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The National Rotor Testbed: Airfoils

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High level design goals

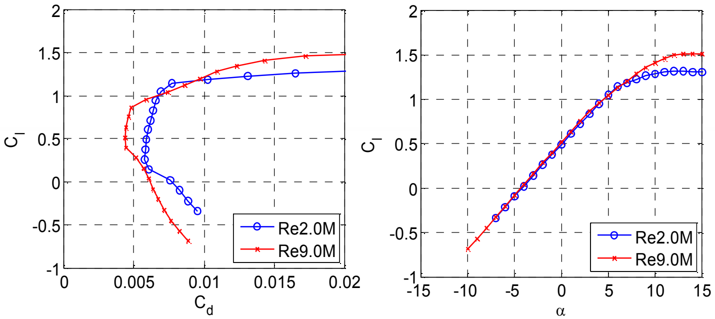
- **Retrofit to the existing SWiFT turbines**
  - Loads and rotational speed constraints

- **Replicate rotor loads and wake formation of a utility scale turbine to support turbine-turbine interaction research at SWiFT; i.e. produce wakes of similar geometry, velocity deficit and turbulence intensity.**

Airfoil Drivers

- **Predictable rotor performance**
- **Roughness insensitivity**
  - Sensitivity increases as Reynolds number decreases (at least below the design Reynolds number)
- **Thickness reqt. For structures (different limits than utility rotor)**
  - Also reqt. For instrumentation and access (becomes more important as size decreases)

Reynolds number effects



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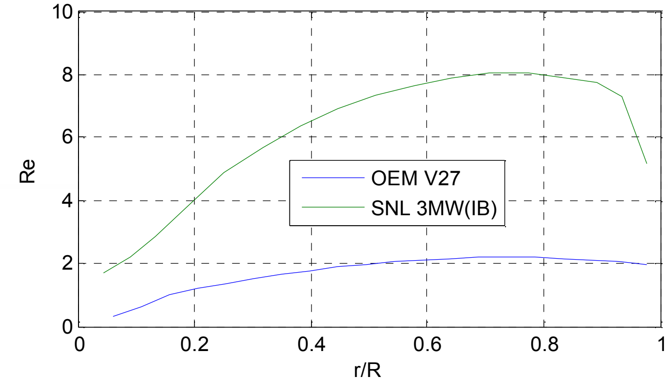
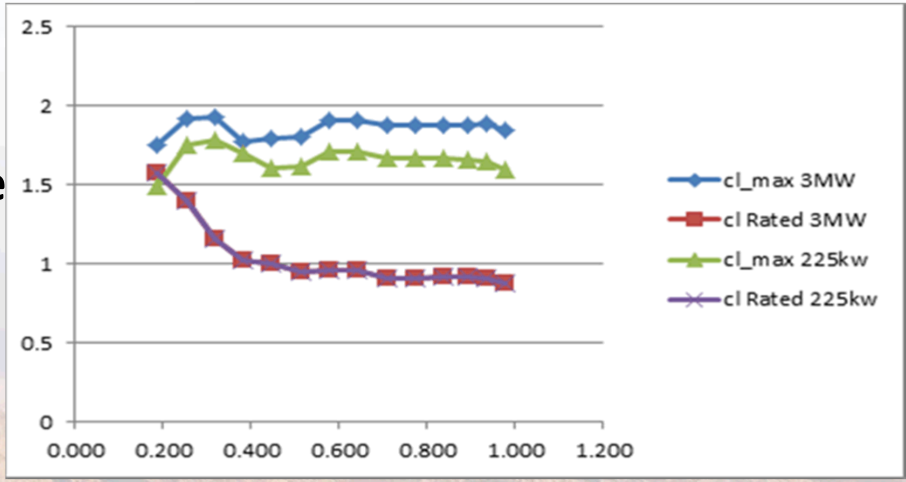


- Reynolds numbers will not match between scales – we seek merely to understand and account for the effects
- A reduction in Reynolds number for a given airfoil (generally) causes
  - Decrease in max C_l
  - Increase in profile drag
- It can affect the scaled rotor design if the chord and twist are not modified to account for new polars
- Different or modified airfoils might be required in extreme cases



