Notes on the use of conventional NACA airfoils in super circulation aerodynes

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ABSTRACT

Since their advent in the late 1930's, lenticular aerodynes have been regarded as strong candidates for high efficienc, low noise vertical takeoff and landing platforms (VTOL). Variations on the use of the principle has led to a pleiade of hybrid aircraft and unmanned aerial vehicles such as the Antonov An 71, Boeing YC 14 and the NASA experimental QUESTOL aircraft.

This note investigates the usefulness of conventional airfoils in achieving super circulation lift. The methods used are numerical, RANS simulations having been carried out. It was found that the relevant parameter in our case was the upper surface curvature of the airfoil. This is a more precise statement than the current state of the art which consideres the airfoil thickness alone. We hereby prove that not only thickness but camber height must be factored in.

Key words: Lenticular aerodyne, airfoil, super circulation,Coandã effect.

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INTRODUCTION

In Coandã's lenticular aerodyne Ref [1] lift is achieved through a form of circulation control named super circulation in which a high velocity thin jet of air washes a curved wall in order to generate down-pressure.

Reference [2] provides a modernized variation of the original lenticular aerodyne, passing the stream of air from a fan past a super-circulated annular airfoil. One of the conclusions drawn in Ref.[2] is that a thicker airfoil will provide higher lift than a thinner one.

True as the statement may be in the cases studied in Ref [2], it should be stated that the thickness of the airfoil is just a secondary aspect to the super circulation lift. The relevant aspect in super circulation is the curvature of the upper surface of the airfoil. Previous numerical studies based on Menter's k-omega SST viscosity model presented in Ref. [3] indicate that a curved ramp causes the jet to accelerate whilst creating a pressure drop. This has been attributed mainly to the deflection of the flow however the physical phenomenon is more complex. Figure 1 shows the initial computational mesh and Fig.2 the correlation between the velocity of the fluid and the static pressure on the ramp.

References [4], [5], [6] support these findings whilst seeking different applications or the principle. Comparisons between viscosity models have been performed in Refs [3] trough [6] in order to validate the numerical results. It is common knowledge that whilst Large Eddy

Simulations (LES) and Direct Numerical Simulation (DNS) are somewhat more accurate, the quicker Reynols Averadged Navier-Stokes (RANS) viscosity models Reynolds Stress Model (RSM) and k-omega Shear Stress Transport (SST) are close approximations since they factor in the stress transport effects.

$$C_\mu = \frac{T_{static}}{q \cdot S} \quad (1)$$

$$q = \frac{\rho \cdot v^2}{2} \quad (2)$$

$C_\mu = the\ momentum\ coefficient$
$q = dynamic\ pressure$
$T_{static} = static\ SLS\ Thrust\ of\ the\ engine$
$S = Surface\ area\ of\ the\ super\ circulated\ wing$
$\rho = air\ density$
$v = free\ stream\ velocity$

THE COMPUTATIONAL FLUID DYNAMICS TEST

Next we will present a computational fluid dynamic (CFD) study on three different NACA airfoils, two of which were considered by Ref [2] and a third which has the same thickness of NACA 0012 while having the same upper surface curvature of the NACA 0024, as it can be seen in Fig.3.

