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HYDROSTATIC AND HYDRODYNAMIC CHARACTERISTICS OF SWIMMI ANIMALS-AN INSPIRATION FOR HYBRID BUOYANT AIRCRAFT

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ABSTRACT

In today's world, the biological sciences are mostly considered separate from the existing modern knowledge of various other fields of sciences and engineering; however, there are many properties of nature and known facts of biological sciences that can be proved in the other domains of science and technology as well. Correlation of the geometric and buoyant properties of the swimming animals with the hybrid buoyant aerial vehicles is an example of this hypothesis. In the present work, some experiments related to the geometric parameters of a California sea lion were carried out. It was found that the fineness ratio of this animal is of the same order as the optimum value of that for the condition of minimum drag and power required for the buoyant aerial vehicle. The role of multiple fins on the elongated bodies of shark is also discussed in its application for yaw stability as well as to shroud the antennas that are used in the aircraft for various communication systems.

Keywords: Fineness ratio, California sea lion, Dorsal fin, minimum drag, Aerodynamic lift, Hybrid buoyant aircraft, Minimum drag, Buoyant independent drag.

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Contribution/ Originality

The paper's primary contribution is to show that the hydrodynamic and a few geometric parameters of a California Sea Lion resemble to that of the well-known facts of buoyant and hybrid buoyant aerial vehicles.

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1. INTRODUCTION

Research in the area of biological sciences being carried out in this era is as promising as in the other fields of science and engineering. Research in this area when coupled with that of other fields can do wonders and can make a significant contribution to the advancement of technology. Hydrodynamic characteristics of swimming animals are one such area that has recently been explored for its application in aviation industry i.e. for hybrid buoyant (HB) aircraft. It is a type of aircraft in which partial weight is balanced by the buoyant lift; similar to a swimming animal like Steller sea lion, Haque *et al.* (2015a). For example, the body of California sea lion has a cambered profile because of having flippers attached at an anhedral angle to it; where this geometric feature is perhaps to decrease the coefficient of pitching moment and to increase the roll stability. Similar findings are there from the static longitudinal stability analysis of HB aircraft (Haque *et al.*, 2015b). In the present work, hydrodynamic and geometric variables of California sea lion are explored in comparison with the known knowledge of the same for hybrid aerial vehicles. In this regard, a series of experiments were conducted on a 16 years old California sea lion present at the Zoo Negara, Kula Lumpur. The geometric parameters so obtained were further utilized for the purpose of comparison with what is known in the field of hybrid buoyant aerial vehicles. Moreover, the dorsal fin of Shark is discussed regarding biological sciences and its further application for HB aircraft.

2. RESEMBLANCE OF CALIFORNIA SEA LION WITH BUOYANT AND HYBRID BUOYANT VEHICLES

Some experiments were conducted recently on California sea lion, Fig. 1. These tests include the flow visualization on these animals while swimming in water. Also, major geometric parameters were estimated with the help of four trainers; that took them a week to train the animal for these measurements. The maximum length (including the rear flippers), maximum width, span of the front flippers was 116 inch (2.93 m), 10.5 inch (0.266 m) and 21.0 inch(0.53 m), respectively. To be able to find the correlation of this marine animal in the water to a flying buoyant vehicle in the air, the fluid dynamic conditions, as well as the geometrical shape, have to be similar. But the body of the animal is quite flexible, and it is quite hard to take measurements while the animal is inside the water. Therefore, all the measurements are done on the ground and hence are approximate values.

