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A Study on the Composite Blade Performance Variation by Attaching Erosion Shield for Hovercraft

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Abstract : This study intends to study about the blade performance loss occurred due to the variation in the shape of airfoil from the attachment/non-attachment of blade erosion shield for hovercraft. This study model has used NACA 4412, has designed NACA 4412 by using Auto CAD and designed the shape that has attached an erosion shield to this model according to the thickness and length. By using these models, we have generated a grid by using GAMBIT and calculated the lift coefficient (Cl) and drag coefficient (Cd) by using the FLUENT code for flow analysis. Through this, we have calculated and compared the lift-to-drag ratio that is an indicator of airfoil performance according to the shape and attachment/non-attachment of erosion shield.

Key words : Lift-to-drag ratio, High-lift system, Erosion shield, Chord, Hovercraft

1. Introduction

Since composites are better in the specific strength, specific rigidity, lightness and corrosion resistance than existing metallic materials, they are widely used in various industries such as aerospace and automobile industries. Recently although the shipping industry also uses composite materials.[1,2]

Hovercraft set a ship afloat by generating a mass of high-pressure air in the section that the pressure below the ship rises against the ground or surface of the water.

Since hovercraft can be operable where the place is hard or soft like the land or swamp as well as in the sea or river, it is used as a means of transportation for the army or police. Also in the private sector, hovercraft is used for the rescue or leisure purpose. Hovercraft consists of the rotor that generates buoyancy, rotor for propulsion, and skirt that lets to form a layer of high-pressure air.

Since hovercraft floats and drives a ship by using two or more rotors as described earlier, the role of rotor blade could be regarded as an important component like the blade of a rotor-blade aircraft. However since the blade for hovercraft rotates at a high speed of 1,500~4,000rpm and has more exposure to the inflow of

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foreign particles as compared to the blade of rotor-blade aircraft. Hence, the life of blades is short with about 400 hours due to the damages made by foreign particles and this requires high repair/maintenance costs from the frequent replacement of blades. Therefore, the erosion shield is attached on the surface of blades in order to reduce the manufacture costs and repair/maintenance expenses. At this time, it is inevitable to have a loss in the blade performance by the existing blade of not having attached erosion shield and new blade of having erosion shield attached.

Although the performance test study according to the shape of airfoil have been actively carried out up until now, the study on the loss in the performance by attaching the erosion shield has not been made sufficiently.

Since the performance is directly connected to the speed and energy consumption of hovercraft, the studies on the performance loss by attaching the erosion shield are greatly in need. Accordingly, this study is focused on the measures of minimizing performance loss according to various shapes of erosion shield.

If the erosion shield is attached to the blade as shown in the Figure 1, the flections as in the Figure 2 are made. If the flections are made on a section of airfoil, this affects on the lift-to-drag ratio, deteriorating performance of the blades for hovercraft. However if the width of erosion shield is minimized in order to cut the performance loss, the adhesive property between blade and erosion shield is weakened and this raises a problem that a noticeable erosion prevention effect can not be achieved.

Figure 1: Actual Shape of a Blade after Attaching an Erosion Shield

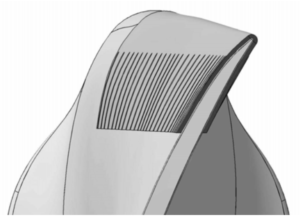


Figure 2: Front Diagram of a Blade after Attaching an Erosion Shield

The objective of this paper is intended to calculate the dragging and lifting forces by using the FLUENT code, to minimize the performance loss of blades by obtaining the lift-to-drag ratio through this, to make the process convenient, and to find the shape of erosion shield that can reduce the erosion effect of blades effectively.

