Vortical Structures of an Impinging Jet in Cross-flow

K. Kucinskas[1]

[1]University of Hartford, Bloomfield, CT, USA

Abstract

COMSOL Multiphysics® was utilized to generate a computational fluid dynamics simulation of an impinging jet in a cross-flow. The k-ε model for turbulence available in the 3D single phase flow module was used to evaluate an airflow experiment of an impinging jet against a cube surface from previous literature as detailed in Fig. 1. This resulting complex three dimensional vortices and flow phenomenon were compared to prior studies using velocity contour plots as presented in Fig. 2. The model was then altered utilizing the hydraulic analogy for an experiment planned within a water tunnel that will maximize the visualization capabilities of the secondary flows that develop. Solutions to this hydraulic version of the study were completed in both steady and time dependent states. The results were examined through non-dimensionalized comparisons of the velocity components to previous work, steady state cross-sectional data throughout the computational domain, and time dependent data. The features of the flow structures and insight into the physics that form them are established.

The structure of the complex three dimensional flow can be seen in Fig. 3 streamline plots. A low velocity and kinetic energy horseshoe vortex forms at the front edge of the cube. At the rear side of the cube the upwash and downwash vortices form that result in an area of high turbulent kinetic energy. Compared to previous literature the COMSOL k-epsilon model indicates considerable agreement with the results. The study presented here however depicts an increasing diameter of the counter-rotating vortex pairs as the flow progresses in the computational domain. It also portrays a less rigidly defined diameter of the downwash vortices. The non-dimensionalized analysis of the axial velocity component divided by the average jet velocity at multiple cut planes of the computational domain further reiterate these subtle differences in flow as depicted in Fig. 4.

Conclusions regarding the flow development are made through comparison of the steady and time dependent results of the COMSOL k-epsilon model to vortical structures from a study completed by Rodi et al. without the presence of a jet at the top face. The up-wash vortex and the low velocity pocket at the top of the cube face are solely due to dynamics created by the cross-flow. The other aspects of the flow are due to the impinging jet interacting with the cross-flow.

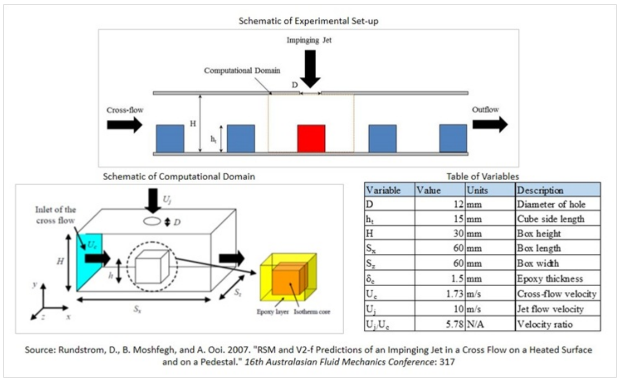
By utilizing the CFD model results found in this examination, a future study in a water tunnel can be completed where the predicted can be compared with actual experimental data. Confirming the existence, size, and shape of the vortex structures will further validate this study. This physical experiment will be made possible by the refurbishment and construction of a water table donated

to the University of Hartford and summarized in the next section.

Reference

1. Davidson, P. A. 2004. Turbulence: An Introduction for Scientists and Engineers. Oxford: Oxford UP
2. Holley, Brian Matthew. 2008. Surface Measurements of Flow in a Plane Turbine Cascade. Ph. D. diss. University of Connecticut
3. Kumar. V., I. Ng., G.J. Sheard, K. Hourigan, A. Fouras. 2009. "Hydraulic Analogy Examination of Underexpanded Jet Shock Cells using Reference Image Topography." 8th International Symposium on Particle Image Velocimetry – PIV09, August 25-28 in Melbourne Australia
4. NASA. Flow Visualization Facility. http://www.nasa.gov/centers/dryden/history/pastprojects/FVF/index_prt.htm (accessed July 15, 2013)
5. Rodi, W., J. H. Ferziger, M. Breuer, and M. Pourquiée. 1997. "Status of Large Eddy Simulation: Results of a Workshop." Journal of Fluids Engineering 119.2: 256
6. Rundstrom, D., B. Moshfegh, and A. Ooi. 2007. "RSM and V2-f Predictions of an Impinging Jet in a Cross Flow on a Heated Surface and on a Pedestal." 16th Australasian Fluid Mechanics Conference: 316-323.
7. Rundstrom, D., and B. Moshfegh. 2009. "Large-eddy Simulation of an Impinging Jet in a Cross-flow on a Heated Wall-mounted Cube." International Journal of Heat and Mass Transfer 52.3-4: 921-31.
8. Tummers, M. J., M. A. Flikweert, K. Hanjalic, R. Rodink, and B. Moshfesh. 2005. "Impinging Jet Cooling of Wall-mounted Cubes." Proceedings of ERCOFTAC International Symposium on Engineering Turbulence Modeling and Measurements - ETMM6: 773-782

