and align the activities of the two Joint Undertakings. The aim is to better support the hydrogen-aviation ecosystem to develop technologies for hydrogen-powered commercial aviation compatible with an entry into service by 2035.

Clean Aviation joined forces with the Occitanie region in France, as well as the Campania and Piedmont regions in Italy, renowned for their considerable initiatives in sustainable aviation.

5.3.2 GARTEUR and ACARE

In addition to its responsibility for developing the SRIA, the *Advisory Council for Aviation Research and Innovation in Europe* (ACARE)[4] plays an integral role in advancing aviation innovation within Europe by developing policy positions on European aviation initiatives and working closely with European Commission officials to ensure that Horizon 2020 funding calls - as well as calls associated with the Clean Sky 2 and SESAR Joint Undertakings - are closely aligned with the SRIA. This approach is continuing within the Horizon Europe programme.

In June 2022, ACARE, on behalf of all aviation stakeholders throughout Europe, presented the new European aviation vision “Fly the Green Deal[5]” which succeeds the 2011 vision document Flightpath 2050. The new vision presents a single global vision, addressing the three main objectives of the sector: achieving climate-neutral aviation in 2050, putting the citizen at the center and improving leadership and global competitiveness. To ensure that this vision will deliver impact towards its goals, it goes beyond research and includes also topics of new product development, deployment, energy, fuel, infrastructures, digitalisation and the implementation framework and synergies. The Vision and its goals were structured as depicted below.

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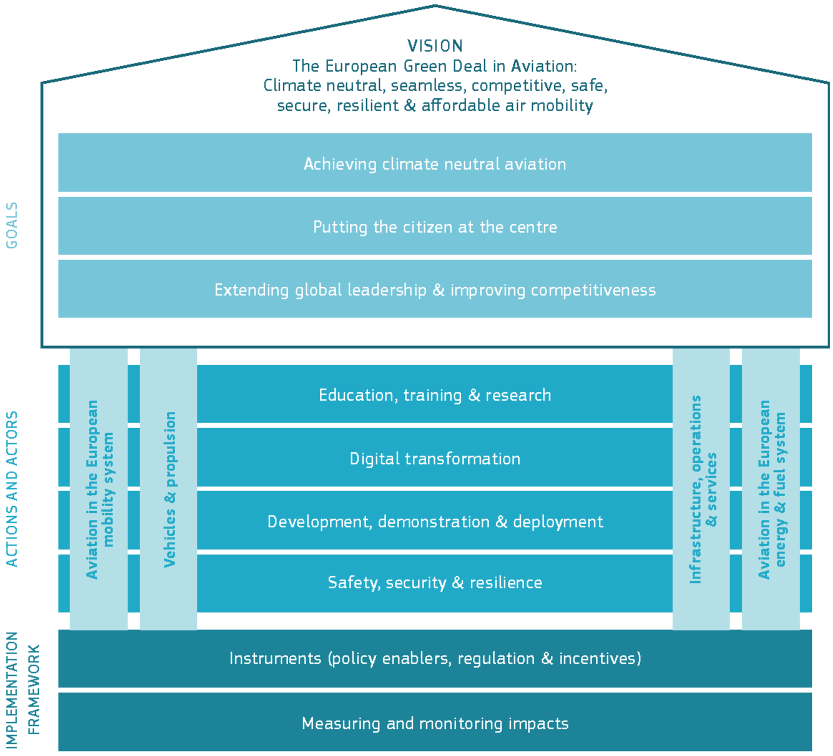
[4] https://www.acare4europe.org/

[5] https://www.acare4europe.org/news/fly-the-green-deal/



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

5.3.3 GARTEUR and EREA

EREA[6] is the *Association of European Research Establishments in Aeronautics*, whose members are Europe's most outstanding research centres in the field of aeronautics and air transport.

In 2012 EREA proposed a Joint Research Initiative, named Future Sky[7], 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.

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[6] https://erea.org/

[7] https://futuresky.eu/

In June 2021 the “EREA Vision Study – The Future of Aviation in 2050”[8] was published, updating the previously released “EREA vision for the future –Towards the future generation of Air Transport System” published in 2010. This new study, describing EREA’s own vision, has as objectives:

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

In July 2022 EREA welcomed the European sustainable aviation vision prepared by ACARE “Fly the Green Deal”, observing how the strength of the vision is the broad, sector wide support and the holistic approach, taking the full spectrum of stakeholders into consideration, where dedicated research and innovation are key to achieving the goals.

This renewed way of thinking, among other aspects, is also recommended by the “EREA 7-Point plan[9]”, one of the key inputs to the new ACARE vision:

1. Climate: reducing the impact towards zero
2. Quality of life: serving society by means of seamless, accessible and affordable mobility with the least impact on environment and people
3. Serving society: special missions required under extraordinary circumstances
4. Digitalization: an enabler for making society greener and part of artificial intelligence and cloud computing (Gaia-X)
5. Competitiveness: be most innovative on the worldwide scale
6. Prosperity: guaranteeing the workforce, research and infrastructures through European industrial and operational leadership
7. Implementation: from the 6 points stated above to a new concept for sustainable aviation in Europe.

In February 2023 EREA contributed to the public consultation of the European Union with the “EREA position on the past, present & future of the European Framework Programmes for Research and Innovation 2014-2027”. This position paper highlighted that it is of utmost importance that the Framework Programme for Research and Innovation funds and supports the entire R&I chain, increasing R&I investment, from basic research, application-oriented research, technology demonstration and validation up to innovation, to ensure European leadership and European competitiveness in the world. EREA emphasized the need to consider and support Technology Infrastructures (TIs) in an appropriate way. EREA has advocated for action on European level as there are clear gaps in the test and validation capability landscape.

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[8] https://erea.org/erea-vision-studies/

[9] https://erea.org/news/erea-publishes-the-erea-7-point-plan-for-sustainable-civil-aviation-in-europe

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.

5.4 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.

5.4.1 European Defence Agency

The *European Defence Agency* (EDA)[10] is an intergovernmental agency of the Council of the European Union, comprising all EU members with the exception of Denmark and also including from non-EU member states, Norway, Switzerland, the Republic of Serbia, and Ukraine, through special administrative arrangements. Through close cooperation the EDA seeks to improve European defence by supporting the development of capabilities, and nurturing technology and research to meet future defence requirements, and to promote defence interests in wider EU policies. The EDA operates at ministerial level and connects over 4000 nationally based experts collaborating on defence projects.

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

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

Research & Technology (R&T) continues to be one of the Agency's top priorities[11]. At the end of 2023, 48 new R&T projects were under negotiation at EDA with a value of €260 million. Added to EDA's existing R&T portfolio of 53 ad hoc R&T projects, the total number of projects will have an overall value of €518 million. CapTech Aerial Systems (Air) aids the development of the air-domain Capability Development Priorities in areas such as: Air combat platforms and weapons; Airborne Command and

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

[11] https://eda.europa.eu/news-and-events/news/2024/04/24/filling-gaps-in-eu-defences-eda-publishes-its-2023-annual-report

Information Capabilities; and Air Transport and Military Mobility. In 2023, a new project on Enhanced RPAS Autonomy (ERA2.1) was launched. Furthermore, three new projects with a total value of €15 million were under preparation.

Recent data on defence R&T spending indicates a positive trend over the past few years[12]. Following a period of underspending evident between 2008 and 2016, there has been a notable increase in R&T expenditures, reflecting a growing focus on this category. In 2023, total defence R&T expenditure reached €4 billion. This corresponds to an increase by 8% in real terms compared to 2022. In 2024, data indicates that defence R&T expenditure may pick up speed and could reach €5 billion. Yet, the expected 31% increase in defence R&T spending will likely not be sufficient for MS to achieve the 2% benchmark, with expenditure expected to amount to 1.6% of total defence expenditure, with respect to the 1.4% achieved in 2023.

Despite increased spending dedicated to defence research and technology, Member States are still failing to reach the 2% benchmark of defence expenditure dedicated to R&T activities with two countries accounting for more than 80% of R&T spending at EU level. EU collaborative endeavours such as EDA's ad hoc frameworks and funding via the EDF can collectively bring the EU closer to achieving the benchmark for defence spending allocated to R&T activities.

GARTEUR intends to strengthen its cooperation with EDA, harmonising its activities in the defence domain with the CapTech Air Strategic Research Agenda (SRA). This cooperation is facilitated by the very nature of GARTEUR, an MoU between Governments of 7 European countries, and will lead to research efforts on new disruptive technologies driven by the operational needs.

5.4.2 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;

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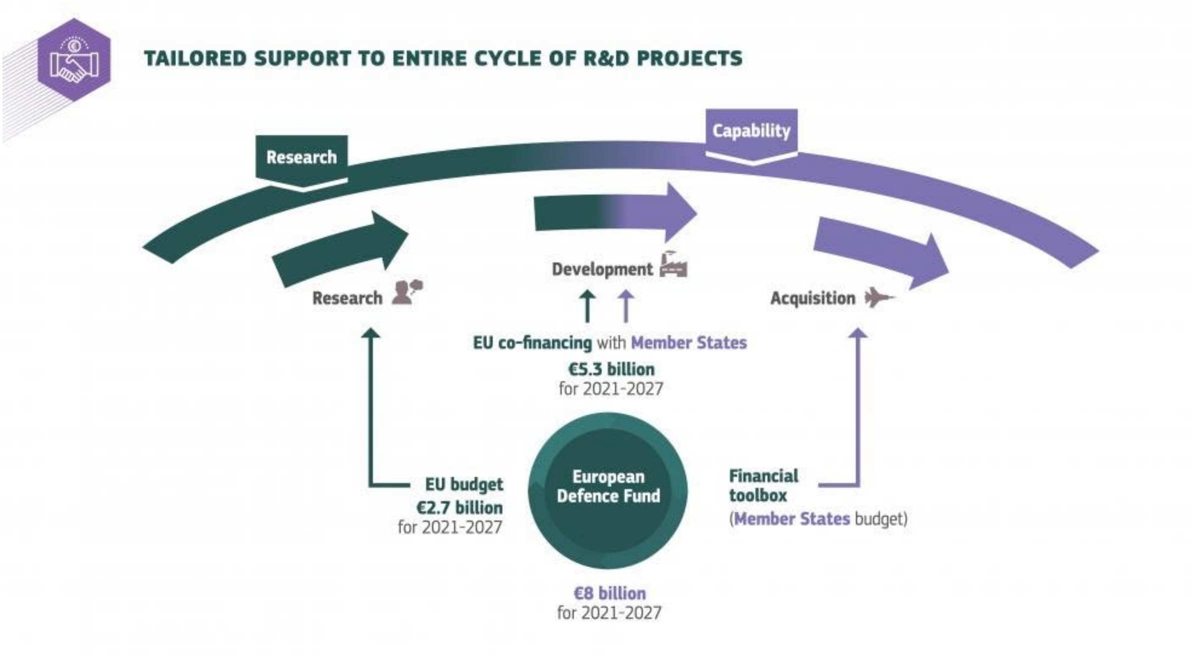
[12] https://eda.europa.eu/news-and-events/news/2024/12/04/eu-defence-spending-hits-new-records-in-2023-2024

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

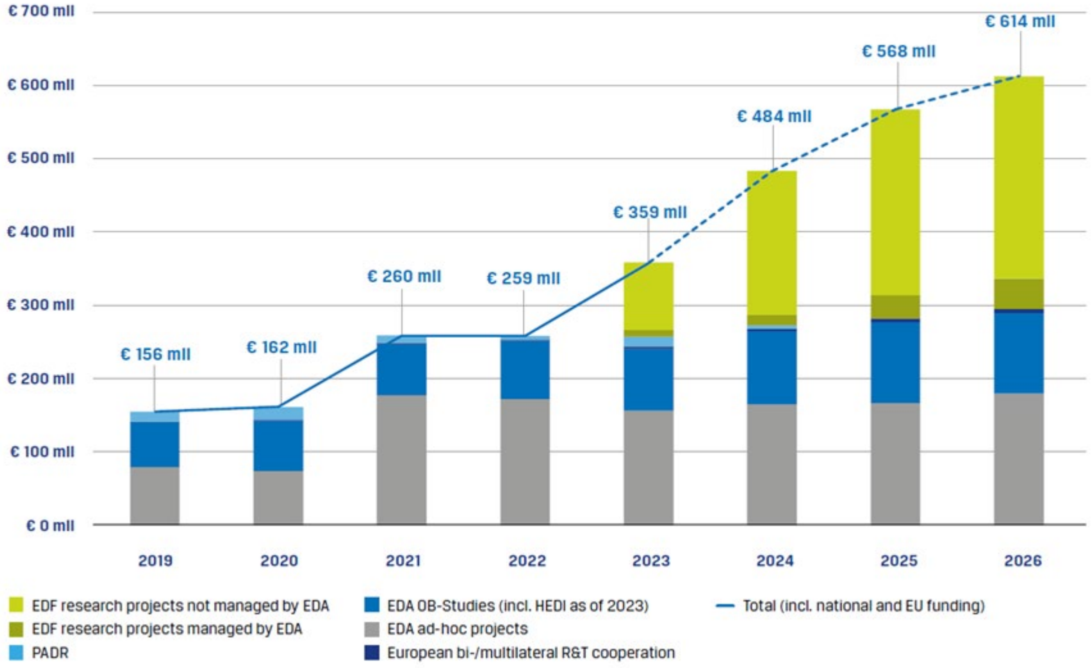


The first EDF call was launched in 2021 with a total budget of almost 1.2 billion euros. Of this the largest share went to the military aircraft sector, for an amount of nearly 200 million euros divided between three major projects: 40 million euros for research on technologies for the new generation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

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

The 2023 EDF calls for proposals closed in November 2023. The Commission is intending to fund 61 additional EDF projects worth €1 billion, which will bring the total EU budgetary investments to more than €3 billion in collaborative defence R&D projects since the start of the EDF Regulation in May 2021. The selected proposals respond to the funding priorities of the 2023 EDF work programme, addressing 34 topics structured along four thematic calls for proposals, plus bottom-up calls focused on SMEs.

2023 marked the first year that the EDF had such an effective and visible financial impact on the European defence landscape. In 2023, total funding for collaborative R&T projects launched under the EDF calls 2021 and 2022 amounted to around €100 million for projects. EU-funded research actions are projected to grow to almost €320 million in 2026. Combined with other financial instruments and national funding by MS, the total European collaborative R&T spending is estimated to increase from €359 million in 2023 to more than €600 million in 2026 (current prices).



Source: EDA, DEFENCE DATA 2023-2024

6. Summary of GARTEUR technical activities

During 2023 the five GARTEUR Groups of Responsables (GoRs) continued facilitating and delivering vital research in the field of aeronautics. The GoRs are responsible for monitoring and encouraging the progress of Action Groups (AGs) and Exploratory Groups (EGs). These groups are collaborations of researchers from national aerospace institutes, universities and industry. Although GARTEUR is not a source of funding, the GoRs constitute a powerful network and provide a unique forum for aeronautical research in Europe. The GoRs aid potential research consortia by critically reviewing their proposed research objectives and methodologies.

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

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

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

6.1 Group of Responsables – Aerodynamics (AD)

6.1.1 GoR-AD Overview

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

- aerodynamics;
- aerothermodynamics;
- aeroacoustics;
- aero-(servo-)elasticity;
- aerodynamic shape optimization;
- aerodynamics coupled to flight mechanics;
- aerodynamics systems integration.

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

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

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

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

6.1.2 GoR-AD Activities

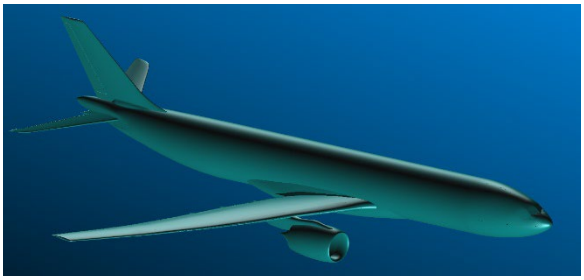
Four Action Groups and five Exploratory Groups have been running throughout 2023. In this period no new AGs have been launched, but there has been the launch of four new Exploratory Groups.

Action groups (AG)

The following Action Groups were active throughout 2023:

AD/AG-56

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



The CAD geometry of the XRF-1.

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

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

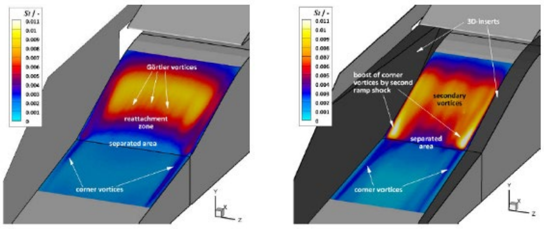
- ✓ A flight mechanics model for flexible structures,
- ✓ CFD methods with robust grid handling technique capable of modelling a combination of large rigid body motion and flexible aircraft structure,
- ✓ Fluid-structure interaction procedures that are capable of modelling large translations and finite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

The chairperson is Richard van Enkhuizen (NLR).

AD/AG-58

Supersonic Air Intakes

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



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

- ✓ 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.

