Helicopter fuselage drag reduction investigation.

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Abstract The performance of large helicopter transport has been investigated with the aim of reducing the fuselage drag and increasing the performance. The fuselage drag is responsible for a quantity close to the 70% of the total helicopter drag. Heavy and medium transport helicopters are characterized by large and flat aft loading ramps that induce large pressure drag with enounced flow separation or strong counter rotating vortex flow. Scope of the work is investigating the flow phenomena in the rear bottom region of the fuselage by carrying out an experimental test campaign on a simplified helicopter fuselage model. Two active flow control (AFC) systems have been designed and built. In particular a "steady jet" actuator and a "pulsed jet" actuator located on the edges of the loading ramp. A laboratory test campaign was dedicated for the full characterization of the two AFC systems and it is reported in the paper. A comprehensive wind tunnel test campaign was carried out in order to evaluate the effects and the expected gains of the AFC actuators on the fuselage aerodynamics. The test campaign foresaw the measurements of the fuselage surface pressure distribution and the characterization of the flow field velocity. The incidence model angle (α) was investigated in the range between +11° and -11° with and without AFC systems operating. Different AFC operating configurations were tested for different values of the blowing coefficient and of the pulsed jet reduced frequency. The results indicated that one operating condition was decisively more efficient of the others. Threshold values were observed in the functioning of the AFC actuators. Useful information and deeper understanding of the flow behavior was obtained for the future test campaign schedule on larger scale in an industrial wind tunnel. The paper reports the experimental set-up, the steady and pulsed jet flow control systems, a selection of the gathered results and a perspective of the futures activities.

1. Introduction
The performance of heavy transport helicopters, having a large, and almost flat, aft loading ramp suffer from the poor aerodynamics of the aft body. For helicopters in cruise flight condition, the component of the rotor power due to counter balance the parasite force was of the order of 40% to 55% of the total requirements, as stated by Gatard et al in 1997 [1]. Nowadays fuselage and rotor head drag breakdown studies [2]- [3] indicate that about the 70% of the total drag can be ascribe to the fuselage and the remaining 30% is due to the rotor head, a further fuselage drag breakdown indicates that the cabin contributes with about 60%, tail, sponson, and exhaust respectively for about 16%, 14% and 10%. Consequently in order to improve the helicopter speed, range, capability, stability and reduce the fuel consumption and the environmental impact, the fuselage drag reduction is one of the main objectives of the industrial designers. The presence of the aft door (or “loading ramp” as it often referred to) dictates flat and inclined surface connected to the fuselage at almost its widest cross section. This simplifies and accelerates the loading/unloading operations but in turn affect the fuselage aerodynamic characteristics. The flat loading ramp causes flow separation at the lower corner, generating a separated bubble and a system of streamwise vortices at the ramp sides. The flow separation and the longitudinal vortex cohabit on the aft region, when the flow separation is predominant the flow is named “eddy flow”, when the flow separation is reduced and the longitudinal vortices are predominant the flow is called “vortex flow.”

