HELICOPTER FUSELAGE OPTIMISATION

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Abstract

This paper is devoted to the aerodynamic shape optimization of the fuselage of the prototype of the light helicopter ANSAT, produced by the Kazan Helicopter Plant of the Russian Federation. This fuselage has so far been investigated using wind tunnel experimentation and numerical simulation. The optimization process is based on Genetic Algorithms with Kriging surrogate models. Shape parameterization is carried out with the super ellipse technique employed for the well-known ROBIN fuselage. The simulation of the flow around the helicopter fuselage was based on the RANS equations solved using the HMB CFD code. It is shown that a decrease of fuselage drag around 2.5% is possible without compromising the structure and the functionality of the design.

1. INTRODUCTION

The design of a helicopter fuselage is a difficult and complex task for helicopter manufacturers. The design process aims to compromise between structural and aerodynamic requirements, and most of the times, engineers are looking for small changes in geometry and structure to improve the aerodynamic characteristics. Past and recent studies show that a significant contributor to the total drag of the helicopter fuselage is the suction at its rear due to the aft-facing surfaces used for ramps and rear-access [1-9]. This high drag region is also characterized by the presence of a vortical flow. It is known that two types of vortical structures can be found at this separated flow region: eddies, that are located across the flow close to the fuselage/tail boom junction area, and vortex pairs, located symmetrically to the mid-plane of the helicopter and aligned with the free stream flow direction. Numerical investigations of the vortex structure behind an isolated helicopter fuselage were presented in [8].

One of the ideas for improving the fuselage aerodynamic characteristics is to change these vortical structures. This can be achieved in several ways: active flow control by flow suction and blowing [4], passive flow control using devices like vortex generators [5] [16] and shape optimization [6].

Active flow control at the rear of a helicopter fuselage was investigated in [4], [10-13]. The investigation was carried out using an experimental approach, as well as, numerical simulation. The active flow control was realized by blowing actions (steady and pulsed blowing). The results of these investigations show that the helicopter fuselage drag can be reduced up to 10-35%. The drag reduction depends on the type of actuators, blowing flow ratio etc. The disadvantage of this approach is the necessity to install additional equipment that requires additional power.

An alternative approach is based on changing the fuselage geometry. In [13] and [14] different changes of the fuselage shape and of the landing skids were investigated. New geometries were constructed, and results of these investigations show potential for decreasing the fuselage drag.

Another way is to find the optimal shape of the helicopter fuselage. To this aim, different optimization approaches are used. Any optimization requires parameterization of the geometry. The fuselage geometry can be fully [3], or partly parameterized [6], [15], [17]. A fully parameterized geometry is a good approach for the first steps in the design of a new helicopter. Due to design constrains, however, a partial parameterization is more useful.

The type of parameterization determines the number of the design parameters and the design space. For a real helicopter, it is important to improve the aerodynamic characteristics by small changes in the geometry that can be easily implemented.

2. TEST CASE CONSIDERED

This paper is devoted to an aerodynamic shape optimization method for the fuselage of the prototype light helicopter ANSAT, produced by the Kazan Helicopter Plant of the Russian Federation (fig.1).

Figure 1. The ANSAT Helicopter

The ANSAT is a multi-purpose light helicopter with a classic single-rotor design. The main rotor consists of four blades and the tail rotor consists of two. The main characteristics of this helicopter are presented in table 1.

During the early stages of this investigation a wind tunnel model of the helicopter was constructed. The wind tunnel model broadly corresponds to an ANSAT prototype (fig.2).

