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National Aerospace Laboratory NLR

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A. Pagano[1], M.H.L. Hounjet, J.V. Miller[2], M. Gracey[3] and A. Pisoni[4]

1 CIRA
2 DERA
3 GKN Westland
4 AGUSTA

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ROSAA: A EUROPEAN SIMULATION SYSTEM FOR THE MULTIDISCIPLINARY NUMERICAL PREDICTION OF ROTOR PHENOMENA

Antonio Pagano[⋆], **Michel Hounjet**[†], **Judith Miller**[‡], **Mark Gracey**[*], **and Andrea Pisoni**[⋄]

[⋆] CIRA, via Maiorise, I-81043 Capua (CE), Italy, a.pagano@cira.it

[†]NLR, P.O. Box 90502, NL-1006 BM Amsterdam, the Netherlands, hounjet@nlr.nl

[‡]DERA, Hants GU14 OLX Farnborough, U.K., jvmiller@dera.gov.uk

[*]GKN-Westland, Box 231, BA20 2YB Yeovil, U.K, graceym@gkn-whl.co.uk

[⋄]AGUSTA, Via G. Agusta 520, I-21017 Cascina Costa (VA), Italy, aer@agusta.it

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Abstract. *This paper gives an overall overview of the Brite/EuRam project ROSAA (ROtorcraft Simulation with Advanced Aerodynamics) in which the first common European integrated simulation system, the ROSAA system, for the multidisciplinary numerical prediction of rotor phenomena has been developed. The ROSAA system is a software simulation environment in which specialist codes belonging to different disciplines (CFD, Grid Generation, Aeroacoustics, Dynamics and Aeroelasticity) are able to exchange data within numerical processes. This kind of tool, where comprehensive rotor codes are integrated with CFD technology (including grid generation and aerodynamic post-processing) and an easy link is established with sophisticated aeroacoustic codes, can not only lead to an improved numerical prediction of aerodynamic, aeroacoustic and aeroelastic rotor phenomena but it can also reduce, by means of a high degree of automation, the time and cost of bringing products to the market.*

1 INTRODUCTION

Literature in rotorcraft research is full of articles describing how difficult the accurate and efficient simulation of the helicopter rotor flowfield is. It has been recognized that structural dynamics and aerodynamics are so mutually dependent that a complex structural dynamic model without a fine aerodynamic model cannot predict dynamic properties accurately and, vice versa, a complex aerodynamic model without accurate trim conditions and elastic deformations cannot accurately predict the aerodynamic phenomena. The correct (deformed) position of the blade and the flowfield around it together with the proper wake modelling have a direct effect on the aeroacoustic predictions. We often read that the numerical simulation of rotorcraft requires the mastering of numerous disciplines from structural dynamics to flight dynamics and control, from aerodynamics to aeroacoustics.

Research and development efforts indicate that comprehensive rotorcraft analyses can solve the multidisciplinary nature of the rotorcraft problem more satisfactorily. In the US, over the last decade, comprehensive codes have been developed to an extremely high degree of sophistication (2GCHAS[1], COPTER[2], CAMRAD*II*[3], TECH01/02[5], ...) with the extensive use of advanced CFD codes and of the most recent aeroacoustics codes. In Europe while the CFD codes are rapidly tending to maturity both for the complex mathematical models used and for the accuracy reached, comprehensive codes have not evolved to the same degree of sophistication and only in a few cases can count on CFD data as they generally adopt simplified aerodynamic and aeroacoustic models. Still today, it is common practice to calculate complex rotorcraft phenomena by analysing the various disciplines in isolation. It usually happens that such an approach leads to a very sophisticated analysis in a particular technical area (the analyst's core discipline) and very simplified analyses in other areas. This undoubtedly limits the exploration of new rotor designs clearly putting at risk the competitiveness of European rotorcraft manufacturers in today's global market.

To remain competitive on the international market the helicopter manufacturers must be able to change the design of new helicopters and their derivatives continuously towards more cost efficient development cycles. Indeed, the need to decrease the time and cost of bringing products to market is so intense that virtual prototyping and virtual testing are welcomed capabilities required of the new numerical simulation systems. Furthermore, if the dominant reason for that lies with the high cost and time required for testing, another important aspect is the safety of the product. To be able to extend the flight envelope while avoiding a likely structural failure, for example, is of great interest for potential legal and liability costs and for the impact on public image.

A way to meet all these needs is to build a software environment based on a high level of automation in which comprehensive analysis is integrated with CFD technology (including grid generation and aerodynamic post-processing) and which includes an easy link to sophisticated aeroacoustic codes.

This simulation system is intended to be flexible, fast and user-friendly while having a wide range of mono-disciplinary tools so as to have sufficiently attractive features both for industries and research centres.

2 THE BRITE/EURAM PROJECT ROSAA

The ROSAA Consortium, composed of CIRA[1], DERA[2], NLR[3], ONERA[4], UNIRM3[5], GWHL[6] and AGUSTA[7] was formed in 1996 at the end of the Brite/EuRam HELISHAPE project (1993-1996). During this project it turned out that the full potential CFD code HELIFP[6], the first example in Europe of a successful cooperation for the development of a common rotor code, needed to be coupled to a "comprehensive rotor type" code to make a better prediction of the flowfield around real blades. This idea also prompted the title of the new project: "Integration of Advanced Aerodynamics in Comprehensive Rotorcraft Analysis" which was later synthesised in the acronym ROSAA.

The two-year ROSAA project started on March 1998 and is partially funded by the European Commission (EC) in the framework of the Industrial and Materials Technologies Programme.

