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Flow characteristics and tip vortex formation around a NACA 0018 foil with an endplate

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ABSTRACT

Tip vortex structure around a NACA 0018 foil with and without an endplate is studied using PIV method in a circulating water channel. The Reynolds number based on the chord length (100 mm) is $Re=2.5\times10^4$. The analysis also includes varying angles of attack $\alpha=10^\circ$ and $\alpha=20^\circ$. Velocity profiles are obtained from 1C (chord length) to 3C, measured from the trailing edge. Sectional velocity profiles are also obtained and compared both foils at the same angles of attack. Vortex formation is changed near the end-span section due to the prevention of roll-up phenomenon. The endplate also decreases Reynolds shear stress in the wake region. It can be judged that the flow formation around the foil is affected by the endplate untill the mid-span.

1. Introduction

Control surfaces are used on a wide range of marine vehicles as rudders, stabilizers and pitch damping foils. The fundamental concept of a movable device to steer a ship has been in use since ships were conceived. The purpose of the devices, or rudders, is either to maintain the ship on a particular course or direction, or to enable it to manoeuvre. It may be composed of a single movable surface or the combination of fixed and movable devices. An extensive amount of researches and investigations into ship rudders and control surfaces has been carried out for years, including wide ranging investigations by the authors into rudder–propeller interaction (Ahn and Kim, 2003; Paik et al., 2010; Lam et al., 2011). The hydrodynamic forces and moment induced by propellers and rudders are formulated based on the flow fields around the propellers and rudders Kobayashi and Ishbashi (1993).

The practical use of special rudders has increased with the advantage of stability, course keeping ability, navigational safety, maneuverability and work efficiency. Maneuverability has been received a great deal of attention both concerning navigation safety and the prediction of ship-steering characteristics, especially at the preliminary design stage. Maneuvering characteristics have not been clarified due to the complicated hydrodynamic forces at the stern form, propellers, rudders and skegs. These forces and moment are generated as a result of rudder rotations and attack angles then determine the maneuvering characteristics of marine vehicles. These impart turning or yawing motions to the vehicles.

Lee et al. (2008) reported that the development of a high-lift rudder is needed because of the maneuvering of low speed full ships. The vessels have difficult to obtain enough side forces from a common rudder. The design of high-lift rudder should be considered with the interactions between hull, propellers and rudders. Tang and Dowell (2006) carried out an experiment on flow control devices based on an oscillating foil with small trailing edge strips. The device can significantly increase the maximum dynamic lift and the stall angles of attack. Gurney flap can move the separation position forward on the lower surface. Farsimadan and Dehghan (2010) conducted an experimental study on the near-wake of a NACA 0012 placed upstream of a 90° bend section. They confirmed that the freestream velocity alters the boundary layer development on the foil and that the flow angle has more effect on the boundary layer development on the upper surface of the foil. Yu et al. (2005) and Cory et al. (1998) carried out a numerical simulation on the effect of Gurney flap over a foil. Gurney flaps increase the foil lift coefficient with only a slight increase in drag coefficient. The separation point of the foil with a Gurney flap rests farther aft at moderate angles of attack than that of a clean foil. They insisted a significant increase in lift-to-drag ratio relatively at low angles of attack. Weier and Gerbeth (2004) insisted that Lorentz forces could be used to influence the flow of conducting fluids. They applied time periodic Lorentz forces to the control of the suction side flow on a NACA 0015 hydrofoil within the range of $10^4 \leq Re \leq 10^5$. The Lorentz force allows for a great flexibility in providing the time dependency of the forcing.

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They offer a potential for further energetic optimization of the flow control by unsteady Lorentz forces.

Seo et al. (2007) reported that a considerable improvement in performance of a fin stabilizer is achieved with adoption of the tail blades. Wang et al. (2009) also studied a drag-based active fin stabilizer used in zero-speed conditions based on the reaction force from the fluid.

Daichin and Zhao (2007) investigated on the near wake flow of an airfoil above the free surface in a wind-wave tunnel at $Re=3.5\times10^3$ using PIV system. The lift force and pressure drag acting on the airfoil increased as the airfoil was getting closer to the free surface.

Grant et al. (2006) carried out an experimental investigation to measure the total lift and induced drag of NACA 0015. In compared with previous researches using Pitot pressure techniques and CFD, they proved that PTV is a viable tool in obtaining quantitative flow field characteristics rapidly. PIV time-averaged data allowed a more exact comparison with CFD and traditional data collection methods.

