10ème Congrès Français d'Acoustique

Lyon, 12-16 Avril 2010

Characterization of a hybrid active-passive absorber by means of Laser Doppler Velocimetry

Benjamin Betgen[1], Marie-Annick Galland[1], Estelle Piot[2], Frank Simon[2]

[1] Centre Acoustique du LMFA - UMR CNRS 5509 - Ecole Centrale de Lyon - 36, av. Guy de Collongue - 69134 Ecully Cedex, France

[2] ONERA Centre de Toulouse, Département DMAE, Unité C2A, 2, avenue Edouard Belin - BP 74025 31055 Toulouse Cedex 4, France

benjamin.betgen@ec-lyon.fr

The LMFA has been developing hybrid absorbers for about 10 years now. Combining passive absorption and active control, these absorbers are well suited to applications that feature a grazing flow. The absorber consists of distinct cells covered by a thin porous layer, each cell containing a control microphone and a secondary source. Active control is used to reduce the acoustic pressure at the rear side of the porous layer at low frequencies. This results in a cancellation of the imaginary part of the surface impedance and permits to approach optimal impedance, i.e. the one that results in maximum noise reduction. The presence of a uniform grazing flow has little influence on optimal impedance. The control system being well protected against the flow, there are by the way no convergence or stability problems. However, the performance of the absorber decreases significantly in presence of grazing flow. In order to explore the origin of this behavior, an absorber composed of three hybrid cells has been tested in the "B2A" test bench at ONERA Toulouse. Laser Doppler Velocimetry (LDV) measurements are performed that permit to assess acoustic velocity in a plane above the hybrid liner in a non-intrusive way. These measurements confirm the good performance without flow. In particular, one observes that the three cells cannot be distinguished anymore but appear as a homogeneous impedance surface. The absorber has a rather global influence on the duct. In presence of a grazing flow of bulk Mach number 0.1, however, the influence of the absorber on the duct is reduced on the immediate vicinity of each hybrid cell.

1 Introduction

With the objective of designing an absorber effective over a broad frequency range, hybrid active-passive absorber have been developed at the LMFA. Details about this absorber are given in section 2.
One interesting application would be the treatment of turboengine nacelle inlets and outlets. This implies grazing flow of relatively high Mach number. Error microphones and secondary sources of the hybrid absorber are well protected against grazing flow behind the porous layer. In fact, fast convergence and excellent stability have been observed, even at M=0.3. However, the measured transmission loss decreases clearly with increasing flow speed (flow in the direction of sound propagation). Even though this behaviour can to some extent also be observed with passive liners, it is especially pronounced for our hybrid absorbers. In order to better understand this loss of performance, the sound field should be observed locally in vicinity of the absorber.

Laser Doppler Velocimetry (LDV) offers the opportunity of such a local and non-intrusive determination of acoustic parameters. The measurements that are presented in this paper have been conducted at the French Aerospace Lab ONERA at Toulouse. The LDV measurement technique developed at ONERA and the corresponding aeroacoustic test bench are briefly described in section 3. The results of a first measurement campaign (given in section 4) indeed give some hints about the origin of the loss of performance due to the presence of flow.

2 The hybrid liner

2.1 Principle

At low frequencies, viscous forces in a porous material predominate over inertial ones and the acoustic velocity across a resistive layer can be approximated using Darcy's law. This means that acoustic velocity is proportional to the pressure difference between both sides of the resistive layer and inversely proportional to its flow resistance R, as given by equation (1).

$$v = \frac{p_1 - p_2}{R} \tag{1}$$

Hence, when acoustic pressure on the rear side of the layer is cancelled ($p_2 = 0$), the surface impedance is given by the flow resistance R (equation (2)).

$$Z = \frac{p_1}{v} = R \tag{2}$$

Pressure cancellation is for example obtained with a cavity of depth $d = \lambda/4$ on the rear side of the layer. Alternatively, it can be realized by means of active control which offers more compactness at low frequencies. In addition, the "resonance condition" $p_2 = 0$ can be obtained over a broad frequency range this way.

