Category *INT: Aircraft Interior Noise*

Simulation of wall pressure fluctuations with synthetic anisotropic turbulence

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The prediction of the high Reynolds number turbulent boundary layer wall pressure spectrum is important for the estimation and reduction of its impact on aircraft cabin noise level. Flat plate turbulent boundary layers are simulated using synthetic anisotropic turbulence generated by the fast random particle-mesh method [1] [2]. The anisotropy is taken into account in two different stages. The first one considers the one-point statistics of the Reynolds stress tensor and the second additionally realizes anisotropic turbulence length scales. The impact of the turbulence structure on the resulting wall pressure spectra is studied.

To determine spectra of wall pressure fluctuations, a Poisson equation is solved with unsteady right-hand side source terms derived from the synthetic turbulence realization. The contributions to wall pressure fluctuations from the mean-shear (ms) turbulence interaction term and the turbulence-turbulence (tt) interaction term are studied separately.

The results show that contributions from both source terms have the same order of magnitude if turbulence anisotropy is considered, see Fig. 1. The result with anisotropic Reynolds stress tensors and a length scale stretching factor of 1.5 (turbulence length scale ratio between the streamwise and spanwise directions) is mostly consistent with the direct numerical simulation results from Kim [3]. Also good agreement for the correlation characteristics of the wall pressure field is found between the present results and databases from other investigators. Results of the spatial correlation shown in Fig. 2 represent similar contour shapes between the mean-shear term and the total result. In contrast, the turbulence-turbulence term exhibits isotropic correlation characteristics. From Figs. 3 and 4, it illustrates that the coherence from the turbulence-turbulence term decays much faster than the mean-shear term over the distance in both streamwise and spanwise directions.

