FRIENDCOPTER

Publishable Final Activity Report

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Publishable Final Activity Report

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Project ref: 502773
Acronym: FRIENDCOPTER
Title: Integration of technologies in support of a passenger and environmentally friendly helicopter

Co-ordinator:	VERTAIR	VER	BE
Contractors:	Eurocopter Deutschland	ECD	D
	AGUSTA	AGU	IT
	ANOTEC	ANO	ES
	CIRA	CIRA	IT
	DLR	DLR	D
	Daher L'hotellier	DLA	F
	EADS	EADS	D
	Eurocopter SAS	EC	F
	Free Field Technologies	FFT	BE
	Formtech	FOR	D
	Aernnova (formerly Gamesa)	AES	ES
	Aircelle (formerly Hurel-Hispano)	ACL	F
	INECO	INE	ES
	Inst. de Soldadura e Qualidade	ISQ	PT
	ISDEFE	ISD	ES
	Paulstra	PAUL	F
	LMS	MS	BE
	NLR	NLR	NL
	NOLIAC	NOL	DK
	ONERA	ONE	F
	PZL-Swidnik	PZL	PL
	Turbomeca (TM)	TM	F
	VZLU	VZLU	CZ
	Westland Helicopter	WHL	UK
	ZF Luftfahrttechnik	ZFL	D
	Cranfield University	CU	UK
	Inst. Superior Technico	IST	PT
	Kungl Tekniska Högskolan	KTH	S
	Politecnico di Milano	POLIMI	IT
	University of Oldenburg	UNOL	D
	University of Patras	U-PAT	EL
	RIGA-TU	RIGA-TU	LV
	University Roma Tre	U-ROM	IT
Website	http://www.friendcopter.org/		

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Starting date: 1st March 2004   Duration: 69 months
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List of Abbreviations

ACT-FHS	Active Control Technology Demonstrator - Flying Helicopter Simulator
Ansys tool	Software tool for Finite Element analysis (Numerical Simulation)
ARHIS	Onera Aerodynamic Code
ATT	Active Twist Team
BVI	Blade Vortex Interaction conditions
Catia V4	Software platform produced by Dassault, v4 = version four
CAATS	Cooperative Approach to Air Traffic Services
CDR	Critical Design Review
CFRP	Carbon Fibre Reinforced Plastic
CMS	Cut multilayer stack
CSWP	Common Software Platform
DoW	Description of Work (Annex I of the EU contract)
DSP	Digital Signal Processing
ERF	Electro Rehological Fluid or European Rotorcraft Forum
EPNL	Effective Perceived Noise Level
EPNdB	Effective Perceived Noise Level in dB (dB== Decibel)
EUROPA 2000	Helicopter flight performance code
FAA	Federal Aviation Administration of the USA
FACE	EU Project (Friendly Aircraft Cabin Environment)
FPR	FRIENDCOPTER Internet Repository (Internet storage of documents)
GFRP	Glass/graphite? Fibre Reinforced Plastic
HART	International Project on Blade Vortex Interaction (BVI)
HEACE	EU Project (Health Effect in Aircraft Cabin Environment)
H/C	Helicopter
Helena	Helicopter Environmental Noise Analysis (common software platform developed in WP2)
Helishape	EU funded project on
HESOPE	Helicopter External noise Simulation of Operations for Protection of Environment
HIS	Hihj-Speed Impulsive Noise
HM	High Modulus
HOST	Software which is enabled to receive additional modules
IDE	Interdigitated electrodes
ICAO	International Civil Aviation Organization
ICCAIA	International Coordinating Council of Aerospace Industries
INM	Integrated Noise Model. FAA has developed this software with support from VOLPE
INM-HNM	Helicopter Noise model. FAA has developed this software with support from VOLPE
IPR	Intellectual Property Rights
LPS	low profile stack
MESIR	Onera Aerodynamic free wake code
MENTHE	Onera Vortex roll-up modelling code
MIMO	Multiple Input Multiple Output (Control)
MFC	Macro fibre composite
MSR	Model and Simulator Repository
MTOW	Maximum Take-Off Weight
NDA	Non disclosure Agreement
NITINOL	nickel-titanium alloy developed by NIckel TItanium Naval Ordnance Laboratory
NVH	Noise Vibration and Harshness
NOISEMAP	Noise calculation software
PDR	Preliminary Design Review
PARIS	Onera Acoustic Code
PZT	lead-titanate-zirconate (special kind of piezoceramic material) or piezoelectric
RT-AI	Real Time Application Interface
RTU	Riga Technical University
SACLD	Segmented Active Constrained Layer Damping
SEA	Statistical Energy Analysis
SILENCER	EU funded project on aircraft noise reduction
Simulink	Matlab-based software for dynamic systems analysis (www.mathworks.com)"
SMA	Shape Memory Alloy
SOPRANO	Common Software Platform, developed in Silencer
T.E.	Trailing Edge
TPA	Transfer Path Analysis
VAM	VibroAcoustic Modelling
VRS	Vortex Ring State
VOLPE	Org. within US Dept. of Transportation, research and special programmes
WP	Workpackage
w.r.t.	with respect to

1 OVERVIEW

Helicopters generate external noise, cabin noise and vibrations due to the complex nature of their dynamic systems. They suffer from NOx emission, like other transport systems. New generation rotorcraft address these issues trying to become environmentally friendly and acceptable to the general public.

On the other hand, modern society needs the helicopter due to its ability to fly medical, rescue and law enforcement missions. The related flight profiles typically close to populated areas require however the environmental enhancements described above. The IP FRIENDCOPTER was intended support this process by addressing the following goals:

- Acoustic footprint areas reduced between 30% and 50% depending on the flight condition,
- A reduction of fuel consumption up to 6 % for high speed flights,
- Cabin noise levels near 75 dBA similar to airliner cabins for normal cruise flight and
- Cabin vibrations below 0,05 g corresponding to jet smooth ride comfort for the same flight regime.
-

Because of the large and fast rotating rotor, the non-symmetric rotor flow, the close vicinity of main gearbox and passenger heads and the specific requests of maximum engine performance, the targets mentioned above were highly challenging, requiring a strong high tech initiative.

Main Challenges

The main challenges of today's helicopters with respect to environmental compliance and public acceptance are:

- Annoying external noise emissions in form of the so-called blade slapping, especially during descent – i.e. near the ground - and during flight manoeuvres,
- Compressor and combustion noise stemming from the engines,
- Significant NOx emissions by these engines,
- High cabin noise levels provoked mainly by the unsteady forces at the main gearbox wheel teeth, and
- Significant vibration levels caused by the non-symmetrical and unsteady rotor aerodynamics.

Main Activities

The activities envisaged can be split into two sections:

The Friendly Helicopter as short term goal, i.e.:

- The noise abatement flight procedures
- The reduction of engine noise by acoustical treatment of engine inlet and outlet
- The cabin noise reduction

The Friendly Helicopter as long term goal, i.e.:

- The lowering of impulsive exterior noise, of excessive cabin vibrations, and of high fuel consumption by rotor blades controlled by high frequency actuation distributed along the outer blade surface.

The programme's work break down structure is depicted in Figure 1. Table 1 summarises the structure of the consortium
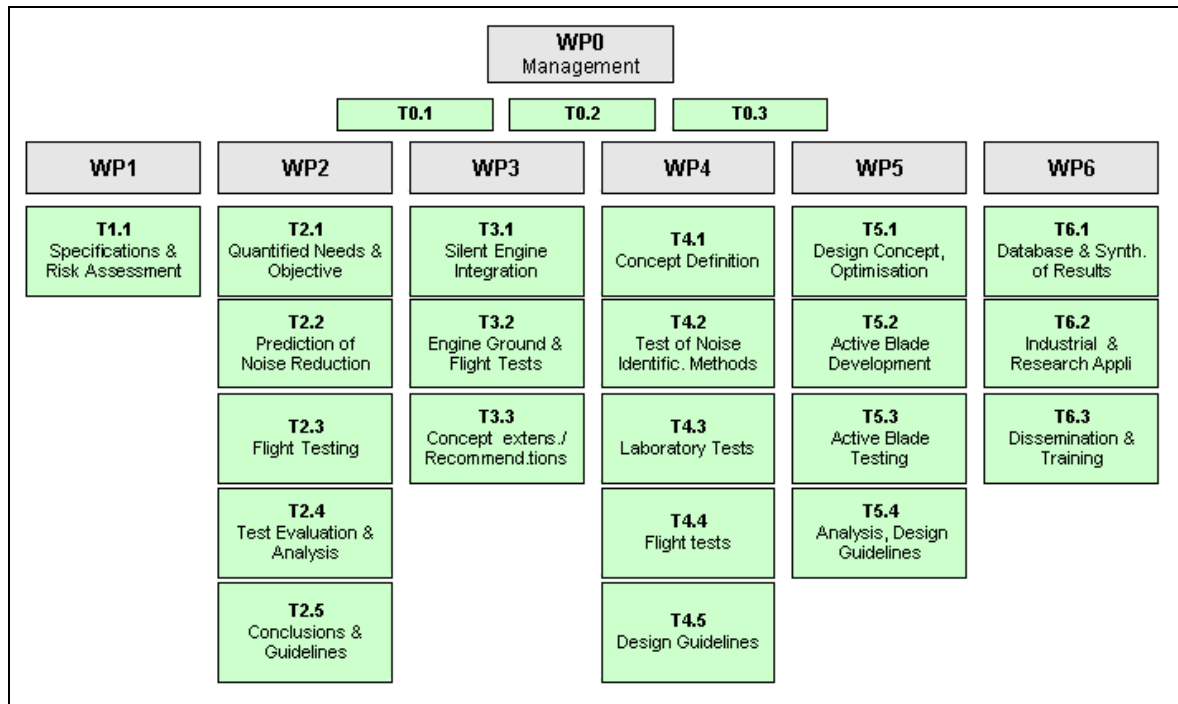

Figure 1 Organigram of FRIENDCOPTER workpackages

Table 1   lists contractors and subcontractors of Friendcopter.

