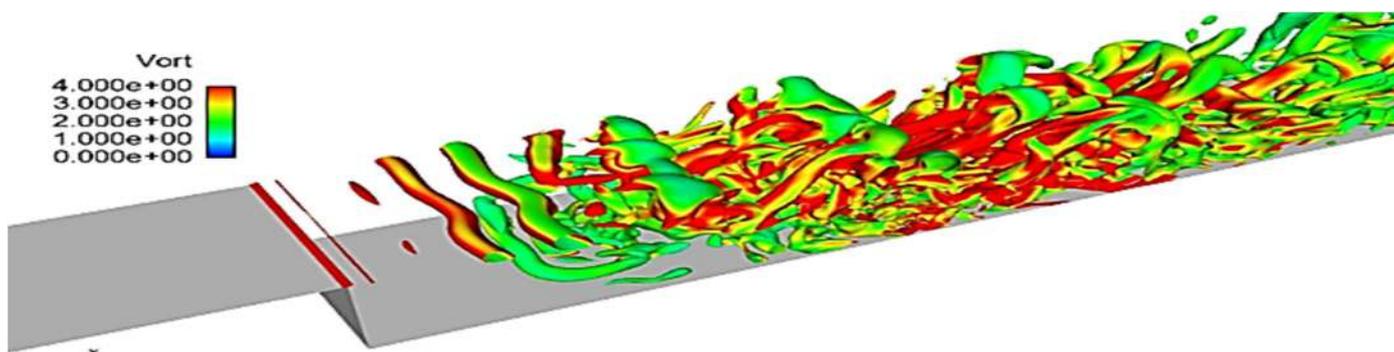


# GARTEUR

ANNEXES - ANNUAL REPORT 2018



GROUP FOR AERONAUTICAL RESEARCH AND TECHNOLOGY IN EUROPE



Front cover image: Stock image and vortex behind the  
“backward facing step”, outcome of GoR AD - AG54.

Back cover image: Stock image

# ANNEXES - GARTEUR ANNUAL REPORT 2018

## Table of Contents

ANNEX 1. ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "AERODYNAMICS" .....	2
ANNEX 2. ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "AVIATION SECURITY" .....	27
ANNEX 3. ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "HELICOPTERS" .....	39
ANNEX 4. ANNUAL REPORT FROM THE GROUP OF RESPONSABLES "STRUCTURES AND MATERIALS" .....	59

**ANNEX 1****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 experiment 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.

## Table of Contents

### AERODYNAMICS

GoR-AD Overview .....	4
GoR Activities .....	4
Management.....	4
Dissemination of GARTEUR activities and results.....	4
Status of Action Groups and Exploratory Groups.....	5
Rolling plans .....	9
GoR membership .....	9
Table of participating organisations .....	10
Total yearly costs of AG research programmes.....	11
Action Group Reports .....	11

## GoR-AD Overview

### GoR Activities

The primary task of the GoR is to monitor Action Groups, encourage Exploratory Groups and instigate new ideas. In 2018, six Action Groups (51, 53, 54, 55, 56, 57) and two (75, 76) Exploratory Groups were active. Details about these groups can be found below. Two of the AGs (56 and 57) started during 2018.

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 AG56. 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.

In 2018, several new ideas have been formulated. Among those that have not yet resulted in an Exploratory Group are: Natural Laminar Flow Monitoring, Morphing, Convective Heat Transfer, Immerse Boundary Simulatio and Hypersonics.

### Management

Two meetings have been held in 2018. The meetings were physical meetings planned some weeks ahead of the respective Council meetings. The AD/A- 100 meeting took place at Leonardo, Turin, Feb 21-22; and the AD/A- 101 meeting at DLR, Brussels, September 26-27.

About seven members attended physically both two meetings. In average, three of them from Industry. As usual lack of funding and time were the reasons for the members who could not attend.

As can be seen from the GoR membership list below, there is no British representation in the GoR. 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 report was published by AD Action Groups in 2018:

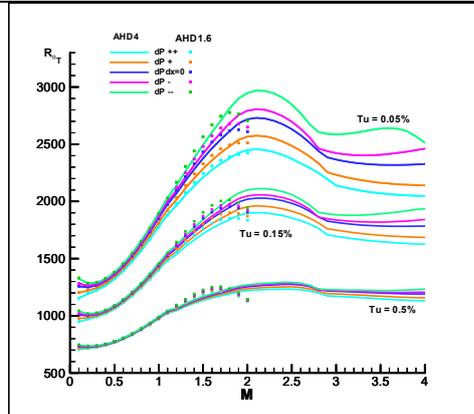
AD/AG51 on "Laminar-Turbulent Transition in Hypersonic flows" (GARTEUR Confidential).

## Status of Action Groups and Exploratory Groups

Six Action Groups and two Exploratory Groups were active in 2018. Four of the six Action Groups have finished their technical activities (AG-51 already completed the Final Report) and are mostly involved in writing the Final Report. The two other started during 2018.

### AD/AG-51

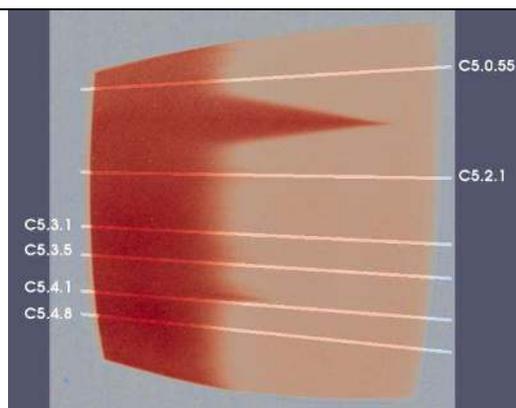
### Laminar/Turbulent Transition in Hypersonic flows



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 has already been completed and distributed (GARTEUR Confidential). The chair is Jean Perraud of ONERA.

### AD/AG-53

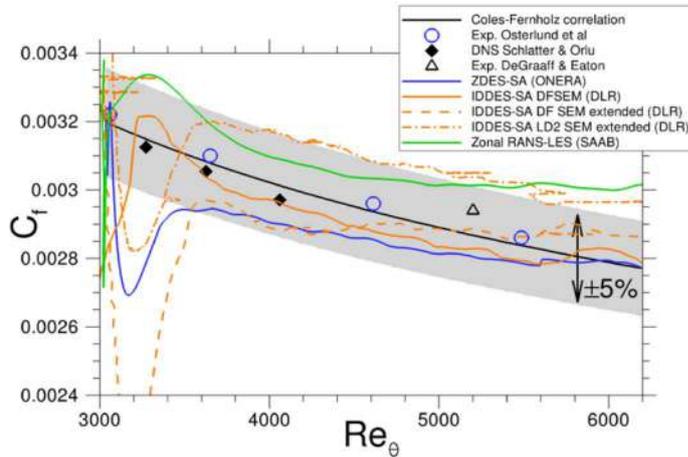
### Receptivity and Transition Prediction: Effects of surface irregularity and inflow perturbations



The main objective of the group 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

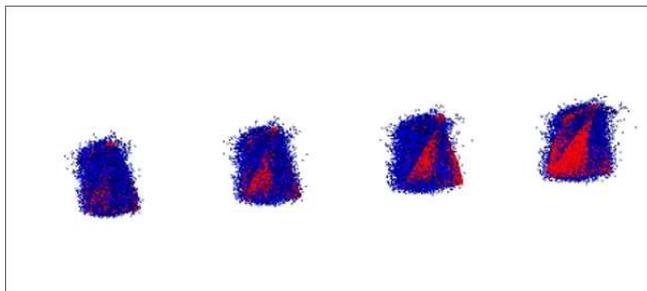
RANS-LES Interfacing for Hybrid and Embedded LES approaches



The main objective of the 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 the Final Report will be ready in 2019. 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

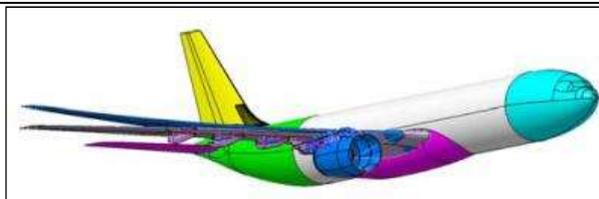


AG-55 arose out of preliminary studies carried out in EG-71 and was launched early 2015, with an expected finishing date of early 2018. The work is divided into two work packages, the first deals with the dispersion of chaff using both Eulerian and Lagrangian approaches. The second work package deals 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. and the Final Report will be ready in 2019. The Final Report is expected in 2019. The chair is Torsten Berglind (FOI).

AD/AG-56

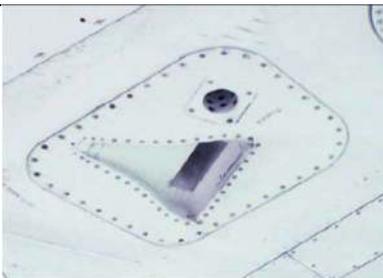
Coupled fluid dynamics and flight mechanics simulation of very flexible aircraft configurations



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 proposal has been written and the group has been endorsed by both the GoR and the Council. The action group, AD/AG-56, had its kickoff in 2018. Chair is Mario Verhagen (NLR).

AD/AG-57

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 proposal has been written and the group has been endorsed by both the GoR and the Council. The action group, AD/AG-57, had its kickoff in 2018.

Chair is Jose Angel Hernanz-Manrique (Airbus Operations).

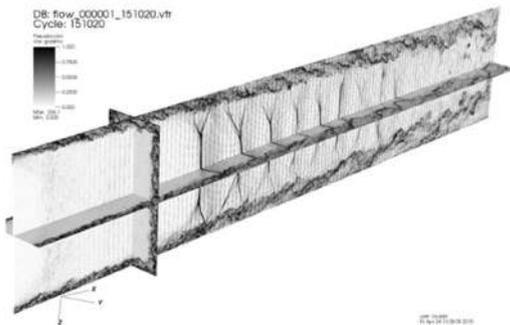
AD/EG-74

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, but due to recent changes in the management it seems difficult to start.

AD/EG-75

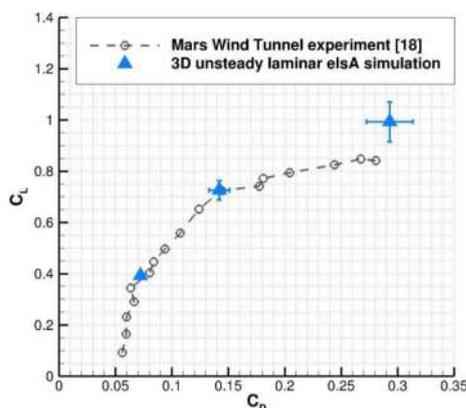
Supersonic air intakes



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 diffusers on the flow distortions at the end of the diffusers. A meeting was held in May 2017 and a final proposal was prepared in 2018. The chairman is Christoffe Nottin (MBDA).

AD/EG-76

Laminar separation bubbles



Laminar separation bubbles are one of the main critical aspects of flows at low Reynolds number, of order of magnitude  $10^4$  to  $10^5$ , which are relevant for small aircraft such as UAV. The proposed action group will deal with the numerical reproduction of laminar separation bubbles. A final proposal was prepared in 2018.

The chairman is Pietro Catalano (CIRA).

## Rolling plans

Cat	Topic	2014	2015	2016	2017	2018	2019	2020
AD/AG51	Laminar-Turbulent Transition in Hypersonic Flows	█	█	█	█	█	█	
AD/AG52	Surrogate-based Global optimization methods in preliminary designs	█	█	█	█			
AD/AG53	Receptivity and Transition prediction	█	█	█	█	█	█	
AD/AG54	RANS-LES Interfacing Hybrid RANS-LES and embedded LES approaches		█	█	█	█	█	
AD/AG55	Countermeasures Aerodynamics			█	█	█	█	
AD/AG56	Coupled Fluid Dynamics and Flight Mechanics simulation for very flexible Aircraft Configurations				EG72 →	█	█	█
AD/AG57	Secondary Inlets and Exhausts for Ventilation				EG73 →	█	█	█
AD/AG58	Supersonic Air Intakes					EG75 →	█	█
AD/AG59	Laminar Separation Bubbles					EG76 →	█	█
AD/EG74	Integration of innovative nozzle concepts with thrust vectoring for subsonic aircraft (in standby)				█	█	█	
AD/EG77	Machine learning ... approaches for aerodynamic optimization and UQ						█	█
AD/EG78	WMLES and Embedded LES						█	█

## GoR membership

### Chairman

Harmen van der Ven

NLR

The Netherlands

### Vice-Chairman

Fernando Monge

INTA

Spain

### Members

Eric Coustols	ONERA	France
Giuseppe Mingione	CIRA	Italy
Heribert Bieler	Airbus Operations GmbH	Germany
Bruno Stefes	Airbus Operations GmbH	Germany
Frank Theurich	Airbus Operations GmbH	Germany
Per Weinerfelt	SAAB	Sweden
Magnus Tormalm	FOI	Sweden
Kai Richter	DLR	Germany

### Industrial Points of Contact

Thomas Berens	Airbus Defence & Space	Germany
Nicola Ceresola	Leonardo Company	Italy
Michel Mallet	Dassault	France
Didier Pagan	MBDA	France
Luis P. Ruiz-Calavera	Airbus Defence & Space	Spain

### Table of participating organisations

	AG-51	AG-53	AG-54	AG-55	AG-56	AG-57	EG-75	EG-76
<b>Research Establishments</b>								
CIRA	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		<input checked="" type="checkbox"/>
DLR	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		
FOI			<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>			<input type="checkbox"/>	
INTA			<input type="checkbox"/>					
NLR			<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>		
ONERA	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<b>Industry</b>								
Airbus Defense& Space				<input type="checkbox"/>	<input type="checkbox"/>			
Airbus Operations GmbH		<input type="checkbox"/>			<input type="checkbox"/>			
Airbus Operations S.A.S			<input type="checkbox"/>			<input checked="" type="checkbox"/>		
Airbus Group Innovations		<input type="checkbox"/>						
Leonardo Company								
Dassault Aviation								
EADS			<input type="checkbox"/>					

LACROIX				<input type="checkbox"/>									
MBDA-F	<input type="checkbox"/>				<input type="checkbox"/>							■	
MBDA-LFK												<input type="checkbox"/>	
SAAB					<input type="checkbox"/>							<input type="checkbox"/>	
<b>Academic Institutions</b>													
Imperial College				<input type="checkbox"/>									<input type="checkbox"/>
Institute of Saint-Louis (ISL)	<input type="checkbox"/>												
Royal Institute of Technology KTH													
Technical University Munich						<input type="checkbox"/>							
Bundeswehr University Munich	<input type="checkbox"/>												
University of Manchester						<input type="checkbox"/>							
Zurich University of Applied Sciences						<input type="checkbox"/>							<input type="checkbox"/>
Von Karman Institute (VKI)	<input type="checkbox"/>												
University of Napoli "Federico II"													<input type="checkbox"/>
Marche Polytechnic University													<input type="checkbox"/>

**Total yearly costs of AG research programmes**

GoR	AG	2014		2015		2016		2017		2018*		2019*	
		pm	k€	pm	k€	pm	k€	pm	k€	pm	k€	pm	k€
	51	12	40	0	0	0	0	2	0	2	0		
	52	23	63	23	63	23	63						
	53	13	24	13	24	2	12	2	0	2	0		
	54	18	100	22	140	18	80	20	100	12	50		
	55			16	24	18	24	16	24	4	5		
	56									14	15	12	15
	57									21	29	22	29
<b>AD</b>	<b>TOTAL</b>	<b>66</b>	<b>227</b>	<b>74</b>	<b>251</b>	<b>61</b>	<b>179</b>	<b>40</b>	<b>124</b>	<b>55</b>	<b>99</b>	<b>34</b>	<b>44</b>

**Action Group Reports**

AD/AG-54: RaLESin

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

Action Group Chairman: Professor 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, ZHAW

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  $Re_h = 2900$  and 1200. Focus on modelling/resolving initial instabilities of the mixing layer.

TC O1 Backward-facing step flow Incoming BL with  $U = 50$  m/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  $U = 70$  m/s and  $Re_h = 3040$ . Focus on turbulence-resolving capabilities on the attached BL after the RANS-LES interface.

TC O2 NASA hump flow Incoming BL has  $U = 34.6$  m/s,  $Re_h = 936000$  ( $c =$  hump length). Focus on the turbulence-resolving capabilities on the flow separation over the hump.

Task 3: Modelling assessment (Task Leader: ONERA) Evaluation and assessment of the methods developed in Tasks 1 and 2 with one TC.

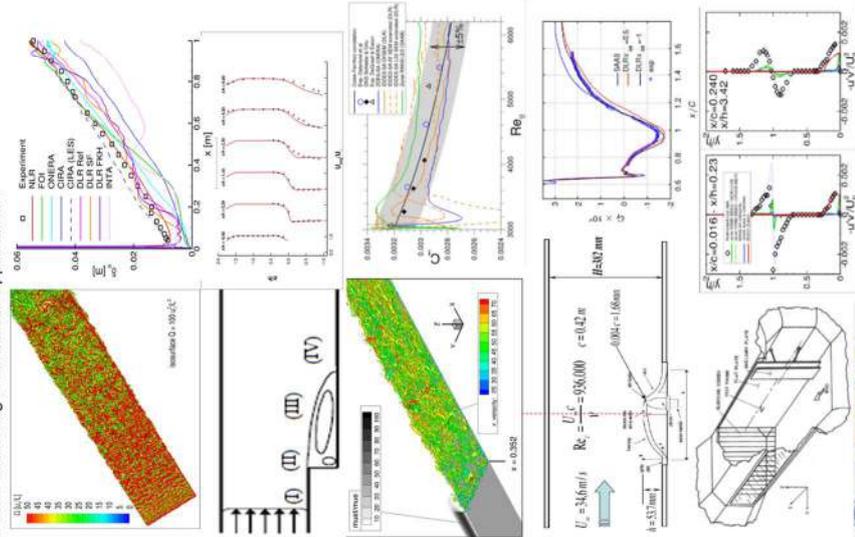
TC M3 Co-flow of BL and wake  $Re = 2.4 \times 10^6$ /meter and  $M = 0.2$ . Examination of modelling capabilities for a complex flow case.

