Paper 128

GARTEUR HELICOPTER COOPERATIVE RESEARCH

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Abstract: This paper starts with an overview about the general structure of the Group for Aeronautical Research and Technology in EURope (GARTEUR). The focus is on the activities related to rotorcraft which are managed in the GARTEUR Helicopter Group of Responsables (HC GoR). The research activities are carried out in so-called Action Groups. Out of the 5 Action Groups which ended within the last four years results generated in the Helicopter Action Groups HC(AG14) "Methods for Refinement of Structural Dynamic Finite Element Models", HC(AG15) "Improvement of SPH methods for application to helicopter ditching" and HC(AG16) "Rigid Body and Aeroelastic Rotorcraft-Pilot Coupling" are briefly summarized.

Introduction

The mission of the Group for Aeronautical Research and Technology in EURope (GARTEUR) is to mobilize, 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. The fundamental and traditional approach of GARTEUR is to strengthen collaboration between European nations which have major aeronautics capabilities and industry in order to maintain and increase the competitiveness of European industry, both civil and military. To achieve this GARTEUR tries to extract the best of European long term innovative R&T from upstream research undertaken nationally at universities and basic R&T at research institutes, and pulls it through for applications in industry. This is different to the progress being made by other European fora which promote short and medium term R&T and which address either civil or military applications only. GARTEUR also provides a platform and network for scientists to pool technology and knowledge to develop ideas and concepts in various aeronautics areas. The relevant emerging technologies for industry are progressed through GARTEUR and then proof of concept and demonstrations are followed on through GARTEUR and other fora such as Framework programmes of the EU for final application by industry. Figure 1 shows the position of GARTEUR research groups in relation to long, medium and short term research and to the volume of resources used. GARTEUR research projects are typically upstream.

GARTEUR was formed in 1973 by the governments of France, Germany and the United Kingdom. The Netherlands joined it in 1977; a memorandum of understanding was signed between the four nations on 6th April 1981; Sweden joined GARTEUR on 28th November 1991 (Addendum No1), then Spain on 26th April 1996 (Addendum No2) and, finally, Italy on 10th May 2000 (Addendum No3).

The organisation of GARTEUR is presented in Figure 2. 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 in the fields of

Aerodynamics (AD), Flight Mechanics, Systems and Integration (FM), Structures and Materials (SM) and Helicopters (HC). The GoR Helicopters is by nature multidisciplinary in contrast to the more disciplinarily oriented other GoRs. 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.