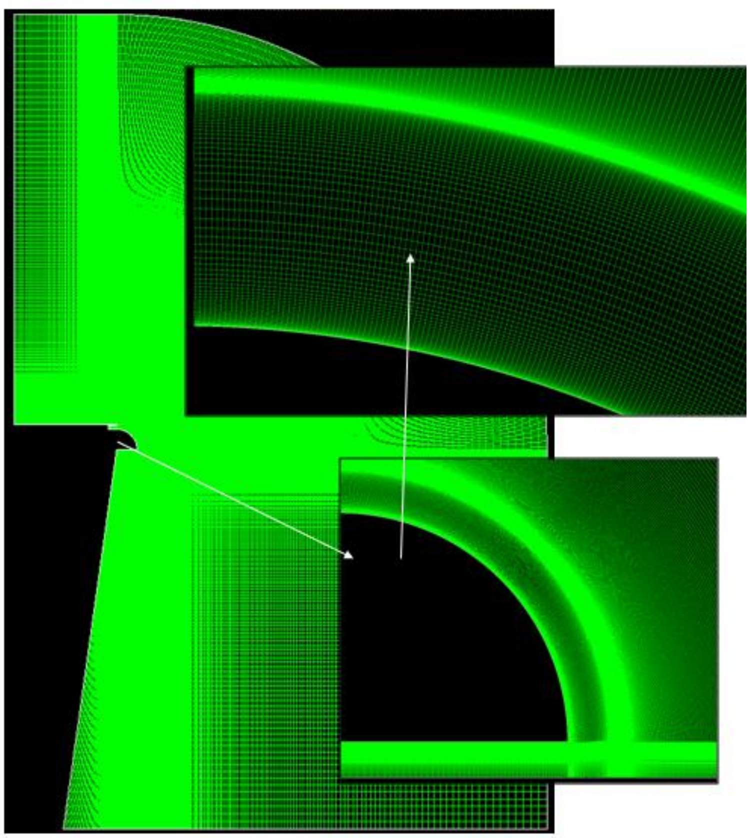

Fig.1 The computational mesh used in the initial quarter-circular ramp CFD test

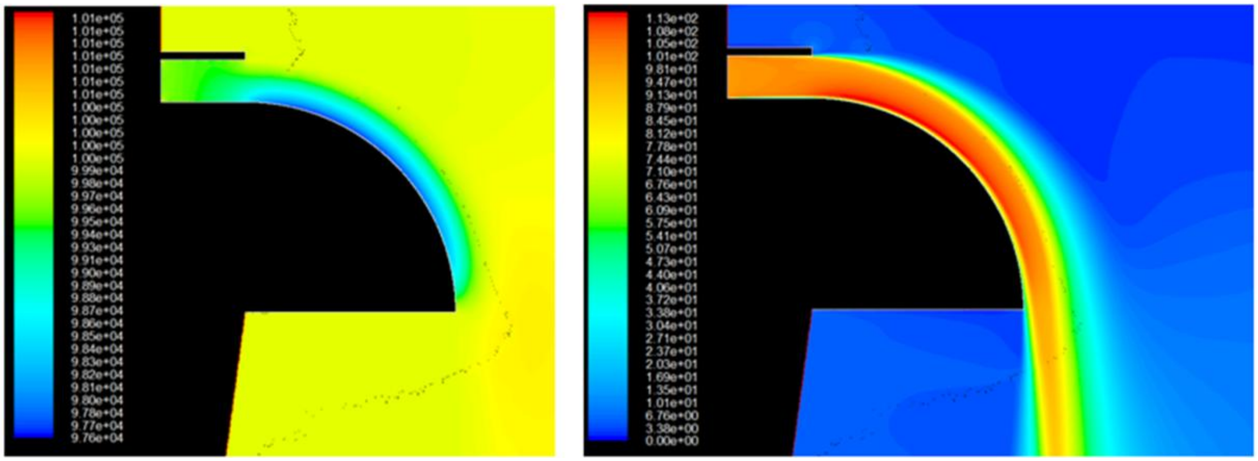

Fig.2 The correlation of static pressure (left) and velocity (right) over the quarter circular ramp

The high camber of the considered NACA 6212 is expected to generate a similar pressure drop as the thicker NACA 0024. Furthermore, due to the lower thickness the NACA 6212 should deflect the fluid at a higher angle therefore obtaining more lift. This later aspect is however of little relevance since the further study proposed by Ref [2] involves direct super circulation of the upper surface of the annular wing hence not relying on the direct deflection of the flow.

