# AIRFOIL SELF NOISE REDUCTION BY APPLICATION OF DIFFERENT TYPES OF TRAILING EDGE SERRATIONS

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## Abstract

*The present paper will address the trailind edge noise reduction by the means of trailing serrations. An experimental study of the effect of adding three different geometries of trailing-edge serrations, to a two-dimensional NACA 0012 is presented. The wing model has 92 pressure tapings for aerodynamic analysis which was complemented with trailing edge boundary layer measurements using hot wire measurements. For aeroacoustic tests, an array with 106 microphones was employed to measure noise sources location, using a beamforming technique. The antenna is suitable for acoustic measurements up to 16 kHz. It was found that for realistic airfoil geometries overall self-noise reductions of 2−3dB are possible without adversely affecting aerodynamic performance. Nevertheless, the reduction in self-noise amplitude was found to be most significant at lower frequencies, and the effect became more pronounced with increasing wind velocity. It appears that applying serrations to the airfoil trailing edge is a valid means of reducing airfoil self-noise without compromising aerodynamic performance.*

## 1 Introduction

The airfoil trailing edge noise is one of the main noise sources aero-engines and wind-turbines. Its noise generation mechanism is mainly given by the self-generated airfoil turbulence scattered on the trailing edge. The trailing edge noise prediction has theoretically been addressed initially by Amiet [1]. Amiet adopted the linearized airfoil theory to predict the trailing edge airfoil forces fluctuations and he combined these results with the Curle Analogy [2] to predict the airfoil far-field noise. Brooks et al. [3] studied systematically geometric influences on the airfoil self-noise, considering effects like thickness, angle of attack and trailing edge bluntness; he developed a semi-empirical noise prediction methodology able to predict with some accuracy the airfoil self-generated noise. The efficient airfoil self-noise reduction is a challenge that has been addressed by several authors. Among them Herr [4] [5] [6] systematically studied trailing edge features presenting some promising results. More recently this problem has been studied with new proposals i.e. serrations of non-insertion type [7]; the use of poroelastic trailing edge materials, inspired on owns [8] and the combination of leading and trailing edge serration for the case of in tandem airfoils [9]. Following the classification of Brooks et al.[3] four mechanisms for airfoil self-noise are generated by disturbance interaction with the airfoil trailing edge. Turbulent fluctuations in the vicinity of a sharp edge of a solid body scatter more efficiently at low Mach numbers than fluctuations in free-space hence trailing-edge noise is increasingly significant at low Mach numbers. It is apparent then, that in order to reduce total airfoil noise further, trailing-edge noise must be considered. Trailing edge modified by the presence of serrations possessing a sawtooth profile may have the intensity of radiation at the trailing edge reduced by such a modification, with the magnitude of the reduction depending on the length and spanwise spacing of the teeth, and the frequency of the radiation. It was determined that the dimensions of an individual serration should be at least the order of the turbulent boundary layer thickness, and that longer, narrower teeth should yield a greater intensity reduction. For aeronautical application serration with large aspect ratio may not be easily certified and its use in certain wing systems such as slat may produce parasitic drag at cruise conditions or promote boundary layer transition. To use serrations as a noise reduction technology (NRT) not only a maximum noise reduction should be addressed but also its feasibility to real use in aeronautics. The present paper will address the trailing edge noise reduction by the means of trailing serrations. The present work was developed with an airfoil NACA 0012 On the present problem the beamforming technique was adopted to identify the the airfoil main noise sources. The microphone antenna was constructed with 106 GRAS microphones, presenting a relation of main to secondary lobe of 10 dB. Three trailing edge treatments were investigated on the preset work: rectangular, triangular and a wishbone format.

## 2 Experimental Set-up

The experimental work was conducted at the wind tunnel LAE-1 of the Aerodynamics Laboratory of the Aeronautical Department of University of Sao Paulo. The wind-tunnel test section dimensions are 3.00 m long, 1.30 m high and 1.70 m wide. The maximum design flow speed is 50 m/s, with a turbulence level of 0.20%. On the flow stabilization section there are two mesh screens 54% porosity following by the 1:8 contraction cone designed using two 3rd order polynomials. Recently, the LAE-1 wind tunnel passed to an upgrade to reduce the background noise in order to carried-out beamform noise measurements. Details of this upgrade and characterization can be found in [10]. Fig. 1 shows the final results for the wind tunnel background noise after the modifications.

