International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com, http://go.to/Research

Aerodynamic and Acoustic Parameters of a Coandã Flow – a Numerical Investigation

Valeriu Drãgan[a*]

[a] *Department of Aerospace Sciences Faculty of Aerospace Engineering, Politehnica University of Bucharest, ROMANIA*

ARTICLEINFO

Article history:
Received 05 January 2012
Received in revised form
30 January 2011
Accepted 30 January 2011
Available online
30 January 2011

Keywords:
Coanda effect
Aerodynamics
Acoustics
Computational Fluid Dynamics

ABSTRACT

Coandã flows have been the study of aircraft designers primarily for the prospect of achieving higher lift coefficient wings. Recently the environmental problem of noise pollution attracted further interest on the matter. The approach used is numerical; the computations were made using a large eddy simulation (LES) technique coupled with a *Ffowcs*-Williams-Hawkings (FWH) acoustic analysis. The spectrum of the flow was measured at three locations in the vicinity of the ramp showing that the low frequency region is dominant. The findings may be used as reference for the development of quiet aircraft that use super-circulation, as it is the case with the Upper Surface Blown (USB) configurations.

1. Introduction

Super circulation techniques have been used in the aeronautical industry for many years with good results. However aircraft such as the Antonov An-71 and the Boeing YC 14 do not fully use the benefits of the Coandã lift – in that they only divert the fan flow and do not generate pressure drops on the upper side of the wing.

Reference [9] seeks to prove that a Coandã flow over a curved wall will cause the static pressure to drop hence producing lift. It is therefore important for us to investigate the prospect of using this effect to improve on the state of the art and also to understand the more subtle aspects associated with it. One such aspect is the environmental problem of noise generation, in other words such an aircraft will need to be acoustically certified in order to be allowed to fly. Hence an aero-acoustic study is required in order to estimate the radiated sound pressure levels (SPL) and noise spectrum of such flows.

2. Computational Fluid Dynamics Setup

Traditionally simulation of Coandã flows over curved surfaces has proved to be problematic in the case of Reynolds Averaged Navier-Stokes (RANS) methods. This is because of their viscosity modeling. Some of the best results of RANS methods can be obtained through the use of k-omega SST (Menter) described in [5] and Reynolds Stress Model (RSM), according to most authors in [2] and [4]. This is because the Menter SST introduces a limitation in the shears stress in adverse pressure gradients. The RSM does not rely on the turbulent viscosity hypothesis and solves transport equations for the individual Reynolds stresses [3].

The advantages of LES over RANS methods are that the results are generally more accurate due to the sounder modeling of the physical flow phenomena. However, LES methods may prove to be problematic in converging and much more demanding in terms of computational effort. For this reason authors have suggested curvature and rotation additions to RANS viscosity models. Reference [10] describes a rotation and curvature model for the Menter SST and Ref [7] a similar model for the Spalart – Allmaras (S-A) viscosity model.

In [1] a comparative study is made in which both S-A RC and Menter SST RC models are compared to a LES benchmark. The results proved the corrections of rotation and curvature to be in fairly good agreement to the LES simulation whilst being significantly faster.

Detatched Eddy Simulations (DES) were considered however the time advantages of this hybrid RANS-LES method were did not overweigh the accuracy of the LES methodology.

2.1 Computational Mesh and Boundary Conditions

The test has been carried out on a ramp with a quarter circular section and the flow was injected through a straight nozzle so that the initial flow was tangential to the ramp. In order to avoid any complications with the compressibility effects associated with higher velocities, the 100 m/sec velocity was chosen. For the temperature of the flow this corresponds to a Mach number of M=0.29. The pressure outlets were moved as far away from the ramp in order to avoid the so-called boundary effect which could have interfered with the attachment over the ramp.

