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Longitudinal static stability requirements for wing in ground effect vehicle

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ABSTRACT: *The issue of the longitudinal stability of a WIG vehicle has been a very critical design factor since the first experimental WIG vehicle has been built. A series of studies had been performed and focused on the longitudinal stability analysis. However, most studies focused on the longitudinal stability of WIG vehicle in cruise phase, and less is available on the longitudinal static stability requirement of WIG vehicle when hydrodynamics are considered: WIG vehicle usually take off from water. The present work focuses on stability requirement for longitudinal motion from taking off to landing. The model of dynamics for a WIG vehicle was developed taking into account the aerodynamic, hydrostatic and hydrodynamic forces, and then was analyzed. Following with the longitudinal static stability analysis, effect of hydrofoil was discussed. Locations of CG, aerodynamic center in pitch, aerodynamic center in height and hydrodynamic center in heave were illustrated for a stabilized WIG vehicle. The present work will further improve the longitudinal static stability theory for WIG vehicle.*

KEY WORDS: Ground effect; Longitudinal stability; Aerodynamics; Hydrodynamics; Hydrofoil; Vehicle dynamics.

NOMENCLATURE

$M_{a,h}, M_{a,z}, M_{a,\dot{q}}, M_{a,\dot{w}}, M_{a,\theta}, Z_{a,h}, Z_{a,z}, Z_{a,\dot{q}}, Z_{a,\dot{w}}$ Differentiation of aerodynamic forces with respect to corresponding variable

$M_{h,h}, M_{h,z}, M_{h,\dot{q}}, M_{h,\dot{w}}, M_{h,\theta}, Z_{h,h}, Z_{h,z}, Z_{h,\dot{q}}, Z_{h,\dot{w}}$ Differentiation of hydrodynamic forces with respect to corresponding variable

$M_{hb,h}, M_{hb,\theta}$ Differentiation of hydrodynamic forces of fuselage with respect to h and θ

$M_{hf,h}, M_{hf,\theta}$ Differentiation of hydrodynamic forces of hydrofoil with respect to h and θ

INTRODUCTION

The Wing-in-Ground (WIG) effect vehicle is considered to be a promising form of transport, due to its high speed and low fuel consumption (Rozhdestvensky, 2000; Yun et al., 2010; Yang and Yang, 2009). WIG craft lies between a sea-going ship and an aircraft in terms of its characteristics. It is generally slower than airplane but has much lower fuel consumption than ship. The WIG craft would have application wherever there are: (a) significant spans of overwater operations; (b) inadequate aircraft operational bases to support airline operations; (c) beaches or simple port unloading facilities for roll on-roll off operations.

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WIG craft characteristics exceed those of ship and aircraft because of it can carry greater than aircraft payloads over significant distances at general aviation aircraft speeds (Yang and Czysz, 2011). Unlike conventional air vehicle, the characteristics of force and moment of a WIG vehicle vary due to pitch and height, when the vehicle approaches the ground. Only appropriately designed, can WIG vehicle escape from the potential danger of kissing the ground (or water surface). The most important issue for the operation of WIG vehicle is the longitudinal static stability, for the longitudinal dynamic stability can be usually fulfilled when the system parameters, which provide the static stability, are within a certain range.

The issue of longitudinal stability of Wing-in-Ground effect vehicle has existed for decades as a very critical design factor since the first experimental WIG vehicle has been built. A series of studies were performed and focused on the longitudinal stability analysis. Kumar (1968) derived equations of longitudinal motion of a WIG vehicle by using quasi-steady aerodynamic derivatives. Irodov (1970) carried out his work on longitudinal stability of ekranoplans and formulated the criterion of longitudinal static stability as the requirement. Rozhdestvensky (1997) applied mathematics of Extreme Ground Effect (EGE) to study the cross-section of wing in ground effect. Taylor (1995) has carried out an elegant experimental verification of the stability of a schematized Lippisch configuration. The longitudinal stability analysis on a 20-passenger WIG was conducted by Chun and Chang (2002) based on wind tunnel test data. The effect of configurations on longitudinal stability was studied by Yang et al. (2010) and Lee et al. (2010). Considering hydrodynamics, Shi et al. (2007) studied the course stability and longitudinal stability of WIG vehicle in takeoff and landing phases by compling hydrodynamic and aerodynamic forces. Yang et al. (2011) investigated the influence of hydrodynamic forces on longitudinal motion of WIG vehicle. Benedict et al. (2001) proposed a complex mathematical model of WIG motion including the takeoff mode to provide a predictive tool for the design of WIG vehicle. At the same time, WIG vehicles with different configurations considering longitudinal stability have been built (Halloran and O'Meara, 1999; Rozhdestvensky, 2006; Matveev, 2008; The WIG Page, 2009).

In regard to the longitudinal stability of WIG vehicle, the equations of equilibrium in the longitudinal plane has been addressed in the current study, taking into account the aerodynamic, hydrostatic and hydrodynamic forces acting on WIG vehicle. Static stability criterion has been discussed, and effects of hydrodynamics and hydrofoil were also considered. The present work aims to provide reference for design and control of WIG vehicle, and shows a picture of longitudinal stability requirements of a WIG.

LONGITUDINAL DYNAMIC MODEL

Axis system

To describe the motion of a WIG vehicle and the forces acting on it, a stability-axis (XOZ) system was used. The relationship between body-axis (X_BOZ_B) and stability-axis are presented in Fig. 1. They are all right-handed and orthogonal. The origin of axis system is located at the Center of Gravity (CG). In the following is illustrated the mathematical model developed for this work, based on the model proposed by Collu et al. (2010).

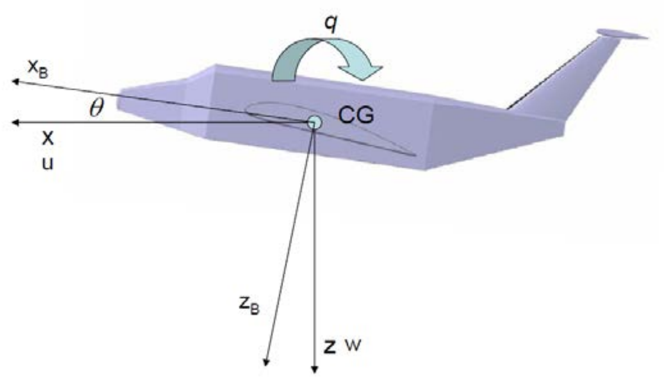

Fig. 1 Stability-axis and Body-axis.