BLUECOPTER DEMONSTRATOR – AN APPROACH TO ECO-EFFICIENT HELICOPTER DESIGN

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Abstract

The "BLUECOPTER DEMONSTRATOR" presented in this paper has been developed to prove the feasibility of future eco-friendly helicopter concepts and to demonstrate "green" technologies in-flight. The main objectives are:

- Significant reduction in CO_2 emission and fuel consumption up to 40%
- Noise reduction of around 10 EPNdB below ICAO §8.4.1 noise certification limits
- Development of "transversal" technologies allowing for serial applications to all helicopter classes.

A major contribution to the improved efficiency and reduced acoustic emission of the BLUECOPTER DEMONSTRATOR is provided by the newly developed rotor system. It includes an innovative five-bladed bearingless main rotor with increased diameter, BlueEdge™ style blade shape, new twist distribution and low tip speed design. Moreover it features an advanced Fenestron® with an optimized blade and stator design. Several measures were applied to reduce the drag of the aircraft including fairings for the main rotor and landing skids, a special design of the aft-body and a low-drag empennage including a "T-Tail" horizontal stabilizer. Additional features like the active fin rudder and the "acoustic liner" for the Fenestron shroud have been applied to further improve the acoustic footprint of the demonstrator. The BLUECOPTER DEMONSTRATOR has been successfully flight tested in 2014 and will be further improved and tested in 2015. This paper gives an overview on the technologies proven in-flight and summarizes the benefits achieved in terms of performance and acoustic emissions.

1. INTRODUCTION

Environmental protection is a key driver for aviation industry. The air transport industry is paying increasing attention to the growing public concern about air pollution, noise and climate change. Today's air transport produces 2% of the global CO_2 emissions and it is expected that this amount will increase to 3% by 2050. Helicopters contribute only a relatively small part to the pollution caused by the general aviation. However, the reduction of the environmental footprint is a main driving factor for Airbus Helicopters since many years.

The BLUECOPTER DEMONSTRATOR (BD) presented in this paper has been developed to prove the feasibility of future eco-friendly helicopter concepts and to demonstrate "green" technologies in-flight. The main objectives of the demonstrator are:

- Significant reduction in CO_2 emission and fuel consumption up to 40%
- Noise reduction of around 10 EPNdB below the ICAO § 8.4.1 noise certification limits
- Development of "transversal" technologies allowing for serial applications to all helicopter classes.

The BD is based on a light/medium twin engine helicopter (EC135 S01) used as a test bed for a set of innovative and widely patented technologies. A strong focus was on reducing the power required by the aircraft, a smart power management and several measures to minimize the acoustic footprint.

A major contribution to the improved efficiency and minimized acoustic emission of the BD is provided by the newly developed rotor system. It includes an innovative five-bladed bearingless main rotor with increased diameter, a BlueEdge™ style blade shape, a new twist distribution, new eco optimized airfoils and a low tip speed design. Moreover it features an advanced Fenestron with an optimized blade and stator design.

Several measures were applied to reduce the drag of the aircraft including an optimised aerodynamic design of the blade cuffs, fairings for the main rotor hub and the landing skids, a special design of the aft-body and a low-drag empennage including a "T-Tail" horizontal stabilizer.

The optimized rotor system has been complemented by additional features like an active fin rudder and an "acoustic lining concept" (integrated into the Fenestron shroud) to further reduce the acoustic emission of the demonstrator.

To achieve the ambitious targets in terms of CO_2 emission, a dedicated power management was mandatory. In the case of the BD this has been achieved by setting one engine inoperative for those parts of the mission where one engine delivers sufficient power. Since a higher loaded engine operates more efficiently than two engines partly loaded, a significant reduction of fuel consumption can be achieved for cruise flight conditions.

The BD has been successfully flight tested in 2014 and will be further improved and tested in 2015. This paper gives an overview on the technologies proven in-flight and summarizes the benefits achieved in terms of performance and acoustic emission.

1 AERODYNAMIC AND ACOUSTIC LAYOUT

1.1. Main rotor

Within the scope of several German research projects (LuFo IV) such as ECO-HC, IKOROZ and LOCAR the five bladed bearingless main rotor of the BD was developed.

Figure 1: BlueEdge™ style main rotor blade

Main objective of the main rotor design is the improvement of the performance characteristics especially in hovering flight with less performance penalties in forward flight and simultaneously reducing the annoying blade vortex interaction noise in descent flights. Therefore, the aero-acoustic design point primarily corresponds to the certification approach at best rate of climb speed V_y and an aerodynamic glide slope of 6°. But the acoustic objective is also to achieve a robust design that minimizes the sound emission in a wide range of operationally relevant descent angles and flight speeds. One distinctive attribute of the main rotor blade is the BlueEdge™ style leading edge shape that reduces parallel interactions of blade vortices and thus ensures that acoustic pressure peaks are not received by observers on the ground. Further features are an increased rotor radius, newly designed airfoils and a highly non-linear twist law. Additionally the main rotor sizing is driven by a particularly low tip-speed requirement in order to achieve maximum noise reduction in all acoustically relevant flight conditions. Finally the main rotor blade comprises a newly designed flexbeam and an aerodynamically optimized control cuff including a blade folding mechanism.

1.2. Fenestron

The advanced and innovative Fenestron® design of the BD is mainly driven by objective to improve the acoustic characteristics while maintaining its highly efficient thrust generation. The key features of the new Fenestron® rotor and stator design are presented in Figure 2 and hereafter described in detail.

