2D Hydrofoil의 유체력과 Trim Tab효과에 대한 수치해석적연구

정노택, 사임(세이무자만 엠디.)

Computaional Study on the hydrodynamic force of 2D Hydrofoil and the Effect of Trim Tab

Rho-Taek Jung, Md. Sayeemuzzaman

This paper is concerned about the hydrodynamic coefficients of hydrofoil. We discretized the incompressible Navier- Stokes equation with second order Runge-kutta for the time in the second order compact scheme for the spatial. The three-dimensional CFD code based on hybrid mesh on the finite volume method is used to simulate flow around NACA series foils. Lift and drag coefficient is calculated for several NACA series foils using different mesh types. Our aim is to obtain the lift and drag coefficient to evaluate the robustness of the solver and to show the advantage of using trim tab at the trailing edge. It concludes with a discussion of results and recommendations for future work.

Keywords: *CFD Code, Trim Tab, NACA Hydrofoil*

1. Introduction

Even though the use of hydrofoil began in the early 1900s the use and the development is still going strong, the hydrofoils used in yachting industry in particular. For the cruising yachts the aim is to make keel with increased aspect ratio of the keel and then comes the idea of manipulation of tip flow. The important effect is that in case of trim tab the lift curve shifts as a result giving it a side force even at zero angle of attack. If we can adjust it properly then we will have enough side force to balance the sails may be generated without leeway moving the hull straight through water [1].

The effective design of keel or rudder can make a big difference in balancing the hydrodynamic force and the aerodynamic force from the sails. In the aerodynamic industry the use of multi element airfoil is nothing new. Bruce et al.[2] reported the effect of a lift enhancing tab at the main element trailing edge increased the maximum lift by 10.3% for the 42-deg flap case.

The use of tab should be considered with the shape of the rudder or fin keel since the NACA 00 rudder generates the largest maximum lift coefficient [3]. For a device like tab at the trailing edge the kutta condition is altered immediately [4].

Assistant Professor, NAOE, University of Ulsan
*E-mail: rtjung@ulsan.ac.kr (corresponding author)
Graduate Student, NAOE, University of Ulsan,
*sayeem_plexus@yahoo.com

2. Numerical Methods

2.1 Governing Equation and computational scheme

The incompressible Navier-stokes equation and continuity equation (1) in two- dimension is solved.

$$\frac{d}{dt}u + u.\nabla u = -\nabla p + \nu \Delta u + a$$
$$\nabla . u = 0 \tag{1}$$

In the present fractional step method, an explicit second-order scheme in time for momentum for time discretization is used.

By splitting into the two intermediate steps:

$$\frac{u_i^* - u_i^n}{\Delta t} = CONV + DIFF \tag{2}$$
$$\frac{u_i^{n+1} - u_i^*}{\Delta t} = -\nabla p^{n+1} \tag{3}$$

CONV is the convective term, DIFF is the diffusion term. u* is an intermediate velocity component, where superscript n denotes the solution at the n-th time step.

By taking the divergence and making use of the incompressibility condition for um+1,which mcorresponds to eq(4), the poisson equation for pressure increment using the intermediate velocity is obtained.

$$\frac{\nabla \cdot \hat{u}_i}{\Delta t} = \nabla^2 \delta p^m \quad (4)$$

Approximating u at cell face, the upwind interpolation scheme is used. Depending on the flow direction, the approximation value u at cell face is decided.

$$\int \mathbf{uu.n}\ dA = \sum_i u_i \times FLUX_i \quad (5)$$

To calculate the convection fluxes, the value of ui(x,y,z) and its gradient at the cell center are required. For a higher order scheme, a limiter function should be employed in order to avoid oscillate solutions. In this study,the cell face values are obtained by using the Taylor series expansion with second order accuracy.

$$\begin{aligned} u(x,y,z) &= u(x_P, y_P, z_P) + \psi_C \cdot \Delta r + O(\Delta r^2) \\ &\approx u(x_P, y_P, z_P) + \psi_x\big|_C \cdot (x - x_C) \\ &\quad + \psi_y\big|_C \cdot (y - y_C) \quad + \psi_z\big|_C \cdot (z - z_C) \end{aligned} \quad (6)$$

where, the Ψc is

$$\psi_i\big|_C = \frac{1-\lambda}{2}\nabla u_P + \frac{1+\lambda}{2}\nabla u_J \quad (7)$$

