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ENCIK CHENG SEE YUAN
Pensyarah
Fakulti Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka
Karung Berkunci 1200, Ayer Keroh
75450 Melaka

Tandatangan : ....

Nama Penyelia : MR. CHENG SEE YUAN

Tarikh : 30/04/2008

THE STUDY OF THE EFFECTS OF SURFACE ROUGHNESS OF LOGGERHEAD SEA TURTLE SHELL IN RELATION TO DRAG COEFFICIENT

ALAN CHAN KAH POH

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The Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

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DECLARATION

"I hereby, declare this thesis is result of my own research except as cited in the references"

Signature : ....
Author's Name : Alan Chan Kah Poh
Date : 13/05/2008

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ABSTRAK

Kajian ini menumpu kepada penyelidikan kesan kekasaran permukaan kepada pekali seretan, Cd kerangka penyu Loggerhead dengan menggunakan terowong angin *sub-sonic.* Pekali tekanan, Cp pada permukaan atas model Loggerhead turut dikaji dan dibandingkan dengan tren Cp sebuah *airfoil* dengan tujuan untuk mengulas ciri-ciri aerodinamik kerangka Loggerhead. Model pada skala satu kepada lima direka dan difabrikasikan berdasarkan dimensi penyu Loggerhead yang sebenar. Tiga skala kekasaran telah digunakan untuk menganalisa tren Cd pada nilai angka Reynolds, Re yang berbeza. Seperti yang dijangkakan, nilai Cd menunjukkan keadaan mendatar untuk keempat-empat model yang dikaji. Namun, nilai Re dimana nilai Cd yang tetap bermula adalah berlainan untuk keempat-empat model. Hasil daripada kajian menunjukkan korelasi atau hubung kait diantara Cd dan kekasaran relatif. Data yang diperolehi turut menunjukkan bahawa Cd maksima dicapai pada sudut dongakan -30 °. Perbandingan tren Cp model Loggerhead dengan model berbentuk *airfoil* mencerminkan ciri-ciri *streamline* dengan syarat model Loggerhead mempunyai sudut dongakan bernilai 0 ° dan kebawah. Ini dapat mencetuskan penyelidikan reka bentuk kenderaan merendam air sepertimana yang diterajui oleh seorang penyelidik Jepun, Konno (Konno A. et al. 2005).

ABSTRACT

The present investigation primarily studies the effect of surface roughness on the drag coefficient, Cd of a Loggerhead sea turtle carapace using a subsonic wind tunnel. The pressure coefficient, Cp distribution across the Loggerhead carapace was also investigated and is compared to the Cp trend of an airfoil in order to deduce the aerodynamics features of the Loggerhead carapace. One-to-five-scaled models are created based on the dimensions of a real Loggerhead turtle with simplification. Three roughness scales were employed to capture the Cd trend at increase Reynolds number, Re. As expected, the Cd leveled off with Re for all four models investigated. However, the Re where constant Cd begins varies with relative roughness of the carapace models. The results also show good correlation between the Cd and relative roughness. In addition, the wind tunnel results are able to capture the Cp trend of the carapace models where maximum Cd was achieved at an angle of attack of -30 °. Cp comparisons with an airfoil body both qualitatively classifies the upper surface of a Loggerhead carapace to be of stream-line-nature so long as its angle of attack is kept to a zero or negative-value (counter-clockwise direction) region from the horizontal axis, as analyzed from the Cp values at different angles of attack. This would trigger development in submergence vehicle research as spearheaded by a Japanese researcher, Konno (Konno A. et al. 2005).

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LIST OF SYMBOLS

Concise list of symbols in order of appearance:

F_d = the force of drag,
ρ = the density of the fluid
v = the velocity of the object relative to the fluid,
A = the reference area, and
C_d = the drag coefficient
U = the free stream velocity
F_L = the total lift force on the body
S = the projected frontal area of the specimen
C = the area of the wind tunnel test section
Ac = Frontal area of carapace
Ar = Frontal area of reference cuboid (100mm x 100mm)
Pc = Black pixel count of carapace
Pr = Black pixel count of reference cuboid
L = Length
μ = fluid viscosity
c = speed of sound
α = Angle of attack
ε = Roughness height
D = Chord length
Re = Reynolds Number
Cp = Pressure Coefficient
i = Taping point number
P_i = Pressure tap at 'i'
P_∞ = Free stream static pressure (Pa)
q_∞ = Free stream dynamic pressure (Pa)

