Large-Eddy Simulation (LES) based turbulence modeling is a developing area of research in Fluid-Structure Interaction (FSI). There is considerable scope for further scientific research in this field and this dissertation aims to extend it to the study of flow-induced motion. The emphasis of this work is on autorotation, an important category of flow-induced motion that is commonly seen in energy applications such as wind turbines and in aviation applications such as the autogyro. In contrast to existing works on FSI that typically assume prescribed motion of structures in a flow field, this research develops LES based FSI studies for large-scale flow-induced motions as seen in autorotation. The uniqueness of the formulation and modeling approach lies in the development of a numerically stable computational scheme that incorporates a moving and morphing mesh structure. The method is first demonstrated for the autorotation of a square flat plate and then extended to a rotor structure similar to that of a helicopter.

In order to simulate an autorotating square flat plate, a coupled Computational Fluid Dynamics (CFD) - Rigid Body Dynamics (RBD) model is proposed, employing the delayed-detached-eddy simulation (DDES) and the Smagorinsky turbulence models to resolve subgrid-scale stresses (SGS). The plate is allowed to spin freely about its center of mass. Computational results are compared to experimental measurements and Reynolds Average Navier-Stokes (RANS) simulations found in the literature. When compared to RANS, the results from the LES models provide better predictions of the pressure coefficient. Moreover, LES accurately captures the transient behavior of the plate, and close correspondence is found between the predicted and measured moment coefficients. The qualitative prediction of vortex structures and the quantitative computation of pressure coefficients are in good agreement with experimental results. Hybrid models, such as improved Delayed-Detached-Eddy Simulation (iDDES), are shown to provide very similar results to those of pure LES. Therefore hybrid models are found to be a good alternative to use for the simulation of FSI in autorotation, saving valuable computational time. The iDDES method combines both RANS and LES, dividing the flow domain into LES far away from a solid wall and RANS near a solid wall, overcoming the computational costs of pure LES.

Encouraging results from this effort prompted the extension to a realistic scenario, namely the autorotation of a flapping-blade rotor in a prevailing wind field. A coupled CFD - Multi Body Dynamics (MBD) model is developed to study the complex FSI of an autorotating 3-blade rotor, similar to that of a helicopter, employing the iDDES turbulence model. In addition to the rotor being allowed to spin freely about its axis, each of the individual blades is free to rotate about hinges at the root. This adds degrees of freedom to the kinematics of the rotor and necessitates localized mesh morphing around the blades to capture the FSI with accuracy. The model is validated against experimental data and shows excellent agreement. The experimental apparatus consists of a flapping blade rotor and a fixture used to mount it at different angles of incidence with respect to the wind field. The rotor is instrumented with a DC motor that is operated in generator mode. The setup is dual-purpose, providing speed measurement using the motor’s back-emf and regenerative braking by varying the current draw. Overall, the presented research can help obtain accurate values of aerodynamic parameters at a high spatial resolution that would be otherwise difficult to acquire in experiments. Ultimately this approach can be a cost effective means of aerodynamic modeling in applications involving large scale FSI.

Major: Mechanical Engineering

Educational Career:
Bachelor's of Aerospace Engineering, BS, 2007, University of Miami
Bachelor's of Mechanical Engineering, BS, 2007, University of Miami
Master's of Mechanical Engineering, MS, 2009, University of Miami