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Analytical Investigations of Coupled Rotorcraft/Engine/Drive Train Dynamics

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Abstract

The fundamental characteristics of the coupled rotor, engine, and drive train dynamics of a rotorcraft are investigated with two different models. A detailed finite element model of a complete vehicle including flexible rotor blades, fuselage, engine, transmission, tail rotor, and a feedback control system was studied with the Second Generation Comprehensive Helicopter Analysis System (2GCHAS). To complement and aid in interpreting the comprehensive analysis results, a simpler five degree of freedom model and associated computer program, Rotor/Engine/Drive Train (REDT), were developed to perform rapid parametric analyses and illustrate system dynamic behavior. Eigenanalysis results including frequencies, damping, and mode shapes are presented for the linearized systems without the effects of rotor aerodynamics. Closed form solutions for limiting cases with the REDT model were found to be helpful in understanding the modes. Parametric analyses provided further insight and expanded the scope to a wider class of rotorcraft.

1 Introduction

The design of modern rotorcraft involves careful integration of airframe, rotor, engine, drive train and control system characteristics. Consequences of inadequate integration may include excessive loads in the rotor or drive train components, inadequate maneuvering performance or unacceptable vehicle handling qualities. The more comprehensive report of this work in Hopkins et al. (1995) cites several examples, including the recent difficulties with the AH-64A Apache following introduction of the upgraded T700-GE-701C engine. Such problems arise from the inherent complexity of modern high performance rotorcraft systems, the inadequacy of the available analytical tools and the paucity of generic research exploring the fundamental behavior of complex rotorcraft dynamic systems. They combine to prevent the designer from accurately addressing the true nature of interaction phenomena. A number of investigators have addressed these problems and developed a wide variety of vehicle and propulsion system models. Several of these investigations are also cited in Hopkins et al. (1995). While, in many cases, these investigations employ sophisticated models and address a variety of engine/airframe interaction phenomena, there are many other details of the problem that deserve attention.

Recently comprehensive analysis tools for rotorcraft aeromechanics have become available. A comprehensive tool can provide general finite element structural models, sophisticated aerodynamic models together with the capability of including propulsion system/drive train and flight/engine control system representations. The capabilities of one such tool, the Second Generation Comprehensive Helicopter Analysis System (2GCHAS), for supporting rotorcraft/propulsion system dynamic analysis motivated this investigation of the complex dynamic interactions associated with a reasonably high fidelity model of a physical system. An overview of the Second Generation Comprehensive Helicopter Analysis System (2GCHAS) is provided in Ormiston et al. (1994) and more details may be found in 2GCHAS (1993a), 2GCHAS (1993b) and 2GCHAS (1993c). As the research progressed, it became evident that the results from 2GCHAS could be confirmed and interpreted and the basic characteristics of the system could be clarified with the simplified, five degree of freedom model and program REDT (Rotor/Engine/Drive Train). Further insight was gained by deriving closed form solutions for limiting cases of the REDT model. Behavior of the system was further investigated by varying system parameters in both the simplified and comprehensive models. This research focused on eigensolution frequency, damping and mode shape results for linearized structural dynamic and propulsion system models. It did not address time domain transient responses arising from pilot control inputs nor rotor aerodynamic interactions. The use of a comprehensive 2GCHAS model, a simplified REDT model, closed form solutions and parameter variations complemented one another in achieving the overall objectives of this work.

2 Summary

The comprehensive model is based on Chapter 19 of 2GCHAS (1993c) and combines simple rotor, airframe, engine/drive train and control components into a single rotorcraft model containing 39 finite elements and 115 degrees of freedom. The rotor and fuselage portions of the airframe are patterned after the UH-60. The engine/drive train is based on the T700-GE-700 turboshaft engine, which has been used in both the Apache and UH-60 rotorcraft. The normalized frequency and damping versus normalized rotor speed for some of the smaller non-zero eigenvalues obtained with 2GCHAS for nominal parameter values are presented and identified.

The simplified Rotor Engine Drive Train (REDT) five rotational degree of freedom model was developed to confirm and facilitate understanding of the dynamic behavior of the 2GCHAS comprehensive model, abstracting its salient characteristics. A virtual work approach was used to develop the kinematically non-linear equations of motion for the model and the equations were linearized about an undeformed, steady Ω state. This resulted in the set of second order ordinary differential equations. The REDT computer program supported highly interactive parameter modification, very short run times and immediate on screen plotting of results, some of which are reproduced for nominal parameter values. The ten roots are identified.

Closed form solutions provide explicit expressions for the functional relationship between eigensolutions and model parameters. Considerable insight was obtained from closed form solutions for six limiting cases with the REDT model. The approximations were generally excellent, with closed form and computed solutions typically agreeing to a fraction of a percent except in regions where the roots were strongly coupled. The first limiting case was for no elastic motion. The second limiting case was for no rotor motion and negligible shaft stiffness. The third limiting case was for no fuselage, engine or transmission motion and negligible shaft stiffness. The fourth limiting case was for cantilevered blade lag (no fuselage, hub or drive train motion). The fifth limiting case was for no flexibility except in the rotor shaft. The sixth limiting case was for no fuselage motion, no engine flexibility and no damping which provides the low rotor speed asymptote for the basic coupled mode of rotor/engine/drive train dynamics in the absence of damping.

To provide further insight into the fundamental dynamic behavior of rotorcraft, and to investigate a wider range of rotorcraft, a large number of parametric variations were performed. Results and their interpretation for five of the more important variations are summarized. The first set of parametric variations were changes to the blade lag-damping. The second set of parametric variations simulated a soft in-plane hingeless rotor. The third set of variations considered a wide variety of engine parameters. The fourth set of variations used the comprehensive model to gauge the effects of tail rotor dynamics on the system. The fifth set of variations used the comprehensive model to investigate the effect of engine controller feedback gain.

This study has investigated the fundamental characteristics of coupled rotorcraft/engine/drive train dynamics. A comprehensive model of a representative rotorcraft was developed and its eigensolutions were obtained using the Second Generation Comprehensive Helicopter Analysis System (2GCHAS). A simplified Rotor/Engine/Drive Train (REDT) model and program was developed and served to validate the comprehensive results and facilitate parametric investigations. Closed form solutions for limiting cases of the simplified model provided considerable insight into the system's characteristics. Parametric studies with both the comprehensive and simple models expanded the range of applicability and further increased the understanding of the system. The use of comprehensive models and programs (i.e., 2GCHAS), simplified models and programs (i.e., REDT), closed form solutions and parametric studies complemented one another in providing insight into the fundamental dynamic behavior of rotorcraft.

References

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