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AEROACOUSTIC EFFECT OF A SEAL POSITION ATTACHED IN SLAT COVE SUERFACE

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Abstract. *The development of Environment Regulations observed last decades led to a search for noise reduction of aircrafts. With inclusion of turbofans engines, the airframe noise provenient from landing gear, high-lift surfaces as leading edge slat and flap became more representative noise sources. Most studies in slat noise, considers idealized surfaces in order to better understanding of noise mechanism that is still not fully understood. In practice, slat geometry presents excrescences in form of mechanical insulation attached inside its cove. We present a numerical study of the noise produced by slat geometry that includes this seal. Experimental results shows intense change in noise spectra compared to clean slat for some positions of this seal. Patterns of mean flow and nearfield fluctuation are also explored. The software used is the comercial code PowerFLOW based in Lattice-Boltzmann Method.*

Keywords: *Aeroacoustics, Slat, Seal, Lattice-Boltzmann.*

1. INTRODUCTION

The noise sources of aircraft operation are related to engines, landing gear and airframe components. However, with development of high bypass turbofans, noise contribution of motors decreased substantially in last decades, increasing airframe importance, manly for high-lifts devices as flap and slat. Flap shows a pontual noise source related to edge but slat is present along almost whole wingspan becoming a distributed noise source (Crighton, 1991; Dobrzynski, 2010).

Generic slat noise spectra present hump in high frequency, a broadband component in low and mid-frequency and tonal peaks over broadband. Numerical and experimental studies concluded that the hump in high frequency are related to shedding of vortices in the blunt slat trailing edge that is present only in models not in real airplanes (Khorrami *et al.*, 2000). Broadband and tonal peaks remains not fully understood but it is well accepted that this components are related to structures development through shear layer formed from cusp to reattachment point and its convection through slat trailing edge (Jenkins *et al.*, 2004; Dobrzynski, 2010; Imamura *et al.*, 2009). The theory that peaks are related to Rossiter modes inside slat cove similar to cavity problem, has presented good agreement in prediction of some conditions (Roger and Perennes, 2000; Kolb *et al.*, 2007; Terracol *et al.*, 2011; Dobrzynski, 2010).

Most studies however considers slat clean geometry. Real slats have excrescences over its surfaces as seals to avoid contact between structures. Initial studies concerned to this excrescence indicated not significant increasing in noise spectra (Khorrami and Lockard, 2010). Latter experimental and numerical works presented a significant change in the dynamics of recirculation region of slat cove and sensitivity of tonal peaks of spectra to parameters of this seal (Bandle *et al.*, 2012; Souza *et al.*, 2015).

POD (Proper Orthogonal Decomposition) technique applied in numerical data showed that structures through slat shear layer are more organized compared to clean geometry and this coherence could be related to more efficient process of noise generation observed for baseline geometry (Souza *et al.*, 2015).

In order to study the sensitivity of the strutures in shear layer and the mean flow around slat sealed geometry, we present a numerical analysis of nearfield region and compare to baseline one. The software used is the commercial code PowerFLOW, based in Lattice-Boltzmann Method to solve the flow.

METHODOLOGY

PowerFLOW

Code used in this work is the PowerFLOW 5.0 (EXA), commercial software based on Lattice-Boltzmann Method that solves the discrete Boltzmann equation for probability density function:

$$f(\vec{r}+\vec{c}\delta t,\vec{c},t+\delta t)-f(\vec{r},\vec{c},t)=\Omega(f). \tag{1}$$