2.2 Optimal impedance

In active mode, the surface impedance is given by the resistance of the layer, its choice is therefore of high importance. For maximum absorption at normal incidence, the best suited resistive layer would be of resistance $R = Z_0 = \rho c_0$. This is not the case for grazing incidence. Cremer[2] found an analytic expression for the optimal impedance of a treatment covering one face of an infinitely long rectangular duct. This optimal impedance given by $Z_{Cremer} = Z_0(0,91 - 0,76j)kh/\pi$ only depends on frequency and the dimension of the duct (more precisely only the dimension perpendicular to the liner). Tester[3] gives a correctional factor of $1/(1+M)^2$ to account for the presence of uniform flow of Mach number M in the direction of sound propagation.
In the case of infinitely long liners the optimal impedance is simply the one that produces the highest absorption. For a liner of finite length, optimal impedance is better defined as the one producing the highest transmission loss (TL). A priori it cannot be given analytically but needs to be determined numerically. However, the qualitative behavior of optimal impedance is common to the infinite as well as to the finite liner: The real part is positive and increasing with frequency, the imaginary part is negative and decreasing with frequency. Mean flow in the direction of sound propagation lowers the optimal impedance; in the opposite direction it heightens the optimal impedance.

In the low frequency region, the flow resistance of a thin porous screen is generally constant with frequency. The choice of this screen represents a trade-off between low and high frequency performance. Two different resistive layers are tested: A Feltmetal sheet of $R/\rho c_0 = 0.3$ and a wiremesh glued on a perforated panel of $R/\rho c_0 = 0.5$. Experiments are conducted at excitation frequencies between 496 Hz and 1592 Hz. Calculations predict better performance of the Feltmetal sheet over virtually the entire frequency band. At the upper limit, both resistive screens are supposed to be similarly effective.

2.3 Practical realization

In previous studies (see for example reference [4]), piezoceramics have been chosen as secondary sources in order to obtain a compact system. Here, simple electrodynamic loudspeaker (Monacor SP-5) are used as secondary sources which offer lower cost and a smoother frequency response.
A prototype of 30 mm x 150 mm surface, adapted to the B2A test bench at ONERA, has been built. It contains three hybrid cells of 26 mm x 46 mm each. The

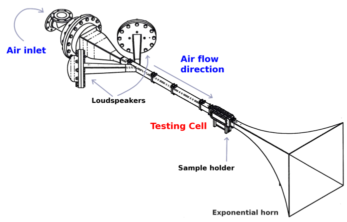


Figure 1: Sketch of the Aero-Thermo-Acoustic test bench

error microphones are simple electret condenser microphones Panasonic WM65. Primary excitation consists of three pure tones at 496 Hz, 992 Hz and 1592 Hz. The algorithm that performs the pressure minimization is an Internal Model Control (IMC) version of the well known filtered reference least mean squares (FXLMS) algorithm. The synthesized references are filtered by means of bandpass filters centered around the treated frequencies. One FXLMS algorithm is then used per cell and frequency. The filtering also permits to pilot each cell independently of the other cells. In fact, thanks to the filtering the system remains stable despite the neglect of the coupling between cells. More information about this algorithm named IMC-MD-FXLMS (MD for MIMO-Diagonalized) can be found in references [5] and [6].

3 LDV measurements

Some basics about the measurement of acoustic parameters by means of Laser Doppler Velocimetry are recalled in this section. More details about the used technique and the test bench at ONERA can be found in reference [7].

3.1 Aeroacoustic test bench at ONERA

The aeroacoustic test bench at ONERA Toulouse is made of a stainless steel tube of section 50 mm x 50 mm; its total length is of about 4 m (see figure (1)). The termination is equipped with an anechoic outlet. Excitation is provided by two loudspeakers installed in pressurized cabinets. Temperature can be adjusted up to 300 degrees C, however, the present tests are conducted at ambient temperature. Experiments were conducted without grazing flow and with a grazing flow of bulk Mach number 0.1. This corresponds to a maximum speed in the center of the duct of about M = 0.16.

Let us define x as the axial coordinate and (y,z) as the coordinates normal to the axis. The test section has a silica window of 200 mm x 60 mm on each side (i.e. at y = 0 mm and y = 50 mm), the lower (i.e. z=0) part is equipped with a liner sample holder. The dimension of the sample is limited to 30 mm x 150 mm, therefore it does not cover the entire width of the duct. Note that the predictions presented above deal with a liner that covers the entire duct with. Here, the liner covers only 30 mm of 50 mm, a quantitative comparison between predictions and measurements is therefore not possible.