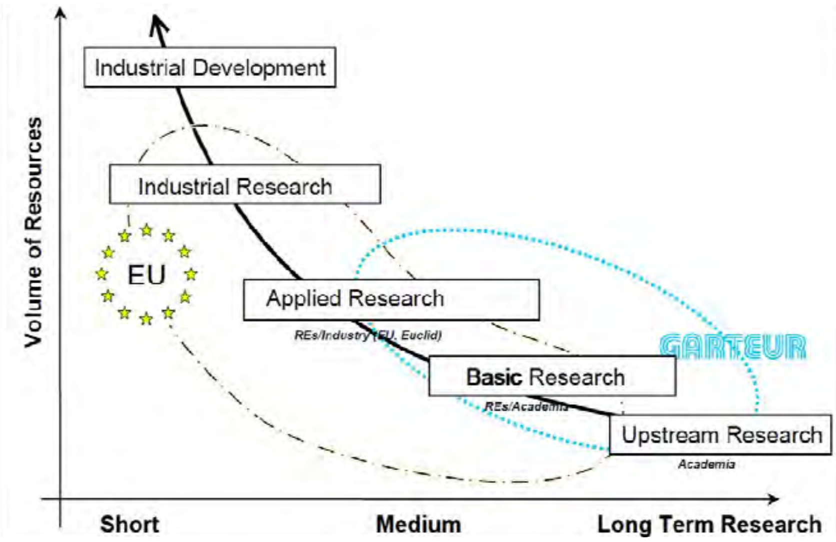

Figure 1 Position of GARTEUR research topics

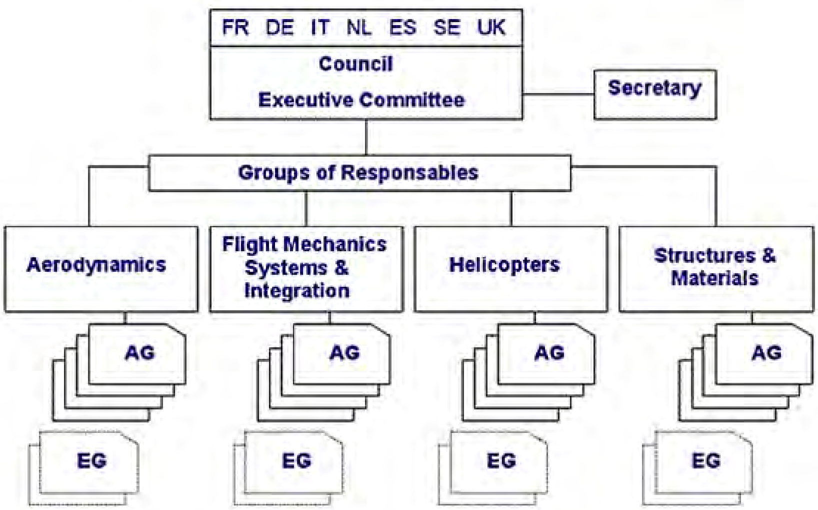

Figure 2 GARTEUR Organisation

GARTEUR Helicopter GoR

The GoR Helicopter 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. Technical disciplines include, but are not limited to, aerodynamics, aeroelastics 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 and tilt rotor research 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 members of the GoR Helicopters represent the major national research centres or governmental organisations (CIRA, DLR, dstl, NLR, Onera, Qinetiq) of and helicopter manufacturers (AgustaWestland, Euro-copter) in the European Union involved in civil and military rotorcraft related research. The GoR Helicopter is used as a forum for briefings by members on their organisations' activities and for discussion of new innovations 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.

In order to identify relevant research topics so called Exploratory Groups (EG) are initiated which explore and assess the scientific relevance of a certain field of interest. If the EG concludes that this field of interest is well suited for a cooperative research it is proposed as an Action Group (AG) of GARTEUR or as an EU project in a coming call.

The following Action Groups ended during the last four years:
HC(AG11) "Helicopter yaw axis handling qualities modelling"
HC(AG13) "Validation of rotor blade / hub load synthesis techniques"
HC(AG14) "Methods for Refinement of Structural Dynamic Finite Element Models"
HC(AG15) "Improvement of SPH methods for application to helicopter ditching"
HC(AG16) "Rigid Body and Aeroelastic Rotorcraft-Pilot Coupling"

The following Action Groups are active in the year 2010:
HC(AG17) "Wake Modelling in the presence of Ground Obstacles"
HC(AG18) "Data and methods for error localisation and model refinement of structural dynamics FE models"
HC(AG19) "Methods for improvement of structural dynamics FE methods -using in flight test data"

The next chapter gives an overview of selected results of three closed Action Groups, i.e. AG14, AG15 and AG16.

Figure 3 Test of Lynx Mk. 7 airframe at QinetiQ Farnborough

Results

HC(AG14) Methods for Refinement of Structural Dynamic Finite Element Models

Vibration in helicopters is a major issue affecting crew and passenger comfort and safety. It is also the cause of significant operating costs through the resulting damage to airframe and equipment. Finite element modelling is the main tool used by manufacturers for the analysis of helicopter structures and in particular for the prediction of vibration. Finite element models that accurately represent the structural dynamics are therefore of major importance if successful and efficient designs are to be achieved in a safe and cost effective way. Current finite element models do not represent the dynamic properties of real helicopter structures sufficiently accurately to enable assessment of structural design modification for reduced vibration without recourse to test. The main purpose of AG14 was to explore methods and procedures for improving finite element models through the use of dynamic testing. For the foreseeable future it is expected that shake tests combined with finite element models will be the major tool for improving the dynamic characteristics of the helicopter structural design. It is therefore of great importance to all manufacturers that the procedure of validating and updating helicopter finite element models is robust, rigorous and effective in delivering the best match based on realistic engineering adjustments to the finite element model.
In January 2003, AG14 was established to conduct research on "Methods for refinement of structural dynamic finite element models". The group comprised representatives from the European aerospace industry (AgustaWestland, Eurocopter and QinetiQ), research establishments (ONERA France, DLR Germany, NLR Netherlands) and universities (Bristol, Liverpool and Kassel). The core activity of AG14 was provided by a systematic study of a Lynx airframe (see Figure 3). The airframe was tested and modelled in various build states from a simple skin stringer baseline airframe to one of increasing complexity as engine and gearbox components were added to the structure (see Figure 4). A finite element model of the structure was provided to all the participants as an initial model and improvements in the match between

model and test structure response were sought. Test techniques were examined and best practice discussed and reviewed so as to obtain the best data possible from a helicopter vibration test. Obtaining repeatable good quality data was one objective of the study.