Both flow typologies provide an important contribution to the fuselage drag-form. Together with an increasing of the pressure drag the flow separation interacts with the fuselage tail structures inducing strong vibration and submitting the airframe to fatigue cycles. The fuselage drag depends on the fuselage incidence angle (α) and on the loading door upsweep angle (ϕ) as investigated and described by Seddon in 1990. For fixed upsweep angle, Seddon describes the influence of the flow topology on the drag coefficient with the diagram shown in Fig. 1a, an abrupt increment of the pressure drag occurs passing from eddy flow to vortex flow. This aspect must be taken into account designing the flow control system, not always the suppression of the flow separation induces a decrement of the drag, in the case that the longitudinal vortices come closer
to the pressure surface the induced negative pressure produce an increment of the drag as well as of the lift
download. Seddon also provided a summary diagram of the flow topology (Fig. 1b) for a wide range of
incidence angles and upswipe values. The knowledge of the flow topology on rear loading ramp is the first
step for designing a flow control systems capable to reduce the fuselage drag not at detriment of the lift.
Seddon proposed some passive control systems for reducing the drag-form, ones was to install several
deflectors on the fuselage side immediately ahead of the upswipe face in order to prevent the formation of
vortex flow. Successive industrial tests indicated that the use of deflectors, strakes or ridges were not feasible
because although the vortex flows was lightened the fuselage drag increased. Recently vortex generators
systems are investigated in order to reduce the fuselage drag, Boniface et al [5] claimed a reduction between
3 and 5% for zero attitude angle. During the last years the research in the field of the active flow control
(AFC) actuators drawn large interest in the aeronautical field, one of these actuators was the zero-net-mass-
blowing actuator (or synthetic jet). In 2005 Martin et al [6] investigated numerically and experimentally the
influence of 12 SJ actuators on a helicopter fuselage obtaining drag reduction in the range between 6 and
10% and an impressive reduction of the lift download of a value of 40%. Martin also investigated the
influence of the position of the SJ slot on the fuselage, claiming that for eddy flow the SJ located on the
bottom of the upswipe ramp were more effective whereas for vortex flow the main contribution to the drag
reduction was obtained by the fuselage side slots. Analogous results were obtained by Ben-Hamau in 2007
obtaining similar drag reductions in the range between 3 to 11% for different attitudes and claiming that the
side SJs were more effective for the case characterised by yaw angles [7]. In 2010 a NASA and ONERA [8]
collaboration investigated numerically and experimentally the behaviour of different AFC systems (steady
blowing, pulsed Jet and SJ), obtaining remarkable result in drag reduction, with the steady blowing system
able to reduce up to 35% the fuselage drag but requiring pressurised air and the zero-net-mass-flux blowing
actuator inducing a decrement up to 26%. A contribution to understand the ACF influence on the helicopter
fuselage has been provided by Lienard et al [9] and Le Pape et al [10] with their comprehensive work
investigating the effect on helicopter fuselage aerodynamics of different types of AFC systems. A further
promising control system is the COMPACT (Combustion Powered actuation) [11] a novel technology which
exploits the chemical energy of gaseous fuel/oxidizer mixture to create a high pressure burst and subsequent
high momentum jet of exhaust products. In 2011 Georgia Tech. University in collaboration with Virtual
Aerosurface Tech. [12]-[13] investigated the chemical powered actuators on a ROBIN fuselage model
obtaining a drag reduction of the order of 12 to 17 % but also a significant increment of the lift download.
Although many effort have been performed and nowadays are carried out by several research groups in the
attempt to improve the fuselage aerodynamic characteristics there is still a lot to be done to fully understand
the phenomenon and the contribution of the actuators on it.

![Diagram](image_url)

**Fig. 1:** a) Drag Coefficient vs incidence angle (α) and b) Up-sweep angle (θ) vs incidence angle (α) indicating flow
topology and excess drag region (Seddon 1990).

This work aims to investigate the flow characteristics of a typical helicopter transport fuselage and the
possible benefit in terms of drag reduction by using steady and pulsed jet blowing flow control systems. The
research has been carried out in the framework of the fuselage drag reduction task of the Green Rotorcraft
ITD of the Clean Sky Project founded by the European Union. The task combines CFD and experimental
activities for jointly investigate the phenomena. The project foresees to investigate the performance of the
steady and pulsed blowing jet at laboratory level on a limited size helicopter model for successively to be
applied on a larger scale in an industrial wind tunnel on the scaled 1 to 7 fuselage of the AW101 transport Helicopter. A devoted unsteady blowing system, based on a rotating valve has been designed, built and characterised in terms of mass flow, mean and instantaneous velocity, pulse frequency both at the valve exit and both at the fuselage slot exits. This work presents part of the comprehensive experimental work performed for characterizing the AFC systems and the test campaign carried out at CIRA CT-1 wind tunnel on the small helicopter fuselage model at Reynolds number of 1 million. The paper describes the experimental set-up, the adopted measurement systems, the flow control actuator, the simplified fuselage model, the performed test matrix, the steady and pulsed Jet flow characterization, the reference fuselage aerodynamic characterization for different incidence angle and the effect of the different AFC systems and the different selected configurations.

