Süleyman Demirel Üniversitesi
Mühendislik Bilimleri ve Tasarım Dergisi
2(3),ÖS:BiyoMekanik2014, 293-297, 2014
ISSN: 1308-6693

Suleyman Demirel University
Journal of Engineering Sciences and Design
2(3),SI:BioMechanics2014, 293-297, 2014
ISSN: 1308-6693

UNDERSTANDING FLOW CHARACTERISTICS OF SWIMMING SQUID USING 2D AXISYMMETRIC NUMERICAL MODEL

Mahdi TABATABAEI[1], Ali Bahadır OLCAY*[2], Gökhan GÖKÇEN[3], Abdulkerim OKBAZ[1], Hasan A. HEPERKAN[1]

[1]Yildiz Technical University, Faculty of Mechanical Engineering, Istanbul, 34349, Turkey
[2]Yeditepe University, Mechanical Engineering Department, stanbul, 34755, Turkey
[3]Dogus University, Mechanical Engineering Department, Istanbul, 34722, Turkey

Keywords
Numerical Solution
Moving wall
Jet propulsion
Squid

Abstract
Squids in nature generate pulsed jet to be able to move by expelling high pressure water through funnel in a short period of time. In this study, unsteady jet flow of squids was investigated during its fast swimming phase. Numerical model has been generated from a real squid's computer tomography images. 2D axisymmetric jet flow has been simulated by using dynamic mesh to mimic the motion of squid's mantle cavity wall. Specifically, diameter of the squid's mantle cavity decreases from 13 cm to 4 cm and a periodic sine velocity profile has been defined for squid's mantle cavity wall. Besides, the funnel of squid seems to be a 3 cm long nozzle which has about 3 cm and 0.5 cm diameters at the inlet and outlet, respectively. Physical behaviors of jet flow has been investigated to be able to calculate change of ejected fluid's momentum and flow energy in this study

1. Introduction

Jet propulsion is a system that causes acceleration during movement forward. Squids can move by a combination of fin and jet propulsion that propel themselves. In this study, we focus on characteristics of the squid jet system because jet propulsion appears to be providing high forward speeds. Bartol and Krueger (2009) investigated jet propulsion of squids by using experimental methods. They used DPIV technique to obtain velocity and vorticity vector fields of the domain and they explained relation between jet angel and speed. Anderson and Grosenbaugh (2005) perused squid locomotion that includes jet propulsion and fin. He exposed effect of relative between fin and jet propulsion. Squid can change fin shape at high speeds and the fins use to control its dynamic balance. Characteristics of vortex ring formation were studied by some researchers experimentally and numerically (Gharib et al. (1997); Rosenfeld et al. (1998); Olcay and Krueger (2009)). They used cylinder and piston mechanism for ejecting water into motionless water to explain the formation of vortex rings in a jet flow. Behavior of vortex ring is different and it is highly depend on L/D. When L/D was greater than about 3.6-4.5, a trail of vorticity followed head vortex ring (Gharib et al. (1997)). Bera et all. 2001 studied a purely alternating jet with zero mass-flux and a mixed pulsed jet with an additional blowing component via particle image velocimetry (PIV). The jets was emanated from a two-dimensional slit connected to a converging nozzle opening normally from a flat wall. The pulsatile motion of the jet was achieved by a loudspeaker. It was stated that a large lateral expansion of the jet and a large entrainment rate of external fluid occurred for unsteady jets, compared to usual steady jets. They concluded that in the case of purely alternating jet, the expansion took place close to the slit, on the other hand in the case of mixed pulsed jet the vortices developed farther from the orifice.Jing-lei et al 2007 experimentally investigated the instantaneous flow characteristics of a circular orifice synthetic jet, including the forming, developing and breaking down of the vortex of the jet via phase-locked Particle Image Velocimetry method. They changed orifice depths from 1.5 mm to 2 mm and 3.5 mm in order to study the effect of orifice depth on the flow structure. It was concluded that the peak of the mass flux and momentum flux increased as the orifice depth increased. Carpy and Manceau 2006 studied the ability of different turbulence models to close the phase-averaged Navier-Stokes equations of statistically periodic Synthetic jet flows. They compared their results with literature. They showed that the evolution of the vortex dipole generated by inviscid mechanisms was essentially inviscid during the early blowing phase, when the flow was more transitional than fully turbulent. Bremhorst and Gehrke 2000 investigated fully pulsed air jet exhausting into still air examining turbulent kinetic energy budges in the jet flow. Measurements were conducted via hot-wire anemometers. Quasi-steady jet was achieved by pulsing with very low Strouhal numbers. They concluded that axial diffusion of turbulent energy varied strongly with distance but radial diffusion was almost self-similar for the region