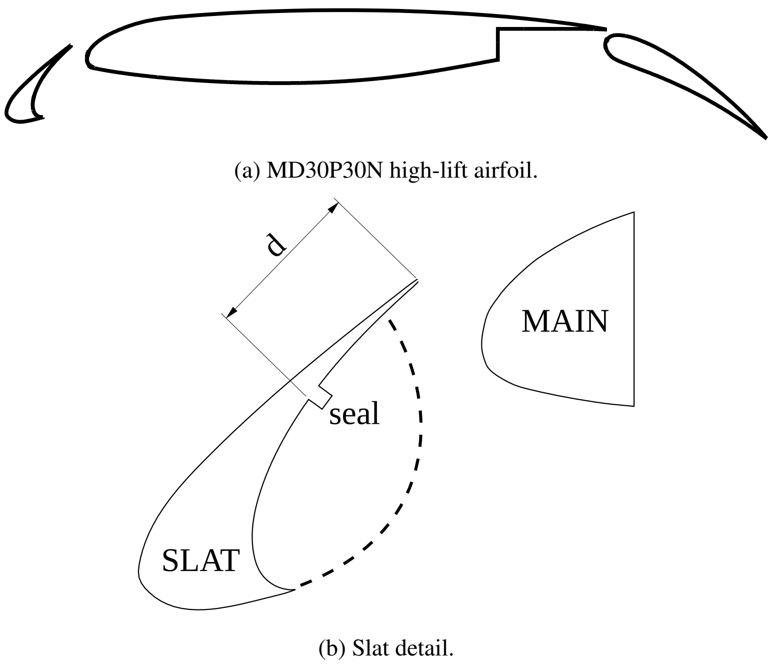
Function $f(\vec{r},\vec{c},t)$ represents the tendency to find a particle at time t in position $\vec{r}$ with velocity $\vec{c}$. The collision term represented by Ω, is related to momentum exchange between particles and were approximated for aeronautical problems by Bhatnagar *et al.* (1954) as $\Omega(f)=\frac{1}{\tau}\cdot(f-f^{eq})$, where τ represent the relaxation time and f^{eq}, the equilibrium probability density function; so we have

$$f(\vec{r}+\vec{c}\delta t,\vec{c},t+\delta t)-f(\vec{r},\vec{c},t)=-\frac{1}{\tau}[f(\vec{r},\vec{c},t)-f^{eq}(\vec{r},\vec{c},t)]. \tag{2}$$

Mesh performed by PowerFLOW is composed of cubic volumes aligned with the cartesian coordinates. To represent the effect of the smallest turbulent scales a Renormalization Group k-ϵ turbulence model is used. For analyses of farfield propagated sound, code uses a *Ffowcs Williams-Hawkings* (FW-H) analogy algorithm, based on Farassat's 1A formulation (Bres *et al.*, 2009). Since the Mach numbers in present analysis are low, the quadrupole sources in the flow were not taken into account in the FW-H calculations. Therefore, only the slat and the aft portion of the main element surfaces are taken into integration account for near field.

Numerical and Experimental Descriptions

Simulations presented here uses MD30P30N high-lift airfoil widely studied in literature (Jenkins *et al.*, 2004; Khorrami *et al.*, 2004; Bandle *et al.*, 2012; Souza *et al.*, 2015) presented in Figure 1, airfoil stowed chord (c_{stowed}) were $0.5\ m$. Simulations considers sharp flap trailing edge and slat trailing edge with thickness of 0.092% from c_{stowed} but mesh in this region are not refined enough to capture vortex shedding. Simulations presented in this work considers the geometry of square seal with $3\ mm$ of dimension, at positions of $d=0.23\ mm$, 0.41 and 0.60, where d is non-dimensionlized by slat chord ($c_{slat}=15\%c_{stowed}$) and the angle of attack analysed were $3°$. The domain height dimension reproduces wind tunnel experiments ($1.7\ m$), in spanwise direction a periodicity condition was assumed (Choudhari and Khorrami, 2007) while the streamwise direction dimension was choose after domain convergence test. The infinite flow velocity is considered $U_\infty=34\ m/s$, Mach number 0.1 and Reynolds 10^6. Time simulation was $0.25\ s$ where the initial transient (around $0.1\ s$) was desconsidered in calculations.



(a) MD30P30N high-lift airfoil.

(b) Slat detail.

Figure 1: Slat geometry with seal.

The experiments used for validate code were run in the closed circuit wind-tunnel of the Sao Carlos Engineering School. The dimensions of the tunnel was $1.7\ m$ for height, $1.3\ m$ wide and $3\ m$ long. The tunnel was able to reach velocities up to 34 m/s. To provide more two-dimensional flow, wall boundary layer control was done by applying suction upstream of the slat and on the suction side of the main element. The MD30P30N wing model used in the experiments was basically manufactured in aluminum alloy and spanned the entire tunnel height and the airfoil chord at stowed configuration was 0.5 m. The model has tappings along the span at two positions in the suction side of the main wing, one positioned near its leading edge and another near its trailing edge, which were used to monitor two-dimensionality of the time averaged flow over the model.

RESULTS

In order to validate code the pressure coefficient for cases with no seal (baseline geometry) and with seal ($d = 0.41$) are showed in Fig. 2. Good agreement are observed compared to experimental data even in the region of slat. Some difference could be noted only in flap region where software predicts earlier separation but this is explained by consideration of initial fully turbulent flow made by software but flap noise generation is not the focus of this study.