The wind tunnel model fuselage has a length 1.8 m and a mid-ship section 0.1085 m^2

Table 1. Main characteristics of the helicopter ANSAT

Performance	
Max speed	275 km/h
Cruise speed	220 km/h
Max. flight range with main fuel tanks	515 km
Operational ceiling	4800 m
Hover ceiling (OGE)	2500 m
Weight Parameters	
Max. take-off weight	3600 kg
Max. payload in transport cabin	1234 kg
GT engines (2xPW207K)	
Take-off power	630 h.p
Contingency power	710 h.p
Cabin Dimensions	
Length	5700 mm
Width	1770 mm
Height	1370 mm
Volume	8.0 m^3
Capacity	
Aircrew	1-2
Passengers	7+1


Figure 2. Wind tunnel model

A CAD model was also constructed (fig.3). The CAD model consists of the fuselage, landing skids, and tail plane. During this investigation the flow around isolated parts, as well as, the complete fuselage were considered.

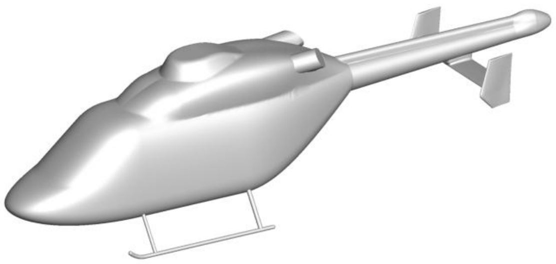


Figure 3 – CAD model

3. HMB CFD CODE

The simulation of the flow around the helicopter fuselage was conducted using the RANS equations with the HMB CFD code. HMB uses the finite volume method and to close the RANS equations system, turbulence models are used. The solver has different turbulence models like the Spalart – Allmaras, the k-ω, and the k-ω-SST models, as well as, hybrid approaches like DES, SAS, and LES. In the current investigation the k-ω turbulence model was used.

For spatial discretization, this solver requires multi-block hexa-grids. These are constructed using the ICEM Hexa tool.

The HMB code has been used for investigations of the flow around the isolated helicopter fuselage [7-9], and for validation, results wind tunnel tests were used.

4. Optimization process

The optimization process consists of several steps. The first step is a parameterized geometry. There are many different approaches to create a parameterized geometry. Shape parameterization of the current investigation was carried out with the super ellipse technique employed for the well-known ROBIN fuselage. This technique allows to reproduce a part of the geometry with high quality, and with few design parameters.

The aim of the optimization process is to find the optimal shape. The fuselage drag was considered as the objective function. The search process for the optimal shape was based on Genetic Algorithms.

Due to the high computational cost of the target function evaluation by the CFD a surrogate model was used based on Kriging [18]. To construct the surrogate model, an initial CFD field was calculated. To create the initial design space the Latin Hypercube sampling approach was used.

For the current investigation, a mesh adaptation algorithm was developed. This algorithm allows automatic updates and calculation of the grid for new design variants of the fuselage geometry.

5. Landing skids cross section optimization

The first task was to optimize the cross section of the landing skids. The baseline landing skids has a cylindrical cross section. Due to this reason their aerodynamic drag was high. To minimize drag it is necessary to install a fairing over the landing skids. The question is to find the optimal geometry of the fairing.

To solve this task, the cross section of the skids was parameterized as a super ellipse:

$$y + y_0 = r \cdot \cos\varphi$$
$$x + x_0 = r \cdot \sin\,\varphi$$
$$r = \left|\frac{(AB)^N}{(A \cdot sin\varphi)^N + (B \cdot cos\varphi)^N}\right|^{1/N}$$

The parameterization of the cross section for the leading and trailing parts was carried out separately. The height of the ellipse was kept constant. The length and the curvature of the leading and trailing parts were modified (fig.4.). Thus at the current investigation, 4 design variables were considered.

