UNIVERSITY OF CAMBRIDGE

Large Eddy Simulations in Low Pressure Turbines

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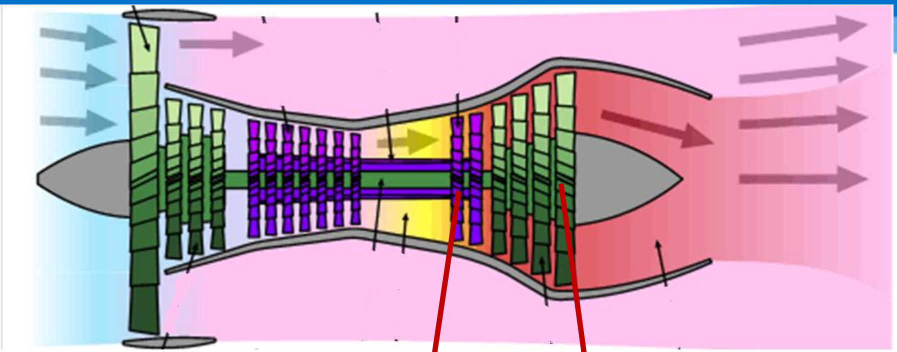
Introduction



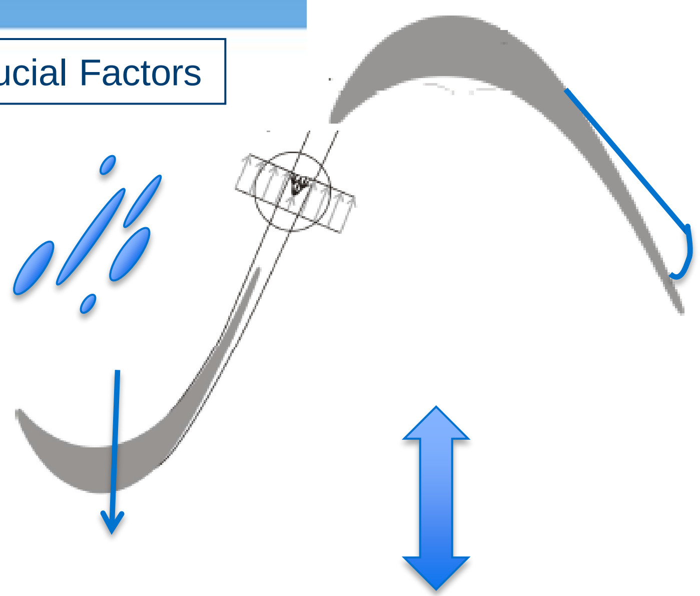
Paolo Pisani [2007]

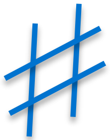
Bons [2003]

At deployment

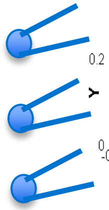
After few years in service

3 Crucial Factors



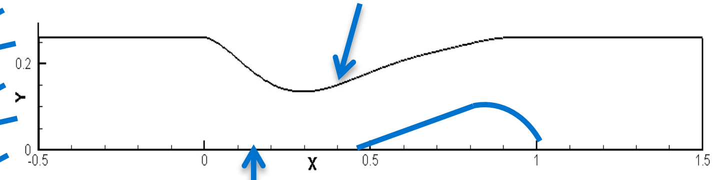


Turbulence Grid



Moving bars

Contoured wall

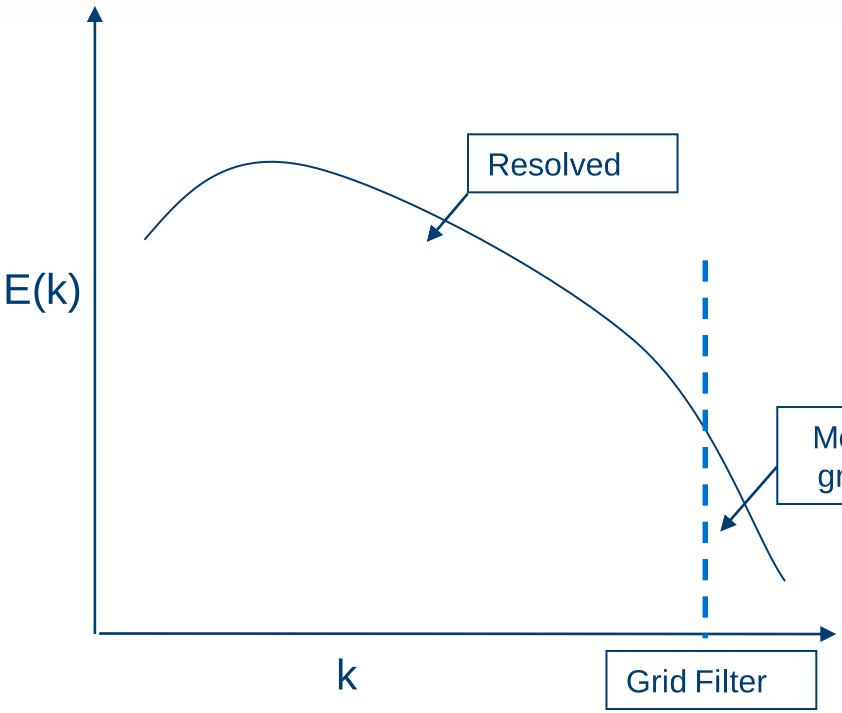


Suction surface

(Impose rough patches over flat plate)

