World Applied Sciences Journal 20 (3): 470-475, 2012
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2012.20.03.2664

Effect of Impinging Distance for Convective Heat Transfer of Synthetic Jet

Harinaldi, Christoforus Deberland and Damora Rhakasywi

Department of Mechanical Engineering, Faculty of Engineering,
University of Indonesia, Kampus UI-Depok, Jawa Barat, 16424, Indonesia

Abstract: Numerical simulations and experimental methods are conducted to discover the effect of various distance between the orifice and the heated plated (L). The investigation focusing on the characteristics of convective heat transfer by a synthetic jet circular orifice. The results is verified by the time history of convective heat transfer characteristic and validated against existing experimental results. The model was simulated to investigate the dispersion of heat flow on the walls using a mathematical turbulent model of k-w SST. The Reynolds number (Re) is in the range of 1421-2843 based on average velocity, while the normalized impinging distance varies between 0 and 3.3. The movement of the piezoelectric membrane is assumed of sinusoidal wave function. The results showed the significant influence of L/d Ratio and sinusoidal wave frequencies to the heat transfer rate obtained. At small axial distance (L), average Nusselts number decrease due to confinement effect. However, at larger axial distances, the synthetic jet velocity weaken which again reduces the convective heat transfer coefficient.

Key words: Cooling · Convective · Efficient · Impinging distance · Nusselts number · Optimum

INTRODUCTION

Due to miniaturization of IC (Integrated Circuit), overheating is one of the major causes for failure of electronic devices. Generally heat sinks with different fin geometries and fan arrays are used for heat dissipated with air as the working fluid. In this study, synthetic jet impingement cooling which can potentially be used for microelectronic cooling is investigated.

A synthetic jet can be described as zero-net-mass flux appliance commonly formed by suction and ejection of fluid from a small cavity [1]. Due to pulsating nature of the flow, the entraintment of ambient fluid into the synthetic jet is high if compared to that in a continuous jet, which helps in effective heat removal [2]. Synthetic jet was driven by a piezoelectric actuator membrane that has a zero net mass input but produce non-zero momentum output. Synthetic jet can be visually described as in Fig. 1.

Computational simulation work was conducted by King and Jagannatha [4] on the microelectronic cooling that agree with the increased heat load correspond with higher manufacturing process. With CFD simulation, the model

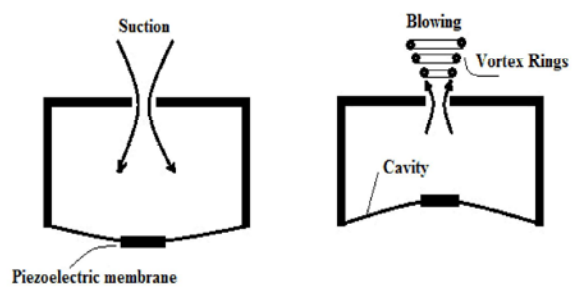

Fig. 1: Synjet Experimental Physical Ilustration

utilized a two-dimensional synthetic jet with k-ω SST turbulence model to investigate the flow turbulence intensity. Some comparisons of the heat transfer between sinusoidal and non sinusoidal operation showed higher convective heat transfer aproximately about 5 to 10 percent higher for non-sinusoidal results.

Another numerical study was conducted by Gerty *et al*. [3] that performed numerical investigation for heat dissipations of 5 W in heatsink area of 27x38 mm with thermal resistance for the heatsink is 2.61 K/W and using a variation of synthetic jet membrane excitation this thermal resistance

Corresponding Author: Harinaldi, Department of Mechanical Engineering, Faculty of Engineering, University of Indonesia, Kampus UI-Depok, Jawa Barat, 16424, Indonesia.

can be decreased to a minimum value of 1.53 K/W. These value is approximately 60% lower from the initial heatsink without performing the synthetic jet.

Another experiment was conducted in 2D computational fluid dynamics field using impinging synthetic jet methods [5]. An UDF (User Defined Function) was used to represent the motion of the membrane because the synthetic jet membrane had two phase i.e. suction and blowing. This UDF method was accurately in capacity of the membrane velocity profile that has a positive value (blowing) and negative value (suction).

