Advanced rotorcraft aeromechanics studies in the French-German SHANEL project

M. Costes[1], J. Raddatz[2], S. Borie[3], L. Sudre[3], A. D'Alascio[4], M. Embacher[5], P. Spiegel[2]

[1] Onera, 8 rue des Vertugadins, 92190 Meudon, France
[2] DLR, Lilienthalplatz 7, 38108 Braunschweig, Germany
[3] Eurocopter SaS, Marignane, France
[4] Eurocopter Deutschland GmbH, Munich, Germany
[5] IAG, Universität Stuttgart, Pfaffenwaldring 21, 70550 Stuttgart, Germany

ABSTRACT

The present paper gives an overview of the SHANEL research project (partly supported by the French DGAC and the German BMWA) which was started at the end of 2006 between the German and French Aerospace Research Centres DLR and ONERA, the University of Stuttgart and the two national helicopter manufacturers, Eurocopter and Eurocopter Germany. This program represents the continuation of the bi-national CHANCE project [1], involving the same partners. The objective of the project is to enhance and further validate the CFD tools: the structured multi-block *elsA* software of Onera and the unstructured TAU code of DLR, for computing the aerodynamics of the complete trimmed helicopter, accounting for the blade elasticity by coupling with blade dynamics and structural mechanics tools. A coupling activity between the FLOWer code of DLR and the HOST tool of Eurocopter is also completed to achieve the free flight trim of a complete helicopter. In this program particular attention is being given to wake conservation, to the modelling of elaborated complex shapes such as rotor hubs and consequently to interactional phenomena, with the global objective of improving the prediction of helicopter performance and noise. Rotorcraft noise prediction chains were rationalized, enhanced and compared. The validation activity of the flow solvers *elsA* and TAU is progressing from the CHANCE results and is now focussing on more complex problems such as the simulation of a rotating rotor head mounted on its fuselage [2], of a complete helicopter in steady mode through the use of actuator discs and engine boundary conditions, the time-accurate simulation of a complete trimmed helicopter in forward-flight, and the numerical simulation of Blade Vortex Interactions. All along the research program the updated versions of the CFD and acoustic codes are systematically delivered to industry. This approach, also followed during the former CHANCE project, is chosen to speed up the transfer of capabilities to industry and check early enough that the products meet the expectations for applicability in the industrial environment of Eurocopter.

1. INTRODUCTION

Simulation of rotorcraft aerodynamics is a complex problem which requires the use of advanced numerical techniques. The flow fields around a helicopter combine regions of very low speed, particularly in hover, with zones where compressibility effects are significant. Moreover, the flow is naturally unsteady due to the relative motion of the rotor blades with respect to the fuselage, and in forward flight transonic flows and shock waves occur at the tip of the advancing blade, as well as low-speed high angle-of-attack conditions and eventually dynamic stall, on the retreating one. In addition, the helicopter architecture features complex geometric shapes, such as the main rotor head or the landing skids, whose aerodynamic characteristics need to be predicted. Another challenging aspect typical of rotorcraft simulations is represented by the aerodynamic-dynamic coupling for the rotor blades due to the mechanical constraints at the hub. All these difficulties led DLR, Onera, IAG (University of Stuttgart), Eurocopter and Eurocopter Germany to launch together mid 1998 the CHANCE project, which lasted till end 2004 [1]. Its goals were the development of the basic CFD techniques necessary to compute the flow field around a complete helicopter, including the coupling with the HOST helicopter comprehensive analysis of Eurocopter. The CFD codes developed for this purpose were the *elsA* and FLOWer structured multiblock codes both implementing the chimera overset grids method.
However, it was clear from the beginning of CHANCE that having the technical capability to compute complete helicopter aerodynamics does not mean that such tools can be operational in the design office as a numerical

wind-tunnel to provide all data necessary in a new product development. One of the most difficult aspects in the numerical simulation of the helicopter aerodynamics is represented by the strong interaction between the wakes generated by some components impinging on others. For instance the rotor hub wake convected downstream can interact with the tail causing the “tail shake” phenomenon, if the frequency of the aerodynamic excitation gets close to the eigen-frequency of the tail. The tip-vortex shed behind a rotor blade interacts directly with the following ones, especially at low speed, generating the well known BVI noise, an important penalty for the use of rotorcraft in the civil environment. The main rotor wake also interacts with the fuselage, and during acceleration from hover to cruise flight it passes in the vicinity of the horizontal stabilizer, causing the pitch-up phenomenon. Unfortunately, correct wake evolution is particularly difficult to compute with the existing CFD techniques, penalized by numerical dissipation. Furthermore, the capability to represent in detail complex shapes, important for instance to accurately predict the drag thus the helicopter performance, required the further development of the numerical methods already developed in CHANCE. Finally, the aerodynamic-dynamic coupling developed in CHANCE was limited to isolated rotors; therefore it needed to be generalized to be able to simulate a complete trimmed helicopter in free flight.
These motivations were at the source of the new German-French SHANEL project. The purpose of this paper is to present the main lines of this on-going research program and to illustrate some typical results.

2. THE SHANEL PROJECT

2.1. Introduction

As previously mentioned the main purpose of the new SHANEL project is to enhance and extend the capabilities of the existing tools and integrate them in the industrial design offices of Eurocopter with the final goal of solving the difficult problems which arise during the development of a new helicopter. The partners involved in SHANEL are the same as those who cooperated in CHANCE: the research centres DLR, Onera, the IAG institute of the University of Stuttgart and the helicopter manufacturer Eurocopter both in France and Germany. SHANEL stands for Simulation of Helicopter Aerodynamics, Noise and Elasticity which can be considered the three pillars of the program. Indeed the major points of investigation to be considered are improved aerodynamic simulation of helicopters, including realistic geometric details and wake effects in order to better predict helicopter performance and BVI, through a better representation of the rotorcraft dynamics. The research started in the second half of 2006 and is expected to last about five years.

2.2. Aerodynamic tools development

One important objective of SHANEL is to get the capability to simulate the complex geometries which are present on actual helicopters. Considering the constraints imposed by efficiency and user-friendliness, the whole process (grid generation, pre-processing, computation and data post-processing) shall be made affordable in a design office environment. For this purpose two complementary strategies are considered, based either on structured or on hybrid grid techniques.
The structured mesh approach is developed in *elsA*, the CFD method used at Onera for multi aerodynamic applications [3]. For current applications, standard second-order finite-volume space discretization for multi-block structured curvilinear grids and time implicit iterative methods are used for solving the Euler/RANS equations. Furthermore, for helicopter applications, the chimera overset grids technique in an ALE formulation of the equations is considered to describe the multiple bodies in relative motion. Cartesian grids are generally used in the background mesh, which can be automatically generated and adapted to the solution. The developments performed in SHANEL in this frame mainly concern the improvement of the chimera overset grids technique to deal with complex geometries, in order to get it more automatic and efficient. Consequently part of the effort is made on the minimization of the requirements for overlapping, e.g. by developing implicit interpolation techniques, and also to have the maximum number of operations of the chimera method automatically performed by the code in order to improve user-friendliness. Additional work was devoted to the improvement of the method on parallel architectures, particularly when considering unsteady computations with moving bodies.