Introduction (continued)

Large Eddy Simulation: LES



Need for Reliable Numerical tool to accurately capture these interactions

LES : Large Eddy Simulations

- Resolve Large eddies, Model small eddies
- Filtering – Not Averaging
- Accurate description of turbulence and computationally affordable
- Used Variational Multi-scale approach to model SGS stress in current study

Overview

Computational Details:

- Flow Configuration and Boundary Conditions
- Details of test cases: FST, Roughness and their combination

Results:

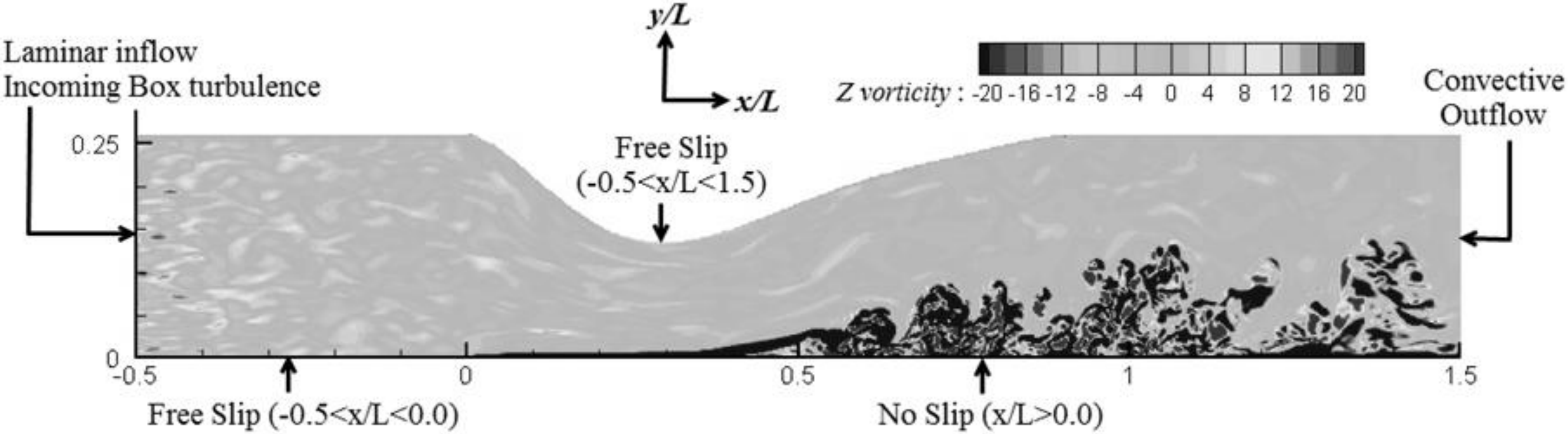
- Validation
- Time Averaged flow field
- Instantaneous flow features
- Effect of combination of Wakes and FST

