The GOAHEAD Project

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Abstract: The 6th Framework Programme EU-Project GOAHEAD is presented. The consortium is described and the project structure is explained. The main objective of GOAHEAD is 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. The wind tunnel model integration is ongoing. On the CFD side first results were obtained for trimmed Unsteady Reynolds Averaged Navier Stokes (URANS) simulations of a complete helicopter including fluid structure coupling. The wind tunnel experiment is scheduled for January 2008 in the DNW LLF.

1. INTRODUCTION

During the last fifteen 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, and others are being developed, which are capable of predicting the viscous flow around main rotor-fuselage configurations or even complete helicopters. The greatest shortcoming for qualifying these methods as design tools in the industrial design process in Western Europe is the lack of detailed experimental validation data for the aerodynamics of complete helicopters.

To overcome these shortcomings, the GOAHEAD-project [1] (Generation Of Advanced Helicopter Experimental Aerodynamic Database for CFD code validation) was initiated by 15 partners (DLR, Onera, CIRA, FORTH, NLR, UG, CU, PoliMi, USTUTT-IAG , ULIV, ECD, EC SAS, Agusta, WHL, AS (see Table 1 for the full names), i.e. five national research centres, five universities, four helicopter manufacturers and one SME) with the following main objectives:

- To enhance the aerodynamic prediction capability with respect to complete helicopter configurations.
- 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.
- To evaluate and validate Europe's most advanced solvers of the Unsteady Reynolds-averaged Navier-Stokes (URANS) equations for the prediction of viscous flow around complete helicopters including fluid-structure-coupling.
- To establish best practice guidelines for the numerical simulation of the viscous flow around helicopter configurations.

All partners in GOAHEAD have a profound knowledge of helicopter experimental testing and CFD modelling. 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 as in GOAHEAD brings the critical mass of expertise and funding together. The overall project budget is about 5 Mill. Euro. The project started in July 2005 and will have a duration of 4 years. Four main milestones are to be achieved. After the test matrix is defined and the configuration is specified a so-called blind test computation exercise is carried out. The results were delivered before end of June 2007 and collected by NLR. This allows a first judgment of the aerodynamic effects to be expected in the wind tunnel. Furthermore a cross comparison between the different CFD results is carried out before the experimental data is available. The next main milestone is the wind tunnel entry which is scheduled for Jan. 2008 this will give sufficient time for the data post-processing and a detailed comparison with the numerical prediction within the duration of the GOAHEAD project. Based on these findings the post-test computations will be carried out with improved grids and models. With the delivery of the results of the post test computations the third milestone will be reached. Finally the fourth main milestone will be to release guidelines for the URANS simulation of complete helicopter configurations.

Short Name	Legal Name	Country
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.	Germany
ONERA	Office National d'Etudes et de Recherches Aérospatiales	France
ECD	EUROCOPTER Deutschland G.m.b.H.	Germany
EC SAS	EUROCOPTER S.A.	France
Agusta	Agusta S.p.A.	Italy
WHL	Westland Helicopters	United Kingdom
CIRA	Centro Italiano Ricerche Aerospaziali S.C.P.A.	Italy
FORTH	Foundation for Research and Technology	Greece
NLR	Stichting Nationaal Lucht-en Ruimtevaartlaboratorium	The Netherlands
UG	University of Glasgow	United Kingdom
CU	Cranfield University	United Kingdom
PoliMi	Politecnico di Milano	Italy
USTUTT-IAG	Institut für Aerodynamik und Gasdynamik der Universität Stuttgart	Germany
AS	Aktiv Sensor GmbH	Germany
ULIV	University of Liverpool	United Kingdom

Table 1 List of GOAHEAD Partners

In chapter 2 of this paper the Work Package structure is briefly described. Chapter 3 explains the configuration which was chosen and chapter 4 presents the wind tunnel setup. The CFD methods applied in the project are briefly listed in chapter 5 and finally chapter 6 describes the status of the project as in July 2007.