Figures used in the abstract



Variable	Value	Units	Description
D	12	mm	Diameter of hole
h_t	15	mm	Cube side length
H	30	mm	Box height
S_x	60	mm	Box length
S_z	60	mm	Box width
δ_c	1.5	mm	Epoxy thickness
U_c	1.73	m/s	Cross-flow velocity
U_j	10	m/s	Jet flow velocity
U_j/U_c	5.78	N/A	Velocity ratio

Figure 1: Experimental Setup and Computational Domain.

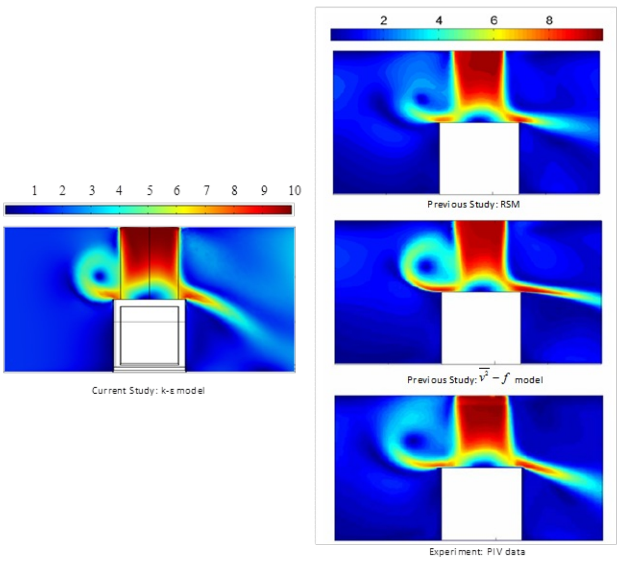


Figure 2: Velocity Profile Comparison.

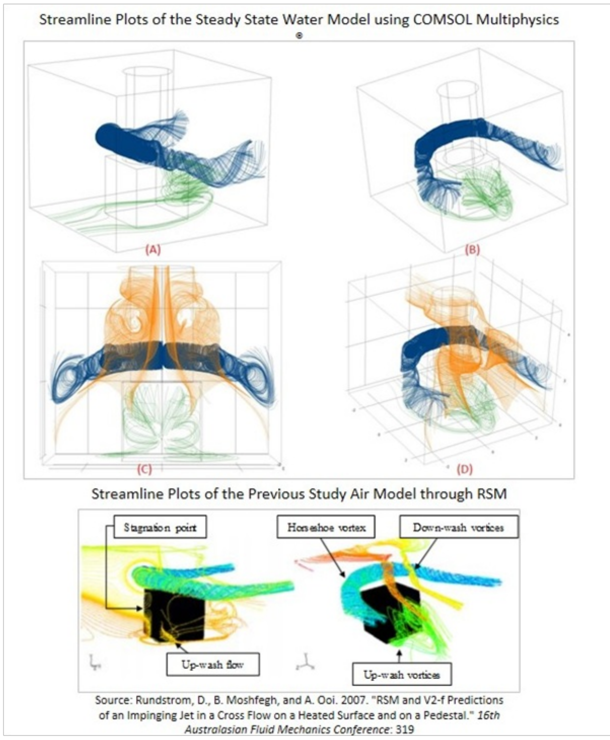


Figure 3: Streamline Plots.

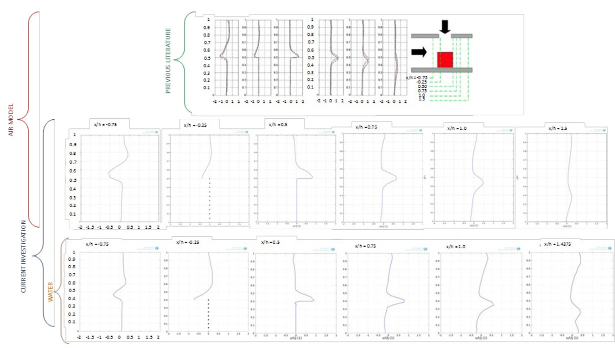


Figure 4: Non-dimensionalized comparison of velocity (u/Uj) at various cut planes of x/ht.