GARTEUR

ANNEXES TO THE ANNUAL REPORT 2016

GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE

GARTEUR X/D 54

Annexes to the GARTEUR Annual Report 2016 (X/D 53)

This report gathers the Annual Reports from the GARTEUR Groups of Responsables (GoRs)

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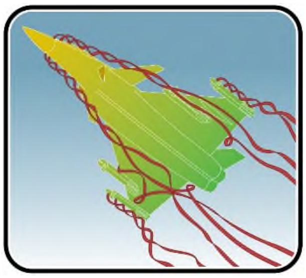
ANNEX A

ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "AERODYNAMICS"



Remit

The GoR AD initiates and organises basic and applied research in aerodynamics. Whilst in general terms aerodynamics makes up the majority of the research done within the GoR, some of the work has a significant amount of multi-disciplinary content. This trend is driven by industrial interests, and is likely to increase in the future.

The current scope of the aerodynamic activities in the GoR covers the following topic areas:

- Aerodynamics;
- Aero-thermodynamics;
- Aero-acoustics;
- Aero-elasticity;
- Aerodynamic Shape optimum;
- Aerodynamics coupled to Flight Mechanics;
- Aerodynamics Systems integration.

In general terms the work consists of both computational and experimental aspects of aerodynamics with the emphasis on the provision of data to validate the computational approaches. In addition, the experimental activity has resulted in improvement of measurement techniques and further understanding of basic flow physics in a number of areas.

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

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

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AERODYNAMICS

GoR-AD Overview

GoR Activities

The primary task of the GoR is to monitor Action Groups, encourage Exploratory Groups and instigate new ideas. In 2016, five Action Groups were active and four Exploratory Groups have been set up. Details about these groups can be found below.

Secondary task of the GoR is interaction with the other GoR's by promoting interdisciplinary topics. An example of such a topic is the aero-servo-elastic simulations of EG-72. The chairs of the different GoR's interact primarily during the Council meetings.

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. Nonetheless, the Council has expressed its interest in the development of road maps, if only to identify knowledge gaps. In 2016, first steps have been taken by the GoR (indeed by all GoRs) to develop road maps.

In 2016, several new ideas have been formulated. Among those that have not yet resulted in an exploratory group are: vortical flows on transonic and supersonic slender configurations; simulation of the flow in S-ducts; design of an experiment for the basic understanding of synthetic jets; laminar bubbles; non-intrusive characterization of the laminar wing surface.

Management

Three meetings have been held in 2016. Two meetings were physical meetings planned some weeks ahead of the respective Council meetings. The AD/AG-96 meeting took place at ONERA Palaiseau, Feb 29/Mar 1; and the AD/AG-97 meeting at Airbus Bremen, Oct 6/7. A telephone meeting was set up on June 7 to keep alive the discussions on ideas for new action groups, as there is concern within the GoR about the number of Action Groups. At the end of 2016, four Exploratory Groups are active and the list of new ideas has matured, so the efforts have been fruitful.

Attendance at the physical meetings was generally good with about ten members physically present, and another five connecting by phone. The current chairman strongly feels that face-to-face meetings are more effective, but travel funding seems not always to be available.

Industrial participation in the GoR has always been good, and 2016 was not different in this respect. As can be seen from the GoR membership list below, there is no British representation in the GoR (Chris Newbold has retracted from the GoR end of 2016). This is a point of concern, as British input in both GoR and Action Groups has always been much appreciated.

Dissemination of GARTEUR activities and results

The following papers and books have been published by AD Action Groups in 2016:

Daniel González-Juárez, Esther Andrés-Pérez, Mario J. Martin-Burgos “Constrained multi-point aerodynamic shape optimization of the viscous DPW wing through evolutionary programming and support vector machines”, ECCOMAS 2016, June 5-10, Crete.

Esther Andrés-Pérez, Daniel González-Juárez, Mario J. Martin-Burgos, Leopoldo Carro-Calvo, Sancho Salcedo-Sanz, “Surrogate-based global optimization of a cylinder by the use of evolutionary algorithms, support vector machines and non uniform b-splines”, ECCOMAS 2016, June 5-10, Crete.

Raul Yondo, Esther Andrés, Eusebio Valero, “On the influence of a priori sampling methods on surrogate models accuracy in aircraft aerodynamic design optimization”, ECCOMAS 2016, June 5-10, Crete.

E. Iuliano, E. Andrés. Application of Surrogate-based Global Optimization to Aerodynamic Design. Springer Verlag, ISBN 978-3-319-21506-8. 2016.

J. Perraud, D. Arnal, “A Mach 0 to 4 Laminar-turbulent Transition criterion”, 50th 3AF Int. Conf. Applied Aerodynamics, Toulouse, France, 29-30 March - 01 April 2015.

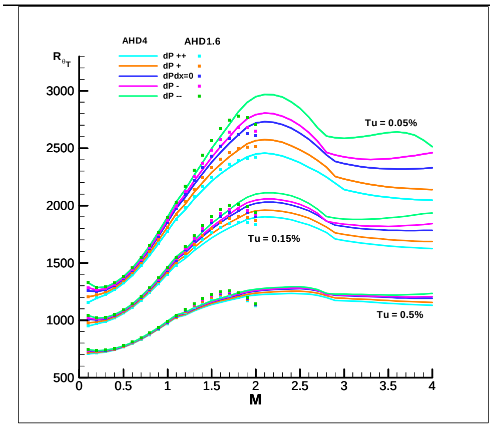
Reports issued

None.

Status of Action Groups and Exploratory Groups

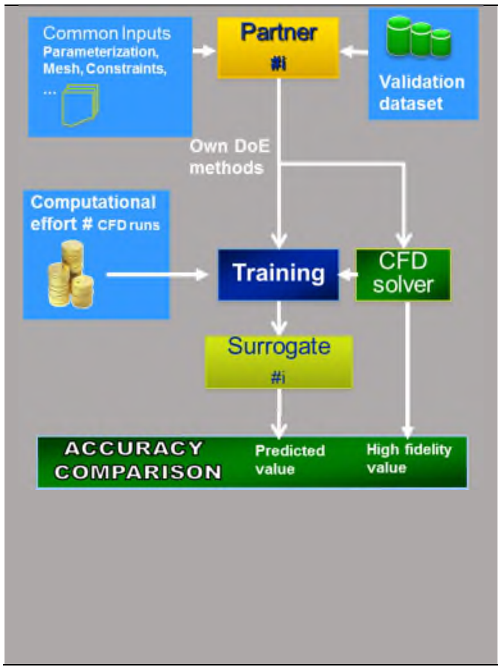
Five action groups and four exploratory groups were active in 2016. Three of the five action groups have finished their technical activities and are mostly involved in writing the final report.

AD/AG-51 — **Laminar/Turbulent Transition in Hypersonic flows**



The objective of the group is to improve knowledge of the flow and methods dedicated to the prediction of and factors leading to the triggering of laminar/turbulent boundary layer transition on bodies in hypersonic flow. Work consisted of both wind tunnel tests and CFD predictions. Significant progress has been obtained in extending the AHD transition criterion up to Mach 4. Mach 6 stability computations predicted higher instability frequencies than expected. The work has been finalised early 2016 (with modified objectives) and the final report is currently being written. The chair is Jean Perraud of ONERA.

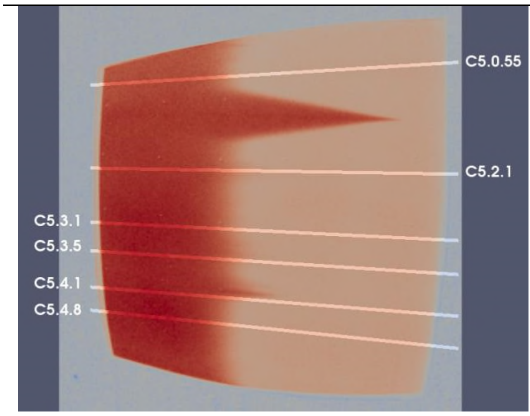
AD/AG-52 — **Surrogate-based global optimisation methods in aerodynamic design**



A current need in aircraft design is to have the ability to determine aerodynamic characteristics rapidly and accurately within the design process. This programme of work is associated with looking at the use of surrogate methods in the design of aerodynamic shapes. Design of experiments (DoE) techniques have been tested against reference geometries allowing cost / accuracy studies between different approaches to be made. A major output of the work is best practice guidelines for industrial use of SBGO methods in shape optimisation. The work has been finalised in 2016 and the final report will be available in March 2017. The chair is Esther Andrés (INTA).

AD/AG-53

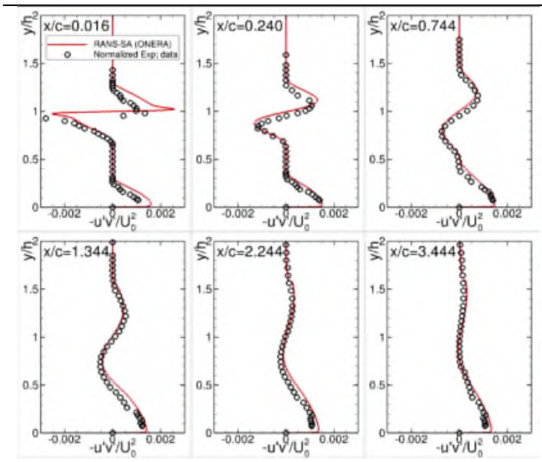
Receptivity and Transition Prediction: Effects of surface irregularity and inflow perturbations



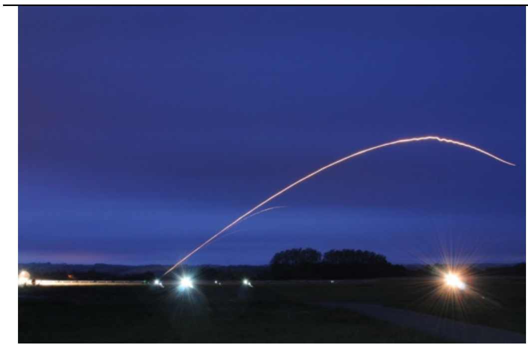
The main objective of this project is to understand the effects of surface irregularities and disturbances in the oncoming flow on transition in three dimensional onset flows, and the evaluation of transition control techniques. The work covers both experiment and associated numerical calculations. Experimental studies on a gap with realistic filler shape on a NLF wing have shown that for relatively shallow gaps transition moves forward, which is not predicted by stability codes. The work has been finalised in 2016 and the final report is currently being written. The chair is Ardeshir Hanifi (KTH).

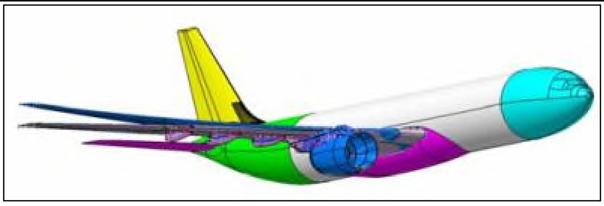
AD/AG-54

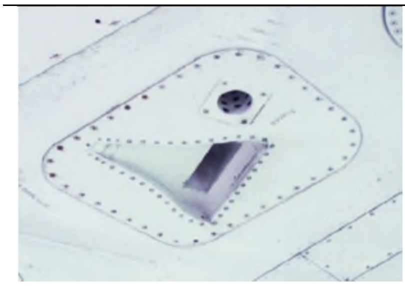
RANS-LES Interfacing for Hybrid and Embedded LES approaches



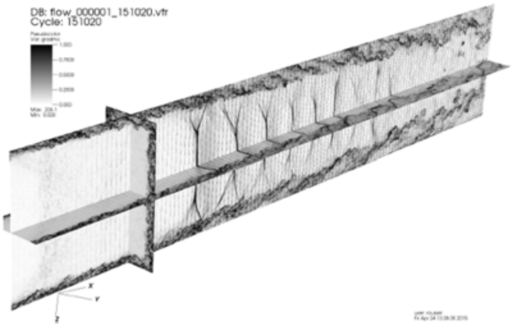
The main objective of this group is to make use of a comprehensive and transnational effort to explore, and further develop theoretical methods, in order to improve RANS-LES coupling in the context of Embedded LES and Hybrid RANS-LES methods thus enabling the “Grey Area” problem to be resolved. Both zonal and non-zonal approaches are considered. Three fundamental flows have been selected to test the different methods. The project started in April 2014, and is extended to May 2018. The work in this project is a follow on from that in AD/AG-49. The chair is Shia-Hui Peng (FOI).

AD/AG-55	Countermeasure Aerodynamics
	AG-55 arose out of preliminary studies carried out in EG-71 and was launched early 2015, with an expected finishing date of early 2018. The work is divided into two work packages, the first deals with the dispersion of chaff using both Eulerian and Lagrangian approaches. The second work package deals with the aerodynamics characteristics of burning flares, and their resulting trajectories. Work includes both methods development and the procurement of experimental data with which to validate the models. The chair is Torsten Berglind (FOI).

AD/EG-72	Coupled fluid dynamics and flight mechanics simulation of very flexible aircraft configurations
	Light-weight constructions require multi-disciplinary design tools. This EG will develop and compare aero-servo-elastic models. An EG meeting has taken place in June 2016. A detailed work plan is currently being written. Chair is Mario Verhagen (NLR).

AD/EG-73	Secondary Inlets and Outlets for Ventilation
	Aircraft require a variety of secondary inlets and outlets mostly for environmental control systems, APU operation, ventilation and cooling purposes, e.g. engine bay ventilation or cooling of electronic equipment. New shapes of aircraft wing secondary inlets and outlets could be designed and assessed in search for optimized solutions. New concepts include adaptive structures and hidden integration within the engine intake. A meeting is planned in the Spring of 2017. Chair is Jose Angel Hernanz-Manrique (Airbus Operations).

AD/EG-74	Integration of Innovative Nozzle Concepts with Thrust Vectoring for Subsonic Aircraft
	Advanced integration of nozzles makes (fluidic) thrust vectoring especially interesting. Replacement of conventional controls and/or augmentation of control power for civil as well as military aircraft represent attractive goals within this technological field. Investigations based on CFD will be performed for aerodynamic performance, stability and control. Currently the group is looking for a chair.

AD/EG-75	Supersonic air intakes
	Supersonic air intakes are of foremost importance in the design of a supersonic air-breathing vehicle, whatever its propulsion system: turbojet, ramjet or scramjet. Investigations may include the control of cowl oblique shock / boundary layer interactions, internal bleed flows, or shaping effects of diffusors on the flow distortions at the end of the diffusors. A meeting is planned in the Spring of 2017.

Rolling plans

Cat	Topic	2013	2014	2015	2016	2017	2018
AD/AG-51	Lamiminar-Turbulent Transition in Hypersonic flows						
AD/AG-52	Surrogate-based Global optimisation methods in preliminary designs						
AD/AG-53	Receptivity and Transition prediction						
AD/AG-54	RANS-LES Interfacing Hybrid for Hybrid RANS-LES and embedded LES approaches	EG69 ➔					
AD/AG-55	Countermeasures Aerodynamics		EG71 ➔				
AD/EG-70	Plasma aerodynamics						
AD/EG-72	Coupled fluid dynamics and flight mechanics simulation of very flexible aircraft configs						
AD/EG-73	Secondary Inlets and Exhausts for ventilation						
AD/EG-74	Integration of innovative nozzle concepts with thrust vectoring						
AD/EG-75	Supersonic air intakes						
		Active	Extended	Closed	Inactive		

GoR membership

Chairman			
Harmen van der Ven	NLR	The Netherlands	harmen.van.der.ven@nlr.nl

Vice-Chairman			
Fernando Monge	INTA	Spain	mongef@inta.es

Members			
Eric Coustols	ONERA	France	eric.coustols@onera.fr
Giuseppe Mingione	CIRA	Italy	g.mingione@cira.it
Heribert Bieler	Airbus Operations GmbH	Germany	heribert.bieler@airbus.com
Kai Richter	DLR	Germany	kai.richter@dlr.de
Per Weinerfelt	SAAB	Sweden	per.weinerfelt@saab.se
Torsten Berglind (till mid 2016)	FOI	Sweden	torsten.berglind@foi.se
Magnus Tormalm (from mid 2016)	FOI	Sweden	magnus.tormalm@foi.se

Industrial Points of Contact			
Thomas Berens	AIRBUS Defence & Space	Germany	thomas.berens@airbus.com
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Michel Mallet	Dassault Aviation	France	michel.mallet@dassault-aviation.com
Didier Pagan	MBDA	France	didier.pagan@mbda-systems.com
Luis P. Ruiz-Calavera	AIRBUS Defence & Space	Spain	luis.ruiz@airbus.com
C. Newbold	QinetiQ	United Kingdom	

Table of participating organisations

	AG-51	AG-52	AG-53	AG-54	AG-55	EG-72	EG-73	EG-74	EG-75
Research Establishments									
CIRA	□	□	□	□		□	□		
DLR	□		□	□		□	□	□	
DSTL									
FOI		□		■	■				□
INTA		■		□					
NLR				□	□	■	□		
ONERA	■	□	□	□		□	□		□
Industry									
Airbus Defense & Space		□			□	□			
Airbus Operations GmbH			□			□		□	
Airbus Operations S.A.S				□			■		
Airbus Group Innovations			□						
Leonardo Company									
Dassault Aviation									
EADS				□					
LACROIX					□				
MBDA-F	□				□				■
MBDA-LFK									□
QinetiQ									
SAAB		□		□					□
Academic Institutions									
Imperial College			□						
Institute of Saint-Louis (ISL)	□								
Royal Institute of Technology KTH			■						
Technical University Munich				□					
University of Alcala		□							
Bundeswehr University Munich	□								
University of Manchester				□					
University of Zurich				□					
University of Surrey		□							
Von Karman Institute (VKI)	□								
Brno University of Technology		□							

Total yearly costs of AG research programmes

GoR	AG	2013		2014		2015		2016		2017*		2018*	
		pm	k€	pm	k€	pm	k€	pm	k€	pm	k€	pm	k€
	44	1	0										
	45	1	0										
	46	3	3	0	0								
	47	1	0	0	0								
	48	6	8	1	0								
	49	7	70										
	50	10	20										
	51	12	40	12	40	0	0	0	0				
	52	20	45	23	63	23	63	23	63				
	53	10	12	13	24	13	24	2	12				
	54			18	100	22	140	18	80	20	100	12	50
	55					16	24	18	24	16	24		
AD	TOTAL	71	198	67	227	74	251	61	179	36	124	12	50

GoR-AD Action Group Reports

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

AD/AG-52: SBGO methods for aerodynamic design

Action Group Chairpersons: Dr. E. Andrés (INTA) and Dr. E. Iuliano (CIRA)

Background

Surrogate-based global optimization methods (SBGO) can meet the requirement of performing a broad exploration of the design space, as they have the ability to work with noisy objective functions without assumptions on continuity and with a high potential to find the optimum of complex problems. However, global optimization methods involve a vast number of evaluations even for a small number of design variables. As each evaluation requires a CFD complete analysis, this would make the method unfeasible, in terms of computational cost. Therefore, there has been a **raising interest in surrogate modeling** which promises to provide sufficiently accurate solution of complex problems with reduced computational efforts.

Main work focused on the assessment of different surrogate modeling techniques for fast computation of the fitness function and the evaluation of SBGO strategies for the shape design of the selected configurations..

Specific challenges: Deal with the "curse of dimensionality", off-line and on-line model validation strategies, proper error metrics for comparison, efficient DoE techniques for optimal selection of training points towards validation error mitigation, reduction of the design space, improvement of surrogate accuracy at fixed computational budget, and variable fidelity models.

Aerodynamic applications: Aerodynamic shape optimization problems in an early stage. "Best practice" guidelines for the industrial use of SBGO methods

Partners: Research, academic organizations and industries: INTA, CIRA, AIRBUS-Military, Brno University of Technology, FOI, ONERA, SAAB, University of Alcala and University of Surrey.

Programme/Objectives

Main objectives: To analyze the feasibility and possible contributions of SBGO methods in an early phase of the aerodynamic design, where the design space will be broadly analyzed to get the optimum solution

Project duration: 3 years (2013-2016)

AG52 — Work Breakdown Structure

- **Task 1 — Basic configurations**: To make comparatively studies of partners' simulations to highlight the benefits and drawbacks of different SBGO methods
- **Task 2 — Industrial-relevant configurations**: To validate the experience gained from T1 in designing industrial-relevant configurations
- **Task 3 — "Best Practice" Guidelines**: To give a clear statement about the possibilities and restrictions in using SBGO methods. To facilitate their **use in aeronautic industries**

Work plan: The work in AG52 is divided into three tasks. Task 1 and 2 are test-case based and each contains two different test cases. "Best-practice guidelines" are addressed in Task 3.

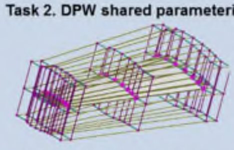
Two test cases are defined in Task 1:
TC 1.1 RAE2822 airfoil
Design points: DP1 M=0.734, Re=6.5x106, AoA=2.65°. DP2 M=0.754, Re=6.2x10^6, AoA=2.65°
Objetive: maximize C_L/C_D

TC 1.2 DPW-W1 wing
Design points: DP1: M=0.76, C_L=0.5, Re=5x10^6, DP2: M=0.78, C_L=0.5, Re=5x10^6, DP3: M=0.20 and C_L^{max} (optima) >= C_L^{max} (original). Objective: Minimize C_D with constant C_L

Task 1.2 Surrogate models comparison

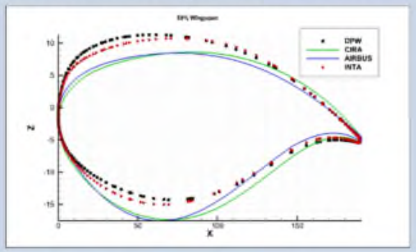
	Mean OF (TAU, MSES, ZEN 3 levels)	Mean OF (only TAU and ZEN fine)
RAE 2822 baseline	1	1
CIRA-POD	0.6223	0.6266
CIRA-EGO	0.6208	0.6236
INTA/UAH	0.6243	0.6211
ONERA	0.6494	0.6498
UNIS	0.6367	0.6338
VUT	0.6969	0.7063

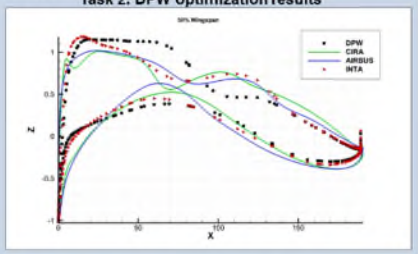
Task 2. DPW shared parameterization



In order to minimize the sources of discrepancies and allow a fair comparison between surrogates, the **geometry parameterization**, the **computational grids** (unstructured and structured) and the **surface deformation algorithm** are **shared** between all partners.

Task 2. DPW optimization results





Results

- Assessment of SBGO methods investigated by AG members in terms of their respective advantages and disadvantages for the application to the aerodynamic shape design, by means of cross comparisons of solutions.

Partial reports delivered:
- PR01: RAE2822 definition and common geometry parameterization
- PR02: DPW-W1 definition and common geometry parameterization
- PR03: Strategy for surrogate validation in aerodynamic shape optimization
- PR04: CFD cross-analysis
- PR05: Summary of task 1 results
- Final AG52 report (to be delivered)

Current Status:
This group has finished. Main activities are summarized here:
- Common data (parameterization, grids and surface mesh deformation) for all TCs of Task1 were made available for surrogate model validation and optimization comparison:
- Common meshes for all the test cases
- Geometry parameterization for all the defined test cases
- Surface deformation tool and volume mesh deformation tool executable
- NURBS parameterization parser
- Tutorials for the common tools
- A website has been created for dissemination: www.ag52.blogspot.com
- A CFD cross-analysis to identify the error sources of using different CFD solvers was performed.
- Results on task 1 (surrogate validation and rae2822 optimization) have been provided
- Results on task 2 (opt of the dpw) have been provided by CIRA, AIRBUS and INTA.
- Participation and organization of Special Sessions at EUROGEN 2013, ECCOMAS 2014, EUROGEN 2015 and ECCOMAS 2016.
- Organization of the EUROGEN 2017 in progress (eurogen2017.etsiae.upm.es/)

INTA · CIRA · AIRBUS MILITARY · Brno University of Technology · FOI · ONERA · SAAB · Universidad de Alcalá · University of Surrey

AD/AG-52

AD/AG-52	SURROGATE-BASED GLOBAL OPTIMIZATION METHODS IN AERODYNAMIC DESIGN	
Monitoring Responsable:		F. Monge INTA
Chairpersons:		E. Andrés INTA
		E. Iuliano CIRA

Objectives

The objective of this Action Group was to **investigate and analyse the feasibility and contributions of Surrogate-based Global Optimization (SBGO) methods** in an early phase of the aerodynamic design, where the design space will be broadly analysed to get the optimum solution.