2. WORK PACKAGE STRUCTURE

The project consists of 5 Work Packages (WP). The WP structure is given in Figure 1. In WP1 the detailed specifications for the test matrix for the wind tunnel experiment and the CFD evaluation and validation task were elaborated. WP2 is the CFD Work Package in which existing CFD codes are applied for complete helicopter configurations in a blind-test and a post-test exercise. The test cases have been distributed among the partners, such that all main flight conditions ranging from medium lift at low speed to maximum lift at high speed will be covered by at least one time-accurate computation of the complete helicopter with a state-of-the-art method. The wind tunnel experiments will be carried out in WP3. The configuration to be investigated in the DNW LLF is a Mach scaled model of a modern transport helicopter (NH90) consisting of the main rotor (R=2.1m), the fuselage (including all control surfaces) and the tail rotor. As can bee seen in Figure 1 a huge effort is spent in this project to provide high quality experimental data.

The data will be used in WP4 for the validation of the CFD methods. Additionally there will be a separate data analysis task in WP4 to ensure a detailed understanding of the data and to provide consistent data for CFD validation. WP4 will draw conclusions out of WP2 and 3 and establish best practice guidelines for the URANS simulation of complete helicopter configurations. WP5 concerns itself with the project management and is responsible for the project exploitation.

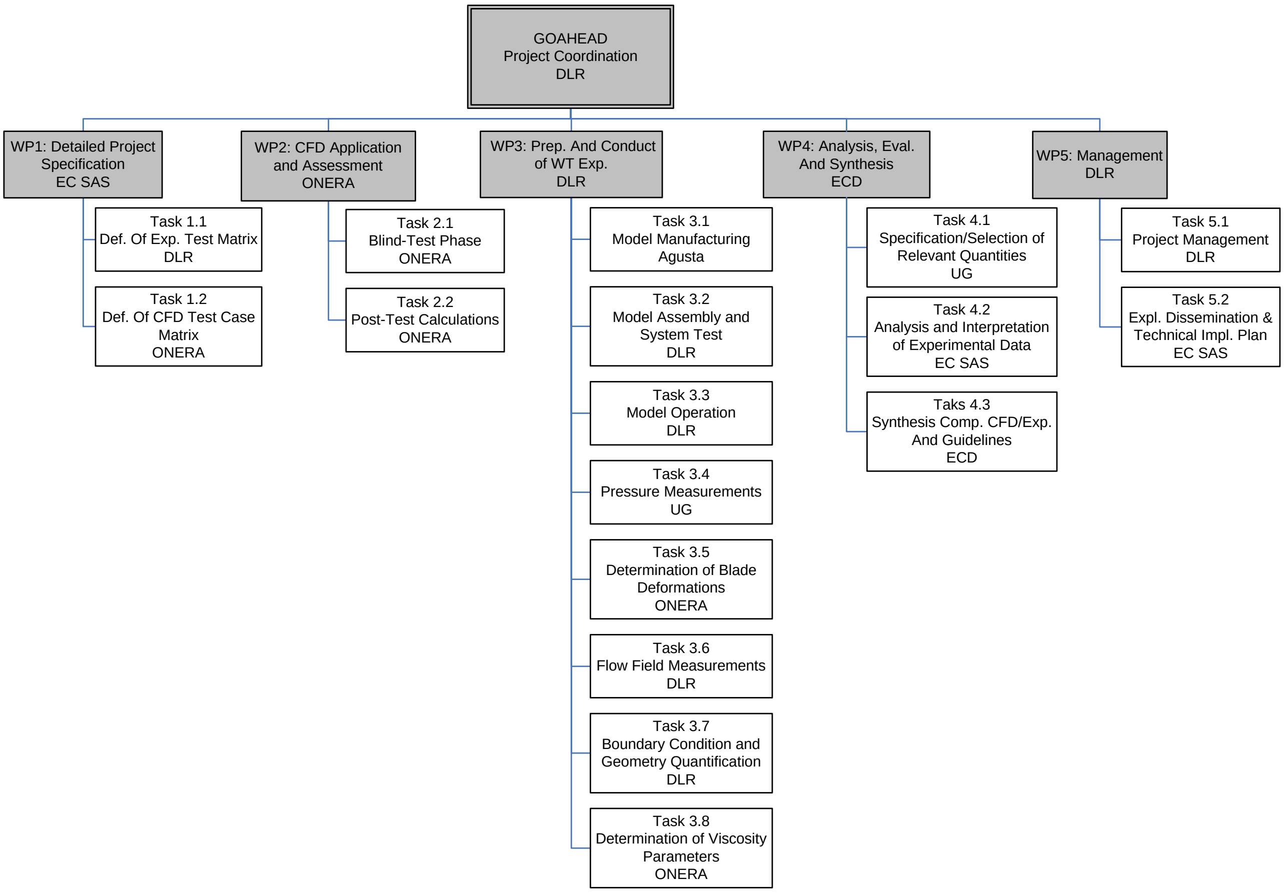

Figure 1 Organisation Chart of GOAHEAD

3. CONFIGURATIONS AND FLIGHT CONDITONS

The model to be tested is a Mach scaled model with a geometry similar to the NH90 helicopter. The main rotor diameter is 4.2 m which corresponds to a 1/3.9 scale. In order to keep the costs of the experimental campaign as low as possible, existing components will be reused, i.e. the fuselage (slightly modified NH90 geometry), the instrumented 4-bladed main rotor (Onera 7AD geometry), and the instrumented 2-bladed tail rotor (Bo105 geometry, diameter 0.733m). This means that