*Corresponding author: bahadir.olcay@yeditepe.edu.tr

investigated. Kim et al 2008 examined the two-time-scale irrotational-strain-sensitized turbulence model in literature comparing experimental data for steady and fully-pulsed turbulent round jets. The fully-pulsed turbulent round jets was simulated for over a range of frequencies from 2 to 10 Hz. Ma et al. 2012 examined and compared two cases with different simulation methods in low Reynolds number laminar flow. They used periodic velocity inlet and dynamic mesh boundary conditions to simulate oscillatory piston of synthetic jet. They revealed that the vortex dye-structure was almost same outside of cave and the velocity profiles near the orifice were different distinctly on 0° and 180° phase, the max speed difference at center of orifice was about 0.017m/s at the end of third period, which increased by 150% of the simulating results with dynamic mesh boundary method. At least they concluded that the simulation method with dynamic mesh was more reasonable because it was realistic motion of piston. Hsu et al. 2013 conducted experiments to compare flow fields of non-zero-net-mass-flux double-acting synthetic jets and single-acting synthetic jets was performed with water as the working fluid. The actuation frequencies were changed in the range of 2 Hz to 12 Hz. They concluded that double-acting synthetic jets revealed good potential with significant vorticity enhancement for the design of synthetic jet in heat transfer applications. Yang et al. 2010 presented a study to illustrate a framework for combining Digital Particle Image Velocimetry measurements with Lagrangian analysis tools that analyze the starting vortex ring generated by a thin circular disk. They showed that the existence of a flux window between repelling Lagrangian Coherent Structures and attracting Lagrangian Coherent Structures, though that the shear flow was entrained into vortex. The results showed that the vortex formation process was completed at time t=2714 ms.

2. Materials and Methods

A squid contracts its mantle cavity wall in order to pressurize the enclosed water in the mantle cavity prior to ejection of water. Once the squid starts to eject this pressurized water, mantle cavity wall must contract to provide required pressure for the jet flow. In this study, we investigated squid locomotion by using numerical methods by a commercial CFD package namely Ansys-Fluent. The geometry of domin is axisymmetric thus plane of axial (x) and radial (r) direction is shown in Figure 1. The domain area is 300 D in length and 40 D in height while 26 D is the length of mantle wall, 6 D is the nozzle length and 6 D is nozzle inlet diameter where D is the jet exit diameter. Squid's mantle cavity wall was moved during jet ejection by mimicking mantle cavity contraction. Geometry of squid's mantle cavity wall and domain used for jet propulsion analysis are shown in Figure 1-A. Dynamic mesh method was utilized to move squid's mantle cavity walls. In this method, mantle cavity wall diameter decreases from 13cm to 4 cm at 1 second time period. This wall movement is programmed such that wall actually follows a periodic sine velocity profile as shown in Fig.2a thru 2f. Movement of squid's mantle wall forces the fluid to accelerate passing through nozzle (enlarged view is given in Figure 1b). Once the fluid passes thru the nozzle exit plane, it enters to the solution domain where impulse and kinetic energy calculations are performed.