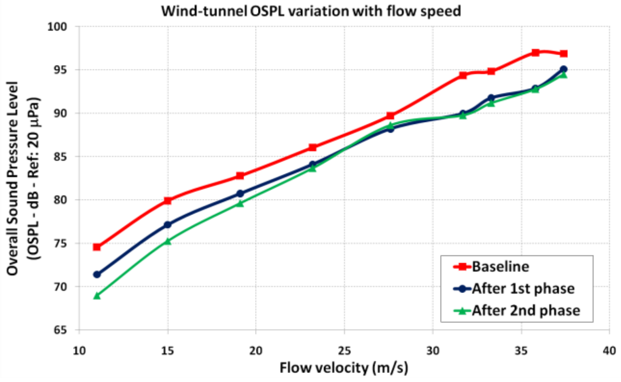

**Fig. 1. OSPL variation with the wind-tunnel flow speed.**

The wing model has a NACA0012 aerodynamic profile with a 0.224m chord and a span of 1.30m. The model is positioned vertically spanning the horizontal walls of the working section. Chordwise pressure distribution was measured through 92 tapings distributed at both surfaces in a roll inclined 15degres in relation to the central chord line. Pressures were measured by two D48 mechanical Scanivalves using ±1.0psia Setra transducers of accuracy of ±0.1%FS. The serrations geometries used in the experiments are shown in Fig.2. They were glued at the wing model trailing edge only at the center of the wing in a strip of 0.4m. Along the spam dimension, the wing was divided in three sections of equal length and the treatment was applied to the central part. This approach is convenient since, at the same experiment, it is possible to have the test and the control region at the same beamforming image and also guarantees same conditions for the test and control regions.

On this paper, in the beamforming figures, the trailing edge treated region is represented by a dashed line, while the continuous line represents the untreated region.

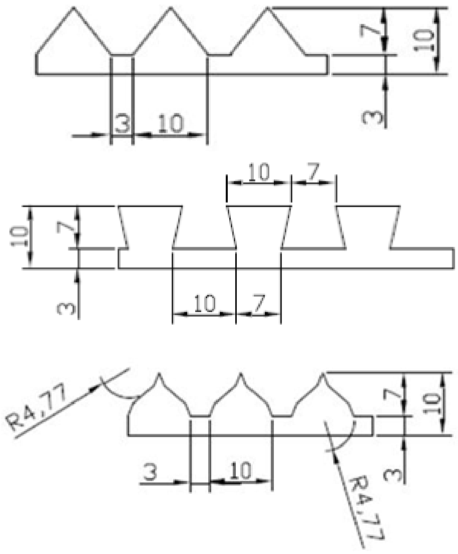

**Fig. 2 Serration geometry, triangular, trapezoidal and wish bone.**

A beamforming technique was adopted to identify the airfoil main noise sources. The microphone antenna was constructed with 106 GRAS microphones, presenting a relation of main to secondary lobe of 10 dB. Trailing edge boundary layer and wake were measured using a DANTEC CTA hot wire anemometer and the single wire probe was traversed by a traverse gear in steps of 0.2mm. In order to verify the coherence of the experimental results of beamforming performed in wind tunnel LAE-1, with the available literature, it was adopted for comparison the work of Brooks et al [3]. This NASA report presents a detailed study of the sources of noise of NACA0012 airfoil and systematization of all these results in a set of semi-empirical equations. This work has wide recognition in the literature as reference for validation aeroacoustic testing.

## 2 Results and Discussion

The results will be presented in the following sequence: aerodynamics results of the application of serrations, trailing edge boundary layer characteristics for the clean wing for validation of the beamforming results and, the results and analysis of the beamforming.

### 2.1 Aerodynamic results

Figure 3 presents the pressure distribution for the wing at α=0° for the three serrations. It can be seen in Fig 3 that the presence of the serrations changes the pressure at the trailing edge region due to the increase of local circulation.