Main achievements

The AD/AG52 took off on February 2013.

Nine members participated in this Action Group: four from research establishments (**INTA, CIRA, FOI, ONERA**), three universities (**UAH, UNIS, VUT**) and two from industry (**AIRBUS-Military and SAAB**). VUT is not a member of the GARTEUR organization but all partners agreed to welcome the VUT into the team and was accepted by the GARTEUR council.

The work in AG52 was divided into three tasks. Task 1 and 2 were test-case based and each contained two different test cases. “Best-practice guidelines” were addressed in Task 3.

Two test cases were defined in Task 1:

<u>TC 1.1 RAE2822 airfoil:</u>

DP1: M=0.734, Re=6.5x10^6, AoA=2.65º.

DP2:M=0.754, Re=6.2x10^6, AoA=2.65º.

Objective: maximize C_L/C_D subject to certain aerodynamic and geometric constraints

<u>TC 1.2 DPW-W1 wing</u>

DP1: M=0.76, C_L=0.5, Re=5x10^6

DP2: M=0.78, C_L=0.5, Re=5x10^6

DP3: M=0.20 & C_L^{max}(optima)>=C_L^{max} (original).

Objective: Minimize C_D with constant C_L subject to certain aerodynamic and geometric constraints

Main work focused on the assessment of different surrogate modeling techniques for fast computation of the fitness function and the evaluation of SBGO strategies for the shape design of the selected configurations.

The specific challenges faced in this activity were: dealing with the “curse of dimensionality”, off-line and on-line model validation strategies, proper error metrics for comparison, efficient DoE techniques for optimal selection of training points towards validation error mitigation, reduction of the design space, improvement of surrogate accuracy at fixed computational budget, and variable fidelity models.

In order to minimize the sources of discrepancies and allow a fair comparison between surrogates, the geometry parameterization, the computational grids (unstructured and structured) and the surface deformation algorithm were shared between all partners. The initially selected set of surrogate techniques for task 1.1 were in the table.

Partner	SVMs	POD	Kriging	GE Kriging	RBF	Ensemble
INTA	TC1.2					
CIRA		TC1.1	TC1.1			
FOI					TC1.2	
ONERA		TC1.1	TC1.2	TC1.2		
UAH	TC1.2					
UNIS						TC1.1
VUT			TC1.1		TC1.1	

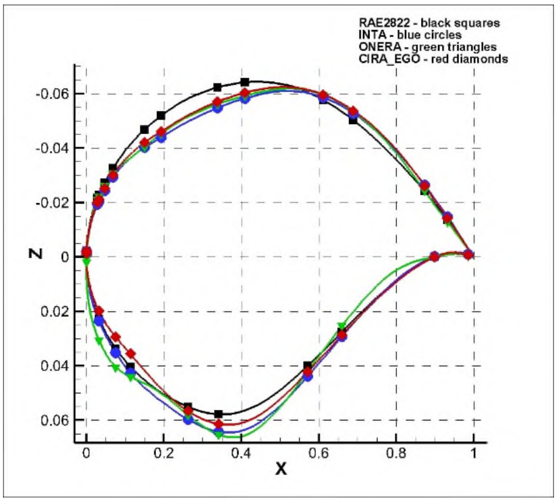
Partial reports delivered:

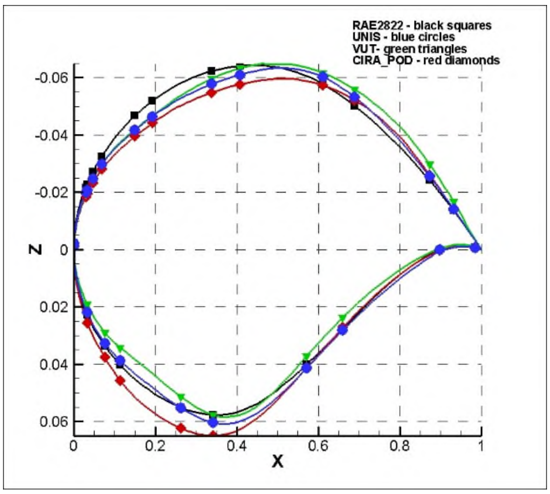
- **PR01**: RAE2822 definition and common geometry parameterization
- **PR02**: DPW-W1 definition and common geometry parameterization
- **PR03**: Strategy for surrogate validation in aerodynamic shape optimization
- **PR04**: CFD cross-analysis
- **PR05**: Summary of task 1 results
- **Final AG52 report (to be delivered, expected March 2017)**

Current Status:

This group has finished. Main activities are summarised here:

- **Common data** (parameterization, grids and surface mesh deformation) for all TCs of Task1 were made **available** for surrogate model validation and optimization comparison:
  - o Common **meshes** (CIRA, INTA and ONERA) for all the test cases
  - o Geometry **parameterization** (INTA) for all the defined test cases
  - o Surface deformation **tool** (INTA) and volume mesh deformation tool executable (FOI)
  - o NURBS parameterization **parser** (INTA)
  - o **Tutorials** for the common tools (INTA)
  - o A website has been created for dissemination: www.ag52.blogspot.com
- A **CFD cross-analysis** to identify the error sources of using different CFD solvers was performed.
- Results on task 1 (surrogate validation and rae2822 optimization) have been provided
- Results on task 2 (optimization of the dpw test case) have been provided by CIRA, AIRBUS and INTA.
- Participation and organization of Special Sessions at **EUROGEN 2013**, **ECCOMAS 2014**, **EUROGEN 2015** and **ECCOMAS 2016**.
- Organization of the **EUROGEN 2017** in progress (eurogen2017.etsiae.upm.es/)



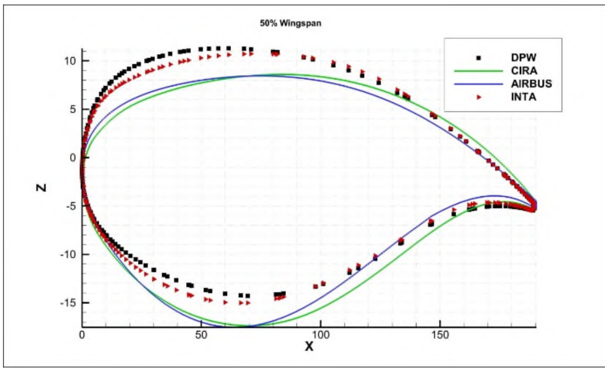


	Mean OF (TAU, MSES, ZEN 3 levels)	Mean OF (only TAU and ZEN fine)
RAE 2822 baseline	1	1
CIRA-POD	0.6223	0.6266
CIRA-EGO	0.6208	0.6236
INTA/UAH	0.6243	0.6211
ONERA	0.6494	0.6498
UNIS	0.6367	0.6338
VUT	0.6969	0.7063

Figure 1: Results from task 1, cross-comparison of surrogate results and rae2822 optimization

Next steps:

- Delivery of the **final report** (on process, expected March 2017).
- Organization of the **EUROGEN conference** (expected high attendance from AG52 partners, **specific minisymposium on AG52 topic**, organized by Emiliano Iuliano and Daniel González)



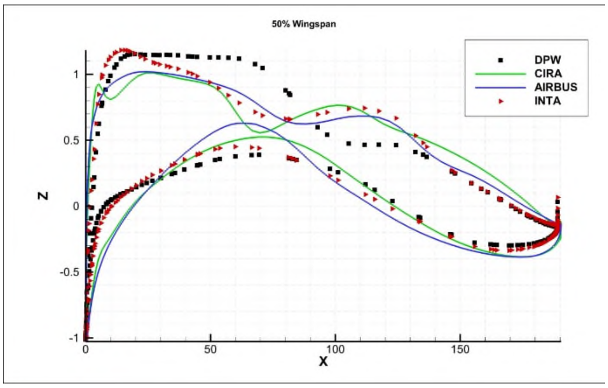


Figure 2: Results from task 2, dpw optimization

Expected results / benefits

This AG was expected to yield better understanding of SBGO techniques and their application to aerodynamic shape optimization. At the end of the proposed AG, the involved partners have improved global shape optimization capabilities and valuable knowledge of the selected set of techniques. Through the proposed activities, it was expected that some “best practice” guidelines will be concluded and, consequently, facilitating the use of surrogate-based global optimization methods in aeronautic industries. It was also foreseen that the AG will lead to publications, either as conference or journal articles.

Management issues

Due to the maternity leave of Esther Andrés, the management of the group during the second half 2016 was performed by Emiliano Iuliano (CIRA) with the support of Daniel González (INTA).

Olivier Amoignon left FOI and therefore FOI was not able to contribute to the group during the last period.

Most inputs required for task 2 were not delivered by partners (reason given: limited resources to be dedicated to AG52) and the comparison in that task was only with CIRA, AIRBUS and INTA results).

A final face-to-face meeting was expected to take place in December, but it had to be cancelled due to limited attendance. Available results were collected and a webex meeting took place.

A specific minisymposium will be organised at the EUROGEN 2017 conference, and it is expected to show main AG52 results.

Meetings

- The Kick-off meeting took place at INTA Madrid on 12nd and 13rd of February 2013.
- Review teleconf. number 2 was held on 5th of April 2013.
- Review teleconf. number 3 took place on 31st of May 2013.
- Review teleconf. number 4 was held on 8th of November 2013.
- Review teleconf. number 5 was held on 28th of January 2014.
- Face-to-face meeting number 6 took place on the 19&20 of February 2014 at INTA.
- Review teleconf. number 7 was held 14th of May, 2014.
- Face-to-face meeting number 8 took place on the 23 of September 2014 at FOI.
- Face-to-face meeting number 9 took place on the 23&24 of February 2015 at CIRA.
- Review teleconf. number 10 was held on the 2nd of November 2015.
- Review teleconf. number 11 was held on the 8th March, 2016.
- Review teleconf. number 12 was held on the 28th September, 2016.

In the AG52 web page, there are minutes and presentations of all the meetings.

AD/AG-52 Membership

Member	Partner	E-mail
Esther Andrés **Daniel Gonzalez**	INTA	eandres@isdefe.es gonzalezjd@inta.es
Emiliano Iuliano **Davide Cinquegrana**	CIRA	e.iuliano@cira.it D.Cinquegrana@cira.it
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Petr Dvorak **Ropert Popela**	VUT	dvorak.p@fme.vutbr.cz popela.r@fme.vutbr.cz

Resources

Resources	Year			
	2013	***2014***	***2015***	***2016***
Person-months	P22.7	P22.7	P22.7	P22.7
Other costs (in k€)	P63	P63	P63	P63

Progress/completion of milestones

The integration of the common tools at the beginning of the project, implied a significant delay in the rest of the activities. Therefore, a one-year extension was agreed.

Work package / Task	Planned		Actual
	Initially (end of….)	Currently (updated)	
Task 1 – DPW-W1 definition and common geometry parameterization	March 2013		March 2013
Task 1 – RAE2822 definition and common geometry parameterization	March 2013	May 2013	May 2013
Task 1 – Shared unstructured grids	April 2013		April 2013
Task 1 – Shared structured grids	April 2013	Sept 2013	Sept 2013
Task 1 – Common tools	May 2013		May 2013
Task 1 – Report on strategy for surrogate models comparison	Sept 2013	Dec 2013	Dec 2013
Task 1 – Surrogate validation results	Nov 2013	Feb 2014	Dec 2015
Task 2 - Optimization	June 2015	Dec 2016	Dec 2016
Final report	Dec 2016	March 2017	March 2017

GARTEUR GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE

FRANCE GERMANY ITALY THE NETHERLANDS SPAIN SWEDEN UNITED KINGDOM

AD/AG-53: Receptivity and Transition Prediction: Effects of surface irregularity and inflow perturbations

Action Group Chairman: Ardeshir Hanifi, KTH
Group of Responsables: Aerodynamics

Background

The transition process of boundary layers is mainly characterised by three stages. These are generation, growth and breakdown of disturbances. The process of birth of disturbances inside a boundary layer is called receptivity. Disturbances can be generated by surface roughness or other sources of forcing like free-stream turbulence or the acoustic field. Understanding the receptivity process and ability to accurately model/compute it belong to key issues for a reliable transition prediction. It is noteworthy that commonly used transition prediction methods lack any information about the receptivity.

Programme

Objectives of AD/AG-53
Main objective of the proposed activities is to understand the effects of surface irregularities and perturbations in incoming flow on transition in three-dimensional flows and efficiency of transition control methods. The activities cover both experimental and numerical investigations.

Approach
The activities are grouped under three topics:
• Acoustic receptivity in 3D boundary-layer flows
• Receptivity to free-stream perturbations
• Effects of steps and gaps on boundary-layer perturbations

Experiments on effects of free-stream perturbations using the ONERA D profile. Experimental and numerical work concentrated on effects of steps and gaps. The intention is to use a similar configuration as that used in Bippes' experiments. Numerical investigations of acoustic receptivity in 3D boundary layers. Comparison of direct numerical simulations with simpler methods like linearized Navier-Stokes computations and adjoint methods.

Partners: KTH, FOI, CIRA, ONERA, DLR, Imperial College, Airbus, Airbus Group Innovations
Project duration: September 2013 – December 2016

The Outcomes

Results/benefits
Understanding of capability of existing prediction methods through comparison with experimental and DNS data, and improvement of these computations.

Main achievements
Detailed wind tunnel tests have been performed at ONERA to investigate the effects of freestream turbulence on laminar-turbulent transition on a wing. A change in the instability characteristics is observed when freestream turbulence is increased.

IC has developed a number of numerical tools for receptivity analysis of three-dimensional flows. A number of different flow cases has been investigated, including instability of the flow behind bumps and gaps (ring-wing experiment case).

The ring wing experiments (ALFET project) has been conducted by AGI. A range of gaps with realistic filler depths has been studied and the effect of laminar-turbulent transition was assessed. The results shows, somewhat contrary to expectations, that for a filled gap on a natural laminar flow wing at cruise conditions, there is a marked forward movement in transition for gaps as shallow as D/L=0.02.

KTH have completed highly accurate simulations of the leading-edge acoustic receptivity, showing pervious results overestimating the receptivity coefficient. KTH has also performed direct numerical simulations of the interaction of acoustic waves with roughness-induced crossflow vortices, corresponding to the experiments performed within the RODTRAC project.

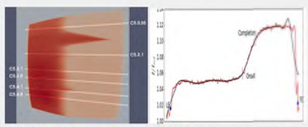
DLR has improved its in-house numerical tools (NoLoT code) for linear stability analysis of boundary-layer flows past forward- and backward-facing steps. Further, in order to experimentally investigate the stability of three-dimensional flows, DLR has designed and performed a set of wind tunnel experiments.

CIRA has further developed its acoustic receptivity tools based on the adjoint methods and investigated an empirical transition prediction method, which is based on the solution of a transport equation for some local flow parameters.

Gap Analysis

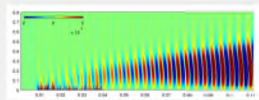
BiGlobal Stability Analysis a new approach to solve the spatial modes associated with the flow modifications generated by the step-gap region.

Local EVP: $q(y)\,exp(i\alpha x - i\omega t)$ BiGocal EVP: $q(x,y)\,exp(-i\omega t)$

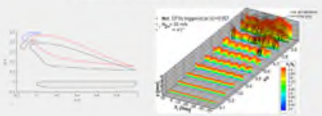


Left: TSP data from the ring wing (ALFET) experiment. Right: The use of TSP intensity ratio to determine transition.

Receptivity model development

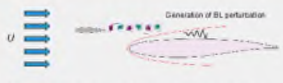


Perturbations generated by randomly distributed surfaces roughness of 5 microns.

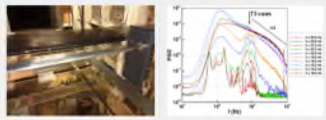


Different designs of the displacement bodies for DLR experiments (left). Visualization of the measured perturbation field (right).

Receptivity & transition experiment

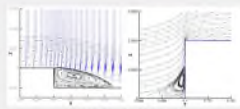


Aim: determine the onset of by-pass transition on a 2D wing due to upstream turbulence increase

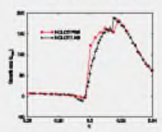


Left: Free stream turbulence was introduced through the turbulent wake of a small wing placed upstream the main wing. Right: Effect of distance from wake on generation and growth of perturbations inside the boundary layer over the ONERA D wing. *h* is distance between the two wings.

Backward/Forward-facing step



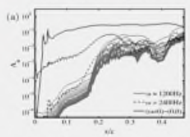
Mean-flow field from CFD.



Disturbance growth rate from PSE and LNS for a flow past a backward-facing step (step at x=0.3)

Leading-edge acoustic receptivity

Direct numerical simulations of flat plate with modified super elliptic leading edge.



Amplitude evolution of the steady and unsteady disturbances for interaction of acoustic waves with surface roughness in the boundary layer over a swept wing.

AIRBUS GROUP | CIRA | DLR | FOI | Imperial College London | KTH | ONERA THE FRENCH AEROSPACE LAB

AD/AG 53

AD/AG-53	**Receptivity and Transition Prediction: Effects of surface irregularity and inflow perturbations**
Monitoring Responsable:	M. Tormalm FOI
Chairman:	A. Hanifi KTH

Objectives

The transition process of boundary layers is mainly characterised by three stages. These are generation, growth and breakdown of disturbances. The process of birth of disturbances inside a boundary layer is called receptivity. Disturbances can be generated by surface roughness or other sources of forcing like free-stream turbulence or the acoustic field. Understanding the receptivity process and ability to accurately model/compute it belong to key issues for a reliable transition prediction. It is noteworthy that commonly used transition prediction methods lack any information about the receptivity.

Main objective of the proposed activities is to understand the effects of surface irregularities and perturbations in incoming flow on transition in three-dimensional flows and efficiency of transition control methods. The activities cover both experimental and numerical investigations.

Main activities

Major activities of AG53 are

– Experiments on effects of free-stream perturbations using the ONERA D profile. The work includes investigations of 2D and 3D flows. The free-stream perturbation will be generated by wake of a moveable body placed upstream of the wing.

– Experimental and numerical work concentrated on effects of steps and gaps. The intention is to use a similar configuration as that used in Bippes' experiments.

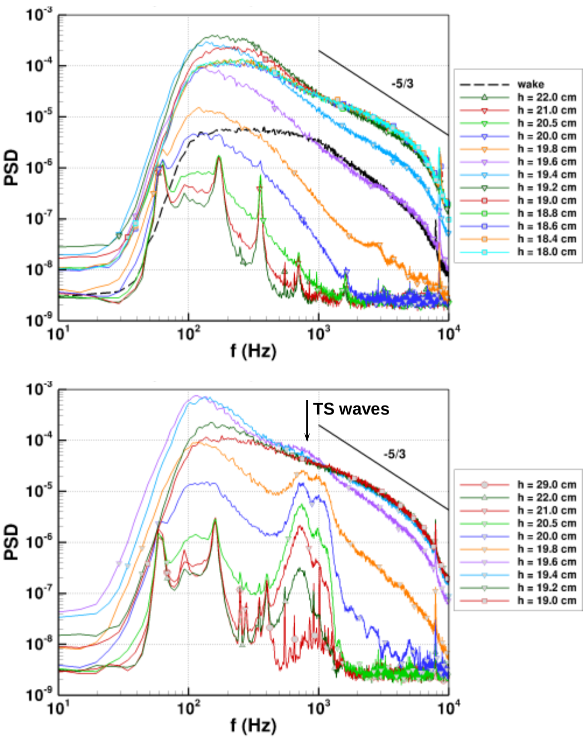
– Numerical investigations of acoustic receptivity in three-dimensional boundary layers. Comparison of direct numerical simulations with simpler methods like linearized Navier-Stokes computations and adjoint methods.

Expected results/benefits

Outcome of the suggested activities will improve our understanding of the underlying physical phenomena. The investigations will increase our knowledge about the capability of existing prediction methods through comparison with data form experiments and numerical simulations, and also contribute to improvement of these methods.

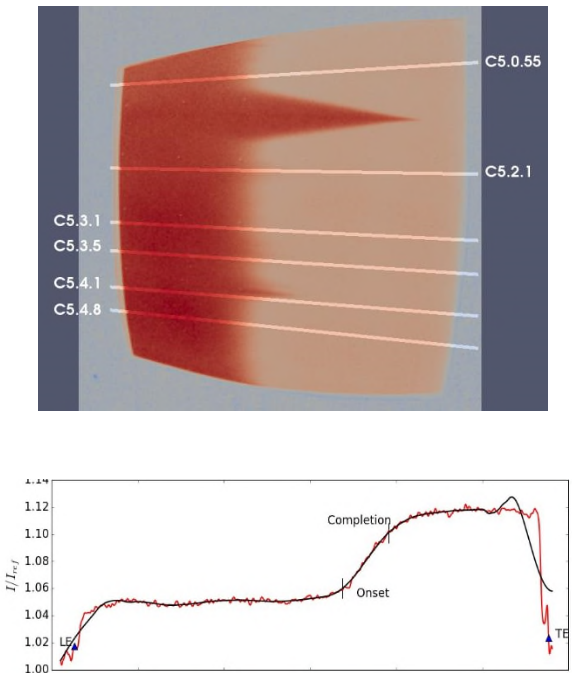
Main achievements

The analysis of the ONERA experiments has been completed. The aim of these experiments is to investigate the effects of freestream turbulence level on the transition scenario over a wing. Here, the freestream turbulence has introduced through the turbulent wake of small wing placed 50 cm upstream of the main wing. It was observed that when the small wing is in high position, the transition occurs slightly earlier compared to the case with the wing alone, but the exponential growth of the perturbations follows a similar path. For lower positions of the small wing, an algebraic growth of the fluctuations can be observed, starting close to the leading edge.



Effects of wake distance on generation and growth of perturbations inside the boundary layer over the ONERA D wing. h is distance between ONERA D and the small wing. x/c=0.5 (top) and x/c=0.8 (bottom).

The wind tunnel tests of the ring wing (ALFET project) have been performed. The aim of these studies is to examine the effect of gap with realistic filler shape on the laminar-turbulent transition in the boundary layer over wings. A wide range of depths of the filler surface has been investigated. AIG and IC performed complementary numerical simulations for the same geometry. This study has shown, somewhat contrary to expectations, that for a filled gap representative of the junctions between leading edge and wingbox components on a natural laminar flow wing for conditions similar to cruise there is a marked forward movement in transition for gaps as shallow as D/L=2.0x10^{-2}. However as the depth of the gap increases beyond this point there is no further movement. Stability calculations based on PSE predict no further movement beyond a certain depth but completely fail to predict the initial movement. It is suggested that this may result from the introduction of new modes at the gap through a receptivity mechanism.

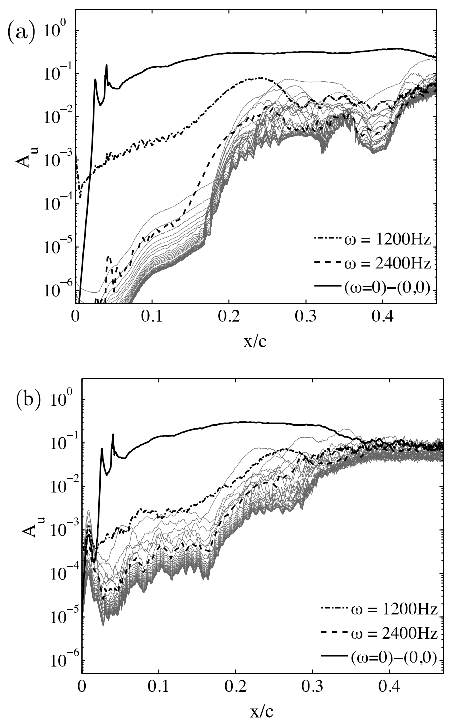


Example of TSP data (top) and use of TSP intensity ratio to determine transition (bottom).

IC has also developed methods for analysis of effects of ‘sand paper’ type of surface roughness on stability characteristics of the instability modes.