Figure 2: Innovative Fenestron® Design

<u>**Fenestron® stator design**</u>

To achieve a low noise Fenestron® stator design several measures were taken. First, the number of stator vanes was reduced in order to reduce the interferences between the Fenestron® rotor and stator. The rotor-stator interaction noise is caused by the interceptions of periodic trains of viscous wake velocity defects from the upstream rotor with the stator vanes. These velocity disturbances produce fluctuating lift forces at the stator vanes which account for the harmonic noise component. The second effect deals with the stator broadband interaction noise, which is a result of the turbulent outflow of the rotor. Furthermore the azimuthal position and inclination of the stator vanes in the Fenestron® duct were optimized. For a low-noise design the interferences between the rotor and the stator have to be limited by avoiding that any angular difference between two rotor blades corresponds to an angular difference between two stator blades. Additionally the distance between the rotor and stator is maximized by tilting the stator vanes from the rotor plane. Moreover a curved leading edge design of the stator vanes was introduced to further increase the distance between the rotor and stator. Finally the shape of the Fenestron® drive shaft fairing was aerodynamically optimized so that the aerodynamic interferences between the rotor and the drive shaft fairing are minimized and the obstruction in the duct is minimal.

Fenestron® rotor design

The low noise Fenestron® rotor design includes the well-known phase modulation already successfully applied in many Airbus Helicopter products (e.g. [12]). Phase modulation describes the technique of reshaping the noise-frequency spectrum by modifying the geometric positions of equally spaced Fenestron® blades about their nominal positions in a sinusoidal amplitude pattern. The noise levels are reduced by distributing the acoustic energy over the entire frequency spectrum. Therefore, the blade passing frequency is destroyed and the fundamental rotation period is restored. The remaining peaks are to a large extent masked by the main rotor spectrum. Further a low tip speed design is implemented. The most innovative feature is the advanced Fenestron® rotor blade design including an S-shaped leading edge and a non-linear chord distribution. The S-shaped leading edge design reduces the acoustic effect of the drive shaft fairing by avoiding parallel interaction during the passage of the rotor blades.

Besides numerical simulations the development of the Fenestron® rotor blades was supported by bench test measurements in the acoustic laboratory of Airbus Group Innovations in Ottobrunn.

Figure 3: Fenestron® test bench @ Airbus Group Innovations (Ottobrunn)

For this purpose an existing CROR test facility was used and extended with a 70%-scaled EC135 Fenestron® model as shown, shown in Figure 3.

1.3. Fuselage and non-lifting rotating system

A light-weight twin-engine Helicopter featuring a rear loading capability and landing skids (e.g. EC135) is usually characterised by higher parasite drag than an equivalent one having retractable landing gear and aerodynamically streamlined (fish-tail) rear segment such as the EC155. In this case, excluding the tail unit, being responsible for lower drag generation than the rest, the fuselage, the landing skids and the rotor head are equivalent in the generation of drag [4]. To improve the BD, aerodynamic modifications to the fuselage aft body, the landing skids, the rotor head fairings and the tail unit itself have been introduced with the objective of reducing the parasite drag as much as possible, without losing the operational advantages of a rear loading capability and landing skids.

The first elements to be aerodynamically improved were the forward and aft bending tubes of the landing skids. Aerodynamic fairings have been designed by applying airfoils available from literature. 2D-CFD analysis has been used to select the best performing airfoil for this particular application. The airfoil thickness was scaled to vary its chord length, while keeping the same minimal thickness in accordance with the structural constraints set by the airframe specialist. The airfoil setting angle increases along each bending cross-tube from skid to fuselage junction of about 2°. This is made to have a neutral effect on the cabin lift and pitching moment so that the static stability of the cabin itself is not negatively affected, i.e. the values of the S01 prototype are conserved. Due to constructional constraints the airfoil's trailing edge had to be truncated. Since the front cross tube is destabilising, whereas the rear one has a stabilising pitching moment, the rear fairing features a higher chord-length than the front one, while keeping the thickness constant. Respecting the S01 constructional constraints, further aerodynamic improvements was achieved by better integrating the cross tubes into the fuselage: belly fairings have been designed, which assure a smooth water-tight closure of the floor/bending tubes junctions. A detail of the landing skid fairings is shown in Figure 4.

Figure 4: Detail of the landing skid fairings on the BD

The *second element* addressed was the blunt aft body of the S01 prototype. The aerodynamic design strategy followed two steps. In the first step, the aft body has been modified according to the experience of the aerodynamicists of AH: the curvature of the surfaces in the backdoor region between the floor and the backdoor and between the side shells and the backdoor have been smoothened, the inclination of the backdoor has been slightly reduced and the rear cowling elongated to assure a smooth continuity among all new surface panels. In the second step, automatic optimisation based on the adjoint-method in conjunction with the TAU flow solver of DLR [6] has been applied to the improved surface to search for minimum drag. For details about the numerical procedure refer to [1]. The aft body surface was modified by the optimisation method in such a way that two longitudinal strakes were pulled out from the original surface starting from the tail-boom flange down until the mid of the backdoor surface pointing to the rear landing skids junctions with the fuselage. The modified surfaces out of the optimiser were improved, with the support of shape designers, into the current strakes present on the BD aft body, as depicted in Figure 5.

Figure 5: Detail of the BD aft body with the longitudinal strakes

Wind tunnel tests conducted at the Aerodynamic Faculty of the Technical University of Munich (TUM-AER) in the frame of the partner project ADHeRo [7] of the Clean Sky JTI confirmed the benefits in terms of drag reduction derived from the faired landing skids and the new designed aft body at about 18% referred to the total drag of the EC135 helicopter model of Figure 6.

Flight tests in the early phase of the S01 demonstrator confirmed a reduction of 17% with respect to the global drag value of the helicopter.

