A STUDY OF CONVENTIONAL UPPER SURFACE BLOWN WING CONFIGURATIONS

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Abstract: *The goal of this paper is to investigate the particularities of Upper Surface Blown (USB) wing aircraft configurations and to establish criteria for their further optimization. The method used is numerical, a series of CFD simulations being carried out and their output parameters compared. It was found that although a low aspect ratio nozzle offers better lift and thrust, it also is prone to asymmetrical loadings on the turbine disk. Therefore, a higher aspect ratio nozzle is safer to use. The work can be used as a starting point in designing a USB aircraft that offers the desired balance of safety and performance.*

Keywords: *Upper Surface Blown wing, Coandã Effect, Computational Fluid Dynamics.*

1. INTRODUCTION

Circulation control has been a popular theme for achieving Short Take-Off and Landing (STOL) aircraft for military transport. Although there is a large number of circulation control methods (Kuethe and Chow, 1998) the Upper Surface Blowing (USB) has the most applications in large transport aircraft: the Boeing YC 14 and the Antonov An-72 series.

In a USB wing configuration, super circulation is achieved by passing the airflow from the fan onto the wing section. There are two reasons why a USB wing achieves more lift:

1. Higher angles of attack are permitted due to the fact that the boundary layer is controlled.
2. Because the airfoil section has a curved upper surface, air accelerates due to the Coandã effect. This leads to a decrease in static pressure – hence lift.

Current USB designs rely on conventional supercritical airfoils, common in high-subsonic aircraft. This means that the curvature of the upper surface is quite low and thus the lift component due to the Coandã effect is low. Design methodologies are described in (Johnson and Phelps 1974) and (Lan and Campbell, 1974).

This study investigates the impact of the aspect ratio of the fan nozzle on the Coandã effect over the conventional airfoil.

2. THE USB TESTING

2.1 Initial conditions and parameters. In this section we will test two existing super circulation configurations. Because the current applications use only low by-pass ratio turbofans, we will have to re-design a USB configuration that accomodates a high by-pass ratio turbofan. This is necessary because theese engines offer higher efficiency and lower specific fuel consumption.

All tests are based on the geometry of the General Electric GE 90 turbofan engine. The basic parameters used are:

Maximum Diameter: 3124 mm

By pass ratio: 8.4

Total mass flow: 1350 kg/s

Exhaust Gas Temperature: 1100 K

From which we deduce:

Fan mass flow 1206 kg/s

Core mass flow 143,6 kg/s

The geometry of the nacelle is done in accordance with (Kroo and Alonso, 2000)

The wing airfoil is similar to that of an Airbus A340 airliner (van Dam, 2002).

2.2 Full scale simulation of the high by-pass turbofan engine All simulations are made using the k-epsilon Reynolds Averadged Navier Stokes viscosity model, with a cartesian mesh, as seen in Fig.[1] . Because the flow is expected to have a high velocity, in the compressible regime, the boundary conditions were mass flow inlets for the fan and turbine discharges and mass flow outlet for the engine intake.

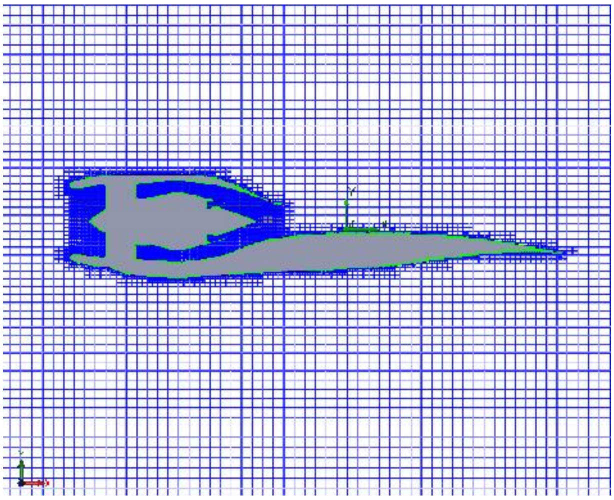

Fig. 1. Geometry and discretisation of the engine considered

Calculated core thrust: 114184.4 N
Calculated full Thrust: 499261.3 N
Certiffied full thrust: 500000 N
deviation: 0.147746268 %.