2. Experimental set-up

2.1. Model and instrumentation description

The investigation was carried out on a simplified helicopter fuselage model of the AW101 transport helicopter with an upsweep angle of $\phi=35^\circ$. The fuselage model is characterized by the following main sizes: length of 422.5 mm, height of 70 mm and width of 70 mm. The model was instrumented with 64 pressure taps located on the model centerline, on the region of the rear hatch and tail boom in order to investigate the pressure distribution (Fig. 2 a). The pressure taps were connected to two ZOC22/32px differential pressure transducers with full scale (FS) value of 1 psi (6894 Pa) and accuracy of 0.12% of Full Scale. The ZOC modules were connected to analog/digital module mounted on the RAD3200 acquisition system. For each different test condition the mean pressure values were recorded. The estimated accuracy for the pressure coefficient is equal to 0.011. The location of the pressure taps was limited by the internal pneumatic route of the AFC system.

![Fig. 2: PTS locations on the model (a) and slot location on the loading ramp (b).](image)

2.2. Wind tunnel description

The test campaign was conducted in the CIRA CT-1 low speed tunnel, an Eifel type open circuit. Test section main sizes are 305 mm by 305 mm by 605mm as height, width and length. Maximum achievable flow speed is 55 m/s with a turbulence level of 0.1%. The full test campaign was carried out at constant speed of $V_\infty=34$ m/s and Reynolds number based on the fuselage length of $9.9*10^5$, varying the fuselage incidence angle in the range between $+11^\circ$ to $-11^\circ$ with step of 2.75°. The blockage ration was between 5.3 to 6.1 % respectively for $\alpha=0$ and $\alpha=\pm11^\circ$ inducing some wall interference effect to be taken into account. The model was mounted up-side down in order to avoid any disturb on the ramp region coming from the ventral support.

2.3. Flow control system description

The simplified fuselage model was designed so that three slots were positioned in the loading ramp region, in particularly, the slot 1 on the bottom of the loading hatch and the slot 2 and 3 on the ramp sides as shown in Fig. 2 b. Each slot was connected to a dedicated pneumatic circuit feed by pressurized air. Up-stream each slot a resonant cavity was present in order to level the flow coming out from the slots. The slots were characterised by the same jet axis angle inclined respect the ramp surface of $\alpha_j=45^\circ$ and by the same slot
thickness equal to 0.5mm. The slot lengths were slightly different, slot-1 was equal to \( L_{S1}=63.5 \text{mm} \) whereas slot 2 and 3 lengths were \( L_{S2} = L_{S3}=54.7 \text{mm} \).

Two different AFC systems were considered: steady jet and pulsed jet blowing from the rear slots. The steady blowing jet was obtained by a steady pressurized air feeding the cavity. The pulsed jet was obtained through a steady air supply modulated by a rotating valve (Fig. 3) inducing unsteady excitation that was transmitted to the actuator (cavity) by a pneumatic line.

The pneumatic system was connected to the pressurized air source and was composed by the following main components: a first pressure regulator for a preliminary volume flow control, a pressurised tank for stabilizing eventual pressure fluctuations and a needle valve at the input of the rotating valve for fine volume flow regulation. For the pulsed jet actuation, the rotating valve was installed downstream. The rotating pneumatic valve consists of two concentric cylinders. The inner cylinder (or rotor) rotates around its axis of revolution driven by an electrical stepper motor.

**Fig. 3: Pneumatics rotating valve (a) and Actuator set-up – Hw measurements (b)**

The Outer cylinder (or stator) is fixed. The inner cylinder contained 11 apertures with diamond shape and equally angular spaced (\( \Delta \phi=32.72^\circ \)) on the same circumference. The outer cylinder contains 6 circular apertures along the circumference and in correspondence of the rotor apertures. The air transfer is obtained when the rotor apertures aligns with the stator apertures. The rotating valve can feed at maximum three pneumatic lines simultaneously. The six stator apertures are angularly spaced in order to allows the following pulsed jet configuration: a) Three pulsed jet phased between them, b) three pulsed jets each other shifted by \( \Delta \phi=120^\circ \), c) two phased pulsed jet and a third jet in opposition of phase and d) only two pulsed jets in phase opposition (\( \Delta \phi=180^\circ \)). The rotating valve is monitored by a pressure transducer and by a decoder that provides angular position and rotating speed on the inner cylinder, the rotating speed and consequently the jet frequency is controlled by a dedicated computer. The pulse frequency \( f \) is calculated multiplying the rotating speed by the number of rotor slots \( f=\omega^\circ N_c \). The rotating valve can supply the pressurised air at a maximum of three output apertures at the same time. On each pneumatic line a flow meter measures the mean flow volume feeding the model blowing slots. The complete functioning scheme of the pneumatic system is summarised by the block diagram presented in Fig. 4.