2. Airfoil Modeling and Calculation Conditions

2.1 Airfoil Modeling

We have prepared an air-foil shape while using a spline curve by connecting a numerous number of coordinates from AUTO CAD. In this paper, we have selected NACA 4412 as a comparison target. As for the shape, the maximum size of average camber holds 4% of the chord; the location of maximum average camber is positioned at about 40% of the chord from the vertical hem of the wing; the maximum size of thickness becomes 12% of the chord.[3]

As for the coordinate determination of airfoil, the points of airfoil surface could be calculated by using the equation of Eq. 1 according to the shape of Figure 3.[4]

$$y_t = \frac{t}{0.20}(0.2969\sqrt{x} - 0.126x - 0.3516x^2 + 0.2843x^3 - 0.1015x^4) \quad (1)$$

$$y = (y_t)(c) \quad (2)$$

y_t = Dimensionless thickness
t = Maximum thickness
x = Dimensionless chord (0≤x≤1)
c = Chord

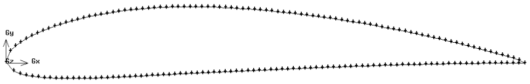


Figure 3: Point Distribution Defining NACA 4412 Airfoil Geometry

From the NACA 4412 Airfoil, let t=0.12 (thickness: 12%) and substitute the respective x values for the expression (1). Then, we can obtain various yt values. If this value is substituted for the expression (2), we can obtain the final y value.[5]

2.2 Calculation Conditions

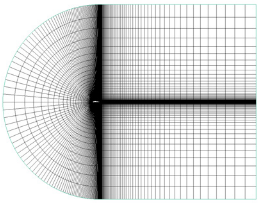
In this paper, we have used the far-field boundary 20 times as large as the chord in the grid system used according to the shape of chord. The validity of this value was proven through the numerical analysis of Navier-stroke that was performed while varying the location of far-field.[6]

FLUENT, as for the turbulence model, provides the Spalart-Allmaras model of 1-eq, k- model of 2-eq (standard, RNG, realizable), and Large Eddy Simulation model. This study has used the Spalart-Allmaras model[7] (a relatively accurate model) in the airfoil calculation of external flow and has concentrated the grid points on the forward area and surface of the airfoil in order to calculate the flow and boun-dary layer around the erosion shield. We have set the distance between the grid points of airfoil surface to 0.02c.[8] Also, we have distributed a sufficient number of grids (about 150 grids) by constructing a quad type of 12,451 nodes using GAMBIT.[9] Table 1 shows the detailed test conditions.

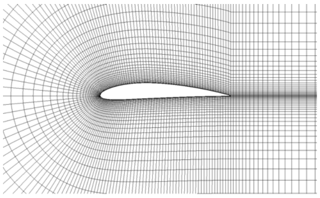
Table 1: Program Information & Test Condition

Program information
1) Design : Auto CAD2005 (Airfoil drafter)
2) Meshing : GAMBIT2.4.6
3) Solver : FLUENT6.3.26
Test condition
1) Space : 2D
2) Turbulent model : Spalart-Allmaras (1eq)
3) Reference values surface integrals[m2]:2.046454 Velocity [m/s] : 156.1859 Density [kg/m³] : 1.176674 Enthalpy [j/kg] : 14059.47 Pressure [pascal] : 101325 Re=2.1e07 Temperature [k] : 300
4) Angle of attack : a=0°
5) Mesh information Cells : 12195 ea Faces : 24646 ea Nodes : 12451 ea

The numerical analysis was performed for 4 shapes by linking each airfoil shape to the grid system with 0.33% and 0.66% of the erosion shield thickness and 8.3% and 13.3% of the airfoil length as shown in the Figure 5 when having attached or not having attached the erosion shield to the far-field boundary grid as con-structed in the Figure 4.



(a) Grid used in Computations



(b)Close up of Grid

Figure 4: Grid formation

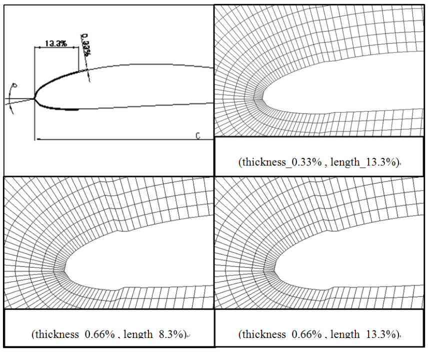


Figure 5: Airfoil shape by the attachment of erosion shield

3. Result and Consideration

We have computed by using 0° for the angle of attack of NACA 4412 Airfoil, 0.45 for the Mach number, and 2.1 x 107 for the Reynolds number while using the FLUENT code. The mach number and the reynolds number could be calculated by using the Equation (3) and (4).

