DLR - Onera Common Research Programme for Rotorcraft

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Abstract: Onera and DLR are both national research centres involved in aeronautic research since early 1900. In 1998, Onera and DLR signed an agreement to join their competencies and manpower in the helicopter and tilt rotor domain. The first common research programme was issued in 2000. The authors constitute the common management structure.

The paper will shortly present Onera and DLR, the rationale of the cooperation and management structure and share the experience of combining studies and tests made jointly and funded by different sources. For several years now, this common programme produces results from common, cooperative or single side studies. The paper recalls main results obtained in the cooperation within the last years such as computational tools (e.g. CFD development and validation for aerodynamics and aeroacoustic), environmental studies such as external and internal noise, new technologies for active rotor control and active blades, flight mechanics and handling quality studies, recent developments for tiltrotor applications and helicopter flight tests.

This common organisation has reached now a kind of cruise trip and the teams are addressing future challenges for rotorcraft technology. These challenges and the studies running to contribute to the improvement of rotorcraft technologies will be presented. Future plans are also presented.

Introduction

DLR and Onera decided for a close partnership in rotorcraft related research [1], [2], [3]. Consequently an ‘Agreement on a DLR-Onera Partnership in Rotorcraft Research’ was signed on 2nd December 1998 by the Onera President and the DLR Chairman of the Board of Directors.

With respect to the common research activities the main objective is to obtain the best efficiency at minimum cost by avoiding duplications but still allowing for a certain scientific competition. Additionally the common interest of both research centres is to act in a harmonized position and to speak with one voice in front of the public and private partners and customers.

The main objective of this common organization is to manage vehicle oriented multidisciplinary projects and tasks, to co-ordinate, integrate, and market all rotorcraft related research activities of both research centres. The execution of the research work remains in the institutes and departments involving the appropriate experts and scientists in the corresponding disciplines.

The DLR-Onera partnership is based on the following general principles:

It is full intention of both partners to create a win-win situation with no one-sided and unfair shortcoming for one of the partners.

In general, the partnership is established on a 50% by 50% venture, applied to the overall activity and to the resources

The financial principles are established on a full cost basis of personnel, facilities, and equipment for both, partners and customers.

The costs for the use of the facilities and equipment of each partner are based on a no-money-exchange policy and are incorporated in the common research programme.

In order to realize this project the management charge has been given to a Permanent Common Management Team (PCMT) which reports to a common Steering Committee. This PCMT is composed by one person from DLR, in charge of the DLR rotorcraft programme and one person from Onera, responsible of the helicopter overall activity within Onera.

The year 2008 is the ninth year of the DLR-Onera partnership. A close partnership with industry has been also settled as well as a high level of cooperative activities through EU project participation.

Due to the national research role of DLR and Onera, multiple cooperations with academia are also settled.

French and German research centres

Onera

Onera is the French national aerospace research centre. It is a public research establishment, with eight major facilities in France and about 2,000 employees, including 1,500 scientists, engineers and technicians.

Onera was originally created by the French government in 1946, and assigned six key missions:

Direct and conduct aeronautical research

Support the commercialization of this research by national and European industry

Construct and operate the associated experimental facilities

Supply industry with high-level technical analyses and other services.

Perform technical analyses for the government

Train researchers and engineers

The research carried out at Onera results in computation codes, methods, tools, technologies, material and other products and services which are used to design and manufacture aerospace products: civil aircraft, military aircraft, helicopters and tiltrotors, propulsion systems, orbital systems, space transport, missile and defence systems, security systems.

Onera's funding comes from contract research from industry and agencies (60% of the annual budget) and 40% by an annual grant from the French government. The average annual budget is 190 M€.

The strategic challenge for Onera is to organize this broad knowledge stream, ranging from the acquisition of knowledge to transferring it to industry.

Onera operates a wide range of wind tunnel and test rigs facilities.

DLR

DLR is Germany's national research centre for aeronautics and space. DLR acts as National Space Agency.

DLR's research portfolio ranges from fundamental research to innovative development of the applications and products of tomorrow. In this way, DLR contributes the scientific and technical know-how that it has gained, thus enhancing Germany's industrial and technological reputation. DLR operates large-scale research facilities for the centre's own projects and as a service provider for clients and partners. It also promotes the next generation of scientists, provides advisory services to the German government and is a driving force in the regions centered on its various locations.

Approximately 5600 people work for DLR; the centre has 29 institutes and facilities at 13 locations in Germany: Berlin, Bonn, Braunschweig, Bremen, Cologne (headquarters), Goettingen, Hamburg, Lampoldshausen, Neustrelitz, Oberpfaffenhofen, Stuttgart, Trauen and Weilheim. DLR also has offices in Brussels, Paris and Washington, D.C.

The DLR budget for in-house research and development work and other internal operations amounts to approximately € 450 million, of which 33 % comes from revenues earned by DLR. DLR also administers the space budget of the German government, which totals some €846 million. The Aeronautic domain budget volume is about 170M€.

DLR-Onera Common Research Programme

In terms of volume of budget and fulltime people, for 9 years now, the collection of activities shows a good balance between both organisations:

- about 10 M€ yearly budget level
- about 65 full time employees

for each.

This common programme, established yearly, with a mid-term (5 years) projection, gathers all rotorcraft oriented activities of both organisations, performed by common team, within international cooperation or performed only by one partner.

Personnel exchanges are encouraged and strengthen the communication, as well as technical or more formal meetings.

Moreover, the use of common:

- tools: CFD (elsA [4], FLOWer [5], TAU [6], …) or comprehensive codes (HOST [7])
- data basis (HART I [8], HART II [9], GOAHEAD [10])
- test facilities (S1MA, DNW, local test rigs)
- flight test helicopters (Bo105, EC135-FHS)

eases the cooperation.

In addition to the cooperation for rotorcraft, Onera and DLR have a partnership on commercial aircraft research projects.

Onera & DLR within the EU Community

EREA

Onera as well as DLR are founding members of EREA, the association of European Research Establishments in Aerospace. EREA was founded in 1994 by six European research centres. The other members are NLR (NL), INTA(Sp.) FOI (Sw), VZDLU(P). Its mission is to coordinate projects and resources, thus enhancing efficiency and avoiding duplication.

ATA

ATA, the Aero Testing Alliance, groups the wind tunnels of Onera and DNW, a bilateral alliance that operates the wind tunnels of DLR (Germany) and NLR (Netherlands).

GARTEUR

Within the GARTEUR organisation, the Group of Responsables for Helicopters (GoR (HC)) facilitates the advancement of civil and defence related rotorcraft technology within European research establishments and industry through collaborative research activities, and through identification of future projects for collaborative research.

The GoR (HC) initiates, organises and monitors basic and applied, computational and experimental aeronautics oriented research for application to rotorcraft (helicopters and tilt rotor aircraft) vehicle and systems technology, through Action Groups (AGs).