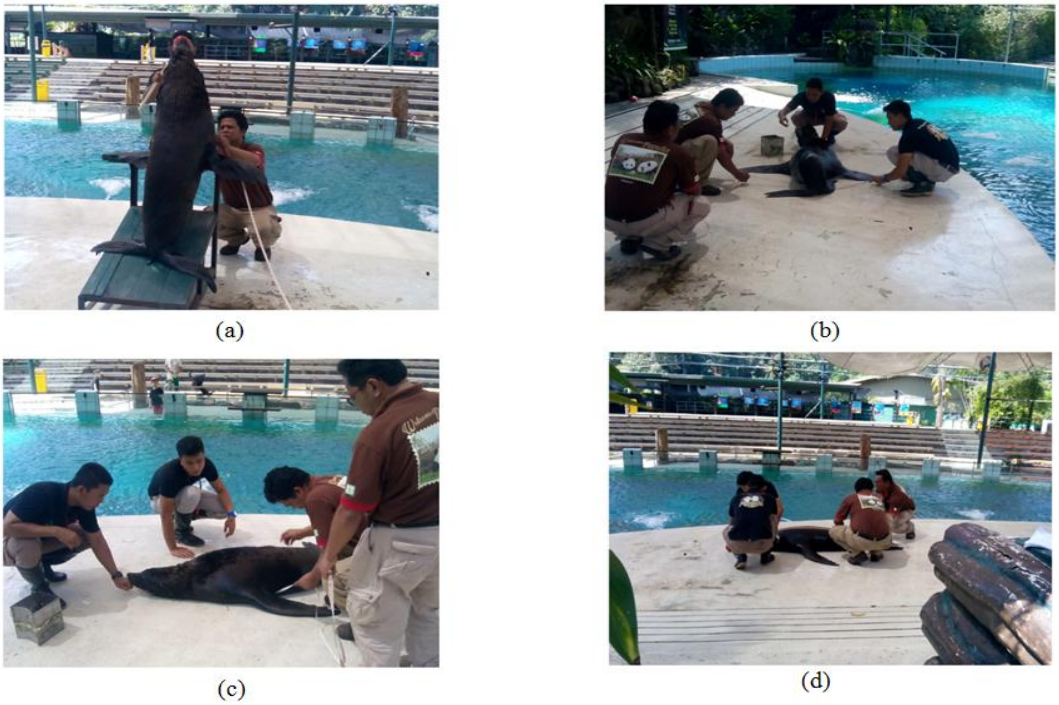


Fig-1. Measurements for the geometric parameters of California sea lion

2.1. Buoyant Lift

Sea animals utilize buoyant lift to stay uplift to balance the effect of gravity. This buoyant lift is independent of the drag force exerted on the body of a sea lion (Suzuki *et al.*, 2014). Buoyant lift is independent of the surface/wetted area of the marine animal. But, similar to any aerodynamic and hydrodynamic coefficient, the drag coefficient is dependent on the reference area of the body immersed in the fluid. In 1990, Alexander (1990) carried out a study related to the effect of different reference areas for estimation of the drag coefficient of swimming animals. He found that there was a drastic reversal in the drag coefficient data obtained by using the wetted area as a reference area for two species of Idotea; genus of isopod crustaceans. He mentioned that that there is no powerful hydrodynamic basis for the selection of reference area for the estimation of drag coefficient and the same holds good for hybrid aerial vehicles as well. As far as buoyant lift is concerned, it is mainly linked with the criterion of good performance for an animal that takes into account that how much energy it can process and store (guts, so to speak) and how many offspring it can produce (gonads, loosely put). In the case of Sealion, the maximum available buoyant lift is 50% of the gross weight (Suzuki *et al.*, 2014). This digit is consistent with the recent findings related to the optimum buoyancy ratio for hybrid airship (Raymer, 2006).

2.2. Lifting Profile of California Sea Loin

Marine animal's body can generate additional lift; hydrodynamic profile of California sea lion is one of the examples of it. This marine animal has big guts and gonads to utilize the buoyant lift to stay uplift to balance the effect of gravity; maximum value of which is of the same order as recommended for hybrid buoyant aircraft; an airplane that specialized as a volume maximizer. Based on our predicted similarity between California sea lion and man-made buoyant aerial vehicles, we have proposed that California sea lion's body *"can be tailored for aeronautical applications such as the lifting fuselage of a hybrid buoyant aircraft"* (Haque *et al*., 2015c). Complete geometric details of the outer contour of the California sea lion are not yet available. Perhaps, due to the flexible body of sea lions, it is nearly impossible to measure the same; the only information available is the location of maximum thickness, which is about 34 % of body length (Suzuki *et al*., 2014). In one of our studies related to the hybrid lifting hull, we selected Eppler-1200 airfoil for the hybrid hull, based on the visual judgment of geometric profile of California sea lion and requirement of takeoff ground roll angle to fulfill future certification requirement (Haque *et al*., 2014).