On the historical technical notes of Pass (1940), the endplate effect of the horizontal tail increases the effective aspect ratio of a single vertical tail by about 50%. Other technical notes for Carter (1961), the endplate prevent the flow exiting through the wing tip instead of the small gap at the trailing edge and increase the ground effect exerting on the wing surface. It noted that the endplate effect of preventing the stagnated air on lower surface from flowing out around the wing tips and produced a substantial improvement in lift-drag ratio. Park and Lee (2008) and Park et al. (2008) numerically studied on the effect of an endplate at various angles of attack for a wings-in-ground craft. They found that the endplate prevented the high-pressure air from escaping out of the lower surface and so reduced the influence of the tip vortex and further augmented the lift and lift-drag ratio. The endplate also reduced the deviation of the static height stability with respect to angles and heights. The purpose of the present paper is to investigate the influence of an endplate on the flow around a foil at $Re=2.5\times10^4$. Two-dimensional flow characteristics around NACA 0018 with and without an endplate was investigated. The experiment was carried out with 10 and 20 angles of attack to obtain the flow information around the foil using two-frame grey-level cross-correlation PIV method.

2. Experimental setup and conditions

The rudder model used for this study consists of NACA 0018 with and without a plate in a flow. Experiments were conducted in a circulating free surface water channel on a case-by-case basis. The coordinate system adapted through the whole experiments is shown in Fig. 1. It is to measure two dimensional flow characteristics of the rudder. The angles of attack (α) are varied 10°, 20° respectively. The channel has a section of 1000 mm (L) $\times$ 300 mm (W) $\times$ 300 mm (H) which is made from 15 mm-thick transparency Plexiglas sheet. The water as a working fluid used in this experiment was kept at a constant value of 25 ± 1 °C, fresh water. The water pump is driven by an electric motor with a variable speed controller. The flow is driven by the effect of gravity under atmospheric conditions in room temperature. The model is installed in the middle of the water channel which has a distance h=300 mm between the free surface and the bottom of channel. The experimental configuration used in this study consists of a flow imposed around a rudder at a Reynolds number ($Re=2.5\times10^4$) based on the chord length 100 mm.

The l overview of the circulating water channel with the model installed is shown in Fig. 3. The distribution of u-components is more complicated near the bottom than the free surface of the channel. That is the reason why the Reynolds number should be

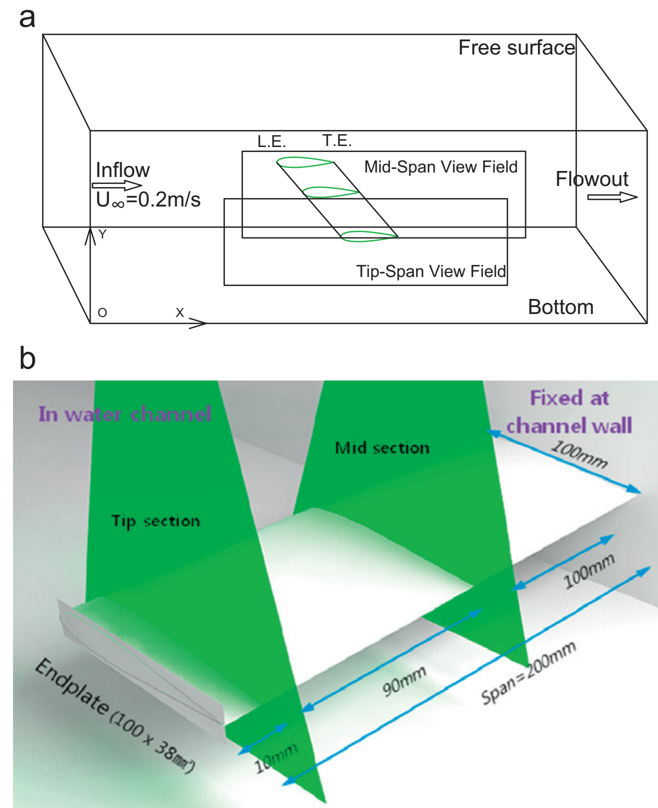

Fig. 1. Schematic diagram of model setup and coordinate system. (a) Circulating water channel and coordinate system and (b) Physical model setup, location of mid-span section and tip-span section.

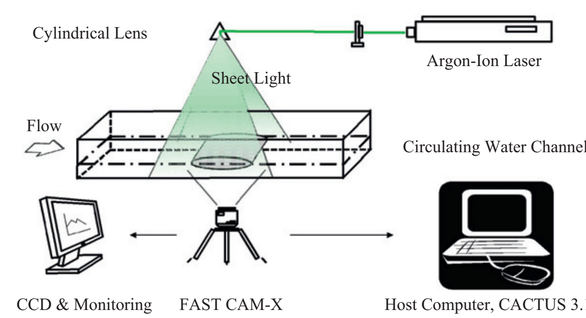

Fig. 2. Schematic arrangement of PIV system.

Fig. 3. High-speed camera and image grabber.

$Re=2.5\times10^4$ in this study. The model is an endplate foil consists of NACA 0018, 100 mm in chord length. The dimensions of the endplate which is attached at the span end of the foil is a rectangular plate,