# Natural vortex shedding frequency and design of synthetic jet generator

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**Abstract** The paper deals with preliminary design of the synthetic jet generator. The effect of the synthetic jet to the flow field strongly depends on frequency of the synthetic jet. Frequency of the synthetic jet should correspond to the natural vortex shading frequency of the flow behind the body. This frequency can be found using Strouhal number (nondimensional frequency). The design of generator of the synthetic jet must be done with respect to the vortex shading frequency of the flow and with respect to the acoustics properties of the synthetic jet generator. Lumped Element Model (LEM), which is based on analogy between electrical and acoustic domain, for preliminary design of the synthetic jet generator can be used. Acoustics properties of the synthetic jet generator are possible to be defined applying of electro-acoustic theory to the individual part (cavity, output orifice, membrane) of the synthetic jet generator. Amplitude-frequency characteristic (output velocity x frequency) of the synthetic jet actuator is obtained from LEM.

## 1 Introduction

Synthetic jet is well known flow control techniques. By means of synthetic jet, alternating blowing and suction, is possible to lower drag, increase lift or to intensify mass and heat transfer in wide range of different applications like airplanes, cars, compressors, turbines, etc. An important advantage of the synthetic jet, comparing to a conventional blowing or suction, is a significantly lower value of the supplied momentum needed for the same effect. One of the first who showed that turbulent boundary layer separation can be controlled by synthetic jet was Seifert et al., [1]. Increase of mixing Chen et al., [2] was focused. Smith & Glezer, [3] demonstrated the possibility to use synthetic jet for jet vectoring. Summary of application of the synthetic jet for flow control particularly on airfoils was done by Greenblatt & Wygnanski, [4].

The Kelvin – Helmholtz instability can be specified as instability on boundary of streams with different velocities. Vortex structures arise at this boundary due to mixing of streams with different velocities, such as boundary layer. Frequency, which vortex structure originate is called vortex shedding frequency. Synthetic jet can influence this mixing process. The influence of the synthetic jet to mixing process – separation is positive, if frequency of the synthetic jet corresponds to the natural vortex shedding frequency. This can be described like a change of the rate of vortex structures splicing. The efficiency of the flow control by means of a synthetic jet depends on a correct design of the synthetic jet generator. The design of the synthetic jet generator must be made in relation to the character of the flow field mentioned above.

Several approaches can be used to influence the flow field by the synthetic jet. The first possibility is to use exciting frequency of the synthetic jet, which corresponds to the natural vortex shedding frequency, [1], [3], [4]. Other possibility is the application of high frequency synthetic jet with amplitude modulation, [5], [6]. Amplitude modulation is used to generate lower frequencies, which agrees with the natural vortex shedding frequency. Many authors used exciting frequency of the synthetic jet much higher comparing to frequency of the natural vortex shedding frequency. This case was explained by Dandois et al., [7].

## 2 Design of synthetic jet generator

The synthetic jet is creating vortex structures. These vortex structures originate from the interaction of the boundary layer (main flow) with pulsating stream from output orifice of the synthetic jet generator and influence the flow field downstream.

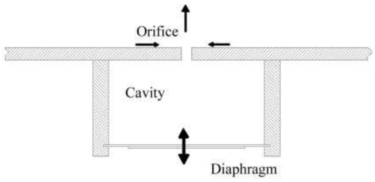


**Fig. 1:** The synthetic jet generator - schema.

The efficiency of the flow control under influence of the synthetic jet strongly depends on the exciting frequency of the synthetic jet f - nondimensional frequency $F^+$ (1). Value of nondimensional frequency $F^+$ should corresponds to the vortex shedding frequency of the flow and intensity of the synthetic jet. Optional value of nondimensional frequency $F^+$ can be set at value of 1.2, [8], [3]. This optimal value is also connected with the intensity of the synthetic jet, which is defined by unsteady momentum coefficient $c_\mu$.

$$F^+ = \frac{f \cdot X_{te}}{U_\infty} \tag{1}$$

$$c_\mu = \frac{\rho_o \cdot u_o'^2 \cdot h}{1/2 \cdot \rho_\infty \cdot U_\infty^2 \cdot l} \tag{2}$$

From relation for nondimensional frequency (1) can be express frequency f of the synthetic jet. Value of $X_{te}$ is the distance from output orifice of the synthetic jet position to the point of reattachment – mixing length. Size of output orifice h from the equation (2) can be calculated. High velocity of the synthetic jet $u_o$' can cause negative effects to the flow field, so the maximum output velocity from the synthetic jet generator should be comparable to the mean flow velocity. Minimal value of momentum coefficient $c_\mu$ is associated with nondimensional frequency $F^+$. Then minimal value of momentum coefficient $c_\mu$ corresponding to the optimal value of nondimensional frequency $F^+$ is about 0.2%, [8].

