GARTEUR: Long Term R&T collaboration in Europe

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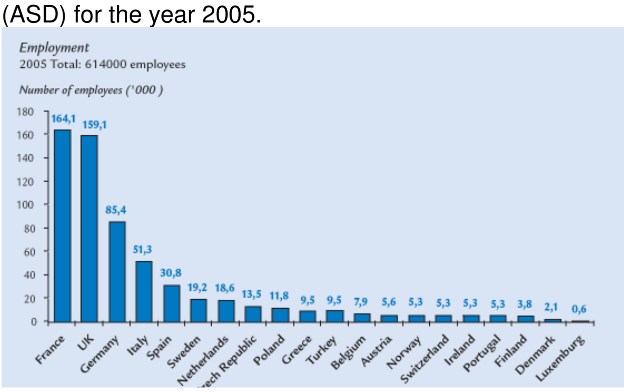
ABSTRACT

The paper presents an overview of collaboration in aeronautics between European countries as stimulated continuously by the Group for Aeronautical Research and Technology in Europe (GARTEUR) over the last thirty years. GARTEUR (Group for Aeronautical Research and Technology in Europe) 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, their human resources and facilities in aeronautics for the purpose of strengthening collaboration between European countries.

1. INTRODUCTION

GARTEUR (Group for Aeronautical Research and Technology in Europe) 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, their human resources and facilities in aeronautics for the purpose of strengthening collaboration between European countries.
The GARTEUR objective is to improve the competitiveness of aerospace industries by performing high quality, precompetitive research in the field of aeronautics by research establishments, industry and academia. Subjects of investigation cover civil as well as military Research & Technology (R&T), and provide for synergies and mutual benefits to the GARTEUR member countries. The GARTEUR nations are also the seven European Union countries with the largest direct employment in the aerospace business, as can be seen in the figure below from the statistical survey by the Aerospace and Defence Industries Association of Europe (ASD) for the year 2005.



Aerospace employment in the EU (ASD Facts & Figures 2005)

GARTEUR identifies the best of European long term innovative R&T, both in terms of upstream research performed nationally at universities, as well as in terms of basic R&T performed at research institutes. GARTEUR aims at the readiness of this R&T outcome for applications in industry. Within GARTEUR, emerging technologies relevant to industry are matured. Subsequently, technology readiness is presented by GARTEUR to qualify these technologies for application by industry. Some proposals submitted to the Framework Programmes of the EU are based on activities of GARTEUR Action Groups.
The European context is of great importance for GARTEUR because of the more recently developed EU environment promoting co-ordinated aeronautics R&T. There exists a permanent mutual influence between this EU environment and GARTEUR.
The objective of this paper is to present the GARTEUR organisation, to highlight its technical activities and to identify the factors that have led to the success of the GARTEUR organisation over the last three decades. Conclusions are drawn at the end.

2. THE GARTEUR ORGANISATION

This section provides background information on GARTEUR, its mission and operating principles, and organisation.

2.1. Origin of GARTEUR

Airbus was established in 1970 after its first aircraft, the A300B, was launched at the 1969 Paris airshow. In 1973, GARTEUR was formed, as it became clear that only through cooperation, would European R&T activities become competitive in the global playing field.
The initiative to strengthen R&T activities was taken by the governments of France, Germany and the United Kingdom. The Netherlands joined the GARTEUR in 1977, followed by Sweden in 1991, Spain in 1996 and Italy in 2000. The collaboration is based on a Memorandum of Understanding between these seven European Nations with major research and test capabilities in aeronautics.
The GARTEUR focus is on research topics aimed at long term R&T because this is considered essential to assure sustained competitiveness of the European aerospace industries. Subjects of interest within the GARTEUR programme are not restricted to particular application areas. The GARTEUR scope is wide and covers civil, defence and dual use applications. As such, it is one of the few mechanisms in Europe that allow for transfer of aeronautical technology between the military and civil fields. It offers a unique forum to aeronautical experts from research establishments, industry and academia. GARTEUR interacts with other bodies, such as the European Union, the Association of European Research Establishments in Aeronautics (EREA), the Aerospace

and Defence Industries Association of Europe (ASD) and the European Defence Agency (EDA).