Within the GoR Helicopter members, the main European actors of the rotorcraft domain are represented. Together with the 2 leading world manufacturers of civil helicopters, Eurocopter and AgustaWestland, the National research centres working in close cooperation with their respective industry DLR, Onera, NLR, CIRA, Dstl and QinetiQ, are members of GoR. Within the AGs and Exploratory Groups (EGs) participation, University Laboratories and others (smaller) industries are partners. This context gives to the discussions a real interest and a guarantee to be on the leading edge of the progress.

European R&D

Onera and DLR take an active role in the European Commission's framework research & development projects and are both associates in the new JTI project Clean Sky for the Green Rotorcraft Integrated Technology Demonstrator.

Open cooperation

Together or separately DLR and Onera are cooperating with many other research centres in the world. For example, both were part of well known HART I and HARTII cooperation with US Army & NASA which led to relevant progress in knowledge of higher harmonic control on rotor performances and especially on noise. Within this cooperation a well documented data base was created (including surface pressures, blade motion, flow field data (Particle Image Velocimetry (PIV)). This cooperation led to a worldwide open code validation exercise.

Structure of the Common Research Programme

The common programme is organized in 8 "Research Concepts" (RC), headed by one responsable from Onera and one from DLR. They have together the responsibility to define the activity, to run studies and present relevant results. Common or individual papers are issued each year within international congresses to present significant achievements.

Research Concepts:

- RC1: The Virtual Aerodynamic Rotorcraft
- RC2: The Quiet Rotorcraft
- RC3: The Smart Rotorcraft
- RC4: The Safe Rotorcraft
- RC5: The Comfortable Rotorcraft
- RC6: The Active Rotorcraft
- RC7: The Advanced Rotorcraft
- RC8: The Specialised Military Rotorcraft

Examples of results coming from the Common Research Programme

Except for RC8 dedicated to Specialized Military studies, the following will present significant results recently published by DLR and Onera scientists.

The Virtual Aerodynamic Rotorcraft

The work done within this RC includes:

- Development and extension of CFD codes for complete rotorcraft with focus on interactional phenomena
- Development and validation of dynamic stall prediction codes
- Application studies
- Generation of experimental wind tunnel data for code validation.

Three examples are shown:

BVI calculation with elsA : [11]

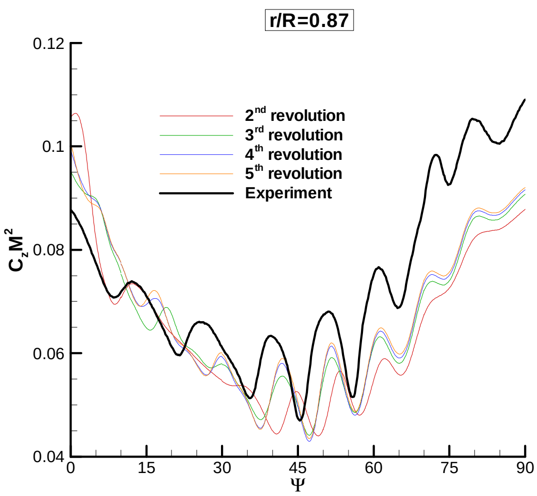
This paper refers to the work accomplished in the French-German SHANEL (Simulation of Helicopter Aerodynamics, Noise and ELasticity) project.

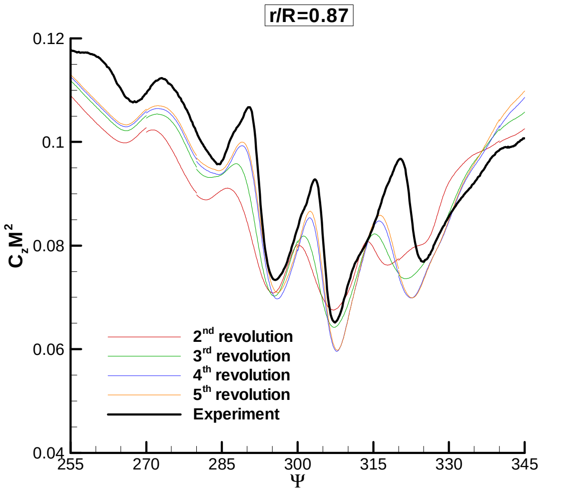
The numerical simulation of the flow field around helicopter rotor blades remains a challenging problem. In particular, the interactions between the blades and the wake play a major role for performance, blade loads, vibrations and acoustics. These interactions are predominant in hover and in descent flight configurations when the wake below the rotor is swept away with low velocities. In these conditions, an accurate prediction of the wake geometry remains one of the most difficult problems in helicopter rotor aerodynamics. In particular, the capture by CFD of the blade-vortex interaction (BVI) of a rotor in descent flight conditions is of interest.

The CFD numerical methods are developed to calculate helicopter wakes conservation and interaction, such as rotor or fuselage configurations and the studies are running in cooperation since 2001.

In the framework of the French-German CHANCE cooperation [12] (2001-2006), the Chimera techniques have been developed and used for automatic mesh generation and adaptation in the elsA solver. In 2004, these methods have been applied to the HART Baseline testcase, but no BVI was simulated due to too coarse blades and background grids. The SHANEL common project, funded by respective governmental civil agencies addresses this issue.

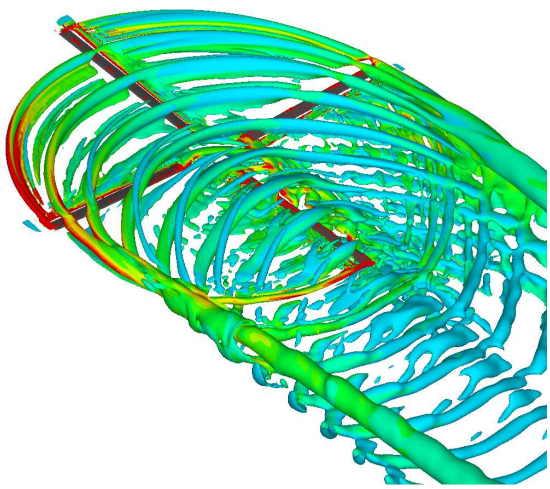
The objective of this new task is to capture the blade-vortex interaction with fine reference meshes and to improve the efficiency of the computations by applying recent numerical methods (high-order schemes, vorticity confinement…). The CFD results serve as input data for noise analysis and are compared to the HART measurements for validation purposes.





Convergence of the sectional load C_ZM^2 for the fine background grid

Figure 1 : BVI calculation by elsA within SHANEL project using HART experimental data.



Fine background grid

Figure 2 Visualization of the rotor wake with the iso-surface of Q-criteria colored by vorticity magnitude

Dynamic Stall simulation and control [13], [14]

A new concept of passive dynamic-stall control was developed at DLR and tested on an OA209 rotorcraft airfoil during two wind-tunnel test campaigns in 2004 and 2005. Small vortex generators are mounted at the leading edge of the rotor blade. At low incidence they are located close to the stagnation point and do not impact the flow field. At high angles of attack the so-called Leading Edge Vortex Generators (LEVoGs) induce longitudinal vortices which impact the suction side flow. It was shown that the use of LEVoGs can significantly increase the overall time-averaged lift while an unwanted negative pitching-moment peak is reduced compared with the clean blade case (see Figure 3). Furthermore, overall drag is reduced at dynamic-stall conditions.

