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SIMPLIFIED OSCILLATORY BOUNDARY CONDITION FOR EFFICIENT CFD SIMULATION OF AFC EFFECT

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Abstract: *CFD simulations of the Active Flow Control (AFC) effect are usually highly time consuming and require extensive computational resources and effort. These aspects almost exclude the simulation of actuator arrays and disables AFC in the design process. This study is focused on the development of the simplified surface boundary condition of the actuator's effect on the flow field and to enable to significant reduction of the computational resources. The simplified boundary condition is based on the high-fidelity unsteady CFD simulations of the Suction and Oscillatory Blowing (SaOB) actuator in still air and takes into account the flow field variables at the actuator's exit.*

Keywords: Active Flow Control, CFD, Suction and Oscillatory Blowing actuator, boundary condition.

1. Introduction

The Active Flow Control (AFC) techniques are still regarded as a key evolution, offering new solutions for the performance maximization of existing designs. In the last decades it becomes very popular to control the flow in many aeronautical, transport and industrial applications. CFD simulations of AFC is still very challenging mainly due to the high complexity of the actuators themselves requiring very complex computational grids and also from the aerodynamic and turbulence modeling point of views. Some efforts have been done by Chow (1993), Galbraith (2006) and Vrchota (2012) to simulate the effect of AFC by surface boundary condition applying uniform flow field on it. Throshin (2014) used a Proper Orthogonal Decomposition to create reduced order model of the actuator's effect on the flow field. Lakebrink (2017) in his paper has found that it is necessary to model also the actuators' geometry or part of it at least, to enable the development of the velocity profile inside these cavities to obtain more realistic flow field at the actuator's exit. But on the other hand the embedded actuators or cavities increase the workload during the grid creation process and also make the CFD simulations more time consuming from higher number of cells point of view, especially if arrays of actuators are used. Shatzman et.al. (2015) in their paper defined the functional representation for the nozzles' oscillatory velocity profiles, which can be used as boundary conditions for a complex AFC simulation by CFD. It matched the measured velocity profile at the nozzle's exit quite well, on the other hand this representation is only 2D.

The developed boundary condition described in this paper is based on the high-fidelity CFD simulations of the internal flow field of the Suction and Oscillatory Blowing actuator developed by Arwatz (2008).

2. SaOB actuator

Oscillatory blowing is an effective tool to delay boundary-layer separation. The general idea of oscillatory blowing actuators is the use of periodic blowing through a narrow spanwise slot or array of holes to enhance shear-layer mixing and transfer high momentum fluid from outside the shear layer to the wall region and thus prevent boundary-layer separation. The SaOB actuator combines steady suction and

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oscillatory blowing, both proven to be very effective AFC tools. The actuator is a combination of an ejector and a bistable fluidic amplifier (see Fig. 1). The ejector (Fig. 1a) is a simple fluidic device based on Bernoulli's law. When a jet stream is ejected into a bigger conduit, it creates a low-pressure region around it due to entrainment. The cavity behind the jet is open to the free atmosphere or to a lower-pressure environment (such as the upper surface of an airfoil). As a result, the pressure gradient around the internal jet will cause the external air to be sucked into the cavity. More detail description of SaOB actuator and its principle can be found in Arwatz's paper (2008).

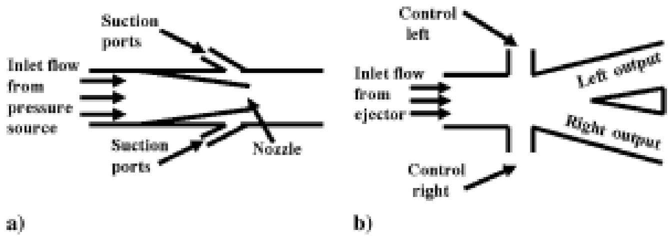

Fig. 1: Schematic rendering of the SaOB actuator: a) ejector; b) switching valve (Dolgopyat, 2014).

3. CFD simulations of SaOB actuator

The CFD simulations of the SaOB focusing on the internal flow field and on the flow at the nozzle exit have been done on isolated single SaOB actuator. These simulations corresponded to the bench top test of the SaOB in laboratory conditions without any cross flow done by Dolgopyat (2014). The main aim of this study was to obtain the time dependent flow field variables at the nozzle exit for different supply pressures.