the test configuration is not a true scaled model of an existing helicopter. But this is of no importance for the GOAHEAD objectives because the aim is to produce data for CFD validation for any realistic configuration. The model will be installed with a belly mounted sting and a so-called beany, i.e. a fairing of the upper part of the rotor head.

In order to allow a systematic assessment of different features of the CFD methods two configurations will be investigated: the fuselage with rotor heads but without blades for a range of Mach numbers and angles of attack and the full model as given in Figure 2. The flight conditions foreseen for the full model are

i. a low-speed (pitch-up) condition,
ii. a cruise condition (free stream Mach number ≈ 0.2),
iii. a high-speed tail-shake condition,
iv. a highly-loaded rotor (dynamic-stall) condition, and
v. a very high speed condition (free stream Mach number ≈ 0.25, $M_{\omega R}$ =0.66).

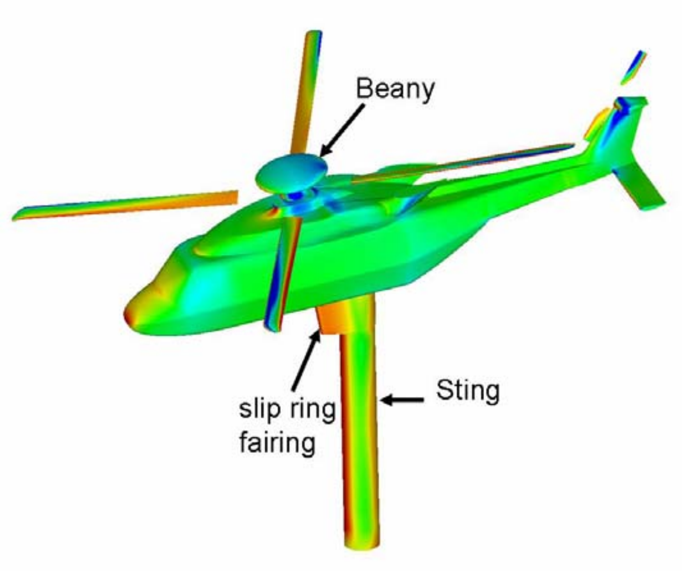

Figure 2 GOAHEAD model

In iii it is foreseen to measure in detail a flight condition experiencing a strong interaction of the main rotor and fuselage wakes with the control surfaces of the tail boom (aerodynamic excitation similar to a tail shake condition). In fact the fuselage model is not dynamically scaled. Therefore only the aerodynamic excitation that would lead to a tail shake in full scale will be measured. In addition to pressures and forces 3D flow field data will be measured in order to better understand which are the dominant sources for the tail shake phenomenon. With respect to flight condition iv it should be noted that it is intended to measure in detail dynamic stall for a high speed/high thrust case where stall occurs not only close to the blade root but along a large percentage of the blade, increasing dramatically the rotor power and limiting the flight envelope.

The Mach number due to the blade rotation $M_{\omega R}$ is 0.617 for all cases except the very high speed case. In order to simplify the comparison of the experimental with the CFD data the ratio between the main rotor RPM and the tail rotor RPM is set to 1:5.