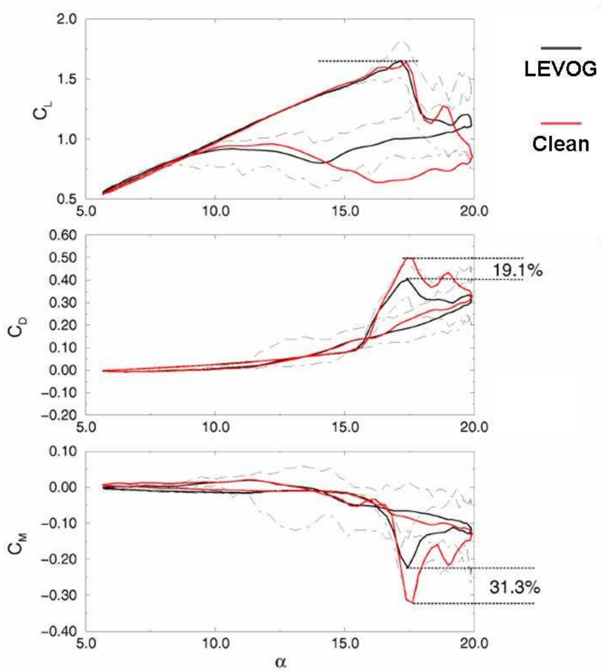
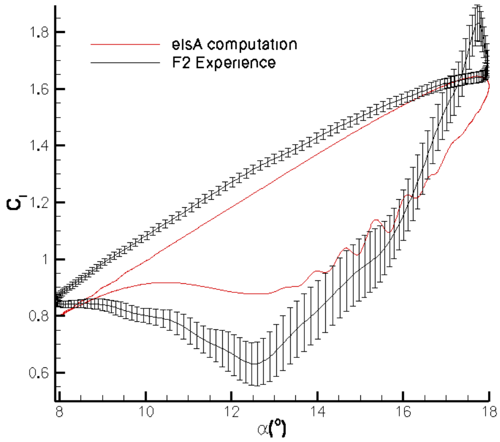


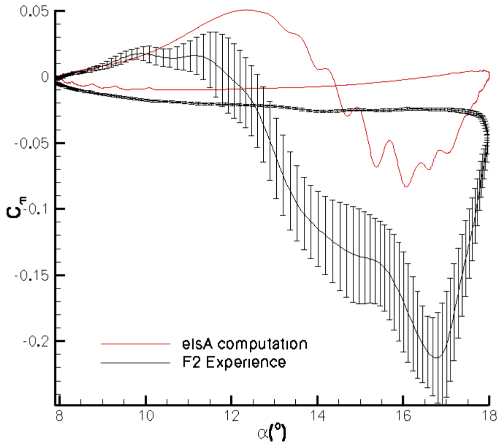
Figure 3 Measured mid-span lift-, pitching-moment- and pressure-drag hysteresis loops integrated from measured unsteady pressure distributions for a deep dynamic-stall case with and without LEVoGs (M=0.31, Re=1.15e6, alpha=12.9°+7.1° sin(omega*t), red. freq. =0.1)

The elsA URANS solver has been developed and validated for an oscillating OA209 airfoil under dynamic stall conditions. The large amount of experimental data available (unsteady pressures, skin-friction, velocity field, turbulent fluctuations) allows to deeply analyze the CFD results and check the validity of the physical models. Fully turbulent and laminar-turbulent computations are shown in [13]. The transition criteria are taking into account both the development of instabilities and of laminar separation bubbles, this last phenomenon being very important for the low speed configurations considered. While the fully turbulent computations only correctly describe the occurrence of trailing edge separation, the consideration of laminar-turbulent transition provides a much better simulation of the flow behavior in the leading edge region, and this strongly affects the capture of dynamic stall events.

The objective of [13] was a detailed comparison between numerical predictions and the F2 experiment, focusing on the influence of laminar/turbulent transition on the dynamic stall of the OA209 airfoil.



Comparison between computation with transition and experimental lift coefficient for a deep stall case, Re=1.8M



Comparison between computation with transition and experimental pitching moment coefficient for a deep stall case, Re=1.8M

Figure 4 Dynamic stall prediction compared to experimental results

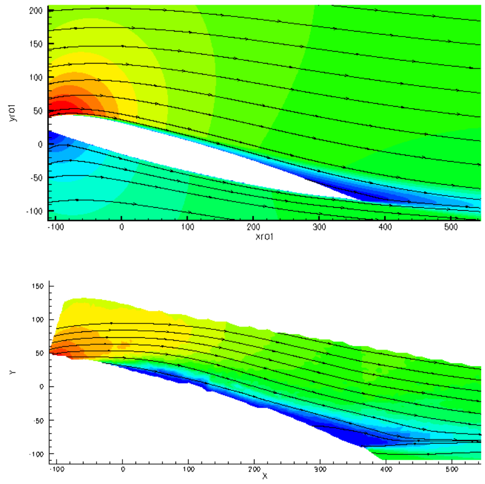


Figure 5 :Comparison of axial velocity component at alpha=14.5º

The results shown in the previous paragraph have been achieved within the Onera/DLR cooperative project SIMCOS. In this project URANS tools are applied to the definition and test of several dynamic stall control devices. The efficiency of these devices will be assessed using CFD and wind tunnel experiments.

GOAHEAD-project (Generation Of Advanced Helicopter Experimental Aerodynamic Database for CFD code validation) [10]

The GOAHEAD project objectives are:

- 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.

This project is supported by a contract of EU 6^{th} FP. 15 partners, including Onera, DLR (coordinator) and other EU research Centres as well as universites and helicopter manufacturers are participating.

The model tested in April 2008 is a Mach scaled model with a geometry similar to the NH90 helicopter (see Figure 6). The main rotor diameter is 4.2 m which corresponds to a 1/3.9 scale with an instrumented 4-bladed main rotor (Onera 7AD geometry), and an instrumented 2-bladed tail rotor (Bo105 geometry, diameter 0.733m). The model was mounted on a belly sting. The upper part of the rotor head had a so-called beany fairing.

In order to allow a systematic assessment of different features of the CFD methods two configurations have been 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 6. The flight conditions for the full model are

- a low-speed (pitch-up) condition,
- a cruise condition (free stream Mach number ~ 0.2),
- a high-speed tail-shake condition,
- a highly-loaded rotor (dynamic-stall) condition, and
- a very high speed condition (free stream Mach number ~ 0.25, MωR =0.66).

In order to have clear boundary conditions the closed test section was used in the wind tunnel. The tunnel walls are simulated in the CFD simulations for having a true validation case (Figure 7).

