CFD Analysis of NACA4415 Airfoil with $\gamma - Re_\theta$ Model considering Natural Transition

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Main Contents

Introduction

Background

- Airfoil lift and drag over a wide range of Reynolds number (Re) are fundamental to wind turbines.
- Transition from laminar to turbulent flow in the airfoil boundary layers affects lift and drag.
- There are different types of transition (e.g. natural, by-pass, wake induced, reversed, separated flow) and modeling them is not straightforward.
- One of the popular transitional models in Computational Fluid Dynamics (CFD) analysis is the local correlation-based transitional model called $\gamma - Re_\theta$ which was originally proposed by Menter et al. (Menter et al., 2004).
- The model solves transport equations for the intermittency, γ, and the transition momentum thickness Reynolds number.
- Different correlations for calculating the two parameters required by the $\gamma - Re_\theta$ model.

Introduction

Scope of the Presentation

- CFD analysis of NACA 4415 airfoil for a low turbulence intensity (Tu) of 0.03% which will cause natural transition.
- The $\gamma - Re_\theta$ model is used in OpenFOAM (OpenFOAM, 2013) with five different correlations, proposed by:
  1. Sørensen (2009)
  2. Malan et al. (2009)
  3. Suluksna et al. (2009)
  4. Langtry and Menter (2009) and
  5. Tomac et al. (2013)
- Results are compared with Xfoil (Drela, 1989) and experimental datasets for validation. The turbulence is predicted using the $k - \omega$ model.

Computational Domain and the Mesh

O-Type grid

- An O-Type grid was prepared. It is more appropriate for CFD analysis of airfoils with blunt trailing edges.

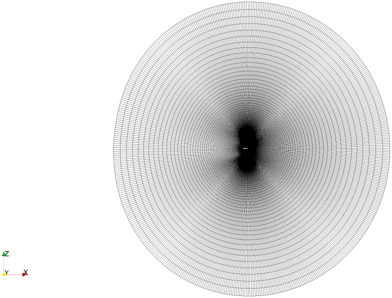

Figure: Computational Domain

Computational Domain and the Mesh

Mesh around the NACA 4415 Airfoil

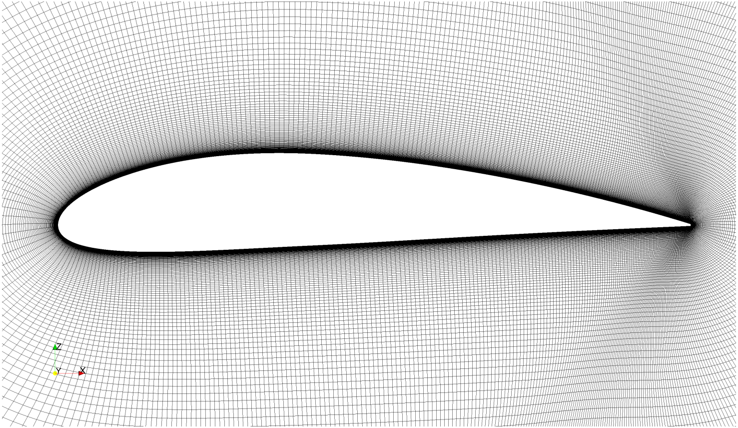

Figure: Mesh around the NACA 4415 Airfoil

Mesh around the NACA 4415 Airfoil

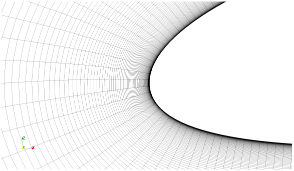

Figure: Mesh around the Leading Edge of the NACA 4415 Airfoil

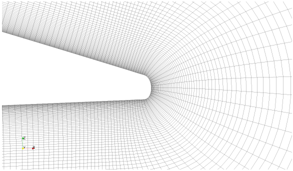

Figure: Mesh around the Trailing Edge of the NACA 4415 Airfoil

Details of the OpenFOAM Cases

- The steady-state solver called "simpleFoam" is used;
- $Re = 700{,}000$;
- $Tu = 0.03\%$;
- Three angles of attack (α): -8°, 0° and +8°;
- "Gauss linearUpwind" scheme was used for the 5 transport variables in OpenFOAM.
- Lift and drag coefficients are compared with Xfoil (Drela, 1989) and experimental values available in Miley (1982). These experimental results were obtained from NACA LTT in 1945 for 2-D situation at turbulence level of 0.03% .
- Skin-friction coefficients are only compared with Xfoil results as experimental results are not available.