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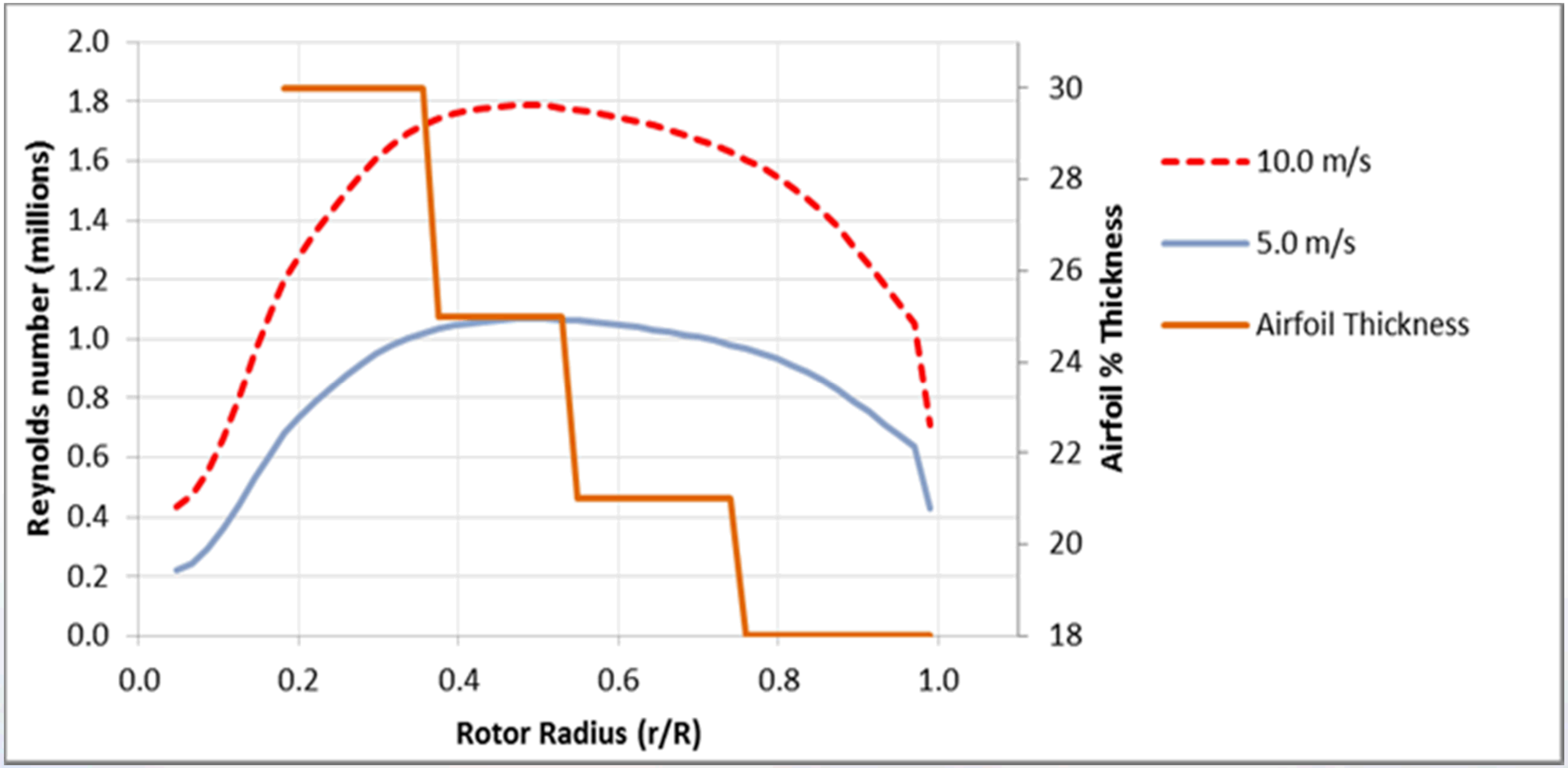
Airfoil Considerations

- **The first design iteration uses the same airfoil family as the DOWEC and NREL 5MW turbines, as this airfoil data is publically available**
- **The most recent design iteration uses the original versions of the DU airfoils:**
  - There is a large amount of wind tunnel data available,
  - Includes some lower Reynolds number data
  - We have been given permission to publish this data
- **The NRT/SWiFT rotors will operate at lower chordwise Reynolds numbers than where these airfoils were designed for**
- **The most recent airfoil**

Estimated Reynolds Number Range



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Nominal Operating Reynolds Number

- 'Re Low' is the range of Reynolds number of an airfoil at 5 m/s wind speed.
- 'Re high' is the range of Reynolds number of an airfoil for the 10 m/s wind speed.

SWiFT 13.5m			Reynolds number in millions	
Span Start	Span End	Airfoil Thickness	Re Low	Re High
18%	35%	30%	0.7-1	1.2-1.75
35%	55%	25%	1.00	1.75-1.8
55%	75%	21%	1.00	1.6-1.75
75%	99%	18%	0.43-1	0.7-1.6

*Note: a transition area needs to be added between each airfoil section. 5% span should suffice, although the details of the transition area needs more work to define. General practice for this family of airfoils?