**Fig. 4: Pneumatic system block diagram**
2.4. AFC system laboratory characterization

Before to perform the test campaign, particular care was taken in the characterization of the steady and pulsed jet system. The mean and instantaneous jet velocity was measured by a micro static Pitot tube and by a Constant Temperature Anemometer (CTA) system together to the volume flow rate. A dedicated set up was installed for investigate the actuator characteristics in quiescence air (Fig. 3b).

For steady blowing jet, the transfer function between the volume flow rate and the jet mean speed was obtained for each individual slot and for each different operational configuration: all slot blowing, side slots blowing and single bottom slot. In this way, evaluating eventual interference on the jet velocity due to the simultaneous functioning of other steady jets was possible. Some examples of the obtained results are presented in Fig. 5. Slot 1 mean velocity behaviour versus the air volume flow rate indicates similar trend both for the case of single slot operating and for all slots simultaneously functioning save for a slightly higher velocity values of the former case (Fig. 5 a). In case of all slots blowing, the slot 3 jet speed is greater than slot 1 (Fig. 5 b). It is due to a deformation under pressure of the slot 1 aperture, resulting in an increment of the slot surface with a consequent reduction of the jet speed. The last example compares the slot 3 jet velocity for the cases of: all slots blowing and side slots operating. Also in this case the jet velocity measured for all slots operating presented higher values. The results clearly indicated that the jet velocities are deeply dependent not only on the flow volume rate but also on the adopted configuration. This drove to calculate the transfer function between the flow volume rate and the jet velocity for each different slot and each operating configuration.

![Graphs showing mean jet velocity vs flow rate for different configurations.](image)

**Fig. 5: Mean Jet velocity vs Flow rate:** a) Slot 1 behavior for the case of single slot and all slots operating, b) Slot 1 and 3 comparison for all slots operating, c) Slot 3 comparison for the cases of all slot operating and side slots functioning.

The Pulsed Jet actuator function was carefully characterised varying the pulsed frequency, volume flow rate, and blowing configuration. The instantaneous velocity was measured at different locations of the pneumatic system in particular at the exit of the rotating valve as well as to input of the model pneumatic line and to the slot exit.

The velocity measured at the rotating valve exit (Fig. 6a) presents a steady flow fluctuation of about the 50% around the mean velocity value (Fig. 6b). The null velocity is never reached as minimum due to small leakages between the stator and the rotating components. The minimum and maximum values are calculated for each time period (T=1/f) and after averaged on the total data samples (N=t/T=recording time/period).
The velocity fluctuation is investigated in terms of maximum and minimum averaged values versus the pulsed frequency. The amplitudes present a decrement increasing the frequency reaching a bottle neck at 170 Hz for the case of mean velocity of 30 m/s and at 73 Hz for higher mean velocity for than increase and remaining constant around a value of 50% of the mean value (Fig. 6 c). The instantaneous velocity was measured at the model input as well as at the model slot exit in order to evaluate the influence of the pneumatic line and of the resonator cavity. The velocity time history normalised respect the mean velocity presents an attenuation of the flow fluctuation between the model input and the slot jet exit of the order of 70% (Fig. 7a). The pulsed frequency affects the velocity fluctuation amplitude as indicated by the diagram representing the maximum and minimum velocity measured at the model input and at the slot exit for different values of the pulsed frequency (Fig. 7 b). At the input of the model pneumatic line the fluctuating component of the velocity decreases as the frequency increases for reaching a constant value for $f_j > 180$ Hz. The slot exit presents a similar behaviour although the reduction is more limited.