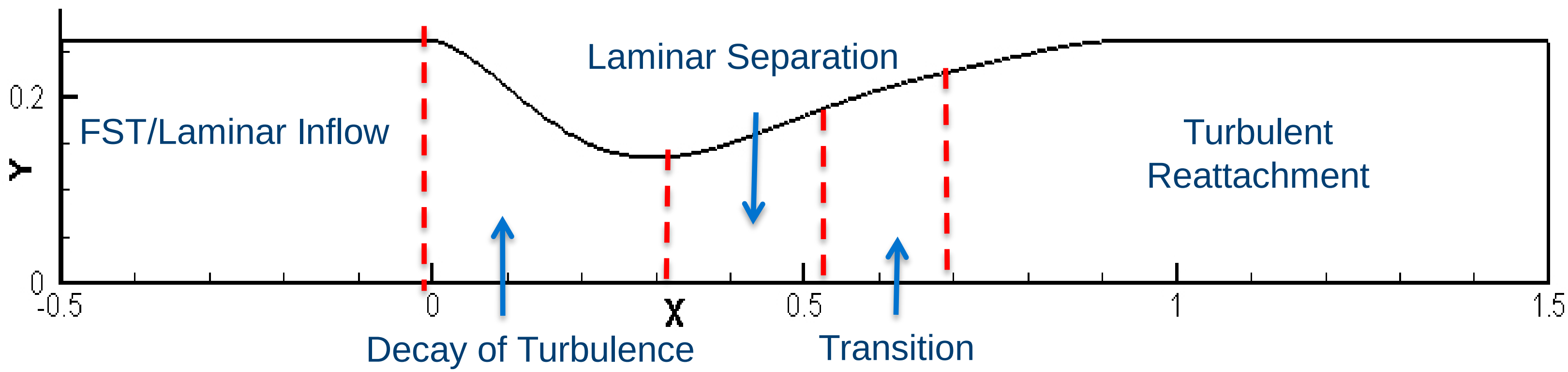
Conclusions

Ongoing work: Endwall Separation and effective Inflow boundary Conditions

Computational Details

Flow Configuration and Boundary Conditions

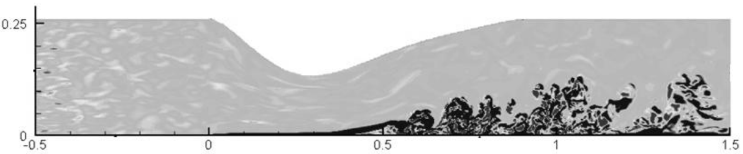


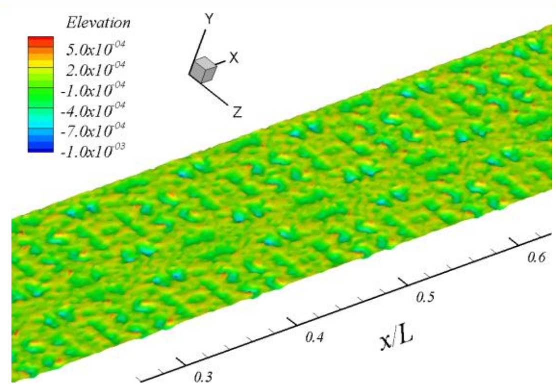


Re = **60,000**, Mesh density: **4 x 10^{6}** , Solver: **BOFFS**

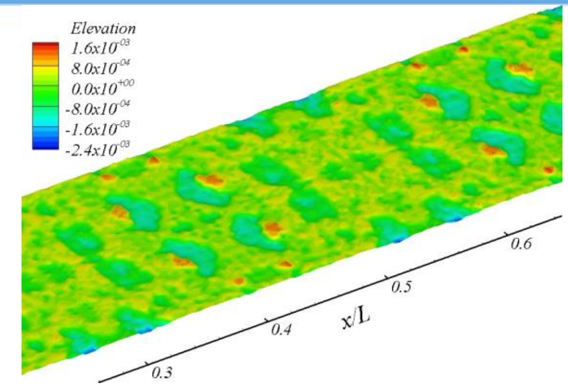
Computational Details

Details of test Cases Simulated





Topology of Rough surface A



Topology of Rough surface B

Test Cases (*TC*)

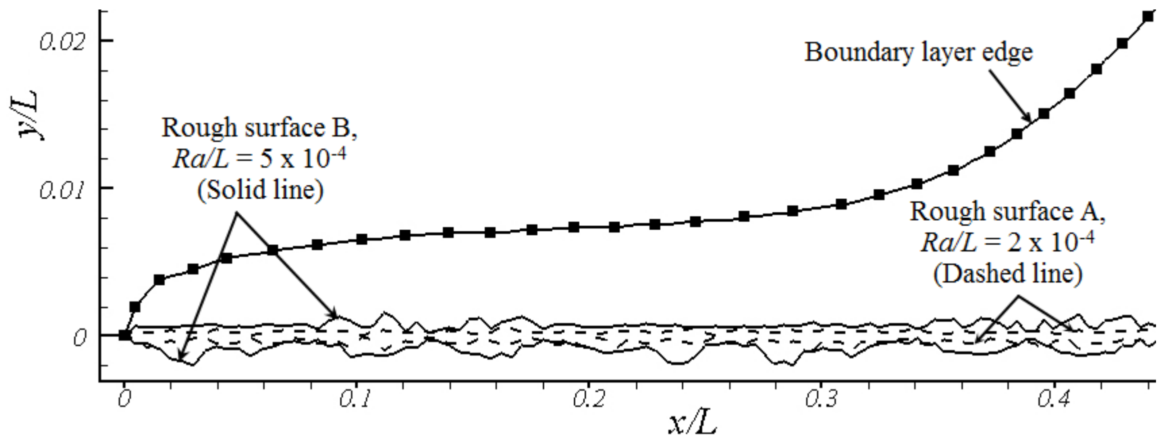
TC1: Laminar Inflow

TC2: *FST* ~ 1.2 % at separation

TC3: Rough Surface A of *Ra/L* ~ $2x10^{-4}$

TC4: Rough Surface A + *FST*

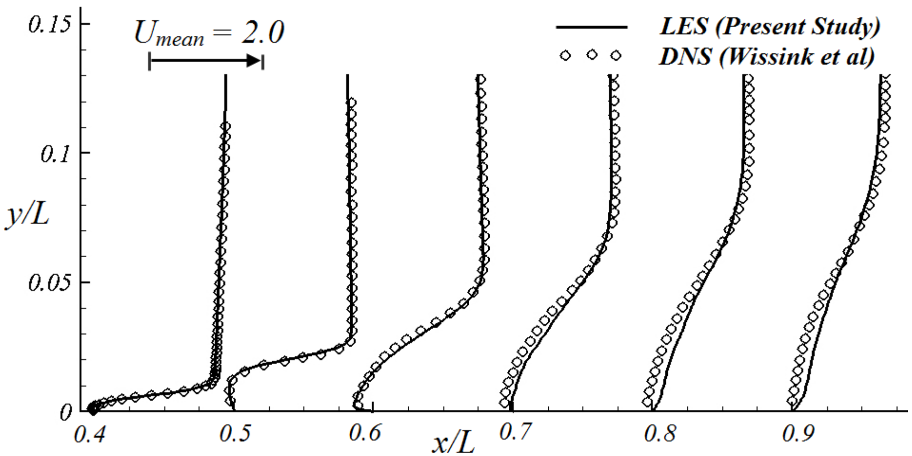
TC5: Rough Surface B of *Ra/L* ~ $5x10^{-4}$