For the characterization of passive liners, the excitation signal is made of thirteen pure tones, at third octave frequencies between 312 and 3136 Hz, with an overall sound pressure level of 140dB. As mentioned, in active mode the excitation has been limited to three pure tones of 496 Hz, 992 Hz and 1592 Hz. SPL of each peak is of about 120 dB.

3.2 Data extraction and data processing

A 2D fringe mode Laser Doppler Anemometer allows the measurements of the longitudinal (x) and normal (z) velocity components in almost the entire volume of the test section. For the present tests, only the plane y = 25 mm has been scanned. In order to accelerate the measurements, not the entire plane is scanned but only till z = 30 mm. An LDV system has the particularity to provide an unevenly sampled signal due to the random arrival of particles (incense smoke) in the measurement volume. A reconstruction method is used to re-sample the raw data at a constant rate. Data processing is performed by a TSI IFA 755 system. The emitting optics produces a 100 μm-diameter measurement volume. A minimum sampling data rate of $f_m = 13000$ measurements per second is generally ensured, for each velocity component.

Each velocity component u_x and u_z is measured by the LDV system at a given spatial location. The acoustic velocity (i.e. the component of the signal that is correlated with the excitation signal) can be educed from the extraneous noise by a technique similar to the three-microphone signal enhancement technique [8, 9]. It consists in calculating the cross-spectral density function $G_{u_i,ls}$ between the velocity signal u_i and the loudspeaker signal ls. The auto-spectral density function of the acoustic velocity reads as :

$$G_{u_i'} = \frac{|G_{u_i,ls}|^2}{G_{ls}} \tag{3}$$

where G_{ls} is the auto-spectral density function of the excitation signal. The acoustic velocity *in the frequency domain* is then given by [10] :

$$u_i' = \sqrt{G_{u_i'}} \exp[i\Phi(u_i/ls)] \tag{4}$$

where the phase of the acoustic velocity, referenced by the excitation, is defined as :

$$\Phi(u_i/ls) = \arctan \frac{\Im(G_{u_i,ls})}{\Re(G_{u_i,ls})} \tag{5}$$

Then, acoustic pressure and acoustic active intensity are deduced from the acoustic velocity field thanks to a mixed Eulerian-Lagrangian propagation model [11].

4 Experimental results

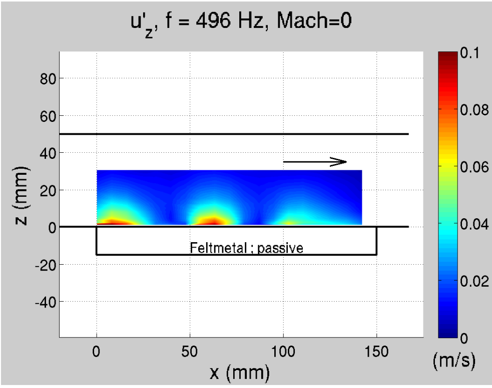
As outlined above, acoustic velocity is the first acoustic parameter that is assessed. Determination of acoustic pressure and intensity require some extra data processing. However, acoustic velocity normal to the absorber already provides a good estimation of the absorber performance. In fact, as acoustic pressure behind the resistive layer is minimized by active control, acoustic velocity through the layer, and therefore dissipation, should be enhanced. Figures (2) and (3) represent this normal velocity at 496 Hz in the y = 25 mm plane without flow and at M = 0.1 respectively. Acoustic propagation and mean flow go from the left to the right. The lowest frequency is chosen because the difference between passive and active mode is maximum there. In fact, the behavior for increasing frequencies is very much as predicted. We therefore focus on the comparison between the two different resistive layers on the one hand and the cases without and with flow on the other hand.

Without flow the situation is the following: In passive mode, normal velocity is small for both layers. The layer of smaller resistance (the feltmetal sheet, figure (2(a)) results in slightly higher velocity than the layer of higher resistance (the wiremesh, (figure 2(c)). Splices between the cells can be recognized, regions of non-zero normal velocity are limited to the vicinity of the three cells.
Active control largely enhances normal velocity, especially for the case with the feltmetal sheet (figure 2(b)). The colorscale has been chosen to a range from 0 to 0.1 m/s, maximum values in (figure 2(b)) reach about 0.2 m/s however. The third cell is fairly inactive; it appears as if most of the sound power was absorbed before reaching the last cell. Figure (2(d)) is disturbed in vicinity of the third cell. In fact, the incense smoke did not sufficiently reach this region and measurements are inaccurate. Normal velocity at some distance above the third cell is very similar to the one above the first cell and we expect the same thing being true for closer distances. However, the most important result is the following: In active mode, the influence on the duct is quite global for both layers. At a certain distance from the absorber, the splices between the cells become invisible.