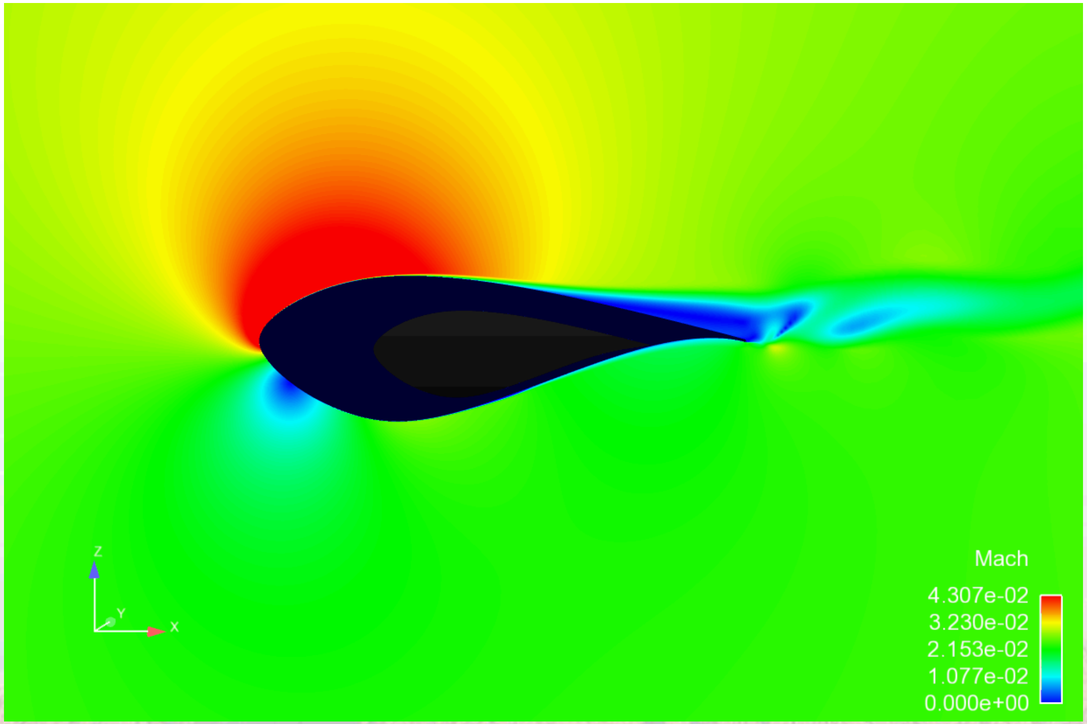
Current Airfoil Selection

DU Airfoils	DOWEC	Nominal Thickness
DU 95-W-180		18%
DU 93-W-210		21%
DU 91-W2-250		25%
DU 97-W-300		30%
DU 99-W3-350	Adjusted DU 35	35%
DU 99-W3-405	Adjusted DU4050	40%

- The 35% and 40% thick airfoils are currently not included on the main part of the blade, although they may be used in the inboard transition region.
- The 35% and 40% thick airfoils have significantly reduced performance at lower Reynolds numbers, especially with roughness.
- The 30% section has more predictable behavior and has a significant amount of wind tunnel data, so it has replaced the 35% thick sections.

CFD: Overflow

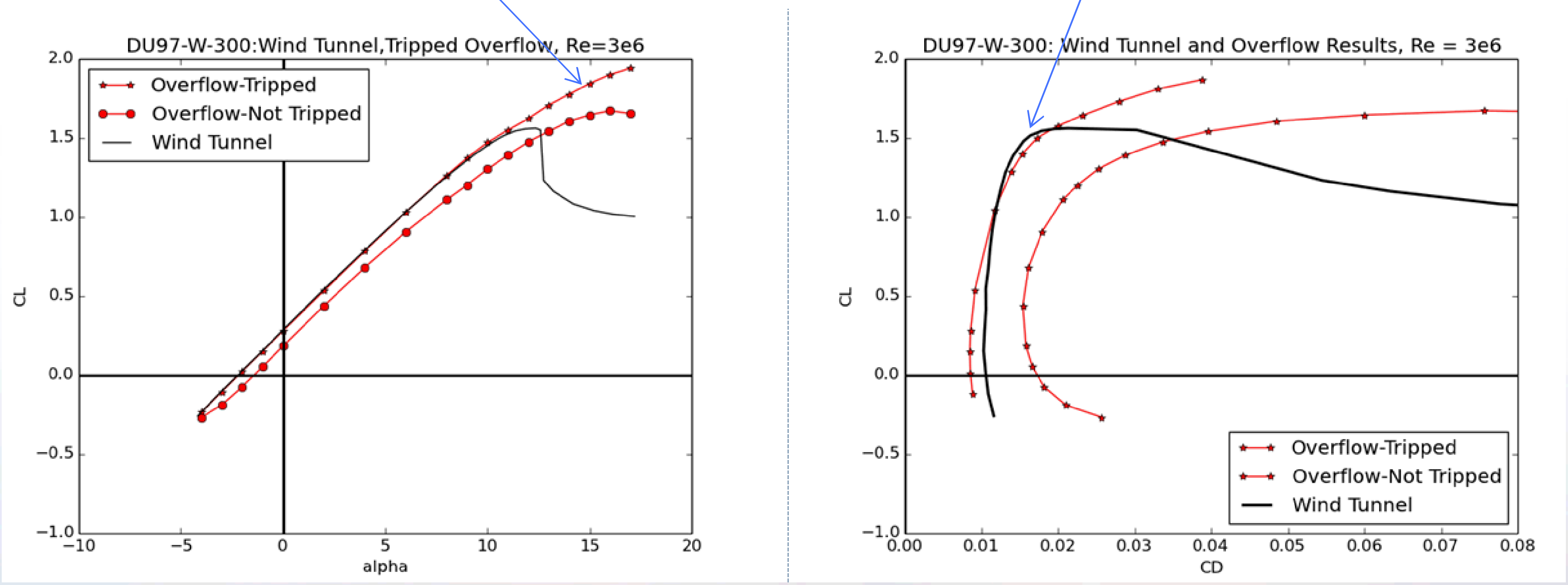
- Assess RANS CFD code at predicting airfoil performance
- Predict airfoil polars at lower Reynolds numbers (0.7-2 million)
- Capability to extend to full rotor (3D) simulations