Next step is to check, if the synthetic jet fulfill criteria of existence of the synthetic jet, [9], [10], [11]. Criteria of existence of the synthetic jet is defined by nondimensional numbers: Strouhal number of output orifice of the synthetic jet generator $Sh_o$, Reynolds number of output orifice of the synthetic jet generator $Re_o$ and Stokes number of output orifice of the synthetic jet generator $St_o$..Value of Strouhal number of output orifice $Sh_o$ must be smaller than about 2 (value of $L_o$/D must be greater than 0.5) and Reynolds number $Re_H$ must be greater than about 50. Stokes number St influences the range of the synthetic jet, [9], and shape of velocity profile in output orifice of the synthetic jet generator.

## 3 Design of synthetic jet generator

Preliminary design of the synthetic jet generator can be done using Lumped Element Modeling (LEM), [12]. LEM is based on analogy between electrical and acoustic domain. Schema from Fig. 1 represents the synthetic jet generator converted to electrical circuit, see Fig. 2.

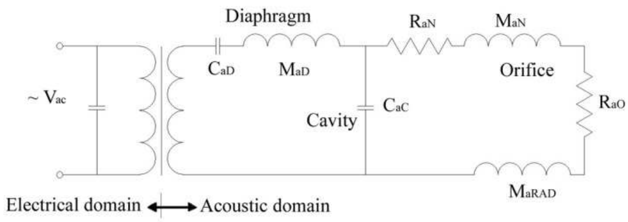


**Fig. 2:** Lumped Element Mode - equivalent electrical circuit

Individual parts of the synthetic jet generator components (Diaphragm/membrane, Cavity, and Orifice) are modeled as elements of an equivalent electrical circuit using conjugate power variables. Those variables are expressed using electro-acoustic theory, [12], [13]. Value of variables depends on geometry of generator and material properties. Impedance of electrical circuit can be calculated from above mentioned values. Impedance Z, expressed from those values, is used to calculate volume flow rate in output orifice. All variables as flow rate in output orifice, voltage and impedance are function of s = ω.j, where ω = 2.π.f. Thereafter the related equation is:

$$\frac{\dot{V}_{orifice}(s)}{U_V(s)} = \frac{da(s)}{a_4 \cdot s^4 + a_3 \cdot s^3 + a_2 \cdot s^2 + a_1 \cdot s + 1} \tag{3}$$

where „$a_i$" are constants determined via simple algebraic expression as a function of geometry and material properties. The output velocity can be calculated from size of area of output orifice of the synthetic jet generator and flow rate in output orifice Vorifice. Amplitude – frequency characteristic, dependence of velocity on exciting frequency, is shown in Fig. 3. One or two resonant frequencies from amplitude – frequency characteristic are obtained. Output velocity of the synthetic jet at these resonant frequencies reaches the maximum value.

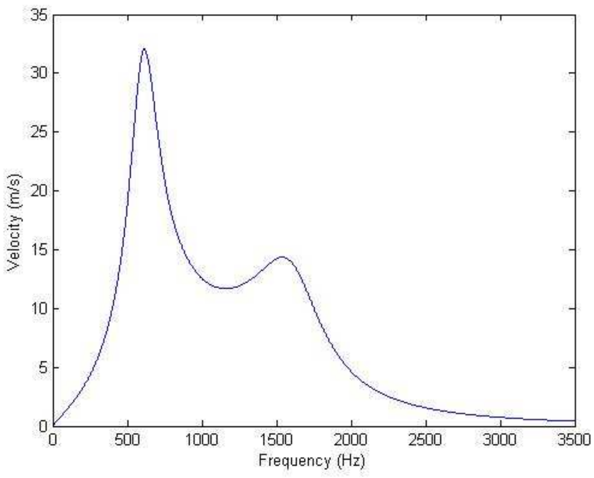


**Fig. 3:** Amplitude – frequency characteristic, dependence of velocity to exciting frequency

## 4 Conclusions

Flow control technique using synthetic jet was summarized. Corresponding frequency of the synthetic jet must be used to obtain positive influence to the flow field. Procedure for the synthetic jet generator design using LEM was introduced. Mutual dependency between natural vortex shedding frequency, exciting frequency f of the synthetic jet, intensity (momentum coefficient $c_{\mu}$) of the synthetic jet and design of the synthetic jet generator was mentioned.

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