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GARTEUR: NEARLY HALF A CENTURY OF EUROPEAN COLLABORATION IN AERONAUTICS

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Abstract

This paper gives an overview of the role played by the *Group for Aeronautical Research and Technology in EURope* (GARTEUR) over nearly half a century in the European collaboration in aeronautics research. The mission of GARTEUR, its organisation and principles, and its vision, as well as its fields of activities are presented. Conclusions and perspectives for future cooperation are addressed, addressing the challenges Europe has identified both in the civil and military domains.

Keywords: aerodynamics, aviation security, flight mechanics, systems and integration, rotorcraft, structures and materials

1. Introduction

The *Group for Aeronautical Research and Technology in EURope* (GARTEUR) is the only framework for both civil and military R&T collaboration in the field of aeronautics in Europe. GARTEUR is a government-to-government agreement between France, Germany, Italy, the Netherlands, Spain, Sweden and the United Kingdom to mobilise their scientific and technical skills, human resources and facilities in aeronautical research and technology. Formed in 1973 by three nations, GARTEUR today involves seven nations with major research and test capabilities in aeronautics through a Memorandum of Understanding.

GARTEUR focuses on collaborative civilian, dual-use or defence research topics mainly aimed at long-term R&T that are essential to ensure sustained European aeronautical industry competitiveness. GARTEUR is considered as a unique European forum of aeronautical experts from Academia, Research Establishments and Industry mainly functioning in a bottom-up approach and according to the principle of an overall balance of benefits between the member countries.

As regards communication GARTEUR regularly presents its organisation, provides the latest achievements obtained through its activities and outlines its orientations [1, 2, 3]. In 2004 GARTEUR received the ICAS von Kármán Award for International Cooperation in Aeronautics “to honour all persons who contributed in the spirit of Theodore von Kármán’s vision on cross-border co-operation among scientists and engineers” [4].

The objectives of the paper are to present:

- the mission, objectives and vision of GARTEUR;
- the organisation and the rules of cooperation of the various groups;
- its position on the aeronautical R&T scene with the major stakeholders in the civil and defence domains, how it operates on a daily basis and how it adapts to changing sectoral scenarios;
- a review of current activities in the fields of “Aerodynamics”, “Aviation Security”, “Flight Mechanics, Systems & Integration”, “Rotorcraft” and “Structures & Materials”, and major success stories.

Conclusions and indications on future GARTEUR activities and orientations are drawn at the end.

2. Mission, Objectives and Vision of GARTEUR

For nearly 50 years GARTEUR has been a key player in providing the member countries, and Europe as a whole, the advanced research capabilities that have accompanied the major aeronautical developments in Europe.

The European aviation and technology sector is currently confronted with various urgent internal and external mainstreams that will see developments:

- in the field of Environment, where, among others, the Green Deal will pose quite a challenge on the aeronautical world;
- in the field of Defence and Security (e.g. cyber, UAV's, space), where recent activities of different states undermining security demand a strong and coordinated answer, and
- in the field of Mobility, where multi-modal transport and Urban Air Mobility are rising topics as a possible answers to Urban Congestion.

In addition, in 2020 we have been confronted by the Corona-virus. This virus restricted our lives and work, but also it showed the need to look into other important aspects of aviation, such as Safety.

These mainstreams and the COVID-19 crisis are showing related challenges that can only be solved in a joint effort by multiple stakeholders from Academia, Research Institutes, Defence and Industry.

GARTEUR member countries may benefit from having a consolidated collaboration platform that:

- covers both Civilian and Military topics, at several managerial and TRL levels
- includes people from Academia, Research Institutes, Defence and Industry.

Considering the Mission of GARTEUR:

> '…*to mobilise, for the mutual benefit of the GARTEUR member countries, their scientific and technical skills, human resources and facilities in the field of aeronautical research and technology*…'

it can provide added value for all partners, both in a coordinating role for collaborative research and at a technical level to jointly execute research not (yet) covered in other ways.

In terms of technical research, we see added value in the work done by the Groups of Responsables (GoR) (our backbone) covering the above challenges in Environment, Defence & Security, Mobility, and recently COVID-19, in a more and more integrated way (multi-disciplinary, integrated and multi-partner). With this integrated and collaborative approach, focused on the mainstreams, GARTEUR provides additional knowledge to its partners that cannot be done by each partner individually.

For the next 5 years, GARTEUR will continue to actively focus on bringing added value to its network in a coordinating role for its research, as well as in executing technical research that adds value to all partners aiming at Environmental, Defence & Security, Mobility and other relevant topics.

GARTEUR's consolidated approach to R&T will be ever more inclusive so that future generations will take the future of aviation in their own hands.

GARTEUR also aims at continuously stimulating achievements in the aeronautical sciences and at pursuing topics of application-oriented research in order to maintain and strengthen the competitiveness of the European aerospace industry by concentrating existing resources in an efficient manner and seeking to avoid duplication of work.

These objectives are accomplished by performing joint research work in fields suitable for collaboration and within research groups specifically established for this purpose. Technology gaps and facility needs are identified and effective ways are recommended to the member countries to jointly overcome such shortcomings. Finally, scientific and technical information is exchanged among the GARTEUR member countries at all levels of the organisation.

GARTEUR adopts the principle of operation that an overall balance of benefits between the member countries is pursued. However, the possibility of bilateral cooperation between member countries continues to exist. Another operating principle is that major decisions in the organisation have to be taken by unanimity of participating countries.

Participation of industry is sought at senior advisory level in both the planning and execution of programs. Organisations from non-GARTEUR countries can participate in specific research activities after a specific agreement.

Full safeguarding of intellectual property rights is obtained through compliance with a set of agreed written regulations. In addition, all participants work according to a set of security regulations.

3. Organisation

GARTEUR is organised at three main levels (Figure 1).

