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The GOAHEAD project – overview and selected results

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In the European GOAHEAD project a wind tunnel experiment for a Mach scaled model of a generic complete helicopter was performed for the Generation of an Advanced Helicopter Experimental Aerodynamic Database for CFD code validation. Focus of the experiment was to investigate four typical flight conditions of a helicopter in detail with a highly instrumented model as well as with flow field measurements. In parallel to the wind tunnel campaign CFD solvers were applied in a blind and post test phase. A brief overview over the activities and results of the 15 partners involved in the GOAHEAD project is given. Conclusions on the project outcome are drawn.

1 Introduction

During the last ten years considerable progress has been made in developing aerodynamic prediction capabilities for isolated helicopter components such as an isolated main rotor or an isolated fuselage. Today leading edge CFD software systems are available which are capable of predicting the viscous flow around main rotor-fuselage configurations or even complete helicopters. The greatest shortcoming for qualifying RANS methods as design tools in the industrial design process for helicopters is the lack of detailed experimental validation data for the aerodynamics of complete helicopters. This issue was addressed by the European GOAHEAD research project (Generation of Advanced Helicopter Experimental Aerodynamic Database for CFD code validation) [1]. The main objectives of the GOAHEAD-project were:

1. To enhance the aerodynamic prediction capability of Europe's helicopter industry with respect to complete helicopter configurations.
2. To create an experimental database for the validation of 3D CFD and comprehensive aeromechanics methods for the prediction of unsteady viscous flows including rotor dynamics for complete helicopter configurations, i.e. main rotor – fuselage – tail rotor configurations with emphasis on viscous phenomena like flow separation and transition from laminar to turbulent flow.
3. To evaluate and validate Europe's most advanced solvers of the unsteady Reynolds averaged Navier-Stokes equations for the prediction of viscous flow around complete helicopters including fluid-structure-coupling.
4. To establish best practice guidelines for the numerical simulation of the viscous flow around helicopter configurations.

The GOAHEAD project was formed by 15 partners including the helicopter manufacturers

1. AgustaWestland, Italy
2. AgustaWestland, United Kingdom
3. Eurocopter SAS, France
4. Eurocopter Germany, Germany

five national research centres

5. CIRA (Centro Italiano Ricerche Aerospaziali), Italy
6. DLR (Deutsches Zentrum für Luft- und Raumfahrt), Germany
7. FORTH (Foundation for Research & Technology - Hellas), Greece
8. NLR (Nationaal Lucht- en Ruimte-vaartlaboratorium), The Netherlands

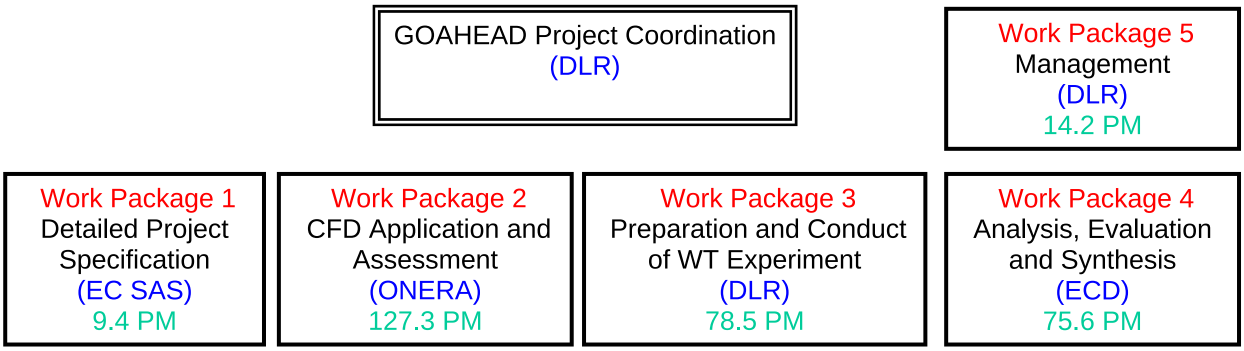

Figure 1: Organisation chart of the GOAHEAD project including the work package leaders and the effort spent within each work package (PM = person months)

9. ONERA (Office National d'Études et de Recherches Aérospatiales), France

five universities

10. Univ of Cranfield, United Kingdom
11. Univ. of Glasgow, United Kingdom
12. Univ. of Liverpool, United Kingdom
13. Politecnico di Milano, Italy
14. Univ. of Stuttgart, Germany

and one SME

15. AktivSensor, Germany

under the lead of DLR. The project had a duration of four and a half years (July, 1st, 2005 – December 31st, 2009). The GOAHEAD research project was conducted under the Integrating and Strengthening the European Research Area Programme of the 6th Framework, priority theme 4 “Aeronautics and Space”.

