DTU Library

# Prediction of airfoil performance at high Reynolds numbers.

**Sørensen, Niels N.; Zahle, Frederik; Michelsen, Jess**

*Publication date:*
2014

*Document Version*
Publisher's PDF, also known as Version of record

# Prediction of airfoil performance at high Reynolds numbers

## EFMC 2014, Copenhagen
## 17-20 Sept 2014

**Niels N. Sørensen[1], F. Zahle[1], J.A. Michelsen[2]**

[1] Wind Energy Department · DTU, Risø Campus, DK
[2]Department of Fluid Mechanics, DTU

# 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

# Airfoil performance at high Reynolds Numbers

We expect that increasing the Reynolds Number will:

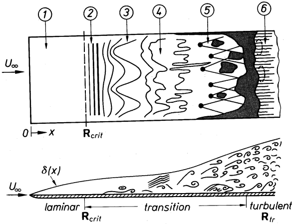
- Decrease the viscous effects due to the thinning of the boundary layer
- Promote earlier transition due to increased Reynolds number

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

# 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



## 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

# $E^n$ model for natural transition

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

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

- 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.

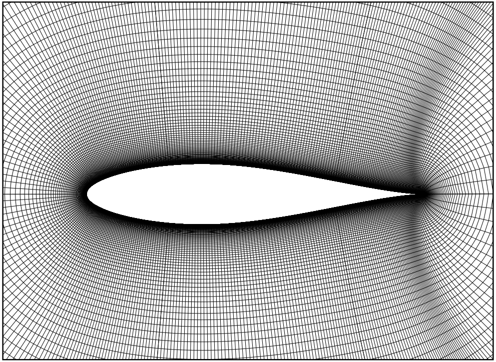
## Flow Solver and test cases

- 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

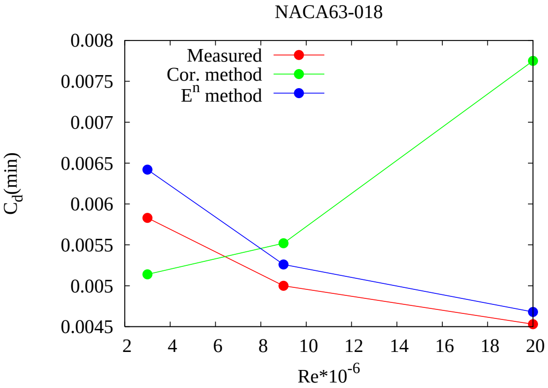
We will analyze a series of airfoils at Reynolds numbers [3-40] million

# 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 $384 \times 256$



# Test Case, NACA63-018
## Performance for varying Re

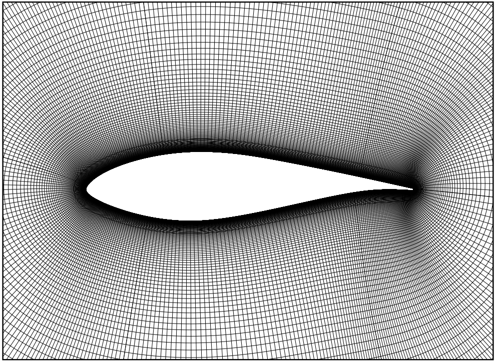



The correlation based model do not respond correctly to varying Re !

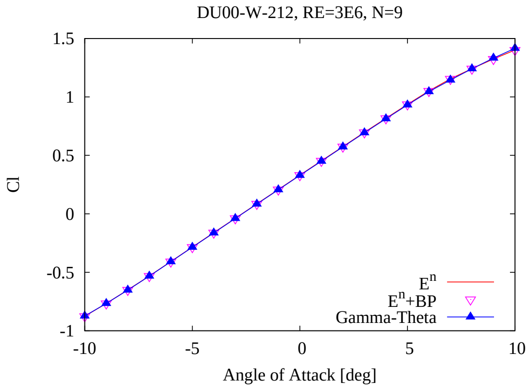

Niels N. Sørensen, F. Zahle, J.A. Michelsen

# 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 $\times$ 256



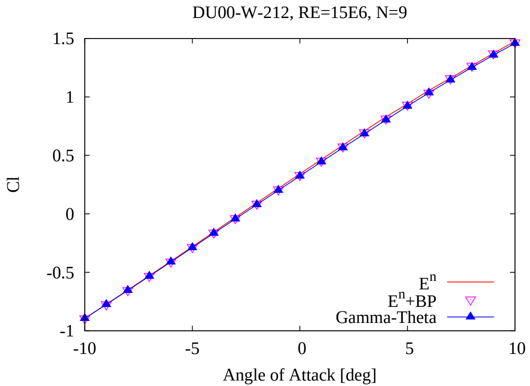
# Test Case, DU00-W-212
## Lift, Natural Transition