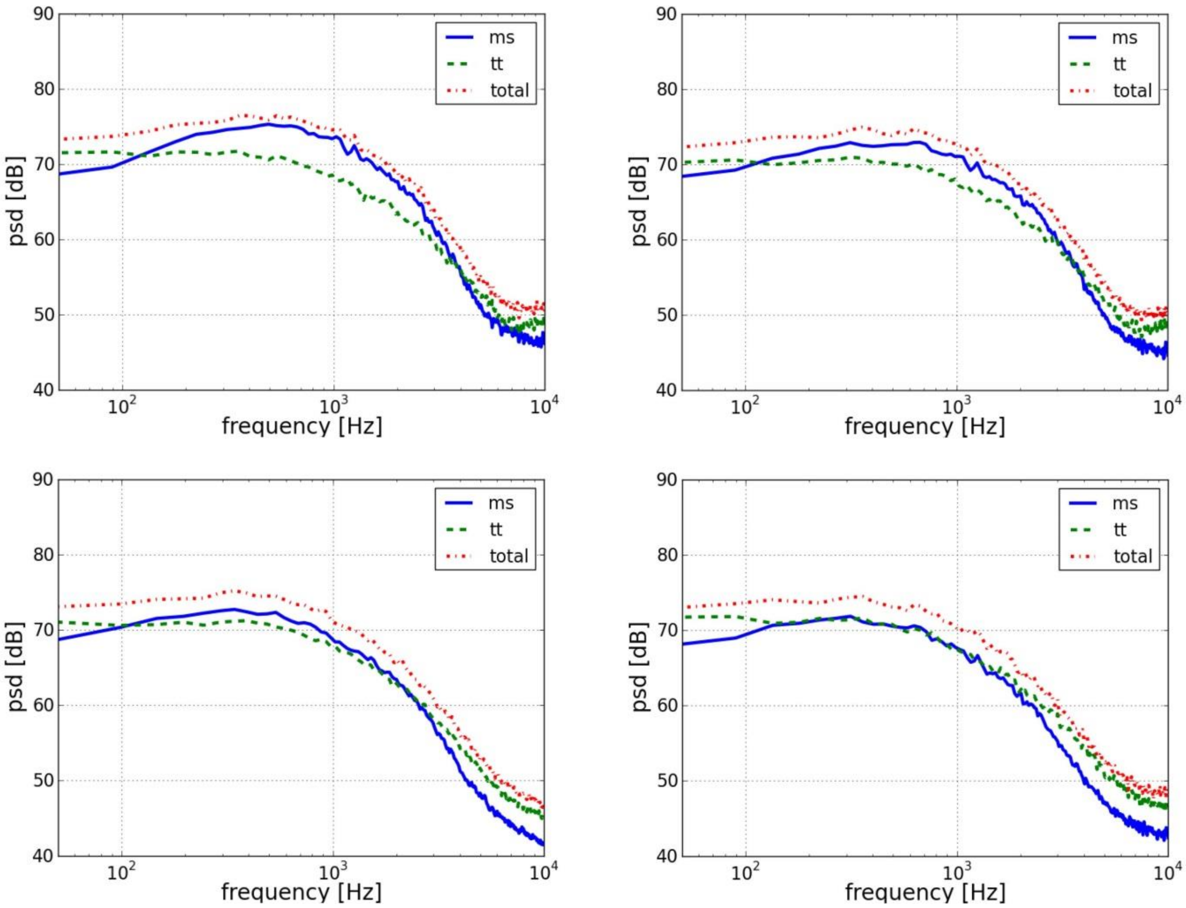

Figure 1: Wall pressure spectra; (top left) isotropic turbulence approach; (top right) anisotropy of Reynolds stress tensors; (bottom left) anisotropy of Reynolds stress tensors and a length scale anisotropy stretching factor of 1.5; (bottom right) anisotropy of Reynolds stress tensors and a length scale anisotropy stretching factor of 2.

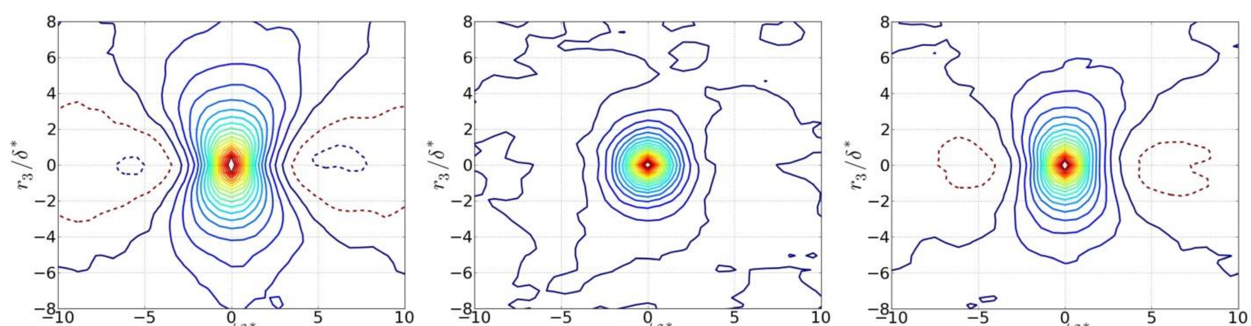

Figure 2: Contour plots of spatial correlation; (-), iso-contours, 0 to 0.9 with increment of 0.05; (- -), iso-contours, -0.05 and -0.1; (left) mean-shear (ms) contribution to R_pp(r_1,r_3,0); (middle) turbulence-turbulence (tt) contribution to R_pp(r_1,r_3,0); (right) combined (total) contribution to R_pp(r_1,r_3,0).

