Time & Location: March 31, 2016 at 2:00 PM in Eng.1 381
Title: Dynamic Modeling of Autorotation for Simultaneous Lift and Wind Energy Extraction

The goal of this thesis is to develop a multi-body dynamics model of autorotation with the objective of studying its application in energy harvesting. A rotor undergoing autorotation is termed an Autogyro. In the autorotation mode, the rotor is unpowered and its interaction with the wind causes an upward thrust force. The theory of an autorotating rotorcraft was originally studied for achieving safe flight at low speeds and later used for safe decent of helicopters under engine failure. The concept can potentially be used as a means to collect high-altitude wind energy. Autorotation is inherently a dynamic process and requires detailed models for characterization.

Existing models of autorotation assume steady operating conditions with constant angular velocity of the rotor. The models provide spatially averaged aerodynamic forces and torques. While these steady-autorotation models are used to create a basis for the dynamic model developed in this thesis, the latter uses a Lagrangian formulation to determine the equations of motion. The aerodynamic effects on the blades that produce thrust forces, in-plane torques, and out-of-plane torques, are modeled as non-conservative forces within the Lagrangian framework. To incorporate the instantaneous aerodynamic forces, the above-mentioned spatial averaging is removed. The resulting model is causal and consists of a system of differential equations. To investigate the dynamics under energy-harvesting operation, an additional in-plane regenerative torque is added to simulate the effect of a generator. The aerodynamic effects of this regenerative braking is incorporated into the model. In addition, the dynamic model relaxes assumptions of small flapping angles, and the periodic flapping behavior of the blades are naturally generated by the dynamics instead of assuming Fourier expansions. The dynamic model enables the study of transients due to change in operating conditions or external influences such as wind speeds. It also helps gain insight into force and torque fluctuations.

Model verification is conducted to ensure that the dynamic model produces similar steady-operating conditions as those reported in prior works. In addition, the behavior of autorotation under energy harvesting is evaluated. The thesis also explores the viability of achieving sufficient lift while extracting energy from the prevailing wind. A range of regenerative torques are applied to determine the optimal energy state. Finally, a complete high-altitude energy harvesting system is modeled by incorporating a tether utilizing a catenary model. Overall, the thesis lends support to the hypothesis that a tethered autogyro can support its weight while harvesting energy from strong wind-fields, when augmented with appropriate control systems.

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The public is welcome to attend.