Süleyman Demirel Üniversitesi
Mühendislik Bilimleri ve Tasarım Dergisi
2(3),ÖS:BiyoMekanik2014, 287-291, 2014
ISSN: 1308-6693

Suleyman Demirel University
Journal of Engineering Sciences and Design
2(3),SI:BioMechanics2014, 287-291, 2014
ISSN: 1308-6693

INVESTIGATION OF HYDRODYNAMIC DRAG IN A SWIMMING SQUID

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, Istanbul, 34755, Turkey
[3]Dogus University, Mechanical Engineering Department, Istanbul, 34722, Turkey

Keywords
Hydrodynamic Drag
Swimming
Fineness Ratio
Squids

Abstract
In this study, hydrodynamic drag on an adult squid was investigated during its fast swimming phase. Numerical model has been generated from a real squid's computer tomography images. It has been documented that squids can typically swim at velocities from 3.21 m/s to 9.23 m/s under the water. Therefore, by considering the flow on squid's surface and behind the squid, variation of drag coefficients (at these velocities) has been studied for the squid having about 7.58 fineness ratio. It has been noted that streamlined shape of the squid affects drag force associated with total wetted surface area and flow separation; more specifically, streamlined shape both helps to have delayed flow separation and in return to have lower drag coefficient.

1. Introduction

Swimming techniques of marine animals for developing new technologies have been attracted many engineers and researchers. The shape of modern submarines and ship are an example that engineer applies for design. One of the marine animals that is studied by researchers is a squid. Squid can move very fast under water and control its propulsion by providing high velocity in a short time period and obtain high swimming performance. Many marine animals swimming performance were investigated by researcher such as squid, sea lion, dolphin and penguin. The drag is a resistance force for forward motion and it has been used for comparing swimming performances. A streamlined body shape is most important to reduce drag in a high viscosity environment and swimming performance in under water animals (Fish, 1996; Fish, 2008). Relation between Reynolds number and drag coefficient in marine animals was studied experimentally by Stelle (2000). He measured drag coefficient and boundary layer thickness in Sea Lion by using video analysis. Fish (1993) defined swimming of dolphins at different velocities in large pools. The study includes coefficient of drag and lift in different angle of attack and the maximum angle of attack causes a linear decrease with velocity. Locomotion of squid was determined by O'Dor (1988). He applied video model for calculating drag coefficient and lift coefficient in different speeds and mantle diameters because squid mantle diameter change when it accelerates forward.

Rahman et. al. studied flow computation around the swimming motion of a squid-like robot with two undulating side fins, mimicking those of a Stingray or a Cuttlefish. They did numerical simulations for various aspect ratios, fin angles and frequencies in order to validate the proposed relationship among principal dimensions. They discussed flow characteristics and hydrodynamic forces acting on the body and fin. They established a simple relationship among the fin's principal dimensions. Yu et all 2011numerically investigated a fish's mechanical capability and suitable timing to execute maneuvers from a steady straight-line swimming state. They calculated longitudinal forces and yaw moment acting on a fish for varied slip number. They concluded that decreasing slip number increases mechanical capability for a fish to execute both longitudinal and sideway maneuvers because the amplitudes of both net longitudinal force coefficient and net yaw moment coefficient are enhanced. Yi-gang and De-cheng 2012 investigated numerically the self-propelled motion of a fish with a pair of rigid pectoral fins. They developed a Navier-Stokes equation solver incorporating with the multi-block and overset grid method to deal with the multi-body and moving body problems. It is concluded that the fin can generate great thrust and at the same time have no generation of lift force for the lift-swimming mode. On the other hand they investigated unsteady flow features such as periodic vortex structure generation and shedding.