A second structured solver in use at IAG, Eurocopter Germany and DLR is the FLOWer code. FLOWer [4] is a portable software system particularly designed for industrial aeronautical applications, which can be run on a large variety of computers with high efficiency. The domain of application is similar to that of *elsA* although FLOWer has not been adapted for hypersonic flows. FLOWer was developed by DLR and solves the compressible Euler/Navier-Stokes equations for structured multi-block meshes. The numeric is based on a Finite Volume method, providing a variety of spatial discretisation schemes. The RANS equations are integrated by a 5-stage hybrid Runge-Kutta scheme, which is accelerated by implicit residual smoothing and multigrid. For unsteady applications the dual time-stepping technique is used. A specific implicit treatment has been integrated for the robust time integration of multi-equation turbulence models. The development of a fully general chimera technique for moving bodies was achieved during the run of the CHANCE project. Although this flow solver is no longer enhanced by DLR within SHANEL, the periodic or loose coupling procedure with the HOST code developed within CHANCE for the isolated rotor is being extended by IAG to other helicopter components to achieve the free flight trim within CFD.

The other alternative, which had not been considered within CHANCE, concerns the development of unstructured methods for helicopter applications. In SHANEL, they are based on the hybrid TAU solver of DLR, which is already operational for fixed wing configurations. The Navier-Stokes code TAU [5] makes use of the advantages of unstructured grids. The mesh may consist of a combination of prismatic, pyramidal, tetrahedral and hexahedral cells and therefore combines the advantages of regular grids for the accurate resolution of viscous shear layers in the vicinity of walls with the flexibility of grid generation techniques for unstructured meshes. The numeric is very similar to the one implemented in FLOWer. In order to efficiently resolve detailed flow features, a grid adaptation algorithm for hybrid meshes based on local grid refinement and wall-normal mesh movement in semi-structured near-wall layers was implemented. This algorithm has been extended to allow also for de-refinement of earlier refined elements thus enabling the code to be used for time-accurate adaptation in unsteady flows.

With respect to unsteady calculations, the TAU-code has been extended to simulate a rigid body in arbitrary motion and to allow grid deformation. One of the important features of the TAU-Code is its high efficiency on parallel computers. The code is further optimized for cache processors through specific edge colouring procedures. The features necessary to compute rotorcraft architectures are being developed, such as the simple time-averaged actuator disc approach, already available in *elsA* and FLOWer [6] from the CHANCE project. The actuator disc boundary condition transforms the unsteady induced flow generated by the rotors to quasi-steady ones still capturing, in average, the effect of the rotors on the fuselage. The general unsteady rotor application is also being considered, using a similar overset grids technique as the one used for structured meshes.

A second important aspect of the aerodynamic part of SHANEL is the development of efficient wake conservation techniques in order to be capable to compute blade-vortex interactions or the effect of the main rotor wake on the tail surfaces of the helicopter. These developments include higher-order schemes and automatic adaptation of unstructured grids for TAU or of Cartesian background grids for *elsA*. ONERA is also working on vorticity confinement. Different types of higher-order schemes are being studied (compact, non-compact), and the combined use of the various techniques will also be investigated.

2.3. Aeroelastic coupling

The simulation of elastic blades is an important aspect of helicopter aerodynamics: it has a large effect on the blade loads and consequently on the shed vorticity and the vortex trajectories. Additionally, it is important that these couplings be capable to deal with free flight trim conditions. This is why a significant effort in SHANEL is also being put on the coupling between CFD, comprehensive analyses and structural dynamic simulations.

A part of the activity concerns the generalisation of the coupling between CFD and the comprehensive helicopter aeromechanics code HOST in order to make it more versatile. One important item concerns the trim of a complete helicopter in free flight conditions, which requires to account for a larger number of degrees of freedom in the coupling procedure. Related activities also aim at extending the coupling to a wider range of possibilities, e.g. by including the fuselage or rear surfaces loads in the coupling

loop. Additionally, the CFD – HOST coupling is needed for steady flow computations around a helicopter where the rotors are represented by actuator discs.
Another important subject dealt with within SHANEL is the improved blade structural dynamics. For the purpose three strategies have been selected: improve the beam model in HOST, couple CFD and HOST with the SIMPACK multi-body dynamics [7], and couple CFD and HOST with a 3D finite-element representation of the blade. The final goal is to improve the aerodynamics/dynamics, and thus to be capable to accurately predict the rotor performance and loads for highly non-rectangular blade shapes.

2.4. Aerocoustic simulations

In SHANEL, DLR worked on aeroacoustic computation chains in order to make available and compare versatile chains. The objective is to improve the prediction capabilities, particularly concerning BVI and flyover noise starting either from simulated or from measured noise directivities. The purely numerical noise simulation chain involves the APSIM code [8], which addresses the porous and the impermeable surface formulations of the Ffowcs-Williams and Hawkings (FW-H) equation. Figure 1 illustrates the various available aero-acoustic computation chains: each continuous arrow path from top to bottom right.

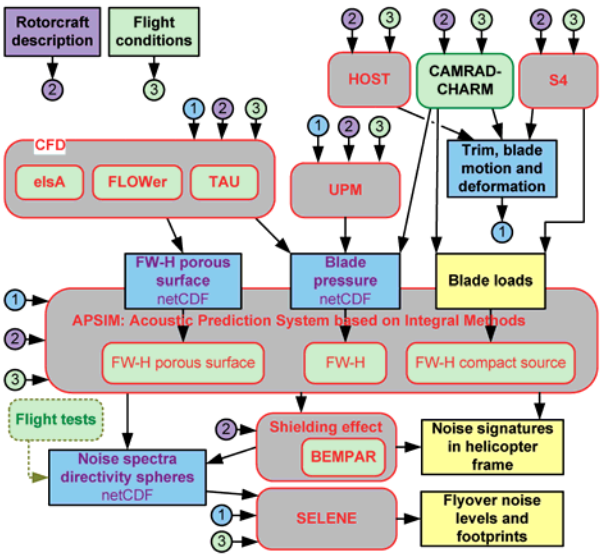


Figure 1: Possible tool (rounded boxes) linking into rotorcraft aeroacoustic prediction chains.

Aligned with the constant harmonization effort on data and paradigms, towards efficient tool inter-changeability, comparisons, validations and coupling, DLR harmonized the files exchanged between the codes, using variables and coordinate systems of the Friendcopter dictionary [9] and the netCDF format. The upstream part of Figure 1 simulation chains comprises HOST and various aerodynamic tools (elsA, FLOWer, TAU, CAMRAD-CHARM, S4 [10] and UPM [11]).
The output of APSIM is isolated-rotor noise on microphones moving with the helicopter. Fuselage shielding effects on rotor noise have been investigated within SHANEL by coupling APSIM with the DLR in-house BEM frequency domain tool BEMPAR [12].
The SELENE code [13] simulates the ground noise of arbitrary flights starting from noise spectra directivity spheres either from APSIM or resulting from flight tests. SELENE is coupled with HOST and simulates manoeuvres and various propagation effects (spherical spreading, Doppler Effect, absorption, ground reflection…). SELENE has been intensively used for noise abatement procedure optimization [9], [13].