The highest level is the Council composed of representatives of each member country who constitute the national delegations. These representatives come from all relevant Ministries and Research Establishments. An Executive Committee (XC) assists the Council. This XC is composed of one member from each national delegation, and a Secretary.

The second highest level is formed by the Groups of Responsables (GoR) that act as scientific management bodies. They also represent the think-tank of GARTEUR. The GoRs are composed of representatives from national research establishments, industry and academia. Currently, five GoRs manage GARTEUR research activities:

- Aerodynamics (AD);
- Aviation Security (AS);
- Flight Mechanics, Systems and Integration (FM);
- Rotorcraft (RC);
- Structures and Materials (SM).

Action Groups (AGs) compose the third level of GARTEUR. AGs are the technical expert bodies that formulate the GARTEUR research programme and execute the research work. Potential research areas and subjects are identified by the Groups of Responsables and investigated for collaboration feasibility by Exploratory Groups (EGs). If an Exploratory Group establishes an agreed proposal, an Action Group is launched. A GARTEUR AG needs participation from at least three GARTEUR countries.

The GARTEUR operating principles provide for participation by organisations from non-GARTEUR countries in GARTEUR technical activities, under a special procedure subject to approval by the Council.

GARTEUR has interfaces with the European aeronautical industry through Industrial Points of Contact in the Groups of Responsables and through direct industry participation in the Action Groups.

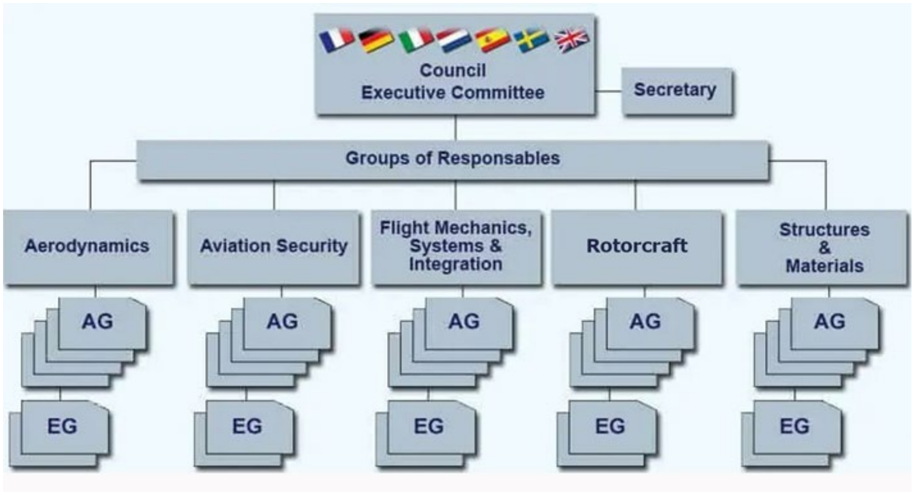

Figure 1 – GARTEUR organisational diagram

4. GARTEUR and the international aeronautical R&T scene

As a unique forum of aeronautical experts from Academia, Research Establishments and Industry fostering research initiatives for the benefits of all the member countries, obviously the 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).

4.1 Civil aeronautics

Civil aeronautics research and technology development (RTD) in Europe is centred around collaborative research calls performed within the Framework Programmes for Research and Innovation. The current Framework Programme, Horizon 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 need for reducing aviation's environmental footprint has been a primary issue since the late 90s and the initiative of the European Commission to set up the *Advisory Council for Aviation Research and Innovation in Europe* (ACARE) in 2000 created the necessary fora to set the path of European aviation and to develop position papers over time (SRIA, Flighpath 2050). 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.

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

Likewise, GARTEUR has many members that are also part of EREA, the *Association of European Research Establishments in Aeronautics*, whose members are Europe's most outstanding research centres in the field of aeronautics and air transport. EREA is promoting a joint research initiative, named Future Sky, joining forces with the European industry and universities to design a new air transport system allowing environmentally friendly, smooth and efficient air vehicles and associated mobility. It 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. Synergies and complementarities with GARTEUR activities are taken into account in a continuous basis.

4.2 Military aeronautics

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

The *European Defence Agency* (EDA), an intergovernmental agency of the Council of the European Union, was created in 2004 and soon set up a strategic framework for defence, built around three main pillars: Research & Technology Strategy; Armaments Cooperation Strategy; and European Defence Technological and Industrial Base Strategy, headed by a Capability Development Plan.

EDA has established a number of specific Capability Technology groups ('CapTechs') to undertake research & technology (R&T) activities in response to agreed defence capability needs. In particular, CapTech Aerial Systems (CapTech Air in short) promotes R&T in the aerial systems in general, and in a range of technologies. The core objectives for the CapTech Air are: 1) draft and maintain the Strategic Research Agenda (SRA) for the air defence domain; 2) foster collaborative innovation among the EDA participant Members States, and 3) generate innovative collaborative R&T projects around air systems through a system approach.

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.

The European Commission is providing continued investment for collaborative defence R&D in Europe's industry through the European Defence Fund (EDF). The 2022 work programme introduces a series of new tools to promote defence innovation, all under one new umbrella called the EU Defence Innovation Scheme (EUDIS), which also intends to support the maturity of ideas from a technological perspective. The GARTEUR community will closely monitor these measures of the European Commission in order to respond to the rapidly changing challenges of the defence scenario.

Although GARTEUR is a European organisation, its actions are not limited to Europe. Representatives of GARTEUR Council and AG/EG participants are often involved in NATO groups and/or interact with their scientific community to contribute to the development of the knowledge in the aeronautics field.