2.2. Mission and principles

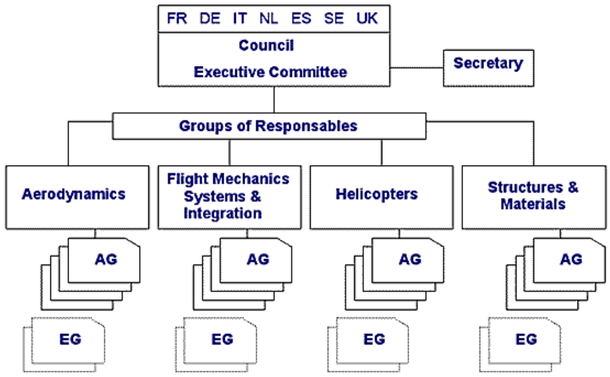
The mission of GARTEUR is to mobilise, for the mutual benefit of the GARTEUR member countries, their scientific and technical skills, human resources and facilities in the field of aeronautical research and technology for the purposes of strengthening collaboration between European countries with major research capabilities and government funded programmes. GARTEUR also aims at continuously stimulating advances 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 man ner 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 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 the member countries continues to exist. Another principle is that major decisions in the organisation have to be taken by unanimity of the member countries. Participation of industry is sought at senior advisory level in both the planning an execution of programmes. A flexible approach is taken towards participation of non-GARTEUR countries and organisations in the programmes. 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.

2.3. Organisation

GARTEUR is organised at three main levels. 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, four GoRs manage GARTEUR research activities:

- Aerodynamics (AD);
- Flight Mechanics, Systems and Integration (FM);
- Helicopters (HC);
- Structures and Materials (SM).

In the early nineties, a Group of Responsables for Propulsion Technology (PT) has been operational for a number of years; however, this GoR has been discontinued. Action Groups (AGs) form 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 principals 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, through industry participation in the Action Groups, and through the Industrial Management Group (IMG4). IMG4 is a committee within the Aerospace and Defence Industries Association of Europe (ASD) that is involved in the R&T activities performed in the Framework Programmes of the EU.



GARTEUR organisational diagram

GARTEUR is an independent organisation without permanent secretariat and headquarters. The co-ordination of GARTEUR and the information centre of GARTEUR reside with the Chairman of the XC and the GARTEUR Secretary. The seven GARTEUR nations take their turn in fulfilling the functions of the Chairmanship of the Council and its XC, and the Secretariat for periods of two consecutive years. The necessary resources are made available by the governments of the member countries or by the participating organisations on the basis of balanced contributions.

3. GARTEUR STATISTICS

Up to the end of 2006, 112 Action Groups have been active within GARTEUR. Average participation per individual AG from organisations such as research establishments (REs), industrial companies, academia and other entities (governmental organisations) amounts to 8.6 participating organisations per AG, see the table below. This level of participation ranges from 7 to 11 organisations per AG, depending on the particular GoR under consideration. The field of aerodynamics contained the largest number of Action Groups (44); this is also reflected in the distribution of the total number of participating organisations over the various research areas although the total number for the GoR(SM) is slightly higher. On GARTEUR scale, research establishment and industry participation is fairly of the same size; but in GoR(SM) work the number of industrial participants is substantially larger than RE participants, while the opposite applies for the GoR(AD) and GoR(FM). The FM Action Groups feature a relatively large number of academic participants.

	Group of Responsables (Number of Action Groups)					
Particip.	**AD (44)**	**FM (17)**	**HC (16)**	**SM (33)**	**PT (2)**	**Total (112)**
RE	200	78	50	131	8	467
Industry	113	38	39	165	10	365
University	8	38	15	29	1	91
Other	13	6	2	19	3	43
Total	**334**	**160**	**106**	**344**	**22**	**966**
Average	**8**	**9**	**7**	**10**	**11**	**8,6**
Status December 2006						

This distribution of activities over the research areas is also reflected in the amounts of manyears spent, as shown in the second table. Resources spent in Action Groups have been recorded from 1989; in the past 18 years 507 man-years have been invested in GARTEUR research.