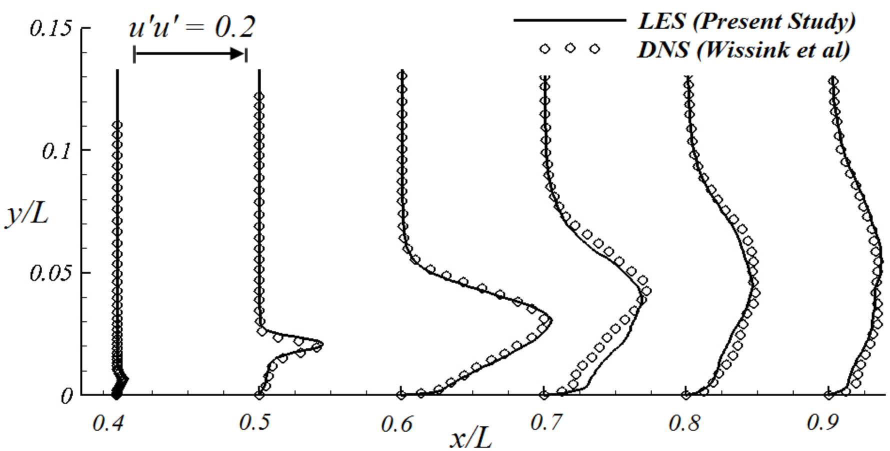


Streamwise variation of the peaks and valleys of roughness

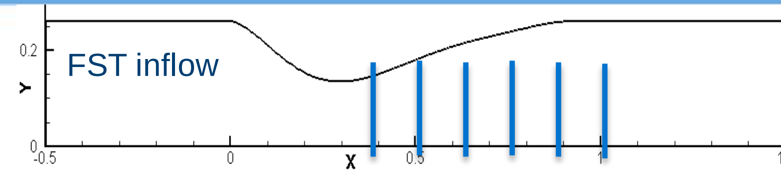
Results

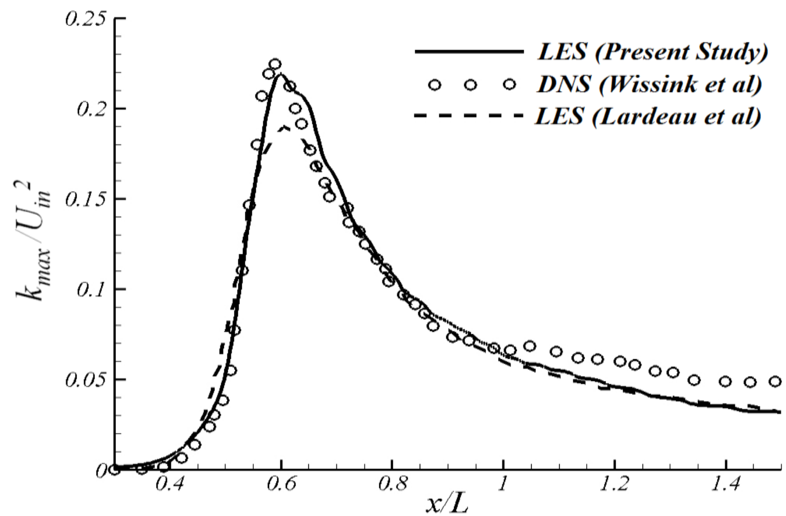
Validation:





Reynolds stress profiles (*u'u'*)





Streamwise variation of maximum turbulent kinetic energy

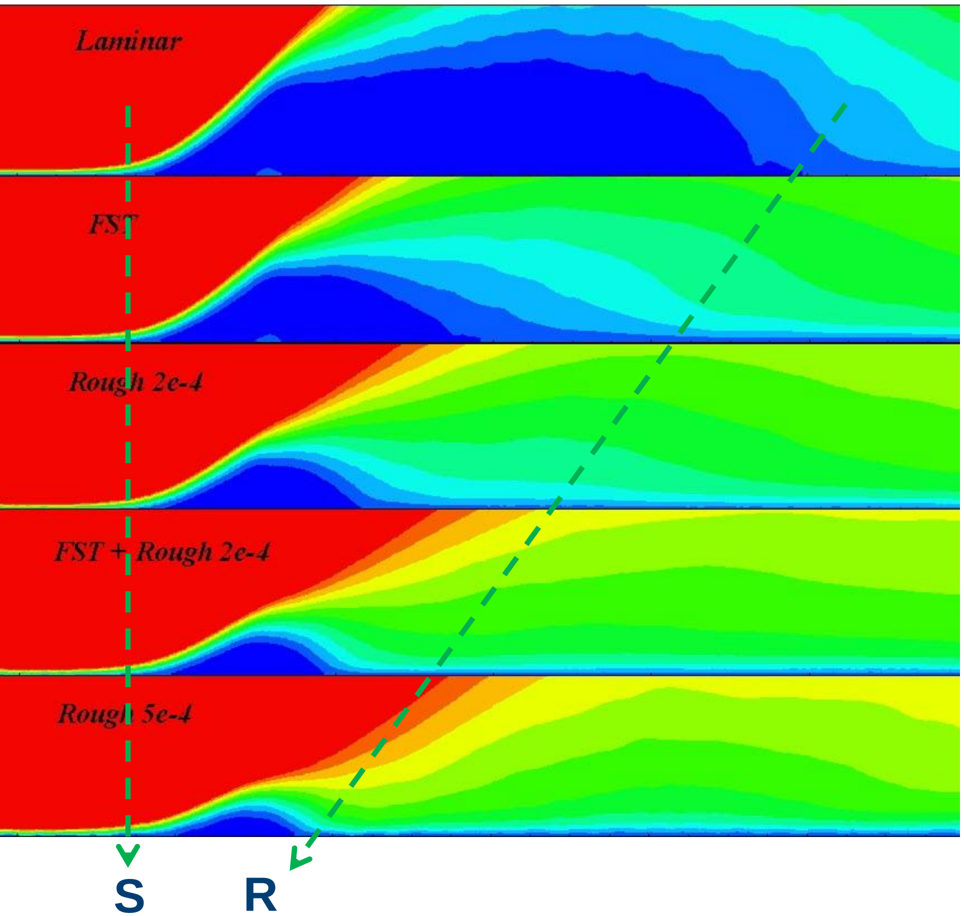
Validation for FST Inflow with DNS of *Wissink and Rodi [2004]*

