The porpoising effect : wind tunnel testing and reduced-order-modelling.

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The Porpoising Effect: Wind Tunnel Testing and Reduced-Order Modelling

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Ground-effect aerodynamics can generate large amounts of downforce, but it also makes the aerodynamic loading highly sensitive to ride height. When this ride-height sensitivity interacts with the vertical dynamics of a vehicle, self-sustained oscillations may appear. This phenomenon, commonly referred to as porpoising, became a major issue after the reintroduction of ground-effect aerodynamics in Formula One, but its underlying aerodynamic mechanisms remain difficult to isolate on a complete vehicle.

This work investigates porpoising using a simplified wind-tunnel model based on a two-dimensional inverted Tyrrell026S wing operating in ground effect. Static tests were first performed to characterize the evolution of the aerodynamic loads with angle of attack and ground clearance. Dynamic tests were then conducted using two aeroelastic setups: a plunge–pitch setup, allowing both vertical translation and rotation, and a plunge-only setup, designed to isolate the vertical instability mechanism.

The experimental results show that the post-critical response is mainly dominated by plunge motion. Based on this observation, a reduced-order model is developed. The model is first formulated as a two-degree-of-freedom plunge–pitch system and is then reduced to a single-degree-of-freedom plunge formulation. Two aerodynamic descriptions are compared: a quasi-steady model based on the static aerodynamic database, and an unsteady model based on experimentally identified plunge flutter derivatives.

The quasi-steady model predicts the static aeroelastic deflection with reasonable accuracy, but fails to reproduce the measured evolution of modal frequency and effective damping. In contrast, the unsteady model captures the stability trends of the plunge-only system for most tested ground clearances. The results therefore show that static aerodynamic data alone are not sufficient to model porpoising dynamics, and that motion-induced unsteady aerodynamic effects must be included to predict the onset of instability.

Keywords: Porpoising, ground effect, aeroelasticity, inverted wing, wind-tunnel testing, reduced-order modelling, unsteady aerodynamics, flutter derivatives.

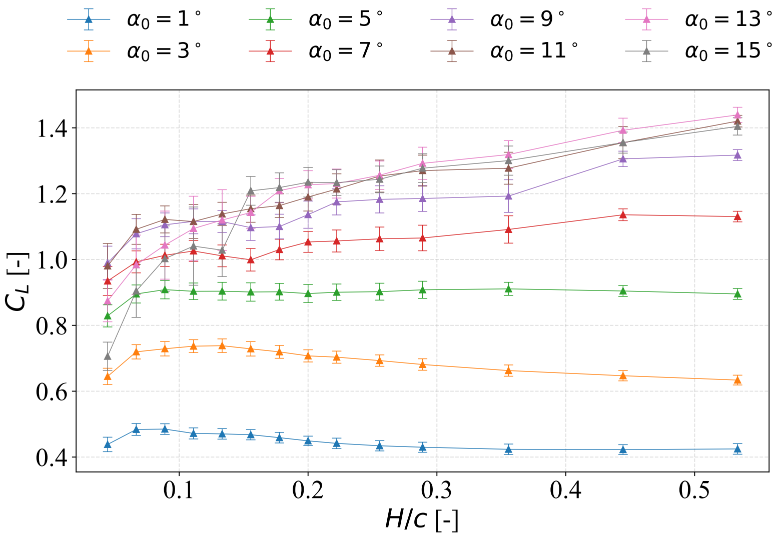

Figure 1: Evolution of the lift coefficient C_L of the inverted Tyrrell026S wing as a function of the normalized ground clearance H/c, for several initial wing incidences α_0.

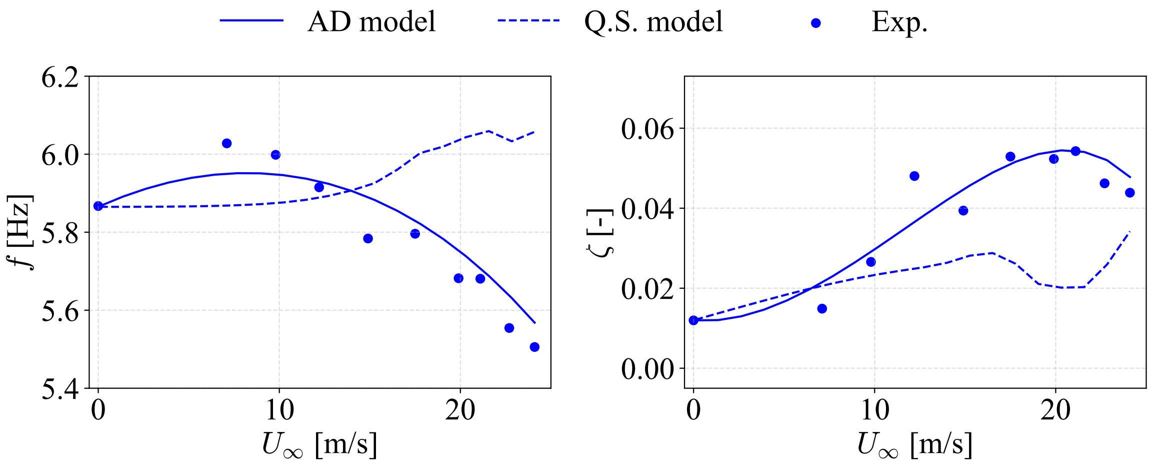

Figure 2: Comparison between experimental and modelled plunge-mode stability results for an initial ground clearance $H = 67$ mm. The left plot shows the modal frequency f, while the right plot shows the effective damping ratio ζ, both as functions of freestream velocity U_∞. The experimental results are compared with the aerodynamic-derivative model (based on *flutter derivatives*) and the quasi-steady model.