Table: CFD codes used in GOAHEAD

CFD Code	Helicopter Industry	Research Institute
elsA	EC SAS	Onera
FLOWer	ECD	DLR, Univ. Stuttgart, Cranfield Univ.
HMB	AgustaWest-land	Univ. Liver-pool
ROSITA	AgustaWest-land	Politechnico Milano
Discontinnu-ous Galerkin MIMG + EN-SOLV		NLR
Unstructured FORTH in house method		FORTH

Figure 6 : GOAHEAD model in DNW wind tunnel

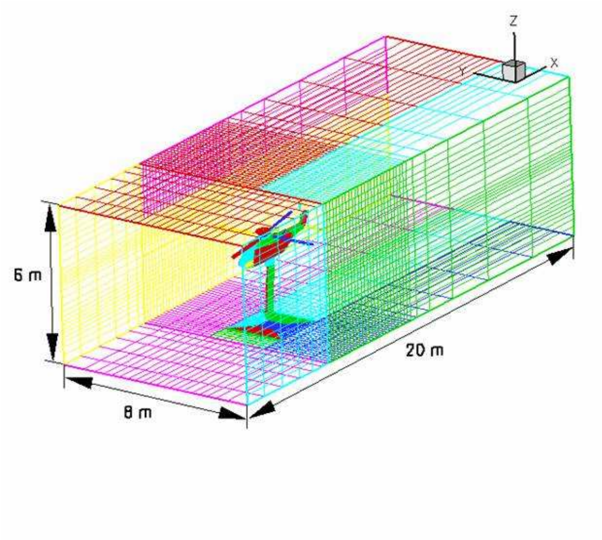


Figure 7 : GOAHEAD CFD grid system including wind tunnel walls

<u>The Quiet Rotorcraft</u>

The studies performed within this RC include:

- Development and validation of main and tail rotor aeroacoustic prediction codes
- Definition and demonstration of low noise flight procedures
- Prediction of turboshaft engine noise
- Studies on helicopter external noise reduction.

Codes application for blade shape optimisation: ERATO blade [15]

The HMMAP is an aeroacoustic calculation chain defined at Onera, with some common parts with DLR aeroacoustic chain. Such a prediction tool was used in the ERATO rotor optimization programme launched in 1992 by Onera and DLR with involvement of Eurocopter (France and Germany).

An overview of the running activities is given in [16]

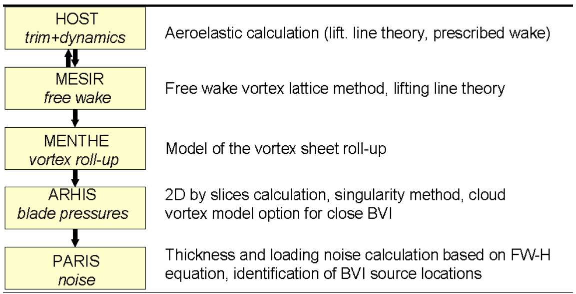


Figure 8 : HMMAP calculation chain for BVI noise

The objective of the ERATO project was to design, build and test a quiet model rotor for wind tunnel demonstration of a 6 dBA noise reduction (in terms of averaged ground noise level) compared to a reference rotor of current technology, in ICAO descent flight certification condition, that is 6 degree descent, 125 km/h (67 kts).

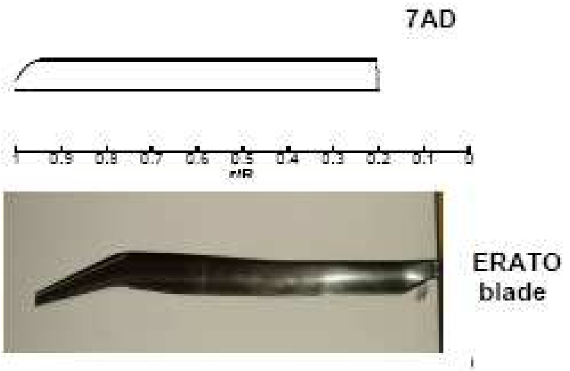


Figure 9 : ERATO shape compared to reference rotor

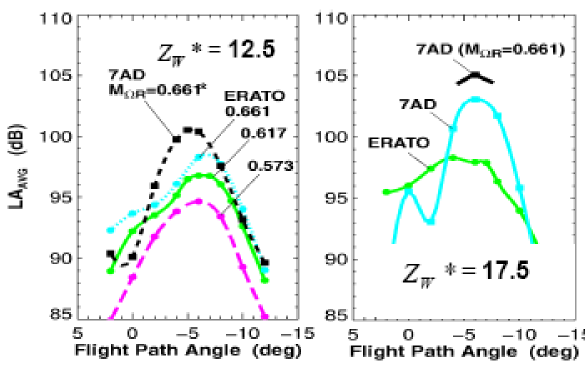


Figure 10 : 7AD-ERATO acoustic comparison at 125 km/h, DNW measurements, dBA levels: left Zb =12.5, right Zb = 17.5

This study led to a common DLR Onera patent for the ERATO blade. The studies are going on with a dynamic optimization.

Simulation of complete helicopter noise in manoeuver flight [17]

Recent developments are conducted by DLR to set up a calculation tool able to compute and minimize the ground noise footprint created by a complete helicopter in flight (including maneuvers). The computational tool relies on a hybrid approach: generation of an arbitrary trajectory then propagation of noise down to the ground is performed numerically whereas noise emission characteristics are provided by an aeroacoustic database. The aeroacoustic database was generated during the DLR flight campaign PAVE 2004. When computing the noise of an arbitrary flight, interpolations within the aeroacoustic database are used. The whole method has been successfully validated versus experimental data, including ground noise footprint measurements.

This tool is used within the European project FRIENDCOPTER and the DLR project PAVE2 to minimize the ground noise footprint of flyable and comfortable flight procedures including manoeuvres with particular emphasis on landing approach. These investigations lead to modified flight procedures in terms of height profile and flight speeds evolution alowwing noise reductions larger than 10 dBSEL under a EC135 helicopter.

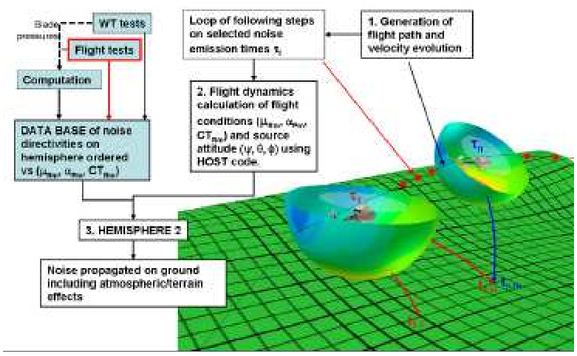


Figure 11 Schematic representation of the computational chain.