Another even more challenging component to be aerodynamically optimised is the rotor-hub and pylon. Its drag can vary depending on the helicopter type from 20% up to 50% of the total helicopter drag. The first element of the rotor hub to be addressed was the blade cuffs of the BMR mounted on the BD. This aerodynamic optimisation activity was conducted within the LuFo IV Program ECO-HC and is documented in [2]; therefore, it will not be repeated here again. After improving the blade cuffs the drag reduction of the overall hub has been addressed. This activity was conducted in the context of the Green RotorCraft ITD of the Clean Sky JTI.

Figure 6: Serial EC135 wind tunnel model (scale 1:7) in the TUM-AER facility A

A semi water-tight full fairing concept was developed comprising a new slender pylon fairing, new hub-cap fixed on top of the mast and 5-blade collars each of them fixed on the new designed blade cuffs. To improve the aerodynamic of the mast fairing the exhaust of the oil cooler has been displaced at the trailing edge of the pylon fairing. Moreover, to assure cooling of the rotor-head lead-lag dampers a grid air-outlet has been designed on the upper surface of the pylon (so called surf-board). The details are depicted in Figure 7. Wind tunnel tests carried out by TUM-AER on a 1:5 down scaled model showed a potential drag reduction of about 2% [4] [5] referred to the S01 prototype mounting the new 5-bladed rotor hub.

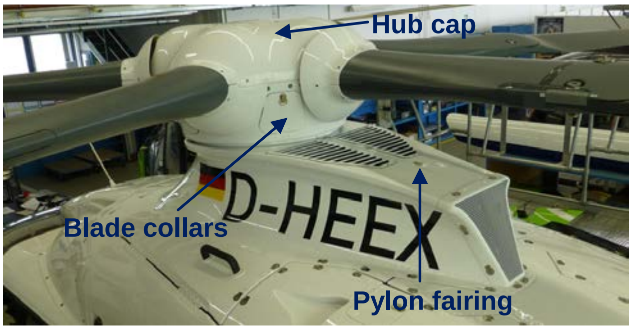


Figure 7: Detail of the semi water-tight full faring about the 5-bladed BMR of the BD

1.4. Tail unit

The tail unit shown in Figure 8 comprises an active rudder, a T-shaped tail (T-tail), an aerodynamically improved Fenestron shroud, vertical fin, bumper and the already described Fenestron®. Applying the same aerodynamic shape optimisation strategy already used to design the strakes on the cabin rear part, which makes use of the adjoint-method in conjunction with the TAU code of DLR [1], the shroud has been optimised too. Its innovative design took also advantage from the past experience gained during the development of the EC145-T2 helicopter tail unit.

Figure 8: Tail unit

Looking at the BD lateral control surfaces (fin, shroud and bumper, one notices that the shroud lateral area has been reduced in favour of an augmentation of the fin and bumper ones. By doing so, the frontal area of the lateral control surfaces has been diminished, thus reducing their drag while increasing the lateral force, finally improving its lift over drag value. A drag reduction of about 2% - referred to the whole helicopter – could be assessed by the faculty of aerodynamics of the technical University of Munich in its Wind tunnel facility A, on a 1:7 downscaled model, in the context of the Lufo IV project ECO-HC2 (Economic Helicopter 2).

To improve lateral stability of the BD the leading edge of the vertical fin has been extended into the shroud leading edge towards the tail-boom so to create a discontinuity in the shroud leading edge curvature. This triggers separation along the shroud leading edge, thus reducing side-force fluctuations on the shroud front part in lateral and quartering flight conditions. For the same purpose the shroud trailing edge has been truncated diagonally generating a sharper edge on its right side. This geometrical feature assures in lateral flight to the left a definite flow separation along the shroud trailing edge. Extensive use of CFD has been made to make sure that no flow separation occurs on the shroud, fin and bumper and in the junction between the vertical fin and the horizontal stabiliser in forward flight, as it can be verified in Figure 9.

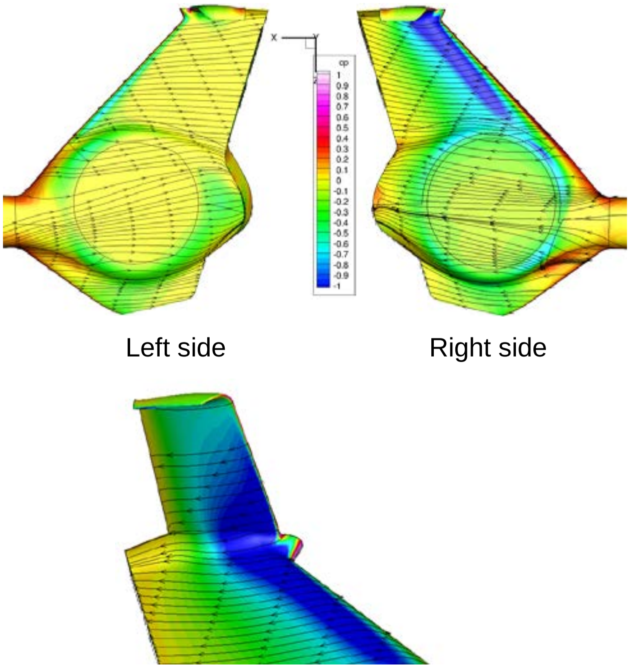


Figure 9: Pressure coefficient with superimposed friction lines on the BD tail unit (level flight 130kts)

An important feature of the BD is the horizontal stabiliser mounted on the extremity of the vertical fin: T-tail (see Figure 8). This architecture assures several advantages with one calculated risk, which need to be taken into account at an early design phase. The advantages are manifold:

- The fuselage download is reduced to a minimum and pay load is increased of about 50kg. This is basically due to the fact that for a classical configuration, featuring a horizontal stabiliser on the tail-boom, most of the fuselage download is generated by the horizontal stabiliser surfaces.
- The horizontal stabiliser lever arm is maximised so that its surface can be minimised, while assuring the same pitching static stability to the helicopter.
- The horizontal stabiliser acts as an endplate for the vertical fin, thus increasing its efficiency. This allowed reducing the fin surface.
- No pitch-up effect in conversion from hover to forward flight is encountered (for more detail on the phenomenon refer to [9]).