Convective heat transfer is a very important aspect in synthetic jet cooling technology since the generated vortices tend to adsorb the heat from heatsink. Impinging synthetic jet as a new alternative potential technology for microelectronics cooling applications was recently studied focusing on the distribution of flow and heat transfer characteristics from jet sprayed on the surface by blowing with jet at the Reynolds number of 1100-4900 and orifice diameter of 1-6 mm [6]. The results obtained conclude a deal between measured average and fluctuating heat transfer distributions and local acceleration of synthetic jet. Travnicek and Tesar [7] reccomended that the basic goal in convective heat transfer is to move the cooling fluids as near as the heated surface and the synthetic jet impinging mechanism are influenced by the actuator geometry such as the orifice and cavity parameters.

Numerous numerical studies covering different aspects of the synthetic jet formation and applications have been carried out by earlier investigation. The primary challenge in a numerical simulation study is the modelling of the moving piezoelectric diaphragm either as moving piston [12] or moving membrane [13-15] or a wall normal initial velocity boundary condition at the orifice exit plane [8-11]

This paper also note that some of the earlier studies [8, 12, 14] have used incompressible flow solver in their numerical simulations because the frequencies employed were relatively slight, this assumption may not apply at high excitation frequencies because the rapid oscillations in the flow at high excitation frequencies can create rise to compressible flow behaviour. Most of the numerical studies in the past have simulated only a single case, over a limited piezoelectric membrane driven frequency range, with variation of some parameters such as cavity and orifices parameters. There is therefore a need to investigate the influence of individual parameters separately and compare them with a baseline case; such results can be used for maximization of synthetic jet flow by using various the distance between the orifice and the heated surface or can be called as impinging distance (L) on the ensuing synthetic jet flow.

MATERIALS AND METHODS

A computational study was performed to describe the fundamentals mechanism of a synthetic jet to the rapid increase of cooling perform over a heatsink. The computational model used to complete the analysis of heat flow field in the synthetic turbulent jet applied a mathematical model of k-ω SST (Shear Stress Transport). The work was conducted by using a commercial Computational Fluid Dynamics (CFD) FLUENT software package under a standard Finite Volume Method (FVM) computational scheme. The SST k-ω model is similar to the standard k-ω model, but includes the following refinements [16]:

- The standard k-ω model and the transformed k-ε model are both multiplied by a blending function and both models are added together. The blending function is designed to be one in the near-wall region, which activates the standard k-ω model and zero away from the surface, which activates the transformed k-ε model.
- The SST model incorporates a damped cross-diffusion derivative term in the ω equation.
- The definition of the turbulent viscosity is modified to account for the transport of the turbulent shear stress.
- The modeling constants are different.

The original design of the synthetic jet actuator used for computation is described in Fig 2. It has 6.7 cm total diameter and 2.1 cm height. It has a total of 20 outlet nozzles with 3 mm of diameter. The arrangement comprises an oscillating

