Effect of Control Inceptor Dynamics on Helicopter Vertical Bounce Proneness

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Rotorcraft-Pilot Couplings

The problem of the interaction of aircraft with the pilot is well known and deeply investigated. Pilots are known to interact with the dynamics of aircraft in two manners. The first, often called Pilot-Induced Oscillations (PIO), is a sustained or uncontrollable unintentional oscillation resulting from the efforts of the pilot to control the aircraft [1], while the second, often called Pilot-Assisted Oscillations (PAO), is the result of the inadvertent application of controls caused by vibrations in the cockpit at frequencies above the bandwidth of voluntary activity.

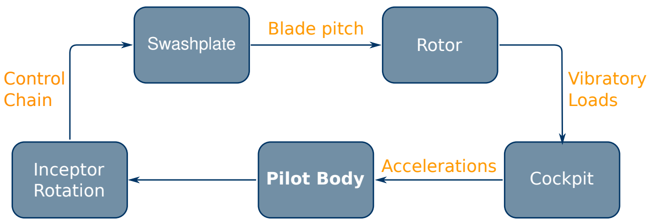

Figure 1: Rotorcraft-pilot inadvertent coupling through control system.

Less attention has been dedicated to interaction with rotorcraft, although interest in recent years has grown on this topic, resulting in joint research efforts within the Group of Aerospace Research and Technology in EURope (GARTEUR) [2] and, subsequently, in the ARISTOTEL project [3], sponsored by the European Commission under the 7th Framework Programme. Within these research activities, the rotorcraft aeroservoelasticity research group at Politecnico di Milano focused on aeroelastic Rotorcraft-Pilot Couplings (RPCs), with the objectives of understanding these phenomena and the design of operational factors that affect them, to develop techniques for the analysis of the problem, involving rotorcraft aeroservoelasticity and pilot biomechanics, in support of the design of RPC-free rotorcraft.

This work takes into account the pilot's biomechanics and investigates the nonlinear control inceptors' properties on helicopter vertical bounce proneness. This phenomenon is caused by the pulsating thrust induced by an oscillation of collective control lever introduced by the pilot. The proposed approach is based on the use of multibody techniques to

Figure 2: Biomechanical multibody models of the upper limbs and torso.

analyze the details of the complex interaction between the aeromechanics of the vehicle [4] and the biomechanical response of the pilot's upper body. For this purpose, a full musculoskeletal biomechanical multibody model of the upper body [5] is coupled with a simplified representation of the heave dynamics of the rotorcraft, including the coning mode [6]. The collective lever is modeled as a rigid stick assembly hinged to a torque tube. A balancing spring is designed in order to equilibrate the moment due to the collective lever weight at a specific position of the lever excursion. The torque tube is characterized by a modular friction, modeled through a Coulomb approach, and a nonlinear force–trim spring is also added to maintain the collective trim position. The vertical bounce stability is investigated as a function of the nonlinearities introduced on the pilot/control device model. This research is intended to be a first step towards the definition of control inceptor design guidelines to avoid RPC phenomena and to guarantee good levels of pilot's workload.

Description of the proposed work

A detailed multibody model of the pilot's upper limbs, including the collective lever dynamics, has been implemented in the free and general purpose software MBDyn (`http://www.mbdyn.org/` [7]).
As a test bed, an aeroelastic model of a five bladed medium-lift helicopter has been developed, using the analytical model proposed in Ref. [6]. The helicopter model, characterized by the heave and collective coning motion, is able to reproduce the vertical bounce phenomenon.

The typical analysis procedure consists in performing time-domain simulations where the rotorcraft system is either trimmed to a specified condition, or a specified transient is performed, including the pilot's biomechanics in the loop. Results will highlight the effect of the varied parameters both on the biodynamic feedthrough (BDFT) functions relating the involuntary control input to the airframe heave acceleration and time-domain responses, useful to highlight the effect of nonlinearities on the stability of the close loop system. The friction and the force–trim are subsequently considered, in order to understand how they modify the vertical bounce stability boundaries.

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