Stability in Hovering Ornithopter Flight

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ABSTRACT

The quasi-steady aerodynamics model is coupled to a dynamic model of ornithopter flight. Previously, the combined model has been used to calculate forward flight trajectories, each a limit cycle in the vehicle's states. The limit cycle results from the periodic wing beat, producing a periodic force while on the cycle's trajectory. This was accomplished using a multiple shooting algorithm and numerical integration in MATLAB. An analysis of hover, a crucial element to vertical takeoff and landing in adverse conditions, follows. A method to calculate plausible wing flapping motions and control surface deflections for hover is developed, employing the above flight dynamics model. Once a hovering limit cycle trajectory is found, it can be linearized in discrete time and analyzed for stability (by calculating the trajectory's Floquet multipliers a type of discrete-time eigenvalue) are calculated. The dynamic mode shapes are discussed.

Keywords: Ornithopter, stability, trim, hovering flight, Floquet

NOMENCLATURE

ϕ	=	instantaneous wing heaving angle
C_h	=	amplitude of flapping oscillation
C_t	=	amplitude of wing twist at the tip
f	=	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_u	=	local force on the wing parallel to chord
dF_v	=	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

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