Effect of Porous Materials on the Acoustic Emissions of a Circulation-Control High-Lift Airfoil

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Introduction

In the frame of the collaborative research initiative CRC880, Technische Universität Braunschweig, Leibniz Universität Hannover and the German Aerospace Center, DLR, combined their compentence to perform fundamental and applied research in high-lift systems for future commercial aircraft. This long term research initiative focuses on a new transport aircraft segment for operation on airports with short runway length in commercial air transport. This calls for a community-friendly aircraft, designed for operations much closer to the home of its passengers compared to today's technologies. This scenario sets challenging, seemingly contradictory aircraft technology requirements, namely those for extreme lift augmentation and low noise. Novel aircraft concepts appropriate to reach these requirements would need to be equipped with active high-lift systems to enable high aerodynamic efficiency and increased lift augmentation capabilities, therefore reducing the necessary runway length for take-off and landing.

Compared to conventional high-lift systems, an active high-lift system would be inherently silent, in the mid- to high frequency range, through the lack of slots where high-velocity flows occurs [1]. The mechanisms by which a high-lift system without conventional flap or slat produces noise are, however, not well understood. Therefore, the aim of the current research effort is to gain a better understanding of the relevant source mechanisms and investigates noise mitigation technologies based on porous aluminum materials.

Experiment

The experiment was conducted in the Acoustic Wind Tunnel Braunschweig (AWB). The AWB is DLR's small-scale high-quality low-speed anechoic testing facility. It is an open-jet Göttingen-type wind tunnel capable of running at speeds of up to 65 m/s, optimized for noise measurements at frequencies above 250 Hz [2].

The airfoil geometry is based on the DLR-F16 profile. It has an effective chord length of c = 0.3 m and a wetted span of 0.8 m. It has a droop nose leading edge and a 0.25c flap deflected at 65°, the geometric chord length of the airfoil is 0.23 m. Circulation control was realized via a high-speed jet from a high-aspect ratio slit on the suction side ahead of the flap segment (see Fig. 1). The height of the slit is 0.0002 m, for a slit width of 0.8 m. The high-speed jet was generated by feeding pressurized air into the airfoil through two input lines, one on each

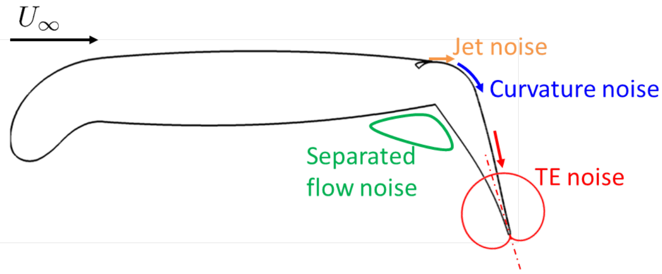

Figure 1: Airfoil section and its most important sources of noise

side of the model (Fig. 2). Tuning of the jet momentum coefficient, c_μ allows one to effectively ensure that the flow remains attached to the airfoil's flap, thus greatly increasing its lift. The far-field noise radiation, above the airfoil, was quantified using a phased microphone array (see Fig. 3). In this contribution, the analysis focuses on data acquired with the phased microphone array located above the airfoil to take advantage of the maximum in trailing-edge noise directivity (see Fig. 1).

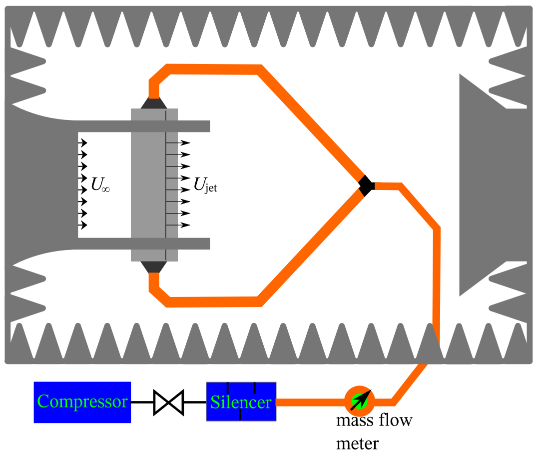

Figure 2: Pressurized air supply into the airfoil

Results

We hypothesize [5] that noise generation, for the type of circulation-control airfoil describe above, finds its origin in four types of sources. Namely jet noise, trailing-edge noise, curvature noise and separated flow noise; each characterized by a different source mechanism. The location where these sources occur is depicted schematically in Fig. 1. In the experiment, the focus is put on an assessment of the jet and trailing-edge noise contributions.