The technical activities were prepared on the basis of the following considerations:

- the main goal of the project is the development of a unique common European integrated aeromechanics simulation system for the improved analysis of the aerodynamic, aeroacoustic and aeroelastic performance of rotors;
- the project has limited resources and time schedule; under these constraints, there is no point in developing a comprehensive rotor code from scratch;
- the organizations' rotor codes are embedded in the simulation system as proprietary codes, thus implying the choice of loose coupling procedures;
- fully capitalizing on the outcome of the previous Brite/EuRam projects, the most recent common specialist codes are incorporated, whenever possible, with only minor adaptations;

[1] Centro Italiano Ricerche Aerospaziali, Italy
[2] Defence Evaluation and Research Agency, United Kingdom
[3] National Lucht- en Ruimtevaartlaboratorium, the Netherlands
[4] Office National d' Etudes et de Recherches Aérospatiales, France
[5] Università di Roma 3, Italy
[6] GKN Westland Helicopters Limited, United Kingdom
[7] AGUSTA S.p.A., Italy

- a new CFD full potential code must be developed updating and improving the HELIFP code with the most promising technologies in order to have a fast and reliable tool especially in light of an aeroelastic coupling procedure;
- the aeroacoustic codes must be updated and the ones already available must be incorporated in the simulation system;
- a software environment in which the specialist codes are coupled or simply linked is developed and the numerical processes prepared by using a GUI.

The project is broken down into seven tasks:

Task 1: Industrial Requirements

Task 2: Aerodynamic Prediction Method

Task 3: Aeroacoustic Prediction Methods

Task 4: Coupling to Comprehensive Rotor Loads Codes

Task 5: Rotorcraft Simulation System & Software Coordination

Task 6: Verification of Simulation System

Task 7: Management

CIRA is the coordinating organization and each task has a leader monitoring the work packages in which the task is divided. The activities pertinent to each task are described briefly in the next sections.

3 INDUSTRIAL REQUIREMENTS

The ROSAA simulation system has been conceived to allow the simultaneous improvement of its various components (such as the CFD code, the grid generator and the aeroacoustic codes) and the development of the interfaces linking the codes. The basic engineering requirements, software coding standards and verification cases have been clearly laid down by the industrial partners since experience from the past Brite/EuRam projects has shown that in the area of common code developments they are needed at the very beginning of the project.

4 AERODYNAMIC PREDICTION METHOD

The main objective of this task was the improvement of two existing codes developed/enhanced in the Brite/EuRam project HELISHAPE: the CFD full potential code HELIFP (HELIcopter Full Potential) and the grid generator VIS12.GRID[6]. It was recognized that the HELIFP code needed a better physical and numerical modelling and a reduced turn-around time in routine applications especially in light of the use of CFD in comprehensive rotor analysis (Task 4). Indeed, the VIS12.GRID grid generator needed to be improved in order to be able to generate both grids for advanced blade tip geometry and grids suitable for aeroacoustic applications (Task 3).

These initial requirements were later extended with the appearance of an Euler solver (EROS code[8]) and an algebraic grid generator GEROS code[9]) both developed in the Brite/EuRam project EROS (1996-1999). The high level of cooperation among Brite/EuRam projects which have been promoted by European Commission and the fact that many researchers involved in the ROSAA project also contributed to the EROS project, suggested the idea that I/O interfaces could be shared. There are many advantages.

- The user interacts with both codes (EROS and the new full potential code) using the same shell. Everyone knows that it takes some time to "familiarize" with a code and with the logic or philosophy on which it is based.
- Since the majority of input files are identical, the user can run a simulation knowing that the input parameters, grids, motion, wake model are exactly the same. The user can even build a unique data base of test case input files.
- The user can postprocess the data using the same procedure as for EROS since the output files have the same quantities stored and in the same format.
- All the modules that will be added to EROS can be easily implemented into the new full potential code or vice versa.
- In the near future both codes can be embedded into one code that could perform, according to an user choice, Euler and potential simulations during the same run.

In conclusion, the planned improvement of HELIFP and VIS12.GRID actually turned out to be the development of two new codes, respectively, HELIFPX and GEROSV. Both will be briefly described (further details will be included in [7]).

4.1 HELIFPX

The most significant features of HELIFP which allow the prediction of flows around isolated helicopter blades in hover or forward flight, are: the equation in conservative form is written in the inertial frame of reference; a streamwise density flux biasing is applied in order to avoid non-physical solutions (expansion shocks) and to stabilize the computation in supersonic flow regions; entropy correction takes into account shock-generated entropy; a finite-volume scheme is adopted for metrics computations; the equation is discretized so that the resulting numerical scheme is first order in time and second order in space for subsonic regions and first order in space for supersonic regions; the boundaries conditions imposed are non-penetration for wall boundaries, unsteady transport equation on the wake and non-reflecting conditions at the far field; the discretized equation is solved using an approximate factorization (AF) technique with upwinding in supersonic regions.

The new code HELIFPX has arisen from the HELIFP code in the sense that the mathematical model and the AF scheme have been retained but the main program structure, the grid velocity computation and the I/O modules have been completely revisited. Furthermore, as initially planned, both the physical and numerical modelling have been improved with the embedding of the following modules: the viscous correction module, the acceleration technique module, and the free wake modelling module.