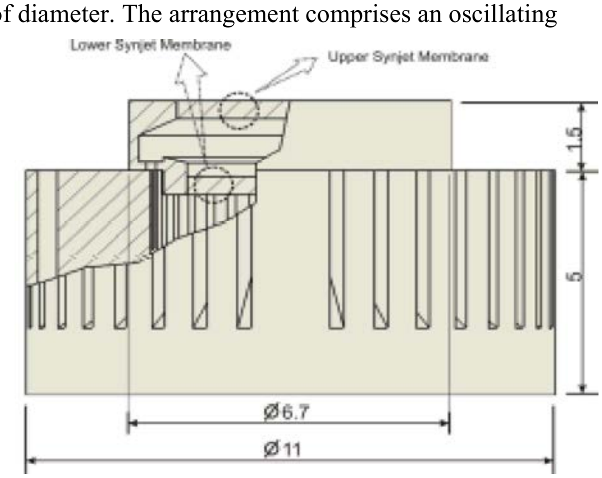

Fig. 2: Synjet Experimental Physical Ilustration

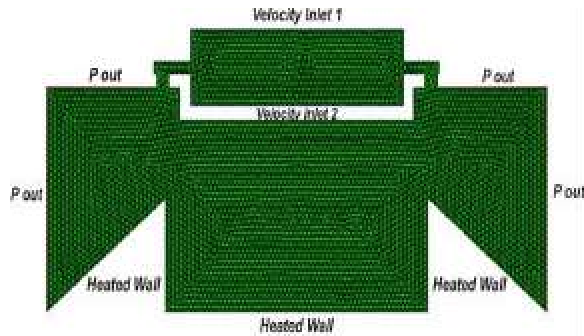

Fig. 3: Computational Domain

Table 1: Computation condition

Computation Condition		
Model Settings		2D, Unsteady
Fluid		Air
Fluid Properties	Density	1.225 kg/m^3
	Viscosity	1.7894 e^{-2} kg/m-s
	Specific Heat	1006.43 J/kg-K
	Thermal Conductivity	0.0242 W/m-K
BoundaryCondition	Velocity Inlet 1,2	UDF
	Pressure Outlet (Gauge Pressure)	0 Pascal
	Heat source	60 °C
	FrequencyExcitation	80 Hz, 120 Hz and 160 Hz
	Excitation Amplitude	1 m/s

membrane that is set in motion back and forth forcing fluid inside the cavity to flow through a nozzle which is located at the bottom of synthetic jet. In its suction motion, the membrane imparts the ejectted air of high-speed into the surrounding fluid while the retreating membrane draws fluid back from the surroundings into the cavity. The membrane operation over one cycle depends on it selected frequency. The jet delivers very high net outflow of fluid momentum, consequently very intense cooling rates while having no net change of fluid mass within the cavity. Due to this unique ability, this jet flow is known as a synthetic jet or Zero-Net-Mass-Flux (ZNMF) jet.

The present study proposed a new periodic jet cooling configuration. A structured mesh was developed for the solution domain with the mesh generation facility GAMBIT as shown in Fig 3. As the working fluid, air was assumed to be isothermal and incompressible. The thermodynamic properties of air were taken to be at 30 °C under standard atmospheric conditions.

The heated wall at the bottom of the domain where the jet impingement occurs, was maintained at an isothermal temperature of 60 °C. The boundaries on either side of the actuator were treated as constant static pressure outlets with a pressure of one atmosphere. The movement of the diaphragm was modelled with a user defined function that incorporated dynamic layering technique. Segregated solution method with implicit solver formulation was used as the solution algorithm while the second order discretization schemes were employed for density, momentum, pressure, turbulence kinetic energy, specific dissipation rate and energy. The normalized impinging distance (L/d) is various in range of 0-3.3.

In this study, the jet flow occurs in oscillatory manner within a confined region. It is predicted that turbulence would be induced in some regions of the domain while the flow would mostly remain under laminar conditions indicated by low values of the Reynolds number encountered. Table 1 shows the computational conditions of the simulation to the impinging synthetic jets model. The parameters used in the simulation include the model settings, fluid, fluid properties and the value of boundary condition.

In order to describe the diaphragm movement in the present study, a special user defined function (UDF) was developed and used along with the solver [7]. By using excitation frequencies Sine 80 Hz, Sine 120 Hz and Sine 160 Hz.

The quality of results is verified by time history of convective heat transfer studies and the results are validated against existing experimental data. Experimental activities were carried out by measuring the temperature at the heatsink using a digital thermometer for 120 minutes. The heatsink module used in this study has circular form with 32 fins. The material was made of aluminum. The heatsink diameter was 11 cm and height of 5 cm. Heat source was obtained from the heater mat at 60°C which was controlled by using a thermostat. Measurements were performed using k-Thermocouple under open conditions at ambient temperature 30°C. The impinging synthetic jets modul used in this study were constructed in the form of a cylinder cavity having two piezoelectric membrane at the top and bottom. Piezoelectric wass working to move the surrounding fluid in order to remove the air from the nozzle. Impinging synthetic jet nozzle had 20 exits hole each with outlet diameter of 3 mm. The casing was made of nylon material that could be assembled easily.

Fig. 4 shows the detail of the experimental apparatus used in this study which consisted of the thermostat, heater mat, impinging synthetic jet module, heat sink and DAQ (Data Acquisition).

Dimensional parameters in this studies as depicted in Fig. 5 includes distance between the orifice and the heated surface (L) or can be called as impinging distance on the ensuing synthetic jet flow and diameter of circular orifis (d).