In Figure 1 the computational mesh can be observed, the high order of discretization is necessary in order to meet the low y+ non-dimensional wall distance required for the high precision of the analysis. After successive adaptations, the averaged y+ over the span of the curved ramp was 2.79 for the unsteady k – omega SST simulation and 1.55 for the LES.

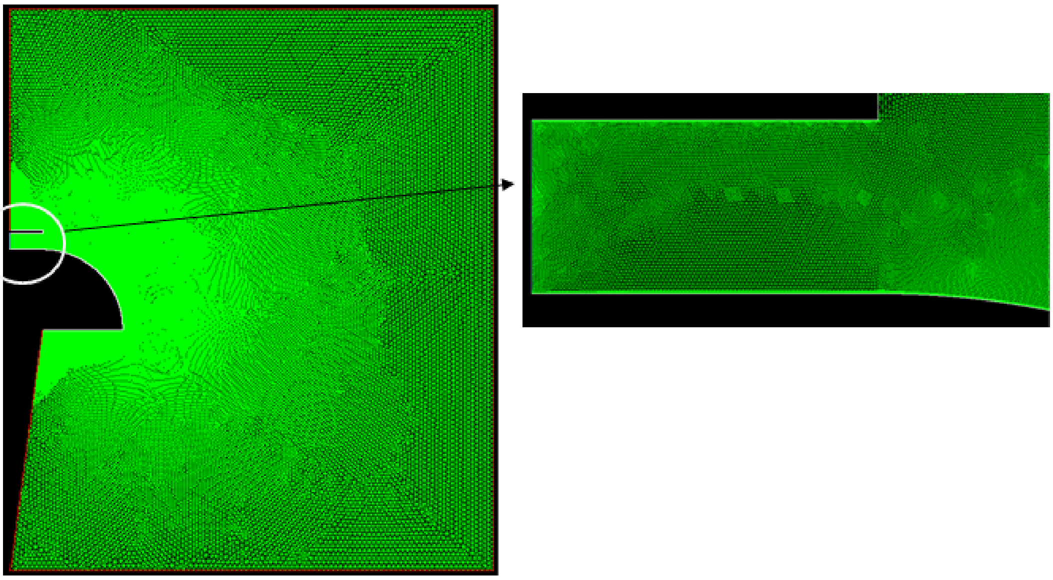

Figure 1: The computational mesh after successive adaptations.

The CFD test was performed as follows:

1. Initial computation with Menter k- omega SST, double precision (dp), first order upwind, SIMPLE pressure-velocity coupling.

2. adaptation of the y+ Reiteration of steps 1 and 2

3. Simulation k-omega SST, dp, second order upwind conditions for all parameters

*Corresponding author (**V.Drăgan**). E-mail addresses: drvaleriu@gmail.com

monitored, SIMPLE pressure-velocity coupling

4. Simulation LES, PISO pressure coupling, Smagorinsky-Lilly model sub-grid scale turbulence model. Time step 10^{-4}sec

5. k-omega SST, double precision, second order upwind conditions for all parameters monitored, SIMPLE pressure-velocity coupling, unsteady, time step 10^{-4}sec.

The Large Eddy Simulation technique relies on the filtration of the spectrum of turbulent eddies that are smaller than the mesh elements and modeling them through a sub grid scale model, in this case the Smagorinsky-Lilly. All the other eddies are then solved directly numerically from the transient Navier Stokes equations. This is similar, in part, to the direct numerical solving (DNS) which is regarded as the most accurate method for solving Navier-Stokes equations but which requires formidable computation power and time.