Figure 3 present a comparison of simulation cases varying the seal position on slat cove. The results show that c_P over airfoil is not affected by seal presence for main element and flap but only for the slat cove region. This mean that only structures in nearfield region of the slat are affected by this excrescence but total airfoil lift are not affected drastically.

Farfield noise spectra are presented in Figure 4 showing the comparison between numerical and experimental data. For calculation of farfield noise the Ffowcs Williams-Hawkings analogy was applied considering only the surfaces in the half center span of the slat and main element leading edge for integration. Time series were divided in blocks with 50% of overlap and a Hanning filter was applied before power spectrum calculation. Similar procedure was used for experimental data.

Analysis of the experimental spectra shows that the slat cove seal have a considerably influence on slat noise depending on its position. Tonal peaks observed for all cases but its intensity are very increased when this excrescence are placed in position of 0.41 and 0.60. However, for case 0.23 this is not observed. The frequency of this tonal peaks are also shifted. Numerical results shows a good comparison with experiments for baseline and 0.23 cases but for sealed geometries with $d = 0.41$ and 0.60, the intensity of the tonal peaks were not capted. However, the frequency where they occurs agreed with experiments.

The meanflow field are present in Fig. 5 to understand the differences observed in farfield noise spectra. The streamlines and resolved Turbulent Kinect Energy ($\frac{1}{2}(\overline{u'^2} + \overline{v'^2})$) shows that is possible to identify two categories of cove flow dynamics: first with only one recirculation and the second with additional counter-rotating recirculation. The recirculations are highlighted in case 0.41 in same figure. Baseline and seal at position 0.23 are in the first category and cases with seal at 0.41 and 0.60 in the second one. According to noise spectra, the first category represent the quieter and second, the noisier cases considering the tonal peaks levels. It is also noted that the seal presence cleans the region near to cusp from turbulence generated in reattachment point. This behaviour is even noticed in the case 0.23 compared to baseline one but did not influenced in the propagated noise as seen earlier in Fig. 4. For cases 0.41 and 0.60, the second bubble increased the turbulence level at earlier stages of reattachment point across shear layer. The effect of seal working as a barrier from turbulence across cove wall are also noted but in this category of cases, the turbulence travels through the mixing layer between two recirculations from seal to slat cusp.

Conclusions

The presence of cove seal changes the noise level intensity increasing the tonal peaks of spectra. This pattern however are dependent of the seal position on cove surface where it is possible to indentify two categories of cases, one recirculation zone and cases with two recirculations. The first category are similar to baseline geometry and second presents higher intense peaks. Seal also work as barrier from turbulence that travels across cove wall and it seems not affect the generated noise but for positions of seal far enough from reattachment point, the mean flow indicates the presence of additional recirculation that could be related to the increasing level of the tonal peaks compared to cases where just one recirculation is observed. Further investigations on this behaviour and its influence in slat propagated noise mechanism are proposed.

