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ORNITHOPTER TRAJECTORY GENERATION WITH STABILIZATION

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ABSTRACT

Ornithopter flight dynamics and a method for developing flight trajectories are described. These are used to study the unstable modes in hovering ornithopter flight. Stabilization is accomplished through three strategies: pitch-rate feedback control, linear quadratic regulator, and discrete-time periodic linear quadratic regulator. The discrete time controller is the only controller tested that was capable of stabilizing position of the vehicle in hover.

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

INTRODUCTION

Ornithopter flight has long been plagued by its incomprehensibly complex dynamics. Until the advent of modern computers, it has been impossible to study their dynamic modes outside of observing nature or through expensive model vehicles. Several breakthroughs have allowed computer simulations to provide adequate insight to flight dynamics and control strategies necessary for ornithopter design.

Ellington [1] and his cronies developed a quasi-steady understanding of insect aerodynamics that became applicable to flapping-wing flight at larger scales. These informed later researchers such as Wang [2] and Larijani and DeLaurier [3].

Experimentalists such as Cox et al. [4] and DeLaurier verified dynamic models and provided additional insight as to what wing flapping designs produce more thrust and control.

Dietl and Garcia employed the computational approach [5] to develop robust stability analysis for flapping flight. The next step is to develop a corresponding control theory.

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
W = vehicle velocity normal to forward velocity
Q = vehicle pitch rate
θ = vehicle pitch angle