Results

- Further calibration and evaluation of hybrid RANS-LES methods of zonal and non-zonal modelling in computations of all 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 four 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 made on, among others, stochastic backscatter model plus temporal and spatial correlation, velocity-gradient-based energy backscatter, vorticity-based length scale and other verified hybrid length scale, commutation terms etc..
  - 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 used 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 cross plotting of partners results.
  - Progress meetings were held in Oct. 2014, Oct. 2015, Nov. 2016 & Nov. 2017, respectively.



**AD/AG54:** RaLESin: RANS-LES coupling in hybrid RANS-LES and embedded LES approaches  
**Monitoring Responsible:** Mr. M. Tormalm, FOI  
**Chairman:** Prof. S.-H. Peng, FOI

• Objectives

The overall objective of AG54 has been, by means of international collaborative effort, to explore and further to develop and improve RANS-LES coupling for embedded LES (ELES) and hybrid RANS-LES methods, particularly, to address the “grey-area” problem present in zonal and non-zonal hybrid models, for aerodynamic applications. The main objectives have been: (1) To evaluate RANS-LES interfacing methods adopted in current hybrid RANS-LES modelling approaches; (2) To develop “Grey-Area” Mitigation (GAM) methods for improving RANS-LES interaction, 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 scale-resolving simulations of test cases.

• Main Achievements

AG54 consists of 12 members, including three universities, six research organizations and three industries. The work in AG54 has been divided in three technical tasks. Task 1 deals with non-zonal hybrid RANS-LES methods, and Task 2 focuses on RANS-LES coupling for zonal (including wall-modelled LES, WMLES) and embedded LES. Two test cases, a mandatory TC and an optional TC, are defined respectively for Tasks 1 & 2. The methods developed are then further verified and assessed in Task 3 in computations of a mandatory and relatively complex flow test case.

In 2018, the group has progressed in line with the technical work plan and has successfully completed the overall technical work. The main activities and achievements have in general been marked by: (a) Completion of computations of all TCs for evaluating zonal and non-zonal hybrid RANS-LES methods; (b) Progress made in coordinated cross-plotting and comparisons of results for all three mandatory TCs, as well as the two optional TCs, based on contributions by involved AG members; (c) Refined modelling to enhance turbulence-resolving capabilities with special focus on the “grey-area”; (d) Assessment and verification of modelling methods based on comparative studies of computations of the TCs. (e)

Setup of a framework of the final report in terms of the technical contents and timelines.

Task 1 has been progressed in addressing the “grey-area” problem for non-zonal (or seamless) hybrid modelling by means of improved modelling formulation, among others, X-LES based model with stochastic backscatter, high-pass filter and/or temporal/spacial 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, commutation terms as a measure for enhancing resolved turbulent diffusion. Figure 1 shows an example of computations using non-zonal methods for the mixing layer (TC M1) and a cross-plotting example of some partners’ contributions, which show the improved capabilities in resolving the mixing layer and mitigating the grey-area in the initial stage of the mixing layer.

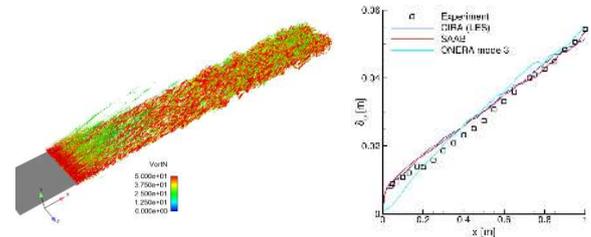


Figure 1: An example of some computations for TC M1 (mixing layer). Resolved turbulent structures (Left) and predictions of mixing-layer vorticity thickness (Right).

For zonal hybrid RANS-LES modelling in Task 2, the main work has been dedicated to improving the method of generating synthetic turbulence (ST) for improving RANS-LES interface and enabling effective 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 as a robust GAM method.

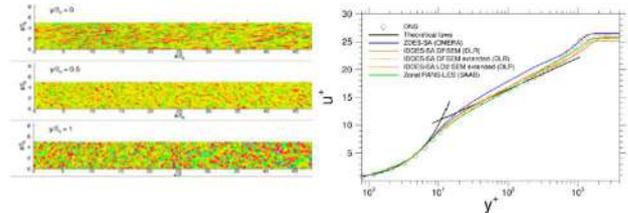


Figure 2: Computation of TC M2 (spatially developing turbulent boundary) using synthetic turbulence. Turbulent structure in relation to ST (Left) and mean Velocity in the boundary layer (Right).

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 along the bottom wall and the resolved turbulent stress

profile at  $x/C=1.1$  in comparison with measured data, showing reasonable agreement.

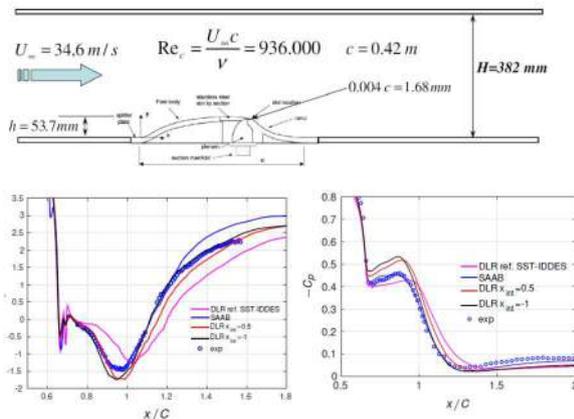


Figure 3: Example for TC O2 using zonal modelling supported by ST methods. The lower row shows bottom wall skin-friction coefficient (Left) and pressure coefficient (Right).

TC M3 (co-flow of boundary layer and wake) in Task 3 has been adopted for overall assessment and verification of methods developed in Tasks 1 & 2. All partners have made computations using the IDDES, WMLES, DDES, ZDES and HYB0 models, and some are further supported by ST and low-dissipative/dispersive schemes. Some results by partners are compared for this test case in Figure 4.

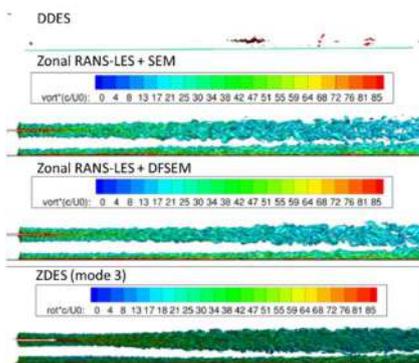


Figure 4: Example for TC M3. Resolved turbulent structures downstream by means of zonal methods supported by ST after the RANS-LES interface.

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 a few partners. For all these test cases, cross-plotting has been processed.

Resources

Resources		Year					Total
Person-months	Actual/Planned	2014	2015	2016	2017	2018	
		A18 P18	A22 P22	A18 P18	A20 P20	A12 P12	A90 P90
Other costs (in K€)	Actual/Planned	A100 P100	A140 P138	A80 P80	A100 P100	A50 P50	A470 P468

Completion of milestones

Work package	Planned		Actual
	Initially	Currently	
Kick-off meeting	April 2014		April 2014
Tasks 1, 2 & 3 def. TCs	Oct 2014		Oct. 2014
1 <sup>st</sup> progress meeting	Oct. 2014		Oct. 2014
Tasks 1, 2 & 3: Website	Oct. 2014		Nov. 2016
Expt. data of all TCs	Sept. 2015		Nov. 2015
2 <sup>nd</sup> Progress meeting	Oct. 2015		Oct. 2015
3 <sup>rd</sup> Progress meeting	June 2016	Nov. 2016	Nov. 2016
4 <sup>th</sup> Progress meeting	Nov., 2017		Nov., 2017
Final meeting	Nov. 2018		Nov. 2018

Expected results/benefits

AG54 has successfully achieved its technical goals, by which a set of zonal and non-zonal hybrid models have been improved with particular focus on the grey-area problem existing in hybrid models. These improved methods have been, or will be, implemented further into the CFD tools of AG members and, consequently, being exploited in other related R&D activities and in industrial applications.

AG membership

Member	Organisation	e-mail
P. Catalano	CIRA	<a href="mailto:p.catalano@cira.it">p.catalano@cira.it</a>
F. Capizzano	CIRA	<a href="mailto:f.capizzano@cira.it">f.capizzano@cira.it</a>
T. Knopp	DLR	<a href="mailto:Tobias.Knopp@dlr.de">Tobias.Knopp@dlr.de</a>
A. Probst	DLR	<a href="mailto:Axel.probst@dlr.de">Axel.probst@dlr.de</a>
D. Schwamborn	DLR	<a href="mailto:Dieter.schwamborn@dlr.de">Dieter.schwamborn@dlr.de</a>
S.-H. Peng	FOI	<a href="mailto:Shia-Hui.Peng@foi.se">Shia-Hui.Peng@foi.se</a>
C. Lozano	INTA	<a href="mailto:lozanorc@inta.es">lozanorc@inta.es</a>
J. Kok	NLR	<a href="mailto:j.kok@nlr.nl">j.kok@nlr.nl</a>
S. Deck	ONERA	<a href="mailto:sebastien.deck@onera.fr">sebastien.deck@onera.fr</a>
S. Arvidson	Saab	<a href="mailto:sebastian.arvidson@saabgroup.com">sebastian.arvidson@saabgroup.com</a>
C. Breitsamter	TUM	<a href="mailto:Christian.Breitsamter@aer.tum.de">Christian.Breitsamter@aer.tum.de</a>
A. Revell	UniMan	<a href="mailto:alistair.revell@manchester.ac.uk">alistair.revell@manchester.ac.uk</a>
L. Tourrette	Airbus-FR	<a href="mailto:Loic.tourrette2airbus.com">Loic.tourrette2airbus.com</a>
Righi Marcello	ZUAS	<a href="mailto:rigm@zhaw.ch">rigm@zhaw.ch</a>

# AD/AG-55: Countermeasure Aerodynamics

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



## The Background

Countermeasures are used to decoy enemy tracking systems. Two commonly used countermeasures are chaff and flares, which are the main focuses of this action group. 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 propulsion systems. In the test cases of this action group, countermeasures are ejected from generic aerial platforms. Their trajectories are significantly affected by the surrounding air.

## The Programme

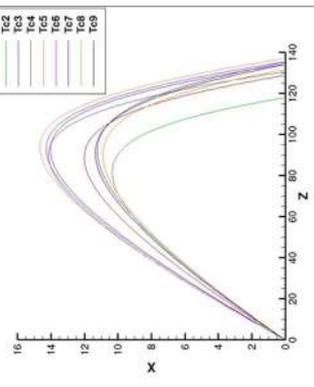
### Objectives of AD/AG-55

The main objective is to evaluate computational methods to predict movement of countermeasures. The purpose of predicting chaff clouds is to be able to support development of tactics for usage of chaff. The trajectory of flares are important to predict accurately since the flare might damage the aircraft.

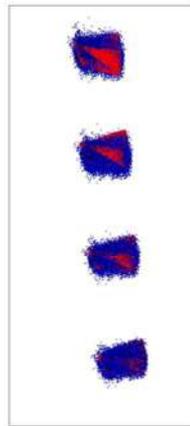
### Approach

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 approach in which individual chaff are tracked. Both methods are applied in a separate post processing step, assuming that the countermeasures do not affect main flow field properties.

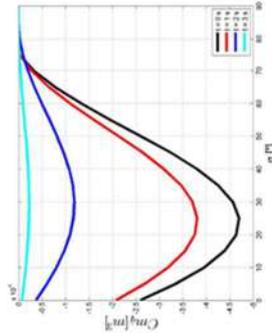
The ejection of a flare involves complicated physics. The cold flare model includes changes in shape, mass, moments of inertia in addition to 6 DoF movement. The hot flare model consists of the same features and in addition includes high boundary temperature flow and exhaust gases. The objective is to determine an appropriate level of modelling the flare that gives sufficiently accurate flare trajectories.



Experimental flare tracks



Lagrangian simulation of spherical chaff dispersed from a generic helicopter. FOI's results in blue and NLR's in red. The temporal increment between the chaff clouds is 0.1 sec.



Pitch damping coefficient

## The Outcomes

### Expected results/benefits

The action group is expected to yield increased understanding of simulation of chaff dispersion and flare trajectory modelling. A natural outcome is also that the partners obtain improved simulation tools

### Management issues

One physical meeting, where all member organisations except LaCroix participated, was held at NLR in Amsterdam April 18th and 19th. In addition, four tele-conference meetings were held on January 31st, June 20th, September 12th and November 8th.

This Action Group has applied for a 6 month extension since some additional computations, and the major part of writing the final report remain. The next tele-conference meeting is planned on February 7th. Eventually, there will be an additional physical meeting in Madrid during spring 2018.

### Main achievements

A thorough investigation of deviations between FOI's and NLR's results has led to good agreement of the computational results. Evaluation has started comparing the movement of mass centre and standard deviation of chaff particle clouds.

Aerodynamic databases have been created for both the cold flare and hot flare models. Airbus D&S and MBDA have delivered a model for the aerodynamic damping of the flare.

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

Project duration: January 2015 – June 2018



**COUNTERMEASURE  
AERODYNAMICS**

**AD/AG-55**

**Monitoring Responsible:** M. Tormalm  
FOI

**Chairman:** T. Berglind  
FOI

- *Background*

This action group has studied movements of countermeasure objects, chaff and flares, ejected from generic aerial platforms. The main objective has been to evaluate computational methods predicting movement of counter-measure objects.

- **Main achievements**

A remaining computational investigation is evaluation of chaff clouds modelled as thin circular cylinders.



*Chaff cloud evolution without turbulent dispersion behind a generic helicopter. Cylindrical chaff particles are initially aligned with the z-direction. FOI's results in green and NLR's in blue. The temporal increment between chaff clouds is 0.1 sec.*

- **Management issues**

This year has mainly been devoted to finalise the report. Tele-conference meetings were held on February 16<sup>th</sup> and April 13<sup>th</sup>.

One physical meeting, where all member organisations except LaCroix participated, was held at Airbus in Madrid the 13<sup>th</sup> – 14<sup>th</sup> of June. The flare part of the action group is since September considered as finished.

- **Expected results/benefits**

The project is expected to yield increased understanding of simulation of chaff and flare trajectory movements.

- *AD/AG-55 membership*

Member	Organisation	e-mail
L. Ruiz	Airbus D&S	<a href="mailto:Luis.Ruiz@military.airbus.com">Luis.Ruiz@military.airbus.com</a>
S. Cid Arroyo	Airbus D&S	<a href="mailto:sergio.cid@airbus.com">sergio.cid@airbus.com</a>
O. Estibals	Etienne Lacroix	<a href="mailto:Olivier.Estibals@etienne-lacroix.com">Olivier.Estibals@etienne-lacroix.com</a>
C. Saez	Etienne Lacroix	<a href="mailto:christian.saez@etienne-lacroix.com">christian.saez@etienne-lacroix.com</a>
T. Berglind	FOI	<a href="mailto:torsten.berglind@foi.se">torsten.berglind@foi.se</a>
O. Grundestam	FOI	<a href="mailto:olof.grundestam@foi.se">olof.grundestam@foi.se</a>
S.-H. Peng	FOI	<a href="mailto:shia-hui.peng@foi.se">shia-hui.peng@foi.se</a>
C. Jeune	MBDA France	<a href="mailto:Christophe.jeune@mbda-systems.com">Christophe.jeune@mbda-systems.com</a>
S. Tusseau	MBDA France	<a href="mailto:simon.tusseau@mbda-systems.com">simon.tusseau@mbda-systems.com</a>
H. Van der Ven	NLR	<a href="mailto:Harmen.van.der.ven@nlr.nl">Harmen.van.der.ven@nlr.nl</a>

- *Resources*

I. Resources		Year				Total
		2015	2016	2017	2018	
Person-months	Actual/Planned	16/16	18/16	18/16	9/16	61/64
	Other costs (in K€)	24/24	24/24	24/24	10/24	82/96

- *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	Delivered
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	Apr. 2017	Delivered
MS 8. Deliver flare data properties: gas constant, $\gamma$ -value. If possible, chemical composition (Lacroix)	Dec 2016	Dec 2016	Delivered
MS 9 Skeleton report with responsible organisation for each chapter (FOI)	Feb 2017	Jan 2017	Delivered
MS 10. Computations of flare trajectory test cases (Airbus, MBDA, FOI)	Mar 2017	Dec 2017	Delivered
MS 11. Flare trajectory experiments(Lacroix)	Apr 2017	Apr 2017	Delivered
MS 12. Final report	Dec 2017	June 2018	In progress

**AD/AG-56** COUPLED FLUID  
DYNAMICS AND FLIGHT  
MECHANICS  
SIMULATION OF VERY  
FLEXIBLE AIRCRAFT  
CONFIGURATIONS

**Monitoring Responsible:** H. Van der Ven  
NLR

**Chairman:** M. Verhagen  
NLR

- **Background**

With the increasing importance of environmental issues, various technologies are being developed to create more efficient aircraft designs, reducing fuel burn. In terms of airframe enhancements, these include utilizing lighter structures and higher aspect ratio wings, leading to very flexible configurations. By more actively accounting for the large structural deformations in very flexible configurations, greater weight savings and larger aspect ratios can be realized.