All partners involved in GOAHEAD have a profound knowledge of helicopter experimental testing and CFD modelling, thus creating a unique European added value. None of the single partners or even nations could today incur the costs and the effort required to tackle this problem on their own. Only a joint approach brings the critical mass of expertise and funding together that will allows progress.

2 Work package structure

The project was organized in five work packages as shown in Figure 1. Work package 1 was active at the beginning of the project in order to define the test matrix for wind tunnel testing and CFD exercises, and to define the experimental set-up and measurement techniques. The partners involved in work package 2 carried out CFD simulations in a blind and post test phase before and after the wind tunnel experiment, respectively. In work package 3 the wind tunnel experiment was prepared and conducted. In work package 4 the experimental data were deeply analyzed and stored in a data base. Furthermore, the CFD results were compared with the experimental data. The project management was done in work package 5. The project leader was DLR. The total effort in the GOAHEAD project was 305 person months.

3 Wind tunnel model

The wind tunnel experiment within GOAHEAD concerned itself with the Mach scaled model similar to a modern transport helicopter. In order to put as much effort in model instrumentation and measurement equipment as possible, existing components of previous wind tunnel experiments were reused: i.e. the fuselage of a NH90, the instrumented four bladed 7AD main rotor and an instrumented two bladed BO105 tail rotor, see Figure 2. The test configuration is therefore not a scaled model for an existing helicopter but a generic one. The experimental set-up was tailored to serve the needs of the aerodynamic validation for methods based on the unsteady Reynolds-averaged Navier-Stokes equations. After validation for the generic GOAHEAD configuration the CFD methods can be applied with good confidence to any similar real configuration.

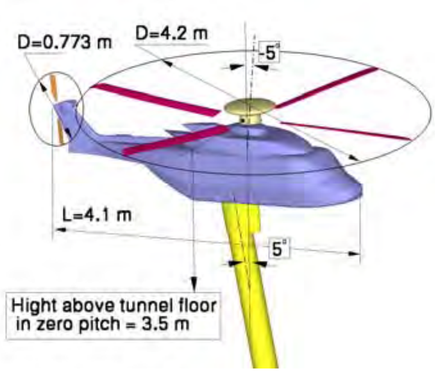

Figure 2: The GOAHEAD wind tunnel model

The assembly of the model was shared among several partners: The fuselage shell was modified by AgustaWestland (Italy) for the integration of the pressure sensors and the tail rotor. The 7AD-rotor blades have been overhauled by ONERA and equipped with hot films for transition measurements. Both, the fuselage shell and the main rotor blades were delivered to DLR for final assembly. At DLR the fuselage was connected to the modular wind tunnel model of DLR and the BO105 tail rotor was integrated into the tail unit, see Figure 3. A streamlined fairing for the belly mounted wind tunnel support strut was built in order to minimize flow interferences on the rear of the model. The displays for the rotor control room were coded by DLR and the complete model set-up was checked for correct operation.

Figure 3: Internal structure of the GOAHEAD model

For the wind tunnel campaign the GOAHEAD model was equipped with the following instrumentation:

Fuselage (see Figure 4):

- six component balance for the fuselage
- two component balance for the horizontal stabilizer
- 130 unsteady pressure transducers
- 292 steady transducers
- 38 hot wires for detection of transition or flow separations

Main Rotor:

- six component rotor balance
- 125 unsteady pressure transducers
- 40 hot wires for transition detection
- 29 strain gauges for blade deformation measurements

Tail Rotor:

- 38 unsteady pressure transducers
- 4 strain gauges for thrust calculation

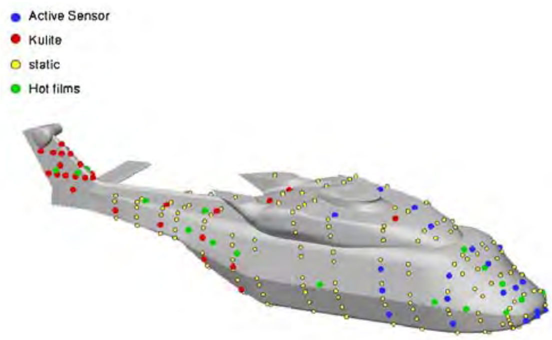

Figure 4: Distribution of unsteady pressure sensors (ActiveSensor, Kulites), steady pressure sensors and hot films on the fuselage

Differences in the CAD description and the manufactured model often cause problems in the comparison of experimental data with CFD results. Therefore, the geometry of the model was scanned by a structured-light 3D scanner and a new CAD description of the manufactured model was created.

4 Wind tunnel experiment

The wind tunnel experiment was performed during 14 days from March 28th to April 14th in the DNW-LLF at Marknesse, The Netherlands [2]. The test was conducted in the 6 m x 8 m closed test section, see Figure 5. This option was preferred before an open test section in order to have clear boundary conditions for the CFD validation.

Configuration	Test case	Inflow Mach number	Fuselage angle of attack	Main rotor, tip Mach number	tail rotor, tip Mach number
isolated fuselage	low speed, pitch up	0.059	-11° … 9°	-	-
	cruise/tail shake	0.204	-11° … 9°	-	-
	dynamic stall	0.259	-11° … -1°	-	-
complete helicopter	low speed, pitch up	0.059		0.617	0.563
	cruise/tail shake	0.204		0.617	0.563
	dynamic stall	0.259		0.617	0.563
	high speed	0.28		0.617	0.563

Table 1: selected Test cases for GOAHEAD

Figure 5: GOAHEAD-wind tunnel model in DNW-LLF

In GOAHEAD it was decided to concentrate on a limited number of test conditions but to perform detailed experimental flow analysis for each test case. The test cases were selected to represent a wide range of typical helicopter flight conditions:

1. a low speed - pitch up condition, where the loads on the horizontal stabilizer due to the rotor downwash are maximized
2. a cruise flight - tail shake condition, where the dynamic content of the fuselage balance as well as the dynamics pressures on the fin is maximized
3. a dynamic stall condition
4. a high speed forward flight condition.

The inflow and rotor parameters are given in Table ***1***. The rotor settings were pre-computed with Eurocopter's comprehensive rotor code HOST [3] in order to check if the wind tunnel model can operate at the required power consumption and rotor settings. During the wind tunnel experiment the pre-computed settings were adjusted for the dynamic stall and high speed test case.

In order to complement the experimental data for the complete helicopter, polars were taken for the isolated fuselage including rotating stubs on the hub. The measurements for the isolated fuselage provide additional data for CFD validation as well as they allow to get the tare loads on the hub and the loads for the isolated rotor.

During the wind tunnel campaign the model was operated by DLR. It was possible to perform all planned measurements at all test conditions. The measurements comprised global forces of the main rotor, the fuselage and the horizontal stabilizer, steady and unsteady pressures, transition positions, stream lines, velocity fields in the wake, vortex trajectories and elastic deformations of the main rotor blades. In addition, velocity profiles and the turbulent kinetic energy were measured at the inflow plane. The partners involved in the measurements are given in Table 2.

Measurements	Partners involved
wind tunnel parameters	DNW
wind tunnel inflow profile	Politecnico di Milano
model parameters	DLR
balance loads	DLR
steady/unsteady pressures	DNW/ Glasgow Univ. (installation: AgustaWestland/ DLR/ONERA)
hot films fuselage (boundary layer state)	Cranfield University
hot films main rotor (boundary layer state)	ONERA

fuselage thermography (transition detection)	DLR
stereo pattern recognition (blade deformation)	DNW
strain pattern analysis (blade deformation)	ONERA
micro tufts (surface stream lines)	DLR
Particle Image Velocimetry	DLR/DNW/CIRA

Table 2: Measurements in GOAHEAD and partners involved

5 Experimental results

After the wind tunnel campaign the experimental data were postprocessed by the partners and gathered by the University of Glasgow. In total more than 400 GB experimental data are archived in the data base. University of Glasgow also developed a data post processing tool which allows an easy access to the data base. A comprehensive documentation for the data base was written by the partners involved in the measurements. By including several measurements in the interpretation of data conclusions were drawn on transition, fluid structure interaction and blade aerodynamic response. Some selected results of will be highlighted in the following. A more detailed description can be found in references [2][4][5].