5. GARTEUR's action zone

5.1 The operational model

The five GARTEUR Groups of Responsables (GoRs) continuously strive to facilitate and deliver vital research in the field of aeronautics. The GoRs are responsible for monitoring and encouraging the progress of Action Groups (AGs) and Exploratory Groups (EGs). These groups are collaborations of researchers from national aerospace institutes, universities and industry. Although GARTEUR is not a source of funding, the GoRs constitute a powerful network and provide a unique forum for aeronautical research in Europe. The GoRs aid potential research consortia by critically reviewing their proposed research objectives and methodologies. The activities promoted by GARTEUR span from the upstream to the applied medium- to long-term research, characterized by a low TRL (Technology Readiness Level), from 1 to 3 (Figure 2).

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. Despite this aspect might represent a deterrent condition for the participation in the AG projects, it is however worth highlighting that in many circumstances this is an extremely important step toward the creation of the necessary expertise which is then spent in funded projects. Indeed, GARTEUR does not contrast other funded initiatives but, rather, helps putting the basis for a fruitful participation in them.

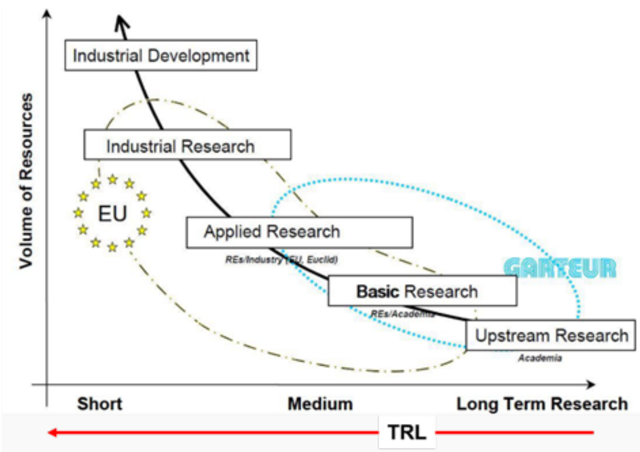

Figure 2 – GARTEUR's perimeter of activities

5.2 Keeping up to date

GARTEUR, as a watchtower of technology needs in the aeronautics arena and as a tool to generate technical response for them, has also changed during the years, sometimes in a subtle way, sometimes more decidedly. Along the years, the work of the Action Groups, set up by the Groups of Responsables across the different specialties, have built up an impressive record of projects dealing with every aspect of the technologies needed for keeping European aeronautical industry at the lead.

Over nearly 50 years of its existence, GARTEUR has developed an extensive research and technology portfolio delivering a wealth of leading-edge projects. Research has traditionally focused on early stage, low TRL technologies, guided by the wider European priority research areas as set out in the strategic research agendas of ACARE and EDA.

The need for GARTEUR to produce technical achievements in line with the demands from the society it has to serve, requires a constant update, or even reinvention, of the Technical Groups involved at different levels. Hence, the periodic identification of Strengths, Weaknesses, Opportunities and Threads (SWOT) allows GARTEUR to prioritise its activities in its current technology and research mainstreams (38 topics, classified by “Military”, “Artificial Intelligence, Big Data and Uncertainty quantification”, “Breakthrough”, “Certification / Standardization”, “Security” and “Multidisciplinary”).

The chairs and members of the GoRs systematically review the relevance of the work being investigated in the Action Groups, Exploratory Groups or EU collaborations to the wider GARTEUR strategy, in addition to identifying links and interdependency between projects. Roadmaps also enable identification of collaboration opportunities both within and across the GoRs, providing a mechanism to measure impact against ACARE and defence targets. Further to streamlining research areas, the roadmaps also highlight where gaps may exist, from which an assessment can then be made as to whether these need to be acted upon or considered out of scope.

GARTEUR actively disseminates information on its scientific and technical activities and researchers are encouraged to publish their results in conference and scientific journals. Furthermore, the GARTEUR website [3] is a precious repository of information on AG projects, including many final reports.

The scientific nature of GARTEUR has also allowed it to serve an important higher education role in preparing young researchers for the work environment, where the ability to innovate is a highly searched skill. Numerous Master and PhD theses are related to GARTEUR research activities.

GARTEUR’s consolidated approach to R&T will be ever more inclusive so that future generations will take the future of aviation in their own hands.

6. Fields of scientific and technical activities

This section presents an overview of the activities that are executed in the Action Groups that operate under the supervision of the five Groups of Responsables in GARTEUR, with highlights on some of the most successful projects and an outlook on future activities.

6.1 Aerodynamics

The Group of Responsables for Aerodynamics (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 remit covers aerodynamics, aeroacoustics, and aeroelasticity. The GoR AD is supporting a multi-disciplinary cooperation with the other GARTEUR Groups in areas where a mono-disciplinary approach is not meaningful.

The GoR AD initiates and organises basic and applied aerodynamic research in the field of aeronautics. The current scope of activities cover 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 collaborative aerodynamics research in Europe, combining both numerical and experimental research. Dedicated experiments are carried out using advanced experimental techniques and measurement 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.

Today computer codes are quite mature, nevertheless GARTEUR continues its role has vanguard addressing new challenges and new topics that cannot be tackled within frame of European funded where often only mature topics and technologies can be addressed. GARTEUR Aerodynamics remains one of the unique areas where international cooperation on basic aerodynamics research topics can be performed. The new challenges are toward unsteady and multidisciplinarity, use of new accurate CFD methods and finally introducing new technologies such as artificial intelligence. Some of the more recent topics addressed by GARTUER AG are reported in the following.

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

The overall objective of AD/AG-54 has been, by means of an international collaborative effort, to explore, develop and improve RANS-LES coupling for embedded LES (ELES) and hybrid RANS-LES methods. A particular focus was to address the “grey-area” problem present in zonal and non-zonal hybrid models for aerodynamic applications. The main objectives have been: (1) To evaluate RANS-LES interfacing methods adopted in current hybrid RANS-LES modelling approaches; (2) To develop Grey-Area Mitigation (GAM) methods for improving RANS-LES interaction and improving the RANS and LES modes in hybrid modelling; (3) To develop improved RANS-LES coupling methods for zonal and non-zonal hybrid RANS-LES modelling and for embedded LES methods; (4) To validate and verify the developed methods for a number of selected scale-resolving simulation test cases.

