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Optimization of Perching Maneuvers Through Vehicle Morphing

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This paper discusses the development and optimization of trajectories designed to bring a long endurance unmanned aerial vehicle from a loitering state to a planted landing referred to as a perching maneuver. These trajectories are developed for attached, partially stalled, and fully stalled flow regimes. The effects of nonlinear aerodynamics and vehicle shape reconfiguration are shown to lessen the initial distance from the landing site required to initiate the maneuver, reduce the spatial bounds on the trajectory, and decrease the required thrust for the maneuver. The aerodynamics are modeled using empirical and analytical methods in both attached and separated flow regimes. Optimal solutions of varying thrust-to-weight ratio and center-of-gravity location are compared. Additionally, perching trajectories that compare morphing versus fixed configuration and stalled versus unstalled aircraft are presented to demonstrate the effects of relaxed constraints on vehicle geometry and flight envelope. Control effort is also evaluated in these simulations; specifically, the available control for disturbance rejection is compared for morphing versus fixed-configuration aircraft. The results of these comparisons show that morphing increases the controllability of the aircraft throughout the maneuver as well as decreases the cost of the optimal perching trajectory.

Nomenclature

C_D	=	drag coefficient
C_d	=	section drag coefficient
C_L	=	lift coefficient
C_l	=	section lift coefficient
C_M	=	pitch moment coefficient
c	=	local chord length
$\bar{c}$	=	mean aerodynamic chord
g	=	acceleration due to gravity
h	=	vertical position
I_y	=	principal moment of inertia about pitch axis
J	=	cost function
l	=	characteristic length
m	=	aircraft mass
p	=	dynamic mixing parameter
p_0	=	static mixing parameter
q	=	pitch rate
S	=	planform area
T	=	thrust magnitude
T/W	=	thrust-to-weight ratio
t	=	time
V	=	aircraft velocity magnitude
$\mathbf{x}$	=	aircraft longitudinal state vector
x	=	horizontal position
x_{cg}	=	aircraft center of gravity
x_{cp}	=	airfoil center of pressure
x_{np}	=	aircraft neutral point
α	=	angle of attack
γ	=	flight path angle
δ_e	=	elevator deflection angle
θ	=	pitch angle
θ_b	=	tail boom angle with respect to fuselage
θ_t	=	tail angle with respect to boom
ι	=	wing incidence angle with respect to fuselage
κ	=	pitch moment scaling factor
ρ	=	air density
τ_1, τ_2	=	time constants

Subscripts

att	=	attached flow regime
climb	=	climb phase
dive	=	dive phase
f	=	final
fuse	=	fuselage lifting surface
sep	=	separated flow regime
tail	=	tail lifting surface
wing	=	wing lifting surfaces
0	=	initial

I. Introduction

LATELY, advances in smart materials, actuators, and control systems have enabled the development of new capabilities for aircraft [1]. Several studies have indicated that gross airframe reconfiguration in particular can lead to increased flight performance and mission potential [2–4]. These studies have shown that in-flight vehicle morphing can grant a single aircraft increased performance by several typically incompatible metrics such as endurance, turn radius, and dash speed. Traditionally, aircraft reconfiguration has been limited to discrete control surfaces such as flaps and slats or variable-swept wings, such as those on the F-14 or B-1 aircraft; however, recent programs have been focused on more radical shape changes. For example, Lockheed Martin Skunkworks [5] and NextGen Aeronautics [6] have each produced flight-tested morphing unmanned aerial vehicles (UAVs) that address the problem of adding dash capabilities to intelligence, surveillance, and reconnaissance (ISR) platforms. The primary hurdle is that long endurance aircraft typically have high aspect ratio wings to increase lift-to-drag efficiency, whereas strike aircraft have shorter delta wings for improved high-speed flight. Both morphing UAVs use segmented folding wing mechanisms, the former a gull-like wing and the latter a batlike wing, to reduce the planform area and span of the wing drastically, thereby enabling high endurance and dash capabilities on a single airframe. In addition, new research has focused on developing bioinspired

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