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Hover Performance of Rotor Blades at Low Reynolds Numbers for Rotary Wing Micro Air Vehicles

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Abstract

Rotary wing Micro Air Vehicles (MAV's) are especially well suited for a broad range of missions that fixed wing MAV's cannot accomplish. An efficient small-scale hovering rotor is required to make this configuration practical. Experimental studies show that for a variety of rotors at low Reynolds numbers (Re<50,000), poor performance was consistently measured. The current investigation explores the influence of a series of parameters such as airfoil shape and tip Reynolds number on the rotor's performance, as well as the different stall mechanisms present on different rotor blades. Figure of merit was measured experimentally, and surface flow visualization was implemented on the rotor blades with the use of fluorescent oil. A Blade Element Momentum Theory model of the rotor was used to calculate the airfoil characteristics from the hover tests. The model also showed that the profile contributions to the total power requirements are considerably larger than for full-scale rotors, reducing the effect of any blade planform optimization. The ongoing research will bring some insight on the behavior of the flow over the rotor blade at low Re, establishing the basis for an optimized rotor design.

Introduction

The concept of a small-scale flying machine capable of collecting or transmitting information for intelligence or surveillance use was first introduced in the early nineties. Just until then, the miniaturization and cost reduction of electronic components reached the point where a small affordable flying robot was conceivable. Realizing the great potential of this new type of vehicles, in 1996 DARPA started the Micro Air Vehicle (MAV) program. The program's objective was to develop a system with an endurance of 60 min, no dimension larger than 6 in, and a gross takeoff weight close to 100 gm. At the end of the six year program a series of successful fixed wing aircraft, such as the Black Widow (Aerovironment)[1] and the Microstar (Lockheed Martin) were developed. These prototypes achieved the weight and size requirements set by DARPA, however their endurance was inferior to 30 min. On the other hand, no successful hovering MAVs have been developed. Existing prototypes such as the LUMAV (Auburn University) and the hovering entomopter MENTOR (SRI), lack the endurance to make them practical, achieving flying times inferior to 8 minutes.

The objective of this paper is to explore the physics behind the poor performance of rotary-wing configuration MAVs, in order to determine some basic guidelines for small-scale rotor design.

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Motivation

The Alfred Gessow Rotorcraft Center has developed over the last three years its own rotary-wing MAV called MICOR (MIcro COaxial Rotorcrat). The second generation of the battery powered vehicle has a coaxial configuration and a GTOW of 100 gm. Each three-bladed rotor has a diameter of 17.2 cm and a solidity of 0.118. MICOR can hover for 4 min when powered by three LIMnO2 3V batteries, each with a capacity of 430 mAh. An initial study on the vehicle's performance showed that two main factors directly influence the vehicle's endurance.

First, the large current flow (about 3 A) required by the two electric motors exceeds the batteries capabilities. The batteries used are designed to provide a maximum current flow of 1 A. When forced to discharge at higher current levels, the effective energy density of the batteries is reduced, shortening the flying time.

The second factor, which is the source of the large