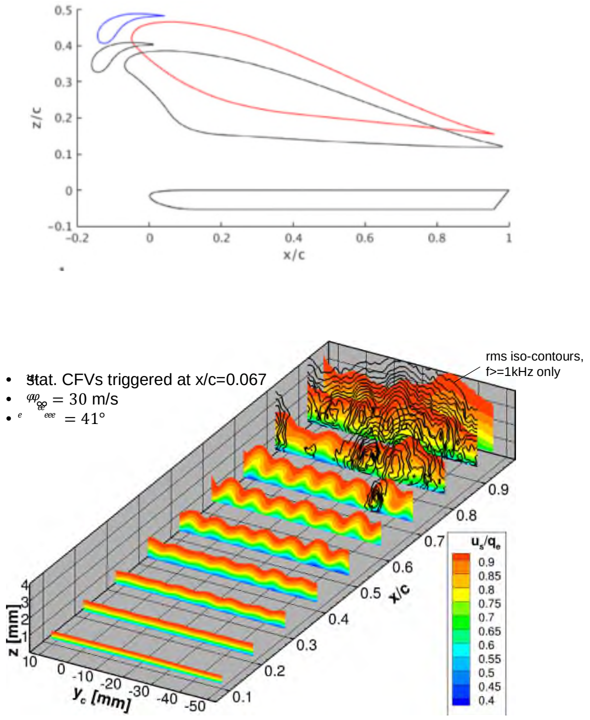
CIRA has worked on implementation of the intermittency model suggested by Menter in the in-house ZEN RANS code. This is an empirical transition prediction method, which is based on the solution of a transport equation for some local flow parameters.

KTH has completed the direct numerical simulations of the interaction of acoustic waves with roughness-induced crossflow vortices. The geometry and flow conditions correspond to the experiments performed within the RODTRAC project. The simulations once again confirmed the possibility to control the cross-flow dominated transition by micro-size roughness elements, similar to experimental results. Introduction of acoustic waves with the frequency of the most amplified unsteady crossflow mode to the controlled flow promotes the transition location. This result is in agreement with the experimental findings in presence of the high level of freestream turbulence.



Amplitude evolution of the steady and unsteady disturbances in presence of the control roughness elements with only acoustic waves (a), and with acoustic waves and background noise (b).

In order to experimentally generate the three-dimensional boundary layers over a flat plate with the desired characteristics, two different displacement bodies have been designed and manufactured by DLR. Wind tunnel test has been made to verify the quality of the base flow. Further, experiments have been performed to study the development of the crossflow vortices. These vortices have been generated by means of small roughness elements placed close to the leading edge of the flat plate. The perturbation field has been investigated with hot wire measurements.



Different designs of the displacement bodies for DLR experiments (top). Visualization of the measured perturbation filed (bottom).

Management issues

The chairman A. Hanifi left FOI in 2016 and is now fully representing KTH. FOI is no longer involved in the activities of AG53.

Final meeting was held on December 13, 2016 at KTH in Stockholm.

Final report is expected in end of March 2017.

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

AD/AG-54: RaLESin

RANS-LES Coupling in Hybrid RANS-LES and Embedded LES

Action Group Chairman: Dr Shia-Hui Peng (FOI)

Background

Hybrid RANS-LES modelling aims at turbulence-resolving simulations, in particular, for unsteady aerodynamic problems with massive flow separation and extensive vortex motions, benefitting from the computational efficiency of RANS (Reynolds-Averaged Navier-Stokes) and the computational accuracy of LES (Large Eddy Simulation). Its development has been greatly facilitated by industrial needs in aeronautic applications.

Over nearly two decades since the earliest DES (detached Eddy Simulation) model by Spalart and co-workers, a number of alternative hybrid RANS-LES modelling approaches have been developed in previous work, being validated in and applied to a wide range of turbulent flows. In the EU framework program, a series of noticeable collaborative work has been dedicated to improved hybrid RANS-LES methods, as well as to applications of hybrid RANS-LES models in numerical analysis of numerous flow problems in relation to, typically, unsteady aerodynamics, flow& load control and aero-acoustics. While hybrid RANS-LES modelling has been proved a powerful methodology in these and other previous work, its weakness and drawback has also been revealed for further improvement

AG54 has been established after EG69 and the work has been set up on the basis of AG49, which has explored the capabilities of a number of existing models in resolving underlying physics of typical aerodynamic flows. AG54 focuses further on effective RANS-LES coupling methods towards novel and improved hybrid modelling and embedded LES modelling.

Partners: Airbus-F, Airbus-Innovations (formerly EADS-IW), CIRA, DLR, FOI (AG Chair), INTA, NLR,ONERA (AG vice-Chair), Saab, TUM, UniMan, ZUAS

Programme/Objectives

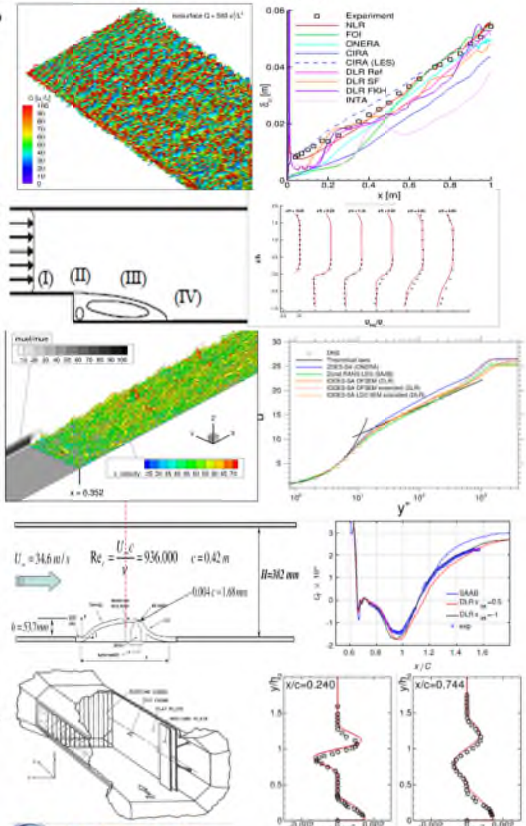
Main objectives: By means of comprehensive and trans-national collaborative effort, to explore and further to develop RANS-LES coupling methods in the context of embedded LES (ELES) and hybrid RANS-LES modelling and, consequently, to address the "grey-area" problem in association with the RANS and LES modes and their interaction so as to improve ELES and hybrid RANS-LES modelling for industrial applications.

Work program: The work in AG54 is divided into three tasks. Task 1 and Task 2 deal with non-zonal and zonal hybrid RANS-LES methods, respectively, and an overall assessment of the developed methods is conducted in Task 3.

Task 1: Non-zonal modelling methods
(Task Leader: **NLR**)
For models with the location of RANS-LES interface regulated by modelling (not prescribed), typically, for DES-type and other seamless hybrid methods. Two TCs are defined.
TC M1 Spatially developing mixing layer
Initiated from two BLs of U_1 = 41.54 and U_2 = 22.40 m/s, respectively, with Re_θ = 2900 and 1200. Focus on modelling/resolving initial instabilities of the mixing layer.
TC O1 Backward-facing step flow
Incoming BL with U = 50m/s and Re_h = 40000. Focus on modelling/resolving the free shear layer detached from the step (h = step height).

Task 2: Zonal modelling methods
(Task Leader: **UniMan**)
For models with the location of RANS-LES interface prescribed, Including embedded LES. Two TCs are defined.
TC M2 Spatially developing boundary layer
Inflow defined with U = 70m/s and Re_θ = 3040. Focus on turbulence-resolving capabilities on the attached BL after the RANS-LES interface.
TC O2 NASA hump flow
Incoming BL has U = 34.6m/s, Re_c = 936000 (c = hump length). Focus on the turbulence-resolving capabilities on the flow separation over the hump.

Task 3: Modelling assessment
(Task Leader: **Airbus-Innovations** (EADS-IW))
Evaluation and assessment of the methods developed in Tasks 1 and 2 with one TC.
TC M3 Co-flow of BL and wake
Re = 2.4x10[6]/meter and M = 0.2. Examination of modelling capabilities for a complex flow case.



Results

- Further evaluation of existing hybrid RANS-LES methods of zonal and non-zonal modelling in computations of test cases.
- Improved modelling formulation to enhance turbulence-resolving capabilities with special focus on "grey-area" mitigation.
- Assessment and verification of improved modelling in computations of different test cases by means of cross comparisons.

Summary:
The project kick-off took place in 2014. Since then, AG54 has had three progress meetings with the following results reported by AG members.

- Evaluation of existing baseline hybrid RANS-LES models in TC computations, including SST- & SA-IDDES, HYB0, HYB1, X-LES, ZDES, 2-eq. based hybrid zonal model, 2-velocity method, WMLES, LES, RSM-based hybrid model and other variants.
- For non-zonal hybrid RANS-LES modelling, improvement has been progressing on, among others, using stochastic backscatter model plus temporal and spatial correlation, velocity-gradient-based energy backscatter, vorticity-based length scale and other verified hybrid length scale.
- For ELES and zonal hybrid RANS-LES modelling, methods of generating synthetic turbulence has been examined, among others, the synthetic eddy method (SEM) and its improved variant (e.g., DFSEM).
- All test cases have been well defined and experimental data have been collected for modelling validation and verification.
- Progress of AG work has been made in line with the plan. Computations of TCs have been progressed well with relevant results reported and in preliminary cross plotting.
- The 1st and 2nd progress meetings were held in Oct. 2014, Oct. 2015 & Nov. 2016, respectively.

AD/AG54

AD/AG54:	RaLESin: RANS-LES coupling in hybrid RANS-LES and embedded LES approaches
Monitoring Responsable:	Mr. T. Berglind & M. Tormalm, FOI
Chairman:	Dr. S.-H. Peng FOI

Objectives

The overall objective of AG54 is, by means of international collaborative effort, to explore and further to develop and improve RANS-LES coupling in the context of embedded LES (ELES) and hybrid RANS-LES methods, particularly, to address the “grey-area” problem for zonal and non-zonal hybrid models. More specifically, the major objectives of AG 54 are: (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, as well as improving further 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 verify and assess the developed methods in turbulence-resolving simulations of different test cases.

Main Achievements

AG54 consists of 12 members, including three universities, six research organizations and three industries. The work in AG54 is divided in three technical tasks. Task 1 deals with non-zonal hybrid RANS-LES methods (including seamless hybrid models). In Task 2, the RANS-LES coupling for zonal (including wall-modelled LES) and embedded LES is explored. In Tasks 1&2, two test cases are defined for each task, including a mandatory TC and an optional TC. The methods developed in Task 1 and Task 2 are then assessed in Task 3 in computations of a mandatory test case.

In 2016, the group has progressed in line with the technical work plan. The main activities and achievements have in general been marked by: (a) Computations of TCs by all AG members for evaluating existing hybrid RANS-LES methods of zonal and non-zonal modelling; (b) coordinated cross-plotting of results based on contributions by involved AG members; (c) Further modelling exploration in order to enhance turbulence-resolving capabilities with special focus on the “grey-area” mitigation; (d) Refined verification of developed methods using defined TCs on refined spatial and temporal resolution.

Task 1 has been progressed in addressing the “grey-area” problem for non-zonal hybrid modelling by means of improved or refined modelling formulation, among others, X-LES based model with stochastic backscatter, high-pass filter and/or temporal/spatial correlation, HYB0- and HYB1-based energy backscatter using velocity gradients and vorticity-based LES length scale, improved ZDES with vorticity-based length scale, SST-IDDES model with a well-defined hybrid length scale. Figure 1 shows an example of computations for the mixing layer (TC M1) by NLR and a preliminary cross-plotting of partners’ contributions, which shows how the improved modelling has progressed in resolving the mixing layer and mitigating the grey-area in the initial stage of the mixing layer.

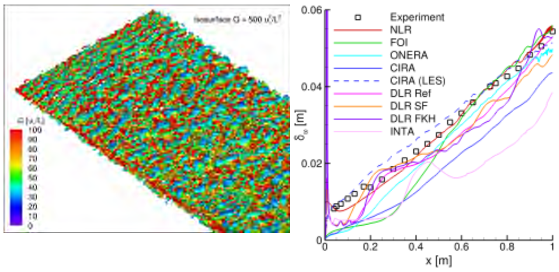


Figure 1: Computations for TC M1 (mixing layer). Resolved turbulent structures by the NLR model (Left) and a preliminary cross plotting of mixing-layer vorticity thickness (Right).

For zonal hybrid RANS-LES modelling in Task 2, as planned, the main work has been dedicated to improving the method of generating synthetic turbulence (ST) and using this method for better RANS-LES interface and grey-area mitigation. The modelling verification is based on TC M2 (Spatially developing turbulent boundary layer), of which an example is shown in Figure 2 to illustrate the synthetic-turbulence method has supported the GAM and also to present a preliminary comparisons of results between partners.

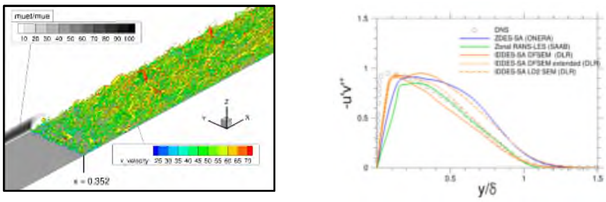


Figure 2: Computation of TC M2 (spatially developing turbulent boundary) using synthetical turbulence. Resolved turbulent structure (Left) and resolved turbulent shear stress (Right).

The effectiveness of re-establishing turbulence after the RANS-LES interface section is further verified in Figure 3 for test case TC O2 (NASA hump flow) by displaying the predicted wall surface pressure and skin friction along the bottom wall in comparisons with experimental data. The computations made by three partners show reasonable agreement.

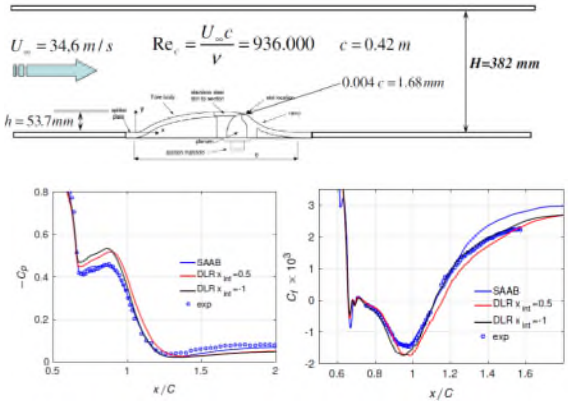


Figure 3: Example for TC O2 using zonal modelling supported by ST methods. The lower row shows the surface pressure (Left) and skin friction (Right) distribution along the bottom wall.

TC M3 (co-flow of boundary layer and wake) in Task 3 has been adopted for overall assessment of methods developed in Tasks 1 & 2. Several partners have started RANS computations for verifying the computational settings. TUM has computed TC M3 using a wall-modelled LES method, and ONERA has used IDDES for this test case as shown in Figure 4.

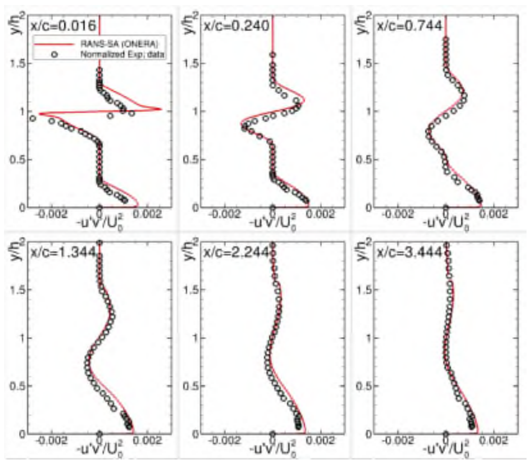


Figure 4: Example for TC M3 by ONERA using IDDES. Resolved turbulent shear stress at different stations downstream from the plate TE.

In addition to the mandatory test cases (M1, M2 and M3) and the optional case TC O2 shown here, computations on the optional case TC O1 have also been carried out by partners. For all these test cases, preliminary cross-plotting has been initiated.

Resources

Resources		Year					Total
		2014	2015	2016	2017	2018	
Person-months	Actual/ Planned	A18 P18	A22 P22	A18 P18	Axx P20	Axx P12	Axx P90
Other costs (in K€)	Actual/ Planned	A100 P100	A140 P138	A80 P80	Axxx P100	Axxx P50	Axxx P468

Completion of milestones

Work package	Planned		Actual
	Initially	Currently	
Kick-off meeting	April. 2014		April 2014
Task 1 & Task 2: def. TCs	Oct 2014		Oct. 2014
Task 3: TC M3 testing for definition & computation	Oct. 2014		Oct. 2014
1st progress meeting	Oct. 2014		Oct. 2014
Tasks 1, 2 & 3: Website	Oct. 2014		Nov. 2016
Exp. data of all TCs	Sept. 2015		Nov. 2015
2nd Progress meeting	Oct. 2015		Oct. 2015
3rd Progress meeting	June 2016	Nov. 2016	Nov. 2016

Expected results/benefits

AG54 aims at a collaborative development of hybrid RANS-LES methods. Improved zonal and non-zonal hybrid models (including ELES) are expected with particular focus of addressing the grey-area problem encountered commonly in existing hybrid models. These improved methods will be implemented into the CFD tools of AG members and, consequently, being exploited in other R&D activities and industrial applications.

AG membership

Member	Organisation	e-mail
P. Catalano	CIRA	p.catalano@cira.it
F. Capizzano	CIRA	f.capizzano@cira.it
T. Knopp	DLR	Tobias.Knopp@dlr.de
A. Probst	DLR	Axel.probst@dlr.de
D. Schwamborn	DLR	Dieter.schwamborn@dlr.de
S.-H. Peng	FOI	Shia-Hui.Peng@foi.se
C. Lozano	INTA	lozanorc@inta.es
J. Kok	NLR	johan.kok@nlr.nl
S. Deck	ONERA	sebastien.deck@onera.fr
M. Schneider	EADS-IW	manfred.schneider@eads.net
S. Arvidson	Saab	sebastian.arvidson@saabgroup.com
C. Breitsamter	TUM	Christian.Breitsamter@aer.tum.de
A. Revell	UniMan	alistair.revell@machester.ac.uk
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Righi Marcello	ZUAS	rigm@zhaw.ch

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

AD/AG-55: Countermeasure Aerodynamics

Action Group Chairman: Torsten Berglind, FOI (torsten.berglind@foi.se)

The Background

In order to increase the defensive capability of aircrafts, countermeasures are used to decoy enemy tracking system. Two commonly used countermeasures are chaff and flares.
Chaff is a radar countermeasure consisting of small pieces or threads of metal or metalized glass fibre. The chaff interacts with the electromagnetic radar wave and can thereby decoy or distract enemy radar. Chaff are dispensed in very large numbers from specific dispenser devices, for an aircraft typically located on the fuselage or under the wing. Chaff dispensed from an aircraft propagate through the wake of the aircraft with the motion induced by trailing vortices. When simulating chaff dispersion it is consequently of major importance to obtain an accurate description of the flow in the wake.
Flares are used against IR-seeking missiles. They are a few decimetres in length and can have built in propulsions systems.
Flares are "solid bodies" for which the burning constantly changes their aerodynamic and mechanical properties.

Ejection of a flare at the Lacroix high speed track by night.

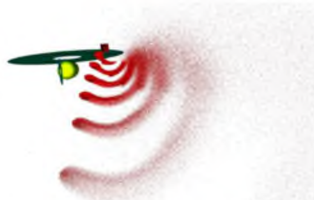
The Programme

Objectives of AD/AG-55
The main objectives of the proposed activities are improved understanding of the underlying physics and improved modelling tools for chaff dispersion and flare trajectory simulation. The project consists of two work packages: WP1 for chaff and WP2 for flares. The main focus of WP1 is to compare and investigate differences in various numerical approaches for modelling transport of chaff clouds.
For WP2, primary concern is to investigate the requirements on the model of the flare in order to be able to predict the flare trajectories sufficiently accurate.

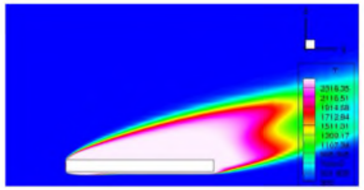
Approach
For WP1 two methods of predicting chaff dispersion, Eulerian and Lagrangian, is be considered. The principle behind the Eulerian method is that chaff is traced as a concentration instead of individual specimen. The aim is to include directional information for the Lagrangian approach. In addition to this, parametric studies will be performed.
In WP2 an aerodynamic database for the flare with shape changes has been generated. In the next step the procedure is going to be repeated for a model for which the real surface temperature and the exhaust gases is modelled. The data bases are used to simulate flare trajectories.

Partners
Airbus Defence & Space, Etienne Lacroix, FOI, MBDA, NLR

Project duration: January 2015 – December 2017



Simulation (FOI) of chaff dispensed from a generic helicopter seen from behind. There is 0.1 sec increment between the chaff clouds.



First CEDRE calculations by MBDA to check the feasibility of combustion gases effects, with fixed mass flow rate.

FOI AIRBUS DEFENCE & SPACE LACROIX Protection Superiority MBDA MISSILE SYSTEMS nlr

The Outcomes

Expected results/benefits
The action group is expected to yield increased understanding of how simulation of chaff dispersion and flare trajectory modelling should be performed. A natural outcome is also that the concerned partners obtain improved simulation tools, as the work packages are finalized.

Main achievements
One physical meeting, where all member organisations participated, was held at Lacroix production facility outside Toulouse June 21st and 22nd 2016. In addition to that, two tele-conferences where held on February 4th and November 8th.

FOI has, during this year, implemented the non-directional Lagrangian approach with a diffusivity model. Cross comparisons with numerical results for NLR's method are currently carried out.
Airbus, FOI and MBDA had delivered aerodynamic data bases for the flare with solely shape changes. Airbus determined inertia data for the various flare shapes. MBDA is investigating an appropriate way to implement aerodynamic damping.

FOI demonstrated preliminary simulations of the flare trajectory. Lacroix has delivered combustion data properties: gas constant R, C_p and C_v-values and data for numerical simulations of the combustion. MBDA will investigate the feasibility of combustion gases effects. The experiments at Lacroix has been postponed until week 7, 2017.

AD/AG 55

AD/AG-55	COUNTERMEASURE AERODYNAMICS
Monitoring Responsable:	M. Tormalm FOI
Chairman:	T. Berglind FOI

Background

In order to increase the defensive capability of aircrafts, countermeasures are used to decoy enemy tracking system. Two commonly used countermeasures are chaff and flares.

Chaff is a radar countermeasure consisting of small pieces or threads of metal or metalized glass fibre. Flares are used against IR-seeking missiles. They are a few decimetres in length and can have built in propulsions systems. Both countermeasures are, when ejected from an aerial platform, strongly affected by surrounding air.

Objectives

One objective is to compare modelling methods for chaff. Another objective is to the effect of shape changes, boundary temperature and combustion gases on the flare trajectory. The goal is to determine an appropriate flare model that gives sufficiently accurate flare trajectories.

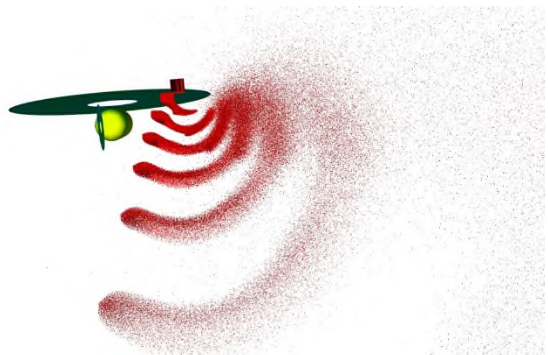


Fig. 1 Simulation (FOI) of chaff dispensed from a generic helicopter seen from behind. There is 0.1 sec increment between the chaff clouds.

There are two main methods to simulate chaff dispersion, an Eulerian approach in which the chaff concentration is represented as a scalar field, and a Lagrangian method in which individual chaff are tracked. Both methods are applied in a separate post processing step, once the flow field has been determined. Furthermore, chaff will be modelled as fibres having a spatial extension and direction. Directional information is required to enable computations of electromagnetics in order to study the effects of radar signals from chaff clouds.

Chaff dispensed from an aircraft propagate through the wake of the aircraft with the motion induced by trailing vortices. When simulating chaff dispersion it is therefore of major importance to obtain an accurate description of flow in the wake. Visualisation of a chaff cloud propagating in the wake of a generic helicopter is shown in Figure 1.

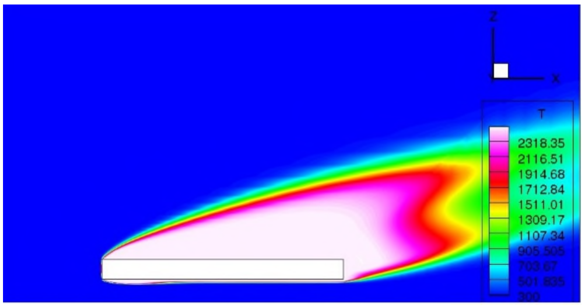


Fig. 2 First CEDRE calculations by MBDA to check the feasibility of combustion gases effects, with fixed mass flow rate.

