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DESIGN FABRICATION AND PERFORMANCE ANALYSIS OF A MODEL HYDROFOIL VESSEL

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Abstract-*The paper presents a conceptual design of a hydrofoil based ship. The research results are based on CFD analyses using the SolidWorks software. The CFD analyses are conducted for a combination of different ship speed values and four foil angles of attack. The CFD simulations are done to determine the lift forces, drag forces and the maximum achievable lift-to-drag ratio (L/D). The results are briefly presented in a systematic manner to analyze its performance at different condition. In order to verify the CFD process, a comparison is made between analytical, experimental and SolidWorks results. A wooden hydrofoil vessel model according the design is tested. The model is equipped with two lifting foils. In addition, lift forces are measured in different angle of attack in a specific velocity.*

Keywords: Hydrofoil vessel, CFD.

1. INTRODUCTION

A hydrofoil is classified as any vessel that harnesses the lift forces generated when water flows over a wing-like surface. Originally, hydrofoils were affixed to small hulls in simple stacked designs. The successful achievements of hydrofoil craft to date and the possibility of high speeds at sea are due to the greatly increased understanding in recent years of the flow past hydrofoils and also to the development of foil configurations and control systems for coping with the roughness of the sea surface. When designing a hydrofoil, engineers must be extremely conscious of weight. The hull must have the strength to resist wave impact at high speed as well as distribute concentrated loads at the strut attachment points. Additionally, a major consideration in hydrofoil design is fulfilling sea-keeping requirements in a heavy sea [1]. In the 1930's an engineering known as Grunberg formed an idea of a submerged foil system that featured a single main lifting foil with forward floats or surface riders [2]. A hydrofoil design concept based on friction reduction by partial cavitations was suggested by Amromin. This concept was recently validated experimentally for 2D flows by Amromin, and Kopriva [3]. Since a prescribed lift must be generated to keep the hull above the sea surface; an increase in L/D provides a substantial performance advantage.

2. THEORY

In order to improve the marine transportation, engineers have focused on the total drag of the ship. One of the most thorough literature reviews of the dynamics of polymer molecules in turbulent flows was written by Lumley [4]. He reported a consensus option that drag-reducing polymer molecules in turbulent boundary layers are stretched by the flow, resulting in an increase in the total increase in the local fluid viscosity. A recent theoretical study was conducted by Rabin & Zielinska [5]. The total drag of the ship is divided into three main parts: (a) Friction resistance, (b) Wave making resistance, (c) Form resistance [6].

The last two parts are treated together as the residual resistance. The friction number is governed by the Reynolds (Re) number and the residual resistance is governed by the Froude (Fr) number [7].

There are two main forces acting on the hydrofoil itself, lift and drag. Lift is the force that makes an airplane fly and a boat rise out of the water. Drag opposes the motion of the vessel, and is much less than the vessels drag force and therefore reduces the amount of power needed at the design speed. The Eq. (1) to calculate lift is:

$$L = \frac{1}{2} C_l \rho A V^2$$

And the Eq. (2) for drag is:

$$D = \frac{1}{2} C_d \rho A V^2$$

where, C_l and C_d are the coefficients of lift and drag, ρ is the water density, V is the forward speed, and A is the wing area [8]. Once the terminus of cavity of foil is about 1/3 to 1/2 chord downstream of the trailing edge, the force on the hydrofoil becomes essentially steady [9].

3. HULL AND FOIL DESIGN

To design a hull dimension, three important factors are considered [10]. Light weight: Weight of the ship itself when completely empty; Dead weight: This is the weight that ship carries; Displacement: this is the volume of the water that ship displaces.

Here is the design which is designed for this project. The design is done by SolidWorks. It is the basement of the project. This is the preliminary step to perform a job.

