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Prediction of airfoil performance at high Reynolds numbers

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Introduction

Large Scale Wind Turbines

Increasing the rotor size may potentially lead to two obvious aerodynamic issues

- ◆ High Mach numbers in the tip region
 - ◆ Might be harmful for performance
 - ◆ Possible to avoid
- ◆ High Reynolds numbers
 - ◆ Might be beneficial for performance
 - ◆ Hard to avoid



DTU 10 MW Reference Turbine

Introduction

Airfoil performance at high Reynolds Numbers

We expect that increasing the Reynolds Number will:

- ◆ Decrease the viscous effects due to the thinning of the boundary layer
- ◆ Promote earlier transition due to increased Reynolds number

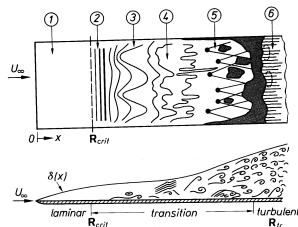
Quantification of the effects can be done by:

- ◆ Measurements
 - ◆ Tunnel measurements are difficult to obtain at high Re and low Mach
 - ◆ Openly available data are sparse
- ◆ Computations
 - ◆ Model performance in this range is unknown

Introduction

Laminar turbulent transition

- ◆ The transition process depend on many parameters
 - ◆ Reynolds Number
 - ◆ Free stream turbulence level
 - ◆ Laminar separation bubbles
 - ◆ Cross flow
 - ◆ Surface roughness
 - ◆ Mass injection
- ◆ Typically approaches for transition modeling
 - ◆ e^n method (Orr-Sommerfeld eqn.)
 - ◆ Empirical correlations
 - ◆ Michel
 - ◆ Mayle
 - ◆ Abu-Ghannam and Shaw
 - ◆ Suzen



Approach

The $\gamma - Re_\theta$ Correlation based transition model

- ◆ The model is based on comparing the local Momentum Thickness Reynolds number with a critical value from empirical expressions

$$Re_\theta = Re_{\theta t}$$

- ◆ In the present form the model handles natural transition, by-pass transition, and separation induced transition
- ◆ The model is based on transport equations, and can easily be implemented in general purpose flow solvers

Approach

 E^n model for natural transition

- ◆ The E^n method is based on analyzing the behavior of small disturbances in the boundary layer

$$\psi(y) = \phi(y) \exp [i(\alpha x - \omega t)]$$

- ◆ The disturbances are inserted in the Navier-Stokes equations, and linearized to give the Orr-Sommerfeld equation

$$(U^* - c^*)(\phi'' - \alpha^2 \phi) - (u^*)'' \phi = \frac{-i}{\alpha Re_\theta} (\phi'''' - 2\alpha^2 \phi'' + \alpha^4 \phi)$$

- ◆ The model is heavily related to BL physics, and not straight forward to implement in general purpose flow solvers.
- ◆ In our inhouse code the EllipSys, the E^n model can be used together with a bypass and a bubble criteria.

Approach

Flow Solver and test cases

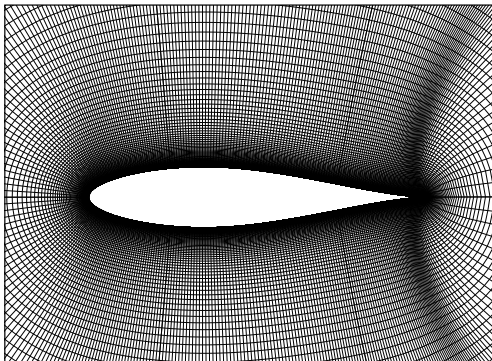
- ◆ We use the EllipSys2D incompressible solver.
- ◆ Diffusive terms by second order accurate central differences.
- ◆ Convective terms by QUICK.
- ◆ Steady state computations.
- ◆ Turbulence modeling by the $k - \omega$ SST model
- ◆ Transitional computations using $\gamma - Re_{\theta t}$ transition model and E^n model

We will analyze a series of airfoils at Reynolds numbers [3-40] million

Test Case, NACA63-018

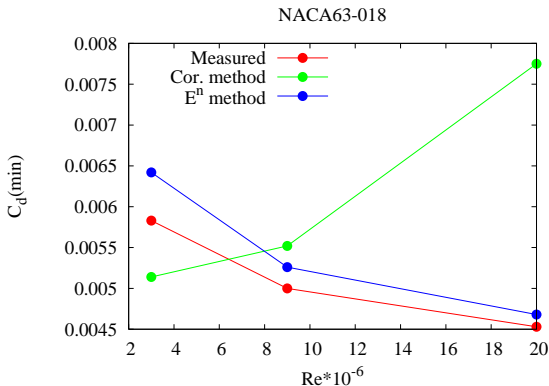
Computational setup

- ◆ Airfoil computations for $Re=[3, 9, 20]$ million
- ◆ Using two transition models, E^n and $\gamma - Re_\theta$
- ◆ Assuming natural transition ($N=9$)
- ◆ Mesh resolution 384×256