Viscous correction module

Viscous effects have an important role in any region of the rotor disk: although the most predominant effects occur on the retreating blade where large separation may be experienced, they are not negligible on the advancing blades where they affect the shock position and thus the moment prediction for high speed helicopters. In order to obtain an adequate estimation of torque and improved moment prediction, as required for the coupling procedure between comprehensive rotor codes and CFD codes, a viscous-inviscid interaction approach (VII) has been developed. The inner field solution, implemented in a stripwise fashion (2D locally unsteady viscous solution) and extended to Coriolis effects, is provided by the VIS05[12, 13] code developed at ONERA by J.-C. Le Balleur and based on his "*Defect Formulation Theory*".

At each time step the method is solved as a marching thin-layer numerical technique with non-linearly implicit schemes, in direct or inverse modes. At each viscous station, the method discretizes parametric turbulent velocity profiles, designed for attached as well as deeply separated flows, in the direction normal to the local inviscid streamlines. The method includes the full unsteady viscous terms and uses a box discretization in $x - t$ plane. The turbulence is computed either with an algebraic model (mixing length plus velocity profiles), or with an original 2-equation $k - u'v'$ model forced by parametric velocity profiles (2 half-equations $k - u'v'$). A 1-equation k model is also possible. In laminar zones, the method is simplified and it is a simple integral one. With respect to the full original VIS05 method, the coupling algorithm embedded into HELIFPX has been restricted, at the present step, to attached flows and incipient separation applications.

Acceleration techniques module

The acceleration techniques module, developed by NLR, consists of several software packages which can be activated/deactivated by the user. They allow the increase of code performance and/or the numerical accuracy and robustness through:

Second order time accuracy. It has been obtained by taking numerical time-derivative of the density with a second order approximation formula. It allows forward flight simulations with larger time steps and it makes the Newton process less sensitive to the start up guess solution.

GMRES. The Generalized Minimum RESidual algorithm[22] is an efficient and robust algorithm for solving non-symmetric matrices when the Krylov space is of limited dimensions so that the linear storage and the quadratic computational cost associated with it result in being restricted. GMRES is primarily embedded as an afterburner and it uses either the matrix-free or the preconditioned approach inside the Newton iteration loop. The latter approach freezes the linear system. The method might also be applied directly (without first applying the standard AF solver). Severe under-relaxation is applied when the amplitude of the first Krylov vector or the correction vector differs significantly from a reference vector obtained from the previous GMRES application and/or the AF solution. The embedding of GMRES method reduces the factorization errors making the solver more efficient and robust and less sensitive to the quality of grids.

FAS-MG. The multigrid algorithm, implemented according to the Full Approximation Storage MultiGrid algorithm[23], consists of three important operators. The prolongation operator takes care of the transformation of the solution from a certain coarse grid to a finer grid by using tri-linear interpolation in the computational space. The restriction operator performs the inverse operation, *i.e.*, moves the solution from a fine grid to a coarser grid. Fully weighted operators are applied to the mass and far-field equations while injection operators are applied to the wake and slit equations. The smoothing operator consists of the AF method and a RBK method. The RBK method applies implicit solving along the k direction with (i, j) RBK ordering strategy. The multigrid algorithm is developed and verified for steady hover applications. Provisions have been made to allow for its time-accurate extension which will enable rapid pre-conditioning of flow and be usefull for cases involving very low frequencies and inefficient grids.

Free-wake modelling module

The free wake modelling module, developed by UNIRM3, provides an adequate prediction of the velocity field induced by the far wake which has to be taken into account by CFD codes which employ a finite computational domain and/or suffer wake dissipation. This module is based on a boundary integral element methodology (BEM)[14] for prescribed wake modelling (initially developed in the EROS project) which has been extended to free wake modelling.

The influence of the far wake on the forces acting on the blade is very important especially for rotors in hover and in low speed forward flight. Indeed, contrary to fixed wing configurations, where the wake is soon convected downstream, the wake generated by the rotor blades floats in the vicinity of the helicopter and strongly interacts with fuselage and other helicopter components mainly at low advance ratios. The choice of a proper wake model is a crucial point to be considered when performing the aerodynamic analysis of the helicopter.

The coupling to the outer flow potential solver is performed by using two alternate approaches.

Inclusion of a transpiration velocity correction (predicted by BEM) in the computation of solid-wall boundary conditions. It is based on the assumption that all the sources of pertubation to the flow-field that fall outside the computational domain may be taken into account by introducing a transpiration velocity correction in the boundary conditions over the surface of the blade. It should be noted that the present wake-model allows the evaluation of the actual distribution of the inflow over the whole surface of the blade.

Evaluation of the far-field boundary conditions by using values of flow variables at the external boundary of the computational domain predicted by BEM. In this case BEM is used to predict the potential field (and eventually, the velocity field) at the external boundary of the computational domain (far-field boundary). This prediction is used to improve the evaluation of the boundary conditions required at the far-field by the CFD solver. It must be noted that, by using this approach, the inclusion of far-field effects in CFD computations is almost exact. The only approximation is related to the fact that in the boundary integral equation the nonlinear transonic effects are neglected.

4.2 VIS12.GRID

The grid generator VIS12.GRID, developed by ONERA, allows the generation of 3D structured grids of CH topology by means of a series of evolutive 2D sectional grids wrapped around cylindrical surfaces. The basic 2D C-mesh generator is an original hybrid "algebraic-numerical" grid generator: the method generates C-grids by a numerical integration along k at i=*const* (i chordwise index, k normal index), where the quasi-normal lines i=*const* are parametric but non-conformal parabolas. In this project it has been extended with the capability of clustering points outside the blade tip along the region near the characteristic curves to improve the prediction of shock delocalization thus providing improved aerodynamics to the aeroacoustic codes. Furthermore, it has also been extended so as to treat grids around blades with complex tip planform shapes (blades presenting a tip shape with the chord length approaching zero).

