ParCFD'2019
31st International Conference on Parallel Computational Fluid Dynamics
May 14-17 2019, Antalya TURKEY

NOISE REDUCTION OF OPEN CAVITIES BY PASSIVE FLOW CONTROL METHODS AT TRANSONIC SPEEDS USING OPENFOAM

OĞUZHAN DEMIR[*], BAYRAM ÇELIK[*] AND KÜRŞAD MELIH GÜLEREN[†]

[*] Istanbul Technical University (ITU)
Faculty of Aeronautics and Astronautics
34469 Istanbul, TURKEY
e-mail: demirog16@itu.edu.tr, web page: http://www.uubf.itu.edu.tr/

[†] Eskişehir Technical University (ESTU)
Faculty of Aeronautics and Astronautics
26555 Eskişehir, TURKEY
Email: kmguleren@anadolu.edu.tr

Key words: Cavity, Passive flow control, OpenFOAM, Detached Eddy Simulation

Summary. *Flow over a cavity is one of the most intriguing and competiting problems in the field of aeronautics and aeroacoustics. Even though the geometry is simple, the physics behind the cavity is more complex than it seems. In this study, an open cavity along with the various passive flow control techniques related to aft wall modifications are analyzed numerically with Detached Eddy Simulation technique via the well-known open-source Computational Fluid Dynamics (CFD) software OpenFOAM. Numerical simulations are conducted in transonic regime, namely 0.85 Mach, for a cavity that has a length-to-depth (L/D) ratio of 5. Parallel computations of the analyses are conducted using National Center of High Performance Computing (UHeM). Results are compared with both experimental and numerical data. Contours of Mach number, turbulence intensity and OASPL are examined. It has been seen that by applying passive flow control, noise generated by cavity might decrease by ~10 dB.*

1 INTRODUCTION

Cavity flows are one of the fundamental problems in the fluid dynamics community. It has been a point of interest since 1950s[1]. The complex and highly turbulent nature of flow makes the cavity problem one of the problems that require a minute inquiry. Basically, when the flow encounters a cavity in flow direction, a shear layer above the cavity resulting from the separation of boundary layer from the front wall of the cavity takes place. Depending on the cavity type, the resultant shear layer might or might not bridge the cavity. In the case of an open cavity, where L/D ratio is smaller than 10, shear layer which has the sufficient energy to bridge the cavity impinges on the cavity aft wall. Pressure waves generated by this impingement, along with the oscillatory shear layer, generate acoustic waves which travel upstream and subsequently, noise. The schematic representation of a cavity flow can be seen in Figure 1**.**

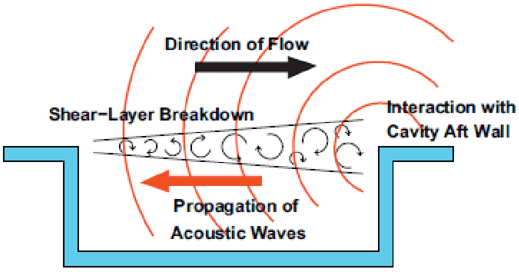

Figure 1. Schematic representation of cavity flow[2]

The major source of the noise in the cavity is the aft wall. Various passive flow control techniques such as spoilers, wall modifications, vortex generators etc. are investigated and showed that using such techniques, the noise level can be reduced.

In this study, passive flow control methods such as slanting, curving or cascading the aft wall are applied to the cavity problem. Three dimensional numerical analyses are conducted in transonic regime (0.85 Mach) for a Reynolds number of $\sim 10^7$ using OpenFOAM[3]. Mach number, turbulence intensity and OASPL contours are investigated for each case. Additionally, OASPL distributions along the cavity floor are examined to clearly see the effect of applied methods to the noise reduction.