2.5. Validation

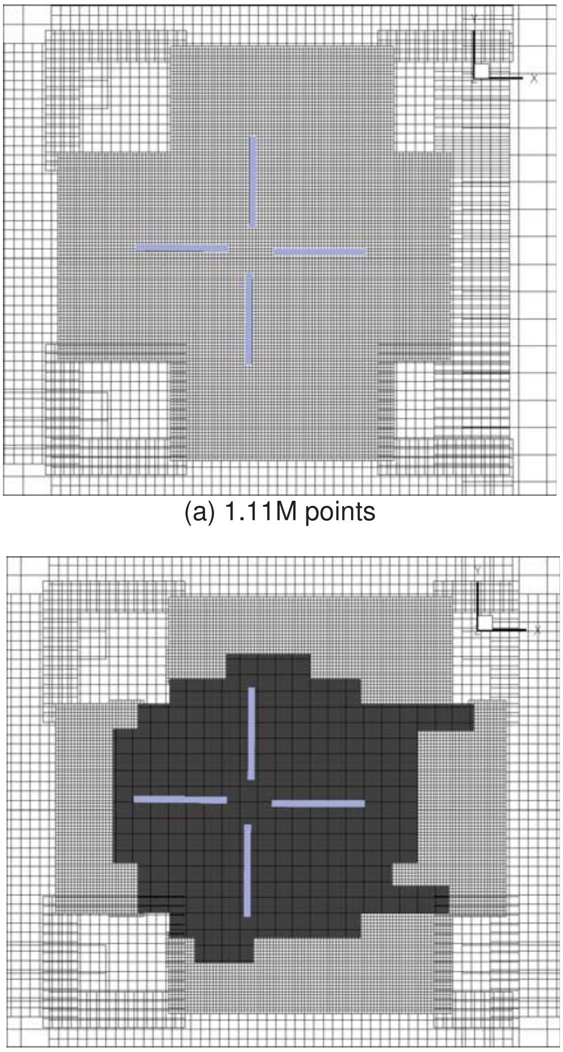
Another crucial aspect of the SHANEL project is the validation of the enhanced or newly developed tools for simulating the flow around helicopter components (e.g. isolated fuselage, rotor or rotor head) as well as around the complete helicopter in relevant flight conditions. The tools are validated about complex geometries, quite close to the real ones, and also using more basic research-oriented configurations. Industrial validation on complex geometries aims at quantifying the accuracy of numerical methodology on typical problems treated in industry, whereas validation on simpler geometries, typically dealt with by research centres, aims at a deeper verification of the accuracy of the tested methodology. A few examples of both types of validations are given in the following chapter.

3. TYPICAL RESULTS

3.1. Introduction

Some typical examples of what was already achieved in SHANEL are presented here. They deal with blade vortex simulation and noise prediction, fluid structure coupling, free flight of a complete trimmed helicopter, quasi-steady complete helicopter and rotor head analysis.

3.2. BVI simulation



(a) 1.11M points

(b) 5.93M points

Figure 2: Automatic background grid refinement process for BVI: view of the initial and final meshes

The HART baseline test case is considered here for testing the automatic background mesh adaptation and the use of higher-order schemes to capture the transport of vorticity in *elsA*. The details of these computations were already given by Renaud et al in [14], and just a few important points are recalled here. In order to test the code capability to convect rotor wakes independently of other developments, a rigid blade assumption was done in these computations, which is a reasonable approximation as shown from previous studies, the BVI being very little affected by the blade deformation for this particular case without HHC [15]. An example of automatic mesh adaptation is presented here, using the Cassiopée module which is especially devoted to Cartesian grids in *elsA*, and includes higher-order schemes as well. The background mesh is automatically adapted to the solution every quarter of revolution for this 4-bladed rotor, using the q-criterion as refinement indicator and a user-prescribed grow factor at each new mesh generation (Figure 2). The minimum grid size used corresponds to 15% chord, and the mesh adaptation was stopped once the full rotor disc solution had been adapted, thus allowing to follow the vortices from their emission to their interaction with the blade. A view of the computed blade loads is presented in Figure 3 for the azimuthal sectors where BVI occurs on the advancing and the retreating blade sides. Second-order and third-order accurate results for the Cartesian background mesh are plotted, using either a scalar or a matrix version of the Jameson artificial viscosity. The influence of the numerical scheme on the capture of BVI is noticeable, and illustrates both the effect of dissipation and dispersion errors on the convection of vortices. In general, the matrix method, which is less dissipative, allows to better capture the load gradients due to BVI, while 2^{nd} and 3^{rd} order discretisation lead to similar BVI predictions. This is clear for the advancing blade side, but not quite true for the retreating blade where the 2^{nd}-order scheme with matrix dissipation tends to smooth out the interactions. As a matter of fact, both 2^{nd} and 3^{rd} order schemes have the same leading dissipative term in the truncation error, which justifies their similar behaviour in capturing the interactions, but the dispersion error of the 3^{rd} order scheme is smaller so that the vortex transport is better simulated. Indeed, the 3^{rd} order scheme with matrix dissipation provides the best results and captures correctly the advancing and retreating blade interactions.

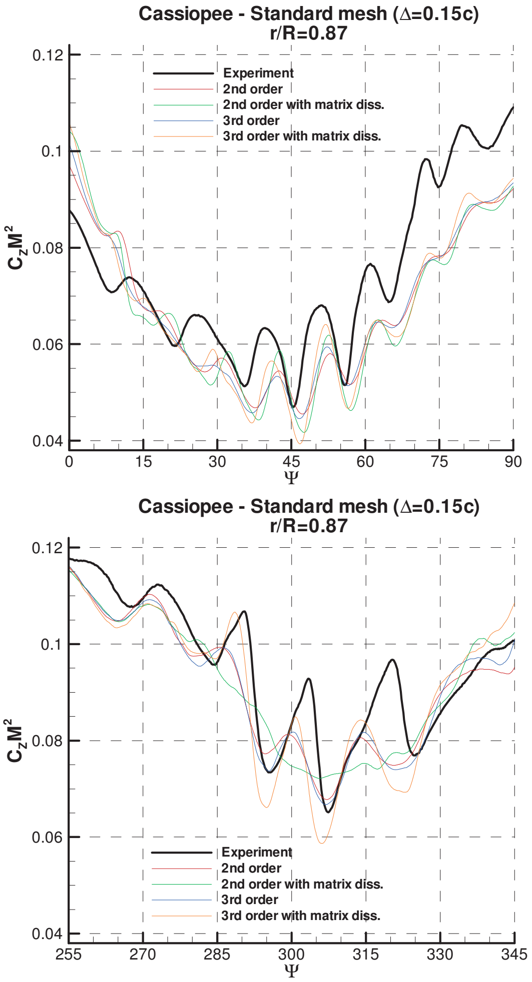


Figure 3: Computed BVI events on the advancing and the retreating blade sides

3.3. BVI noise prediction

Hereafter, some BVI noise prediction examples are mentioned, resulting from the fastest tools to the most high-fidelity ones.