To allow for better optimization of such flexible configurations, studies are carried out in bringing closer the various disciplines supporting aircraft design, especially taking into account the large structural deflections in flight mechanics analyses. Building upon GARTEUR (FM) AG-19 where use has been made of simplified aerodynamic models, AG-56 makes use of high fidelity aerodynamic models coupled with structural models for such very flexible aircraft. Within AG-56, capabilities will be developed to perform aeroelastic simulations of very flexible aircraft. These capabilities will be assessed and benchmarked by performing simulations with varying degrees of fidelity.

- **Objectives**

The goals of AG-56 are twofold: firstly, this endeavour aims to enhance each partner's capabilities in aeroelastic simulations pertaining to very flexible aircraft. This entails more accurately predicting aerodynamic loads and structural deformations for manoeuvre and disturbance conditions. A second aim of AG-56 is to define and develop a common test case in terms of aircraft and manoeuvre. This will allow the various partners to benchmark their solvers and tools.

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

- A flight mechanics model for flexible structures,

- CFD methods with robust grid handling technique capable of modelling a combination of large rigid body motion and large flexible motion,
- Fluid-structure interaction procedures that are capable of modelling large translations and finite rotations.

- **Approach**

Analyses will be performed using the Airbus XRF-1 benchmark model which has been modified to accommodate for more wing flexibility. The baseline XRF-1 model has been made available by AI-O.

Four scenarios will be considered; two gust disturbance conditions and two manoeuvres. The manoeuvre conditions are a 2.5g pull-up and an elevator deflection. Aeroelastic simulations with six degrees of freedom will be performed in a CFD environment. To achieve this, the complexity of the simulations will be increased step-by-step, starting with a purely aerodynamic (assuming a rigid aircraft) simulation, subsequently followed by an aeroelastic simulation without motion, and finally the 6-DOF aeroelastic simulation. Results will be compared to lower fidelity aeroelastic simulations that do not consider a CFD environment. This is done in the NASTRAN and ZAERO environments by means of aeropanel. As stated earlier, the underlying goal of more accurate aeroelastic analyses for very flexible aircraft is to impose less stringent stiffness criteria, allowing for fuel burn reductions with lighter structures and higher aspect ratios. As such, a final analysis will consider an MDO optimized aircraft. This will provide insight in the potential gains and aeroelastic behaviour when optimizing very flexible aircraft wings.

- **Main achievements**

Due to challenges in obtaining the XRF-1 FEM and CAD models, work has been limited in the first year. Thus far, the disturbance and manoeuvre conditions have been defined. Additionally, the generic FEM and CAD models are being modified for AG-56 purposes, after which the envisioned simulations can commence in the near future. For the CAD geometry, modifications included geometry clean-up for CFD (un)structured mesh generation and the inclusion of an elevator surface (see fig. 1). For the FEM model, wing elasticity is currently being modified for increased tip deflections; aiming for 10 percent tip deflection in 1g flight (see fig. 2). Partners will subsequently run the various simulations making use of these common CAD and FEM models.

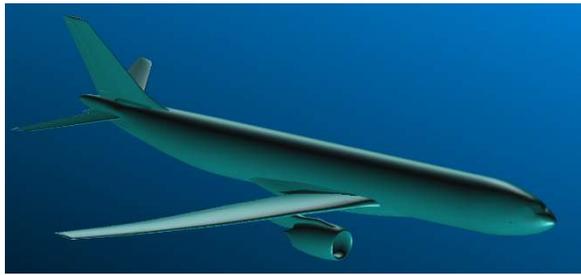


Fig. 1 The CAD geometry of the XRF-1.

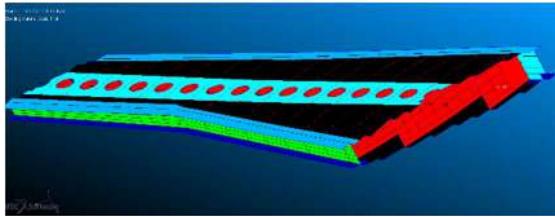


Fig. 2 Depiction of the wing structure in the FEM model. The elasticity of the front and rear spar are tuned for 10 percent tip deflection in 1g flight.

• **Project management**

It has been decided to have alternating physical and teleconference meetings every 3 months. The kick-off meeting took place on the 9<sup>th</sup> of March 2018 in Amsterdam, hosted by NLR. Two teleconference progress meetings have been held on the 25<sup>th</sup> of October 2018 and the 25<sup>th</sup> of March 2019, as well as a physical meeting in Manching, hosted by Airbus Defence and Space on January 24<sup>th</sup>, 2019.

• **Expected results/benefits**

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

• **AD/AG-56 membership**

Member	Organisation	E-mail
K. Elssel	Airbus D&S	kolja.elsel@airbus.com
H. Bleecke	Airbus O	hans.bleecke@airbus.com
P. Vitagliano	CIRA	p.vitagliano@cira.it
M. Ritter	DLR	markus.ritter@dlr.de
M. Verhagen	NLR	mario.verhagen@nlr.nl
F. Huvelin	ONERA	fabien.huvelin@onera.fr
C. Poussot-Vassal	ONERA	charles.poussot-vassal@onera.fr

• **Resources**

Resources		Year			Total
	Actual/ Planned	2018	2019	2020	
Person-months		14 14	12	12	38
Other costs (in K€)	Actual/ Planned	7 7	14 14	14 14	36

• **Progress/Completion of milestones**

Mile stone	Planned		Actual
	Initially (end of ...)	Currently (updated)	
MS 1: Access to common research model	Jul 2015	Oct. 2015	Completed
MS 2: Completion of CAD model for CFD mesh generation	Jul 2015	Sep. 2015	Completed
MS 3: Completion of FEM model for simulations	Aug 2015	Jul. 2009	In progress
MS 4: Panel code lower fidelity free-free simulations (disturbance)	Nov 2015	June 2016	
MS 5: Initial CFD 1g static aerodynamic analyses around flight shape	Feb 2016	June 2017	
MS 6: Rigid structure CFD simulations (manoeuvre + disturbance)	Sep 2016	Oct. 2016	
MS 7: Aeroelastic CFD simulations with linear structure (manoeuvre + disturbance)	Dec 2016	Apr. 2017	
MS 8: Aeroelastic CFD simulations with non-linear structure (manoeuvre + disturbance)	Dec 2016	Dec 2016	
MS 9: Generation of MDO optimized linear XRF-1 aircraft model	Feb 2017	Jan 2017	
MS 10: Aeroelastic CFD simulations with MDO optimized linear structure (disturbance)	Mar 2017	Dec 2017	
MS 11: Cross-plotting and analysis of all results	Apr 2017	Apr 2017	
MS 12: Final report	Dec 2017	June 2018	

AD/AG-57

SECONDARY INLETS AND OUTLETS FOR VENTILATION

**Monitoring Responsible:** G.Mingione  
CIRA

**Chairman:** J.A. Hernanz  
Airbus OP

• **Background**

Aircraft capture outside air for the purpose of air conditioning, ventilation and cooling. This is achieved by means of secondary air inlets. Their shapes differ widely depending on integration possibilities, performance requirements and minimization of interference effects (including drag). In case of transport aircraft (civil and military), it is expected that the capabilities of secondary air inlets have to increase considering the tendency to replace bleed air from the main engines by the acquisition of outside air for air-conditioning purposes. This tendency is also driven by the requirement to prevent fumes from entering the cabin as well as to create a possibility to utilise engine bleed air for active flow control purposes.

Furthermore future propulsion technologies as hybrid or electrical engines are based in the used of storage batteries which required the evacuation of high level of heat. The correct design of auxiliary intakes and outlet permits an easily method to reject the heat without penalizing the new engines performances.

• **Objectives**

Analyse the efficiency of a submerged NACA type air intake for multiple flight envelopes using state-of-the-art CFD and performance evaluation methods. Investigate whether such an air intake can comply with novel requirements for air-conditioning for large transport aircraft (civil and military).

Analyse the feasibility of a low-observable secondary inlet integrated in the main air intake duct of a combat aircraft and assess the impact on the intake duct flow field and on engine/intake-compatibility. Investigate different types of secondary inlets, shapes, locations, and sizes with respect to advantages regarding radar cross section and aerodynamic performance.

• **Approach**

The proposed activities concern the application of secondary air inlets on multiple aircraft platforms, i.e. transport aircraft (civil and military) and combat aircraft. The submerged air intake (NACA type) is predominantly selected for application on the fairing of transport aircraft (civil and military) whereas the hidden inlet is utilized for application inside the engine air intake of combat aircraft in order to reduce the radar signature.

• **Main achievements**

**WP 1: Submerged air intake studies**

**Task 1.1: NACA standard intake in a fuselage surface**

- NLR preliminary geometry and mesh generation around NACA inlet first calculations to check the methodology
- CIRA Secondary NACA intake provided by AIRBUS has been simulated by means of the CFD code ANSYS Fluent R18
- After a preliminary check, the intake with Far Field and the exit duct has been meshed by means of the ANSYS ICEM CFD grid generator
- An unstructured grid of has been generated with about 20 layers on the body and a  $y^+$  close to 1



NLR Progress Report AG57

- Conducted literature study for secondary air intakes (new colleague)



- Application of the in-house CFD method of NLR to the reference geometry provide by AIRBUS:
  1. Determination of the boundary layer characteristics on the fuselage
  2. Conducting a mass-flow sweep for the NACA intake for  $M=0.85$



Fig. 1 NLR preliminary studies, geometry cleaning and intake mesh for CFD

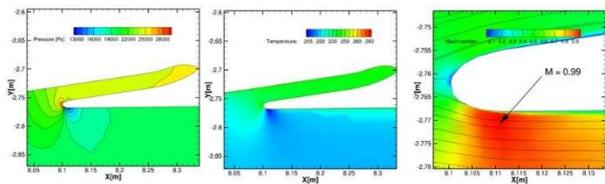


Fig. 2 CFD results of NACA intake prepared by CIRA. Detail of velocities in inlet lip

**Task 1.3: Air outlet study for passive flow control**

- DLR presented the results of a WTT campaign to evaluate the achievable mass flow at the flap outlet in the VTP for different open angles
- AI-Operation Bremen show the Hybrid Laminar Flow Control outlet flap performance validation with wind tunnel test 2D model (PIV measurements) and 3D (nearly) full size A320 VTP placed in Low Speed Wind Tunnel. In this model the flap outlet is located in a lateral zone of the VTP leading edge.

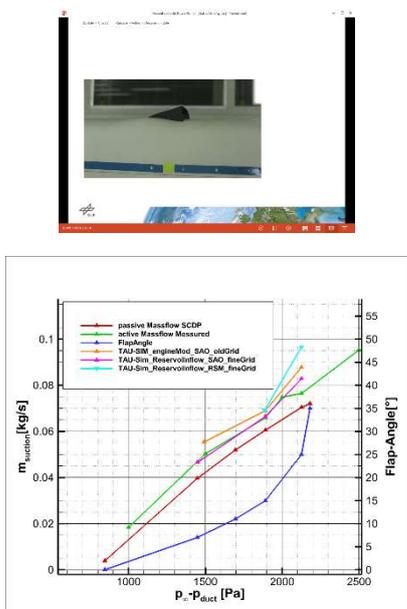


Fig. 3 Mass flow at flap outlet for a VTP function of the open angle. DLR wind tunnel test



Fig. 4 Project OptiHyL in DNW-LLF wind tunnel: Hybrid Laminar Flow Control (HLFC) / Low Speed Wind Tunnel campaign of A320 VTP in DNW-LLF facility / The Netherlands

**Task 1.4: Inlets/outlets connection devices**

- CIRA works in a code to code comparison, based on an existing actual air-intake, in order to assess methodologies able to carry out the secondary inlets design.
  - Secondary NACA intake, the P180 oil cooler & NACELLE provided by PIAGGIO AEROSPACE Inds
  - Its performance will be investigated by means of the CFD code ANSYS Fluent R18
  - After a preliminary check, the geometry has been meshed by means of the ANSYS ICEM CFD grid generator
  - An unstructured grid of «» has already been generated with about 20 layers on the body and a  $y^+$  close to 1
  - The far-field is located at 10 times the characteristic length L
- Airbus DS
  - Geometry checked and translated in ICEM CFD
  - Geometry modifications: dummy aircraft Wing-Body and nacelle rear components
  - Initial meshing checks .

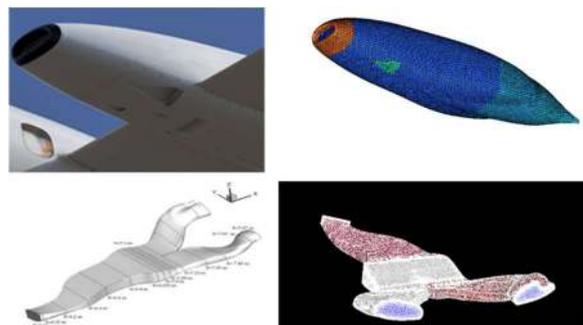


Fig. 5 CIRA generated grid for PIAGGIO nacelle and internal intake and outlet ducts

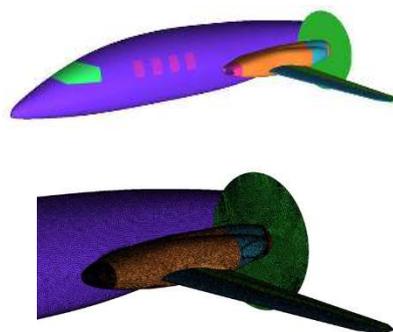


Fig. 6 Airbus DS generated grid for PIAGGIO nacelle and internal intake and outlet ducts including part of fuselage and wing

**WP 2: Hidden secondary inlet within main intake studies**

AI-DS presented some review of internal reports for the intake location in fan duct and has generated the first geometry including a first computational mesh

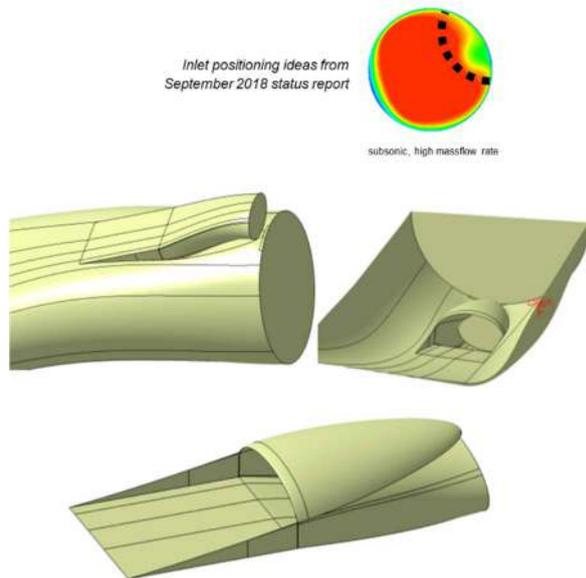


Fig. 7 Airbus DS generated geometry for inner fan duct at best location to improve fan inlet losses

• **Management issues**

Physical kick off meeting, where all member organisations, was held at Airbus DS in Manching May 17th 2018. In addition, two tele-conference meeting where held on September 2018 and February 2019. The next physical meeting is planned for May 9<sup>th</sup> 2018 in Amsterdam at NLR facilities

• **Expected results/benefits**

The project is expected to yield improve the capabilities of secondary air inlets for transport aircraft (civil and military) and combat aircraft facing increasing mass flow demands in combination with more stringent integration requirements

• **AD/AG-57 membership**

Member	Organisation	e-mail
J.A. Hernanz (chairman)	Airbus Op	<a href="mailto:jose.hernanz@airbus.com">jose.hernanz@airbus.com</a>
U. Krause (vice chairman)	Airbus Op	<a href="mailto:udo.krause@airbus.com">udo.krause@airbus.com</a>
R. Ehrmayr	Airbus DS	<a href="mailto:robert.ehrmayr@airbus.com">robert.ehrmayr@airbus.com</a>
A. Carozza	CIRA	<a href="mailto:A.Carozza@cira.it">A.Carozza@cira.it</a>
C. Gonzalez	Airbus DS	<a href="mailto:carlos.z.gonzalez@airbus.com">carlos.z.gonzalez@airbus.com</a>
J. Himisch	DLR	<a href="mailto:Jan.Himisch@dlr.de">Jan.Himisch@dlr.de</a>
H. Maseland	NLR	<a href="mailto:hans.maseland@nlr.nl">hans.maseland@nlr.nl</a>

• **Resources**

Participant	Year 1			Year 2			Year 3		
	M	CP	T	M	CP	T	M	CP	T
CIRA	6	5	1	6	10	1	6		1
Airbus D&S	6	5	5	6	20	5	6		5
Airbus Op	3	5	1	4	10	1	4		1
NLR	2	5	2	2	10	2	2		2
DLR	4	5	2	4	10	2	4		2

• **Progress/Completion of milestones**

**Status of planning activities for WP1**

WP	Task	YEAR 1				Status March 2019
		Q1	Q2	Q3	Q4	
1.1	Task 1.1 NACA standard intake in a fuselage surface					
1.1.1	Task 1.1.1 Design point simulation for code-to-code verification					
	Translation of geometries and grid for different solver					On time
	RANS simulations					On time
	Harmonization of Postprocessing					
	Finalization & Reporting					
1.1.2	Task 1.1.2: Assessment for the flight envelope of civil transport aircraft					
	Selection of the points of flight envelope					not yet started
	RANS simulations					
	Harmonization of Postprocessing					
	Finalization & Reporting					
1.1.3	Task 1.1.3: Parameter study for main geometrical parameters					
	Translation of geometries and grid for different parameters					
	RANS simulations					
	Harmonization of Postprocessing					
	Finalization & Reporting					
1.2	Task 1.2: Assessment for the flight envelope of military transport aircraft					
	Selection of the points of flight envelope					not yet started
	RANS simulations					
	Harmonization of Postprocessing					
	Finalization & Reporting					
1.3	Task 1.3: Air outlet study for passive flow control					
	Translation of geometries and grid for distributed flap locations on the VTP					on going
	RANS simulations for a variation of pressure conditions					on going
	Harmonization of Postprocessing					
	Finalization & Reporting					
1.4	Task 1.4: Inlets/outlets connection devices					
	Translation of geometries and grid for different solver					on time
	RANS simulations					
	Harmonization of Postprocessing					
	Finalization & Reporting					

**Status of planning activities for WP2**

WP 2 Time schedule plan		YEAR 1				Status March 2019
WP	Task	Q1	Q2	Q3	Q4	
2.1	Preparation of first geometries and grid generation					on going
	Update of geometries and grid generation					
	Harmonization of Postprocessing					not yet started
2.2	Provision of operating conditions for simulations					not yet started
	First Navier-Stokes simulations					not yet started
	Navier-Stokes simulations for updated geometries					
2.3	Performance assessment for first geometries					
	Performance assessment for updated geometries					
2.4	Secondary outlet study for passive flow control					
	Finalization & Reporting					

**AD/AG-58** SUPERSONIC AIR INTAKES AERODYNAMICS

**Monitoring Responsible:** D. Pagan  
MBDA

**Chairman:** C. Nottin  
MBDA

• **Background**

Supersonic air intakes are of foremost importance in the design of a supersonic air-breathing vehicle, whether the propulsion system is a turbojet, a ramjet or a scramjet. They are critical in the performance (thrust, drag, consumption) but also in the mass budget, the general architecture and the radar signature. They need to be accurately designed very early in the development phase. Currently their design heavily relies on numerical simulations (CFD).