$$Ma = \frac{U}{C} \tag{3}$$

$$R_n = \frac{\rho Vl}{\mu} \tag{4}$$

U = Blade rotational velocity
C = Sound velocity
ρ = Density
V = Velocity
l = Chord length

Looking at the pressure distribution of default NACA 4412 airfoil according to the chord of airfoil as in Figure 6, we could see that the pressure is evenly distributed since there is no much variation on the surface. Observing the pressure distribution when the thickness of erosion shield is 0.33% and the thickness is 13.3% on the Figure 7, we could see that the distribution is not smooth as the dragging and lifting forces increase around 0.2m. This is due to the vortex by the spreading of streamline around substance, Looking at the Model (C) of Figure 8 that the thickness of erosion shield is 0.66% and the length is 8.3%, the graph has changed abruptly as compared to the Model (B). From the graph, we could identify a section that the pressure in the upper and lower sections of the airfoil becomes identical. This shows that the stall occurred by the increase of dragging force and the lifting force disappeared by the vortex.

As we can see in the Figure 9, the

variation in the pressure of pressure distribution diagram in the model (D) has abruptly increased. Likewise, we could see that a performance loss has occurred in the bent section on the surface of airfoil as the erosion shield is attached.

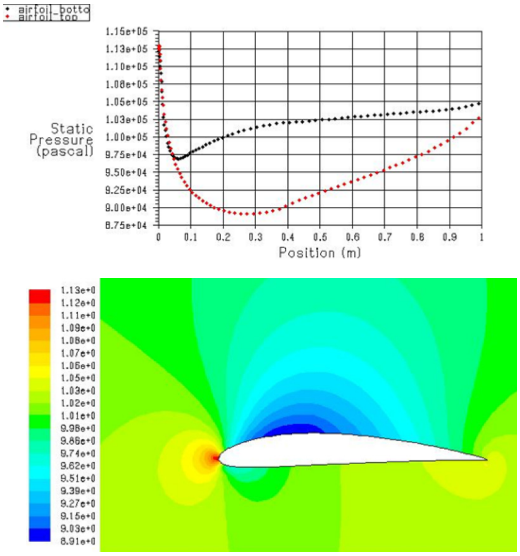


Figure 6: Pressure Distribution of Default NACA 4412 Airfoil (A)

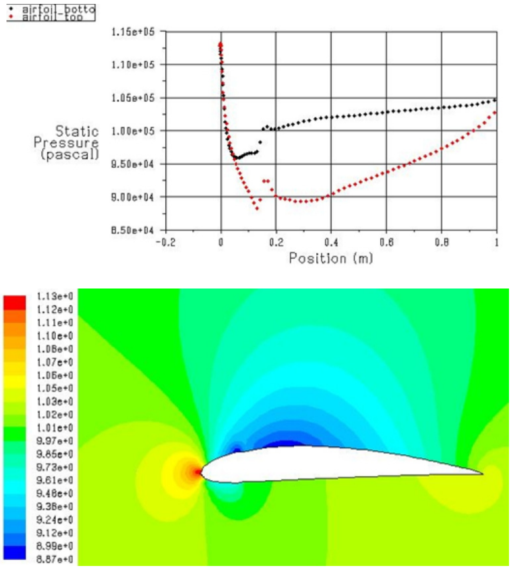


Figure 7: Pressure Distribution of NACA 4412 Model (B)