2. ACKNOWLEDGEMENTS

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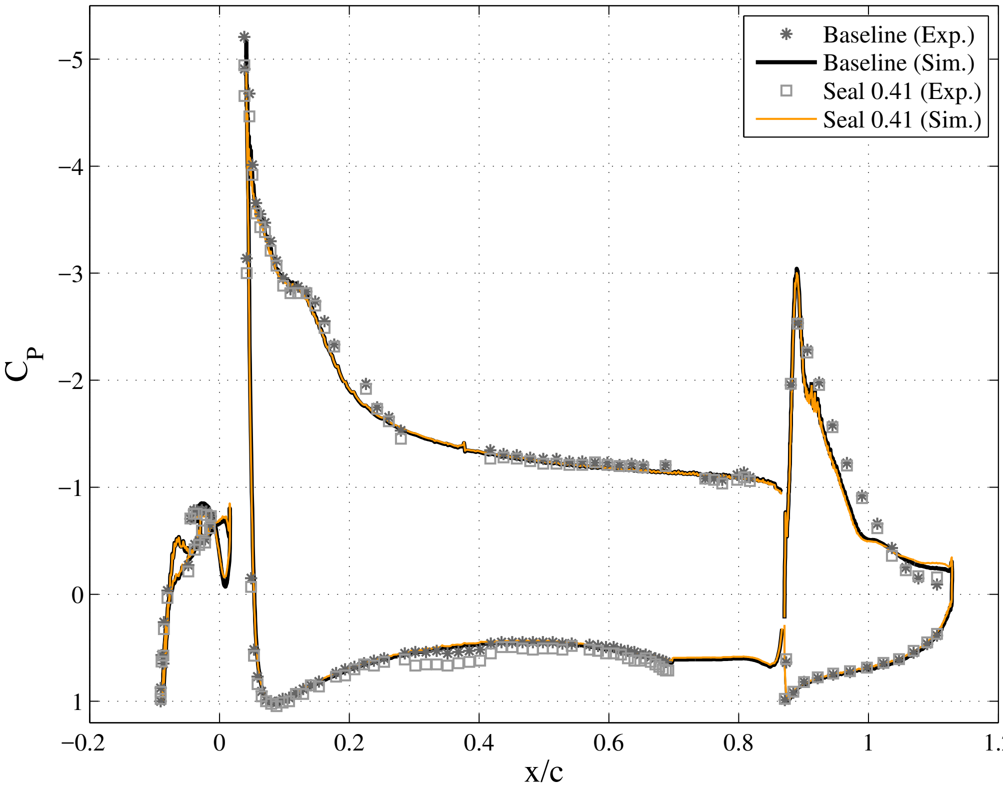
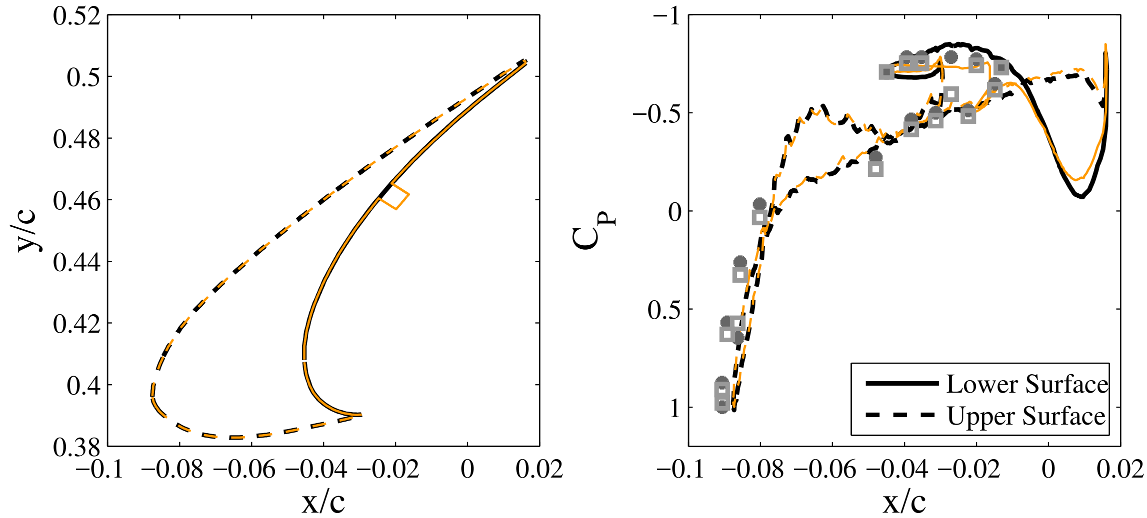


(a) c_P over MD30P30N.



(b) Slat detail.

Figure 2: Numerical and experimental c_P over airfoil for baseline and sealed case with $d = 0.41$.

