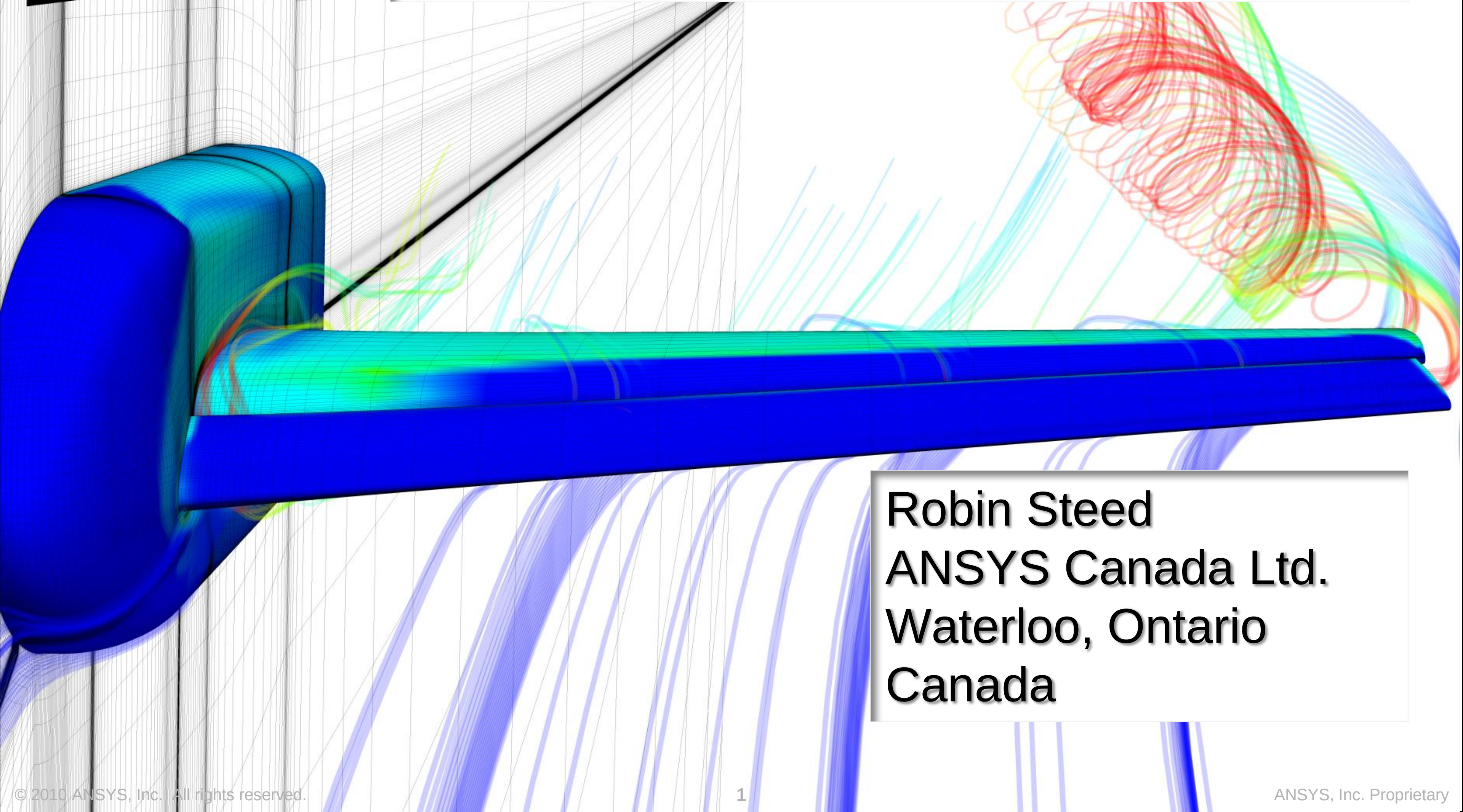
High Lift CFD Simulations with an SST-Based Predictive Laminar to Turbulent Transition Model



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Outline

- About ANSYS
- ANSYS CFX Software and Solver Method
- SST γ-R_θ Transition Turbulence Model
- Model, Grids and Operating Conditions
- Results from SST γ-R_θ Transition Turbulence Model
- Comparison to Fully Turbulent SST results
- Conclusions and Recommendations