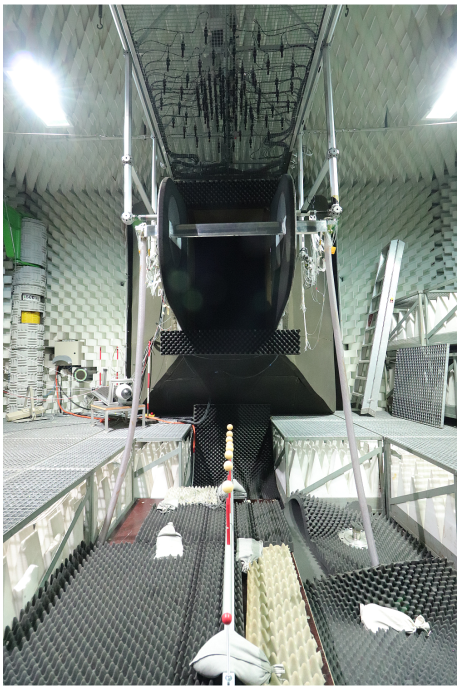

Figure 3: Experimental setup in the AWB. Phased microphone array above the test section. Free-field microphones below the test section.

The jet noise source can be isolated and quantified, while the bandwidth and sound pressure level (SPL) related to trailing-edge noise will be inferred through edge modifications and scaling arguments.

Jet noise occurs due to the high velocity flow exiting at the rectangular slit (aspect ratio = 4000) on the wing's upper side short before the flap hinge (see Fig. 1). Characteristic spectra of the jet noise contribution are given in Fig. 4 for a phased array position above the test section. These results are obtained by running only the jet, with the wind tunnel set to 0 m/s freestream velocity. The results reveal the expected 8$^{\text{th}}$ power law velocity scaling of the third-octave band data for Strouhal numbers larger than 30 (see Fig. 5). The Strouhal number based on the jet velocity and the free-stream velocity are defined as

$$St_j = \frac{fh}{U_j},\ St_\infty = \frac{fc}{U_\infty} \qquad [-] \qquad (1)$$

with h the slit height and U_j the jet velocity. U_∞ is the free-stream velocity. This source is dominant only at high frequencies ($f > 10$ kHz, e.g. 10) and for the upward radiation direction. Results of measurements below the airfoil (not shown here) reveal lower SPLs, in excess of 10 dB, above 10 kHz. The wing acts as a shield, blocking sound radiation to the ground and redirecting it mostly upwards. The origin of the low frequency part of the spectra in Fig. 4 and Fig. 5 remains to be clarified.

In Figs. 6, 7, 8 and 9, results in terms of normalized SPL spectra, measured above the test section, are given for variations in free-stream Mach number ($M_\infty = U_\infty/a_0$),