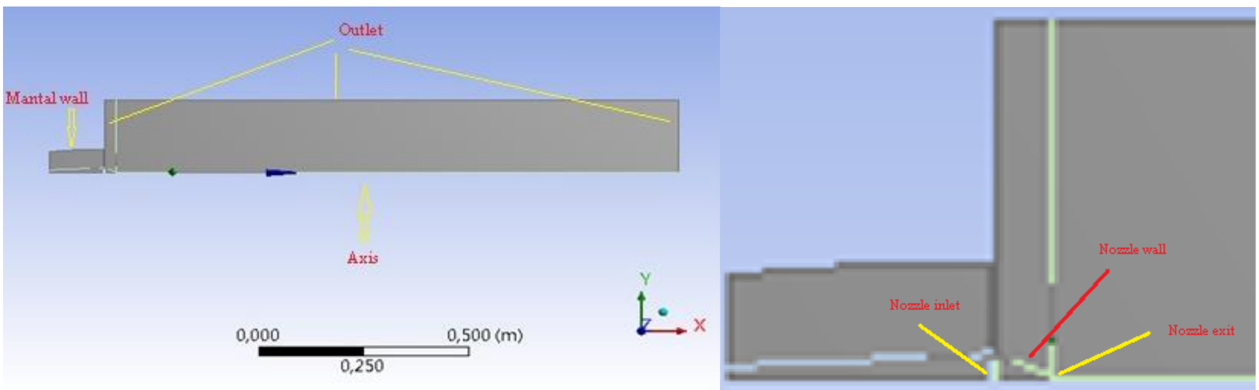
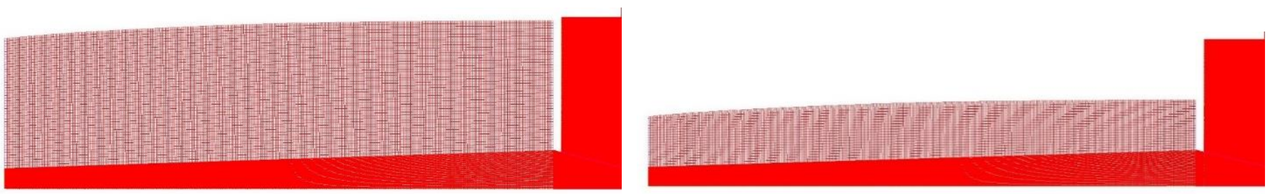


Figure 1. a) Analysis domain of jet flow and squid mantle simulation, **b)** Enlarged view of nozzle