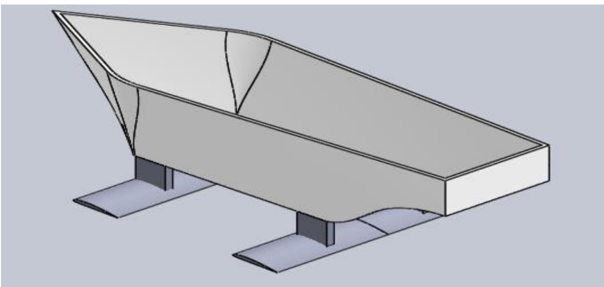

Fig.1: Orthogonal view.

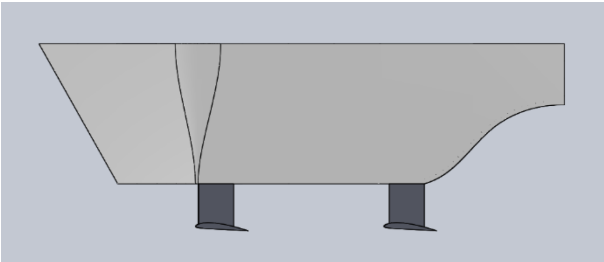

Fig.2: Side view.

The material for the whole body is PVC sheet of thickness 2 mm. There are two propellers behind the body. The main function of the propeller is to do the propulsion that is not mentioned in design.

3.1 Hull Dimension

From information on ships already built, we may select a highly used value of L/B and B/H value. Selecting these values we can use the following Eq. (3) for length which is known as cube root format [11]:

$$L = \left(\frac{dwt * \left(\frac{L}{B}\right)^2 * \left(\frac{B}{H}\right)}{\rho * C_{B*} C_D} \right)^{\frac{1}{3}} m$$

Where, C_D= dwt/W

C_B= 1.20-0.39($V/L^{0.5}$); (Global formula given by C.B. Barras [11])

C_B=1-0.235($V/L^{0.5}$); (Alexander's formula [11])

In modern Ship practice, the parameters L and B can be linked as following Eq. (4) [11]:

$$B = (L/10) + (5 \text{ to } 7.5) \text{ m}$$

The length of ship is 600 mm, width is 140 mm and height is 160 mm.

3.2 Foil Dimension

Here we use famous Clark Y hydrofoil profile. The Clark Y has found tremendous favor for the construction of model aircraft, thanks to the flight performance that the section offers at medium Reynolds number airflows.

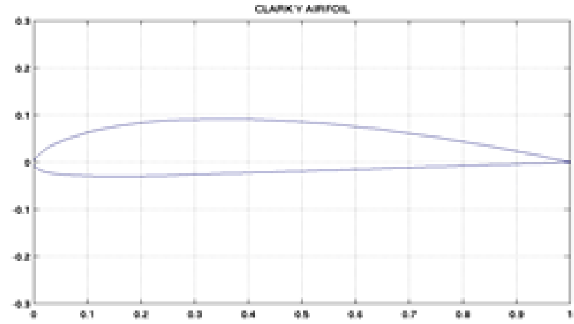

Fig.3: Clark Y airfoil [12].

The Clark Y is appealing for its near-horizontal lower surface, which aids in the accurate construction of wings on plans mounted on a flat construction board [13]. The foils are attached by two supports each with the hull. The foil dimensions are: chord length is 90 mm, thickness is 9 mm and length is 350 mm

4. CFD ANALYSIS

In the basis of different velocity of ship and different angle of attack of foil which are assembled with ship hull, the model is simulated in SolidWorks. The acquired data are represented with their criterion. All the tables contains drag force, lift force, lift and drag ratio.

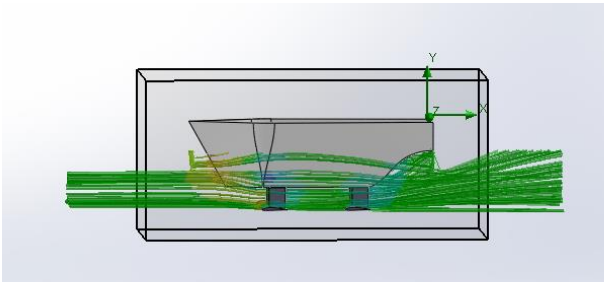

Fig.4: CFD analysis of ship.