Convergence History

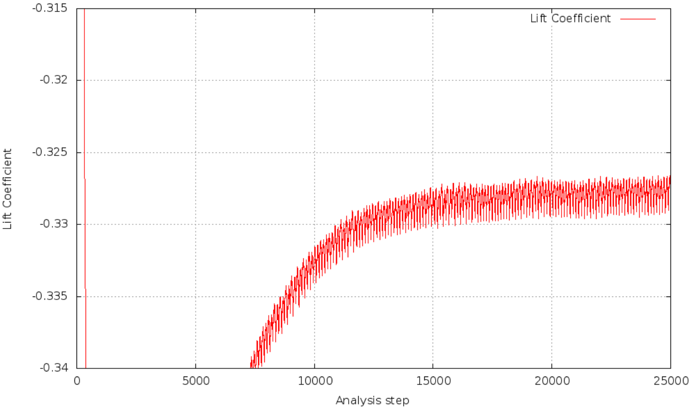

Figure: Convergence of Lift Coefficient at α=-8°

Results

Skin-Friction Coefficients

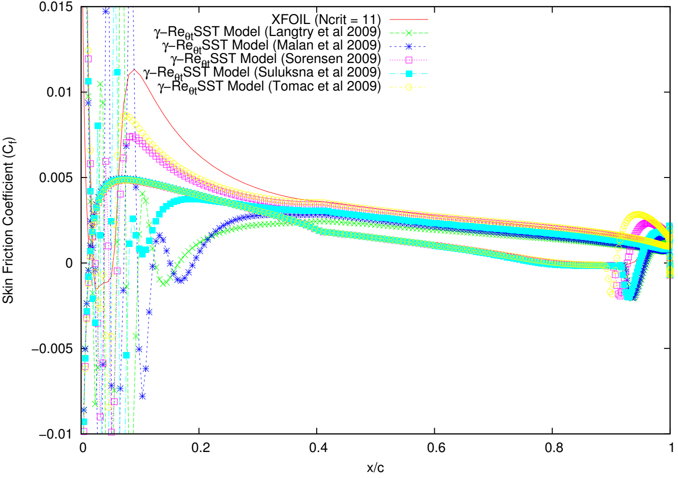

Figure: Comparison of Wall Shear Stress at α=-8°

Results

Skin-Friction Coefficients

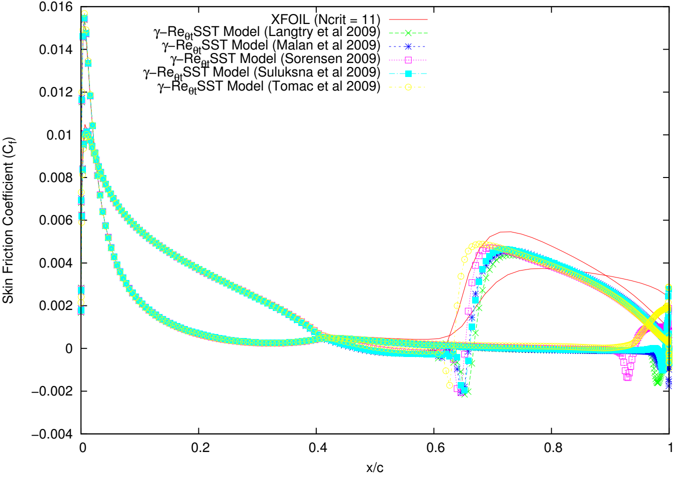

Figure: Comparison of Wall Shear Stress at α=0°

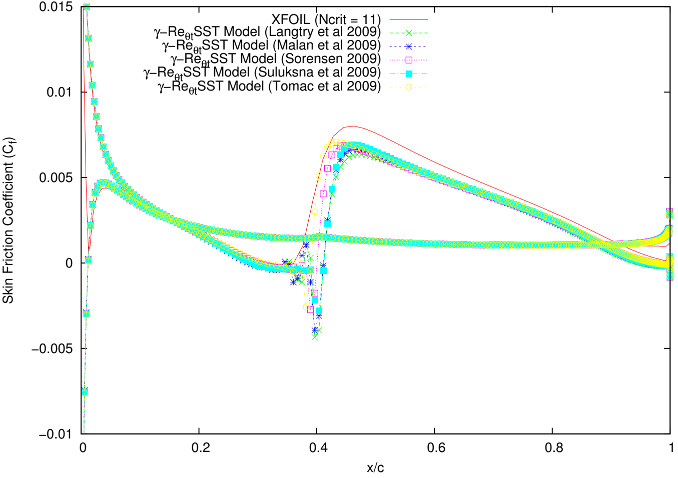

Figure: Comparison of Wall Shear Stress at α=8°

Results

Table: Lift and Drag Coefficients at α=-8°

	C_l	C_d
$\gamma - Re_\theta$ (Langtry and Menter, 2009)	-0.34	0.0216
$\gamma - Re_\theta$ (Malan et al., 2009)	-0.34	0.0211
$\gamma - Re_\theta$ (Sørensen, 2009)	-0.38	0.0139
$\gamma - Re_\theta$ (Suluksna et al., 2009)	-0.36	0.0171
$\gamma - Re_\theta$ (Tomac et al., 2013)	-0.39	0.0132
XFOIL 6.99	-0.39	0.0135