(a) t = 0s

(d) t = 0.6s

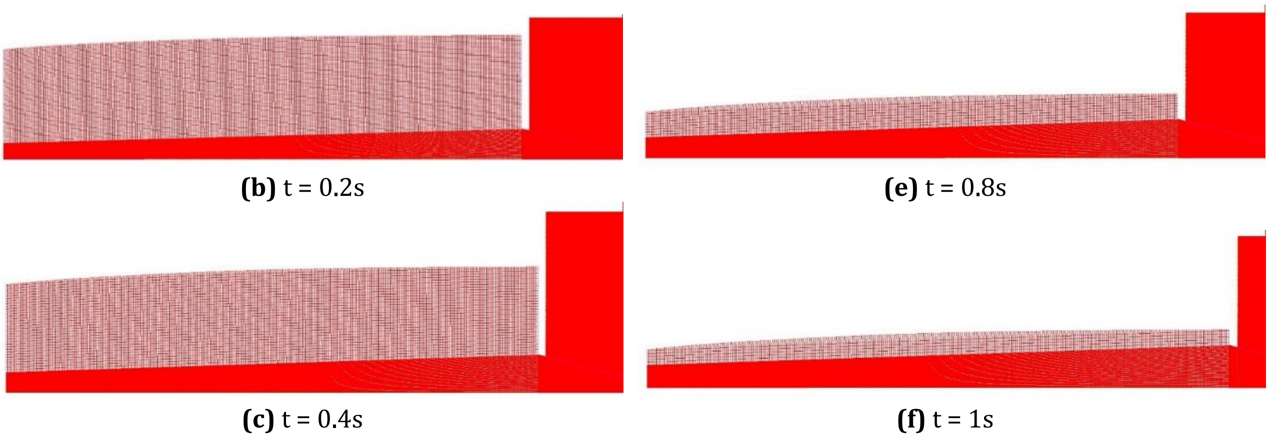


Figure 2. Wall movements at different time points

3. Results

In this study, we investigated jet flow that was generated by squid in 1s periodic time. the behaviors of velocity magnitude in various time shown Fig. 3a thru 3f. By moving mantle cavity wall of squid the fluid flows at nozzle and jet flow starts to generate in the nozzle then develop on fluid field.

