

# Airframe Noise Reduction via Near-Wall Turbulence Control

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## Introduction

Turbulence control has been one of the major research issues to improve the aerodynamic performance at high Reynolds number. In most cases the flow-induced noise involves a restricted region of turbulence which is either a free mixing layer or a wall-bounded flow. The understanding of turbulent flow phenomena is strongly related to the development of energy saving technologies. Furthermore, the turbulent flows in contact with solid wall generate airframe noise which possesses a serious impact on any community in the vicinity of an airport.

Trailing-edge noise is generated when turbulent flow encounters an abrupt change in the boundary condition, i.e., the flow characteristics changes from a wall-bounded to a free shear flow. Theoretically, dipole sources traveling near the solid surface are assumed to produce sound by acoustic scattering. To clarify the sound mechanism Amiet [1] considers the convecting surface pressure spectrum as a proper source. Howe [2] uses Lighthill's acoustic analogy to introduce a sound generation model determined by eddy convection velocity, spanwise coherence function, and Mach number. Brooks and Hodgson [3] extend existing theories and manipulate the measured surface pressure to formulate sound generation. However, the complexity of turbulent sources which are bounded by solid surfaces and scattered by wall discontinuities prevents further progress of those ideas to noise reduction.

Concerning the prediction and reduction of airframe noise the current state and future prospective technologies are reported, for instance, by Dobrzynski et al. [4]. They discuss numerous efforts including full scale investigations conducted by experimental and numerical approaches to reduce noise generation and to develop silent aerodynamic devices. Moreover, a numerical analysis by Gröschel et al. [5] of a realistic short cowl nozzle configuration, i.e., a high Reynolds number coaxial jet of a cold secondary and a heated primary stream, indicates the potential to effectively lower the overall downstream noise without enhancing the annoying high frequency noise components. A silencing high density fluid is injected at several positions. Especially, the injection between the inner and outer stream shows the attenuation of sound at acute angles from the jet axis compared to the clean configuration. Considering the flow over a trailing edge of a flat plate Koh et al. [6] modify the turbulent structures near the trailing edge by injecting carbon dioxide gas as a control fluid. At an acute ejection angle to the wall surface they achieve 4dB reduction of the overall sound pressure level. This result indicates that the near-wall coherent structures caused by the mixing of the outer and the ejected fluid change the velocity gradient of in the shear layer and weaken turbulent wall-pressure fluctua-

tions which have been directly recognized as the major source of airframe noise.

The objective of the current numerical analysis is to improve the aforementioned technique to lower the noise level by manipulating the shear layer. A secondary fluid at a high density is injected into the shear layer to modify the near-wall coherent structures. The detailed analysis of the numerical solutions evidences the noise mechanisms of wall turbulence. To reduce the computational effort, the physical problem represents a fluid controlled wall-bounded shear layer passing over a trailing edge. The noise reduction is expected to be achieved by smoothing the rapid break-up process of the coherent structures when the wall-bounded shear layer changes into the free shear layer. The investigation is to reveal the acoustic differences of controlled and non-controlled flows and to evidence the noise reduction by heavy gas injection.

## Numerical Method

To compute the acoustic field a two-step method using large-eddy simulation (LES) for the flow field and acoustic perturbation equations (APE) for the acoustic field [7] is used. Successful applications of this approach to airframe noise are published in [8, 9] and the capability of the LES code to compute non-reacting multi-species flow is shown by several analyses [6, 10]. The source terms in the APE formulation are related to certain acoustic noise generation mechanisms. Therefore, based on this information of the separate sources it is conjectured to develop a more focused control device to lower the noise level.

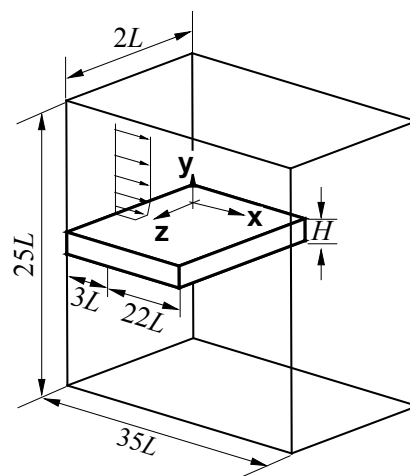


Figure 1: Schematic of the LES domain,  $L$  is the reference length ( $L = \delta_0$ ),  $H$  is the thickness of the trailing edge.