Equations 1 through 4 describe the LES technique in its mathematical form from the Navier Stokes Eq.1 through the filtered Navier Stokes in Eq.3 to the SGS turbulent stress, Eq.4:

$$\frac{\partial u_i}{\partial t}+\frac{\partial u_i u_j}{\partial x_j}=-\frac{1}{\rho}\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\nu\frac{\partial u_i}{\partial x_j}\right) \tag{1}$$

$$\mathbf{u}(\mathbf{x},t)=\underbrace{\overline{\mathbf{u}}(\mathbf{x},t)}_{\substack{\text{scale of eddies}\\ \text{directlly solved}\\ \text{from Navier Stokes}}}+\underbrace{\mathbf{u}'(\mathbf{x},t)}_{\substack{\text{scale of eddes}\\ \text{modeled trough}\\ \text{Sub Grid Scale}\\ \text{turbulence models}}} \tag{2}$$

$$\frac{\partial \overline{u}_i}{\partial t}+\frac{\partial \overline{u}_i \overline{u}_j}{\partial x_j}=-\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\nu\frac{\partial \overline{u}_i}{\partial x_j}\right)-\frac{\partial \tau_{ij}}{\partial x_j} \tag{3}$$

$$\tau_{ij}\equiv\overline{u_i u_j}-\overline{u}_i\overline{u}_j \tag{4}$$

The PISO pressure-velocity coupling was chosen as the iteration time was already expected to be higher than the previous 3 steps however, due to the addition of a second correction stage, the Pressure Implicit solution by Split Operator method (Issa 1982 PISO) scheme needs fewer iterations, hence reducing computation time [8].

Figure 2 depicts the correlation between the velocity field and the static pressure field across the ramp for the RANS k-omega SST and the LES simulations respectively. We can draw the preliminary conclusion that, indeed the fluid is accelerated across the curved ramp and-as a consequence of Bernoulli's law- the static pressure drops.

This correlation is useful in showing that in conventional airfoils, the acceleration of the fluid on the upper side is due to the Coandã effect over the curved region rather than the path difference as it is traditionally thought. This remark however is not the object of this investigation and will be discussed in a separate note.

The aero-acoustic processing was done with the FWH formalism and after a Fourier Transform; the acoustic spectrum was obtained for each of the three chosen points in the vicinity of the ramp. Figures 4 through 6 show the spectrum observed for the respective coordinates of the points.