CFD: Overflow

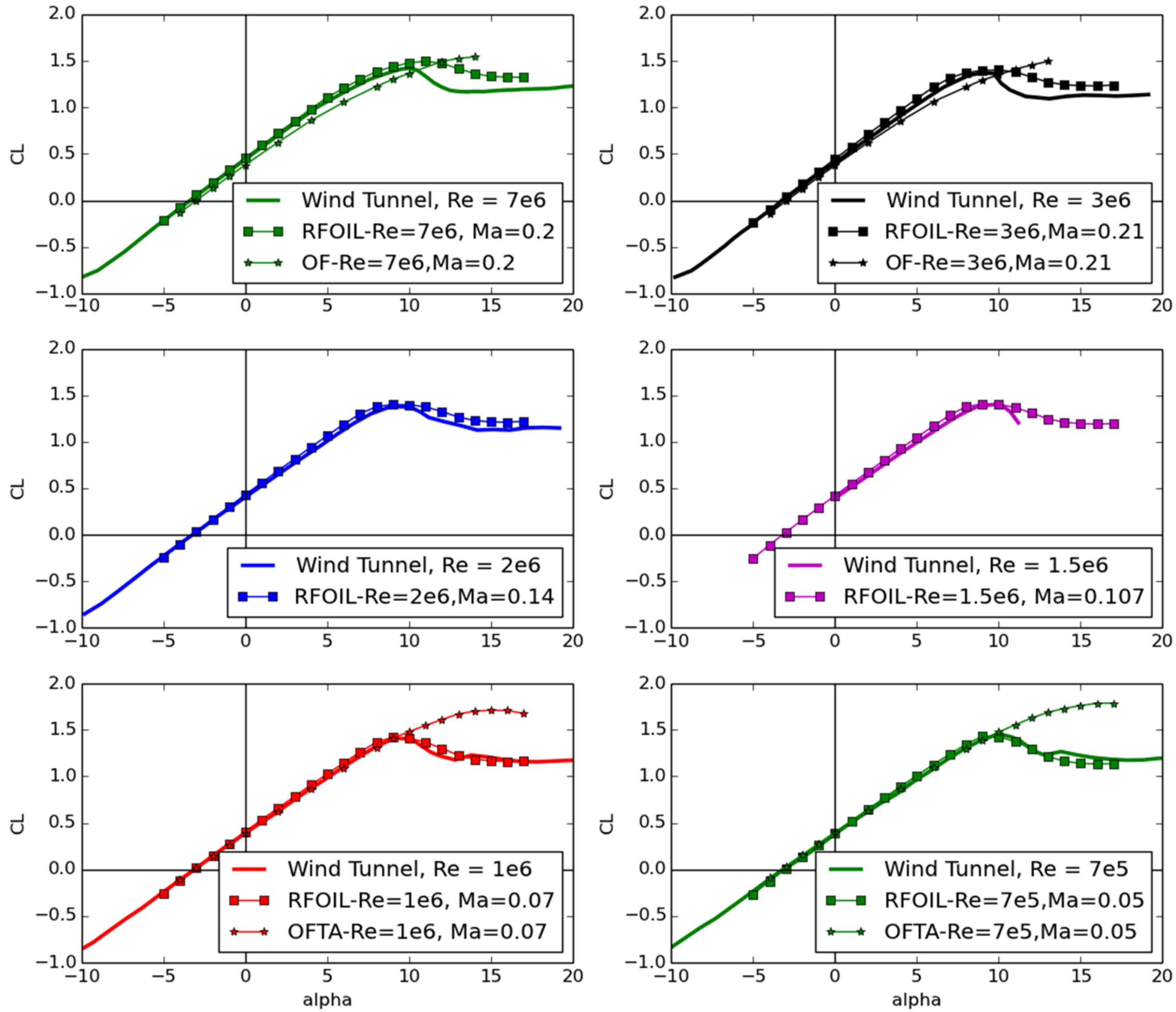
Over predicts lift

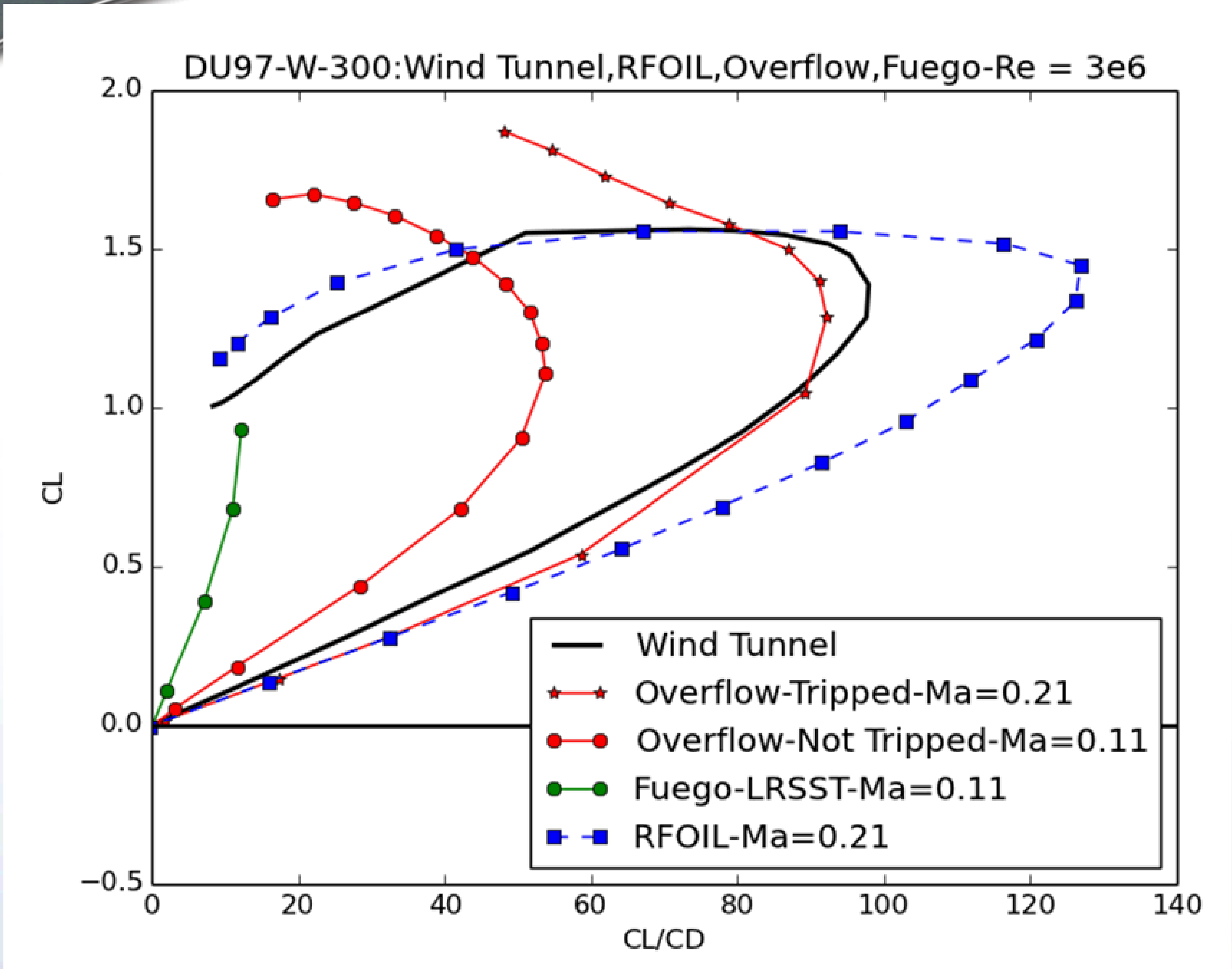
Predicts corner of drag polar well



- Overflow with tripped boundary layer (red stars) and the non-tripped data (red circles), both using DU97-W-300Mod, compared to experimental (solid black) data using DU97-W-300

DU91-W2-250lm: Wind Tunnel,RFOIL and Overflow Results





Rfoil tends to have the lowest total error over a range of Reynolds numbers, but it tends to underestimate drag.

- Lift to drag ratio for DU 97-W-300Mod at Re = 3×10^6 for RFOIL, tripped and un-tripped Overflow, and Fuego compared to DU97-W-300 wind tunnel data

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Roughness Insensitivity

- **Roughness insensitivity**
  - Modern (relatively) airfoils are designed to be insensitive at design Reynolds number
    - We are operating below that design point for airfoils meant for utility scale
  - Sensitivity increases as Reynolds number decreases (at least below the design Reynolds number)
  - Sensitivity increases with thicker airfoils
- **Can give up peak performance to make performance less sensitive to roughness**
  - Lower design cl: means higher solidity and stronger gust response