Test Case, NACA63-018

Performance for varying Re

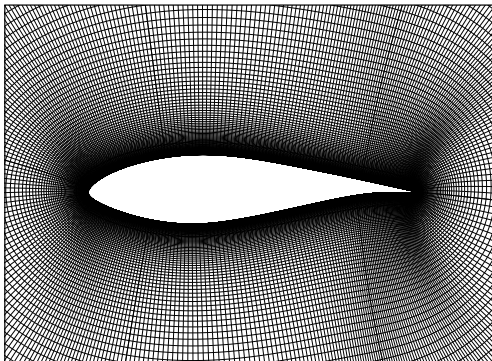


The correlation based model do not respond correctly to varying Re !

Test Case, DU00-W-212

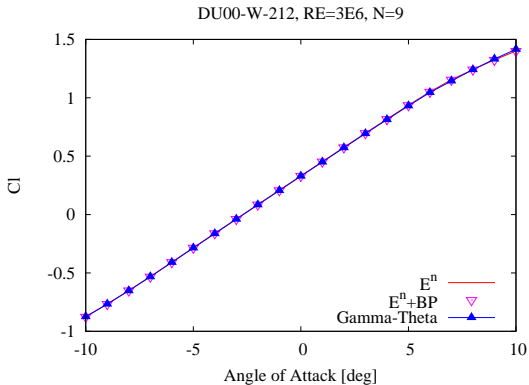
Computational set-up

- ◆ Airfoil computations for $Re=[3, 15]$ million
- ◆ Using three transition models, E^n , $E^n + BP$ and $\gamma - Re_\theta$
- ◆ All assuming natural transition ($N=9$)
- ◆ Mesh resolution 384×256