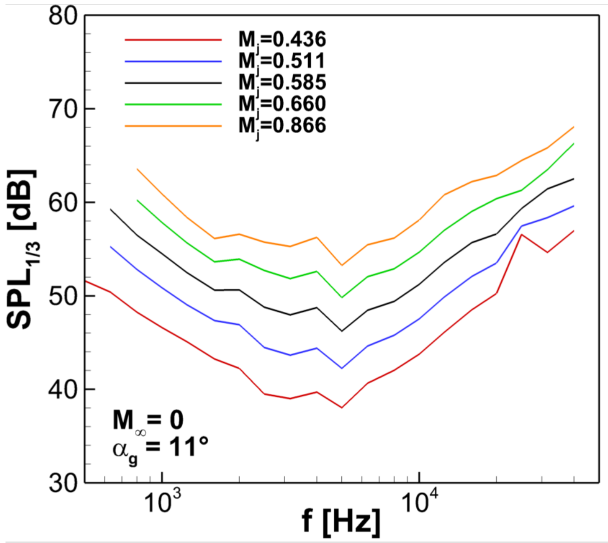

Figure 4: Jet noise contribution above the airfoil vs. jet Mach number, unscaled

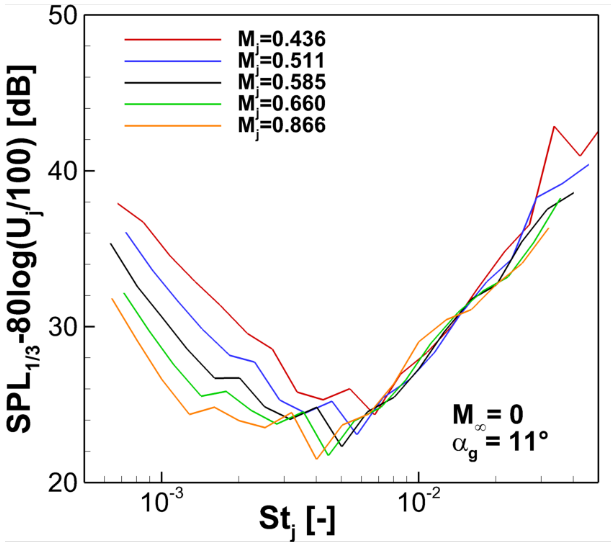

Figure 5: Jet noise contribution above the airfoil vs. jet Mach number, scaled

jet Mach number ($M_j = U_j/a_0$), with a_0 is the speed of sound in air, jet momentum coefficient (c_μ) and geometrical angle of attack (α_g). The jet momentum coefficient is defined as

$$c_\mu = \frac{2\rho_j U_j^2 b_{slit} h_{slit}}{\rho_\infty U_\infty^2 A_{ref}} \qquad [-] \qquad (2)$$

with A_{ref} the airfoil's planform area, b_{slit}, i.e. the slit span and h_{slit}, i.e. the slit height.

The SPL are normalized by assuming a power law relationship of the form, $\overline{p'^2} \propto U^n$, between the acoustic power, $\widetilde{p} = \overline{p'^2}$, and a characteristic velocity, i.e. U_j or U_∞.

The results of Figs. 6, 7, 8 and 9 indicate that the free-stream velocity does not appear as the most