Nr	Organisation	Abbreviation	Country
1	VERTAIR (Coordinator)	VER	Belgium
2	Eurocopter Deutschland	ECD	Germany
3	AGUSTA	AGU	Italy
4	ANOTEC	ANO	Spain
5	CIRA	CIRA	Italy
6	DLR	DLR	Germany
7	Daher L'hotellier	DLA	France
8	EADS	EADS	Germany
9	Eurocopter SAS	EC	France
10	Free Field Technologies	FFT	Belgium
11	FormTech GmbH	FOR	Germany
12	Aernnova Engineering Solutions, S.A (formerly Gamesa)	AES (GAMESA)	Spain
13	Aircelle (formerly Hurel-Hispano)	ACL (HH)	France
14	INECO	INE	Spain
15	Inst. de Soldadura e Qualidade	ISQ	Portugal
16	ISDEFE	ISD	Spain
17	Paulstra	PAUL	France
18	LMS	LMS	Belgium
19	NLR	NLR	Netherlands
20	NOLIAC	NOL	Denmark
21	ONERA	ONE	France
22	PZL-Swidnik	PZL	Poland
23	Turbomeca I	TM	France
24	VZLU	VZLU	Czech Republic
25	Westland Helicopter	WHL	United Kingdom
26	ZF Luftfahrttechnik	ZFL	Germany
27	Cranfield University	CU	United Kingdom
28	Inst. Superior Technico	IST	Portugal
29	Kungl Tekniska Högskolan	KTH	Sweden
30	Politecnico di Milano	POLIMI	Italy
31	University of Oldenburg	UNOL	Germany
32	University of Patras	U-PAT	Greece
33	RIGA-TU	RIGA-TU	Latvia
34	University Roma Tre	U-ROM	Italy

2 ACTIVITIES AND RESULTS

2.1 Overall methodology

Short Term objectives

Noise Abatement Flight Procedures

By dedicated flight procedures, the most annoying impulsive noise (blade slap noise) during approach was tackled. A combination of glide path angle and flight speed tries as far as possible to circumvent the area of high blade slap. The procedures were demonstrated in flight by different helicopter types and can now be introduced in the respective flight manuals.
A new semi-empirical noise footprint prediction tool was established, envisaged to issue by and by the noise emission data of all relevant helicopter types for heliport planning, certification, acoustic flight procedure optimisation and quiet design.

Cabin Noise Reduction

The reduction of the cabin noise level was addressed in a twofold way, viz.:

- by tackling cabin noise emission at the source:

  In order to favourably influence the emission characteristics of the gearbox as main source, its elements were modified and damping features were added. In addition, at the interfaces between gearbox and fuselage active and passive elements were implemented to interrupt the transmission of structure-born noise. Dedicated tests were performed by several partners on rigs and in flight on different helicopter types.

- by reducing cabin noise in the cabin:

  By applying optimised cabin panel materials and stiffnesses, by improved seals, as well as by active structural control acting on the panels, structureborne and airborne noise were reduced. In order to focus the cabin treatment measures on critical areas, methodologies to simulate noise fields and transmission losses as well as to identify acoustic leaks were developed. These methodologies and the effectiveness of the cabin treatment were verified by on ground and by flight testing of different helicopter types.

Engine Noise Reduction

To improve performance, for an engine with a so-called plenum chamber inlet, an additional lateral aperture was developed. This opening as well as the engine's outlet duct was noise proofed by noise absorbing treatment sheets.
Bench and flight tests proved the efficiency of the actions taken.

Long Term Objectives

Active Blade Control

In order to accomplish in a long term approach:

- Larger noise reductions during approach flight
- Lower NOx emission and
- Minimised cabin vibrations

the technology of Active Blade Control (ABC) through actuation distributed along the blade surface or parts of it was brought to maturity and validated. This technology allows:

- to blow away the blade tip vortices responsible for the blade slap noise,
- to use thin blade tips but to delay flow separation on the retreating side by reducing high blade incident angles leading to lower power requirement, as well as
- to generate secondary excitation loads counteracting the original unsteady forces and moments at the rotor hub.

For this reason, piezo-ceramic actuators were integrated into the rotor blade:

- as benders in form of active trailing edges
- as sheets on upper and lower blade sides to provide active blade twist

The tests conducted incorporated:

- for the active trailing edge technology: the investigation of integration aspects by blade rig tests of full scale blade segments and
- for the active twist technology: the study of the controllability of the rotor blades through spin tests of a model rotor blade in hover conditions.

These tests yielded a decision point for a continuation within the JTI Clean Sky in the Green Rotorcraft platform.

2.2 Workpackage overview

WP1 - Specifications

Objectives

The objectives of workpackage 1 were:

- to ensure a well defined and harmonised start of the project by confirming and quantifying the project targets and key deliverables envisaged through the main helicopter manufacturers and the engine manufacturer,
- to provide guidelines for an overall integrated research approach on development and operation of environmentally friendly helicopters by specifying the methods to be applied,
- to take precautions against technical imponderabilities by a risk assessment with respect to the methods applied and by identification of potential alternative procedures.

Methodologies and approaches employed

The following methods were used:

- the provision of guidelines for the work planning of the other workpackages,
- rough quantification of the final results expected in the different workpackages
- specifications of the methods planned including risk assessment.

Achievements related to the state-of-the-art

A specification report defining targets and methods of the programme was issued.

Impact on industry or research sector

Industry and research institutions were enabled to follow in their research and development work clearly defined guidelines.

WP2 - Noise Abatement Flight Procedures

Objectives

WP2 is concerned with the reduction of noise on the ground through operational means (noise abatement procedures), and the prediction of the acoustic impact of such rotorcraft flight operations. Specifically, WP2 aims to:

- Develop methodologies for the design of operationally viable noise abatement procedures,
- Design and validate the necessary prediction tools to assess the acoustic impact of rotorcraft flight procedures on the ground and assist in the development of low-noise flight procedures.

In terms of noise reduction, the objective is to reduce acoustic footprint areas between 30% and 50% depending on the flight condition.

Methodologies and approaches employed

The tasks within this workpackage were split into three main topics, viz.:

1. Identification of the needs and specific objectives relating to noise abatement procedures,
2. Development of the models needed to predict the noise emitted by helicopters during various phases of flight and the tools necessary to design low-noise flight procedures and
3. Full scale flight tests on different helicopter models in order to provide noise data to the prediction models and assess the low-noise procedures

1. Identification of the needs and specific objectives relating to noise abatement procedures

Within this task, a review of the state-of-the-art of helicopter acoustic measurement and prediction methodologies was performed and the needs and expectations relating to noise abatement procedures were identified. A thorough review of the existing national and international regulations was also conducted in order to clearly put in context the expected improvements resulting from this workpackage. In order to gather feedback in terms of the expectations concerning helicopter noise, a thorough survey was conducted, which yielded answers from operators, local and national legislators, as well as airport management officials. In addition to this survey, two public workshops were organised early in the project to discuss the project with the main European and international experts, legislators, and rotorcraft operators.

The main psycho-acoustic characteristics of rotorcraft noise were reviewed with respect to existing metrics, with the objective to identify the most appropriate noise metric for the assessment of noise abatement objectives.

2. Development of the models needed to predict the noise emitted by helicopters during various phases of flight and the tools necessary to design low-noise flight procedures

This task was separated into different subtasks (a – c), grouped into distinct activities:

a) The improvement of computational tools

Complex aeroacoustic prediction codes are often used in order to obtain a preliminary assessment of the potential impact of design changes or new flight procedures before resorting to flight test. Within FRIENDCOPTER, some of these tools were improved and validated against flight test data. It was for example demonstrated that blind predictions resulting from these aeroacoustic codes could be used to determine which specific flight conditions could lead to lower noise within the flight envelope of an aircraft.

b) The development of a common software package for environmental impact studies (HELENA – HELicopter Environmental Noise Analysis)

Once the noise source is fully characterised (either by complex prediction codes or noise measurements), a tool is required to allow the assessment of the impact of a given flight procedure on the ground. For helicopters, this is very complex, because the noise source can change dramatically in level and direction according to the flight condition, helicopter type, and atmospheric condition. Therefore, a new and powerful tool, called HELENA (HELicopter Environmental Noise Analysis) was developed for that purpose. It allows the users to plot noise footprints on the ground for a given flight procedure and aircraft type, with a much higher degree of precision than existing tools. The partners of this project can for example use HELENA to study the impact of new designs or of a design change on a helicopter, or separate the various sources on the helicopter (e.g., main rotor, tail rotor, engine) and assess the contribution of each individual source. A public version of the code was also developed for land-use planning studies (representing an expected new noise certification measure), featuring an easy-to-use graphical user interface (see Figure 2).
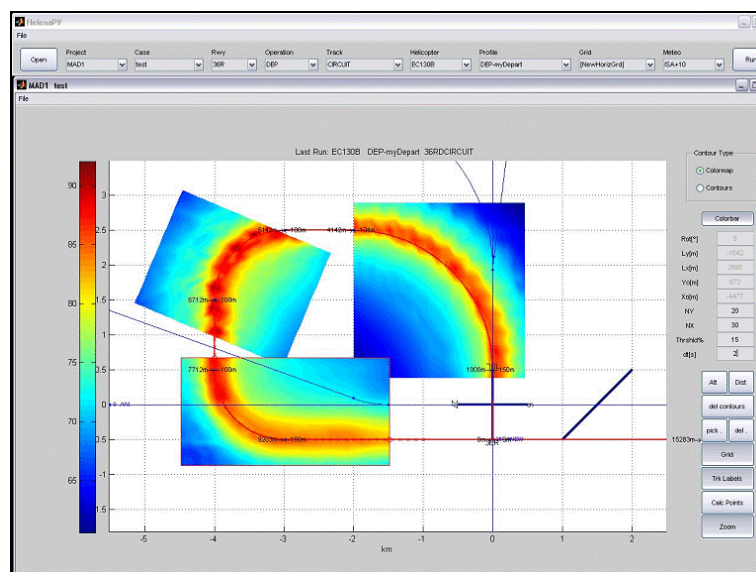

Figure 2 Sample screenshot of the HELENA public version software.

c) The implementation of noise footprint minimisation capabilities

The ultimate goal of this workpackage is to reduce the noise on the ground by using alternative, low-noise flight procedures. Based on computational tools and environmental impact assessment codes, various strategies were used to design noise abatement flight procedures, i. e.: from simplified empirical models that take advantage of the existing knowledge of a particular helicopter model to powerful fully automatic optimisation codes

that are able to take into account amongst others different atmospheric conditions. In all of these methodologies, priority was of course given to ensuring safety of flight throughout the procedure.

