EXPERIMENTAL AND NUMERICAL INVESTIGATION OF SEPARATED-REATTACHED FLOWS BEHIND UNIFORM AND NOTCHED SPOILERS

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1. INTRODUCTION

Interior noise in road vehicles is an important source of discomfort, leading to reduced speech intelligibility, and passenger fatigue. Aerodynamically excited noise from the open sunroof of a vehicle is of particular interest due to the high pressure oscillations that may be generated inside the cabin for certain vehicle speeds. Spoilers are often used to reduce interior noise by deflecting the flow stream over the opening.

Notched spoilers have frequently been observed to be more effective than uniform spoiler for buffeting suppression. It is generally understood that the notches break down the coherence of the flow downstream of the spoiler, leading to a reduction in the equivalent excitation pressure due to local interferences between the fluctuating pressures at different locations. The study of the turbulent wall pressure fluctuations[1, 2] downstream of a wall mounted notched spoiler may thus be useful in order to develop a better understanding of vortex shedding and convection over the region where a sunroof would normally be located, and quantify the single point and two-points statistics of the hydrodynamic and acoustic pressure fields.

2. METHODS

2.1 Experimental Instrumentation

The experimental cases under investigation consisted of uniform and notched automobile sunroof spoilers mounted into the test section of a low-speed, quiet wind tunnel. The notched spoiler used was from a Fiat LanciaY. The spoiler was trimmed on each side to fit in the wind tunnel test section, maintaining the symmetry with respect to the center of the spoiler. The spoiler height, *h*, was varied for both notched and uniform spoiler cases with heights of 20 mm and 24 mm from the floor of the wind tunnel test section. The angle of the frontal spoiler surface was approximately 62 degrees with respect to section floor.

A circular plate of a rectangular array of 15 x 22 pinholes was installed 5 cm downstream from the spoiler to measure static and dynamic surface pressures (Fig. 1). To allow flush mounted microphone installation, the 10.26 mm diameter array holes were counter-sinked to a depth of 11.7 mm. A 0.5 mm pinhole was then drilled through the center of each array hole and the superior surface of the plate. The separation distance between each measurement point in the rectangular grid was constant at 12.7 mm.

A dual sensor hot-wire probe was employed to measure streamwise and vertical velocity components of the mean flow. The hot-wire measurements included x-y and y-z field scanning in the flow where streamwise, cross-streamwise (or transverse) and vertical directions were coordinated as x, y and z, respectively. Flow visualization was also performed using an oil based smoke generator.

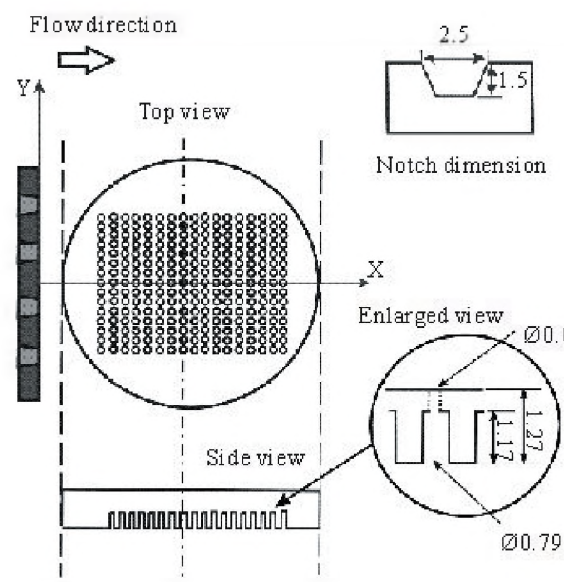

Fig. 1. Schematic of the experimental apparatus. The circular plate with 330 microphone pinholes is located 5 cm behind (downstream of) the spoiler. Dimensions in cm.

2.2 Numerical Simulations

The commercial software PowerFLOW™ was used. A number of pre- and post-processing operations were followed in order to prepare and verify the spoiler geometry, to set flow parameters, define variable resolution regions, impose boundary conditions, and analyze results. PowerFLOW™ consists of a range of specialized modules that were used at various stages to retrieve, visualize, check, and set-up the case. The simulation results were verified based on comparisons between the simulation results and measured flow field statistics from hot-wire anemometry.