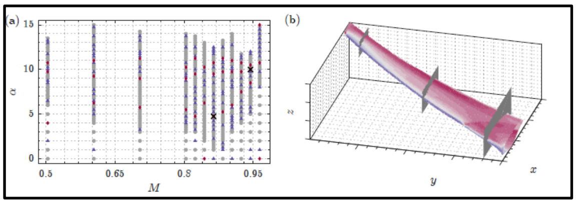
The chairperson is Christophe Nottin (MBDA).

AD/AG-60

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

The objectives of the 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.



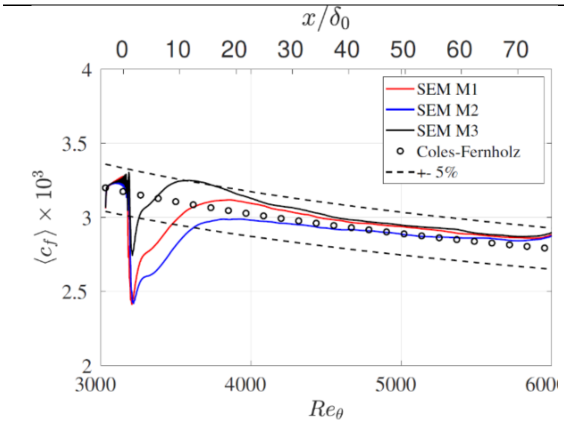
Test case used for Machine Learning training and selected test cases

The chairperson is Esther Andrés (INTA).

AD/AG-61

WMLES and Embedded LES

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



Test case 4: flat plate (SAAB)

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

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

The chairperson is Nicolas Renard (ONERA).

Exploratory Groups (EG)

The following Exploratory Groups were active throughout 2023:

AD/EG-79	*Hypersonics* EG-79 Hypersonic flows was active since 2022. Partners of the EG are: DLR, CIRA, NLR, FOI, VKI, MBDA France and University of Munich. The EG has started with email communication and online meetings in order to discuss the potential topics for a future AG. Topics currently under discussion are ablation, radiation heat flux measurements, thermal fluid structure interaction, and shock wave boundary layer interaction. Each topic is discussed both with respect to numerical and experimental activities.
AD/EG-80	*Morphing for load control of high aspect ratio wings* Partners of the EG are: CIRA, DLR, NLR, ONERA. The

objective of EG-80 will be to investigate both aerodynamic efficiency and load control & alleviation capabilities of a High Aspect Ratio wing concept equipped with morphing devices while limiting weight increase and mechanical complications due to morphing technology.

The proposal research will focus on the strut braced wing aircraft, referred to as U-HARWARD reference model, that will be made available by ONERA

AD/EG-81

Virtual certification

For new civil transport aircraft program, the certification phase is critical in terms of planning and costs. In 2019, a common paper by Airbus and Boeing indicated how CFD could contribute to the certification of civil transport aircraft for off-design flight characteristics.

The purpose of this EG is to have more physics-based analysis tools, less empirical and/or sub-scale methods, fully-integrated multi-physics and multi-scale aircraft modelling and minimize usage of ground test rigs.

The objective of the proposed activity is to foster scientific activities in collaboration with industrial leaders and EASA towards a larger usage of CFD in the certification process.

AD/EG-82

Corner flows for turbulence model developer

The understanding and the prediction of the development of flows at the junction of two orthogonal surfaces is still an important topic in the different aspects of aircraft design, e.g. in the design of the wing-fuselage junction, the intersection of horizontal and vertical tail planes or the pylon-fuselage junction which exists in a rear engine aircraft configuration.

The idea of this GARTEUR initiative is to form a working group dealing with the investigation of aircraft related

	junction flows (both civil and military applications), the comparison and validation of state-of-the-art transition and/or turbulence modelling approaches for such flows as well as the improvement of the physical modelling. For this purpose, experimental data is needed for comparison and potential partners are encouraged to share WT data if available. Furthermore, potential partners are equally encouraged to bring in their expertise in transition and turbulence modelling as well as in the application of different CFD tools and modelling approaches.
AD/EG-83	*Hydrogen combustion* The exploratory group will address use of hydrogen in aeronautic combustion engine. Three different lines of activities have been identified: 1. To create a validated software tool suitable for use in design of future aero-engines employing hydrogen combustion. The work will proceed by conducting a series of simulations on a set of flames and comparing the numerical results with experiment. 2. To model heat fluxes associated with hydrogen leakage within a future aircraft hydrogen powered propulsion system 3. To explore potential alternative of hydrogen combustion aero-engine turbine technology: The Rotating Detonation Engine A very strong consortium has been formed, partners are: CIRA, CERFACS, CRANFILD Un., ENEA, FOI, IMFT, INTA, Piaggio, Tu Darmstadt, Un. of Beira Interior, Politecnico di Bari

New topics under consideration are:

Cartesian methods / Immersed boundary methods

Use of non-conventional CFD methods such as immersed boundary tools

Thermal management for electric propulsion

Electrical hybrid aircraft cooling simulation

6.1.3 GoR-AD Membership

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

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

6.2 Group of Responsables – Aviation Security (AS)

6.2.1 GoR-AS Overview

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

The GoR-AS initiates, organises and performs research on detection and mitigation of unlawful interferences against aviation. Both physical and digital interferences are considered. Topics such as Cybersecurity, Unauthorized drones, Laser Dazzling, Chemical, Biological & Explosive detection are addressed by the GoR.

6.2.2 GoR-AS Activities

Two high priority research topics were established a few years ago following discussions with various industrial, institutional and academic stakeholders. GoR-AS is focusing on the investigation of these two topics: detection and mitigation of unauthorized drones, assessment of security risks caused by AI in Aviation.

Unauthorized Drones

ONERA, INTA and CIRA have completed by the end of 2022 the activities within ASPRID Project - Airport System Protection from Intruding Drones - belonging to Horizon 2020 Call: H2020-SESAR-2019-2 (SESAR 2020 EXPLORATORY RESEARCH). In 2023 several scientific publications were written in order to disseminate the results of the project. Furthermore, the final report for the associated Action Group 1 was prepared.

In 2023, several meetings explored follow-up activities of this Action Group. The group investigated the detection and protection of coordinated drone attacks in a large geographical area managed by a U-space service provider. The U-space set of services that deal with the management of authorized drone trafic should be extended with services that detect and manage cyberattacks involving drones. Several emerging threats were identified by the group: large-scale GNSS disruption, traffic data spoofing attacks where a large number of fake aircraft or drone positions are emitted in order to saturate the ATM or the U-space service provider capabilities.

This topic was discussed by researchers of CIRA, INTA, ONERA and ZHAW (CH) as well as members of Eurocontrol Civilian/Military coordination team (EU), ENAC (I), Hologarde (F), Thales U-space (F). A SESAR Exploratory Research proposal on this topic was submitted in 2023 but it was not funded.

AI and Aviation Security

AI Assistant cybersecurity is another topic that GoR-AS started to explore in 2023. Members of the GoR as well as members of other GoR are investigating the use of digital assistant based on Machine Learning in various domains of aviation. Due to the role played by AI assistants in safety critical tasks, their safety and certification are extensively investigated by EASA as well as the industrial and academic community. EASA AI Roadmap recognizes the important role of cybersecurity but it provides by now limited guidance on this topic. Research is needed on the identification of the threats applicable to AI assistants developed for Aviation.

The group identified other research themes related with AI and cybersecurity. Several Partners have ongoing projects on AI for Aviation Security. They have investigated the use of Machine Learning algorithms in order to detect or mitigate illegal interferences. For instance, they developed AI tools for detection of anomalous ADS-B messages or GPS measures, detection of fake or replayed Air Traffic Controller voice messages. A final area of research investigates the protection of aviation against attackers using AI techniques. In that case, AI could be used in order to help attackers learn vulnerabilities about the system that has to protected. AI can also be used to automate the attack and improve its efficiency.

The AI Assistant cybersecurity topic was discussed by researchers of CIRA, DLR, ONERA, U of Porto (P), U of Bremen (D) and industrial partners Collins (I) and Leonardo (I). A proposal on this topic in relation with Horizon Europe was discussed but not submitted due to the lack of maturity of the proposal.

Research and Innovation Roadmaps

The AS-GoR has also monitored the main research and innovation roadmaps applicable to Aviation Security. EASA Roadmaps were mainly used for the definition of past and future topics: Counter-Drone Task-Force, AI Certification Roadmap, and more generally the European Plan for Aviation Safety (EPAS). In 2023, an update of SESAR JU ATM Master Plan is being produced, the current version includes a Cybersecurity vision for the years 2025 to 2030. This Cybersecurity vision will be analysed by the group in 2024.

In the future, the group will also monitor military roadmaps established by European Defence Agency and NATO.

6.2.3 GoR-AS Membership

The membership of this GOR in 2023 is presented in the table below:

Chairperson		
Pierre Bieber	ONERA	France
Vice-Chairperson		
Tim Stelkens-Kobsch	DLR	Germany
Members		
Angela Vozella	CIRA	Italy
Rene Wiegers	NLR	The Netherlands
Jaime Cabezas	INTA	Spain

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

6.3.1 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.

6.3.2 GoR-FM Activities

The activities in 2023 have been focused to establishing the EG30 “AI for fault detection”, and contributing to the 50th anniversary event in Italy, reporting particularly on GoR-FM key themes and highlight within the last 50 years: More than 80 reports about many aspects have already been published by GoR-FM, covering a variety of the research topics mentioned above, from Handling Quality research, fault tolerant control up to research towards greater autonomy for multiple Unmanned Air Vehicles. These reports are available at the GARTEUR website, but many results have been published in conference proceedings or as scientific books like publication about Nonlinear Analysis and / Synthesis Techniques for Aircraft Control (Springer Verlag). In addition, future research fields and activities like actually planned in EG30 have been addressed.

Exploratory Groups (EG)

The following Exploratory Group was kicked-off in 2023:

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.

6.3.3 GoR-FM Membership

The membership of GoR-FM in 2023 is presented in the table below.

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

6.4 Group of Responsables – Rotorcraft (RC)

6.4.1 GoR-RC Overview

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

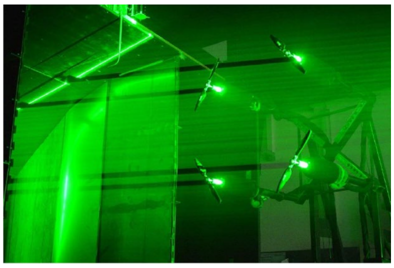
The GoR-RC initiates, organises and monitors basic and applied, computational and experimental multidisciplinary research in the context of application to rotorcraft vehicles (helicopters and VTOL aircraft such as: tilt rotors; compounds and multi-copters) and systems technology.

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

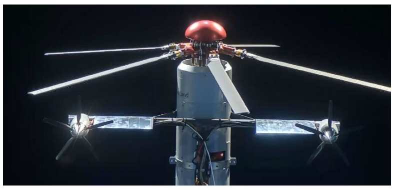
- decrease costs (development and operation) through Virtual Engineering using numerical tools based on low/medium-order (analytical, BEM) to high-order (CFD) methods, validated with relevant tests campaigns;
- increase operational efficiency (improve speed, range, payload, all-weather capability, highly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

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

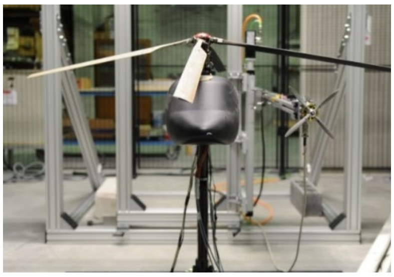
A characteristic of helicopter, tilt rotor, compound and multi-copter aircraft is the need for a multidisciplinary approach due to the high level of interaction between the various technical disciplines for tackling the various issues for rotorcraft improvement.



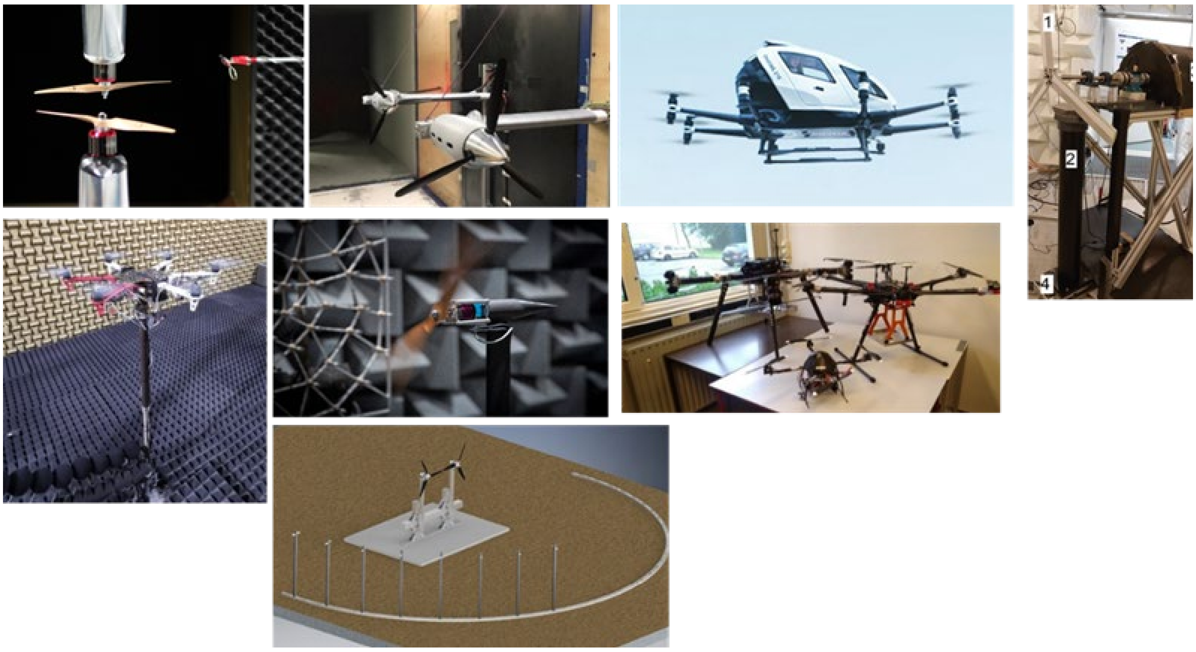
Multicopter experiment in RTG at DLR Göttingen (HC/AG-25)



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



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



Overview of experimental activities in RC/AG-26

6.4.2 GoR-RC Activities

Three Action Groups and one Exploratory Group have been running throughout 2023.

Action groups (AG)

The following Action Groups were active throughout 2023:

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 and was concluded in May 2023.
RC/AG-26	*Noise Radiation and Propagation for Multirotor System Configurations* The objective is to investigate, both numerically and experimentally, the noise radiation and propagation (installation effect) of multirotor systems and to gain knowledge in the physics of noise generation and near-field noise propagation of multirotor systems under the influence of the installation effects and to establish tools for the noise prediction. Compared to conventional helicopters, the importance of the various noise sources and the influence of noise scattering can be totally different for multi rotor configurations. The AG started in February 2022. Both, a common validation study and a common experiment are foreseen. The common validation study aims at evaluating and improving the prediction accuracy of different simulation methods.
RC/AG-27	*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 AG is to study the application to rotary wings of aerodynamic force analysis and decomposition methods. The kick-off meeting of this AG was held on April 2023.

Exploratory Groups (EG)

The following Exploratory Groups were active or decided to start in January 2023:

RC/EG-40	*Gust Resilience of VTOL Aircraft* The objective is to set-up a team of researchers able to investigate and test the different approaches that might be employed to achieve gust resilience of multi-rotor vehicles. This EG was identified in 2019 and was expected to be active in 2020. Unfortunately, Cranfield's application for UK funding, to support this activity, was not successful, and for this reason, Cranfield had to withdraw from chairing this EG. Prof. Lovera from Politecnico di Milano accepted to take over the chairmanship from Cranfield Univ. with the aim to restart this EG in 2021. Nevertheless, during the years 2021, 2022 and 2023 no meeting was organised and no updates were received from Prof. Lovera. In 2023 the RC-GoR decided to keep this EG active, standing its utmost importance, mainly for UAM applications, and tried to identify another chairman willing to lead this EG.

New topics under consideration are:

Drone impact on Helicopters (rotating parts)

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

Helicopter Icing & De-Icing

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

Human Factors issues and Training methods for complex automation in cockpit

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

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

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

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

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

Installation effect of propeller noise (wing, ducts)

The development of eVTOL architectures require a deeper understanding of the noise generated by propellers when ducted or installed in close proximity to wings or airframe.

Verification & Validation: defining metrics for the quality of simulations.

There is an international interest about this topic, especially related to VTOL applications.

Vortex Ring State for eVTOL configurations.

To investigate the potential impact of the Vortex-Ring-State (VRS) phenomenon on the safety and operational characteristics of new eVTOL aircraft architectures integrating multirotor/propeller systems as well as fixed wings.

6.4.3 GoR-RC Membership

The membership of GoR-RC in 2023 is presented in the table below. Alicia Verónica Barrios Alfonso of INTA resigned from her position of Spanish GoR-RC member. No substitute was indicated by INTA during the year.

