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Helicopter drag reduction by vortex generators

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ABSTRACT

The performance of vortex generators in reducing the helicopter drag was investigated by computational fluid dynamics and wind tunnel tests. Numerical simulations were carried out to define the layout and the position of vortex generators to be tested on a heavy-class helicopter fuselage model. A comprehensive experimental campaign including loads, pressure measurements and stereo particle image velocimetry surveys was then performed to assess the results of the numerical activity. Experiments confirmed the main trends predicted by computations. Tests for an array of vortex generators positioned on the model back-ramp showed a maximum drag reduction of about 5% with respect to the clean geometry. Moreover, the analysis of the velocity field and of the pressure distribution around the backdoor/tail-boom junction enabled to investigate the flow physics related to the effect of vortex generators on the fuselage drag.

1. Introduction

The recent expansion of the helicopter use has drawn the attention on its high environmental impact. Such an impact can be alleviated by decreasing the helicopter fuel consumption and, therefore, by reducing its drag. Among several possibilities, an interesting way to reduce drag is to employ simple passive devices such as vortex generators (VGs).

Vortex generators were widely used to increase the performance at high angles of attack for low speed, delaying the stall by promoting the reattachment of separated flows [13]. In particular, the potential of these devices were also investigated to reduce the aerodynamic drag of blunt ground vehicles operating with high average speed such as trucks or coaches [9,10]. Potential benefits were also proven for wind turbine applications by lowering noise levels through mitigation of blade stall effects [24] and in rotorcraft applications for the critical issue of alleviating the dynamic stall on the retreating blade side of helicopter rotors [11,14,15]. VGs can also improve the efficiency and the range of stable operation of highly loaded compressors, characterising the current trend of the gas-turbine engine design with a notable increase of the thrust-to-weight ratio [7,17].

Since VGs are inexpensive and can be easily installed also on existing helicopters, they are being considered for drag reduction of blunt helicopter fuselages at cruise speed. Blunt fuselages are characterised by a pronounced upsweep of the after-body shape which is responsible for a recirculating region at the junction with the tail boom, yielding penalties on helicopter drag. Surprisingly, little effort was spent to study the drag reduction effect on a helicopter fuselage equipped with VGs to date. The study of the effectiveness of these devices was therefore introduced in the work plan of the GRC (Green RotorCraft) project in the framework of Clean Sky programme. The Clean Sky JTI (Joint Technology Initiative) was launched in 2008 as a Public–Private Partnership between the European Commission and the industry. Its mission is to develop technologies that increase the environmental performances of air transport.

Among other platforms, a heavy-weight class helicopter was studied by the GRC2 Consortium. The considered geometry is basically the same one tested in the GOAHEAD project [22] funded by the EU's Sixth Framework Programme for Research (FP6). However, in the present investigation the fuselage geometry included the sponsons. Thus, in the following the fuselage geometry is named GOAHEAD-like model. The present paper shows the results of the investigation on the use of VGs for this heavy-weight class helicopter. The study was initially conducted by means of CFD simulations [4]. Then, CFD results were validated by wind tunnel tests, in the ROD (ROtorcraft Drag reduction) GRC2 project.

The vortex generators were installed on the rear door ramp to reduce the corresponding recirculating region. Since the effect of main and tail rotors on the rear ramp wake is expected to be negli-

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Nomenclature

Cd	drag coefficient	
CFD	Computational Fluid Dynamics	
Cp	pressure coefficient	
H_{VG}	VG height	m
L_{VG}	VG chord length	m
M	Mach number	
P	static pressure	Pa
P_∞	free-stream static pressure	Pa
PIV	Particle Image Velocimetry	
RANS	Reynolds-Averaged Navier–Stokes	
Re	Reynolds number	
Solidity	ratio between two VG trailing-edge spacings and VG chord length	
U_∞	free-stream velocity	m/s
VG	Vortex Generator	
x_{VG}	axial position of VG arrays	m
X	longitudinal coordinate	m
Y	spanwise coordinate	m
Z	vertical coordinate	m
u	longitudinal velocity component	m/s
v	spanwise velocity component	m/s
w	vertical velocity component	m/s
α	angle of attack	deg
α_{VG}	VG pitch angle	deg
β	sideslip angle	deg
δ	boundary layer thickness	m
ΔCd	drag coefficient difference evaluated with VG with respect to clean geometry	
y^+	non-dimensional wall distance	