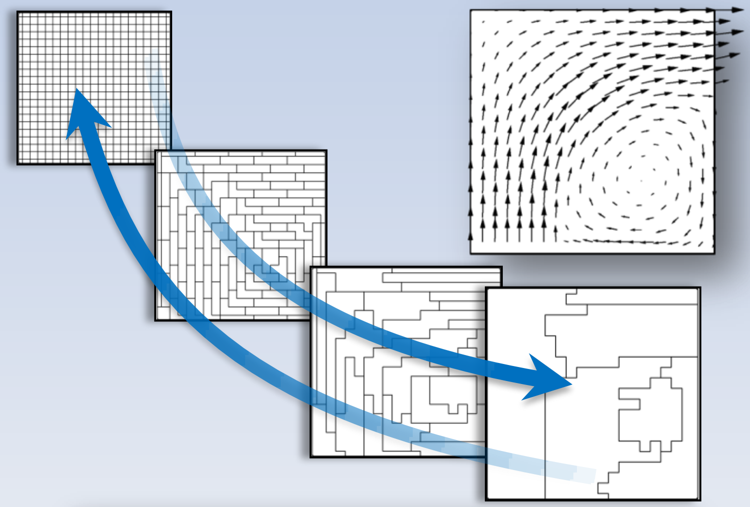
ANSYS, Inc.

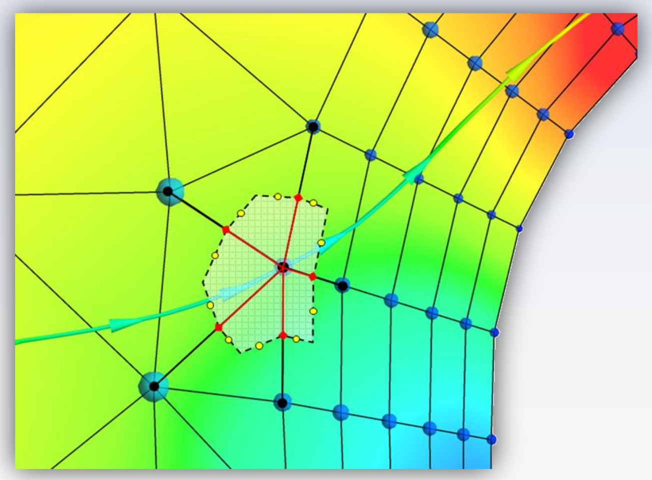
- **Broad range of advanced simulation software**
  - Structural Mechanics
  - Fluid Dynamics
  - Electromagnetics
- **People and Locations**
  - 1,600 employees
  - 60+ locations & network of 200+ channel partners in 40+ countries
  - 21 major development centers on 3 continents
  - ~500 developers worldwide
- **Many CFD solutions**
  - General purpose solvers
    - FLUENT and CFX
  - General purpose grid generation
    - ICEM CFD and ANSYS Meshing
  - Special purpose tools
    - Airpak, Icepak, POLYFLOW, BladeModeler, and Turbogrid
  - Integrated solutions
    - FLUENT for CATIA v5

CFX Solver

ANSYS CFX Software

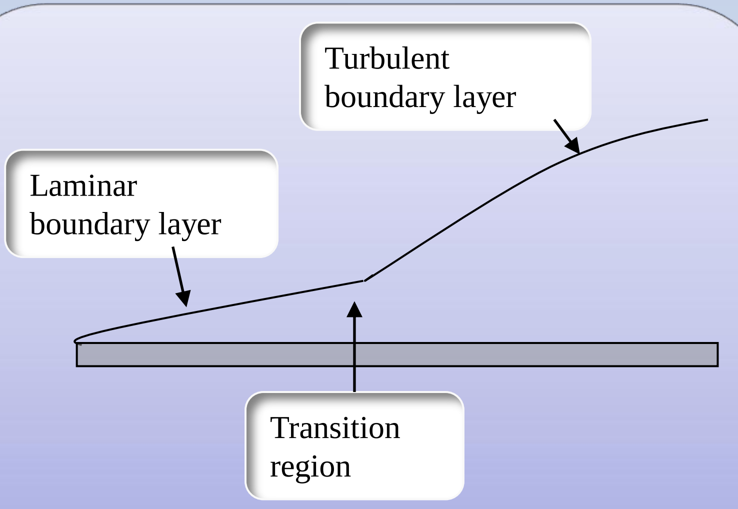
- **General purpose CFD solver**
  - Single solution method for all flow regimes
- **Discretization**
  - Fully implicit
  - Element Vertex Finite Volume Method
  - Bounded 2nd order upwind advection
- **Solution Method**
  - Psuedo-transient relaxation
  - Coupled Mass and Momentum (u,v,w,p)
  - Linear equations solved using Algebraic Multigrid