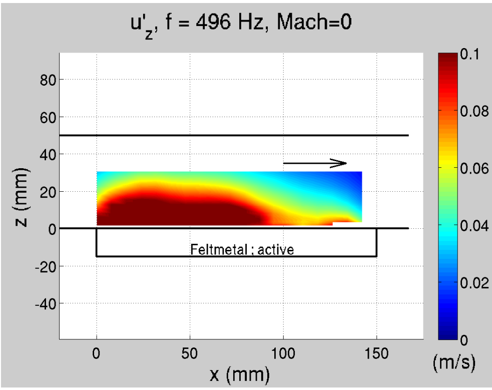
Let's now consider the situation with flow (figure 3). In passive mode, the situation appears rather similar to the no flow case, however, due to the flow, the colormap is "less clean". In active mode, normal velocity is increased for both materials, however, zones of high normal velocity remain close to the three cells. The influence on the duct is much less global than without flow. This is consistant with the experimental observation that transmission loss in active mode decreases significantly in presence of flow [1].

It has been stated that the amplification of acoustic velocity normal to the absorber enhances absorption. However, the presented figures do not visualize absorption directly. In order to clarify the influence of the absorber on the duct, intensity fields are given in figure

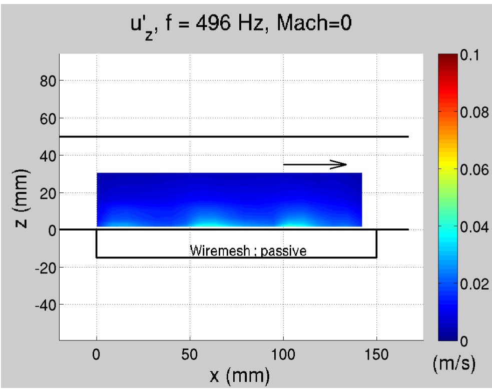
[1]In the present experiment, only SPL upstream and downstream of the treated section are measured with flush mounted microphones. Transmission loss, properly speaking, has been measured in previous experiments and it is always found to decrease rapidly with increasing flow speed.