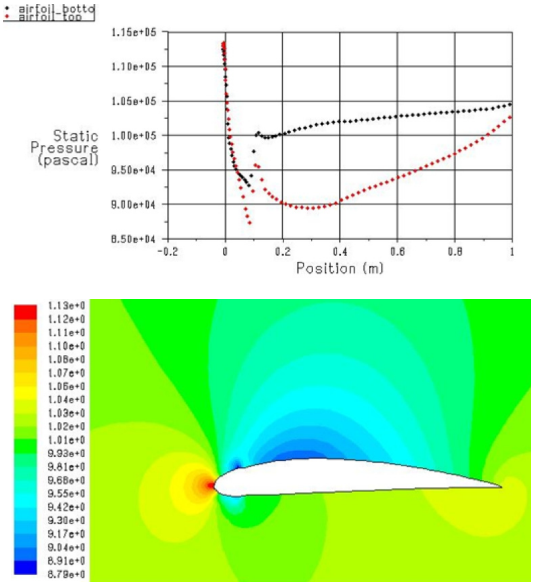


Figure 8: Pressure Distribution of NACA 4412 Model (C)

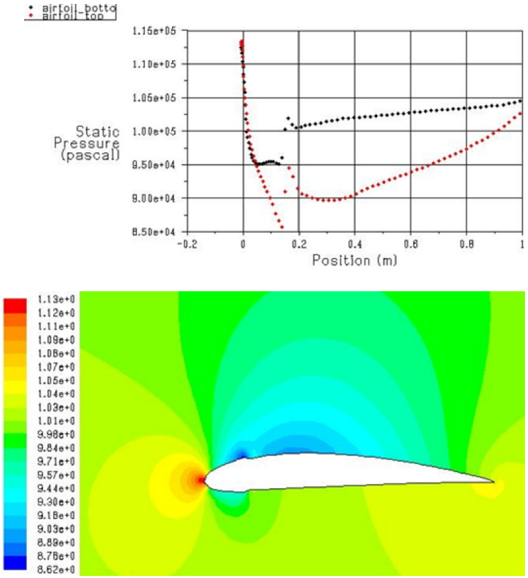


Figure 9: Pressure Distribution of NACA 4412 Model (D)

Looking at the Table 2, we could check the performance loss by comparing the lifting coefficient (Cl), dragging coefficient

(Cd), and lift-to-drag ratio (Cl/Cd: indicator of airfoil performance) when having or having not attached the erosion shield. The lifting coefficient and the dragging coefficient could be calculated by using the equation of (5) and (6) for FLUENT 6.3 code.

$$C_L = \frac{2L}{\rho V^2 S} \tag{5}$$

$$C_D = \frac{2D}{\rho V^2 S} \tag{6}$$

μ = Viscosity
L = Lift
D = Drag
S = Wing area

We could compute the magnitude of lifting coefficient (Cl) and dragging coefficient (Cd)according to the bernoulli's principle and the lift-to-drag ratio (L/D: indicator of airfoil performance) holds the value identical to the value of Cl/CD. The values obtained in this way are shown on the Table 3.

Here, the lifting force means the driving forcing of Hovercraft. In all the four cases, it is satisfied with the thrust blade condition over 15 KPa. It seems that it doesn′t affect the whole blade.

Table 2: Lifting and Dragging Coefficients of NACA 4412 by the Erosion Shield

E-s T_L (Model) Coef.	0%_0% (A)	0.33_13.3 (B)	0.66_8.3 (C)	0.66_13.3 (D)
Cl	0.5425	0.5375	0.5252	0.5240
Cd	0.0182	0.0194	0.0215	0.0216
Cl/Cd	29.8104	27.6786	24.4623	24.3056

(NACA 4412. Re=2.1×10^7)

Table 3: Lifting Force, Dragging Force and Drag-to-Lift Ratio by the Erosion Shield

E-s T_L (Model) Coef.	0_0(A)	0.33_ 13.3(B)	0.66_ 8.3(C)	0.66_ 13.3(D)
L(Pa)	15,933	15,869	15,588	15,558
D(Pa)	534	573	637	640
Cl/Cd	29.8104	27.6786	24.4623	24.3056

(NACA 4412. Re=2.1×10^7)

Looking at the Figure 10, we could see that the magnitude of lifting force decreases as the thickness of erosion shield is larger and the length of erosion shield is shorter. However when having compared only with the magnitude of lifting force, the difference between the model (A) of holding the highest value and model (D) of holding the lowest value was 374.6pa, showing a loss of about 2.35%.