3.1. Model's geometry

A single SaOB actuator has been used to obtain the all needed information for development of the simplified boundary condition. It is depicted in Fig. 2. The effect of the neighbouring actuators was simulated by periodic boundary conditions. These conditions were connected to the sides of the box where the suction holes are located. The boundary, where the different supply pressures were adjusted, was weak characteristic type with defined values of the pressure and temperature. The same boundary condition was used to define the suction rate through holes with prescribed ambient pressure corresponded to the pressure in the laboratory.

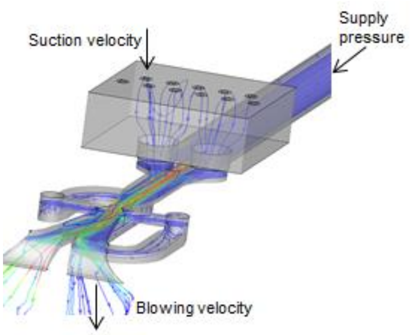

Fig. 2: Geometry of SaOB actuator used for CFD simulations.

3.2. Grid generation and flow solver

The internal grid of the SaOB actuator and the computation domain was created in Pointwise grid generation software. The grid was hybrid unstructured with a first cell height at y^+ 0.7. The grid inside the actuator has approximately 5.5 million grid points.

All simulations were carried out by means of URANS approach by an in-house CFD solver. It uses the finite volume technique to solve the governing flow equations with the EARSM k-ω turbulence model.

3.3. Verification by experimental data

The data obtained from the bench top test in the Meadow Aerodynamics Laboratory at Tel Aviv University have been used to verify the CFD results. The peak blowing velocity along the streamwise and spanwise direction at the actuator's nozzle exit has been extracted from the simulations in order to compare its value with the experimental data (see Fig. 3). The Fast Fourier Transformation (FFT) technique was used to obtain the oscillation frequency of the flow. The comparisons of the peak blowing velocity and oscillation frequency depending on the supply pressure from the simulations and experiments are depicted in Fig. 4. Very good match of the CFD results with experimental data have been reached.

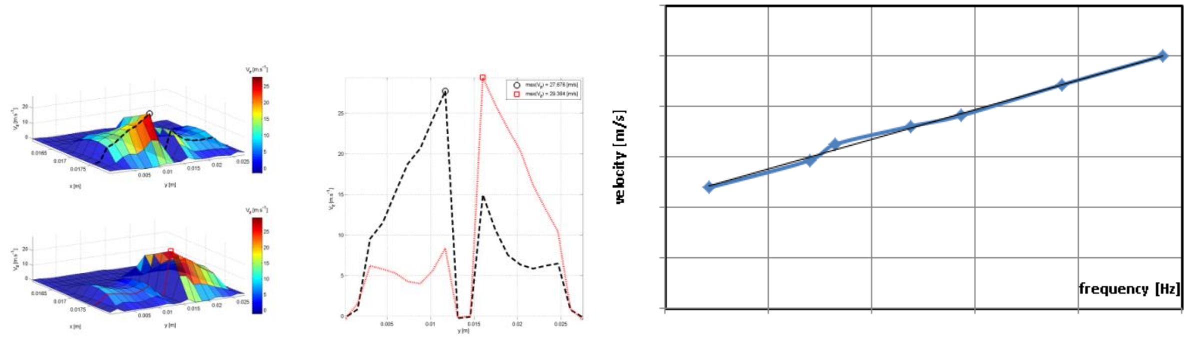

Fig. 3: Determination of the peak velocity from the surface interpolation of the velocity vector at the nozzle's exits.

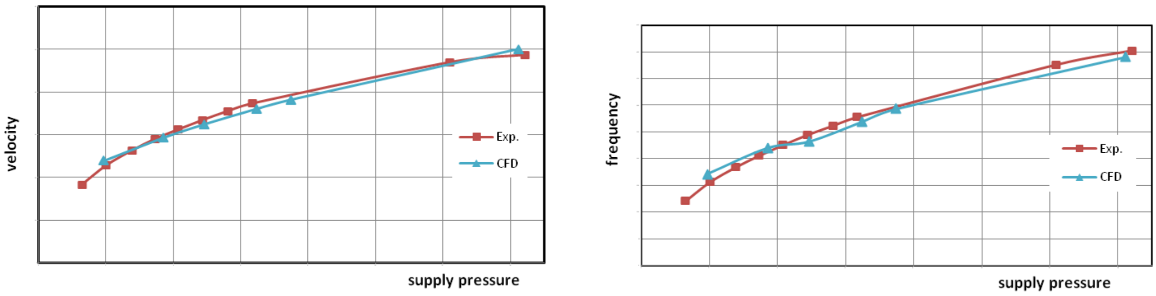

Fig. 4: Dependence of the blowing velocity and oscillation frequency on supply pressure compared with experimental data.