Roughness Insensitivity

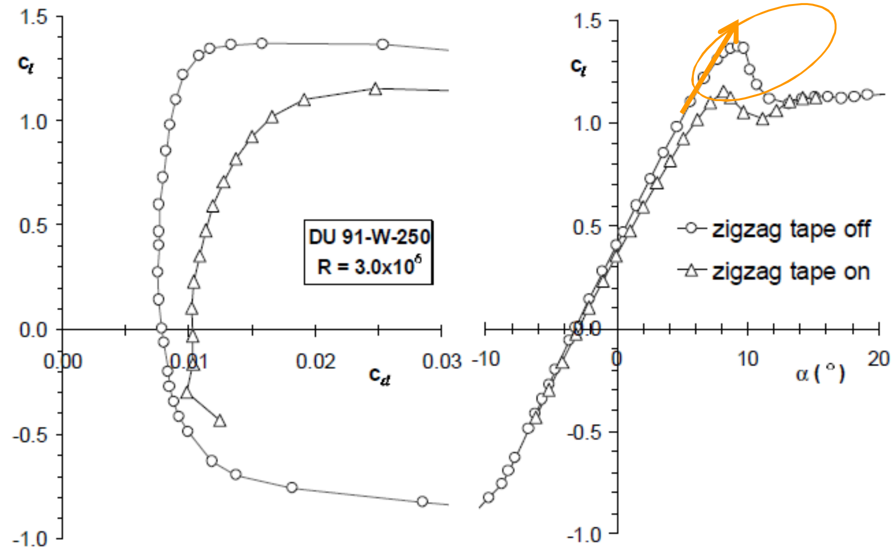


Figure 5: Measured airfoil performance of DU 91-W2-250 at $R=3x10^6$.

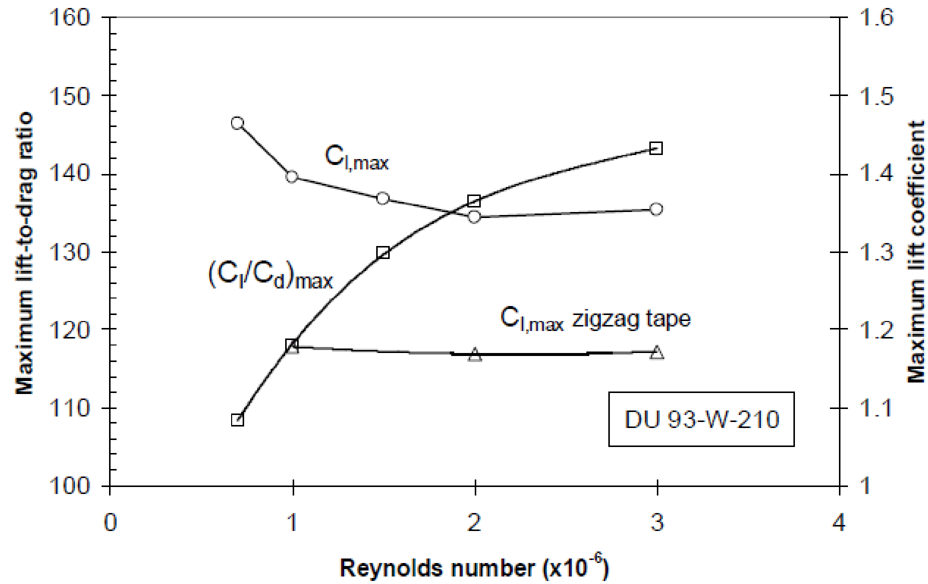
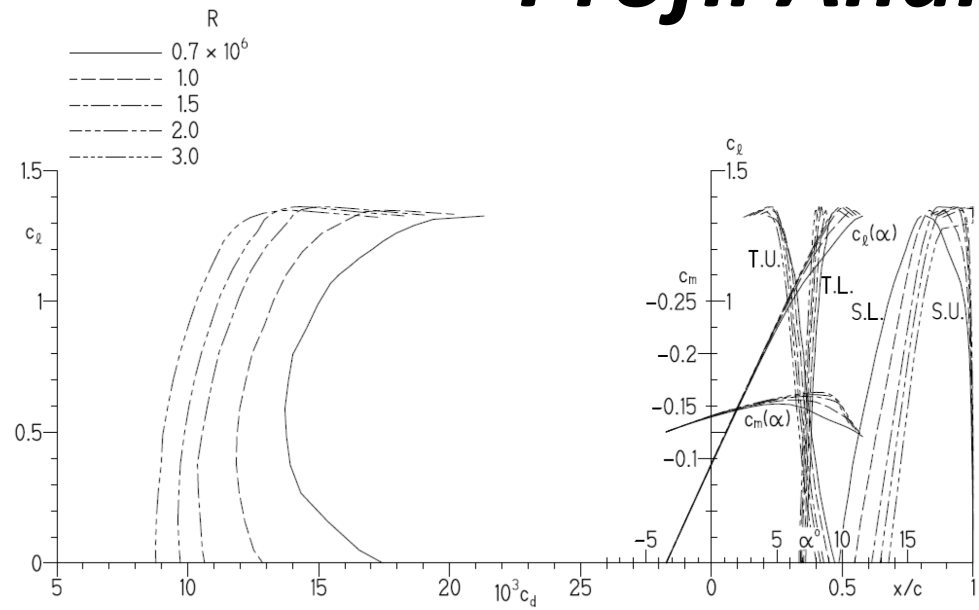
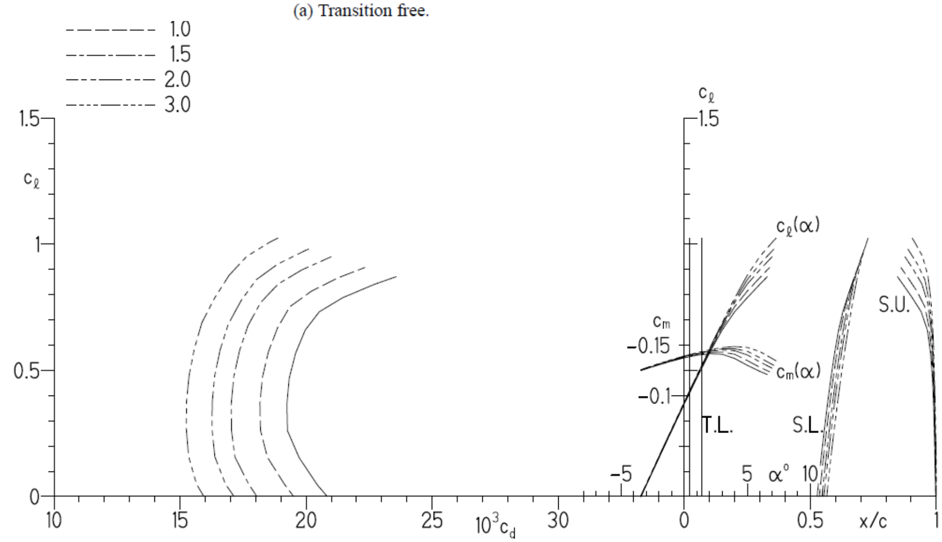