The risk concerns the interaction of the 5-bladed main rotor wake with the horizontal stabiliser, which might cause load variations at the 5/rev frequency in level or descent flight. To early evaluate the risk, to provide the construction and dynamic experts of Airbus Helicopters with the relevant data and to be able to correctly define the setting angles of the lifting tail unit surfaces, trimmed computations [9] of the whole BD have been carried out. A picture of the wake system generated by the main rotor, the Fenestron, the rotor head and the fuselage aft body is given in Figure 10. Here it can be seen that the flow separation on the aft body of the BD has been reduced drastically thanks to the faired landing skids and the new designed rear fuselage section. The distance between the blade tip vortices and the horizontal stabiliser can be also evaluated and of course the time history of the loads on the relevant elements is predicted.

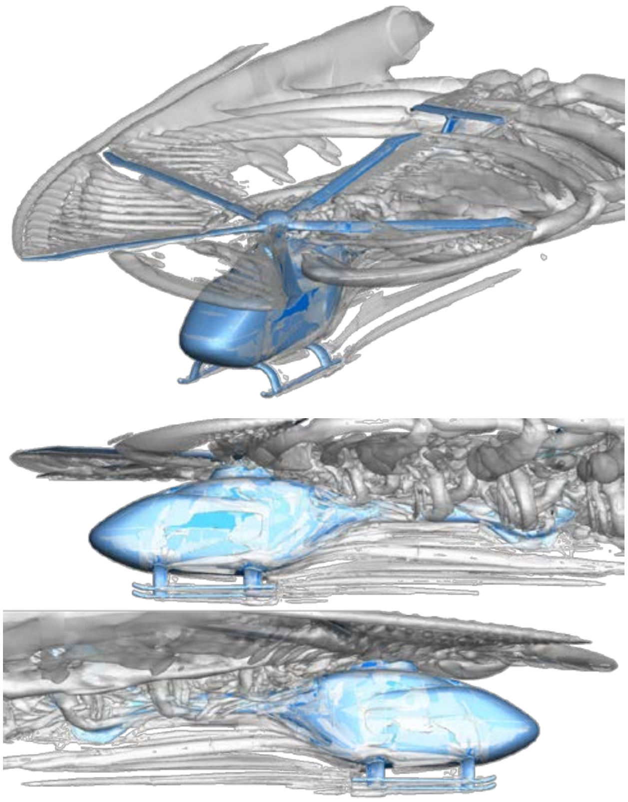


Figure 10: Coupled CFD-CSM simulation in level flight @ 130kts: wake system visualized by the λ2 criterion

The prediction results were confirmed in flight. In fact, the trim status of the machine obtained by adjusting the setting angles of the tail unit lifting surfaces in the coupled simulation was from the first flight hours exactly the desired one without further adjustments. Moreover the rotor horizontal stabiliser interactions and the dynamic response of the tail unit did not cause relevant difficulties in flight.

One additional degree of freedom in the yaw axis is gained by implementing a rudder in the vertical fin. Besides flight mechanics and performance, main focus of the active rudder is on acoustics. Previous wind tunnel measurements to identify the Fenestron® noise characteristics showed that for each defined flight condition a specific Fenestron® thrust setting can be found that leads to minimum noise emission. The objective is to avoid reverse flow and very low thrust condition of the Fenestron® by deflecting the active rudder. Additionally, the loading of the Fenestron® at high torque condition as for take-off can be reduced.

2 POWER MANAGEMENT

A significant contribution to the ambitious fuel consumption and CO2 emission targets is provided by the engine power management. For twin or multi-engine helicopters, engine power management means that only part of the engines installed is operative when flight operation allows it. The remaining engine/s is set to a “dormant” mode, providing no power to the helicopter drive train. The “dormant” mode is characterized by as little energy/ fuel consumption as possible, so preferably engine shut down. This kind of engine power management takes advantage of the characteristic behaviour of gas turbine engines with better efficiency at higher loads (see Figure 11). So to improve the propulsion system efficiency of a twin engine helicopter, a given power required is covered by only one engine. This provides a reduction of fuel consumption up to 25% compared to conventional operation.

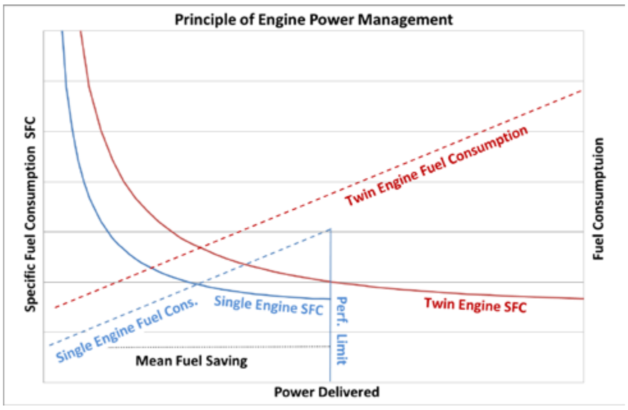


Figure 11: Characteristic engine efficiency behavior and effect on power management

Key element of the BD engine power management is the enhanced avionic system. It supports the crew by continuously monitoring the flight conditions and the system status. Based on these parameters the dormant mode is enabled or disabled. Furthermore the avionic system automatically commands the reactivation of the inoperative engine when a system failure or an emergency situation, e.g. operative engine fail, is detected. So the BD allows shutting down and restarting one engine in flight as part of the normal operation and can offer both, twin engine performance and safety as well as improved propulsion efficiency.

