Abstract Submitted
for the DFD10 Meeting of
The American Physical Society

Vortex Formation vs. Aerodynamic Force Coefficient Variations
for Rapidly-Pitching Flat Plates

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U.S. Air Force Research Lab — We consider a flat plate in constant-rate (linear)
pitch, from angle of attack $\alpha = 0^\circ$ to $90^\circ$, at a Reynolds number of 20,000. The
motion is via a three-component electric rig fitted atop a water tunnel. Various
smoothing transients at motion initiation and cessation are applied. Pitch pivot
point is at the plate chordwise locations $x/c = 0, 0.25, 0.5$ and $0.75$. Pitch rates
range from $K = c\dot{\theta}/2U_\infty$ of $0.0025$ through $1.0$. Plate geometries include nominally
2D and aspect ratio $2.0$; both have round edges. Lift, drag and pitching moment
were measured directly with a force balance, while flowfield data included dye in-
jection and PIV. For reduced frequencies $K < 0.05$, lift for the 2D plate followed
the usual relation of $2\pi\alpha$, with stall delay in proportion to pitch rate, and stall
behavior increasingly smoother as pitch rate increases. At higher $K$, acceleration or
noncirculatory effects are manifest, with a rise in lift at low $\alpha$, and a rise in drag at
high $\alpha$. Noncirculatory and circulatory effects are additive and the noncirculatory
portion is well predicted by potential-flow methods. $K > 0.02$ evinces the formation
of a leading edge vortex. Peak in lift correlates to the angle of attack where the
leading edge vortex reaches maximum circulation and begins to shed. Lift and drag
are seen to obey a scaling with pitch rate, for $K > 0.03$.

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Date submitted: 11 Aug 2010

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