The VIS12.GRID grid generator has been embedded in the GEROS environment so that a new, extended version has been released: GEROSV. Within GEROSV, VIS12.GRID coexists with the GEROS grid generator and can be selected as an alternative fully exploiting all the features of GEROS such as the interactive user interface and the visualization procedures including the grid quality analysis.

5 AEROACOUSTIC PREDICTION METHODS

The main objectives of this task are to provide the ROSAA system with the aeroacoustic codes and to develop the proper software to link these codes with CFD tools embedded in ROSAA.

Of fundamental importance to any helicopter design programme is the consideration of noise levels. As the restrictions on aircraft noise increase, rotor noise becomes an increasingly important factor. However, waiting until after the first flight of a new design to reduce noise levels would be impractical: on one hand, development costs, including major redesign work, could escalate to levels at which the process could not continue; on the other hand, it may be necessary to redefine the flight envelope to avoid regions of greatest noise, a solution which would prove unacceptable to the customer if the operational requirements could no longer be met.

It is therefore critical that efficient and accurate aeroacoustic prediction methods are available. This must involve the development of basic physical considerations in such a way that they produce equations which can be solved for the particular problem of the helicopter rotor in as efficient a manner as possible. Uniquely amongst powered lift aircraft, the helicopter's primary lift and control surfaces are invariably the dominant sources of external noise in all modes of flight. As a consequence, any noise calculations can be performed in conjunction with aerodynamic prediction codes and are established almost completely once the main and tail rotor configuration and their position relative to one another have been set.

5.1 Aeroacoustic codes

In consideration of the above discussion, a number of aeroacoustic prediction algorithms were incorporated within the ROSAA program by coupling with HELIFPX.

Four aeroacoustic codes have been selected for integration:

ACBEM is a newly designed code by UNIRM3 in the framework of ROSAA based on the Unified Boundary Integral Element Method[15, 16]; the pressure is evaluated at the acoustic collocation points when the velocity potential is known on the rotor blade;

HERNOP-3 was developed in the HELISHAPE project; in its initial release it basically calculated the aeroacoustic signature by means of the linear FW-H equations; it has been extended by CIRA outside the ROSAA project in order to fully handle the quadrupole terms[10];

KIRAC was developed by DERA in the HELISHAPE project for hover conditions solving the Kirchhoff equations on a non-rotating cylindrical control surface; in this task, the algorithm has been extended to forward flight conditions, including rigid blade motions and using a translating cylindrical control surface;

BENP is an AGUSTA proprietary code[11] that allows for the aeroacoustic prediction of rotors by applying one of the following methodologies: acoustic analogy based on FW-H theory (linear), FW-H theory (nonlinear) with quadrupole evaluation for transonic flight, Kirchhoff approach, and modified Kirchhoff approach (by P. di Francescantonio) for transonic flight.

5.2 Aeroacoustic Data Base and Interfaces

Each of the aeroacoustic codes requires a different set of CFD input data for its formulation. This set of data may be very large especially for forward flight cases. In order to reduce the large amount of data, to maintain a good level of accuracy and to avoid losing generality, it was decided not to link the acoustic codes directly to the CFD codes (it would have required as many dedicated interfaces for each aeroacoustic code as the number of CFD codes) but to let each CFD code generate a data base containing aerodynamic quantities for aeroacoustic calculations in a specified format. Hence some suitable software interfaces have been set up between the common database and the relevant acoustic codes. Obviously this strategy resulted in an additional work in task 2 since a new output module had to be included into HELIFPX. This also means that any other CFD code which could be integrated in the ROSAA system would have to produce the data base.

6 COUPLING TO COMPREHENSIVE ROTOR LOADS CODES

The ability to predict the loads, performance and aeroelastic stability of helicopter rotors is essential in order to develop new or improved design features and to allow assessment of proposed new purchases or mid-life updates. Rotor loads and performance prediction methods are computationally intensive, using so-called comprehensive codes which combine dynamics and aeroelastics models with simplified aerodynamic representations. This causes difficulties when applying the methods to blades with fully three-dimensional changes of section and planform, such as rotors with advanced geometry tip shapes. The prediction of the aerodynamics for blades with these advanced layouts calls for the use of unsteady three-dimensional computational fluid dynamics (CFD) codes. However, these codes still require the additional modelling of blade dynamics and aeroelastic distortions.

This requirement to model the rotor blade dynamics and aeroelastic distortions exists at every level of CFD modelling of rotors. Two possible approaches arise: a hybrid scheme in which there is an iteration between a comprehensive rotor analysis code and a CFD code, or a scheme in which full dynamic analysis is coupled with a CFD code supplemented where necessary by a dynamic stall model. Within the first approach, the iteration can be in the form of a “weak” or “strong” coupling, depending on the nature of the interaction between the codes. The codes are weakly coupled if a complete azimuthal calculation with one is followed by a complete azimuthal calculation of the other; they are strongly coupled if the iteration between the codes is performed at each azimuthal position or time-step. However, the latter approach is not available if the aeroelastic code is based on harmonic analysis or frequency domain solution methods.

