On the flow and noise of a two-dimensional step element in a turbulent boundary layer

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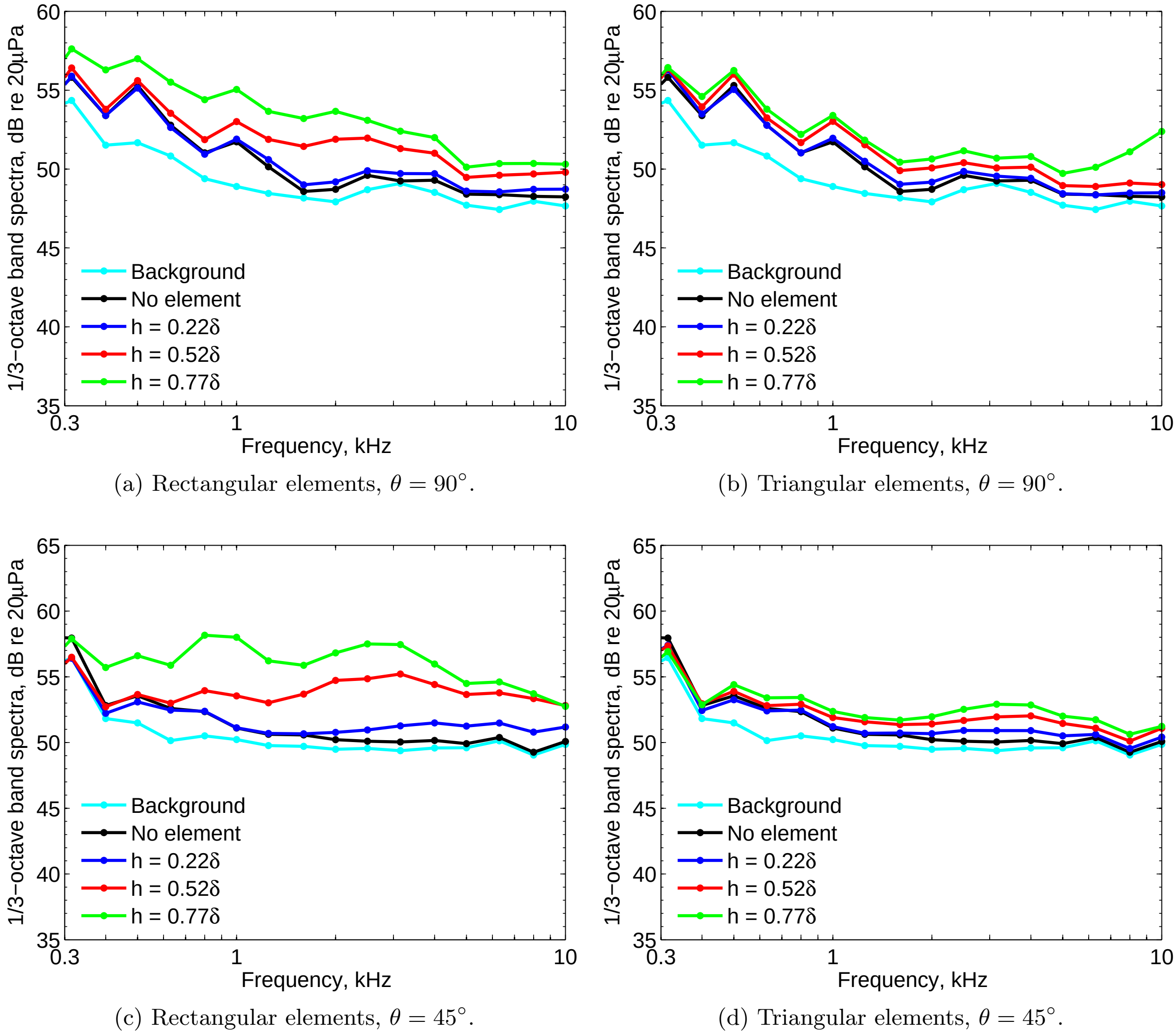
Aerodynamic sound is an important source of the noise produced by modern air, land and underwater vehicles. Surface roughness due to geometric discontinuities (rivets, ribs, joints), environmental contamination or errors in machining can disturb the turbulent boundary layer that develops over a vehicle and generate increased levels of aerodynamic noise. Given the prevalence of roughness noise, it is important that the underlying noise generation mechanisms are well understood so that the noise radiated into the far-field can be minimised.

This paper presents results from an investigation of the noise produced by a two-dimensional surface roughness element in a low Mach number turbulent boundary layer. Testing is conducted for six different roughness elements attached (one at a time) to a flat plate: three with rectangular cross-section and three with triangular cross-section. The three roughness elements of each type have a height of h = 26%, 52% and 77% of the local unperturbed boundary layer thickness, δ. The rectangular elements have an aspect ratio (ratio of length to height) of l/h = 8, 4 and 2.7, while the aspect ratio of the three right angled triangular elements (ratio of base length to height) is $l/h = 2$.

Measurements of the far-field noise and wall pressure fluctuations around the roughness elements have been taken in the anechoic wind tunnel at The University of Adelaide at a range of flow speeds ($U_\infty = 15 - 35$ m/s). An example of the one-third-octave band far-field noise spectra measured at a flow speed of $U_\infty = 35$ m/s is shown in Fig. 1. In this figure, the noise spectra have been measured at a radial distance of 520 mm from the centre of the roughness element and at angles of $\theta = 90^\circ$ and 45°. For both roughness element geometries, the sound levels are shown to increase with roughness element height over the entire frequency range. The most significant increase in noise level is observed for the rectangular roughness elements with a height of $h = 0.52\delta$ and 0.77δ and this is particularly evident at a measurement angle of 45°.

In addition to experimental measurements, numerical simulations of boundary layer flow over the two-dimensional roughness elements are also presented in this paper. The experimental and numerical results show the influence of surface roughness element height and shape on far-field sound and the local flow field, giving insight into the flow mechanisms responsible for noise generation.

Keywords: Surface roughness, roughness noise, surface pressure, turbulent boundary layer



(a) Rectangular elements, $\theta = 90°$.

(b) Triangular elements, $\theta = 90°$.

(c) Rectangular elements, $\theta = 45°$.

(d) Triangular elements, $\theta = 45°$.

Figure 1: Sample experimental results: One-third-octave band spectra for the rectangular and triangular roughness elements at $U_\infty = 35$ m/s. 'Background' refers to the noise produced by the anechoic wind tunnel jet only and 'No element' refers to the noise produced by the unperturbed boundary layer on the flat plate.