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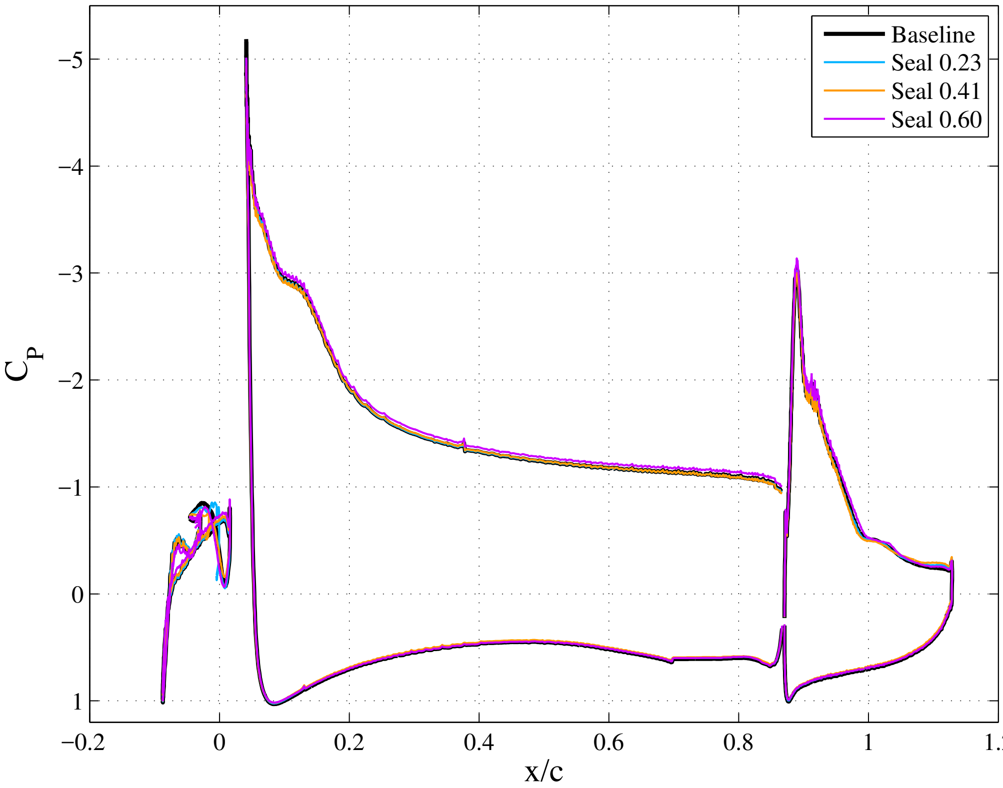
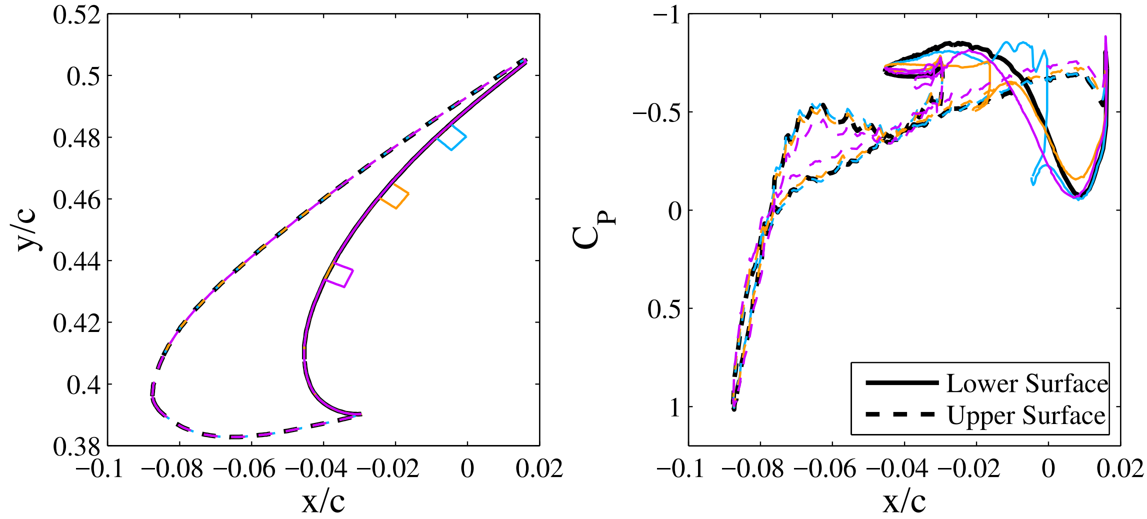


(a) c_P over MD30P30N.



(b) Slat detail.

Figure 3: Numerical c_P for baseline and sealed cases.