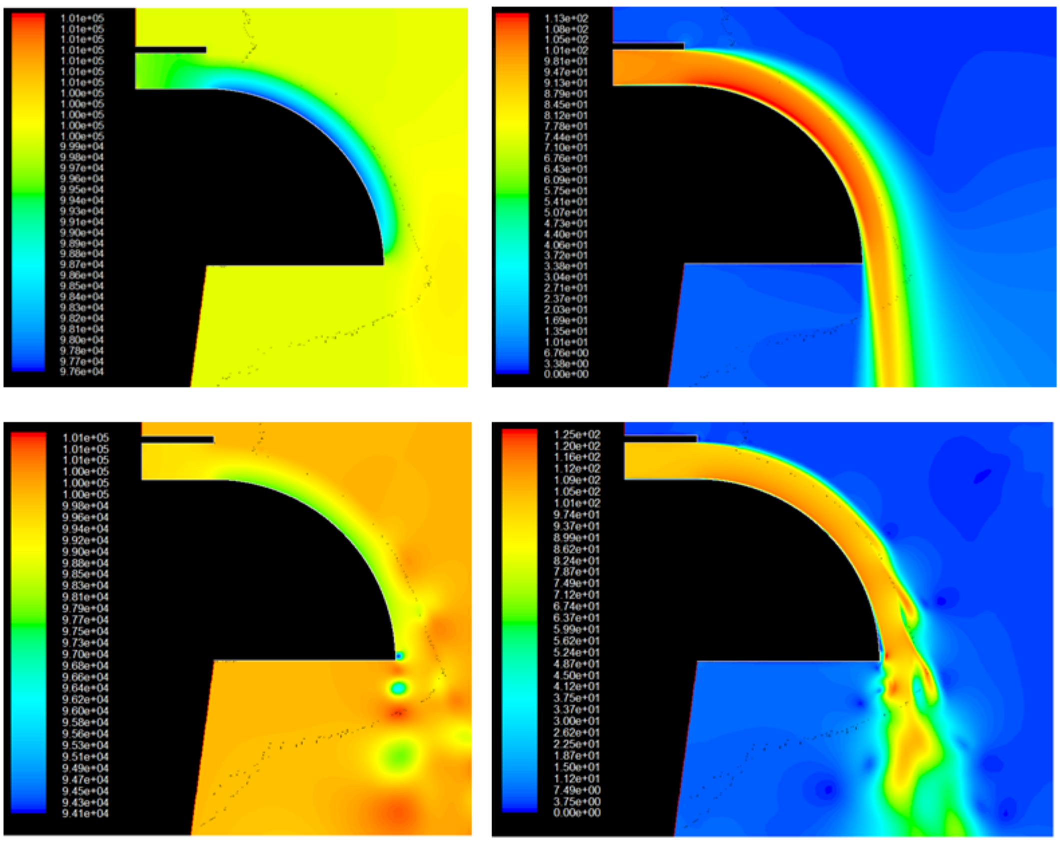

Figure 2: Plots correlating velocity and static pressure of k-omega SST (up) and LES (down).

*Corresponding author (**V.Drãgan**). E-mail addresses: drvaleriu@gmail.com

3. Results

By integrating the pressure drop over the ramp we can calculate the lift that it would provide in a real airfoil application. Comparing it to the thrust of the bare jet exhausted through the considered nozzle we can verify the claim of Henri Coandã's patent [5]. Equation 5 was used for the assessment and the results were compared with the estimated force resulted from the diversion of the fluid by the observed 87°. The comparison showed that jet diversion alone is not responsible for the total lift generated by the ramp which proves, numerically, Coandã's claims.