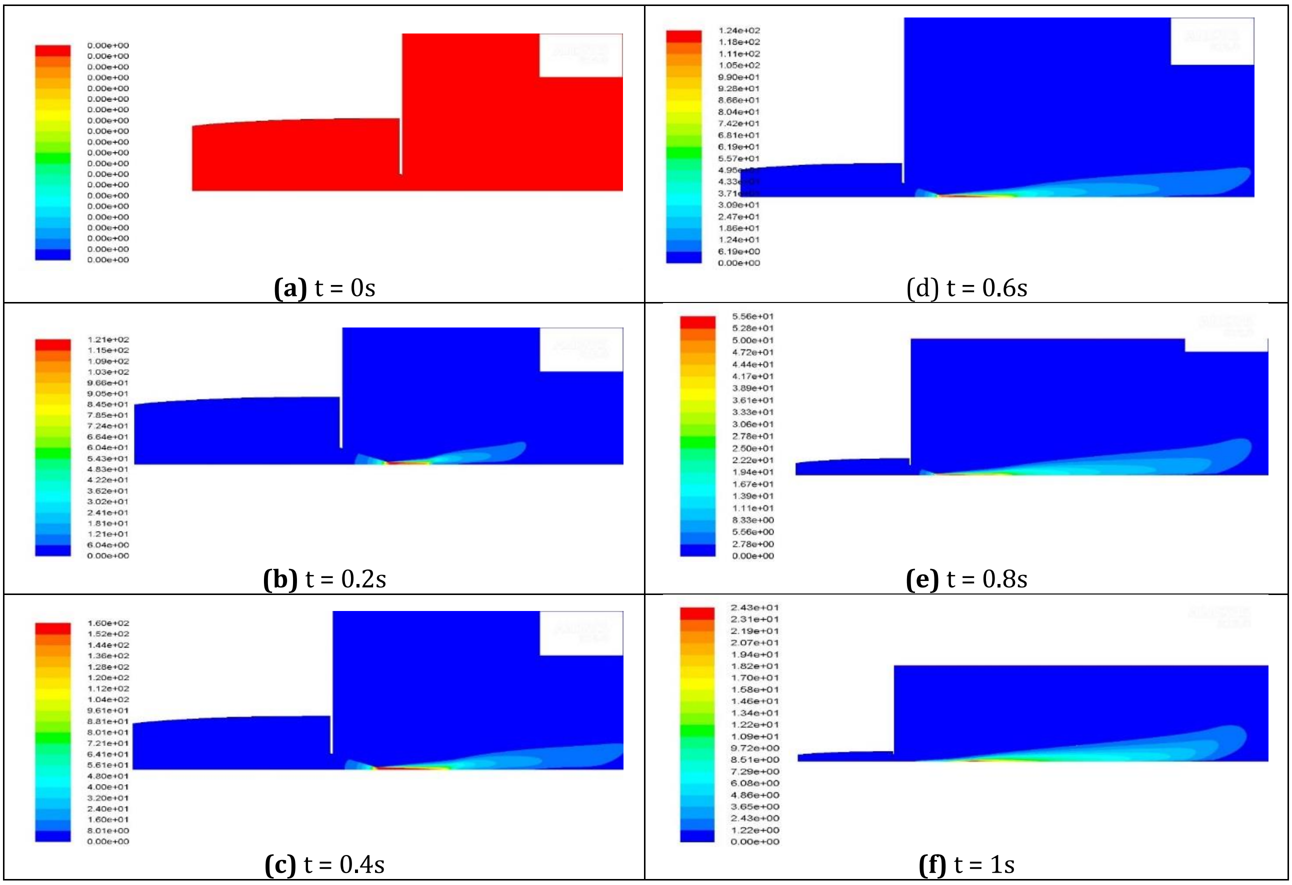


Figure 3. Velocity magnitudes at different time points

The hydraulic impulse (Olcay and Krueger, 2009) of jet flow that was created by fluid movement is shown in Figure 4. It is noted that highest impulse is achieved when squid ejects water at 0.25 seconds that refers to Reynolds number of 2,542,372. When kinetic energy calculations are performed, it is also realized that highest energy is left to the flow field at Reynolds number of 2,542,372. Besides, when jet duration is increased to 0.5 seconds from 0.25 seconds, value of kinetic energy drops more than half.