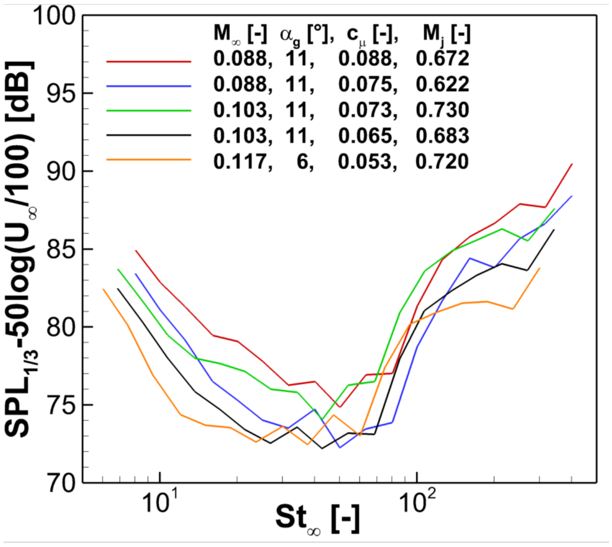

Figure 6: Normalized spectra, $\widetilde{p} \propto U_\infty^5$

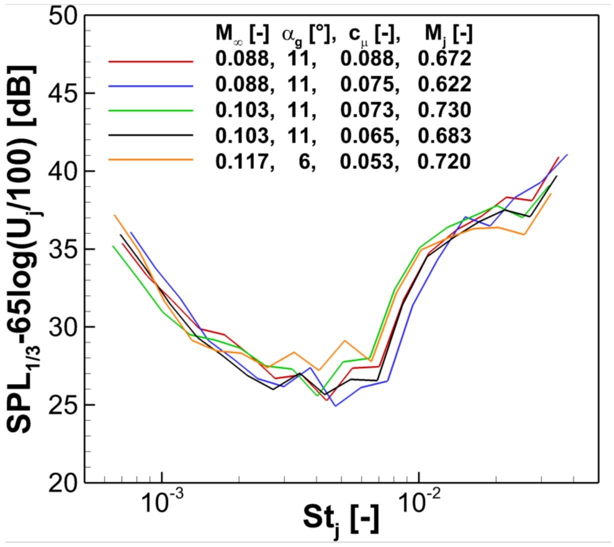

Figure 8: Normalized spectra, $\widetilde{p} \propto U_j^{6.5}$

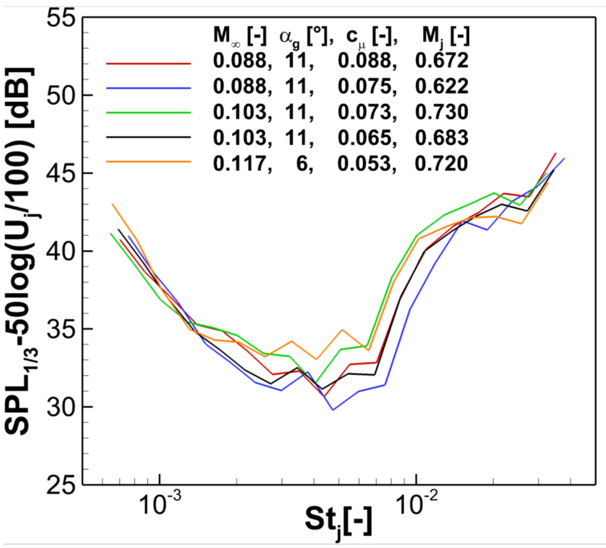

Figure 7: Normalized spectra, $\widetilde{p} \propto U_j^5$

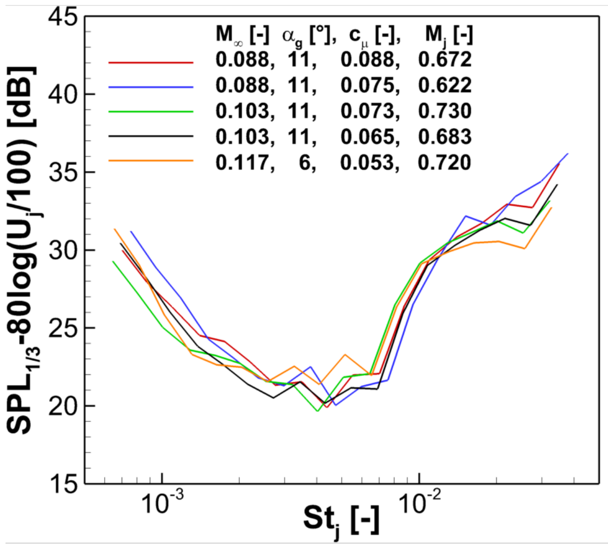

Figure 9: Normalized spectra, $\widetilde{p} \propto U_j^8$

important parameter, but rather the jet velocity. This suggests that the acoustic radiation is mostly driven by the local flap flow field characteristics. A power-law scaling of the acoustic power, $\widetilde{p} \propto U_j^n$, with n=5 provides the best data collapse at low frequencies, i.e. for $St_j < 0.0015$. In the mid-frequency range, i.e. for $0.0015 < St_j < 0.005$, n=6.5 appears to be better suited. At high-frequencies, i.e. for $St_j > 0.005$, n=8 provides the best results. Thus, below approx. 10 kHz ($St_j < 0.005$), the dominant source mechanism is therefore expected to be edge scattering of flow turbulence which is typically proportional to the fifth power of a characteristic velocity.

Permeable aluminum foam materials [3] were utilized in an attempt to modify the hydrodynamic impedance jump at the wing's trailing-edge and, in consequence, promote a reduction of the trailing-edge noise levels. This type of porous trailing-edge insert is already known to provide an effective means to mitigate trailing-edge noise at conventional airfoil profiles. Their application at a circulation-control high-lift airfoil is, however, novel.

Two porous aluminum were selected, i.e. the PA80-110 and PA120-150. The material denomination, i.e. PA80-110 or PA120-150, refers to the effective pore sizes of 80–110 μm or 120–150 μm according to single pass test results (ASTM E 1294) as provided by the manufacturer. The PA120-150 material was used in a graded form, i.e. with a streamwise permeability gradient. This configuration was obtained through cold rolling of the material samples prior to the manufacturing of the trailing-edge inserts, as described in [4]. Each insert had a spanwise length of 400 mm.