Eloy 2012 evaluated the swimming performances of aquatic animals using the dimensionless quantity Strouhal number. Experimental observations showed that flapping foils had maximum propulsive efficiency in the interval $0.25<St<0.35$. Polidori et al 2006studied determining skin-friction drag analysis in underwater swimming quantifying the effect of the temperature gradient between swimmer's body and pool water. In steady flow conditions, they determined surface shear stresses and the skin-friction drags. They concluded that the skin-friction drag decreased 5.3%, independently from swimming speeds, with increasing average boundary-layer temperature provided that the flow remained laminar. Loebbecke

* Corresponding author: mtabatabaei66@hotmail.com

et al 2009 investigated olympic level athletes swimming underwater using the dolphin kick. Swimming velocity is varied in the range of 1.12 and 1.85 which corresponded to a range of effort levels. They measured body length, time taken by the swimmer to traverse a body length, kick amplitude at the toes. Using these parameters average velocity of the swimmer, kick frequency, the reduced or length-specific velocity and the non-dimensional quantities kick amplitude were determined. They concluded that human and cataceans had comparable non-dimensional kick amplitudes, but kick frequency in humans was greater than for cetaceans swimming at equivalent speeds.

In this study, we investigate the total body drag (skin friction drag and pressure drag) of squids over a range of natural swimming velocities numerically. Their swimming performance is compared with that of other marine vertebrates, especially sea lions, dolphin and penguin in same Reynolds numbers.

2. Methods

In this study, real squid was modeled by computer tomography images for numerical simulation. A2-D geometry was generated for analysis of drag force in different Reynolds numbers as illustrated in Fig.1.

The equation describing Reynolds numbers is given by

$$Re = \rho\ U\ L\ /\ \mu \qquad (1)$$

where U is the flow velocity, L is the characteristic linear (e.g., body length), ρ and μis the density and absolute viscosity of the fluid, respectively.

The equation describing total body drag is given by

$$\text{Total Drag} = \frac{1}{2}\rho V^2 C_d \qquad (2)$$

Where ρ is the density of the fluid, V is the velocity of the fluid relative to the body, A is the characteristic area of the body, and C_d is the drag coefficient. Two primary types of drag were investigated for this study: Firstly, skin friction drag, a tangential force, results from shear stresses in the water sliding by the body. Secondly, pressure drag which is a perpendicular force on the body associated with the pressure difference between the front and back of the body. As body becomes more streamlined, the pressure drag becomes lower causing total body drag of a swimmer smaller. The fineness ratio of a squid, defined as maximum body length / maximum body diameter, in this study is 7.58.

The geometry of domain is axisymmetric; thus, x coordinate is selected to be axis while r coordinate is chosen as radial direction. The domain area is 150 D in length and 9 D in height. A total 1,715,018 tet and quad elements with increased mesh density near the squid body were used for computation as shown in Fig. 2-A and Fig. 2-B. Governing equations for the flow field were solved by a commercial CFD package, namely ANSYS Fluent.