Figure 7: The effect of Reynolds number on the maximum lift-drag ratio and maximum lift coefficient of airfoil DU 93-W-210

Profil Analysis: Effect of Roughness



(a) Transition free.



(b) Transition fixed.

Under predicted maximum lift, so results are conservative.

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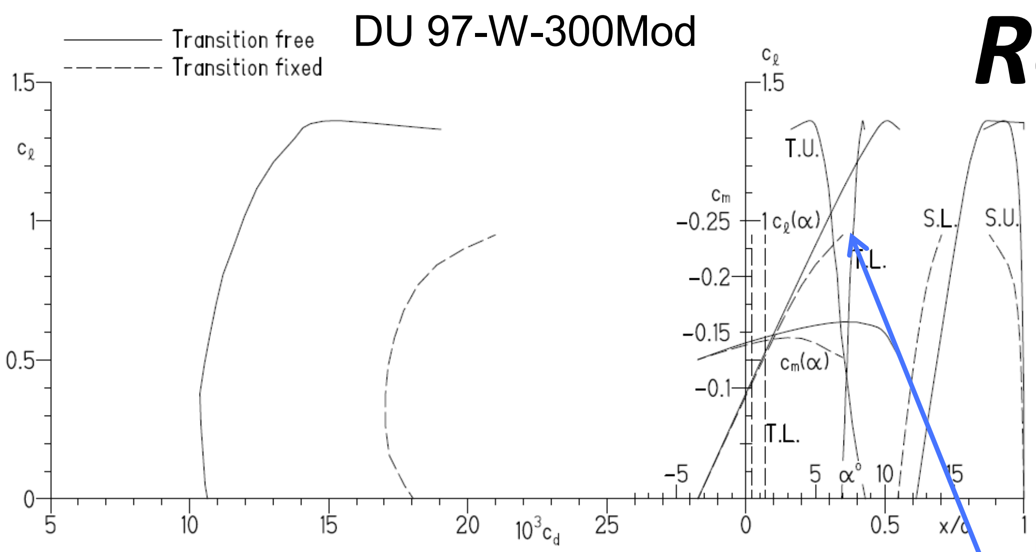
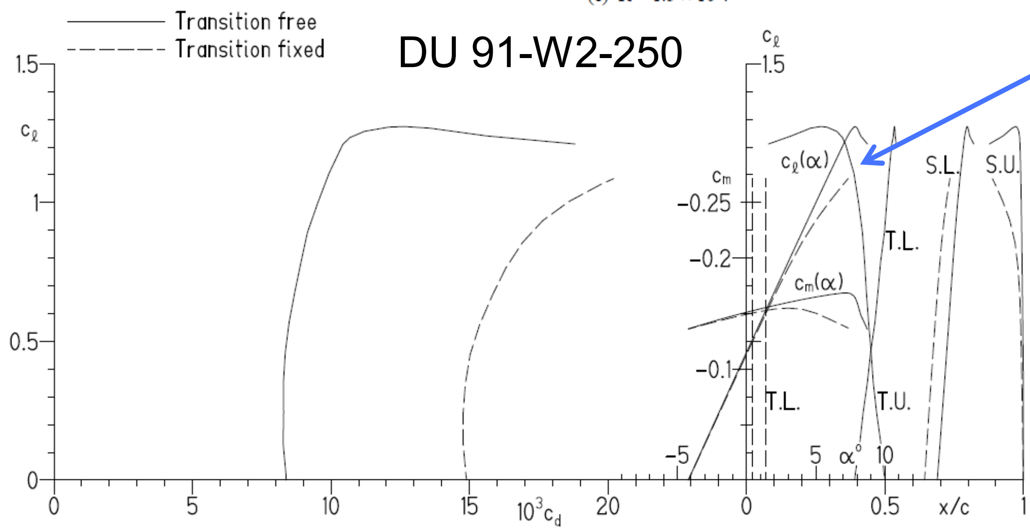
Profil Analysis: Effect of Roughness



(c) $R = 1.5 \times 10^6$.