2.3. The Position of Maximum Thickness of Body

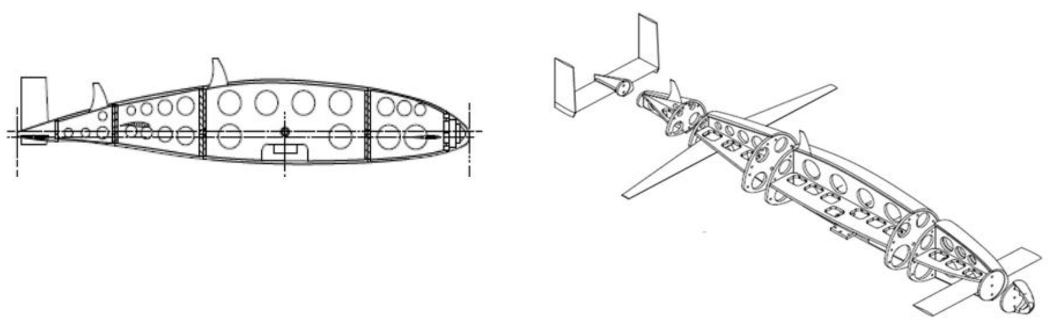
The position of the maximum thickness is an important aerodynamic as well as hydrodynamic parameter to define the point where the transition of the boundary layer occurs. It's position further aft is desirable to have more laminar flow as well as less drag. During the measurements of California sea lion on a flat surface, it has been observed that the position of maximum thickness is about 36 percent of the length of the body. This value is slightly lower than that observed by Feldkamp (1987). Interestingly, this is the location of the shoulders and flippers of this animal as well. Eppler -1200 is one of the airfoils with the location of its maximum thickness close to that measured earlier for sea lion (Haque *et al*., 2015b). This airfoil has recently been used for the design of a hybrid lifting hull. The selection of this airfoil was based on the location of maximum thickness, visual judgment of geometric profile of California sea lion and requirement of takeoff ground roll angle to fulfill future certification requirement (Haque *et al*., 2015c).

2.4. Optimum Fineness Ratio

It is well known that conventional non-rigid airships usually have fineness ratio value of about 2.3-2.8. However, a fineness ratio between 5 and 6 was found to be optimal for maximum propulsion efficiency of a fixed maximum diameter buoyant vehicle (Ilieva *et al*., 2014). Interestingly, as per the findings of Suzuki *et al*. (2014) this range of fineness ratio is found comparable to the California sea lion. This marine animal has a fineness ratio of 5.55 and location of maximum thickness of outer profile is at 34% of the overall length (Cheneval, 2005). This fineness ratio is also common with other marine mammals like dolphins, fishes, and whales (Fish, 1994). To have optimum drag and the propulsion power, a fineness ratio between 5 and 6 can be used for the design of hybrid lifting hull

