Progress in Aerospace Sciences 84 (2016) 48–69

Contents lists available at ScienceDirect

Progress in Aerospace Sciences

journal homepage: www.elsevier.com/locate/paerosci

Mimicking the humpback whale: An aerodynamic perspective

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A R T I C L E I N F O

Article history:
Received 18 August 2015
Received in revised form
8 March 2016
Accepted 9 March 2016
Available online 22 June 2016

Keywords:
Biomimetics
Low Reynolds number aerodynamics
Humpback whale tubercles
Leading edge flow control

A B S T R A C T

This comprehensive review aims to provide a critical overview of the work on tubercles in the past decade. The humpback whale is of interest to aerodynamic/hydrodynamic researchers, as it performs manoeuvres that baffle the imagination. Researchers have attributed these capabilities to the presence of lumps, known as tubercles, on the leading edge of the flipper. Tubercles generate a unique flow control mechanism, offering the humpback exceptional manoeuverability. Experimental and numerical studies have shown that the flow pattern over the tubercle wing is quite different from conventional wings. Research on the Tubercle Leading Edge (TLE) concept has helped to clarify aerodynamic issues such as flow separation, tonal noise and dynamic stall. TLE shows increased lift by delaying and restricting spanwise separation. A summary of studies on different airfoils and reported improvement in performance is outlined. The major contributions and limitations of previous work are also reported.

Contents

Abbreviation: AoA, Angle of Attack; AGI, Airfoil Gust Interaction; CAA, Computational Aero Acoustic; CFD, Computational Fluid Dynamics; DDLE, Dynamically Deformed Leading Edge; DES, Direct Eddy Simulation; HWAT, Horizontal Axis Wind Turbine; LDV, Laser Doppler Velocimetry; LES, Large Eddy Simulation; LEV, Leading Edge Vortex; MAV, Micro-Air Vehicle; MOGA, Multi-Objective Generic Algorithm; NASA, National Aeronautics and Space Administration; OpenFOAM, Open Source Field Operation And Manipulation; PIV, Particle Image Velocimetry; PNLLT, Prandtl's Nonlinear Lifting Line Theory; RANS, Reynolds Averaged Navier Stokes; SLE, Straight Leading Edge; SMA, Shape Memory Alloys; TLE, Tubercle Leading Edge; VG, Vortex Generators

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http://dx.doi.org/10.1016/j.paerosci.2016.03.002
0376-0421/

1. Introduction

The dream of flying has baffled humans since earliest times. Greek mythology depicts the flight of Icarus, with wings made of wax, flying towards the sun. The Ancient Egyptian god Khensu had wings and was known as a traveller journeying through the skies. These stories have been a dream for man, inspiring him to achieve the goal of flying. Only at the beginning of the 20th century was this dream realised. The first human photographed in an airplane is Otto Lilienthal. He made over 2000 successful glider flights and inspired the powered flight efforts by the Wright brothers [1]. The current goal of the aerospace industry is to develop greener technologies. This can be achieved only by reducing the structural weight, using a highly efficient propulsion system, increasing the aerodynamic efficiency and decreasing the overall drag.

1.1. Biomimetics

The study of the structures and functions of biological systems in the design of engineering systems is known as biomimetics. In general, this means imitating nature to solve engineering problems. A detailed review and the in-depth technological applications of various biological systems in relation to engineering have been compiled by Bar-Cohen [2]. Some of the most fascinating biomimicking studies, from the aerodynamic perspective, include the flight of owls and seagulls [3–8]. Owls have the ability to approach their prey in total silence, and the flapping sound is damped by leading edge serrations, giving them the ability to control the flow [5–7].

Aerodynamic engineers draw inspiration from marine animals. Designing an aircraft skin similar to that of sailfish and swordfish, or implementing riblets inspired by sharks, has been beneficial in reducing the skin friction drag on aircraft. Bhushan [9] summarises various inspirations drawn from nature and their applications as shown in Fig. 1.

The successful integration of biomimetics into mechanical systems has been a challenge. Recent technological advancements in the field of material science and engineering have made the dream of mimicking nature a reality [10–12]. Due to its huge importance, research in the field of biomimetics is gaining popularity.

1.2. Flow control and biomimetics

The major areas where flow control is necessary are wings, rudders, fans and turbines. Flow on aerodynamic surfaces has to be attached at a high Angle of Attack (AoA), as this increases operational capability, efficiency, range and endurance [13]. Aerodynamic flow control is classified into active, passive and hybrid. The active flow control technique is one where actuators and other mechanisms are used. Passive flow control mainly employs devices or modifications without involving actuators and complex mechanisms. In hybrid control, both active and passive mechanisms are implemented. The main aim of these devices is to control separation. Fig. 2 shows the interrelation of separation to lift, drag, transition and reattachment. A detailed description of the various flow separation control methods, both active and passive, has been elaborately covered by Gad-el-hak [14].

1.3. Humpback whale

The humpback whale (*Megaptera novaeangliae*) is a species of baleen whale of the Balaenopteridae family. This mammal has existed for the past 55 million years and comes under the order of