Paper II

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EXPERIMENTAL INVESTIGATION OF A SIMPLE SYNTHETIC JET ACTUATOR FOR ACTIVE FLOW CONTROL PURPOSES

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Abstract

An experimental investigation of an actuator is carried out. The actuator consists of a loudspeaker inside a cavity covered with an aluminium plate with a slot. The experiment investigates different slots and cavity volumes, measuring the corresponding velocity profile and maximum velocity out from the slot. Results show that velocity magnitudes up to $40m/s$ is reached and corresponds to momentum coefficient of about $C_{\mu} = 1\%$.

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1 Introduction

Active flow control (AFC) is shown to be a promising technique for achieving improvements in the aerodynamics of vehicles, e.g. reducing the aerodynamic drag of trucks [1, 2]. In order to make use of this technique, a reliable and enough powerful synthetic jet (also known as zero-mass flux) actuator is to be evaluated for experimental full-scale tests. There are a large number of sophisticated synthetic jet actuators. We have chosen the most simple and cheap one. The actuator is active when the loudspeaker membrane is set in vibration; the air will be compressed out from the slot and produce a sinusoidal synthetic jet.

The aim is not to have an optimized and effective actuator, considering size, weight, effectiveness (power input) and powerfulness (maximum momentum output). The aim is to have a simple prototype model that can produce enough power and is cheap and easy to manufacture for testing purposes. This actuator has to be enough powerful in the low-frequency domain. Our frequency domain is between $15 - 20Hz$ and the goal is to reach a momentum coefficient of $0.5\% \leq C_\mu \leq 1\%$.

$$C_\mu = \frac{u_{amp}^2 \cdot h}{\frac{1}{2}w \cdot u_\infty^2} \tag{1}$$

where h is the slot width and w a characteristic length used in the model in which AFC is applied. In this case w is the width of a truck [2].

2 Experimental Setup

2.1 Overview

The experimental set up is shown in figure 1.

2.2 Calibration and hot-wire anemometry

Measurements were performed by a hot-wire probe using Dantec's DISA 56C17 anemometer. A standard Dantec's single hot-wire probe was equipped with a tungsten wire of $5\mu m$ diameter and $3mm$ length. The hot-wire was operated at the overheat ratio of 1.8.

The calibration of the hot-wire probe is performed using a calibration system (low turbulent jet), see figure 2, with a characteristic constant between the linear relation of kinetic energy achieved by the pressure difference of the contraction outlet. The actual velocity is calculated as

$$q = \Delta P \cdot 1.045, \quad \left[q = \rho \frac{u^2}{2}\right] \;\; \Rightarrow \;\; u = \sqrt{\frac{2\Delta P \cdot 1.045}{\rho}} \tag{2}$$

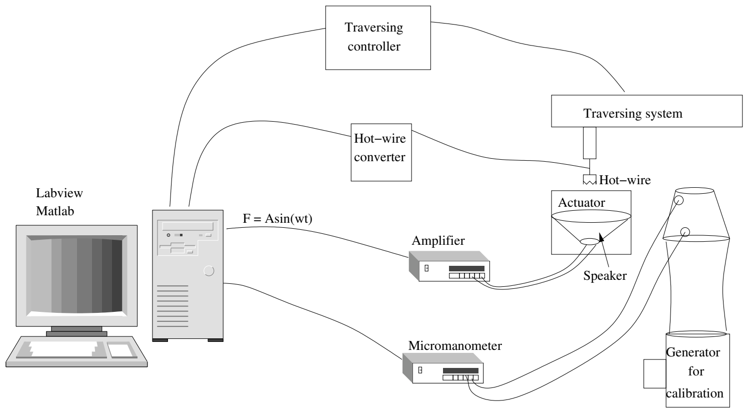


Figure 1: Schematic view of the experimental set-up.

where ρ is the air density. The pressure difference is measured by a micro manometer with user input of the ambient temperature and pressure in order to calculate the actual density of the air. The manometer has precision of 0.1% of actual pressure reading. The hot-wire was calibrated at 9 different velocities in the range from 5 to $50 m/s$. During the calibration and measurements the ambient temperature was constantly monitored and the changes in the temperature were within $\pm 0.2°C$.