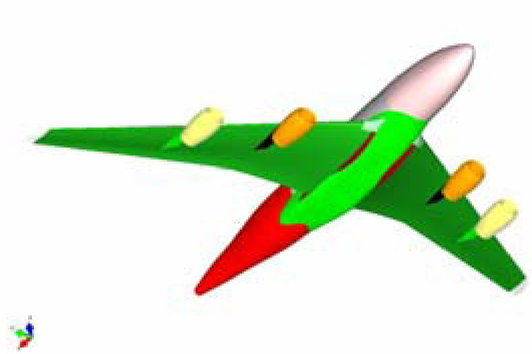
	GoR					
	AD	**FM**	**HC**	**SM**	**PT**	**Total**
Manyear	**185**	**132**	**48**	**136**	**6**	**507**
Status December 2006						

4. FIELDS OF SCIENTIFIC AND TECHNICAL ACTIVITIES

This section presents an overview of the activities that are executed in the Action Groups that operate under supervision of the four Groups of Responsables in GARTEUR.

4.1. GoR for Aerodynamics, GoR(AD)

The GoR(AD) is active in initiating and organising basic and applied research in aerodynamics and aerothermodynamics. The first discipline is a cornerstone of aeronautics that determines the shape of the aircraft. The latter is closely related to space operations and flight through the earth's atmosphere at very high speeds, and is also required for exploring wing-icing phenomena.



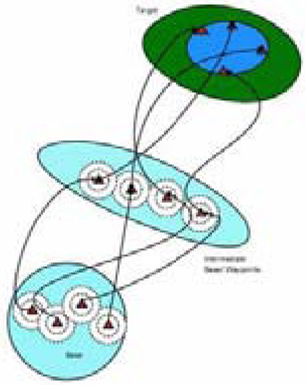
Environmental issues are of great concern in aeronautics for civil aircraft, and advanced aerodynamic design has a significant impact on fuel consumption and the noise of aircraft. For military aircraft, the requirements of stealthy operation require new aircraft shapes to be considered and these shapes must be aerodynamically effective.

The GoR(AD) remit covers aerodynamics, aeroacoustics and aeroelasticity. This GoR is active in experimental and theoretical fields of aerodynamics to contribute to the development of methods and procedures. Work in experimental areas is performed to obtain data for the validation of numerical methods. Measurement techniques are developed and refined to increase accuracy and speed of experimental investigations. Numerical studies give insight into the mechanisms of basic flow phenomena.

Current GoR(AD) projects are, for example, on 'Ice shape effects on the aerodynamic performance of airfoils, phase II' and 'Ice accretion prediction, phase II' to carry out in-depth detailed studies on the problems of performance degradation due to ice and ice accretion. Another AG is 'Navier-Stokes methods for transonic and subsonic flows about slender bodies' whose results will contribute to the understanding of various methods for the modelling of viscous turbulent flow in missile aerodynamics and to the assessment of the applicability of these methods. Such knowledge will help engineers select appropriate flow modelling techniques to tackle their challenges

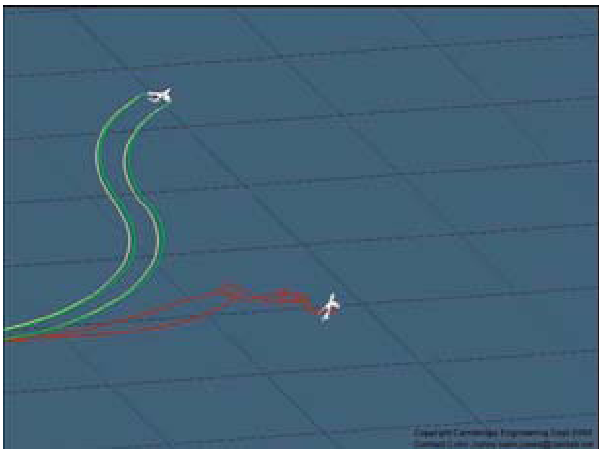
4.2. GoR for Flight Mechanics, Systems and Integration, GoR(FM)

The GoR(FM) is active in the field of air vehicle systems technology in general, including but not limited to safety, avionics systems, certification, multidisciplinary design aspects, performance, and stability & control. Flight testing technologies as well as flight simulations are tools that require further research. Apart from flight mechanics, the GoR(FM) is also responsible for subjects concerning flight guidance, air traffic control, sensor technology and systems, and human factors.



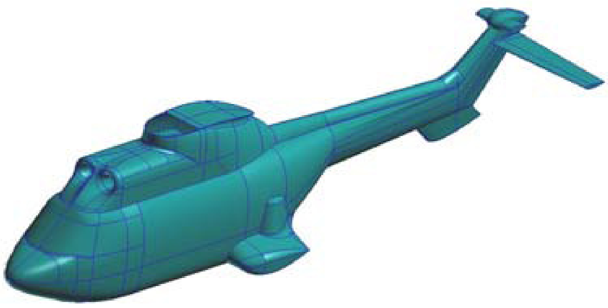
Current GoR(FM) AGs are on 'Fault tolerant control' that investigates fault tolerant flight control laws that can maintain stability and control following various levels of faults and damage occurring in fixed wing aircraft.