Considering the velocity behaviour in the field of the frequency, from the analysis of the power spectrum the presence of the imposed main pulse frequency and its harmonic of superior order are present both at the model input both at the slot exit. The signal at the slot exit is characterised by higher turbulence energy content.

Once that the steady and pulsed jet were characterized in term of mean and peak velocity and achievable
frequency range it was possible to calculate the characteristic non dimensional quantities defined for evaluate the flow control system. In particular the pulse jet frequency normalised as 

$$ F^* = f_i \frac{W}{V_\infty} $$

where \( f_i \) is the pulse jet frequency, \( W \) the fuselage width and \( V_\infty \) the free stream velocity and the blowing coefficient, defined as the sum of the contribution of each blowing jet: 

$$ c_\mu = \sum_j \frac{\rho_j A_j V_j^2}{A_\infty 0.5 \rho_\infty V_\infty^2} \quad \text{where } A_j, \rho_j \text{ and } V_j \text{ are respectively the actuator slot surface, flow density and maximum speed and } A_\infty, \rho_\infty \text{ and } V_\infty \text{ are the fuselage cross section, free stream density and velocity.}

2.5. Flow visualization and PIV measurement.

In order to characterise the flow topology on the loading ramp region a series of flow visualization have been performed using wool microtaft followed by a quantitative flow velocity measurements by means of PIV measurements. The flow behaviour in proximity of the model bottom surface was investigated along the full model length on three parallel longitudinal planes \((y/(W/2)) = 0; 0.29 \text{ and } 0.60\) using two components PIV measurements and by three components PIV measurements on several cross parallel planes starting immediately downstream the loading ramp \((x/L=0.58, 0.63, 0.68, 0.72, 0.75, 0.77)\). The PIV system was composed by two Nd-Yag resonator heads providing a laser beam of about 300 mJ each at 532 nm and by two double frame CCD cameras (2048x2048 px). Particles of about 1 \( \mu \)m of diameter, composed by DEHS oil, were used as seeding. The laser sheet was delivered from above in the measurement region. For the longitudinal planes measurements, the camera was located on the left side of the test section mounted on 2D traversing system in order to follow the full length of the model. Several lenses were mounted for varying the flow field space resolution. The PIV data resolution ranges from 1.1 to 0.6 vectors per millimetre for Field of View sizes ranging from 140x140mm\(^2\) to 80x80mm\(^2\). The Cross plane measurement foresaw stereo measurements. The cameras were equipped of motorised Scheimpflug systems and located on both sides of the test chamber. Each Camera was mounted on 2D linear traversing system. The laser lens was installed on a linear traversing system in order to automatically traverse the region of interest synchronizing with the camera positions. The cameras aimed to the cross pane with and angle of about 45\(^\circ\). For the cross plane measurements the spatial resolution obtained was equal to 1.1 vector for millimetre for a field of view of 150x100mm\(^2\). Ensemble average and RMS values were calculated for each test condition on a data sample of 150 velocity maps.

![Stereo PIV experimental setup](image)

Fig. 9: Stereo PIV experimental set up

3. Test Matrix

The test campaign foresaw the investigation of the aerodynamic behaviour of the baseline model without AFC system in order to characterise the different flow topology in loading ramp region varying the angle of attack. The model incidence angle was varied in the range between +11\(^\circ\) to -11\(^\circ\) with a step of 2.75\(^\circ\) and with a further intermediate position at \( \alpha = -1.5\(^\circ\). Once that the baseline behaviour was assessed the influence of the steady and pulsed jet was analysed varying the flow control parameters for all the selected incidence angles in the range reported in Table 1, on a selected number of test In particular the influence of the different operating conditions respect the flow topology varying the functioning parameter was investigated first by an extensive campaign performing pressure measurements detecting the threshold values inducing an improvements of the pressure distribution and in a second time performing flow velocity measurements.
conditions.