The anemometer signal was digitized by the National Instruments USB 9215 16-bit analog-to-digital converter. Post processing of experimental data was performed using Matlab software package. Voltages from the hot-wire anemometer was converted to velocities by using calibration polynomials, and after this the velocity traces were statistically evaluated.

2.3 Positioning system

The calibrator and the actuator were placed closed to each other for practical purposes. A positioning system is used to move the hot-wire probe between each. The system is also used for measuring the velocity profile out from the actuator slot. The positioning system is a high-performance, multi-axis, fully-automated servo traverse system, manufactured at Chalmers.

Figure 2: The air jet generator used in the calibration procedure.

2.4 The actuator

The manufactured actuator is simple and cheap. It consist of a rectangular wood cavity ($V_1 = WxLxH = 28.3x28.4x5$ $[cm]$), loudspeaker and an aluminum plate with a by cut slot in the middle. The cavity volume can be adjusted by moving the loudspeaker, i.e. different H, see figure 3. Three volumes were investigated: V_1, $2V_1$ and $4V_1$. There are also several aluminium plates with different slots (h). The slot length is $28cm$ and the different slot widths (h) are $0.5mm$, $1.0mm$, $2.0mm$ and $5.0mm$. One slot ($2.0mm$) was also cut with a $25°$ angle to the surface. The actuator is shown in figure 4. The speaker mainly used is AUDAX PR 240 Z0 with $24cm$ diameter [3], different speakers were also investigated, see section 2.5. The running voltage was $22.0V$ RMS giving a power of $80W$. The frequency was set to $f = 16.67Hz$ which is a typical frequency used in the AFC. The actuator was well sealed inside in order to maximize the momentum output.

2.5 Speakers

Five different speakers were investigated in the same cavity volume $4V_1$ with slot width $h = 5.0mm$. The aim is to find an effective and cheap speaker available at the market. Table 1 summarize the specifications of the different speakers used [3–6]. Abbreviations used in the table: Fs is the resonance frequency and Imp is the impedance.

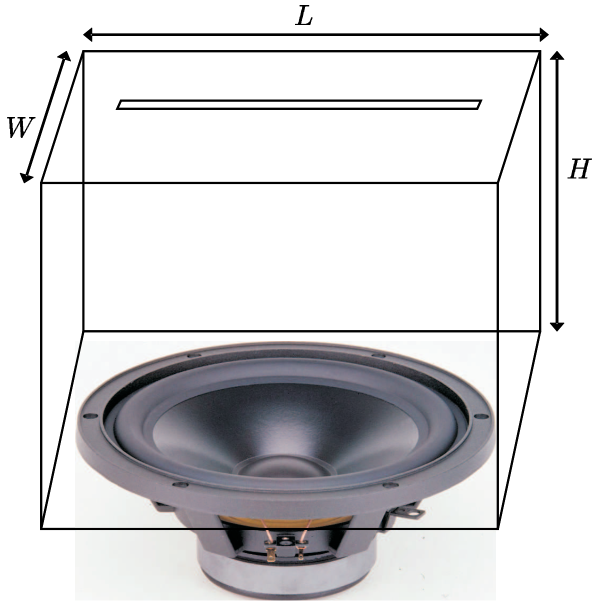
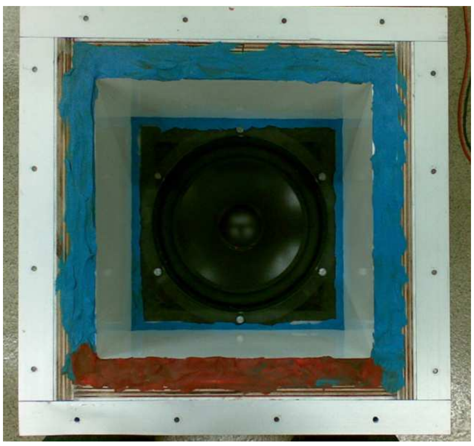


Figure 3: Schematic view of the actuator.



(a) Inside the actuator, top-down view

(b) Outside view.

Figure 4: The investigated actuator.