All unsteady pressures on the rotors and the fuselage were gathered for 150 main rotor revolutions with 2048 samples per main rotor revolution. The high temporal resolution allows, for example, to clearly resolve the blade passing frequency, see Figure 6. An example for the unsteady pressure distributions on the main rotor is shown in Figure 7.

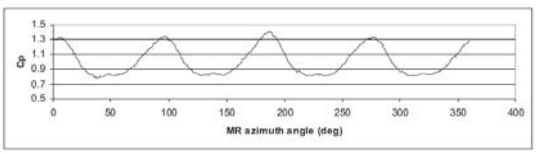

Figure 6: unsteady pressure signal on the nose of the fuselage, low speed/pitch up condition

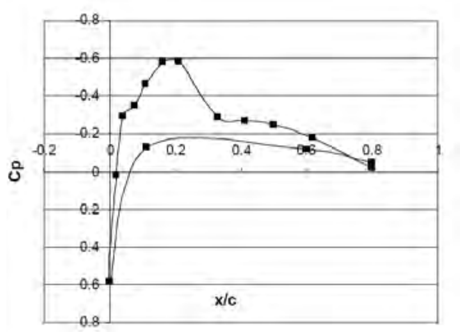

Figure 7: pressure distribution at 82.5% r/R , Ψ=90° for cruise condition

Transition detection was performed by two methods: Infrared termography gives a global view of the transition lines, see Figure 8. In contrast, hot films give local information on the turbulent content of the flow, see Figure 9.

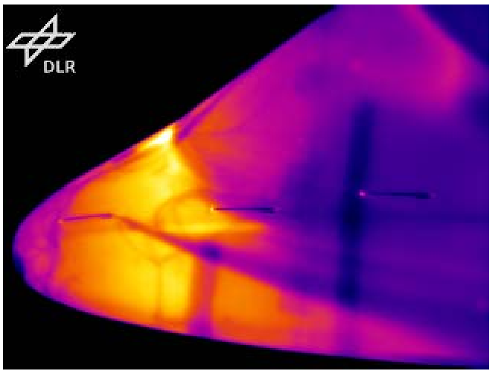

Figure 8: Infrared image of fuselage, regions with laminar flow at the nose are violet, turbulent flow is orange, M=0.059, a=-2°

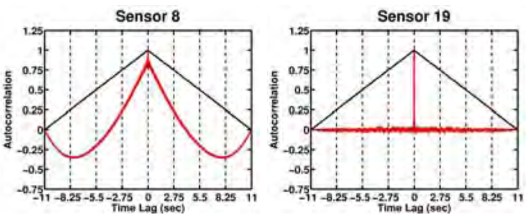

Figure 9: autocorrelation of hot film results on the fuselage for laminar (left) and turbulent (right) flow

Information on the flow field were measured by means of Particle Image Velocimetry (PIV). Several regions were analyzed, see Figure 10. The regions behind the rotor hub as well as at the rear of the fuselage were analyzed for the cruise condition with time resolved three component PIV (windows PIV1 and PIV2), see Figure 11. For the low speed – pitch up condition the downwash including the tip vortices above the horizontal stabilizer were investigated with PIV-window PIV3. The flow field behind the helicopter was studied for cruise condition by the PIV4-window. The windows PIV6a-d allowed to investigate the shock structure on the advancing blades for the high speed test case and the dynamic stall effect on the retreating side for the dynamic stall test case, see Figure 12.

