

Dynamics of Ornithopter Flight

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A quasi-steady model of flapping-wing aerodynamics developed for falling cards and insect flight is adapted for ornithopter design. The time-variant force calculations are coupled with the standard vehicle dynamics equations. Trim is defined for vehicles with periodic forcing as a condition of periodic state trajectories (with the same period). An optimization method is used to find wing motion parameters and initial conditions producing trim conditions at a specified average forward speed and elevation, while minimizing power consumption.

Nomenclature

ϕ	=	angle of flapping oscillation
C_h	=	amplitude of flapping oscillation
C_t	=	amplitude of wing twist at the tip
ω	=	frequency of flapping
t	=	time
r	=	coordinate along span of a wing
η	=	instantaneous wing twist
ϕ_0	=	phase of flapping oscillation
$\phi_{\eta 0}$	=	phase of twisting oscillation
Γ	=	circulation around the airfoil
C_L	=	translational lift coefficient
C_R	=	rotational lift coefficient
$c(r)$	=	local chord value
u	=	local section velocity parallel to chord
v	=	local section velocity normal to chord
F_v	=	viscous force
ρ	=	air density
$C_D(0)$	=	drag coefficient at zero angle of attack
$C_D(\pi/2)$	=	drag coefficient at 90° angle of attack
dF_x	=	local force on the wing parallel to chord
dF_y	=	local force on the wing normal to chord
m_w	=	wing mass
m_{11}, m_{22}	=	added mass parameter
α	=	angle of attack
R	=	wing length
τ	=	airfoil moment
U	=	vehicle forward velocity
W	=	vehicle velocity normal to forward velocity
Q	=	vehicle pitch rate
Φ	=	vehicle pitch angle
g	=	gravitational constant
F_x	=	total aerodynamic force on vehicle in forward direction

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