The flare work package is focused on predicting flare trajectories. Of special interest is how burning of the IR payload affects the aerodynamic and mechanical properties of a flare. These effects include both exhaust gases, see Figure 2, as well as deformation of the exterior surface due to the burning process.

Main achievements

FOI has, during this year, implemented the non-directional Lagrangian approach with a diffusivity model. Cross comparisons with numerical results from NLR's method are currently carried out. Furthermore, FOI will during 2017 develop a model of chaff as rigid cylinders having a spatial extension and direction. NLR will during next year develop a measure to enable comparisons of features of chaff clouds.

Airbus, FOI and MBDA have delivered aerodynamic data bases for the flare with solely effects of shape changes. MBDAs database had larger angle increment than 10º. MBDA later delivered a new database with the same interpolated values of angles as Airbus and FOI. Airbus determine inertia data for the various flare shapes. MBDA is investigating an appropriate way to implement aerodynamic damping.

FOI demonstrated preliminary simulations of the flare trajectory. It was decided to have cross comparisons of numerical simulations, preferably before the experiment.

In the next phase a similar database is going to be generated including the effects of surface temperature and exhaust gases. Lacroix has delivered combustion data properties: temperature, C_p and C_v-values and data for numerical simulations of the combustion. MBDA will investigate the feasibility of combustion gases effects.

The experiments at Lacroix have been postponed until week 7, 2017. Finally, comparisons of computed and experimental trajectories will be analysed.

Next meeting will be held at NLR Amsterdam in April 18th-19th 2017.

Fig. 4. Ejection of a flare at the Lacroix high speed track by night.

Management issues

One physical meeting, where all member organisations participated, was held at Lacroix production facility outside Toulouse June 21st and 22nd. In addition to that, two tele-conferences where held on February 4th and November 8th.

Expected results/benefits

The project is expected to yield increased understanding of how chaff dispersion and flare trajectory modelling should be done. A natural outcome is also that the partners obtain improved simulation tools, as the work packages are finalized.

- *AD/AG-55 membership*

Member	Organisation	e-mail
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T. Berglind	FOI	torsten.berglind@foi.se
S.-H. Peng	FOI	shia-hui.peng@foi.se
C. Jeune	MBDA France	Christophe.jeune@mbda-systems.com
S. Tusseau	MBDA France	simon.tusseau@mbda-systems.com
H. Van der Ven	NLR	Harmen.van.der.ven@nlr.nl

- *Resources*

1. Resources		Year			Total
		2015	2016	2017	
Person-months	Actual/ Planned	16 16	18 16	16	48
Other costs (in K€)	Actual/ Planned	24 24	24 24	24	72

Progress/Completion of milestones

Mile stone	Planned		Actual
	Initially (end of …)	Currently (updated)	
MS 1: Provide helicopter test case + grid + flow field (NLR)	Jul 2015	Oct. 2015	Delivered
MS 2: Use VULCAD to compute flare section and evolution vs time (Lacroix)	Jul 2015	Sep. 2015	Delivered
MS 3: Grid around initial flare geometry (MBDA)	Aug 2015	Jul. 2009	Delivered
MS 4: Aero data base for flare without exhaust gases (Airbus, MBDA and FOI)	Nov 2015	June 2016	Delivered
MS 5: Comparisons of chaff computations with Eul. and Lagr. Appr. (FOI)	Feb 2016	June 2017	In progress
MS 6. Determine the inertia properties for the flare (Airbus D&S)	Sep 2016	Oct. 2016	Delivered
MS 7. Determine the aerodynamic damping coeff. for the flare (MBDA)	Dec 2016		In progress
MS 8. Deliver flare data properties: gas constant, □-value. If possible, chemical composition (Lacroix)	Dec 2016	Dec 2016	Delivered
MS 9 Skeleton report with responsible organisation for each chapter (FOI)	Feb 2017		
MS 10. Flare trajectory test case for computations (Airbus, MBDA, FOI)	Mar 2017		
MS 11. Flare trajectory experiments(Lacroix)	April 2017		

ANNEX B

ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "AVIATION SECURITY"

The Group of Responsables on Aviation Security was created during the GARTEUR Council meeting in March 2014. This GoR is composed of specialists from Research Establishments and Industry who have identified relevant topics to be studied in the Aviation Security area. GoR AS pursues research in the Aviation Security field dealing with both military and civil R&T.

The investigated research fields regard:

- Cybersecurity in the aviation sector,
- Chemical, Biological and Explosive (CBE) detection,
- Dazzling,
- Malevolent use of RPAS.

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AVIATION SECURITY

GoR-AS Overview

Remit

The Group of Responsables on Aviation Security was created during the GARTEUR Council meeting in March 2014. GoR AS pursues to do research in the Aviation Security field dealing with both military and civil R&T.

Four research themes have been identified inside this GoR and corresponding four Exploratory Groups are under consideration:

- AS/EG-1 (Cybersecurity): Towards an Information Security Management System for the aviation sector;
- AS/EG-2 (CBE): Enhancing airport security against CBE threats;
- AS/EG-3 (Dazzling): Detection of threatening laser radiation on aircrafts or helicopters for future protection of pilots;
- AS/EG-4 (RPAS): Analysis of new threats posed by malevolent use of Unmanned Aerial Systems (UAS) and/or Remote Piloted Aircraft Systems (RPAS). Threat mapping.

The main results in 2016 were the involvement of industries to let them express their activity priorities in the previous domains, the analysis of other similar initiatives in aviation security domain and the definition of a shared approach to tackle the identified topics.

GoR activities

In 2016 the AS GOR started to involve the industries interested in aviation security and to define an approach to face with aviation security domain for the identified research themes. A preparation meeting (WebEx) was held among the AS GOR in February 2016. During such preparation meeting the list of industries to involve was finalized together with the approach.

AS GoR was presented both to EASA and Eurocontrol, besides GoR members are also members of ACARE WG4. The intent is to harmonize all existing initiatives while trying to avoid duplication of efforts.

Garteur executive committee had informed the Garteur industrial partners of the creation of a new GoR on Aviation Security. Among the industrial partners who expressed their interest for the activities of the GoR there were:

- GE aviation
- Airbus group
- Airbus Defence and Space
- CS
- Selex ES Finmeccanica
- Rhode Schwarz
- BAE systems
- Gifas

A one-day meeting was organized in spring 2016 with the interested industrial partners to present the GoR and discuss potential collaborations. The industrial participation was welcomed by the GoR as a good way to focus the GoR activities and to prepare common projects. On April 21st at ONERA in Toulouse the meeting focussed on the following topics:

- Presentation of GARTEUR and AS GoR
- Presentation of the cybersecurity theme
- Presentation of the MalURPAS theme
- Presentation of industrial interests and activities
- Discussion and planned actions

Presentation of the cybersecurity theme was given by René Wiegers and Angela Vozella.

It was considered that Security and specifically cybersecurity is spread all over different domains and it is necessary to capitalize existing valuable results and experiences. Though cybersecurity is a large domain, there are specificities for aviation: certification brings specific constraints, aircrafts are specific entities where a pilot is in charge, international nature of aviation (that can be an issue with respect to IT rules). GARTEUR AS GoR contribution should address these specificities.

Concerning Risk assessment: avionics has a history of closed systems, the current trend to openness is not accompanied by a sufficient awareness on security issues. There is a need for clear information on issues in this domain. A first necessary step is thus a total risk assessment all over the aviation system life cycle, as there are different competing challenges e.g. safety, security, performance, competitiveness. A potential difficulty is that industrial companies are very protective regarding security issues, it may be difficult to share information. The right approach has to be adopted starting from sharing of needs, vision, methodologies. However security, just like safety, represents a European priority and there are benefits and opportunities in cooperation also at precompetitive level (just like in UK the avionics industry working group). There is also a need to share acceptable level of likelihood of threats (as it is done for safety).

Concerning the contribution to SRIA update: the update of SRIA represents a chance for GARTEUR to contribute, bringing the Garteur position in the updating process, validating and complementing the issues by WG4, which is currently identifying new priorities (contents) and a more manageable structure for the next release. The existing links and interrelations among people involved in the different groups within aviation security, will avoid duplication of effort and enable a more efficient process.

In the following a summary of Industrial interests and activities collected during the meeting are presented:

Finmeccanica

- GAMMA (SESAR) initiative in cybersecurity
- Participation to the European cybersecurity PPP platform
- ATP platform on safety and security in definition (not only aviation)

CS BOREADES project: civilian drone neutraliser system for critical infrastructures - Topics of interest:

- security supervision on board and on ground
- Communication security ground/board (post-quantic, long term, new generation of cryptography)
- Security standards (exchange format, cyber joint common exchange picture)

BAE systems - Topics of interest:

- Risk assessment
- Security Assurance
- Security management systems
- Maintaining security over life of the aircraft

Airbus group - Topics of interest:

- CBE detection for on-board security
- Dazzling
- MalURPAS: need to project on future threats (not only current threats)
- Cybersecurity: main upcoming revolution is SWIM (SESAR). Long term perspective is necessary too.

Rohde Schwarz - Topics of interest:

- Military and civil (secure communications – air traffic control)
- ICONAV project (with DLR)
- A/G communication systems
- Member of Eurocontrol Security sub-group, will ask for permission to disseminate information and make the link between the two groups

Presentation of the MalURPAS theme (Francisco Munoz Sanz): National directives have been published (Italy in September 2015 for example), they should be taken into account by the GoR. Large scope but the GoR should focus on more specific topics:

- Control link
- Future threats: swarm of UAVs, UAVs with auto navigation system
- Increase the ability of RPAS to be safer (sensing capabilities, visual detection technologies).
- Coordinate with FM GoR to profit from Garteur multidisciplinary aspect

Main results concern:

- Agreement on the need to target critical aviation assets, and more specifically aircraft security.
- Vulnerability of aircraft against small UAVs (2-10kg).
- Specific issues around engines.

Need for risk assessment to properly characterize the specific risks for RPAS (security or safety) and the related scenarios.

Detailed conclusions & decisions for 2017

The decision for 2016 was that a global picture of all instances involved in aviation security in Europe (including their respective expertise domain) in order to set up processes for cooperative working avoiding duplications and allowing effectiveness and efficiency should have been identified.

In this perspective the proposed themes, integrated with the interests expressed by industries involved by GARTEUR, should have been transferred and aligned with the current version of the updated SRIA. Specifically the identified actions have been:

SRIA update: AS GoR will contribute to the SRIA update. Angela Vozella will distribute the current SRIA draft and transfer Garteur AS considerations to WG4.

Cybersecurity: an EG could be launched on risk assessment in the cybersecurity theme. René Wiegers will explore this possibility. The objective of this EG would be to see if we could have enough information to define an AG on this topic.

MalURPAS: NLR and CIRA to define a PoC for this theme. ONERA to involve people from the ANGELAS project. Think about defining an EG on vulnerability of aircrafts against small UAVs (2-10kg).

Airport security not very present at European level now, Alberto Bianchi (Finmeccanica) will prepare a discussion on this subject for the next meeting.

In June 2016, Garteur organized a road-mapping meeting with the objectives to position Garteur work with respect to ACARE SRIA and to define road-maps for each of the GoR. Concerning AS GOR the road-maps for each of the previous theme include:

Cybersecurity - Towards an information management system for aviation sector

- Identification of cyber vulnerability for all critical aviation assets
- Identification and development of mitigation actions for cyber attacks
- Integration and continuous risk data collection and analysis

CBE - enhancing airport security against CBE threats

- Verification and evaluation of protection performance for security

Malevolent use of RPAS

- Characterization of threats and possible impact
- Study of the effect of small drone impact on aircraft

During the C61 council meeting the request was to provide more details on specific low TRL research that can be carried out in relation to finalized GoR-AS road-maps with collaborative potential.

Angela Vozella participated in a consultation by EG to identify research priorities supporting the themes proposed by ASGOR

The process of SRIA updating was supported during 2016 by AS GOR members in order to guarantee that the identified topics were included. Furthermore, within another working group launched within EREA (Association of European Research Establishments in Aeronautics), *EREA Security for Aviation Working group* (ES4AWG), a process to identify common security research priorities was launched too. The participation in this working group of AS GoR members has allowed to harmonize the choices made within both the groups (Garteur and ES4AWG). The conclusions are that the proposed themes should be transferred to and aligned with the current version of the updated SRIA, integrated with the interests expressed by industries involved by GARTEUR and harmonised with the choices of ES4AWG.

6 years rolling Plan for AS/EGs

No	Theme	Topic	2012	2013	2014	2015	2016	2017
AS/EG-1	Cybersecurity	- Towards an Information Security Management System for the aviation sector						
AS/EG-2	CBE	- Enhancing airport security against CBE threat						
AS/EG-3	Dazzling	- Detection of threatening laser radiation on aircraft or helicopters for future protection of pilots						
AS/EG-4	Malevolent use of RPAS	- Analysis of new threats posed by malevolent use of Unmanned Aerial Systems (UAS) and/or Remote Piloted Aircraft Systems (RPAS) - Threat mapping						

Active **Closed**
Extended **Inactive**

In 2017 the first meeting will take place in July.

Virginie Wiels

Chairman (2014-2016)

Group of Responsables Aviation Security

Chairmanship

Virginie Wiels has been chair for two years, but the current vice-chair Ingmar Ehrenpfordt has informed the GoR that she would not be able to take over the chairmanship due to a disengagement from DLR.

For 2017 the chairman role has been assigned to CIRA (Angela Vozella).

GoR membership 2016

Chairman			
Ms Virginie Wiels	ONERA	France	virginie.wiels@onera.fr

Vice-Chairman			
Mr. Ingmar Ehrenpfordt	DLR	Germany	ingmar.ehrenpfordt@dlr.de

Members			
Mr Bernd Eberle	Fraunhofer	Germany	bernd.eberle@iosb.fraunhofer.de
Mr. Anders Eriksson	FOI	Sweden	e.anders.eriksson@foi.se
Mr. Francisco Munoz Sanz	INTA	Spain	mugnozsf@inta.es
Ms. Angela Vozella	CIRA	Italy	a.vozella@cira.it
Mr. René Wiegers	NLR	Netherlands	rene.wiegers@nlr.nl

Table 1 Membership of GoR AS in 2016

ANNEX C

ANNUAL REPORT FROM THE GROUP OF RESPONSABLES
"FLIGHT MECHANICS, SYSTEMS AND INTEGRATION"

Remit

The Group of Responsables for Flight Mechanics, Systems and Integration is active in the field of flight systems technology in general.

The GoR-FM is responsible for all research and development subjects concerning a chain starting from the air vehicles and their flight mechanics, concerning embedded sensors, actuators, systems and information technology, cockpits, ground control and human integration issues, with reference to automation for both inhabited and uninhabited aircraft, including, but not limited to:

- Aircraft multidisciplinary design aspects;
- Flight performance, stability, control and guidance;
- Aircraft navigation and mission management ;
- Air traffic management and control;
- Integration of remotely piloted systems in the air spaces;
- Safety critical avionics functions and embedded systems ;
- Scientific and technical expertise for air systems certification and regulatory aspects.

Noticeably, GoR-FM is not active in the rotary wing domain where the GARTEUR Helicopter GoR is.

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FLIGHT MECHANICS, SYSTEMS AND INTEGRATION

GoR-FM Overview

GoR Activities

In 2016 the activities has been limited. As identified already in 2015 budget reductions have been preventing new ideas to grow and Exploratory Groups to transition to Action Groups.

The GoR management also reduced in activity due to changes at NLR.

Two Exploratory Groups were identified in 2015, but are not yet active:

- FM/EG-28 “Non-linear flexible civil aircraft control methods evaluation benchmark”;
- FM/EG-29 “Trajectory V&V Methods: formal, automatic control and geometric methods”.

FM/EG-28, has been scheduled to start after several changes in participation and limited budget at interested parties.

FM/EG-29 showed progress but has not yet finalized a starting paper.

New topics was discussed at GoR meeting and Pilot papers identified on several topics, Electric RPAS, Smart RPAS swarms and Upset Condition Detection as well as RPAS as validation flight test platform.

As in 2015, there were no Action Groups active.

Management Issues

The GoR met only once during 2016. The EGs were discussed and new topics identified. At the meeting industry and research organizations were but since only one meeting was held the yearly participation was limited.

Future Plans

During 2017 the GoR will continue efforts to establish new EGs and transition EGs into AGs. Changes at NLR resulted in an untimely departure of the previous GoR chair and the change in chair delayed the postponed GoR activities which will be taken up second half of 2017.

Managed and Foreseen GoR Activities

The following meeting were held during 2016:

- 105th GoR (FM) meeting at NLR, Amsterdam, The Netherlands, 5 April 2016;

Eight national representatives and IPOCs attended the meetings during 2016. The estimated effort associated with these activities amounts to 1/2 man-month (10 man-days) in total and the associated travel and subsistence costs are roughly 5 k€.

The following meetings are planned for 2017:

- 106th GoR(FM) meeting TBD.

Martin Hagström

Chairman (March 2017 - March 2019)

Group of Responsables

Flight Mechanics, Systems and Integration

GoR Membership

2016 membership of the Group of Responsables Flight Mechanics, Systems and Integration

Chairman			
Mr. Rob Ruigrok	NLR	The Netherlands	ruigrok@nlr.nl

Vice-Chairman			
Mr. Martin Hagström	FOI	Sweden	martin.hagstrom@foi.se

Members			
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TBD	INTA	Spain	
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Mr. Martin Hanel	Cassidian	Germany	martin.hanel@cassidian.com
TBD	SAAB	Sweden	

Status of Action Groups and Exploratory Groups

Action Groups (AG)
None.

Exploratory Groups (EG)
Two Exploratory Groups have continued to be in discussion in 2016:

- FM/EG-28 “Non-linear flexible civil aircraft control methods evaluation benchmark”;
- FM/EG-29 “Trajectory V&V Methods: formal, automatic control and geometric methods”.

Within FM/EG-28, which was defined and started in 2013, there were difficulties and changes in participation and limited budget at interested parties. It has been rescheduled to start.

FM/EG-29 showed some progress in 2016.

Future Topics

Pilot paper discussed and proposed: Electric RPAS, Smart RPAS swarms and Upset Condition Detection, Prevention and Mitigation (depending on outcome of Future Sky Proposal), RPAS as validation flight test platform and verifiable adaptive robust control.

Action Group Reports

No FM Action Groups were active in 2016.

ANNEX D

ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "HELICOPTERS"

Remit

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

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

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

- Decrease costs (development and operation) through Virtual Engineering using numerical tools based on low-order (analytical, BEM) to high-order (CFD) methods, validated with relevant tests campaigns
- Increase operational efficiency (improve speed, range, payload, all weather capability, highly efficient engines, ...)
- Increase security, safety
  - o Security studies, UAVs, advanced technologies for surveillance, rescue and recovery,
  - o Flight mechanics, flight procedures, human factors, new commands and control technologies,
  - o Increase crashworthiness, ballistic protection, …

- Integrate rotorcraft better into the traffic (ATM, external noise, flight procedures, requirements/regulations)
- Tackle environmental issues:
  - Greening, pollution
  - Noise (external, internal)
- Progress in pioneering: breakthrough capabilities

Technical disciplines include, but are not limited to, aerodynamics, aero elasticity 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 matters is the need for a multidisciplinary approach due to the high level of interaction between the different technical disciplines for tackling the various issues for rotorcraft improvement.

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

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HELICOPTERS

GoR-HC Overview

GoR-HC Activities

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

This membership enables the GoR to act as a highly effective forum in its primary function of promoting collaborative research through Exploratory Groups and Action Groups. It has been successful in establishing collaborative research programmes, at a non-competitive level, to the benefit of the European rotorcraft community, including both governmental and industrial interests. In addition, the GoR represents a unique forum within Europe for the interaction of the research establishments and industry, for the exchange of knowledge and understanding in the field of rotorcraft research and technology. An increasing number of University teams are associated to the activities of the action groups, with a real added value. Since 2011 the University of Liverpool is an active member of the GoR. The Helicopter GoR is a kernel for ideas for new research projects and supported the preparation of several EU proposals, even if the number of helicopter dedicated projects within H2020 has significantly been reduced compared to previous framework programmes.

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, and for vibration prediction and management and crashworthiness. This modelling capability has underpinned improvements across the field of rotorcraft performance, enhancing both military and civil market competitiveness, as well as safety for all users. There is no question that the availability of high quality, well-validated modelling tools is essential to the effective design and development of competitive helicopters and it may fairly be claimed that in supporting the creation of such tools over many years, GARTEUR has significantly contributed to place the European industry in the favourable position that it holds in the world market-place today.

In addition, as helicopters require multidisciplinary studies, the AGs discuss and exchange tools with other AGs (for example from FM, AD and SM domains).

The GoR-HC is used as a forum for briefings by members on their organisations' activities and for discussion of new ideas which may be mature for collaboration. The GoR also considers other collaborative initiatives within Europe, bringing mutual understanding and co-ordination and hence contributing to best use of scarce resources. For instance, the GoR is maintaining an awareness of the range of EU Technology Programmes.

Management issues

The chairmanship in 2016 was held by Mark White (University of Liverpool). Vice Chairman is Philippe Beaumier (ONERA) and has taken the chairmanship in 2017.

Generally speaking, the rotorcraft community in Europe is rather small. In fact most GoR members are at the same time deeply involved in the preparation of proposals for EU projects so that automatically there are close relations between GARTEUR research activities and EU projects.

In the Clean Sky and Clean Sky 2 Joint Technology Initiatives and especially for the Green Rotorcraft ITD and Fast Rotorcraft IADP, the GoR members are active. In the view of the GoR-HC, this aspect is advantageous for all, GARTEUR and EU, industry and research establishments. In practice the Exploratory Groups are used both for the generation of proposals for continued GARTEUR activity within an Action Group, normally at a relatively low level of effort, to analyse the state of the art for new topics and to define the framework and specification of further common research programmes, including EU proposals. In general, these activities are complementary, with some EU projects based on earlier GARTEUR research, and GARTEUR Action Groups benefiting from the outcome of EU funded activities. This applies in particular by using extensive wind tunnel and flight test databases, as well as any kind of valuable validation data.

During the reporting period, the GoR-HC held two meetings:

- 73th GoR Meeting: 24-25 February ‘16, TuDelft, Airbus Helicopters, Marignane, France,
- 74th GoR Meeting: 21-22 September ‘16, DLR, Braunschweig, Germany.

The main business of the meetings was to discuss about further topics and to implement the 3-5 year planning process as well as to present the status of the current AGs and EGs. The GoR meetings were used to harmonize the views and the involvement of members regarding preparations for proposals for H2020. These meetings were also used to discuss about Clean Sky and Clean Sky 2 activities, as well as future issues to be considered. Furthermore the dissemination of GARTEUR results on international conferences like the European Rotorcraft Forum (ERF) and the Annual Forum of the American Helicopter Society (AHS) was harmonized and supported.

In 2016 the activities in the HC-AGs was at a high level. 2016 started with six active Action Groups and one running Exploratory Group; at the end of the year two of these Groups closed their activities with their final report delivered early 2017.

Dissemination of GARTEUR activities and results

Results coming from Action Groups are traditionally prone to publication either in Journals or in Conferences. In the fields of Helicopters, the two conferences having the greatest impact are the European Rotorcraft Forum and the Annual Forum of the American Helicopter Society. The following tables lists the technical publications achieved in 2016.