3. BIOLOGICAL SCIENCE OF DORSAL FIN AND ITS POTENTIAL APPLICATIONS FOR HB AIRCRAFT

In the field of aerospace, the dorsal fin is usually referred as the extension of the vertical tail area at the leading edge. It is unlike of a dorsal fin that sticks up by itself (Nakamura *et al.*, 2015) such as one can see on a dolphin or shark; located forward of the vertical tail, but not connected to it. The dorsal fin is one of the potential solutions to increase the yaw stability as the moment arm between the aerodynamic center of the dorsal fin and center of gravity is enough for an elongated shaped fuselage to generate the additional yawing moment. When an HB aircraft is subjected to side-slip angle, then it should exhibit static directional stability to return the nose of the aircraft into the wind. An H-tail empennage arrangement has been used earlier in the conceptual design phase for the said purpose (Haque *et al.*, 2015b). The analytical results have shown earlier that this configuration is marginally stable in the yaw, and any further increase in the size of a twin tail will make the weight of the tail heavy. Similar to a shark fish, use of multiple dorsal fins was earlier proposed for HB aircraft. However, such fins should be placed away from the center of gravity, Fig. 2(a), and should not be located at the attachment points of the bulkheads, Fig. 2(b). The body of marine animals is quite flexible, but a flying machine should be rigid enough to bear the flight loads. Such a structural rigidity can be reinforced by the use of bulkheads and additional frames in the lateral direction. Now let's discuss the anatomy and the biological science of dorsal fin in the swimming animals.



(a) Side view (b) Isometric View

Fig-2. Extruded view of different components of a hybrid buoyant aircraft model

3.1. Biological Science

A lot of research has been carried out earlier on the role of dorsal fin towards stability and turning (Harris, 1937; Harris, 1938; Harris, 1953; Webb, 1975; Webb, 1977; Webb and Keyes, 1982; Webb, 1988; Webb, 2002). For example, Drucker and Lauder (Webb and Keyes, 1982) carried out a thorough study about the understanding of the design and function of dorsal fin for different types of fishes. They found that the dorsal fin produced a pair of counter-rotating vortices during turning. During steady swimming, these vortices interact with the caudal fins that are located downstream for wake energy augmentation and also increase the thrust. Such fins are located close to the center of the mass and produce about one-third of the required lateral force for turning (Standen, 2008). It was observed by the scientists mentioned earlier that irrespective of the fineness ratio of the body, the location of the paired pectoral fins (a lift producing component, marked with red colour) is always ahead of the *CG*. Interestingly, it can be observed from Fig. 1 (Standen, 2008) that Percoid has small fineness ratio and also it has a big dorsal fin as compared with Salmonid. But as the fineness ratio increases, the location of dorsal fin moves downstream for Sturgeon to fulfill the requirement of the long moment arm. Among all, Shark has the highest fineness ratio and has multiple dorsal fins, with the first fin of big size as compared to the secondary dorsal fin, located downstream of the center of the mass.

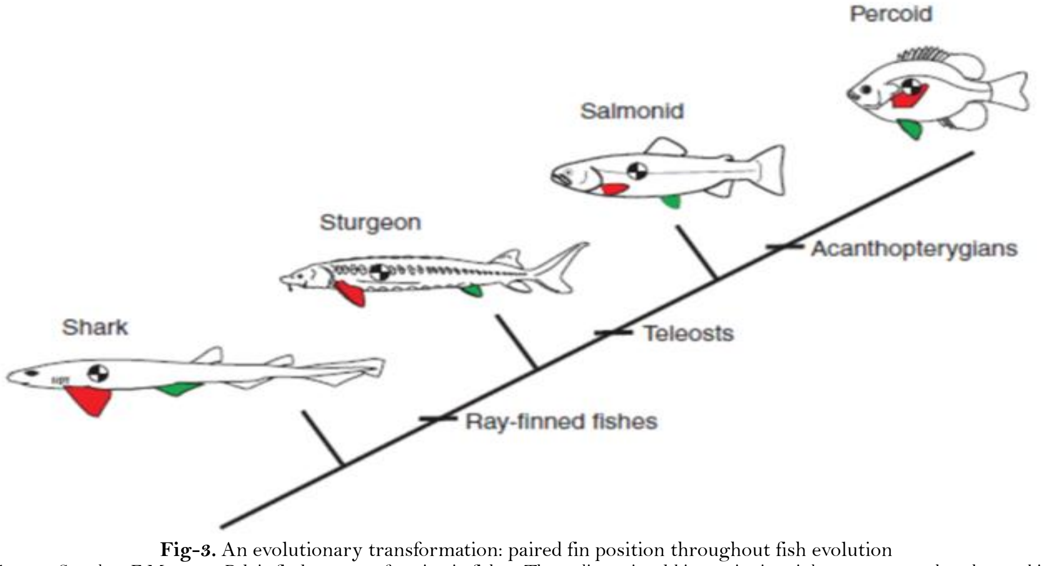


Fig-3. An evolutionary transformation: paired fin position throughout fish evolution

Source: Standen, E.M., 2008. Pelvic fin locomotor function in fishes: Three-dimensional kinematics in rainbow trout oncorhynchus mykiss. Journal of Experimental Biology, 211(18): 2931–2942.

