How a jet flow interacting with a streamwise/spanwise corrugated surface causes an increase in turbulence kinetic energy.

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Introduction

Rapid-distortion theory (RDT) uses linear analysis to study the interaction of turbulence with solid surfaces. It applies whenever the turbulence intensity is small and the length (or time) scale over which the interaction takes place is short compared to the length (or time) scale over which the turbulent eddies evolve. The basic theory can be used to model the sound radiated by a turbulent flow interacting with a leading or trailing edge embedded in the flow (Goldstein et al. JFM, vol. 824, pp.477-512, 2017).

The canonical leading-edge problem

The type of problem we are concerned with is one where non-homogeneous turbulence in a jet flow interacts with a flat plate positioned parallel to the level curves of the jet mean flow. The scenario is depicted in the schematic below in Fig. 1.

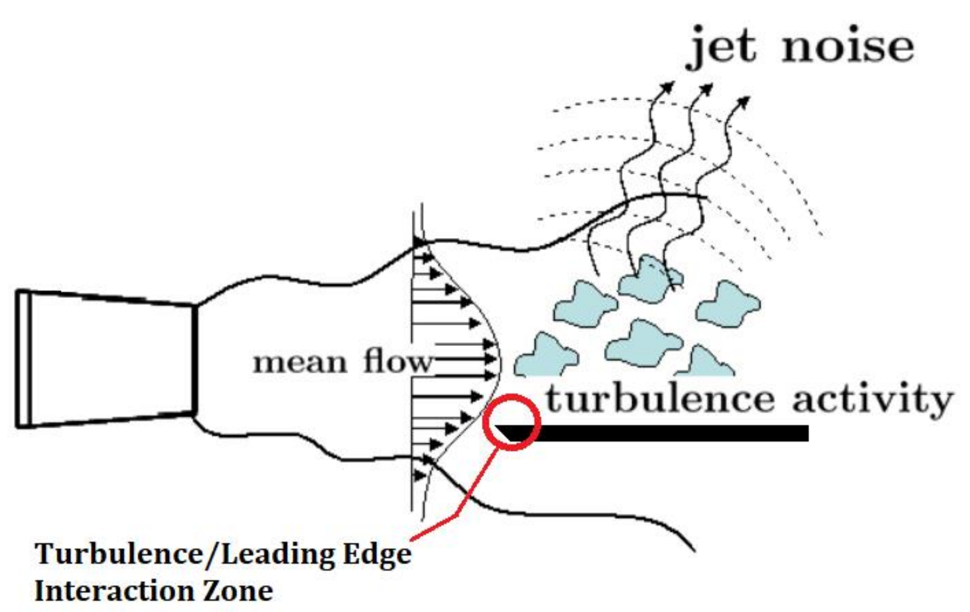

Figure 1 Schematic showing noise production when a jet impinges on a flat plate.

To fix ideas we consider a rectangular jet of 8:1 aspect ratio. The acoustic Mach number is fixed to 0.9 and the temperature ratio is unity. The noise radiated by this configuration after interacting with the edge represents a problem of technological interest owing to the high flow speed (Bridges 2014, Afsar *et al*. 2017). The mesh for the flat plate is depicted below.

