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Longitudinal Dynamics of a Perching Aircraft

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This paper introduces a morphing aircraft concept whose purpose is to demonstrate a new bioinspired flight capability: perching. Perching is a maneuver that uses primarily aerodynamics, as opposed to thrust generation, to achieve a vertical or short landing. The flight vehicle that will accomplish this is described herein with particular emphasis on its addition levels of actuation beyond the traditional aircraft control surfaces. The dynamics of this aircraft are examined with respect to changing vehicle configuration and flight condition. The analysis methodologies include an analytical and empirical aerodynamic analysis, trim and stability analyses, and flight simulation. For this study, the aircraft's motions are limited to the longitudinal plane only. Specifically, cruise and the perching maneuver are examined, and comparisons are drawn between maneuvers involving vehicle reconfiguration and those that do not.

Nomenclature

D	=	aircraft drag force
f_x, X	=	x-component of external force
f_z, Z	=	z-component of external force
$\mathbf{f}$	=	external force vector
g	=	gravity magnitude
$\mathbf{g}$	=	gravity vector
I_y	=	principal moment of inertia about y-axis
$\mathbf{I}$	=	moment of inertia matrix
L	=	aircraft lift force
M	=	aircraft pitch moment
m	=	aircraft mass
m_y	=	y-component of external moment
$\mathbf{m}$	=	external moment vector
q	=	pitch rate
$\mathbf{q}$	=	quaternion
T	=	thrust magnitude
$\mathbf{T}$	=	transformation matrix from body- to earth-coordinates
u	=	x-component of aircraft velocity
V	=	aircraft velocity magnitude
v	=	y-component of aircraft velocity
$\mathbf{v}$	=	aircraft velocity vector (body coordinates)
w	=	z-component of aircraft velocity
x	=	forward direction
$\mathbf{x}$	=	aircraft position vector (inertial coordinates)
y	=	sidereal direction
z	=	vertical direction
α	=	angle of attack
β	=	sideslip angle
δ_a	=	aileron deflection angle
δ_e	=	elevator or symmetric ruddervator deflection angle
θ	=	pitch angle
θ_b	=	boom angle with respect to fuselage
θ_t	=	tail angle with respect to boom
Θ_0	=	trim pitch angle
ι	=	wing incidence angle
ϕ	=	roll angle
ψ	=	yaw angle
$\boldsymbol{\omega}$	=	aircraft angular velocity vector
$\boldsymbol{\omega}^{\times}$	=	skew-symmetric cross product matrix of $\boldsymbol{\omega}$

Introduction

ONE of the major goals of the morphing aircraft program is the enabling of new flight capabilities and missions [1–3]. With additional levels of sensing and actuation, morphing aircraft are able to mimic more closely the capabilities of man's inspiration for flight: birds. The gross extent to which birds morph their bodies allow them to perform maneuvers irreproducible by conventional aircraft; one such avian maneuver is perching. Perching can be described as a high angle-of-attack approach with the purpose of using high-drag, separated flow for braking, followed by a vertical or very short landing [4]. This maneuver is based off of several avian landing techniques, including maximizing drag by flaring the wings and tail, and diving under the intended landing site and then pulling up into a climb to reduce speed. Although vertical landings have been accomplished by rotary and V/STOL aircraft, it is desired to perch using primarily aerodynamics, with little input from thrust-generating devices. This will alleviate the need for the heavy thrust generators required to land vertically, which are not compatible with long endurance aircraft systems. Thus, perching will be especially useful for small, efficient reconnaissance aircraft, for example, whose thrust-to-weight ratios might be on the order of $1/10$.

This paper presents a concept for a perching aircraft and an analysis of its longitudinal dynamics. This concept is based on the aerial regional-scale environmental survey (ARES) Mars scout craft, an aircraft designed to unfold from a Viking derivative aeroshell and fly for approximately 70 min over a Martian landscape, collecting data on atmospheric chemistry, geology, and crustal magnetism [5]. The idea to try to perch a similar airframe grew from the challenge to save the ARES scout from a high-speed crash landing at the end of its mission by using drag to slow it down enough to land with its instruments intact. It is desired to perform the perching maneuver without complicating the aircraft system unnecessarily and by adding the fewest number of additional actuators. The original ARES craft features a blended-wing body with folding tail boom, tail surfaces, and wings, shown in Fig. 1. The inverted V-tail features two ruddervators which combine the functionality of a rudder and an elevator. To add perching capabilities, actuators are incorporated into the tail degrees of freedom and variable incidence is added to the folding wing sections. These additional degrees of actuation in the perching flight vehicle, dubbed the ARES-C, are shown in Fig. 2.

The level of geometric reconfigurability required to recreate the perching maneuver in a man-made aircraft falls far outside the bounds of conventional aircraft designs. To maintain stability and controllability at the high angles of attack required for aerodynamic braking, the aircraft's wings are rotated to a negative incidence angle

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