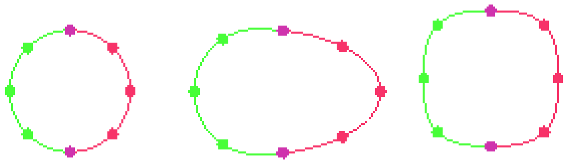
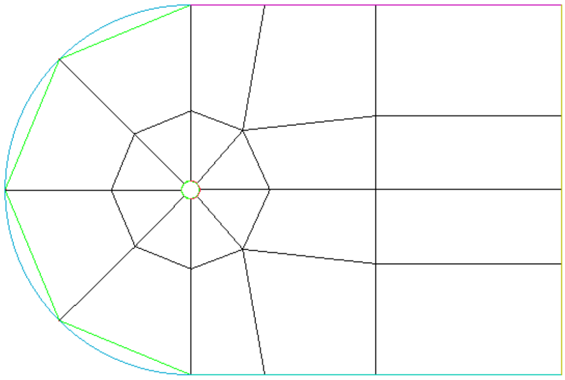


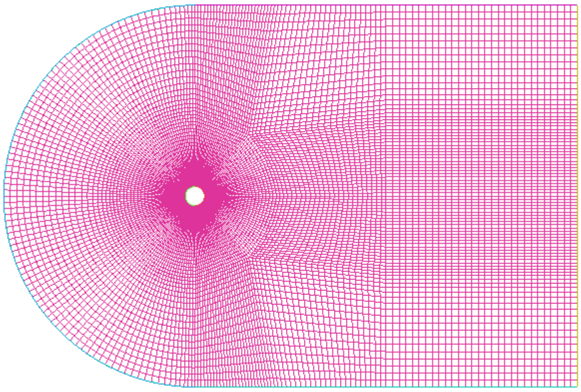
Figure 4. Modification of cross section

To simulate the flow around the skids cross section a grid was constructed in

ICEM Hexa. The blocking structure and the mesh are presented in figure 5.



(a)



(b)

Figure 5. Blocking structure (a) and grid (b) near cross section of landing skids

The boundaries of the computational domain were placed more than 10 diameters away from the fairing. The total number of grid cells was 26300, and the cell size near the cross section was $1 \cdot 10^{-5}$ of its diameter.

At every design iteration, the grid was automatically updated. The simulation of the flow around the cross section was carried out at Mach number M=0.1 and Reynolds number $Re=1 \cdot 10^5$.

Taking into account that 2D calculations do not require a lot of time the Genetic Algorithm did not use the surrogate model.

As a first step, 10 variants of the fairing were created for the initial generation. After evaluation of the target function (drag coefficient) of each variant, the results were normalized according to their fitness

$$C_i = \frac{1/CD_i}{\sum_{i=1}^{N}(1/CD_i)}$$

Based on 5 parents, a new generation was produced by a crossover technique. For more flexibility during optimization, random mutations were realized.

After the definition of a new generation the optimization loop was closed. The process stopped when the minimum of drag coefficient did not change any more (fig.6).

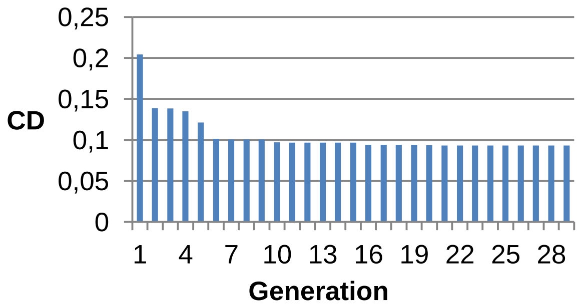


Figure 6. Convergence history

As a result of this investigation the parameters of the optimal fairing cross section were obtained. The optimal geometry looks like a symmetric airfoil with thickness of 38.835%C. In figure 7, the optimal cross section is presented in comparison with a NACA 00XX aerofoil.