Maia and Wilga (2013) has recently conducted experiments to evaluate the functionality of dorsal fin in bamboo shark for the steady condition. Their experimental data indicated a continuous oscillation in the lateral position. They also estimated the thrust produced by such an oscillation motion and found a loss in lateral stability due to the different orientation of dorsal fin. Moreover, deflection in the tip of the dorsal fin was found. Though, the major contribution towards longitudinal stability is due to the tail, but such a deflection can be related to longitudinal stability as well. Deflection of the complete dorsal fin is also observed in other aquatic animals, having more than one dorsal fin. Harris (Harris, 1937; Harris, 1938; Harris, 1953) found that the first dorsal fin of spiny dogfish behaves like a stabilizer, and it moves independently. But the second dorsal fin moves with the body and also acts as a thruster for forward motion. Based on his experiments, he concludes that *"vertical lift force at the posterior end produces a negative pitching moment that neutralizes the positive moment of the trailing pectoral fins."*

3.2. Application

For all wireless communication systems, one important factor is the design of the antennas at low frequencies with desired compact size and enhanced performance characteristics such as matched impedance bandwidth, better efficiency, and good gain. In an aircraft communication system, antennas are used for various operations such as for direction finding (DF), VHF communications, distance measuring system (DME), global positioning system (GPS), microwave landing system (MLS) and radar altimeter (RadAlt), etc., covering the frequency range from 30MHz up to 4GHz and more (Macnamara, 2010). It has been studied in the past that wrong placement of antennas and any additional weight and size on the aircraft increases the aerodynamic drag that negatively affects the flying ability of an aircraft, for example, an increase in the fuel consumption and puts a limitation on the speed of aircraft (Jahoda, 2006). They introduce the noise and increase the parasitic drag. By making the antenna low profile, it comes very close to the metal body of an aircraft which degrades its performance (Josephson, 1957; Sievenpiper, 1999). Such antennas can be housed inside the dorsal fin as well.

4. CONCLUSION

Fineness ratio, the location of maximum width and buoyant independent drag of a California sea lion are the three quantities, which are common with hybrid buoyant aircraft. Hence, the known knowledge of hydrodynamic characteristics of swimming animals is adjoined with the aerospace application so that aerospace when dealt in line with biology, can provide inspiration for the design of HB aircraft. In aircraft, antennas are used for communication as well as for various navigation systems of aircraft, which can be shrouded by a dorsal fin. However with a slight yaw, dorsal fin causes a lot of drag, and it can produce a restoring yawing moment but not that enough such as a rudder produces.

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REFERENCES

Alexander, D.E., 1990. Drag coefficients of swimming animals: Effects of using different reference areas. Biological Bulletin, 179(2): 186-190.

Cheneval, O., 2005. Biomechanics of turning manoeuvers in Steller sea lions. Doctoral Dissertation, University of British Columbia.

Feldkamp, S.D., 1987. Swimming in the California sea lion: Morphometrics, drag and energetics. Journal of Experimental Biolog, 131(1): 117–135.

Fish, F., 1994. Influence of hydrodynamic-design and propulsive mode on mammalian swimming energetics. Australian Journal of Zoology, 42(1): 79-101.

Haque, A.U., W. Asrar, A.A. Omar, E. Sulaeman and J.S.M. Ali, 2014. Stability and takeoff ground roll issues of hybrid buoyant aircraft. Advanced Material Research, 66(1): 503–507.