Another one covers 'Non Linear Analysis and Synthesis Techniques for Aircraft Control' and studies application of modern nonlinear methods for system analysis and control synthesis to fixed wing aircraft control in an industrial setting. The goal is to identify and evaluate methods that are easy to use, accurate, reliable and time saving that can replace the traditional tools used in the aircraft industry for control synthesis and analysis today.

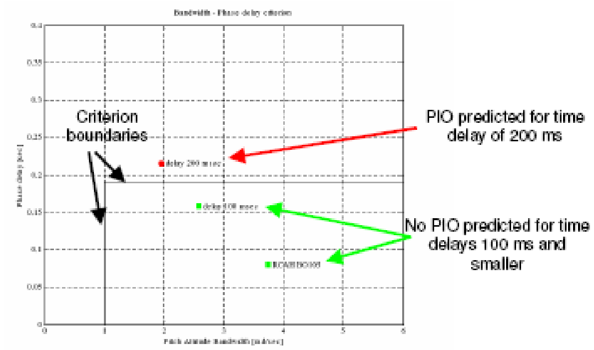


4.3. GoR for Helicopters, GoR(HC)

The GoR(HC) is active to facilitate the advancement of civil and military rotorcraft technology in Europe through collaborative research programmes and information exchange. Benefits to rotorcraft are being sought from advances in technology to obtain an extension of the flight envelope and performance, to increase safety and survivability, to increase public acceptance by paying attention to environmental issues, to increase crew and passenger comfort, and to focus on cost, affordability and time-to-market.
Interests of the GoR(HC) cover the full range of appropriate technical disciplines including aerodynamics, aeroelastics, flight mechanics, handling and control, flight tests and simulation, human factors, and internal and external acoustics.



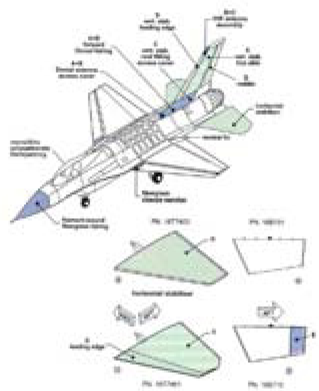
Current GoR(HC) projects are on measurements of a Lynx airframe. The work is aimed to improve the mathematical modelling capability for helicopter fuselage dynamics, in order to apply suitable and reliable models for new aircraft design, structural upgrades, equipment installation and vibration management system design; this with a reduced dependency on test.
Another AG aims at optimising design for crashworthiness of an helicopter when ditching, through the accurate modelling of the structural loads generated by impact with water, achievable by the application of Smooth Particle Hydrodynamic (SPH) methods. The planned work also addresses alternative – non SPH - methods newly implemented in several commercial codes, in order to compare with and assess the true potential of various methods. As a support to this numerical objective, the project also addresses generation of an experimental database of water impact tests.



Application of PIO toolbox (ONERA): Bandwidth-phase delay criterion BO105 with RCAS

4.4. GoR for Structures and Materials, GOR(SM)

The GoR(SM) is active in initiating and organising aeronautics-oriented research on structures, structural dynamics and materials. Structural research is devoted to computational mechanics, loads and design methodology. Research on structural dynamics involves vibrations, responses to shock and impact load, aeroelasticity, acoustic response and adaptive vibration suppression.
Materials-oriented research is related to material systems, primarily for the airframe but also for the landing gear and the aero-engines. It includes specific aspects of polymers, metals and various composite systems. The group is active in theoretical and experimental fields of structures and materials to assist in the development and improvement of methods and procedures. Of great importance is the mutual stimulation of alternative scientific approaches. Experiments give new insights into the mechanisms of structural behaviour that can initiate better models. Theoretical work provides advancement in analytical and numerical procedures to investigate the models. Finally, the results must be verified and validated by suitable experiments or trials.



