Proceedings of the ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems
SMASIS2008
October 28-30, 2008, Ellicott City, Maryland, USA

SMASIS2008-650

THE EFFECTS OF SHAPE RECONFIGURATION ON MORPHING AIRCRAFT IN PERCHING MANEUVERS

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ABSTRACT

This paper focuses on a novel morphing aircraft capability called perching: the ability of an aircraft to make a planted landing using primarily aerodynamic forces in lieu of high thrust. Specifically, the modeling of the perching aircraft's aerodynamics and the problem of computing and optimizing a perching trajectory using this model are presented. The aerodynamic model discussed herein is designed using empirical and analytical methods in both separated and attached flow regimes, including nonlinear and time-varying effects such as flow separation and dynamic stall. This vehicle model is used to optimize the landing trajectory with respect to its spatial boundaries; these include the maximum undershoot – or dip below the landing point – and the required starting distance from the landing site. Optimal solutions of varying thrust-to-weight ratio and center of gravity location are compared. Additionally, perching trajectories that compare stalled versus un-stalled and morphing versus fixed-configuration aircraft are presented in order to demonstrate the effects of relaxed constraints on flight envelope and shape reconfiguration, respectively. The available control for disturbance rejection is distinguished between morphing and fixed-configuration aircraft. These results show that vehicle morphing increases the controllability of the aircraft throughout the maneuver as well as decreases the spatial requirements of the optimal perching trajectory.

INTRODUCTION

Traditionally, aircraft reconfiguration has been limited to discrete control surfaces such as flaps and slats or variable-swept wings; however, recent programs have been focused on more radical shape changes. For example, Lockheed Martin Skunkworks [1] and NextGen Aeronautics [2] have each produced flight-tested morphing UAVs that address the problem of adding dash capabilities to ISR (Intelligence, Surveillance, and Reconnaissance) 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 utilize segmented folding wing mechanisms – the former, a gull-like wing, and the latter, a bat-like wing – in order to reduce the planform area and span of the wing drastically, thereby enabling high endurance and dash capabilities on a single airframe.

In addition to enhancing or expanding the flight performance of an aircraft, morphing can also be used to enable new flight capabilities. One such bio-inspired capability under development 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 planted landing [3,4]. Whereas vertical landings are relatively straightforward for high thrust-to-weight aircraft, it has yet to be demonstrated for high efficiency reconnaissance platforms. The addition of a perching capability could enable an ISR mission length to be extended dramatically, for example: once a target has been found, the aircraft may land on a nearby structure and continue to survey an area without consuming fuel for flight. Depending on the size and weight of the aircraft, this structure could assume a variety of forms in an urban or natural environment, such as a building ledge, power line, cliff side, or tree branch. It is for this reason that the development of practical perching maneuvers for low thrust-to-weight aircraft is the focus of this paper.

Aerodynamic perching has been studied before in the form of stalled landings for conventional airframes [5]; however, the controllability of a typical low-thrust aircraft in a deep stall is questionable, and the large undershoot of the trajectory relative to the landing site is undesirable. In the present work, it is proposed that in-flight shape reconfiguration will be able to alleviate both of these concerns. This study expands upon the previous work by considering shape changing aircraft with varying constraints on the actuators and by optimizing the overall trajectory instead of just minimizing the landing velocity.

The particular aircraft used to develop the perching maneuver is a blended wing body aircraft based on the Aerial Regional-Scale Environmental Survey (ARES) Mars scout craft [6] and is described in detail in Ref. [4]; however, the