A set of modelling approaches have been explored by AD/AG-54 members, with a primary focus on the RANS-LES interface that has a direct impact on the scale-resolving capabilities of the LES mode. The modelling methods considered in the investigation include approaches of DES-based variants, usually using the S-A or k-ω model as base model, wall-modelled LES and a number of other hybrid RANS-LES methods, e.g., HYB0, HYB1, X-LES and ZDES. To improve scale-resolving modelling, different Grey-Area Mitigation (GAM) approaches have been verified by means of adaption of, among others, SGS-turbulence length scale, stochastic and high-pass filtering-based modelling, energy-backscatter function and commutation terms incorporated into the LES mode. Some typical results are given in the following figures.

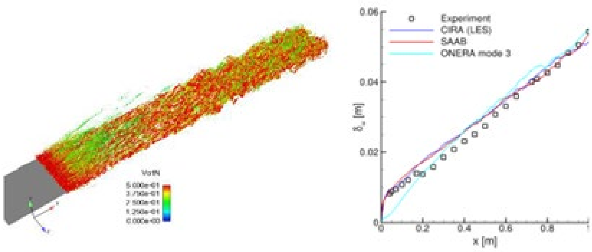

Figure 3 – Resolved turbulent structures (Left) and predictions of mixing-layer vorticity thickness (Right).

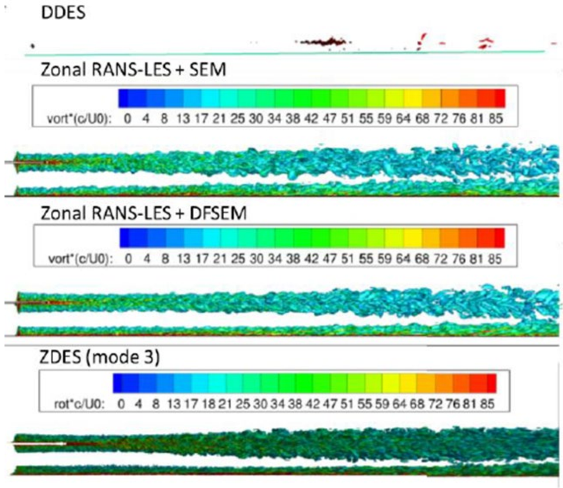

Figure 4 – Resolved turbulent structures downstream by means of zonal methods supported by ST after the RANS-LES interface.

Advances made such as in AD/AG-54 on the RANS-LES coupling have led to significant enhancements in efficiency and accuracy for scale-resolving simulations. It is now possible to employ zonal methods at, or in close proximity to, a complex flow feature such as separation without an overbearing loss of accuracy. This advance offers the ability to focus computational resources in pre-determined regions of importance and enables increasingly advanced applications to be considered in industrial aerodynamics.

In embedded simulation, further work is needed where a fully three-dimensional, time-dependent, mean flow is presented by the RANS at the interface to the LES region, rather than the relatively simple span-homogeneous steady conditions we have tested in the present work. Where for instance on occasion the mean flow could even move backwards across the interface from the LES to the RANS rather than being fixed to move in a single direction. This has motivated a new GARTEUR EG/AG on WMLES and embedded LES.

AD/AG-60 Machine learning and data-driven approaches for aerodynamic optimization and uncertainty quantification

Fluid dynamics has traditionally dealt with massive amounts of data from experiments, field measurements, and large-scale numerical simulations. Big data has been a reality in fluid mechanics over the last decade due to high-performance computing architectures and advances in experimental measurement capabilities. Over the past decade, many techniques were developed to handle data of fluid flows, ranging from advanced algorithms for data processing and compression, to databases of turbulent flow fields. However, the analysis of fluid dynamics data has relied to a large extent on domain expertise, statistical analysis, and heuristic algorithms.

The main purpose of the AD/AG-60 is to perform an extensive comparison of deep learning, surrogate models and machine learning techniques for aerodynamic analysis and prediction. The action group consists of 11 partners, including eight research establishments, two industrial partners and one SME. Partners are currently working on the developments of different machine learning models applied to the industrial XRF1 configuration, an Airbus-provided industrial standard multi-disciplinary research test case representing a typical configuration for a long-range wide body aircraft.

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

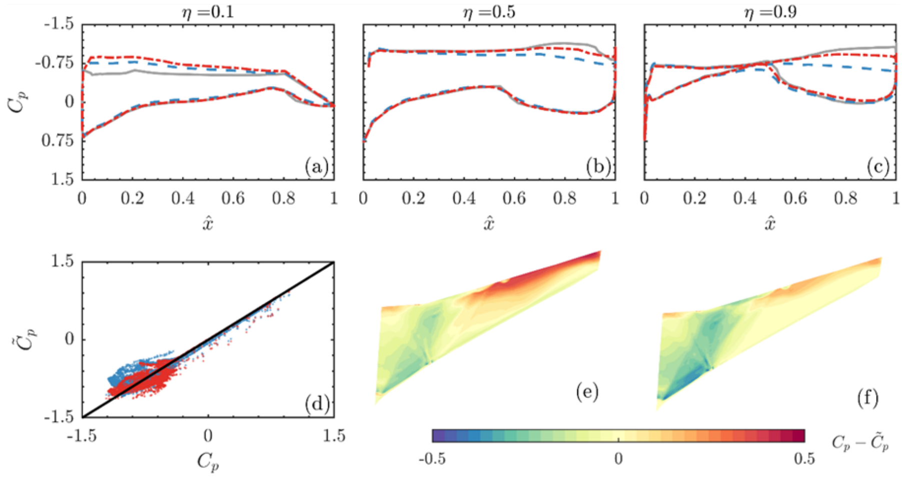

Figure 5 – (a-c) Cp distribution for Mach of 0.9440 and Alpha 10 at wing sections 10%, 50% and 90%. Solid grey line for input Cp, short dashed red line for Cp from random forest and long dashed blue line for Cp from the random forest with POD. (d) Error regression representation between Cp's predicted. (e,f) prediction error for the Cp distribution for random forest (e) and random forest with POD (f).