Brand	AUDAX	VISATON	DLS	Response	VOLVO
Type	PR 240	W250	W610	250W 10	−−
Power $[W]$	120	90	180	160	−−
Fs $[Hz]$	27	37	32.9	25.55	30
Imp $[\Omega]$	8	8	4	8	2
Weight $[Kg]$	3.6	1.5	3.7	1.7	−−
Price $[SEK]$	−−	356	1800	575	−−

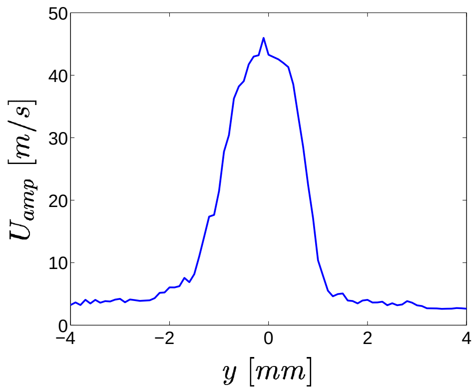
Table 1: Different speakers and specifications

3 Results

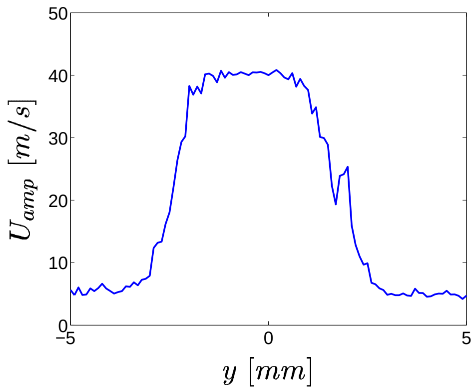
Phase averaging is adopted in order to achieve high accuracy and decrease the turbulent characteristics of the signal. The sampling rate was $f_s = 50\,000Hz$ and the number of samples $n_s = 1.5 \cdot 10^6$, thus the sampling time is $t_s = 30s$. Considering the fact that a single hot-wire is unable to measure the direction of the flow, the signal will consist of two half-periods with positive amplitude: one for the blowing and the other for the suction. A trigger signal is then placed at the beginning of each blowing which is used for phase averaging. When measuring the velocity profile, the sample time at each position is $1sec$ and the spatial resolution is $0.1mm$ with an adaptive range that covers more than the whole slot width.

3.1 Velocity profile

The velocity profiles for the most interesting slots are presented here. Those are slot widths $2.0mm$ and $5.0mm$. In each position the signal is phase averaged and then the maximum velocity signal of the time is found which is equal to u_{amp} is chosen. It is favourable to have a plug profile out from the slot so that the momentum is maximized. The profiles are plotted in figure 5. It is clear that the wider slot looks more like a plug profile.



(a) $2.0mm$ slot.

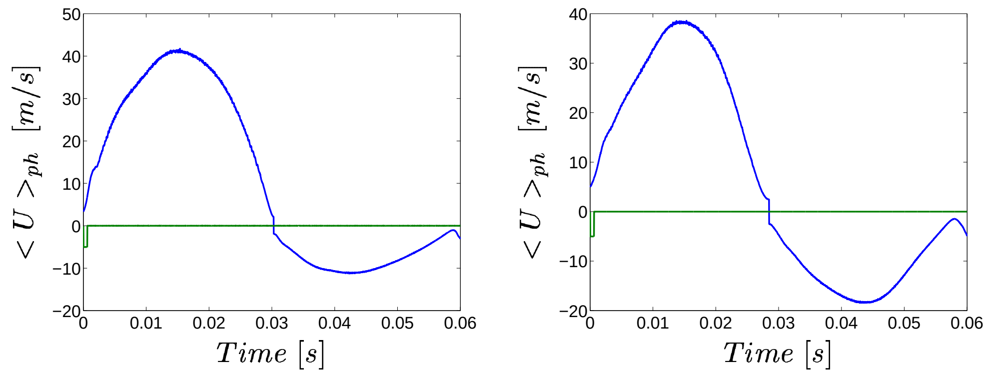


(b) $5.0mm$ slot.