	Conference	Venue, Date	Authors	Title
AG20	ERF2016	Lille, Sept. 2016	R. Wijntjes, F. Simon, T. Haase, O. Unruh, E. Tijs	Benchmark for Experimentation of Acoustic Transmission Los Applied to Helicopter Trim Panels
AG20	ERF2016	Lille, Sept. 2016	F. Simon, T. Haase, O. Unruh, G.L. Ghiringhelli, A.Parrinello, R.Vescovini	Benchmark for Modelization of Acoustic Transmission Loss Applied to Helicopter Trim Panels
AG20	ERF2016	Lille, Sept. 2016	M. Pohl, T. Haase	Experimental Test of Semi-Active Shunt Damping on a Helicopter Trim Panel
AG20	ERF2016	Lille, Sept. 2016	J. Derré, F. Simon	Concept of "Fractal" Helicopter Trim Panel
AG21	AIAA SciTech 2016	4-8 Jan. 2016, San Diego	White MD, Manso S and Hodge S, AIAA-2016-2138	An Investigation of Task Specific Motion Cues for Rotorcraft Simulators
AG22	AHS 72nd Annual Forum	West Palm Beach, (FL) USA, May 2016	Zagaglia, D., Giuni, M., Green, R.B.,	Rotor-Obstacle Aerodynamic Interaction in Hovering Flight: An Experimental Survey
AG22	ERF2016	Lille, Sept. 2016	Zagaglia, D., Gibertini, G., Droandi, G., Antoniazza, P., Oregio Catelan, A.	CFD Assessment of the Helicopter and Ground Obstacles Aerodynamic Interference
AG22	ERF2016	Lille, Sept. 2016	Zagaglia, D., Gibertini, G., Giuni, M., Green, R.	Experiments on the Helicopter-Obstacle Aerodynamic Interference in Absence of External Wind
AG23	ERF2016	Lille, Sept. 2016	B. G. van der Wall	Impact of Wind Energy Rotor Wakes on Fixed-Wing Aircraft and Helicopters
AG23	HeliTech 2016	Amsterdam, Oct. 2016		
AG23	German Aerospace Conference 2016	Braunschweig	Lehmann, P.; Jones, M.; Höfinger, M	Impact of Turbulence and Degraded Visual Environment on Pilot Workload
AG24	22nd AIAA/CEAS Aeroacoustics Conference	Lyon, France, 30 May - 1 June, 2016	Gennaretti, M., Bernardini, G., Poggi, C., Testa, C.,	A Boundary-Field Integral Formulation for Sound Scattering of Moving Bodies. ISBN: 978-162410386-5
AG24	ERF2016	Lille, Sept. 2016	M. Barbarino, D. Bianco, J. Yin, M. Lummer, G. Reboul, M. Gennaretti, G. Bernardini, C. Testa	Acoustical methods towards accurate prediction of rotorcraft fuselage scattering. Paper #62
AG24	ERF2016	Lille, Sept. 2016	J. Yin, K-S Rossignol, J. Bulté	Acoustic scattering experiments on spheres for studying helicopter noise scattering. Paper #127
	ERF2016	Lille, Sept. 2016	White MD	GARTEUR Helicopter Cooperative Research Activities

	Journal	Reference	Authors	Title
AG20	Journal of Sound and Vibration	361:20–31, (2016)	Pohl M. and Rose M.	Piezoelectric shunt damping of a circular saw blade with autonomous power supply for noise and vibration reduction

Reports issued

In 2016, no final reports were issued.

Status of Action Groups and Exploratory Groups

Action groups (AG)

The following Action Groups were active throughout 2016:

HC/AG-19 "Methods for Improvement of Structural Dynamic Finite Element Models Using In-Flight Test Data" has been started May 2010 for 3 years duration. This AG was extended up to the end of 2016, and the final report has been issued in Feb. 2017.

HC/AG-20 "Cabin internal noise: simulation methods and experimental methods for new solutions for internal noise reduction" started in October 2012. The activities in 2016 were focused on the dissemination of the results, and the final report has been issued in Jan. 2017.

HC/AG-21 "Rotorcraft Simulation Fidelity Assessment. Predicted and Perceived Measures of Fidelity" has been launched April 2013. Main goal of the project is the development of new simulation assessment criteria for both open loop predictive fidelity and closed-loop perceived fidelity. Final simulation trials were done in 2016.

HC/AG-22 "Forces on Obstacles in Rotor Wake" has been launched in November 2014. The objective is 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. Most of experimental activities were completed in 2016 and the numerical simulations have been continued. It is expected that HC/AG-22 will close as scheduled end 2017.

HC/AG-23 "Wind turbine wake and helicopter operations" has been launched in November 2014. The objectives are the analysis of the behaviour of helicopters in a wind turbine wake, the identification of the safety hazards and the definition of measures to mitigate identified safety issues. The University of Glasgow has joined this AG due to the movement of one of the AG members, Professor G Barakos, to that University. A 15-months extension up to the end of 2018 was asked for during the C62 Council meeting to complete the activities and propose several publications.

HC/AG-24 "Helicopter Fuselage Scattering Effects for Exterior/Interior Noise Reduction" was launched in January 2015, with an initial plan to run for two years with an option to run for a third year. The extension to a 3 year duration was decided in the March 2016 Council. The main objective is to examine rotor noise propagation in the presence of a fuselage. The activity will establish an experimental acoustic database and prediction design tools for main and tail rotor noise in the influence of a fuselage (2016 activities) and will also include main/tail rotor interactions (on-going). The last test campaign is planned for September/October 2017.

Exploratory groups (EG)

HC/EG-29 “Intelligent Lifeing & HUMS” was launched in 2011, and started in April 2013. The exploratory group has not produced its report in 2016 and is expected to conclude its activities in 2017.

Rolling plans

The Environmental issues are included in the studies of the Green Rotorcraft Integrated Technological Demonstrator, within the Clean Sky JTI programme, launched by European industries and partially funded by EU. The follow up of the programme, the Clean Sky 2 JTI, started in 2014. The GoR members, are associates (research centres) and leaders (industry) in the CS1 initiative while in CS2 the industrial members are leaders and the research institutions are core-partners.

The 3–5 year planning will continue to be implemented and was presented in more detail to the Council in the March 2017 meeting in Amsterdam. This list is implemented with new topics according to the GoR discussions.

During the GoR meetings, several topics of mutual interest have been discussed and their potential for GARTEUR collaborative programmes has been examined.

Topic	ST	2012	2013	2014	2015	2016	2017	2018
Methods for Impr. of Struct. Modell. In-Flight Data	HC/AG19						▲	
Simulation/Testing for design of passive noise absorption panels	HC/AG20	EG28 =>					▲	
Rotorcraft Simulation Fidelity Assessment	HC/AG21	EG30 =>						
Forces on Obstacles in Rotor Wake	HC/AG22		EG32 =>					
Wind Turbine Wake and the effect on helicopters	HC/AG23		EG32 =>					
Helicopter Fuselage Scattering Effects for Exterior/Interior Noise Reduction	HC/AG24			EG34 =>				
Testing/Modell. for Internal Noise Investig.	HC/EG28							
HUMS	HC/EG29							
Simulation Fidelity	HC/EG30		=> AG21					
Conceptual design of Helicopters CoDHe	HC/EG31			x				
Forces on Obstacles in Rotor Wake	HC/EG32			=> AG22				
Wind Turbine Wake and the effect on helicopters	HC/EG33			=> AG23				
CFD based flow prediction for complete helicopters	HC/EG34			x				
Helicopter Fuselage Scattering Effects for Exterior/Interior Noise Reduction	HC/EG35			=> AG24				
(Centrifugal Effects on Boundary Layer)	ID							
Rotor Rotor Interactions	ID						=> EG36 ?	
Noise Annoyance Generated by Helicopters	ID							
(Man-machine interface in cockpit operations)	ID							
(Virtual Engineering: Verification & Validation)	ID							

▲ Final report delivered

GoR membership

Chairman			
Mark White	Uni. of Liverpool	United Kingdom	mdw@liverpool.ac.uk

Vice-Chairman			
Philippe Beaumier	ONERA	France	beaumier@onera.fr

Members			
Odile Parnet	Airbus Helicopters	France	odile.parnet@airbus.com
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Joost Hakkaart	NLR	The Netherlands	joost.hakkaart@nlr.nl
Lorenzo Notarnicola	CIRA	Italy	l.notarnicola@cira.it
Observer			
Richard Markiewicz	Dstl	United	rhmarkiewicz@mail.dstl.gov.uk

Table of participating organisations

	HC/AG and HC/EG numbers						
	AG19	AG20	AG21	AG22	AG23	AG24	EG29
Research Establishments							
ONERA		■	□	□	□	□	□
DLR		□	□	□	□	■	□
CIRA		□		■	□	□	
NLR	■	□	□	□	■	□	□
Dstl							
CNR-INSEAN						□	
Industry							
Airbus Helicopters, France							
Airbus Helicopters, Germany							□
AgustaWestland / Leonardo	□		□				
Thales			□				
LMS (Belgium)	□						
CAE (UK)			□				
ZF Luftfahrttechnik GmbH (D)							□
IMA Dresden (D)							□
MICROFLOWN		□					
Qinetiq	□						
Academic Institutes							
University of Liverpool (UK)			■	□	□		
University of Cranfield (UK)							□
Imperial College, London (UK)							
University of Manchester (UK)							
University of Glasgow (UK)				□	□		
University of Bristol (UK)	□						
University of Brunel (UK)	□						
TU Delft (NL)			□		□		
University of Twente (NL)							
University of Munich (D)					□		■
University of Roma La Sapienza (IT)	□						
University of Roma 3 (IT)						□	
Politecnico di Milano (IT)		□		□	□	□	
Politecnico di Torino (IT)							
National Technical Univ. of Athens				□	□		

□ = Member ■ = Chair

The large number of UK Universities involved in AGs is noticeable.

Total yearly costs of AG research programmes

	2010	2011	2012	2013	2014	2015	2016	2017	Total
Person-month	16	7	13	36.5	44,5	88.7	79.5	55	340.2
Other costs (k€)	4	10	6	13	38	103.1	102.9	54	331

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

HC/AG-19: Improvement of Structural Dynamic FEM using In-flight Test Data

Action Group Chairman: Hans van Tongeren (Hans.van.Tongeren@nlr.nl)

Interest of the research

AG-19 investigates methods to improve the structural dynamic representation of a helicopter fuselage.

Background

The issue of vibration in helicopters is of major concern to operators in terms of the maintenance burden and the impact on whole life costs. Operators are demanding smooth ride vehicles as a discriminator of vehicle quality, which requires close attention to the vehicle dynamics.

Good mathematical models are the starting point for low vibration vehicles. The ability to faithfully simulate and optimize vehicle response, structural modifications, vehicle updates, the addition of stores and equipment is the key to producing a low vibration helicopter. However, there are many issues affecting the creation of an accurate model and it is clear that much research is needed to further that understanding.

A recent GARTEUR Action Group, HC/AG-14, concluded that helicopter dynamic models are still deficient in their capability to predict airframe vibration. The AG looked at the methods for improving the model correlation with modal test data along with the suitability of existing shake test methods.

Among others, the following recommendations were made for continued research:
• Study effects of configuration changes in the structure. How significant are these effects? How can uncertainties be handled in the context of an FE model. What is the influence of flight loads.
• The helicopter structure tested in HC/AG-14 was suspended in the laboratory. However, this is not the operational environment where there are very significant mass, inertia and gyroscopic effects from the rotor systems. Could in-flight measurements be made? What are the benefits?

Other recommendations with respect to ground vibration testing are considered in the closely related GARTEUR Action Group HC/AG-18.

Programme/Objectives

Objectives
The main purpose of this AG is to explore methods and procedures for improving finite element models through the use of in-flight dynamic data. For the foreseeable future it is expected that validated 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 participants that the procedure of validating and updating helicopter finite element models with such in-flight data is robust, rigorous and effective in delivering the best finite element model.

The members will present further developments of methods used to update the finite element model whether automated, manual or both. Advantages and disadvantages of the approaches should be given and possible future developments of the procedures for localizing the areas of the models causing the discrepancies and for improving the updating process presented. The members will present developments of methods for the prediction of the effect of configuration changes on FRF behaviour. These can be based on a finite element model. Advantages and disadvantages of the approaches should be given and possible future developments of the procedures presented.

Finally the group shall assess the methodology with respect to evaluating vibration measurements from flight tests where effects of aerodynamic and rotating machinery affect the vehicle response. The objective is to extract modal parameters from in-flight measured data. Advantages and disadvantages of the approaches should be given and possible future developments of the procedures presented.

Traditional analysis versus OMA analysis

Available flight test data
Three sources of flight test data are available to the action group:

A flight test programme on an attack helicopter resulted in vibration response measurements on the stub wings for a wide range of manoeuvres and store configurations. A Full Aircraft GVT on RNLAF attack helicopter was conducted by Agusta Westland Ltd (with NLR assistance) on 5-7 March 2012.

The department of mechanical and aerospace engineering of "La Sapienza" University has a model helicopter at it disposal. Flight tests have been conducted with this helicopter. A finite element model is available. Ground vibration tests have been conducted. The advantage of this helicopter is that it is available for additional ground vibration and flight tests.

The third data set is based on LMS flight test data for Polish Helicopter

Results

The project should result in a review of various methods to process acceleration (or other) time signals. Sine inputs from rotating components in the flying helicopter dominate the response signals and obscure the structural responses related to structural vibration modes. The methods should separate the rotating component contributions from the structural vibration content. The updated finite element models will be used to predict in flight vibration responses of existing and new store configurations. This may reduce the amount of flight testing required to validate new store configurations. This is beneficial to both operators and manufacturers. This could involve coupling the structure model to simulation models that predict the main and tail rotor hub excitation levels.

So far, available experimental flight test data for validation purposes has been analyzed to update the related FE models. For the attack helicopter, model mass and construction of the complete helicopter model is finished. The GVT on a Dutch Attack helicopter was used to update the complete helicopter model. The flight test data will be used to further improve this model.

Members of the HC/AG-19 group are:

Nima Ameri	Bristol University
Giuliano Cappotelli	Sapienza University Rome
Johnathan Cooper	Bristol University *previously Liverpool University*
David Ewins	Bristol University
Cristinel Mares	Brunell University
Bart Peeters	LMS
Hans van Tongeren	NLR
Trevor Walton	Agusta Westland Ltd

GARTEUR Responsable:
Joost Hakkaart NLR

University of Liverpool · Brunel University West London · LMS Engineering Innovation · University of Bristol · NLR · Sapienza Università di Roma · AgustaWestland · University Technology Centre

HC/AG-19

HC/AG-19	**METHODS FOR IMPROVEMENT OF STRUCTURAL DYNAMIC FE MODELS USING IN FLIGHT TEST DATA**	
Monitoring Responsable:		J. Hakkaart NLR
Chairman:		H. van Tongeren NLR

- **Objectives**

The issue of vibration in helicopters is of major concern to operators in terms of the maintenance burden and the impact on whole life costs. Operators are demanding smooth ride vehicles as a discriminator of vehicle quality, which requires close attention to the vehicle dynamics. Good mathematical models are the starting point for low vibration vehicles. The ability to faithfully simulate and optimize vehicle response, structural modifications, vehicle updates, the addition of stores and equipment is the key to producing a low vibration helicopter. However, there are many issues affecting the creation of an accurate model and it is clear that much research is needed to further that understanding. The main purpose of this AG is to explore methods and procedures for improving finite element models through the use of in-flight dynamic data. For the foreseeable future it is expected that validated 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 participants that the procedure of validating and updating helicopter finite element models with such in-flight data is robust, rigorous and effective in delivering the best finite element model. The members will present further developments of methods used to update the finite element model whether automated, manual or both. Advantages and disadvantages of the approaches should be given and possible future developments of the procedures for localizing the areas of the models causing the discrepancies and for improving the updating process presented. The members will present developments of methods for the prediction of the effect of configuration changes on FRF behaviour. These can be based on a finite element model. Advantages and disadvantages of the approaches should be given and possible future developments of the procedures presented.

Finally the group shall assess the methodology with respect to evaluating vibration measurements from flight tests where effects of aerodynamic and rotating machinery affect the vehicle response. The objective is to extract modal parameters from in-flight measured data. Advantages and disadvantages of the approaches should be given and possible future developments of the procedures presented.

- **Main achievements**

For the main achievements, distinction is made between: Method development, Model updating based on GVT results, Processing of flight test data and Model updating based on flight test data.

Methods development

LMS used recently developed software enhancements to process flight test data. Agusta Westland (AW) and the UoB cooperated in using AW proprietary software to process the flight data. AW uses an as Operational Modal Analysis (OMA) enhanced with advanced order domain filter to remove rotor orders. La Sapienza further developed its proprietary software “NIMA”.

Model updating based on GVT results

The FE models of the stubwing were updated using the stub wing GVT results. Brunell University and Qinetiq undertook this activity initially. At a later stage, students from La Sapienza University continued this work. The stubwing FE model was integrated in the whole aircraft FE model. The whole aircraft FE model was updated using the GVT on the RNLAF helicopter. This activity was undertaken by students of the La Sapienza University as a master thesis subject, while stationed at NLR.

Processing of flight test data

The limited number of data points in the flight tests is insufficient for updating the whole aircraft FE model, but it did allow evaluation of various signal processing / system identification methods and updating of the stubwing FE model as a component in the whole aircraft FE model. Two different approaches to deal with the modal identification of in-flight helicopter data were evaluated. In the first, the acceleration spectra are analysed and the harmonic components are identified. A frequency-domain model is fit to the spectrum of the identified harmonic component and is then removed from the original spectrum. The underlying “harmonic-free” model is then identified using the Hilbert transform method to obtain the modal parameters. The second approach tries on the other hand to remove the harmonics from the time domain signals, using both angle-domain time synchronous averaging and the spectral method. LMS then fed the filtered data to the new PolyMAX Plus estimation technique to identify the modal model of the structure. Similar work was done by a student of the La Sapienza University as a master thesis subject, while stationed at NLR. La Sapienza proprietary software “NIMA” was used for this activity. AW has processed attack helicopter flight data for selected flight events where the rotor speed varies slightly: transitions to hover and rotor stop events. NLR extracted these events from the original flight test time recordings of flight 4. AW was able to separate the rotor frequencies and extract some of the structural modes.

Model updating based on flight test data

Femtools was used by a student of the La Sapienza University stationed at NLR to update the FE model of the stub wings with the modal parameters extracted from flight test data.

- **Management issues**

Both Kick-Off meeting and the first technical meeting took place in 2008. Major achievements were made in 2012-14 and final report issued early 2017.

- **Results/benefits**

Conclusions

With the available data directly from flight tests and data from a ground test excited with in-flight recorded accelerations the group managed to identify harmonic components in the measured responses. This data was used to clean the measured signals and to use the cleaned signals for the identification of the structural modal parameters. Although the amount of signals in the flight test was limited to stubwing data only, it proved to be possible to further update a FE model of this area in the FE model of the whole helicopter.

Impact

The AG published intermediate results in a dedicated Garteur AG-19 session at the ISMA 2012 conference in Leuven.

Future Work

Prediction of the effect of configuration changes on FRF behaviour was not covered in AG-19. Significant benefits are to be gained if a method would be available. This would result in a possible reduction of the number of flight tests by eliminating tests for less critical configurations. Another benefit could be the prediction of local fatigue behaviour. This could be useful in evaluating the effect of local design changes to resolve fatigue related problems. This prediction will be based on the best representative model available and in-flight vibration data for a range of store configurations.

- **HC/AG-19 membership – core team**

Member	Organisation	e-mail
Giuliano Cappotelli	La Sapienza Uni Rome	chiara.grappasonni@uniroma1.it
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Hans v Tongeren *c*	NLR	Hans.van.tongeren@nlr.nl
Trevor Walton	Agusta Westland Ltd	Trevor.Walton@agustawestland.com

- **Resources**

Resources		Year								Total
		08-09	2010	2011	2012	2013	2014	2015	2016	
Person-months	Actual/ Planned	A5 P6	A16 P6	A7 P18	A12 P10	A3 P8	A10	A2	A1	A56 P42
Other costs (in K€)	Actual/ Planned		A4 P4	A10 P10	A5 P5	P3				A19 P22

- **Progress/Completion of milestone**

Work package	Planned		Actual
	Initially (end of …)	Currently (updated)	
Task 1: model updating based on ground vibration tests	2009	2013	2013
Task 2: Prediction of configuration changes on FRF behaviour	2011	2013	2014
Task 3: How to measure and use in-flight dynamic data for the extraction of modal parameters that include the effects of aerodynamic loads, and rotating machinery	2011	2013	2014
Task 4: Vibration prediction based on hub load predictions for the flight test conditions	2011	2013	2014
Task 5: Reporting	2011	2013	2017

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

HC/AG-20: Simulation methods and experimental methods for new solutions for internal noise reduction

Action Group Chairman: Frank Simon (frank.simon@onera.fr)

Interest of the research

AG-20 investigates methods to reduce the cabin noise of a helicopter.

Background

Since several years, aeronautical industries have wished to improve internal acoustic comfort. It is particularly true within the cabin of a helicopter where the passenger is in very close proximity to disturbing sources that contribute to interior noise: main and tail rotors, engines, main gearbox (tonal noise) and aerodynamic turbulence (broadband noise).

Nevertheless, to reduce global mass, the trim panels in cabin are generally provided with a core in Nomex honeycomb and external layers in composite fibres. This light assembly is not subjected to high static force and must just assure a sufficient stiffness not to be damaged during the helicopter life. Each material satisfies specific tests to be certified: behavior in high temperature, with humidity... To use these components can worsen the internal acoustic comfort because their behaviour is essentially due to mass effect.

It appears that conventional passive systems (trim panels, passive anti-resonance isolation systems as well as classical vibration absorbers and pendulum absorbers) are still the main way to control the acoustic of the cabin whereas active systems (active vibration and noise control) are not completely reliable or applicable (problems of robustness or time convergence of algorithms – often reduction in some area but increase outside – high added mass and electrical power – difficult identification of optimal locations for actuators and sensors).

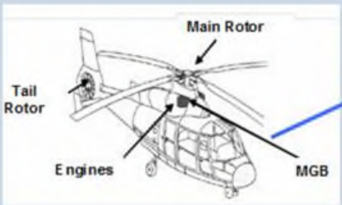
Programme/Objectives

Objectives

HC/EG-28, about internal noise and associated passive acoustic solutions (soundproofing, e.g. 1cm-thick trim panels designed for optimizing the absorption or the transmission loss), development of a vibro-acoustic model of the cabin (SEA coupled with FEM), human factors (subjective annoyance, speech intelligibility)" brought to launch the HC/AG20.

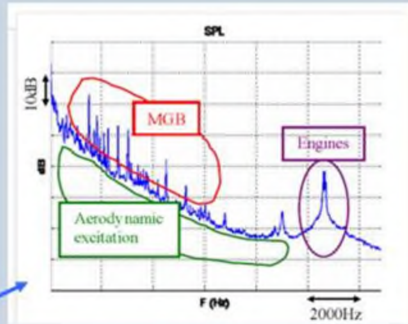
The HC/EG-28 conclusions listed the following needs:

1) to improve quality of absorption of materials with absorbing fillings or foam material tuned to control specific frequency bands
2) to design composite trim panels with industrial requirements and simulate acoustic performances of treatments after integration in cabin
3) to develop reliable vibro-acoustic "methodologies" to reproduce the interior noise levels in large frequency range by combined numerical models/ experimental data
4) to estimate mechanical power sources and contribution of vibration panels radiating in cabin (Structure-borne transmission of energy from gearbox and engines through helicopter frame to the trim panels)
5) to take into account "subjective or human annoyance" in specific frequencies
6) to study influence of noise on the communication between pilot and crews (problem of speech intelligibility)



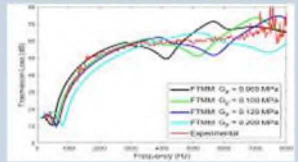
The activities in the new HC/AG-20 constitute the conclusion of HC/EG-28 and explore the points 2 to 4:

- applying different types of simulation methods to design and optimize composite trim panels according to common acoustic cost functions, and to validate numerical approaches by tests in laboratory
- applying different types of experimental techniques to characterize composite trim panel acoustic radiating in both a standardized test set –up and a generic helicopter cabin.
- experimental methods to separate correlated and uncorrelated acoustic sources in cabin. This identification is essential to reproduce internal noise from experimental database and also to apply sound source localization methods as beamforming or holography.



Results

The AG results in a benchmark of the appropriateness of tools for complex configurations (multiple anisotropic layers with various mechanical characteristics) and applies complementary passive and active concepts for composite trim panels.



Panel 2: Simulations Polimi / expérimentation Onera

Members of the HC/AG-20 group are:

F. Simon	ONERA
A. Grosso	MICROFLOWN
T. Haasse	DLR
R. Wijntjes	NLR
Gian Luca Ghiringhelli	Politecnico di Milano

GARTEUR Responsable:
Ph. Beaumier ONERA

Microflown Technologies — Charting sound fields
NLR
ONERA — THE FRENCH AEROSPACE LAB
DLR
POLITECNICO MILANO

HC/AG-20

HC/AG-20	**CABIN INTERNAL NOISE: SIMULATION METHODS AND EXPERIMENTAL METHODS FOR NEW SOLUTIONS FOR INTERNAL NOISE REDUCTION**	
Monitoring Responsable:		P. Beaumier ONERA
Chairman:		Dr. F. Simon ONERA

- **Objectives**

EG28, about internal noise and associated passive acoustic solutions (soundproofing, e.g. 1cm-thick trim panels designed for optimizing the absorption or the transmission loss), development of a vibro-acoustic model of the cabin (SEA coupled with FEM), human factors (subjective annoyance, speech intelligibility)" brought to launch the AG20.