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

6.2 Aviation Security

The Group of Responsables for Aviation Security (GoR AS) supports the advancement of civil and defence related security technology in European research establishments, universities, industries and other relevant European entities involved in security for aviation through collaborative research activities, and through the identification of future projects for collaborative research.

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

The main aim is to increase security, safety and operation performance for critical assets in the aviation domain. This Group of Responsables was created in 2014 following the publication of the ACARE SRIA which for the first time identified "Ensuring safety and security" as a specific challenge.

Recent efforts have been aimed at maintaining links with other European initiatives like ES4AWG, Optics2 project, ACARE WG4. This in order to assure that the topics under discussion are kept:

- in line with FlightPath 2050;
- further dealt in the ACARE SRIA update and its dedicated Challenge on Aviation Safety & Security;
- fitting with what emerged from the PADR (Preparatory Action on Defence Research);
- aligned with EREA Security for Aviation initiative;
- a priority for Europe.

In recent years the GoR AS has carried out exploratory activities on the malevolent use of RPAS which has resulted in the SESAR JU Exploratory Research project ASPRID (Airport System Protection from Intruding Drones). The project addresses the problem of protecting airport operations from unauthorized drone intrusions; exploring new ideas, concepts and emerging technologies under a complete and operationally oriented approach, to get a solution that, tuned to a specific situation, restore airport operations to nominal conditions within acceptable time constraints.

Airport operations are particularly susceptible to unauthorized drone intrusions and an increasing of the awareness is required in regard to this phenomenon. A quantitative assessment of the historical features of drone intrusions in airports, by using different public databases with reports about real sightings has been carried out [5]. The available features are modelled in terms of probability distributions. Also, a risk classification model is proposed by means of supervised machine learning. Lastly, a preliminary analysis is provided for the definition of an Airport Vulnerability Index with respect to drone intrusions.

Some results of this project are displayed in the following figure:

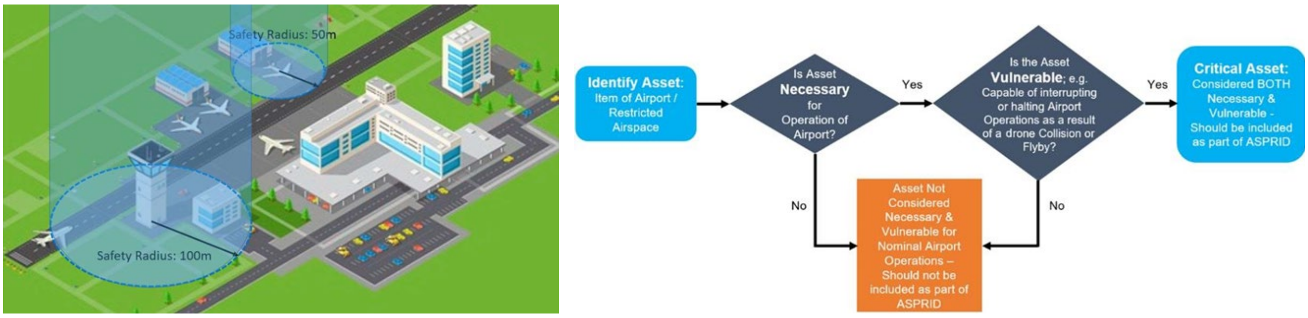

Figure 6 – Analysis of some specific threat scenarios (Fly-By or drone flying too close to an asset, Collision) and procedure for the assessment of critical assets

Current topics under evaluation by the GoR AS members are: safety and security assessment, cybersecurity for aviation assets, artificial intelligence security, security by artificial intelligence, cybersecurity of aviation assets, counter UAS technology, security for drone swarms, …

6.3 Flight Mechanics, Systems and Integration

The Group of Responsables for Flight Mechanics, Systems and Integration (GoR FM) 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 Rotorcraft GoR is active (see the next section).

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 recent times GoR FM has played a central role among GoRs in order to identify topics that

GARTEUR could address on UAVs. Topics under current evaluation, for action by multiple GoRs are:

- Load control of Fixed wing UAV's (HALE MALE);
- Gust resilience of VTOL aircraft;
- Morphing for load control of high aspect ratio wings;
- Properly understand threads of drones (knowledge-based danger evaluation);
- Icing conditions for next generation drones.

An internal down-selection process has led to writing a pilot paper on control allocation using distributed propulsion. Furthermore, the following two topics are under consideration for a pilot paper:

- Flexible aircraft control;
- Guidelines on certification.

Recently, FM/EG-30 on AI for fault detection has been launched with the aim to investigate the feasibility of AI techniques 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 techniques. A more precise objective of the EG is to investigate AI techniques 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.

6.4 Rotorcraft

Since its creation in 1980, the Rotorcraft Group of Responsables (GoR RC), formerly Helicopters GoR, has supported 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 members 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.

The GoR RC acts as a highly effective forum in its primary function of promoting collaborative research through Exploratory Groups and Action Groups. In particular, it initiates, organises and monitors basic and applied, computational and experimental multidisciplinary research in the context of application to rotorcraft vehicles (helicopters and other VTOL aircraft, such as tilt rotors, compounds and multi-copters) and systems technology. The 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 rotorcraft 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 field for exploration, analysis and requirements definition 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 test campaigns;
- increase operational efficiency (improve speed, range, payload, all weather capability, highly efficient engines, more electric rotorcraft ...)
- increase security and safety:
    - security studies, UAVs, advanced technologies for surveillance, rescue and recovery;
    - flight mechanics, flight procedures, human factors, new commands and control technologies,
    - increase crashworthiness, ballistic protection, etc.
- improve rotorcraft integration into the traffic (ATM, external noise, flight procedures,

requirements/regulations)
- tackle environmental issues:
  - greening, pollution
  - noise (external, internal)
- progress in pioneering: breakthrough capabilities.