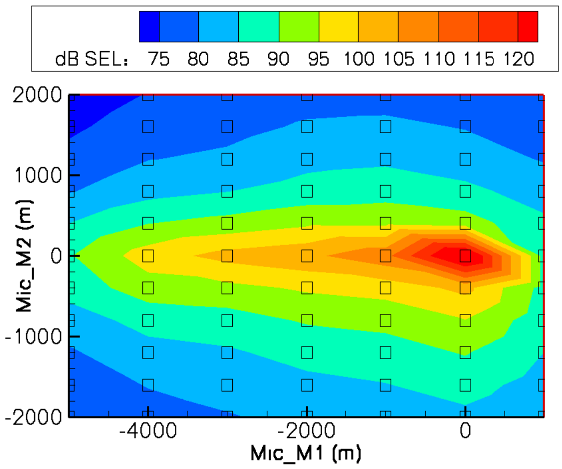


Figure 12 Ground noise footprint (SEL level) for an optimized descent flight

Good agreement with the experimental ground-noise footprints is observed. The tool performs fast and is thus appropriate to design flight procedures minimizing the ground noise footprint.

This will be further used within the JTI Clean Sky Green Rotorcraft Work Package “Environment Friendly Flight Paths”.

The Smart Rotorcraft

This RC includes studies dealing with:

- Technology research and integration for 24 h all weather capability, easy handling, and pilot assistance
- Flight dynamics code development and validation, and handling qualities evaluation
- Development and operation of ground and flight test facilities

Flight domain limits: VRS study for steep approaches [18]

Specific flight procedures are being studied in order to reduce considerably rotorcraft noise pollution (Noise Abatement Procedures). These procedures are based on several contiguous steep approach segments. However, during steep approaches, rotorcraft can face strong aerodynamic effects which are directly sources of flight envelope limitations. These effects are produced by a specific rotor regime called Vortex Ring State. VRS may be compared to stall on fixed-wing aircraft in terms of the adverse effect on vertical flight path and flight control and has been the cause of several accidents on rotorcraft over many years.

VRS onset is characterized by severe thrust fluctuations, vibrations, rapid and sudden increase in rate of descent due to thrust loss and finally control sluggishness and vibrations. VRS results in a sudden and unintentional drop of the altitude.

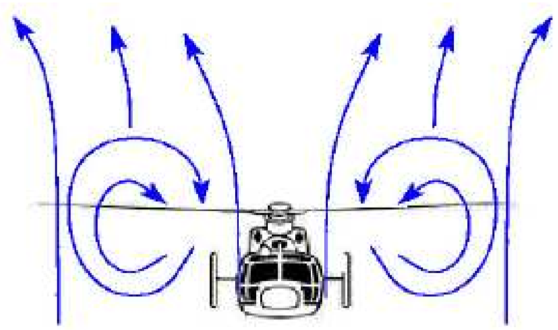


Figure 13 VRS Regime

The risk of VRS occurrence in steep descent was studied at Onera, on a generic helicopter model. The work was based on calculations performed with the HOST code and simplified rotor aerodynamic models adapted to descent flights, using available tools.

These models were used in order to identify, through a sensitivity study, a first set of parameters for modifying the VRS domain.

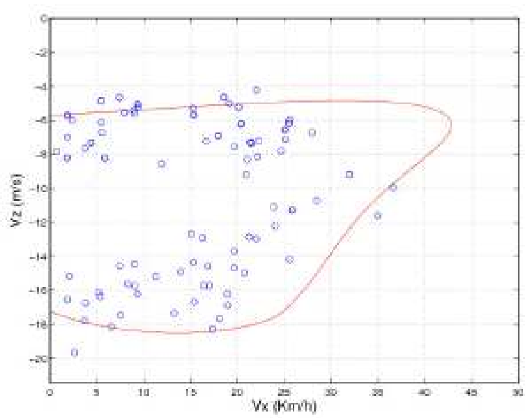


Figure 14 Model prediction of VRS domain

These calculations were compared to Dauphin flight tests in VRS, and some of the selected parameters were already identified as playing a role in VRS domain limits. In addition, the models developed at this time demonstrated their capability to reproduce the trends observed in flight.

Figure 15 D6075 (DGA/CEV) with beam for measurement probes

The studies on flight domain limitation are going on in both organizations, in relation with industry projects.

Pilot assistant systems: example of PAVE (Pilot Assistant in the Vicinity of hElipads) [19]

PAVE is a project for the development of a prototype of a helicopter pilot assistant system in which numerous experts in different areas are involved. The pallet extends from flight control, acoustics, aerial photograph processing, and human factors up to data processing and structure of hardware and integration. Several institutes of DLR are involved in this project. Onera is also participating with a quite low activity.

Flight tests were performed in 2006 and 2007 on the FHS in the countryside of Braunschweig. The validation of the automatic flight guidance with the use of noise abatement procedures is one of the objectives in the context of the flight campaign.

Figure 16 EC135 FHS (Flying Helicopter Simulator)

This study concentrates especially on safe takeoff and landing phases even in very difficult visual conditions.

The main function of the helicopter assistant system is the capability to generate an optimal plan according to different constraints like setting waypoints, defining speed, altitude, and time of arrival constraints at waypoints.

Figure 17 Flight planning with consideration of noise sensitive areas.

As an example, a flight path in terms of an aerodrome circuit has been defined for the flight test campaign to analyze both the flight path performance and the flight technical error especially for horizontal turns. Figure 18 shows a 3D diagram of both recorded tracks: the planned trajectory and the actual flight path. The horizontal deviations depend on the speed, the radius of the horizontal turn, the wind conditions and the kind of realisation of the guidance algorithm.

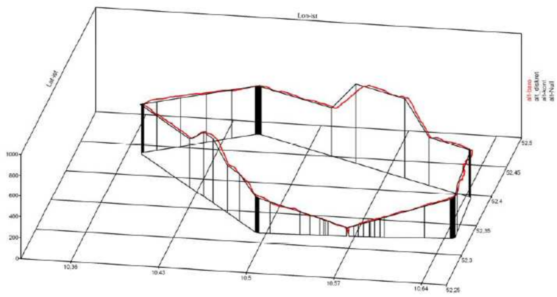


Figure 18 Comparison between preplanned trajectory and manual flow path (3D)

The comparison between variables of state and guidance parameters (altitude, speed, heading, lateral deviation to preplanned flight path) subdivided into different flight phases (after each phase a curve is following) objectives are in good accordance.

The outputs of PAVE are used within the EU project OPTIMAL. This project is dedicated to investigate how helicopters can be merged into the airport traffic management in the future.

The Safe Rotorcraft

This RC addresses safety oriented studies:

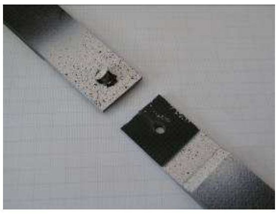
- Studies on helicopter crashworthiness and safety systems
- Studies on all weather flight conditions (Icing codes and experiments for airfoils, rotors, and engine air intakes; lightning aggression, bad-weather sensors)

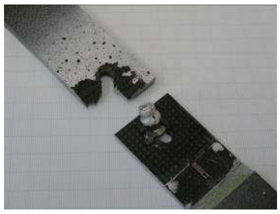
Due to the inherent risky operation of helicopters close to ground and due to the complexity of the aircraft, new helicopters have to demonstrate a high level of crash survivability to fulfill existing crashworthiness specifications. Robust helicopter structures are also required to withstand impact threats during service due to bird strike, ice debris, blast loads, ballistic threats, etc. The studies performed aimed to create a more cost/weight effective method to design crashworthy and robust helicopter structures and to reduce the test requirements for certification/qualification. This is achieved by studying experimentally damage in composite materials and structures under dynamic crash and impact loads to extend the materials database and by developing and validating theoretical tools and FE codes such as PAMCRASH and MADYMO for crash and vulnerability studies.