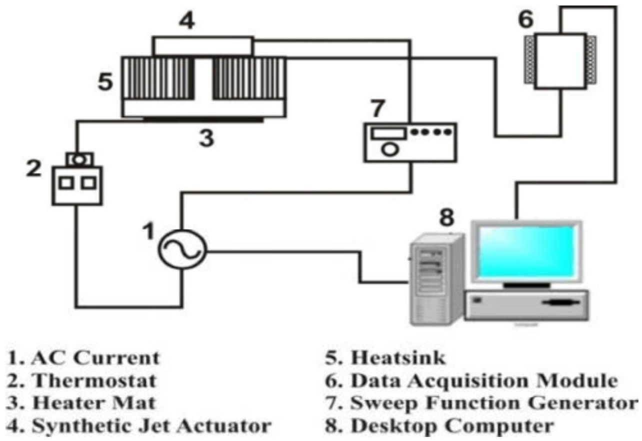

Fig. 4: Experimental Apparatus

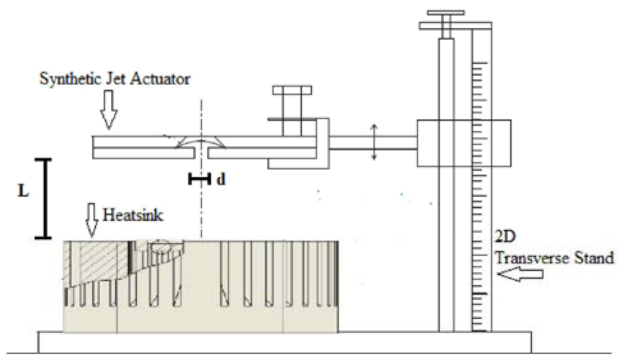

Fig. 5: Dimensional parameters.

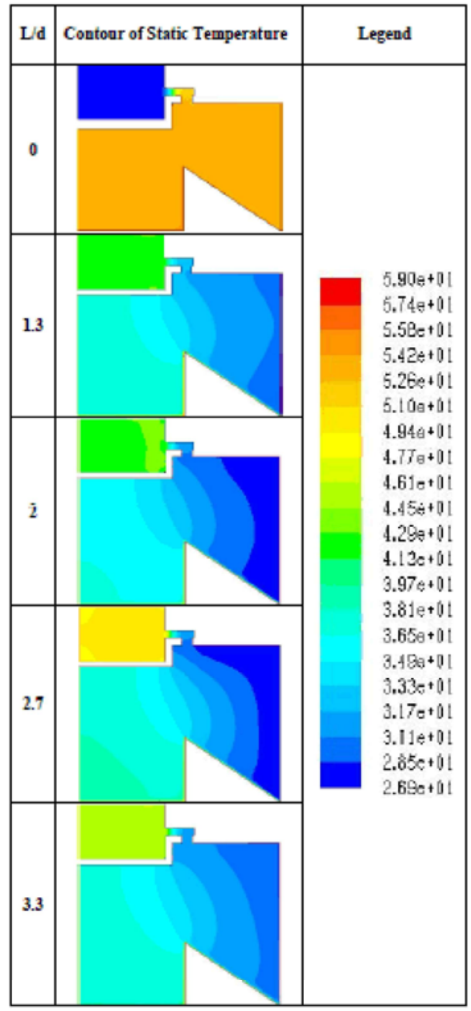

Fig. 6: Contour of Static Temperatur Sine 160Hz

RESULTS AND DISCUSSION

The air generated by the synthetic jet membrane is desired to take away the heat. This process is time dependent, and in each time the temperature is different until it reaches constant phase. Fig. 6 below shows a static temperature contours development after 60 minutes. These contours indicate the temperature condition inside and outside the cavity along the heat sink.

At zero impinging distance (L/d 0), the heat is penetrating the cavity through the outlet nozzle. However, after 60 minutes the heat has been accumulated in the small axial distance near orifice. There is some natural convection phenomenon in the middle area of the heatsink. This heat is rising instead of being blown away by the synthetic jet flow. Recirculation of fluid occurs due to confinement, owing to the presence of the orifice plate.

At L/d 1.3, there is small increase of air in the cavity. With an increase in the axial distance, the amount and strength of the recirculation decreases so the convective heat transfer get enhanced. At L/d 2, impinging distance were increase so the confinement effect decrease, this is the optimum cooling with excitation sine 160Hz which can be seen from the contours which are dominated by low temperature region. Inside air of cavity not too accumulated with heat from heated wall.

At L/d 2.7, air in cavity have increasing temperature. So the cooling perfomance does not increase due to the increase of impinging distance. And at L/d 3.3, cooling perfomance reduces. It seems that, at large axial distances, the jet velocity reduces due to entrainment of still ambient air which again reduces the heat transfer coefficient.