First, the validity status of S4-APSIM computations is shown in [10] on HART cases. Second, the UPM-APSIM-SELENE main rotor computation of a BO105 descent flight (HeliNovi Case at Ct = 0.00511), is compared to a SELENE computation using a flight test data base [16]. This second SELENE simulation results from complex interpolation of measured data to match the actually simulated condition. UPM was also used for the rotor trim. In Figure 4 the noise level evaluated for certification microphones is shown for both solutions. The comparison is satisfying knowing that here only the main rotor noise is simulated.

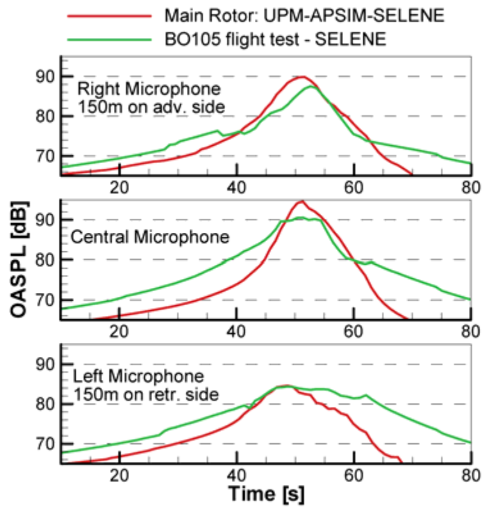


Figure 4: Fully simulated main rotor (red) and flight test interpolated (green) noise level time histories for a BO105 noise certification descent.

Finally, starting from the *elsA* computed blade pressure provided by Onera to DLR for the HART1 Baseline Case computation of [14], corresponding to the third-order results presented above, the near field noise footprint has been computed with APSIM. The experiment-simulation comparison is shown in Figure 5 for the noise level corresponding to the 6^{th} to 40^{th} blade passage frequency. The simulated directivity pattern is correct, except on the top left figure corner, due to the fuselage shielding effect, not accounted for here. The maximum noise levels are underestimated by only 2 dB, which is a very good result for CFD simulated strong BVI.

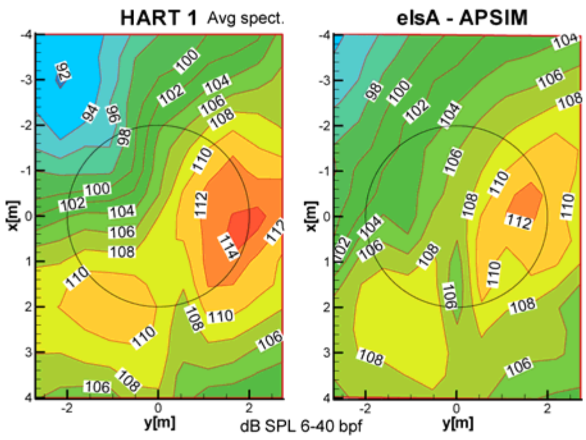


Figure 5: Measured and simulated noise levels for the HART1 Baseline Case.

3.4. Fluid-structure coupling

A new topic undertaken within SHANEL in fluid-structure coupling is the introduction of a CSM model to replace the blade dynamics model of HOST in the HOST-*elsA* coupling. Details of this work performed by Ortun et al were presented in [17], and only a few results from this work are shown here. The CSM method used is the MSC-Marc commercial software [18], and several levels of approximations are being tested for the structure, starting from a standard beam model up to the full 3D blade discretisation. A schematic of the coupling procedure is shown in Figure 6. A modular approach was chosen, where each component (HOST, CFD, CSM) exchanges with the others through a server written in Python language. Each code is running in a time marching approach, with the synchronization of the data exchange performed through the server which makes the data available to the components' requests. All exchanges are based on the CGNS standard format for the fluid quantities with extensions to structural data. In order to trim the rotor towards desired conditions, an active trim option was developed in HOST, based on the time-history of the various trim control and objectives, which continuously corrects the current control parameters in order to reach the trim objectives. An example of time evolution of the collective pitch angle for the 7A rotor is plotted in Figure 7, together with the rotor lift evolution, showing how the auto-trim adapts the input controls in order to reach the requested mean value for the rotor lift. A comparison of the coupled *elsA*/MSC-Marc/HOST results and of the *elsA*/HOST results for a beam representation of the 7A blade in MSC-Marc (Figure 8) is presented in Figure 9, showing that the external blade structure model of MSC-Marc is correctly coupled to HOST and *elsA*.

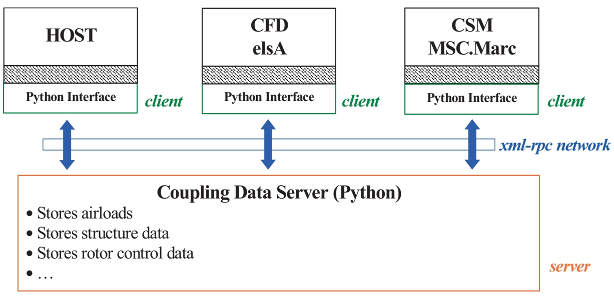


Figure 6: Schematic of the HOST-CFD-CSM coupling

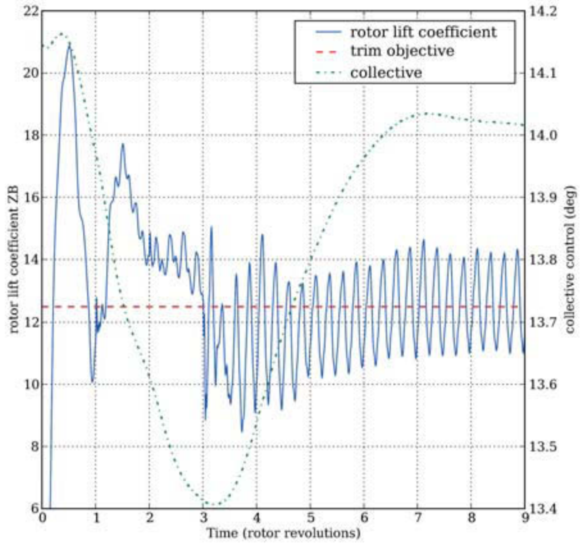


Figure 7: Evolution of collective pitch and lift coefficient for the 7A rotor at high-speed forward flight