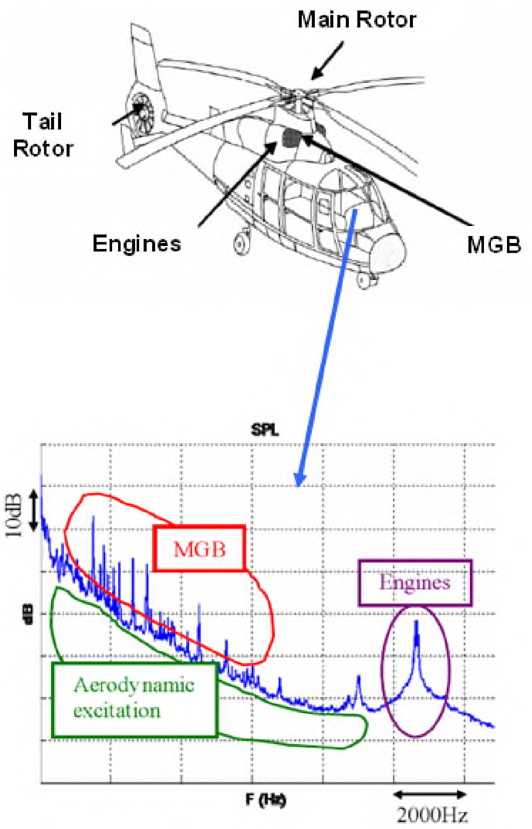
The EG28 conclusions listed the following needs:

1) To improve quality of absorption of materials with absorbing fillings or foam material tuned to control specific frequency bands
2) To design composite trim panels with industrial requirements and simulate acoustic performances of treatments after integration in cabin
3) To develop reliable vibro-acoustic "methodologies" to reproduce the interior noise levels in large frequency range by combined numerical models/ experimental data
4) To estimate mechanical power sources and contribution of vibration panels radiating in cabin (Structure-borne transmission of energy from gearbox and engines through helicopter frame to the trim panels)
5) To take into account "subjective or human annoyance" in specific frequencies
6) To study influence of noise on the communication between pilot and crews (problem of speech intelligibility)

- **Activities**

The activities of AG20 explored the following points:

- Applying different types of **simulation methods** to design and optimize composite trim panels according to common acoustic cost functions, and to validate numerical approaches by tests in laboratory
- Applying different types of **experimental techniques** to characterize composite trim panel acoustic radiating in both a standardized test set –up and a generic helicopter cabin.



- **Management issues**

Management in 2016 was mainly focussed in the preparation of the 4 papers delivered at ERF2016 in Sept. 2016 in Lille, with one full session dedicated to AG20.

- **Results/benefits**

Firstly, the research has led to a comparison between different facilities (NLR, DLR and ONERA) and measurement techniques (conventional and in situ) to measure the Transmission Loss (TL) applied to two ONERA reference sandwich trim panels (frequency range 200-10000 Hz):

- Repeat measurements at a single facility showed that the amount of deviation is within limits, 95% of the data is within a maximum difference of 2 to 3 dB.

- Higher deviation between facilities (about twice as high), although the same ISO standards are used to perform the measurements, can be explained essentially by a modification of some elastic properties, in particular for melamine foam (after several years of storage).

- A "clamped" boundary condition is preferred to a "free-free" suspension because of flanking noise, difficult to suppress.

- The PU probes of Microflown (Pressure - Velocity) showed good results when used in conventional TL measurement setups (compared with classical techniques using pressure sensors as PP intensity probe).

- The possibility of measuring transmission loss with an "in situ" technique is investigated for several sample types, but their small size (0.84 x 084 m²) makes impossible the using of this technique.

Secondly, a comparison between numerical methods (DLR, ONERA and PoliMI) has been done to compute the Transmission Loss (TL) applied to two ONERA reference sandwich trim panels (frequency range 200-10000 Hz):

- Three methods take into account the finite size of panel, i.e. "multi-layered model" (ONERA), FE-model (DLR) and SL Ritz (PoliMI).

- Two other methods lie in more analytical frames applied to infinite panel i.e. "transverse dilatation model" (ONERA) and TMM (PoliMI).

- The results are satisfactorily comparable, despite the difficulties in modelling dynamic problems in the specific frequency range.

- All the methods are able to catch typical physical phenomena, e.g. the TL decay due to a double wall effect.

- Furthermore they match well with experimental data.

- The little time required by the analysis of "infinite" approaches (few seconds against many minutes for other approaches) and a negligible time for model building make TMM and "transverse dilatation model" suitable candidates for optimization activities.

- To improve the TL of sandwich panels, an approach using local heterogeneities (mass type or damping material) distributed over the sandwich panel according to a "self-similar" or "pre-fractal" pattern (ONERA) has been investigated.

- Finally, the applicability of a semi-active shunt damping system applied to one of reference sandwich panel was tested in a Transmission Loss facility (DLR).

- **HC/AG-20 membership**

Member	Organisation	e-mail
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Thomas Haase	DLR	Thomas.Haase@dlr.de
Frank Simon	ONERA	frank.simon@onera.fr
Gian Luca Ghiringhelli	PoliMI	gianluca.ghiringhelli@polimi.it

- **Resources**

Resources		Year					Total
		2012	2013	2014	2015	2016	
Person-months	Actual/ Planned	A1	P18	P20	P18	P9	P66
Other costs	Actual/ Planned	A1	P10	P28	P28	P28	P95

- **Progress/Completion of milestone**

All milestones were achieved in 2016.

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

HC/AG-21: Rotorcraft Simulation Fidelity Assessment: Predicted And Perceived Measures Of Fidelity

Action Group Chairman: Mark White (mdw@liv.ac.uk)

Interest of the research

AG-21 aims at quantifying the perception of a of a rotorcraft simulator fidelity.

Background

The qualification of rotorcraft flight simulators is undertaken using the new framework detailed in "Certification Specifications for Helicopter Flight Simulation Training Devices CS-FSTD(H). This document contains a number of component fidelity requirements, flight loop data matching tolerances (i.e. Qualification Test Guide) and some brief guidance material on the requirements for the final subjective assessment of a simulator in order for it to be qualified to a certain Level.

The work from a previous GARTEUR activity, HC/AG-12, "Validation Criteria for helicopter real-time simulation models", indicated that there were a number of shortcomings in the current civil simulator standards, namely the tolerances contained within JAR-FSTD H (predecessor to CS-FSTD(H)) have no supporting evidence for their definition and there is not a systematic approach identified for overall fidelity assessment.

HC/EG-30, (Simulation Fidelity) examined the state of play of current research and industrial practice and recommended a focussed activity for a future Action Group to examine critical aspects of simulator fidelity and fitness for purpose, e.g. the flight model tuning process, metrics and tolerances, integrating predicted and perceived fidelity. The GARTEUR work highlighted the need for the evaluation of overall fidelity of the integrated system of pilot and machine and is driver for the new GARTEUR activity in this area.

Programme/Objectives

Objectives

Helicopter simulation training device qualification is a complex activity, requiring a large number of resources. In order to effectively address some of the key challenges identified previously a work programme has been developed in order to enhance current simulator qualification standards.

The principal objective of the Action Group is to gain a better understanding of the various components that contribute to the definition and perception of rotorcraft simulation fidelity. This may subsequently result in the development of new criteria for fidelity assessment. This activity would require an examination of the influence of the flight loop tolerances on predicted fidelity assessment together with an investigation of the role of simulator cueing on subjective or perceived fidelity assessment.

The research outcomes will be in the form of new metrics which would define rotorcraft simulation fidelity boundaries together with guidelines for the subjective fidelity assessment process.

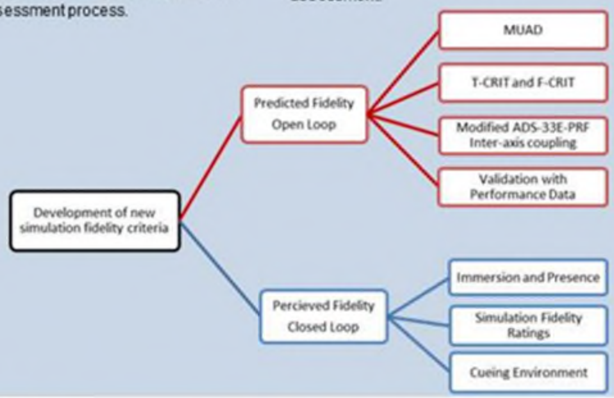
The work programme has two strands:

Predicted Fidelity assessment using off-line flight models with a range of standard control inputs

Perceived Fidelity assessment using ground-based pilot-in the-loop simulations at partners' own facilities.

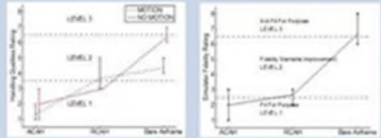
Specific areas of interest for helicopter flight simulation device fidelity include:

1. An investigation of validation techniques for the definition of predicted or flight loop fidelity
2. Definition of new criteria for predicted fidelity assessment
3. Definition of new rotorcraft flight test manoeuvres to be used during the subjective evaluation of a simulator
4. An investigation of the effect cueing on the subjective assessment of fidelity
5. Development of metrics for subjectively perceived fidelity
6. Development of an overall methodology for fidelity assessment.



Results

Flight simulator tests have shown that the Simulation Fidelity Rating (SFR) Scale is a useful tool for measuring fidelity in the absence of objective tests. It has been used to demonstrate that simulator fidelity motion cueing requirements are not only task based, but are also dependent on the handling qualities of the aircraft being flown. Immersion questionnaires have been developed to subjectively assess the fidelity experienced by users are currently being used in simulation fidelity trials.



Handling Qualities and Simulator Fidelity Ratings awarded for the Hover Task.

Members of the HC/AG-21 group are:

M White	University of Liverpool
G.Meyer	University of Liverpool
M. Pavel	TuDelft
O. Stroosma	TuDelft
J. vd Vorst	NLR
C. Seehof	DLR
F. Cuzieux	ONERA
B. Berberian	ONERA
M. Theophanides	CAE
S. Richard	Thales

GARTEUR Responsable:
J. Haakkart NLR

UNIVERSITY OF LIVERPOOL THALES NLR DLR TUDelft CAE ONERA THE FRENCH AEROSPACE LAB

HC/AG-21

HC/AG-21 "ROTORCRAFT SIMULATION FIDELITY ASSESSMENT: PREDICTED AND PERCEIVED MEASURES OF FIDELITY"

Monitoring Responsable:	J. Hakkaart NLR
Chairman:	Dr. M. White UoL

- **Objectives**

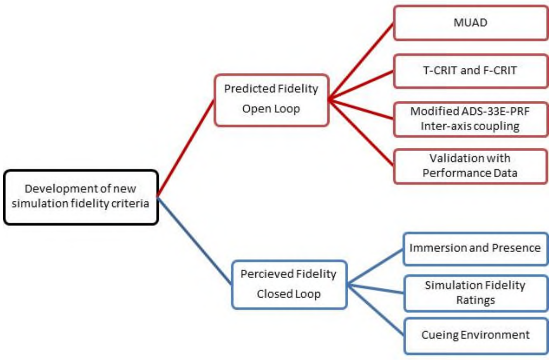
The principal objective of the Action Group (AG) was to gain a better understanding of the various components that contribute to the definition and perception of rotorcraft simulation fidelity. This activity required an examination of the influence of the flight loop tolerances on predicted fidelity assessment together with an investigation of the role of simulator cueing on subjective or perceived fidelity assessment.

Specific areas of interest for helicopter flight simulation device fidelity include:

- An investigation of validation techniques for the definition of predicted or flight loop fidelity
- Definition of new criteria for predicted fidelity assessment
- Definition of new rotorcraft flight test manoeuvres to be used during the subjective evaluation of a simulator
- An investigation of the effect cueing on the subjective assessment of fidelity
- Development of metrics for subjectively perceived fidelity
- Development of an overall methodology for fidelity assessment.

- **Activities**

The activities in AG21 were formed out of the conclusion of EG30. The work programme had two strands within the AG activity, related to predicted and perceived fidelity, shown in the figure below:



1. Predicted Fidelity assessment using off-line flight models with a range of standard control inputs
2. Perceived Fidelity assessment using ground-based pilot-in-the-loop simulations at partners' own facilities.

In the predicted fidelity activity, existing models were used to provide the framework for the evaluation of the different validation techniques. Activity 2 focussed on perceived fidelity assessment in examining the effect of the cueing and virtual environment on subjective evaluation of fidelity A series of flight simulation trials have been completed to examine the effect of motion cueing on task performance and analysis of the results is ongoing. The Simulation Fidelity Rating (SFR) scale has been used to obtain subjective feedback from pilots when flying a range of ADS-33E Mission Task Elements.

- **Management issues**

Management in 2016 focussed on completing a motion cueing paper for the SciTech Conference in 2016 and completion of the Immersion and Presence flight simulator testing.

- **Results/benefits**

The research outcomes have begun to determine new metrics which could be to define rotorcraft simulation fidelity flight loop boundaries. Recommendations and methodologies for undertaking subjective fidelity assessment process has also been evaluated. The key results are presented as follows:

Predicted Fidelity
- ValCrit-T is a useful metric for quantifying and comparing the relative statistical significance of errors between two models.
- ValCrit-T is not an absolute metric of model quality but could be used to place bounds on acceptable data noise amplitude.

Perceived Fidelity
- A simulator fidelity process was proposed with the use of the Simulator Fidelity and Motion Fidelity rating scales as an improved method of subjective assessment.
- An Immersion/Presence Questionnaire used in other VR applications has been shown to be an effective tool in capturing the subjective experience of users in Flight Simulators
- The Subjective Assessment has been used to demonstrate that simulator fidelity motion cueing requirements are not only task based, but are also dependent on the handling qualities of the aircraft being flown.
- A process for defining flight simulator assessment manoeuvres has been developed.
- Two low- to moderate-aggression manoeuvres have been developed for flight simulator fidelity assessments to evaluate motion and visual cues when operating close to the ground.

- **HC/AG-21 membership**

Member	Organisation	e-mail
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Sylvain Richard	Thales	sylvain.richard@thalesgroup.com

- **Resources**

Person month resources were confirmed during the kick-off meeting and have been split tentatively in years. Other costs will be assessed at the next progress meeting.

Resources		Year				Total 08-12
		2013	2014	2015	2016	
Person-months	Actual/ Planned	P18/ A15.5	P24.5 /A14.5	P18/A6	P0/A4	P60.5/ A40
Other costs (in K€)	Actual/ Planned		P10/ A10	P10/A10	P0/A8	P20/A28

- **Progress/Completion of milestone**

Work package	Planned		Actual
	Initially (end of …)	Currently (updated)	
WP 1 Simulation Models and Mission Task Elements (MTE) Definition	2013	2014	2015
WP 2 Simulator cueing – motion fidelity metrics	2015	2016	2016
WP3 Flight Loop Fidelity	2015	2016	2016
WP 4 Immersion and Presence	2015	2016	2016
WP 5 Perceived Fidelity Assessment	2015	2016	2016

GARTEUR — GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE
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HC/AG-22: Forces on Obstacles in Rotor Wake

Action Group Chairman: Antonio Visingardi (a.visingardi@cira.it)

Interest of the research

AG-22 investigates methods to better understand and predict the obstacles-rotorcrafts relative influence.

Background

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 wind conditions, the distance and the height of the helicopter from the obstacles and the ground are the main factors due to which the wake generated by the obstacle in the vicinity of the ground may result in: high compensatory workload for the pilot; degradation of the handling qualities and performance of the aircraft; unsteady forces on the structure of the surrounding obstacles. These forces are of aerodynamic nature and arise from the interaction between the wake induced by the rotor and the airflow around the obstacles.

A helicopter sling load is another, however particular, case of obstacle subject to forces produced by its interaction with the rotor wake. Once airborne a sling load comes under the influence of aerodynamic forces and moments associated with its size, shape, mass, and transport speed. The instabilities that can arise from these forces affect the rotorcraft and/or the load itself and their avoidance is therefore crucial not only for safety reasons, but also when a controlled attitude of the load is required.

Several publications address the problem of the helicopter ground effect in confined areas, the majority of them concerning investigations of the helicopter-ship interactional problem. Nevertheless, references of the evaluation of forces acting on obstacles in rotor wake are scarce. Likewise, there are few experimental databases for the validation of numerical methodologies, their accessibility is uncertain, and do not provide force measurements on obstacle surfaces.

Programme/Objectives

The principal objective of HC-AG22 is then to promote activities which could contribute to fill these gaps. This will be accomplished by investigating, both numerically and experimentally:

- the effects of the confined area geometry on a hovering helicopter rotor from the standpoints of both the phenomenological understanding of the interactional process and the evaluation of the forces acting on surrounding obstacles;
- the downwash and its influence on the forces acting on a load, loose or sling, at low to high separation distances from the rotor disc.

The project, started in November 2014, has a duration of three years during which the following activities are carried out:

- application and possible improvement of computational tools for the study of helicopter rotor wake interactions with obstacles;
- set-up and performance of cost-effective wind tunnel test campaigns aimed at producing a valuable experimental database for the validation of the numerical methodologies applied;
- final validation of the numerical methodologies.

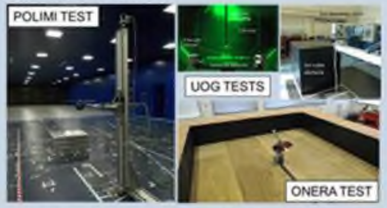
The know-how acquired by the HC/AG-17 about the wake modelling in the presence of ground obstacles, was capitalized and sets-up the basis for this new research activity.

The work programme is structured in four work packages:

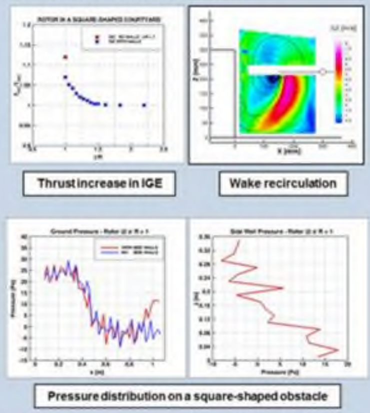
- WP0 – Management & Dissemination: fulfilment of all the obligations concerning the project management and the dissemination of the results;
- WP1 – Preliminary Computations & Code Enhancements: preparation phase during which partners are involved in literature review and preliminary computational activities;
- WP2 – Wind Tunnel Test Campaigns: performance of the following four wind tunnel test campaigns:
  1. HOGE/HIGE rotor with a loose/sling load (CIRA);
  2. HIGE rotor in proximity to a square-shaped obstacle (ONERA);
  3. HIGE rotor in proximity to an obstacle in wind-on conditions (PoliMi);
  4. HIGE rotor in proximity to an obstacle in wind-off conditions (Univ. Glasgow).
- WP3 – Final Validation of Codes: final validation of the numerical tools proposed by partners.

Results

Each experiment covers different aspects of the rotor wake/obstacle interaction. There is a strong collaboration in experimental tests between POLIMI and UOG (exchange of personnel). The cuboid obstacle is put at disposal by DLR.

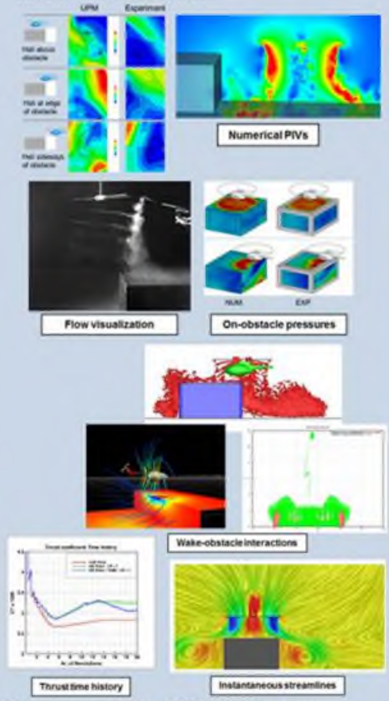


- The thrust of a helicopter rotor hovering above an obstacle is increased wrt both an OGE and IGE rotor. The thrust of a rotor hovering aside of or surrounded by obstacles is increased wrt to an OGE rotor but is reduced wrt a IGE rotor. The reason lies in the wake recirculation induced by the side walls of the obstacle;
- The ground pressure is the highest below the rotor. It reduces gradually away from the rotor but increases again in the vicinity of a side wall. The side wall pressure is positive about the ground/side wall corner but becomes negative at higher z because of the wake recirculation.



Solvers ranging from Flight Mechanics-based to Navier Stokes are employed.

- The rotor-obstacle interactional process requires lengthy calculations to reach a converged solution (> 15 revs.);
- Inviscid potential methods require a specific modelling of the wake-obstacle interaction and the inclusion of viscous effects.



Members of the HC/AG-22 group:

A. Visingardi, F. De Gregorio	CIRA
T. Schwarz	DLR
R. Bakker	NLR
S. Voutsinas	NTUA
Q. Gallas, R. Boisard	ONERA
G. Gibertini	Politecnico di Milano
G. Barakos, R. Green	University of Glasgow

GARTEUR Responsable:

K. Pahlke DLR

CIRA DLR nlr ONERA THE FRENCH AEROSPACE LAB University of Glasgow

HC/AG-22

HC/AG-22	**"FORCES ON OBSTACLES IN ROTOR WAKE"**	
Monitoring Responsable:		K. Pahlke DLR
Chairman:		Mr. A.Visingardi CIRA

- **Objectives**

Helicopters are largely 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. In these conditions the wake generated by the obstacle may result in: (a) high compensatory workload for the pilot and degradation of the handling qualities and performance of the aircraft; (b) unsteady forces on the structure of the surrounding obstacles.

A bibliographic research, performed during the Exploratory Group HC/EG-32 "Forces on Obstacles in Rotor Wake", highlighted that there is a general lack of:

- experimental databases including the evaluation of the forces acting on obstacles when immersed in rotor wakes;
- both numerical and experimental investigations of the rotor downwash effect at medium-to-high separation distances from the rotor, in presence or without sling load.

The principal objective of HC/AG-22 is thus to investigate, both numerically and experimentally:

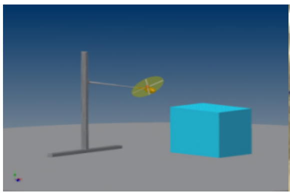
- Primarily, the effects of the confined area geometry on a hovering helicopter rotor from the standpoints of both the phenomenological understanding of the interactional process and the evaluation of the forces acting on surrounding obstacles;
- Secondly, the downwash and its influence on the forces acting on a load, loose or sling, at low to high separation distances from the rotor disc.

- **Activities**

The timescale for the project is three years during which the following activities are planned:

- Application and possible improvement of computational tools for the study of helicopter rotor wake interactions with obstacles;
- Set-up and performance of cost-effective wind tunnel test campaigns aimed at producing a valuable experimental database for the validation of the numerical methodologies applied;
- Final validation of the numerical methodologies.

The know-how acquired by the HC/AG-17 about the wake modelling in the presence of ground obstacles, would be capitalized and would set-up the basis for this new research activity.



- **Management issues**

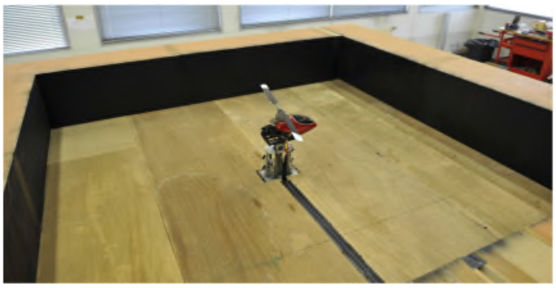
The Mid-Term meeting was held at ONERA Lille (F), after 42nd ERF, 9 September 2016. The Mid-Term report was delivered in November 2016.

- **Results/benefits**

The action group started the activities in November 2014.

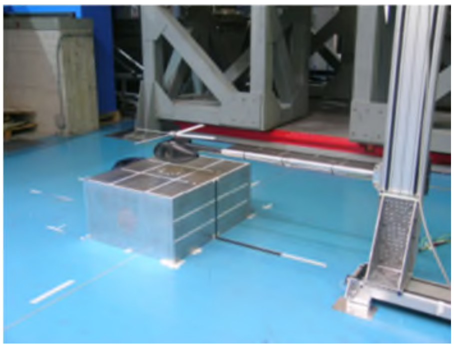
An experimental database, dealing with a helicopter rotor in HOGE (Hover Out of Ground Effect)/HIGE (Hover In Ground Effect) in wind off conditions (tests executed in a large chamber) in the vicinity of a cuboid obstacle, was provided by Politecnico di Milano in a first test campaign with the aim to help partners in evaluating the initial modelling capabilities and the possible improvements applicable to the available numerical tools.

