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Computational Modeling of Transitional Flow over Low Reynolds Number Airfoils

A Thesis Submitted in Partial Fulfillment for the Requirements of the Degree of Master of Science in Mechanical Engineering

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Egypt- Cairo 2021

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Statement

This thesis is submitted in partial fulfillment for the degree of Master of Science in Mechanical Power Engineering to the Faculty of Engineering, Ain Shams University.

The present work in this thesis was conducted by the author, primarily at the laboratories of the Mechanical Power Engineering Department, Faculty of Engineering, Ain Shams University.

No part of this thesis has been submitted for degree or qualifications at any other universities.

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Date: / /2021

Paper Publication

Mohannad Y. Al Orabi, Ahmed M. R. Elbaz, Nabil A. Mahmoud, Ashraf M. Hamed. **Computational modeling of transitional flow over NACA-0018 airfoil at low Reynolds Number**, International Journal of Advance Research, Ideas and Innovations in Technology.

https://www.ijariit.com/manuscript/computational-modeling-of-transitional-flow-over-naca-0018-airfoil-at-low-reynolds-number/

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Abstract

Predicting the aerodynamic aspects of airfoils for various engineering applications is considered one of the most aerodynamic researcher's objectives. This can actually be accomplished through different theoretical, experimental and numerical approaches. Each of such techniques has its own advantages and weaknesses represented in accuracy and complexity. Computational fluid dynamics (CFD) is considered one of the most common techniques used in such studies.

This thesis introduces a full numerical study of the NACA-0018 airfoil operating at low chord R_e of 10^5 that provides overall optimized numerical procedures for accurate transition predictions, thus the airfoil aerodynamic characteristics can be obtained precisely.

All numerical computations were performed using Reynolds-Averaged Navier-Stokes (RANS) equations in two-dimensional simulations using the ANSYS-FLUENT 19.0. The transition modeling was provided as the main strategy obtaining the airfoil associated flow field.

The numerically predicted results were compared to previously obtained experimental data in order to validate the used computational procedures, which showed a good agreement.

Keywords: Aerodynamics, NACA-0018 airfoil, Transition Modeling, Low Reynolds number airfoils, CFD, RANS solver.

Acknowledgment

I would like to express my greatest gratitude to Prof. Dr. Nabil Abdel-Aziz Mahmoud, Prof. Dr. Ahmed Mohamed Reda Elbaz and Dr. Ashraf Moustafa Hamed for guiding and supervising throughout this research.

Nomenclature

Abbreviations

2D	Two-Dimensional
3D	Three-Dimensional
AOA	Angle Of Attack
ASW	Aerodynamic straight wall
CFD	Computational Fluid Dynamics
DNS	Direct Numerical Simulation
ERCOFTAC	European Research Community On Flow Turbulence And Combustion
GSW	Geometric Straight Wall
LES	Large Eddy Simulation
LSB	Laminar Separation Bubble
RANS	Reynolds Averaged Navier-Stokes
RMS	Root Mean Square
SST	Shear Stress Transport

Greek Letters

		Units
c	Chord length	[m]
C_{ax}	Blade axial chord length	[m]
C_D	Drag coefficient	[-]
C_f	Skin friction coefficient	[-]
C_L	Lift coefficient	[-]
C_P	Surface pressure coefficient of the airfoil	[-]
$C_{P,W}$	Surface pressure coefficient of the domain wall boundaries	[-]
F_D	Drag force	[N]

F_L	Lift force	[N]
K	Turbulent kinetic energy	[$m^2.S^{-2}$]
Ḱ	Flow acceleration parameter	[-]
P	Surface pressure at a location on the airfoil surface	[Pa]
P_W	Surface pressure at a location on the domain wall boundaries	[Pa]
P_∞	Free stream static pressure	[Pa]
Re	Reynolds number based on airfoil chord length	[-]
Re_θ	Momentum thickness Reynolds number	[-]
$\widetilde{Re}_\theta$	Local transition onset momentum thickness Reynolds number	[-]
Tu	Turbulence intensity	[%]
U	Local mean velocity	[m/s]
U_e	Edge velocity	[m/s]
U_∞	Free stream velocity	[m/s]
u_τ	Friction velocity	[m/s]
ũ	Local root-mean-square velocity	[m/s]
U^+	The dimensionless velocity	[-]
X	Distance measured from the airfoil model axle in the stream-wise location	[m]
x	Distance measured from the airfoil leading edge along the chord	[m]
x_R	x location of reattachment	[m]
x_S	x location of separation	[m]
x_T	x location of transition	[m]
Y	Vertical distance from the airfoil model axle	[m]
y	Distance from the airfoil model surface	[m]
y^+	Non dimensional distance from wall	[-]
ỳ	Vertical distance to nearest wall	[m]

γ	Intermittency	[-]
δ	Boundary layer thickness	[m]
θ	Boundary layer momentum thickness	[m]
μ	Molecular viscosity	[Pa S]
μ_t	Eddy viscosity	[Pa S]
ρ	Density	[kg.m^{-3}]
ν	Dynamic viscosity	[m^2/s]
ω	Specific turbulence dissipation rate	[m^2.S^{-3}]
τ_w	Wall shear stress	[Pa]

Subscripts

L.E	Airfoil leading edge
S	Separation location as predicted from skin friction coefficient distribution
S_P	Separation location as predicted from surface pressure coefficient distribution
T	Transition location as predicted from skin friction coefficient distribution
T_P	Transition location as predicted from surface pressure coefficient distribution
R	Reattachment location as predicted from skin friction coefficient distribution
R_P	Reattachment location as predicted from surface pressure coefficient distribution
T.S	Turbulent separation

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