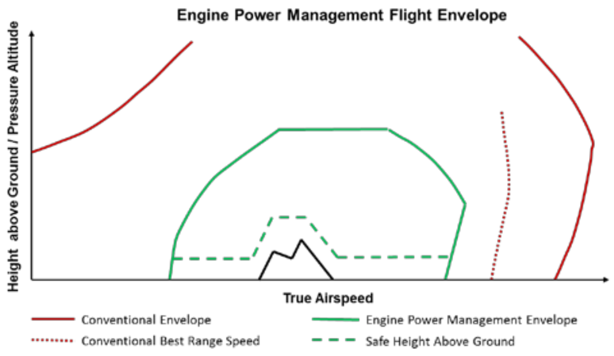


Figure 12: Flight envelope applicable to engine power management

The flight envelope allowing the "eco-mode" is shown in Figure 12. Clearly speed, climb rate and service ceiling are limited by the performance of the remaining engine. Thus the eco-mode is dedicated to any kind of missions that require improved fuel-efficiency, range and endurance. The optimization of the overall system (e.g. Main Gearbox, Electrical System, Engines etc.) towards single engine operation could further increase the mission capability of the Bluecopter concept.

Engine power management is an important technology for the environmentally friendly helicopter approach. Nevertheless a successful introduction will require further efforts in terms of certification and customer acceptance.

3 FLIGHT TESTS

Up to mid-2015 the BD accomplished 19 hours in ground testing and 34 flight hours.

The different technologies like the optimised fuselage, the new rotor system, tail boom, engines and acoustic measures were implemented and tested in a number of consecutive flight phases. Thus the benefits in terms of efficiency and acoustics could be evaluated step by step.

3.1 Performance

In the frame of the BD flight test campaign several performance flights were conducted. The goal of the tests was to investigate the beneficial effects of the aerodynamic modifications (new main rotor, optimized aft body and faired landing skids) on the helicopter performance.

While the main objective of the new main rotor design was a reduction of the power required in hover, the aerodynamic modifications on the helicopter fuselage should improve the level flight performance.

Hover

The hover tests were conducted at lower altitude and medium temperature conditions. The gross mass of the helicopter was varied to show the power consumption as a function of rotor loading. To show the performance benefits from the new main rotor design a reference helicopter was compared with the Bluecopter Demonstrator.

In Figure 13 the power consumption of the helicopter as a function of reduced gross mass m is plotted for the reference helicopter and the Bluecopter Demonstrator.

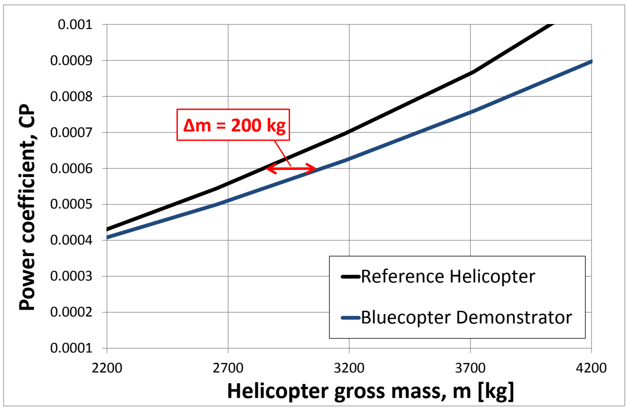


Figure 13: Power required of the helicopter as a function of reduced gross mass m in hover out of ground effect

The diagram clearly shows the performance benefits of the new main rotor in hover. Here especially for the higher loaded rotor a significant reduction of the power consumption could be achieved. The resulting benefits in hover are an increased gross mass of $\Delta m = 200$ kg in lower altitudes and up to $\Delta m = 360$ kg for higher altitudes at a certain power level.

Level flight

To show the impact of the different aerodynamic modifications of the BD on the level flight performance the reference helicopter and the BD were also tested in forward flight. Therefore a speed envelope from low to maximum speed was flown. In Figure 14 the flight test results are presented for a medium altitude condition. Here the impact of the modifications on the helicopter fuselage and also the new main rotor are shown by an increased maximum forward speed of $\Delta V = 10$ Knots. Considering the reduced power required a reduction of the fuel flow of up to 13% at a certain flight speed can be achieved.

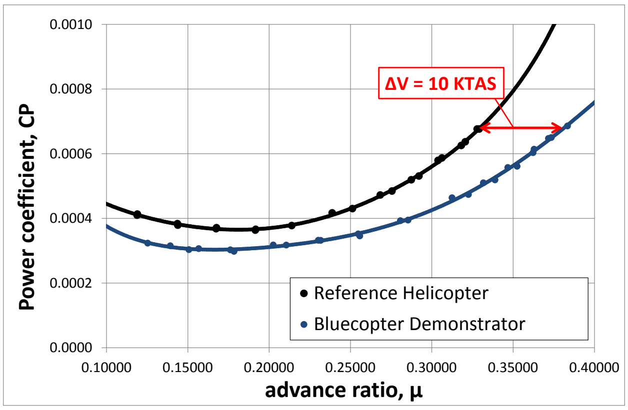


Figure 14: Comparison of power required in forward flight between reference helicopter and Bluecopter demonstrator

3.2 Acoustic Emission

Within the scope of the BD project acoustic flight tests were conducted over the military dropping area of Manching in July 2014. The measurements were performed in general accordance with international noise certification regulations considering tolerances on flight parameters, trajectory constraints and meteorological conditions. This allows a direct comparison of the BD noise levels with the noise levels of other helicopters. The microphone setup includes three 1.2m-height microphones which were installed perpendicular to the flight track at lateral distances of 0m and ±150m and additionally five microphones placed above ground plates at lateral distances of 0m, ±75 and ±150m. Main emphasis of the flight test campaign was put on the acoustic assessment of the main rotor in various flight states. For statistic reasons each flight condition was repeated three to six times. Hereafter the acoustic measurement results of the BD are highlighted in more detail.