An Action Group on supersonic air intakes was completed in 2007 (AG34). It was focused on shock / boundary layer interactions and the modelling of porous walls and bumps. It is proposed to build on the results of this AG and to launch a new research activity in this domain which is of primary interest for military aircrafts and missiles.

• **Objectives**

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

- Cowl oblique shock / boundary layer / mixing layer interactions
- Internal bleed flows
- Supersonic air intake diffusers and scramjet isolators including corner flows description.

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

The main conclusions of the activities carried out during the proposed Action Group should cover the following specific issues:

- Clarify the benefit of new CFD methods (unsteady ZDES approach) and HPC capacities in comparison with the last AG34 for example,

- Assess RANS methodology (including turbulence modelling, grid mesh refinement) to tackle the proposed research topic, and
- Estimate the CPU cost of the comparative methodologies.

• **Main achievements**

**WP1 : Management**

One physical meeting, where all member organisations participated, was held at MBDA-France in Le Plessis Robinson in February 13th 2019.

A next tele-conference meeting will be planned for Q3 2019. There will be an additional physical meeting during spring 2020.

**WP2 : Supersonic diffusers flows**

The case proposed in WP2 involves shock trains prediction.

The main challenges are:

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

The classical turbulence models based on linear closures generally fail to reproduce accurately these flows. More advanced models may be required based on RANS with non linear closures or LES/DES techniques.

A 3D test case with thick BLs  $Re\delta_2 \approx 6000$  and strong effect of corner flows from Fiévet et al (AIAA J, 2017) was identified by ONERA but the paper seems not self-sufficient to be used as a test-case.

ONERA proposed to design of a test-case similar for AG58 but with well-known flow conditions at boundaries, see Figure 1.

Preliminary RANS computations were performed by ONERA. Inlet flow profiles are now available to all partners, see Figure 2. Outlet condition is a prescribed back pressure. ONERA will perform a DES mode 3 calculation that can be used as a reference to compare with RANS models. Members will perform DES and/or RANS calculations including non linear closure turbulence models (SAQCR, RMS, ...).

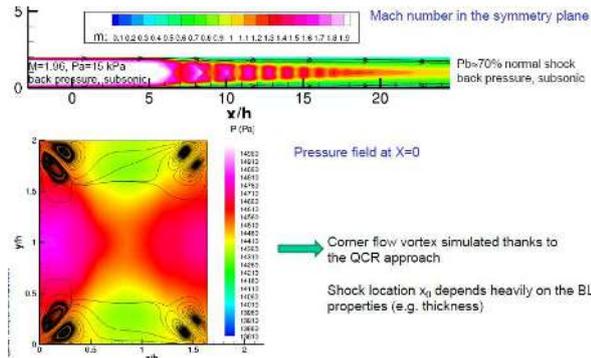


Fig. 1 Shock train in a rectangular cross-section channel. ONERA test-case.

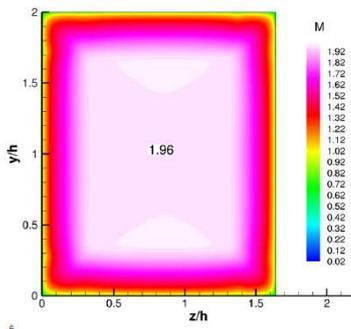


Fig. 2 Common inlet flow field proposed by ONERA for shock train case computations.

WP3 : Mach 3 ramjet intake

DLR has described in detail experimental results obtained in several existing wind-tunnel test campaigns for a ramjet intake design for Mach 3, see Figure 3.

- Design point of baseline configuration: Mach 3
- Modular design for configurations from  $3 \leq Ma \leq 4.5$  in steps of  $\Delta Ma = 0.5$ 
  - Achieved by exchanging ramp and cowl components
- Self-startable, self-start Mach number  $Ma = 2.1$
- Contraction limit at  $Ma = 3$  is 21.8%
- Contraction ratio about 10%
- Angle of attack:  $-6^\circ \leq \alpha \leq +6^\circ$

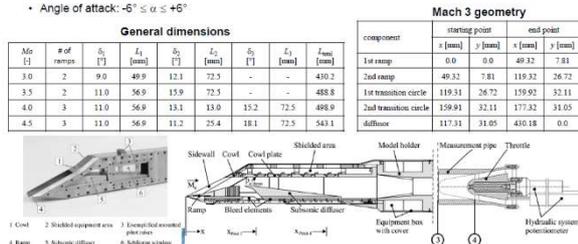


Fig. 3 DLR experimental model for the Mach 3 ramjet intake.

This large existing database includes several effects:

- internal bleed geometry, see Figure 4
- flow conditions such as Mach number (on and off design conditions) and angle of attack
- geometry of the ramps and cowl

It was decided to focus on one bleed geometry effect and one effect of Mach number (on/off-design).

The available experimental data contain:

- pressure recovery ratio and mass flow rate for several throttling ratios of the debitmeter
- Schlieren images
- wall pressures and Pitot pressures from rake measurements
- frequency analysis of buzz

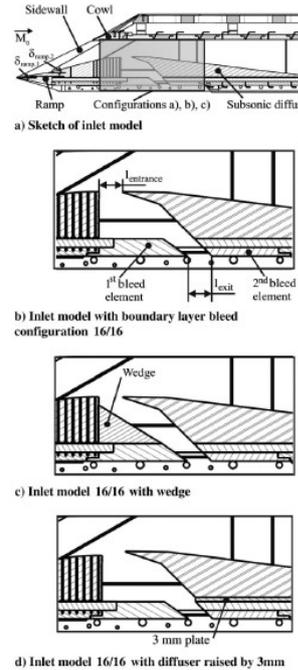


Fig. 4 DLR experiments with bleed geometry effects on the ramjet intake.

A CAD file and the experimental conditions for which most reliable measurements are available are to be provided by DLR to all members.

WP4 : Mach 7.5 scramjet intake

The proposed test-case is illustrated on the Figure 5.

- Windtunnel model geometry
  - Scale: 1.5:1
  - Capture area:  $0.1 \times 0.1 \text{ m}^2 = 0.01 \text{ m}^2$
  - Throat height 15.5 mm  $\rightarrow$  contraction ratio = 6.45
  - Internal contraction ratio  $A_{up}/A_{th} = 1.19$  in basic configuration
    - Can be increased up to 1.88 for 2D-configuration
  - Ramp angles  $\delta_1 = 9.5^\circ$ ,  $\delta_2 = 20.5^\circ$  (against x-axis)
  - Isolator bottom wall divergent by  $1^\circ$
  - Height at combustion chamber entry 18 mm

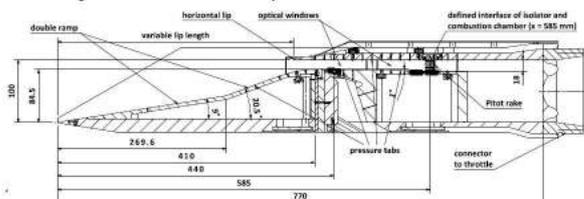


Fig. 5 DLR experimental model for the scramjet Mach 7.5 intake

One topic for WP4 will be the aerothermal fluxes prediction and effects of sidewalls compression, see some examples of experimental results on Figure 6.

Best conditions for CFD validation are to be fixed for future calculations.

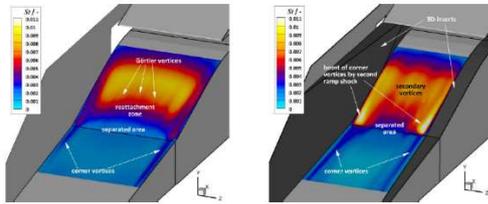


Fig. 5 DLR experiments on the scramjet intakes, with IR thermography. Effect of sidewalls compression on heat fluxes and corner flow.

• **Expected results/benefits**

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

• **AD/AG-58 membership**

Member	Organisation	e-mail
Patrick Gruhn	DLR	<a href="mailto:patrick.gruhn@dlr.de">patrick.gruhn@dlr.de</a>
Oliver Hohn	DLR	<a href="mailto:Oliver.hohn@dlr.de">Oliver.hohn@dlr.de</a>
Magnus Tormalm	FOI	<a href="mailto:magnus.tormalm@foi.se">magnus.tormalm@foi.se</a>
Henrik Edefur	FOI	<a href="mailto:henrik.edefur@foi.se">henrik.edefur@foi.se</a>
Didier Pagan	MBDA France	<a href="mailto:didier.pagan@mbda-systems.com">didier.pagan@mbda-systems.com</a>
Christophe Nottin	MBDA France	<a href="mailto:christophe.nottin@mbda-systems.com">christophe.nottin@mbda-systems.com</a>
Scott Shaw	MBDA UK	<a href="mailto:scott.shaw@mbda-systems.com">scott.shaw@mbda-systems.com</a>
Sébastien Deck	ONERA	<a href="mailto:sebastien.deck@onera.fr">sebastien.deck@onera.fr</a>
Neil Sandham	University of Southampton	<a href="mailto:n.sandham@soton.ac.uk">n.sandham@soton.ac.uk</a>

• **Progress/Completion of milestones**

Mile stone	Planned		Actual
	Initially (end of ...)	Currently (updated)	
WP1: Kick-off meeting	Q4 2018	February 2019	Done
WP1: 2020 Meeting	Q1 2020	Q1 2020	Not started
WP1: 2021 Meeting	Q1 2021	Q1 2021	Not started
WP1: Final report and meeting	February 2022	February 2022	Not started
WP2: Definition of a numerical case for shock train computations	Q1 2019	Q1 2019	Done
WP2: Each member to prepare his grid and obtain RANS computations	Q4 2019	Q4 2019	In progress
WP2: DES computations	Q3 2020	Q3 2020	In progress
WP3: Fix experimental conditions and provide CAD file	Q3 2019	Q3 2019	In progress
WP3: Each member to prepare his grid and obtain preliminary computations	Q4 2020	Q4 2020	Not started
WP3: Final computations	Q3 2021	Q3 2021	Not started
WP4: Fix experimental conditions and provide CAD file	Q4 2019	Q4 2019	In progress
WP4: Each member to prepare his grid and obtain preliminary computations	Q4 2020	Q4 2020	Not started
WP4: Final computations	Q3 2021	Q3 2021	Not started

**AD/AG-59**

**IMPROVING THE SIMULATION OF LAMINAR SEPARATION BUBBLES**

**Monitoring Responsible:** G. Mingione  
CIRA

**Chairman:** P.Catalano  
CIRA

• **Background**

The laminar separation bubble is one of the main critical aspects of flows at Reynolds number of order of magnitude  $10^4$ - $10^5$ . However, the reproduction of this phenomenon results to be crucial also for flows at higher Reynolds number. In fact, very tiny laminar separation bubbles are present in airfoil used for turbine applications operating at Reynolds number of the order of magnitude of  $10^6$ .

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

• **Objectives**

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

- The determination of the transition location and of transition region,
- The enhancement of the production of the turbulent kinetic energy in the separated flow inside the recirculation region,

- Evolution of the bubble with the incidence and with turbulence level,
- Possible burst of the bubble at high incidence and consequences on the stall characteristics,
- Critical evaluation of the laminar boundary-layer instability analysis methods treatment of laminar separation bubbles.

• **Approach**

The focus is placed on the methods based on the Reynolds Averaged Navier Stokes (RANS) equations and on the hybrid RANS-LES methods. Boundary layer instability analysis tools will also be used and compared with the RANS results to ascertain deficiencies of the turbulent onset point; moreover, the RANS embedded turbulence/transition models will also provide significant insight into the efficacy of the boundary-layer instability and hence transition criteria. A particular contribution will be provided by the Zurich University of Applied Sciences (ZUAS) that will apply the open-source code SU2, a flow solver that is becoming more and more popular in the aerospace community. The action group represents a good chance to compare the reliability and accuracy of SU2 with several codes developed by Universities and research centers

• **Main achievements**

The project is just started. A ftp site has been set-up. A sample of letter of acceptance and adherence has been sent to all members.

• **Management issues**

The kick-off meeting, where all member organisations except University of Marche, was held at CIRA on February 13th and 14th.

• **Expected results/benefits**

The project is expected to yield increased understanding of modelling of laminar separation bubbles. A natural outcome is also that the partners obtain improved simulation tools.

• **AD/AG-55 membership**

Member	Organisation	e-mail
P.Catalano	CIRA	<a href="mailto:p.catalano@cira.it">p.catalano@cira.it</a>
D. deRosa	CIRA	<a href="mailto:d.derosa@cira.it">d.derosa@cira.it</a>
J. Perraud	ONERA Toulouse	<a href="mailto:Jean.Perraud@onera.fr">Jean.Perraud@onera.fr</a>
G. Delattre	ONERA Toulouse	<a href="mailto:gregory.delattre@onera.fr">gregory.delattre@onera.fr</a>

		• Resources				
			Year			Total
			2019	2020	2021	
I. Bernardos	ONERA Meudon	<a href="mailto:luis.bernardos_barreda@onera.fr">luis.bernardos_barreda@onera.fr</a>	Resources planned			
P. Molton	ONERA Meudon	<a href="mailto:pascal.molton@onera.fr">pascal.molton@onera.fr</a>	16	21	21	58
S. Hien	DLR	<a href="mailto:stefan.hein@dlr.de">stefan.hein@dlr.de</a>	Other costs			
			9.3	12.5	14	35.8
		• Progress/Completion of milestones				
			Mile stone	Planned		Actual
R: Tognaccini	University of Napoli	<a href="mailto:rtogna@unina.it">rtogna@unina.it</a>	MS 1: first assessment of models)	T0+15		
B. Mele	University of Napoli	<a href="mailto:benmele@unina.it">benmele@unina.it</a>				
Z. HU	University of Southampton	<a href="mailto:Z.Hu@soton.ac.uk">Z.Hu@soton.ac.uk</a>	MS 2: Results for optional test cases of WP 1	T0 + 27		
V. D'Alessandro	Marche Polytechnic University	<a href="mailto:v.dalessandro@univpm.it">v.dalessandro@univpm.it</a>				
S. Mughal	Imperial College	<a href="mailto:s.mughal@imperial.ac.uk">s.mughal@imperial.ac.uk</a>	MS 3: Results for test cases of WP 2	T0 + 29		
			MS 4: Results for mandatory test cases of WP 1	T0 + 30		
			MS 5: Results for 2D test cases of WP 3	T0 + 21		
			MS 6: Results for 3D test case of WP 3	T0 + 27		

**ANNEX 2****ANNUAL REPORT FROM THE GROUP OF RESPONSABLES  
“AVIATION SECURITY”**

## Remit

The Group of Responsables on Aviation Security was created during the GARTEUR Council meeting in March 2014. This new 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 to do research in the Aviation Security field dealing with both military and civil R&T. Future GoR AS projects will initiate activities in research fields regarding cybersecurity in the aviation sector, CBE detection, dazzling or RPAS.