Chairperson		
Antonio Visingardi	CIRA	Italy
Vice-Chairperson		
Mark White	Univ. Liverpool	United Kingdom
Members		
Klaus-Dieter Pahlke	DLR	Germany
Barbara Ohlenforst	NLR	The Netherlands
Arnaud Le Pape	ONERA	France
Industrial Points of Contact		
Rainer Heger	Airbus Helicopters (D&F)	Germany
Observer		
Richard Markiewicz	Dstl	United Kingdom

6.5 Group of Responsables – Structures and Materials (SM)

6.5.1 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 upstream research intended to discover valuable areas of future activity; in this context, many new ideas were proposed and explored during the year 2020.

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

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

6.5.2 GoR-SM Activities

In 2023, GoR-SM monitored two Action Groups and three Exploratory Groups:

Action groups (AG)

The following Action Groups were active throughout 2023:

SM/AG-36

Additive layer Manufacturing

This Action Group started in March 2022 and is a result from SM/EG-47. AG-36 deals with new Novel aluminium alloys (ScanCromal and AlMg1Cr1.5Mo0.5Sc0.5Zr0.25) suitable for processing via metal additive manufacturing techniques. There is an increasing need for high strength aluminium alloys that can be processed with AM for production of applications that require low weight combined with high specific strength. The selected alloys will be investigated in Laser Powder Bed Fusion (L-PBF) and Directed Energy Deposition (DED).

SM/AG-37

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. 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 topics of this AG-37 are:

- Investigation on the key components which require the integration with shock absorber;
- identification and classification of the shock absorbers (material and geometry);
- material investigation (Alternative materials, Hybridization);
- integration strategies;
- analytical methods for designing hybrid shock absorber;

- numerical analysis and design;
- unit cell optimization (weight minimization and/or shock absorbing capability maximization);
- thermal stress analysis;
- experimental tests and validation;
- certification issues;
- definition of guidelines for an effective integration in each scenario.

Exploratory Groups (EG)

The following Exploratory Groups were active throughout 2023:

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. The topic of high temperature polymer matrix composites was also submitted in a Clean Aviation proposal. The outcome of the Clean Aviation call (expected in September 2022) will determine whether this EG/AG will be continued.
SM/EG-45	*Characterization and modelling of CMC submitted to severe thermo-mechanical loading* The main objectives of the EG consist in: • understanding of the damage and failure mechanisms under static and fatigue loading at very high temperatures;

	• definition of standard tests to measure 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 simulating CMC composite structures under static or fatigue loading (evaluation of predictive capabilities of models).
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.

6.5.3 GoR-SM Membership

The membership of GoR-SM in 2023 is presented in the table below.

Chairperson		
Bert Thuis	NLR	Netherlands
Vice-Chairperson		
Javier San Millan	INTA	Spain
Members		
Aniello Riccio	UdC	Italy
Robin Olsson	RISE	Sweden
Peter Wierach	DLR	Germany
Andrew Foreman	QinetiQ	United Kingdom
Mats Dalenbring	FOI	Sweden
Florence Roudolff	ONERA	France
Industrial Points of Contact		
Thomas Körwien	Airbus Defence and Space	Germany
Christian Weimer	Airbus Operations	Germany
Thomas Ireman	SAAB	Sweden

7. 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

ICAS: International Council of the Aeronautical Sciences

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

PEGASUS: Partnership of a European Group of Aeronautics and Space Universities

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

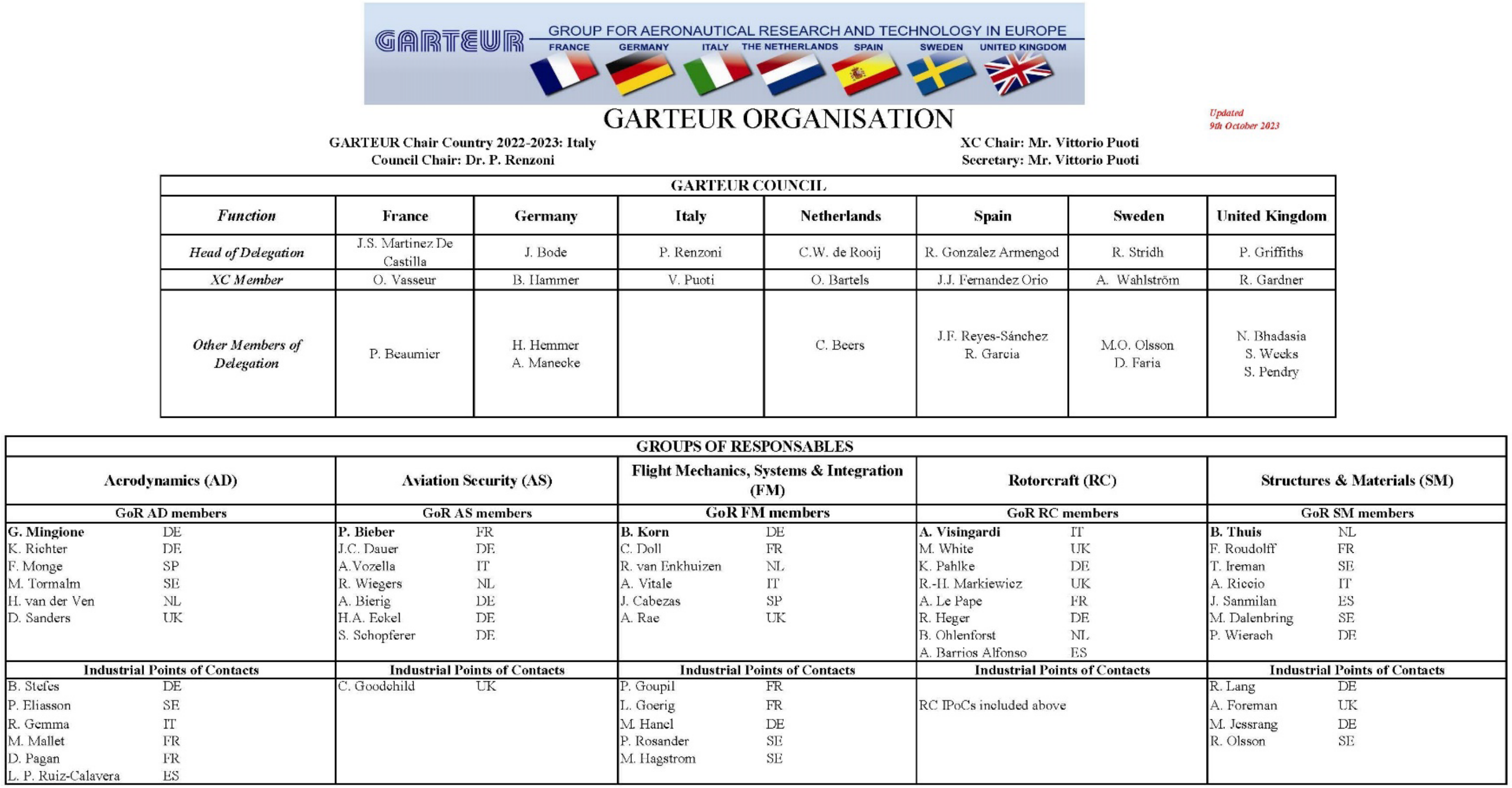
STO: Science and Technology Organisation

TRL: Technology Readiness Level

UAV: Unmanned Air Vehicle

XC: Executive Committee

8. Organigram



GARTEUR ORGANISATION

Updated
9th October 2023

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

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

GARTEUR COUNCIL

Function	**France**	**Germany**	**Italy**	**Netherlands**	**Spain**	**Sweden**	**United Kingdom**
Head of Delegation	J.S. Martinez De Castilla	J. Bode	P. Renzoni	C.W. de Rooij	R. Gonzalez Armengod	R. Stridh	P. Griffiths
XC Member	O. Vasseur	B. Hammer	V. Puoti	O. Bartels	J.J. Fernandez Orio	A. Wahlström	R. Gardner
Other Members of Delegation	P. Beaumier	H. Hemmer A. Manecke		C. Beers	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**	
G. Mingione	DE	**P. Bieber**	FR	**B. Korn**	DE	**A. Visingardi**	IT	**B. Thuis**	NL
K. Richter	DE	J.C. Dauer	DE	C. Doll	FR	M. White	UK	F. Roudolff	FR
F. Monge	SP	A.Vozella	IT	R. van Enkhuizen	NL	K. Pahlke	DE	T. Ireman	SE
M. Tormalm	SE	R. Wiegers	NL	A. Vitale	IT	R.-H. Markiewicz	UK	A. Riccio	IT
H. van der Ven	NL	A. Bierig	DE	J. Cabezas	SP	A. Le Pape	FR	J. Sanmilan	ES
D. Sanders	UK	H.A. Eckel	DE	A. Rae	UK	R. Heger	DE	M. Dalenbring	SE
		S. Schopferer	DE			B. Ohlenforst	NL	P. Wierach	DE
						A. Barrios Alfonso	ES		
Industrial Points of Contacts		**Industrial Points of Contacts**		**Industrial Points of Contacts**		**Industrial Points of Contacts**		**Industrial Points of Contacts**	
B. Stefes	DE	C. Goodchild	UK	P. Goupil	FR			R. Lang	DE
P. Eliasson	SE			L. Goerig	FR	RC IPoCs included above		A. Foreman	UK
R. Gemma	IT			M. Hanel	DE			M. Jessrang	DE
M. Mallet	FR			P. Rosander	SE			R. Olsson	SE
D. Pagan	FR			M. Hagstrom	SE				
L. P. Ruiz-Calavera	ES								

APPENDICES

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Appendix A: Annex GoR-Aerodynamics (AD)

**ANNUAL REPORT FROM THE GROUP OF RESPONSABLES
“AERODYNAMICS”**

Remit

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

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

The Group is active in experimental, theoretical, analytical, as well as in numerical fields of aerodynamics to support the development of methods and procedures. Work in experimental areas is performed mainly to obtain valuable data for the validation of methods. Measurement techniques are developed and refined to increase accuracy and efficiency of experimental investigations. Other numerical studies give insight in the mechanisms of basic flow phenomena.

GoR-AD Overview

GoR Activities

Four Action Groups have been running throughout 2023. In this period no new AGs have been launched, but there has been the launch of four new Exploratory Groups. The active Action groups are:

Management

Two meetings have been held:

AD/A- 112 Meeting INTA, Madrid (Spain) March 2nd, 3th 2023

AD/A- 113 Meeting at Pozzuoli (Italy), October 4th, 5th 2023

GoR-AD has contributed to the event organized in occasion of 50th anniversary of GARTEUR by providing a presentation illustrating an overview of the GoR-AD activities along these 50 years of GARTEUR.

Along AD/A 113 meeting it has been officialised the change of chairman. From 2024 chairman will be Jean-Luc Hantrais-Gervois from ONERA, and vice-chairman will be Magnus Tormalm from FOI.

Next GoR-AD meeting is planned on march 5th and 6th at FOI (Sweden).

Dissemination of GARTEUR activities and results

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

Status of Action Groups and Exploratory Groups

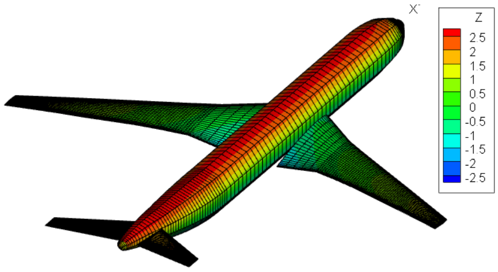
Five Action Groups and one Exploratory Group have been running throughout 2023.

Action groups (AG)

The following Action Groups were active throughout 2023:

AD/AG-56

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



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

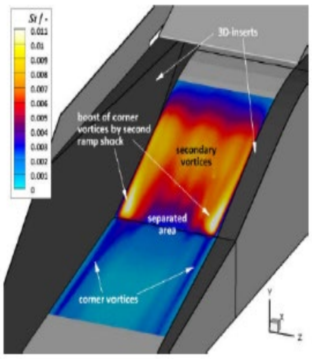
- A flight mechanics model for flexible structures;
- CFD methods with robust grid handling technique capable of modelling a combination of large rigid body motion and large flexible motion;

- Fluid-structure interaction procedures that are capable of modelling large translations and finite rotations.

The chairperson is Richard van Enkhuizen (NLR).

AD/AG-58

Supersonic Air Intakes



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

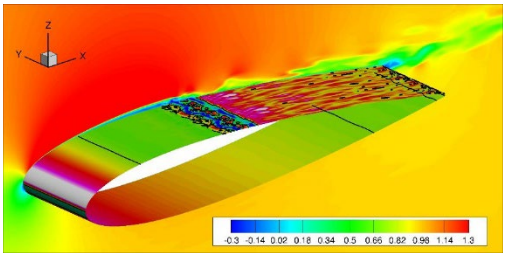
- cowl oblique shock / boundary layer / mixing layer interactions;
- internal bleed flows;
- supersonic air intake diffusers and scramjet isolators including corner flows description.

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

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

The chairperson is Christophe Nottin (MBDA).

AD/AG-59



Improving the Simulation of Laminar Separation Bubbles

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

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

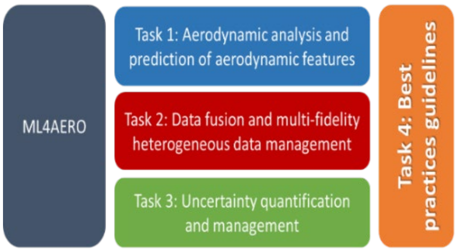
The chairperson is Pietro Catalano (CIRA).

AD/AG-60

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

The objectives of the Action Group are:

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



The chairperson is Esther Andrés (INTA).

AD/AG-61

WMLES and Embedded LES

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

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

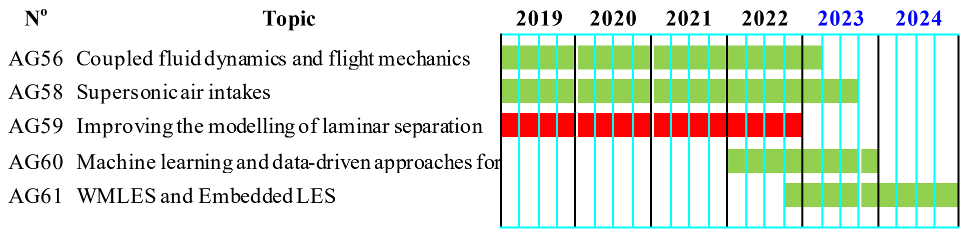
The activities of the group aim at facilitating the introduction of family II in industry. The several turbulent relative topics are investigated through 4 test cases.

Exploratory Groups (EG)

The following Exploratory Groups were active throughout 2023:

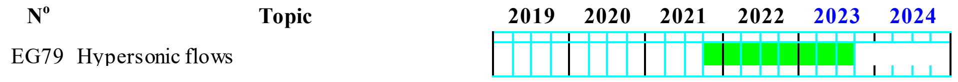
AD/EG-79	*Hypersonics* Partners of the EG are: DLR, University of Munich, CIRA, DLR, TU Munich, NLR, FOI, VKI. After some preliminary meetings there have been no additional activities. Even if only one Exploratory group is active, there are several topics under discussion that could generate new Exploratory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

Rolling plan



N°	Topic	2019	2020	2021	2022	2023	2024
AG56	Coupled fluid dynamics and flight mechanics						
AG58	Supersonic air intakes						
AG59	Improving the modelling of laminar separation						
AG60	Machine learning and data-driven approaches for						
AG61	WMLES and Embedded LES						

🟥 Closed 🟩 Active Status Decem



N°	Topic	2019	2020	2021	2022	2023	2024
EG79	Hypersonic flows						

🟥 Closed 🟩 Active Status Decem

GoR membership

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

After years of active contribution in the GoR-AD and in European Union research programme, Eric Coustols has retired. The GoR-AD members thank him for everything he brought to the group, both on the scientific and personal levels. Eric Coustols as ONERA representative has be replaced by Jean-LucHantrais-Gervois.

At present time we still do not have an UK member for the aerodynamics GoR. Neverthless during last Council it has been announced that UK GoR-AD member will be Drewan Sanders, from the University of Cranfield.

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

Table of participating organizations

	AG-56	AG-58	AG-60	AG-61
Research Establishments				
CIRA	☐		☐	☐
DLR	☐	☐	☐	☐
FOI		☐	☐	☐
INTA			■	
NLR	■		☐	☐
ONERA	☐	☐	☐	■
Industry				
Airbus Defence & Space			☐	
Airbus Operations GmbH	☐		☐	
Airbus Operations S.A.S.				
Leonardo				
Dassault Aviation				
MBDA-F		■		
MBDA-D		☐		
SAAB		☐		☐
OPTIMAD			☐	
Academic Institutions				
Imperial College				
Technical Univ. Munich				
University of Manchester				☐
Zurich Univ. of Applied Sciences				
Univ. of Napoli “Federico II”				
Marche Polytechnic University				
Univ. of Strasbourg				☐
Univ. of Southampton				
Institute of Marine Engineering (INMCNR)				
Nat. Institute for Research in Digit. Science and Technology			☐	
University of Twente			☐	

Action Group Reports

AD/AG-56 **Coupled fluid dynamics and flight mechanics simulation of very flexible aircraft configurations**

Monitoring Responsable: H. Van der Ven
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 Figure 12). For the FEM model, wing elasticity has been modified for increased tip deflections; aiming for 10 percent tip deflection in 1g flight (see Figure 13). This has been done for a worst-case mass condition. The front and rear spar have been tuned to attain the desired tip deflection; iterating for the gust condition of interest in a panel code environment (see Figure 14).