2.3 Conventional super-circulation nacelle-wing configurations

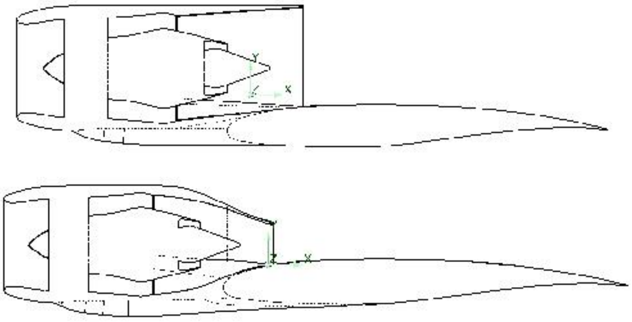

Fig. 2 Conventional super circulation configurations for Upper Surface Blown wings, low aspect ratio (top) and high aspect ratio (bottom)

Two cases were selected:

1. Low aspect ratio exhaust nacelle
2. High aspect ratio exhaust nacelle.

In the first case, the following parameters were obtained trough the CFD simulation:

Total engine thrust=480577.5 N

Thrust-Wing Drag = 478836.9 N

Representing: 95.76% of the bare engine thrust

Lift/Thrust ratio = 4.1398

By plotting the static pressure distributin onto the turbine outlet section we obtain the immage presented in Fig. 3. It can be easilly observed that the presence of the wing near the fan flow influences dramatically the pressure distribution of the engine core. This in its turn will lead to un-even turbine disk loadings and induce mechanical oscilations onto the entire low pressure rotor.

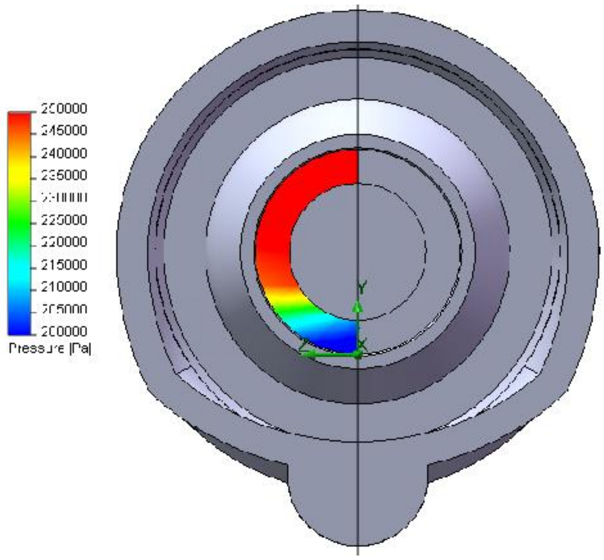

Fig.3 Pressure distribution at the turbine outlet section of the low aspect ratio exhaust nacelle. We can observe the large inhomogeneities induced by the presence of the wing. This in turn can lead to asymetrical loadings on the low pressure (LP) turbine disk

The plots in Fig. 4 represent the static pressure and velocity distributions across the super circulated wing section. A comment can be made, the pressure drop is localized only in the regions where the fluid is accelerated due to the Coandã effect.