## Table of Contents

### AVIATION SECURITY

GoR-AS Overview .....	29
GoR Activities .....	29
Management.....	32
Dissemination of GARTEUR activities and results.....	32
Reports issued.....	32
Status of Action Group.....	33
GoR membership .....	33
Total yearly costs of EG research programmes .....	33

## GoR-AS Overview

### GoR Activities

The GoR AS focusses on basic and applied research in Aviation Security, exchanging ideas and experiences matured in different contexts. This topic is quite new in the scenario and expertise and results are spread over different activities. Most of work has a significant amount of multi-disciplinary content especially in domain different from aviation, so a lot of efforts have been dedicated to analyse external sources of information and assess current initiatives on aviation security with the aim to get awareness on the state of the art and build within Garteur a coherent harmonised approach with the external initiatives. This trend is driven by industrial interests, which have been properly analysed and the importance of multi-disciplinary work is likely to increase in the future. Two thesis have been finalised to build a common knowledge on topics of interest in the AS area.

During 2018 work has been done by the active members on two research themes:

- Cybersecurity.
- Malevolent use of RPAS.

The approach in 2018 has aimed at keeping links with other running initiatives like ES4AWG, Optics2 project, ACARE WG4.

The intention to start an action group has been agreed among the members. The investigated topics have been kept:

- in line with FlightPath 2050;
- further dealt in the ACARE SRIA update and its dedicated Challenge on Aviation Safety & Security;
- fitting with the PADR (Preparatory Action for Defence Research ) in Horizon 2020 and FP9.
- Aligned with EREA Security for Aviation initiative
- a priority for Europe

The main actions in 2018 were:

1. To further develop and share ideas among the active members (CIRA, ONERA, INTA, NLR) to identify research challenges and collaboration approaches.
2. To involve the industries interested in the chosen topics Eurocontrol, Soulsoftware, ALISCARL, Leonardo, Hungarocontrol, Embraer.

3. To support existing initiatives in aviation security at European level in order to promote harmonization among them and with Garteur.
4. To extend the participation to the GoR to UK and Germany.
  - Specifically (Action C64/01):
    - communication to to M. Scott on some possible candidates from UK
    - Availability of a list of 3 people to be contacted.
  - (Action C64/05) An exploratory group has been created producing a PP, two thesis have been finalized

Regarding the elaboration of the PP Pilot Paper: Cyber Attacks to Small Civil Drones in order to use them for malicious the following actions were performed:

- Action C64/06 to contact a person in DLR -> he positively answered communicating the name of the person who will join ASGor: Dr HANS-HANS-ALBERT ECKEL

<b>Id</b>	<b>Action</b>	<b>Deliverable</b>
1	Finalize the choice of the common topic	Contribution to pilot paper
2	Drafting the pilot paper	Pilot paper
3	Identify the objectives	Pilot Paper
3	Identify/Propose tasks	Plan for AS GOR activities
4	Allocate Tasks	Plan for AS GOR activities
5	Monitor Progress and organize webexes	Scheduling AND AGENDA
6	Finalize the PP	PP

A preparation meeting (webex) was held among the AS GOR in July 2018.

During this meeting information was shared about the current activities in each involved institution to finalize the action group approach.

A national survey has already been performed to assess the state of the art.

In Italy contacts with the following stakeholders increased awareness about their interests.

- Aeronautica militare: definition of threat Impact on national aerial defence, Intelligence, Surveillance, and Reconnaissance-ISR. LEAs (use of drones to support activities): Increasing reliability and robustness .

- National Aviation Authority: Malicious use of drone as intruder in critical areas, to carry offensive payload; and as a weapon.
- SMEs: Strong Detection and Identification Capability. Distributed Jamming Capability.
- Leonardo: Hostile Drone Interception, Drone Identification, Drone Localization & Tracking and challenge.

According to the discussion within the ASGOR, a pilot paper was delivered by ASGOR in July 2018.

An exploratory group has been created expressing also interests for each partner, such exploratory group has produced a PP, two thesis have been finalized.

Partners	Cyber attacks to unmanned vehicles subtopics			
	(1)Definition of possible operational scenarios where drones are used to support activities (also highly automated / autonomous drones and swarms)	(2)Definition of possible attacks to the drones which could transform them in weapons	(3)Definition of means and strategies of counteraction according to the scenario, the abilities of aggressive actors and the performance of own systems, also controlling reaction time.	(4)Simulation of some case studies
<b>CIRA</b>		X	X	
<b>INTA</b>	X	X		
<b>ONERA</b>				X
<b>NLR</b>		X	X	

The strategy consists of supporting current European initiatives in aviation Security in order to avoid duplication of efforts and harmonize vision, AS GOR members, as members of ACARE WG4 and another initiative within EREA focussing on aviation security ( Erea Security for Aviation Working

Group), have actively participated in specific meetings and events. The intent has been to harmonize all existing initiatives, as well as build consortia to propose Garteur topics in E.C. calls.

## Management

Next meeting will be held in Bucharest Aerodays 2019 to assess the related activities.

## Dissemination of GARTEUR activities and results

The dissemination events during 2018 are represented by the following list:

- EREA Security For Aviation Working Group, meeting held in (2018) in Brussels with EREA representatives.
- The Industrial pull on a national basis has been promoted during a one-day meeting organized with the Italian civil aviation authority:
  - Presentation of GARTEUR and AS GoR
  - Presentation of the cybersecurity theme
  - Presentation of the MalURPAS theme
  - Discussion and planned actions

The aims were to:

- share information on and status of current issues and proposed research activities in the field of Security for Aviation,
- discuss options for establishing new cooperation and a possible joint approach for the potential development of research issues.

Other meetings and contacts with Italian stakeholders have allowed the collection of information about the initiatives in progress on the chosen topic.

## Reports issued

Pilot paper on the proposed collaboration topic (June 2018).

Minutes of meetings

Power point presentations.

## Status of Action Group

A proposal for an action group has been agreed.

## GoR membership

### Chairman

Angela Vozella CIRA Italy

### Vice-Chairman

Francisco Munoz Sanz INTA Spain

### Members

Pierre Bieber ONERA France

Rene Wiegiers NLR Netherlands

## Total yearly costs of EG research programmes

	<2017>	<2018>	<Year>	<Year>	<Year>	<Year>	<Year>	<Year >	Total
Person-month	2	3							
Other costs (k€)	1	1							

Pilot Paper: Cyber Attacks to Small Civil Drones in order to use them for malicious purposes

Background:

The use of small (below 150 kg) Unmanned Aerial Systems (UASs), commonly called drones, today is massively growing with a wide range of purposes, it is estimated that in the next four years the number of drones will triple (mass market) and these aircraft will crowd the skies of all the world. Unmanned Aerial Systems can be remotely piloted (RPAS - Remotely Piloted Aircraft System) or they can automatically fly, these modalities are both technological and regulatory different, and above all pose different safety and security issues. The number of civil applications where they can be both effectively and efficiently used has increased in recent years, thanks to a considerable reduction in costs. The same government agencies in many countries have equipped themselves with drone fleets for security, rescue and recovery applications. Other areas of application can be found in science and research, and many private companies have been created to offer paid services for the most disparate business applications. There are applications that can be carried out with a single drone, but recently applications are emerging which require the use of a fleet of drones (both formation and swarm flights) to ensure better performance and reliability. Due to their broad diffusion and low costs they represent an attractive target for intentional attacks, which can turn them into weapons.

Some applications require the use of drones in critical areas, where there are sensitive infrastructures and/or gatherings of people, in these cases security, as well as safety issues, become crucial. In fact, while drones are operating in applications, hostile subjects with malicious purposes can exploit them to create damage to objects and people.

In the Cybersecurity Roadmap published in 2015 EASA strongly supports the development of a resilient and secure European Aviation System operating through promotion, regulatory activities as well as international cooperation to incorporate cybersecurity in the existing safety notion.

Indeed our countries' critical infrastructures are vulnerable to operation disruption which may result from many kinds of hazards in terms of physical and/or cyber-attack on installations and their interconnected systems.

EASA in the European Plan for Aviation Safety EPAS 2018-2022, considering drones as an emerging safety issue, asks for a coordinated research effort for assuring the safe integration of such systems.

The complete assessment of the vulnerabilities of such systems in order to check where security can be compromised, as well as the danger deriving from the cyber-attack which depends on the mission scenario, represents a prerequisite to properly identify possible countermeasures and mitigations which can be adopted.

Last but not least, the degree of residual danger after the countermeasures for specific missions and application domains has to be properly analysed.

Proposal of work:

It is proposed that a GARTEUR EG be called to generate the TOR for an AG to investigate the concept of *Cyber Attacks to Small Civil Drones in order to use them for malicious purposes*

The main activities will be:

- A classification of the possible application domains in order to identify the classes of missions, focus will be put on transport critical infrastructures.
- For each class of mission the characteristics of the drones, the level of required autonomy, the fleet size, the onboard sensors, the level of interoperability and other attributes that can be associated to the particular application.
- The identification and classification of the possible operating scenarios associated with the applications.
- The assessment of the vulnerabilities of both drone (fleet or single) and Ground Control Station (communications, onboard operational systems, decision making algorithms), in order to check where security can be compromised, as well as the danger deriving from the cyber-attack which depends on the mission scenario.
- According to the type of cyber-attack, the identification of possible countermeasures and mitigations which can be adopted, as well as the degree of residual danger after the countermeasures for specific missions and application domains.
- Fast-time numerical simulations or even in-flight tests definition and implementation in order to validate the results of the analyses carried out in this work.

The participants in this EG are the following:

Angela Vozella - CIRA

Francisco Muñoz Sanz – INTA

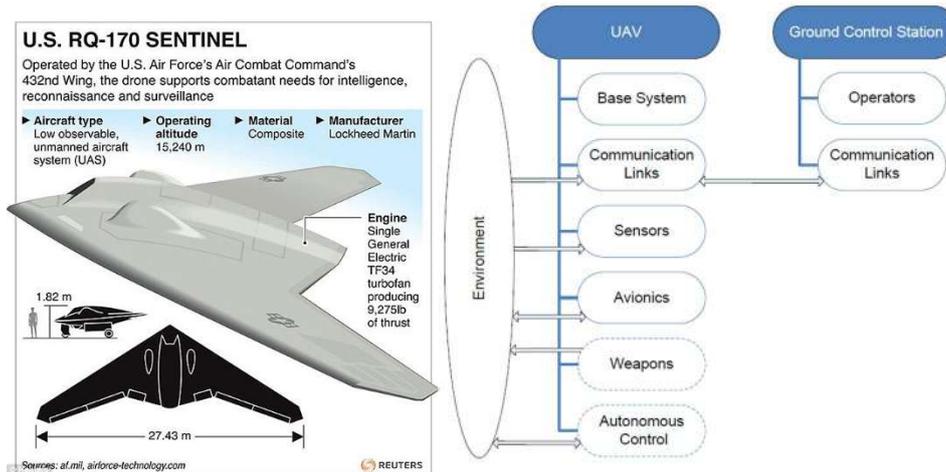
Rene.Wiegers – NLR

Pierre Bieber – ONERA

Example of outcome:

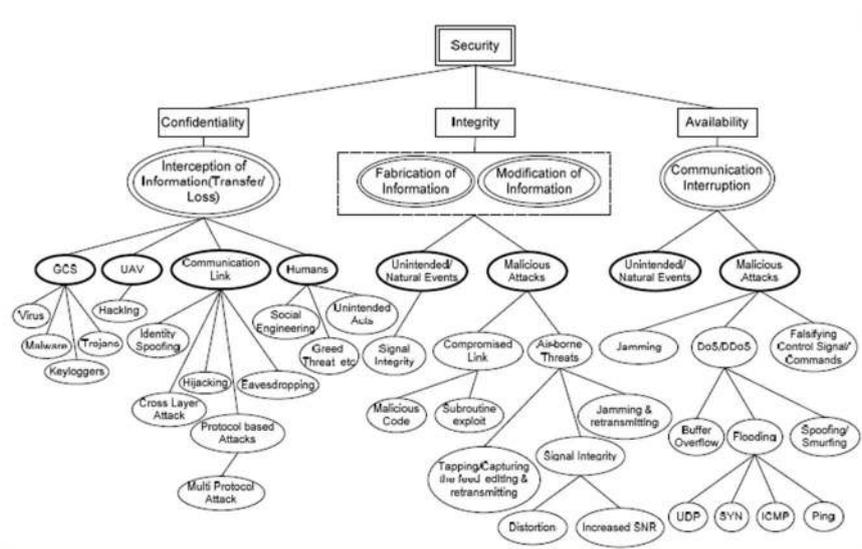
Cyber Attacks classification

- Hardware Attack: attacker has access to the UAV components directly
- Wireless Attack: Attacker carries out the attacks through one of the wireless communication channels
- Sensor Spoofing: attacker passes false data through the on-board sensors of the UAV



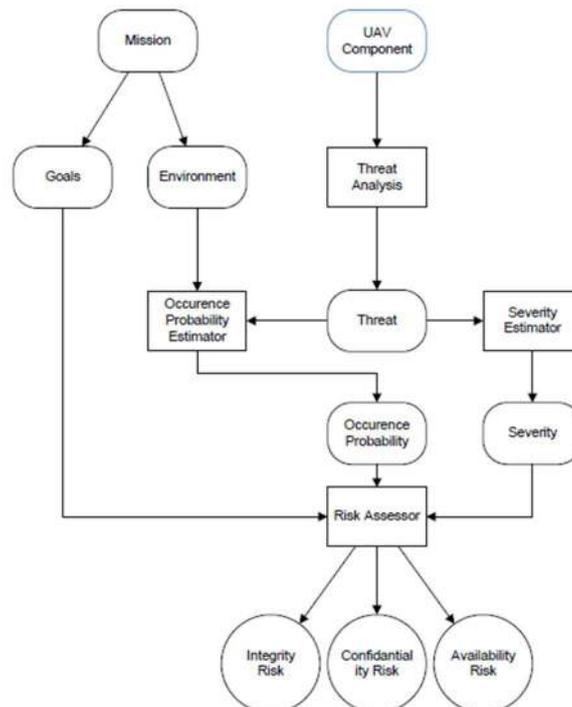
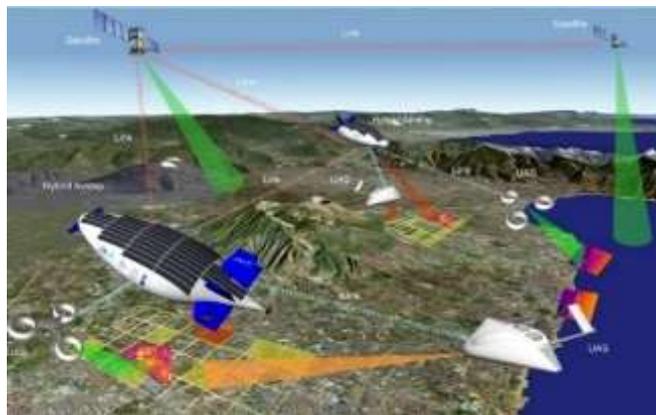
Comprehensive analysis of threats on RPAS security and integrity according to the security threats

- Study of GPS, C2 link, ADS-B Vulnerabilities
- Jamming
- Denial-of-service
- Eavesdropping (Spoofing)
- Analysis of their functional consequences



Future work:

- Study of protection techniques and operational procedures
- Investigate an autopilot system robust to gps spoofing
- Define a standard VV plan according to the risk model
- Model the integration of a Cyber risk assessment within engineering lifecycle phases
- Investigate a complete taxonomy to better understand the propagation mechanisms of attacks and handle them in attack models
- Analyse the challenge of Interoperability among heterogenous aerial platforms and study security of protocols (e.g.: Mavlink)



## International collaboration

### Collaboration within the NATO Information Systems Technology Panel

#### **NATO IST-151 'Cyber Security of Military Systems'**

- CAN (chair), CCDCOE, DEU, ITA, NLD, TUR

Objective: Share and apply methodologies, processes, tools and technologies to assess military systems' cyber security. Report lessons learned and, potentially, assessment results and mitigations

#### **NATO IST-ET-099 'Mission Assurance and Cyber Risk Assessment for Multi-Domain Unmanned/Autonomous Vehicles and Systems'**

- USA (chair), NATO CMRE, NOR, NLD, ITA, DEU, PRT

Objective: Consider existing/emerging methods and frameworks in mission assurance, cyber security and risk assessment.

Modeling of multi-domain (air and maritime) mission conducted by UAxs and Cyber Physical Systems; Preliminary cyber security analysis

**ANNEX 3****ANNUAL REPORT FROM THE GROUP OF RESPONSABLES  
“HELICOPTERS”**

*Scattering Test with rotor model(HC/AG-24) Helicopter in offshore wind turbine mission  
(www.airbus.com) (HC/AG-23)*

## 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 aircraft, such as tilt rotors, compounds and multicopters) and systems technology.