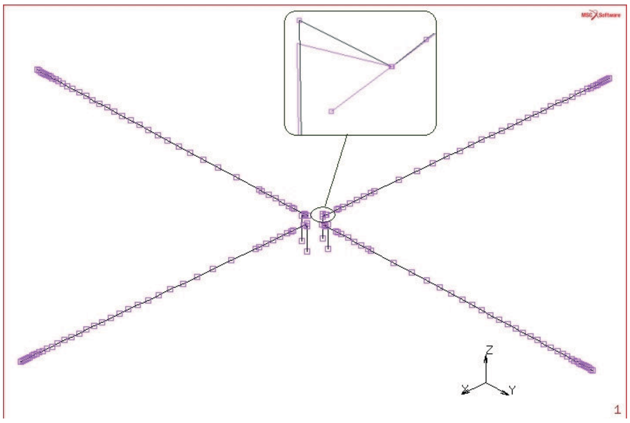


Figure 8: Finite-element modelling of the 7A rotor as beams with MSC-Marc

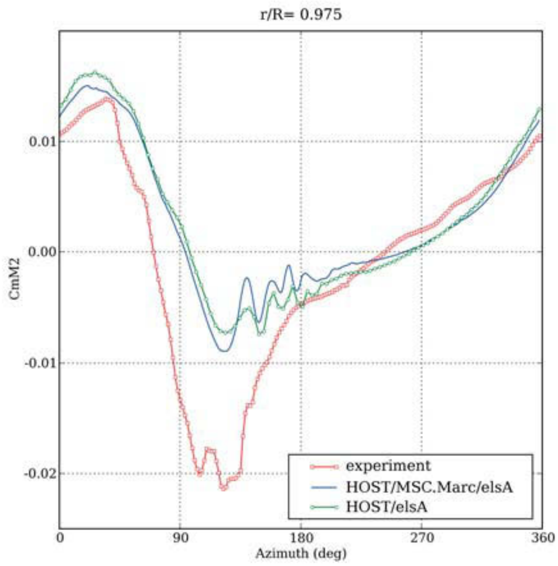


Figure 9: Comparison of HOST/MSC-Marc/elsA and HOST/elsA computed pitching moment evolution at r/R=0.975 for the 7A rotor

3.5. Trim at free flight conditions

During the CHANCE project, weak fluid-structure coupling with simultaneous trimming of three rotor parameters was applied to isolated rotor simulations. Typically, trimming consisted in meeting realistic objectives for rotor average thrust, rolling and pitching moment, hence the trim was geared towards the reproduction of wind tunnel experiments with a-priori known trim conditions, or towards comparative studies. Applying this simulation environment to rotors in free flight condition, however, calls for an expansion of the trim procedure to establish load equilibrium for the helicopter in a chosen steady flight condition. In SHANEL two further degrees of freedom are introduced in order to additionally adjust the average horizontal forces generated by the rotor. Such extension of the set of trim objectives is enabled by trimming the rotor mast orientation, or equivalently the helicopter attitude, and is currently tested at IAG.
In contrast to the three-component “wind tunnel trim”, the free flight trim features non-constant and unknown trim objectives for the rotor loads. Requiring the equilibrium state for the helicopter entails, from the main rotor’s perspective, the necessity to balance fuselage drag and moments. These vary in a non-linear manner with the trimmed helicopter attitude during the iterative solution procedure.

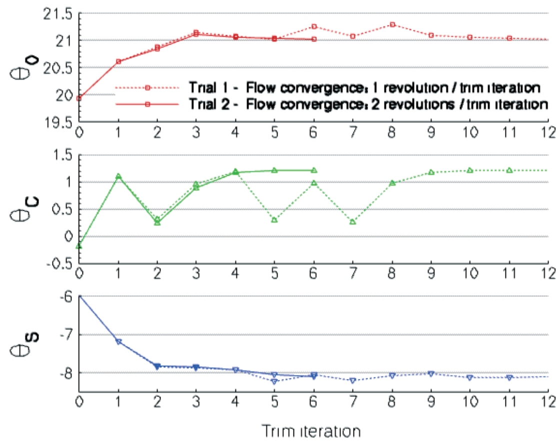


Figure 10: Free flight trim: Development of main rotor control angles θ_0 (collective) and θ_C, θ_S (cyclic).

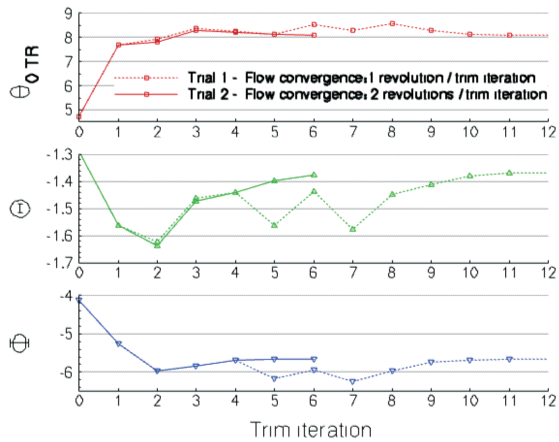


Figure 11: Free flight trim: Development of trim parameters θ_{0TR} (tail rotor collective) and Θ, Φ (fuselage pitch and roll attitude).

For the time being, the flow field is solved only for the isolated main rotor, whereas fuselage loads are estimated from tabulated aerodynamic data. The CFD method used is the structured DLR RANS-code FLOWer. Fluid-structure coupling with the aeromechanics tool HOST is done in a weak fashion. Thereby, the exchange of periodic coefficients is accompanied by the update of control and fuselage attitude angles, with the trim jacobian established from HOST internal aerodynamics.
Thus CFD loads replace HOST loads at the main rotor, while fuselage forces and moments for the present are treated solely by the simplified aerodynamics and analytic rotor-fuselage interaction models of HOST. Similarly, tail rotor thrust prediction remains a task of HOST in order to avoid difficulties arising from non-harmonizing rotor frequencies.

Figures 10 and 11 show the development of the trim parameters in two tests of free flight trimming towards a cruise flight condition at 135kts. A flight mechanics model for the EC145 helicopter is used in HOST. Convergence of control angles θ_0, θ_C, θ_S, θ_{0TR} and helicopter attitude Θ, Φ is achieved in the two trials differing in CFD effort, though within a varying number of 6 or 12 trim iterations depending on the occurrence of interim oscillations.

These trials, coupling CFD loads for an isolated rotor, form one step towards flow simulations of a complete helicopter configuration in free flight trim. Further work in the first instance encompasses the development of a generalized coupling interface between FLOWer and HOST, which allows to extend the aeroelastic coupling function at the isolated rotor towards other helicopter components, notably the fuselage and tail rotor.

Recently, CFD simulations of the EC145 have been conducted at IAG (see Figure 12 and also [19]). The aerodynamic loads calculated by this setup will be transferred to HOST within the weak coupling framework. Thus the HOST internal aerodynamics will entirely be replaced by CFD solutions, while at the same time free flight trimming without a-priori knowledge about loads and attitude is possible, which is considered valuable in the prediction of performance and loads during the design phase.

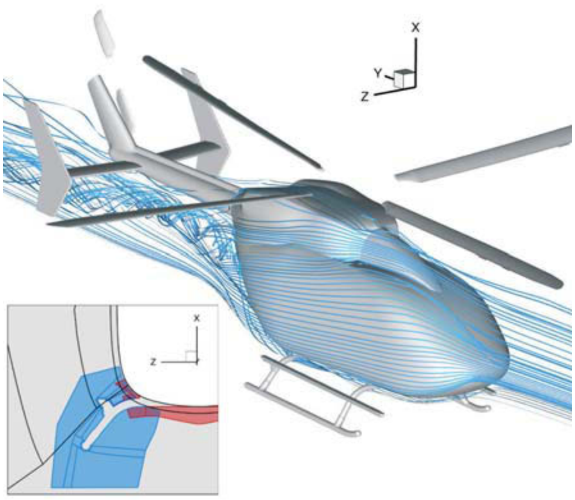


Figure 12: FLOWer simulation of EC145 helicopter, near-body streamlines on starboard half model. Insert: chimera blocks at skid attachment.