3. Full scale flight tests on different helicopter models in order to provide noise data to the prediction models and assess the low-noise procedures

A total of five acoustic flight campaigns were performed on three different helicopter models (EC130, A109, and EC135). These flight tests were some of the most extensive rotorcraft acoustic tests ever conducted. Two approaches, representing different standards, were used for the flight test: the 'manufacturer approach' and the 'research approach'.
In the first approach (on the EC130 and A109 (
Figure 3) the flight tests were split into a data gathering phase for steady-state flights on a simplified microphone array, and a manoeuvring flight / noise abatement validation phase on a large two-dimensional microphone array. Noise abatement procedures were developed and validated, with the aim to provide straightforward guidance to the pilot and also to assess flight testing methodologies relating to noise abatement and land-use planning purposes. In addition to allowing for the development of noise abatement procedures, the high quality data resulting from these tests were used to enrich the database of the HELENA prediction tool.
For example, from the analysis of the EC130 flight test results it was shown that for the initial takeoff segment alone, the proposed noise abatement procedures reduced the loudest noise contours by at least 50%. For a given observer location under the flight path, a noise reduction of up to 10dB (in Effective Perceived Noise Level, EPNL) was demonstrated on that segment alone.

Figure 3   Flight tests: EC130 at La Fare airfield (left) & A109 at Cameri airbase

In the second flight testing approach (on the EC135 helicopter), emphasis was placed on taking into account all the complex physical parameters involved in noise generation and propagation and integrate these parameters in an automatic optimisation chain. Basic 'flyability' and comfort limits were applied, but the operational constraints were relaxed in order to assess the full potential of noise abatement procedures.

The results from these flight tests on the EC135 (Figure 4) were also very good. Indeed, at certain ground locations, a reduction in Sound Exposure Level of more than 10 to 12dB was observed (in Sound Exposure Level, SEL). Complete noise abatement approach procedures yielded more than 50% area reduction on the loudest noise contours with

respect to a baseline approach. This complies with one of the major research objectives of the programme.

Figure 4   EC135 at Cochstedt airport during flight tests

In addition to assessing the optimised flight paths, a flight path guidance system was developed (screen with tunnel-in-the-sky - Figure 5) to allow precise execution of the chosen noise abatement procedures. This high-tech system proved a valuable aid to the pilot.

Figure 5   View of the tunnel-in-the-sky guidance system installed in the EC135

For the flight test results and databases, a 'variables dictionary' was developed in order to facilitate data harmonisation and exchange, as well as streamline the interface between the various prediction and analysis codes. This generic rotorcraft dictionary will be made publicly available following the conclusion of FRIENDCOPTER.

Achievements related to the state-of-the-art

- A new noise footprint model was developed and validated (HELENA). This model takes into account the complexity of noise generation specific to rotorcraft.
- Fully automatic optimisation routines were demonstrated for the development of noise abatement procedures.
- Extensive noise measurement means were deployed and guidance was provided for future noise campaigns.
- Flight guidance hardware dedicated to noise abatement procedure was developed and successfully flight tested.
- Considerable noise footprint reduction was demonstrated on all three aircraft through the use of noise abatement procedures (up to 50% noise footprint reduction, more than 10dB reduction at specific observer locations).

Impact on industry or research sector

- A new tool is available (HELENA) for noise footprint prediction, for methodologies of automatic low-noise procedure design as well as for quiet helicopter layouts.
- The computational tools available for rotorcraft noise predictions have been improved.
- The lessons learned from flight tests will allow future tests to be performed at lower cost, with better resulting data quality.
- Noise abatement procedures for VFR flight are now available for the EC130, A109, and EC135, ready to be implemented in the flight manuals.

WP3 – Engine Noise Reduction

Objectives

The objective of WP 3 is to reduce a component of helicopter noise, relevant mainly during take-off and climb, i.e. the noise emitted by the helicopter engines. To accomplish this, the goal must be to reduce both the noise emitted by the air intake (compressor noise) and the one stemming from the engine's outlet nozzle. The new design should also reduce the existing engine installation losses (pressure losses of a plenum chamber-type engine inlet, particularly by unintended temperature increase through contiguous ancillary units (see air flow in
Figure 9). The performance gained hereby was to compensate the take-off mass increase evoked by the acoustic technologies envisaged. Hence, two noise sources had to be addressed (Figure 10).

The corresponding approaches started off with engine static tests and ended with flight tests. As final deliverables, there were expected:

- Design proposals for appropriate inlet and outlet geometries,
- Liners for quiet air intakes and exhaust nozzles
- Related recommendations for airworthiness and performance aspects

Methodologies and approaches employed

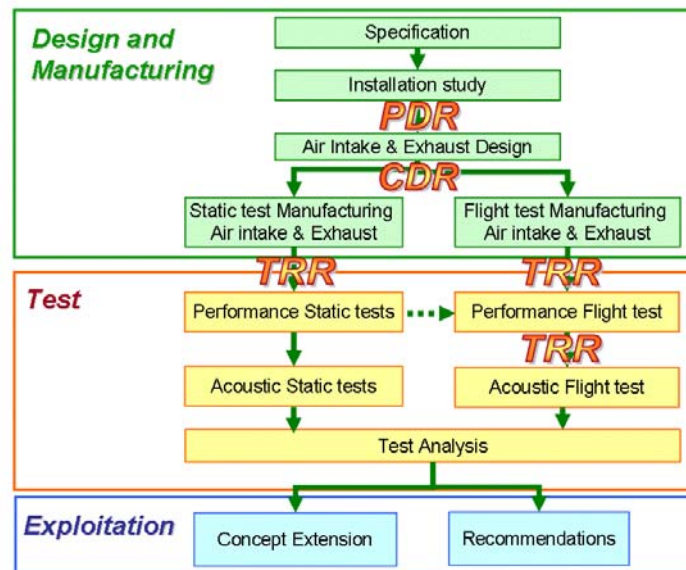To accomplish such goals, the following steps have been used (see Figure 6).

Figure 6   Methodology toward a more silent engine. PDR: Preliminary Design Review, CDR: Critical Design Review, TRR: Test Readiness Review

Design and Manufacturing

Design and manufacturing was split between engine inlet and outlet:

Exhaust

The EC135 is a twin-engine helicopter equipped with an ejector downstream the engine nozzle (Figure 7). The specific design constraint was to keep the same interface between

for the new silent hardware and the serial one; in particular, the exterior shape of the helicopter could not be modified.

First, an acoustic study was performed in order to determine which area is best suited to host an acoustic treatment (liner with frequency-adapted cavities). This study provided the surface parts on which the liner could be placed as well as the liner definition (cavity depth and definition of the perforated cover plate).

 The technology demonstrated in Friendcopter is based on the use of an acoustic liner on the ejector itself. Its shape was modified in a way to comply with the installation constraints, i. e. the conservation of mainly engine performances and engine bay ventilation. The quiet ejector (Figure 8) is made out of high temperature titanium using amongst others Super Plastic Forming, a technique mastered by partner Formtech while the rest of the manufacturing was performed by partner Aircelle.
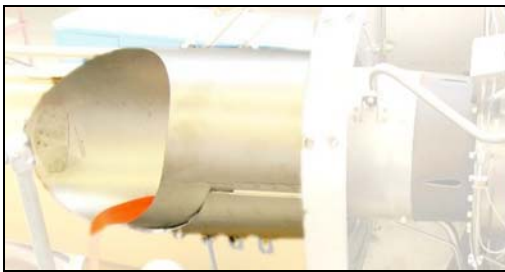

Figure 7   Serial Arrius 2B 2 ejector

Figure 8   Quiet Arrius 2B 2 Ejector

Air intake

In order to recover the mass added by the acoustic treatment of the ejector, the performance of the engine had to be raised. The related air intake modification consisted in an additional lateral intake supplying fresh, cool air directly to the compressor chamber (
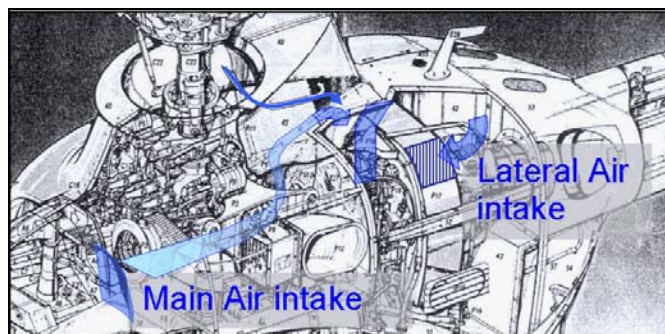Figure 9). This limits the pressure losses of the standard plenum chamber inlet.

Figure 9   Location of the additional lateral air intake (drawing from Flight International)

Since the new opening to the compressor chamber would represent a new noise source, jeopardizing the benefit of the quiet ejector, it had to be sound proofed.

Figure 10 Two technologies tested on the EC135 with Arrius2 engines: static silent air intake and quiet ejector

Tests

The tests - static and in-flight - yielded the following results:

- The static performance test results allow to identify the mass flow and the characteristics of the ejector, and to verify that the pressure distortion criteria remained within the engine installation manual. The measured mass flow splitting between both air intakes resulted in a substantial power increase.
- Flight performance tests confirmed the results found during the static tests for low speed and hover conditions. For higher speeds, this correlation decayed, since the main air intake would beneficiate from the helicopter velocity, in contrast the lateral air intake.
- Static acoustic tests show an exhaust noise attenuation of 2.6 PNdB at 150m sideline at take-off conditions and a dramatic reduction of the lateral air intake noise by the liner (up to 10 dB of acoustic power compared to the untreated lateral opening). Thanks to a large, moveable antenna developed by ONERA (Figure 12) knowledge of the engine directivity pattern could be gained, unknown before.
- For take-off, the acoustic flight tests demonstrated a noise reduction of 1.3 EPNdB. The identification of the relevant noise sources during flight was achieved by the acoustic antenna of partner EADS-IW (Figure 11).