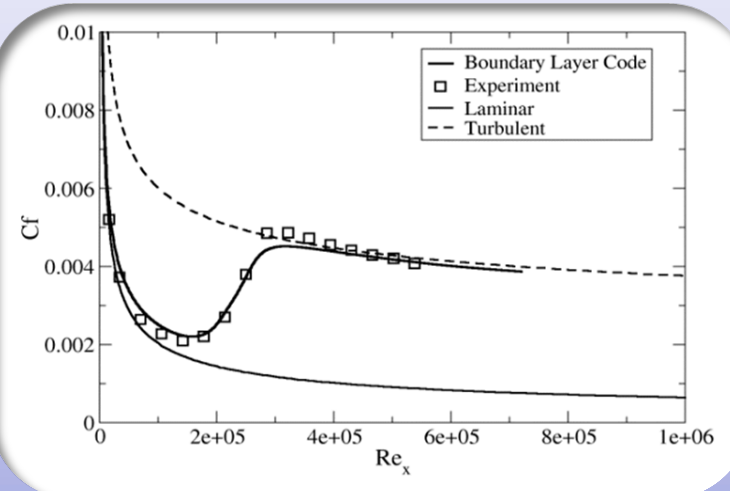




New Approach to Transition Modeling

What is Transition?





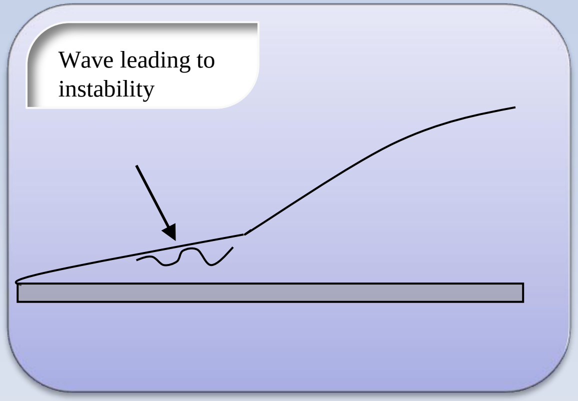
Transition Mechanisms

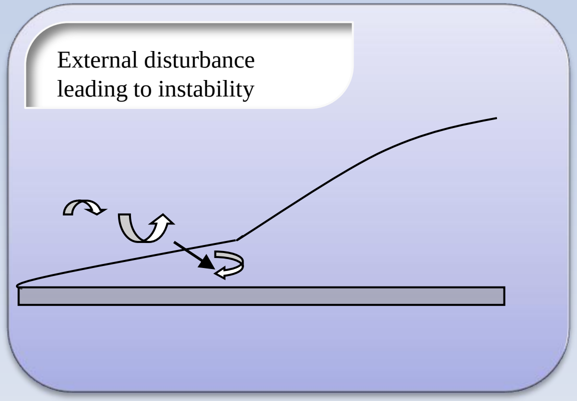
- Natural Transition
- Bypass Transition
- Separation Induced Transition

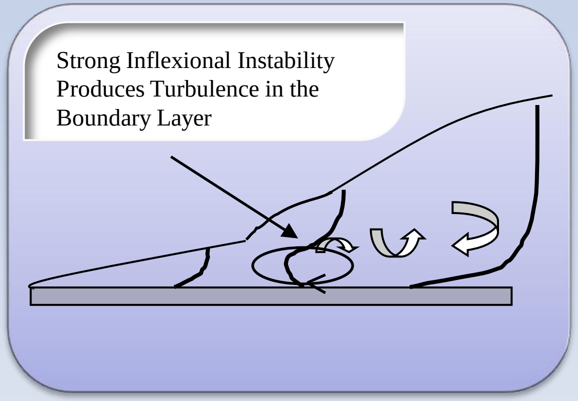
Effect of Transition

- Increase in wall shear stress.
- Influence on separation behaviour.
  - Separation induced transition on suction side determines reattachment point (controls stall, lift and drag)
- Dramatic increase in wall heat transfer
- Change in flow topology.

Transition Mechanisms







Natural Transition

- Result of flow instability magnified in boundary layer (Tollmien-Schlichting instability)
- Occurs under low freestream turbulence (< 1%)

- Typical Examples:
  - Wind Turbine blades
  - Fans of jet engines
  - Helicopter blades
  - Any aerodynamic body moving in still air

Bypass Transition

- Occurs if flow outside the laminar boundary layer has a high level of turbulence (> 1%).

