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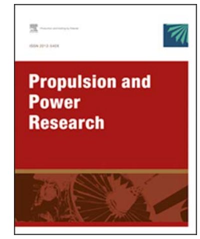

ORIGINAL ARTICLE

Light-weighting in aerospace component and system design

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Abstract Light-weighting involves the use of advanced materials and engineering methods to enable structural elements to deliver the same, or enhanced, technical performance while using less material. The concept has been extensively explored and utilised in many industries from automotive applications to fashion and packaging and offers significant potential in the aviation sector. Typical implementations of light-weighting have involved use of high performance materials such as composites and optimisation of structures using computational aided engineering approaches with production enabled by advanced manufacturing methods such as additive manufacture, foam metals and hot forming. This paper reviews the principal approaches used in light-weighting, along with the scope for application of light-weighting in aviation applications from power-plants to airframe components. A particular area identified as warranting attention and amenable to the use of light-weighting approaches is the design of solar powered aircraft wings. The high aspect ratio typically used for these can be associated with insufficient stiffness, giving rise to non-linear deformation, aileron reversal, flutter and rigid-elastic coupling. Additional applications considered include ultralight aviation components and sub-systems, UAVs, and rockets. Advanced optimisation approaches can be applied to optimise the layout of structural elements, as well as geometrical parameters in order to maximise structural stiffness, minimise mass and enable incorporation of energy storage features. The use of additive manufacturing technologies, some capable of producing composite or multi-material components is an enabler for light-weighting, as features formally associated with one principal function can be designed to fulfil multiple functionalities.

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1. Introduction

Light-weighting design is an extensively explored and utilised concept in many industries, especially in aerospace applications and is associated with the green aviation [1] co-opted concept. The contribution of aviation to global warming phenomena and environmental pollution has led to on-going efforts for the reduction of aviation emissions. The international civil aviation organization target is to reduce aviation emissions by 50% by 2050 [1,2]. Approaches to achieve this target include developing clean energy such as solar power, as well as increasing energy efficiency. An effective way to increase energy efficiency and reduce fuel consumption is reducing the mass of aircraft, as a lower mass requires less lift force and thrust during flight [3]. For example for the Boeing 787, a 20% weight saving resulted in 10%–12% fuel efficiency improvement [1]. In addition to reduction of carbon footprint, flight performance improvements such as better acceleration, higher structural strength and stiffness, and better safety performance, could also be achieved by lightweight design [1,4] as well as economic benefits. Light-weighting optimization of a solar powered unmanned aerial vehicle (UAV) is an example of using both clean energy and lightweight structures to achieve green aviation operation. Current solar powered UAV designs face challenges such as insufficient energy density and wing stiffness. Lightweight design is essential for ultralight aviation; as an example an empty weight (less than 115 kg) with limited fuel capacity (19 L) can be necessary [5]. Lightweight design enables longer flight duration and other improved performance parameters. Light-weighting is also necessary in rocket design.

The principle of lightweight design is to use less material or materials with lower density but ensure the same or enhanced technical performance. A typical approach to achieve lightweight design for aerospace components and systems is to apply advanced lightweight materials on numerically optimised structures, which can be fabricated with appropriate manufacturing methods. As such, the application of advanced lightweight materials can effectively achieve both weight reduction and performance improvement. Although metal materials especially aluminium alloys are still the dominant materials in aerospace application, composite materials have received increasing interest and compete with aluminium alloys in many new aircraft applications. Structural optimization is another effective way to achieve light-weighting, by distributing materials to reduce materials use, and enhance the structural performance such as higher strength and stiffness, and better vibration performance. Conventional structural optimization methods are size, shape and topology optimization. Lattice structural optimization enables multi-scale optimization. Manufacturability is a crucial constraint in the both processes of material selection and structural optimization. The development of advanced manufacturing technologies such as additive manufacturing [6,7], foam metal and advanced metal forming not only enable the application of advanced materials, but relax constraints, enhancing the flexibility of multi-scale structural optimization.

Many examples of lightweight design have been successfully applied in the design of lightweight aircraft. Figure 1 (a) [8] illustrates the SAW Revo concept aircraft, produced by Orange Aircraft, which is an ultralight aerobatic airplane with carbon fibre reinforced composite wings and a topologically optimised truss-like fuselage. The empty weight of this 6 m wing span aircraft is 177 kg [8]. Figure 1(b) [9] shows a high altitude pseudo-satellite solar powered UAV from Airbus [9]. The Zephyr 7 currently holds the world record for the longest absolute flight

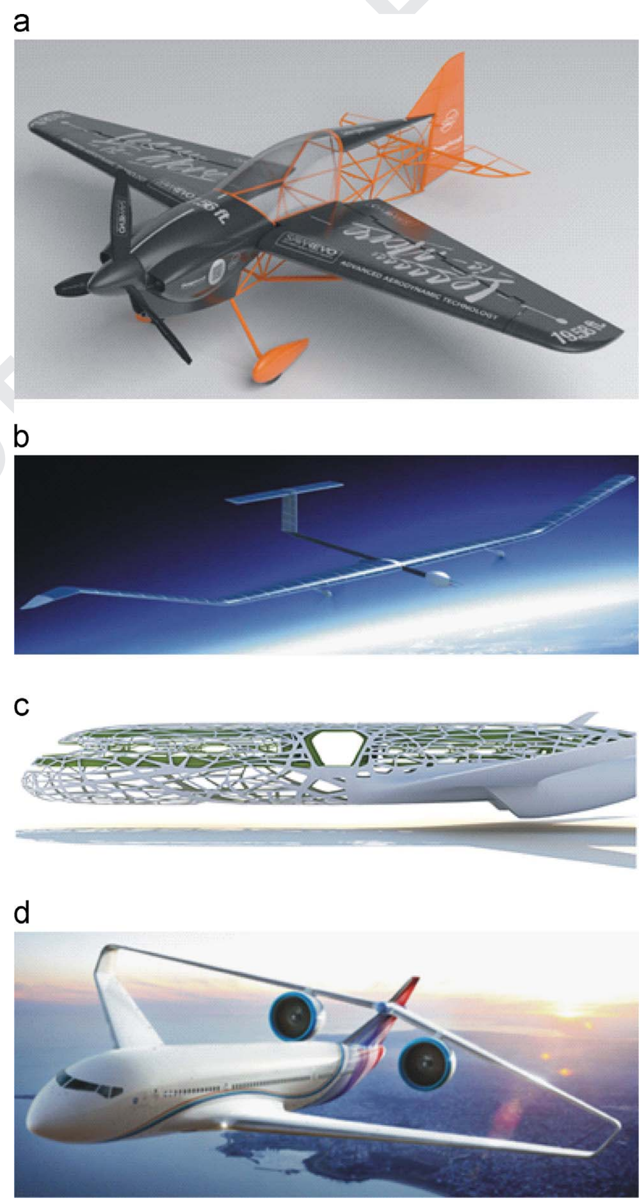

Figure 1 Light-weighting design example: (a) SAW Revo manufactured by Orange Aircraft [8], (b) high altitude pseudo-satellite UAV: Zephyr [9], (c) concept Airbus future airplane model [10] and (d) concept design for a box wing aircraft [12].

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