Generally speaking, it can be stated, that the objectives formulated in the beginning of the programme could be accomplished.
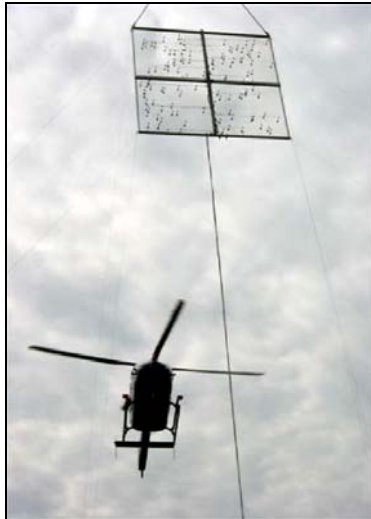
Figure 11 EADS-IW acoustic antenna for flight tests

Figure 12 ONERA acoustic antenna for static tests

The exploitation of the results achieved is described in the following:

Achievements related to the state-of-the-art

There are currently no turboshaft silent technologies flying on serial helicopters. Therefore, the demonstrated technologies have no known equivalent in helicopter industry.

The exhaust liner made of titanium alloy beneficiated from the know-how acquired during the EU HORTIA program as well as from a technology transfer from the airplane industry. The new manufacturing process developed in Friendcopter for integrating acoustic liners in composite material reduces the manufacturing time and costs, increasing the technology's attractiveness and enabling the product to be offered to a broader range of potential applications.

An important outcome of the project is also the improvement of the state of the art measurement techniques through the use of acoustic antennas that allow the development of new methodologies to determine engine acoustic power both during static tests and in flight (see Figure 12 and Figure 11).

Impact on industry or research sector

The results accomplished validate 10 years of engine noise research. The technologies demonstrated are now ready to be embedded in new designs due to quantified evidence of their efficiency.

The results of the silent lateral air intake provide support for specific configurations of similar geometry, such as filters. Industry will also benefit from the technology developed for: the integration of acoustic liners into any kind of composite hardware, allowing an even broader application than aeronautics only. The newly developed one-shot process reduces the manufacturing time making such technology affordable for a broader range of application.

The workpackage's work share between the participating partners is highlighted in the following:

Company	Main Task/Field of expertise
Agusta-Westland	Specification
ANOTEC	Acoustic Flight test expertise
Aircelle	Technological study of the quiet exhaust and titanium exhaust manufacturing
Cranfield University	Aerodynamic calculations
Daher Group	Technological study of the quiet air intake and composite manufacturing
EADS-IW	Noise source localisation and quantification techniques (Source Distribution Modelling algorithm), source breakdown algorithm and signal processing.
Eurocopter Deutschland	Helicopter provider, Specifications, general support on the design including aerodynamics calculations, integration, investigation. Flight tests.
Eurocopter France	Specification
Formtech	Super Plastic Forming of high temperature titanium
FFT	Support in the acoustic analysis and provider of the acoustic propagation software ACTRAN
IST	Thermal/Mechanical calculations
ONERA	Acoustic antenna for directivity measurements and signal analysis.
Turbomeca	Engine provider, specifications, installation study. Engine static tests.

WP4 – Cabin Noise Reduction

Objectives

The objectives of WP 4 were to enhance the helicopter cabin interior environment of present and new helicopters by increasing the ride comfort of the passengers or in the case of medical transport or emergency missions by facilitating the conversation between medical staff and patients.

The work performed in this workpackage fully complies with Annex I - Description of Work (DoW) even if the envisaged cabin noise reduction could not be achieved hundred percent. On the other hand, additional work, originally not planned, was performed, because it was considered to enable a better understanding or to better support partners' work.

Examples of modifications to the original DoW were the Virtual Helicopter Sound or the in-flight Transfer Path Analysis (TPA) on A109. They substituted the originally planned Operating Modal Analysis because they were considered to have a better connection to the other activities.

As reported in the DoW, the expected results in WP4 were to:

- Identify acoustical leaks and noise transmission paths,
- Tackle the dominating cabin noise source at its origin, i.e. the main gearbox noise,
- Actively interrupt the transmission of structure-borne noise from gearbox to fuselage,
- Actively and passively damp by cabin trim panels the noise having overcome the above barriers and reached the cabin structure.

In order to achieve these objectives, the mutually connected activities shown in Figure 13, were performed.
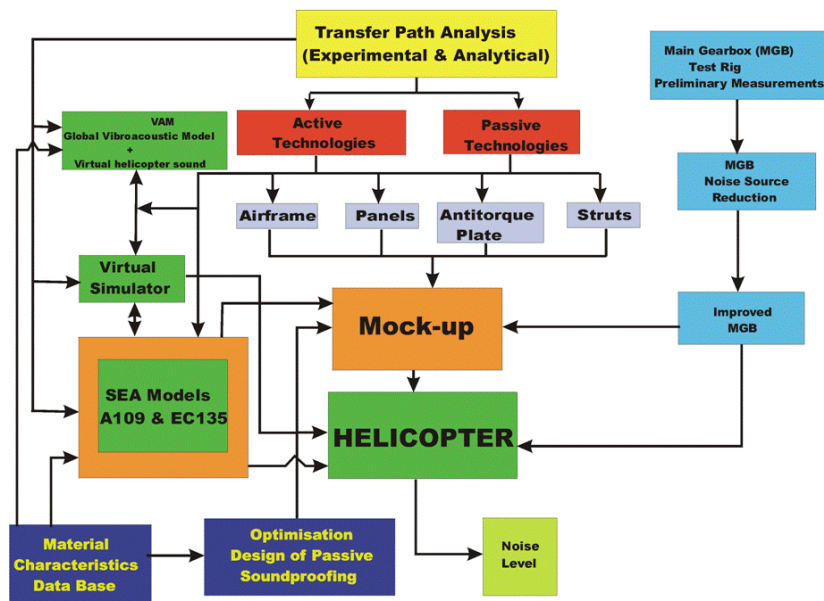

Figure 13   Inter-connection between various activities

Methodologies and approaches employed

As described in the DoW, a number of methodologies and approaches were used:

- Experimentally validated methods/technologies to identify acoustical leaks and noise transmission paths have been tested on real helicopter cabins.
- To reduce the dominating cabin noise source at its origin, the serial gearboxes of the Agusta A109 and the Eurocopter EC135 have been modified. At the A109, mainly gear profiles have been optimised and tolerances minimised while at the EC135 gearbox, mass and stiffness tuning as well as a reduction of the oil cooler fan noise have been main issues.
- Active and passive technologies have been used:
  - To interrupt the transmission of structure-borne noise from the gearbox to the fuselage and
  - To damp the noise which has overcome the above barriers and has reached the cabin structure, by use of cabin trim panels?

In the following (paragraphs a - d), a detailed description of the technologies applied is given.

a) Identification of acoustical leaks and noise transmission paths.

For the identification of structural and acoustic transmission paths a real helicopter (EC 135) and both a mock-up and a real helicopter (A 109) have been used (Figure 14). The method used is known from other means of transportation as the "Matrix Inversion Method". This method has been applied here for the first time to helicopters being particularly complex structures. The approach considers the helicopter gearbox as the main source affecting cabin vibro-acoustic comfort and focuses on the structural joints connecting the gearbox to the helicopter frame, corresponding to the main transmission paths (see Figure 15).

Figure 14   Helicopters used for experimental TPA. A109 (left), EC135 (right)

Problems in the application to helicopters were highlighted and the validity of the method was confirmed. However, the experimental activity is very time consuming, requiring the availability of the test helicopter over a long period. Therefore, to calculate the transmission paths into the cabin by an alternative approach, Statistical Energy Analysis models (SEA models) for EC 135, A109 and the civil version of the EH 101 were developed and experimentally validated.
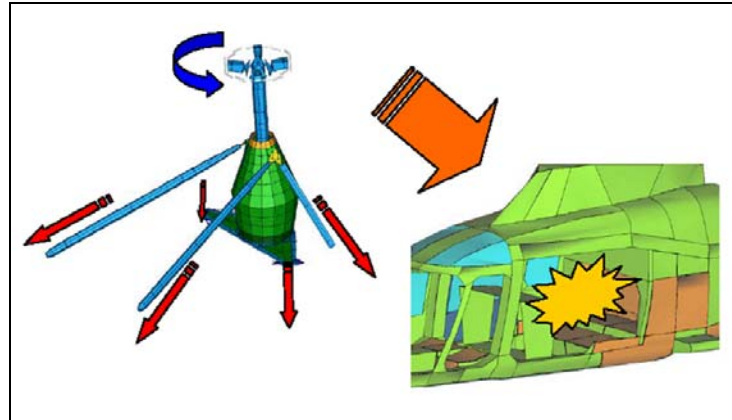
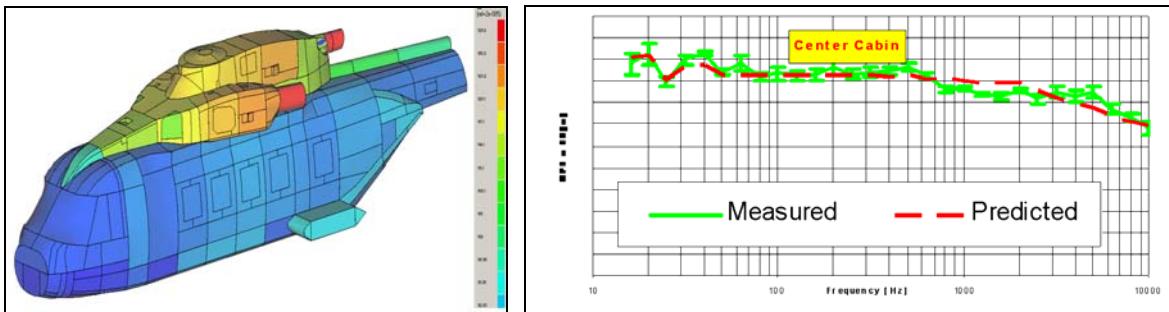Figure 15   Structure-borne noise transmission due to the main gearbox

Figure 16   Transfer Path Analysis results using EH101 SEA model: measured (green line) vs analytical (red line)

Good agreement between measured and calculated TPA using the SEA model was shown. The right hand graphic in Figure 16 shows the SPL results in the centre of the EH101.