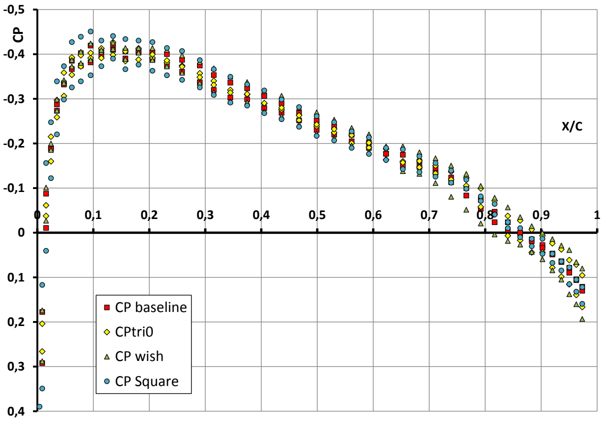

**Fig.3. Pressure distribution α=0° all serrations.**

This local circulation increase is due the distribution of vortices pair at each serration which induces a downwash and therefore an effective camber. Those vortices may be the key for noise reduction all the wake vorticity scale and structure are changed. Fig. 4 shows the same results from Fig. 3 but for α=8°. In order to clarify the local effect of the serrations Fig. 5 shows a close detail of the pressure distribution at the trailing edge region.

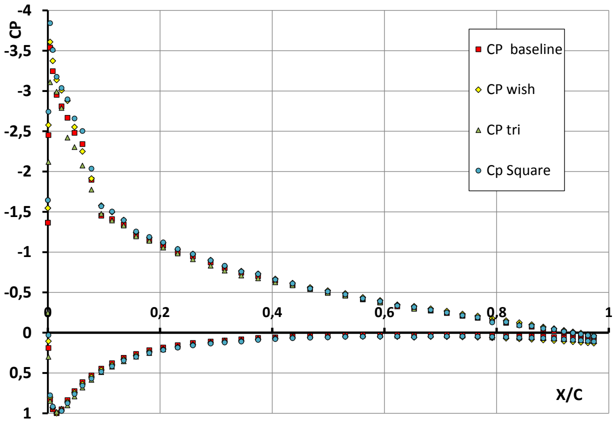

**Fig. 4. Pressure distribution, α=8° all serrations.**

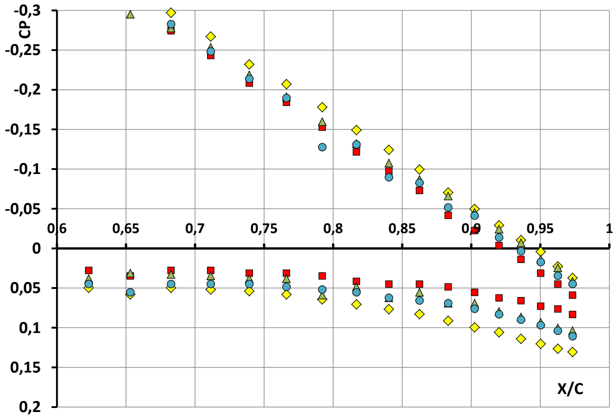

**Fig. 5 Detail of pressure distribution at the trailing edge.**

Using the XFoil program and adjusting the n factor by comparing with the experimental pressure it was found that n=7.5 best fit all the results. Therefore, XFoil results are compared with CLxα curves from pressure distribution integration in Fig.6. From Fig. 6 is clear the increase of the effective camber as for the same incidence angle all the modified wing produce slightly more lift.

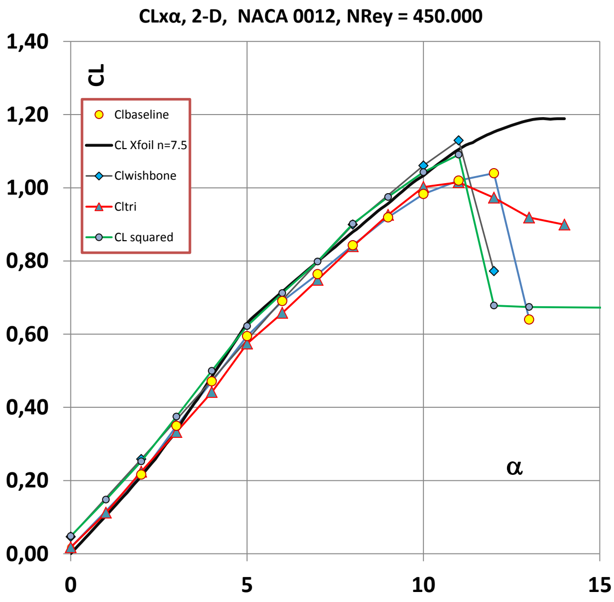

Fig. 6 CL curves from pressure distribution.

Fig. 7 shows the transition front at upper surface as observed by the kink of the laminar separation bubble and compared with the XFoil program results for the baseline case. Fig. 7 shows a quite good agreement when adopting n=7.5 for the calculations.