In 2015, CIRA, DLR, NLR and NTUA made improvements to their respective computational methodologies. UoG performed first comparisons with the existing database provided by PoliMi. ONERA and UoG performed the respective WT test campaigns. Further measurements were performed by ONERA for a helicopter hovering in a court surrounded by buildings (i.e. a shallow square pit obstacle).



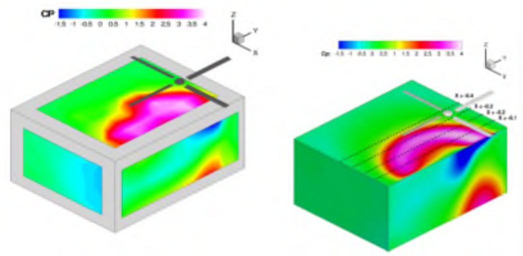
Helicopter in square pit obstacle

The PoliMi test campaign in the Large Wind Tunnel (GVPM) Wind Engineering Test Section was conducted, while the CIRA one is still in the preparation phase. The PoliMi tests provided results for wind-off and wind-on conditions.



PoliMi First Test Campaign: Wind-off

Comparisons of numerical results with the PoliMi wind-off and wind-on results of the flow around a helicopter hovering over or close to an obstacle were carried out by several partners.



Helicopter hovering over the edge of a cuboid
(left Experiment, right CFD (Glasgow))

PoliMi: Second Test Campaign in GVPM

In 2017 all test campaigns will be closed and detailed comparisons between numerical results and the experimental data but also between the different numerical methods will be conducted.

- **HC/AG-22 membership**

Member	Organisation	e-mail
A. Visingardi	CIRA	a.visingardi@cira.it
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S. Voutsinas	NTUA	spyros@fluid.mech.ntua.gr
R. Boisard	ONERA	ronan.boisard@onera.fr
G. Gibertini	Politecnico di Milano	giuseppe.gibertini@polimi.it
R. Green	Glasgow Uni.	richard.green@glasgow.ac.uk
G. Barakos	Glasgow Uni.	g.barakos@liverpool.ac.uk

- **Resources**

Resources were confirmed during the kick-off meeting.

Resources		Year			Total 08-12
		2015	2016	2017	
Person-months	Actual/ Planned	A28/ P15	A28/ P18	P15	P48
Other costs	Actual/ Planned	A33/ P20	A35/ P33	P20	P73

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

HC/AG-23: Wind Turbine Wakes and Helicopter Operations

Action Group Chairman: Richard Bakker (richard.bakker@nlr.nl)

Interest of the research

AG-23 investigates the impact of large wind turbine wakes on the flight safety of rotorcrafts.

Background

The amount of energy produced by wind turbines is still on the rise and seems to continue to do so in the near future. In addition the rotor size of wind turbines increases, with current rotor diameters that may range up to 126m.

At the same time we see the development that helicopters operate more and more in non-regulated airspace with the advent of medical air services, police surveillance and fire fighting helicopters etc., where they may encounter the air wakes from wind turbines.
More and more wind farms consisting of a large number of wind turbines are spreading across the North Sea. Also the military with their low level flying exercises are more likely to come upon the wind turbine wakes at some moment in time. Ultimately the likelihood of air traffic encounters with wind turbine wakes is increasing, showing the need for a detailed study on the interactions of rotorcraft and the wind turbine wake.

An extensive study of the wind turbine wake and its effect on helicopter flight with regard to stability, handling quality and safety has not yet been performed. The Action Group under the Garteur Group of Responsables Helicopters (GoR-HC) will aim to investigate the issue. This will be done by performing a survey on the wind turbine wake characteristics and using this data for the identification of relevant flow phenomena for the study of its effects on rotary flight.

Programme/Objectives

Objectives

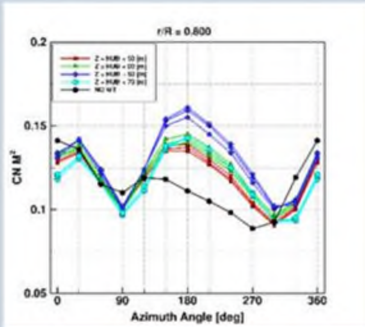
Despite the amount of literature on both wind turbine wakes and helicopter – fixed wing tip vortex encounters, not much research has been done on the interactions of wind turbine wakes and helicopter flight.
The aim of the Action Group is to set up a team of researchers from universities and research institutes to cooperate and perform the following activities:
•Perform a survey of available experimental and analytical wake data for typical wind turbines. Collect and assemble the data to produce a database of wind turbine wake properties. Identify appropriate wake characteristics with regard to the effect it has on the helicopter flight characteristics
•Define representative test cases for a wind turbine and helicopter combination. Several combinations of small/large helicopter and wind turbines, depending on available experimental data, available helicopter models, pilot-in-the-loop facilities etc. should be considered
•Perform computations and piloted simulator experiments and analyse the effects of wind turbine wake on the stability, handling qualities and safety aspects of a helicopter
•Validate the results of the computational tools and simulator trials with available experimental data.
•The group should provide recommendations for legislation and disseminate the findings to the appropriate authorities and parties concerned.

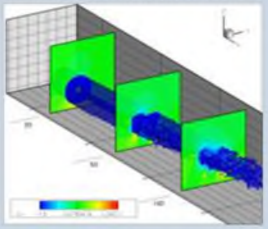
Programme

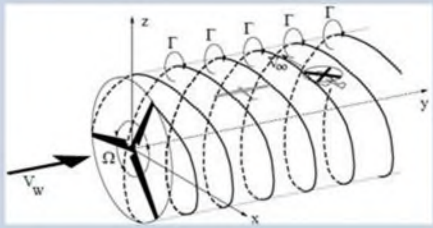
The programme consists of 5 work packages

0. Project Management and Dissemination
1. Wind turbine wake identification
2. Wind turbine wake experiments and computations
3. Helicopter - Wind turbine off-line simulations
4. Helicopter - Wind turbine wake piloted simulations.

The kick-off of the Action Group HC-AG23 took place 6 November 2014







Results

- A reference wind turbine (NREL5), a reference helicopter (BO105, and a set of test cases to be studied has been selected
- An overview of wind turbine wake characteristics, methods and tools has been prepared. Both analytical, computational and experimental data has been collected.
- Computed wind turbine wake velocity fields using a variety of CFD tools and with different methodologies have been prepared and are available to the partners to use for helicopter-wake encounter simulations.
- Evaluating the effect of the WT wake on a helicopter rotor entering the WT wake effects have been evaluated in terms of hub loads (thrust, torque) and roll, pitch and yaw moment coefficients of the rotorcraft.
- Computations of a helicopter-wake encounters and the resulting attitude rates.
- Preparations have been made for the implementation of a wind turbine wake and a helicopter for use in a full-scale simulator.
- Study for the definition of objective criteria to assess handling qualities in a wind turbine wake has been conducted.

Members of the HC/AG-23 group are:

G. Barakos	University of Glasgow
M. Pavel	Technical University Delft
A. Visingardi	CIRA
P. M. Basset	ONERA
F. Campagnolo	Technical University Munich
M. White	University of Liverpool
S. Voutsinas	NTUA
P. Lehmann	DLR
R. Bakker	NLR

GARTEUR Responsable:
J. Hakkaart NLR

UNIVERSITY OF LIVERPOOL
TUDelft Delft University of Technology
TECHNISCHE UNIVERSITAT MÜNCHEN
NLR
ONERA THE FRENCH AEROSPACE LAB
CIRA
DLR

HC/AG-23

HC/AG-23	**"WIND TURBINE WAKE AND HELICOPTER OPERATIONS"**
Monitoring Responsable:	J. Hakkaart NLR
Chairman:	Mr. R. Bakker NLR

- ## Objectives

The amount of energy produced by wind turbines is still on the rise and seems to continue to do so in the near future. In addition the rotor size of wind turbines increases, with current rotor diameters that may range up to 126m.

Ultimately the likelihood of air traffic encounters with wind turbine wakes is increasing, showing the need for a more detailed study on the interactions of rotorcraft and the wind turbine wake.

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- Perform a survey of available experimental and analytical wake data for typical wind turbines. Collect and assemble the data to produce a database of wind turbine wake properties. Identify appropriate wake characteristics with regard to the effect it has on the helicopter flight characteristics
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- ## Activities

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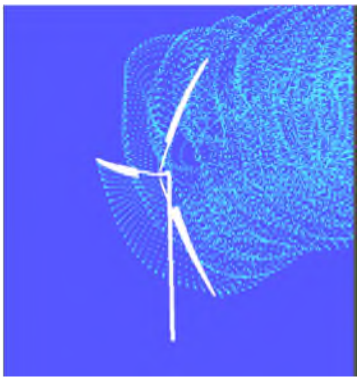


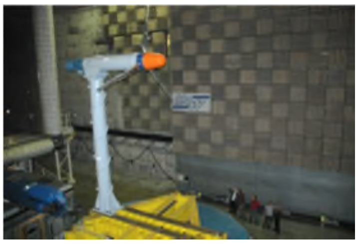
- **Management issues**

The kick-off meeting was held on November the 7th, 2014. During the meeting the membership, resources and work packages were discussed and confirmed. Professor Barakos has moved to the University of Glasgow and will continue his CFD contribution there. Dr White at the University of Liverpool will contribute to the flight simulation activities. Two teleconferences were held on 21st May and 9th December 2015. On 6 October 2016 the planned Mid-Term Meeting was combined with the 3rd Technical Meeting. Due to availability of the partners it was not possible to organise a live meeting in Glasgow. Instead a teleconference was organised.

- **Results/benefits**

The outputs from this AG would be used to provide recommendations for legislation and disseminate the findings to the appropriate authorities and parties concerned.

The first deliverable, a technical report on wind turbine wake characteristics, is in progress and the NREL5 model is selected as reference wind turbine for the AG23 activities. Initial CFD work and wind tunnel test preparation has commenced. The Bo105 helicopter has been chosen as the reference helicopter and a model validation exercise has been planned. The partner's contributions for both the Wind Turbine Wake survey (WP1.D1) and the Mid-Term report (WP0.D1) have not been received by all partners. The reports are in progress. Other reports are planned at the end of the project period (month 30 and 36). The activities for these WP deliverables are well on the way and preliminary results have been presented and communicated. Partners have been working on the generation of a representative wind turbine wake (ONERA, CIRA, NTUA, UoG, NLR) and have produced results for WT-wake and helicopter encounters (DLR, TUDelft, UoL, NLR, CIRA, NTUA). A variety of parameters have been produced: attitude response, attitude rate response, trimmed hover and forward flights, hub loads etc. To formalise and coordinate the processing of results, a selected set of test conditions has been agreed on, with the purpose of better be able to compare partners results. Other activities that were performed include the validation of wind turbine wakes with experimental data (NTUA, UoG) and validating and harmonising the BO105 flight dynamics model (UoL, DLR, NLR).



- **HC/AG-23 membership**

Member	Organisation	e-mail
Richard Bakker	NLR	rbakker@nlr.nl
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George Barakos	Glasgow Uni	George.Barakos@glasgow.ac.uk
S. Voutsinas	NTUA	spyros@fluid.mech.ntua.gr
Mark White	Liverpool Uni	mdw@liverpool.ac.uk

- **Resources**

Person month resources were confirmed during the kick-off meeting and have been split tentatively in years. Other costs will be assessed at the next progress meeting.

Resources		Year			Total
		2015	2016	2017	
Person-months	Actual/ Planned	18/18	17/22	P18	35/58
Other costs	Actual/ Planned	1.6	1.3	tbd	2.9

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

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

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

Interest of the research

AG-24 investigates how the helicopter rotor noise propagates in presence of the fuselage.

Background

A negative undesirable by-product of the helicopter during its operation is noise generation. Both the main and the tail rotors (including Fenestron) of a helicopter are major sources of noise and contribute significantly to its ground noise footprint. With rising concern for environmental issues and increasingly stringent noise regulation, helicopter noise has gained importance in comparing with performance, safety and reliability.

The main research effort in the past was concentrated on the helicopter rotor noise generation and the reduction of the noise. Extensive work, both theoretical and experimental helped to deepen the understanding of the noise generating mechanisms. Even though the scattering of noise generated by helicopter rotors has been recognized as a significant influence on the noise spectra and directivity, the research effort towards the scattering of noise, especially the scattering of tail rotor noise has not been studied extensively.

To accurately predict the effective helicopter external noise under the influence of the fuselage, advanced analysis tools that overcome the so-called free-field limitation of classical acoustic analogy methods are required. For this purpose, validations of the tools with the experiment data need to be conducted. Until now little activities for generating such database for validation are conducted. Moreover, the evaluation of the scattered acoustic field is of interest for the prediction of the internal noise in the fuselage and its vibrations that, in turn, are a source of interior noise. In addition, the possibility to develop and install acoustically treated panels (liners) on some parts of the fuselage and thus estimate the effect of a wall impedance on the external noise levels, require a particular care in the choice of the wave model. Concerning the helicopter interior noise, vibro-acoustic numerical analyses of different physical sophistication levels require the accurate knowledge of the acoustic pressure distribution on the external skin of the fuselage, and this can be only predicted through an accurate external noise computation.

Programme/Objectives

Objectives

The present research work will address noise propagation in presence of the fuselage. The principal objective of HC-AG24 is then to promote activities to:

- establish unique quality database - for unsteady scattered acoustic pressure on the fuselage and in the far field as well as flow field, including flow refraction and convection effect;
- validated prediction design tools for main and tail rotor noise under influence of fuselage - including main/tail rotor interactions;
- proof of rotor noise reduction through adding acoustic absorbing liner on the part of fuselage.

The timescale for the project is three years during which the following topics are to be addressed:

- Investigate the capability and reliability of tools capable of predicting the effects of noise scattering problems;
- Perform computations of numerical benchmark cases and incorporation of the convective flow effects;
- Study the possibility to account for a surface impedance;
- Define representative test cases for generating a data base with a generic configuration, including sound pressure and flow field data

The work programme is structured in three work packages:

➤ WP 1: Simulation on the acoustic scattering effect

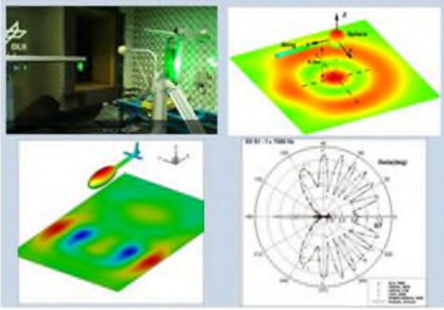
- Code adaptation & prediction
- Code validation & improvement of prediction tools
- Evaluation of noise scattering of various components using validated codes

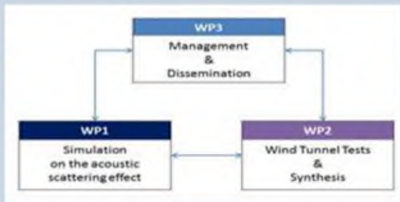
➤ WP 2: Wind Tunnel Tests & Synthesis

- Model preparation
- Test preparation
- Model setup and installation
- Test matrix & instrumentation
- Test conduct
- Test data compilation & distribution
- Test data analysis

➤ WP 3: Management & Dissemination

- Action group Management
- Exploitation & Info dissemination
- Technology Implementation Plan (TIP)





Results

The action group started the activities in 1st of January 2015.

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

1. Description of available analytical, experiment test cases including database completed and distributed;
2. Specifications on the common simulation for the sphere scattering defined and the results of sphere simulation completed and compared. In addition the comparison results published in ERF 2016;
3. The Sphere scattering tests composed of 3 spheres, two support systems, and two noise sources were conducted and the results published in ERF 2016;
4. The generic helicopter and model tail rotor were manufactured; tests for generic helicopter with three different sources will be made in Sep. 2017;
5. Specifications on the test for the GARTEUR helicopter scattering defined;
6. The abstract related to the group activities in terms of the simulations and experiments is accept for AHS 2017;
7. 4 publications and 7 reports were produced

Members of the HC/AG-24 group are:
(only contact persons are listed here)

M. Barbarino	CIRA (Vice Chairman)
C. Testa	CNR-INSEAN
J. Yin	DLR (Chairman)
H. Brouwer	NLR
G. Reboul	ONERA
L. Vigevano	Politecnico di Milano
G. Bernardini	Roma TRE University

GARTEUR Responsable:
K. Pahlke DLR

CIRA Centro Italiano Ricerche Aerospaziali — Marine Technology Research Institute INSEAN — DLR — NLR — ONERA THE FRENCH AEROSPACE LAB — Politecnico Milano — Roma TRE Università degli Studi

HC/AG-24

HC/AG-24	**"HELICOPTER FUSELAGE SCATTERING EFFECTS FOR EXTERIOR/INTERIOR NOISE REDUCTION"**	
Monitoring Responsable:		**K. Pahlke DLR**
Chairman:		**J Yin DLR**

- **Objectives**

The present research work addresses rotor noise propagation in the presence of a fuselage. The focus is on the development and validation prediction methods. The present research work will also generate a unique experimental database for acoustic scattering using a generic configuration, including sound pressure data in the field as well as clearly prescribed noise sources; such a database is not currently available. The database will be used as a benchmark for code validation.

The effect of acoustic scattering is likely to be more significant for tail rotor noise because the wavelength of the tail rotor harmonics is comparable with or smaller than the characteristic dimension of the fuselage. The noise shielding and refraction effect can significantly alter the tail rotor noise directivity in the far field. Therefore the AG will give more focus on the scattering problem of the tail rotor.

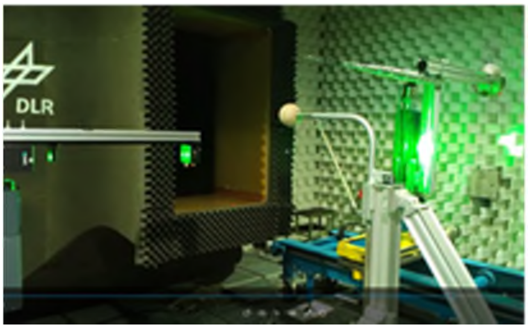
For internal noise studies, the present research will also provide a reliable estimation of the acoustic pressure on the helicopter fuselage. Furthermore passive technology installed on the fuselage for noise reduction will be investigated.

- **Activities**

The AG consists of 3 work packages:
1: Simulation of the acoustic scattering effect
2: Wind tunnel tests and synthesis
3: Management and dissemination
To date a code to code comparison regarding a monopole scattering by sphere has been completed and distributed and the specification of the common simulation for NACA 0012 test arrangement has been issued; numerical simulations by all partners is on-going.

- **Management Issues**

The AG was planned to run for two years with a mid-term review to enable an extension for a third year. The kick-off meeting was held at DLR Braunschweig, Germany in Jan. 2015 and the technical review meetings were held 15-16-July, 2015, at CIRA, Napoli, 3-4 Febr. 2016 at INSEAN, Rome and at ONERA 22 Sept. 2016 in Lille. The decision to extend this AG by one year was taken during the Council March 2016.



- **Results/benefits**

From a scientific point of view the main innovation of the AG comprises of:

- Unique quality database for unsteady scattered acoustic pressure measurements on the fuselage and in the far field as including flow refraction and convection effects

- Validated prediction tools for main and tail rotor assessment in the presence of a fuselage, including main rotor/tail rotor interactions.
- Proof of rotor noise reduction through adding an acoustic aborning liner on part of the fuselage.

This AG will expand the limits of current noise prediction tools. The tools will enable the development of new helicopter designs which will exploit shielding effects and controlled surface impedance to further reduce noise emissions on the ground, reducing the environmental impact of helicopters.

The following results were achieved:

1. Description of available analytical, experiment test cases including database completed and distributed;
2. Specifications on the common simulation for the sphere scattering defined and the results of sphere simulation completed and compared. In addition, the comparison results were published in ERF 2016;
3. The Sphere scattering tests composed of 3 spheres, two support systems, and two noise sources were conducted and the results published in ERF 2016;
4. The generic helicopter and model tail rotor were manufactured; tests for generic helicopter with three different sources will be made in Sep. 2017;
5. Specifications on the test for the GARTEUR helicopter scattering defined;
6. The abstract related to the group activities in terms of the simulations and experiments is accepted for AHS 2017;
7. 4 publications and 7 reports were produced.

- **HC/AG-24 membership**

Member	Organisation	e-mail
J. Yin (Chair)	DLR	Jianping.yin@dlr.de
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J. Bulte	ONERA	jean.bulte@onera.fr
L. Vigevano	PoliMi	luigi.vigevano@polimi.it
G. Bernardini	Roma TRE Uni	g.bernardini@uniroma3.it
C.Testa	CNR-INSEAN	claudio.testa@cnr.it

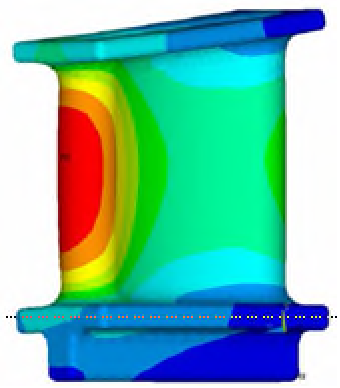
- **Resources**

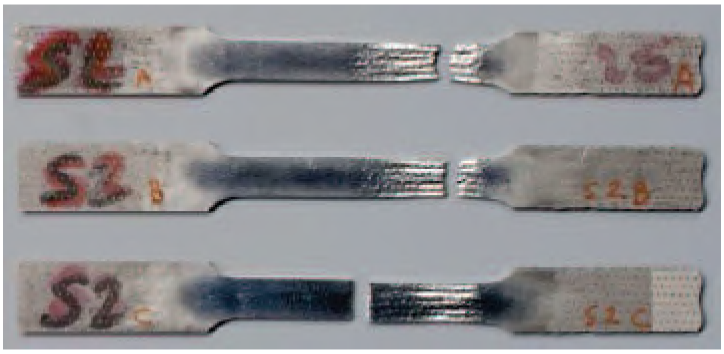
Person month resources were confirmed during the kick-off meeting and have been split tentatively in years. Other costs will be assessed at the next progress meeting.

Resources		Year			Total
		2015	2016	2017	
Person-months	Actual/ Planned	A16.7/ P30	A20.5 /P25	P22	59.2
Other costs (in K€)	Actual/ Planned	A30.5/ P66	A30.6 /P48	P34	95.1

ANNEX E

ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "STRUCTURES AND MATERIALS"





Remit

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

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

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

Table of Contents
STRUCTURES AND MATERIALS

GoR-SM Overview

GoR Activities

The activities within the Action Groups cover several aspects of new technologies, new structural concepts and new design and verification criteria. Recent and current work is devoted to:

- High velocity impact;
- Fatigue and damage tolerance assessment of hybrid structures;
- Damage repair in composite and metal structures;
- Bonded and bolted joints;
- Additive layer manufacturing.

The activities on high velocity impact are aimed to the increase of safety of aircraft structures and to the reduction of design and certification costs by improving numerical approaches for simulation of bird strike on pre-stressed structures and by predicting damage caused by impact from foreign objects. Emphasis is put on novel/hybrid materials and structures with complex geometries.

A major challenge in the fatigue analysis and subsequent fatigue testing of hybrid structures originates from the differences in deriving fatigue spectra for metal and composites and incorporation of required environmental load factors for composites. For example elimination of peak loads in the spectrum for metals is conservative as crack retardation is prevented whereas for composites this is not conservative. Also the effect of larger scatter and environmental effects are for composites incorporated by means of a Load Enhancement Factor, thereby applying in the order of 10-20% higher loads which will result in potential premature failure of metal components in the fatigue test.

The structure of aircraft in service will obtain various types of damage e.g. from impact loading. It is therefore important to have effective repair methods. Damages caused by impact are in general much more severe in composite structures than in metals structures. Reparability of such damage is an important consideration in the selection of composites for aircraft applications. Repair techniques both for civil and military aircraft structures are defined through the development of numerical/experimental methodologies. The following issues are addressed: repair criteria, design of patches and repair strategies, analysis of the repair, manufacturing and test, repair strategies and technology, effective repair methods.

