

A Dynamic Analysis of an Integrated Aircraft-Floating Structure-Water Interaction System Excited by the Impact of an Aircraft Landing

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The dynamic response of an integrated aircraft-floating structure-water interaction system excited by the impact of a landing aircraft is investigated. The aircraft and the floating structure are considered 2 elastic substructures, and the water is treated as a fluid subdomain. The landing gears of the aircraft are modeled by 3 supporting systems, each consisting of a spring and a damper. A mixed finite element-boundary element approach is developed to model this complex interaction system. The solution strategies of the numerical equations are proposed. A 2-dimensional numerical example is presented to illustrate and demonstrate the mathematical model and the numerical method.

INTRODUCTION

When designing a large floating airport or an aircraft carrier, the naval architect needs to address the transient dynamics problem involving impacts of aircraft landing on these structures. The difficulties in solving this problem involve the following 3 phases. The first is that the problem necessitates interdisciplinary studies relating to the fluid, aircraft, floating structure and their interactions. The second is that the integrated system is a time-dependent system in which the relative position between the aircraft and the floating body changes due to the aircraft landing motion. The third is that the fluid defined in an infinite domain requires a particular numerical treatment. As result of these difficulties, only a few simplified studies of this transient problem have been reported to date. Using a finite element (FE) program, Watanabe and Utsunomiya (1996) presented the numerical results for elastic responses due to prescribed impulsive loading on a circular very large floating structure (VLFS). Kim and Webster (1996) and Yeung and Kim (1998) studied transient phenomena of an infinite elastic runway using a Fourier transform approach. Endo (1999) adopted a FE scheme and Wilson- θ method (Wilson, 1973; Bathe, 1982) to investigate the transient behavior of an airplane taking off from and landing on a VLFS in rough sea conditions using a triangle time impulse load applied at the nodes of the structure to represent the loads introduced by the weight of the airplane. Kashiwagi and Higashimachi (2003) and Kashiwagi (2004) presented the transient elastic deformation of a pontoon-type VLFS caused by the landing and takeoff of an airplane based on the prescribed time histories of the airplane's position, velocity and loading on the runway. In these reports, the interaction between airplane and VLFS has not been considered because the loads applied to a VLFS by an airplane landing or taking off are prescribed.

When other available mathematical models and software packages are used to solve such airplane-VLFS-water interaction dynamic problems, difficulties arise. For example, numerical methods developed by Xing (1988), Xing and Price (1991),

Morand and Ohayon (1995), Xing, Price and Du (1996) and Dervieux (2003) can be efficiently used to solve fluid-structure dynamic interaction problems involving compressible fluids defined in finite domains, but they fail to deal efficiently with problems involving infinite domains. Boundary element (BE) methods (Cruse, 1977; Brebbia, 1978; Ciskowski and Brebbia, 1991), the theory of ship motions (Newman, 1978), and the hydroelasticity theory of ships (Bishop and Price, 1979; Bishop, Price and Wu, 1985) based on various source distribution methods provide a general way to transfer an infinite domain problem to a numerical problem on defined boundaries. However, they have not specifically addressed transient impact interactions between the floating structure and the landing aircraft traveling on it. Recently, authors (Xing, Jin and Price, 2003; Xing and Jin, 2004) have proposed a mathematical model based on the mode functions and BE techniques to solve the problems. As is well known, for beam-like or plate-like structures these theoretical mode functions are available, but for complex aircraft or floating structures it is very difficult to find their analytical mode functions. Thus practical applications of the proposed method are limited. This paper continues this research to develop a mixed FE-BE method and then provide a more powerful and practical numerical approach to deal with this type of complex dynamic coupling problems. In order to clearly describe the essential process of this method, a simplified 2-D example is given.

GENERAL DESCRIPTION OF PROBLEM

Fig. 1 illustrates a large flexible 3-D body, $\Omega_s^{(1)}$, with unit outer normal vector $\nu_i^{(1)}$, floating in calm water and occupying a domain, Ω_f , with unit outer normal vector η_i and a flexible 3-D aircraft, $\Omega_s^{(2)}$, with outer normal vector $\nu_i^{(2)}$, landing on it. The Cartesian coordinate system $o^{(1)}-x_1^{(1)}x_2^{(1)}x_3^{(1)}$ fixed in space at point $o^{(1)}$ has the plane $x_1^{(1)}o^{(1)}x_2^{(1)}$ initially coincident with the calm water surface. The coordinate system $o^{(2)}-x_1^{(2)}x_2^{(2)}x_3^{(2)}$, with horizontal plane $x_1^{(2)}o^{(2)}x_2^{(2)}$, is fixed at point $o^{(2)}$ in the aircraft, and initially the point $o^{(2)}$ coincides with the mass centre of the aircraft. This system moves with the horizontal velocity of the mass centre of the aircraft. Due to a landing resistance, the forward velocity varies with time, hence this moving system is a noninertial system. It is assumed that the landing resistance is a constant along the negative direction of the axis

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