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An iterative boundary element method for a wing-in-ground effect

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ABSTRACT: *In this paper, an iterative boundary element method (IBEM) was proposed to solve for a wing-in-ground (WIG) effect. IBEM is a fast and accurate method used in many different fields of engineering and in this work; it is applied to a fluid flow problem assessing a wing in ground proximity. The theory and the developed code are validated first with other methods and the obtained results with the proposed method are found to be encouraging. Then, time consumptions of the direct and iterative methods were contrasted to evaluate the efficiency of IBEM. It is found out that IBEM dominates direct BEM in terms of time consumption in all trials. The iterative method seems very useful for quick assessment of a wing in ground proximity condition. After all, a NACA6409 wing section in ground vicinity is solved with IBEM to evaluate the WIG effect.*

KEY WORDS: Iterative boundary element method; Wing-in-ground effect; Method of images; NACA6409.

NOMENCLATURE

h	Clearance of the wing from the ground	c	Chord length of the wing
AoA	Angle of attack	N	Number of discretized panels
ε	Pre-described error for the IBEM analyses		

INTRODUCTION

Effect of the ground has several impacts on a structure flying above the surface. These structures use the several benefits that the surface serves to them, which is named as ground effect flight. Different definitions of ground effect can be found in the literature and one of them defines it as “a phenomenon of aerodynamic, aeroelastic and aeroacoustic impacts on platforms flying in close proximity to an underlying surface” (Reeves, 1993; Rozhdestvensky, 2006). Efficient utilization of the ground effect proposed a different transportation technique other than mainly used, when the Russians first made use of it during the cold war (Rozhdestvensky, 2006).

Although first built for militaristic purposes, ground effect is a phenomenon that is generally exploited by Wing-in-Ground (WIG) effect crafts to improve transportation efficiency. Analyzing the Von Karman-Gabrielli Diagram (see Fig. 1), WIG vehicles fill the gap between very efficient but slow conventional ships and not that efficient but very fast airplanes.

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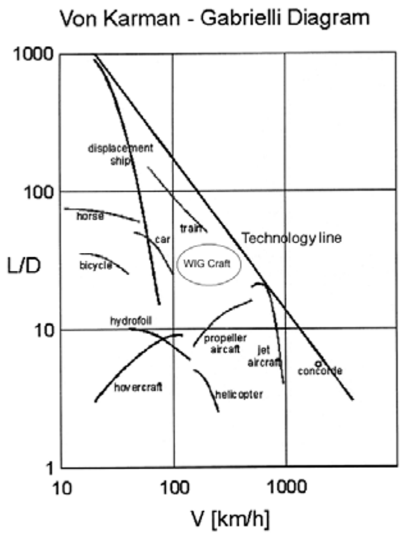

Fig. 1 Von Karman-Gabrielli Diagram for transport efficiency of vehicles (Halloran and O'Meara, 1999).

WIG crafts can be a good alternative for transport over the sea due to their lower fuel consumption. They spend less fuel than hydrofoil vessels and hovercrafts which are also accepted to be high speed marine vehicles like WIG crafts. The closeness of WIG crafts to the technology line assures these vehicles' availability to be widely used.

Up to now, these vehicles have not been built and exploited from their advantages due to a few reasons. On behalf of stability problems and some safety issues, there is still some way to go to improve their efficiency. The efficiency of a wing is determined by the lift-drag ratio and these parameters may either be calculated numerically or experimentally. There are many works on wing-in-ground effect and a large part of these works focus on the augmentation of lift and reduction of drag that the ground creates over the wing. An optimal design with the goal to achieve maximum lift satisfying the height stability criteria of a WIG craft was developed by Kim et al. (2009). They have assumed inviscid flow and used vortex lattice method to optimize WIG by sequential quadratic programming. Wing configurations on a wing-in-ground effect in terms of efficiency were investtigated by Lee et al. (2010). Djavareshkian et al. (2010) have investigated the effects of a smart flap under ground effect and proved an increase in efficiency by CFD. Ahmed and Sharma (2005) analyzed a symmetrical NACA0015 wing section experimentally and concluded their work with the optimum conditions for maximum lift and minimum drag. Evaluation of a power augmented ram (PAR) as a lift booster in take-off and landing was made by Zhigang and Wei (2010). Flow around a WIG craft with and without PAR was analyzed by CFD in their work.

Although WIG analyses are generally made with commercial softwares that use RANSE such as (Abramowski, 2007; Jamei et al., 2012), potential flow codes are also frequently used to assess a wing-in-ground effect. Other than the work of Kim et al. (2009), lifting surface theory which adopts the inviscid flow assumption was used in numerous works by Liang and Zong (2011), Zong et al. (2012) and Liang et al. (2013). Phillips and Hunsaker (2013) have used potential based lifting line theory to assess the closed-form relations that were offered to assess the effect of the ground over the wing sections. Some benchmark experimental studies are found in the literature as well, like Luo and Chen's (2012) work on NACA0015 wing or the work of Jung et al. (2008) on NACA6409 wing. Daichin (2007) analyzed the near-wake flow of a NACA0012 airfoil above a free surface experimentally with PIV. It is concluded in his study that as the clearance from the free surface decreases, the wake flow of the airfoil remarkably changes.

WIG crafts may have complex geometries and solution of the flow around these bodies may be time consuming using RANSE. Construction of the mesh system and to produce a result takes relatively greater times. Due to this reason, many potential theory based articles implement the boundary element method as a numerical approach. Boundary element methods panelize the objects inside the fluid rather than meshing the whole fluid domain to calculate the flow characteristics around them. The number of objects in the fluid does not matter; as there may be single or multiple object(s) inside the fluid. Direct application of boundary element methods enables solving the whole flow even if there are many objects inside the fluid. However, a different treatment of the method that leads to the solution iteratively produces faster results. In this article, an iterative boundary element method (IBEM) will be used to solve the two-dimensional fluid flow around a wing in ground proximity.