On EC135, an identification of noise sources as well as a characterisation / quantification of the acoustic leakage impact on helicopter cabin interior noise were performed using for the first time the new p-v sensor array and an ultrasonic system for acoustic mapping under operating conditions.
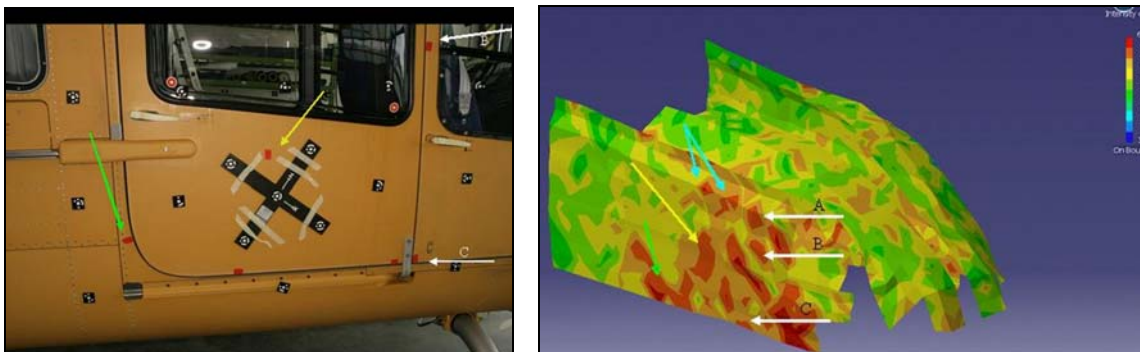

Figure 17   Sound leakage investigation on EC135 using ultrasonic system

It is well visible from the results shown in Figure 17 that the leakages were specific to the right door of the cabin. As an EC135 ground test showed, improved panelling, soundproofing and sealing could gain at least 1 - 2 dBA.

b) Tackling of the dominating cabin noise source at its origin, i.e. at the main gearbox.

The main noise source of cabin interior noise is the gearbox. Its noisiest components could be identified by rig tests and underwent a re-design (EC135:
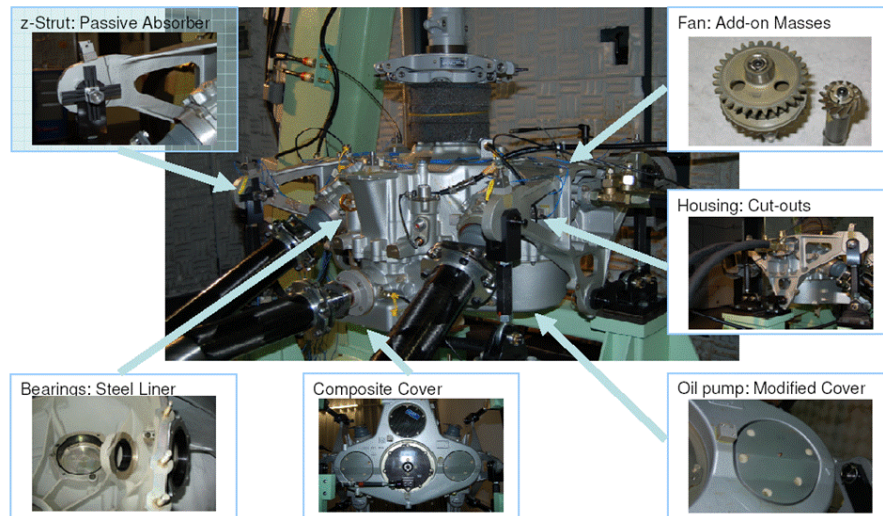Figure 18 and A109:
Figure 20).

Figure 18   Modifications applied to an improved FS108 gearbox

Figure 20 for example, clearly shows the difference in noise emission between the baseline or standard MGB (2005) compared to the improved one (2007).

The results of noise reduction measured on the test rig were confirmed by flight tests.
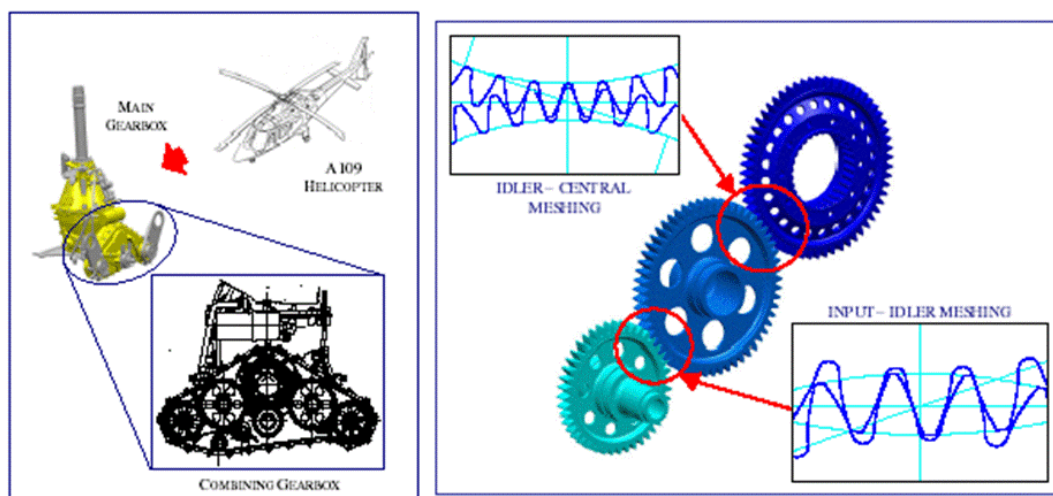

Figure 19   Modifications applied to an improved A109 gearbox
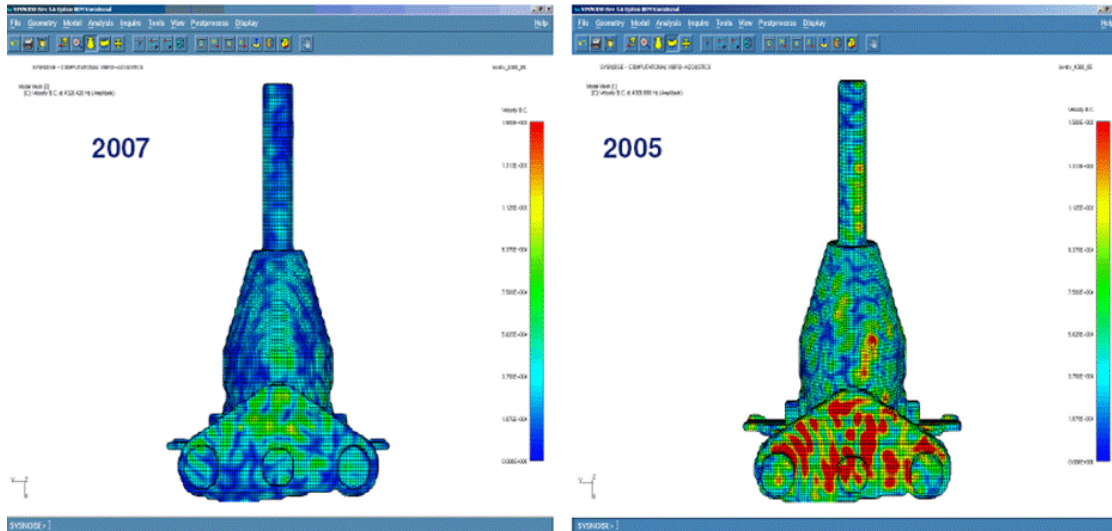
Figure 20   Modifications applied to an improved A109 gearbox

c) Active interruption of the transmission of structure-borne noise from the gearbox to the fuselage.

To actively interrupt the transmission of structure-borne noise from the gearbox to the fuselage, different approaches of active control have been used. So, piezoelectric patches applied to A109 struts (Figure 21) and to the anti-torque plate were tested both on a mock-up and on a helicopter on ground.

Figure 21   Active control using piezo patches

Figure 22 shows the influence of the active control system on the SPL in particular controlling one of the main gear box mesh frequency at 1825 Hz. This approach is ready to be industrialized with a reduced weight of the necessary instrumentation for the control system.