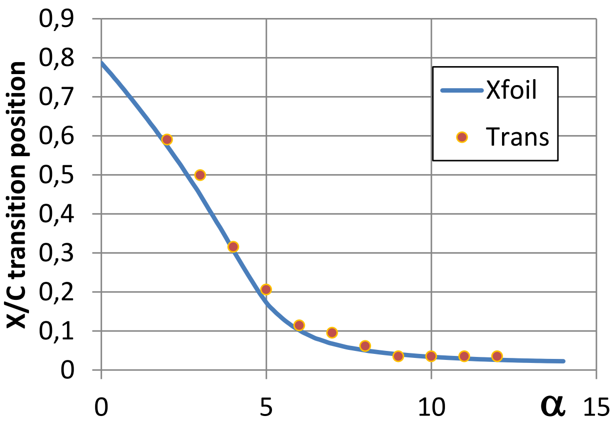

Fig. 7 Transition position for the baseline wing.

It was found that the presence of serrations slightly change the transition position moving it forward as expected due more CL produced.

## 2.2 Boundary Layer results.

As pointed out before, in order to verify the coherence of the experimental results of beamforming performed in wind tunnel LAE-1, with the available literature, a comparison with the work of Brooks et al [3] was performed. Figure 8 shows the experimental set up for the boundary layer measurements at the trailing edge region.

Fig. 8. Experimental set-up for boundary layer measurements with hot wire.

The results for both smooth and tripped wing are shown in Fig. 9 and Fig.10. The results showed a good agreement with [3]. From the experimental results the displacement thickness were calculated and compared with the results from Brooks et al [3]. Figure 11 the comparison of the displacement thickness from the present work and those obtained in [3].

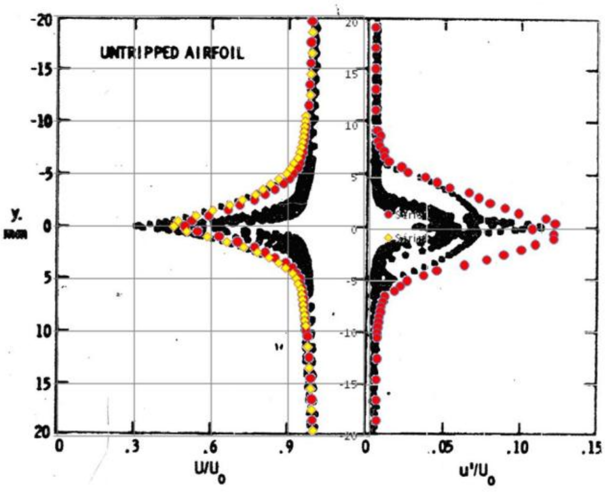

Fig. 9 Boundary layer velocity distribution at TE compared with [3], $\alpha=0^{o}$ smooth.

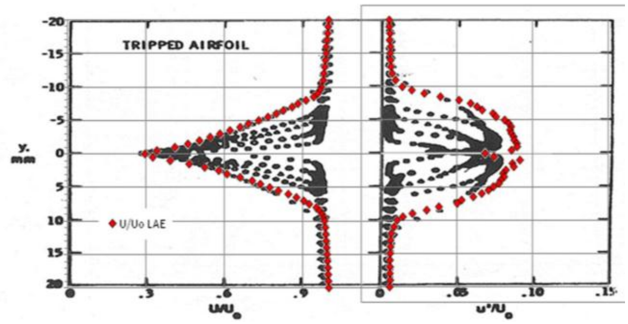

**Fig. 10 Boundary layer velocity distribution at TE compared with [3], α=0° tripped.**

The results presented in Figs 11 and 12 show good agreements with those obtained from Brooks [3]. Despite the fact some testing conditions are not exactly the same such wind tunnel size and model size ratio, flow turbulence, the results from the LAE-1 gave enough confidence to carry-out the beamforming tests.