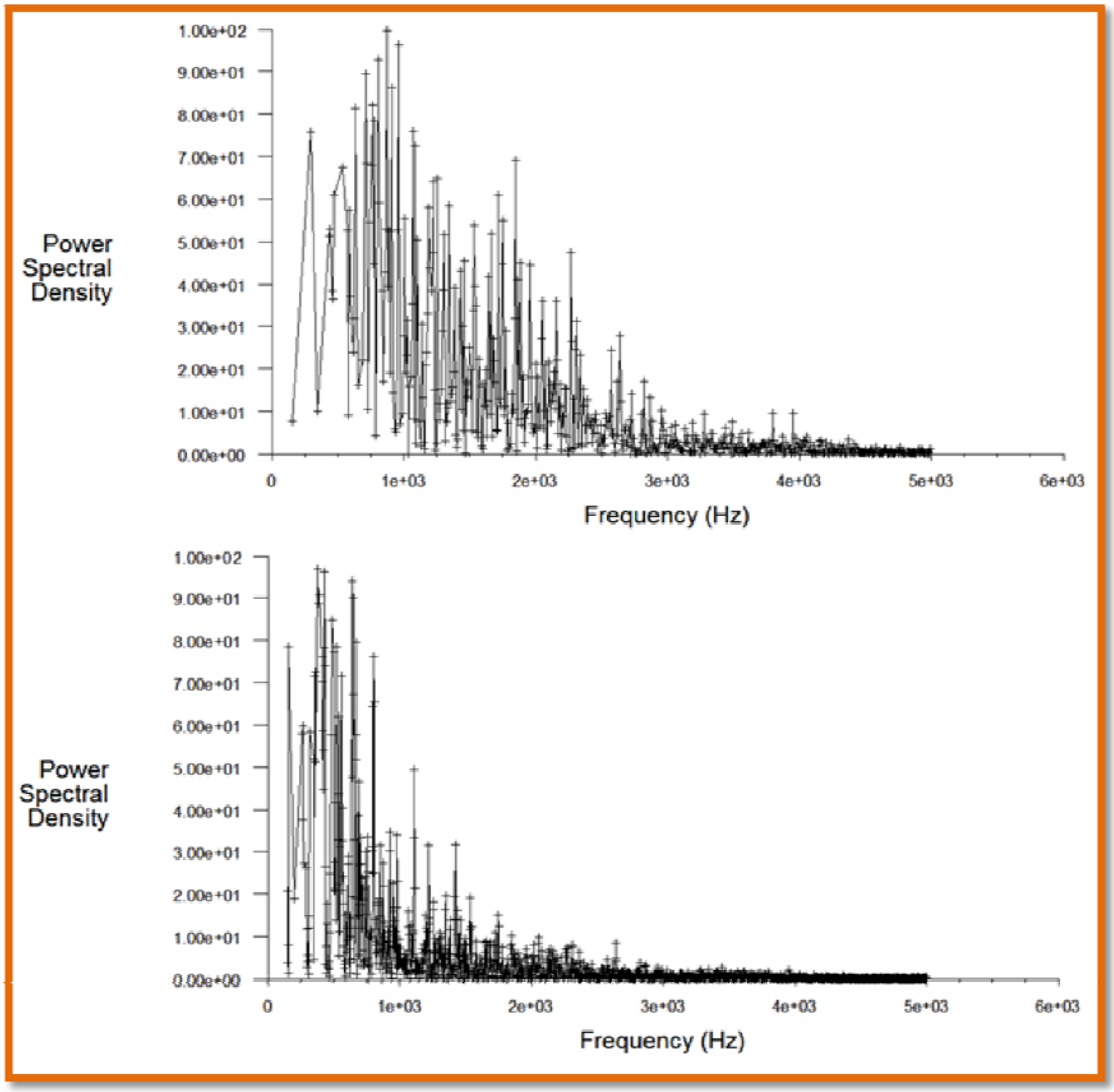

Figure 3: First receiver location spectrum, notable differences between 1kHz and 2 kHz LES (up) k-omega SST (down)

Table 1: relevant aerodynamic parameters of the three simulations.

Simulation model	y+	Average static pressure	Karman vortex street	100*Ramp lift/jet thrust
Steady k-ω SST	5.71	98103.56 [Pa]	Not observed	121.5881 %
Large Eddy Simulation	1.55	97870.69 [Pa]	Observed	136.5185 %
Unsteady k-ω SST	2.79	98019.23 [Pa]	Not observed	126.9948 %