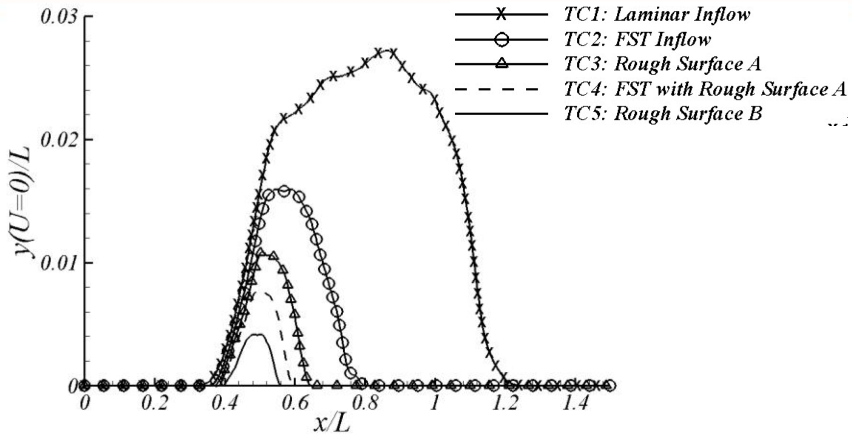
(8 times higher resolution)

Results

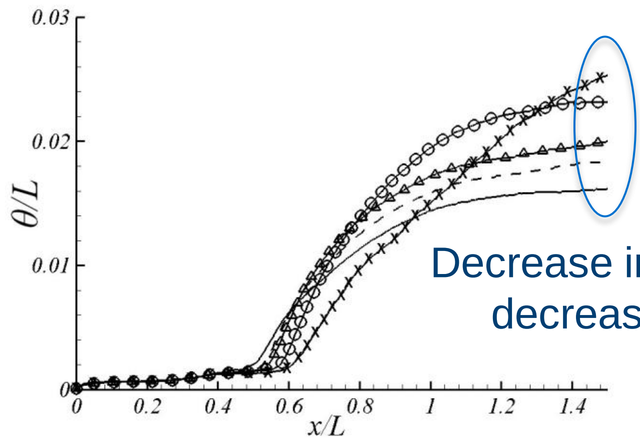
Time and Span Averaged flow

Time Averaged streamwise velocity contours





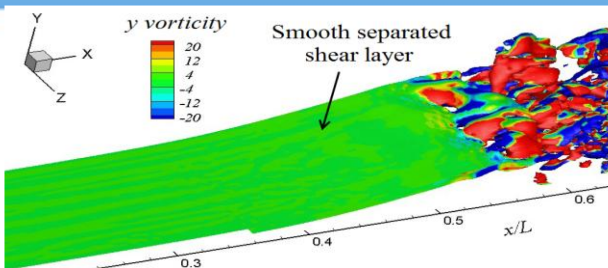
Comparison of Bubble half-heights

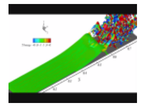


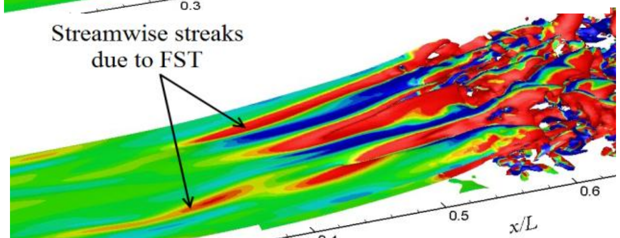
Decrease in θ_{TE} implies decrease in Loss

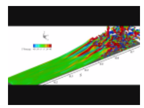
Streamwise evolution of momentum thickness