4. WIND TUNNEL SETUP

The wind tunnel campaign in DNW LLF which was originally scheduled for October 2007 had to be rescheduled to January 2008. The configuration to be investigated is described in chapter 3 and the wind tunnel setup is presented in Figure 3. This figure gives a good impression of the position of the model inside the closed test section using the vertical sting. The experimental set-up will be tailored to serve the needs of the aerodynamic validation for methods based on the unsteady Reynolds-averaged Navier Stokes equations. Clear boundary conditions are of higher importance than wind tunnel simulations as close as possible to free flight. This means that closed walls are to be preferred to slotted walls/open jets, etc. Therefore the 6mx8m closed test section will be used. The application of closed walls excludes acoustic measurements but the interest in very clear and clean conditions for aerodynamic measurements is in this case of higher importance. The experience with past acoustic prediction activities clearly showed that the weak part in the prediction chain is the aerodynamic prediction. Whenever the aerodynamics on the blade surface (pressures and skin friction) and in the field (pressure, density, velocities) is correctly computed, the existing acoustic methods are well capable of predicting the pressure signal at the microphone position. Therefore the outcome of GOAHEAD will considerably improve the reliability of acoustic prediction although no acoustic measurements will be carried out.

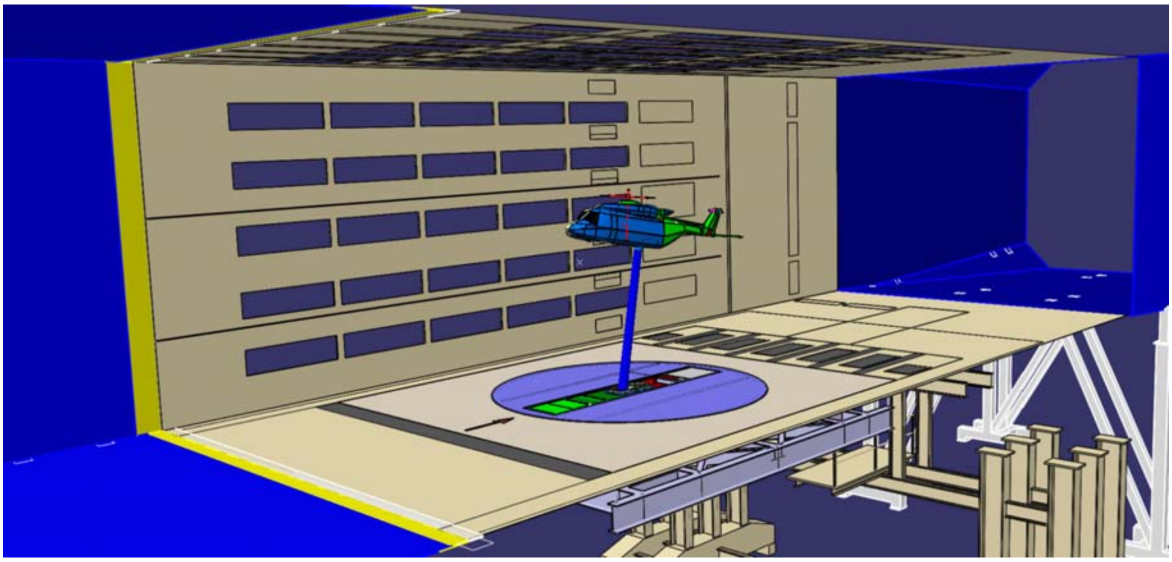

Figure 3 GOAHEAD wind tunnel setup

The measurements will comprise global forces of the main rotor and the fuselage, steady and unsteady pressures, transition positions, stream lines, position of flow separation, velocity fields in the wake, vortex trajectories and elastic deformations of the main and tail rotor blades.
The following measurements are foreseen:

- The global rotor and fuselage forces will be measured by the balances of the DLR Modular Wind tunnel Model test rig (MWM, see Figure 5). In addition the forces on the horizontal stabilizer will be recorded with a separate balance.