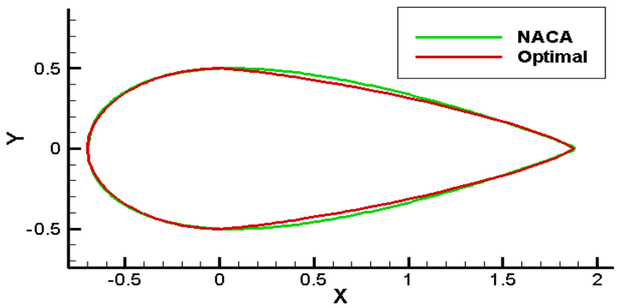


Figure 7. Optimal cross section and aerofoil NACA 00XX

6. Fuselage optimization

As noted earlier, the high drag coefficient of an isolated fuselage is due to the vortical flow behind it. For this reason, a part of the fuselage was considered for optimization as presented in figure 8. This part has a leading boundary near the midline cross section, and a trailing boundary near the tail boom root.

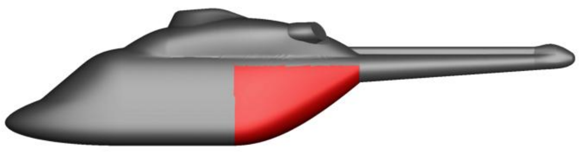


Figure 8. Considered part of isolated fuselage

The parameterization is based on the super ellipse equation. To modify the geometry it was decided to change the parameters of one cross section (termed, the control section). The other sections were changed according to a sinusoidal law such that the boundaries were constant. In this case height (dB), curve power (dN), and position of the control section (dX) were considered as design variables. This approach allows to change the geometry without any modification of the tail boom, engine cowling or midline section.

Due to the high computational cost of the target function (drag coefficient) the optimization process was based on the surrogate model. To create a surrogate model Kriging was used. The Kriging model was constructed based on 40 samples from the design domain.

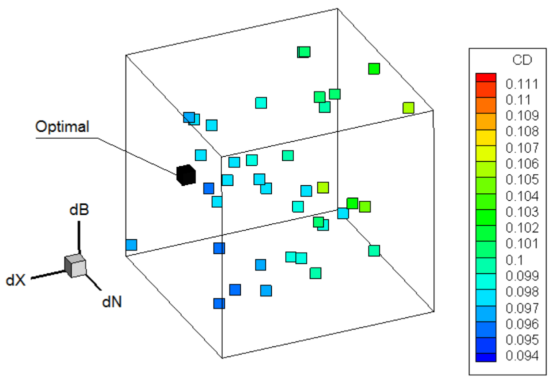
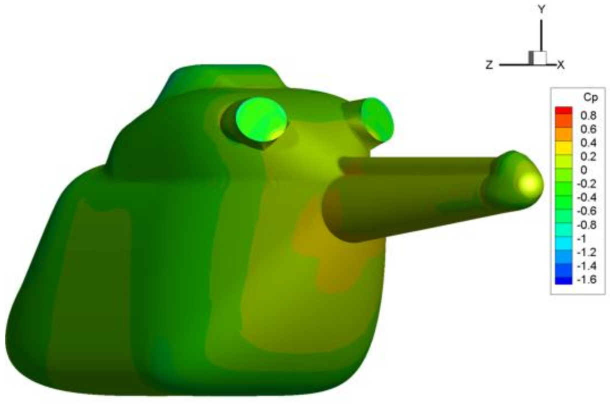


Figure 9. Design domain and result of optimization

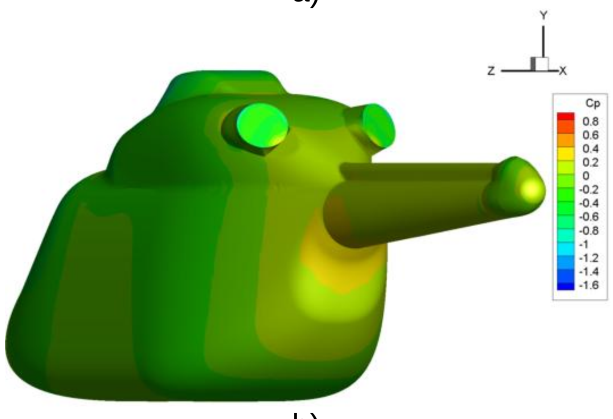
To find the optimal parameters a Genetic algorithm was used. Results of the optimization process and the evaluation of the target function are presented in figure 9.

