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An upper limb musculoskeletal model using bond graphs for rotorcraft-pilot couplings analysis

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1. Introduction

Under certain flight conditions, a rotorcraft fuselage motions and vibrations might interact with its pilot voluntary and involuntary actions leading to potentially dangerous dynamic instabilities known as rotorcraft-pilot couplings (RPCs). A better understanding of this phenomenon could be achieved by being able to reproduce the phenomenon during simulations. Design guidelines could be then obtained at an early stage of development of rotorcrafts improving flight safety for pilots and passengers.

In this work, an upper limb musculoskeletal model using bond graphs is presented. It is then integrated in a larger aeroelastic rotorcraft bond graph model that allows simulating pilot-rotor-fuselage couplings under several flight conditions. Simulations are performed and compared to literature's models and experimental data.

2. Methods

A different approach to analytical derivation of the equations of a dynamical system can be performed using bond graphs. While generating the same mathematical model than traditional methods and based on the same physical principles, it allows a modular approach that might ease the modelling process of large multiphysical systems [1]. Bond graphs describe systems as an interconnection of more elemental subsystems by exchanging energy. This paper contributes to the development of a multiphysical system involving pilot biodynamics, quasi-steady aerodynamics and coupled rotor-fuselage dynamics to study RPCs. In this work, firstly an upper limb skeletal model representing the helicopter's pilot as a multibody system using bond graphs is detailed. Secondly, muscles are added to the skeleton. The muscle models are based on the classic three element Hill model reviewed by Zajac in [2] and implemented using bond graphs in [3].

3. Results and Discussion

The multibody skeletal model is integrated in a rotorcraft model. In order to evaluate its validity, we estimate the pilot's biodynamic feedthrough (BDFT) in the lateral rotorcraft axis: magnitude of the cyclic lever roll angle divided by the fuselage lateral acceleration. Simulation results are compared to Venrooij's experimentally identified transfer functions model during a relax task [4], see Figure 1. The multibody simulation results are obtained by applying a sinusoidal force at a given frequency on the fuselage lateral axis.

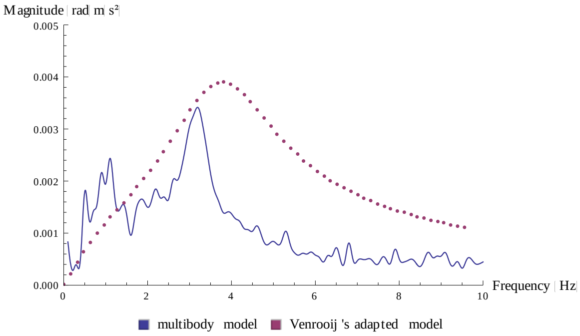

Figure 1. Pilot's biodynamic feedthrough simulation results

The behavior of the model after 2Hz does not match with Venrooij's. However, a resonant peak is found in both models around 3.5-4Hz. This frequency is of interest for rotorcraft dynamicist since the natural frequency of the roll motion of some helicopters is between 2 and 4Hz. The addition of muscles to the skeletal model will also be discussed.

4. Conclusions and future work

This study explores the implementation of musculoskeletal models in bond graphs to better understand RPCs and contribute to their alleviation by analysing simulation results early in the design stage of rotorcrafts.

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