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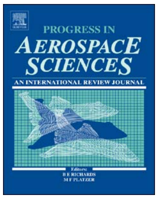

Energy harvesting by means of flow-induced vibrations on aerospace vehicles

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ABSTRACT

This paper reviews the design, implementation, and demonstration of energy harvesting devices that exploit flow-induced vibrations as the main source of energy. Starting with a presentation of various concepts of energy harvesters that are designed to benefit from a general class of flow-induced vibrations, specific attention is then given at those technologies that may offer, today or in the near future, a potential benefit to extend the operational capabilities and to monitor critical parameters of unmanned aerial vehicles. Various phenomena characterized by flow-induced vibrations are discussed, including limit cycle oscillations of plates and wing sections, vortex-induced and galloping oscillations of bluff bodies, vortex-induced vibrations of downstream structures, and atmospheric turbulence and gusts. It was found that linear or linearized modeling approaches are commonly employed to support the design phase of energy harvesters. As a result, highly nonlinear and coupled phenomena that characterize flow-induced vibrations are neglected in the design process. The Authors encourage a shift in the current design paradigm: considering coupled nonlinear phenomena, and adequate modeling tools to support their analysis, from a design limitation to a design opportunity. Special emphasis is placed on identifying designs and implementations applicable to aircraft configurations. Application fields of flow-induced vibrations-based energy harvesters are discussed including power supply for wireless sensor networks and simultaneous energy harvest and control. A large body of work on energy harvesters is included in this review journal. Whereas most of the references claim direct applications to unmanned aerial vehicles, it is apparent that, in most of the cases presented, the working principles and characteristics of the energy harvesters are incompatible with any aerospace applications. Finally, the challenges that hold back the integration of energy harvesting technologies in the aerospace field are discussed.

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1. Introduction

One of the greatest challenges in aerospace engineering is the limited energy available during flight. This problem affects aircraft endurance and operational flight missions. Of particular interest are unmanned aerial vehicles (UAVs) and micro aerial vehicles (MAVs) which are designed to conduct intelligence, surveillance, and reconnaissance missions [1]. The availability of more energy could contribute to higher performance and extended mission profiles.

Generally, batteries are used as storage of electricity, offer a high energy density at low cost, have a low self-discharge, and provide potentially long lifetime cycles. However, there are critical aspects related with the use of batteries which hold back their use [2]. The first practical and economical penalty is the need to replace the batteries when they achieve the end of the operating life. Thereby, they are likely to be deployed in large numbers in remote areas. A second problem is linked to safety, because modern batteries may suffer from thermal runaway, ignite, and explode due to short-circuit, extreme temperatures, or inappropriate charge or discharge, not to forget poor design.

A potential technology that may replace batteries in the near future is energy harvesting (EH). EH takes advantage of ambient energy sources to generate usable electric energy based on various transduction approaches. The harvested energy, through appropriate transducers specific to each application, can be stored and used to recharge on-board batteries and to operate low power consumption devices, making these self-sufficient in energy supply. Various potential energy sources for EH are shown in Fig. 1 [3]. Benefits of EH are that: (a) there is no need to replace batteries; (b) there is no need of cabling; (c) they are easy to retrofit infrastructures; and (d) they represent a “truly fit-and-forget” approach that allows reducing physical installation, replacement and maintenance costs, and time [4]. For these properties, EH are commonly used for systems that are designed to operate in remote areas with limited power supply and maintenance, and the requirement of long service time, such as electronic sensors used for structural health monitoring. Of specific interest herein is the application of EH in aerospace problems, generally targeting UAVs. With EH technology, future UAVs may achieve better performance: enhanced cruise range and duration time, better maintainability and viability, and larger mission payload.

Potential energy sources for aerospace applications include wind, solar radiation, and mechanical vibration, see Fig. 1. Among these EH approaches, the study on aircraft solar EH is quite mature. Table 1 summarises the power density of different EH methods [5], and it is found that solar EH through photo-voltaic conversion provides high power output density. Solar cells have been practically implemented in high-altitude long-endurance (HALE) aircraft, and being currently demonstrated on the Solar Impulse[1] set to travel around the world using solar energy. Developing a solar EH system to harvest sufficient energy for a sustained flight throughout the day and night is still a challenging task. This becomes more critical for smaller scale aircraft because of the lower aerodynamic performance compared to HALE configurations. Furthermore, the design of a solar EH module involves complicated trade-offs, and the expense of solar EH systems is still relatively large. Therefore, it is worthwhile to explore EH from other applicable energy sources such as piezoelectric or vibrational EH.

Turbines using one or more flapping foils can be used as an alternative to rotary wind turbines and river, oceanic and tidal current water turbines, although industrial development is at very early stages. Such flapping foil turbines have some key potential advantages, including lower foil velocities (and hence lower noise and wildlife impact), and more effective small-scale and shallow water operation. Reference [6] presented an extensive review on the progress in flapping foil power generation in the last few decades. The effects of a number of parameters were investigated, including foil kinematics (modes, frequencies, amplitudes and time histories of motion), foil and system geometry (shape, configuration and structural flexibility), and flow physics effects (Reynolds number and turbulence, shear flows and ground effect).

Flow-induced vibrations (FIVs) are generally considered as negative phenomena since in many cases these unwanted vibrations may cause a reduction of the life span and structural damage. For example, in the aerospace field, aeroelastic vibrations can jeopardize the aircraft structural integrity (e.g. flutter, limit cycle oscillations, and dynamic response to atmospheric turbulence)

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[1] The Solar Impulse project: http://www.solarimpulse.com/

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