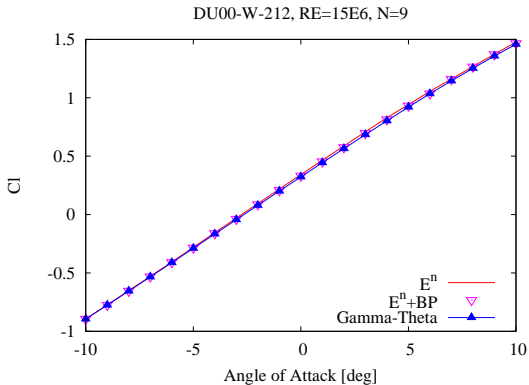
Test Case, DU00-W-212

Lift, Natural Transition



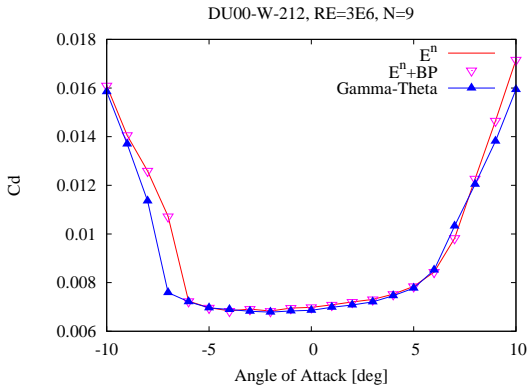
Test Case, DU00-W-212

Lift, Natural Transition



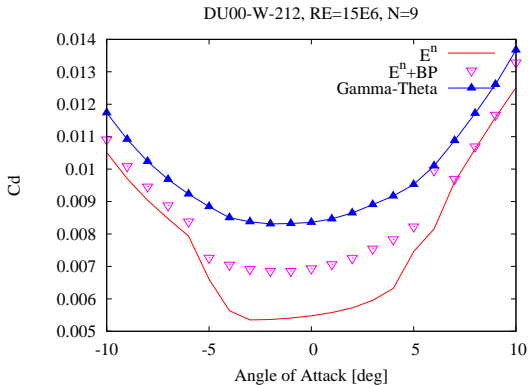
Test Case, DU00-W-212

Drag, Natural Transition



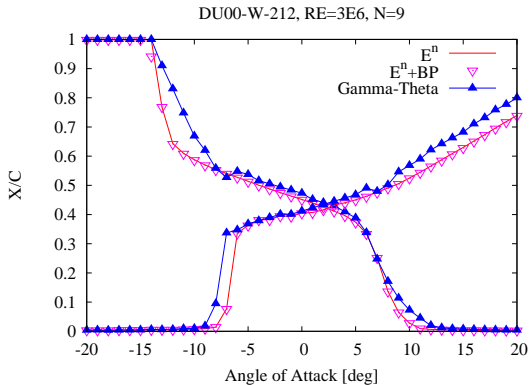
Test Case, DU00-W-212

Drag, Natural Transition



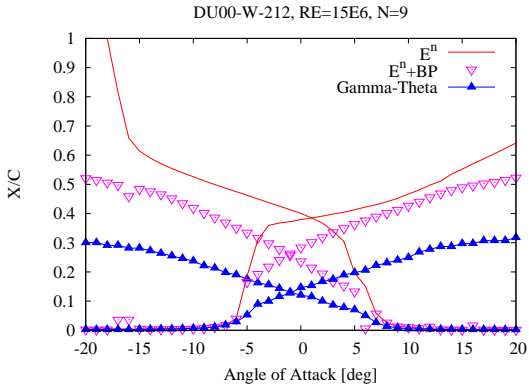
Test Case, DU00-W-212

Transition Location, Natural Transition



Test Case, DU00-W-212

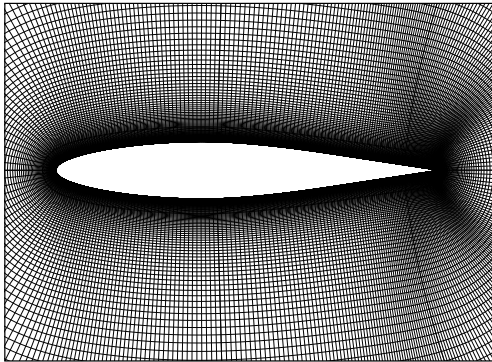
Transition Location, Natural Transition



Test Case, NACA64₂A015

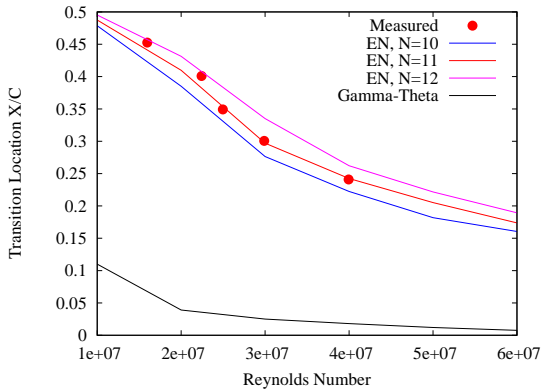
Computational setup

- ◆ Airfoil computations for $Re=[10:40]$ million, $AOA=0$ deg.
- ◆ Using two transition models, E^n and $\gamma - Re_\theta$
- ◆ Mesh resolution 384×256



Test Case, NACA64₂A015

Performance at high Re

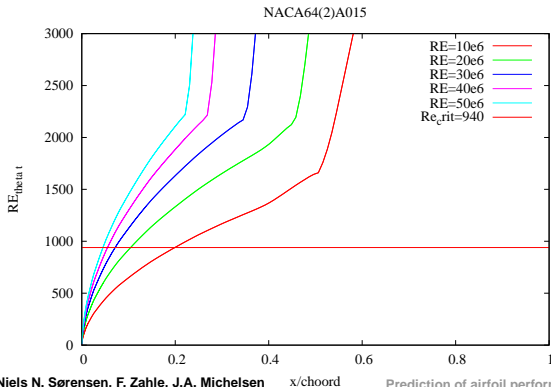


Explanation

Behavior of the correlation based model

The following behavior is observed

- ◆ The Reynolds number is varied through the viscosity
- ◆ The pressure distribution stays nearly constant
- ◆ Turbulent quantities are unchanged away from the airfoil
- ◆ The critical Reynolds number predicted by the $\gamma - Re_\theta$ model stays constant



Conclusion

Conclusion and outlook

- ◆ Wind turbine rotors will face high Re with increasing size
- ◆ Lift is weakly dependent on the transition location in normal operation even at high Re
- ◆ The available data show that the $\gamma - Re_\theta$ model over-predict drag at high Re
- ◆ The present computations indicate that the $\gamma - Re_\theta$ model do not react correctly to changes in Re
- ◆ There is very little data available for comparison
- ◆ The present study suggest to use the E^n model to correctly capture effects of the Re

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