As a result of the optimization process, the parameters of the fuselage were obtained. The simulation of the flow around the modified geometry shows that the drag of the isolated helicopter fuselage decreased up to 2.5% in comparison with the baseline geometry. The reason behind the reduction of the aerodynamic drag was the change of the pressure distribution (fig. 10).

The considered modification leads to an increase of the pressure coefficient at the rear part of the fuselage (fig. 11).



a)



b)

Figure 10. Pressure coefficient distribution: a) baseline; b) modified

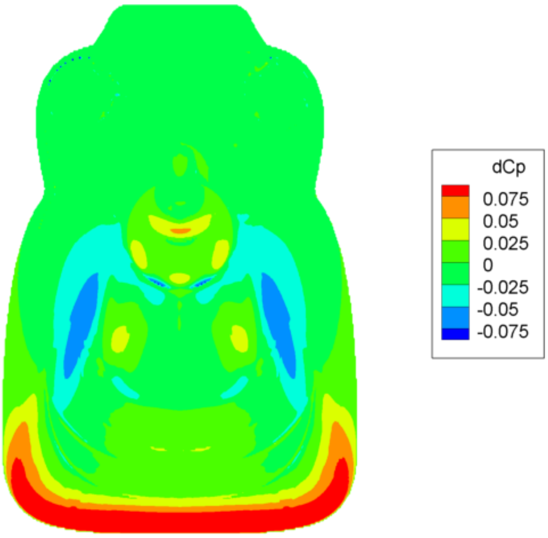


Figure 11. Difference in pressure coefficient distribution between initial and optimized shapes at the rear fuselage

7. Fuselage layout

The previous section presented optimization results of an isolated fuselage. The components of the fuselage (for example landing skids) can also influence the flow structure and change its aerodynamic characteristics.

For this reason, flows around different fuselage configurations were considered. A more complex configuration consists of the fuselage (Fus), landing skids (LS), and tail plane (TP). The results of the drag evaluation for different layouts with the baseline and modified fuselage geometries are presented in figure 11.

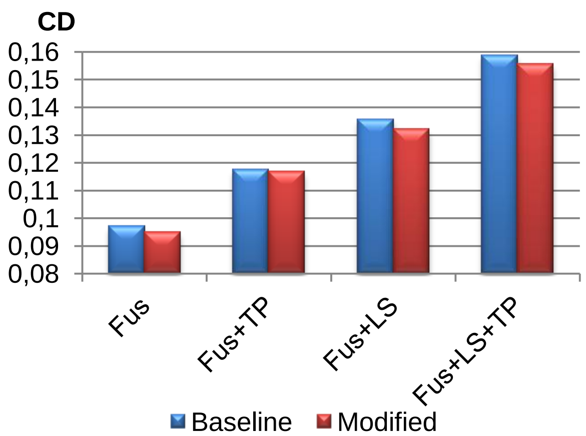


Figure 11. Drag coefficient for different fuselage layouts

It is shown that all configurations with the modified fuselage geometry have lower drag coefficient. Note that the drag decrease for the fuselage with landing skids is larger than the decrease for the isolated fuselage. One of the reasons is the influence of the landing skids on the pressure distribution of the rear fuselage (fig.12).

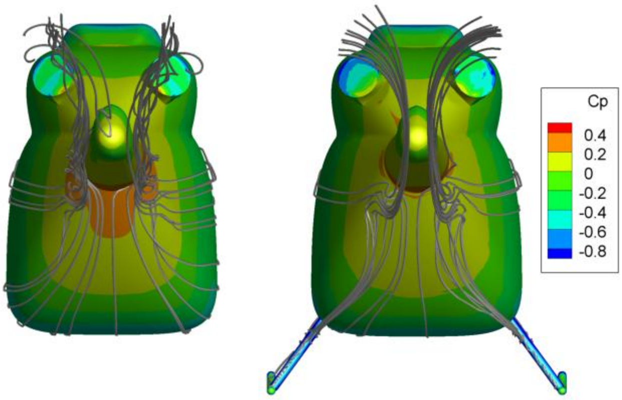


Figure 12. Pressure distribution on the isolated fuselage and fuselage with landing skids

The difference of the pressure distribution due to shape optimization for the fuselage with landing skids on, is presented in figure 13.