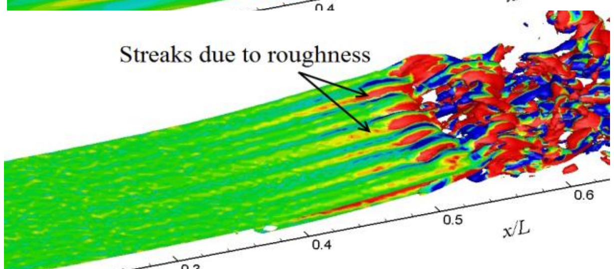
Instantaneous Picture of flow

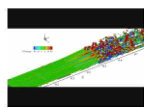


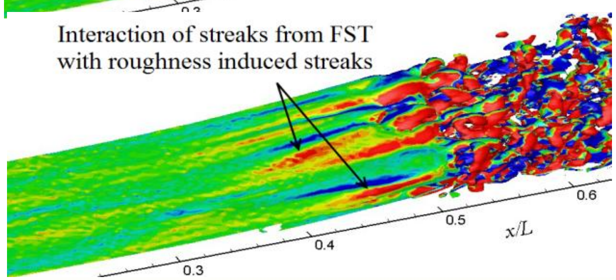


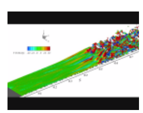


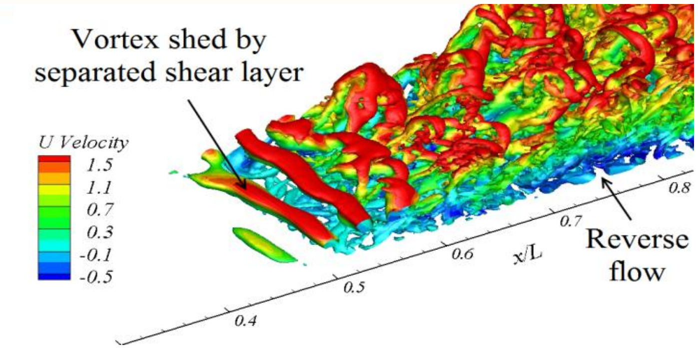




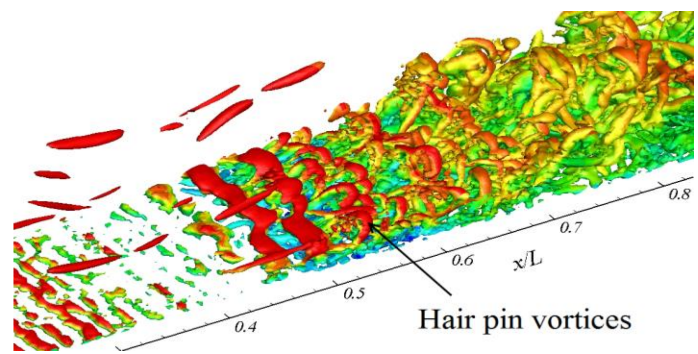






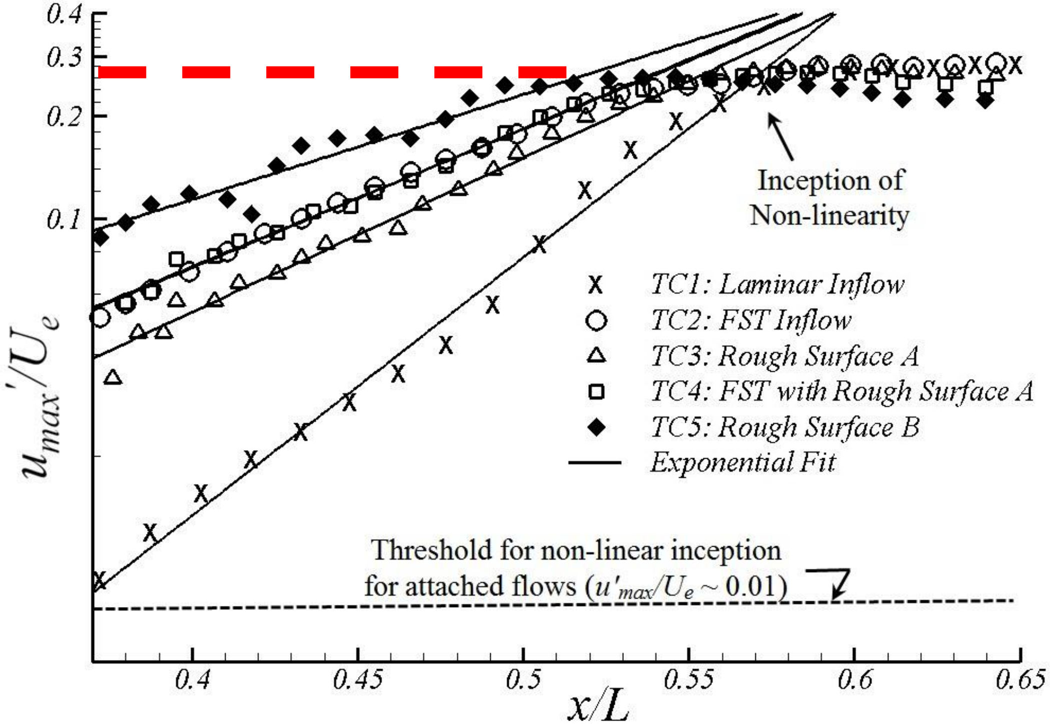


Streamwise streaks promote mixing and cause early transition

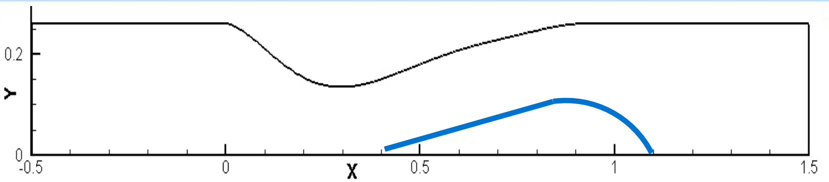


Results

Applicability of Linear Stability Theory



Semi-log plot showing Streamwise variation of maximum disturbance amplitude