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.

Some of the more recent topics addressed by GoR RC are reported in the following.

HC/AG-22 Forces on Obstacle in Rotor Wake

Helicopters are routinely employed in missions within "confined areas", regions where the flight of the helicopter is limited in some direction by terrain or by the presence of obstructions, natural or manmade. Rescue operations, emergency medical services, ship-based rotorcraft operations are some examples of near-ground and near-obstacle operations.

The objective of the HC/AG-22 was to investigate, both numerically and experimentally, the interactional process between a helicopter rotor wake and the surrounding obstacles and the evaluation of the forces acting on these obstacles. An extremely fruitful cooperation was carried out among 7 partners, going well beyond the expected effort, with four valuable databases being produced to deepen the knowledge of very complex interactional phenomenology and to validated the single computational tools [6]. Some typical results are given in the following figures.

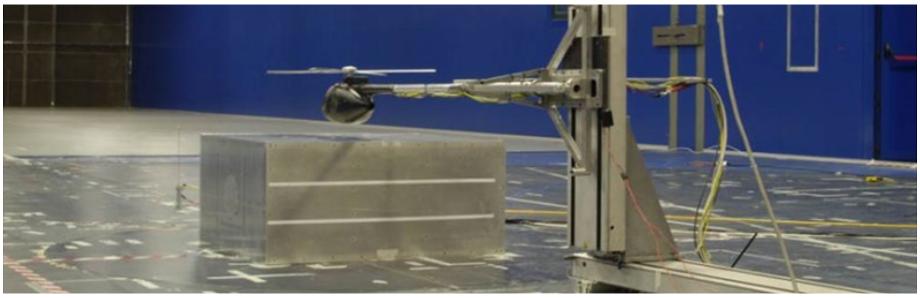

Figure 7 – Experimental test rig at Politecnico di Milano wind tunnel

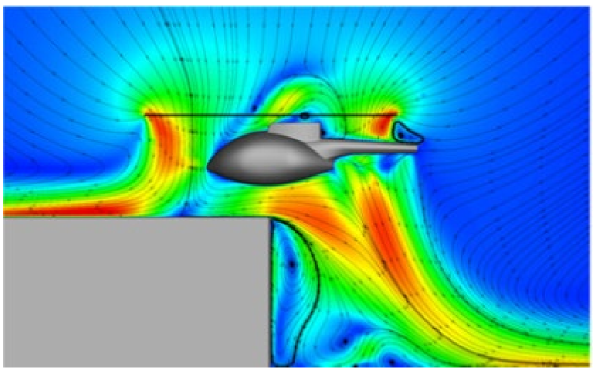

Figure 8 – Resolved turbulent structures (Left) and predictions of mixing-layer vorticity thickness (Right).

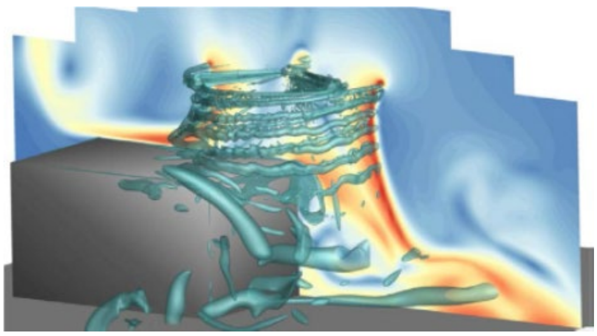

Figure 9 – Resolved turbulent structures downstream by means of zonal methods supported by ST after the RANS-LES interface.

HC/AG-25 Rotor-Rotor-Interaction

Although today we have reached the capability to simulate rotor-rotor or rotor-propeller interactions 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, the GoR RC has identified a clear need for 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 highlighted the lack of such experimental databases.

GARTEUR responded to this need by launching 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. A significant effort is being made by the partners in order to set up some cost-effective wind tunnel test campaigns aiming at producing experimental database for the validation of numerical methodologies. The following figures show some of the test articles that will be used in the forthcoming wind tunnel test campaigns.

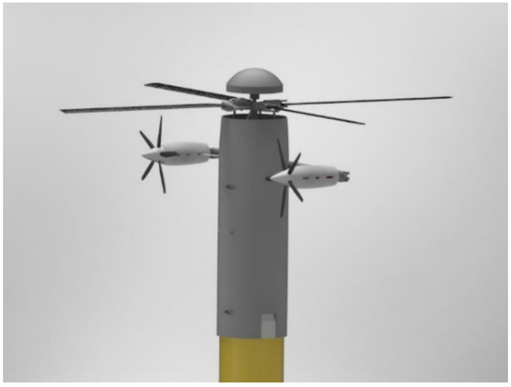

Figure 10 – Design of Politecnico di Milano Test Rig

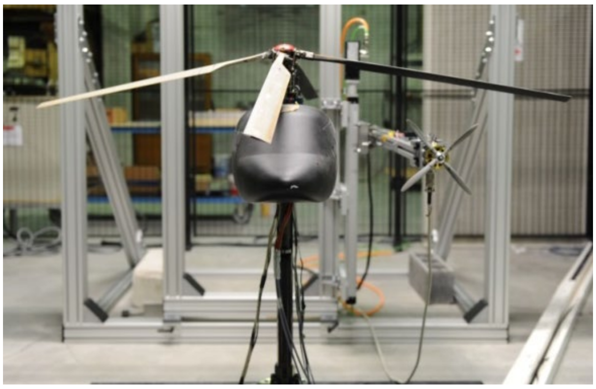

Figure 11 – Generic Main Rotor/Propeller Configuration (ONERA)

GoR RC, despite its dimension, has shown, during the years to be a successful group which has had and is having the capabilities to promote activities in which the cooperation, despite the lack of funding, has been very successful and has produced many experimental databases employed to validate the numerical tools applied and improved during the life cycle of the AGs. In many occasions, the expertise matured in GARTEUR has been profitably put at disposal of later funded research projects.