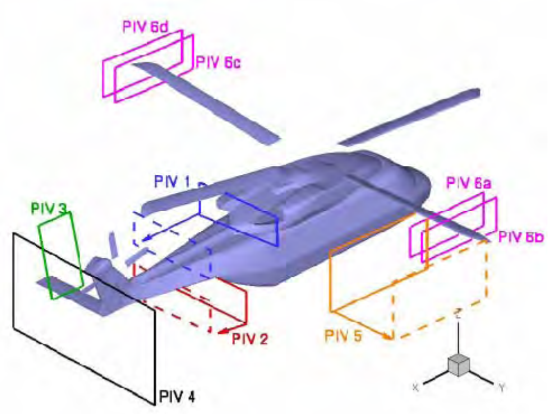

Figure 10: Positions of PIV-planes

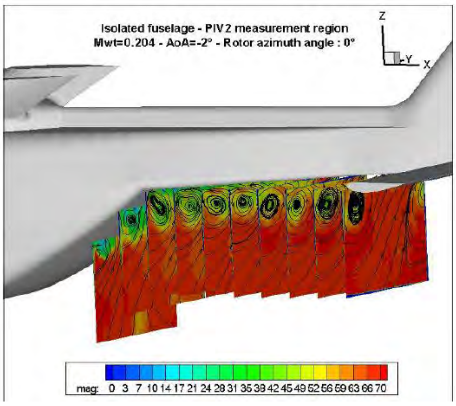

Figure 11: Vortical structure behind the rear door

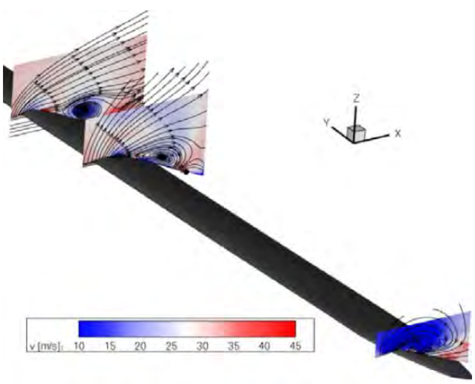

Figure 12: PIV-image of the dynamic stall test case

6 CFD application and assessment

11 partners were involved in the CFD activities, see Table 3. The partners have been selected because they either provide CFD software to industry (DLR, ONERA, Politecnico Milano, University of Liverpool) or because of specific code features (NLR, FORTH, University of Stuttgart, University of Cranfield). No commercial codes were applied. All codes solve the Reynolds-averaged Navier Stokes equations with second order spatial discretization. The only unstructured solver involved was the in-house solver of FORTH. The other codes use structured grids. elsA, FLOWer and ROSITA use overset grids to account for the relative motions of the rotors. ENSOLV and HMB use sliding meshes to treat the rotation of the rotors and mesh deformation to account for blade pitching and flapping. All simulations with FLOWer were loosely coupled to Eurocopter's comprehensive rotor code HOST in order to account for the correct rotor trim and elastic blade deformation.

No code developments were foreseen in GOAHEAD except for University of Cranfield who implemented an ILES method into FLOWer with third or fifth order WENO reconstruction. However, most partners used other funding in order to significantly improve their codes for complete helicopters simulations during GOAHEAD.

A comparison of the aforementioned solvers for complete helicopter simulations has never been performed before. A comparison of the codes provides therefore an assessment of different code features, allows to evaluate the reliability of the codes and gives directions for further code developments.

CFD Tool	CFD Provider	CFD User
elsA	ONERA	Eurocopter SAS
FLOWer	DLR	Eurocopter Germany, Univ. Cranfield, Univ. Stuttgart
HMB	Univ. Liverpool	AgustaWestland
ROSITA	Poli. Milano	AgustaWestland
ENSOLV	NLR	
FORTH	FORTH	

Table 3: CFD codes applied in GOAHEAD

test case / partner	isolated fuselage			complete helicopter			
	pitch-up	cruise/tail Shake	dynamic stall	pitch-up	cruise/tail shake	dynamic stall	high speed
DLR	✓	✓	✓		✓	✓	
ONERA					✓		✓
Eurocopter Germany	✓	✓				✓	
Eurocopter SAS				✓	✓		
AgustaWestland					✓		
FORTH							✓
NLR	✓	✓			✓		
Univ. of Cranfield		✓	✓				
Politecnico Milano					✓		
Univ. of Stuttgart				✓			
Univ. of Liverpool		✓	✓		✓	✓	

Table 4: CFD computations within GOAHEAD

The test cases chosen in within GOAHEAD were distributed among the partners, such that all flight conditions were covered by a time-accurate computation of the complete helicopter. Table 4 summarizes the investigated test cases and their distribution to the individual partners.

The CFD activities were performed in a blind test phase before the wind tunnel experiment and a post test phase after the experiment. The objective of the blind test exercise was to assess the prediction capabilities of the codes for complete helicopter simulations and to provide additional information for the set-up of the wind tunnel experiment. The objective of the post test activities was to run the CFD simulations again taking into account the true model geometry and wind tunnel conditions as well as the lessons learned from the blind test exercise. A comparison of the blind test results was published in [6]. Presentations by the individual partners can be found in references [7] to [18]. A comparison of the post test computations with experimental data is presented in [19]. Papers prepared by the individual partners on post test results are given by references [20] to [23].