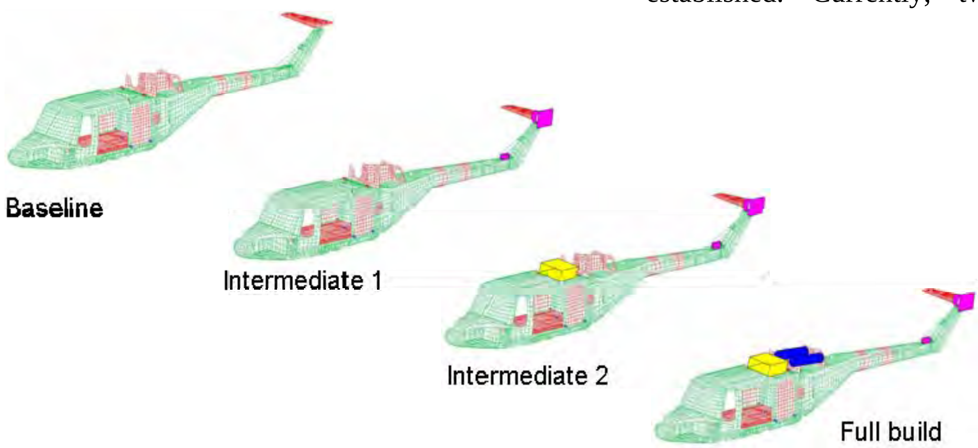

Figure 4 Serious of build states of Lynx airframe from simple stringer baseline to one with added engine and gear box components

Various algorithms and existing modelling tools were used to assess the differences in test data and theoretical predictions with the intention of identifying regions in the structure that required modification to improve the data correlation. The aim was to identify modifications that represented 'real' engineering changes rather than mathematical solutions unrepresentative of physical structural changes. Non-linearity of the structure was also examined looking primarily at engine attachments and levels of pre-stress in structural components. The project has involved many eminent engineers and scientists from national Government, Industry and Academia. All made significant contribution both to the research and the programme final report [1].

The group established improvements to the model-test correlation through the combined efforts of the individual participants. A combination of updating algorithms and engineering judgment proved to be very effective; however some shapes proved immune to repeated attempts at updating. As a result some limitations with the testing were identified and recommendations for improvements have been made. The collaborative effort within this GARTEUR 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. The close working group linking academia, research establishments and industry has proved very effective and greater understanding of the issues and a way forward have been established. Currently, two new working groups are pursuing the recommendations of AG14, i.e. AG18 and AG19. Please see references [1] and [2].

HC(AG15) Improvement of SPH Methods for Application to Helicopter Ditching

This Action Group aimed at assessing analytical tools for modelling helicopter impacts on water. Works especially focused on the Smooth Particle Hydrodynamic (SPH) formulation available in most codes used within the project (Radioss, PamCrash, Dyna3D, LS-Dyna) but also addressed alternative non SPH methods newly implemented (PamCrash, LS-Dyna, Radioss), in order to compare with and assess the true potential of SPH methods.

Figure 5 CIRA's LISA drop test facility

As a support to this numerical objective, the project also addressed the generation of an experimental database of water impact tests, including low (laboratory tests of droplet impacts performed by ONERA) and mean (impact tests of rigid or deformable shapes – cylindrical and triangular – performed at Politecnico di Milano and CIRA) scale structures. Both kinds of data were to be modelled in order to fulfil the following objectives:

1- to evaluate the prediction capacities of numerical tools and

2- to assess their numerical efficiency with respect to the model size (trade-off between computational costs and accuracy of modelling).

Complementary to this latter goal, simulations on a scale 1 model representative of a generic helicopter structure were conducted for numerical/numerical comparisons.