Due to the world-wide pandemic in 2020, Covid-19, very limited progress is achieved in 2020. Some progress is achieved to setup first simulations, but simulation results have not been achieved in the year 2020.

In the year 2021, partners have run trim simulations using their methods with either rigid models or the flexible model. As shown in Table 1 and Table 2, the results are reasonably close together even though there are known differences between the models of the partners. Some of these differences are investigated further at the beginning of 2022. DLR decided to run the simulation only with the very flexible aeroplane and has reported issues with their approach to run the very flexible model of AG-56. Hence, no trim results of this model are available yet.

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

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

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

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

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

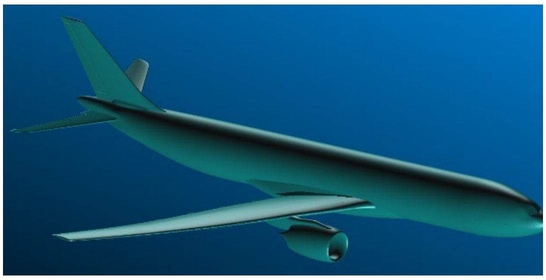


Figure 13: CAD geometry of the XRF-1.

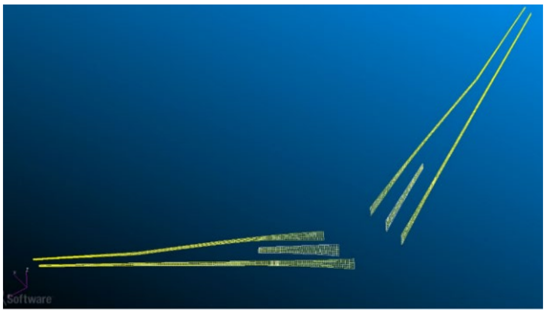


Figure 14: Depiction of the wing structure in the FEM model. The elasticity of the front and rear spar is tuned for 10 percent tip deflection in 1g flight.

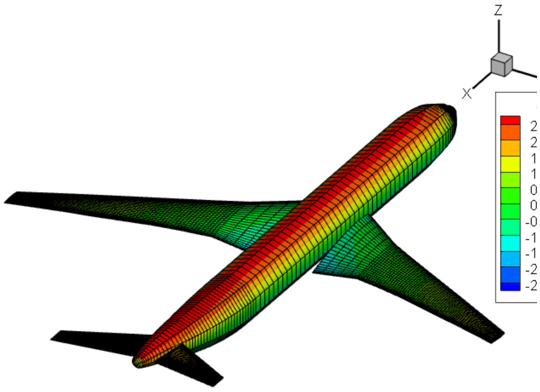


Figure 15: Panel model used to tune the wing structure for 10% tip deflection for worst-case gust.

- **Project management**

It has been decided to have alternating physical and teleconference meetings every 3 months. The kick-off meeting took place on the 9th of March 2018 in Amsterdam, hosted by NLR. Two teleconference progress meetings have been held on the 25th of October 2018 and the 25th of March 2019, as well as a physical meeting in Manching, hosted by Airbus Defence and Space on January 24th, 2019. July 4th 2019, a teleconference meeting pertaining to model updates, while various teleconferences have been held between partners pertaining to model generation.

In autumn 2020 the chairmanship has been transferred to M.J. van Enkhuizen.

During the year 2021, preliminary results of the trim simulations are discussed on the four meetings that were organised by NLR on January 25th, April 9th, June 18th, October 27th. Additionally, during the fall 2021 meeting the manoeuvre and disturbance conditions are discussed to further specify the required input to perform the simulations.

During the year 2022, preliminary results of the disturbance and manoeuvre conditions are discussed on the four meetings that were organised by NLR on January 12th, June 21th, October 24th, November 29th.

- **Expected results/benefits**

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

- **AD/AG-56 membership**

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M. Ritter	DLR	markus.ritter@dlr.de
MJ. van Enkhuizen	NLR	richard.van.enkhuizen@nlr.nl
Cédric Liauzin	ONERA	cedric.liauzun@onera.fr

AD/AG-58 Supersonic Air Intakes Aerodynamics

Monitoring Responsable:	D. Pagan 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. Some other priorities in 2022 have lead to other delays. It is proposed to restart the collaboration by summer 2023 and to prepare the final report in December 2024. An updated list of milestones is proposed.

WP2 : Supersonic diffusers flows

The case proposed in WP2 involves shock trains prediction.
The main challenges are:

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

The classical turbulence models based on linear closures generally fail to reproduce accurately these flows. More advanced models may be required based on RANS with non linear closures or LES/DES techniques.
A 3D test case with thick BLs $Re\delta2\approx6000$ 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 15.
Several RANS computations were performed by ONERA. Inlet flow profiles are now available to all partners, see Figure 16. Outlet condition is a prescribed back pressure. ONERA will perform a DES mode 3 calculation that can be used as a reference to compare with RANS models. Members will perform DES and/or RANS calculations

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

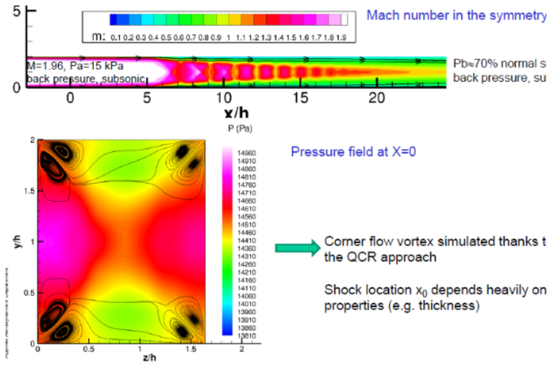


Figure 16: shock train in a rectangular cross-section channel. ONERA test-case.

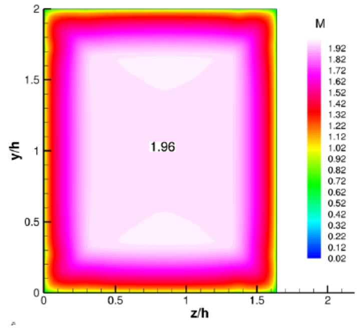
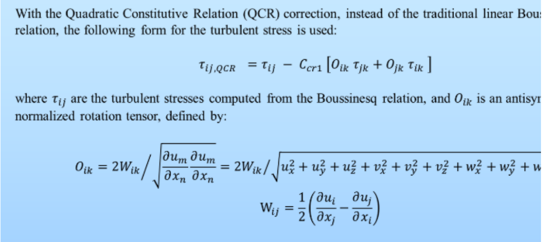


Figure 17: common inlet flow field proposed by ONERA for shock train case computations.

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

QCR generic formulation are detailed below.



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

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

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

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

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

Figure 18: principle of QCR non-linear closure for turbulence models.

Results obtained with SA-QCR model are quite different compared to those obtained with the standard SA model. The prediction of the corner flows is strongly modified resulting in a non-symmetric development of the shock train inside the duct for the SA and a symmetric one for the SA-QCR (see Figure 18).

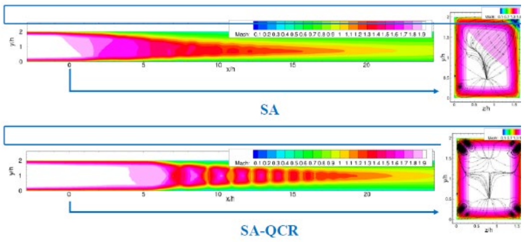


Figure 19: effects of QCR closure with the Spalart Allmaras model on corner flows and shock train development for WP2 test-case (ONERA).

Comparisons of CFD predictions with available pressure measurements and published DNS results show local improvements with the non-linear closure of the turbulence model (see Figure 19 and Figure 20).

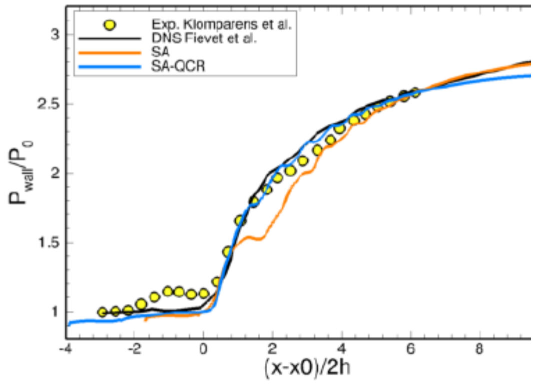


Figure 20: effects of QCR closure with the Spalart Allmaras model and comparison with wall pressure measurements (ONERA).

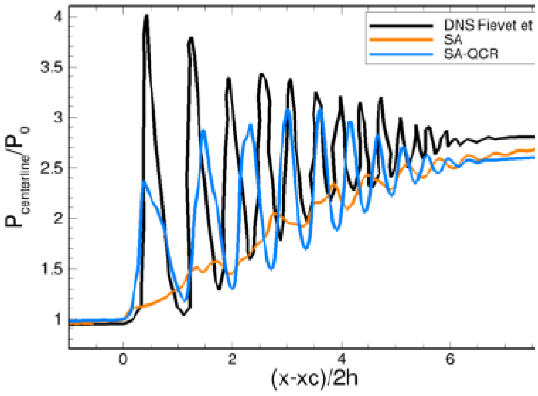
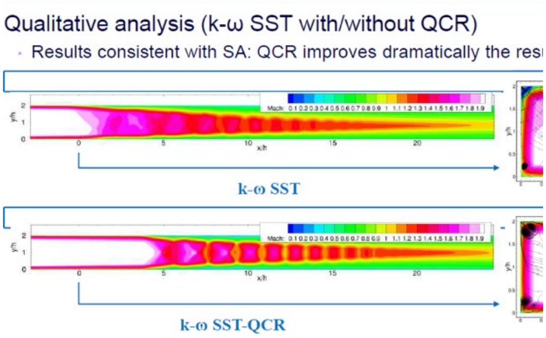


Figure 21: effects of QCR closure with the Spalart Allmaras model and comparison with axial pressure computations from DNS published by Fiévet et al. (ONERA).

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

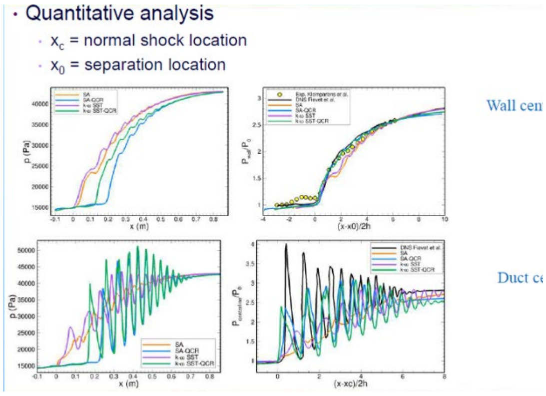


Qualitative analysis (k-ω SST with/without QCR)

- Results consistent with SA: QCR improves dramatically the resı

Figure 22: effects of QCR closure with the k-omega SST model on corner flows and shock train development for WP2 test-case

These results (Figure 21) confirm the trends from previous results obtained with SA model. QCR correction leads to strong improvement regarding corner flow effects (Figure 22).



- Quantitative analysis
  - x_c = normal shock location
  - x_0 = separation location

Figure 23: Effects of QCR closure with the k-omega SST model and comparison with wall pressure measurements and SA/SA-QCR results.

Further investigations will be made on Reynolds Stress Model (RSM) and final issue regarding ZDES computations are on-going work at ONERA (see Figure 23).

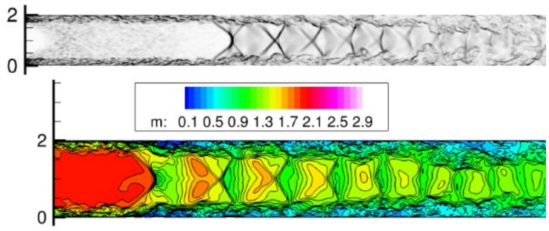
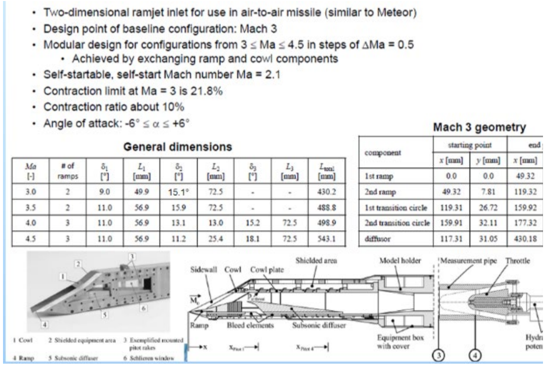


Figure 24: ongoing ZDES simulations on WP2.

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 24.



- 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 $3 \leq Ma \leq 4.5$ in steps of $\Delta Ma = 0.5$
  - 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: $-6° \leq \alpha \leq +6°$

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

Figure 25: DLR experimental model for the Mach 3 ramjet intake.

This large existing database includes several effects:

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

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

The members agreed to select the following experimental conditions:

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

The available experimental data contain (see Figure 25):

- 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.

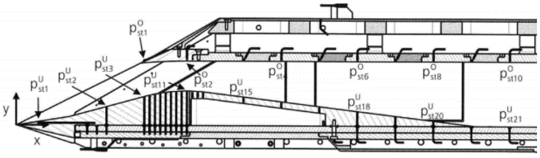


Figure 26: DLR experiments with measurements and rakes location.

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

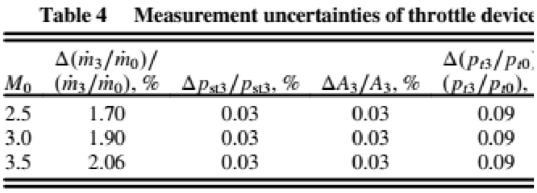


Table 4 Measurement uncertainties of throttle devic

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

After a detailed investigation of the model and the boundary conditions needed for the calculations, DLR prepared and shared the CAD files with the fixed modifications commonly agreed at last teleconference meeting.

Regarding boundary conditions, DLR will assess by 2D computations the potential effect of wind-tunnel walls on the bleed mass flow rate, as the internal bleed has no sonic outlet as illustrated by Figure 26.

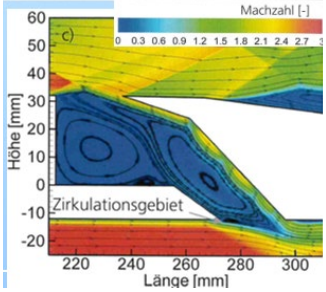


Figure 27: illustration of Mach number of the internal flow inside the bleed (DLR).

The 3D CAD file, ready to mesh, has been provided to all members (see. Figure 27).

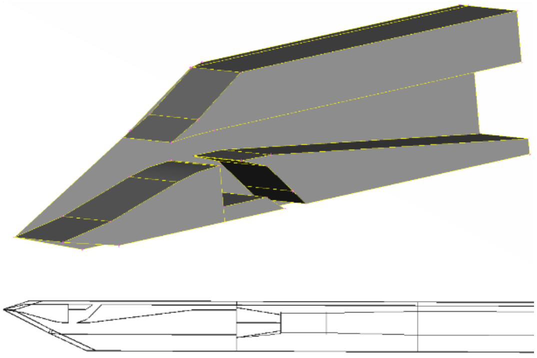


Figure 28: CAD provided by DLR for the WP3 computation (open bleed case).

The CAD extension down to the throttling device (plug) has been provided as an option so that throattling effect can be computed either using back pressure on short domain or by modifying the sonic throat on the full domain in the computational process. This could have an effect in case unsteady computations of surging regime is planned (this is not a priority of the WP3).

The experimental measurements will be provided shortly by DLR to all members.

Computations efforts will be focused on RANS approach with same turbulence models effects as those proposed in WP2 as well assessing adaptive grid refinement improvements.

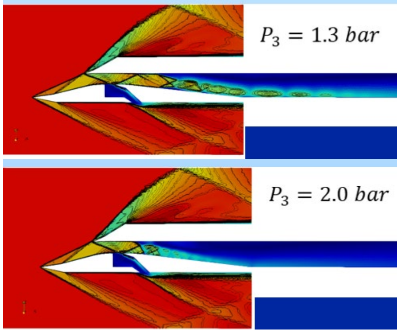
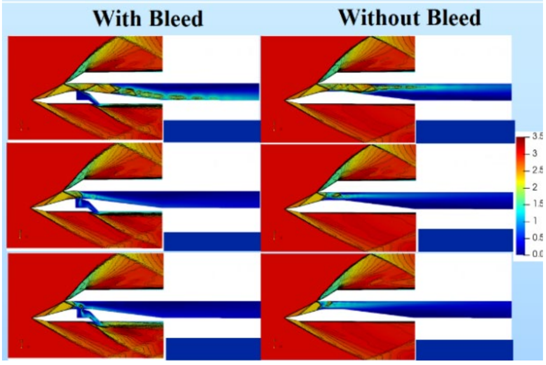


Figure 29: caracteristic curves at Mach 3.0 using CEDRE code.