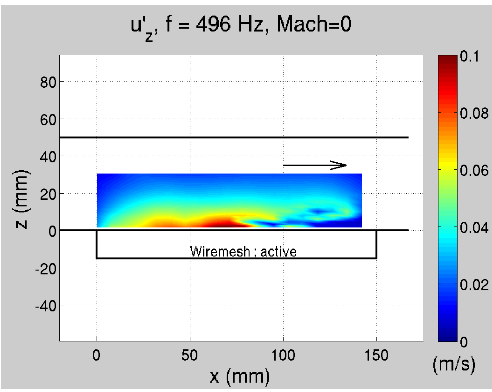
(a) Feltmetal, passive



(b) Feltmetal, active

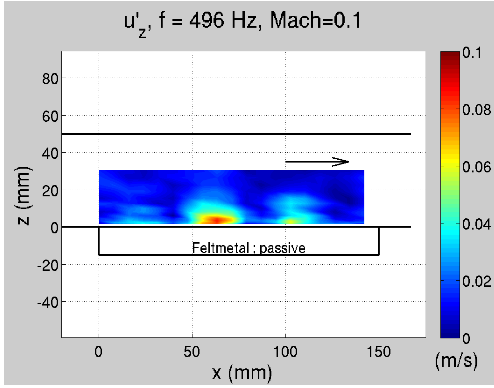


(c) Wiremesh, passive

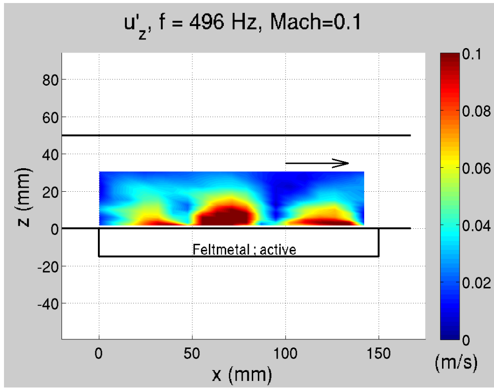


(d) Wiremesh, active

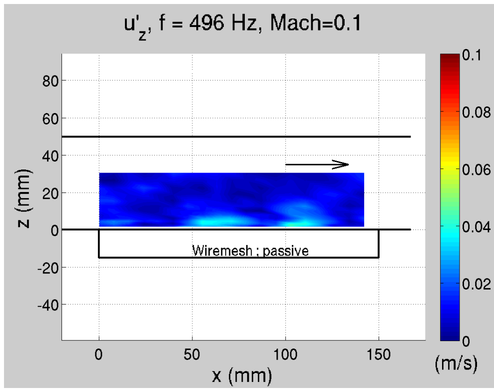
Figure 2: Acoustic velocity in z-direction at 496 Hz, comparison Feltmetal / Wiremesh screen, M = 0



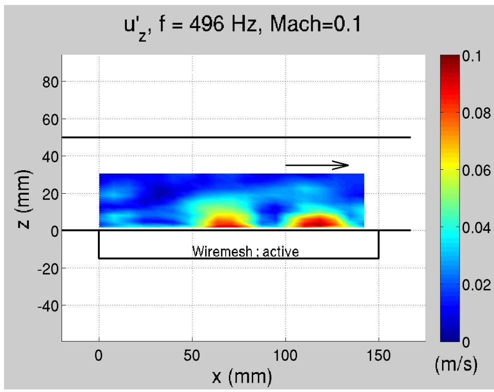
(a) Feltmetal, passive



(b) Feltmetal, active



(c) Wiremesh, passive



(d) Wiremesh, active

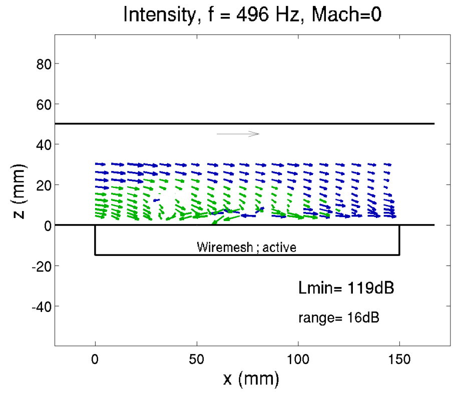
Figure 3: Acoustic velocity in z-direction at 496 Hz, comparison Feltmetal / Wiremesh screen, M = 0.1

(4). Vectors in the direction of the absorber are traced in green color. Considering the length of the intensity vectors, it can be seen that acoustic power downstream the absorber has decreased in respect to the incident power. As expected, absorption is less pronounced in presence of flow. As it has been stated already, determination of intensity requires the estimation of acoustic pressure. This estimation is subject to larger errors at low frequencies, therefore the intensity fields at 496 Hz are somewhat fuzzy. At 992 Hz, the intensity fields are much cleaner and the degradation of the liner performance in presence of flow is explicit.

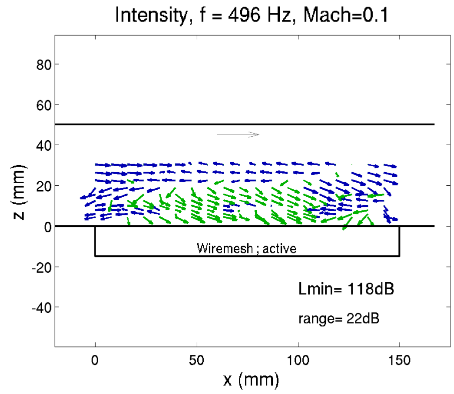
5 Conclusion

The LDV metrology of ONERA has been successfully employed for the characterization of the hybrid passive/active absorber developed at LMFA. When subject to grazing flow, these hybrid absorber suffer from an important loss of performance in respect to the no-flow case. The investigation of the local sound field by means of LDV measurements has thrown a little light on the origin of this phenomenon.
Without flow, active control permits to increase the velocity normal to the liner in a quite global way. This means that the different cells of the absorber cannot be distinguished anymore. At a certain distance, the liner appears as a homogeneous and locally reacting liner. In the presence of grazing flow, this is not the case anymore. Normal velocity is only increased in the vicinity of the cells. The liner does not appear as a homogeneous impedance condition, the influence on the duct remains local and absorption remains small.

