Cairo University

EXPERIMENTAL STUDY ON BIO-INSPIRED WINGS WITH TUBERCLES

By

MOHAMAD AHMED ABDEL-RAHIM DESOKY

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Aerospace Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Title of Thesis:

Experimental Study on Bio-Inspired Wings with Tubercles

Key Words:
Sinusoidal leading-edge wing; Wings with tubercles; Wavy leading-edge wings; Humpback whale flipper.

Summary:
This work aims to answer some questions about the humpback whale flipper with its ability to delay stall and enhance post stall performance. A series of wind tunnel tests on 14 different wings with NACA 0021 profile and with different leading-edges are performed. The tests were divided into two groups: one of aspect ratio 7 which is as a convenient representative to a conventional airplane's wing, and the other group is with aspect ratio 2 as a convenient representative of a control surface aspect ratio or a MAV wing. These experiments led to the discovery of a wing leading-edge geometry constructed with peaks of the sine wave that proved to reduce the drag coefficient up to 28% and increase the lift to drag ratio up to 48% relative to its comparable sinusoidal wing. They also led to suggesting an additional design parameter that should be included in the design process to maximize the aerodynamic gains of the wings with tubercles which is the peak (or trough) width.

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I thank my beloved little daughter Farida whose smile offers me something to come home to. My candle on the road indeed.

Dedication

Dedicated with Love to the Memory of Dr. Ahmed Khaled Tawfik

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Nomenclature

AOA	Angle of Attack
α	Angle of Attack
α_u	Uncorrected Angle of Attack
AR	Aspect Ratio
b	Wing Span
c	Wing Chord
C	Test Section Area
C_D	Drag Coefficient
C_{D_i}	Induced Drag Coefficient
C_{D_o}	Zero-lift Drag Coefficient
C_{D_U}	Uncorrected Drag Coefficient
c_i	Sensitivity Coefficient
C_L	Lift Coefficient
$C_{L_{max}}$	Maximum Lift Coefficient
C_{L_u}	Uncorrected Lift Coefficient
D	Drag Force
δ	Boundary Correction Factor
ε_{sb}	Solid Blockage Correction Factor
ε_{wb}	Wake Blockage Correction Factor
F_C	Force in Chord Direction
F_N	Force Normal to Chord Direction
Ґ	Circulation
K	Coverage Factor
K_1	Body Shape Factor
L	Lift Force
l_t	Tail Length
λ	Wavelength
P_w	Peak Width
R	Half Width of Wind Tunnel
Re	Reynolds Number
S	Wing Surface Area
σ	Standard Deviation
T_w	Trough Width
u_c	Combined Uncertainty
U_i	Uncertainty of Interest
U_∞	Wind tunnel airspeed

v_{eff}	Effective Degrees of Freedom
v_i	Degrees of Freedom

Abstract

This work aims to answer some questions about the humpback whale flipper with its ability to delay stall and enhance post stall performance. A series of wind tunnel tests for 14 different wings with NACA 0021 profile and with different leading-edges are performed. The tests were divided into two groups: one of aspect ratio 7 which is as a convenient representative to a conventional airplane's wing, and the other group is with aspect ratio 2 as a convenient representative of a control surface aspect ratio or a MAV wing.

These experiments led to the discovery of a wing leading-edge geometry constructed with peaks of the sine wave that proved to reduce the drag coefficient up to 28% and increase the lift to drag ratio up to 48% relative to its comparable sinusoidal wing. They also led to suggesting an additional design parameter that should be included in the design process to maximize the aerodynamic gains of the wings with tubercles. This suggested design parameter is the peak (or trough) width. These questions also drew the attention to the tubercles found near the tip of the trailing edge of the humpback and its potential to enhance the post-stall hydrodynamic performance of the whale. They extended the idea of this configuration found in nature to a fully sinusoidal trailing edge to see if further aerodynamic enhancement can be captured.

This work also tested leading edge functions other than the sine wave approximation for the tubercles by studying elliptic and triangular functions spread along the leading edge of the wing and comparing them to a sinusoidal leading-edge wing to quantify the differences. It also studied the effect of some important aerodynamic parameters such as the sweep back angle and Reynolds number on the wings with tubercles.

Keywords: Sinusoidal leading-edge wing, Wings with tubercles, Wavy leading-edge wings, Humpback whale flipper.