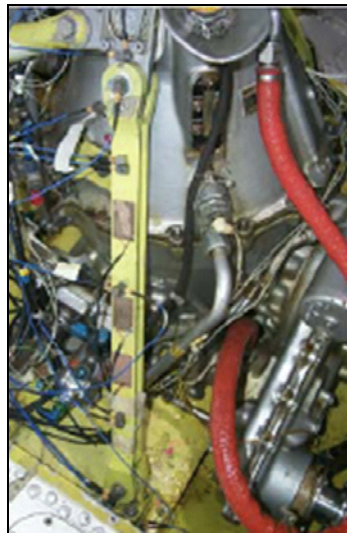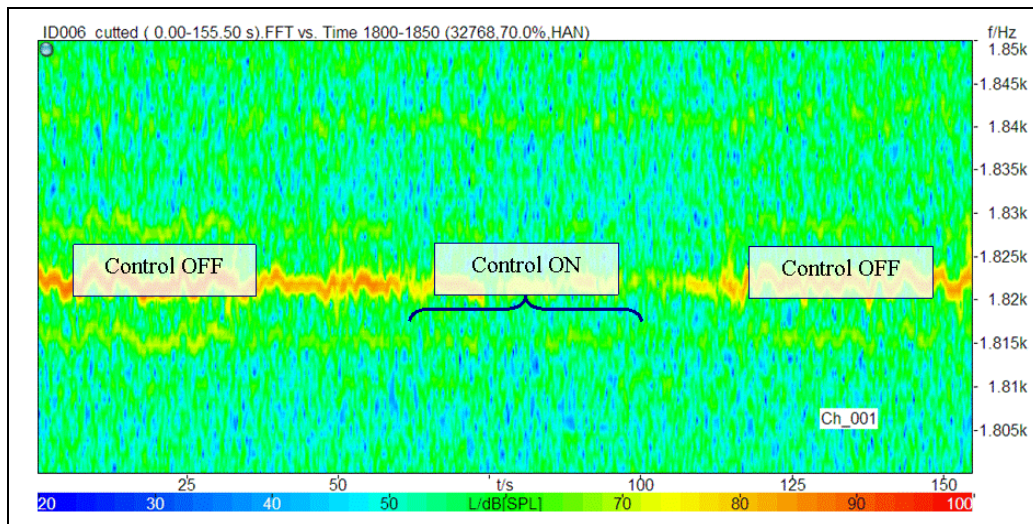Figure 22 Variation of SPL with the active control system switched OFF-ON-OFF controlling the main gear box mesh frequency at 1825 Hz
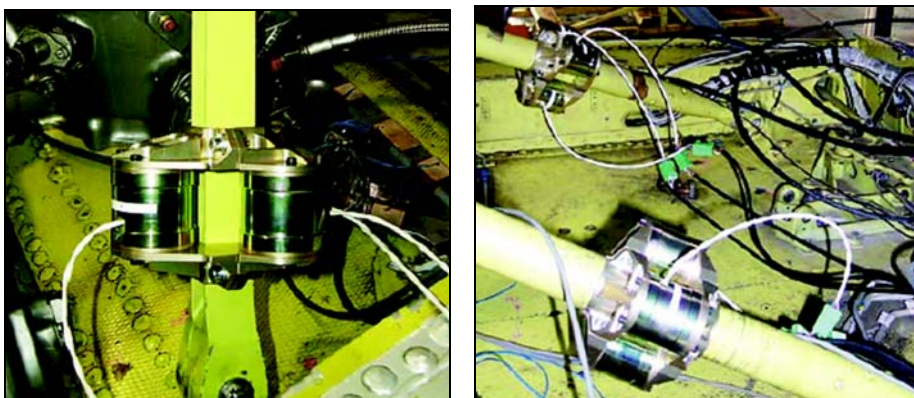
Figure 23 shows another type of active control using inertial actuators - one for each control axis. This technique has been tested on a mock-up yielding good results. It is however not mature enough to be installed in a helicopter.

First of all, there will be required a reduction of the system weight, now at around 22 kg, without a reduction of the performances when controlling four gearbox struts and the anti-torque plate synchronously (expected added mass below 12.4kg (20 actuators with brackets); at the same time lighter driving electronics (currently about 24kg).

Second, fatigue tests of the system, certified to be flight-tested on a real helicopter will have to be conducted.
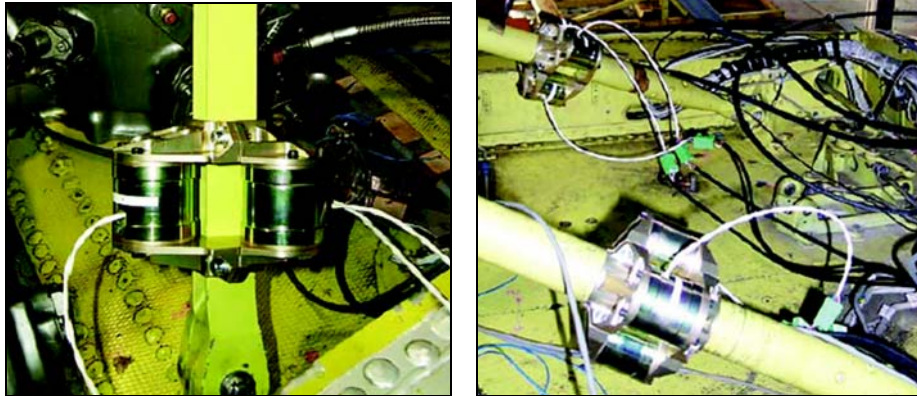
Figure 23   Inertial Actuators

d) Active and passive damping of the noise having overcome all barriers applied and having reached the cabin structure by cabin trim panels

Innovative trim panel configurations with reduced core stiffness, alternative core material and increased internal structure damping were studied, produced and tested in the laboratory. A panel configuration yielding significant transmission loss was ground-tested on the helicopter.

One of the main problems encountered when working with FEM, BEM and SEA is to have a data base of passive materials providing for example porosity, flow resistivity, tortuosity etc. Such data base was not available to the programme partners, and related information from other countries is generally restricted. Therefore, first of all, procedures for testing the foreseen materials and test parameters were determined. The current data base consists of about a hundred data sheets in Excel format, one for each type of material (Figure 24).

Figure 24   Material data sheet layout

In addition to the passive damping approaches, actively controlled panels were developed and tested on the ONERA cabin mock-up VASCO (

Figure 25). By piezo actuator pads, integrated in the panel structure, the noise emission by the panel's surface is minimised. This technology is well suited at cabin surfaces, where the need for high damping and the availability of appropriate installation space are conflicting.

Figure 25 Tests of active cabin panels in ONERA cabin mock-up VASCO

Achievements related to the state-of-the-art

The work performed in WP4 has improved partners' professional knowledge and their capabilities to apply advanced measurement systems and technologies. In particular, there should be mentioned:

as analytical methods:
-   the Matrix inversion method, stemming from ground transport systems,
-   an SEA procedure extended to low frequencies,

as experimental methods:
Systems for noise mapping on cabin surfaces based on p-v sensor arrays

as abatement technologies:
-   Noise oriented gearbox modifications.
-   More mature active and passive means to interrupt structureborne noise transfer as well as to damp the noise by advanced cabin panelling.

One of the most relevant achievements was however the analytical prove that drastic cabin noise reductions can be accomplished by proper superposition of a number of different abatement technologies, all demonstrated separately on the helicopter.

Impact on industry or research sector

A number of the results of this project are now ready to be industrialised, covering both

-   evaluation methods, such as low frequency SEA and noise mapping with ultra sound methods as well as
-   abatement technologies, like modifications to the main gear box and advanced panelling and sealing.

On the other hand, new technologies, methodologies and measurement techniques, some of them applied in Friendcopter for the first time, such as:

- the Matrix inversion method and
- active noise reduction methods

will need further development.

WP5 – Rotor Noise Control

Objectives

WP 5 is the most innovative task in FRIENDCOPTER demonstrating active rotor blade control technology by distributed actuation. In the low risk technology stream, an active twist rotor in model scale and a full scale blade segment with deformable active trailing edge were developed. In the high risk technology stream, more advanced airfoil shape morphing concepts and static blade twist based on shape memory alloy actuation were investigated for feasibility.

In parallel to the detailed development and optimisation activity leading to hardware manufacturing and testing, the benefit potential of the said technologies was explored by numerical simulations.

An important aspect of the numerical activity was the conception of optimum control laws that yield maximum benefit for noise, vibration and performance. Active rotor control is expected to reduce rotor noise footprint areas by 30% to 50% depending on the flight condition, vibration levels shall be reduced by 90% down to 0.05 g, power savings at the border of the flight envelope shall be realised that result in reduced fuel consumption by 6%.

Methodologies and approaches employed

Active Twist

Active twist is a concept proposed by DLR. It deals with applying distributed piezo active patches on upper and lower blade skin under ~45deg relative to the radial axis of the blade. The piezo patches induce direct shear forces to the skin that create a torsion moment around the control axis resulting in an elastic twist deformation. This deformation can be created at elevated frequencies, enabling higher harmonic blade control required for noise, vibration and performance benefit.

The development activities spanned:

- Piezo actuator patch manufacturing and packaging (here as macro fibre composite),
- Blade cross section lay-out and optimisation for maximum twist per meter span,
- Detailed model blade and tooling design, manufacturing concept, ply lay-up and instrumentation strategy,
- Blade manufacturing and instrumentation and finishing for test readiness,
- Preparation of measurement techniques.
- Testing on spin facility (Figure 26), characterisation of blade structural properties and verification of design, as well as
- Up-scale investigation to transfer findings from model to full scale blades.

The test results yielded as main parameters:

- Twist amplitude: 4.6° tip twist
- Twist rate: 3.3°/m span

Figure 26   Active twist blade tested in DLR's spin facility

Active Trailing edge

The active trailing edge concept is proposed by EADS and ECD. Instead of implementing a discrete trailing edge flap, a chord and span wise distributed actuation was conceived. The key points are:

-   to avoid high numbers of components as in case of a discrete flap,
-   to maintain a smooth aerodynamic contour, and
-   to enable continuously varying actuation along the blade span.

Again, piezo patches were used for their high frequency capabilities. The fundamental actuator design is that of a multi-layer or multi-morph bender, having piezo tiles glued on both sides of a passive carrier layer. Such benders are attached to the blade structure via a slotted trailing edge interface.

The development activities spanned:

-   Piezo actuator manufacturing (here as low profile stacks, or cut multilayer stack tiles),

-   Bender layer optimisation for maximum deflection,

-   Bender module manufacturing and proof of concept,

-   Blade trailing edge interface lay-out and optimisation for minimum lead-lag bending strain,

-   Detailed blade segment and tooling design, manufacturing concept, ply lay-up,

-   Blade manufacturing and instrumentation and finishing for test readiness, as well as

-   Build-up of the component test bed, industrial component testing for fatigue life time of trailing edge interface and verification of design.