- Typical Examples:
  - Compressor or Turbine blade, where upstream blades have generated large disturbances traveling with the freestream.

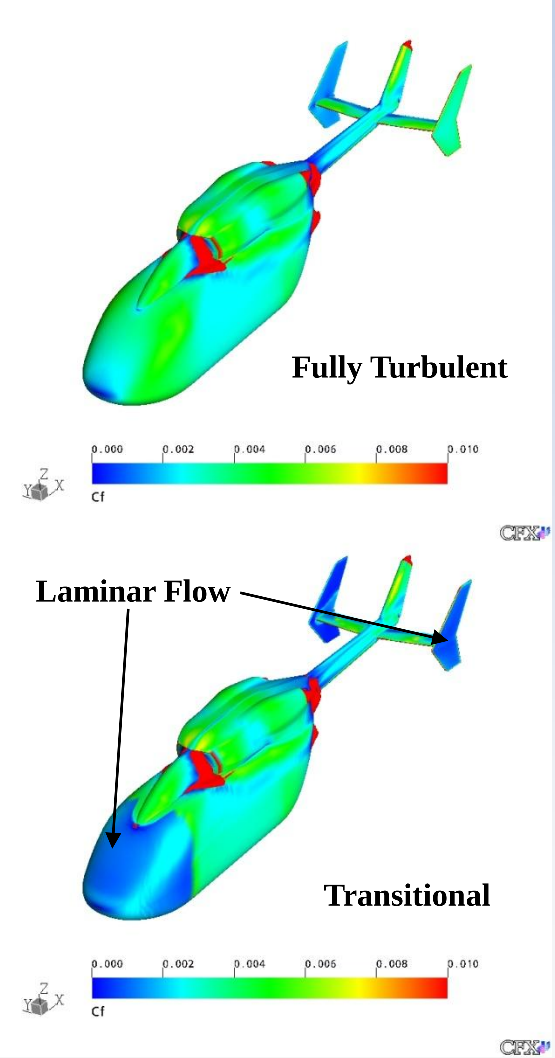
Separation Induced Transition

- Takes place after a laminar separation of the boundary layer.
- Leads to a very rapid growth of disturbances and to transition.
- Can occur in any device with a pressure gradients in the laminar region.
- ***If flow is computed fully turbulent, the separation is missed entirely.***

- Typical Examples:
  - fans, wind turbines, helicopter blades, axial turbomachinery

Transition Model Requirements

- **Compatible with modern CFD code:**
  - Unknown application
  - Complex geometries
  - Unknown grid topology
  - Unstructured meshes (no search directions)
  - Parallel codes – domain decomposition
- **Requirements:**
  - Absolutely no search algorithms
  - Absolutely no integration along lines
  - Local formulation
  - Different transition mechanisms
  - Robust
  - No excessive grid resolution



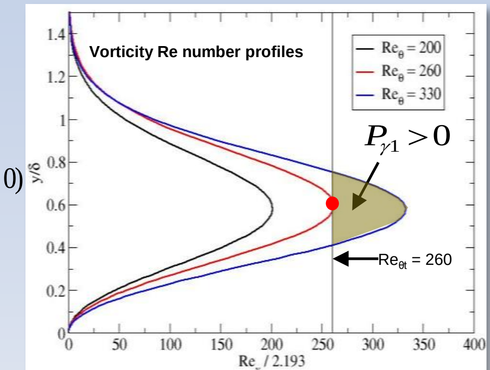
SST γ-R_θ Transition Turbulence Model Formulation

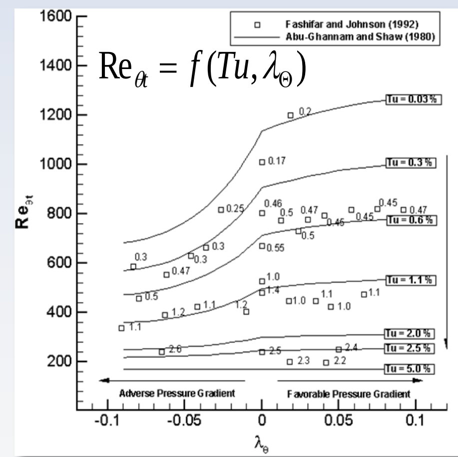
- **SST + two additional transport equations**
  - Intermittency (γ)
    - Fraction of turbulent vs laminar flow
    - Transition onset controlled by relation between vorticity Reynolds number and $Re_{\theta t}$
  - Transition Onset Reynolds number (R_θ)
    - Used to pass information about free stream conditions into boundary layer (e.g. impinging wakes)
- **New Empirical Correlation**
  - Similar to Abu-Ghannam and Shaw, improvements for Natural transition
- **Modification for Separation Induced Transition**
  - Forces rapid transition once laminar sep. occurs
  - Locally Intermittency can be larger than one

