A tale of three TBL excited plates

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The normalized vibration response of three flat rectangular plates excited by turbulent boundary layer flow is calculated and compared to measured data. The plates are different sizes, made from different materials, and have different boundary conditions. The boundary layers have different heights and flow speeds. The ratios of plate flexural and convective wavenumbers k_b/k_c range from about 0.1 to 2. The measurements were made in three different facilities by Wilby at ISVR [1], Han at Purdue University [2], and Robin at University of Sherbrooke [3], spanning 50 years of time.

Wall pressure fluctuation autospectra were also measured by the previous investigators so that plate vibration may be normalized. This wide range of structural and flow conditions and the use of plate vibration spectra normalized by wall pressure autospectra allows for an objective assessment of various TBL wall pressure fluctuation cross-spectral empirical models. Two models are considered: the traditional Corcos model [4] and Mellen's elliptical extension [5]. Smolyakov's empirical models for convection velocity and streamwise and spanwise surface pressure length scales supplement the Corcos and Mellen models [6].

Figure 1 shows simulated and measured normalized surface-averaged plate vibrations for one of the Sherbrooke plates. Modal damping was estimated from the measured vibration spectra using Output Modal Analysis (OMA) and applied to the calculations. These conditions correspond to $0.09 < k_b/k_c < 0.20$, which is well below aerodynamic coincidence. Calculations using the Corcos cross-spectral model overestimate the vibrations by about an order of magnitude at lower k_b/k_c ratios, whereas the augmented Mellen model leads to good agreement with measurements.

Results from the Wilby panels (not shown in this abstract) where $k_b/k_c \sim 1$ indicate there is little difference between the Corcos and Mellen cross-spectral models since the flow speeds are high enough to reach coincidence with the plate flexural waves. The Han flow speeds are slower and the plate wavespeeds faster, leading to more visible differences in vibrations simulated using the different models (also not shown in this abstract). The Sherbrooke panels are tested at the lowest flow speed to flexural wave speed conditions, showing the largest differences between the cross-spectral models.

The Mellen cross-spectral pressure model, supplemented with Smolyakov's empirical models for convective wave speed and streamwise and spanwise surface pressure length scales, is demonstrated to be suitable for calculating plate vibrations due to TBL flows with flow speed/flexural wave speed ratios ranging from 0.1 to 2 for a wide range of plate and flow conditions.

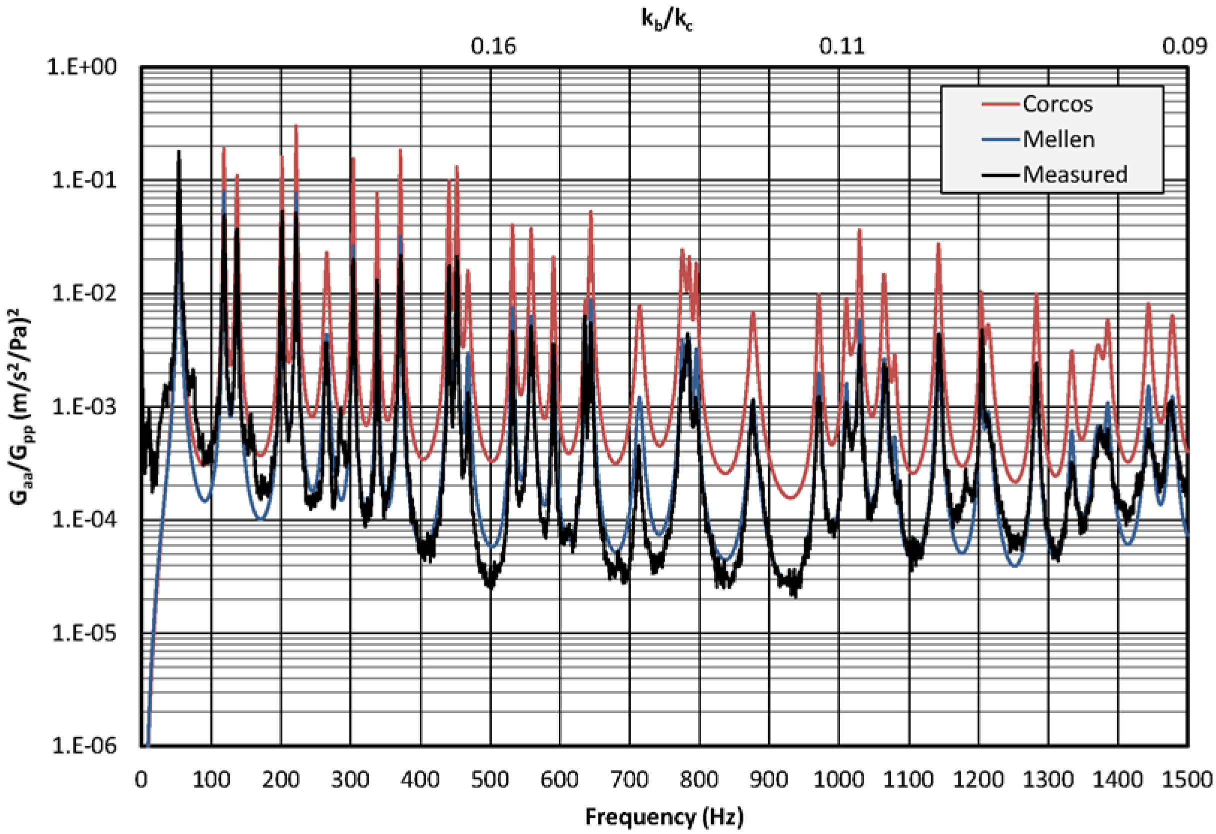

Figure 1: Surface averaged acceleration, normalized by measured wall pressure autospectrum, of Sherbrooke Panel A2, 28 m/s flow speed

References

[1] J.F. Wilby, *The response of simple panels to turbulent boundary layer excitation*, Technical Report AFFDL-TR-67-70, 1967.

[2] F. Han, R.J. Bernhard, L.G. Mongeau, "Prediction of Flow-Induced Structural Vibration and Sound Radiation Using Energy Flow Analysis," *Journal of Sound and Vibration*, vol. 227, pp. 685-709, 1999.

[3] O. Robin, F. Franco, E. Ciappi, S. De Rosa, and A. Berry, "Exact geometric similitude laws for flat plate vibrations induced by a turbulent boundary layer" in *Flinovia - Flow Induced Noise and Vibration Issues and Aspects II* (E. Ciappi, S. D. Rosa, F. Franco, J.-L. Guyander, R. Leung, S. Hambric, and A. Hanford, eds.), Springer, 2018.

[4] G.M. Corcos, "Resolution of pressure in turbulence," *Journal of the Acoustical Society of America*, Vol. 35, No. 2, pp. 192-199, 1963.

[5] R.H. Mellen, "On modeling convective turbulence," *Journal of the Acoustical Society of America*, Vol. 88, No. 6, pp. 2981-2893, 1990.

[6] A.V. Smolyakov, "A new model for the cross spectrum and wavenumber-frequency spectrum of turbulent pressure fluctuations in a boundary layer," Acoustical Physics, Vol. 52, No. 3, pp. 331-337, 2006.