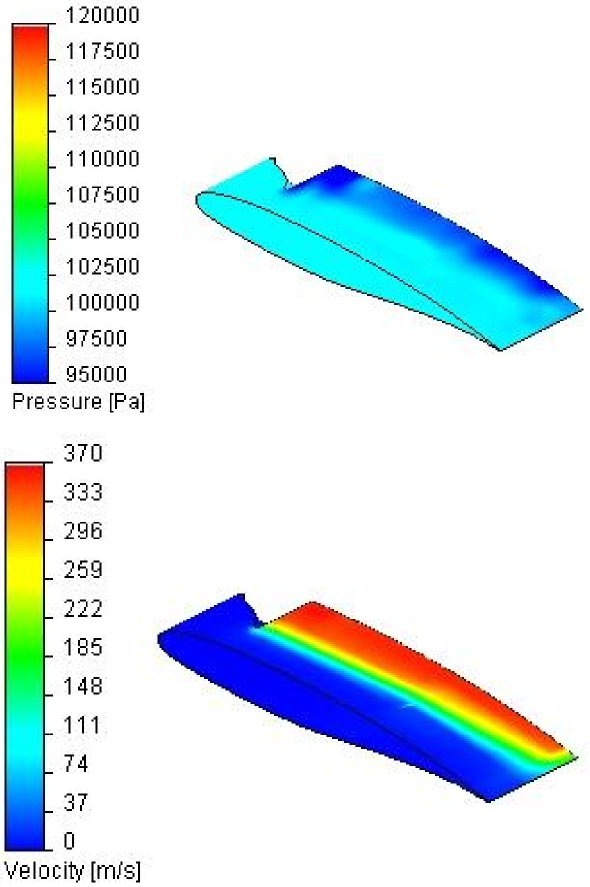

Fig. 4. Static pressure distribution (top) and velocity distribution (bottom) due to the fan flow over the super circulated wing section in the case of the low aspect ratio exhaust nacelle.

In the second case, the high aspect ratio nacelle, the following parameters were determined:

Total engine thrust-Wing Drag = 397007.9 N Representing 79.4 % of the initial thrust

Super circulation lift = 188356 N

Lift/Thrust = 0.377269

From the above data we can deduce that because of the transition duct of the high aspect ratio nozzle, part of the energy of the flow is lossed. Also, because the nozzle does not allow the total expansion of the core flow, its contribution to the total engine thrust is signifficantly lower. However, from the flight safety stand point, this version is substantially better. This is because the pressure distribution on the core exhaust section is much more even – leading to less vibrations of the LP rotor. Figure 5 shows the pressure distribution on the turbine exit section. It can be observed that the static pressures are higher than in the first case-due to the fact that the core flow is not allowed to expand fully because of the narrowed nacelle.

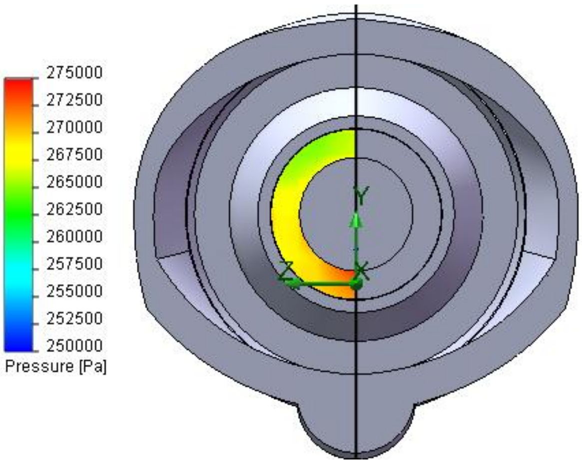

Fig.5 Static pressure distribution over the turbine exhaust section

Figures 6 trough 8 depict the pressure, velocity and temperature distributions over the wing in the high aspect ratio nozzle case.

