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Chaotic Assessment of the Heave and Pitch Dynamics Motions of Air Cushion Vehicles

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ABSTRACT

In this study, three degrees of freedom nonlinear air cushion vehicle (ACV) model is introduced to examine the dynamic behavior of the heave and pitch responses in addition to the cushion pressure of the ACV in both time and frequency domains. The model is based on the compressible flow Bernoulli's equation and the thermodynamics nonlinear isentropic relations along with the Newton's second law of translation and rotation. In this study, the dynamical investigation was based on numerical simulation using the stiff ODE solvers of the Matlab software. The chaotic investigations of the proposed model are provided using the fast Fourier transform (FFT), the Poincaré maps, and the regression analysis. Three control design parameters are investigated for the chaotic studies. These parameters are ACV mass (M), the mass flowrate entering the cushion volume (ṁ_in), and the ACV base radius (r). Chaos behavior was observed for heave and pitch responses as well as the cushion pressure.

KEYWORDS

Air Cushion Vehicles, Bernoulli's Equation, Chaos, Fast Fourier Transform (FFT), Heave Motion, Pitching Motion, Poincaré Map

1. INTRODUCTION

Air Cushion Vehicles (ACV) are mainly operated by highly pressurized air which is fed to the air cushion using blowers. The flow of air is maintained due to a momentum change at the high-velocity peripheral air curtain. These blowers yield a large volume of air cushion that has a pressure, a little higher than the atmospheric pressure creating a pressure difference. This pressure difference produces vehicle lift, which causes the bottom air cushion to float above the running surface. The ACVs have the capability to function in many different environments that can be coarse such as ice, water, or forests.

The hydrodynamic action of the ACV is ideally equivalent to that of a pressure distribution acting on the free surface of water. This idealization prohibits any physical contact of the lower part of the ACV with the water (Bliault, A., 2000). Abundant studies were performed in the literature regarding proper designing and dynamics of these vehicles. The rest of this section is a summary of the related study that are available in the literature.

A linear analysis of a two-dimensional section of the cushion equipped with a bag-and-finger skirt was subjected to only input heave motion by Chung et al. (2000). The skirt mass was lumped in the fingers, with the bag being modeled as a combination of massless inelastic membranes and links. The findings of the study suggested that changes in skirt geometry could not be used to radically modify an undesirable heave response, but reducing the skirt mass might be effective. They also found in

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their study that the air compressibility affected the heave response at high frequencies, with the effect becoming more prominent at low cushion-flow rates commonly used in practice.

All prior research studies combined together formed the basis of a standard physics-based dynamic simulation model for ACVs. It should be noted that the response motions computed from the previous physical simulation models of the ACVs did not display similar response when compared with the experimental results of the scaled-model tests. Lack of understanding the physical damping mechanisms in the ACV motion led to the discrepancy between the simulations and experiments. Wave generation on the free surface and deformation of the viscoelastic skirt material was used as a damping source by Chung (2002) in his investigation while Graham and Sullivan (2002) researched the effect of other sources of damping on the motion of the ACVs, such as the unsteady air flow throughout the fan, skirt, and cushion system.

The general configuration of ACVs including the overall dimensions, weight distribution, parametric properties, and several subsystems, was designed and optimized by Jung et al. (2002) using the expert system at the initial design phase. The skirt bag and finger systems of ACV were further optimized for improving ride quality and stability of the vehicle using the genetic algorithm. Hence, Chung's work opened up the new avenues for designing ACVs using artificial intelligence techniques. Chung et al. (2004) also used the Genetic Algorithm to optimize the undesirable two dimensional section heave response of the ACV's bag and finger skirt system geometry. They obtained a new skirt geometry that considerably improved the resonating frequencies associated with the skirt mass at which humans were most sensitive.

An analytical model of was introduced by Pollack et al. (2007) to investigate the dynamics of an ideal air cushion cavity of an ACV. The study revealed that skirt impedance strongly affected the resonant frequencies and mode shapes of the ACV. The impedance of modern skirt systems could also dramatically alter the air cushion enclosed volume and vehicle footprint, thus influencing the system resonances and restoring moments Pollack et al. (2007).

Compressibility effect on the dynamic behavior of an ACV was investigated by Milewski et al. (2007) and Milewski et al. (2008) utilizing the deformable free surface condition. The governing equations introduced by Milewski et al. (2007) were solved on a fixed regular grid translating at the vehicle mean forward speed using the Immersed Boundary Method (IBM). Whereas, Milewski et al. (2008) developed a numerical program called ACVSIM (Air Cushion Vehicle Simulation), that used the boundary element method with a higher order spline based model to study the skirt and the ACV dynamics. ACVSIM coupled a high-order Rankine panel method with models for air cushion and skirt dynamics to calculate the motions of the ACV.

The incompressible viscous ñuid mechanics problem around ACV near the free surface was investigated numerically using the Semi-Implicit Method for Pressure Linked Equations (SIMPLE) algorithm and volume of fluid (VOF) method with staggered grid by Nikseresht et al. (2008). Many parameters were examined in the numerical procedure such as the ACV under skirt pressure distribution, initial air gap under the ACV, and effect of Froude number. A versatile and robust computational coding was done and tested in their study by applying the code on a water impacted cylindrical part of the ACV.

Hossain, et al. (2011) presented a new dynamical model for the forces on a small scale intelligent air cushion tracked vehicle (IACTV) moving over swamp peat. The air cushion system in their study partially supported 25% of vehicle's total weight making the vehicle ground contact pressure 7 kN/m,[2] in order to make the IACTV move over the intended terrain without threats. They also mentioned that the relationships between the various vehicle parameters had been experimentally tested. Some of these parameters were: tractive efficiency, power consumption, traction coefficient, load distribution ratio, tractive effort etc. Experimental and simulated results showed a considerable improvement in the vehicle's performance when values of 0.71 and 0.62 were used for the traction coefficient and tractive efficiency respectively.