This task deals with one of the most interesting features of the ROSAA system: the integration of the CFD aerodynamics and the comprehensive rotor analysis. As already mentioned, no technical activities are performed with respect to the rotor codes. The following commercial or in-house-developed rotor codes are embedded in the ROSAA system as proprietary codes (they can only be accessed by the owner):

- CAMRAD-JA[4] (AGUSTA)
- CRFM (DERA)
- HERO (NLR)
- R150 (GWHL)

The technical activities are related to the development of a software package enabling the transfer of data from HELIFPX to any of the rotor codes and vice versa; furthermore, the numerical process which drives the data flow through the coupling procedure has also been implemented. The coupling procedure (see figure 6) is based on the weak interaction: a complete azimuthal rotor code calculation is followed by a complete azimuthal CFD calculation. The rotor codes provide the CFD code with trim conditions, far wake and elastic effects while the CFD code exchanges C_L and/or C_M and/or C_D aerodynamic coefficients. This coupling procedure has been implemented in a separate module which was developed by NLR.

7 ROSAA SIMULATION SYSTEM

The main software elements of the ROSAA simulation system are: the specialist codes which constitute the code library, the data base, the interfaces, the components of aeroelastic coupling procedure, and the GUI which also includes the simulation processes set-up tool and the process control (see figure 1). Among the specialist codes (available to the ROSAA partners as common codes or propriatery codes) which may be involved in a rotorcraft simulation there are: one grid generation environment incorporating two grid generators, two aerodynamic codes, four aeroacoustic codes, five rotor loads codes (NLR is checking the possibility of including the commercial rotor code FLIGHTLAB) and two visualization tools. The data base is considered to be a conceptual component in the sense that it is not a software tool but a zone of the ROSAA system in which files can be stored or retrieved.

The simulation processes can be built by using the GUI capabilities such as the drag-and-drop mechanism which allows the selected applications to be put in a working area where they are automatically connected to each other by means of the appropriate interfaces. Figure 2 presents the main window of the ROSAA system. Once the user has selected the codes from the code library and put them in the working area, they will be represented by boxes having three ports. The codes can be connected in a simulation process just linking the output port of a code with the input port of the successive code; if an interface which translates data in the proper format exists, it will automatically appear. The box representing a specialist code is also characterized by a plotting port which is used to connect any of the output files of that code with the visualization tool accepting the file format. Within the same box, there is a button which, if clicked, allows the editing of any of the input files of that code. The code enabling the aeroelastic coupling is represented by a special box having an extra port dedicated to the feedback connection.

The Graphical User Interface within the ROSAA simulation system is built using Tcl/Tk as GUI toolkit and, due to the small resources allocated, is a basic tool in the sense that only the essential functionalities of this kind of tool are implemented. As a matter of fact, this is the first attempt for the European helicopter community to use both an integrated simulation system for the analysis of phenomena of interest and a GUI for the management of all the capabilities of such an integrated simulation system. The main capabilities of the GUI can be summarized as follows:

- configuration of the simulation system;
- definition and setting of the simulation processes;
- assistance for users while running;
- monitoring of the simulation processes.

The design and the development of the simulation system, including GUI, has been carried out by CIRA.

8 VERIFICATION OF SIMULATION SYSTEM

A number of test cases have been selected to explore and verify all of the capabilities of such a simulation system. These activities, which are under progress, aim at assessing the reliability and identifying any limitations of each of the above mentioned applications both in isolation and in the coupling procedures. Preliminary results are shown in the following pages. Figure 3 illustrates the VIS12.GRID capability of modifying the outer tip slit so as to improve the aeroacoustic predictions. Figure 4 describes the study on the influence of the number of time steps using the second order temporal accuracy for a well known 2D case[17]. Figure 5 shows the harmonic analysis predicted by HELIFPX and EROS for a transport aircraft wing oscillating sinusoidally in pitch[18]. This example is significant since both codes use the same input files (with the only exception of the numerical scheme parameters input file, being the mathematical model different) and produce output files in the same format. Figure 7 and figure 8 give an appreciation of the effect of the aeroelastic coupling between CAMRAD/JA and HELIFPX on the CFD numerical prediction both in terms of C_N and C_p for an advanced lifting rotor in forward flight[19]. Finally, figure 9 and figure 10 show that the use of CFD data in acoustic predictions is very promising both for hover[20] and forward flight conditions[21].

9 CONCLUSIONS

It is expected that at the end of the project the ROSAA system will offer extensive rotor analysis capabilities that go well beyond those currently available within the participating companies. The resultant simulation system will enable the designer to make an efficient examination of the effects due to changes in the geometry upon the aerodynamic, aeroelastic and aeroacoustic performance of a rotor from within an integrated and user-friendly environment. It will provide the capability of designing next-generation rotors having improved pilot control loads, reduced vibratory loads, increased speed and lower noise emission and, ultimately, bring those advanced products to the market at considerably reduced time-scales and cost.

It is also expected that the ROSAA simulation system may become a *standard* in Europe to facilitate the integration of existing and new codes (icing prediction, CAD/CAM interface, blade optimization design, ...) within the same common software environment. The ROSAA system may be the first step towards a complete system for the global simulation of helicopter phenomena.