Approach

Primary objective of the main rotor design was to minimize the generation of the particularly annoying blade vortex interaction (BVI) noise for the certification approach without causing acoustic penalties at other descent angles and flight speeds. Therefore the test matrix comprises besides the noise certification flight conditions also additional flight conditions such as a variation of the aerodynamic glide slope and rotational speed.

To characterize the noise directivity of the main rotor for the ICAO certification approach, the tone-corrected perceived noise level time histories of the three 1.2m-height microphones are considered and compared with the baseline helicopter. In this case the baseline helicopter is the EC135P1 S08 which was used for noise certification. It should be mentioned that the presented PNLT time histories in Figure 15 to Figure 17 are averaged of several valid runs fulfilling the certification regulation. Note that the maximum gross weight for the reference helicopter is 2835kg whereas the maximum gross weight for the BD equals 3175kg.

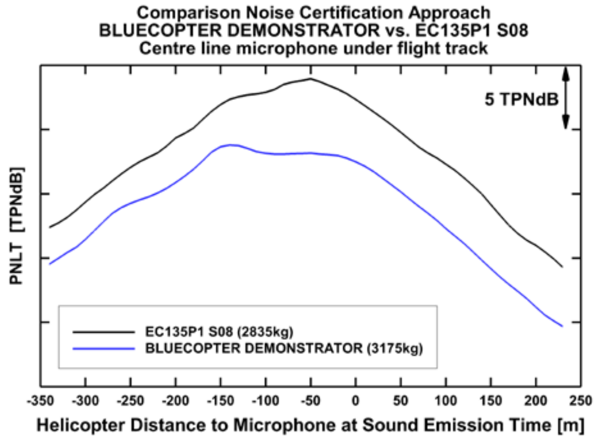


Figure 15: PNLT-TIME History (center line microphone)

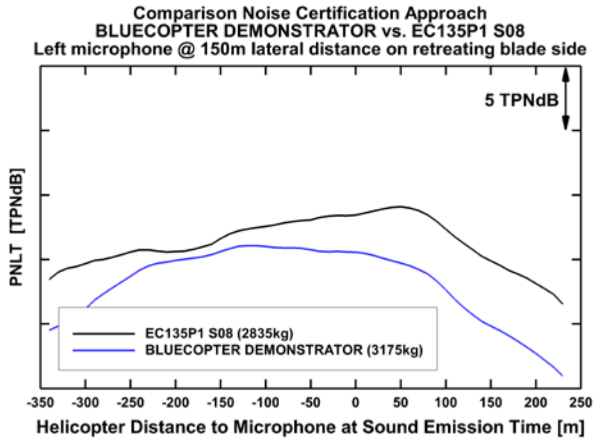


Figure 16: PNLT-TIME History (retreating side microphone)

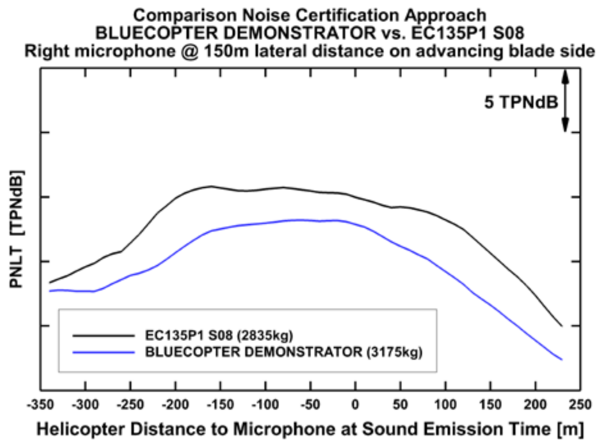


Figure 17: PNLT-TIME History (advancing side microphone)

Compared to the baseline helicopter shown in black solid lines the BD (blue solid lines) shows significantly reduced noise levels on all microphones and over the whole duration of the passing-by event. On the center line microphone the maximum gain of the peak noise level (PNLTMAX) is about 5 TPNdB and for the retreating and advancing side microphone approximately 2.5 TPNdB. Thereby an excellent noise directivity is achieved for the ICAO certification approach.

Even though the noise levels are exceptional low for the design point (ICAO certification approach) a robust low noise design is only achieved when the acoustic emission is reduced also in off-design points. Therefore different aerodynamic glide slope angles were measured at best rate of climb speed. Basis for the comparison is the Friendcopter database. Within this campaign the EC135T2+ S01 was used. Again there is a difference in the maximum gross mass of around 225kg. As already demonstrated for the design point, the BD also clearly shows remarkable reduced noise levels up to 6 EPNdB for the several flown aerodynamic glide slope angles (Figure 18). So a well-balanced main rotor blade design is available for a wide range of glide slope angles which is important for noise mitigation in real life.