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

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

- Flight mechanics, flight procedures, human factors, new commands and control technologies,
- Increase crashworthiness, ballistic protection, ...
- Integrate rotorcraft better into the traffic (ATM, external noise, flight procedures, requirements/regulations)
- Tackle environmental issues:
  - Greening, pollution
  - Noise (external, internal)
- Progress in pioneering: breakthrough capabilities

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

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

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

## Table of Contents

### GoR Helicopters

GoR-HC Overview.....	42
GoR Activities .....	42
Management.....	43
Dissemination of GARTEUR activities and results.....	44
Reports issued.....	45
Status of Action Groups and Exploratory Groups.....	45
Rolling plans .....	46
GoR membership .....	47
Table of participating organisations .....	48
Total yearly costs of AG research programmes.....	48
Action Group Reports .....	48

## GoR-HC Overview

### GoR 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. 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, for vibration prediction and management and crashworthiness, and for acoustics. This modelling capability has underpinned improvements across the field of rotorcraft performance, enhancing both military and civil market competitiveness, as well as safety for all users. There is no question that the availability of high quality, well-validated modelling tools is essential to the effective design and development of competitive 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

The chairmanship in 2018 was held by Philippe Beaumier (ONERA). Vice Chairman is Klausdieter Pahlke (DLR).

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:

- 77<sup>th</sup> GoR Meeting: 7- 8 March '18, Univ. of Glasgow, United Kingdom,
- 78<sup>th</sup> GoR Meeting: 4-5 October '18, ONERA, Salon, France.

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

In 2018 the activities in the HC-AGs were at a medium level. 2018 started formally with four active Action Groups and two Exploratory Groups; one of the Action Groups and two of the Exploratory Groups closed their activities with their report delivered.

## Dissemination of GARTEUR activities and results

Results coming from Action Groups are traditionally prone to publication either in Journals or in Conferences. In the field of 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 2018.

AG	Conference	Venue, Date	Authors	Title
HC/AG-22	74th AHS International Annual Forum	Phoenix, Arizona, USA, May 14-17, 2018	Boisard, R.	Aerodynamic investigation of a helicopter rotor hovering in the vicinity of a building
HC/AG-23	AHS International Technical Meeting	Aeromechanics Design for Transformative Vertical Flight, Fisherman's Wharf, San Francisco, January 16-18, 2018	B. van der Wall, German Aerospace Center	Impact of Orthogonal Vortex-Rotor Interference on Rotor Trim,
HC/AG-23	44th European Rotorcraft Forum	18-21 September 2018, Delft, Netherlands.	R.J.J. Bakker, co-authored by all HC-AG23 partners	Wind Turbine Wakes and Helicopter Operations, An overview of the Garteur HC-AG23 activities, presented at the
HC/AG-23	44th European Rotorcraft Forum	18-21 September 2018, Delft, Netherlands.	A. Visingardi, M.D. Pavel	Numerical investigations of the aerodynamics and handling qualities of a helicopter flying across a wind turbine wake
HC/AG-23	44th European Rotorcraft Forum	18-21 September 2018, Delft, Netherlands.	T.E. Andronikos	Aerodynamic analysis of helicopter in interaction with wind turbine's wake
HC/AG-24	44th European Rotorcraft Forum	18-21 September 2018, Delft, Netherlands.	Jianping Yin, Alex Zanotti, Karl-Stéphane Rossignol, Gibertini, giuseppe; Luigi Vigeveno	Design of a generic rotor noise source for helicopter fuselage scattering tests
HC/AG-24	44th European Rotorcraft Forum	18-21 September 2018, Delft, Netherlands.	Caterina Poggi, Giovanni Bernardini, Claudio Testa, Massimo Gennaretti	Boundary integral formulations for noise scattered by helicopter fuselage

AG	Journal	Venue, Date	Authors	Title
HC/AG-22	The Aeronautical Journal	doi: 10.1017/aer.2016.1	Pickles, D., Green, R.B., Giuni, M.	Rotor Wake Interactions With An Obstacle On The Ground
HC/AG-24	CEAS Aeronautical Journal	DOI: 10.1007/s13272-018-0333-0	Yin, Jianping Rossignol, Karl-Stéphane Barbarino, Mattia Bianco, Davide Testa, Claudio Brouwer, Harry Janssen, Stevie Reboul, Gabriel Vigeveno, Luigi Bernardini, Giovanni Gennaretti, Massimo Serafini, Jacopo Poggi, Caterina	GARTEUR activities on acoustical methods and experiments for studying on acoustic scattering

## Reports issued

In 2018, one AG published its final report:

AG	Report	Reference	Authors	Title
HC/AG-22	GARTEUR	TP-190	Antonio Visingardi	FORCES ON OBSTACLES IN ROTOR WAKE

## Status of Action Groups and Exploratory Groups

### Action groups (AG)

The following Action Groups were active throughout 2018:

HC/AG-21 *Rotorcraft Simulation Fidelity Assessment. Predicted and Perceived Measures of Fidelity*

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 and analysed in 2017. All technical activities are closed. The final report is expected to be issued 2019.

---

HC/AG-22 *Forces on Obstacles in Rotor Wake*

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. All experimental activities were completed in 2017 and the numerical simulations have been finished. The final report was issued in March 2018.

---

HC/AG-23 *Wind turbine wake and helicopter operations*

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. Partners have updated their computational flow and flight mechanics tools. Turbulent unsteady wind turbine wake fields have been computed and have been used to assess handling qualities of helicopter – Wind Turbine wake encounters. Piloted simulations have been performed. The final report is expected in the first quarter 2019.

---

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

The main objective is to examine rotor noise propagation in the presence of a fuselage. The activity established an experimental acoustic database and prediction

design tools for main and tail rotor noise in the influence of a fuselage (2016-17 activities) and also include main/tail rotor interactions (on-going). The last test campaign initially planned for September/October 2017 was postponed to I/2019.

---

### *Exploratory groups (EG)*

---

#### HC/EG-36 *Rotor-Rotor Wake Interactions*

To investigate, both numerically and experimentally the effect of rotor / rotor and rotor / propeller wakes interactions on high speed rotorcraft operating in low speed conditions with the aim to establish low order models to be used in pre-design phases of advanced rotorcraft vehicles or in comprehensive codes.

---

#### HC/EG-37 *Noise Annoyance Generated by Helicopters*

To study the annoyance of helicopter noise on populations. The group considered how to perform listening tests and estimate annoyance through lab tests, using measured and/or predicted helicopter noise data. After several meetings it turned out that due to limited resources only a subcritical volume of activities could be achieved and the group was closed without producing the ToR for an AG.

---

#### HC/EG-38 *Verification & Validation: Metrics for the Qualification of Simulation Quality*

To define metrics for the qualification of the quality of rotorcraft simulations, as a contribution to the Verification and Validation (V&V) process of numerical codes.

---

#### HC/EG-39 *Testing and modelling procedures for Turbulent Boundary layer noise*

To identify ways how to reduce the flow induced noise in rotorcraft

---

### **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 April 2019 meeting in Madrid. 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.

### AGs EGs Rolling Plan

Topic	ST	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Methods for Impr. Of Struc. Modell. In-Flight Data	HC/AG19										
Simulation/Testing for design of passive noise absorption panels	HC/AG20										
Rotorcraft Simulation Fidelity Assessment	HC/AG21										
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 =>								
Rotor-Rotor-Interaction	HC/AG25							EG36 =>			
HUMS	HC/EG29										
Simulation Fidelity	HC/EG30	=> AG21									
Conceptual design of Helicopters CoDHe	HC/EG31		x								
Forces on Obstacles in Rotor Wake	HC/EG32		=> AG21								
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								
Rotor Rotor Interactions	HC/EG36									=> AG25	
Noise Annoyance Generated by Helicopters	HC/EG37										
V&V: define metrics for the quality of simulations	HC/EG38										
Testing and modelling procedures for TBL noise	HC/EG39										
Gust Resilience of VTOL Aircraft	HC/EG40										
Acoustics of drone / e-VTOLs (noise sources)	ID										
Modelling of electric systems for e-VTOLs (pre-design)	ID										
UTM/ATM: maybe not adapted for Garteur activities	ID										
Drone Impact on Helicopters (rotating parts)	ID										
Ice accretion and performance prediction on rotary wings	ID										
HF issues and Training methods for complex automation in cockpit	ID										
PSP/TSP for rotors/propellers (drone,e-VTOLs...)	ID										

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

### GoR membership

<b>Chairman</b>		
Philippe Beaumier	ONERA	France
<b>Vice-Chairman</b>		
Klausdieter Pahlke	DLR	Germany
<b>Members</b>		
Mark White	Uni. of Liverpool	United Kingdom
Joost Hakkaart	NLR	The Netherlands
Lorenzo Notarnicola	CIRA	Italy
Francois-Xavier Filias	Airbus Helicopters	France
Rainer Heger	Airbus Helicopters	Germany
Antonio Antifora	Leonardo	Italy
<b>Observer</b>		
Richard Markiewicz	Dstl	United Kingdom

## Table of participating organisations

	HC/AG and HC/EG numbers							
	AG21	AG22	AG23	AG24	EG36	EG37	EG38	EG39
<b>Research Establishments</b>								
ONERA	☐	☐	☐	☐	■	■	☐	■
DLR	☐	☐	☐	■	☐	☐	☐	☐
CIRA		■	☐	☐	☐	☐		
NLR	☐	☐	■	☐	☐	☐	☐	☐
Dstl								
CNR-INSEAN				☐				
<b>Industry</b>								
Airbus Helicopters, France							☐	
Airbus Helicopters, Germany							☐	
AgustaWestland / Leonardo	☐							
Thales	☐							
LMS (Belgium)								
CAE (UK)	☐							
ZF Luftfahrttechnik GmbH (D)								
IMA Dresden (D)								
MICROFLOWN								
<b>Academic Institutes</b>								
University of Liverpool (UK)	■	☐	☐			☐		
University of Cranfield (UK)								
University of Glasgow (UK)		☐	☐		☐		☐	
TU Delft (NL)	☐		☐				☐	
University of Munich (D)			☐		☐			
University of Stuttgart IAG (D)					☐			
University of Roma 3 (IT)				☐				
Politecnico di Milano (IT)		☐	☐	☐	☐		■	
National Technical Univ. of Athens (G)		☐	☐		☐			
Institut Supérieur de l'Aéronautique et de l'Espace (F)							☐	

☐ = Member    ■ = Chair

## Total yearly costs of AG research programmes

	2011	2012	2013	2014	2015	2016	2017	2018	Total
Person-month	7	13	36.5	44.4	88.7	79.5	55	26.5	350.6
Other costs (k€)	10	6	13	38	103.1	102.9	54	20	347

## Action Group Reports

# HC/AG-22: Forces on Obstacles in Rotor Wake

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

## 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 of the helicopter from the obstacles, and the height of the helicopter from 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 interaction 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 was then to promote activities which could contribute to fill these gaps. This was accomplished by investigating, both numerically and experimentally:

- the effects of the confined area geometry on a hovering rotorcraft 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, had a duration of three years during which the following activities were 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 work programme was structured in four work packages:

- WP0 – Management & Dissemination;
- WP1 – Preliminary Computations & Code Enhancements;
- WP2 – Experimental Test Campaigns:
  - HOGE/HIGE rotor with a loose/sling load (at CIRA);
  - HIGE rotor in proximity to a square-shaped obstacle (at ONERA);
  - HIGE rotor in proximity to an obstacle in wind-on conditions (at Polimi);
  - HIGE rotor in proximity to an obstacle in wind-off conditions (at Univ. Glasgow);
- WP3 – Final Validation of Codes.

## Results

An extremely fruitful cooperation was set among all AG-22 partners. Each partner produced itself in an effort well beyond what was proposed at the beginning of the project.

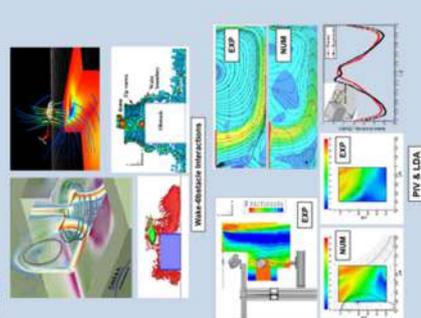
Four valuable databases were produced by investing a relatively low amount of their own internal funding, and using their own laboratory/wind tunnel facilities.

A complete set of measurements was employed to quantify the changes in performance of a helicopter rotor together with the pressure distributions - and then the forces - acting on an obstacle during the flight in mutual close proximity. PIV and LDA measurements were made in order to quantify and visualize the interactional process between the rotor wake and the obstacle. This gave the partners the opportunity to: 1) deepen the knowledge of this complex interactional phenomenology; 2) enable the validation of the computational tools employed for the numerical simulations.

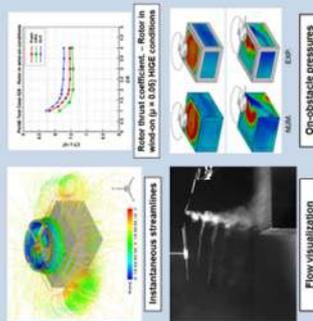


All partners applied and, when necessary, upgraded their own computational tools to numerically simulate these flight conditions of a helicopter rotor.

The full range of methodologies was investigated: from the simpler and faster flight mechanics-based solvers to the sophisticated but significantly more computational demanding Navier-Stokes solvers, with the additional purpose to set the limits of applicability of the various methodologies.



All methodologies proved to be able to evaluate the rotor thrust in almost all the flight conditions investigated. The URANS Navier-Stokes solvers were also fully able to accurately evaluate the pressure distributions induced by the rotor wake on the obstacle and the flow field structure downstream of the obstacle. Instead, the inherent inability of the panel methods and flight mechanics-based solvers to take account of the viscosity and compressibility effects was clearly highlighted. Nevertheless, possible solutions were proposed despite not all implemented during the project: the use of 2D look-up tables could overcome the problem of evaluating the torque of the rotor; the explicit modelling of the wake generated at the obstacle's edges for viscous reasons could be a reasonably effective means to improve the evaluation of the pressure distributions on the side faces of an obstacle and of the flow structure downstream of the obstacle.



Finally, AG22 also represented an occasion for training young researchers who provided their lively contribution to the project activities. In particular, two master thesis and a doctoral thesis, were specifically dedicated to the experimental investigations of this topic.

## 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 Responsible:

- K. Pahlke



**HC/AG-22 “FORCES ON OBSTACLES IN ROTOR WAKE”**

**Monitoring Responsible:** 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. The final meeting took place at CIRA, Capua 12-13 December 2017. The final report was delivered Febr. 2018.

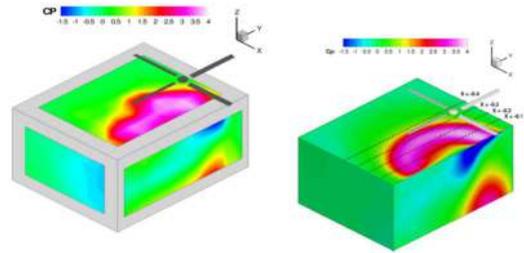
**• Results/benefits**

The action group started the activities in November 2014.

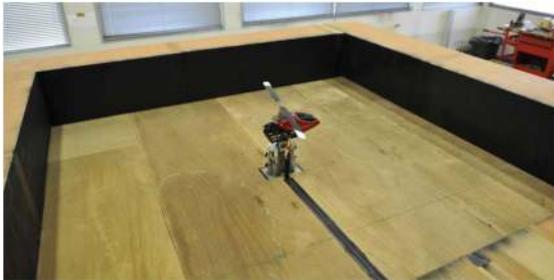
An experimental database, dealing with a helicopter rotor in HOGE (Hover Out of Ground Effect)/HIGE

(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).

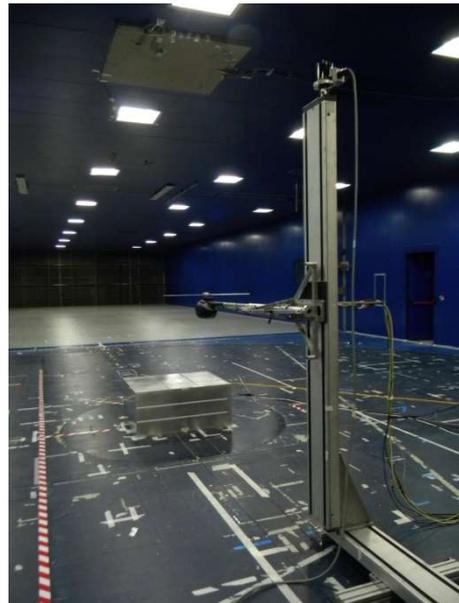


Helicopter hovering over the edge of a cuboid (left Experiment, right CFD (Glasgow))

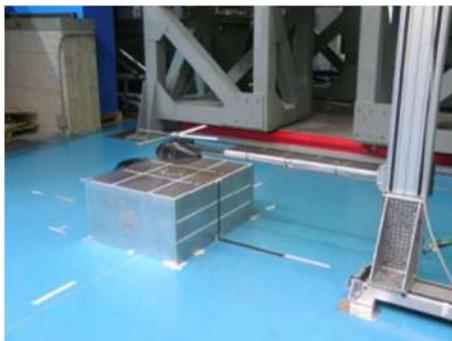


Helicopter in square pit obstacle

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: Second Test Campaign in GVPM



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.

