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Aerospace Science and Technology

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Aerodynamic optimization of helicopter rear fuselage

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ARTICLE INFO

Article history:
Received 18 January 2018
Received in revised form 27 March 2018
Accepted 29 March 2018
Available online xxxx

Keywords:
Aerodynamics
Helicopter fuselage
Optimization
Genetic Algorithm
Kriging model

ABSTRACT

An optimization process for the rear helicopter fuselage part is presented using Genetic Algorithms and Kriging surrogate models. Shape parameterization is carried out with the super ellipse technique employed for the well-known ROBIN fuselage. The simulations were 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. Combined with an optimization of the helicopter skids, benefits of up to 4.6% were possible. The demonstrated method can be applied to fuselages of any shape during the initial design phase.

1. Introduction

The design of a helicopter fuselage is a difficult and complex task with compromises between structural and aerodynamic requirements. Most of the times, engineers are looking for small changes in geometry and structure to improve an already good design. Past and recent studies (for isolated fuselages and full helicopter models) show that a significant contributor to the total drag of the helicopter fuselage is suction at its rear due to aft-facing surfaces used for ramps and rear-access [1–15].

This is the reason for streamlined helicopter fuselage shapes. An example is the Sikorsky UH-60A helicopter with a smooth aft-facing surface at the fuselage tail-boom junction area. In contrast to this trend there are helicopters with a salient area of fuselage/tail-boom junction. Examples include the Bell 206, BK 117, and the EC 135.

This high drag region (at the fuselage/tail boom junction area) is also characterized by the presence of a vortical flow. It is known [1] that two types of vortical structures can be found at this separated flow region: eddies, that run across the flow close to the fuselage/tail boom junction area, and vortex pairs, located symmetrically to the mid-plane of the helicopter and are aligned with the free stream flow direction. Numerical simulation of these structures behind an isolated helicopter fuselage was presented by Batrakov et al. [11].

One of the ideas for improving the fuselage aerodynamic characteristics is to change these vortical structures. This can be achieved in many ways including 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 by Lineard et al. [4] and also in Refs. [17–21]. Investigations were carried out using experiments, as well as, numerical simulation. The active flow control was realized by blowing (steady and pulsed), and results show that the fuselage drag can be reduced by up to 10-35%. The drag reduction depends on the type of actuators and their parameters, like blowing flow ratio etc. The disadvantage of this active approach is the necessity to install additional equipment that requires additional power.

An alternative approach is based on changing the fuselage geometry. Different fuselage shapes and landing skids were investigated by Schneider et al. [21] and Reß et al. [22]. New geometries were constructed, and results of these investigations show good potential for reducing the fuselage drag.

Another way to reduce drag 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, and geometries can be fully [3], or partly parameterized [6, 23,24]. 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.

This work presents a framework for the minimization of helicopter fuselage drag employing CFD in conjunction with a surrogate model based on Kriging method [25], and a Genetic Algorithm (GA) optimization method. GA originated from the theory of natu-

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https://doi.org/10.1016/j.ast.2018.03.046
1270-9638/

Please cite this article in press as: A.S. Batrakov et al., Aerodynamic optimization of helicopter rear fuselage, Aerosp. Sci. Technol. (2018), https://doi.org/10.1016/j.ast.2018.03.046

Nomenclature

x_0, y_0, z_0	origin of super-ellipse center	r, φ	polar coordinates
A, B	length and width of the super-ellipse	CD	drag coefficient
N	power of curve	M	Mach number
x, y, z	Cartesian coordinates	Re	Reynolds number

Fig. 1. The ANSAT helicopter.

ral evolution and is widely used as a global optimization tool [26]. An advantage of the GA is that it does not need gradient information. Therefore, GA is suitable in finding the global optimization point and design variable set. GA application for 3-D aerodynamic design problems presented for example in references [27,28]. As an alternative approach, an adjoint based optimization method [23,24] has also been successfully applied to aft fuselage shape optimization, resulting in an aft body, strake.

The type of employed parameterization determines the number of design parameters, and the size of the design space. For a real helicopter, it is important to improve aerodynamics by introducing small changes in the geometry that can be easily implemented, without severe implications on the strength and weight of the airframe.

2. Fuselage optimization case

This paper demonstrates an optimization approach for the fuselage of the prototype ANSAT helicopter, produced by the Kazan Helicopter Plant of the Russian Federation (Fig. 1). 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 length of the fuselage is 11 m and the mid-ship sectional area is 4 m^2, approximately. The maximum take-off weight is 3600 kg. 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, broadly corresponding to one of the ANSAT prototypes (Fig. 2). The wind tunnel model fuselage had a length 1.8 m and a mid-ship sectional area of 0.1085 m^2. A CAD model was also constructed (Fig. 3), including the fuselage, landing skids, and tail plane. During this investigation the flow around isolated fuselage parts, as well as, the complete fuselage were considered.

Fig. 2. Wind tunnel model.

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 hp
Contingency power	710 hp
Cabin dimensions	
Length	5700 mm
Width	1770 mm
Height	1370 mm
Volume	8.0 m^3

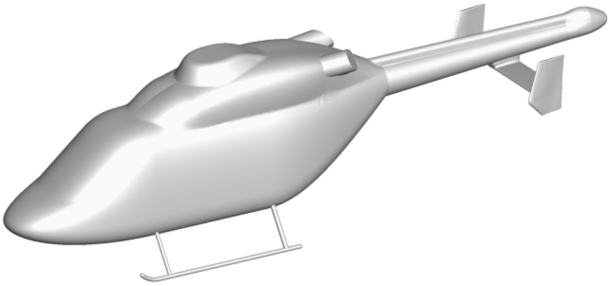

Fig. 3. CAD model of the ANSAT prototype.

3. HMB CFD code

The simulation of the flow around the helicopter fuselage was conducted using the RANS equations with the HMB CFD code [29]. HMB uses the finite volume method and to close the RANS equations, turbulence models are used. The solver has turbulence models like the Spalart-Allmaras [30], the k–ω [31], and the k–ω-SST [32], as well as, hybrid approaches like DES, SAS [33], and LES. This solver employers multi-block hexa-grids, constructed using the ICEM^{TM} Hexa tool. The HMB code has been used for investigations of the flow around the isolated helicopter fuselage [10–12], and for validation, wind tunnel tests were used.

The simulation of the flow around the isolated helicopter was carried out with k–ω SST turbulence model in steady state mode. The baseline grid for the isolated fuselage contained 964 blocks and 13.5×10^6 cells. An O-grid topology was used around the

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