The decrease the heat sink temperature computationally obtained for one hour of heating under the influence of synthetic jet cooling with the variation of sine 160 Hz is shown in Fig. 7. From simulation, the significant temperature decrease occoured in 20-30 minutes after synthetic jet activated. The highest temperature drop was found in variation L/d 2 that is 1.62°C.

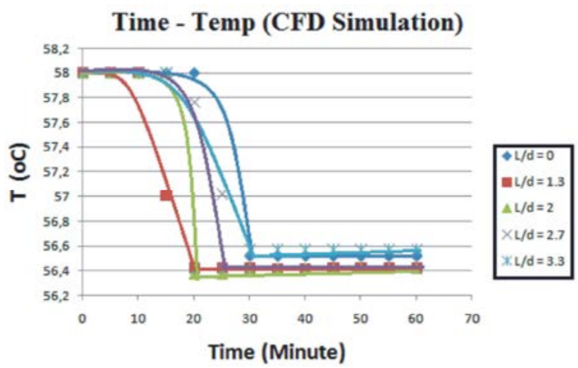

Fig. 7: Time-Temperature by CFD Simulation

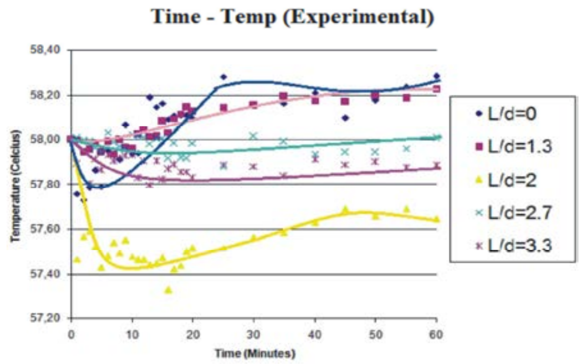

Fig. 8: Time-Temperature by Experimental.

The measurement results of heat sink temperature obtained in an open space conditions within time period of 60 minutes are described in Fig. 8. The figure shows the results of the case synthetic jet cooling under sine 160 Hz and various of impinging distance normalized to orifice diameter (L/d). From the experimental study, the significant temperature decrease occured in 10-20 minutes after synthetic jet activated. The highest temperature drop was found in variation L/d 2 that is 0.88°C

Fig. 9 shows the variation of the average Nusselt number versus the normalized axial distance. From CFD simulation, average Nusselt number increase up to certain impinging distance and then reduce abruptly with high gradient. From L/d 0 Up to L/d 2. This result suggest that confinement effect due to presence or heated wall decrease, so the convective heat transfer increase. However, after L/d 2, the velocity of synthetic jet does not significantly decrease the temperature.

Fig. 10 shows the variation of the average Nusselts number versus the normalized axial distance, from the experimental work, it can be seen that the trend of average Nusselts number has similiar to result from computational simulation. The Nusselts number increase up to L/d 2 and then reduce with smaller gradient if compared to CFD simulation result.

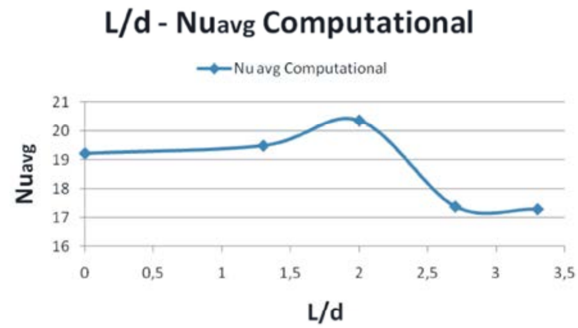

Fig. 9: L/d-Nusselt Average (Nu_{avg}) by CFD Simulation.

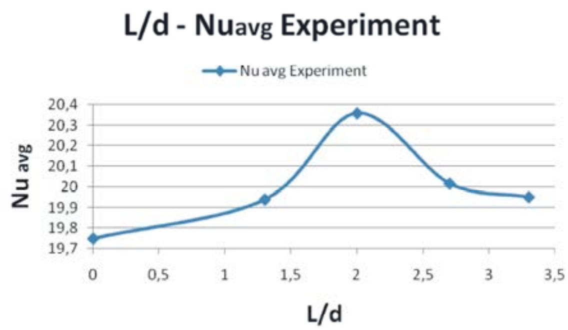

Fig. 10: L/d-Nusselt Average (Nu_{avg}) by Experimental.