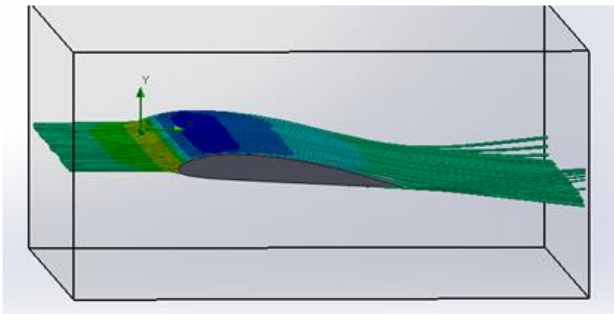

Fig.5: Flow trajectory of a single foil.

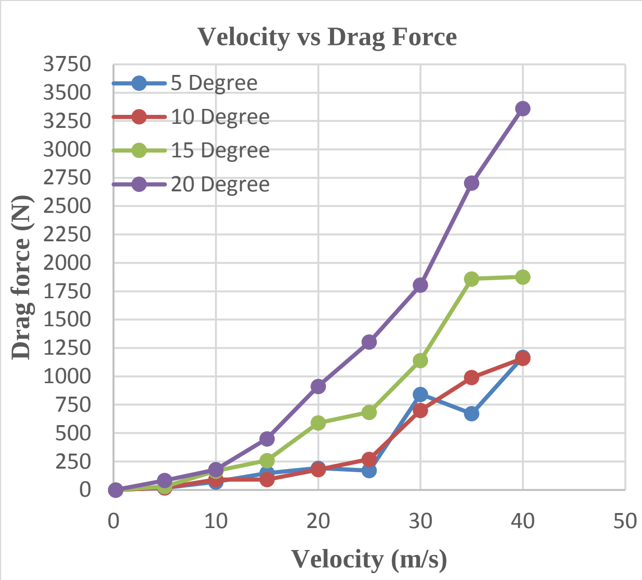

Fig.6: Velocity vs. drag force.

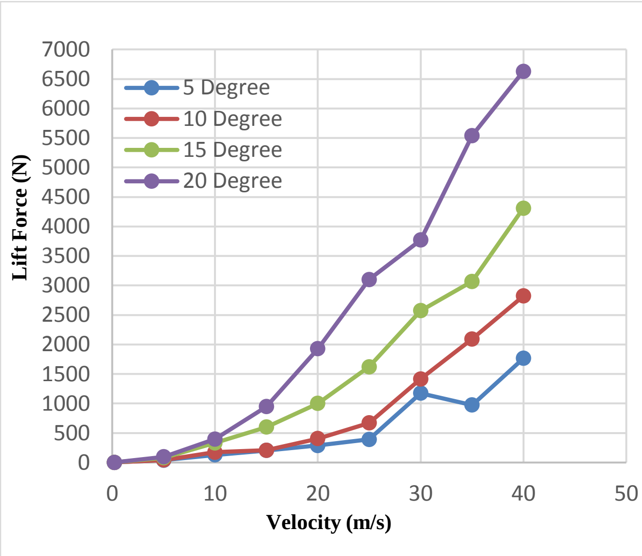

Fig.7: Velocity vs. lift force.

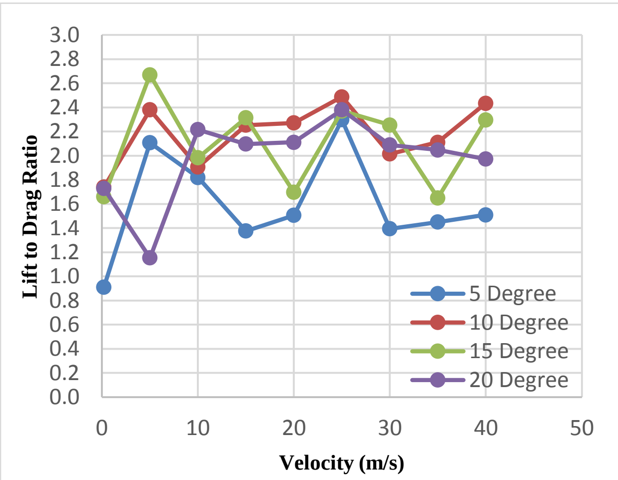

Fig.8: Velocity vs. lift to drag ratio.