Current GoR(SM) projects are on “Interchangeability of composite materials” that aims to reduce the high qualification costs for interchanging composite materials through the development of a probabilistic methodology that permits the assessment of theinterchangeability of composite materials.
‘High velocity impact’ focuses mainly on birdstrike-related issues will but effort is also devoted to modelling the impacted structure, and in particular consideration is given to novel materials, e.g. composites, and to the impact on complex structures, particularly pre-stressed components.

Aircraft was cruising at 35,000 feet when it encountered tennis ball sized hail.

"Damage management of composites Structures for Cost Effective Life Extension Service", aims to develop an approach for the damage management of composite aircraft structures in order to achieve a cost-effective service performance during their operational life.

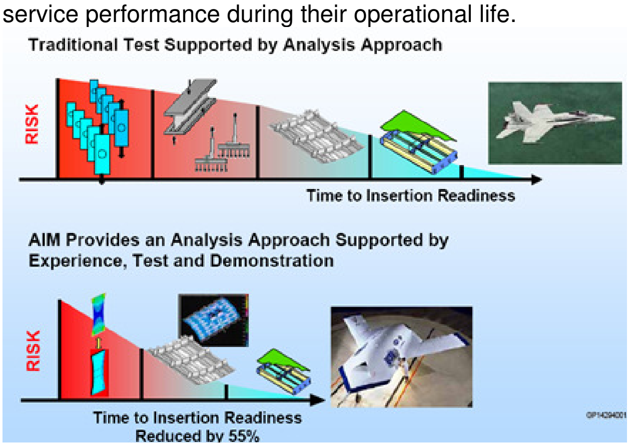


Figure 2 AIM (Accelerated Insertion of Material) approach against traditional test

5. TECHNICAL HIGHLIGHTS

This section presents highlights from a number of Action Groups. One project is described in terms of objectives and results from each of the four areas of research (AD, FM, HC, and SM).

5.1. Aerodynamics highlights

Airframe icing is a topic of great interest to the aerospace industry because it is strongly connected with the safe and efficient operation of aircraft under all-weather conditions. The rate of occurrence of ice-related incidents has to be further reduced in the future taking into account the expected air traffic growth in the next decade in order to maintain confidence of the public in air transport.
The availability of theoretical methods for the prediction of icing shapes is beneficial for the detection of the most dangerous conditions that are to be further investigated in an icing wind tunnel campaign and/or in a 'natural icing' flight test. This opportunity will result into a decrease of the product development costs and time-to-market. Besides, the numerical capabilities will also contribute to an increase of the European aerospace product competitiveness.
The main objective of the group **'Ice accretion prediction, phase II'** is to evaluate the ice accretion shape on lifting airframe components in order to improve the air transportation safety in all-weather air transport operations. It is done with theoretical models and if possible such results will be compared with experimental results. At a group meeting in December 2006 a review of main results has been performed. Concerning the multi-element airfoil some of the partners have presented new results improving the agreement with the other partners.

5.2. Flight Mechanics, Systems and Integration highlights

The group **"Pilot-in-the-Loop Oscillations - analysis and test techniques for their prevention, phase II"** addresses fixed wing aircraft handling qualities with special focus on aircraft – pilot coupling phenomena. The work combines the development of new PIO analysis methods and criteria with experiments in a co-ordinated approach.
Novel methods for phase compensation and stability analysis are developed and evaluated, and new handling qualities/PIO criteria are proposed. Methods for evaluation of flight simulator test results and new flight simulator test techniques are important issues.
Flight-test data are used to calibrate the PIO criteria.
During 2006 the work regarding new phase compensation techniques was taken further by LAAS, Leicester U, tested in ground based simulations by NLR and was successfully flight-tested in ATTAS by DLR in June 2006.
The toolbox has been given a directory tree structure, two new demo programs and some updated documentation. Some of the tools have been adapted to take frequency response as input data, while industrial requirements on input format for the other tools have still not been satisfied.
Work has been done at EADS on improving the OLOP-criterion, STRAERO re-implemented the Admire model in a format suitable for their analysis and continued their work on bifurcation- and limit cycles analysis. TUD has initiated a study to analyse the importance of motion cues in simulator analysis. An intermediate workshop was held in Stockholm in January 2006 followed by an AG-meeting. In March an AGmeeting took place in Braunschweig, Germany, hosted by DLR and a third AG-meeting was held at NLR, in Amsterdam in September. Due to decreased funding FOI was unable to perform the planned work during 2006 but will lead the work on updating handbook and toolbox during the spring 2007. The final workshop will be held in Linköping at Saab in May 2007. An AG-meeting is scheduled to mid January and will be hosted by LAAS in Toulouse.
The group members contributed slightly more than 60 man months of work during 2006 which is around a third of the total planned commitment.