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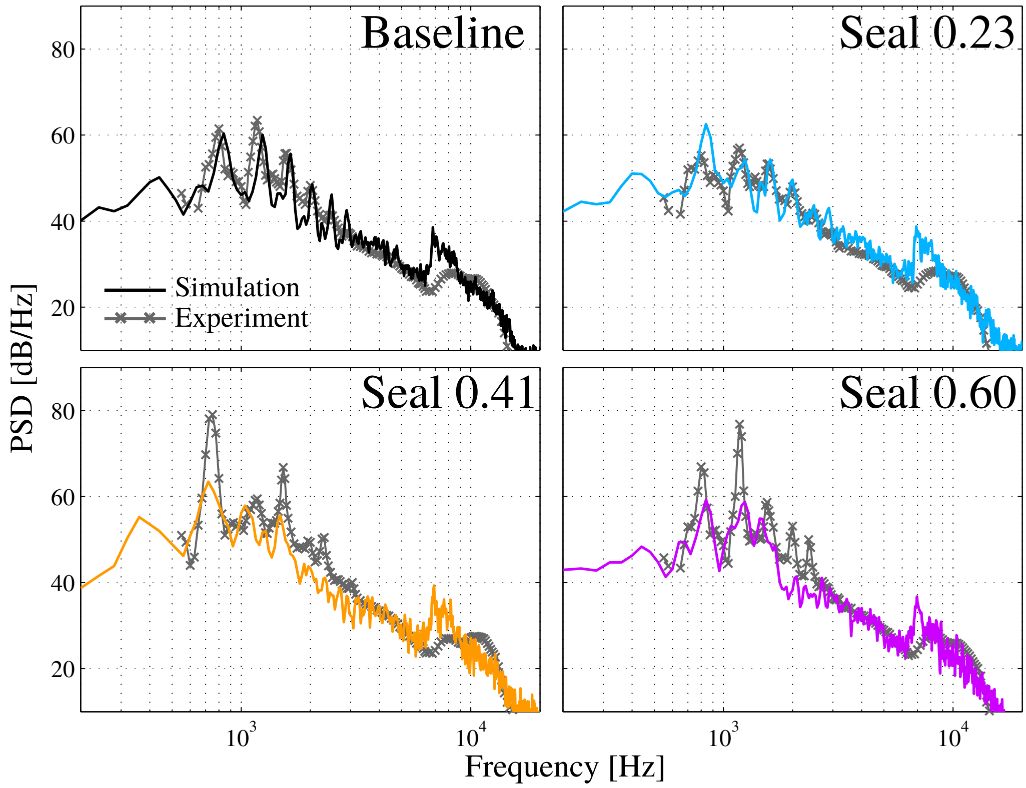

Figure 4: Noise spectra for numerical (full line) and experimental (marked line) results for baseline and sealed cases.

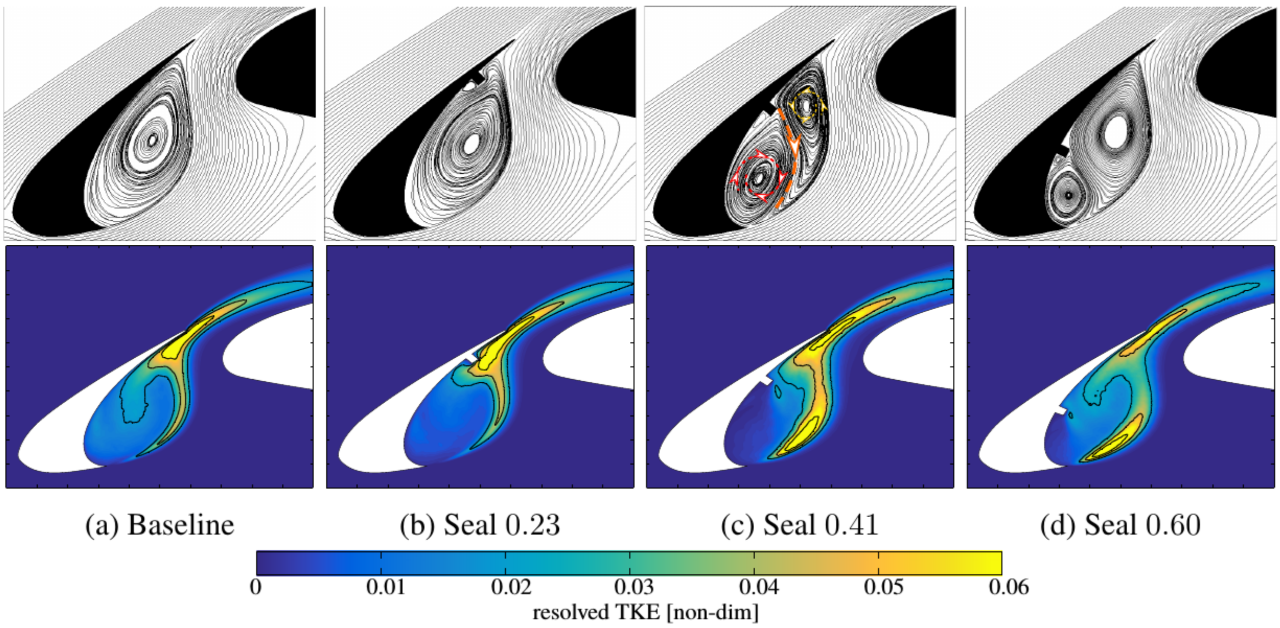

Figure 5: Streamlines and resolved TKE for clean and seal cases.

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