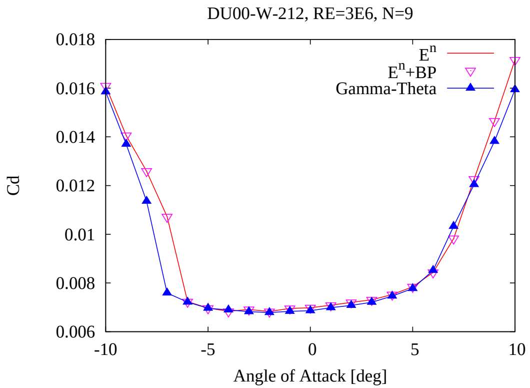


Niels N. Sørensen, F. Zahle, J.A. Michelsen

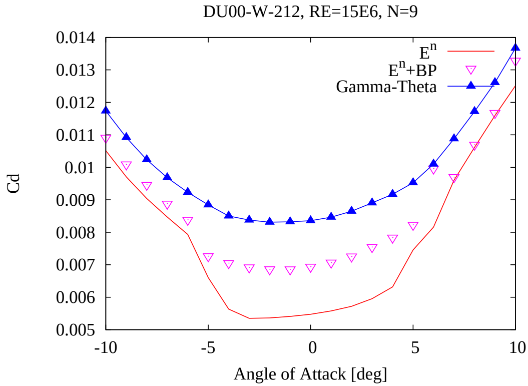
# Test Case, DU00-W-212
## Lift, Natural Transition



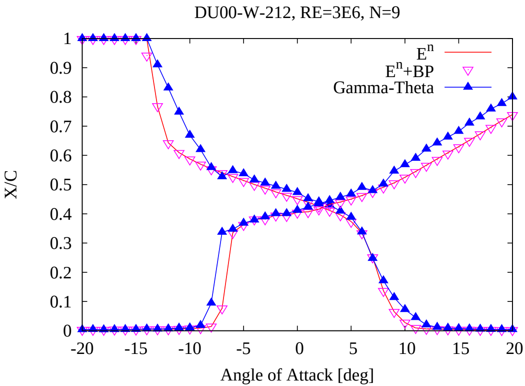
# Test Case, DU00-W-212
## Drag, Natural Transition



# Test Case, DU00-W-212
## Drag, Natural Transition



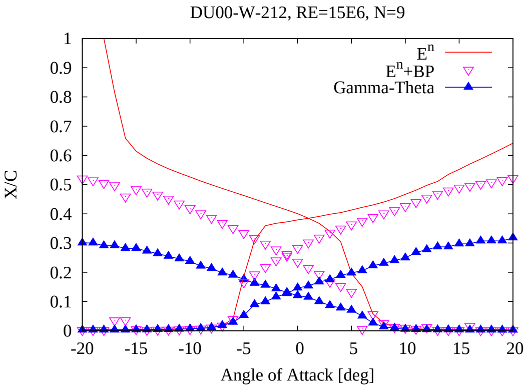
# Test Case, DU00-W-212
## Transition Location, Natural Transition





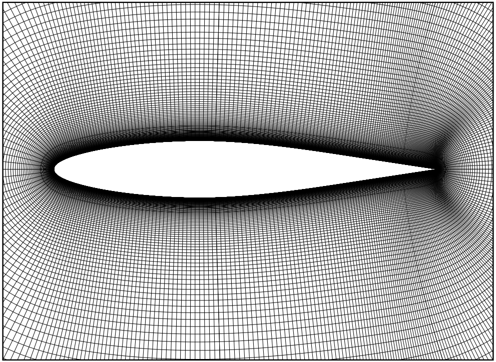
Niels N. Sørensen, F. Zahle, J.A. Michelsen

# Test Case, DU00-W-212
## Transition Location, Natural Transition

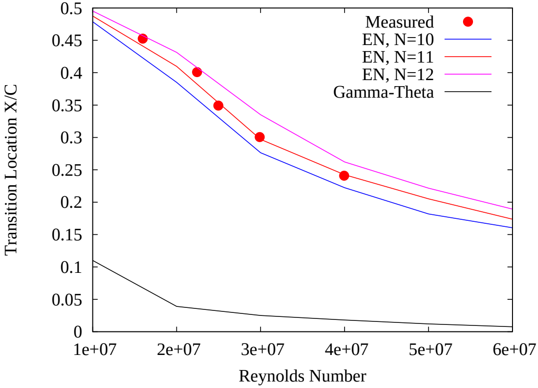


# Test Case, NACA64$_2$A015
## Computational setup

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



# Test Case, NACA64$_2$A015
## Performance at high Re





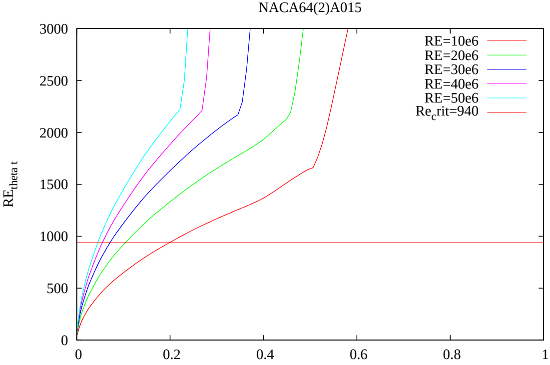
Niels N. Sørensen, F. Zahle, J.A. Michelsen

## 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




 Niels N. Sørensen, F. Zahle, J.A. Michelsen 

## 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

The present work was supported by the InnWind, AVATAR and COMFLOW projects.