5. MODEL AND EXPERIMENT

It is a great experience to prepare the model and assembled them in a proper manner. Here two DC geared motor, two wooden foil, PVC sheet ship model, two water propeller, LiPo power supply are used to fabricate the model.

Fig.9: DC geared motor.

Fig.10: Propeller with shaft.

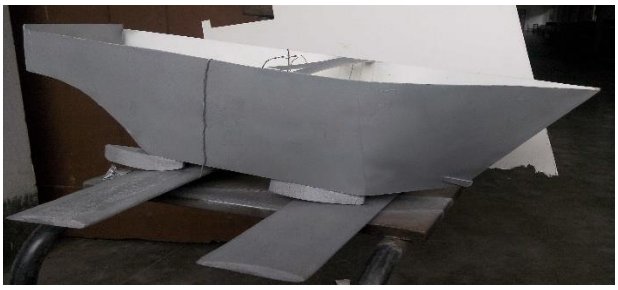

Fig.11: Ship model.

6. RESULTS AND DISCUSSIONS

6.1 Simulation Data Analysis

For constant angle of attack, lift force increases with the increase of velocity of ship. But drag force is not uniform. It is fluctuating. For constant ship speed, lift force increases with the increase of angle of attack. But drag force is not uniform. It is fluctuating. As a result of fluctuation of drag force, the ratio of lift force to drag force fluctuates. Maximum L/D ratio is the optimum velocity and angle of attack for this ship.

6.2 Experimental Data Analysis with Simulation Data

Table 1: Comparison between simulation and experimental data

Motor	DC 12V 800rpm	
Propeller	R3P×31×11	
Thrust Force	0.1565 N	
Velocity of Ship	0.2 m/s	
Foil angle of attack	5 degree	10 degree
Lift force (Experiment)	0.1836 N	0.3235 N
Lift Force (Simulation)	0.4179 N	0.8623 N
Deviation	56.07%	62.48%

6.3 Discussion

Poor Surface finish of foil surface and ship body surface create a large amount of frictional loss. The foil is hand made. So the shape is not perfectly achieved.Unavailability of powerful motor and desired size propeller are the obstacles to acquire desired ship speed. Practically the lift force is measured manually which does not give the real value of lift force.Air is not steady in environment. So it creates more drag force which results reduction of lift force.Because of ununiformed surface finishing of foil the assembled foil is not perfectly horizontal and two consecutive foils are not perfectly parallel.

7. CONCLUSION

In modern times, however, these hydrofoil boats are gaining more momentum on account of them being faster and speedier on the waters. A hydrofoil boat works on very simple terms. The hydrofoil based on the base of the boat allows the boat to move easily through the waters and ensures that the body of the boat – which in marine terms is referred to as the hull – does not come in any contact with the water. It however has to be noted that the hydrofoil that is used in the hydrofoil boats consist of much smaller foils than the foils on a hydroplane. The density of water is much higher than the density of air, because of which not much pressure is needed on the hydrofoils to maneuver the boat on the surface of the water thus explaining the reason about the foils in the hydrofoil of the hydrofoil boat being small. Just like yachts which have revolutionized the shipping and the boating industry to a great level, the hydrofoil boats are also capable of doing something equally great. Right now the usage of a hydrofoil boat is not much but given the benefits and the efficiency of such boats, it is quite possible that more and more parties will take to boats involving the use of hydrofoil as a successful alternative to the existing ones.

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