An Investigation of Initial Shock Cell Formation in Turbulent Coanda Wall Jets

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Turbulent Coanda wall jets are present in a multitude of applications.[1] Their obvious advantages for flow deflection are often outweighed by disadvantages related to the increased noise levels associated with such jets. Better predictions of Coanda jet noise would allow the Coanda effect to be more widely applied, and its potential to be fully realized. This paper applies the method of characteristics to a steady two-dimensional axisymmetric supersonic flow in order to determine the location of the first shock cell downstream of the nozzle. This phenomenon has previously been found to be particularly important in determining both the OASPL and peak frequency of the broadband high-frequency Shock-Associated Noise (BBSAN) emitted by a given jet configuration.[10,20] The current work has also illuminated the relationship between cell location and flow characteristics, and thus the effect of jet operating conditions on BBSAN can now be determined.[11] The relationship between cell location and jet breakaway is also under investigation. Predictions are compared with experimental results obtained using flow visualization techniques. This work is in the process of being extended so that the Rankine-Hugoniot conditions can be used to predict the shock cell structure (and thus the BBSAN) along the entire jet.[22]

NOMENCLATURE

C_+	Characteristic moving towards Coanda surface
C_-	Characteristic moving away from Coanda surface
a	Speed of sound (m/s)
(x, y)	Cartesian coordinates of point of interest
(u, v)	Velocity components at point of interest (x, y) along the x and y-axes respectively (m/s)
θ	Angle streamline makes with x-axis
α	Mach angle
λ_+	Slope of characteristic moving towards Coanda surface
λ_-	Slope of characteristic moving away from Coanda surface
δ	Dirac delta function. $\delta = 1$: axisymmetric flow, $\delta = 0$: planar 2D flow
γ	Ratio of specific heat capacities
R_c	Radius of circular part of flare (m)
R_f	Radius of interior stem of flare (m)
h	Exit slot (mm)
y_0	y-value assigned at lip (m)
p_e	Nozzle exit pressure (psig)
p_a	Ambient (atmospheric) pressure (psig)
p_o	Reservoir pressure (psig)
M_e	Exit Mach number
U_{jx}	Jet exit velocity (m/s)

1. INTRODUCTION

1.1. The Coanda Effect

The Coanda effect, discovered early in the twentieth century by Romanian mathematician and scientist Henri Coanda, is the phenomenon whereby '…when a jet is passed over a curved surface it bends to follow the surface, entraining large amounts of air as it does so…'.[1–3] Consider a fluid element exiting a nozzle adjacent to a curved surface. The radial equilibrium of the element leads to the development of a pressure field which forces the fluid against the surface, and this effect is reinforced by the slightly enhanced viscous drag which is experienced by the jet on its wall side as it exits the nozzle, and which also tends to deflect it towards the wall. Subsequently, this pressure field will continue to force the jet towards the surface. An additional viscous effect, namely the entrainment of the ambient fluid between the jet and the surface, may also help to move the jet towards the wall. The effect breaks down under certain operating conditions, at which point jet breakaway occurs. A hysteresis effect is subsequently observed. The Coanda effect is noticed in the natural world (with both positive and negative consequences) and is frequently invoked in aeronautics, maritime technology and industrial engineering.[1] The substantial flow deflection offered by the Coanda principle is generally accompanied by enhanced levels of turbulence and increased entrainment. A direct consequence of these effects is often a significant escalation in the associated noise levels, and it is posited that this disadvantage has prevented its application from becoming more widespread in recent years.[4] Clearly, bet-