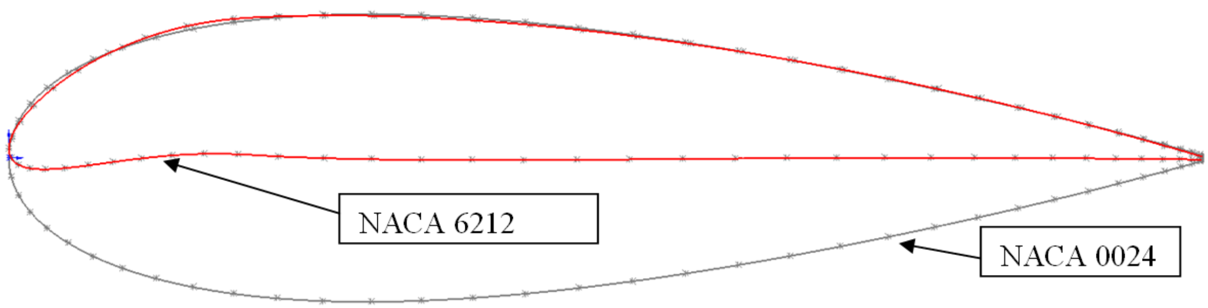

Fig.3 Two of the considered airfoil geometries

Findings of the CFD study are presented in Table 1, velocity plots are presented in Fig.4.

Table1. The aerodynamic coefficients and parameters associated with the airfoils

Airfoil	Section Loading [Pa]	Lift/Drag	Angle of Deflection	Airfoil
NACA 0012	24.95	4.11	~-8.5°	NACA 0012
NACA 0024	20.00	3.51	~-8.5°	NACA 0024
NACA 6112	40.90	4.42	~-18.4°	NACA 6112

As visible in Fig.4, the thicker NACA 0024 airfoil tends to accelerate the passing fluid both on the upper and lower side of the leading edge. This tendency will lead to an unwanted pressure drop on the lower side which translates into lower airfoil lift.

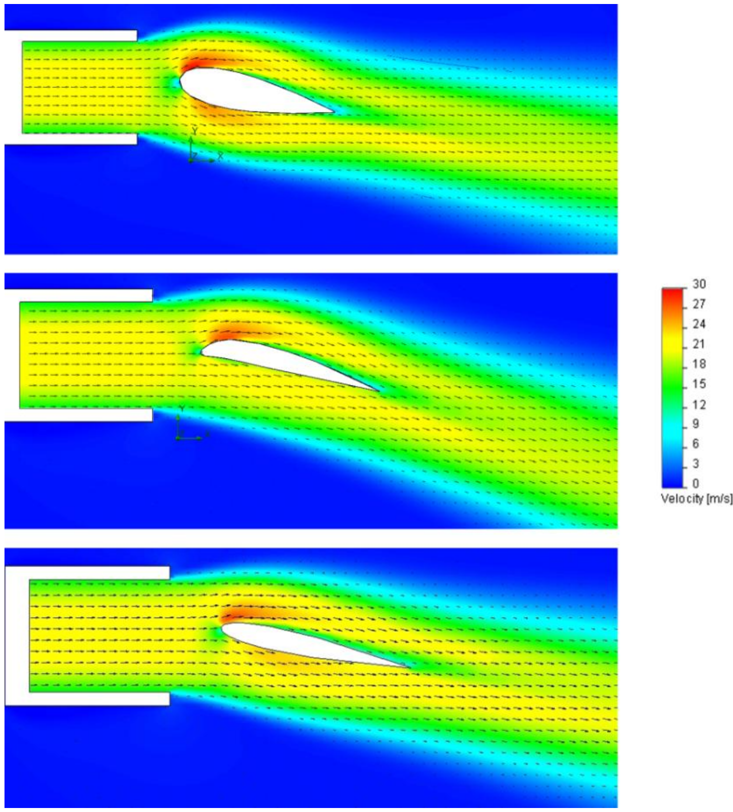

Fig.4 Velocity plots of air injected in front of the NACA airfoils considered

It is a secondary goal of this paper to verify the Bernoulli law in the presence of the Coandã effect over curved surfaces. For that purpose the expression in Eq.3 was calculated for all non-compressible velocities i.e. below Mach 0,3 in the presence of the Coandã effect. The results show virtually no abatements i.e. magnitudes of a thousand of a percent-which is obviously within the margin of error of the CFD simulations.

$$\Delta B = 100\frac{P_{total}-(p+q)}{P_{total}} \quad (3)$$

Figure 5 shows the abatements in the case of a simple quarter circular ramp configuration presented in Fig.1.