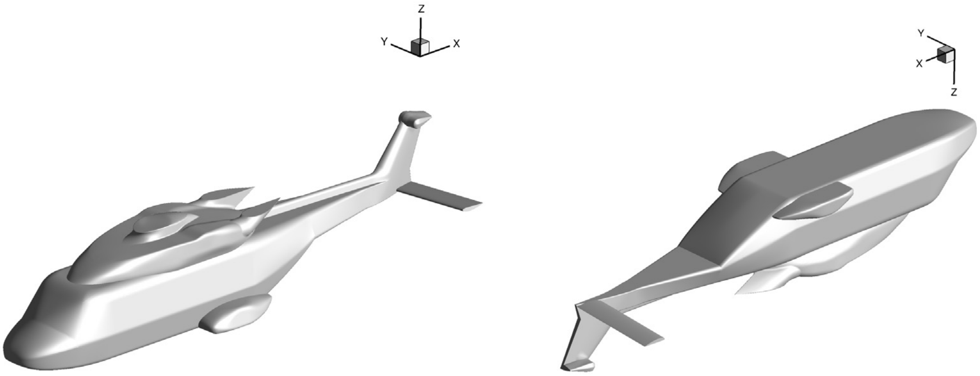

Fig. 1. Geometry of the tested GOAHEAD-like model and reference system.

gible in cruise condition, this study was carried out on a simplified geometry without rotors. The considered geometry is presented in Fig. 1, including the X–Y–Z reference system used in this paper. The X–Z plane is located on the model mid-span plane and the origin of the reference system is positioned on the nose of the fuselage.

Different measurement techniques were employed during wind tunnel tests. In particular, forces and moments were measured by a six-component strain gauge balance. The mean pressure distribution over the helicopter fuselage was evaluated by steady measurements over 300 taps. Moreover, stereo particle image velocimetry (PIV) surveys were carried out in the region of the junction between the rear ramp and the tail boom to investigate the effects of the best VGs configuration.

The paper is organised as follows. Section 2 describes the computational activity, including the CFD methodology used for the calculations and the results obtained with different sets of VGs characterised by different sizes and positions. Section 3 describes the experimental activity, including the test rig employed for the wind tunnel tests. In Section 4 the experimental results are compared with those obtained with the most promising set of VGs indicated by the CFD activity. Section 5 reports the main achievements of the present work.

2. Numerical simulation

2.1. Methodology

All of the CFD computations were performed using the ONERA aerodynamics solver elsA [6]. The RANS equations are discretized in a finite-volume cell-centred formulation on multi-block structured meshes. The simulation of these small control devices scaled according to the local boundary layer thickness required a very high grid density in the nearfield region so that the whole mesh results in a total number of 40×10^6 points. It was found very difficult to perform unsteady computations considering that the time-scale was a priori unknown for such large separated flow. Furthermore, a very small constant time-step would have required a huge computational time which was not affordable in an assessment study in which numerous VG configurations and angles of attack were investigated. Therefore steady-flow was assumed in all computations. It was numerically experienced that after a long transient phase in which the flowfield remains steady and fully attached, the flow starts separating at the backdoor and the fuselage wake starts oscillating. However, the case of a high Reynolds number flow with relatively fixed flow-separation and flow-reattachment locations is addressed in this paper. Additionally, the most promising tested VG configurations promote flow reattachment and the relative drag reduction obtained can be clearly explained by physical flow mechanisms, even considering a steady assumption. It was also anticipated that the rotating lifting surfaces of the main and tail rotors have little influence on the flowfield underneath the fuselage and will not affect significantly the VG effectiveness, especially at cruise speed. This is also supported by the work of Allan and Schaeffler [1] in which unsteady effects were investigated for active flow control by zero-net-mass-flux jets, comparing the flow control performance between the isolated fuselage and rotor/fuselage simulations.

A second-order Jameson scheme was used for the space discretisation. The time integration was ensured by a second-order