Figure 27 illustrates the full scale blade segment developed, manufactured and tested in an industrial bench test for operative loads.
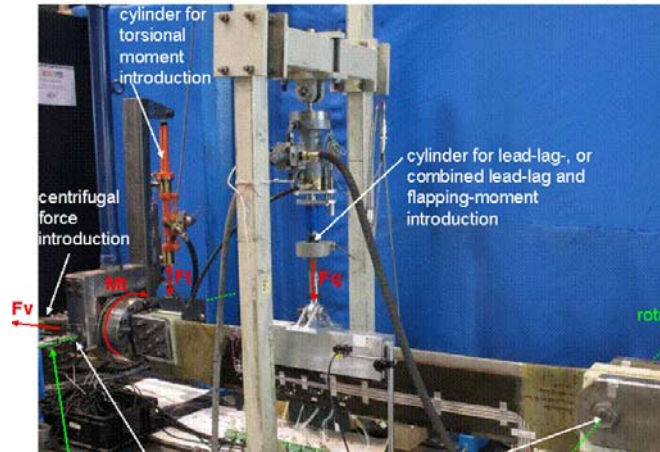
Figure 27   Active trailing edge tested for fatigue in component test bench

The tests yielded as results:

- for controllability aspects: Active trailing edge deflection of bender module: 2.2mm
- for fatigue aspects: no fatal interface damage after roughly 1.500.000 cycles, 300.000 from which under limit load condition, no bender module failure or damage.

Airfoil shape morphing

Even more ambitious is the concept of fully variable airfoils shapes. The investigated ideas range from camber and thickness changes to local airfoil contour modifications. The challenge is to find feasible concepts that are compliant with the underlying blade structure with its specific global elastic and dynamic constraints.
The development activities spanned:

- Specification of aerodynamic targets for morphing airfoils on helicopter blades,
- 2D CFD method development,
- Polar generation for deformable airfoils for use in benefit simulation,
- Development of an airfoil optimisation chain,
- Optimisation and aerodynamic analysis of shape morphing airfoils (Figure 28 right),
- Structural analysis of morphing concepts by FEM (Figure 28, left),
- Identification of actuators and their feasibility assessment, and
- Selection of favourable concepts.
-
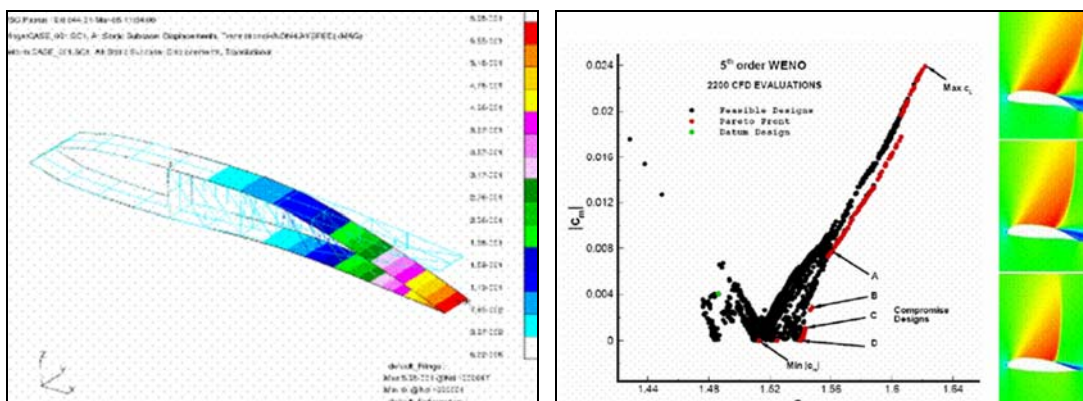
Figure 28   Feasibility assessment and optimisation of different morphing concepts

Shape memory alloy twist

The shape memory twist uses special metal alloys that have the ability to return to a previously defined shape. This specific behaviour stems from a phase shift in the actuator material's microscopic texture induced by heating or cooling the material. Since such materials show the ability to achieve very large strain, i.e. subsequently large deformations, that can be fully recovered, they are interesting for increasing the mean (static) twist of a rotor blade. Hereby the actually applied compromise between high twist requirements for hover and low twist demands for cruise could be beneficially substituted.

The development activities spanned:
- Proposal of different SMA actuator concepts,
- Detailed FEM analysis of these concepts,
- SMA material characterisation,
- Development and test of an active twist concept prototype (Figure 29), and
- Experimental validation of concept as well as proof of control authority.
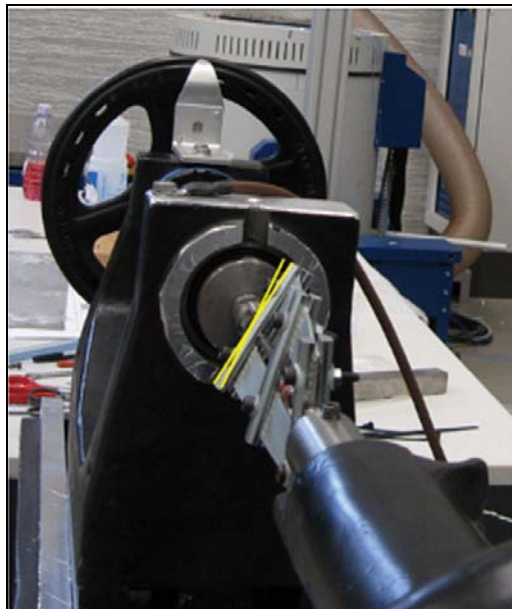
Figure 29   SMA twist actuator prototype tested in CIRA's torsion test bed

As results, there could be identified:
- Twist amplitude: 6° over 0.16m length
- Twist rate: 37.5°/m span

Accompanying benefit simulations

An important industrially driven interest is the achievable benefit of the developed technologies and concepts, in detail:

- noise, vibration and performance (fuel consumption),
- feasibility considerations

The results for both principal control mechanisms complied fully with the FRIENDCOPTER objectives formulated in the introductory paragraph above:

- 90% cabin vibration reduction achievable,
- 50% noise area reduction verified by simulation and
- 6% reduction of power required achievable in high speed forward flight under ideal conditions of a highly loaded isolated rotor.

Achievements related to the state-of-the-art

The development efforts showed the following achievements:

- experimentally validated technologies for controlling the helicopter blades by distributed actuation,
- model rotor blades spin tested on a whirl rig under hover conditions with respect to their controllability of noise and vibrations,
- a full scale blade segment tested on bench for actuation integration and endurance
- numerically approved concepts and
- laboratory tests to support the feasibility investigations.

Impact on industry or research sector

The investigated technologies have been significantly advanced during the FRIENDCOPTER project. For both low risk technologies, i.e. active twist and active trailing edge, the technology readiness level has been increased by more than two levels. The feasibility of the investigated technologies on sub-system level and on blade level could be proven. Transfer considerations to full scale industrial rotors established good confidence for future product application.

Concerning the achievable benefits, active rotor control is a major component to meet the overall FRIENDCOPTER targets. For industrialisation however, the results have to be applied to the complete system with all sub-systems contributing to noise, vibration and power consumption in order to assess the validity for the complete aircraft.
The benefits have been shown by numerical simulations that are widely used in industry and research centres and have been extensively validated on passive rotors in the past. In the future, an important issue will be to validate these findings against experiments, either in model scale wind tunnel campaigns or full scale flight testing. Partially, the Green Rotorcraft Platform of Clean Sky will be a continuation of FRIENDCOPTER for selected active technologies.

WP6 – Exploitation

Objectives

The objective of WP 6 was to ensure an efficient exploitation of the achievements gained in the course of the programme. Individual goals have been:

- to summarise the know-how about the reduction potential of noise, vibrations and engine power consumption of existing and future helicopters by generating a related data base, including a synthesis of the results attained,
- to enable the exploitation of the environmental improvement results attained during the project in industry and research with the help of a dedicated exploitation plan,
- to get a broader view on the technologies in question by an exchange of know-how in the aforementioned areas with companies / institutions also outside the consortium.

Methodologies and approaches employed

The following methodologies / approaches have been used:

- an exploitation committee established by the workpackage leaders to coordinate the WP 6 activities and to monitor the compliance with the specifications made in WP 1,
- an exploitation strategy especially regarding the Common Software Platform HELENA resulting from WP2,
- a plan how to structure the know-how exchange both within the consortium and with experts outside,
- a website and a data repository for internal and external know-how exchange,
- dedicated workshops and
- a monitoring of publications in order to make the related process visible and efficient and to prevent confidentiality problems.

Achievements related to the state-of-the-art

The following achievements could be attained:

- a data bank containing all relevant technical data and all results gained with respect to operation & design of the environmentally friendly helicopter,
- a report containing synthesis, conclusions and guidelines for neighbourly helicopter lay out & operation,
- a recommendation and preparation of a potential continuation of long term items after the end of this programme,
- a plan how to capitalize on the results accomplished by applying them to product improvement or to research support and
- a dissemination plan.

Impact on industry or research sector

Industry and research institutions are taking advantage from the achievements mentioned above by:

- having unlimited access to data bank, publications and methods established,
- interconnections established between the partners and
- continuing FRIENDCOPTER activities in follow-on programmes like Clean-Sky and TEENI.

Outlook

The rationale to launch a research programme addressing mainly helicopter noise emission was driven by the understanding that the helicopter's acceptance as means of transportation could be significantly enhanced compared to the actual status and in view of the respective available technologies. The attempts performed to cope with the corresponding challenges can be split on the one hand into different categories viz.:

- exterior noise annoying mainly residents of airports/heliports and clinics and
- interior noise detracting from comfort, safety and mission success

These are both important parameters of helicopter acceptance which could be remarkably promoted by FRIENDCOPTER.

On the other hand, regarding the aspect of the time horizon of possible applications of the technologies developed, one has to distinguish between:

Near term applications, such as

- noise abatement flight procedures, which could be implemented straight in the flight manual, or
- advanced soundproofing materials for cabin panels,
- elastomeric bearings of the main gear box suspension,
- assessment of cabin noise annoyance by the Virtual Simulator and
- usage of identification tools for noise leaks / transmission paths or

Mid term applications, such as

- noise footprint predictions for planners of heliports, for certification purposes (the so-called Land Use Planning (LUP)) or for an appraisal of the noise emission characteristics of a helicopter under development,
- noise control of lateral inlets to the engine compressor chamber, installed for performance enhancement as well as sound proofed exit nozzles and
- active force generators at gearbox suspension struts, noise emitting surfaces and cabin panels for cabin noise reduction as well as.

Long term applications, such as

active flight control technologies, acting through flexible trailing edges or changeable twist distributions for noise and vibration reduction.