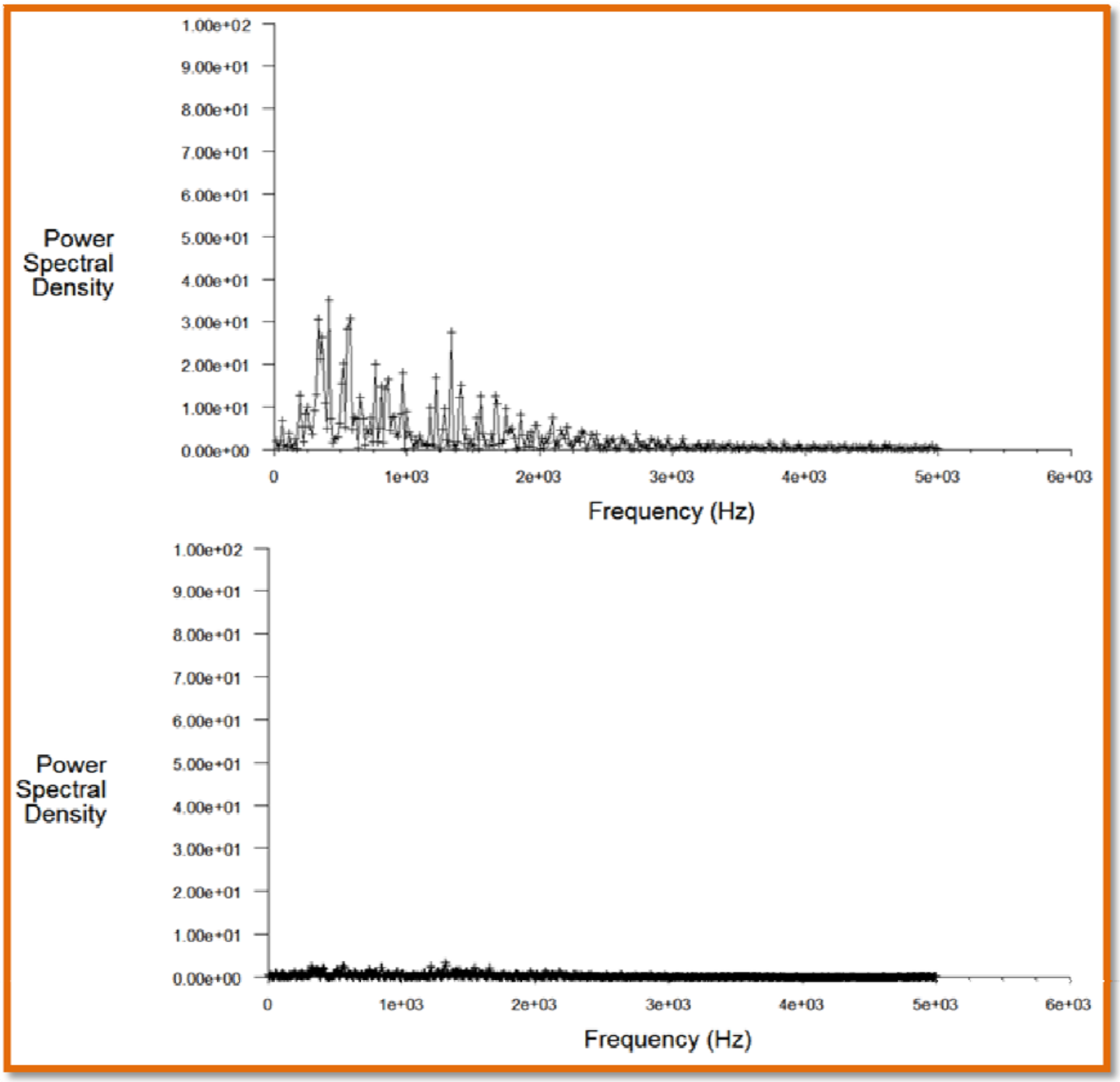

Figure 4: Fourth receiver location spectrum, notable differences between entire spectrum is under predicted by the SST; LES (up) k-omega SST (down).

4. Discussions

Regarding the aspects of numerical computations we can conclude that the results of a steady k-omega SST RANS simulation give fairly similar results to that of the more time and labor intensive Smagorinsky-Lilly LES method. It needs to be said however that the nature of the thin jet in respect to the ramp size makes it prone to unsteady flows therefore RANS and LES simulations alike should be performed in a time dependent manner.

Detachment of the flow was not accurately predicted by the RANS; however, in this particular case the differences were not large. For thinner jets and higher velocities and curvatures failure to predict flow detachment will be an issue that will give optimistic lift values for super circulation airfoils. Hence it is the recommendation of this paper to use, if possible the LES technique at least in those cases.

Regarding the lift obtained through super circulation; the ramp produced a force equal to 136 % of the thrust of the nozzle. This is confirmation that diversion of the fluid alone is not the cause of the super circulation lift and that pelicular jets indeed may provide a new principle of flight as envisioned by Henri Coandã.

This finding is significant in understanding how conventional airfoils work as there is still a widespread belief amongst aerodynamicists that the acceleration on the upper side of the airfoil is due to the difference in path length. While it is not the object of this study, we can only state the opinion that the acceleration is caused by the curvature of the airfoil which is a distinct physical phenomenon in itself.