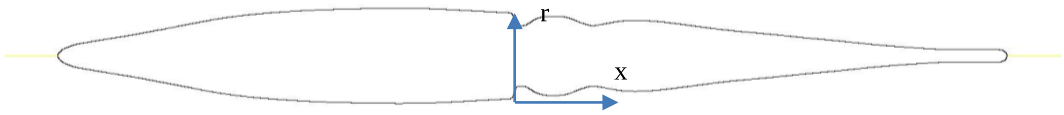

Figure 1. Axisymmetric geometry of squid

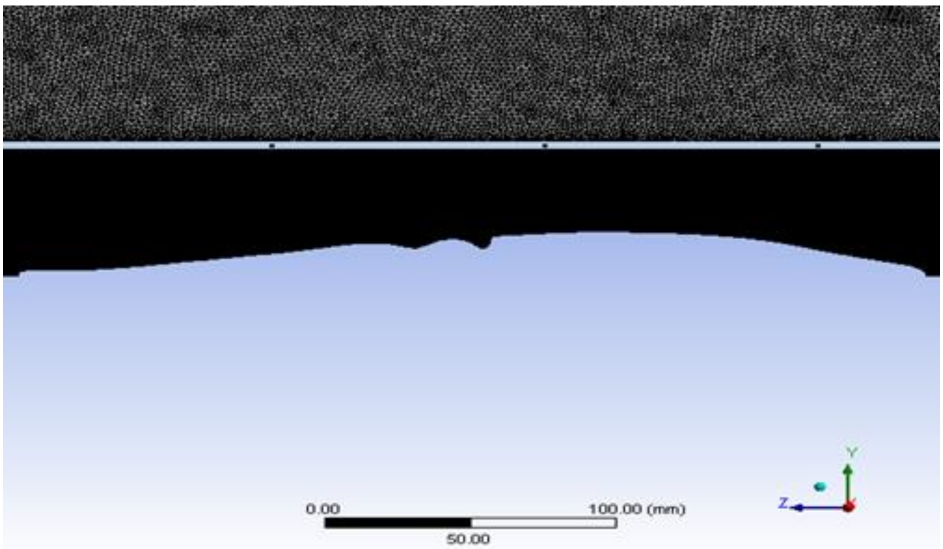

Figure2-A. Meshing of domain for solving

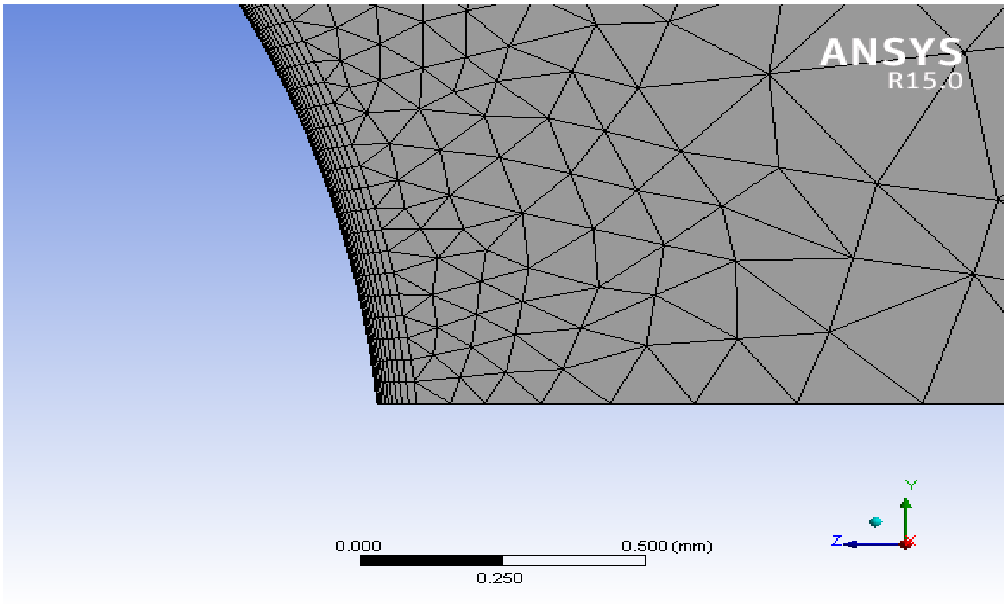

Figure 2-B. Enlarged mesh on squid surface

3. Results and Discussion

Drag coefficient was calculated from 3.21 m/s to 9.23 m/s swimming speeds range and referenced to the animal's total wetted surface area($C_{d,A}$). Drag coefficient was compared for the squid with values obtained for other marine animals for three different Reynolds numbers as given in Table 1-A and Fig 3. The numerical results that were obtained for squid are in good agreement when they were compared by experimental results of sea lion, penguin and dolphin (Feldkamp 1987, Williams 1985, Videler 1985). The results show that drag coefficient decreases with growing Reynolds numbers. Fig.3 shows pressure distribution around squid body and a high pressure region around head of the squid. This causes resisting force to its forward motion in the water. Velocity contours of hydrodynamic boundary layer are shown in Fig.4. No slip boundary condition causes zero velocity on body surface of squid and generate a boundary layer on surface of squid.

Table 1-A. Comparison of drag coefficient

	Re=1,000,000	Re=1,600,000	Re=2,870,000
Drag coefficient- Squid*(present study)	0.00448	0.0042	0.003975
Drag coefficient-Gentoo penguin	0.0044	-	-
Drag coefficient-Estuary dolphin	0.004	-	-
Drag coefficient-Harbor seal	-	0.004	-
Drag coefficient- Sea lion	-	-	0.0039