The value of λ used in the present calculation is -2/3 to achieve third-order accuracy (strictly for regular grids).Since the diffusion term consists of second derivatives, the calculation of first derivatives at cell faces is required. We use a local coordinate system (ξ1,ξ2,ξ3) at each cell face to compute first derivatives. When ϕ is a scalar quantity, it can be evaluated at the cell face.

$$\frac{\partial \phi}{\partial x_i} = \frac{\partial \phi}{\partial \xi_1}\frac{\partial \xi_1}{\partial x_i} + \frac{\partial \phi}{\partial \xi_2}\frac{\partial \xi_2}{\partial x_i} + \frac{\partial \phi}{\partial \xi_3}\frac{\partial \xi_3}{\partial x_i} \quad (8)$$

ξ1 is the direction connecting two cell centroids and ξ2, ξ3 are ones between two nodes on a face.

2.2 Boundary Condition

For velocities, the uniform flow is given at inflow boundary, the zero-gradient Neumann condition is set at outflow boundary, and no-slip condition is for solid surfaces. For pressure, the zero gradient Neumann condition is applied to all boundaries.

3. Results

The mesh is created using Gridgen software. The O-type mesh has a total of 11,024 cells with 22,464 nodes. The boundary has 4 layers to satisfy the boundary condition and smoothing technique was used using Gridgen to improve the skewness and the aspect ratio of the grid cells. The drag Cd and lift Cl coefficients were calculated as follows,

$$C_d = \frac{2F_d}{\rho A v^2}, C_L = \frac{2L}{\rho A v^2} \quad (9)$$

The drag and lift forces were compared with and without tab of the NACA 63-009 airfoil. The lift force was higher Figure 2 with the tab than the without tab Figure 1 foil.If we look at the pressure contour and the velocity profile in the figure 2 we can see that there is a presence of backwash on the upper side of the tab.

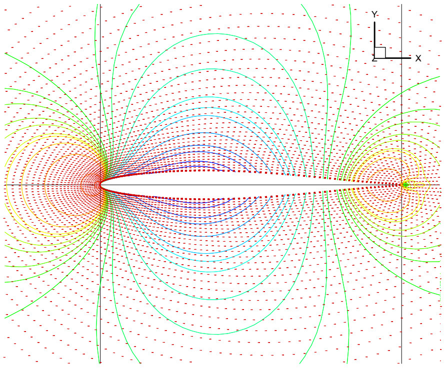

Fig: 1 Velocity vector and pressure contour of NACA 63-009 for Re =2.54e06

In the mean Cp contour there is a sudden spike in pressure at the 0.88c where the tab is attached.

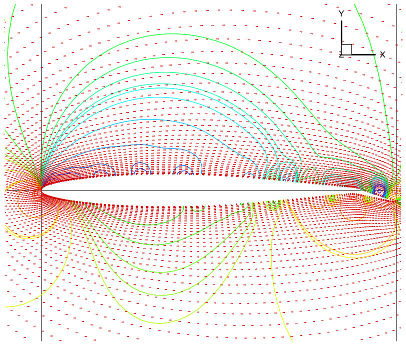

Fig. 2 Velocity vector and pressure contour of NACA 63-009 with tab for Re =2.54e06

4. Conclusion

The tab at the trailing edge increases the lift of the hydrofoil even with a AOA of zero degree. In this case the tab is only 12% of chord length and with an angle of -15 degree with horizontal. The pressure contour, lift and drag of NACA 63-009 was also performed and the foil with the tab showed improved performance.

For the 3 Dimensional design we will run with turbulent condition for higher reynolds number. The design effort is concerned with simpler design with increased lift.

Acknowledgement

Special thanks to SOTOP(Ship and Ocean Top Ranking in the world) project at the University of Ulsan, Korea.

References

[1] Larsson, L., Eliasson, R., E., "Principles of yacht Design," Second Edition, International Marine Publication

[2] Bruce, L. S.,James, C. R.,"Experimental study of lift-Enhancing Tabs on a Two-Element Airfoil," Journal of aircraft, Vol.32,No.5, September-October 1995.

[3] Chau, S., W., Kouh, J., S., Wong, T., H., Chen, Y., J., "Investigation of Hydrodynamic Performance of High-Speed Craft Rudders via Turbulent Flow Computaions, Part 1: Non-Cavitating Characteristics," Journal of Marine Science and Technology, Vol.13, No.1, pp. 61-72(2005)

[4] Dam, C.,P., V., Chow, R., Zayas, J., R., Berg, D.,E., Computational Investigation of Small Deploying Tabs and Flaps for Aerodynamic Load Control.