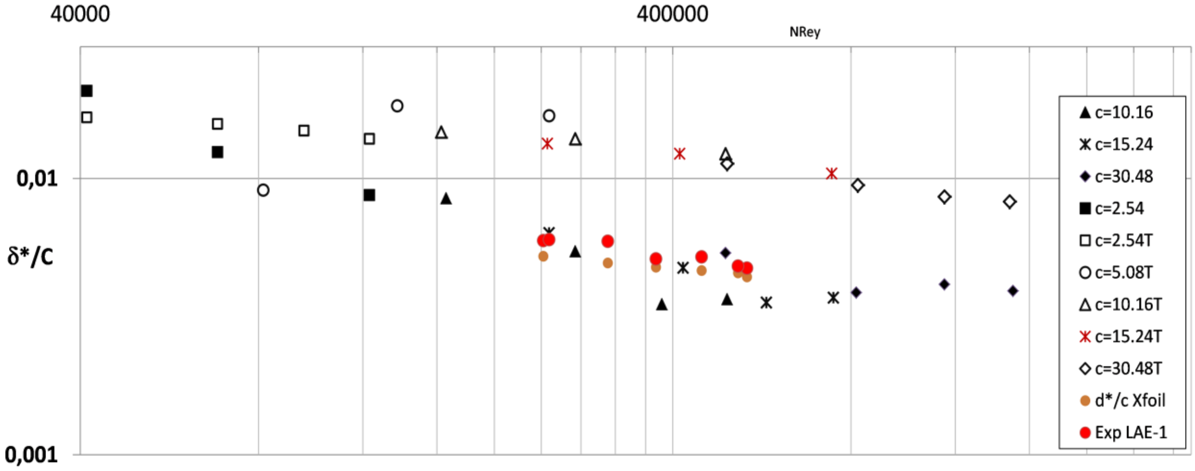

**Fig. 11 Displacement thickness obtained from the experiments and compared with [3] smooth wing.**

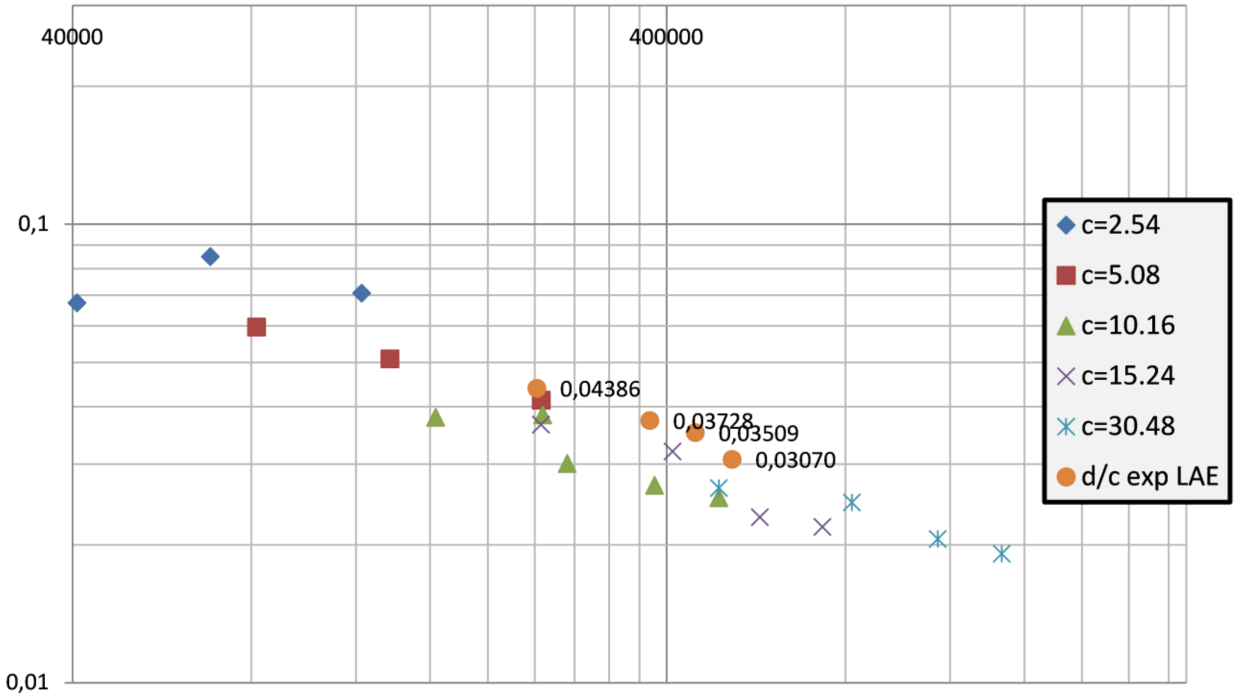

**Fig. 12 Displacement thickness obtained from the experiments and compared with [3] smooth wing.**

## 2.4 Beamform results

Fig. 13, Fig. 14 and Fig. 15 present the results for the rectangular, triangular and wishbone type trailing edge treatment, respectively. These figures show that for all treatments the serrations contribute to reduce the trailing edge noise, at low frequencies. For the frequencies below 5000 Hz it is noticed a reduction of the source intensity can reach 10 db. For this frequency range, it is shown also that the triangular serration performs best than the rectangular one, and by turn, the wishbone performs better than the triangular one. On opposition, it is noticed that for the high frequencies, the serrations cause an increase of the noise intensity, independently of the geometry. Analyzing the source intensity it is noticed that the wishbone serration causes small noise increment when compared with the other two analyzed serrations. This result for the wishbone for noise reduction can be shared with aerodynamic best results achieved for the wishbone as it can be seen in Fig. 5 and Fig 6.