<table>
<thead>
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<th>Parameters</th>
<th>Range</th>
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</thead>
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<tr>
<td>Reduced Frequency &lt; F+&gt;</td>
<td>0.15 – 1.13</td>
</tr>
<tr>
<td>Blowing momentum coefficient &lt;(c_\mu)&gt;</td>
<td>0.02 – 0.1</td>
</tr>
<tr>
<td>Number of slots</td>
<td>3</td>
</tr>
<tr>
<td>Operating configurations</td>
<td>All slots, single slot, side slots</td>
</tr>
</tbody>
</table>

Table 1: Flow control parameters

4. Results

4.1. Baseline configuration

The baseline model configuration was investigated by flow visualization, surface pressure and velocity field measurement. The results clearly indicated that the flow in the region of the loading ramp can be considered as eddy flow being characterized by a marked flow separation in the range from \(\alpha=+11^\circ\) down to \(\alpha=-2.75^\circ\). For lower angle values, the vortex flow characteristic was predominant down to \(\alpha=-11^\circ\). This behavior is clearly detectable from the pressure longitudinal distribution of the lower model surface. The results indicates that for all the positive values of the model attitude the pressure distribution presents a plateau in correspondence of the ramp flow separation for recovering only downstream on the tail cone (Fig. 10 a) with marginal changes due to the model angle variation in the ramp region.

Fig. 10 Centreline pressure distribution varying the incidence angle

Fig. 11: Spanwise pressure distribution on the loading ramp for \(\alpha=0^\circ\) (a) and \(\alpha=-2.75^\circ\) (b)

Whereas starting from \(\alpha=-1.5\) and \(\alpha=-2.75^\circ\) the flow separation starts to reduce and the pressure becomes recovering on the loading ramp (Fig. 10 b). As already said the Eddy and Vortex flow phenomena always cohabitate, so it is not easy to define a clear the transition point but looking at the spanwise pressure distribution on model ramp and comparing the case of null angle of attack (Fig. 11a) with the case at \(\alpha=-2.75^\circ\) (Fig. 11b) it can be appreciated as the last case is characterized by smaller flow separation and by the
presence of the longitudinal vortices on the loading ramp denounced by the lateral increasing of the negative pressure coefficient. We can state that the transition from eddy flow to vortex flow can be pointed out for the model attitude between -1.5 and -2.75°. Confirmation of the flow behavior was provided by the stereo PIV results obtained on the cross flow measurements planes equal space located starting from the loading ramp and moving downward along the tail cone.

![Cross-flow velocity vector field with out of plane colour map varying AoA (x/L=0.675)](image)

Fig. 12: Cross-flow velocity vector field with out of plane colour map varying AoA (x/L=0.675)

Immediately downstream the end of the loading ramp (x/L=0.675), the mean velocity fields (Fig. 12) present for an incidence angle of α=0° a flow separation on the bottom fuselage surface. Flow separation that decreases as the angle of attack decreases as well toward negative values. At the same time while the flow reattachment is occurring a clear couple of contra rotating vortices appears on the edge of the flow separation region for later positioning on the fuselage surface.

![Cross flow velocity development moving downward the loading ramp (α=-1.5°)](image)

Fig. 13: Cross flow velocity development moving downward the loading ramp (α=-1.5°)

As already discussed the two flow topologies are always presents and so the detection of where the transition occurs is almost questionable. In this case the transition is considered occurring between α = -1.5° and -2.75°.
Fig. 13 shows the mean velocity field behavior for $\alpha=1.5^\circ$ at the different longitudinal locations. At the beginning of the loading ramp is detectable the starting of the flow separation for increasing to upper edge of the hatch and for starting to decrease at $x/L=0.67$ and disappear at $x/L=0.72$ leaving space to the vortex flow topology.

4.2. Active flow results

The behavior of the steady blowing jet on the pressure distribution was investigated for all the three different operational conditions on a wide range of jet speed and consequently different blowing coefficients $C_f$. For all the operational conditions the following similar behavior was observed: increasing the velocity jet, an improvement in terms of pressure recovery was witnessed up a limit value beyond that further jet velocity increment was useless in terms of pressure recovery but a negative suction effect was observed at the bottom of the ramp. This threshold values were detected for all the different incidence angles and for all the different operational conditions. It was found that the velocity threshold value was always comparable with the free stream velocity. As example, the pressure distribution on the model centerline for different values of the jet speed and respectively for a single operating slot, for both side slots blowing and for all the slots operating in contemporaneity are presented in Fig. 14 a, b and c. In order to evaluate the most efficient operational condition, the improved pressure distribution was compared for the different configurations. For all angle of attacks, the operating condition characterized by a single slot was the most effective. The configuration with a single slot presented a far better pressure recovery on the ramp on equal terms of jet speed but with smaller values of blowing coefficient: $C_f=0.014$ against values of $C_f=0.028$ and $C_f=0.029$ respectively for side slots and all slots operating Fig. 14 d.

