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DEVELOPMENT OF A COANDĂ EFFECT LIFT-THRUST INTEGRATED SYSTEM: CELTIS

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Abstract: *This paper's scope is to present the development of a new form of Upper Surface Blown super circulation aircraft. The novelty refers to maximizing the influence of the Coanda effect on the USB aerodynamic lift by integrating an oblique circular curvature ramp which provides both lift and thrust. The study uses Computational Fluid Dynamics to estimate the performance of the system. It is shown here that the CELTIS system provides not only substantial additional lift and thrust but also improves the reliabilty of the turbofan engine by making it less prone to wear associated with USB configurations.*

Keywords: *Coanda Effect, CFD, Upper Surface Blown wing, Circulation Control, super circulation*

1. INTRODUCTION

Short take off and landing aircraft using the Coanda effect have been in use since the advent of the Antonov An 72 and the Boeing YC 14 (Blessing, 2011) and (Riddle and Eppel, 1986). These aircraft however make little use of the Coanda effect in cruise mode, relying on it just in the take off and landing phases. This is a major dissadvantage since the loses in fan flow enthalpy are quite high for the entire duration of the flight without adding any benefit.

Another problem with the conventional Upper Surface Blowing (USB) wing is that the presence of the wing surface near the fan flow leads to an uneven pressure distribution on the turbine exhaust section which in turns leads to asymetrical loadings to the turbine causing vibration and wear (Dragan, 2012).

This paper proposes a different USB wing in which a high by pass ratio turbofan engine provides a flow of air to a Coanda ramp with a 45° slant. Due to the Coanda effect, the ramp will produce a pressure drop which will produce a force. Because the ramp is inclined to 45°, the force will have two components: lift and thrust, hence the name : Coanda Effect Lift-Thrust Integrated System (CELTIS).

In addition to obtaining these forces, the system also provides a more homogenous pressure distribution over the LP turbine stage.

2. THE CELTIS CONCEPT AND TESTING

2.1 The CELTIS concept

In this section describes the Computational Fluid Dynamics (CFD) simulation of a super circulation wing in which the exhaust of the turbofan engine is passed over a Coanda ramp.

One of the problems generated by the use of a high by-pass turbofan engine is that the two flows influence eachother i.e. if the nozzle of the core flow is left untreated, the pressure distribution will become uneven and will generate vibrations on the Low Pressure (LP) shaft.

The design tested is presented in Fig. 1, in cross section, the engine nacelle is modeled after a General Electric GE 90 turbofan engine. Figure 1 also serve as an integration study within a conventional wing.

One of the advantages of the CELTIS system presente here is that it places the engine nacelle in a lower – more familiar – position as oposed to other super circulation aircraft designs which require the engines to be placed on top of the wing. The over the wing nacelle generates complications in maintenance due to its decreased accessibility.

The Coanda ramp consists of a 45º circular arc onto which the turbofan flow is discharged.

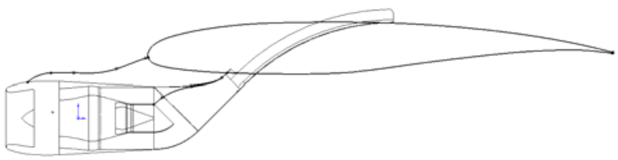

Fig. 1. Proposed way to integrate a CELTIS system using a high by-pass turbofan engine within a supercritical wing

As a benchmark for the further simulations, a large diameter high by-pass turbofan engine not unlike the General Electric GE 90 was simulated and the following results obtained:

Initial parameters (Kroo and Alonso, 2000) and (EASA, 2004)
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

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

2.2 The CFD test. All simulations were carried out without aerial velocity in order to asses the lift and thrust associated only with the Coanda effect.

Because the flow has a high, compressible velocity, the boundary conditions were mass flow related instead of the more simple pressure related inlets and outlets. This is because pressure boundary conditions in this case could lead to computational errors such as negative gauge pressures

Knowing the by-pass ratio and the total mass flow it is easy to deduce the mass flows of the core and fan using the relations:

$$\dot{m}_v = \frac{k}{k+1}\dot{m}_{total} \quad (1)$$

$$\dot{m}_c = \frac{1}{k+1}\dot{m}_{total} \quad (2)$$

The viscosity model chosen is k-epsilon realizable (Fernandez et al., 2007) while the computational mesh was carthesian – due to the fact it is inherentlly structured (Aftosmis, 1997). The computational mesh is presented in Fig. 2.