- Pressures will be measured by 128 dynamic sensors on the main rotor (allowing the computation of local forces and moments in five sections, see Figure 4), by 36 dynamic sensors on the tail rotor and by 300 static and 130 dynamic sensors on the fuselage. This will provide a detailed picture of the loads acting on each component and will allow a deep comparison with the CFD results. An overview of the pressure sensor locations on the fuselage is given in [2]. In addition to the pressure measurements on the model the pressures at the tunnel walls will be recorded on 2 beams per wall with 30 static pressure tabs installed in each beam resulting in a total of 240 tabs on the walls.
- In order to provide information about the laminar turbulent transition on the main rotor blades and on the fuselage a total of 70 hot films will be used. 40 of them have been installed on the main rotor blades, while 30 hot films are distributed on the fuselage. In addition to the hot films an infrared camera will be applied to certain cases in order to measure the transition line on the fuselage.
- Micro-tufts will be used to determine surface stream lines and areas of separated flow on the fuselage.
- The deformation of the main rotor blades will be measured via strain gauges (Strain Pattern Analysis, SPA) and via an optical system using stereoscopic cameras (Stereo Pattern Recognition, SPR). The reason to use two different measurement techniques to measure the blade deformation is twofold: first, accurate information on the blade deformation is crucial to understand the flow around the main rotor, second, it is very important information for the validation of CFD results. Having the continuous data of the strain gauges (SPA) and the digital from the optical measurement system (SPR) is expected to provide reliable and exact blade location and deformation data. Figure 4 presents the SPR markers on the beany and on one 7AD blade.
- The pitch link loads will be measured.
- 3D flow field data will be measured using the Particle Image Velocimetry (PIV) technique.
- The inflow conditions will be measured for certain cases with hot wires in order to provide detailed boundary conditions (Velocity profiles and the turbulent kinetic energy) for the CFD solvers.
- A 3D scan of the real model geometry will be done before the WT measurements in order to have access to the true model geometry which may differ from the original CAD data.

An efficient data acquisition system will be applied to save this large amount of data simultaneously. Therefore several subsystems from different partners will be integrated. A total of 12 measurement days is planned.

Several modifications of the existing components have been necessary in order to build up the complete wind tunnel model including full instrumentation. The existing fuselage model was never equipped with a tail rotor. Therefore a completely new tail fin was designed (DLR) and manufactured (Agusta) for the installation of the tail rotor (see Figure 6). In order to guarantee the stability of the tail unit Agusta re-inforced it. Details of the installation of the hydraulic engine for the tail rotor and the required electronic equipment for tail rotor control and sensor data conditioning are presented in Figure 7. Hot films including the required wiring were installed on the main rotor blades (Onera). Furthermore conditioning units were designed such that they can be installed in a so-called beany above the rotor head (see Figure 8 and Figure 9). These figures also show the blade angles calibration unit. The data transfer from the rotating systems (pressure, hot films and strain gauges signals) to the fixed system is done via slip ring systems. The fairing of the main rotor slip ring can be seen at the lower side of the fuselage in front of the sting in Figure 2.