3 PROBLEM STATEMENT

In this study, four different aft wall modifications are applied to M219 cavity case[4] which has L/D value of 5. The original, base cavity geometry which includes no modification is named as clean cavity configuration (M219CC). Applied passive flow control methods concentrate on the geometric modifications to the aft wall since the major source of the generated noise and flow oscillations is the cavity aft wall. A brief description of each conducted numerical analysis is given in Table 1**.**

Configuration	**Brief Description**
M219CC	Clean Cavity Configuration
PAW1	45° Inclination of Aft Wall
PAW2	45° Semi-Inclination of Aft Wall
PAW3	Spline-Shaped Aft Wall
PAW4	Cascading of Aft Wall

Table 1: List of studied cases in the study

3 METHODOLOGY

Open-source CFD software OpenFOAM is used in the present study. Since the flow regime is compressible, turbulent and time-dependent, rhoPimpleFoam solver is selected. A total number of 280 CPUs for each run is used for the parallelization. CFL number is kept as 1. Simulations are conducted for 50 convective time scales. Data of last 40 convective time scales are saved for the final evaluation of the results.

Cavity-region close up meshes for applied aft wall modifications together with the clean cavity is presented in Figure 2**.**

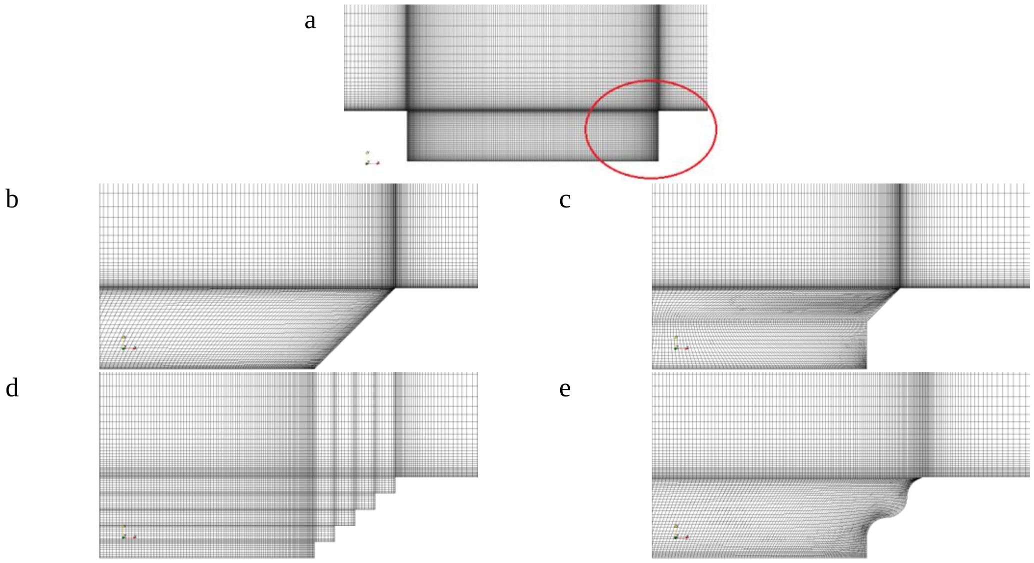

Figure 2: Applied aft wall configurations a) M219CC b) PAW1 c) PAW2 d) PAW3 e) PAW4

3 RESULTS AND CONCLUSIONS

A grid independence analysis is first conducted to validate the solution methodology. OASPL distribution at the floor of the clean cavity is compared with the experimental findings. It is seen that an error margin of ~5 dB is obtained which is acceptable since the distribution trend is similar. Longitudinal velocity profiles at the cavity are also compared with the numerical findings of an older study[5]. These results can be seen in Figure 3.

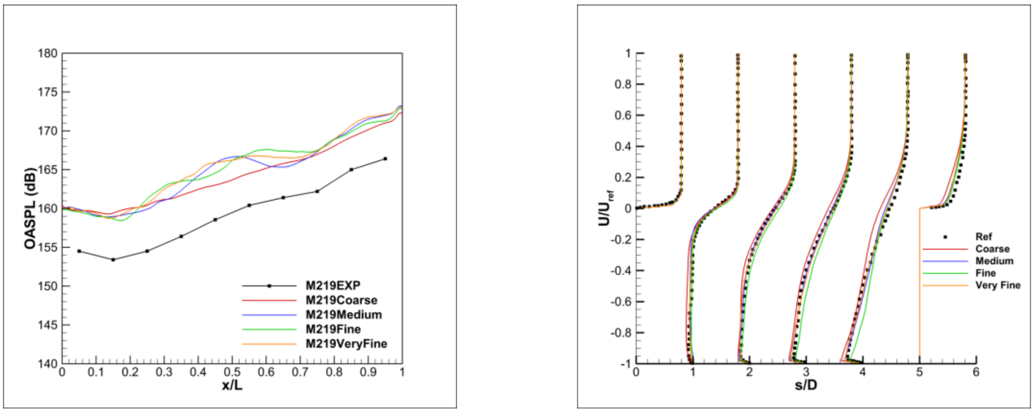

Figure 3: Cavity floor OASPL distribution comparison with experiment (left), longitudinal velocity profile comparison with numerical study (right)