This summary reflects the temporally phased strategy of noise abatement efforts within FRIENDCOPTER. Besides noise, there have been addressed also:

- engine performance improvement (see above) and
- vibration reduction by Active Blade Control.

Planned applications of the technologies summarised above are depicted in the exploitation plan (WP 6)

The continuation of relevant FRIENDCOPTER research activities is assured within the JTI Clean Sky:

- by the already running Green Rotorcraft programme with results from WP5 (GRC),.
- by respective investigations in platform "Sustainable and Green Engines through findings from WP3,
- by social noise impact assessments in platform "Technology Demonstrator" with the aid of the footprint prediction tool HELENA and
- by research on piezo actuator power supply in platform "Systems for Green Operation" using know-how from WP5.

In addition, the engine quietening activities will be continued by the FP7 project TEENI.

The fact that with the exception of WP4 all areas of FRIENDCOPTER are pursued further – especially in the most important actual research programme - shows the up-to-dateness of the problems addressed.

3 ACKNOWLEDGEMENTS

List of Publications and contributions to Conferences

Table 2   list of publications and contributions to conferences

Author(s)	Title of paper	Journal, conference, etc.	Vol. no./Page ref.	Date
Gennaretti, M., Bernardini, G	AIAA Paper 2005-2924 A Novel Potential-Flow Boundary Integral Formulation for Helicopter Rotors in BVI Conditions	11th AIAA/CEAS Aeroacoustics Conference, Monterey, California,	-	May 2005
Bernardini, G., Iannniello, S., Gennaretti, M	Analysis of Blade Deformation Effect on Rotor BVI Noise Prediction	31st European Rotorcraft Forum, Firenze, Italy	-	Sept 2005
Masarati P., Morandini M., Riemenschneider J., Wierach P., Gluhih S. Barkanov E.	"Optimal Design of an Active Twist 1:2.5 Scale Rotor Blade."	Proceedings of the 31st European Rotorcraft Forum Firenze, Italy	-	Sept 2005
Bernardini, G., Serafini, J., Iannniello, S., Gennaretti, M	AIAA Paper 2006-2606 Aeroelastic Modeling Effect in Rotor BVI Noise Prediction	12th AIAA/CEAS Aeroacoustics Conference Cambridge, Massachusetts, USA	-	May 2006
VERTAIR	Friendcopter project survey "Integration of Technologies in Support of a Passenger and Environmentally Friendly Helicopter"	Aerodays 2006	-	June 2006
A. Kovalovs S. Gluhih E. Barkanov P. Masarati M. Morandini D. Muffo J. Riemenschneider	Active Twist Design of Helicopter Rotor Blades	Book of Abstracts of the XIV International Conference on Mechanics of Composite Materials (MCM-2006), Riga, Latvia,	-	June 2006
LMS AG-WHL AGH (Krakow Uni)	Hybrid Modelling of a Helicopter Gearbox	ICSV13, Vienna	-	July 2006
KTH	"Modelling & Characterisation of the Vibration Dynamics Modelling of Anisotropic Porous Foam Materials"	ISMA 2006	-	July 2006
CIRA	"Energy ratio approach for SEA model path identification"	ISMA 2006	-	July 2006
LMS, Agusta Westland	"Experimental Noise Transfer Path Analysis on Helicopters"	ISMA 2006	-	July 2006
Agusta Westland	"Simulation and Evaluation of Noise and Vibration Reduction Techniques in a Helicopter Cabin Using SEA"	ISMA 2006	-	July 2006
Polimi, Agusta Westland	"Active solutions for reduction of the transmission of structure- borne noise to the cabin structure on a A109 mock up"	ISMA 2006	-	July 2006

Author(s)	Title of paper	Journal, conference, etc.	Vol. no./Page ref.	Date
LMS, Agusta Westland	"Hybrid Modelling of a helicopter gearbox using Inverse Boundary Elements Method"	ISMA 2006	-	July 2006
B. A. Grohmann Ch. Maucher T. Prunhuber P. Janker O. Dieterich B. Enenkl M. Bauer E. Ahci A. Altmikus H. Baier	Multidisciplinary Design and Optimization of Active Trailing Edge for Smart Helicopter Rotor Blade	Demeass 1	-	July 2006
RIGA-TU: Barkanov E. Gluhih S. Kovalov A.	Optimal Design of the Active Twist for Helicopter Rotor Blades: Model Scale.	Book of Abstracts of the 1st International Symposium on Design, Modelling and Experiments of Adaptive Structures and Smart Systems (DeMEASS-2006), Bardonecchia (Turin), Italy.	-	July 2006
Agusta, NLR ONERA, WHL CU, IST Lisbon U-PAT, U-ROM	"Assessment of computational tools for rotor blade induced noise"	32nd European Rotorcraft Forum, Maastricht, Netherlands	-	Sept 2006
LMS Ducati Motor Holding Agusta Westland	"Experimental Noise Transfer Path Analysis on the Helicopter A109"	32nd European Rotorcraft Forum, Maastricht, Netherlands	-	Sept 2006
PoliMI	"Experimental Results of Active Longitudinal Vibration Control on a Helicopter Gearbox strut	32nd European Rotorcraft Forum, Maastricht, Netherlands	-	Sept 2006
PoliMI Agusta Westland	Abstract "Preliminary Testing of Cabin Noise Reduction in Helicopters using Active Gearbox Struts"	32nd European Rotorcraft Forum, Maastricht, Netherlands	-	Sept 2006
RIGA-TU: Barkanov E. Gluhih S. Kovalov A.	Optimal Design of the Active Twist for Helicopter Rotor Blades.	Proceedings of the 8th International Conference on Computational Structures Technology, (CST-2006) Las Palmas de Gran Canaria, Spain.	-	Sept 2006
Barkanov E. Gluhih S. Kovalov A.	Optimal Design of the Active Twist for Helicopter Rotor Blades.	Proceedings of the 8th International Conference on Computational Structures Technology, Civil-Comp Press: Stirlingshire, Scotland.	-	Sept 2006
C. Maucher B. Grohmann P. Jänker A. Altmikus D. Schimke H. Baier	Actuator design for a morphing helicopter rotor blade	Deutscher Luft- und Raumfahrtkongress 2006	-	Nov 2006

Author(s)	Title of paper	Journal, conference, etc.	Vol. no./Page ref.	Date
Testa, C. Ianniello, S. Bernardini, G., Gennaretti, M	"Sound Scattered by a Helicopter Fuselage in Descent Flight Condition"	13th AIAA/CEAS Aeroacoustics Conference, Rome, Italy	-	21-23 May 2007
L. Dozio A. Toso W. Corbetta E. Vigoni G.L.Ghiringhelli	"Comparison of Feedback and Feed forward Strategies for Active Structural-Acoustic Control of Broadband Sound Transmission Into a Cavity"	13th AIAA/CEAS Aeroacoustics Conference, Rome, Italy	-	21-23 May 2007
A. Toso W. Corbetta E. Vigoni L. Dozio G.L.Ghiringhelli	"Application of FXLMS algorithm to active control of vibration in thin plates"	Forum on Aeroelasticity and Structural Dynamics (IFASD)	-	June 2007
A. Toso W. Corbetta E. Vigoni L. Dozio G.L.Ghiringhelli	"Recent results in active control of structure-borne noise on a helicopter mockup"	Forum on Aeroelasticity and Structural Dynamics (IFASD)	-	June 2007
Eurocopter SAS Marze, H., Gervais, M., Martin, P., Dupont, P	"Acoustic flight test of the EC130 B4 in the scope of the Friendcopter project"	33rd European Rotorcraft Forum, Russia	-	Sept 2007
A. Toso W. Corbetta E. Vigoni L. Dozio G.L.Ghiringhelli	"Active gearbox isolation systems for helicopter quieter cabin environment"	AIDAA conference, Forlì,Italy	-	Sept 2007
Kovalov A., Barkanov E., Gluhih S.	"Comparative study of optimal active twists for helicopter rotor blades with C and D-spars"	Proceedings of the 33rd European Rotorcraft Forum (33rd ERF), Kazan, Russia	-	Sept 2007
E.Garnier P.Biscay P.L Regaud P.Baude	"Towards efficient and silent engine integration on a helicopter."	ISABE Conference, Beijing	-	Publication Sept 2007
W. Beck W. Jung M. Oberstedt	„Hot Forming and Gas Pressure Forming of Titanium Alloys"	AIRTEC – Supply on the Wing - , Frankfurt am Main/Germany	-	Oct 2007
Uni Roma III Gennaretti, M. Bernardini, G	"Novel Boundary Integral Formulation for Blade-Vortex Interaction Aerodynamics of Helicopter Rotors"	AIAAA Journal	Vol. 45, No. 6, pages 1169-1176	2007
Bernardini, G. Serafini, J. Gennaretti, M., Ianniello, S	"Assessment of Computational Models for the Effect of Aeroelasticity on BVI Noise Prediction"	International Journal of Aeroacoustics,	Vol. 6, No. 3, pages 199-222	2007
Glukhikh S., Barkanov E., Kovalev A., Masarati P., Morandini M., Riemenschneider J. and Wierach P.	"Design of helicopter rotor blades with actuators made of a piezomacrofiber composite"	Mechanics of Composite Materials	Vol. 44, No. 1, 57-64.	January February 2008
TU Dresden ZFL	"Lightweight Acoustic Potential of helicopter main gearbox components made of composite materials"	DAGA 2008 in Dresden, Germany (& on CD Rom 34, to be released Summer 08)	-	March 2008

Author(s)	Title of paper	Journal, conference, etc.	Vol. no./Page ref.	Date
Barkanov E., Gluhih S., Kovalov A.	"Optimal design of the active twist for helicopter rotor blades with C-Spar"	Mechanics of Advanced Materials and Structures	Vol. 15, Issue 3-4, 325-334.	March-April 2008
Kovalov A., Barkanov E., Gluhih S.	"Active twist optimal design of full scale helicopter rotor blade"	Proceedings of the International Conference on Smart Materials and Adaptive Structures: Mathematical Modeling and Computation, Tangier, Morocco	-	April 2008
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