## 3 Conclusions

The present work studied the effect of the addition of trailing edge serrations for the airfoil self-noise reduction. Three different trailing edge geometries were studied: triangular, trapezoidal, and a wishbone type. It was shown that, for the studied cases that the three geometries contribute for noise reduction for frequencies up to 5 kHz, while, the wishbone trailing edge is the most efficient. For frequencies higher than 5 kHz it is noticed that the trailing edge serrations have a negative effect generating a net noise increase, but comparing the three analyzed geometries, the wishbone serrations is the geometry which generate smaller noise increase when compared with the rectangular and triangular treatment. As pointed out by previous results serrations can be used as a NTR for frequencies up to 5kHz and low aspect ratio serration as studied here can be a good option for aeronautical applications. Also, the flow mixing between the lower surface high pressure and the upper surface low pressure can induce an effective downwash moving the kutta point improving circulation and consequently lift.

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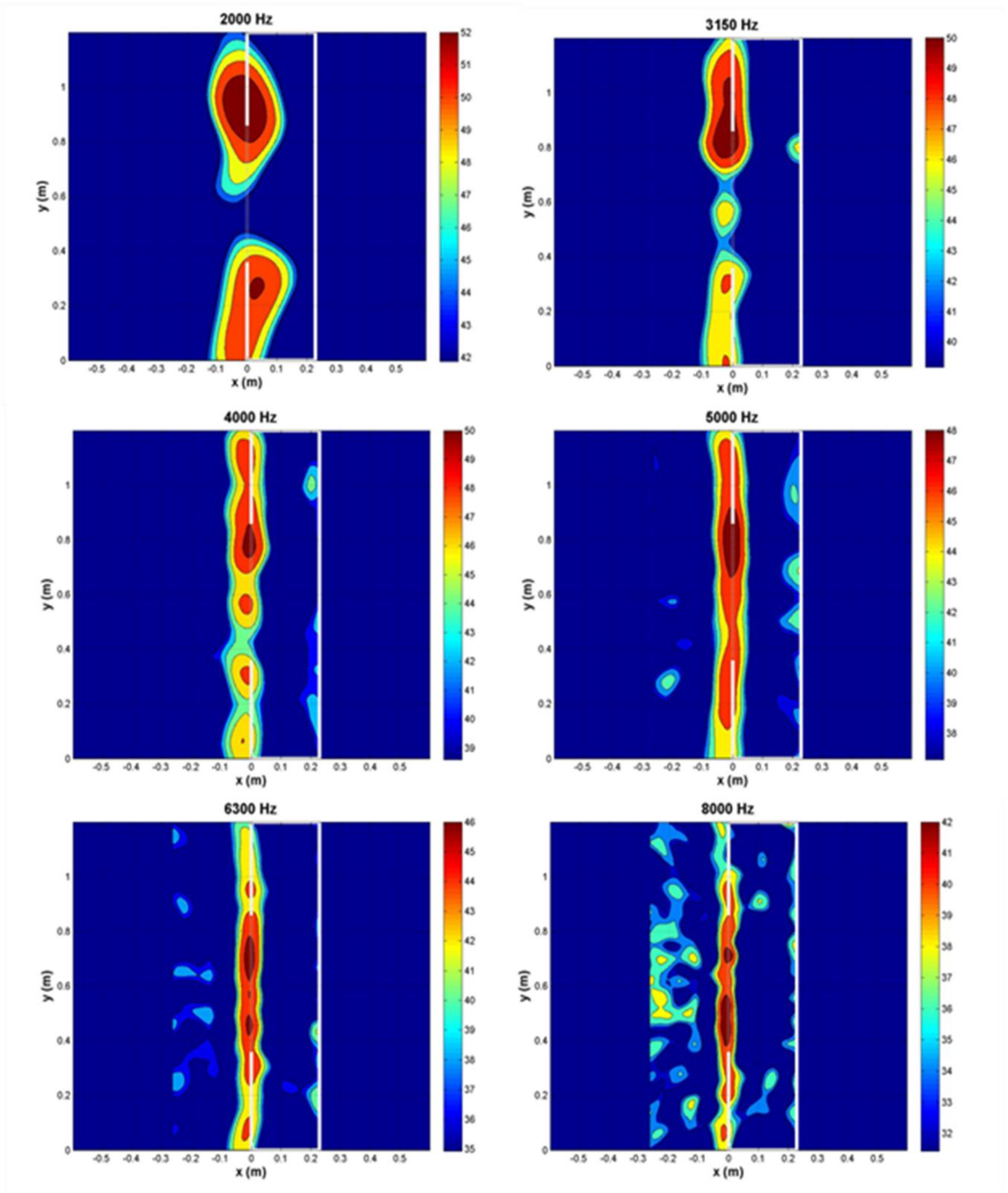