5.3. Helicopters highlights

The aim of GARTEUR Action Group HC AG-14 **'Methods for Refinement of Structural Dynamics Finite Element Models'** was to review and explore methods and procedures for improving finite element models by means of model updating and dynamic shake testing. As a result of this collaborative exercise and the focussed discussions at the meetings, the following observations have been made:

- In the particular case of Lynx XZ649, the lumped mass model had an initial 6% mass error when compared with the actual structure. Industrial experience indicated that a 1% mass error is now typical. The dynamic characteristics of any structure are governed by both the mass and stiffness distributions. As has been shown, certain aspects of the mass distribution can be checked relatively easily but it is very difficult to verify the stiffness properties directly;

- the number of measured degrees-of-freedom must be increased to allow error localisation techniques to resolve discrepancies between test and finite element models much better than is currently possible. The use of optical measurement methods is seen as one possible way in which the quantity of data measured could be increased significantly. It will be necessary to implement different testing techniques (such as 'stepped sine') to those used in the programme so far;
- measurement of a selection of additional point FRFs distributed about the cabin and tail. These FRFs would not be included in the modal analysis for the complete structure (as only a subset of responses would be measured). Information from these measurements will provide independent data for assessment of the performance of the modal analysis and FRF synthesis. Furthermore, these additional point FRFs will enable more simple modification studies to be performed as further confidence building activities;
- attention has been focussed on obtaining a good match for both the frequencies and the mode shapes between the test and finite element models. Ultimately though, it is prediction of the forced response of the structure that is important. For this, the modal masses and the camping values must also be correct, in addition to the mode frequencies and shapes;
- improvements to the finite element model for the baseline configuration have been achieved. The changes giving rise to the improvements were obtained largely through 'engineering judgement' and meticulous attention to detail. Subsequently, the use of automated methods for sensitività analysis or model updating is beneficial. Set up of automated methods requires a detailed examination of the structure and the model and this promotes attention to detail. Neither manual nor automated methods on their own are sufficient to resolve discrepancies between test and finite element models;
- clarification of the industrial requirement for finite element / test models of a structure is required. The nebulous definition as 'fit for purpose' has been refined such that a model (test or finite element) 'should enable accurate prediction and control of vibratory response', given a prescribed excitation input.

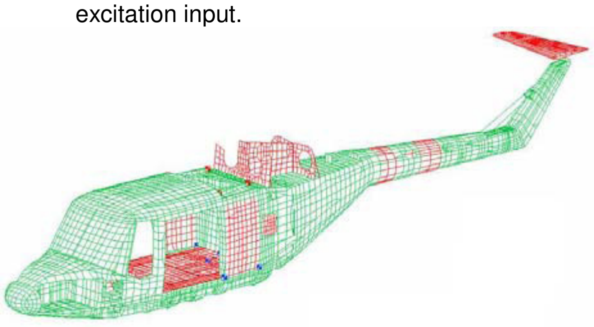


Figure 1 FE model of baseline Lynx

Alignment of test and finite element representations of a helicopter structure is the problem which has been addressed throughout this study. Lessons for the construction of a finite element model of a helicopter when there is no hardware available (the ab initio case) have been learnt through experience rather than specific research.

The collaborative effort within the GARTEUR HCAG14 group has broadened the understanding of error localisation and finite element model updating as applied to helicopter structures. Furthermore, this work has revealed specific ways forward for the research.

Figure 2 Baseline Lynx under test

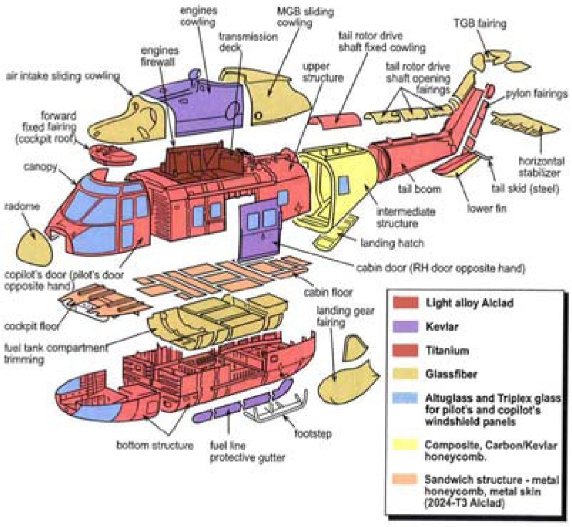
5.4. Structures and Materials highlights