As examples for results of the CFD activities Figure 13 shows the automatically created Cartesian overset background mesh from ONERA.
Figure *14* displays the flow field for the low speed/pitch-up case computed by University of Stuttgart. A comparison of simulated pressure distributions with
experimental data at the symmetry plane of the fuselage are shown in Figure 15. Pressure distributions for the main rotor are compared in Figure 16. Results for the flow field behind the rear door of the fuselage are displayed in Figure 17.

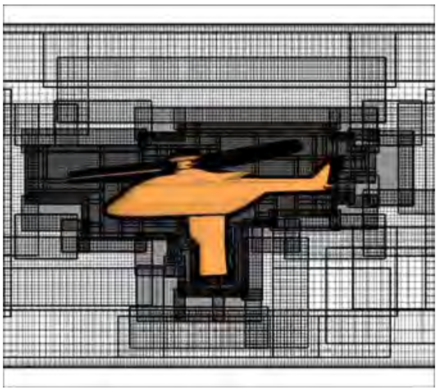

Figure 13: Automatically generated Cartesian background grid, result of ONERA

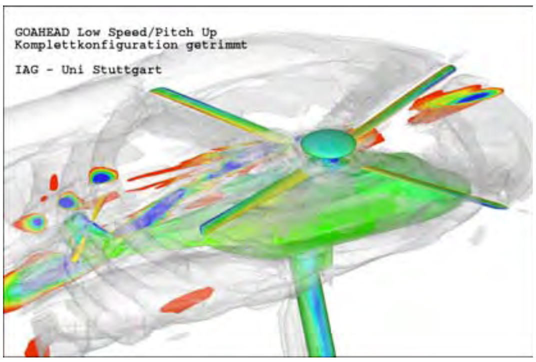

Figure 14: Flow field for complete helicopter

in low speed/pitch up condition, result of University of Stuttgart

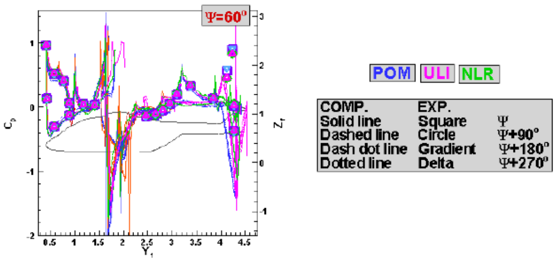

Figure 15: pressure distribution on fuselage predicted by CFD compared to experiment

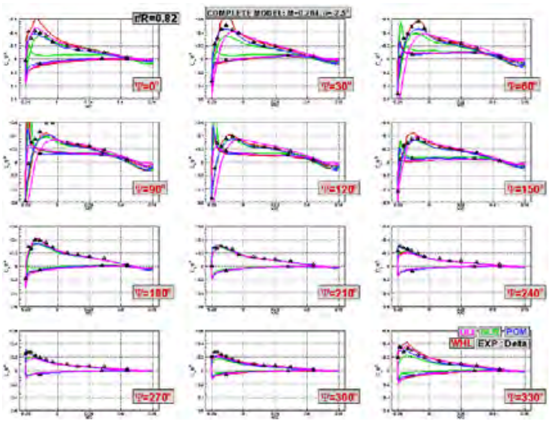

Figure 16: comparison of numerical and experimental results on main rotor pressure distributions

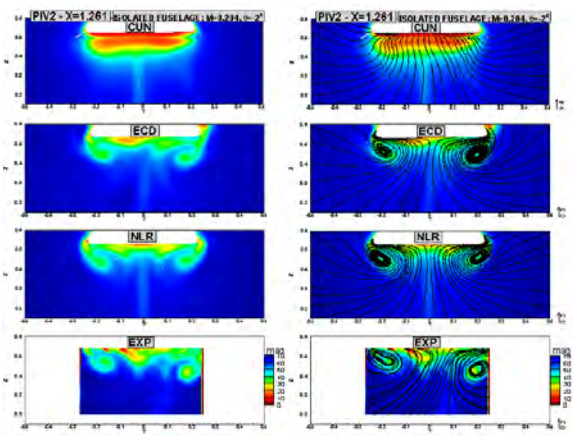

Figure 17: comparison of numerical and experimental flow field behind back door

7 Conclusions

In the frame of the European GOAHEAD project 15 partners were involved in a wind tunnel campaign CFD simulations for a complete helicopter configuration. Main deliverables of GOAHEAD are a deeply analyzed experimental database, the comparison and validation of the CFD solvers and best practice guidelines for the application of URANS methods to complete helicopters.