The acoustics of the Coandã jet appears to be quite similar in nature to that of a normal jet that is injected in a given volume. However we need to point out that the velocity of the fluid that gets detached from the ramp is lower than that of the initial (fully developed) flow due to turbulence generated while attached to the ramp. This leads in the end to a less steep transition to the still ambient air and hence to less noise generation.

5. Applications

The most popular applications for super circulation flows are airfoil surfaces such as airplane wings or turbo machinery blades. Advantages include higher section loadings, higher Angles of Attack (delayed stalling) and higher lift to drag ratios.

Below we present a preliminary comparative study of a super circulated airfoil versus a similar conventional airfoil. Table 2 presents the summary of the aerodynamic performances of the two cases. The super circulated airfoil displayed better aerodynamic performances at both angles of attack tested.

Table 2: Aerodynamic parameters of the tested airfoils.

Airfoil	Section loading N/m^2	Lift to drag ratio
S. C. 10° AoA	1266.06	20.7042
NACA 10° AoA	1130.81	17.2111
S. C. 15° AoA	1136.24	14.6389
NACA. 15° AoA	1143.45	12.8913

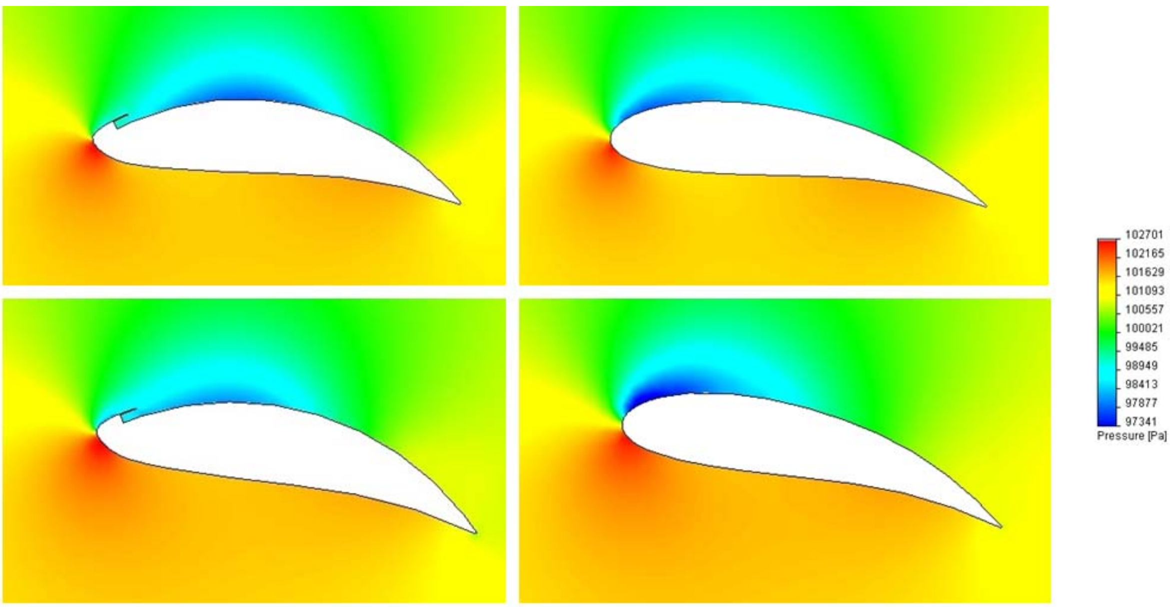

Figure 5: Static pressure plots of normal and super circulated airfoils.

6. Conclusion

Due to increasing interest in the civilian aviation industry for super circulation aircraft, particularly because of the higher lift capacity and lower noise emissions, we sat out to establish a simple CFD research method in order to derive some quantitative aspects of the super circulation concept.

The paper presents a comparative computational fluid dynamics study between the two major Navier-Stokes methods: RANS and LES. It focuses on the flow characteristics such as boundary layer separation and pressure drop due to the Coandã Effect but also on the aero-acoustic particularities of Coandã flows.