Fig. 13 Rectangular serrations.

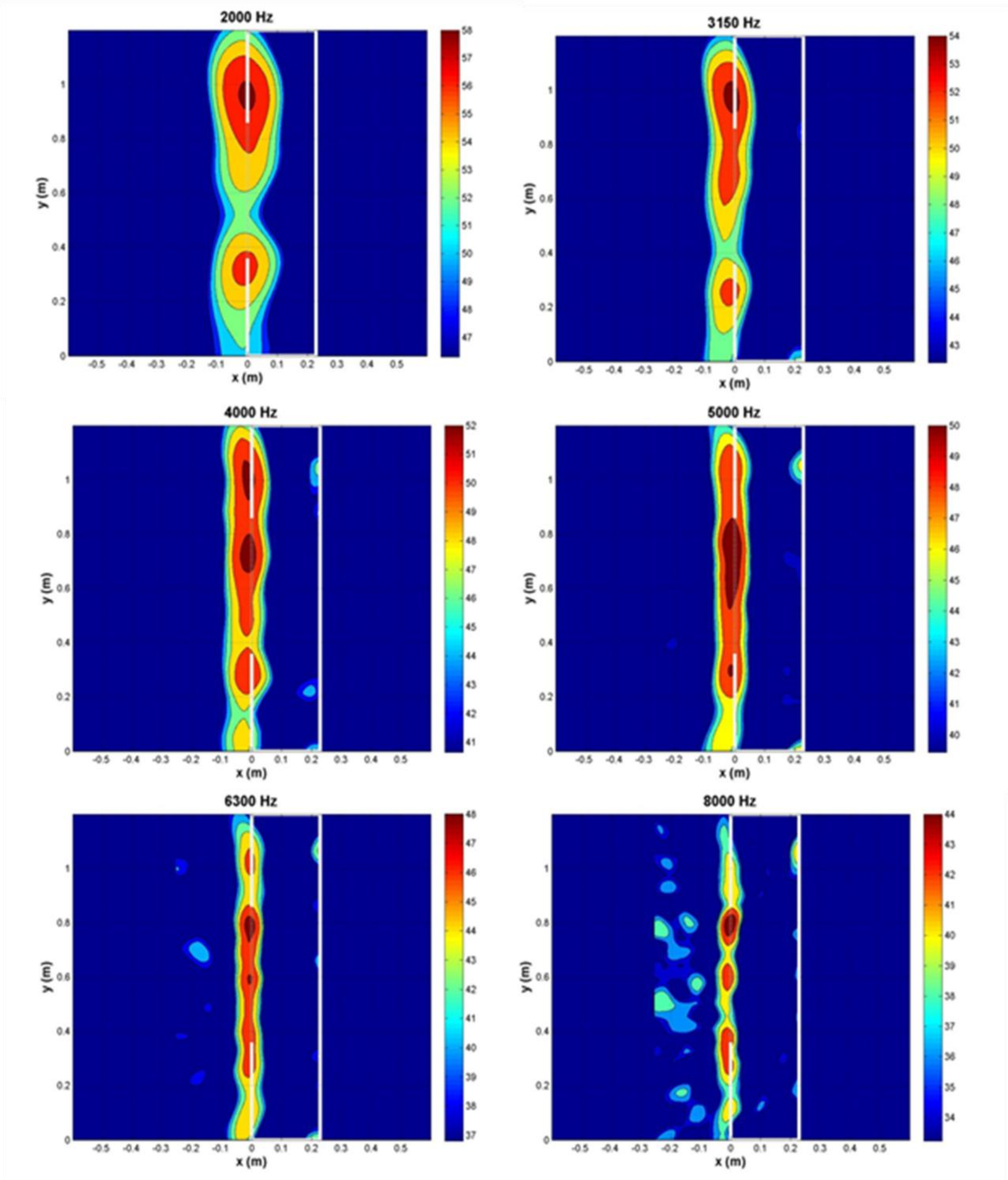

Fig. 14 Triangular serrations flow from the right to the left.