Figure 5: Velocity profile out from the actuator slot for the same cavity volume.

3.2 Phase averaged velocity

At the maximum point found from section 3.1, the maximum velocity can be located, measured and phase averaged. The expectation is a sinusoidal velocity, including blowing and suction. Because the measurement take place about $1mm$ outside the slot, the suction will be weaker than the blowing. This is due to the fact that suction extracts air from all directions outside the slot into the cavity whereas the blowing is much more spatially localized. However, for the wider slot, the suction ability is improved and almost doubled. In figure 6 two different slot width results are compared.



(a) $2.0mm$ slot

(b) $5.0mm$ slot.

Figure 6: Phase averaged velocity $1mm$ outside the actuator slot. Recall that $max\,[< U >_{ph}] = U_{amp}$.

3.3 Cavity volume and slot width dependence

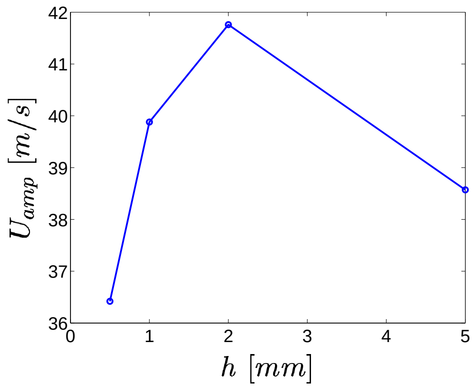
It is quite desirable to have a small cavity volume for practical purposes. Therefore the cavity volume is varied for different slot widths. Different slot widths at each cavity volume are also investigated in order to maximize the momentum coefficient defined in eq. 1

The results for the smallest and largest volumes are plotted in figures 7 and 8 respectively.

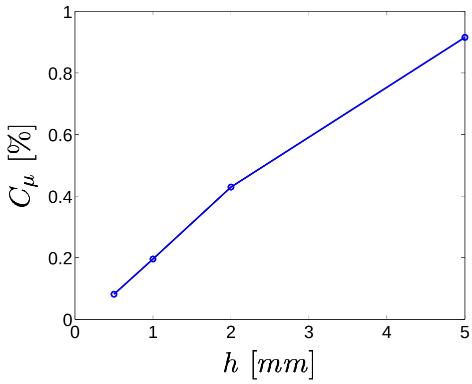
The maximum momentum coefficient is about 1% which is the desired result. Further the cavity volume (CV) dependence is shown in figure 9

3.4 Speakers

The different speakers were if possible run at three different RMS power, $60W$, $80W$ and $120W$ and two different frequencies: $F_1 = 16.67$ and the respectively resonance frequency Fs (see table 1). The results are found in figure 10.

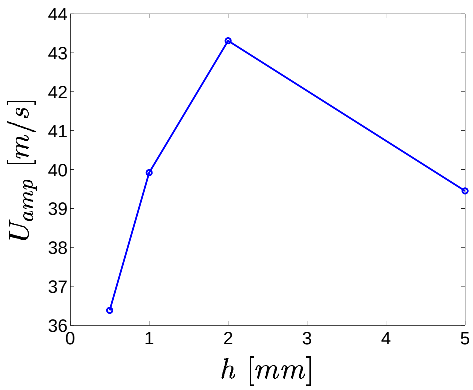


(a) Maximum velocity.

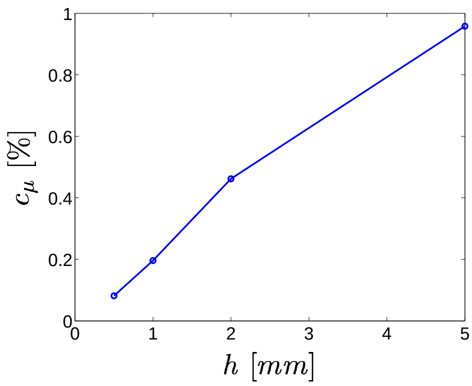


(b) Corresponding momentum coefficient.

Figure 7: Maximum velocity and C_μ with different slot width at constant volume V_1.



(a) Maximum velocity.