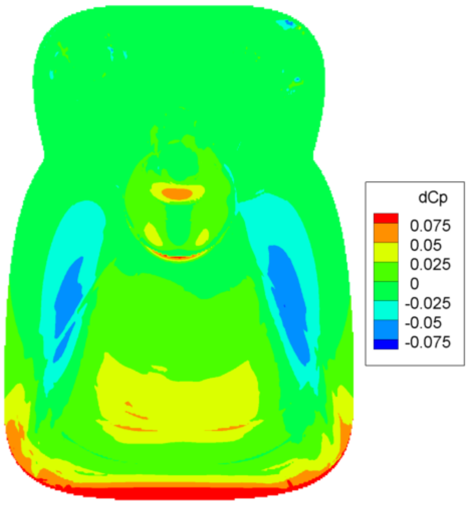


Figure 13. Difference in pressure coefficient distribution between initial and optimized shapes including skids at the rear fuselage

According to the results of the previous section, the landing skids were also modified by adding fairings (fig.14).

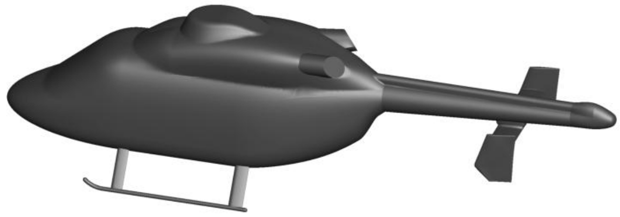


Figure 14. Fuselage layout with modified fuselage and landing fairing

The results of the flow simulation around the fuselage with these additional modifications are presented in table 2. It is shown that the total drag decrease due to the considered modifications was 4.6%. The drag decrease due to the fuselage modification only was 2.1%

Table 2. Drag coefficient of fuselage layout with different modifications

Variant of layout	CD	ΔCD	ΔCD,%
baseline	0,1588	–	–
Modified fuselage	0,1555	0,0033	2,1
Modified fuselage and landing skids	0,1515	0,0040	4,6

8. Conclusion

The paper presented optimization results of a realistic helicopter fuselage. The target function of the optimization process was the drag coefficient. During the current work, optimization of the cross section of the landing skids and the rear part of the fuselage were considered. The optimization was based on a Genetic Algorithm with a Kriging surrogate model.

As a result of the optimization of the landing skids, their geometry evolved to a symmetric aerofoil 38.835% thick. Investigation of the isolated fuselage drag shows that it is possible to decrease it by up to 2.5% without compromising the functionality of the design. Application of the considered modifications for a more complex fuselage layout gave a decrease of the drag coefficient by up to 4.6%.

Acknowledgements

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References

[1] Seddon, J., “Aerodynamics of the Helicopter Rear Fuselage Upsweep”, *8th European Rotorcraft Forum Proceedings*, Aix-en-Provence, France, 1982.

[2] Vogel F., Breitsamter C., Adams N. A., “Unsteady effects of the separated flow at the tail section of a helicopter fuselage”, *35th European Rotorcraft Forum*, Hamburg, Germany, 2009.

[3] Stalewski W., Zoltak J., “Optimisation of the helicopter fuselage with simulation of main and tail rotor influence”, *28th international congress of the aeronautical sciences* (ICAS 2012), Brisbane, Australia, 2012.

