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A numerical parametric study on hydrofoil interaction in tandem

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ABSTRACT: *Understanding the effects of the parameters affecting the interaction of tandem hydrofoil system is a crucial subject in order to fully comprehend the aero/hydrodynamics of any vehicle moving inside a fluid. This study covers a parametric study on tandem hydrofoil interaction in both potential and viscous fluids using iterative Boundary Element Method (BEM) and RANSE. BEM allows a quick estimation of the flow around bodies and may be used for practical purposes to assess the interaction inside the fluid. The produced results are verified by conformal mapping and Finite Volume Method (FVM). RANSE is used for viscous flow conditions to assess the effects of viscosity compared to the inviscid solutions proposed by BEM. Six different parameters are investigated and they are the effects of distance, thickness, angle of attack, chord length, aspect ratio and tapered wings. A generalized 2-D code is developed implementing the iterative procedure and is adapted to generate results. Effects of free surface and cavitation are ignored. It is believed that the present work will provide insight into the parametric interference between hydrofoils inside the fluid.*

KEY WORDS: Tandem hydrofoils; Tandem airfoils; Body interference; Iterative boundary element method; Finite volume method.

INTRODUCTION

Tandem arrangement of bodies can be encountered even in the most ordinary ships. A ship hull and a rudder are arranged in tandem in any conventional ship. A rudder creates a lift force to steer a ship by confronting the flow behind the ship hull with an angle of attack. The maneuverability of a ship is determined by the lift force created by the rudder; therefore the maximization of this lift force is significant.

It is possible to think of the rudder behind the ship hull as a flap behind an aircraft wing. A flap increases the lift force of the wing; however, the parameters affecting the interaction between them must be analyzed carefully before the decision of how this flap will be given. The same situation is valid for the ship - rudder system; some parameters must be maintained in order to receive full performance from the rudder. For example, the distance between the rudder and the ship or the shape of the rudder changes the flow around the ship stern significantly. This study intends to give a general notion on how the objects inside the fluid interact with each other using two NACA0012 hydrofoils arranged in tandem. NACA0012 hydrofoil is selected as a sample object inside the fluid due to its wide usage and a lot of literature work being present. The objects inside the fluid may differ but the effects of the parameters will be about the same. The parameters examined in this study are; the effect of the distance between the hydrofoils, the effect of thickness, the effect of angle of attack, the effect of chord length, the effect of the aspect ratio and the effect of tapered wings.

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The present study focuses on two tandem hydrofoils and the problem is tried to be simplified with a two dimensional approach where possible. There are some works done and papers published about the interaction of bodies in a fluid. The lift/drag ratio with the deflection of spoiler; which in this case is the backward or the second hydrofoil have been improved by Wang et al. (2011). A technical note published by Matveev and Matveev (2001) investigated the tandem hydrofoil system to improve the lift/drag ratio of a high-speed ship.

The iterative boundary element method and RANSE solutions are used within the study. Potential flow solutions are handled by the boundary element method mainly; while for all the viscous flows FVM implementing RANSE was referred to. A low - order and two - dimensional iterative boundary element method was used in this study with a combined source - dipole elements and Dirichlet type of boundary condition. Low - order panel method was chosen due to its smaller computational effort and sufficiency in complex geometries (Lee, 1987). BEM is a widely used method to assess propulsive efficiencies of ships and some works relating to this topic may be found in (Ghassemi, 2009a; 2009b). Although excluding viscous effects, BEM is a very practical method to assess hydrodynamic and even seakeeping characteristics of ships. It allows much faster calculation than FVM can handle and therefore, BEM is a solid method that paves the way for parametric analyses for complex flows inside fluids. Iterative BEM is a tool that relaxes the computer in terms of memory required and therefore may be preferred instead of the direct method (Kinaci et al., 2011; Kinaci, 2014). Bal (2008a; 2008b; 2011) has selected papers on iterative BEM. He has used the iterative boundary element method and divided the wave resistance problem into sub-parts to handle the problem in terms of numerical implementation easily and to reduce computational time. Combined source - dipole elements can model a thick and asymmetric body and therefore refer to a broader set of geometries. Dirichlet type of boundary condition was selected to compute the results more precisely.

The wings are intensively researched by aeronautical engineers mainly; therefore many papers are published by aerodyne-micists looking for conditions to increase wing lift. The steady and unsteady effects of flaps over the main wing are investigated by RANSE in (McGlumphy et al., 2009; McGlumphy et al., 2010; Zhu et al., 2012; Lim and Tay, 2010). Flaps work in the wake of the main wing; therefore, oscillations may occur in the system. These oscillations reduce the lift of the wing and due to this reason, a detailed work involving the unsteady effects of the system is given for some specific airfoils in (Zhu et al., 2012; Lee, 2011). Experiments have also been made for understanding the effects of the tandem airfoil interaction in unsteady cases (Lee, 2011; Muneketa et al., 2008). Some experiments were conducted to improve lift to drag ratio of airfoils and constitute the core of some works (Scharpf and Mueller, 1992).

This study ignores the effects of instant lift reductions due to the unsteady characteristics of the tandem hydrofoil system as well as the possible effects of cavitation and free water surface effects. Free water surface affects the lift of the hydrofoil and its effects are investigated in numerous papers (Duncan, 1983; Hino, 1983; Xie and Vassalos, 2006; Ghassemi and Kohansal, 2013). Cavitation formed at the backward hydrofoil in the wake of the forward hydrofoil (which indicates the rudder in the ship - rudder system) is another important issue and cavitating hydrofoils are examined in (Bal, 2011; Ekinci et al., 2010).

For the iterative boundary element method, the authors have developed their own code while for RANSE applications; a commercial CFD software is used. This work is built upon and a developed follow-up of the paper presented by the same authors in Hydman 2012 conference (Kinaci et al., 2012).

FORMULATION OF THE PROBLEM

Boundary element method formulation

Boundary element method in this study is only used for inviscid and two dimensional flows. Therefore, only 2D formulation of the method will be given. Incompressible and inviscid continuity equation for an irrotational fluid is defined by the Laplace Equation which states that the total potential $\emptyset^*$ of the whole fluid domain is equal to zero.

$$\nabla^2 \phi^* = 0 \tag{1}$$

According to the Green's Identity, a general solution of the Laplace Equation can be given as a sum of source and doublet distributions on the boundary of a 2D surface S: