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Dynamic stall vortex shedding and its cycle-to-cycle variations: the innocent victims of phase averaging

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Dynamic stall occurs on lifting profiles subjected to an unsteady increase of the angle of attack beyond the static stall angle. It affects for example helicopter or wind turbines blades which experience varying inflow conditions during rotation, but also human-engineered bio-inspired flying devices which encounter gusty atmospheric conditions, perform dynamic manoeuvres, or flap their wings to produce thrust. Among the characteristic features associated with dynamic stall are the delay of flow separation to angles of attack beyond the static stall angle and a lift overshoot. More undesirable effects occur after stall onset and include large fluctuations of the aerodynamic loads due to large scale vortex shedding and force and moment hysteresis for periodic pitching motions. Due to a non-deterministic character of the vortex shedding, the load fluctuations are not always identically reproduced in subsequent motion cycles, leading to large so-called cycle-to-cycle variations. The large aerodynamic load excursions decrease the aerodynamic efficiency, introduce strong vibrations, and increase structural forces and bending moments. They are essential ingredients for accurate prediction of the overall aerodynamic efficiency and the structural endurance of wings and blades. Despite their significant impact, dynamic stall vortex shedding and cycle-to-cycle load variations have not been treated in the past with the proper level of diligence. They are often ignored or concealed by phase averaging in experimental and numerical analyses, including simulations solving the Reynolds averaged Navier-Stokes equations.

Following up on previous analyses of dynamic stall onset and associated stall delay, the focus will be directed here on the vortex shedding during full stall ensuing stall onset, the associated aerodynamic load fluctuations and their cycle-to-cycle variations. High spatially and temporally resolved velocity field measurements of the flow past a 2D pitching airfoil experiencing dynamic stall are conducted by means of particle image velocimetry and are complemented by direct force and moment measurements. The experimental data is analysed by a combination of Eulerian and Lagrangian coherent structure identification methods and modal decomposition algorithms. Special emphasis is directed towards characterisation of the trajectories and convection speeds of successively shed dynamic stall vortices and their influence on the aerodynamic forces and moments in function of the reduced frequency or unsteadiness of the motion.

It is a plea to experimentalists and numericists for studying unsteady separating flows by analysing instantaneous time-resolved vortex fields instead of resorting to time-averaged quantities.