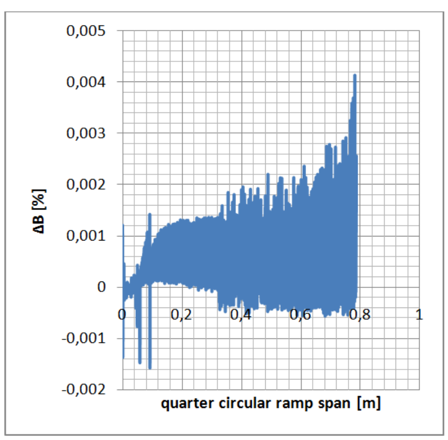

Fig.5 Abatements from Bernoulli's law versus ramp span

CONCLUSION(Times New Roman, Font size:12 ,Bold ,left aligned)

The paper presents a CFD study of a lenticular aerodyne configuration in which three conventional NACA airfoils are tested. The current study is based on the experimental data from Ref.[2] in which they conclude that a higher airfoil thickness is solely responsible for generating improved lift. We show that this statement may be amended trough a better understanding of the Coandã effect, by stating that regardless of the thickness, the main influence of the lift force is that of the curvature of the upper side of the airfoil. This is because, by virtue of the Coandã effect, a fluid passing over a curved wall will tend to accelerate in that region and generate a static pressure drop proportionate to it.

The thickness of the airfoil is of great influence to the super circulation lift; however this is due to the curvature of the upper surface. Other parameters of the airfoil such as maximum camber height and location may be varied in order to achieve similar or even better results.

Super circulation aerodynes can be devised in various layouts however the most advantageous version is that of Ref.[1] since a conventional airfoil will imply higher upper surface curvatures which would imply either higher thicknesses or higher camber both of which generate losses trough friction.

Although the principles of the lenticular aerodyne are fundamentally different, they are not infringing in any way the Bernoulli law. The CFD result verify its the accuracy to the thousand of a Pascal, which is obviously well within the error margin of the numerical simulation.

The abatements calculated were higher that near the more turbulent regions in the immediate vicinity of the fluid injector and downstream along the ramp where the boundary layer becomes increasingly turbulent.

REFERENCE(Times New Roman, Font size:12 ,Bold ,left aligned)

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

[2] B Saeed, G Gratton, Exploring the aerodynamic characteristics of a blown annular wing for vertical/short take-off and landing applications, Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering

[3] 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.

[4] Daniel Wilde, Analysis of Curvature Effects on Boundary Layer Separation and Turbulence Model Accuracy for Circulation Control Applications, American Institute of Aeronautics and Astronautics B.S. thesis 2010

[5] Gregory S. Jones, Robert J. Englar Advances In Pneumatic-Controlled High-Lift Systems Through Pulsed Blowing, AIAA 2003-3411

[6] 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, 2008

[7] A. M. O. Smith, High-Lift Aerodynamics, 37th Wright Brothers Lecture, VOL. 12, NO. 6 Journal of Aircraft, june 1975

[8] Shen, C. C., Lopez, M. L., and Wasson, N. F., A Jet-Wing Lifting-Surface Theory Using Elementary Vortex Distributions, *Journal of Aircraft,* Vol. 12, May 1975, pp. 448-456

[9] Hyun D. Kim, Jeffrey J. Berton, and Scott M. Jones Low Noise Cruise Efficient Short Take-Off and Landing Transport Vehicle Study, AIAA–2006–7738

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