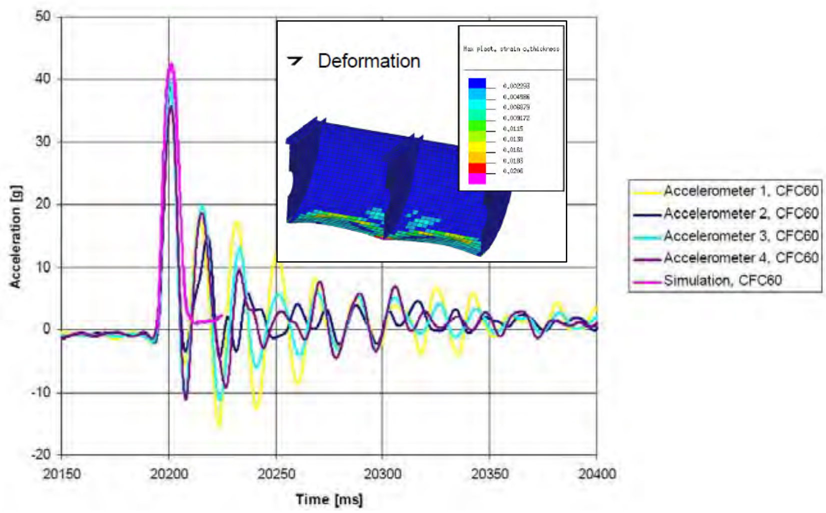

Figure 6 Comparison of measured and simulated accelerations for steel tank – Vz=8m/s

CIRA conducted vertical drop tests on water of a deformable metallic structure and static/dynamic characterizations of the steel material constitutive of the structure.

The vertical drop tests were performed using one article configuration consisting of a demi-cylinder (2 mm thick skin stiffened with 2mm thick frames, reinforced at the top side with metallic stiffeners). Articles were dropped in the CIRA facility, for three increasing velocities (3m/s, 8m/s and 10 m/s). Test configurations (specimen thickness and impact velocities) were identified based on pre-test simulations performed by DLR, with the objective to get a tested article with or without residual deformation.

The results delivered by CIRA - raw and filtered data - include: Pressure measurements (7 pressure transducers on the external face of the skin), acceleration measurements (4 accelerometers fixed on the top of the articles), high speed videos and residual deformation of the article (mapping at referenced points of the deformed skin). In addition to this, material characterization was performed on tensile standard specimens and includes quasi-static tests at 0.001 s^{-1} and dynamic tests at 4 increasing strain rates (from 15 s^{-1} to 60 s^{-1}). Exhaustive data were provided by CIRA, including: Young modulus, yield stress, maximum stress and strain and stress/strain curves at the different strain rates. The data was distributed to partners and a detailed report describing the experiments was delivered.

DLR performed pre-test analysis to help CIRA define their test configuration, notably to help fix the impact velocity range so that tests results involve a purely elastic structural behaviour (no residual deformation) and a plastic behaviour (residual deformation). Modifiable parameters included the skin and frame thickness, and the frame position. Numerical works permitted to define an appropriate specimen configuration and to identify a lower velocity limit (3 m/s) likely to generate no residual strain, which was confirmed by the experiments. In a second step, DLR performed post-test analysis for the selected configurations, which permitted to draw the following general conclusions in terms of numerical prediction, for the considered structures and impact conditions:

The deformations are slightly overpredicted which results in a conservative analysis. The accelerations are quite well predicted (see Figure 6). Pressures are more difficult to predict, notably with a systematic over-prediction when the structure is stiff or only slightly deforms (a refinement of the SPH network shall lead to a better prediction of the pressure).

ONERA and Altair showed SPH simulation's results on complex/generic structures (Radioss code). Results were compared with data coming from an analytical code used by Eurocopter (see Figure 7).
In support to these activities solutions were investigated to reduce CPU costs by optimising domain decomposition based on time step. A multidomain approach for parallel computation was thus studied and showed speed-ups of about 2.
Based on these outputs, one of the objectives was to discuss about developments and recommendations likely to improve SPH method, with respect to helicopter ditching. This concerned the following topics:
- Improvement of the SPH formulation,
- Improvement of the SPH environment (contact interface between the particles and the structure, SPH boundary condition, influence of mesh density and mesh networks, outlets, post-treatments)
- Improvement of the fluid EOS (viscosity, cavitation, incompressibility…)
- Reduction of CPU cost.