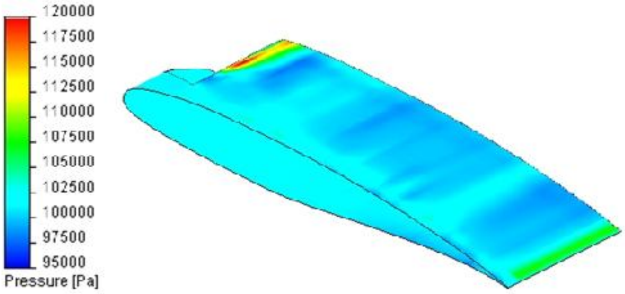

Fig. 6 Static pressure plot over the wing section

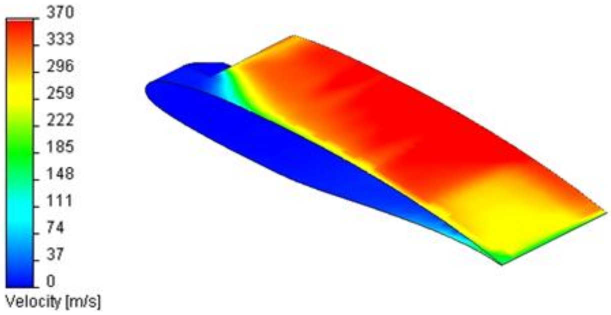

Fig.7 Velocity distribution over the wing section. We can observe the higher spreading of the airflow which leads to a more even pressure drop distribution over the lifting surface.

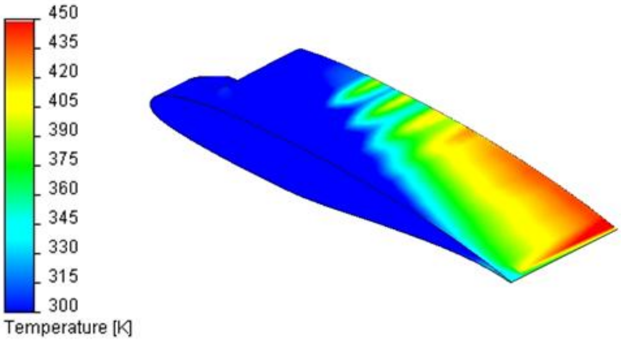

Fig.8 Because in this case the core flow is very close (geometrically) to the wing surface, temperature plots are relevant. It can be seen that the hot exhaust gases do not touch the wing (the temperature increases are not the result of direct contact with the exhaust flow. The temperature rises indirectlly because of the fan-core flow mixing near the trailing edge where typically there is no threat to the integrated fuel tanks.

3. CONCLUSIONS & ACKNOWLEDGMENT

Based on the above CFD simulations, the following conclusions can be formulated:

1.In the case of the high aspect ratio nozzle there are significant thrust losses (by comparison to the conventional turbofan engine), Fig. 9 shows a comparison between the three cases studied.

2. Both super-circulation cases present uneven pressure distributions at the turbine. This leads to the conclusion that the shear presence of the wing that close to the engine exhaust will cause an asymetric loading on the LP turbine disk. Because of this we can state that the durabillity of the engine will be decreased in the sens of increased bearing wear and vibrations. This tendency however is much lower in the high aspect ratio case, making it preferable for USB super circulation aircraft.

The low aspect ratio case clearly is superior however the pressure field inhomogenity issue must be addressed in order to make it viable.

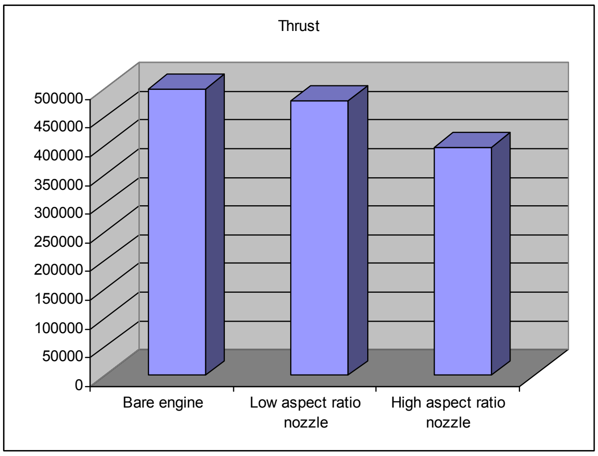

Fig. 9 Relative thrust (as a percent of the initial engine) of the three tested cases

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