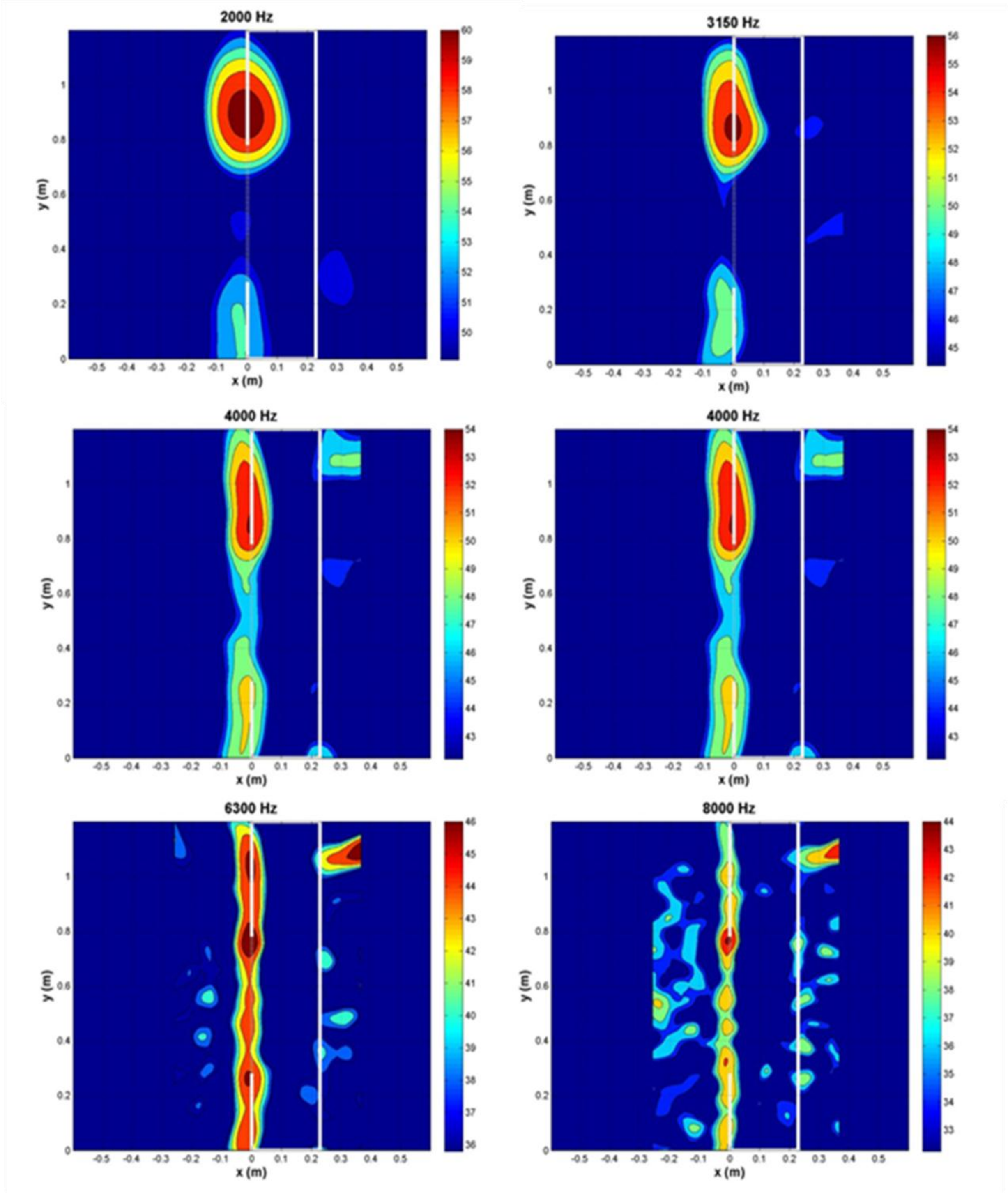

Fig. 15 Wishbone serration. Flow from the right to the left.