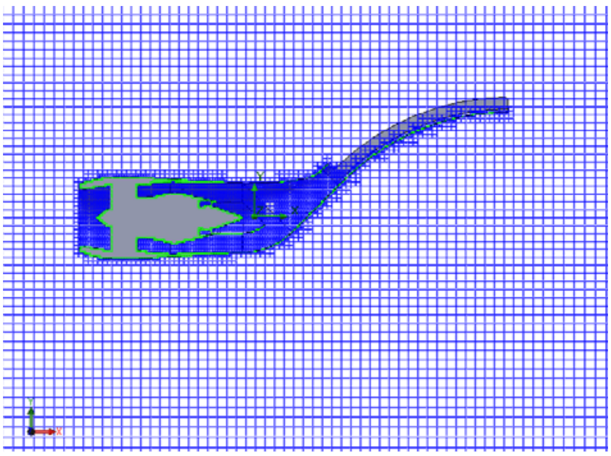

Fig.2 The Carthesian mesh used

The simulation results are as follows:
Engine thrust (without considering the CELTIS ramp thrust) =506808.9106 N
CELTIS ramp thrust = 24892.2 N
Total thrust =531701.1106
Representing: 106.34 % of the thrust of the bare engine

CELTIS lift = 38638.9 N
Representing: 7.72778 % of the thrust of the bare engine

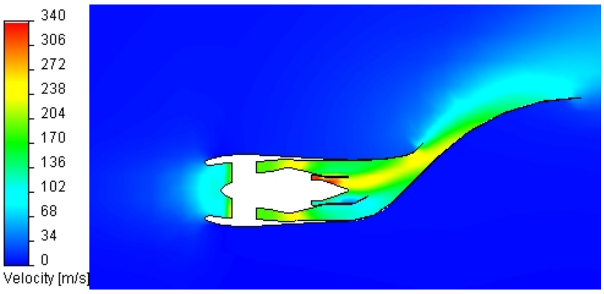

Fig. 3 Velocity distribution accross the CELTIS system, it can be seen that the top of the core flow accelerates to higher velocities due to the fact that it is almost directlly in front of the discharge nozzle.

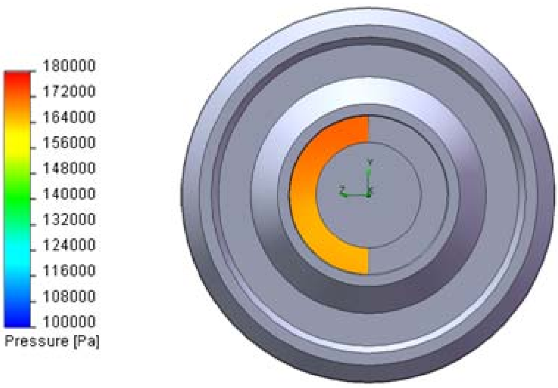

Fig.4 Pressure distribution at turbine exhaust, as opposed to conventional USB designs, the pressure distribution at this section is quite homogenous

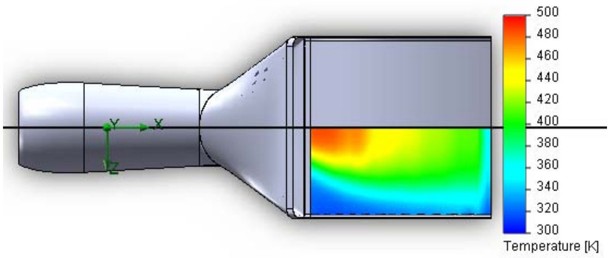

Fig.5 Absolute temperature distribution over the ramp

3. CONCLUSIONS & ACKNOWLEDGMENT

A Computational Fluid Dynamics study was carried out in order to estimate the effectiveness of a proposed Coanda Effect Lift-Thrust Integrated System. The simulation of a large diameter high by-pass turbofan engine was used as a benchmark for the results, with a calculated margin of error of 0.148 % of the real (certiffied) similar engine thrust.

The influence of the CELTIS ramp appears to be beneffícial, in the sens that the thrust of the engine increased by 6kN, representing a little over 1% of the total thrust of the normal engine. This influence can be explained by the fact that the ambient pressure at which the engine flows are discharged is lower than in the conventional case due to the Coanda effect and the fact that the nozzle has a high aspect ratio (it is in the shape of a narrow slot.

In this case, the Coanda effect produced by the ramp lowers the local static pressure which leads to the expansion of the core and fan flows to higher velocities hence increasing the thrust of the engine

However, we must exercise caution, in the absence of experimental results since the increase can be attributed to the computational inaccuracies.

The CELTIS ramp however provides additional thrust due to its 45º orientation. On the Ox axis, the thrust component due to the ramp is of ~32 kN –which cannot be explained away as a computational error, representing 6% of the total thrust of the engine.

The lift component obtained due to the ramp is 38638.9 N, representing ~7.73% of the total estimated thrust of the engine

As with all super circulation aircraft, it is important to study the temperature distribution over the surface of the ramp. In this case, the duct linking the engine to the ramp acts as a flow mixer, cooling the turbine exhaust flow. Thus, the fluid temperature at the ramp surface becomes reasonable, the hottest regions registering under 130°C. Offcourse, this aspect will have to be confirmed with further experimental testing in order to confirm that there is no need for heavy thermal insulators between the ramp and the integrated wing fuel tanks.

The orientation of the exhaust gases is along Ox therefore all of the thrust they provide will be used for propulsion. In the case of a ramp with a larger arc, say 90°, the fluid will be deviated from this axis, decreasing the thrust component while enhancing lift.

Such a device may be considered as a continuation of this study in the sense of a CELTIS-flap system for use on take-offs and landings.

From an aero-acoustic stand point, the system may prove to be quieter than conventional engines since the air exiting the CELTIS ramp has a higher turbulent kinetic energy, hence less prone to the Kelvin-Helmhotlz phenomenon causing most of the jet noise.

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