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

• **HC/AG-22 membership**

Member	Organisation	e-mail
A. Visingardi	CIRA	<a href="mailto:a.visingardi@cira.it">a.visingardi@cira.it</a>
F. De Gregorio	CIRA	<a href="mailto:f.degregorio@cira.it">f.degregorio@cira.it</a>
T. Schwarz	DLR	<a href="mailto:thorsten.schwarz@dlr.de">thorsten.schwarz@dlr.de</a>
R. Bakker	NLR	<a href="mailto:rbakker@nlr.nl">rbakker@nlr.nl</a>
S. Voutsinas	NTUA	<a href="mailto:spyros@fluid.mech.ntua.gr">spyros@fluid.mech.ntua.gr</a>
R. Boisard	ONERA	<a href="mailto:ronan.boisard@onera.fr">ronan.boisard@onera.fr</a>
G. Gibertini	Politecnico di Milano	<a href="mailto:giuseppe.gibertini@polimi.it">giuseppe.gibertini@polimi.it</a>
R. Green	Glasgow Uni.	<a href="mailto:richard.green@glasgow.ac.uk">richard.green@glasgow.ac.uk</a>
G. Barakos	Glasgow Uni.	<a href="mailto:g.barakos@liverpool.ac.uk">g.barakos@liverpool.ac.uk</a>

• **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	A25/P15	A81/P48
Other costs (in K€)	Actual/Planned	A33/P20	A35/P33	A19/P20	A87/P73

# 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.

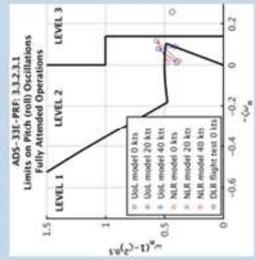
## Background

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 120m.

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 Responsive 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 plotted 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

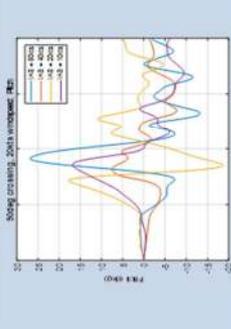
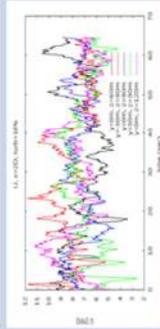
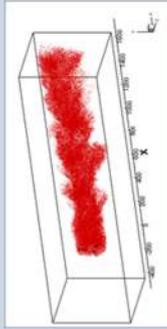


## Programme

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 plotted simulations.

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



## Results

- Partners have updated their computational tools and have computed (turbulent) unsteady wind turbine wake fields
- Experimental data and calculated wind turbine wake velocity fields were shared, and have been used to harmonize the off-line simulation activities with a common wake velocity field
- Handling qualities of the UoL/DLR/NLR BO105 reference helicopter, have been compared w.r.t. stability, bandwidth, response, coupling etc. to use as a common helicopter reference model
- Plotted simulations have been performed or are being prepared
- WTN 250 Offline (Virtual Airbyn) and Plotted simulations show serious degradation of handling qualities levels. Considerable pilot effort at lower helicopter speeds with 30 knot wake
- NREL 5MW plotted simulations show rating 3 and higher for WT wake crossing (work on-going)

### 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
  - B. Van der Wall  
DLR
  - R. Bakker  
NLR
- GARTEUR Responsible:**  
J. Hakkaart  
NLR



**HC/AG-23 “WIND TURBINE WAKE AND HELICOPTER OPERATIONS”**

**Monitoring Responsible:** 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.

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.

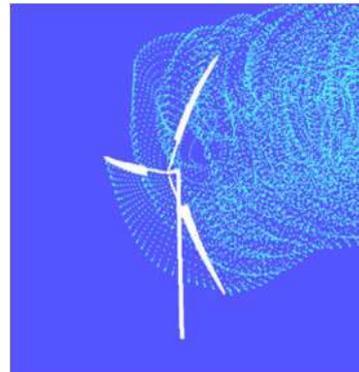
The aim of the Action Group is to set up a team of researchers from universities and research institutes to cooperate and perform the following activities:

- 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.

• **Activities**

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.



• **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. The final meeting took place at the ERF 2018 in September in Delft.

• **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 been received in 2018 by all partners. The reports were delivered. Other reports were planned at the end of the project period (month 30 and 36). The activities for these WP deliverables are successfully closed and 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). All reports and deliverables were distributed in Jan. 2019.



• **HC/AG-23 membership**

Member	Organisation	e-mail
Richard Bakker	NLR	<a href="mailto:rbakker@nlr.nl">rbakker@nlr.nl</a>
Paul Lehman	DLR	<a href="mailto:Paul.Lehmann@dlr.de">Paul.Lehmann@dlr.de</a>
Antonio Visingardi	CIRA	<a href="mailto:a.visingardi@cira.it">a.visingardi@cira.it</a>
Pierre-Marie Basset	ONERA	<a href="mailto:pierre-marie.basset@onera.fr">pierre-marie.basset@onera.fr</a>
Filippo Campagnolo	TUM	<a href="mailto:filippo.campagnolo@polimi.it">filippo.campagnolo@polimi.it</a>
Marilena Pavel	TU-Delft	<a href="mailto:M.D.Pavel@tudelft.nl">M.D.Pavel@tudelft.nl</a>
George Barakos	Glasgow Uni	<a href="mailto:George.Barakos@glasgow.ac.uk">George.Barakos@glasgow.ac.uk</a>
S. Voutsinas	NTUA	<a href="mailto:spyros@fluid.mech.ntua.gr">spyros@fluid.mech.ntua.gr</a>
Mark White	Liverpool Uni	<a href="mailto:mdw@liverpool.ac.uk">mdw@liverpool.ac.uk</a>

• **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	2018	
Person-months	Actual/ Planned	18/18	17/22	20/18	10/10,5	65,5/68
Other costs (in K€)	Actual/ Planned	1,6	1,3	11,2	0,0	14,1

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

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



## Background

A negative undesirable by-product of the helicopter during its operation is noise generation. Both the main and the tail rotors (including Fensstrom) 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.

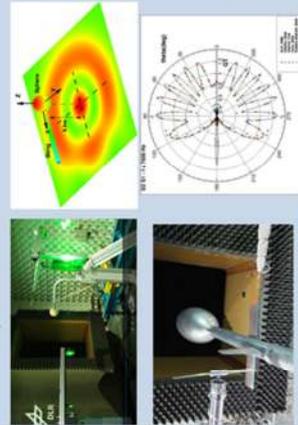
The main research effort in the past was concentrated on the helicopter rotor noise generation and the reduction of the noise. Extensive work, both theoretical and experimental helped to deepen the understanding of the noise generating mechanisms. Even though the scattering of noise generated by helicopter 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



## Results

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

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

- Description of available analytical, experiment test cases including database completed and distributed;
- The common Simulations for the sphere and NACA0012 wing scattering defined and the results compared with the test. In addition the comparison results published in ERF 2016, 2017;
- The Sphere scattering tests composed of 3 spheres, two support systems, and two noise sources were conducted and the results published in ERF 2016; Model tail rotor were manufactured, tested and published in ERF 2018;
- Specifications on the test for the GARTEUR helicopter scattering defined. The generic helicopter were manufactured, tests for generic helicopter with three different sources has been conducted in 2019 at DLR Acoustic Wind Tunnel Braunschweig (AWB); GARTEUR activities on acoustical methods and experiments is published in 2018 CEAS Aeronautical Journal;
- 9 publications and 8 reports related to group were produced

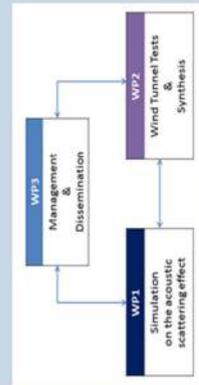
### Members of the HC/AG-24 group are: (only contact persons are listed here)

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

**GARTEUR Responsible:**  
K. Paniké  
DLR

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 data compilation & distribution
  - Test data analysis
- WP 3: Management & Dissemination
  - Action group Management
  - Exploitation & info dissemination
  - Technology implementation Plan (TIP)



**HC/AG-24 “HELICOPTER FUSELAGE SCATTERING EFFECTS FOR EXTERIOR/INTERIOR NOISE REDUCTION”**

**Monitoring Responsible: 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:

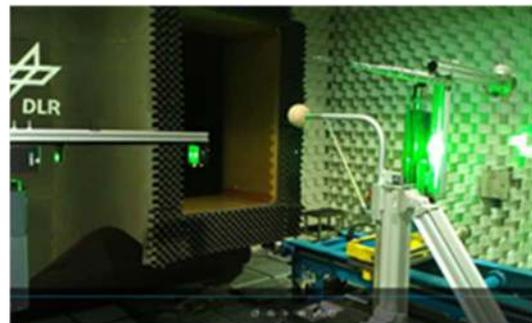
- 1: Simulation of the acoustic scattering effect
- 2: Wind tunnel tests and synthesis
- 3: Management and dissemination

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 were carried out.

**• 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. Due to technical problems with the acoustic wind tunnel at DLR Braunschweig the final tests could not be done in 2018 und HC/AG-24 had to be extended. This was accepted by the Council in April 2019.



**• 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 absorbing 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 were planned for Sep. 2017 but had partially to be postponed for technical reasons to 2018 and even 2019.
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.

Resources		Year					Total
		2015	2016	2017	2018	2019	
Person-months	Actual/	16,7	20,5	22,0	15,0		74,2
	Planned	30,0	25,0	22,0	0,0	0,0	77,0
Other costs (in K€)	Actual/	30,5	30,6	34,0	20,0		115,1
	Planned	66,0	48,0	34,0	0,0	0,0	148,0

#### • HC/AG-24 membership

Member	Organisation	e-mail
J. Yin (Chair)	DLR	Jianping.yin@dlr.de
T. Schwarz	DLR	thorsten.schwarz@dlr.de
M. Barbarino (Vice-Chair)	CIRA	m.barbarino@cira.it
H. Brouwer	NLR	Harry.Brouwer@nlr.nl
J. Kok	NLR	Johan.Kok@nlr.nl
Y. Delrieux	ONERA	yves.delrieux@onera.fr
F. Simon	ONERA	Frank.Simon@onera.fr
G. Reboul	ONERA	gabriel.reboul@onera.fr
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.

**ANNEX 4****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 .....	61
GoR Activities .....	61
Management.....	62
Dissemination of GARTEUR activities and results.....	62
Reports issued.....	63
Status of Action Groups and Exploratory Groups.....	63
Rolling plans .....	65
GoR membership .....	65
Table of participating organisations .....	66
Total yearly costs of AG research programmes.....	67
Action Group Reports .....	67

## 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:

- Fatigue and damage tolerance assessment of hybrid structures;
- Damage repair in composite and metal structures;
- Additive layer manufacturing.

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.

Additive Manufacturing (AM) with metals is an emerging technology that finds more and more applications in different markets such as orthopaedic implants, dentistry and high-end industry. There is also a lot of interest coming from the Aerospace industry. Metal AM technology can provide great advantages with respect to conventional metal working techniques, such as significantly lower waste of materials, a larger freedom of design, high potential for weight reduction and the possibility to integrate additional functionality. Specific design 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.

## Management

There was no physical meeting of members in 2018. Exchange has taken place through bilateral meetings and telephone conferences. Since so far no successor for the chair of the GoR SM could be found, this role is provisionally carried out by chairmen of the preceding period. Also the UK GoR SM membership is presently vacant.

It has to be noted that there has been little activity in the field of structures and materials in recent reporting periods. The work in the Action Groups is largely delayed and new Exploratory Groups have not yet been transferred to Action Groups. In order to revitalize this GoR, it was therefore decided that the current Action Groups should be finalized quickly, preferably on the basis of the available results. Furthermore, it is reasonable to focus the work on the initiation of one Action Group. The greatest interest of the members is currently focused on the topic of Additive Manufacturing, which is currently being addressed in the SM/EG 43.

## 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.

As a result of SM/AG-35 “Fatigue and Damage Tolerance Assessment of Hybrid Structures”, three publications were published in journals during the project:

Zlatan Kapidžić, Hans Ansell, Joakim Schön, Kjell Simonsson, Fatigue bearing failure of CFRP composite in bolted joints exposed to biaxial variable amplitude loading at elevated temperature, Composite Structures, Volume 142, 2016, Pages 71-77

Zlatan Kapidžić, Hans Ansell, Joakim Schön, Kjell Simonsson, Fatigue bearing failure of CFRP composite in biaxially loaded bolted joints at elevated temperature, Composite Structures, Volume 127, 2015, Pages 298-307

Zlatan Kapidžić, Hans Ansell, Joakim Schön, Kjell Simonsson, Quasi-static bearing failure of CFRP composite in biaxially loaded bolted joints, Composite Structures, Volume 125, 2015, Pages 60-71

In addition, NLR produced an internal report:

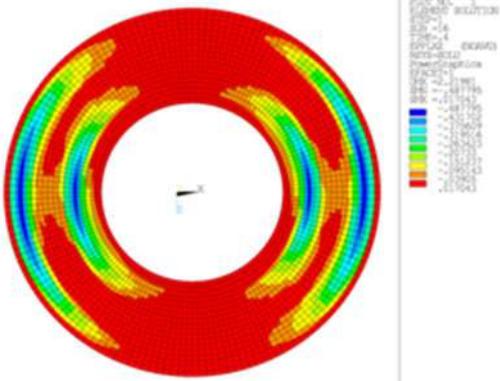
NLR CR-2016-177 “Lifetime aspects of hybrid structures - Durability and damage tolerance demonstrations “

### Reports issued

No new reports have been issued in 2018. The final reports for SM/AG-34 and SM/AG-35 are currently in preparation and will be issued in the next reporting period.

### Status of Action Groups and Exploratory Groups

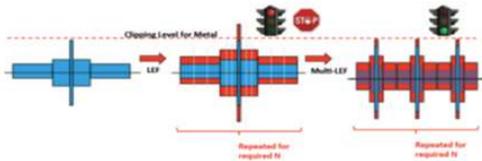
Two action groups and one exploratory group were formally active in 2018. Both action groups have finished their technical activities and are mostly involved in writing the final report.

SM/AG-34	Damage repair in composite and metal structures
	<p>The objective of the group is the definition of effective repair techniques both for civil and military aircraft structures through the development of numerical/experimental methodologies. This will lead to minimized down-time of the aircraft for repair operation, minimized costs for repair, reduced certification costs and time for certification and will promote the repair of components instead of their substitution. The technical activities of this group have finished and the final report is currently under preparation.</p>
The chair is Dr. A. Riccio	

SM/AG-35

Fatigue and Damage Tolerance Assessment of Hybrid Structures

The objective of the group is to validate the basic assumptions for any applied spectrum manipulation techniques for fatigue test of hybrid structures, to examine the capabilities and benefits of a probabilistic approach, to determine the optimum way to account for thermal loads in a non-thermo test set-up with the goal to find a joint 'best practice' approach for testing of hybrid airframe structural components. The technical activities of this group have finished and the final report is currently under preparation.



The chair is J. Laméris

SM/EG-43

Development of additive layer manufacturing for aerospace applications

The objective of the exploratory group is to investigate the influence of powder quality on the properties of AM materials and components, to study the differences between materials and components made with e-beam AM and laser beam AM and to examine the Influence of different machine parameters for laser beam AM Material.



The chair is L. 't Hoen

## Rolling plans

Cat	Topic	2014	2015	2016	2017	2018	2019	2020
SM/AG 34	Damage repair in composite and metal structure	Active						
SM/AG 35	Fatigue and damage tolerance assessment of	Active						
SM/EG 43	Additive Layer Manufacturing	Active						
		Active						

■ Active   
 ■ Extended   
 ■ Stopped   
 ■ Inactive

## GoR membership

<b>Chairman (acting)</b>			
Peter Wierach	Wierach	Germany	<a href="mailto:Peter.wierach@dlr.de">Peter.wierach@dlr.de</a>

<b>Vice-Chairman</b>			
vacant	-	-	-

<b>Members</b>			
Domenico Tescione	CIRA	Italy	<a href="mailto:D.Tescione@cira.it">D.Tescione@cira.it</a>
Aniello Riccio	UCL	Italy	<a href="mailto:Aniello.RICCIO@unicampania.it">Aniello.RICCIO@unicampania.it</a>
Tomas Ireman	SAAB	Sweden	<a href="mailto:Tomas.Ireman@saabgroup.com">Tomas.Ireman@saabgroup.com</a>
Florence Roudolff	ONERA	France	<a href="mailto:florence.roudolff@onera.fr">florence.roudolff@onera.fr</a>
Bert Thuis	NLR	The Netherlands	<a href="mailto:bert.thuis@nlr.nl">bert.thuis@nlr.nl</a>
Javier Sanmillan	INTA	Spain	<a href="mailto:sanmillan@inta.es">sanmillan@inta.es</a>

<b>Industrial Points of Contact</b>			
Roland Lang	Airbus D&S	Germany	<a href="mailto:roland.lang@airbus.com">roland.lang@airbus.com</a>
Mathias Jessrang	Airbus Operations	Germany	<a href="mailto:mathias.jessrang@airbus.com">mathias.jessrang@airbus.com</a>
Angel Barrio	Airbus D&S	Spain	<a href="mailto:angel.barrio@airbus.com">angel.barrio@airbus.com</a>

Hans Ansell	SAAB	Sweden	<a href="mailto:hans.ansell@saabgroup.com">hans.ansell@saabgroup.com</a>
Robin Olsson	RISE/Swerea SICOMP	Sweden	<a href="mailto:robin.olsson@swerea.se">robin.olsson@swerea.se</a>
Andrew Foreman	QinetiQ	United Kingdom	<a href="mailto:adforeman@qinetiq.com">adforeman@qinetiq.com</a>
Luc Hootsmann	Fokker	The Netherlands	<a href="mailto:luc.hootsmans@fokker.com">luc.hootsmans@fokker.com</a>

Table of participating organisations

	AG-34	AG-35	EG-43
<b>Research Establishments</b>			
CIRA	<input type="checkbox"/>		<input type="checkbox"/>
DLR		<input type="checkbox"/>	<input type="checkbox"/>
FOI	<input type="checkbox"/>	<input type="checkbox"/>	
INTA	<input type="checkbox"/>		
NLR	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
ONERA			<input type="checkbox"/>
CNR	<input type="checkbox"/>		
<b>Industry</b>			
Airbus			<input type="checkbox"/>
Fokker		<input type="checkbox"/>	
GKN			<input type="checkbox"/>

Leonardo Company	<input type="checkbox"/>		
RISE/Swerea SICOMP			
QinetiQ	<input type="checkbox"/>		
SAAB	<input type="checkbox"/>	<input type="checkbox"/>	
<b>Academic Institutions</b>			
Imperial College	<input type="checkbox"/>		<input type="checkbox"/>
UCL University of Campania	<input checked="" type="checkbox"/>		<input type="checkbox"/>
Lulea University of Technology	<input type="checkbox"/>		<input type="checkbox"/>
Norwegian University of Science and Technology NTNU	<input type="checkbox"/>		<input type="checkbox"/>

Member     Chair

### Total yearly costs of AG research programmes

	2011	2012	2013	2014	2015	2016	2017	2018
Man-month	6	7	60,5	61	10	10	-	-
Other costs (k€)	10	2	65	61	35	35	-	-

### Action Group Reports

# 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 led 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

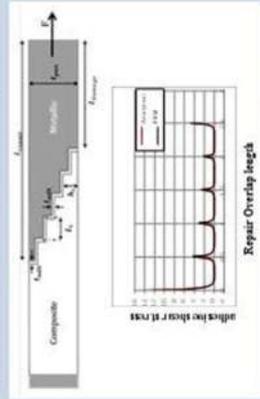
### WP 5 EFFECTIVE REPAIR METHODS

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.