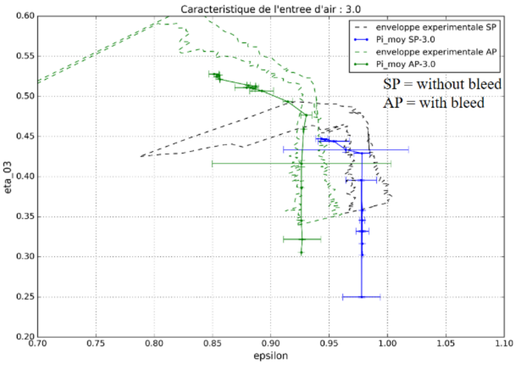


Figure 30: preliminary investigation of internal bleed effect at Mach 3.0, using CEDRE code with k-omega SST turbulence model.

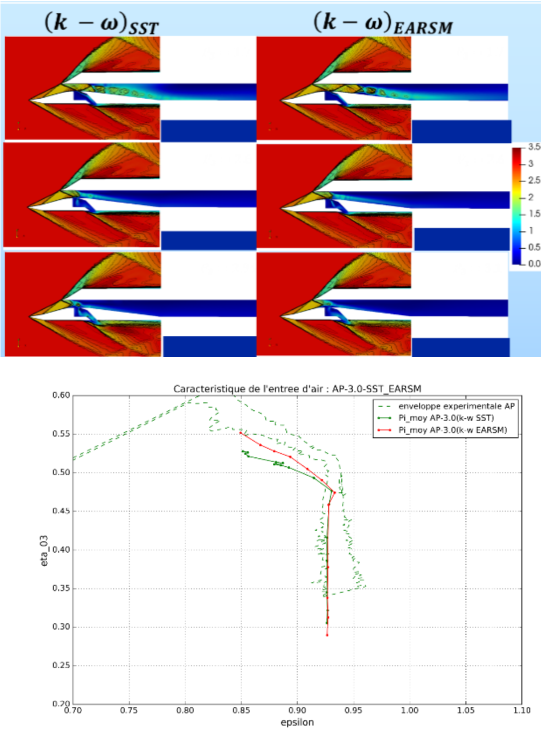
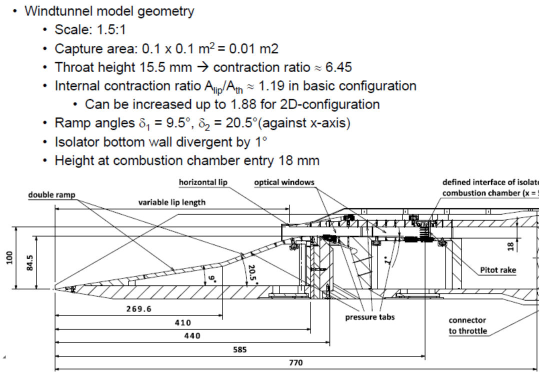


Figure 31: preliminary investigation of turbulence model effect at Mach 3.0, using CEDRE code with k-omega SST turbulence model vs EARSM

WP4 : Mach 7.5 scramjet intake

The proposed test-case is illustrated in Figure 31.



- Windtunnel model geometry
  - Scale: 1.5:1
  - Capture area: 0.1 x 0.1 m^2 = 0.01 m2
  - Throat height 15.5 mm → contraction ratio ≈ 6.45
  - Internal contraction ratio $A_{lip}/A_{th} \approx 1.19$ in basic configuration
    - Can be increased up to 1.88 for 2D-configuration
  - Ramp angles δ_1 = 9.5°, δ_2 = 20.5°(against x-axis)
  - Isolator bottom wall divergent by 1°
  - Height at combustion chamber entry 18 mm

Figure 32: DLR experimental model for the scramjet Mach 7.5 intake

One topic for WP4 will be the aerothermal fluxes prediction and effects of sidewalls compression, see some examples of experimental results in Figure 32. It was decided to compute the closed bleed configuration in supercritical conditions with a downstream extension sufficient to include the Pitot rake available in the experiments.

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

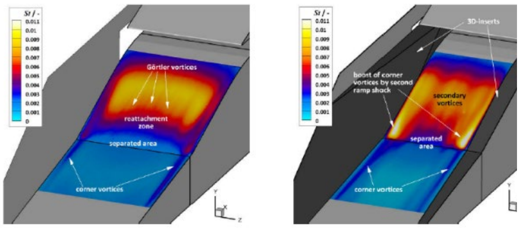
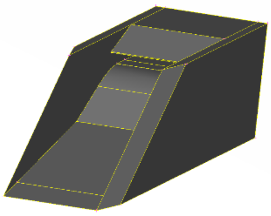


Figure 33: DLR experiments on the scramjet intakes, with IR thermography. Effect of sidewalls compression on heat fluxes and corner flow.

The CAD, ready to mesh, provided by DLR is presented on the Figure 33. The exit plan is located downstream the isolator Pitot rake.

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



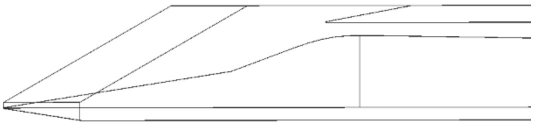


Figure 34: CAD provided by DLR for the WP4 computation (closed bleed case).

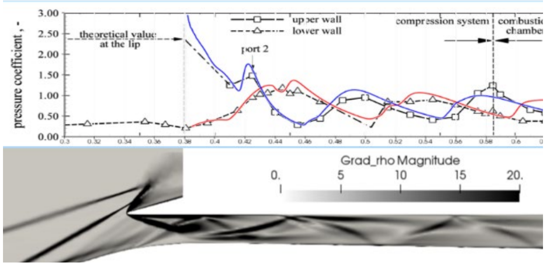


Figure 35: preliminary computation, using CEDRE code

- **Expected results/benefits**

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

- **AD/AG-58 membership**

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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 104-105. However, the reproduction of this phenomenon results to be crucial also for flows at higher Reynolds number. In fact, very tiny laminar separation bubbles are present in airfoil used for turbine applications operating at Reynolds number of the order of magnitude of 10^6.

An interest is growing towards the employment of rotary wing aircraft as valid technological means for a rapid and efficient exploration of planet Mars. The challenge of this new technological solution lies entirely in the specific environmental conditions these aircraft will be required to operate in. Mars atmosphere is 95% constituted by CO2 and the force of gravity is about 1/3 than the Earth's. The reduced atmospheric pressure and density, together with the low temperatures, produce flight conditions characterised by very low Reynolds numbers, about 2% of those on the Earth, in combination with high Mach numbers, 1.5 times higher than the terrestrial ones. The evaluation of the aerodynamic characteristics of airfoils and wings in such particular conditions, scarcely investigated so far, is becoming increasingly more important for the understanding of the feasibility of such technological solution.

- ### Objectives

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

The main issues to be addressed are:

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

- ### Approach

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

- ### Main achievements

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

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

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

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

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

- **Management issues**

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

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

Imperial College has actually left the project.

- **Expected results/benefits**

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

- **AD/AG-59 membership**

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AD/AG-60 Machine learning and data-driven approaches for aerodynamic analysis and uncertainty quantification (ML4AERO)

Monitoring Responsable:	F. Monge INTA
Chairpersons:	E. Andrés INTA D. Quagliarella CIRA

• Background

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

• Objectives

The objectives of the proposed Action Group are:

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

• Approach

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

Two databases are used in this group:

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

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

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

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

Main achievements / current status

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

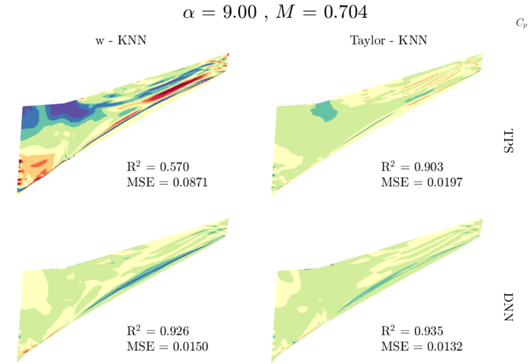

Figure 36: INTA results, cp prediction using Isomap+DNN

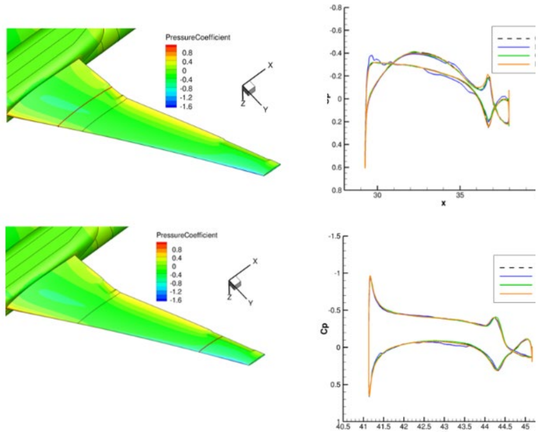

Figure 37: DLR results, cp prediction comparison of PODi, GNSR and DNNN methods

Next steps

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

Expected results / benefits

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

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

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

- **AD/AG-60 membership**

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Matthias De Lozzo	IRT	
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Alessandro Alaia	OPTIMAD	
Angela Scardigli	OPTIMAD	
Philipp Bekemeyer	DLR	
Olivier Amoignon	FOI	
Boban Pavlovic	FOI	
Sergio de Lucas Bodas	Airbus Military	
Daniel González	Airbus Miltary	
Daniel Redondo	AIRBUS	
Marta Gonzalez	AIRBUS	
Blanca Martinez	AIRBUS	
Esther Andrés	INTA	
Andrea Ianiro	UCM3M	
Stefano Discetti	UCM3M	

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

Monitoring Responsable:	J.-L. Hantrais-Gervois ONERA
Chairpersons:	N. Renard ONERA

• Objectives

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

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

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

• Main achievements

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

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

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

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

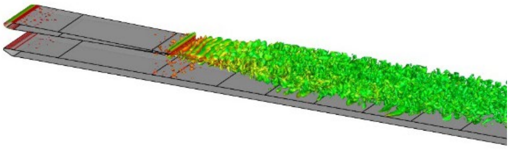

Figure 38: TC1 mixing co-flow (CIRA)

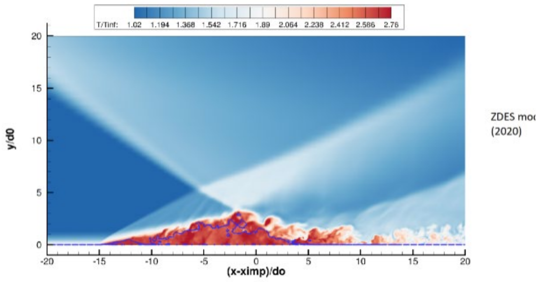

Figure 39: TC2 shock / BL (ONERA)

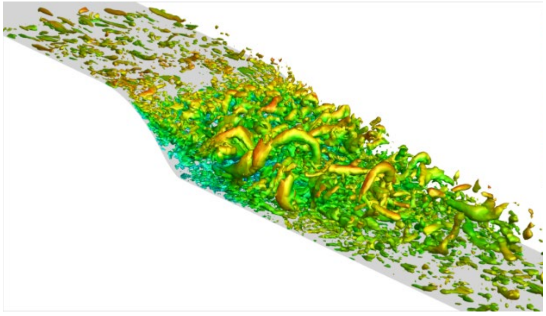

Figure 40: TC3 shallow separation (DLR)

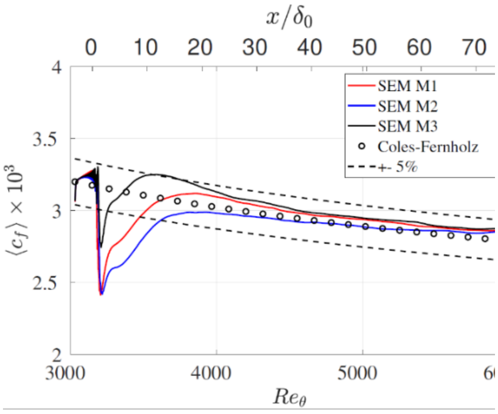

Figure 41: TC4 flat plat (SAAB)

- **Management issues**

The group is active since April 2022 (kick off) and a progress meeting has been held in February 2023. Some initial results are already available and the group is well organised to work actively.

Due to the COVID crisis, the kick-off foreseen in 2021 has been delayed to 2022. A delay in the end date is thus requested. The end date was initially planned at the end of 2024 and a 1-year extension to end 2025 is requested (at constant budget).

- **Expected results/benefits**

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

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

- **AD/AG-61 membership**

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Appendix B: Annex GoR-Aviation Security (AS)

ANNUAL REPORT FROM THE GROUP OF RESPONSABLES “AVIATION SECURITY”

Remit

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

The GoR-AS initiates, organises and performs research on detection and mitigation of unlawful interferences against aviation. Both physical and digital interferences are considered. Topics such as Cybersecurity, Unauthorized drones, Laser Dazzling, Chemical, Biological & Explosive detection are addressed by the GoR.

GoR-AS Overview

GoR-AS Activities

Two high priority research topics were established a few years ago following discussions with various industrial, institutional and academic stakeholders. GoR-AS is focusing on the investigation of these two topics: detection and mitigation of unauthorized drones, assessment of security risks caused by AI in Aviation.

Unauthorized Drones

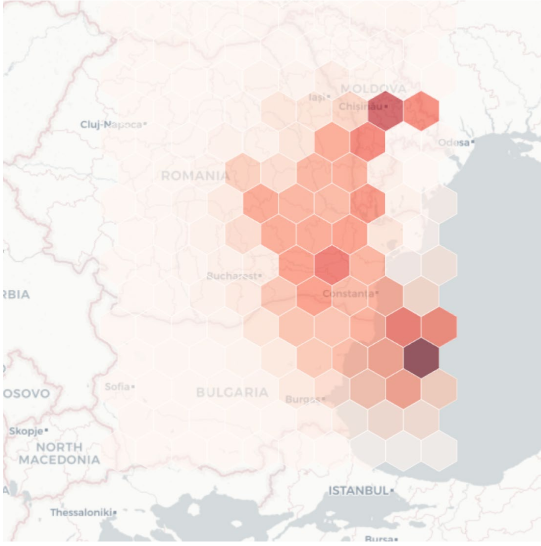
ONERA, INTA and CIRA have completed by the end of 2022 the activities within ASPRID Project - Airport System Protection from Intruding Drones - belonging to Horizon 2020 Call: H2020-SESAR-2019-2 (SESAR 2020 EXPLORATORY RESEARCH). In 2023 several scientific publications were written in order to disseminate the results of the project:

- Domenico Pascarella, Gabriella Gigante, Angela Vozella, Maurizio Sodano, Marco Ippolito, Pierre Bieber, Thomas Dubot and Edgar Martinavarro Evaluation of a Resilience-Driven Operational Concept to Manage Drone Intrusions in Airports, Information 2023, 14, 239, https://doi.org/10.3390/info14040239.

- D Pascarella, P Bieber, M Cioffi, T Dubot, M Ippolito, F J Jiménez Roncero, E Martinavarro Armengo, P Pellegrino, A Remiro Bellostas, M Sodano and A Vozella, Drone intrusion management systems in airports: assessment of ASPRID solution, 13th EASN International Conference on: Innovation in Aviation & Space for opening New Horizons 05/09/2023 - 08/09/2023 Salerno, Italy

- D Pascarella, P Bieber, M Cioffi, T Dubot, M Ippolito, F J Jiménez Roncero, E Martinavarro Armengo, P Pellegrino, A Remiro Bellostas, M Sodano and A Vozella, Drone intrusion management systems in airports: assessment of ASPRID solution, 2024, J. Phys.: Conf. Ser. 2716 012070,

Furthermore, the final report for the associated Action Group 1 was prepared. Several meetings explored follow-up activities of this Action Group. The group investigated the detection and protection of coordinated drone attacks in a large geographical area managed by a U-space service provider. According to a recent study[13] funded by the European Defense Agency, a U-space service provider could manage both the flights of authorized civilian drones and military missions such as training, search and rescue flights and counter UAS missions. The U-space set of services that deal with the management of authorized drone traffic should be extended with services that detect and manage cyberattacks involving drones. Several emerging threats were identified by the group. Since the start of the conflict in Ukraine, very large-scale GNSS disruption are observed all over Eastern Europe. Researchers involved in the GoR-AS have recently published a paper[14] that maps the level of GNSS disruption reported using ADS-B by commercial aircraft flying over Romania and Bulgaria. Such a disruption has the potential to impact a large set of drones managed by the U-space service provider.



Map of GNSS disruption reported over Romania and Bulgaria

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[13] https://eda.europa.eu/docs/default-source/documents/d1---u-space-evaluation.pdf

[14] B. Figuet et al, GNSS Jamming and Its Effect on Air Traffic in Eastern Europe, proceedings of 10th OpenSky Symposium, 2022 https://www.mdpi.com/2673-4591/28/1/12

It was also reported that traffic data spoofing attacks have been performed in the Korean peninsula. In that case, a large number of fake aircraft or drone positions are emitted in order to saturate the ATM or the U-space service provider capabilities.

Research on means to detect these emerging threats is needed. Detection means based on AI algorithms analysing aircraft position, speed, identification data are currently investigated by members of the GoR. Future promising detection approach should combine data-intensive AI algorithm with models of flight performance, signal propagation and traffic management procedure in order to improve detection performance such as reducing false alarms. Furthermore, the resilience of U-space against such attacks should be measured. The airport operation resilience framework developed by GoR members during ASPRID could be extended in order to deal with operations taking place in U-space zone.

