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Aerostructural Analysis and Optimization of Morphing Wings for AWE Applications

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AWE aircraft operate at extreme wing loading over a wide range of wind speeds. Additionally, the presence of flow inhomogeneities and gusts create a complex and demanding flight environment. Until now, maneuvering capabilities and adaptation to different wind speeds is achieved by conventional wing control surfaces and - in case of ground generator-based systems - by varying the reel-out speed. The design of these wings with conventional control surfaces is always the result of a compromise between the requirements at different flight conditions, leading to penalties in terms of power production. In contrast, considerably greater adaptability to different flight conditions can be attained by shape-morphing wings. They achieve optimal aerodynamic characteristics – and hence maximize the extracted energy – across a wide range of wind speeds by adapting the airfoil camber, and thus the lift distribution, along the wingspan. Furthermore, gust loads can be actively alleviated through morphing, which leads to a substantially expanded flight envelope without requiring excessively conservative structural safety margins. Moreover, active load alleviation demands lower control requirements on the ground station reeling system, as the effects of possible disturbances can be mitigated directly by morphing the wing.

In this work, a procedure to analyze and concurrently optimize a morphing wing for AWE applications in terms of aerodynamic shape, compliant structure, and composite layup is presented. The morphing concept is based on distributed compliance ribs and electromechanical linear actuators. The multidisciplinary optimization aims to maximize the power production of the AWE morphing wing by using an evolutionary algorithm. Within the optimization, the response of the investigated morphing wing to aerodynamic loads and actuation inputs is evaluated by a two-way weakly coupled 3-D fluid structure interaction (FSI) analysis. The structural behavior is assessed using a 3-D finite elements model, and the aerodynamic properties are evaluated by means of a 3-D panel method and a nonlinear extended lifting-line technique. To validate the result of the optimization and to analyze the dynamic response of the morphing wing to gusts, a high-fidelity FSI simulation environment is set up. Within this simulation environment, the aerodynamic characteristics of the identified optimal individual are assessed by solving the RANS equations, and by applying momentum source terms to model gusts and flow inhomogeneities.

The application of the proposed multidisciplinary quasi-steady FSI optimization, combined with the high-fidelity transient FSI, allows a relatively fast assessment and identification of the optimal aerodynamic and structural properties of AWE wings. Moreover, it permits to accurately predict the benefits that morphing wings can bring to AWE airplanes, namely a drastic increase in the power production of these systems with limited structural complexity and mass.