Recommendations were worked out for best practice simulations of helicopter ditching on water. Please see also references [3]-[6].

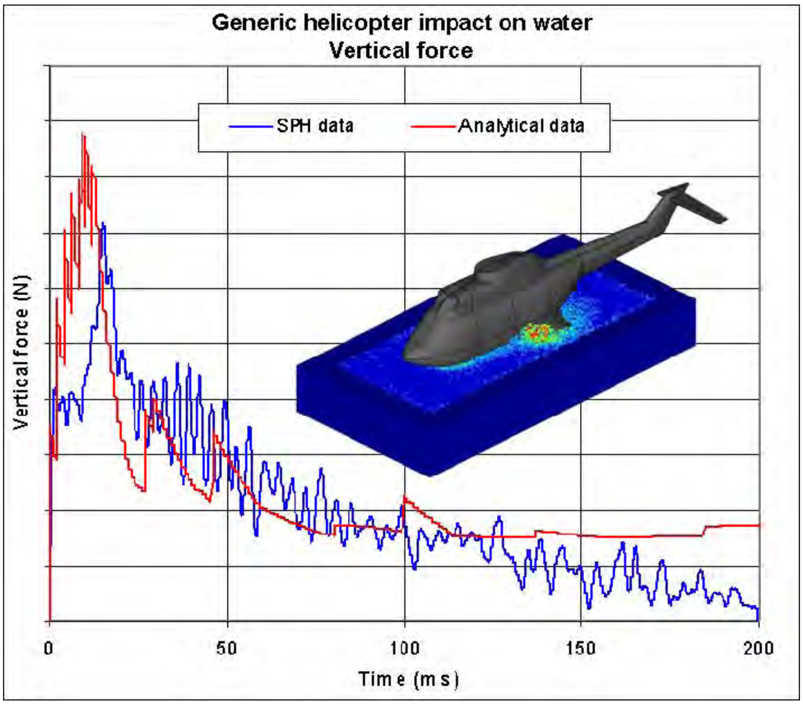

Figure 7 Comparison between SPH and analytical results - Vz=4 m/s / Vx=10 m/s / Pitch=5°

HC(AG16) Rigid Body and Aeroelastic Rotorcraft-Pilot Coupling

Unintended and unexpected oscillations or divergences of the pilot-rotorcraft system have become a critical issue for augmented helicopters with modern flight control systems. The rapid advances in the field of high response actuation and highly augmented flight control systems have increased the sensitivity to aspects that lead to complex oscillations related to unfavourable Aircraft-Pilot Coupling (APC) and Rotorcraft-Pilot Coupling (RPC) events. These undesirable couplings may result in potential oscillatory / non-oscillatory instabilities or annoying limit cycle oscillations which degrade the flight qualities and increase the structural strength requirements. The oscillations are typically triggered by a "mismatch" of pilot and vehicle dynamics. The exceedance of structural strength limits can result in catastrophic accidents. The understanding, prediction and prevention of adverse RPCs are demanding tasks and require the analysis and simulation of the complete feedback loop: pilot – control system – rotorcraft. Based on numerous flight experiences in the past, different types of RPC's have been observed, which are sorted as 'rigid body' RPCs (the realm of flight dynamics) and 'aeroelastic' RPCs (the realm of aeroservoelasticity).

Main objectives of the action group were to improve the physical understanding of both 'rigid body' and 'aeroelastic' RPCs and to define criteria for quantifying the helicopter's susceptibility to RPC. These targets required the development and validation of prediction methods and assessment criteria. In order to link analytical and experimental results a motion base flight simulator served as test bench for correlation with the investigated methods. The research results were summarized in guidelines for the development of means to prevent or suppress critical RPC incidents in future.

In Europe, research activities were launched in 2005 under the umbrella of the GARTEUR organisation in order to improve the physical understanding of RPCs and to define criteria for quantifying the helicopters susceptibility to RPC. The related GARTEUR Helicopter Action Group 16 (HC-AG16) comprised representatives from the European helicopter industry (Eurocopter Germany), research establishments (DLR Germany, ONERA France, NLR The Netherlands) and universities (Delft, Liverpool, Milano and Roma Tre) and terminated 2008.