OASPL distributions at the cavity for each conducted case is given in Figure 4. It can be concluded that all of the applied configurations reduced the OASPL of the cavity. PAW1 configuration which is the 45° inclination of the aft wall is the most efficient flow control technique considering the OASPL distribution. It is seen that OASPL is decreased by ~8 dB in PAW1 passive flow control method.

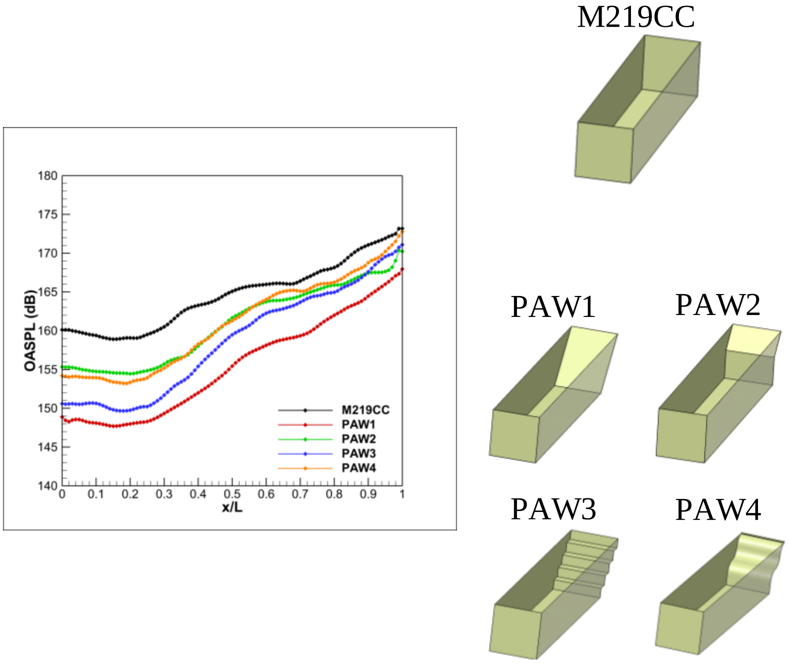

Figure 4: Cavity floor OASPL distribution of aft-wall passive control methods

ACKNOWLEDGEMENTS

Numerical analyses in this study were run on the National Center for High Speed Computing UHEM (http://en.uhem.itu.edu.tr/). This study is supported by the Turkish Aerospace Industries (https://www.tai.com.tr/en) under the grant of TM-2031. The authors are grateful to the authorized staff for their support and assistance with this study.

REFERENCES

[1] K. Krishnamurty. Acoustic radiation from two-dimensional rectangular cutouts in aerodynamic surfaces. Technical Note 3487, National Advisory Committee for Aeronautics, 1955.

[2] Lawson, S. J., and G. N. Barakos. Review of numerical simulations for high-speed, turbulent cavity flows. Progress in Aerospace Sciences, 47.3:186-216, 2011.

[3] Jasak, H., Jemcov, A., & Tukovic, Z. OpenFOAM: A C++ library for complex physics simulations. In International workshop on coupled methods in numerical dynamics (Vol. 1000, pp. 1-20). IUC Dubrovnik, Croatia.(2007, September)

[4] Henshaw, M. J. de C. M219 cavity case. In Verification and Validation Data for Computational Unsteady Aerodynamics, Tech. Rep. RTO-TR-26, AC/323(AVT)TP/19, pp. 473–480.(2000)

[5] Larchevêque, L., Sagaut, P., Le, T. H., & Comte, P. Large-eddy simulation of a compressible flow in a three-dimensional open cavity at high Reynolds number. Journal of Fluid Mechanics, 516, 265-301.(2004).