Haque, A.U., W. Asrar, A.A. Omar, E. Sulaeman and M.J.S. Ali, 2015a. A novel design of a hybrid buoyant aircraft- a potential greener solution for inter-connectivity of Malaysian Islands. 62nd CASI Aeronautics Conference and AGM 3rd GARDN Conference, 19-21 April, 2015, Montreal Canada.

Haque, A.U., W. Asrar, A.A. Omar, E. Sulaeman and M.J.S. Ali, 2015c. Cambered profile of a California sea lion's body. Journal of Experimental Biology, 218(8): 1270-1271.

Haque, A.U., W. Asrar, A.A. Omar, E. Sulaeman and J.S. Mohamed, 2015b. Power-off static stability analysis of a clean configuration of a hybrid buoyant aircraft. 8th Ankara International Aerospace Conference, 10-12 September 2015 - METU, Ankara, Turkey.

Harris, J.E., 1937. The mechanical significance of the position and movements of the paired fins in the Teleostei. Washington, DC: Carnegie Institution of Washington.

Harris, J.E., 1938. The role of the fins in the equilibrium of the swimming fish. II. The role of the pelvic fins. Journal of Experimental Biology, 15(1): 32-47.

Harris, J.E., 1953. Fin patterns and mode of life in fishes. In S. M. Marshall and P. Orr (Eds). Essays in Marine biology. Edinburgh, Scotland: Oliver & Boyd. pp: 17-28.

Ilieva, G., J. Páscoa, A. Dumas and M. Trancossi, 2014. MAAT – promising innovative design and green propulsive concept for future airship's transport. Aerosp. Sci. Technol, 35: 1–14.

Jahoda, J.R., 2006. JTRS/SINCGARS ultrabroad band airborne blade antenna for subsonic aircraft and helicopters. Defense Electron: 20–22.

Josephson, B., 1957. The quarter-wave dipole. WESCON/57 Conference Record, 21(Part. 1): 77 – 90.

Macnamara, T., 2010. Introduction to antenna placement and installation. 1st Edn., USA: John Wiley & Sons.

Maia, A. and C.A. Wilga, 2013. Function of dorsal fins in bamboo shark during steady swimming. Zoology, 116(4): 224–231.

Nakamura, I., C.G. Meyer and K. Sato, 2015. Unexpected positive buoyancy in deep sea sharks, hexanchus griseus, and a echinorhinus cookei. PloS One, 10(6): e0127667.

Raymer, D.P., 2006. Aircraft design: A conceptual approach and Rds-student, software for aircraft design, sizing, and performance set (AIAA Education). AIAA (American Institute of Aeronautics & Ast.

Sievenpiper, D.F., 1999. High-impedance surfaces. PhD Thesis, University of California at Los Angeles.

Standen, E.M., 2008. Pelvic fin locomotor function in fishes: Three-dimensional kinematics in rainbow trout oncorhynchus mykiss. J. Exp. Biol, 211(18): 2931–2942.

Suzuki, I., K. Sato, A. Fahlman, Y. Naito, N. Miyazaki and A.W. Trites, 2014. Drag, but not buoyancy, affects swim speed in captive Steller sea lions. Biol. Open, 3(5): 379–386.

Webb, P.W., 1975. Hydrodynamics and energetics of fish propulsion. Bulletin of the Fisheries Research Board of Canada, 190(1): 1-158.

Webb, P.W., 1977. Designs for stability and maneuverability in aquatic vertebrates: What can we learn. In: Tenth International. Symp. Unmanned Untethered Submersible Tech: Proc. Sp. Ses. Bio-Eng Res. Related to Autonomous Underwater Vehicles, Durham, NH. pp: 85-108.

Webb, P.W., 1988. Simple physical principles and vertebrate aquatic locomotion. American Zoologist, 28(2): 709-725.

Webb, P.W., 2002. Control of posture, depth, and swimming trajectories of fishes. Integrative and Comparative Biology, 42(1): 94-101.

Webb, P.W. and R. Keyes, 1982. Swimming kinematics of sharks. Fish. Bull, 80(4): 803-812.