3.6. Quasi steady approach

During the CHANCE program actuator disc and engine boundary conditions were developed in the multi-block structured URANS solver FLOWer, and validated. For more details refer to [6]. These boundary conditions have been adapted within SHANEL for the unstructured code TAU and validated for helicopter applications. Through the actuator disc boundary condition the loads on the rotor are prescribed to CFD, while the influence of the rotor downwash on the fuselage is inherently computed by the RANS flow solver. With the engine boundary condition the mass flow is given to the “inlet surface” whereas the pressure ratio, the temperature ratio and the mass flow are prescribed to the exhaust “outlet surface”. In this way the effect of the engine inlet and exhaust on the flow around the engine cowling is modelled. The main advantage of an unstructured CFD approach, with respect to a structured one, lays in the level of geometrical complexity which the mesh generator is able to model and the solver to simulate. Normally a smooth clean surface of a helicopter cabin can be quite straightforward modelled by a multi-block mesh generator such as ICEM-Hexa of ANSYS. Whenever components such as the landing gear or a detailed description of the windows are needed, for instance for a more accurate prediction of the fuselage drag, the use of an unstructured mesh approach might represent an advantage. The four modelling levels of complexity for the EC135 helicopter shown in Figure 13,

- the *first* showing the loft of the isolated fuselage including its tail with empennages but with closed Fenestron® duct,
- the *second* including the landing gear,
- the *third* adding on top the engine boundary conditions with the exhaust diffuser and
- the *fourth* completing the third with the main rotor modelled as an actuator disc,

can still be modelled by using a structured multi-block approach, however with increasing manpower with respect to the unstructured one.

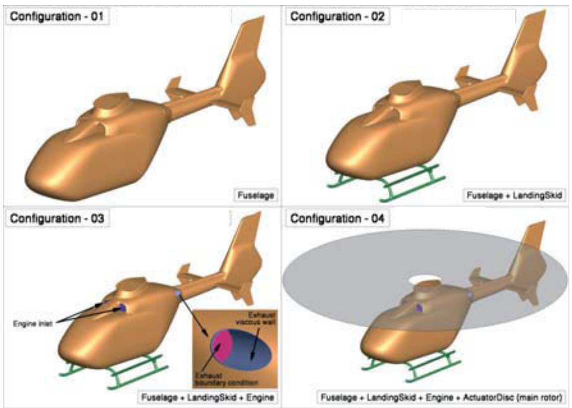


Figure 13: Increasing level of complexity in modelling the EC135 fuselage

If the level of geometrical detail increases further, as shown in Figure 14, where the Fenestron® duct including stator blades and drive shaft fairing, and the engine deck are modelled, even though actuator discs replace main and Fenestron® rotors, the use of the structured approach is no longer affordable as far as mesh generation is concerned.

Figure 14: CATIA model of the EC135 isolated fuselage including Fenestron® and engine deck

Figure 15 depicts the unstructured mesh as generated by CENTAUR (26 million nodes) on the helicopter middle plane. The top view shows the mesh inside the engine deck, whereas the bottom one the mesh around the helicopter fuselage. Here the actuator discs modelling the main and the Fenestron® rotors are also visible.

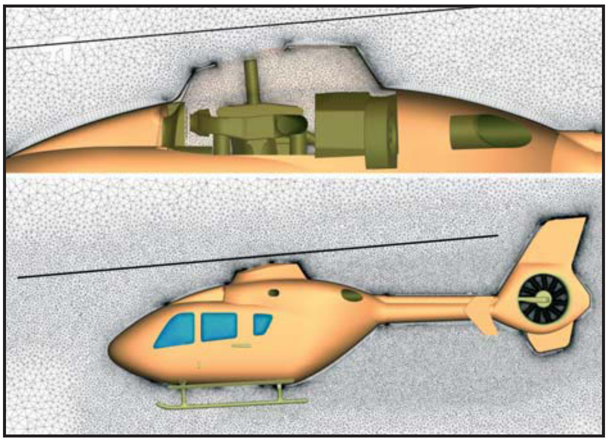


Figure 15: CENTAUR unstructured mesh about the EC135 helicopter including Fenestron® and upper deck with the rotors as actuator discs.

The objective of this complex computation is to have a better understanding of the external/internal flow around the cabin and inside the engine deck. More precisely to compute the mass flow ratio between the first inlet, placed upstream of the gearbox, and the circular mast opening on top of the rotor mast fairing, the so called "surfboard". Another important goal is the prediction of the drag produced by the air flowing inside the engine deck. In this simulation the inlet engine boundary condition will be applied on a section placed just upstream of the compressor and the outlet condition on a section short downstream of the second turbine. In this way the fidelity of the prescribed conditions is much higher. In fact the pressure losses due to the presence of the gearbox, support struts, engine cooler, air inlet duct do not need to be evaluated but will be inherently computed by CFD. Presently the four configurations of Figure 13 have been computed with the TAU code, the first three also with FLOWer, whereas a TAU computation of the last most complex one is being set-up. Figure 16 shows the pressure coefficient distribution on the surface and the stream lines in the field with (top view) and without (bottom view) the main rotor modelled as actuator disc in cruise flight at 5000 feet of altitude as computed by TAU about the fourth EC135 configuration of Figure 13. The comparison shows that the main rotor downwash in cruise has an effect only on the flow behind the mast fairing and around the vertical fin. The stream lines around the fuselage cabin are hardly modified.

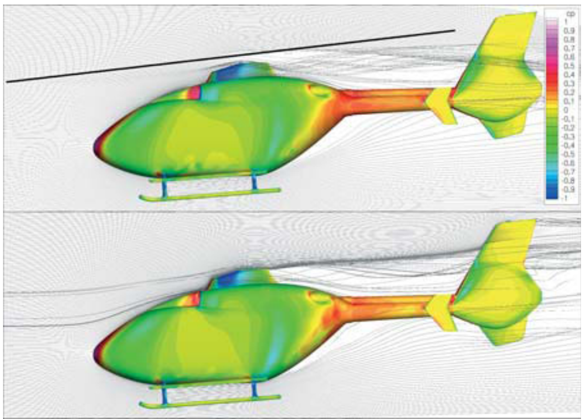


Figure 16: Pressure coefficient distribution on the EC135 surface and stream lines in the field with (top view) and without (bottom view) the main rotor modelled as actuator disc (v=140kt, 5000ft, TAU solution).