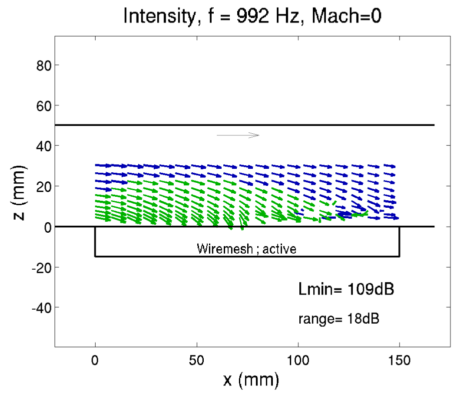
This may also explain why the no-flow performance of the liner is rather well predicted by a simplified analytical model that takes the liner into account as a homogeneous impedance boundary condition. For the case with flow, a finer modeling including splices between the hybrid cells should be performed. The B2A test bench in conjunction with a hybrid absorber in fact constitutes a unique possibility to validate such calculations.



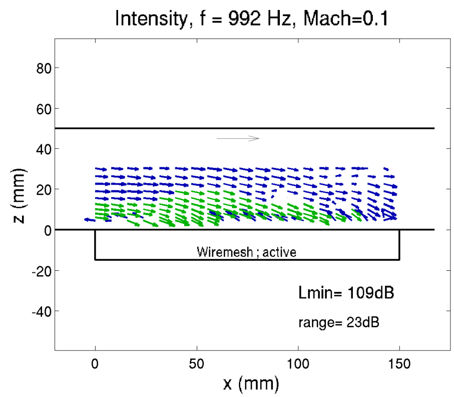
(a) 496 Hz, M=0



(b) 496 Hz, M=0.1



(c) 992 Hz, M=0



(d) 992 Hz, M=0.1

Figure 4: Active intensity at 496 Hz and 992 Hz for the wiremesh-case without and with flow, active mode

References

[1] B. Betgen and M.-A. Galland. Active Control of Complex Surface Impedance, aiaa-2009-3248. *15th AIAA/CEAS Aeroacoustics Conference*, Miami, USA, 11-13 May 2009.

[2] L. Cremer. Theorie der Luftschall-Dämpfung im Rechteckkanal mit schluckender Wand und das sich dabei ergebende höchste Dämpfungsmaß. *Acustica*, 3, 1953.

[3] B.J. Tester. The propagation and attenuation of sound in lined ducts containing uniform or "plug" flow. Journal of Sound and Vibration 28(2), 151-203, 1973

[4] M.-A. Galland, N. Sellen and M. Cuesta. Noise reduction in a flow duct: Implementation of a hybrid

passive/active solution. *Journal of Sound and Vibration*, 297, 2006.

[5] B. Mazeaud, M.-A. Galland and N. Sellen. Design of an adaptive hybrid liner for flow duct applications, AIAA-2004-2852. *10th AIAA/CEAS Aeroacoustics Conference*, Manchester, GREAT BRITAIN, May 10-12, 2004.

[6] B. Mazeaud and M.-A. Galland. A multi-channel feedback algorithm for the development of active liners to reduce noise in flow duct applications. *Mechanical Systems and Signal Processing*, 21(7), 2007.

[7] A. Minotti, F. Simon and F. Gantié Characterisation of an acoustic liner by means of Laser Doppler Velocimrtry in a subsonic flow *Aerospace Science and Technology*, 12, 398-407, 2008.

[8] J. Y. Chung. Rejection of flow noise using a coherence function method. *Journal of the Acoustical Society of America*, 62(2), pp 388-395, 1980.

[9] D. Nance and K. K. Ahuja. Limitations of the Three-Microphone Signal Enhancement Technique, AIAA 2007-441. *45th AIAA Aerospace Sciences Conference*, Reno, NV, January 2007

[10] A. Minotti, F. Simon, J. F. Piet and P. Millan. Signal processing for in-flow measurement of acoustic velocity by LDV. *8th AIAA/CEAS Aeroacoustics Conference*, Breckenridge, Colorado, June 17-19, 2002.

[11] M. Lavieille, F. Simon, and F. Micheli. Measurement of acoustic quantity fields in duct flow by Laser Doppler Velocimetry, AIAA 2006-2550. *12th AIAA/CEAS Aeroacoustics Conference*, Cambridge, Massachusetts, May 8-10, 2006.