Following the Figure 11 that shows a graph of having compared the magnitude of dragging force, we could see that the dragging force has greatly increased as the thickness of erosion shield increases from 0.33% to 0.66%. Looking at the Figure 12 that has computed and compared the lift-to-drag ratio (L/D) with the lifting and dragging forces, we could see that the lift-to-drag ratio has dropped as the thickness of erosion shield increases. The data shows the highest lift-to-drag ratio of 29.81 when having not attached the erosion shield and the lowest lift-to-drag ratio of 24.31 when the model of erosion shield was (D). Observing this result, we could see that the performance of hovercraft blades has dropped by 18.5% from the performance loss of 5.5048.

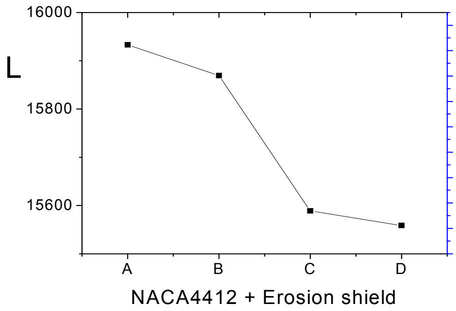


Figure 10: Comparing the Lifting Force by the Thickness and Length of Erosion Shield

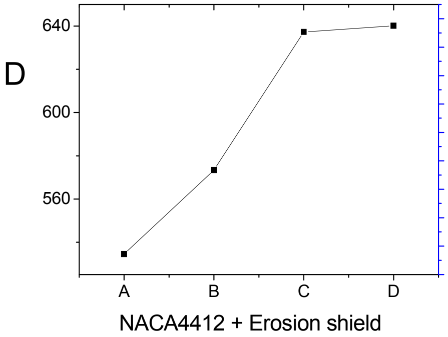


Figure 11: Comparing the Dragging Force by the Thickness and Length of Erosion Shield

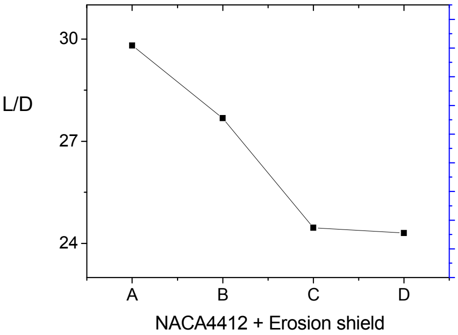


Figure 12: Comparing the Lift-to-Drag Ratio by the Thickness and Length of Erosion Shield

4. Conclusions

In order to minimize the performance loss of hovercraft blades with the erosion shield and to attach the erosion shield mechanically easier with lower cost, this study has analyzed the FLUENT code, finding the optimal shape of erosion shield. This study has used the FLUENT 6.3 code as for the Spalart-allmaras model that the flow used in this experiment is 1-eq and we have computed the shape after attaching erosion shield to the default airfoil. Consequently, we could see that the pressure was not distributed smoothly and the distribution showed an abrupt change as the flections get thicker and longer, decreasing the drag-to-lift ratio relatively much as the lifting force decreases and the dragging force increases. Comparing only with the magnitude of lifting force, the difference between the model (A) of holding the highest value and model (D) of holding the lowest value was 374.6pa, showing a loss of about 2.35%. This refers to a loss in the performance of airfoil. However since the role of erosion shield is essential in order to increase the lifespan of hovercraft blades, we need to reduce damage by foreign particles efficiently while keeping the blade performance. Hence, the data of this paper may be used effectively in selecting the optimal shape according to the shape and material of erosion shield.

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He received his B.S. degree in Marine Engineering from Korea Maritime University in 1983. He then went on to receive his M.S. degree from Tokushima University in 1990. Also he received a Ph.D. degree from Kyushu University in 1993. Prof. Kim was a guest Professor at National Institute of Standards and Technology in the U.S.A. He is currently a Professor at the Division of Marine Equipment Engineering at Korea Maritime University in Busan, Korea. And he is also working as a Director of Innovation Center for Engineering Education in KMU. Prof. Kim's research interests are in the area of composites fabrication, the evaluation of strength and physical metallurgy.

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