3.7. Rotor head simulation

An important task within the SHANEL program is the validation of the *elsA* and TAU/FLOWer flow solvers for the simulation of rotor head aerodynamics, carried out mainly by Eurocopter both in France and Germany. Especially the unstructured approach allows simulating the rotor head including all details. In order to demonstrate the abilities of unstructured grid generation, a conventional rotor with 5 blade stubs, hub cap, swash plate, link rods and further particulars has been selected (Figure 17). Grid generation was done with the software CENTAUR. The grid of simplified rotor contains 7.3 million points, while for the detailed geometry nearly 12 million points are used. The overall time for the generation of both meshes including preparation and cleaning of the CAD-data took about 3 weeks.

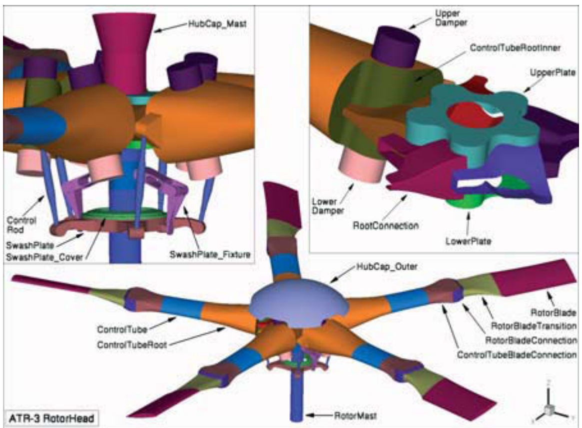


Figure 17: CAD geometry of detailed rotor head.

The computations for both simplified and detailed rotor head configurations have been performed with the DLR TAU code. The comparison of the global forces shows only differences for the drag. Lift, side force and moments are nearly identical. A flow visualization of the complex wake structure of the detailed rotor head is presented in Figure 18.

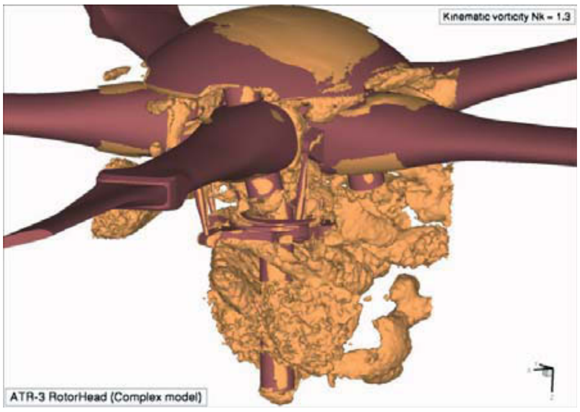


Figure 18: Instantaneous wake structure represented by constant kinematic vorticity surfaces on the detailed hub.

An important aspect considered in SHANEL is the prediction of the rotor head aerodynamic characteristics and the interaction generated by its wake, particularly with the helicopter tail. For this purpose a wind tunnel campaign about the EC145 fuselage with a rotating and fixed rotor head was subcontracted to the University of Munich. Computations have been carried out at Eurocopter Germany by using both the structured flow solver FLOWer and the unstructured one TAU in steady (fixed rotor head) and unsteady (rotating head) modes. A sample of the results is shown in Figure 19. Here the pressure coefficient is shown on the engine cowling and on the rotor head. The solution reaches a periodic state after 4 revolutions. For more details please refer to [2].

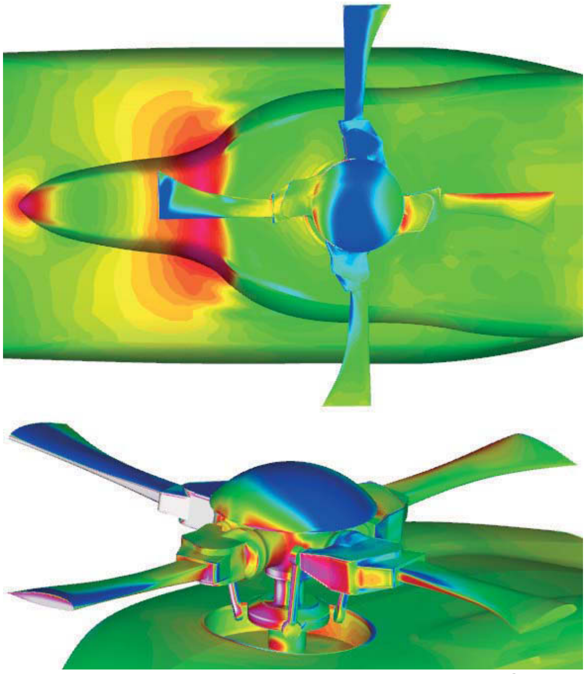


Figure 19: Pressure distribution on the EC145 engine cowling with rotating rotor head (model scale 1:73, v=40m/s, FLOWer solution).

A specific wind tunnel data base concerning rotor hub drag breakdown was also performed in Eurocopter Marignane. This wind tunnel test campaign showed that rotation of the hub has almost no effect on the global hub drag. Additionally, elsA structured multi-block computations were carried out, taking benefit of the chimera assembly for simplifying the structured mesh generation, and allowing also future computations with cyclic piloting of the blade sleeves to be carried out with the same mesh (Figure 20). Two sets of computations were completed, similarly to the EC145 case, either with fixed or with rotating rotor hub. The fixed hub computations showed good agreement with test results in terms of hub drag values. The rotating hub computations showed that even if the global drag is equivalent to the fixed hub result, the drag breakdown was different. For more details, please refer to [20]. An example of vorticity distribution around the non-rotating rotor hub is plotted in Figure 21.

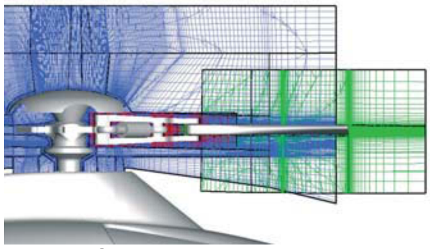


Figure 20: Chimera assembly example for the rotor hub computation.

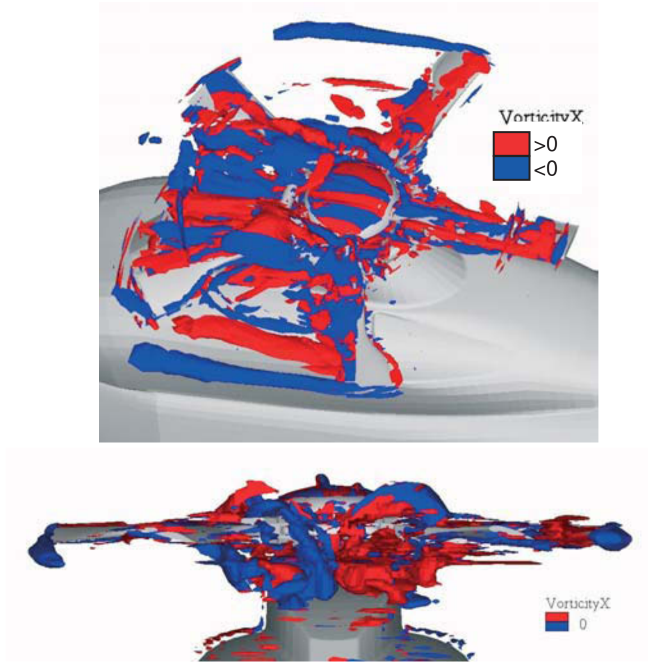


Figure 21: Vorticity distribution around the fixed complete rotor head (elsA computation).