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CHAPTER 1

INTRODUCTION

1.1 Background Study

In the shores of Shark Bay, Western Australia, a relatively undisturbed foraging ground, forms an excellent feeding ground for sea turtles and hosts a rich marine ecosystem (Heithaus *et al.* 2005). A research led by Dr. Mike Heithaus over a span of ten years has revealed the fact that green sea turtles (*Chelonia mydas*) are less likely to be attacked by tiger sharks (*Galeocerdo cuvier*) when compared to loggerheads (*Caretta caretta*), sometimes as much as five times (Heithaus *et al.* 2002). Although both are of the same family of Cheloniidae, the green and loggerhead sea turtle are as different as tanks and flying saucers. This statement already hints of the aerodynamic difference between the loggerhead and the green in terms of swimming efficiently. Not only do they differ in terms of physical attributes, these turtles have different diets, and diving and breathing patterns.

From the overview of the findings made by Dr Heithaus, it can be summarized that the fact of which loggerheads are five times more likely to be attacked by tiger sharks when compared to green sea turtles is due to the loggerhead's increased surface time (breathing pattern), diet practises (do not shift foraging area based on body conditions as greens do) as well the issue of shell cleanliness. Loggerheads do not maintain healthy shell cleaning practise and this of course will lead to the build-up of algae and barnacles. This strongly suggests an increase in drag due to the add-on of unwanted material. Consequently, roughness builds up on the loggerhead shell and is certain to affect its swimming speed.

However, there is limited research on the effects of roughness build up on the loggerhead's shell in terms of drag.

Nature's aerodynamic design (in this case the loggerhead shell) is especially equipped so that loggerhead can move flawlessly underwater. A study by headed by Akihisha Konno (Konno *et al.* 2005), has developed a turtle-like submergence vehicle through the feathering motion of sea turtles. This further explains the potential in revising the aerodynamic elements of the loggerhead whereby results can be referenced in future designs of underwater scavenger-type vehicles. The issue of roughness may affect the efficiency of movement of underwater life more than one can decipher but there is very limited research in this field. Furthermore, data on the effects of roughness on the aerodynamic performance of a loggerhead shell in terms of drag and lift coefficients will go a long way in determining the design parameters.

1.2 Problem Statement

Despite the fact that the cause of the loggerhead sea turtles higher risks of being attacked by tiger sharks at Shark Bay, Western Australia are comprised of many factors, however the fact remains that there are new questions that arise from Dr Heithaus' investigation. There has yet to be any comprehensive study on the aerodynamic effects of roughness build-up on loggerhead carapace. In the context of this project, some open ended question include:-

- What is the corresponding drag coefficient for a certain degree of roughness built up on the loggerhead shell?
- What is the relationship between angle of attack and the drag coefficient in relation to surface roughness?
- What relation can be concluded between the roughness build-up, the drag and the loggerhead's survivability in the waters?

1.3 Objectives

- To study the effects of roughness built up on the shell of loggerhead sea turtles in relation to drag and lift.
- To design a wind tunnel model scaled with issues of similarity and blockage ratio taken into consideration.
- To define surface roughness on the models
- To analyze the data accumulated from wind tunnel tests and draw logical inferences in terms of aerodynamic effects due to roughness and angle of attack as well it's relation to engineering design concepts and apply this relationship to the issue of loggerhead's survivability in the waters.

1.4 Scope

The investigation will focus on the *Caretta caretta* (Loggerhead sea turtle) that dwells within the Caribbean Seas near Curacao (Netherlands Antilles). The ambient temperatures and the salinity of the sea water in the region will be used. A simplified model will be built from the dimensions of a real Loggerhead sea turtle whereby the Standard Carapace Length (SCL) and Standard Carapace Width (SCW) are referenced from an actual loggerhead. Verification of the designed model is reflected based on the values of blockage ratio. Following this, the surface roughness of the models will be defined and analysis based on wind tunnel testing results will be done to examine static drag in relationship with the surface roughness. For wind tunnel testing, the models will be positioned with angles of attack of in increments of 5° from 0° in both directions from the horizontal x-axis (-30°, -25°, -20°, -15°, -10°, -5°, 0°, 5°, 10°, 15°, 20°, 25°, 30°)

1.5 Expected Results

At the end of the research, it is expected that simplified loggerhead carapace models with varying surface roughness that adhere to issues of similitude and blockage ratio have been developed and fabricated for wind tunnel testing. Following this, the acquired data from the wind tunnel tests will give a concise overview of the effects of surface roughness of loggerhead sea turtle shell in relation to drag coefficient. Furthermore, the influence of angle of attack can be analyzed and a reliable relationship between surface roughness and the loggerhead's survivability can be established.