[4] Lienard C., Le Pape A., Verbeke C., “Numerical and Experimental Investigation of Helicopter Fuselage Drag Reduction Using Active Flow Control”, *American Helicopter Society 68th Annual Forum*, Fort Worth, Texas, USA, May 1–3, 2012.

[5] Gibertini G., Auteri F., Campanardi G., Droandi G., Grassi D., Le Pape A., Zanotti A., “A Test Rig to Assess the Effectiveness of Drag Reduction Devices on a Heavy-Class Helicopter”, *41th European Rotorcraft Forum*, Munich, Germany, September 1–4, 2015.

[6] Wentrup M., “An Adjoint Based Gradient Optimization Chain For Complex Helicopter Fuselage Parts Using A Free Form Deformation Or Cad Based Parameterization Method”, *41th European Rotorcraft Forum*, Munich, Germany, September 1–4, 2015.

[7] Batrakov A.S., Kusyumov A.N., Mikhailov S.A., Pakhov V.V., “A Study in Helicopter Fuselage Drag”, *39th European Rotorcraft Forum*, Moscow, Russia, September 3–6, 2013.

[8] Batrakov A.S., Kusyumov A.N., Mikhailov S.A., Garipova L.I., Barakos G.N., “Vortical Flow Behind Isolated Helicopter Fuselage”, *40th European Rotorcraft Forum*, Southampton, UK, September 2-5, 2014.

[9] Batrakov A., Garipova L., Kusyumov A., Mikhailov S., Barakos G., "Computational Fluid Dynamics Modeling of Helicopter Fuselage Drag", *Journal of Aircraft*, Vol. 52, No. 5 (2015), pp. 1634-1643.

[10] Ben-Hamou E., Arad E., Seifert A., “Generic Transport Aft-Body Drag Reduction using Active Flow Control”, *AIAA Paper* 2004-2509, 2004.

[11] Schaeffler, N.W., Allan, B.G., Lienard, C., and Le Pape, A., “Progress Towards Fuselage Drag Reduction via Active Flow Control: A Combined CFD and Experimental Effort”, 36th *European Rotorcraft Forum Proceedings,* Paris, France, September 7-9, 2010.

[12] Allan, B.G. and Schaeffler, N.W., Numerical Investigation of Rotorcraft Fuselage Drag Reduction using Active Flow Control, American Helicopter Society 67th Annual Forum Proceedings, Virginia Beach, VA, May 3-5 2011

[12] Woo, G.T.K, Glezer, A., Bain, J., Sankar, L. and Crittenden, T.M., Rotorcraft Fuselage Drag Reduction using Combustion Powered Actuators, AIAA Paper 2001-34, 2011

[13] Schneider S., Mores S., Edelmann M., D'Alascio A., Schimke D., “Drag Analysis for an Economic Helicopter”, *37th European Rotorcraft Forum*, September 13-15 2011, Vergiate/Gallarate, Italy

[14] Roman Reß, Grawunder M., and Breitsamter C., “Aerodynamic Analysis of a Helicopter Fuselage with Rotating Rotor Head”, *5th European Conference For Aeronautics and Space Sciences* (EUCASS), 2014

[15] Zhang Q., Lee J.-D., Wendisch J.-H., “An adjoint-based optimization method for helicopter fuselage backdoor geometry”, *36th European Rotorcraft Forum* 2010, 7.-9. Sep. 2010, Paris, Frankreich.

[16] Boniface J.-C., “A computational Framework for Helicopter Fuselage Drag Reduction Using Vortex Generators”, *American Helicopter Society 70th Annual Forum*, May 20-22, 2014 Montréal, Québec

[17] Zhang Q., Garavello A., D’Alascio A., Schimke D., “Advanced CFD-based Optimization Method Applied to the Industrial Design Process of Airframe Components at Airbus Helicopters”, *American Helicopter Society 70th Annual Forum*, May 20-22, 2014 Montréal, Québec

[18] Bohling G. http://people.ku.edu/~gbohling/cpe940/Kriging.pdf