Bonded and bolted joints are among the most important structural elements in aircraft structures. Improper design of bonded and bolted joints may lead to structural problems or conservative design leading to overweight structures and high life-cycle cost. There is a need to further develop the numerical methods to predict failure and damage in bolted and bonded joints. Experimental work to support the numerical methods and to improve measurement methods is also needed. This is addressed in a new Exploratory Group within GoR SM.

Additive Manufacturing (AM) with metals is an emerging technology that finds more and more applications in different markets such as orthopaedic implants, dentistry and high-end industry. There is also a lot of interest coming from the Aerospace industry. Metal AM technology can provide great advantages with respect to conventional metal working techniques, such as significantly lower waste of materials, a larger freedom of design, high potential for weight reduction and the possibility to integrate functionality. Specific design guide lines must be taken into account and currently available CAD design tools are considered inadequate for designing for AM. Currently it still is difficult for AM technologies to compete with traditional techniques on reliability and reproducibility because the quality of final products depends very strongly on material and process parameters. Metal AM material qualification and process certification methods are not available yet. Qualification and Certification is essential for high demanding applications for example in aerospace. The goal of the new Exploratory Group is to build up knowledge, skills and corresponding demonstrator products in the field of metal AM processes and materials in order to support the manufacturing industry and increase its competitiveness.

Although the specific topics vary over the years, the scientific basis remains largely unchanged. The work is looked upon as an upstream research intended to discover valuable areas on future activities. In several cases the results of the collaboration have led to research proposals which have been submitted successfully to the EC to be granted by the Framework Programmes and to EDA to be granted by MoDs. Furthermore, some collaborations have formed the basis of relevant national programmes. Besides strengthening links between EREA members, the collaborative research programme satisfies a primary industry requirement and participation by the industry is particularly valuable.

Management issues

The GoR usually meets twice a year to monitor Action Group and Exploratory Group activities; the AGs and EGs themselves meet at various locations in Europe, with the Monitoring Responsable from the GoR present, if necessary. The chairmanship in 2016 was taken over by Peter Wierach (DLR) who followed Jean-Pierre Grisval (ONERA). Currently there is no vice-chairman nominated. Also the UK GoR SM membership is presently vacant. This situation should be solved with help of the GARTEUR council and the UK delegation by actively promoting GARTEUR in the UK. Represented by the chairman the GoR SM contributed to GARTEUR road mapping activity.
During the reporting period, the GoR-SM held one meeting:

- 73rd GoR SM Meeting: 1-2 March, Stade, DLR, Germany

Five of eight members and three of eight industrial point of contacts participated in the meeting.
Currently two Action Groups and two Exploratory Groups are active.

Dissemination of GARTEUR activities and results

Dissemination of reports is a recurring topic on the GoR meetings. For the reporting period no publications with a direct link to GARTEUR activities have been reported by the members.

Reports issued

The final reports for SM/AG-30 (High Velocity Impact) were already finalised and issued in the last reporting period. No new reports have been issued in 2017.

Status of Action Groups and Exploratory Groups

Action Groups (AG)

The following Action Groups were active during 2016:

- SM/AG-34: Damage repair in composite and metal structures. This AG is a result from EG-40. The AG was extended up to 2017 and reports are under preparation.
- SM/AG-35: Fatigue and Damage Tolerance Assessment of Hybrid Structures. This AG is a result from EG-38. The AG was extended up to 2017 and reports are under preparation.

Exploratory Groups (EG)

The following Exploratory Groups were active during 2016:

- SM/EG-39: Design for high velocity impact on realistic structures. EG 39 has been put on hold until IC secure the necessary funding to manage the project.
- SM/EG-42: Bonded and bolted joints. This EG was initiated by FOI and was formally started at the GoR fall meeting 2013. Due to recent reorganisations, FOI won't be able to manage or even participate in the AG. Based on the member feedback a reorientation of the EG with a focus on bonded joints is discussed. A new partner who will take over the management of the EG is sought. Currently EG-42 is set on hold.
- SM/EG-43: Development of additive layer manufacturing for aerospace applications. This EG was formally started at the GoR Fall 2014 meeting and the first EG-43 meeting was held on 10th April 2015. An AG proposal is under preparation.

Rolling plans

Activity	2009	2010	2011	2012	2013	2014	2015	2016	2017
AG30: High velocity impact							▲		
AG33: RTM material properties during curing							▲		
AG34: Damage repair in composite and metal structure									
AG35: Fatigue and damage tolerance assessment of hybrid structure									
EG39: Design for high velocity impact on realistic structure							→ A	G 36	
EG42: Bonded and bolted joints									
EG43: Additive Layer Manufacturing									

In 2016, GoR meetings are planned as follows:

- 74th meeting: 2017, September at NLR, Amsterdam, Netherlands
- 75th meeting: tbd.

Dr. Peter Wierach
Chairman (2016-2017)
Group of Responsables
Structures and Materials

GoR membership

2016 membership of the Group of Responsables Structures and Materials

Chairman			
Dr. Peter Wierach	DLR	Germany	peter.wierach@dlr.de

Vice-Chairman			
vacant			

Members			
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* : Associated member

Table of participating organisations

● = Member ■ = Chair

SM/AG number	34	35
Research Establishments		
DLR		●
CIRA	●	
NLR	●	■
INTA	●	
FOI	●	●
CNR	●	
Industry		
QinetiQ	●	
SAAB	●	●
SICOMP		
ALENIA	●	
FOKKER		●
Academic Institutes		
ICL	●	
LTU	●	
NTNU	●	
SUN	■	

Total yearly costs of AG research programmes

	2009	2010	2011	2012	2013	2014	2015	2016
Man-month	102,5	50	6	7	60,5	61	10	10
Other costs (k€)	128	40	10	2	65	61	35	35

GoR-AS Action Group Reports

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

SM/AG-34: Damage Repair with Composites

Action Group Chairman: Aniello Riccio (aniello.riccio@unina2.it)

Background

Composites are much more prone to be damaged in service than metals, for example, by mechanical impact. Reparability of such damage is an important consideration in the selection of composites for aircraft applications.
In addition, metal structures can be repaired by using composite patches with great potential benefits such as costs reduction and time saving.
Repair techniques can be considered applicable to a wide range of structures both metallic and composites (laminates or sandwich).
The repair scheme used for structural restoration should be the simplest and least intrusive that can restore structural stiffness and strain capability to the required level and be implemented in the repair environment, without compromising other functions of the component or structure.
It is usually necessary to restore the capability of the structure to withstand the ultimate loads of the design and to maintain this capability (or some high percentage of it) for the full service life.
Important functions that must be restored include: aerodynamic shape, balance, clearance of moving parts and resistance to lightning strike. The requirement in military to restore the stealth properties of the component may also have to be considered and may influence the type of repair chosen.
The growing use of composite structures but also the need to reduce costs (both for metals and composites) have lead to an increasing interest in repair and especially in repair with composites and its potential applications.
However, uncertainties remain in the behavior of repaired structures that generally lead aircraft manufacturers to perform repairs only in secondary structures and to prefer bolted repair (mechanical fastened repair) over bonded repair (adhesively bonded repair) limiting the use of bonding only to moderate-size damage.

Programme/Objectives

Objectives
Based on of the emerging needs (detailed in the previous section) related to the composites usage in aerospace applications, the main objective of this Action Group is:

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

This objective addresses the following issue:

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

The activities have been split in Work Packages:

WP 1 REPAIR CRITERIA (WHEN UNDERTAKING REPAIR)

task 1.1) Methodologies for the assessment of residual strength in damaged composite components to decide when repair has to be undertaken

task 1.2) Crack growth analysis (static and fatigue);

WP 2 DESIGN OF PATCHES AND REPAIR STRATEGIES

WP 3 ANALYSIS OF THE REPAIR

WP 4 MANUFACTURING AND TEST

task 4.1) Manufacturing and repair procedure issues;

task 4.2) Experimental tests

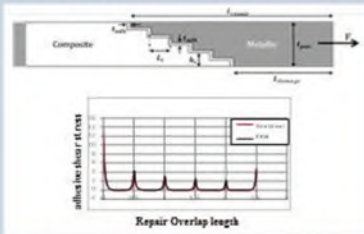
WP 5 EFFECTIVE REPAIR METHODS

task 5.1) Optimization of the patching efficiency;

task 5.2) Certification issues;

task 5.3) Technologies for repair;

task 5.4) Definition of guidelines for an effective repair of both civil and military aircraft structures.



Development of an Analytical tool for Repair Design

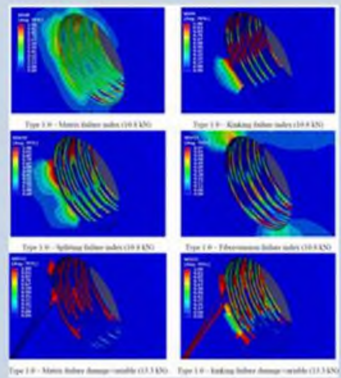
CIRA · Seconda Università degli Studi di Napoli · AleniaAermacchi · The Composites Centre · QinetiQ · NLR · Institute of Composite and Biomedical Materials · FOI · NTNU – Trondheim Norwegian University of Science and Technology · SICOMP · Luleå Tekniska Universitet · INTA

Expected Results

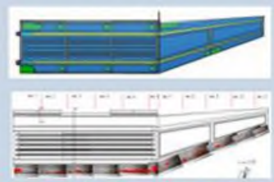
The effective outcomes can be summarized in:

1) minimize down-time of the aircraft for repair operations;
2) minimize costs for repair;
3) promote the repair of components instead of their substitution;
4) reduction of the costs and time for certification of repaired structures

A number of benchmarks have been selected for models validation.



Numerical Analysis - progressive Damage in composite Joint



Repair of an UAV wing

SM/AG - 34

SM/AG-34	Damage Repair with Composites
Monitoring Responsable:	D. Tescione CIRA
Chairman:	Dr. A. Riccio SUN

Objectives

Based on of the emerging needs (detailed in the previous section) related to the composites usage in aerospace applications, the main objective of this Action Group is:

“Definition of effective repair techniques both for civil and military aircraft structures through the development of numerical/experimental methodologies".

This objective addresses the following issues: Repair criteria, design of patches and repair strategies, analysis of the repair, manufacturing and test, repair strategies and technology, effective repair methods.

Statement of work

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

WP 1 Repair criteria (when undertaking repair)

Task 1.1: Methodologies for the assessment of residual strength in damaged composite components to decide when repair has to be undertaken:

Task 1.2: Crack growth analysis (static and fatigue).

WP 2 Design of patches and repair strategies

WP 3 Analysis of the repair

WP 4 Manufacturing and tests

Task 4.1: Manufacturing and repair procedure issues;

Task 4.2: Experimental tests.

WP 5 Effective repair methods

Task 5.1: Optimization of the patching efficiency;

Task 5.2: Certification issues;

Task 5.3: Technologies for repair;

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

Main achievements

Tasks accomplished in 2016

The Second technical meeting has been held in Sorrento (IT) on 23 April 2013. The most of the partners attended the meeting.

Some partners gave presentations on the AG-34 work at the conference.

The Third meeting has been held on 24 October 2013 at INTA.

Between 2014 and 2016 no meeting has been planned, however many partners have continued to work on the project’s topic. The next meeting will be held during 2017.

Expected results/benefits

The effective outcomes can be summarised in:

- minimize down-time of the aircraft for repair operations;
- minimize costs for repair;
- promote the repair of components instead of their substitution;
- reduction of the costs and time for certification of repaired structures.

SM/AG-34 membership

Member	Organisation	e-mail
Aniello Riccio (chairman)	SUN	aniello.riccio@unina2.it
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Resources

Resources		Year					Total 12-16
		2012	2013	2014	2015	2016	
Person-months	Act./ Plan.	-	50/36	50/30	/0	/0	100/66
Other costs (in K€)	Act./ Plan.	-	49/32	20/0	/0	/0	69/32

Progress/Completion of milestone

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

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

SM/AG-35: Fatigue and Damage Tolerance Assessment of Hybrid Structures

Action Group Chairman: Jaap Laméris
(jaap.lameris@nlr.nl)

Background

A major challenge in the fatigue analysis and subsequent fatigue testing of hybrid structures originates from the differences in deriving fatigue spectra for metal and composites and incorporation of required environmental load factors for composites. Specifically, the following aspects can be addressed:

1. Composite structure is sensitive to environmental conditions, metal parts usually are not. If it is decided not to perform fatigue- or residual strength tests under these conditions, which aspects should be taken into account via environmental factors on the applied loads?
2. Material scatter for composites is much larger than for metals; this is usually covered by a combination of a life factor and a load enhancement factor. However, to avoid non-linear behaviour of test set-up and too high stress levels in the metal parts a maximum overall load increase should be respected.
3. In general, damage growth in composite materials is most sensitive for compression-compression cycles, where metal fatigue initiation and crack growth are more sensitive to tension-compression and tension-tension cycles. A generic process for a load spectrum reduction technique covering both aspects should be discussed.
4. Spectrum truncation levels must be different for metals and composites. Where composites experience high damage from high peak loads, metals will experience crack retardation after application of a severe load condition.

Since metals are most sensitive to fatigue damage, it is often chosen to relax one or some of the aspects from the list above for the composite fatigue justification. However, since operational strain levels in new composite designs, using improved material systems, constantly increase, the validity of this approach will be limited in the near future.

Programme/Objectives

Objectives
The main objectives are listed below:

- Validation of the basic assumptions for any applied spectrum manipulation techniques;
- Examination of the capabilities and benefits of a probabilistic approach;
- Determination of the optimum way to account for thermal loads in a non-thermo test set-up;

leading to a joint 'best practice' approach for testing of hybrid airframe structural components.

Task 1 Determination of a Test Spectrum
A benchmark will be defined that will address as much aspects of fatigue and damage tolerance testing/justification as possible, for both the metal and composite structures, for both bolted and bonded joints. The benchmark spectrum will be equivalent to known definitions such as FALSTAFF (fighter wing) or TWIST (transport wing), modified for application to hybrid structure. Testing will be done on hybrid coupons and, if possible on more complex components, addressing all phases of static, fatigue and damage tolerance certification, using a number of derived spectra in order to investigate effects on fatigue and damage tolerance behaviour.
Phase 1 Benchmark definition
Phase 2 Spectrum development
Phase 3 Validation of assumptions

Task 2: Probabilistic approach
Application of probabilistic analyses in combination with virtual testing techniques can be used to incorporate scatter in material properties, loading, etc. The most important scatter sources (model parameters) will first be identified by means of a probabilistic sensitivity analysis. The probabilistic methods will then be applied on a failure model to determine the scatter in derived properties, from which allowable values can be obtained. In case of sufficient correlation with experimental data, the probabilistic simulation model allows for (extensive) virtual testing, reducing the number of tests required in a fatigue material qualification program.

Task 3: Environmental influences
As one of the most important effects of the environment on a hybrid structure, thermally induced interface loads due to the differences in coefficient of elongation between metals and carbon composites come in addition to the 'mechanical' loads. In non-thermo fatigue testing, it is a challenge to apply these loads mechanically.
Phase 1 Identification of the thermal stress condition
Phase 2 Impact on fatigue life
Phase 3 Testing

DLR FOI FOKKER AEROSTRUCTURES NLR SAAB

Results

The AG should results in establishing a joint 'best practice' approach for full scale fatigue testing of hybrid airframe structural components.

The second progress meeting was held at DLR on 19-05-2014 in Cologne and the third progress meeting was at Fokker Aerostructures at Papendrecht on 12-11-2014. SAAB hosted the fourth progress meeting on 22-09-2015 in Lynkoping. In June 2016 the fifth progress meeting was held at the NLR premises in Amsterdam. The next project meeting is planned for Jan/Feb 2017

<u>Task 1: Determination of a test spectrum</u>
A conceptual definition of a specimen geometry was proposed by Fokker/NLR in order to be able to observe the behaviour of the test specimen with respect to the various (conflicting) requirements associated with a hybrid (metal-CFRP) fatigue test. The first part of the work of Fokker/NLR on 3 test approaches (application of probabilistic analyses in combination with virtual testing techniques) has been completed and reporting is almost completed. The second part concerns validation by testing and is planned for 2017
<u>Task 2: Probabilistic approach</u>
The DLR contribution on a probabilistic approach is ongoing. The work on hybrid joints (metal/composite) is in the testing phase. A PhD student is currently working on the completion of this task.
<u>Task 3: Environmental influences</u>
The work of FOI/SAAB on uni- and biaxial loading of bolted joints (SAAB simulation, FOI testing) has been finished except for the reporting which is planned for 2017.

SM/AG-35

SM/AG-35	Fatigue and Damage Tolerance Assessment of Hybrid Structures
Monitoring Responsable:	B. Thuis NLR
Chairman:	R.P.G. Veul (till 31-08-2013) NLR J. Laméris (from 1-09-2013) NLR

Objectives

The main objectives are listed below:

- Validation of the basic assumptions for any applied spectrum manipulation techniques;
- Examination of the capabilities and benefits of a probabilistic approach;
- Determination of the optimum way to account for thermal loads in a non-thermo test set-up;
- leading to a joint 'best practice' approach for testing of hybrid airframe structural components.

Main achievements

Task 1: Determination of a test spectrum

A conceptual definition of a specimen geometry was proposed by Fokker/NLR in order to be able to observe the behaviour of the test specimen with respect to the various (conflicting) requirements associated with a hybrid (metal-CFRP) fatigue test. The first part of the work of Fokker/NLR on 3 test approaches (application of probabilistic analyses in combination with virtual testing techniques) has been completed and reporting is almost completed. The second part concerns validation by testing and is planned for 2017

Task 2: Probabilistic approach

The DLR contribution on a probabilistic approach is ongoing. The work on hybrid joints (metal/composite) is in the testing phase. A PhD student is currently working on the completion of this task.

Task 3: Environmental influences

The work of FOI/SAAB on uni- and biaxial loading of bolted joints (SAAB simulation, FOI testing) has been finished except for the reporting which is planned for 2017.

Management issues

The fifth progress meeting was held in June 2016 at the NLR facilities in Amsterdam. The next project meeting is planned for Jan/Feb 2017

Expected results/benefits

Recent developments and papers in the field of fatigue testing of hybrid structures indicate a few problem areas where conflicts between the 'metal'- and the 'composite' side of the test evidence need to be resolved before compliance with the fatigue and damage tolerance requirements for hybrid structures can be shown with one fatigue test article.

SM/AG-35 membership

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Dr. Joakim Schön	FOI	joakim.schon@foi.se
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Zlatan Kapidzic	SAAB	zlatan.kapidzic@saabgroup.com

Dr.Ing Joachim Hausmann is now working at the IVW GmbH, Kaiserslautern and has obtained consent to be part of the AG.

Planned Resources

Resources		Year					Total 12-16
		2012	2013	2014	2015	2016	
Person-months	Act./ Plan.	1/1	10.5/11	11/11	/10	/10	22.5/42.5
Other costs (in K€)	Act./ Plan.	1/2	16/30	41/41.5	/35	/35	58/128

Progress / Completion of milestone

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

Exploratory Group Reports

SM/EG-39

SM/EG-39	Design for High Velocity Impact on Realistic Structures
Monitoring Responsable:	A. Riccio SUN
Chairman:	M. Willows Imperial college

Objectives

- To determine relevant material characterization required for modelling high performance fibres and composites.
- To identify important parameters to be investigated for design relevant to high velocity impact.
- To establish a fabrication/testing matrix for realistic components on the programme.

Benefits

The fabrication, test and certification/validation of composite components and structures can be extremely expensive, especially when testing shock/explosive/crash events or bird strike. Whilst advanced simulations will never eliminate the testing of structures, numerical modelling can study the effect of different structural and materials parameters, typically enabling new novel structural concepts to be validated without an extensive fabrication and testing programme. This leads to a considerable reduction in conceptual design, thus significantly reducing the time-to-design duration.

Progress

A draft work programme has been prepared.

The project tasks are summarised hereafter:

Proposed Work package breakdown:

Task 1: Material characterisation for potential designs

- Testing of fibres or laminates, temperature and volume effects, high rate testing from existing projects and in-house data.

Task 2: Fundamental characterisation of relevant materials

- Testing associated with missing information from task 1.

Task 3: Review of high velocity resistance designs

- Detailed review of existing designs.

Task 4: Modelling strategies for features relevant to high velocity design

- Modelling sub-component impacts using novel designs or materials.

Task 5: Realistic design of representative components for high velocity impact

- Design of full size designs using numerical techniques.

Task 6: Fabrication of representative components

- Fabrication of designs.

Task 7: Testing of representative components

- Impact testing of selected high velocity resistance designs.

EG 39 has been put on hold until IC secure the necessary funding to manage the project.

- **EG membership**

INSTITUTION	COUNTRY	Contact Point
ONERA	France	B Langrand
ESI	France	A Kamoulakos
DLR	Germany	S Ritt
NLR	The Netherlands	R Houten
EADS	Germany	P Starke
SONACA	Belgium	E Maillard
SICOMP	Sweden	R Juntikka
CIRA	Italy	Rosario Borrelli
SUN	Italy	Francesco Scaramuzzino
Imperial College	UK	Michelle Willows

SM/EG-42

SM/EG-42 Bonded and bolted joints

Monitoring Responsable: Tbd.

Chairman: Tbd.

Objectives

The objective is to further develop the numerical methods to predict failure and damage in bolted and bonded joints. It is planned to do experimental work to support the numerical methods and to improve measurement methods. Furthermore it is intended to study both, metallic and composite joints.

Benefits

Although, aircraft structures are becoming larger there are still a larger number of joints, both bolted and bonded, needed to join them together. If it would be possible to numerically predict damage and failure load for joints the cost of designing joints would be reduced substantially. Even if it would only be possible to interpolate between experimental data it would be useful. When calculating the undamaged stress state in a joint there is no major differences between metallic and composite joints. Therefore, both metallic and composite joints can be considered. Hybrid joints, composite and metallic parts joined together, are considered in AG35 and will not be part of this EG.

Progress

EG was initiated by FOI and was formally started at the GoR fall meeting 2013. Due to recent reorganisations, FOI won't be able to manage or even participate in the AG. Based on the member feedback a reorientation of the EG with a focus on bonded joints is discussed. A new partner who will take over the management of the EG is sought. Currently EG-42 is set on hold.

EG membership

INSTITUTION	COUNTRY	Contact Point
tbd.		

SM/EG-43

SM/EG-43 Development of ALM technologies for aerospace applications

Monitoring Responsable:	H.P.J. de Vries NLR
Chairman:	L. 't Hoen NLR

Objectives

The goal of the proposed research programme is to build up knowledge, skills and corresponding demonstrator products in the field of metal AM processes and materials in order to support the manufacturing industry and increase its competitiveness. This program offers the opportunity for the industrial participants to counteract the shortage of metal AM knowledge and skills and to develop new market opportunities.

Benefits

With Additive Manufacturing (AM) products are constructed in layers from a 3D CAD file. Other commonly used terms for this technology are: 3D Printing, Rapid Manufacturing, Solid Free Form fabrication, digital or direct manufacturing and e-manufacturing. This research program will mainly focus on AM techniques of metal objects.

Three-dimensional solid objects are produced from a digital model by successive application of layers of material. Two fundamentally different techniques can be distinguished:

1. Powder bed method: A product is constructed in layers into a powder bed. The powder is locally melted with a laser or electron beam.
2. Deposition method: Material is continuously fed in the form of powder, wire or strip and melted with a laser or electron beam. The deposition method is faster compared to the powder bed method and it is also suitable for making repairs. It is suitable for making larger parts. The accuracy is lower so that post machining is required.

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

Metal AM technology can provide great advantages with respect to conventional metal working techniques, such as significantly lower waste of materials, a larger freedom of design, high potential for weight reduction and the possibility to integrate of functionality.

There are still significant hurdles for successful commercialisation of metal AM. Specific design guide lines must be taken into account and currently available CAD design tools are considered inadequate for designing for AM. Currently it still is difficult for AM technologies to compete with traditional techniques on reliability and reproducibility because the quality of final products depends very strongly on material and process parameters. Metal AM material qualification and process certification methods are not available yet. Qualification and Certification is essential for high demanding applications for example in aerospace.

Progress

The EG was formally started at the GoR fall (2014) meeting. In the past months more interested members have been found. A first meeting to set-up the project was held in April 2015. An AG proposal is under preparation.

EG membership

INSTITUTION	COUNTRY	Contact Point
CIRA	Italy	R. Borelli
GKN	United Kingdom	A. Bates
DLR	Germany	J. Haubrich
NLR	Netherlands	L. ‘t Hoen
ONERA	France	M. Thomas
Airbus	United Kingdom	M. Muir

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