Piggyback: What we can learn about the Turbulent Boundary Layer from closed Test Section Acoustic Array Measurements

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A large number of aeroacoustic wind tunnel measurements is performed in research facilities around the world aiming at locating noise sources on scaled models. In the following, the focus is however not set on the issue of locating noise sources on the research model, but rather to utilize a bybroduct of such measurements in closed test sections: the hydrodynamic pressure fluctuations from the turbulent boundary layer. In the majority of acoustic measurements, a phased array is being used to locate the sources on the research model. Such arrays consist of hundreds of microphones that are placed at carefully chosen locations either outside the flow in open test section wind tunnels, or underneath the turbulent boundary layer in closed test section wind tunnels. In the latter case, the pressure fluctuations recorded by the microphones are of both, hydrodynamic and of acoustic nature. In acoustic beamforming analysis, oftentimes the hydrodynamic pressure fluctuations are regarded as noise which mostly affects the main diagonal elements of the cross-spectral matrix. Therefore, the diagonal elements are commonly set to zero in order to avoid the effects of this noise on the beamforming map. In the following analysis, it is this ”noise” that the focus will be set on. Analysis of the turbulent boundary layer pressure fluctuations can be used to both, learn about its characteristics, and to design better arrays for future measurements. A successful methodology for this ”noise” evaluation will open up new possibilities of evaluating existing measurements for the the characterization of turbulent boundary layer pressure fluctuations.

There are three frequency-dependent parameters of interest that can be drawn from a wall-mounted microphone array in the wind tunnel. One is the autospectrum resulting from the turbulent boundary layer pressure fluctuations alone. The second parameter is the frequency-dependent phase velocity which was for instance determined by Haxter et. al. [1] using a modified analysis method from Ehrenfried & Koop [2]. The third parameter is the size of the coherent pressure patch in the spatial domain. This characteristic is commonly described by the frequency-dependent coherence length in stream-wise and in cross-stream direction. Dominant acoustic pressure fluctuations can be removed using CLEAN-aSC [1].

For a first evaluation, data from a measurement in a closed test section performed in the European Transonic Wind tunnel (ETW) was used for analysis [3]. The test campaign was originally aimed at checking for the cryogenic capabilities of microphone phased array measurements. A half-model had been installed in the test section for acoustic characterization. However, in the present analysis, neither the model nor the cryogenic measurement were in focus, but rather the capabilities of measuring the boundary layer noise using the existing data from the acoustic measurement in the wind tunnel.

Data from this measurement were now processed in the wavenumber domain to find characteristics of the turbulent boundary layer pressure fluctuations. The analysis method had been performed previously for wind tunnel data by Ehrenfried & Koop [2] focusing on the TBL on a flat plate. The experiment and the array were specifically designed for evaluating the turbulent boundary layer pressure fluctuations. Ehrenfried & Koop used a beamforming technique with planar wave steering vectors to obtain the wavenumber content of the recorded array data. In the wavenumber source map representation, pressure fluctuations from the turbulent boundary layer show up as a ”convective ridge” which - considering subsonic speeds - will be located a streamwise position of $k_c/k_0 > 1$ with k_c being the convective wavenumber (the position of the convective ridge) and k_0 being the acoustic wavenumber with $k_0 = \omega/c_0$ with ω being the angular frequency, and c_0 being the speed of sound.

For the current analysis, a DAMAS2.1 deconvolution scheme [4] was used as it was considered the most suitable for wavenumber data. Two exemplary wavenumber maps are shown in Figures 1 and 2. The acoustic signals are located in the acoustic domain, an elliptic region in the center of the wavenumber domain. At positive k_x, approximately around $k_x/k_0 \approx 6$, a k_y-elongated artifact is visible which represents the pressure fluctuations from the turbulent boundary layer. This is the convective ridge, which position and shape contains characteristic information about the turbulent boundary layer pressure fluctuations. As mentioned previously, the position of the convective ridge yields information about the frequency-dependent convection velocity of turbulent boundary layer pressure fluctuation. In figure 1, the center position of the convective ridge is located at approximately $k_c/k_0 \approx 7.5$, which converts to $u_c \approx 47\,\mathrm{m\,s^{-1}}$. This is $u_c/u_0 \approx 56\,\%$ of the free-stream velocity. In figure 2, the center position of the convective ridge is located at approximately $k_c/k_0 \approx 7.5$, which converts to $u_c \approx 63\,\mathrm{m\,s^{-1}}$. This is $u_c/u_0 \approx 58\,\%$ of the free-stream velocity. Further analysis will be given in the final contribution.

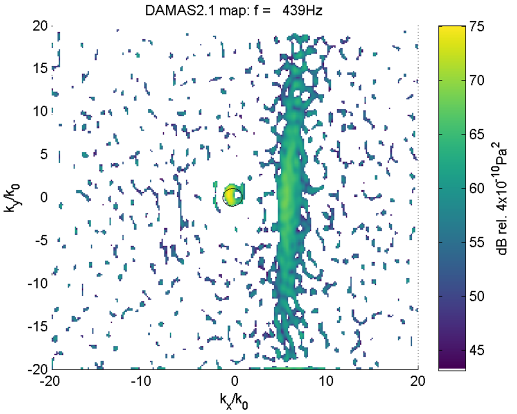

Figure 1: DAMAS2.1 deconvolved wavenumber spectrum at $f = 439\,\mathrm{Hz}$ with flow velocity of $u_\infty = 84.4\,\mathrm{m\,s^{-1}}$

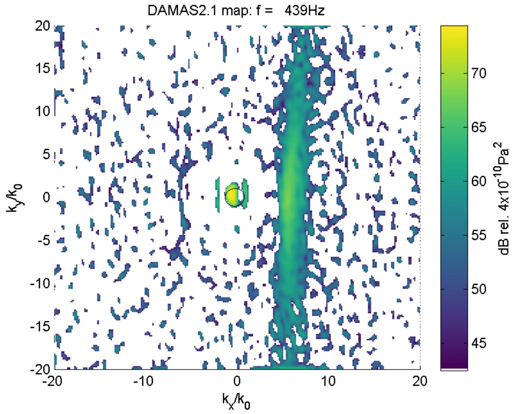

Figure 2: DAMAS2.1 deconvolved wavenumber spectrum at $f = 439\,\mathrm{Hz}$ with flow velocity of $u_\infty = 109\,\mathrm{m\,s^{-1}}$

References

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