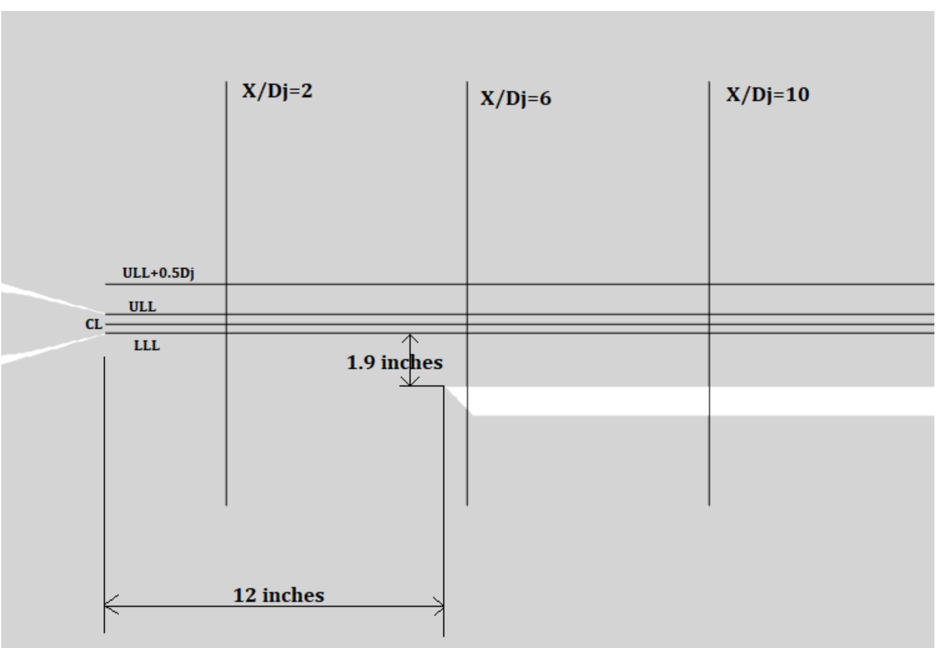

Figure 1: Image showing leading edge location relative to the nozzle's lower lip, also shown are the lines from which data was extracted. Mesh created on Pointwise and Flow solved using STARCCM+.

Numerical Simulations

One way of reducing of possibly reducing the sound is to change the spatial morphology of the surface of the flat plate. While there are several ways one can achieve this, in this study we use CFD simulations to show what happens when to the local turbulence kinetic energy when the surface is morphed with streamwise or spanwise oscillations. We consider a basic shape of a corrugated plate of the form *sin(wx)*, with frequency *w=0.5*, and *w=1*.

Figure 2: Mesh design for streamwise Surface corrugations

	Classification	P / V / Ma	Turbulence Specification	Turbulence Values
Inlet	Pressure Inlet	70000kPa	Intensity & Length Scale	1% & 0.0576m
Farfield Near end	Velocity Inlet	3.43ms^{-1}	Intensity and Viscosity Ratio	1% & 10
Farfield Top & Bottom	Freestream	0.01	k-ε	0.001 J/kg & 0.1m^2/s^3
Farfield Far end	Freestream	0.01	k-ε	0.001 J/kg & 0.1 m^2/s^3
Nozzle Inner and Outer	Wall (no slip)	-	-	-
Plate	Wall (no slip)	-	-	-

Table 1: Boundary Conditions

The "effective stand-off distance"

The streamwise surface corrugations effectively reduce the vertical stand-off distance between the jet and and the discontinuity. This has the effect of increasing the turbulence kinetic energy by almost a factor of 2. See Fig. 3.