(c) $R = 1.5 \times 10^6$.

The 30% thick airfoil has a larger decrease in maximum lift due to roughness than the 25% thick airfoil.

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Where to go from here

- **Investigate potential advantages of alternative airfoils**
  - Looking at some of the SERI wind turbine airfoils
- **Add analysis of gust response and region 2.5 behavior**
- **Define minimum thickness requirements for structural and instrumentation requirements**

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Thank you

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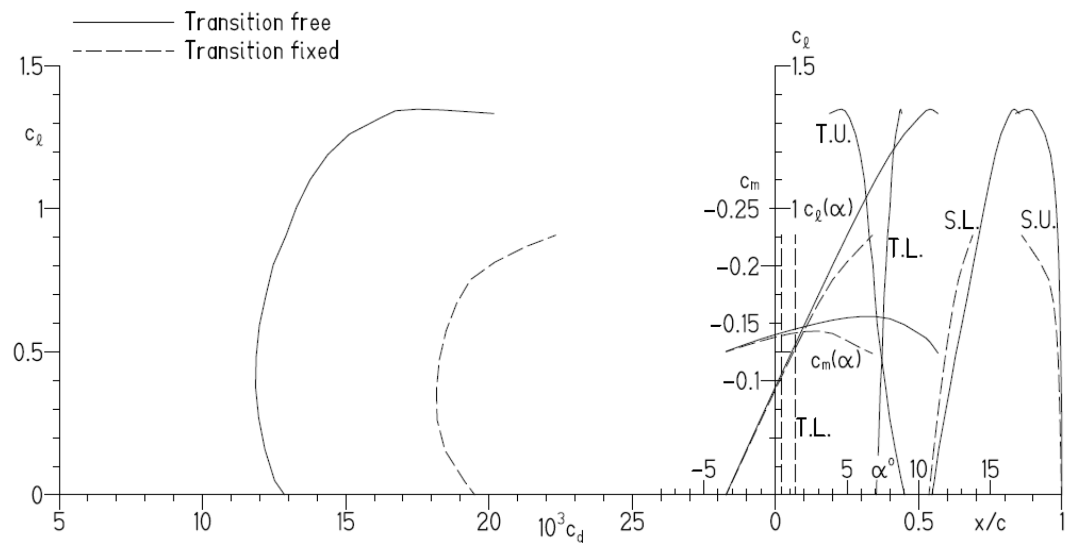
Backup Slides

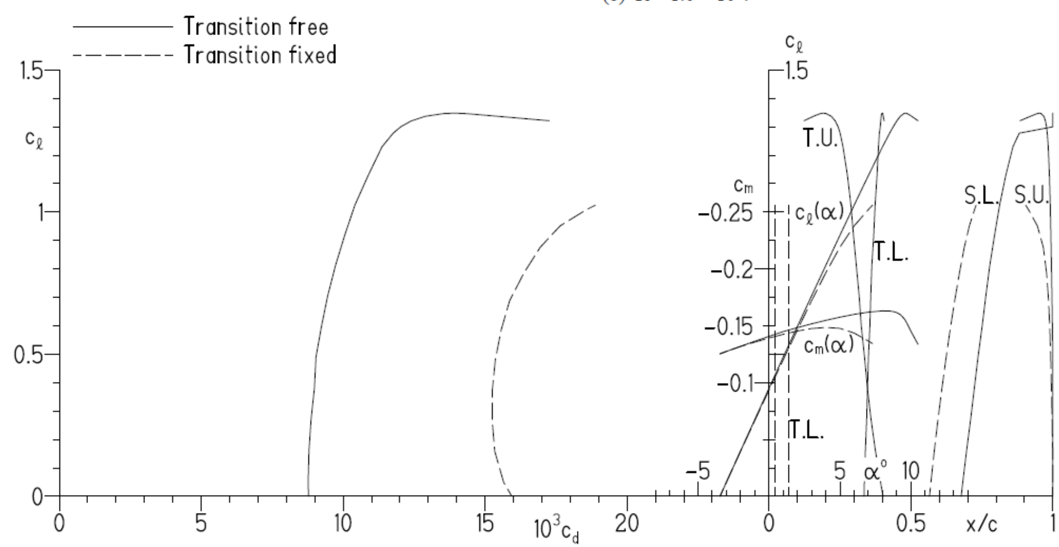
Descriptions of How Reynolds Number changes each airfoil

- Point out main features
- Full scale ReNum, Design ReNum, SwiFT ReNum (Bottom and Top of Region 2, Top of Region 2.5)
- Conclusions (for example, not considering 40%, eliminated 35%)

Profil Analysis



(b) $R = 1.0 \times 10^6$.



(e) $R = 3.0 \times 10^6$.