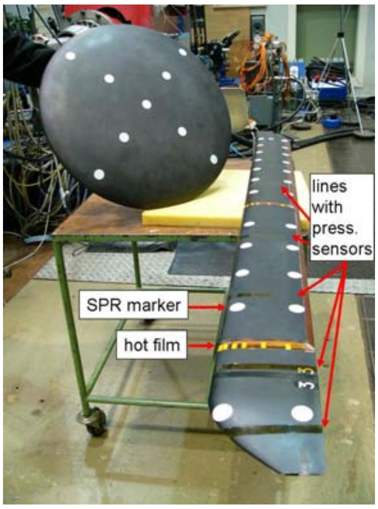

Figure 4 SPR markers on" beany" and 7AD blade

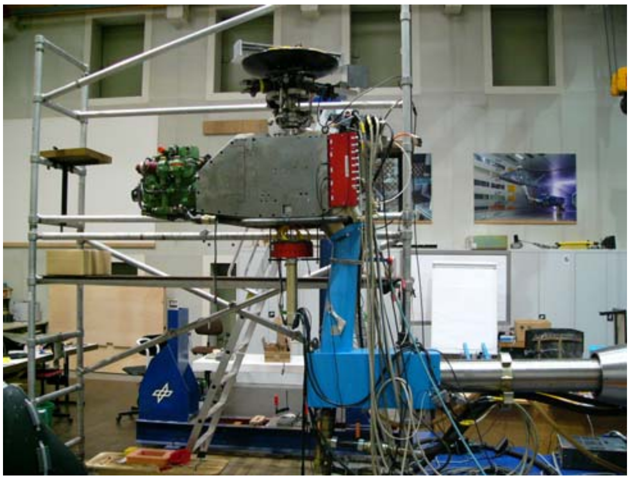

Figure 5 Modular Wind tunnel Model (MWM)

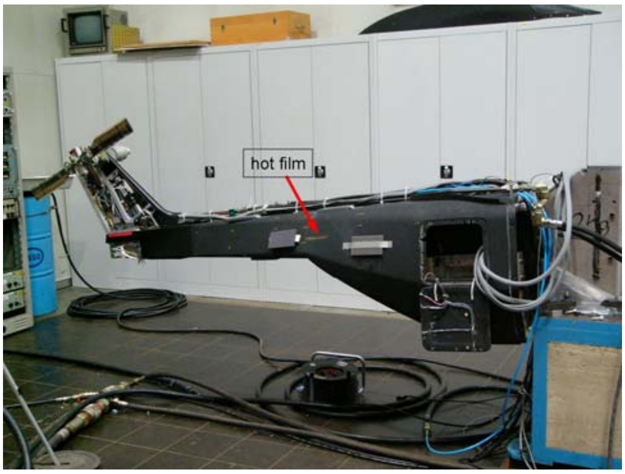

Figure 6 Tail unit

Figure 7 Tail fin with integrated tail rotor

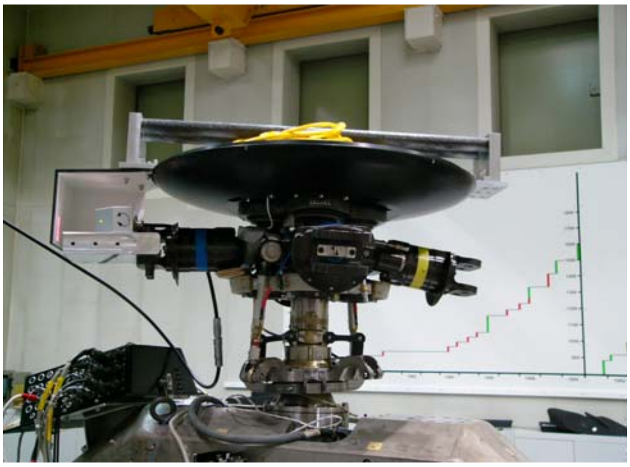

Figure 8 Rotor head with calibration unit

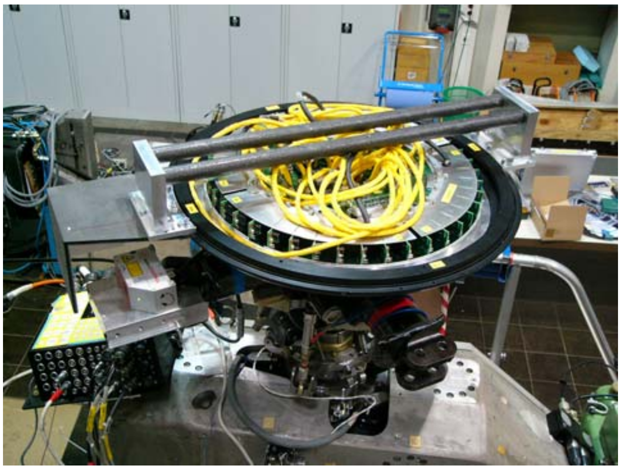

Figure 9 "Beany" with hot film condit. units

5. CFD METHODS

The first group of CFD partners was selected as those who provide CFD codes to Eurocopter, Agusta and Westland Helicopters. In addition to this group other codes were selected because of specific features, like the Discontinuous Galerkin MTMG method of NLR and the unstructured method of FORTH. No commercial CFD codes will be part of the investigations in Work Package 2 because tests in industry have shown that the effort in terms of license fees, cpu-time and man-power is too high for the available methods on the market in order to apply them to configurations of the complexity of a main rotor-fuselage-tail rotor model including fluid-structure coupling. A systematic comparison of Europe’s URANS solvers for complex helicopter configurations has never been carried out before. Past experience with applications to isolated helicopter components has shown that such a comparison not only provides important insights for further code improvements but also defines the reliability range of these methods.