Dynamic failure in riveted composite joints [19]

Joints are now seen as critical elements for accurate failure predictions in composite aircraft structures under both crash and impact loads due to their load transfer function between structural components. Joint behaviour was studied in a dynamic test programme in the DLR high rate (HR) test machine on specimens with single riveted fasteners in order to study failure modes and obtain basic rivet failure properties. Work has focussed on HiLok® countersunk fasteners used to join carbon fabric epoxy laminate structures, loaded at 0.1, 1 and 10 m/s. Fig. 18 shows failed lap-shear test specimens and typical force-deflection curves in the joint up to complete failure. It is seen that at higher speeds there was a 'shear-out' failure with high energy absorption due to fragmentation in the composite, whilst at the slower speeds the rivets themselves fractured with very little energy absorption.

Tension failure of the same fasteners was also studied by pull-through tests on composite laminates. This data is used to define joint failure properties in shear and tension for global joint models on composite structural assemblies. Plate structures were fabricated with two rows of HiLok® fasteners and these have been dynamically tested under line loading from cylinders and by impact from steel balls. Failure modes in the structure were studied which combine rivet pull-through with shear failure and localised composite damage. Based on this data, simplified joint models were developed for structural failure analysis which were validated by FE simulations of dynamic failure in the simplified fastened plate structures.


Rivet failure (0.1 m/s)


Shear out (10 m/s)

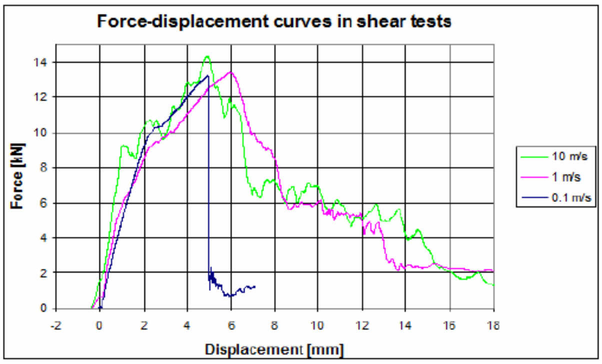


Figure 19 Dynamic shear tests on riveted composite joints showing influence of loading rate

Improved occupant crash safety in helicopters [20]

In the EU project HeliSafe TA, helicopter cabin safety technology is being developed for severe crash scenarios and for realistic cabin and seat configurations. The DLR contribution is concerned with full scale crash modelling in the hybrid code DRI-KRASH of a crash test of a Bell UH-1D, together with development of cockpit models in the simulation code MADYMO for evaluating the effectiveness of new safety features such as airbags and new restraint systems. DLR developed MADYMO models of a helicopter cockpit suitable for analysing occupant response to 'vertical' load crash scenarios for 50%-ile and 95%-ile dummies. The models were verified by comparison with sled test results on a full scale cockpit mock-up carried out at Siemens Restraint Systems, Fig. 19. The influence of different parameters on a new injury index IRSIX was investigated in a sensitivity study. The IRSIX index combines in one parameter 15 different injury criteria like the Head Injury Criterion (HIC) value or the lumbar spine loads according to their importance. In the vertical load cases examined here, the IRSIX value is dominated by the maximum lumbar spine forces and thus mainly dependent on the characteristic of the seat energy absorbers. The influence of different belt related parameters – e.g. belt elongation, pretensioner load, TTF (time to fire), load limiter – was also investigated.

DLR carried out different parametric studies in order to optimise the properties of the energy absorbers used in the cockpit seats and to propose a concept which leads to the lowest possible injury rates for occupants of different weights and sizes. Three different seat energy absorber characteristics (with 'increasing force', 'constant force' or 'decreasing force') were investigated for two different occupant dummy sizes with the IRSIX factor computed for each case. Through this numerical parameter study it was then possible to propose optimised adaptive and non-adaptive attenuator systems to reduce occupant injuries.

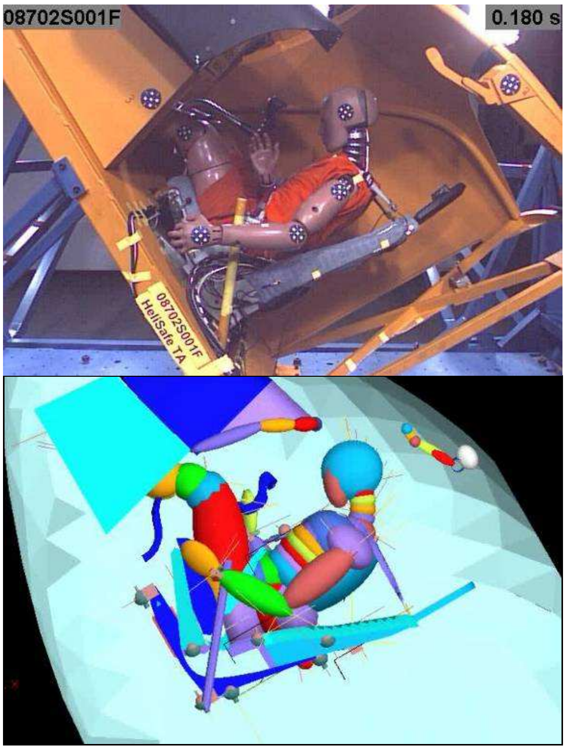


Figure 20 : Validation of cockpit model with sled test pulse representing crash load Vx = 12.8 m/s, Vz = 7.9 m/s, with 50% dummy and 4-Point belt

All Weather Flight Conditions are oriented to safer helicopter operational aspects. They comprise external hazards such as icing/de-icing, lightning, all-weather capability, obstacle collisions, electromagnetic interaction, and - performance related - safe procedures for critical trajectories. Improvements in such areas will also allow the helicopter industry to target new markets and users.

At Onera, tools are available for describing the ice accretion on airfoils. This will lead to an experimental study to measure the influence of blade with ice forms on rotor performance.

These studies, as well as studies on lightning effects on electronic systems and structures will contribute to the certification process for helicopters with validated computational tools.

In parallel, in-flight sensors will be defined to measure critical or dangerous conditions of flight, associated with the restitution of the relevant information to the pilot, by means of an additional function of a pilot assistant.

The Comfortable Rotorcraft

Within this RC vibration and internal noise are studied:

- Prediction codes for dynamics/vibrations of complete rotorcraft
- Internal noise studies and noise reduction means (passive and active)

Vibration prediction using CFD/CSM tools

Vibration level is one of the main ride comfort limiting features of helicopters and the simulation models have to be representative on this matter. This part of work is included in the French project for complete helicopter CFD tool SHANEL (see RC1) with a CSM/CFD coupling.