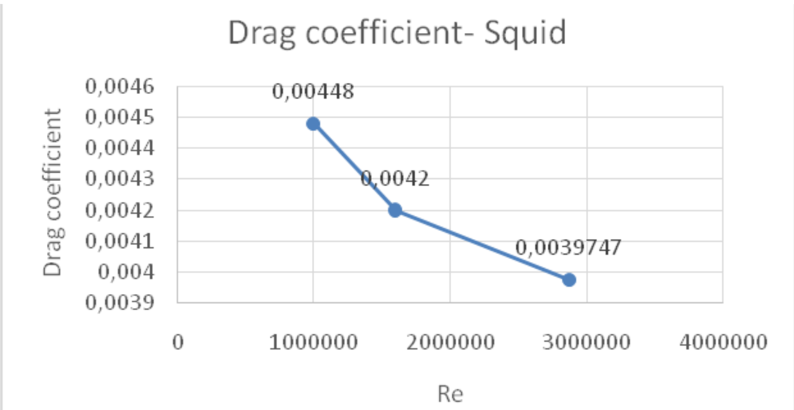

Figure 3. Drag coefficient decrease with growing Reynolds numbers

Tabatabaei, M. et al. 2014. SDU-JESD-5112-287-291

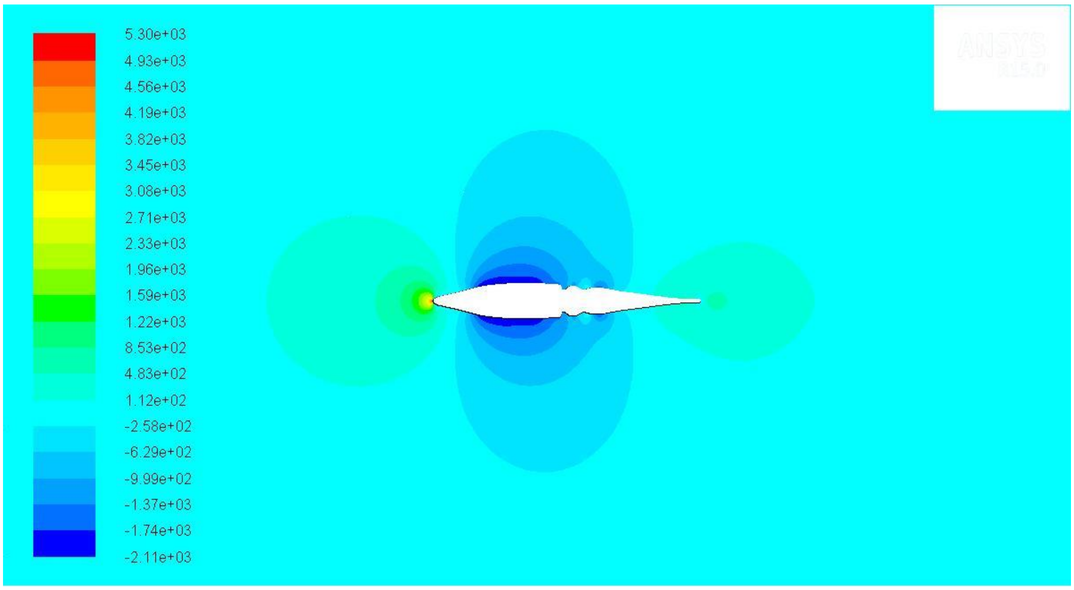

Figure4. Pressure distribution around squid body

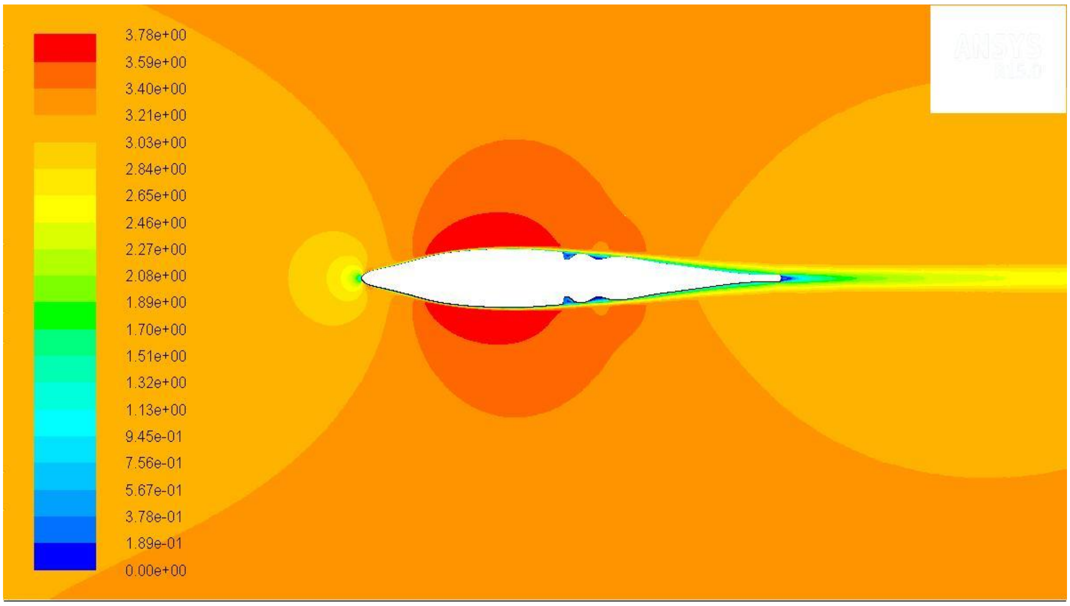

Figure5. Contours of Velocity

4. Conclusion

Squid has a unlike locomotion system, so it can move very fast and achieve high velocity in a short time period. Well-streamlined shape of the squid help to decrease drag coefficient at high Reynolds numbers, also help to delay separation. In this study, computational fluid dynamic method was applied for solving drag coefficient of squid. The results that were obtained by numerical methods are in good agreement with experimental data of other marine animals.

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

Eloy, C., 2012. Optimal Strouhal number for swimming animals. Journal of Fluids and Structures., 30, 205–218

Feldkamp, S. D., 1987. Swimming in the California sea lion: morphometrics, drag and energetics. J. Exp.Biol. 131, 117–135.

Fish, F. E., 1996. Transitions from drag-based to lift-based propulsion in mammalian swimming. Am. Zool. 36, 628-641.

Fish, F. E., Howle, L. E., Murray, M. M., 2008. Hydrodynamic flow control in marine mammals. Integr. Comp. Biol. 48, 788-800.

Fish, F. E., 1993. Power Output and Propulsive Efficiency of Swimming Bottlenose Dolphins (Tursiops Truncatus). J. Exp. Biol., 185, 179–193