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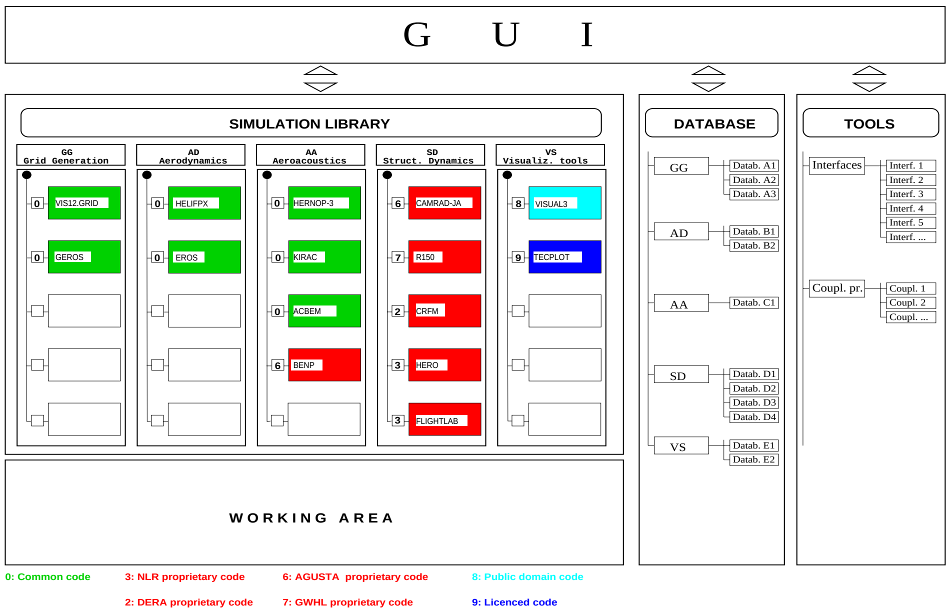

Figure 1: Architecture of the ROSAA simulation system.

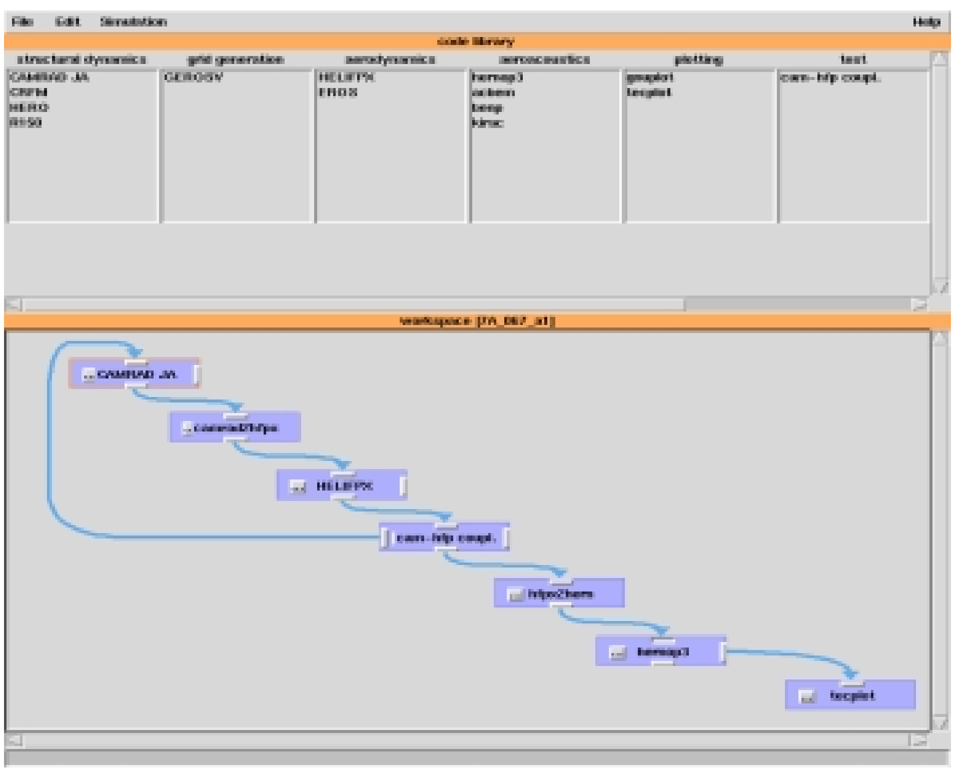

Figure 2: GUI of the ROSAA simulation system.

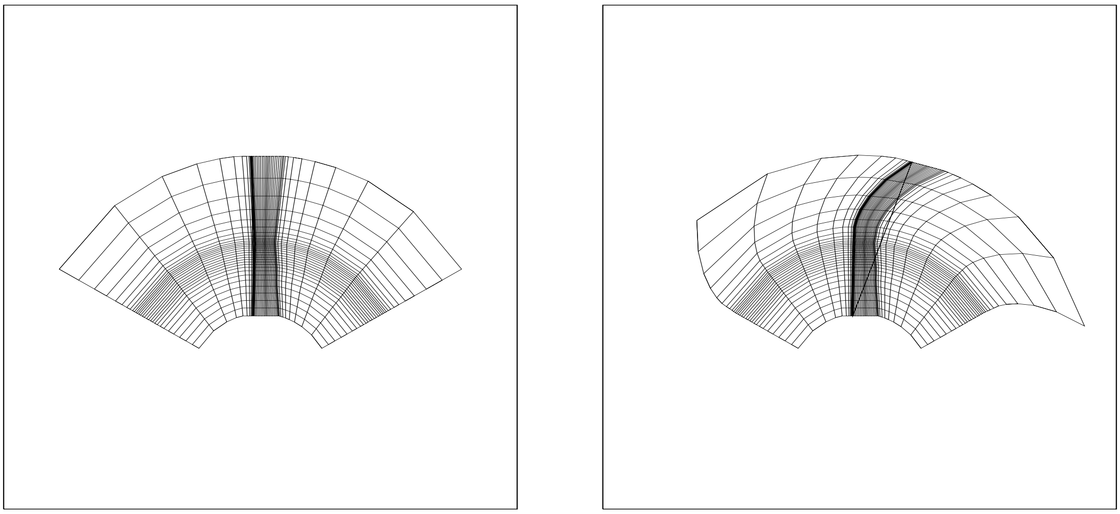

Figure 3: Undistorted and distorted outer tip grids generated by VIS12.GRID.