Vibration reduction by active means [22]

Regarding vibration and noise reduction strategy, the running studies are to develop passive or active absorbers on structures.

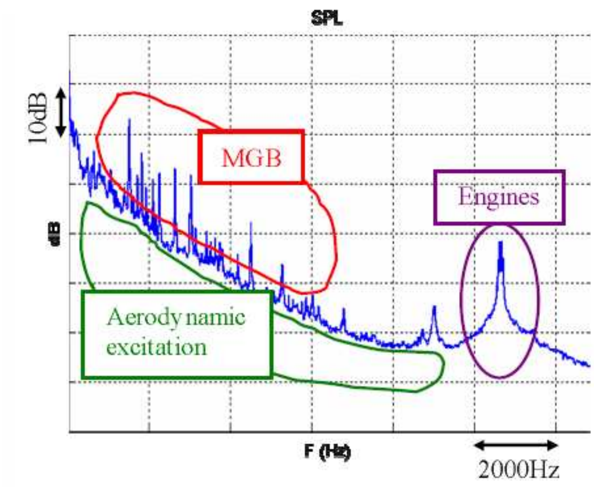


Figure 21 Level and origin of induced vibration and noise, inside the fuselage

The location of actuators is defined according to modal analysis by calculation in order to ensure reduction of radiated acoustic power. But the tools are not yet well adapted to treat conditions of high damping or high modal coupling.

Studies performed within the EU project FRIENDCOPTER used active structural intensity fields to determine a suitable location of absorbers as regards vibration and acoustic aspects. Active panels have been defined. Different types of absorbers have been analyzed prior to define their location in active panels. And 3 locations of the actuators have been tested, depending on locations of sources and sinks. The study demonstrated that the knowledge of internal structural intensity, allowed to place absorbers on active panels with suitable location definition.

The Active Rotorcraft

Several active technologies are developed within this RC to reduce noise and vibration level through blade or rotor modification.

- Studies on active flap, active twist camber rotors
- Applications and testing of actively controlled rotors

Active blades [23], [24]

Individual Blade Control (IBC) for helicopter rotors promises to be a method to increase flight performance and to reduce vibration and noise. A lot of active devices have been studied worldwide. Some of them have already been tested in wind tunnels or on real helicopters. This is the case of active flap rotor designed and manufactured by DLR-Onera and tested by Onera in S1MA [23]. But the drawbacks linked to the "vulnerability" of the mechanical components like hinges, levers or gears in a helicopter environment led to the idea of using smart materials embedded into the rotor blade structure.

The active devices, mainly using piezo actuators can generate a twist deformation of the rotor blade without any friction and wear. In the common DLR-Onera project "Active Twist Blade" (ATB), DLR designed and built a 1:2.5 Mach scaled BO105 model rotor blade incorporating state of the art Macro Fiber Composite (MFC) Actuators [24]. The design of the blade was optimized using a finite element code as well as rotor dynamic simulations to predict the benefits with respect to vibrations, noise and performance. Based on these tools a blade was designed that meets all mass and stiffness constraints.

Figure 22 Active Twist Blade and tip sensors position

The mechanical properties of the blade obtained within the bench tests showed a good correlation between measured and calculated values. The centrifugal tests (see Figure 23) comprised a measurement of the active twist performance at the nominal rotation speed of 1043 RPM at different excitation frequencies from 2/rev up to 6/rev. It was proven, that also under centrifugal loads the predicted twist amplitudes can be achieved (Figure 24).

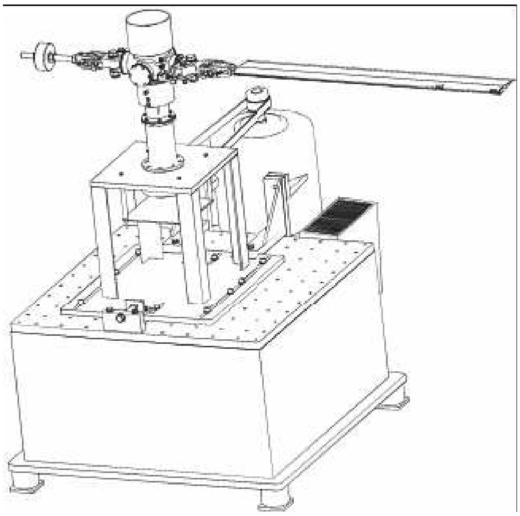


Figure 23 Centrifugal test rig

Parameter	Experiment	Simulation	Ref. (BO 105)
Flap bending stiffness	196 Nm^2	207 Nm^2	250 Nm^2
Torsional stiffness	194 Nm^2	189 Nm^2	160 Nm^2
Twist rate (ΔU = -500..+1500)	2.87 °/m	2.7 °/m	-

Figure 24 Comparison of measured and calculated data of the AT1-Blade

Within this common project, Onera is developing a different technology TWISCA (Onera Patent) for active twist and same centrifugal tests have been performed to evaluate the deformation achieved.

These studies will be pursued to wind tunnel tests with a 4 bladed rotor. Once the efficiency of the technology is demonstrated, the scale 1 implementation will bring new constraints to be studied in strong link with industry.

The Advanced Rotorcraft [25]

Tiltrotor Studies

The core of the studies of this RC are related to tilt-rotor studies within several EU FP funded studies. Developments of systems for autonomous landing of rotorcraft UAVs are also addressed.

A tilt-rotor is an aircraft which can combine both advantages of the good hovering capacity of helicopters and the high speed cruise possibilities of conventional airplanes thanks to the conversion of its nacelles, from the hover position (in helicopter mode) to the cruise position (in propeller mode). Thus, the development of the tilt-rotor technology is challenging. One of the main issues is to understand aerodynamic performance and interactions between the different components.

Therefore, several research programs funded by the EU under 5th and 6th FP aimed to develop competencies in Europe for the new generation of tilt-rotors. The studies are now based on the ERICA half moveable wing concept proposed by AgustaWestland.

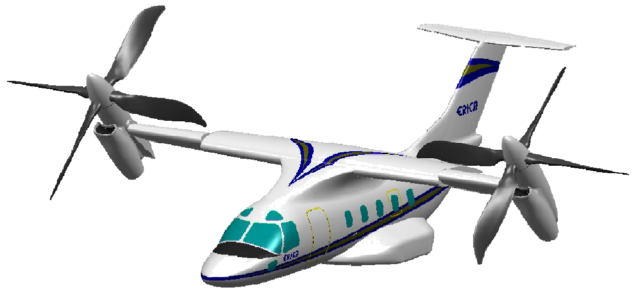


Figure 25 ERICA concept

Measurements were conducted in the 8x6m ¾ open test section of the DNW-LLF wind tunnel on the half-span 40% Mach-scaled model based on the ERICA concept. Several test points in the conversion corridor have been measured with the TILTAERO blades and a comparative study has been done with the aero-acoustic optimized ADYN blades in hover and descent flight.