CHAPTER 2

LITERATURE REVIEW

2.1 Basic Facts about Loggerhead Sea Turtles

The common name, loggerhead is derived from the massive, block-like head and broad, short neck of the animal (Molly 2005). The loggerhead is of the Family Cheloniidae which includes all sea turtle with scutes or horny plates covering their shells. It is the only turtle in the genus *Caretta* (Konno *et al.* 2005). They are one of the largest of the hard-shell turtles, with adults measuring 82 to 105 centimetres in length, and a weight range of 66-101 kilogram, but larger specimens have been reported(Konno *et al.* 2005). The upper shell or carapace is widest near the front, just behind the front flippers, and then tapers toward the rear. The carapace (top shell) is slightly heart-shaped and reddish-brown in adults and sub-adults, while the plastron (bottom shell) is generally a pale yellowish colour. The neck and flippers are usually dull brown to reddish brown on top and medium to pale yellow on the sides and bottom (Molly 2005).

Loggerheads are carnivores whereby the hatchlings feed on small animals living in the sea grasses called sargassum, where they spend their early developmental years (Molly 2005). Juveniles and adults eat mostly bottom dwelling invertebrates such as whelks, other mollusks, horseshoe crabs, and sea urchins [8]. This is in adherence to the design of their powerful jaws to crush their prey [8]. Maturity is reached at between 12-30 years. As loggerheads mature, they travel and forage through near shore waters until the breeding season, when they return to the nesting beach areas. Loggerheads are circum navigators, inhabiting continental shelves, bays, estuaries, and lagoons in temperate, subtropical, and tropical waters.

The majority of mature loggerheads appear to nest on a two or three year cycle. Scientists believe that loggerheads can live up to 50 years of age.

Loggerheads occupy three different ecosystems during their lives--the terrestrial zone, the oceanic zone, and the "neritic" zone (Nagelkerken *et al.* 2003). Loggerheads nest on ocean beaches, generally preferring high energy, relatively narrow, steeply sloped, coarse-grained beaches. Immediately after hatchlings emerge from the nest, they begin a period of frenzied activity. During this active period, hatchlings move from their nest to the surf, swim and are swept through the surf zone, and continue swimming away from land for about one to several days. After this swim frenzy period, post-hatchling loggerheads take up residence in areas where surface waters converge. Once individuals get transported by ocean currents farther offshore, they've entered the oceanic zone. Somewhere between the ages of 7 to 12 years, oceanic juveniles migrate to near shore coastal areas (neritic zone) and continue maturing until adulthood.

Figure 2.1: Figure of a loggerhead sea turtle
(Source *http://www.turtletime.org/*)

2.2 Aerodynamic Studies on Animals

There have been somewhat extensive wind tunnel tests on the aerodynamics of specimens of the animal kingdom, especially focusing on flight. A study by Tian (2006) has researched the mechanics of unsteady flight. This was accomplished by studying flight patterns of bats from a kinematics and dynamics point of view. The experiments presented were the first detailed measurements to couple wing kinematics and wake velocities of bats, and be used as reference to design vehicles capable of performing extreme unsteady aerodynamic manoeuvres. In a separate study (Weinstein *et al.* 2002), wind tunnel was used to obtain to understand the underlying aerodynamic principles behind bat flight.

Another investigation conducted by Dickinson and Gotz (1996) have used flow visualizations and instantaneous force measurements of fruit flies (*Drosophila melanogaster*) to study the dynamics of force generation during flight. Interest of the study of the aerodynamics is not limited only to flying animals but also to that of insects. Usherwood and Ellington (2002) have conducted an extensive research on the aerodynamics of propelling wings focusing on the propeller force coefficients for a large spectrum of specimens which include the pooled hawkmoth, mayfly and bumblebee.

Understanding how animals fly is not only central to providing insight into the biological world; the rich diversity of mechanisms of animal flight can provide abundant inspiration for engineered design. Insects have also stimulated a great deal of interest among physicists and engineers because, at first glance, their flight seems improbable using standard aerodynamic theory. The small size, high stroke frequency and peculiar reciprocal flapping motion of insects have combined to thwart simple explanations of flight aerodynamic (Usherwood and Ellingtion 2002). By learning more about the natural world and observing and analyzing how it works, humankind will be able to make further advancements in the fields of biomechanics, aerodynamics, and evolutionary biology.