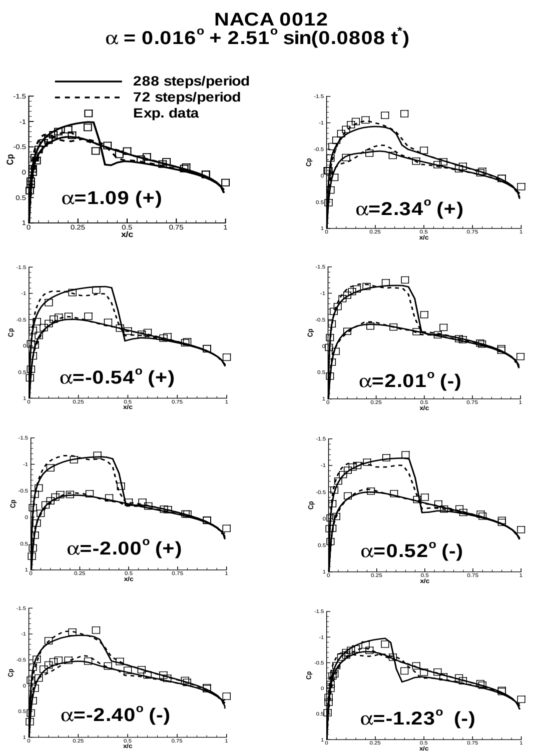

Figure 4: Analysis of the time steps influence on the HELIFPX prediction for a 2D case.

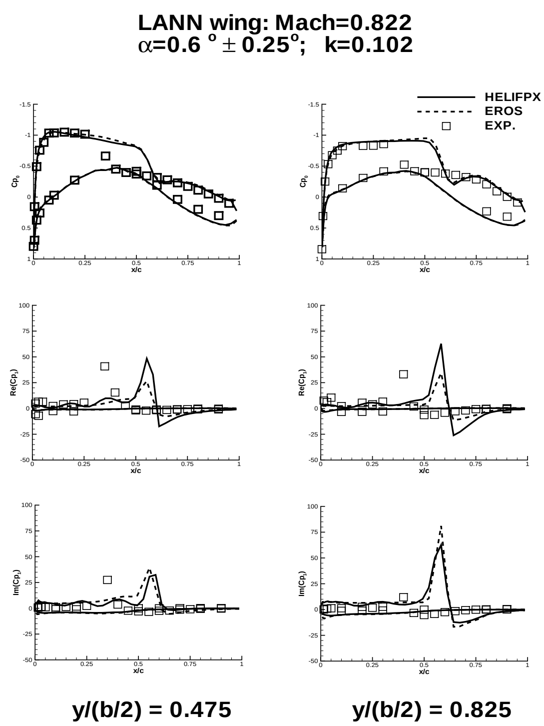

Figure 5: Harmonic analysis as predicted by HELIFPX for a fixed wing.

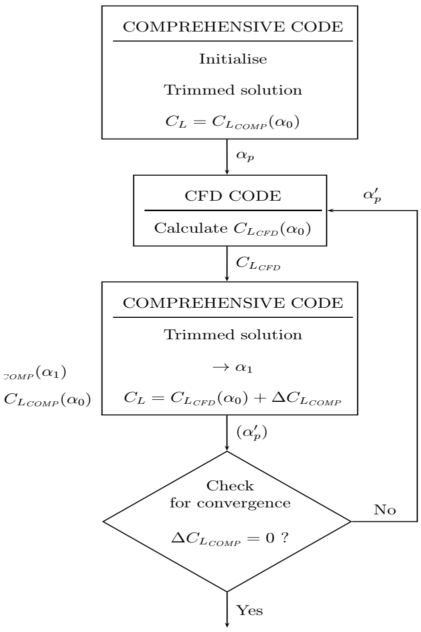

Figure 6: Coupling scheme between comprehensive rotor codes and CFD codes.

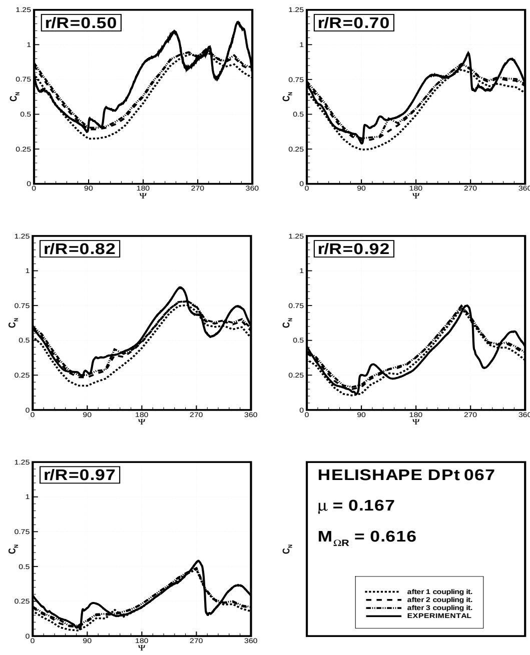

Figure 7: CFD C_n prediction after 3 coupling iterations between CAMRAD/JA and HELIFPX.