Although the development of improved turbulence models will not be part of GOAHEAD, several partners have proven expertise in turbulence modelling and they will bring in state of the art modifications of turbulence models. The flow over a highly loaded helicopter involves separation, non-equilibrium effects, strong streamline curvature and unsteadiness, all of which constitute major challenges for turbulence modelling.

CFD Code	Helicopter industry	Research organisations
elsA [4]	EC SAS	Onera
FLOWer [5]	ECD	DLR, USTUTT-IAG, CU
HMB [6]	WHL	ULIV
ROSITA [7]	Agusta	PoliMi
Discontinuous Galerkin MTMG [8] + ENSOLV [9]		NLR
Unstructured FORTH in house method		FORTH

Table 2 CFD codes used in GOAHEAD

Table 2 provides an overview of the applied CFD codes. All basic solvers use a second order spatial discretisation. elsA, FLOWer and ROSITA use deforming grids within a full chimera framework. The main rotor is trimmed using a weak coupling with the Helicopter Overall Simulation Tool HOST [10]. CU will apply FLOWer in conjunction with high-resolution methods in the context of an unsteady RANS/ILES (implicit large eddy simulation on coarse grids) approach [11] in order to assess the potential of this method for flow separation prediction on helicopter fuselages. HMB uses a so-called sliding mesh approach to allow for the relative motion of the rotors and the fuselage and the elastic deformation of the rotor blades. The simulation uses prescribed blade motions. The simulations with ROSITA in the blind test phase are done with prescribed blade motions. The NLR method is applied to an isolated main rotor including elastic blade deformation and trim. The forces computed for the isolated rotor are then used as an input for a quasi-steady computation with the NLR solver ENSOLV [9]. In ENSOLV the main rotor is simulated via an actuator disk with the forces coming out of the MTMG run. The tail rotor is modeled with constant force distribution. The unstructured FORTH solver is applied to isolated fuselage cases only. It is foreseen to extend this solver also to rotor-fuselage configurations.

Taking into account the tunnel walls in the computations will allow the wall interference effects to be assessed directly. This is achieved by using closed walls in the wind tunnel, which will allow a straight-forward simulation with CFD methods. Such an approach compares simulations of the flow around wind tunnel models with measurements of the same flow instead of comparing free flight simulations with wind tunnel measurements that were corrected for free flight as has been frequently done in the past. Therefore very accurate extrapolation from the wind tunnel experiments to free flight conditions will be achieved using the validated CFD methods.

First results of the ongoing blind test phase are presented in [2]. A detailed analysis of the huge amount of available numerical data is an ongoing task. Within the post-test exercise each partner will apply improved grids and/or more sophisticated physical models (e.g. time accurate simulation of tail rotor instead of actuator disk model, more sophisticated turbulence models, etc.). This will allow the effects of different parameters in the synthesis to be assessed at the end of the CFD task and will form the basis for preparing guidelines for URANS methods for such configurations.

6. STATUS

The detailed specification of the model and the experimental as well as the CFD test matrix was finalized. Based on this specification the surface was defined with CAD tools and the CFD grids were generated. First computations were carried out and the results were collected in a common format in the blind test phase. A blind test report was prepared and results were published in [2] and [3].

All wind tunnel model components were prepared and shipped to DLR for final integration, i.e.

- the fuselage was prepared by Agusta and a new tail fin was manufactured;
- the main rotor was checked, new hot films were installed and new conditioning units were designed and procured by Onera,
- the fuselage hot films were installed by CU
- the tail rotor was integrated and tested at DLR
- the integration work of all other components is ongoing at DLR.

The project is making progress on the CFD side as well as on the experimental side. Therefore the whole GOAHEAD team is looking forward to the wind tunnel campaign in January 2008. The success of the project depends on the success of this campaign.

Acknowlegement

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