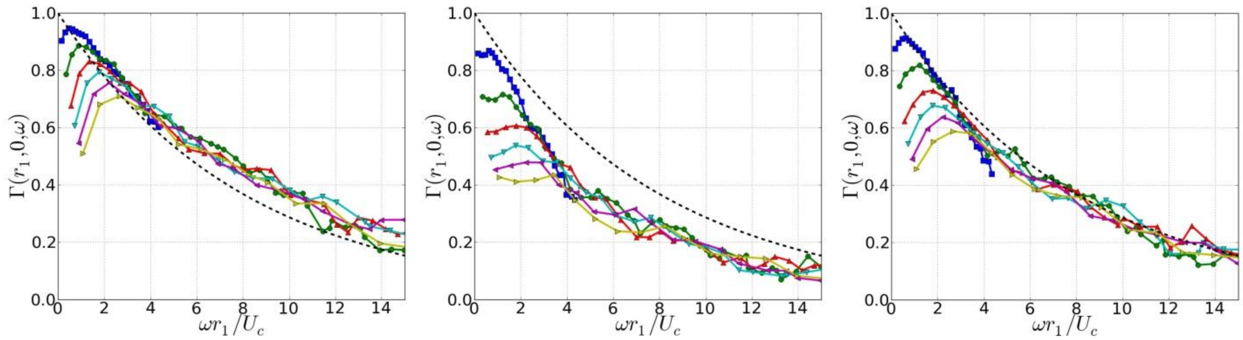

Figure 3: Streamwise coherence as a function of omega r_1 / U_c for fixed space increments, r_1= 1.36 delta^* - 8.18 delta^* with increment of 1.36 delta^*; (- -), exp(-alpha omega r_1/U_c) with alpha=0.125; (left) coherence for p_ms; (middle) coherence for p_tt; (right) coherence for p_total.

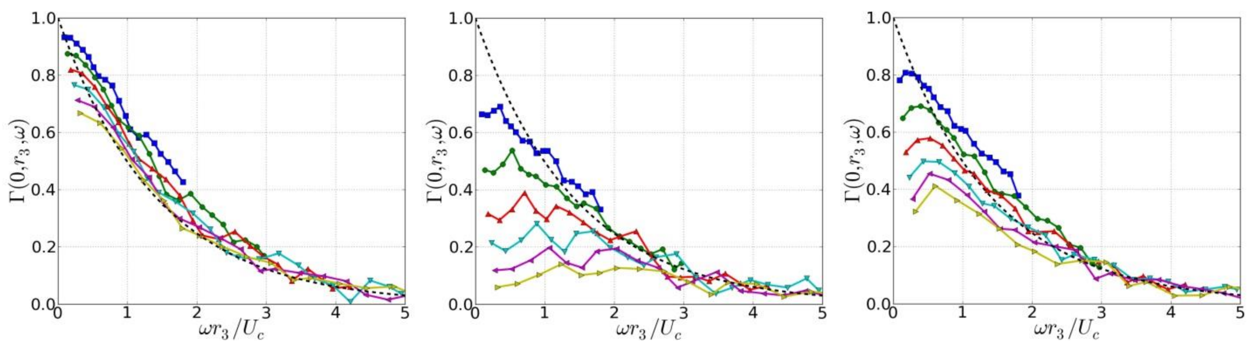

Figure 4: Spanwise coherence as a function of omega r_3 / U_c for fixed space increments, r_3= 0.78 delta^* - 2.73 delta^* with increment of 0.39 delta^*; (- -), exp(-beta omega r_3/U_c) with beta=0.7; (left) coherence for p_ms; (middle) coherence for p_tt; (right) coherence for p_total.

[1] N. Hu, N. Reiche and R. Ewert, Simulation of turbulent boundary layer wall pressure fluctuations via Poisson equation and synthetic turbulence, J. Fluid Mech. 826, 421-454, 2017.

[2] R. Ewert, J. Dierke, J. Siebert, A. Neifeld, C. Appel, M. Siefert and O. Kornow, CAA broadband noise prediction for aeroacoustic design. J. Sound Vib. 330, 4139-4160, 2011.

[3] J. Kim, On the structure of pressure fluctuations in simulated turbulent channel flow, J. Fluid Mech. 205, 421-451, 1989.