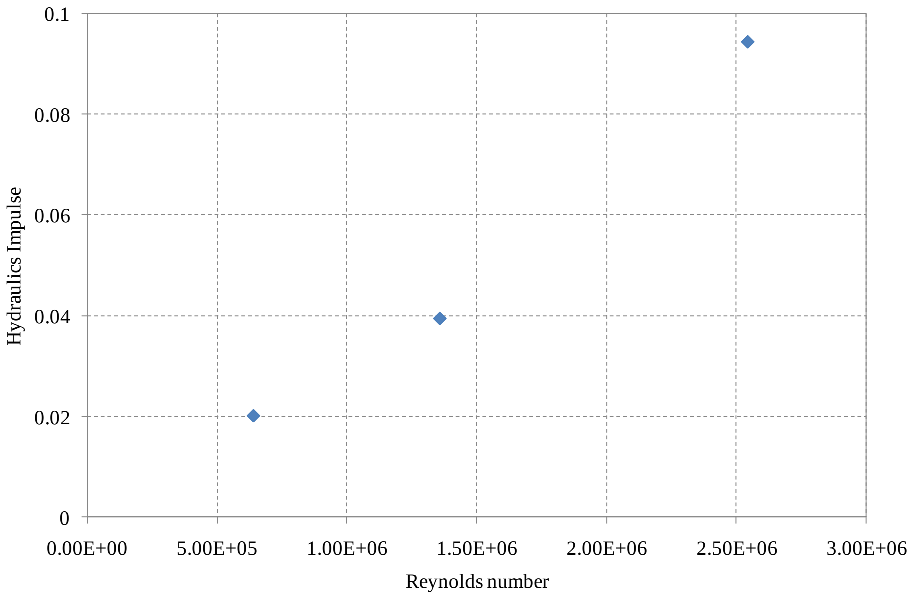


Figure 4 Impulse of jet flow

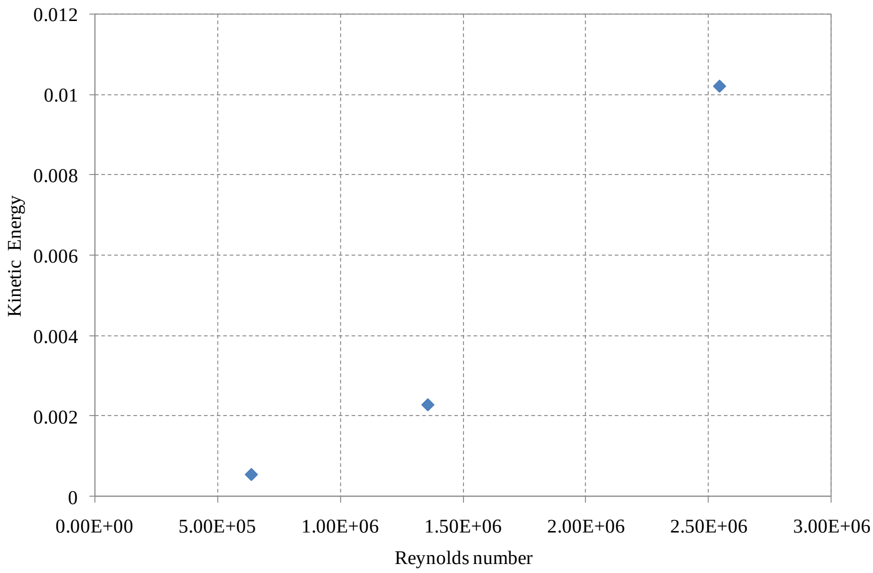


Figure 5 Kinetic energy of jet flow

4. Discussion and conclusion

Squid propel themselves by using jet propulsion. Briefly, squid compresses the mantle cavity wall and pressurized water is ejected thru nozzle. This jet flow has a high momentum that generates locomotive force thus squid moves forward. Jet flow was studied in this paper and dynamic mesh was utilized for modeling of mantle wall movement.

Acknowledgements

This work has been supported by TUBITAK (The Scientific and Technological Research Council of Turkey) under 3501 Program, Project #: 111M598.

Conflict of Interest

No conflict of interest was declared by the authors.

5. References

Anderson, E. J., Grosenbaugh, M. A., 2005. Jet Flow in Steady Adult Squid. The Journal of Experimental Biology, 208, 1125-1146.

Bartol, L. K., Krueger, P. S., 2009. Hydrodynamics of pulsed jetting in juvenile and adult brief squid Lolliguncula brevis: evidence of multiple jet 'modes' and their implications for propulsive efficiency. The Journal of Experimental Biology, Vol. 376212, 1889-1903.

Bera,J. C., Michard, M., Grosjien, N., Comte-Bellot, G., 2001. Flow analysis of two-dimensional pulsed jets by particle image velocimetry. Experiments in Fluids, 31, 519-532

Bremhorst, K.,Gehrke, P. J., 2000. Measured Reynolds stress distributions and energy budgetsof a fully pulsed round air jet. Experiments in Fluids, 28, 519-531

Carpy, S., Manceau, R., 2006. Turbulence modelling of statistically periodic flows: Synthetic jet into quiescent air. International Journal of Heat and Fluid Flow, 27, 756–767

Gharib, M., Rambod, E., Shariff, K., 1997. A universal time scale for vortex ring formation. J. Fluid Mech., 360, 121-140

Hsua,S.-S., TravnicekZ., Choua,C.-Ch., Chen,C.-C., Wang, A.-B., 2013. Comparison of double-acting and single-acting synthetic jets. Sensors and Actuators A, 203, 291– 299

Jing-lei, X.U., Jiang, S., Chun-Feng, L., Kun-Yuan, Z., 2007. PIV experımental research of ınstantaneous flow characterıstıcs of cırcular orıfice. Synthetıc Jet, Ser.B, 19(4), 453-458

Kim, K.R., Cotton, M.A., Craft T.J., 2008. Heynes, O.R., On the dynamics and frequency response of fully-pulsed turbulent round jets: Computations using two-time-scale/strain-sensitized eddy viscosity models, International Journal of Heat and Fluid Flow, 29, 1650–1669

Olcay, A. B., Krueger, P. S., 2010. Momentum evolution of ejected and entrained fluid during laminar vortex ring formation. Theor. Comput. Fluid Dyn., 24, 465-482

Rosenfeld, M., Ramond, E., Gharib, M., 1998. Circulation and formation number of laminar vortex rings.. J. Fluid Mech., 376, 297-318

Xiaoyong, M., Hongtao, G., Zhaolin, F., Lin, Z., 2012. Investigating of Simulation Methods for Synthetic Jet, Procedia Engineering, 31, 416 – 421

Yang, A., Jia, L., Yin, X., 2010. Experimental Study of a Starting Vortex Ring Generated by a Thin Circular Disk. Journal of Bionic Engineering 7 Suppl., 103–108.