In Fig. 10, results are presented for both the PA80-110 and PA120-150 porous aluminum trailing-edge inserts. In both cases the modification provides up to 10 dB of noise reduction between 1.6 kHz and 8 kHz, a strong indication that trailing-edge noise is dominant in this frequency range. For comparison, data obtained for a flexible brush trailing-edge add-on are also given. All modifications provide similar results, except for a slight noise increase, on the order of 2 dB, at low frequency for the PA80-110 trailing-edge. These results are in contrast to earlier measurements at a conventional DLR-F16 airfoil, where the porous aluminum inserts mainly provided a noise reduction below approx. 7 kHz and a noise increase above [3]. In the present experiment, the spectra of Fig. 10 are dominated, at high frequencies, i.e. above 10 kHz, by the jet noise source contribution and therefore, the effect of the trailing-edge inserts is assumed to be masked. Below 1.6 kHz, the data are influenced by the three-dimensional flow field at the wall-airfoil corners which leads to increased turbulence intensities over the airfoil's upper and lower surfaces. The interaction of this three-dimensional flow field with the airfoil's trailing-edge is also responsible for the generation of trailing-edge noise. This is emphasized, at low frequencies, by the flexible brush data with an extended 800 mm spanwise length. This suggests that trailing-edge noise is dominant over the frequency range 0.8 kHz $< f <$ 10 kHz. The high-frequency noise increase, relative to the reference configuration, for this case is due to a higher jet Mach number. For the same reason, the peak noise reduction is slightly diminished compared to the 400 mm brush.

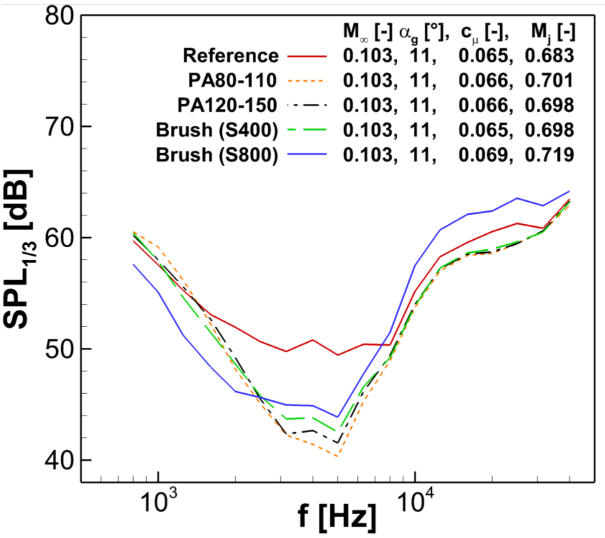

Figure 10: Noise reduction using permeable porous aluminum trailing-edge add-ons. Comparison with flexible brush add-ons with spans of 400 mm (S400) and 800 mm (S800).

Conclusions

The results of a wind tunnel experiment on the acoustics of a circulation-control high-lift airfoil are presented. The aim of the present contribution is to quantify important sources of aeroacoustic noise specific to this configuration and investigate the use of porous materials as a means for trailing-edge noise reduction. We hypothesize [5] that noise generation is due to four types of sources. Namely jet noise, trailing-edge noise, curvature noise and separated flow noise; each characterized by a different source mechanism. The focus of the data presented herein is put on an assessment of the jet and trailing-edge source contributions. Porous aluminum trailing-edge modifications are investigated to evaluate their noise reduction potential. The down-selection of the porous aluminum material is done based on earlier studies dealing with trailing-edge noise reduction at a DLR-F16 two-dimensional airfoil.

The results suggest that a transfer of available design principles for low-noise porous inserts for conventional airfoils also apply to the circulation-control high-lift airfoil considered herein. Both the PA80-110 and PA120-150 porous aluminum trailing-edge inserts provide a noise reduction of up to approx. 10 dB over the frequency range 1.6 kHz $< f <$ 8 kHz. An indication that, in that frequency range, trailing-edge noise is a dominant contributor to the overall noise radiation. All porous materials considered in the experiment deliver similar results in terms of absolute noise level reduction. In the experiment, and for the specific configuration considered herein, the spanwise extent of a porous treatment determines how much noise reduction can be achieved at low frequencies. Jet noise is found to dominate the high-frequency range of the acoustic radiation, i.e. above 10 kHz.

References

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