This topic was discussed by researchers of CIRA, INTA, ONERA and ZHAW (CH) as well as members of Eurocontrol Civilian/Military coordination team (EU), ENAC (I), Hologarde (F), Thales U-space (F). A SESAR Exploratory Research proposal on this topic was submitted in 2023 but it was not funded.

AI and Aviation Security

AI Assistant cybersecurity is another topic that GoR-AS started to explore in 2023. Members of the GoR as well as members of other GoR are investigating the use of digital assistant based on Machine Learning in various domains of aviation. For instance, AI assistant could be used to help aircraft maintenance by automating the inspection of structure in order to detect degradations. In the Air-Traffic Management domain, AI assistant were developed to help controllers detect and correct aircraft trajectory conflicts. AI assistant should also be hosted on-board the aircraft to contribute to the flight control. AG-FM20 is investigating the use of AI techniques for flight control fault detection.

Due to the role played by AI assistants in safety critical tasks, their safety and certification are extensively investigated by EASA as well as the industrial and academic community. EASA AI Roadmap[15] recognizes the important role of cybersecurity but it provides by now limited guidance on this topic. ENISA, the European agency in charge of cybersecurity has investigated generic cyber-threats against Machine Learning[16] but the relevance of these threats to AI Assistants in the Aviation remains to be established.

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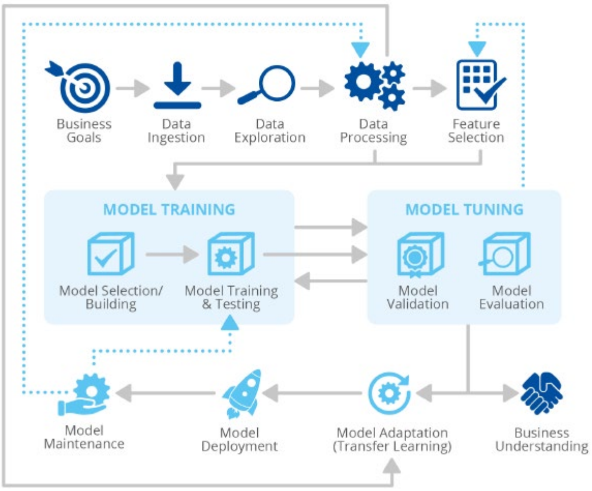
[15] EASA AI Roadmap 2.0, https://www.easa.europa.eu/en/downloads/137919/en

[16] AI Cybersecurity Challenges, https://www.enisa.europa.eu/publications/artificial-intelligence-cybersecurity-challenges/@@download/fullReport



Main components of AI Assistants

The group identified other research themes related with AI and cybersecurity. Several Partners have ongoing projects on AI for Aviation Security. They have investigated the use of Machine Learning algorithms in order to detect or mitigate illegal interferences. For instance, they developed AI tools for detection of anomalous ADS-B messages or GPS measures, detection of fake or replayed Air Traffic Controller voice messages. A final area of research is investigates the protection of aviation against attackers using AI techniques. In that case, AI could be used in order to help attackers learn vulnerabilities about the system that has to protected. AI can also be used to automate the attack and improve its efficiency.

The AI Assistant cybersecurity topic was discussed by researchers of CIRA, DLR, ONERA, U of Porto (P), U of Bremen (D) and industrial partners Collins (I) and Leonardo (I). A proposal on this topic in relation with Horizon Europe was discussed but not submitted due to the lack of maturity of the proposal.

Management

Monthly virtual meetings were organized to explore the two research topics.

Dissemination of GARTEUR activities and results

The main dissemination event during 2023 was the presentation of the activities and future plan of the AS-GoR during GARTEUR 50th birthday event organized in Pozzuoli in October 5-6, 2023.

Documentation issued

Three scientific papers and the final report on the activities of AS-AG1 were prepared.

Status of Action Group

One original aspect of Aviation security is that new threats are constantly emerging. Knowing threats that are applicable to the Aviation domain is a prerequisite for almost all the research performed in the Aviation Security domain. GARTEUR AS-GoR is a good forum in order to identify and assess threats to Aviation Security.

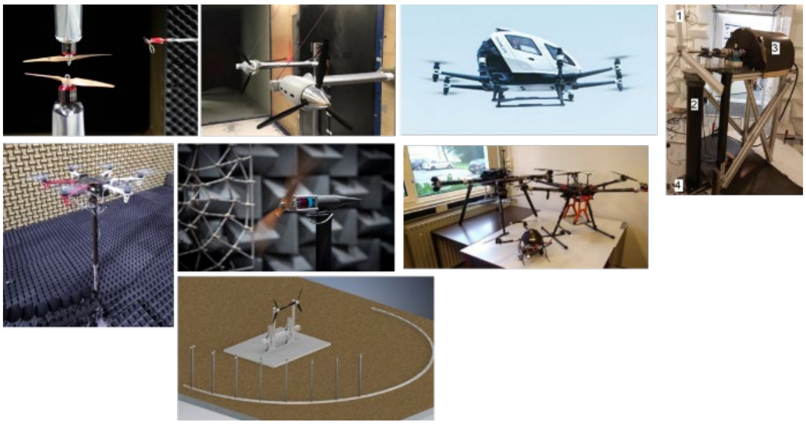
AS-GoR plans to organize in 2024-25 several workshops about new threats to Aviation Security. The aim of this workshop is to produce an up-to-date threat landscape that could foster further research projects.

Prior to a workshop, AS-GoR members will compile a list of potential generic threats extracted from the scientific literature. The workshop will gather experts from AS-GoR as well as invited attendees from industry and academia, they will assess the generic threats. In particular, they will identify the generic threats that are applicable to the Aviation domain. They will also evaluate the impact of the threats on the Aviation domain. The conclusions of the workshop will be published as a GARTEUR paper in order to disseminate broadly the produced Threat Landscape.

Appendix C: Annex GoR-Rotorcraft (RC)

ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "ROTORCRAFT"

Experimental tests in HC/AG-25



Experimental tests in RC/AG-26

Remit

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

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

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

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

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

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

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

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

GoR-RC Overview

GoR Activities

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

This membership enables the GoR to act as a highly effective forum in its primary function of promoting collaborative research through Exploratory Groups and Action Groups. It has been successful in establishing collaborative research programmes, at a non-competitive level, to the benefit of the European rotorcraft community, including both governmental and industrial interests. In addition, the GoR represents a unique forum within Europe for the interaction of the research establishments and industry, for the exchange of knowledge and understanding in the field of rotorcraft research and technology. An increasing number of University teams are associated to the activities of the action groups. Since 2011 the University of Liverpool is an active member of the GoR. The Rotorcraft GoR is a kernel for ideas for new research projects and supports the preparation of several EU proposals, despite in the last few years no project dedicated to rotorcraft has been funded by Clean Aviation. 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).

Finally, 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.

GoR-RC participation in the celebrations of the GARTEUR 50th Anniversary

The year 2023 was the year celebrating the 50th Anniversary of GARTEUR. The celebrations were organized on October 5th and 6th 2023 at the Italian Air Force Academy in Pozzuoli (I), with the sponsorship of CIRA - Italian Aerospace Research Centre and Leonardo, and with the support of the Italian Air Force Academy. Civil and military authorities, representatives of the European industry, Research establishments and Academia met and discussed the main achievements of these first 50 years, the current situation and the future perspectives of this Group.

The GoR-RC participation in the event was very active and successful. The GoR-RC member Dr. Klausdieter Pahlke of the German Aerospace Center (DLR) (D) presented to the audience an interesting retrospective titled “50 years of Civil Rotorcraft Research in the context of GARTEUR: Some spotlights”. Subsequently, The GoR-RC chairman Antonio Visingardi illustrated the structure, the objectives and the main achievements of the GoR-RC group through the presentation “Group of Responsables session – Rotorcraft: Key themes and impact highlights”. The future trends of the European Rotorcraft research were then shown by Assistant prof. Giulio Gori of Politecnico di Milano (I) who gave his contribution in the joint presentation of the five GARTEUR GoRs titled “GARTEUR high level plan on future GoR research". In addition, a roll-up banner was prepared and displayed during the event to the audience.

THE ROTORCRAFT GROUP OF RESPONSABLES

- The RC-GoR 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 RC-GoR initiates, organizes and monitors basic and applied, computational and experimental multidisciplinary research.
- 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;
  - Increase security and safety;
  - Better integrate rotorcraft into the traffic;
  - Tackle environmental issues: Noise and pollution
  - Progress in pioneering: breakthrough capabilities

RC-GoR membership (Oct. 23)

RC-GoR Specifics

- Participation of the major national research centres and helicopter manufacturers* in the EU with many contributions of universities in the EGs/AGs for both civil and military research
- Think tank for new ideas and their assessment (→ GARTEUR EG/AG, → other programmes)
- RC-GoR is a forum for "soft" coordination of other collaborative initiatives in Europe e.g. EU Technology Programmes on rotorcraft.
- The RC-GoR is a kernel for ideas for new research projects and supports the preparation of several EU proposals
- Most AGs have multidisciplinary character

AG-20: Cabin internal noise : "simulation methods and experimental methods for new solutions for internal noise reduction

AG-21: Rotorcraft Simulation Fidelty Assessment. Predicted and Perceived Measures of Fidelity

AG-22: Forces on Obstacles in Rotor Wake

Technical disciplines

- Aerodynamics
- Aeroelastics including stability, structural dynamics and vibration
- Flight mechanics
- Control and handling qualities
- Vehicle design synthesis and optimisation
- Human factors
- Internal and external acoustics
- environmental impact and public acceptance
- Flight testing
- Simulation techniques and facilities for ground-based testing
- Simulation specific to rotorcraft
- Icing
- Extension of flight envelope
- Operational Efficiency
- Safety, Survivability, Security
- Passenger comfort
- Cost, Affordability, Time-to-market
- Pioneering
- Etc.

AG-23: Wind Turbine Wake and Helicopter Operations

AG-24: Helicopter Fuselage Scattering Effects for Exterior Noise Reduction

AG-25: Rotor-rotor wakes interactions

AG-26: Noise Radiation and Propagation for Multirotor System Configurations

What the future holds

The future of the RC-GoR activities is intimately linked to the technological advancements in the rotorcraft field. Three main areas of investigations can be identified:

- **Classical helicopter configurations:**
  - To reduce CO2 and NOX emissions, noise and operating costs;
  - To increase performance, safety and reliability, integration in the air traffic system
- **Fast rotorcraft (tilt-rotors, compound helicopters and coaxial rotors helicopters):**
  - To mitigate the main technological limits of the conventional helicopter such as low flight speed, range and operating altitude:
- **eVTOLs:**
  - a disruptive electric and multi-rotor technology for Urban Air Mobility.

Action Group partners

The RC-GoR roll-up banner

The last day of the event the GoR-RC members Dr. Barbara Ohlenforst of NLR - Netherlands Aerospace Centre (NL), the Assistant prof. Barbara Re of Politecnico di Milano (I), the Assistant prof. Giulio Gori and Antonio Visingardi presented a “UAM Exploratory Group plan”, through which they showed to the audience a proposal for a multidisciplinary technical activity involving as many GoRs as possible on the extremely challenging topic of the Urban Air Mobility (UAM). At the end of the presentation, Eng. Luca Medici of Leonardo Helicopters (I) provided his positive considerations about this initiative.

Management

The chairmanship in 2023 was held by Antonio Visingardi (CIRA). Vice Chairman was Mark White (Univ. Liverpool). In 2023, Mrs Alicia Verónica Barrios Alfonso from INTA resigned from her role of Spanish representative in the GoR-RC. No substituting member was appointed by Spain.

Generally speaking, the rotorcraft community in Europe is rather small. Indeed, 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:

- 87th GoR Meeting: 14th – 15th February 2023, at NLR, Marknesse (NL);
- 88th GoR Meeting: 4th – 5th October 2023, at the Italian Airforce Academy, Pozzuoli (I)

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 harmonise 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) and the Asian/Australian Rotorcraft Forum (ARF) was harmonised and supported.

In the year 2023 three Action Groups and one Exploratory Group were active. One of them, the RC/AG-25 was concluded during the year.

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

- Boisard, R., "Rotor - Rotor Wakes Interactions, Final Report," June 2023, (RC/AG-25);
- Boisard, R., "Experimental and numerical results related to Onera test case Final Report," June 2023, (RC/AG-25);
- Colli, A., "Experimental and numerical results related to POLIMI test case Final Report," June 2023, (RC/AG-25);
- Kostek, A., "Experimental and numerical results related to DLR test case Final Report," June 2023, (RC/AG-25);
- Description on AG26-Matrix-Numerical-Common-Simulations-2023 (Updated);
- Specifications on common simulation, 2023 (Updated).

Theses

- Technische Universität München: "Tonal Noise Prediction for the 2-bladed Accid 13x7 Propeller," 2023.

Publications

- J. Yin, F. De Gregorio, K.-S. Rossignol, L. Rottmann, G. Ceglia, G. Reboul, G. Barakos, G. Qiao, M. Muth, M. Kessler, A. Visingardi, M. Barbarino, F. Petrosino, A. Zanotti, N. Oberti, L. Galimberti, G. Bernardini, C. Poggi, L. Abergo, F. Caccia, A. Guardone, C. Testa, S. Zaghi, "Acoustic and Aerodynamic Evaluation of DLR Small-scale Rotor Configurations within GARTEUR AG26," presented at 49th European Rotorcraft Forum, Germany, 5-7th September, 2023 (RC/AG-26);
- F. De Gregorio, K.-S. Rossignol, G. Ceglia, J. Yin, "Multi-rotor Wake Interaction Characterization," presented at 49th European Rotorcraft Forum, Germany, 5-7th September, 2023 (RC/AG-26);
- De Gregorio, F., Candeloro, P., Ceglia, G., Pagliaroli, T., "Flow Field and Acoustic Assessment of Twin Rotors in Hover Condition, CIRA/UniCusano," XXXI AIVELA Annual National Meeting 2023, December 2023 (RC/AG-26);

- Geng Qiao, George N. Barakos, "CFD Validation for eVTOL Propeller Performance and Acoustics," presented at 49th European Rotorcraft Forum, Germany, 5-7th September, 2023 (RC/AG-26);
- Y. Beausse, B. Cotté, O. Doaré, C. Pascal, T. Toralba, A. Chapoutot, "Effect of Roughness on the Aeroacoustic Performance of Rotor Noise at Low Reynolds Number," presented at Forum Acusticum 2023, Politecnico di Torino (I), 11th-15th September 2023 (RC/AG-26);
- Anna Kostek, Felix Loessle, Robin Wickersheim, Manuel Kessler, Ronan Boisard, Gabriel Reboul, Antonio Visingardi, Mattia Barbarino, Anthony D. Gardner, "Experimental investigation of UAV rotor aeroacoustics and aerodynamics with computational cross-validation," CEAS Aeronautical Journal https://doi.org/10.1007/s13272-023-00680-z, Sept. 2023 (RC/AG-25);
- Anna A. Kostek, Johannes N. Braukmann, Felix Lößle, Sebastian Miesner, Antonio Visingardi, Ronan Boisard, Vasilis Riziotis, Manuel Keßler, Anthony D. Gardner, "Experimental Investigation of Quadrotor Aerodynamics with Computational Cross-Validation," presented at the Vertical Flight Society's 79th Annual Forum & Technology Display, West Palm Beach, FL, USA, May 16–18, 2023 (RC/AG-25).

Status of Action Groups and Exploratory Groups

Action groups (AG)

The following Action Groups were active throughout 2023:

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 and was concluded in May 2023.
RC/AG-26	*Noise Radiation and Propagation for Multirotor System Configurations* The objective is to investigate, both numerically and experimentally, the noise radiation and propagation (installation effect) of multirotor systems and to gain knowledge in the physics of noise generation and near-field noise propagation of multirotor systems under the

	influence of the installation effects and to establish tools for the noise prediction. Compared to conventional helicopters, the importance of the various noise sources and the influence of noise scattering can be totally different for multi rotor configurations. The AG started in February 2022. Both, a common validation study and a common experiment are foreseen. The common validation study aims at evaluating and improving the prediction accuracy of different simulation methods.
RC/AG-27	*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 AG is to study the application to rotary wings of aerodynamic force analysis and decomposition methods. The kick-off meeting of this AG was held on April 2023.