In order to establish guidelines for the development of means to prevent or suppress critical RPC incidents in the future and thus contributing to increased helicopter operational safety, the activities of the action group were partitioned into the following steps:

- Improvement of the physical understanding of RPC
- Definition of criteria to quantify the susceptibility to RPC
- Development of prediction methods for RPCs
- Validation of prediction methods and criteria
- Development of preliminary guidelines, recommendations and methods for RPC prevention and suppression

Figure 8 DLR BO105 research helicopter used for flight tests and system identification

The related numerical studies were performed using a BO105 model (see Figure 8) which served as a numerical test bed for all partners. Although it is well known that the full scale BO105 is not prone to RPC issues, the BO105 theoretical model was applied with additional numerical degradation of its characteristics in such a way as to provoke the different types of unfavourable RPC to be investigated. The application of the flight test simulator for complementary validation purpose is favourable as it uses exactly the same numerical helicopter models for prediction and experiment thus allowing the validation of pilot models and PIO (pilot induced oscilations) criteria to be the main focus of the research. Three different kind of flight test simulator campaigns were performed:

1. A 'rigid body' RPC test campaign for verification of fixed wing aircraft PIO criteria. For this purpose main flight dynamics characteristics of the helicopter model such as time delay were varied in a systematic manner.
2. A biodynamic test campaign for identification of 'passive' pilot behaviour by measuring pilot arm and pilot seat accelerations as well as control motions. The simulator was hereby used a s shaker table applying pre-defined vibration sequences to the pilot.
3. The development of a test methodology for simulating 'aeroelastic' RPC. For this purpose the helicopter model for the simulator includes flexible properties of the airframe and/or slung loads as additional states for simulation of airframe vibrations.

Regarding 'rigid body' RPC, a PIO toolbox originally developed for fixed wing aircraft applications under the GARTEUR groups FM(AG12) and FM(AG15) respectively was successfully applied to rotorcraft problems. The general applicability of fixed wing aircraft PIO criteria to rotorcraft problems was successfully demonstrated for category I and II PIO criteria. Accompanying flight simulator test campaigns were used for the assessment of the PIO criteria.

Figure 9 Test campaign in motion base flight test simulator (Univ. of Liverpool), biodynamic test campaign featuring pilot sensors

Concerning 'aeroelastic' RPC, the vertical bouncing problem was analysed in depth as a representative RPC problem. Parameter studies allowed to identify main parameters affecting

‘aeroelastic’ RPC for vertical bouncing. The identification of pilot models using the simulator as shaker table showed good agreement with models published in literature.
The action group closed with an overview and preliminary assessment of different means for prevention of RPC in both the ‘rigid body’ and the ‘aeroelastic’ domain. Nevertheless – due to the high complexity and the large variety of RPC phenomena to be solved – the obtained results are understood as a first step providing a sound basis for solving the adverse RPC problem in general in the future.
In the frame of the action group the partners performed detailed theoretical and numerical activities based on a BO105 helicopter model (see Figure 8) which was used as numerical test bed. These activities were supported by three different simulator test campaigns performed at the University of Liverpool in the frame of the action group.

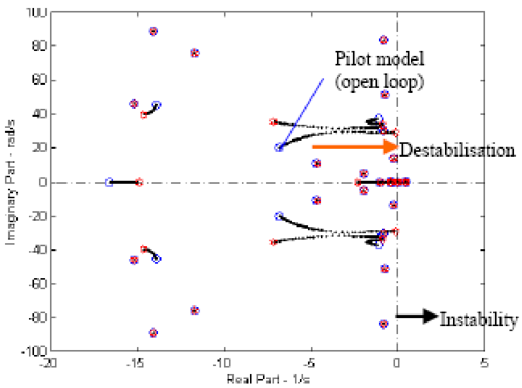

Figure 10 Closed loop system for hover

For the scope of the action group the RPC phenomena were classified into ‘rigid body’ RPC seen at the low frequency scale down to about 1Hz and into ‘aeroelastic’ RPC ranging to frequencies up to 8 Hz or even more. The terms ‘rigid body’ and ‘aeroelastic’ refer to the approach of modelling the helicopter system as either a rigid body enhanced with main rotor flapping degrees of freedom adequate for low frequency phenomena or as an aeroelastic system e.g. represented in addition by elastic airframe and main rotor degrees of freedom suitable to theoretically treat the higher frequency band. See references [7]-[10].