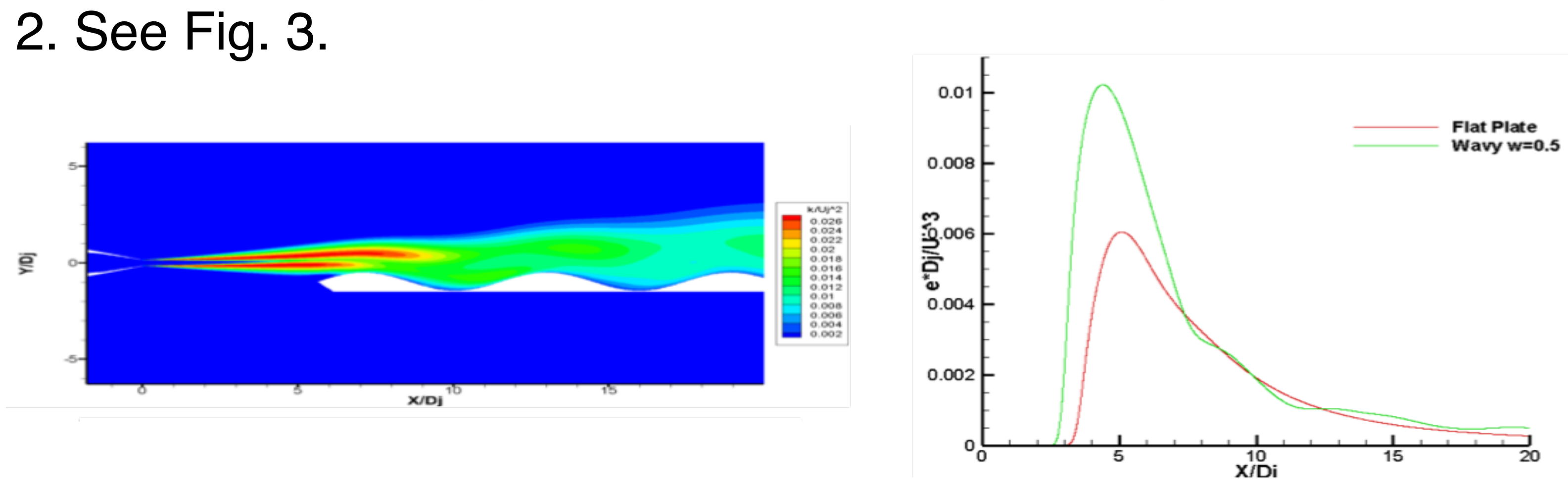

Figure 3: Normalized TKE using STAR-CCM+ as solver and k – ε realizable turbulence model)

The schematic in Fig. 4 shows the structure of the surface corrugation in the streamwise direction. The peak of the surface near the leading edge will always increase the TKE owing the reduced effective distance between the jet measured from the lower lip like to the surface of the plate.

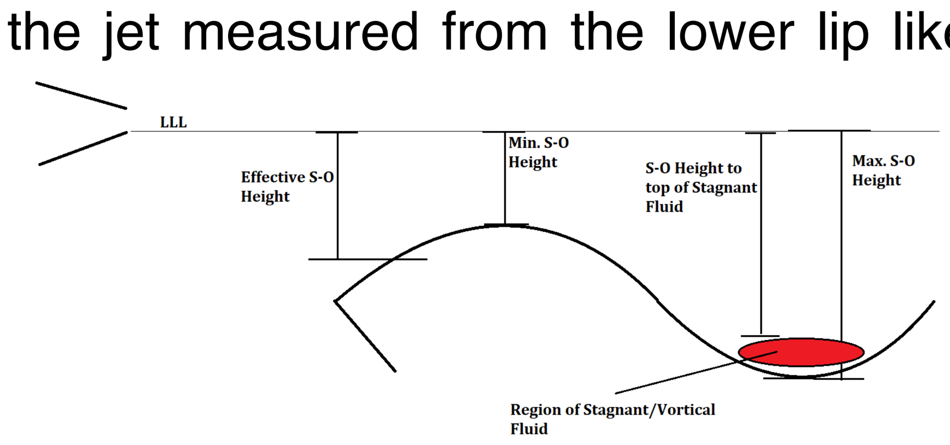

Figure 4: Schematic of the structure of the streamwise surface corrugation showing the increased standoff distance when the peak is near the leading edge.

Conclusions

- Surface corrugations can result in an increase in turbulence kinetic energy when the local curvature of the surface closest to the leading edge is positive (i.e. convex or, concave down).
- Assuming that the low frequency structure of the propagation of sound (determined by the Wiener- Hopf technique) after interacting with a wavy surface is similar to the flat plate solution at lowest order, the sound will be proportional to the turbulence kinetic energy. The type of configuration shown in Figure 3 is therefore likely to result in an increase in radiated sound.

References:

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