Exploratory groups (EG)

The following Exploratory Groups were active throughout 2023:

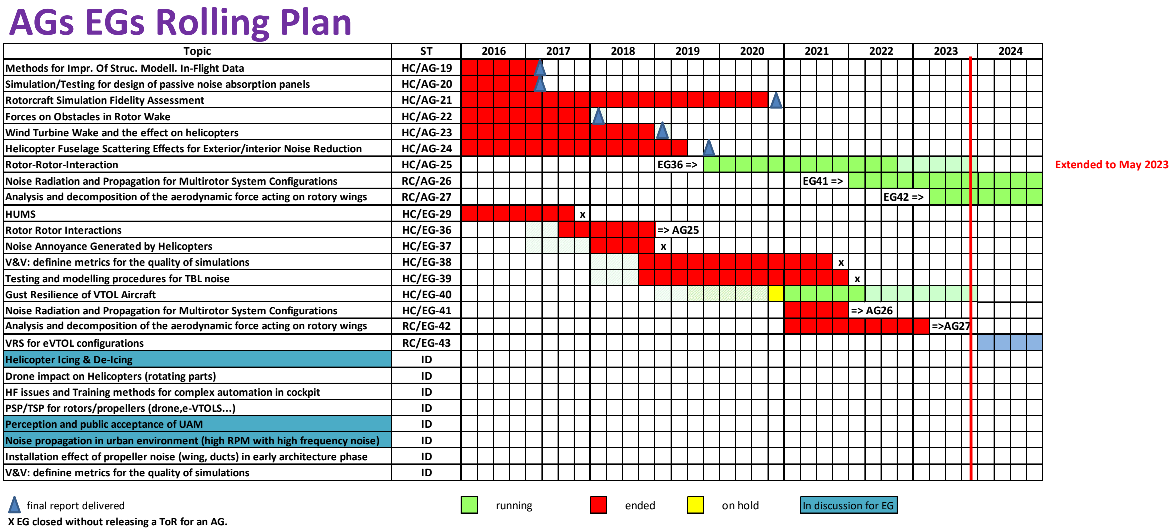
RC/EG-40	*Gust Resilience of VTOL Aircraft* The objective is to set-up a team of researchers able to investigate and test the different approaches that might be employed to achieve gust resilience of multi-rotor vehicles. This EG was identified in 2019 and was expected to be active in 2020. Unfortunately, Cranfield's application for UK funding, to support this activity, was not successful, and for this reason, Cranfield had to withdraw from chairing this EG. Prof. Lovera from Politecnico di Milano accepted to take over the chairmanship from Cranfield Univ. with the aim to restart this EG in 2021. Nevertheless, during the years 2021, 2022 and 2023 no meeting was organized and no updates were received from Prof. Lovera. In

2023 the RC-GoR decided to keep this EG active, standing its utmost importance, mainly for UAM applications, and tried to identify another chairman willing to lead this EG.

Rolling plan

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

During the 2023 GoR meetings, several topics of mutual interest have been discussed and their potential for GARTEUR collaborative programmes has been examined. Some New Ideas were added, some others were cancelled because of lack of interest or manpower unavailability.



AGs EGs Rolling Plan

Topic	ST
Methods for Impr. Of Struc. Modell. In-Flight Data	HC/AG-19
Simulation/Testing for design of passive noise absorption panels	HC/AG-20
Rotorcraft Simulation Fidelity Assessment	HC/AG-21
Forces on Obstacles in Rotor Wake	HC/AG-22
Wind Turbine Wake and the effect on helicopters	HC/AG-23
Helicopter Fuselage Scattering Effects for Exterior/interior Noise Reduction	HC/AG-24
Rotor-Rotor-Interaction	HC/AG-25
Noise Radiation and Propagation for Multirotor System Configurations	RC/AG-26
Analysis and decomposition of the aerodynamic force acting on rotory wings	RC/AG-27
HUMS	HC/EG-29
Rotor Rotor Interactions	HC/EG-36
Noise Annoyance Generated by Helicopters	HC/EG-37
V&V: definine metrics for the quality of simulations	HC/EG-38
Testing and modelling procedures for TBL noise	HC/EG-39
Gust Resilience of VTOL Aircraft	HC/EG-40
Noise Radiation and Propagation for Multirotor System Configurations	HC/EG-41
Analysis and decomposition of the aerodynamic force acting on rotory wings	RC/EG-42
VRS for eVTOL configurations	RC/EG-43
Helicopter Icing & De-Icing	ID
Drone impact on Helicopters (rotating parts)	ID
HF issues and Training methods for complex automation in cockpit	ID
PSP/TSP for rotors/propellers (drone,e-VTOLS...)	ID
Perception and public acceptance of UAM	ID
Noise propagation in urban environment (high RPM with high frequency noise)	ID
Installation effect of propeller noise (wing, ducts) in early architecture phase	ID
V&V: definine metrics for the quality of simulations	ID

▲ final report delivered
X EG closed without releasing a ToR for an AG.

🟩 running
🟥 ended
🟨 on hold
In discussion for EG

Rolling Plan

GoR membership

Chairperson		
Antonio Visingardi	CIRA	Italy
Vice-Chairperson		
Mark White	Univ. Liverpool	United Kingdom
Members		
Klausdieter Pahlke	DLR	Germany
Barbara Ohlenforst	NLR	The Netherlands
Arnaud Le Pape	ONERA	France
Industrial Points of Contact		
Rainer Heger	Airbus Helicopters	Germany
Observer		
Richard Markiewicz	Dstl	United Kingdom

Total yearly costs of AG research programmes

	2015	2016	2017	2018	2019	2020	2021	2022	2023
Person-Month	88.70	79.50	55.00	26.50	10.00	22.50	42.00	78.00	62.25
Other Costs (k€)	103.10	102.90	54.00	20.00	27.00	29.10	64.50	144.60	135.10

Table of participating organisations

	AG25	AG26	AG27	EG40
RESEARCH ESTABLISHMENTS				
CIRA (I)	□	□	□	□
CNR-INSEAN (I)		□		
DLR (D)	□	■		□
DSTL (UK)				
ENSTA Paris (F)		□		
NLR (NL)		□		□
ONERA (F)	■	□	□	
INDUSTRIES				
Airbus Helicopters, France				
Airbus Helicopters, Germany				
CAE (UK)				
IMA Dresden (D)				
Leonardo Helicopters (I, UK)				
LMS (B)				
MICROFLOWN (NL)				
Thales (F)				
ZF Luftfarhttechnik GmbH (D)				
ACADEMIC INSTITUTES				
Institut Superieur de l'Aeronautique et de l'Espace (F)				
National Technical University of Athens (GR)	□			
Netherland Defence Academy (NL)				□
Politecnico di Milano (I)	□	□	□	■
Politecnico di Torino (I)			□	□
Technical University of Delft (NL)		□		
Technical University of Munich (D)		□		
Università Telematica Cusano (I)		□		
University of Cranfield (UK)			■	
University of Glasgow (UK)	□	□		
University of Liverpool (UK)				
University of Magdeburg (D)				□
University of Napoli Federico II (I)			□	
University of Roma Tre (I)		□		□
University of Stuttgart IAG (D)	□	□		□
University of Twente (NL)				□

■ = Chair □ = Member

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

HC/AG-25: Rotor – Rotor Wakes Interactions

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

Background

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

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

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

Programme/Objectives

Objectives

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

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

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

The work programme is structured in four work packages:

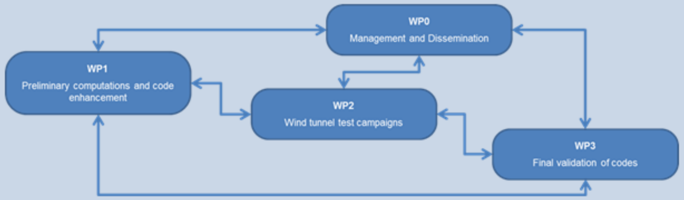
- WP0 – Management & Dissemination: is aimed at the fulfilment of all the obligations concerning the project management and the dissemination of the results.
- WP1 – Preliminary Computations & Code Enhancements: deals with a preparation phase during which partners are involved in literature review and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

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

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

GARTEUR Responsable:

A. Lepape	ONERA



WP0
Management and Dissemination

WP1
Preliminary computations and code enhancement

WP2
Wind tunnel test campaigns

WP3
Final validation of codes

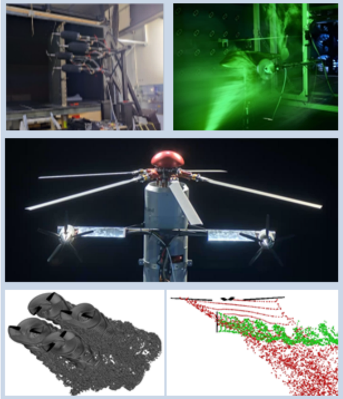
Results

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

All the experiments are over and shared between the different partners

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

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



University of Stuttgart
Institute of Aerodynamics and Gas Dynamics

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:

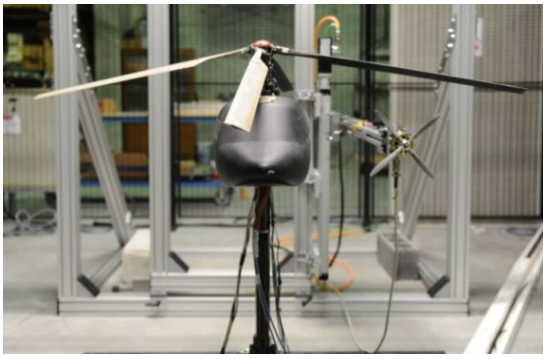
In this work package all the wind tunnel test campaigns that have been identified by partners as particularly meaningful for the phenomenological understanding of the wake interactions will be performed. The resulting experimental databases will be delivered to WP3 for the final validation of the numerical 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 were 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 were also produced by POLIMI and DLR and related geometrical data were shared with the partners for numerical simulation. DLR data were made available in Fall 2021. POLIMI wind-tunnel tests were delivered in 2023.

Most partners performed calculations of the three different configurations (Onera and Polimi: Rotor / Propeller interactions, DLR: multicopter). All the results (numerical and experimental) were gathered and summarized within different reports, along with some best practices for the numerical simulation of wake interactions. The final reports were made available in June 2023, and the action group was therefore concluded.

- **HC/AG-25 membership**

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- **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-	Actual/	8,3	26,0	0,0	0,0	34,3
months	Planned	6,8	30,3	40,0	26,1	103,2
Other costs	Actual/	0,0	33,0	0,0	0,0	33,0
(in k€)	Planned	9,4	64,5	43,0	28,1	145,0

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

HC/AG-26: Noise Radiation and Propagation for Multirotor System Configurations

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

Background

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

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

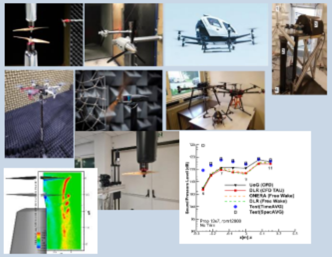
The design of low noise multirotor rotorcraft requires an in depth understanding of the physics related to noise sources, especially multi-interactions and near field sound propagation. Compared to conventional helicopters the importance of the various noise sources and the influence of noise scattering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

Programme/Objectives

Objectives

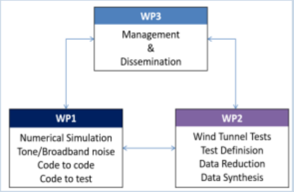
The present research work will investigate noise radiation and propagation (installation effect) of multirotor systems. The objective of the proposed GARTEUR group is therefore to gain knowledge in the physics of noise generation and near-field noise propagation of multirotor systems under the influence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

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



The work programme is structured in three work packages:

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



WP3
Management & Dissemination

WP1
Numerical Simulation
Tone/Broadband noise
Code to code
Code to test

WP2
Wind Tunnel Tests
Test Definision
Data Reduction
Data Synthesis

Results

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

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

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

Members of the HC/AG-24 group are:
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GARTEUR Responsable:
K. Pahlke DLR

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

Monitoring Responsable:	K. Pahlke DLR
Chairman:	J. Yin DLR

• Objectives

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

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

The main innovation of the AG comprises:

- An experimental data base for multirotor acoustics based on experimental data from the partners;
- improved understanding on multirotor noise emissions by analysis of experimental data and numerical simulations considering effects of interaction tone noise installation effects and broadband noise;
- validated prediction tools for multirotor noise including Assessment of different noise modelling approaches;
- validation of the partner's wind tunnels for experimental investigation of multirotor aerodynamics and acoustics by a common experiment.

• Activities

The AG consists of 3 work packages:

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

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

WP2 – Wind Tunnel Tests:

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

WP2 – Wind Tunnel Test Campaigns:

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

WP3 – Management & Dissemination:

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

• Results/benefits

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

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

1. The description of the AG26-Matrix-Numerical-Common-Simulations was updated;

2. the specifications on common simulations were updated;
3. common tests for CIRA/DLR test campaign on DLR test rig defined, test matrix established and tests conducted;
4. common tests for CIRA/Uni-CUSANO test campaign on CIRA/Uni-CUSANO test rig defined, test matrix established and tests conducted;
5. common tests for PoliMi test campaign on PoliMi test rig defined, test matrix established and tests conducted;
6. 3 ERF papers with respect to the common simulation and common test between CIRA/DLR were produced;
7. 2 more papers were produced concerning the: ENSTA database (Forum Acusticum 2023) and the CIRA/UniCusano database (AIVELA 2023);
8. one thesis was produced by Technical University of Munich regarding DLR test rig.

- **RC/AG-26 membership**

Only point of contact persons are listed here

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- **Resources**

Person month resources were confirmed during the kick-off meeting and were tentatively split in years.

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

RC/AG-27 "Analysis and Decomposition of the Aerodynamic Force Acting on Rotary Wings"

Monitoring Responsable: A. Visingardi
CIRA

Chairman: D. Sanders
(Univ. Cranfield)

• Objectives

Far-field methods have been shown to be highly valuable in the performance assessment and design of fixed wing aircraft, by relating phenomenological wake decompositions to aircraft forces, thereby enabling improved accuracy, mitigating uncertainty, and enhancing the understanding of relevant mechanisms. A brief review into rotor aerodynamics has also shown the sensitivity of rotor loadings to wake properties, and much effort has gone into improving the modelling accuracies of wake structures. However, in rotor flows, the wake mechanisms have only been related to the near-field loads implicitly and/or qualitatively. Adapting and improving fixed-wing far-field methods for implementation to rotor aerodynamics, offers the possibility to explicitly relate wake phenomena directly to near-field loads. This would enable enhanced understanding of rotor aerodynamics and provide an aid in mitigating uncertainty and improve modelling accuracy. However, due to the complexities of rotor flows, the adaptation of far-field methods requires incremental steps.

Subsequently, the aim of this project is to lay the foundations for the development of rotor applicable far-field methods, by fully developing the generalised theory and showcasing its potential based on strategic benchmark test cases.

To this end, the AG aim at pursuing the following objectives:

1. Develop and generalise the theoretical formulations of thermodynamic, vortical and energy/exergy far-field decomposition methods for unsteady flows and curvilinear non-inertial reference frames;
2. produce standardised numerical and experimental benchmarking cases for testing, validation and comparison of the methods;
3. apply the methods to benchmark test cases and provide a critical analysis along with a projected roadmap and requirements for future development and best practice guidelines.

To enable a stepped approach toward the development and evaluation of the decomposition methods, the consortium has identified the three scenarios, which are deemed appropriate for different levels of investigation:

- Pitching and Heaving Aerofoils;
- 3D Rotors in Hover;
- 3D Rotors in Advancing Flight.

• Activities

The AG consists of 7 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 – Theoretical Development of Decomposition Methods: is aimed at identifying and providing critical reviews of the state-of-the-art in aerodynamic performance decompositions. The primary outcomes will be to highlight the advantages and disadvantages of each approach, as well as to identifying opportunities for further theoretical development and synergies / unification. The theoretical decomposition formulations need to be developed in a systematic way to be able to account for unsteady, inertial and rotational reference frames.

WP2 – Experimental Datasets of Pitching and Heaving Aerofoils: The first necessary steps to developing decomposition methods appropriate for rotary wings is to consider 2D pitching and heaving aerofoils. This experimental work is required to validate the unsteady CFD with respect to the cartesian unsteady decomposition methods developed in WP1, as well as evaluate the required level of CFD modelling fidelity.

WP3 – Numerical Datasets for Pitching and Heaving Aerofoils: This WP is aimed at providing numerical datasets so that the unsteady extensions to the decomposition formulations (in an inertial reference frame) can be tested and further developed. Different levels of numerical fidelity will be tested, including RANS & DDES CFD.

WP4 – Numerical Datasets for 3D Rotors in Hover: The aim is to provide numerical datasets from RANS, URANS and DES simulations, through which the decomposition formulations may be tested and examined in WP6, to investigate the implications of the decomposition extension to a rotational reference frame.

WP5 – Numerical Datasets for 3D rotors in Advancing Flight: This WP is concerned with providing numerical datasets of 3D rotors in advancing flight and follows closely the format of WP4. This tests the combined development of the methods to accommodate complex unsteady aerodynamics and rotating reference frames

WP6 - Application & Evaluation of Decomposition Methods: This WP will review, investigate and trial various post-processing techniques that will enable the implementation of the decomposition Formulations applied to the test cases of (i) pitching heaving aerofoils, (ii) rotor in hover, and (iii) rotors in advancing flight. The focus will be on utilising the methods to improve the understanding of fundamental rotary wing aerodynamics.

- **Results/benefits**

The duration of action group is 3 years and the AG has started the activities since April 2023.

The first technical review meeting of the AG was held on October 4th 2023. A revision of the WBS was made. In particular:

1. the partners agreed that WP5 is too ambitious, and presents risk in spreading resources too thin.
2. Focus on propellers in axial flight was included as a necessary developmental step.
3. 3D Rotors in advancing flight were discarded while the 3D Hover case was retained.

- **RC/AG-27 membership**

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Panos Laskaridis	Cranfield University	
Anderson Proenca	Cranfield University	
Karthik Depuru-Mohan	Cranfield university	
Camille Fournis	ONERA	
Didier Bailly	ONERA	
Ilias Petropoulos	ONERA	
Luigi Vigevano	Politecnico di Milano	
Guiseppe Quaranta	Politecnico di Milano	
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- **Resources**

Person month resources were confirmed during the kick-off meeting and were tentatively split in years.