4. Simplified oscillatory boundary condition

The time dependent flow field variables at the actuator's exit including the frequency of the flow oscillation corresponding to the different supply pressure into the SaOB actuator have been extracted from the CFD simulations and they have been approximated by the sum of the two-dimensional Gaussian function. Example of the Gaussian function for the vertical velocity component is described by Eq. (1).

$$V^*_{z(x,y,z)} = \sum_{i=1}^{N} A_i \cdot e^{-\left(\frac{(x-x_i)^2}{2\cdot\sigma_{x_i}^2}+\frac{(y-y_i)^2}{2\cdot\sigma_{y_i}^2}\right)} \cdot \left(\sin\left(2\pi f t + \varphi_i\right) + c_i\right) \quad (1)$$

Gaussian itself is defined by the five parameters (A_i, x_i, y_i, σ_{xi}^2, σ_{yi}^2) and the character of the oscillations is described by the sine function specified by additional three parameters (oscillation frequency, phase shift and mean value). The comparison between the calculated and approximate velocity at the nozzle's exit together with the estimated error is depicted in Fig. 5. The difference between the CFD and approximated data is very small and can be neglected at this stage of the development process.

5. Conclusion

The time-dependent simplified boundary condition of the SaOB actuator in still air condition has been developed and verified for different supply pressures at the inlet of the actuator. A linear dependency of the oscillation frequency on blowing velocity has been achieved. Applying this simplified boundary condition will reduce complexity of the problem by omitting the meshing of the actuator's geometry to simulate the internal flow field and hence to save the computational resources and time. The level of complexity reduction is possible to see in Fig. 6. The whole internal geometry is omitted and replaced by the boundary condition with defined time dependent variables on it. This simplified boundary condition will enable the efficient simulations of the actuator arrays used in low-speed and high-speed engineering applications and also include the AFC technique directly into the design process.

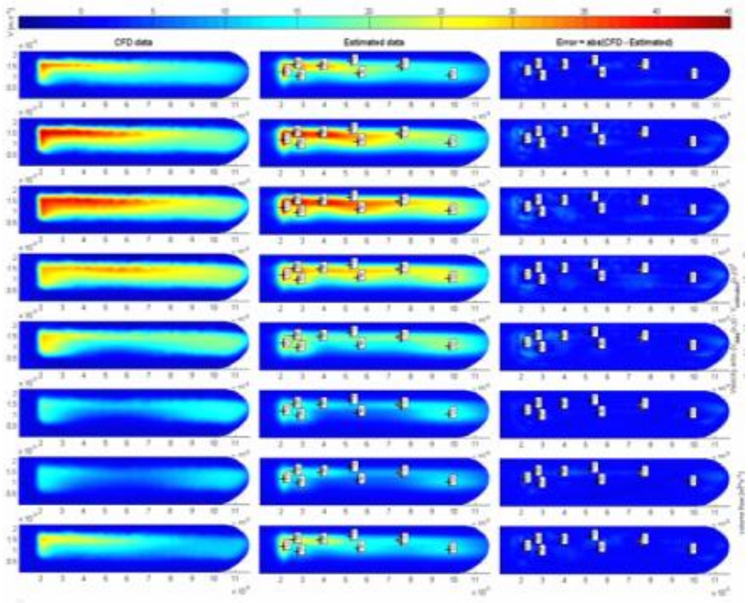

Fig. 5: Comparison of calculated and approximated vertical velocity component.

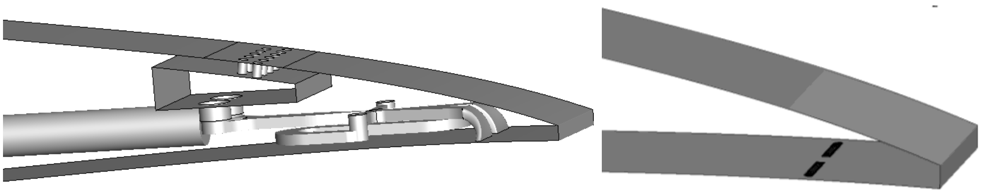

Fig. 6: Level of complexity reduction by applying boundary condition.

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