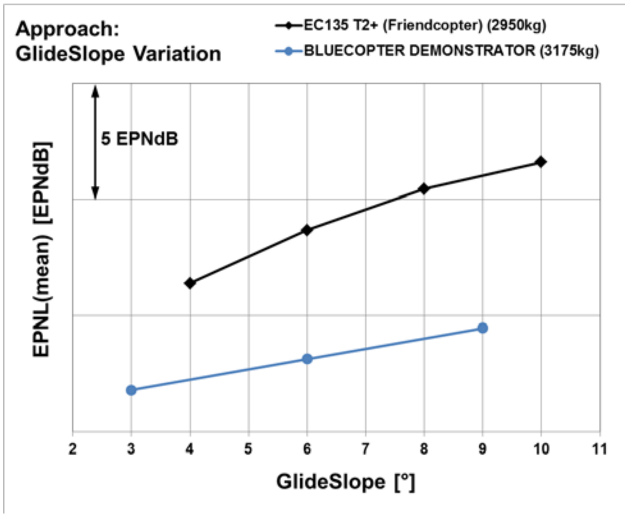


Figure 18: Glide slope variation at Vy with a fixed height above the microphone

Rotational speed is one of the most efficient parameters for reducing the noise emission. This effect is confirmed through several previous flight tests of different helicopters. However when analyzing the BD measurement data of the RPM variation and comparing them with the previous flight tests it remains an additional noise benefit arising from rotor parameters such as leading edge shape, number of rotor blades, twist and chord distribution.

Finally the effective perceived noise level of the BD is determined and compared with the noise certification levels of the world fleet. For this purpose the EPNL values are presented as function of maximum take-off weight. The noise levels of the world helicopter fleet are extracted from the EASA Type Certificate Data Sheet for Noise (TCDSN) database. And here the BD appears as true champion as it shows best-in-world fleet noise signature with about 7.9 EPNdB below the ICAO limits (Chapter 8.4.1). Moreover the noise signature of the BD is very close to an approximated No-BVI (no blade vortex interaction) limit previously postulated by Sikorsky as a kind of physical barrier for approach noise reductions (Ref. [8]).

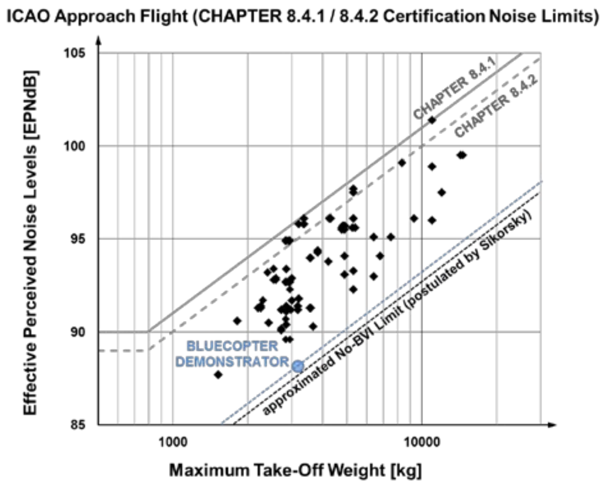


Figure 19: Noise certification approach levels vs. maximum take-off weight compared for ICAO Annex 16, Chapter 8 helicopters

Concluding, the combination of an advanced and innovative blade design with an advanced RPM law featuring low blade tip speed in the acoustic relevant flight states results in exceptional low noise levels of the BD for all measured descent flight conditions.

Take-off and Flyover

Even the certification takeoff and flyover flight condition was not in the main focus of the blade design the BD also shows excellent noise levels with up to 7.8 EPNdB below the ICAO limit (Chapter 8.4.1) for these flight conditions.

Operational aspects

Let us consider an inner-city helipad like a hospital in the direct vicinity of a residential area. The impact of helicopter operational noise can be reduced by two strategies: Either reduce noise by operational means or reduce noise levels at the source. The introduction of noise abatement procedures [11] promises significant benefits but their application is oftentimes limited due to mission requirements and safety aspects to certain heights above take-off or landing decision point. Therefore, there is an additional need for reduced source noise levels coming from the helicopter design to reduce the noise exposure of residents. And here the BD shows its unique strength. Especially for the approach marked by the most annoying sound characteristic (impulsive blade vortex interaction noise) a break-through in noise reduction is achieved and noise levels are significantly reduced. Aside from the pure numerical value also the perceived annoyance is significantly reduced due to the mitigation of impulsive noise peaks. Thanks to the consequent low blade tip speed design noise mitigation is also possible for the hover flight condition while maintaining the highest level of safety for crew and passengers. The take-off condition will further benefit from the active rudder and good climb rates. Finally the level flight is important for frequently used routes, i.e. touristic flights, shuttle service, surveillance. Moreover it is a criterion for operations in Grand Canyon National Park. In this area "flying higher" using varying routes can mitigate the annoyance in addition to low noise design.

4 CONLUSION

The BLUECOPTER DEMONSTRATOR presented in this paper has been developed to prove the feasibility of future eco-friendly helicopter concepts. The demonstrator incorporates a set of innovative technologies, each of them contributing to the ambitious objectives in terms of fuel consumption and acoustic emission. As demonstrated in flight, a major part of the benefits is provided by the newly developed rotor system. It includes an innovative five-bladed bearingless main rotor as well as the advanced Fenestron® with optimized blade and stator design.

In addition, several measures were applied to reduce the drag of the aircraft, including fairings for the main rotor and landing skids, a special design of the aft-body and a low-drag empennage with "T-Tail" horizontal stabilizer. The combination of these technologies results in a reduction of approximately 13% in fuel consumption and an increase of 10 Knots in maximum forward flight speed.

A dedicated power management concept is applied to further improve the fuel-efficiency of the BD. It consists in shutting down one engine and operating the remaining engine more efficiently at higher loading. In combination with the optimized BD configuration a significant overall reduction in fuel consumption of approximately 38% can be achieved. With approximately 8 EPNdB margin to the ICAO limits (Chapter 8.4.1), the BD has the best-in-world acoustic signature for approach conditions. This impressive low-noise design will be completed with the innovative "acoustic liner" for the Fenestron® shroud and the active fin rudder. These elements will help to further improve the acoustic footprint and push the demonstrator close to the physical limits. Noise levels of about10 EPNdB below the ICAO limits are expected for the BD in this final configuration.