Fish, F., E., Howle, L. E., Murray, M.M.,2008 Hydrodynamic flow control in marine mammals. Integr. Comp. Biol., 48 (6): 788-800

Loebbecke, A., , Mittal, R., Fish, F., Mark, R., 2009. A comparison of the kinematics of the dolphin kick in humans and cetaceans. Human Movement Science 28, 99–112

Lun Yu, C, Ting, S-C, Hsu, Y.-H., Yeh, M-K, Yang, J.-T., 2012. Mechanical capability and timing of a fish to maneuver from a steady straight-line swimming state. Mechanics Research Communications, 39, 59– 64

Mahbubar Rahman, M.D., Toda, Y., Hiroshi, M., 2011. Computational Study on a Squid-Like Underwater Robot with Two Undulating Side Fins. Journal of Bionic Engineering, 8, 25–32

O'Dor, R. K., 1988. The forces acting on swimming squid. J. Exp. Biol., 137, 421-442

Polidoria Taiar, G., Fohannoa, R., S., Maia, T.H., Lodini, A., 2006. Skin-friction drag analysis from the forced convection modeling in simplified underwater swimming. Journal of Biomechanics, 39, 2535–2541

Stelle, L. L., Blake, R. W., Trites, A. W., 2000. Hydrodynamic Drag in Steller Sea Lions (Eumetopias Jubatus). The Journal of Experimental Biology 203, 1915–1923

Videler, J., Kamermans, P., 1985. Differences between upstroke and downstroke in swimming dolphins. J. Exp. Biol. 119, 265–274

Williams, T. M. and Kooyman, G. L., 1985. Swimming performance and hydrodynamic characteristics of harbor seals Phocavitulina. Physiol. Zool. 58, 576–589

Yi-Gang, XU, De-Cheng, W., 2012. Numerical simulation of fish swimming with rigid pectoral fins. Journal of Hydrodynamics, Ser. B, 24(2), 263-272