Perching Aerodynamics and Trajectory Optimization

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ABSTRACT

Advances in smart materials, actuators, and control architecture have enabled new flight capabilities for aircraft. Perching is one such capability, described as a vertical landing maneuver using in-flight shape reconfiguration in lieu of high thrust generation. A morphing, perching aircraft design is presented that is capable of post stall flight and very slow landing on a vertical platform. A comprehensive model of the aircraft's aerodynamics, with special regard to nonlinear affects such as flow separation and dynamic stall, is discussed. Trajectory optimization using nonlinear programming techniques is employed to show the effects that morphing and nonlinear aerodynamics have on the maneuver. These effects are shown to decrease the initial height and distance required to initiate the maneuver, reduce the bounds on the trajectory, and decrease the required thrust for the maneuver. Perching trajectories comparing morphing versus fixed-configuration and stalled versus un-stalled aircraft are presented. It is demonstrated that a vertical landing is possible in the absence of high thrust if post-stall flight capabilities and vehicle reconfiguration are utilized.

Keywords: morphing, aircraft, bio-inspired, perching, aerodynamics, stall, optimization

1. INTRODUCTION

To perch a low thrust aircraft on the edge of a building has been to dream the great dream of aerodynamicists and UAV enthusiasts alike. After studying the complicated interaction between bird and vortex during a perching maneuver, researchers and aircraft designers have wondered longingly if a similar feat could be accomplished by man-made systems. While vertical landings are relatively straightforward and uninspiring for high thrust-to-weight aircraft, it has yet to be demonstrated for high efficiency reconnaissance platforms, where heavy thrust generators are frowned upon. It is proposed herein that morphing capabilities might be the key to realizing this lofty goal. Indeed, several studies have indicated that airframe reconfiguration can lead to increased flight performance and mission potential.[1-2] In the present example, perching capabilities could enable an Intelligence/Surveillance/Reconnaissance (ISR) mission length to be extended dramatically; once a target has been found, the aircraft may land on a nearby structure and continue to survey indefinitely, with an arrogant eye on its unsuspecting prey. Hence, the aircraft can remain in-theater far beyond the duration its meager flight endurance would indicate.

Since high thrust and thrust vectoring are unavailable, the primary challenge is to exploit another mechanism for decelerating the vehicle. In addition, the stall speed of low thrust aircraft is usually too high for landing on a small surface without destroying the vehicle or relying on brawny shock absorbers. Akin to majestic soaring birds that roost upon craggy sea cliffs, a perching aircraft of low thrust-to-weight ratio must dive below the point of landing and then "pop up" just before alighting, using gravity to sap the rest of its kinetic energy. While this undershoot is impossible on flat ground, it is necessary for a perched landing on an elevated platform. Luckily, urban environments are rife with this type of landing site, such as a power line or the roof of a chemical weapons plant.

This type of stalled vertical landing has been studied before;[3] however, the controllability of low-thrust aircraft in a deep stall is generally abysmal, and the large undershoot of the trajectory relative to the landing site is undesirable. It is proposed that in-flight morphing will be able to alleviate both of these problems. The particular aircraft used to develop

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