![Diagram](image1)

*Fig. 14: Pressure distribution for $\alpha=5.5^\circ$ varying the jet speed $V_j$ for single slot blowing (a), side slots blowing (b) and all slot blowing (c). Pressure distribution comparison for different operational condition for optimized blowing coefficient (d).*

Once that the threshold values were detected the effect of the pulsed jet on the rear loading ramp was investigated varying the jet frequency as well as the mean jet speed. The results showed that the pressure distribution was almost not affected by the pulsed jet (Fig. 15). Varying the jet frequency no appreciable variation were observed. This was due to the weak velocity fluctuation provided by the AFC system to the jet slot exit. The predominant parameter remained the jet mean velocity.
Fig. 15: Pressure distribution for $\alpha=5.5^\circ$ varying the jet Frequency

The effect of the steady jet on the three dimensional flow field in proximity of the fuselage bottom was well detailed by the stereo PIV results. The steady jet forced the flow reattachment beginning from the loading ramp reducing the eddy flow and altering also the vortex flow behavior moving a part from the centerline the two counter rotating vortices (Fig. 16) with the double result to induce the pressure recovery on the ramp and reducing the suction on the cone tail moving the vortices away from the fuselage.

Fig. 16: In plane velocity vectors and out of plane velocity contour map for the baseline (upper row) and for steady jet activated (lower row) at $\alpha=5.5^\circ$.

5. Conclusion and Future Activities

An extensive experimental test campaign has been performed for investigating the flow characteristics of the aft loading ramp region of a large transport helicopter. A simplified and geometrically scaled model reproducing the fuselage of a transport helicopter with up sweep angle of 35° has been built and instrumented with several pressure taps. In order to reduce the fuselage pressure drag due to the typical eddy and/or vortex flows, two different AFC types have been applied to the model fuselage. In particular a steady jet actuator type and a pulsed jet actuator have been designed and manufactured and fully characterized in laboratory by hot wire and static Pitot tube measurements. The effect of steady and pulsed jet blowing systems on the helicopter fuselage model has been investigated by means of surface pressure measurements and by three velocity components PIV measurements. Three different operating configurations were investigated and the influence of the actuator was observed testing a wide range of blowing coefficient and reduced frequency values. The test campaign results clearly indicated the single blowing slot as the AFC configuration providing better results. The single steady jet actuator induced pressure recovery on the loading ramp reducing the eddy flow and decreased the undesired effect of the counter rotating vortices moving a part from the fuselage. Furthermore the single slot configuration not only obtained better results but at reduced cost in terms of mass flow rate of the order of at least the 50%. The concurrence use of all blowing slots generated higher cost in terms of requested energy being the side jets impeding themselves
Each other. Furthermore the side slots, directed toward the model centerline, induced stronger vortex flow instead of alleviating them. For all the investigated configurations a threshold value was identified for optimizing the use of the actuators. Due to the limited values of the velocity fluctuation blowing from the slot, the pulsed jet was not able to influence the aerodynamic fields neither to reduce the requested flow rate. The data analysis is not yet completed and in the near future comparison with the numerical simulations shall be performed.

The test campaign was successful providing a better understanding of the rear loading ramp flow phenomena and especially the interaction with the selected actuators.

The results provided useful suggestion for the future planned industrial test campaign on the scaled 1:5 model of the AW101 transport helicopter. Some modifications shall be carried out to the rotating valve in order to increase the velocity fluctuation and reach the desired reduction of mass flow rate. The exit angle of the side slots shall be modified and directed toward the external flow in order to prevent the formation of counter rotating vortices or push them outward. Furthermore, in the next test campaign the effect of the side slots shall be evaluated for different yaw angle values.

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Reference