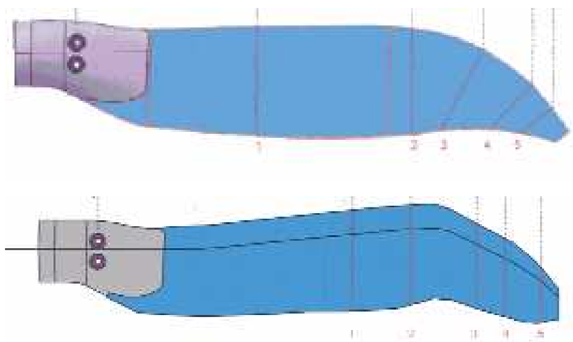


Figure 26 ADYN and TILTAERO blade shapes

Concerning the numerical point of view, Onera used the elsA software and DLR used FLOWer to perform simulations of the complete TILTAERO half-span model. The flight test cases simulated included the conversion corridor, from hover to level flight [25].

Regarding the isolated rotor, advanced numerical methods have also been employed to perform high quality simulations allowing achieving the aero-acoustic performance optimization.

The conversion corridor is the most critical phase of the tilt-rotor flight and the aerodynamic interactions between the rotor, the wings and the nacelle have been studied within the TILTAERO European program.

Moreover, detailed comparisons between numerical and experimental results allow being quite confident in the numerical simulation of the tilt-rotor conversion flight.

The rotor optimization activities carried out in those European programs led to the design of an innovative tilt-rotor equipped with the ADYN blades.

Wind-tunnel tests proved the very good hover efficiency of the ADYN blades compared to the TILTAERO blades. The optimization was based on CFD computations with both elsA and FLOWer. The predicted performance of the rotors correlates well with the experimental data.

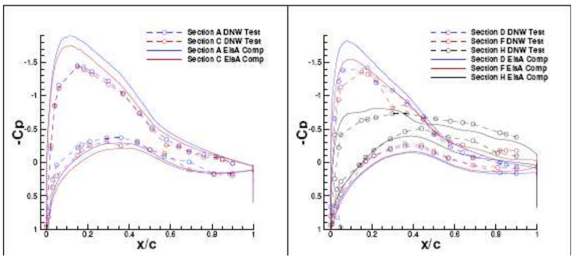


Figure 27 Experimental and numerical pressure coefficient on the inner wing (left) and on the outer wing (right) (conversion case) [26]

With these projects, Onera and DLR are now capable to understand and predict the interaction phenomena during the conversion phase.

The tilt rotor issues are now pursued within the new NICETRIP European project where Onera DLR, Eurocopter, ECD, AgustaWestland and other partners are involved.

Rotorcraft UAVs [27], [28]

In the ReSSAC (Recherche et Sauvetage par Système Autonome Coopérant) project [27], two Yamaha RmaX remote control rotorcraft have been equipped with avionics providing capabilities of autonomous flight, navigation, take-off and landing in prepared area. The project is now working on the problem of autonomous landing in an unprepared area, first with autonomous reactive flight and navigation modules, then with autonomous reactive decision capabilities.

Aircraft (and rotorcraft) operations in adverse environmental conditions may be difficult due to low or bad accuracy of sensors. The ReSSAC aircraft perceives its state in the environment using flight and navigation sensors and embedded computer vision. Relative localization of potential obstacles is achieved by monocular stereovision at higher altitudes and optic flow based algorithms at lower ground heights.

Figure 28 RESSAC autonomous landing with obstacles

Additional experiments have been conducted in order to simulate in flight the decking of a rotorcraft on a virtual mobile deck, the motion of which is emulated by a distant moving platform equipped with an hybrid GPS and Inertial Measurement Unit.

The studies on ARTIS (Autonomous Rotorcraft Testbed for Intelligent Systems) [28] are related to unmanned aerial system that can plan trajectories in urban type scenarios keeping the vehicle below a preset maximum altitude. This is also possible in the case of incomplete or non-existing terrain data bases by the use of sensor based environment mapping. The concept has been tested on the ARTIS UAV testbed using flight test and simulation. The objective is to reduce the burden of UAV operators and to allow operation in areas with temporary data link loss.

Figure 29 ARTIS Flying test bed

The sensor and processing equipment has a very light weight of only 3.5 lbs and has potential for further miniaturization.

The current planning approach needs further research towards effective world sampling techniques, the ability to alter the 3D world model in real time and to adapt mission plans autonomously at mission execution time.

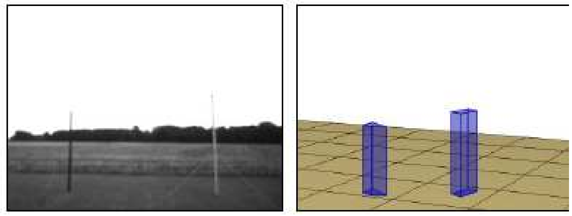


Figure 30 Example of a created map. Original left camera image (left) and resulting 3-D map of the two obstacle posts (right)

The mapping approach uses grid-type and feature-based maps. By integrating sensor data into a grid map and by combining occupied grid cell clusters to features, both advantages of easy sensor fusion and good practicability for obstacle avoidance are achieved. It allows integrating multiple sensors enlarging the detection field and prior knowledge about obstacles to improve the distinction between obstacle measurements and sensor noise.

Future challenges

An important challenge for helicopters is to reduce the environmental impact (fuel consumption, pollution due to engine exhaust, external noise, …).

But the increase of the rotorcraft use relies on:

- Reduction of recurring and non-recurring costs
- Flight domain extension to higher speeds (up to 200 kts)
- Flight domain extension to all weather conditions
- Safety improvement
- Improvement of passenger comfort, such as reduction of vibration level and internal noise.

Onera and DLR will participate to this effort by continuous development of tools (codes and experimentation), expertise and new technologies and concepts.

Conclusion

The examples given above demonstrate the need of multidisciplinary studies to progress helicopter research.

The trends are on “Clean Sky”, addressing environmental issues, such as noise and pollution.

To have a reliable noise prediction requires a high level wake simulation. To apply low noise flight procedures in day to day helicopter operation, a pilot assistant is needed. Active and passive (shape) optimization of the main rotor blades still have a large potential for performance improvement and noise reduction.

This cooperation between Onera and DLR works now for a long time and has seen a renewal of the teams. The exchanges between scientists in the relatively small world of the rotorcraft research community enhanced technical progress by adding competencies and running common analysis.

Besides this, the effect of having strong links with the major helicopter manufacturers is two fold: to be on the right path for technological progress and to have a short transfer time of new tools and technology to industry use.

But, rotorcraft technology still requests breakthrough technologies to improve its use and market development as well as to make it compliant with the new environmental requirements.

Acknowledgments

These 8 years of Common research activities were possible only because of the strong involvement of the research teams.

The authors would like to express their thanks to the researchers from Onera and DLR involved in these tasks. These day to day cooperative works rely on the willingness of DLR and Onera researchers to work together for the benefit of helicopter research.

The authors strongly invite the interested reader to refer to the papers given in the reference list for further technical details.

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