After the end of the project the following conclusions can be drawn:

1. Within the GOAHEAD project a comprehensive data base with high quality data and documentation for complete helicopters has been generated. Almost all data as originally planned were gathered during the experiment.
   However, in the limited time after the wind tunnel experiment it was not possible to analyse all details of the data. A full understanding of the data base will require many more years of research and data analysis like for any other experimental data base.

2. All CFD-solvers applied within the project are capable to simulate the unsteady flow about complete helicopters with good accuracy for certain features. Interaction phenomena are partly captured. This is a big step forward having in mind that the first successful RANS helicopter simulations in Europe have been published in 2002.
   It has to be noted that due to the complexity and instationarity of the flow the solution accuracy has not reached the same level like for fixed wing applications. Further CFD developments and validation is required in order to further improve the CFD software, e.g. turbulence and transition modelling, coupling of CFD methods to structural mechanics and flight mechanics and CPU time reduction.

3. The European helicopter industry took advantage from the improvements and validation of their URANS-CFD tools. By working jointly with research centers industry extended the range of applications for in-house simulations. However, due to the large computational effort complete helicopter simulations will not be routinely run in near future in industry.

4. Within GOAHEAD best practice guidelines for the numerical simulation of the viscous flow around helicopter configurations were established. The guidelines will support users in the set-up

and execution of helicopter simulations and will increase reliability of prediction capabilities.

Overall the results obtained within GOAHEAD significantly advance the state of research for complete helicopter simulations in Europe. In 2010 in total 22 scientific publications are available on GOAHEAD. The data base is ready to be exploited for further understanding of helicopter flows and for validation of future CFD developments. The GOAHEAD project improved the competitiveness and economic prospects of the European helicopter manufacturers by advancing and qualifying their CFD tools and by the increased knowledge. The improved design capabilities will allow for higher aerodynamic performance of helicopters which in turn will reduce the specific fuel consumption and noise emission. This is a benefit for the community in its quest for a clean and healthy environment.

8 Acknowledgements

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9 References

[1] K. G. Pahlke: “The GOAHEAD Project”, 33rd European Rotorcraft Forum, Kazan, Russia, September 11th-13th, 2007

[2] M. Raffel, F. de Gregorio, W. Sheng, G. Gibertini, A. Seraudie, K. de Groot, B. van der Wall: “Generation of an advanced helicopter experimental aerodynamic database”, 35th European Rotorcraft Forum, Hamburg, Germany, September 22nd - 25th, 2009

[3] B. Benoit, A.-M. Dequin, K. Kampa, W. von Grünhagen, P.-M. Basset and B. Gimonet: „HOST, a general helicopter simulation tool for Germany and France“, American Helicopter Society 56th Annual Forum, Virginia Beach, VA, 2000

[4] F. De Gregorio, K. Pengel and K. Kindler: “Industrial Measurement Campaign on Fully Equipped Helicopter Model”, 15th Int. Symp. on Applications of Laser Techniques to Fluid Mechanics, Lisbon, Portugal, 07-10 July, 2010

[5] K. Kindler: “Dynamic stall on a fully equipped helicopter model”, 36th European Rotorcraft Forum, Paris, France, September 7-9, 2010

[6] O.J. Boelens, G. Barakos, M. Biava, A. Brocklehurst, M. Costes, A. D’Alascio, M. Dietz, D. Drikakis, J. Ekaterinaris, I. Humby, W. Khier, B. Knutzen, J. Kok, F. Le Chuiton, K. Pahlke, T. Renaud, T. Schwarz, R. Steijl, L. Sudre, H. van der Ven, L. Vigevano and B. Zhong: “The blind-test activity of the GOAHEAD project”, 33rd European Rotorcraft Forum, Kazan, Russia, September 11th-13th, 2007