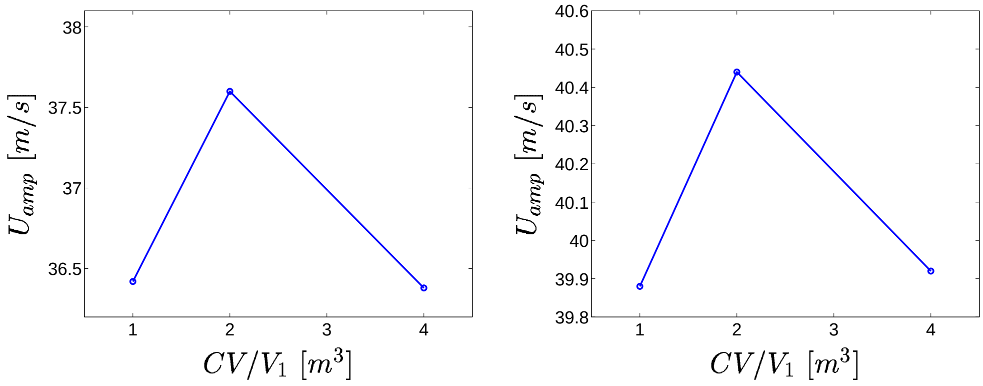


(b) Corresponding momentum coefficient.

Figure 8: Maximum velocity and C_μ with different slot width at constant volume $3V_1$.

4 Error analysis and discussion

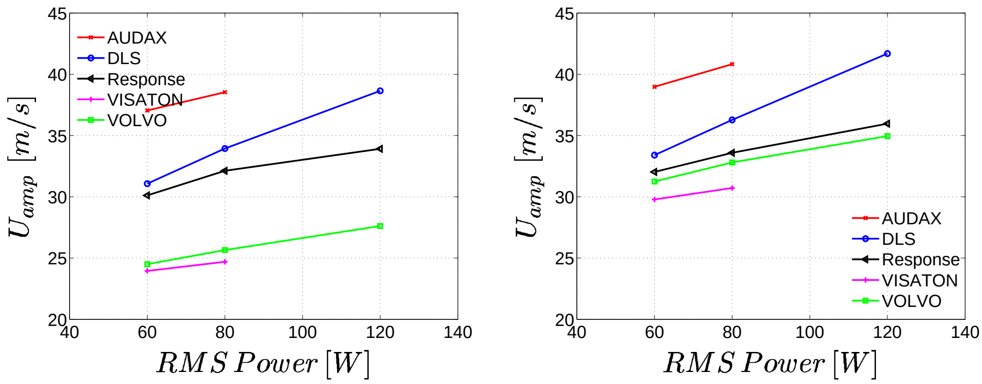
The error sources during this experiment are the calibration, deviation from the calibration curve, ambient temperature and pressure variations and data processing errors. The calibration curve has been fitted with 1% error estimation. The temperature changes during the experiment produces a larger error. During the end of measurement procedure, the hot-wire is checked in order to directly measure the error. The micro manometer showed $41.45m/s$



(a) $0.5mm$ slot

(b) $1.0mm$ slot.

Figure 9: The maximum velocity plotted along different cavity volumes.



(a) $Frequency = F_1$

(b) $Frequency = F_s$

Figure 10: The maximum velocity of different speakers versus RMS power.

and the hot-wire measured 42.09. This is an error about 1%. Adding these errors we end up with a total error estimate about $\pm 1\%$ which is about $\pm 0.5 m/s$ error when measuring velocities around $40 m/s$. In figure 9 the difference was about $1 m/s$ and hence we can conclude that the maximum velocity is independent of the cavity volume.

The aim of this experiment is not to validate any quantity nor giving extremely accurate measurements. The aim is to get an idea of the order of magnitude of the maximum velocities and momentum produced by a simple actuator.

5 Conclusions

This main aim of this experiment is to check the opportunities that one has when using simple actuators and still achieve desired momentum output. This experiment has shown that it is possible to reach $C_\mu = 1\%$. Further it was shown that the cavity volume did not have any effect of the maximum velocity achieved. This is desirable when manufacturing the devise.

6 Acknowledgments

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References

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