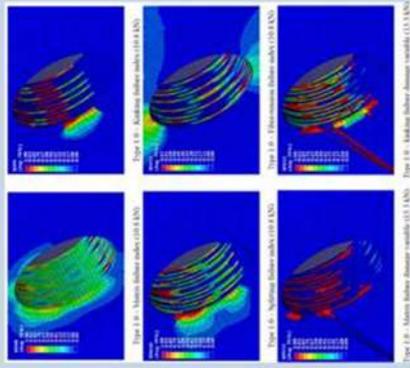
Development of an Analytical tool for Repair Design

## Expected Results

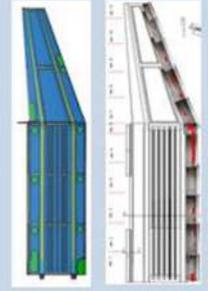
The effective outcomes can be summarized in:

- 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 Damage Repair with Composites

**Monitoring Responsible:** D. Tescione  
CIRA

**Chairman:** Dr. A. Riccio  
UCL

### • 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 2018

- The group is well assorted and complementary activities have been performed
- It was agreed to test the developed models on common benchmark and three main Benchmark have been proposed by INTA, CIRA and LEONARDO - around these three benchmark initial collaborations were started
- A collaboration activity between INTA and UCL has been carried out. An UCL student moved to INTA to perform numerical simulation on delamination propagation in INTA-UAV
- A further collaboration has been performed between UCL and SICOMP for numerical modelling to evaluate the out-of plane properties of NCF uni-weave carbon/epoxy. An UCL student moved to SICOMP to perform the activity
- A parallel collaboration on experiments on bonded joints is going to start between CIRA, UCL and CNR
- At the beginning of the AG there was a great momentum among the project partners, which has declined significantly in the course of work. However many partners have continued to work on the project's topic.
- Though activities have been low since 2014 enough results have been produced to prepare the final report. The final report is currently under preparation and will be issued in the next reporting period.

### • Expected results/benefits

The effective outcomes can be summarised 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.

### • SM/AG-34 membership

Member	Organisation	e-mail
Aniello Riccio (chairman)	SUN	<a href="mailto:aniello_riccio@unina2.it">aniello_riccio@unina2.it</a>
Iñaki Armendariz Benitez (Vice Chairman)	INTA	<a href="mailto:armendarizbi@inta.es">armendarizbi@inta.es</a>
Andrea Sellitto	SUN	<a href="mailto:Andrea.sellitto@unina2.it">Andrea.sellitto@unina2.it</a>
Dimitra Ramantani	SICOMP	<a href="mailto:dimitra.ramantani@swerea.se">dimitra.ramantani@swerea.se</a>
David Mattsson	SICOMP	<a href="mailto:David.mattsson@swerea.se">David.mattsson@swerea.se</a>
Ralf Creemers	NLR	<a href="mailto:ralf.creemers@nlr.nl">ralf.creemers@nlr.nl</a>
Joakim Schon	FOI	<a href="mailto:snj@foi.se">snj@foi.se</a>
Domenico Tescione	CIRA	<a href="mailto:u.mercurio@cira.it">u.mercurio@cira.it</a>

(AG Monitoring Responsible)		
Fluvio Romano	CIRA	<a href="mailto:f.romano@cira.it">f.romano@cira.it</a>
Paul Robinson	IMPERIAL COLLEGE	<a href="mailto:p.robinson@imperial.ac.uk">p.robinson@imperial.ac.uk</a>
Benedetto Gambino	ALENIA	<a href="mailto:benedetto.gambino@alenia.it">benedetto.gambino@alenia.it</a>
Charlotte Meeks	QINETIQ	<a href="mailto:cbmeeks@qinetiq.com">cbmeeks@qinetiq.com</a>
Mauro Zarrelli	CNR	<a href="mailto:m.zarrelli@imcb.cnr.it">m.zarrelli@imcb.cnr.it</a> ; <a href="mailto:mauro.zarrelli@imcb.cnr.it">mauro.zarrelli@imcb.cnr.it</a>
Janis Varna	LULEA UNIVERSITY of TECHNOLOGY	<a href="mailto:janis.varna@ltu.se">janis.varna@ltu.se</a>
Marcus Henriksson	Saab	<a href="mailto:marcus.henriksson@saabgroup.com">marcus.henriksson@saabgroup.com</a>
Andreas Echtermeyer	NTNU	<a href="mailto:andreas.echtermeyer@ntnu.no">andreas.echtermeyer@ntnu.no</a>
Giovanni Perillo	NTNU	<a href="mailto:giovanni.perillo@ntnu.no">giovanni.perillo@ntnu.no</a>

• Resources

Resources	Act./Plan.	Year						Total 12-16
		2012	2013	2014	2015	2016	2017	
Person-months	-	50/36	50/30	/0	/0	/0	100/66	
Other costs (in K€)	-	49/32	20/0	/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 2019
WP3 Report	Apr 2016	Apr 2017	Apr 2019
WP4 Report	Apr 2016	Apr 2017	Apr 2019
WP5 Report	Oct 2016	Oct 2017	Oct 2019
Final Report	Oct 2016	Oct 2017	Oct 2019

# 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

## 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 Lynköping. 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

### 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.



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

**Monitoring Responsible:** B. Thuis  
 NLR  
**Chairman:** R.P.G. Veul  
 (till 31-08-2013)  
 NLR  
 J. Laméris  
 (from 1-09-2013)  
 NLR

interfaces has been submitted by DLR and will be incorporated in the final GARTEUR report.

- 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

- 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

Four specimens with the reference spectrum were tested at different load levels and duration, but no realistic failures were obtained to be used as reference (failure > 8 expected life times). The preliminary conclusion is that the combination of geometry, in-plane loading and spectrum are not suitable for this study. Tests with alternative spectra with LLS and multi-LEF approaches were not performed due to time and budget constraints. Funding and cooperation is being searched for a follow-up study with a better test geometry and spectrum design tools.

Task 2: Probabilistic approach

Discussions on methods used and results from ongoing projects were discussed during several meetings. Due to lack of budget and of suitable new study projects no further reporting was done.

Task 3: Environmental influences

FOI performed static and fatigue tests in a bi-axial test rig at elevated temperature on different composite specimens. Saab conducted FEM studies using a new failure prediction model based on the static and fatigue test of FOI. Results of the FOI/SAAB study are published as three articles in “Composite Structures”. Summaries and links to the articles will be included in final GARTEUR report. A draft of an extensive study about the effect of laser treatment on the interface of titanium-composite

Member	Organisation	e-mail
Dr.-Ing Joachim Hausmann till 1/9/14	DLR	<a href="mailto:joachim.hausmann@dlr.de">joachim.hausmann@dlr.de</a>
Dr. Jan Haubrich from 1/9/14	DLR	<a href="mailto:Jan.haubrich@dlr.de">Jan.haubrich@dlr.de</a>
Dr. Anders Blom	FOI	<a href="mailto:anders.blom@foi.se">anders.blom@foi.se</a>
Dr. Joakim Schön	FOI	<a href="mailto:joakim.schon@foi.se">joakim.schon@foi.se</a>
Tim Janssen	Fokker Aerostructures	<a href="mailto:tim.janssen@fokker.com">tim.janssen@fokker.com</a>
Frank Grooteman	NLR	<a href="mailto:frank.grooteman@nlr.nl">frank.grooteman@nlr.nl</a>
Dr. Jaap Laméris	NLR	<a href="mailto:jaap.lameris@nlr.nl">jaap.lameris@nlr.nl</a>
Hans van Tongeren	NLR	<a href="mailto:hans.van.tongeren@nlr.nl">hans.van.tongeren@nlr.nl</a>
Rudy Veul	NLR	<a href="mailto:rudy.veul@nlr.nl">rudy.veul@nlr.nl</a>
Hans Ansell	SAAB	<a href="mailto:hans.ansell@saabgroup.com">hans.ansell@saabgroup.com</a>
Zlatan Kapidzic	SAAB	<a href="mailto:zlatan.kapidzic@saabgroup.com">zlatan.kapidzic@saabgroup.com</a>

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

- Planned Resources

Resources		Year						Total 12-16
		2012	2013	2014	2015	2016	2017	
Person-months	Act./Plan.	1/1	10.5/11	11/11	/10	/0	/0	22.5/42.5
Other costs (in K€)	Act./Plan.	1/2	16/30	11/41.5	/35	/0	/0	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 2019

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

**Monitoring Responsible:** 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. A first meeting to set-up the project was held in April 2015. Since 2016 there have been only a few coordination activities among the partners. At the last GoR meeting, however, the topic was prioritized and it was decided to include additive manufactured plastics. The focus here is a combination with classical composite production processes and a functionalization of polymer materials (e.g. electrical conductivity). Further partners (e.g. FOI, SAAB) have expressed their interest to participate in this group.

- **EG membership**

<b>INSTITUTION</b>	<b>COUNTRY</b>	<b>Contact Point</b>
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



## GARTEUR Organisation 2018

GARTEUR Chair Country 2018-2019: Spain  
 Council Chair: Mr Bartolome Marques, Spain

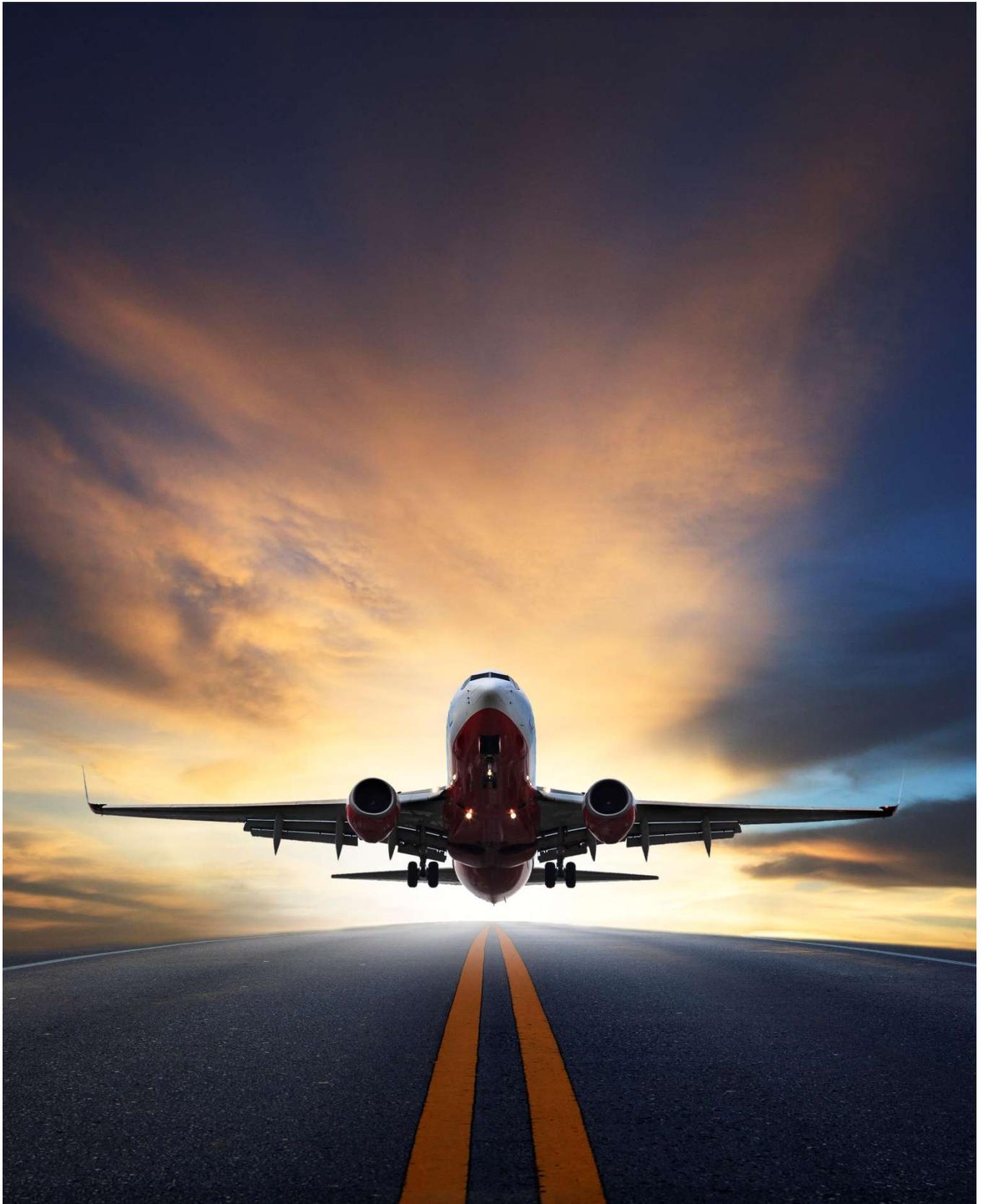
XC Chair: Mr. Francisco Muñoz, Spain  
 Secretary: Mr. Jose Garcia, Spain

### GARTEUR COUNCIL

Function	France	Germany	Italy	Netherlands	Spain	Sweden	United Kingdom
<i>Head of Delegation</i>	J. L'Ebraly	J. Bode	-	C. Mekes	B. Marques	A. Blom	P. Griffiths
<i>XC Member</i>	O. Vasseur	-	L. Papparone	K. Wijnberg	F. Muñoz Sanz	E. Bernhardsdotter	S. Gates
<i>Other Members of Delegation</i>	P. Beaumier	H. Hemmer M. Fischer	-	C. Beers	J.F. Reyes-Sánchez	R. Stridh N. Tooloutalaie	S. Weeks S. Pendry M. Scott

### GROUPS OF RESPONSABLES

Aerodynamics (AD)	Aviation Security (AS)		Flight Mechanics, Systems & Integration (FM)		Helicopters (HC)		Structures & Materials (SM)	
	GoR AS members		GoR FM members		GoR HC members		GoR SM members	
F. Monge Gómez K. Richter H. van der Ven E. Coustols G. Mingione P. Weinerfelt M. Tormalim	A. Vozella V. Wiels I. Ehrenpfort B. Eberle F. Muñoz Sanz A. Eriksson R. Wiegers	IT chair 2017-18 FR DE DE ES SE NL	M. Hagström W. Rouwhorst B. Kom L. Verde P. Mouyon TBC	SE chair 2017 NL DE IT FR SP	P. Beaumier M. White L. Notamicola J. Hakkaart A. Antifora R. Heger F. X Filias R.-H. Markiewicz K. Pahlke	FR chair 2017-18 UK IT NL IT DE FR UK DE	P. Wierach T. Iremam D. Tescione J. Sammilan J. Schön A. Riccio B. Thuis F. Roudloff	DE chair 2016-18 SE IT ES SE IT (Associated member) NL FR
<i>Industrial Points of Contacts</i>	<i>Industrial Points of Contacts</i>	<i>Industrial Points of Contacts</i>	<i>Industrial Points of Contacts</i>	<i>Industrial Points of Contacts</i>	<i>Industrial Points of Contacts</i>	<i>Industrial Points of Contacts</i>	<i>Industrial Points of Contacts</i>	
T. Berens N. Ceresola M. Mallet D. Pagan L. P. Ruiz-Calavera B. Stefes	E. Cortet L. Goerig M. Hanel TBC	AS IPoCs will be included very soon	FR FR DE SE	FR FR DE SE	HC IPoCs included above	H. Ansell A. Barrio Cardaba L. Hootsmans R. Lang C. Petiot A. Foreman M. Jesrrang R. Olsson M. Riccio	SE ES NL DE FR UK DE SE IT	



For further information about GARTEUR please contact:  
**[secretariat@garteur.org](mailto:secretariat@garteur.org)** or go to **[www.garteur.org](http://www.garteur.org)**