The future of the GoR RC activities is intimately linked to the technological advancements in the rotorcraft field (improvement of the classical helicopter configurations, fast rotorcraft, eVTOLs), as declined by industrial stakeholders.

Two exploratory groups (EGs) are currently active and under examination to be converted to action Groups:

- *RC/EG-40: Gust Resilience of VTOL Aircraft;*
- *RC/EG-42: Analysis and Decomposition of the Aerodynamic Force Acting on Rotary Wings*.

Finally, a list of New Initiatives is conceived and constantly updated by the RC GoR members. Current topics under evaluation are:

- Helicopter Icing & De-Icing: extremely important for safer flights in all-weather conditions, an objective to be pursued to reduce the operative costs of rotorcraft;
- Modelling of electric systems for eVTOLs;
- Drone impact on Helicopters (rotating parts): This topic is extremely important for UAM and military applications;

- Human Factor issues and training methods for complex automation in cockpit;
- Pressure Sensitive Paint / Temperature Sensitive Paint for rotors/propellers (drone, e-VTOLS...): innovative means for less expensive experimental measurements on complex geometries in complex flight conditions;
- Perception and public acceptance of UAM and Noise propagation in urban environment (high RPM with high frequency noise): this is a relevant topic for the success of the UAM;
- Installation effect of propeller noise (wing, ducts) in early architecture phase.

6.5 Structures and Materials

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

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

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

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

- Fatigue and damage tolerance assessment of hybrid structures
- Damage repair with composites in composite and metallic structures
- Characterisation and modelling of Composites with Ceramic Matrix submitted to severe thermo-mechanical loading
- Characterisation of composites with polymer matrix at high temperatures
- Characterisation and optimization of shock absorbers for civil aircraft fuselages
- Additive Layer Manufacturing
- Structural health monitoring for hydrogen aircraft tanks.

Some of the more recent topics addressed by GoR SM are reported in the following.

SM/AG-34 Damage repair with composites

Composites are much more prone to being damaged in service than metals, for example, by mechanical impact. Repairability of such damage is an important consideration in the selection of composites for aircraft applications. In addition, metal structures can be repaired by using composite patches with great potential benefits such as cost reduction and time saving. These repair techniques can be considered applicable to a wide range of structures both metallic and composite (laminates or sandwich).

The objective of the group was the definition of effective repair techniques both for civil and military aircraft structures through the development of numerical/experimental methodologies. The aim was to minimized down-time of the aircraft for repair operation, minimized costs for repair, reduced certification costs and time for certification and will promote the repair of components instead of their substitution. The following topics were addressed: repair criteria, design of patches and repair strategies, analysis of the repair, manufacturing and test, repair strategies and technology end effective repair methods. Some typical results are given in the following figure.

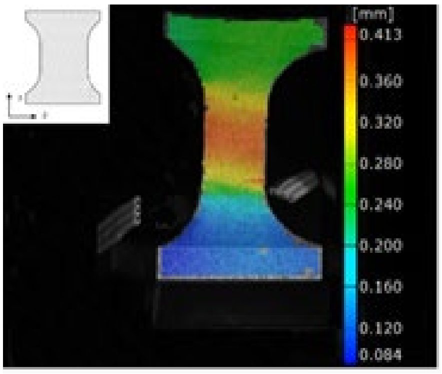

Figure 12 – Digital Image Correlation (DIC) view of Z displacement

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

Hybrid structures i.e. structures consisting of a metallic and CFRP component, are becoming more prevalent in aircraft structures. Structural components made out of metal require a different approach with respect to fatigue analysis and fatigue testing than components made out of fibre reinforced plastics (composites). A major challenge in the fatigue analysis and subsequent fatigue testing of hybrid structures originates from differences in deriving fatigue spectra for metal and composites and incorporation of required environmental load factors for composites. Also the joining of metallic components with carbon fibre reinforced polymers will require additional care and attention in terms of design and assembly requirements.

The objectives of the group were to validate the basic assumptions for any applied spectrum manipulation techniques for fatigue test of hybrid structures, to examine the capabilities and benefits of a probabilistic approach, to determine the optimum way to account for thermal loads in a non-thermo test set-up with the goal to find a joint 'best practice' approach for testing of hybrid airframe structural components.

A joint "best practice" approach for full scale fatigue testing of airframe structural components was established for the different tasks (Figure 13).