2.3 Effects of Roughness on Drag and Lift Coefficients

When a solid body is moved through a fluid (gas or liquid), the fluid resists the motion. The object is subjected to an aerodynamic force in a direction opposed to the motion known as drag and drag force is commonly calculated from the drag equation (Sane 2006). The equation is attributed to Lord Rayleigh and given as:

$$\mathbf{F}_d = \frac{1}{2}\rho \mathbf{v}^2 C_d A$$

Where: F_d is the force of drag,

ρ is the density of the fluid

v is the velocity of the object relative to the fluid,

A is the reference area, and

C_d is the drag coefficient

From the equation above, it can be observed that for two objects of the same reference area and applied with the same fluid medium as well as velocity; the determining factor of the drag force depends on the drag coefficient. The drag coefficient is a dimensionless quantity that describes a characteristic amount of aerodynamic drag caused by fluid flow (Reuss *et al.* 1995). Similarly, the lift coefficient is also a dimensionless quantity that is used to relate the lift generated by an airfoil, the dynamic pressure of the fluid flow around the airfoil, and the planform area of the airfoil (Reuss *et al.* 1995). For any body shape the non-dimensional lift (C_L) and drag (C_D) coefficients are defined as:

$$C_L = \frac{F_L}{A(\rho U^2 / 2)}$$

$$C_D = \frac{F_D}{A(\rho U^2 / 2)}$$

Where:

A = characteristic area of the body (planform area for airfoils)

ρ = the fluid density

U = the free stream velocity

F_D = the total drag force on the body

F_L = the total lift force on the body

Ultimately, lift and drag are associated with the movement of an object through the air, so lift and drag depend on the velocity of the air (Sane 2003). Just as how increased friction on a surface reduces the velocity of the moving object due to increased roughness, drag can be considered as aerodynamic friction. The amount of drag depends on the surface roughness of the object; a smooth, waxed surface produces less drag than a roughened surface. Evidently, The lift and drag on an aerofoil depend on the aerofoil shape, the surface finish and on the Reynolds (Re) and Mach (Ma) numbers of the flow.

The issue at hand now would be to quantify exactly how much roughness effects lift and drag coefficients respectively. However, to do so would result in too much generalization as there are many parameters to consider when studying aerodynamics. A study by Reuss *et al.* (1995) investigated cases with or without leading edge grit roughness. The results showed that lift curve sensitivities to Reynolds number and roughness; the maximum lift coefficient was reduced by as much as 28% by leading edge roughness and caused a 16% change in the pitching moment at zero degree angle of attack.

CHAPTER 3

METHODOLOGY

In order to systematically satisfy the research objectives, the following research methodology was applied. It can be mainly divided in six major divisions with respective subdivisions:

3.1 Data Mining and Experimental Investigation

At the initial stages, basic information regarding the loggerhead sea turtle was obtained which encompasses its living habitat, swimming patterns, physique, etc. In addition to that, supplementary research regarding the tools required to successfully run the experiment to reach the objectives are conducted. These include data mining on wind tunnel testing; the study of roughness and drag; rapid prototyping; modelling and similarity; and other directly or indirectly issue that would contribute to the success of the investigation.

3.2 Modelling

Five simplified models of the loggerhead carapace were created to be used for the wind tunnel tests.

3.2.1 Dimensioning

The pre-requisite to dimensioning a loggerhead shell model would be first to obtain data on the average dimensions of a loggerhead. With this, issues of similarity would have to be addressed. This included ensuring that the dimensions for the model adhered to geometric similarity, kinematic similarity and dynamic similarity. This is achieved through the use of the method of repeating variables and the Buckingham Pi theorem (Cengel and Cimbala 2006). Among the necessary information that needed to be inputted beforehand included:

- The basic dimension of the loggerhead prototype (SCL and SCW)
- The swimming speed of the loggerhead.
- The ambient temperature and density of the sea water whereby the loggerhead swims.

Based on a study by Epperly *et al.* (n.d.) as well as dimensioning conventions used by Dr. Wyneken (2001), the Standard Carapace Length (SCL) and Standard Carapace Width (SCW) were taken at 0.92 m and 0.63 m respectively. As for the swimming speed, a research by Nagelkerken *et al.* (2003) yield a mean swimming speed of 0.5721 m/s. As for the temperature and density of the sea water, the values are taken at 80 ºF and 1027 kg/m^3 respectively. The model dimensions were finalized at using a one-fifth scale of the selected actual size and designed using Solidworks 2006.