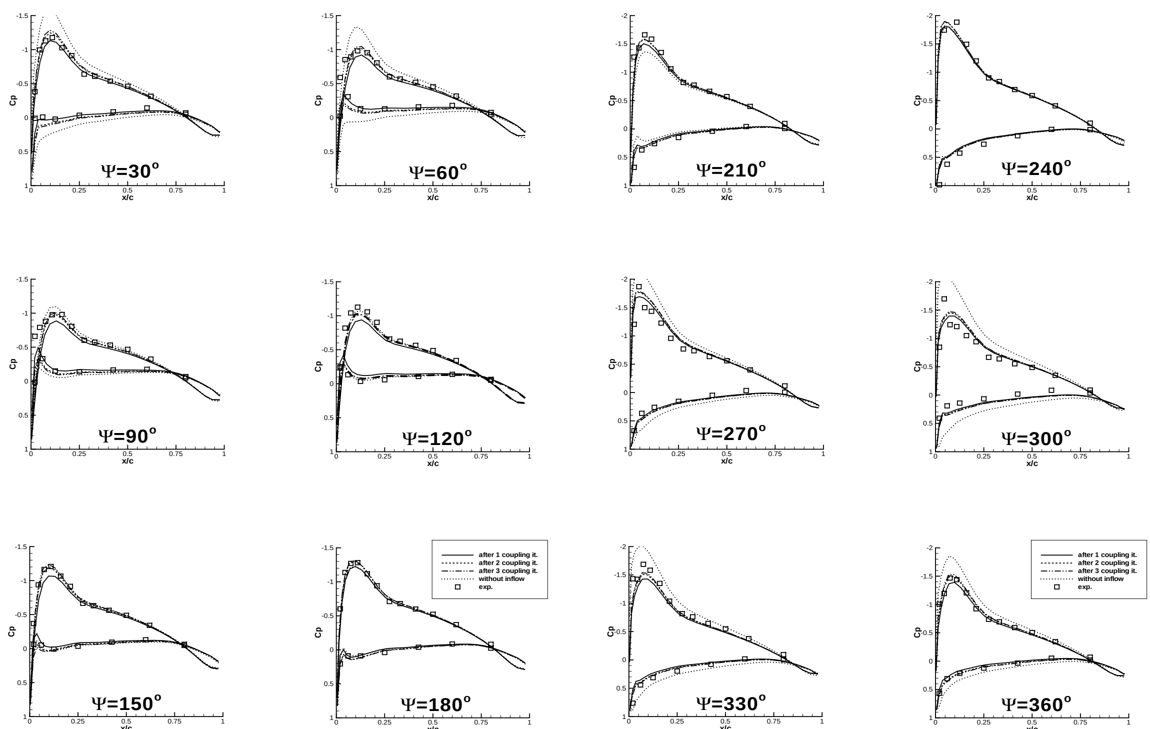

Figure 8: CFD C_p prediction at $r/R = 0.82$ after 3 coupling iterations between CAMRAD/JA and HELIFPX for the test relative to fig. 7.

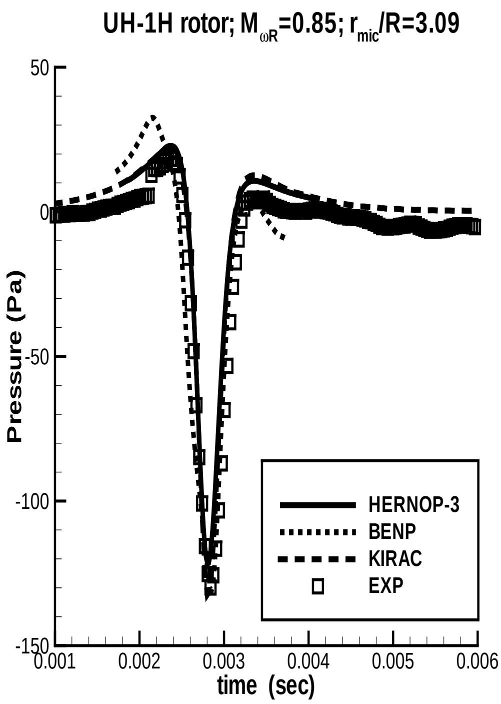

Figure 9: Acoustic signatures obtained from different acoustic codes and one CFD data set.

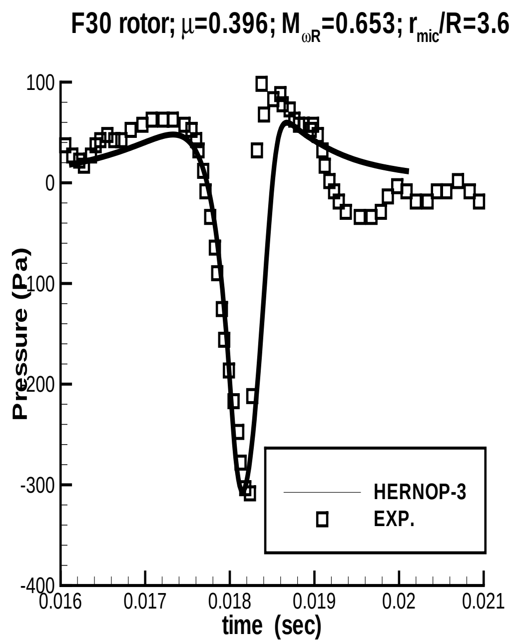

Figure 10: Comparison of the acoustic pressure predicted by HERNOP-3 with experiments.