Implementation of a Free-Vortex Wake Model in Real-Time Simulation of Rotorcraft

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Abstract

Free-vortex wake models are capable of providing an accurate and physically detailed representation of the main rotor wake for flight dynamics simulation. Recent advances in computing power and efficient algorithms have made it feasible to use free wakes for real-time simulation. The CHARM free-vortex wake model was integrated with the GENHEL flight dynamics simulation of the UH-60A helicopter. A high fidelity wake model was defined by increasing the spatial and temporal resolution of the wake until a converged response was observed, but this baseline model could not execute in real-time. A parametric study was performed to find the best combination of wake parameters to achieve real-time execution with minimal deviation from the baseline model. Multiple variations in the wake properties were tested for execution framerate and their frequency and time responses in the pitch and roll axes were compared to those of the baseline model. A real-time model was selected and showed reasonable agreement with the baseline model as compared to a finite-state inflow model. The free wake models resulted in significantly different off-axis response and large amplitude response than the finite-state inflow model. A parallel implementation of the free wake model was also investigated. An increase in computational efficiency could be achieved using a distributed processing approach with asynchronous communications.

Introduction

A critical issue in the development of high-fidelity simulations of rotorcraft is the modeling of the rotor wake.[1] The rotor wake influences the local air velocities in the plane of the rotor, which in turn affect the air loads on the main rotor blades. Furthermore, the rotor wake is responsible for a number of important aerodynamic interactions with the fuselage and empennage.[2,3] A major challenge in wake modeling for flight dynamics simulation is the need for real-time performance. While off-line calculations of flight dynamics are still valuable, real-time calculations can be used in pilot-in-the-loop simulation in order to analyze handling qualities. While high-fidelity free-vortex wake models have been around for many years, their applications have mainly been restricted to off-line analysis of performance and rotor dynamics in trimmed and quasi-steady flight. However, advances in computing power and efficient algorithms are now making free-vortex wake models a viable option for real-time flight dynamics analysis.

It has long been recognized that quasi-static models of the rotor inflow, while sufficient for steady-state analysis or low order dynamic models, fail to capture important characteristics. For example, a quasi-static inflow model fails to capture the dynamic overshoot of thrust and torque following a collective input.[4] The development of dynamic models for the rotor wake has been a challenging problem because the air mass effectively has an infinite number of degrees of freedom. Over the years a number of inflow models have been applied that model the inflow with a small number of dynamic states.[5] The problem was first addressed using simple lag filters to model the inertia of the air mass in order to capture the dynamic effects of the average induced inflow.[6] A major advance occurred with the advent of the finite-state dynamic inflow models developed by Peters et al.[7] The third order Pitt-Peters model and the higher order Peters-He model represent the rotor downwash in the plane of the rotor with a set of radial and azimuthal basis functions. The distribution of downwash is then governed by a finite set of state equations driven by the loading on the rotor blades. The main advantage of these models is that they provide reasonable prediction of downwash in the rotor disk and they are readily incorporated into real-time simulation models. The number of states used in the Peters-He model is scalable in order to achieve the desired tradeoff in terms of fidelity versus real-time performance. The calculations required for a 15-state Peters-He model,

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