	Year 1			Year 2			Year 3			Total	
Partner	**PM**	**FC**	**TC**	**PM**	**FC**	**TC**	**PM**	**FC**	**TC**	**PM**	**FC**
CU*	3	0	2	3	6.5	2	4	0	2	10	6.5
ONERA	3	2	2	3	2	2	3	2	2	9	6
CIRA-UNINA	3.5	2	2.5	3.5	2	2.5	3.5	2	2.5	10.5	6
PoliMi	5	2	2	7	12	2	6.5	4	2	18.5	18
PoliTo	2	4	1.5	3	6	1.5	2.5	4	1.5	7.5	14
Total	**13.75**	**8**	**8**	**16.75**	**25.5**	**8**	**16.5**	**10**	**8**	**47**	**44.5**

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

ANNUAL REPORT FROM THE GROUP OF RESPONSABLES “STRUCTURES AND MATERIALS”

Remit

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

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

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

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

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

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

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

GoR-SM Overview

GoR Activities

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

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

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

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

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

- **Characterization and optimization of shock absorbers for civil aircraft fuselages SM/AG-37**

Commonly adopted shock absorbers and, in general, crashworthy structural components, based on sandwich structural concepts and/or complex dumping mechanisms, are, generally, characterized by high volumes and significant additional mass. The main objective of the proposed work consists in the investigation of the feasibility and effectiveness of novel thin additive manufactured hybrid metal/composite lattice structures as lightweight shock absorbing devices for application to structural key components in impact events.

The topics of this AG-37 are:

- Investigation on the key components which require the integration with shock absorber;
- identification and classification of the shock absorbers (material and geometry);
- material investigation (Alternative materials, Hybridization);
- integration strategies;
- analytical methods for designing hybrid shock absorber;
- numerical analysis and design;
- unit cell optimization (weight minimization and/or shock absorbing capability maximization);
- thermal stress analysis;
- experimental tests and validation;
- certification issues;
- definition of guidelines for an effective integration in each scenario.

Management

In 2023, two meetings were held by video conference on 9th of June and on the 29th of September.

The measures taken in the past years to revitalize the Structures and Materials group were confirmed. Action Group SM/AG-36 was started in the beginning of 2022 and continued according to plan with the proposed research activities. EG46 finalized a work program and the Action Group was launched in December 2022 and as a result they started their research program as SM/AG-37.

For SM/EG-44, SM/EG-45 and SM/EG48 several meetings were held however due to availability issues little progress was made in bringing these EG’s to a potential AG’s.

Dissemination of GARTEUR activities and results

A presentation was given during the 50th Anniversary celebration of GARTEUR at the Italian Air Force Academy in Pozzuoli, Italy on the 5th of October 2023. In this paper an overview of activities and success stories of the GARTEUR GoR-SM were presented.

Reports issued

No reports were issued in 2023.

Status of Action Groups and Exploratory Groups

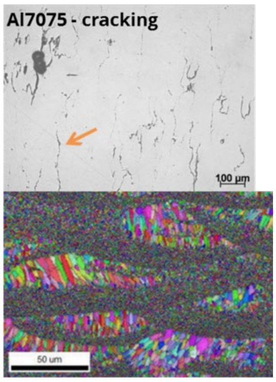
Two action groups were formally active in 2021. Action group SM/AG-36 continued as planned their AG which was launched in 2022. AG-37 started their activities at the beginning of 2023.

Three Exploratory Groups (EG-44, EG-45 and EG-48) were running in 2023. However, during the GoR S&M meeting in September 2023 it was decided to stop EG-44 due to the lack of progress and interest from potential participants.

Action Groups (AG)

The following Action Groups were active throughout 2023:

SM/AG-36 *Additive layer manufacturing*



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

Currently, there are several novel aluminum alloys being investigated for application in AM. Great advancements are being achieved on laser powder bed fusion (L-PBF) and also on directed energy deposition (DED). One of the focus points is to broaden the materials palette towards higher performance aluminum alloys. On one hand, the high-strength 7000 series has been investigated aiming at avoiding solidification cracking during the AM process. Several works have focused on modifying the composition by additions of Zr, Sc or Si in order to avoid cracking and improve the mechanical properties. On the other hand, casting aluminum alloys have been widely investigated with addition of nano-/micron-sized particles such as TiB2 or TiC aiming at increased fatigue performance. Examples of these modifications have resulted in commercially available aluminum alloys such as A20X^{TM} 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. In addition, aluminum processing is still a big challenge due to the laser related high reflectivity & unstable melting behaviour of the alloy.

Update on technical progress in 2023:

WP1 about literature study and alloy design was finished. A new aluminium alloy was selected and purchased.

In WP2, the powder analysis (2.1) was carried out by INTA and Onera. In addition, the process parameter optimization (2.2) for laser powder bed fusion was performed by NLR. The heat treatment optimization (2.3) were produced by NLR and the treatment and characterization is ongoing by INTA and ONERA.

For WP3, NLR produced all the test specimens (3.1) that will be tested in this work package. Next tasks will proceed after the selection of the heat treatments.

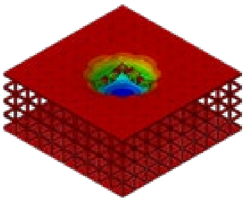
In WP4, the powder characterization (4.1) was performed by INTA and ONERA. The parameter selection for directed energy deposition process was carried out by NLR (4.2).

In 2023, there were four progress meetings with the SM/AG-36. Three of them were online and there was a physical meeting planned by NLR on 22 September. In addition, Maria Montero gave a key-note presentation at the AAMS24 in September about the work performed in the SM/AG-36 project.

The chair is Maria Montero from NLR.

SM/AG-37

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, AG-37 was launched at the beginning of 2023.

In 2023 the following activities were carried out:

In this initial phase of the research project, a comprehensive examination of shock-absorbing devices and dynamic finite element models applied to lattice structures was undertaken. The primary objective was to develop a detailed understanding of these critical elements within the broader context of the project.

The discussions focused on the use of shock-absorbing devices, emphasizing their pivotal role within the project’s framework. Various justifications behind the utilization of these devices were explored, highlighting their adaptability across different scenarios.

Additionally, hybrid shock absorbers were considered, which integrate metallic cores with composite skins, revealing the potential advantages and the applications associated with such configurations.

Furthermore, dynamic finite element models for lattice structures were investigated, and impact test data across various unit cells have been considered, with the aim of extracting invaluable insights into structural responses under differing environmental conditions. Additionally, consideration was given to the implications of varying D/A (diameter-to-section) ratios for beams within lattice structures, underscoring the pivotal role of parameter variations related to structural performance.

In 2023 the following progress meeting were held:

Kick off meeting, held on the 23rd of January 2023 at the Department of Engineering (DI), University of Campania “Luigi Vanvitelli”, via Roma n.29, Aversa (CE), ITALY;

First progress meeting, held online on the 24th of November 2023;

The chair is Andrea Sellitto from University of Campania “Luigi Vanvitelli” (Italy).

Exploratory groups (EG)

The following Exploratory Groups were active throughout 2023:

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:

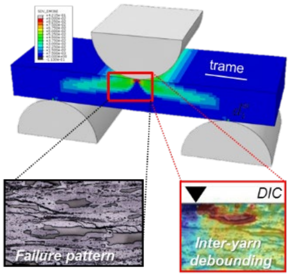
- The definition of experimental methods for mechanical properties for the ply and the interface;
- how take into account the thermal degradation in the characterization process;
- experimental methods and analysis of DMA results in temperature;
- characterization of the thermal expansion coefficient;
- 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.

Due to the lack of progress and potential participation from it was decided by the GoR-SM to stop EG-44 during the September meeting of the GoR-SM.

SM/EG-45

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

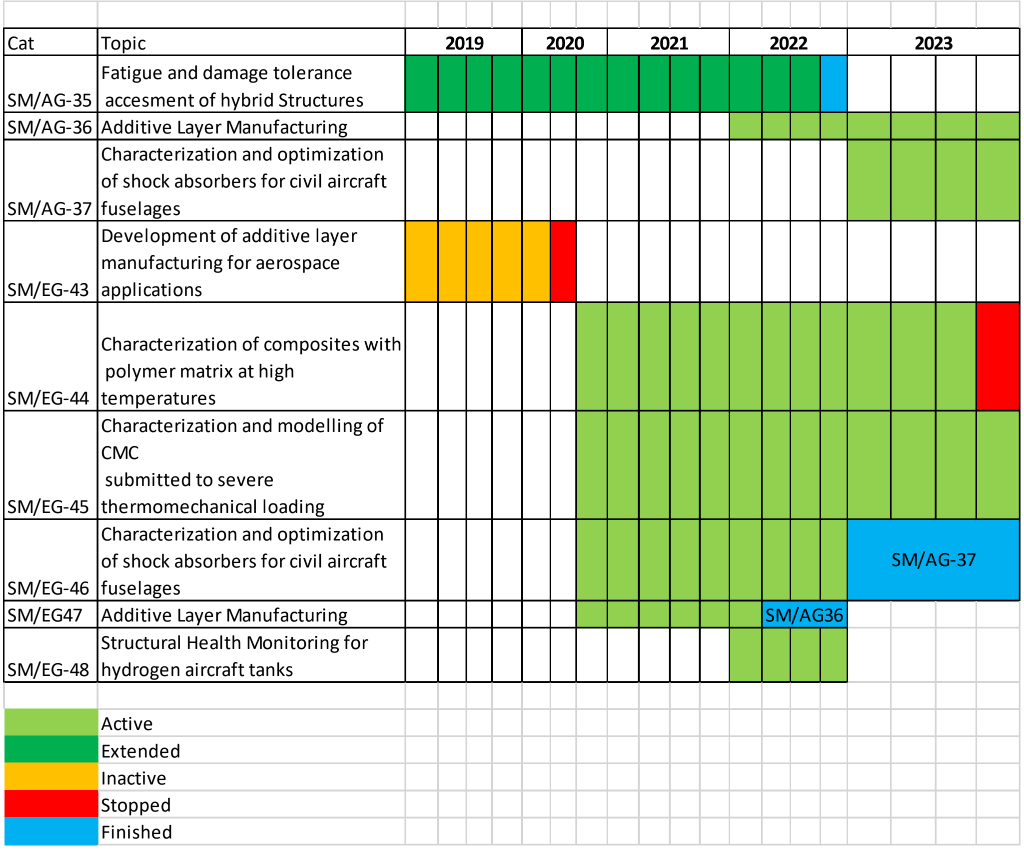


This topic has been proposed by ONERA and DLR. The objective consists in the characterization of the mechanical properties and modelling of Composites with Ceramic Matrix (CMC) submitted to high mechanical loadings and extreme thermal conditions. More detailed objectives consist in the:

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

Rolling plans



Cat	Topic	2019				2020			2021				2022				2023			
SM/AG-35	Fatigue and damage tolerance accesment of hybrid Structures	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟦				
SM/AG-36	Additive Layer Manufacturing												🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SM/AG-37	Characterization and optimization of shock absorbers for civil aircraft fuselages																🟩	🟩	🟩	🟩
SM/EG-43	Development of additive layer manufacturing for aerospace applications	🟧	🟧	🟧	🟧	🟧	🟥													
SM/EG-44	Characterization of composites with polymer matrix at high temperatures							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥
SM/EG-45	Characterization and modelling of CMC submitted to severe thermomechanical loading							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SM/EG-46	Characterization and optimization of shock absorbers for civil aircraft fuselages							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟦 SM/AG-37			
SM/EG47	Additive Layer Manufacturing							🟩	🟩	🟩	🟩	🟩	🟩	🟦 SM/AG36						
SM/EG-48	Structural Health Monitoring for hydrogen aircraft tanks												🟩	🟩	🟩	🟩				

🟩	Active
🟢	Extended
🟧	Inactive
🟥	Stopped
🟦	Finished

GoR membership

Chairperson

Bert Thuis	NLR	The Netherlands

Vice-Chairperson

Javier Sanmilan	INTA	Spain

Members

Florence Roudolff	ONERA	France
Aniello Riccio	Università della Campania	Italy
Peter Wierach	DLR	Germany
Andrew Foreman	QinetiQ	United Kingdom
Robin Olsson	RISE	Sweden
Mats Dalenbring	FOI	Sweden

Industrial Points of Contact

Roland Lang	Airbus Defence and Space	Germany
Mathias Jessrang	Airbus Operations	Germany
Thomas Ireman	SAAB	Sweden

Table of participating organisations

	AG-35	AG-36	EG-44	EG-45	AG-37	EG-48
Research Establishments, Universities	Closed end of 2022	Started in 2022	Stopped in 2023	Under definition	Started in 2023	Under definition
CIRA					☐	
DLR	☐		■	☐	☐	☐
FOI	☐					
INTA						
NLR	■	■			☐	☐
ONERA		☐	☐	■	☐	■
CNR						
ICAS						☐
Industries						
Airbus		☐				
SAAB						
Fokker	☐					
GKN						
Leonardo						
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 Group Reports

SM/AG-36 Additive Layer Manufacturing

Monitoring Responsable:	B. Thuis NLR
Chairman:	M. Montero NLR

- **Context and challenge:**

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

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

- **Scope:**

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

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

- **Expected Impact:**

Development of an AM-process for high-performance novel aluminium alloys opening up the advantages of additive manufacturing for this class of materials, particularly for the aerospace industry, but also elsewhere.

Refinement of the AM process to achieve mechanical performance (static and/or dynamic) for the 3D printed parts that equals or exceeds the current high-performance aluminium alloys allowing the initial steps to be taken towards certification.

- **Main achievements:**

AG-36 started its activities in the beginning of 2022.

In 2022 the alloy composition was selected: AlMg1Cr1.5Mo0.5Sc0.5Zr0.25

Airbus provided Scancromal powder to get familiar with the characterisation techniques.

In 2023, the study of the new alloy started with powder characterization and parameters optimization.

In, September 2023, the first physical meeting took place.

University of Campania stopped being partner in the project due to limited resources.

A key-note presentation was given with the results obtained in SM/AG-36 at the AAMS24.

- **SM/AG-36 membership**

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

SM/AG-37 Characterization and optimization of shock absorbers for industrial applications

Monitoring Responsable: B. Thuis
NLR

Chairman: A. Sellitto
Università della Campania "Luigi Vanvitelli"

- ### Background:

The most important characteristic of any transportation system lies in its ability to ensure passenger safety. To this end, considerable efforts have been directed toward the advancement of innovative shock-absorbing devices, capable of increasing safety standards by reducing acceleration peak and enhancing energy absorption during crash scenarios. Beyond these safety requirements, shock absorber devices must also follow severe weight constraints aimed at cost reduction, fuel economy, and consequent environmental sustainability.

Hence, the proposal of developing hybrid aluminum/composite shock absorbers with minimal thickness and mass emerges as a strategic approach to mitigate vehicle weight and fuel consumption without compromising crash resistance. The use of cutting-edge manufacturing technologies facilitates the creation of increasingly efficient shock absorbers, balancing crashworthiness and weight considerations. Among these, Additive Manufacturing (AM) technologies offer notable advantages, enabling the production of complex microstructures with superior impact energy absorption capabilities impossible through traditional manufacturing processes. Consequently, this production technique may be preferred for crafting highly efficient shock absorber cores. Indeed, the utilization of a metal core maximizes energy absorption through plastic deformations, while the integration of a composite skin reduces weight while increasing the stiffness and strength of the shock absorber device.

- ### Scope:

In response to emerging needs related to the use of hybrid shock absorbers in aerospace applications, the primary scope of this Action Group is as follows: *To design and verify composite/metal hybrid structures for shock absorbers capable of enhancing absorbed energy and mitigating acceleration peaks during crash events.*

This objective requires addressing the following key issues:

- Identification and classification of shock absorbers;
- material investigation;
- integration strategies;
- design of hybrid shock absorbers;
- finite element analysis;
- unit cell optimization;
- experimental tests and validation;

The expected outcomes include:

- Reduction of acceleration peaks in the component;
- integration with pre-existing components;
- low weight characteristics;
- compact volume requirements.

These expected outcomes collectively aim to enhance the safety and efficiency of shock absorbers in aerospace applications.

- ### Expected Impact:

The development of hybrid shock absorbers aims to mitigate peak acceleration transferred to the main structure, ensuring the integrity of the core structure and, ultimately, passenger safety. The design of the developed shock absorber should facilitate the integration with pre-existing structures in a minimally intrusive manner.

Furthermore, the knowledge gained in this work will enable Garteur to advance its exploration of the energy absorption and crashworthiness capabilities of aeronautical structures. This exploration will consider technological advancements such as Additive Manufacturing, which plays a pivotal role in the design of efficient energy absorption devices

- ### Main achievements:

AG-37 started its activities in the beginning of 2023.

- ### SM/AG-37 membership

Member	Organisation	e-mail
A. Sellitto	Università della Campania	
A. Riccio	Università della Campania	
N. Toso	DLR	
M. Waimer	DLR	
B. Noordman	NLR	
W. van den Brink	NLR	
J. Berthe	ONERA	
F. di Caprio	CIRA	f.dicaprio@cira.it
M. Zarrelli	CNR	

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secretariat@garteur.org or go to **www.garteur.org**