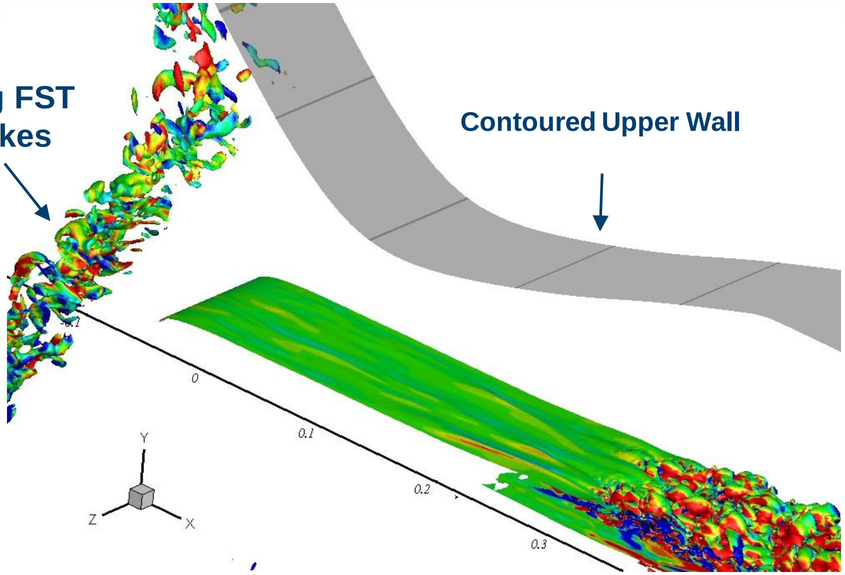
Linear Stability Theory is valid until u' reaches 20% of free-stream velocity
(Diwan and Ramesh [2009])

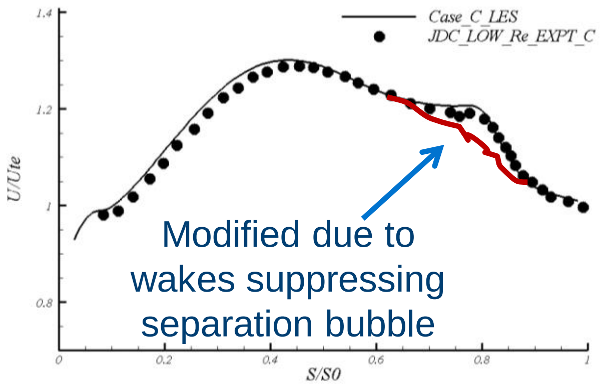
i.e. u' can be expressed as $u'(y)e^{ikx+\omega t}$

Results

Effect of Wakes

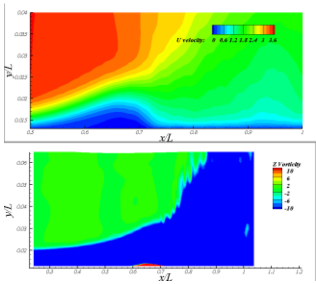
Incoming FST and Wakes

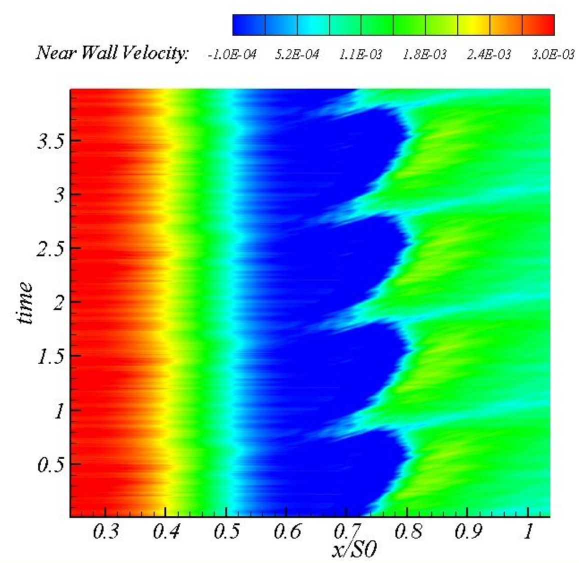


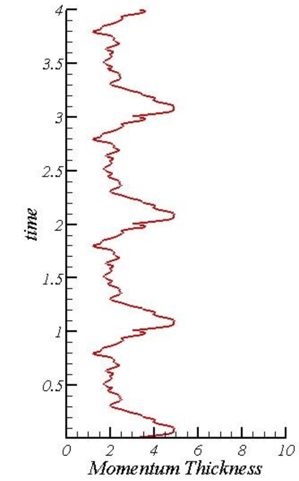


Suction surface pressure distribution

Wakes induce Stronger Streamwise Streaks than FST (periodically in time)