A strong focus of the BD project was on developing "transversal" technologies that can be adapted to serial applications across different helicopter classes. After the finalization of the BD flight test campaign by end of 2015, all technologies will be critically assessed towards a potential serial application. The most promising and mature BD features will gradually find their way into future Airbus Helicopters products. So the innovations incorporated in the BD could open the way for a new generation of rotorcraft that will have lower noise levels, burn less fuel and operate more efficiently.

5 OUTLOOK

To finalise the low-noise Fenestron® design of the BD an advanced lining concept will be integrated in the Fenestron® duct in August 2015. This lining concept focuses on the reduction of the noise emission and the improvement of the overall noise characteristics, including the field of psycho acoustics. Especially the annoyance of the Fenestron® sounds will be noticeably reduced.

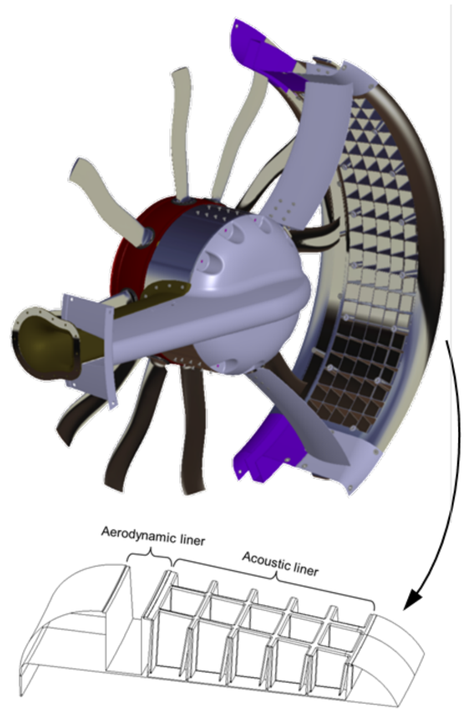
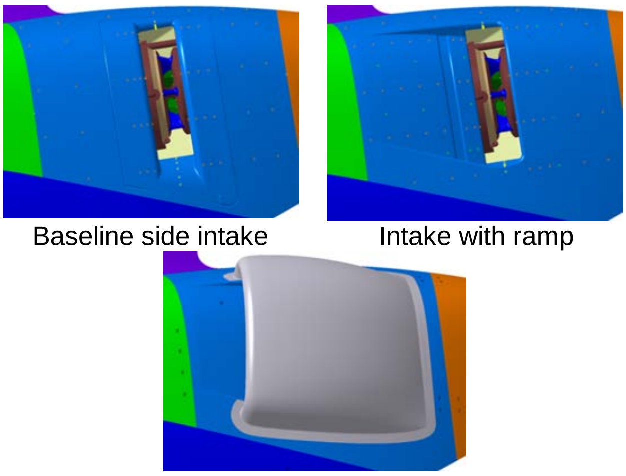


Figure 20: Advanced Fenestron® lining concept

The core idea is to combine an acoustic liner for broadband sound absorption and a so-called aerodynamic liner for source strength reduction of blade tip clearance flow noise. Figure 20 illustrates one segment of the advanced lining concept. The spectral absorption range of the acoustic liner was tuned to the most annoying frequency range, especially to a frequency interval from 400Hz up to 3kHz. Within this frequency interval the human ear shows maximum sensitivity whereas the Fenestron® is emitting most of its tonal harmonic noise. The liner design must therefore allow broadband sound absorption within this range while respecting geometrical constraints that allow its integration into the shroud. The acoustic liner is a combination of Helmholtz resonator and quarter wave length lining concepts.

The aerodynamic liner consists of an annular channel around the rotor covered by a flow resistance optimised facing sheet. This liner is particularly intended to reduce the acoustic source strength of blade tip clearance noise thanks to the flow permeability of the facing sheet. Turbulent velocity fluctuations within the blade tip clearance will be reduced inside this facing sheet.
The lining concept was developed in corporation with Airbus Group Innovations in Ottobrunn and measured in advance in the acoustic laboratory.



Baseline side intake Intake with ramp

Intake with ramp and scoop

Figure 21: Side intake variants for the BD

During the fourth quarter of 2015 a further lay-up phase of the BD is foreseen to install and flight test the newly designed air intakes, developed in the context of the Green Rotor Craft ITD of the Clean Sky Initiative. These air intakes implementing a ramp on the outer cowling, a new plenum and a scoop, to gain Ram effect in forward flight (see Figure 21), have been already tested, in the context of the Clean Sky partner project ATHENAI [10], in the wind tunnel A of the faculty of aerodynamics at the Technical University of Munich. The objective is to reduce pressure losses and distortion and improve swirl upstream of the engine compressor, with the final goal of reducing installation losses thus increasing available power.

6 ACKNOWLEGMENTS

The development of the BD technologies has been partially funded by the European Community's Seventh Framework Program (FP/2007-2013) for the Clean Sky Joint Technology Initiative and by the German Luftfahrtforschungsprogramm (LuFo) IV.

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8 LIST OF PATENT APPLICATIONS

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- Helicopter with a transverse duct, 08.06.2012, EP12400020
- Aft body integrated longitudinal strakes on helicopter blunt fuselages, 26.07.2012, EP12400029
- Rotor head of a rotary wing flying machine and method of manufacturing and assembling such a rotor head, 31.10.2012, EP12400045
- Helicopter with a tail shroud, 10.12.2013, EP13400034
- Rotorcraft with at least one main rotor and at least one counter-torque rotor, 28.02.2014, EP14400015