Running AGs and EGs

In 2010 three AGs are running:

HC(AG17) Wake Modelling in the Presence of Ground Obstacles

The wake trailed from the blades has a significant influence on many aspects of the performance and dynamics of a rotorcraft. The prediction of the interactional phenomena of the wake system with components of the rotorcraft is a very complex task and still mastered only for a limited number of cases. However, the dynamics of the wake are complicated significantly by interaction with the ground or with other obstacles, e.g. buildings or super-structures that are close enough to the helicopter to affect the outwash induced by the helicopter rotors. This topic is being treated at a fundamental level in HC(AG17). The progress in 2009 comprises the creation of a bibliography and the identification of existing experimental data suitable for validation purposes and available to the partners. All partners started to extend their simulation methods to account for the ground (with or without inclination) and for obstacles interacting with the wake. Two papers about the findings were presented at the ERF 2009 in Hamburg, Germany (see [11]and [12]).

HC(AG18) Data and Methods for Error Localisation and Model Refinement of Structural Dynamic Finite Element Models

Smooth ride helicopters are demanded by both civil and military customers who require vehicles with high reliability, low maintenance and reduced through life costs. It is generally accepted that reducing vibration will help to lower unscheduled maintenance and lead to better equipment and airframe life and a better environment for cabin crew making them more effective. Finite Element (FE) models that accurately represent all aspects of the structural dynamic characteristics are recognized as being the key tool used for achieving efficient and effective low vibration designs and configurations. The models are also essential for assessing airframe upgrades, the installation of new equipment and external stores. The main objectives for this AG are drawn directly from the conclusions and recommendations from HC(AG14), with particular emphasis upon the baseline structure used in AG14 and defining the spatial density of measurements required to achieve reliable identification and localisation of discrepancies between test and FE representations of the same structure. One of the main outputs will be the measured data with adapted dense instrumentation.

HC(AG19) Methods for improvement of structural dynamics FE methods using in flight test data

The issue of vibration in helicopters is of major concern to operators in terms of the maintenance burden and the impact on whole life cycle costs. Good mathematical models are needed as the starting point for the design of rotorcraft, taking into account vibration issues. The helicopter structures considered up to now for mathematical model verification and validation were suspended in a laboratory environment. However in doing so, specific effects of the actual operational environment like very significant mass, inertia and gyroscopic effects from the rotor systems are not being taken into account. The main purpose of this AG is therefore to explore methods and procedures for improving finite element FE models making use of in-flight dynamic data.

In terms of EGs, one was initiated:

HC(EG28) "Testing and Modelling for Interior Noise Investigation"

Nowadays improved comfort perceived onboard of helicopters is becoming a more and more a demanding mission requirement. Concerning the acoustic environment of the helicopter cabin, noise level is noticeably higher than the noise inside commercial and executive jets. Helicopter interior noise is generated by main and tail rotors, engines, main gearbox and aerodynamic turbulence. The tonal and broadband noise due to all these sources is very high and needs to be damped or reduced. Conventional passive systems (soundproofing) are still the main way to control the acoustics of the cabin whereas active systems (active vibration and noise control) are not completely reliable or applicable yet. HC(EG28) is assessing the availability of data for material master curve creation (eventually database creation) and test procedures for evaluating damping loss factors in medium-high frequency range and for power sources measurement. The modelling will be considered by comparison between two different interior noise simulation approaches: Energy Finite Element Method (EFEM) and Statistical Energy Analysis (SEA). The objective is also to find new techniques or technologies to improve the intelligibility of communication in the cockpit. The overall themes throughout the activities are the development and validation of predictive tools and the enhancement of safety of operations of rotorcraft.

A Pilot Paper on **Acoustic Monitoring** for Health and Usage Monitoring of rotorcraft components was distributed. The HC GoR is evaluating whether there is sufficient interest in this topic to create an EG.

Conclusion

The rotorcraft related activities within GARTEUR form a well established and well connected network conducting cooperative research using military and civil funds. The focus is on upstream research. Important synergies are achieved by grouping know how, facilities and funds which allows to tackle scientific problems being well out of reach for a single partner. The HC GoR is a proven think tank for new ideas and assessment of them (via EGs). During the last years the GARTEUR HC AGs contributed significantly to progress in many research fields. Furthermore GARTEUR HC GoR initiatives resulted in many non-GARTEUR projects with national or European funding.

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