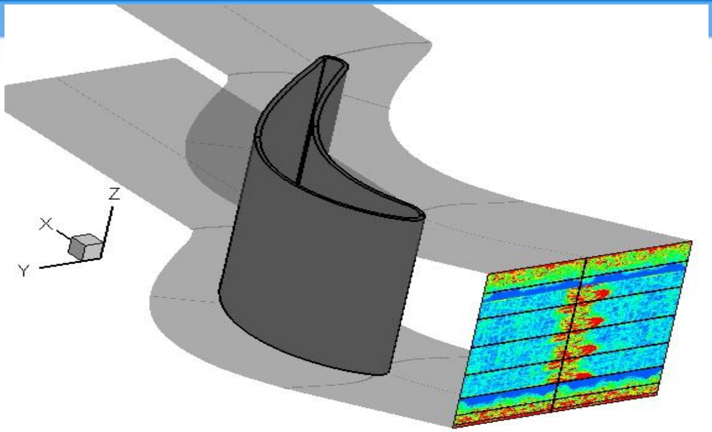


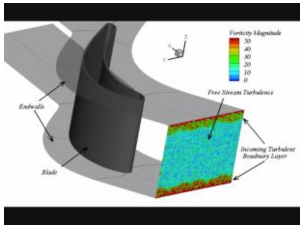


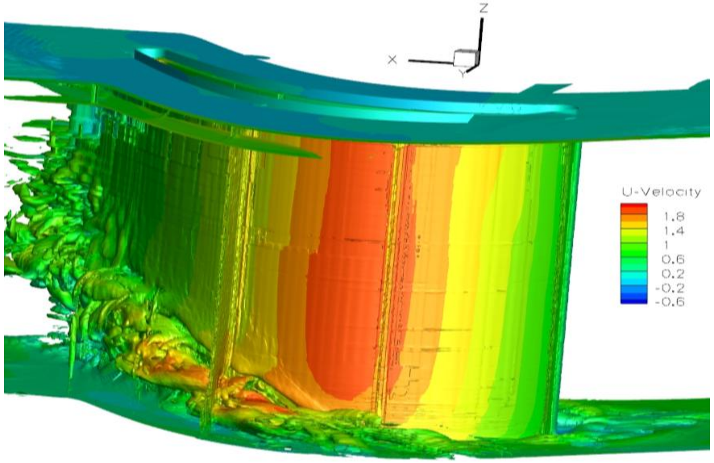
Conclusions

- FST, Roughness and wakes suppressed separation bubble and reduced the loss
- Streamwise streaks are formed due to FST, Roughness and Wakes (These originate Intermittently / Steadily / Periodically in time respectively)
- Combination of FST and Roughness is synergistic
- Linear Stability analysis is valid for higher level of disturbance amplitude ~ 20% U_{fs}
- Analysis on smooth walls would be valid only for few months after deployment – Roughness becomes a crucial factor later on.

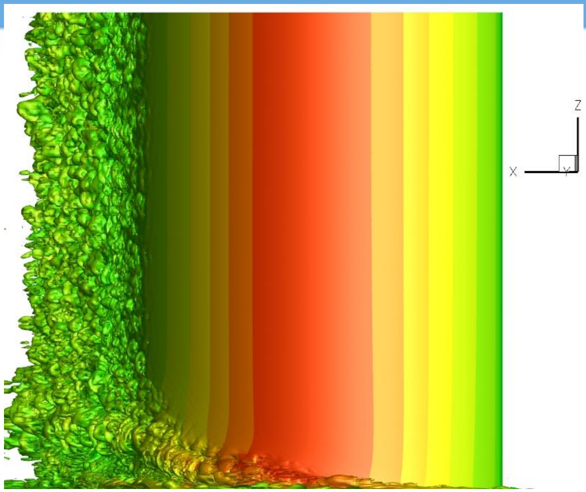
Ongoing Work: Endwall Flows

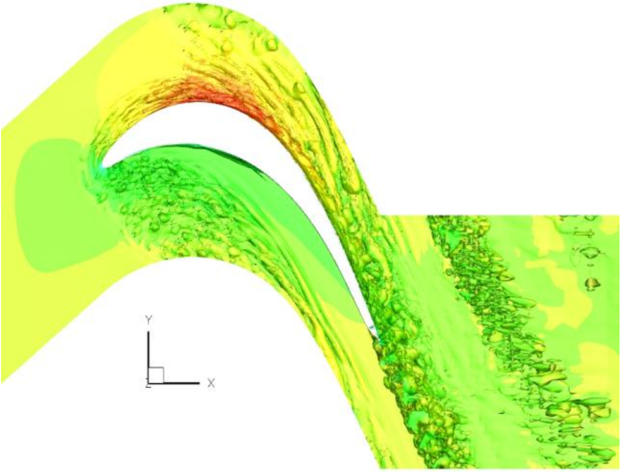






High Pressure Turbine endwall flow





Low Pressure Turbine endwall flow

THANK YOU