3. RESULTS

The reattachment point of the mean flow over the spoiler was observed to occur approximately at *x/h* ~ 15 for the uniform spoiler and *x/h* ~ 13 for the notched spoiler. The reattachment point was estimated using several methods: zero static pressure gradient (Δp~0), root mean square value of pressure fluctuations, and flow visualization. The numerical simulations predicted a reattachment location further downstream (at *x/h*~15 for the notched spoiler).

It was observed from the static surface pressure distribution and the mean flow field obtained from the hot-wire as well as the numerical simulations that the notches created a smaller flow-recirculation zone behind the spoiler.[3] The notches moved the reattachment point closer to the spoiler, and reduced the pressure drop across the spoiler and thus the pressure drag.

Cross-stream variations of the unsteady surface pressure distribution were induced by notches. The coherence of the dynamic surface pressures along cross-stream locations was lower at low frequencies for the notched spoiler (Fig. 2). The numerical simulations yielded similar general trends of coherence spectrum variation. In addition, the cross-stream decay rate[4] of the coherence was larger for the notched spoiler. It was observed that a consistent phase difference existed in the unsteady surface pressures along the cross-stream direction near the notches.

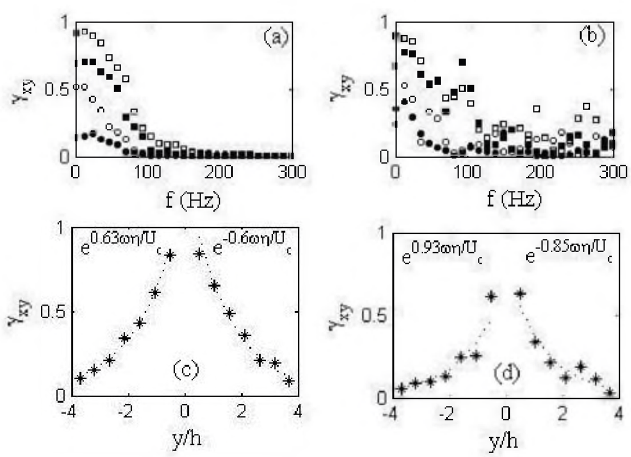

Fig. 2. Coherence spectrum of surface pressures obtained (a) experimentally and (b) numerically between the center reference point (*y/h*=0) and two other transverse locations: *y/h*~-0.5 (□:uniform; ■: notched), *y/h*~-2.08(○:uniform; ●:notched). The streamwise distance of the points is *x/h*~4.4. The transverse decay of the maximum coherence at f=25 Hz is shown for (c) uniform and (d) notched spoilers, respectively, at the streamwise distance of *x/h*~5.4.

4. DISCUSSION

The cross-stream reduction in surface pressure coherence confirms that the notches create turbulent and de-correlated fluctuations, leading to destructive interferences and randomness in vortex development along the span. As a result, the aerodynamically generated surface force obtained by integrating the surface pressure over a surface area roughly equivalent to that of a sunroof is decreased over a wide range of frequency, as shown in Fig. 3, where the excitation force was obtained from the surface integration of the measured unsteady surface pressure values. The numerical simulations allowed the spectrum of the surface pressure to be predicted for frequencies up to 2 kHz. But significant discrepancies were observed around 1 KHz between measured and predicted surface spectra. The simulations did however faithfully reproduce the main trends of the flow- and surface pressure fields.

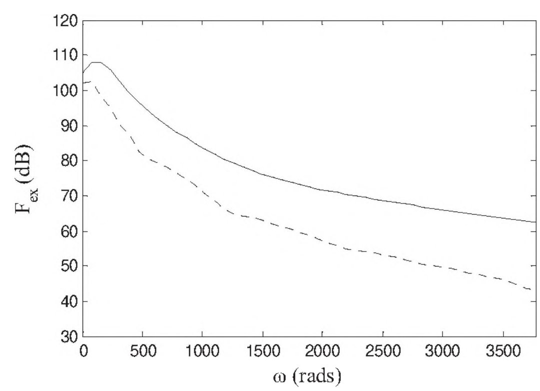

Fig. 3. Estimated excitation force spectra for the uniform (—) and the notched (---) spoilers.

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