The aim of the Action Group "**DAmage Management Of Composite Structures or Cost Effective Life Extensive Service"** is to develop an approach for the damage management of composite aircraft structures to achieve a cost-effective service performance during their operational life. The program focuses on the relevant components of a wing-box structure and on a full-scale wing-box, but the methodologies are applicable to all aerospace structures including fuselage, empennage, etc. A key thrust of this program is the validation of predictive models for damaged assessment for post-buckled structures under fatigue loading, and compare those to existing metallic designs.

QinetiQ explored novel structural design configurations based on geodetic geometry, SMAs (Shape Memory Alloys), morphing characteristics and corrugated reinforcements. The different configurations have been compared in terms of Technology Readiness Level and performance and two different options for the wing box design to be performed have been proposed. The first option is a traditional wing box with T or I beam reinforcements, the second option is a morphing wing with corrugated reinforcements. QinetiQ also gave consideration to structural enhancements (damage tolerance) to permit buckling between limit and ultimate load for an all CFRP primary structure. The aircraft under consideration are typically an un-manned (UAV), manned interceptor and a transport aircraft.

CIRA performed a first overview of the state of the art of certification processes (metal vs. composites) focusing on the damage management aspects. Then a literature review on fatigue damage models for composites was carried out. The most promising approaches have been selected in order to develop a multipurpose/multiapproach numerical tool able to simulate the damage (in terms of delaminations and fibre/matrix cracking) growth in composite structures under cyclic loading conditions. Failure criteria, sudden and gradual properties degradation rules and interface elements with consolidated constitutive laws will be taken into account.

NLR performed a very interesting state of the art research in order to define the composite damage occurrence in current operating aircraft and to prognosticate the damage types in future weapon systems (NH90/JSF).



Composite components in weapon systems

NLR also investigated the state-of-the-art mobile NDE methods and performed a down-selection of most promising techniques for further evaluation. Finally the design methods for patch repairs have been reviewed ad a first development of design methods for sub-structure repairs is being carried out in Microsoft Excel.
The development and demonstration of damage tolerant concepts for composites will have a significant application in all aerospace composite platforms. To focus the programme the research will consider a typical wing-structure although these concepts will impart direct improvements throughout the airframe. The findings of these investigations will also have direct relevance to naval and land structures.

6. CONCLUSIONS

GARTEUR is a multinational organisation that performs high quality, collaborative, precompetitive research in the field of aeronautics by means of research establishments, industry and academia. It offers the only framework in Europe to bring civil and military R&T together and therefore delivers added value through the operation of jointly supported research programmes.
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, and in the absence of organisations like AGARD this role becomes more significant for GARTEUR. Although operating effectively in terms of increased competitiveness of aerospace industries, further 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. Among a number of proposed adaptations, it is considered important to preserve the close relations with industry in civil and defence environments by enhancing
industrial participation at GoR level.
It will also be attempted to increase the direct involvement of universities in basic research issues, as for example in aerodynamics where significant basic research benefits can be foreseen.
Further, it will be explored if 'thematic design concepts' provided by industry could be used to stimulate multidisciplinary activities. At this moment GARTEUR, like many organisations such as NATO-RTO (Research & Technology Organisation) and EUCLID, is split along the lines of traditional disciplines as reflected by the four Groups of Responsables. In recent years, it has become clear that a more interdisciplinary approach is required to achieve specific goals that depend critically on crossfertilisation of ideas between the various GoRs covering traditional disciplines.
It is therefore the role of these GoRs to cope with the changing environment and to be open to new challenges and unforeseen opportunities. The GoRs will remain to be continuously aware of new developments (e.g. nano-technologies) by scanning activities of universities, research institutes and industries in an outlook role (technology watch). Moreover, future GARTEUR strategy aims to strengthen the longer term element of the research programme to ensure that synergy between civil and military R&T is maintained, and to include aviation security aspects as part of the research programme.
Last but not least, various actions with relation to the visibility of GARTEUR and communication with the players in the field of
aeronautics have been undertaken and will remain to be a point of continued attention of the GARTEUR community.

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