Results

Table: Lift and Drag Coefficients at α=0°

	C_l	C_d
$\gamma - Re_\theta$ (Langtry and Menter, 2009)	0.43	0.0074
$\gamma - Re_\theta$ (Malan et al., 2009)	0.43	0.0077
$\gamma - Re_\theta$ (Sørensen, 2009)	0.44	0.0074
$\gamma - Re_\theta$ (Suluksna et al., 2009)	0.42	0.0067
$\gamma - Re_\theta$ (Tomac et al., 2013)	0.41	0.0073
Experimental (Miley, 1982)	0.45	0.0094
XFOIL 6.99	0.47	0.0075

Results

Table: Lift and Drag Coefficients at α=8°

	C_l	C_d
$\gamma - Re_\theta$ (Langtry and Menter, 2009)	1.19	0.0176
$\gamma - Re_\theta$ (Malan et al., 2009)	1.19	0.0176
$\gamma - Re_\theta$ (Sørensen, 2009)	1.21	0.0171
$\gamma - Re_\theta$ (Suluksna et al., 2009)	1.20	0.0173
$\gamma - Re_\theta$ (Tomac et al., 2013)	1.22	0.0169
Experimental (Miley, 1982)	1.16	0.0135
XFOIL 6.99	1.31	0.0113

Results

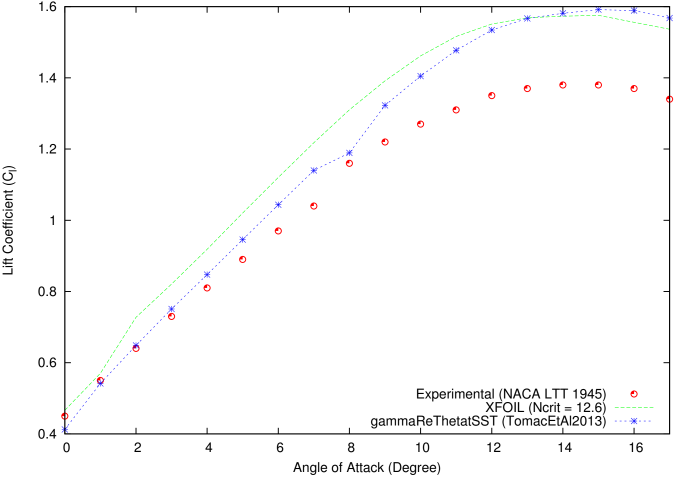

Figure: Comparison of Lift Coefficients

Results

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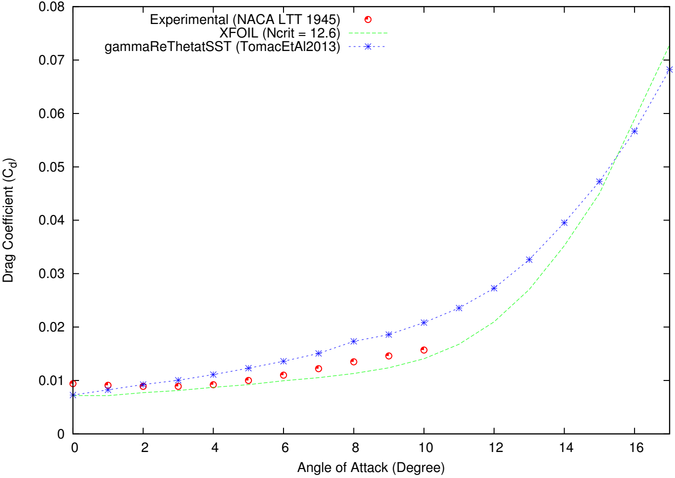

Figure: Comparison of Drag Coefficients

Results

CFD Analysis of NACA4415 Airfoil with $\gamma - Re_\theta$ Model considering Natural Transition

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- Introduction
- Computational Domain and the Mesh
- Details of the OpenFOAM Cases
- Concluding Remarks
- Acknowledgment
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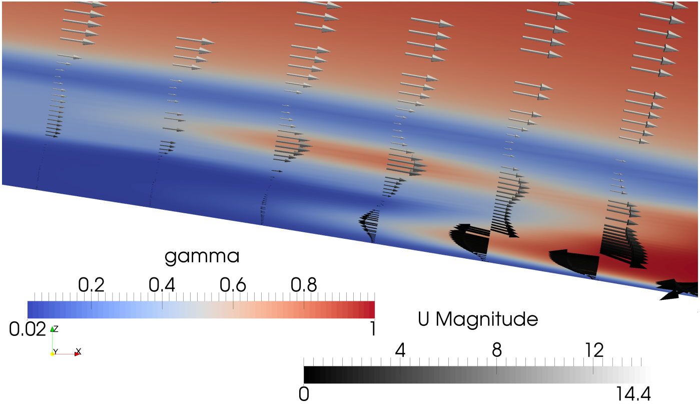

Figure: Flow near separation point at α=0°. U in m/s

Concluding Remarks

- Finding converged solution of lift and drag coefficient obtained from the $\gamma - Re_\theta$ using different correlations was challenging, particularly at $\alpha =$ -8°.
- The transitional flow near separation is not correctly modeled by any of the correlations at any α.

Acknowledgment

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