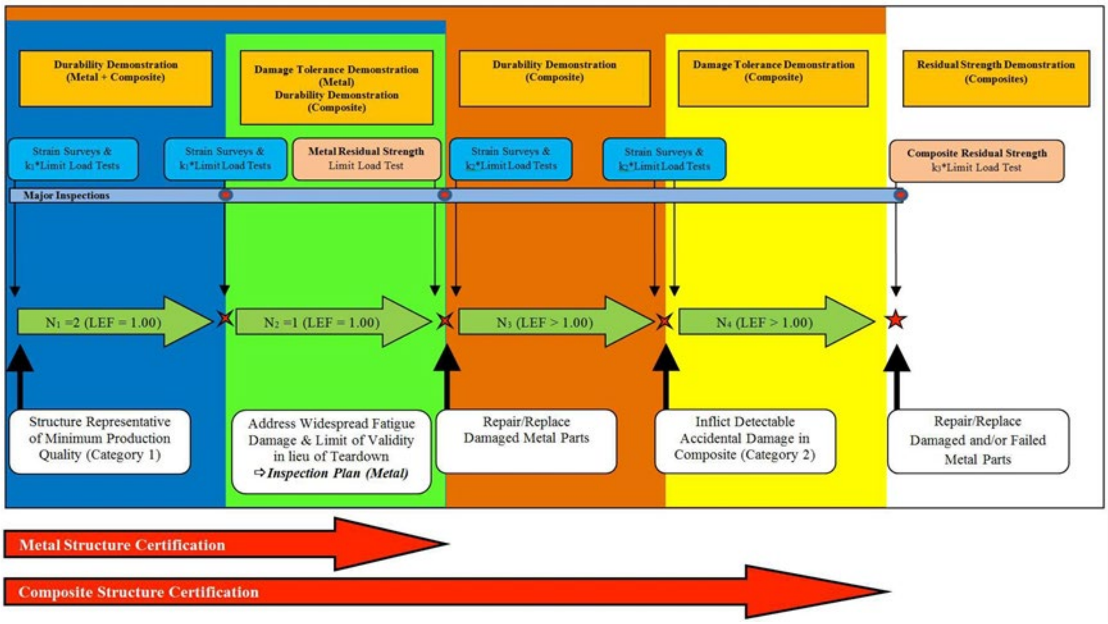

Figure 13 – Example of full-scale test sequence

The research conducted in SM/AG-35 has applications in the fatigue analysis and substantiation of metallic-composite structures, the design of hybrid interfaces such as joints between metal and composite parts, and on the design of adhesively bonded joints between fibre-metal laminate (FML) and composite parts.

Presently the GoR SM is carrying out one action group:

- SM/AG-36 Additive layer Manufacturing of high strength aluminium.

  Additive Manufacturing (AM) with metals is an emerging technology that finds more and more applications in different markets such as orthopedic 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 (e.g. integrated cooling capability). Great advancements are being achieved on laser powder bed fusion (L-PBF) and also on directed energy deposition (DED).

  Based on these considerations Action Group SM/AG-36 was launched in January 2022 and focusses on “Additive Manufacturing of novel high strength aluminium alloys”. The goal of Action Group is to build up knowledge and skills in the field of metal AM processes and materials in order to support the manufacturing industry and increase its competitiveness.

  The expected impact of the AG is to develop AM processes for high performance aluminium alloys (AL-Alloys) and to achieve static and/or dynamic performances that are equal but preferably higher than the current AL-Alloys.

The following exploratory groups are being active in defining projects on the following topics:

- SM/EG-44 Characterisation of composites with polymer matrix at high temperatures;
- SM/EG-45 Characterisation and modelling of CMC submitted to severe thermo-mechanical loading;
- SM/EG-46 Characterisation and optimization of shock absorbers for civil aircraft fuselages;
- SM/EG-48 Structural Health Monitoring for hydrogen aircraft tanks.

7. Conclusions

GARTEUR is a multinational organisation that performs high quality, collaborative, pre-competitive research in the field of aeronautics by research establishments, industry and academia. Still today it offers the only framework in Europe to bring civilian and military R&T together and therefore delivers added value through the operation of jointly supported research programs in line with the programs conducted in other European frameworks.

GARTEUR provides a very useful platform and network for scientists from research establishments, industry and academia to pool technology and knowledge in order to develop ideas and concepts in various aeronautical areas. For this reason, it is essential to preserve the close relations with industry in civilian and defence environments and consequently the enhancement of industrial participation at GoR level is always encouraged.

Improvements to GARTEUR’s performance and efficiency are continuously pursued in view of the changing aeronautical environment and in order to rise to the occasion of new challenges and unforeseen opportunities. The Covid-19 pandemic and the on-going military conflict have shown how essential it is to be able to redirect R&T priorities so as to respond promptly to new challenges.

GARTEUR will continue to be a watchtower of technology needs in the aeronautics arena and at the same time will provide a technical response for them, in close harmonisation with other R&T initiatives in GARTEUR countries and in Europe.

8. Acknowledgements

The author is grateful to all the persons involved in current and past GARTEUR activities. The success of GARTEUR is the result of their efforts and dedication. Special thanks to the participants in the Exploratory Groups and the Action Groups: their work and their results are essential to explore new scientific directions and to support the aeronautical community.

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10. Copyright Statement

References

[1] Consigny H, Vasseur, O and Delot A-L. An overview of the Group for Aeronautical Research and Technology in EURope (GARTEUR). *AIAA Science and Technology Forum and Exposition*, *52nd Aerospace Sciences Meeting*, National Harbor, MD, USA, AIAA-2014-0370, Jan. 2014.

[2] Consigny H, Vasseur, O and Delot A-L. Overall view of the European collaboration in aeronautics research within GARTEUR. *5th CEAS Air and Space Conference*, Delft, The Netherlands, paper no. 40, Sept. 2015.

[3] https://garteur.org

[4] van Hoeck, EA, Oskam, B and van Beek, CM. GARTEUR: 30 years of European collaboration in aeronautics research. *24th International Congress of the Aeronautical Sciences*, von Kármán Lecture, Yokohama, Japan, Aug.-Sept. 2004.

[5] Pascarella D, Gigante G, Nebula F, Vozella A, Redondo de la Mata E, Jiménez Roncero FJ and Martinavarro E. Historical Data Analysis and Modelling for Drone Intrusions in Airports. *13th International Conference on Electronics, Computers and Artificial Intelligence*, *ECAI 2021*, IEEE, Pitești, Rumania, 1-3 July 2021.

[6] Visingardi A, De Gregorio F, Schwarz T, Schmid M, Bakker R, Voutsinas S, Gallas Q, Boisard R, Gibertini G, Zagaglia D, Barakos G, Green R, Chirico G and Giuni M. Forces on Obstacles in Rotor Wake – A GARTEUR Action Group. *Proceedings of the 43rd European Rotorcraft Forum – ERF 2017*, Milan, Italy, Vol. 1, paper n. 530, pp 252-265, 2017.