It was found that the curvature of the Coandã surface tends to accelerate the fluid in the immediate vicinity of the wall which causes the static pressure to drop considerably hence generating lift. The pressure drop across the ramp provided a lift equal to 136.5% of the jet thrust. This is evidence that deviation of the fluid alone cannot be the motive of the lift generated on the ramp.

Section 5 depicts a possible application of the super circulation by Coandã effect on a classic NACA airfoil. The results obtained through CFD simulations in these cases show improved lift to drag ratios thus improving overall aircraft efficiency.

Comparing the two CFD methods used, the RANS k-omega and LES we can conclude that the LES predicted the detachment from the ramp whilst the k-omega did not. Also, the k-omega SST under predicted the pressure drop across the ramp. The LES technique captured the unsteady phenomenon of a Karman vortex street generated at the detachment point.

The acoustic spectrum in the LES case predicts a wider range from 500 Hz to 2000 Hz while the SST only predicts a spectrum from 500 Hz to 1000 Hz. This is an important difference since the human ear is more sensitive in the range 1000-2000 Hz. All four receiver locations registered largely the same differences in the noise spectrum.

7. References

[1] Christopher L. Rumsey, Takafumi Nishino, Numerical Study Comparing RANS and LES Approaches on a Circulation Control Airfoil,

http://fun3d.larc.nasa.gov/papers/cc-paper-6.pdf. Retrieved Nov.1 2011

[2] Daniel Wilde, Analysis of Curvature Effects on Boundary Layer Separation and Turbulence Model Accuracy for Circulation Control Applications, Bachelor of Science Thesis, the Faculty of the Aerospace Engineering Department California Polytechnic State University, San Luis Obispo, AIAA 2010

[3] Fluent User Service Center, Introductory Fluent Notes V6.2,Modeling Turbulent Flows, March 2005

[4] G.S. Jones, J.C. Lin, B.G. Allan, W.E. Milholen, C.L. Rumsey, R.C. Swanson, Overview of CFD Validation Experiments for Circulation Control Applications at NASA, TM 20080031119_200803004, NASA archive, 2008

[5] H. Coandã, Device for deflecting a stream of elastic fluid projected into an elastic fluid. US2,052,869, 1936.

[6]Lars Davidson: MTF270 Turbulence Modelling, The SST Model, Chalmers University, March 26, 2006

[7] R. H. Nichols, Turbulence Models and Their Application to Complex Flows, Chapter 5.0 One-Equation Turbulence Models, University of Alabama at Birmingham HPCMP/PET CFD Onsite – AEDC. Retrieved Nov.1 2011

[8] T. J. Craf, Pressure-Velocity Coupling, School of Mechanical Aerospace and Civil Engineering Advanced Modelling & Simulation: CFD, The University of Manchester, retrieved Nov.1 2011

[9] Valeriu Drãgan, A parametric study on ambient pressure effects on super circulation over a simple ramp, International Journal of Advanced Engineering Sciences and Technologies Journal, Vol. 5, no.1, April 2011.

[10] Wallin, S. and Johansson, A. V., "Modelling Streamline Curvature Effects in Explicit Algebraic Reynolds Stress Turbulence Models," Int. J. Heat and Fluid Flow, Vol. 23, No. 5, , pp. 721-730. 2002.

Valeriu Drãgan is an aerospace engineering PhD student with the Aerospace Engineering Faculty of the Politehnica University of Bucharest. He received his B. Eng diploma in aerospace engineering in 2009 with the thesis "Acoustic Management of the Turbofan Engines" and the Master of Science diploma in 2011 with the thesis "Parametric Studies and Applications of the Coandã Effect". Valeriu Drãgan's scientific interests include aerospace inventics, aero-acoustics, stealth technologies and also theoretical physics and geometry.
.

Peer Review: This article has been internationally peer-reviewed and accepted for publication according to the guidelines given at the journal's website.