CONCLUSION

The heat transfer experiments and CFD simulation are conducted using synthetic jet with various impinging distance normalized to diameter of orifis (L/d). The synthetic jet working under sine wave forcing with various of Impinging distance (L) has been studied on its effect to the cooling of an impinged heated wall. The simulation result indicate that excitation frequency of sine 160 Hz with L/d 2 supports the highest temperature reduction. The average Nusselt number increases up to a certain axial distance and then reduces. Recirculation of fluid occurs due to confinement, owing to the presence of the orifice plate. With an increase in the impinging distance, the amount and strength of the recirculation decreases, so that the confinement effect decrease and eventually leading to an increase in the heat transfer coefficient. However, at larger axial distances, the jet velocity reduces due to entrainment of still ambient air, which again reduces the heat transfer coefficient

ACKNOWLEDGMENTS

This work was supported within the DRPM-UI program of the University of Indonesia (project number 1927/H2.R12.2.1/HKP.05.00/2012).

REFERENCES

1. Smith, B.L. and A. Glezer, 1998. The Formation and Evolution of Synthetic Jets. Physics of Fluid, 10: 2281-2297
2. Chaudhari, M., B. Puranik and A. Agrawal, 2009. Heat transfer characteristics of synthetic jet impingement cooling, International Journal of Heat and Mass Transfer, heat mass transfer, 11: 005.
3. Gerty, D., D.W. Gerlach, Y.K. Joshi and A. Glezer, 2007. Development of a Prototype Thermal Management Solution for 3-D Stacked Chip Electronics by Interleaved Solid Spreaders and Synthetic Jets. ©EDA Publishing/Therminic 2007. ISBN: 978-2-35500-002-7.
4. King, A.J.C. and D. Jagannatha, 2009. Simulation of Synthetic Jets With Non-Sinusoidal Forcing Functions for Heat Transfer Applications. 18th World IMACS/MODSIM Congress, Cairns, Australia 13-17 July 2009. pp: 1732-1738.
5. Jagannatha, D., R. Narayanaswamy and T.T. Chandratilleke, 2007. Performance Characteristics of A Synthetic Jet Module For Electronic Cooling. 10th UK Heat Transfer Conference in International Symposium On phase Change, Session 1, Heat Exchanger.
6. McGuinn, A., T. Persoons, P. Valiorgue, T.S. O'Donovan and D.B. Murray, 2008. Heat Transfer Measurements of an Impinging Synthetic Air Jet With Constant Stroke Length, The 5th European Thermal Sciences Conference, The Netherlands.
7. Travnicek, Z. and V. Tesar, 2005. Pulsating and Synthetic Impinging Jets, Journal of Flow Visualization, 8(3): 201-208.
8. Kral, L.D., F.D. John, A.B. Cain and W.C. Andrew, 1997. Numerical simulation of synthetic jet actuators, AIAA, pp: 97-1824.
9. Rizzetta, D.P., M.R. Visbal and M.J. Stanek, 1999. Numerical investigation of synthetic jet flow fields, AIAA J., 37: 919.
10. Lee, C.Y. and D.B. Goldstein, 2002. Two-dimensional synthetic jet simulation, AIAA J., 40: 510.
11. Mallinson, S.G., J.A. Reizes and G. Hong, 2001. An experimental and numerical study of synthetic jet flow, Aeronaut. J., 105: 41.
12. Fugal, S.R., B.L. Smith and R.E. Spall, 2005. Displacement amplitude scaling of a twodimensional synthetic jet, Phys. Fluids, 17: 045103.
13. Mallinson, S.G., C.Y. Kwok and J.A. Reizes, 2003. Numerical simulation of microfabricated zero mass-flux jet actuators, Sens. Actuators A, 105: 229.
14. Tang, H. and S. Zhong, 2005. 2D numerical study of circular synthetic jets in quiescent flows, Aeronaut. J., 109: 89.
15. Mane, P., K. Mossi, A. Rostami, R. Bryant and N. Castro, 2007. Piezoelectric actuators as synthetic jet: cavity dimension effects, J. Intelligent Mater. Syst. Struct, 18: 1175.
16. User's Guide Manual of Fluent 6.3.26 September 2006.