[7] M. Dietz, M. Kessler and E. Krämer: „Trimmed Simulation of a Complete Helicopter Configuration Using Fluid-Structure Coupling”, In E. W. Nagel, D. B. Kröner, M. Resch (eds): “High Performance Computing in Science and Engineering '07: Transactions of the High Performance Computing Center, Stuttgart (HLRS) 2007”, Springer-Verlag Berlin Heidelberg, 2008

[8] W. Khier, M. Dietz, T. Schwarz, S. Wagner: „Trimmed CFD Simulation of a Complete Helicopter Configuration”, 33rd European Rotorcraft Forum, Kazan, Russia, September 11th-13th, 2007

[9] M. Poinot, M. Costes: “Large and heterogeneous data handling for helicopter CFD”, 8th. World Congress on Computational Mechanics (WCCM8), 5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008), Venice, Italy, June 30 – July 5, 2008

[10] M. Dietz, W. Khier, B. Knutzen, S. Wagner, E. Krämer: „Numerical Simulation of a Full Helicopter Configuration Using Weak Fluid-Structure Coupling”, 46th AIAA

[11] R. Steijl and G. Barakos: “Sliding Mesh Algorithm for CFD Analysis of Helicopter Rotor-Fuselage Aerodynamics”, AHS Specialists’ Conference on Aeromechanics, San Francisco, CA, January 23 – 25, 2008

[12] R. Steijl and G. Barakos: “Computational Analysis of Rotor-Fuselage Interactional Aerodynamics using Sliding-Plane CFD Method”, 34th European Rotorcraft Forum, Liverpool, UK, September 16th-19th, 2008

[13] R. Steijl and G. Barakos: ”Sliding mesh algorithm for CFD analysis of helicopter rotor-fuselage Aerodynamics”, International Journal for Numerical Methods in Fluids, Vol. 58, 2008, pp. 527-549

[14] O. J. Boelens, H. van der Ven, J.C. Kok and B.B. Prananta: “Rotorcraft simulations using a sliding-grid approach”, 34th European Rotorcraft Forum, Liverpool, UK, September 16th-19th, 2008

[15] B. Zhong, S. K. Yadav and D. Drikakis: “Turbulent Flow Simulations Around An Airfoil At High Incidences Using URANS, DES And ILES Approaches”, ERCOFTAC workshop “Direct and Large-Eddy Simulations 7” (DLES7), Trieste, Italy, September 8-10, 2008

[16] B. Zhong, D. Drikakis, F. Le Chuiton, T. Schwarz, J Raddatz: “URANS, DES and ILES approaches for a complete helicopter fuselage flow simulations with, and without, actuator disks modelling”, Capability Computing, Issue 12, Autumn 2008

[17] R. Steijl and G.N. Barakos: “Computational Study of Helicopter Rotor-Fuselage Aerodynamic Interactions”, AIAA-Journal, Vol. 47, No. 9, September 2009, pp. 2143 – 2157

[18] W. Khier: “Numerical Simulation of Air Flow past a Full Helicopter Configuration”, 35th European Rotorcraft Forum, Hamburg, Germany, September 22nd - 25th, 2009

[19] B. Zhong, D. Drikakis, A. Antoniadis, G. Barakos, M. Biava, A. Brocklehurst, O. Boelens, M. Dietz, M. Embacher, W.Khier, T. Renaud, R. Steijl, L. Vigevano: “Assessment of CFD Methods against Experimental Flow Measurements for Helicopter Flows”, 36th European Rotorcraft Forum, Paris, France, September 7-9, 2010

[20] T. Renaud, M. Costes and S. Péron: „Computation of GOAHEAD configuration with Chimera assembly”, 36th European Rotorcraft Forum, Paris, France, September 7-9, 2010

[21] W. Khier, M. Biava and L. Vigevano: “CFD Prediction of Air Flow Past a Full Helicopter Configuration”, 36th European Rotorcraft Forum, Paris, France, September 7-9, 2010

[22] M. Biava, L. Vigevano: “Simulation of a complete helicopter, a CFD approach to the study of interference effects”, 36th European Rotorcraft Forum, Paris, France, September 7-9, 2010

[23] R. Steijl: “CFD analysis of complete helicopter configurations – lessons learned from the GOAHEAD project”, 36th European Rotorcraft Forum, Paris, France, September 7-9, 2010