CONCLUSIONS

An overview of the on-going German-French SHANEL project was presented in this paper, including its motivations and content, as well as typical examples of results achieved to date. This activity constitutes a natural follow-on of the CHANCE project which was already performed by the same partners (DLR, Eurocopter, Eurocopter Deutschland, Onera, University of Stuttgart) between 1998 and 2004. Its ambitious goal is to end-up with validated CFD tools applicable in Eurocopter design office to solve the aero-mechanic and aero-acoustic problems which arise during a helicopter development. This implies that the aerodynamic, dynamic and acoustic simulation tools are able to deal with realistic geometry details and provide accurate results. Moreover focus was put on efficiency, reliability, robustness and user-friendliness of the methods. To achieve this goal both multi-block structured and unstructured unsteady Reynolds-Averaged Navier-Stokes solvers are being enhanced for helicopter applications, together with the chimera overset grids method for representing the relative bodies' motion. Special emphasis is put on wake conservation capability, *i.e.* mesh refinement, high order methods, wake confinement, of the methods in order to efficiently capture the various wake systems which develop and play an important role in helicopter aero-mechanics and acoustics. Another important aspect of SHANEL is the coupling between the aerodynamic flow solvers, the HOST helicopter comprehensive tool, different levels of aeroelastic models and the acoustic codes. The results achieved up to now prove that the chosen strategies are capable to meet the initial objectives of the project.

ACKNOWLEDGEMENTS

The authors would like to thank the German ministry of Economy and Labour (BMWA) for its funding in the framework of SHANEL-L (grant 20A0603C) and the French DGAC (Direction Générale de l'Aviation Civile) for funding the French part of SHANEL, under the technical monitoring of DGA. Furthermore, they also want to acknowledge all members of the SHANEL French-German team.

REFERENCES

[1] M. Costes, K. Pahlke, A. D'Alascio, C. Castellin, A. Altmikus, "Overview of results obtained during the 6-year French-German CHANCE project", AHS 61st Annual Forum, Grapevine, June 1-3, 2005.

[2] F. Le Chuiton, T. Kneisch, S. Schneider and Ph. Krämer "Industrial validation of numerical aerodynamics about rotor heads: towards a design optimisation at EUROCOPTER", Proceedings of the 35th European Rotorcraft Forum, Hamburg, Germany, September 22nd-25th, 2009.

[3] M. Gazaix, A. Jolles, M. Lazareff, "The *elsA* object-oriented computational tool for industrial application", 23rd ICAS conference, September 2002

[4] Raddatz, J. and Fassbender, J., "*Block Structured Navier-Stokes Solver FLOWe*r", MEGAFLOW - Numerical Flow Simulation for Aircraft Design, edited by N. Kroll and J. Fassbender, Vol. 89 of Notes on Numerical Fluid Mechanics and Multidisciplinary Design, Springer, 2005, pp. 27-44.

[5] Gerhold, T., "*Overview of the Hybrid RANS Code TAU"*, MEGAFLOW - Numerical Flow Simulation for Aircraft Design, edited by N. Kroll and J. Fassbender, Vol. 89 of Notes on Numerical Fluid Mechanics and Multidisciplinary Design, Springer, 2005, pp. 81-92

[6] Le Chuiton, F.: "Quasi-Steady Simulation of a Complete EC-145 Helicopter: Fuselage + Main/Tail Actuator Discs + Engines". Proceedings of the 31st European Rotorcraft Forum, Florence, Italy, September 13th-15th, 2005.

[7] Arnold, Jürgen: "Using Multibody Dynamics for the Simulation of Flexible Rotor Blades – Getting the Mechanical Coupling Right ?", Proceedings of the 35th Rotorcraft Forum , Hamburg, Germany, September 22nd-25th, 2009.

[8] J. Yin, J. Delfs, "Improvement of DLR Rotor Aeroacoustic Code (APSIM) and its Validation with Analytic Solution", 29th European Rotorcraft Forum, Friedrichshafen (de), September 16 th -18th, 2003.

[9] P. Spiegel, F. Guntzer, A. Le Duc, H. Buchholz, "Aeroacoustic Flight Test Data Analysis and Guidelinesfor Noise-Abatement-Procedure Design and Piloting", 34th European Rotorcraft Forum, Liverpool, UK, September 16th – 19th, 2008 and AHS Annual Forum, Grapevine, TX, USA, May 2009.

[10] B. van der Wall, J. Yin, "Simulation of Active Rotor Control by Comprehensive Rotor Code with Prescribed Wake Using HART II Data", 65th Annual Forum and Technology Display of the American Helicopter Society International, Grapevine, Texas, USA, May 27 th -29 th, 2009.

[11] J. Yin, and S. Ahmed, "Helicopter main-rotor/ tail-rotor interaction", Journal of the American helicopter society, Vol. 45, No. 4, pp293-302, October 2000.

[12] K.-S. Rossignol, M. Lummer, J. Delfs, "Validation of DLR's sound shielding prediction tool using a novel sound source",

AIAA-2009-3329, 15th AIAA/CEAS Aeroacoustics Conference, Miami, Florida, USA, May 11th-13th, 2009.

[13] F. Guntzer, P. Spiegel, M. Lummer, "Genetic optimizations of EC-135 noise abatement flight procedures using an aeroacoustic database", 35th Rotorcraft Forum , Hamburg, Germany, September 22nd-25th, 2009.

[14] T. Renaud, G. Perez, C. Benoit, G. Jeanfaivre, S. Péron, "Blade vortex interaction capture by CFD", 34th European Rotorcraft Forum, Liverpool, September 16-18, 2008.

[15] N. Jobard, "Calculs aéroélastiques pour l'aéroacoustique des rotors d'hélicoptère en vol d'avancement", PhD Thesis, Paris 6 University, 1997 (in French).

[16] P. Spiegel, H. Buchholz, M. Pott-Pollenske, "Highly Instrumented BO105 and EC135-FHS Aeroacoustic Flight Tests including Maneuver Flights", American Helicopter Society 61st Annual Forum, Grapevine, TX, June 1st-3rd, 2005.

[17] B. Ortun, D. Petot, K.-V. Truong, R. Ohayon, "Towards a new generation of rotorcraft comprehensive analysis; coupling with CSM and CFD", 34th European Rotorcraft Forum, Liverpool, September 16-18, 2008.

[18] MSC Software Corporation, "MSC.Marc Volume B: Element Library", 2007.

[19] M. Dietz and O. Dieterich: "Towards Increased Industrial Application of Rotor Aeroelastic CFD",Proceedings of the 35th European Rotorcraft Forum, Hamburg, Germany, September 22nd-25th, 2009.

[20] Borie, S.; Mosca, J.; Sudre, L.; Benoit, C.; Péron, S.: "Influence of Rotor Wakes On Helicopter Aerodynamic Behaviour". Proceedings of the 35th European Rotorcraft Forum, Hamburg, Germany, September 22nd-25th, 2009.