BVI Noise Prediction using a Comprehensive Rotorcraft Analysis

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ABSTRACT

Blade-vortex interaction (BVI) noise predictions using the CHARM comprehensive rotorcraft analysis and NASA's WOPWOP acoustic prediction code were performed and correlations with HART, JVX, TRAM and XV-15 test data are presented. The analysis directly computes the evolution and rollup of the vortex sheet trailing from the full span of each rotor blade. A refined model of the swirl velocity within rolled-up vortices is used when computing the high resolution airloads associated with BVI noise. No empirical information or user-selected constants are required; values for viscous vortex core radius of rolled-up vortices, which can strongly affect BVI noise levels, are determined by satisfying physical conservation laws. For this reason, the analysis is well-suited for predicting BVI noise (and vibration) for new configurations where vortex core properties are not known a priori and for analyzing BVI mitigation methods that rely on modification of the wake structure. Directionality and peak BVI sound pressure levels were predicted with good accuracy and in low CPU times for the cases examined. Sensitivities and shortcomings have also been identified along with possible remedies.

INTRODUCTION

Efficient, accurate prediction of BVI loading and noise through the use of computer models is an important challenge facing today's rotorcraft designers due to continuing concern over public acceptance of conventional helicopters and tiltrotor aircraft. General success in this endeavor has proven to be difficult for a number of reasons. Radial and azimuthal variations in blade loading and deformation are responsible for the trailing of complex vortical structures into the wake. These vortical structures evolve under their own influence, resulting in complicated wake geometries, particularly at low to moderate forward speeds where BVI noise is of most concern. Highly twisted tiltrotor blades and Higher Harmonic Control (HHC) mitigation techniques further complicate the issue by creating counter-rotating tip vortices and altering the rollup characteristics of the primary vortex during typical BVI flight conditions. Furthermore, the fact that the rotor blades interact strongly with their own wake during approach results in a complex mutual interaction requiring a merging of the disciplines of wake geometry modeling and blade dynamics modeling. And finally, the prediction of BVI noise requires high resolution of blade airloads, to one degree in azimuth or less for general applicability, posing a great challenge for both accuracy and computational efficiency.

The last decade has seen a great deal of research developing rotorcraft analyses capable of predicting BVI noise, (e.g., Refs. 1-22), and several of these efforts have been quite successful. Ref. 1 shows that full CFD solutions are now capable of providing accurate BVI noise predictions if the large CPU requirements to prevent vortex dissipation can be accommodated, (in this case, 80 hours on 30, 1.7Gflop processors running in parallel). Note also that the calculations in Ref. 1 required the blade motion to be prescribed. Others have taken the opposite approach, applying insightful modeling techniques to obtain reasonable BVI predictions in minimal CPU time, such as the "radiation cone principle" described in Ref. 2 and the "spherical method" demonstrated in Ref. 3. The most common approaches lie somewhere between these two extremes, typically combining several, non-CFD, analysis codes that determine blade dynamics, free wake evolution, high-resolution airloads, and far-field noise in succession (see for example, Refs. 4, 5 for a description of several of these). Among the most successful of these types of analyses to date is the TRAC computer program developed by NASA/Langley which has shown good accuracy in predicting BVI noise for both conventional rotors Ref. 6 and tiltrotors Ref. 7. Ref. 8 describes a similar approach taken at ONERA that matches the HART acoustic test data (Ref. 23) with remarkable accuracy while also computing the blade motion. And finally, Ref. 9 describes an analysis applied by ATIC and NAL that couples a 3D Euler code with CAMRAD II to obtain good results for a conventional five-bladed rotor system.

The approach taken here is to provide a BVI noise prediction capability within Continuum Dynamics, Inc.'s (CDI's) comprehensive rotorcraft analysis, CHARM, by enhancing the model and linking it seamlessly to NASA/Langley's WOPWOP acoustic prediction code. An important characteristic of the CHARM analysis is that the wake evolution, rollup and BVI characteristics are determined entirely from first principles – no empirical data

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