## Flow Configuration

A schematic of the LES domain is shown in Fig. 1. The LES computations for the flow over a flat plate are performed at a freestream Mach number  $M_\infty=0.6$  and a Reynolds number based on the boundary layer thickness  $\delta_0$  at the flat plate's trailing edge and the freestream velocity  $Re=12000$ . To achieve an acoustic reduction several gases at different thermodynamic properties are used as control fluid near the trailing edge. The reference configuration has a pure air flow over the trailing edge without any additional gas injection. Two gases heavier than air, i.e., carbon dioxide and halocarbon ( $C_2F_6$ ), are injected at  $x = 2.5L$  upstream of the trailing edge on the upper surface.

## Results

In Fig. 2 the turbulent structures near the trailing edge are visualized by  $Q$ -contours, where  $Q$  is defined by  $Q = W_{ij}W_{ij} - S_{ij}S_{ij}$ ,  $W_{ij} = 0.5(u_{i,j} - u_{j,i})$ ,  $S_{ij} = 0.5(u_{i,j} + u_{j,i})$ . The contours of  $Q = 10a_0^2/\delta^2$  and  $Q = -20a_0^2/\delta^2$  are colored by the mass fraction of  $CO_2$ . The flow configuration possesses an injection upstream of the trailing edge such that they generate strong vortical structures due to the interaction of the freestream fluid with the jet fluid at  $x = 19.5L$ .

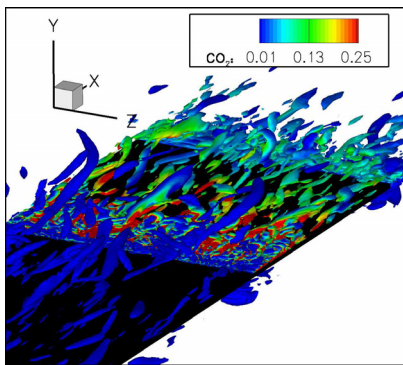


Figure 2:  $Q$ -contours at  $Q = 10a_0^2/\delta^2$  and  $Q = -20a_0^2/\delta^2$  of  $CO_2$  injection-3, the color determines the mass fraction of the control gas.

In Fig. 3 the acoustic directivity which is determined at a radius of  $250H$  from the trailing edge is presented. Surrounding the region at  $-30^\circ \leq \theta \leq 30^\circ$  a zone of silence exists.  $CO_2$  injection-1 at the trailing edge yields a noise reduction of up to 4dB compared to the clean configuration. Considering the complete directivity the highly acute injection configuration at a low momentum ratio, i.e.,  $CO_2$  injection-3, possesses the most promising potential to reduce the overall sound pressure level.

## Conclusion

The flow field and the acoustic field of several trailing-edge configurations have been analyzed based on a hybrid LES/APE method. The flow field shows that the additional momentum flux from the ejection slot changes the vortical structures near the wall. The overall acoustics shows that the immediate flow injection at the trailing edge clearly reduces the overall sound level up to 4dB.

The injection at an acute angle alters the turbulent structures in contact with solid wall and also reduces the noise generation over a wide frequency range by approximately 3dB.

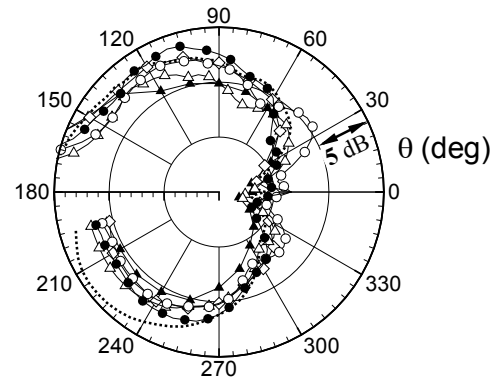


Figure 3: Overall sound pressure level on a circle of a radius of  $250H$  the center of which is located at the trailing edge,  $\cdots$  (clean),  $\blacktriangle$  ( $CO_2$  injection-1),  $\diamond$  ( $CO_2$  injection-2),  $\triangle$  ( $CO_2$  injection-3),  $\bullet$  (halocarbon injection-1),  $\circ$  (halocarbon injection-2).

## References

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