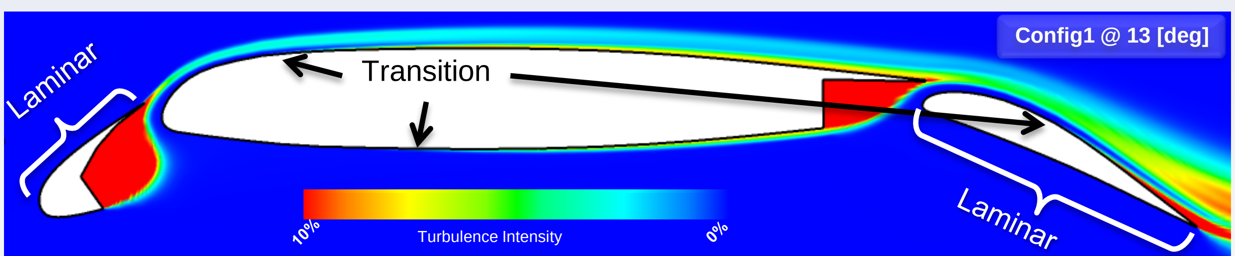
$$Re_v = \frac{\rho y^2}{\mu}\left|\frac{\partial u}{\partial y}\right|$$

$$F_{onset} \sim \max\left(\frac{Re_v}{2.193 Re_{\theta t}} - 1, 0\right)$$

$$Re_{\theta t} = f(Tu, \lambda_\theta)$$





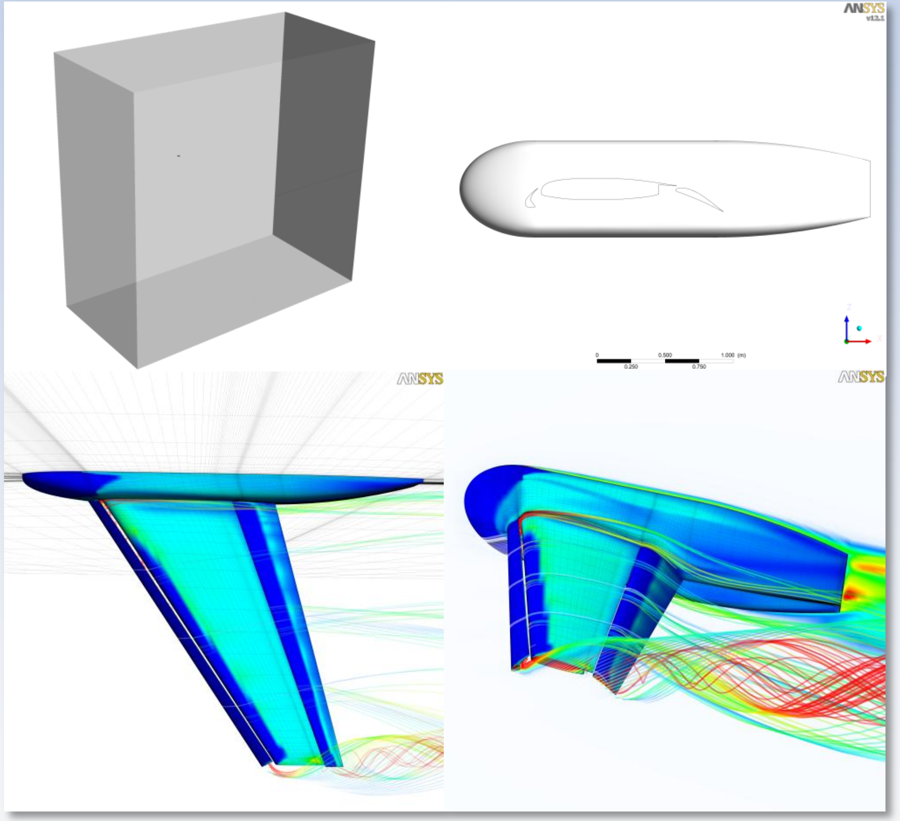


Validating Transition

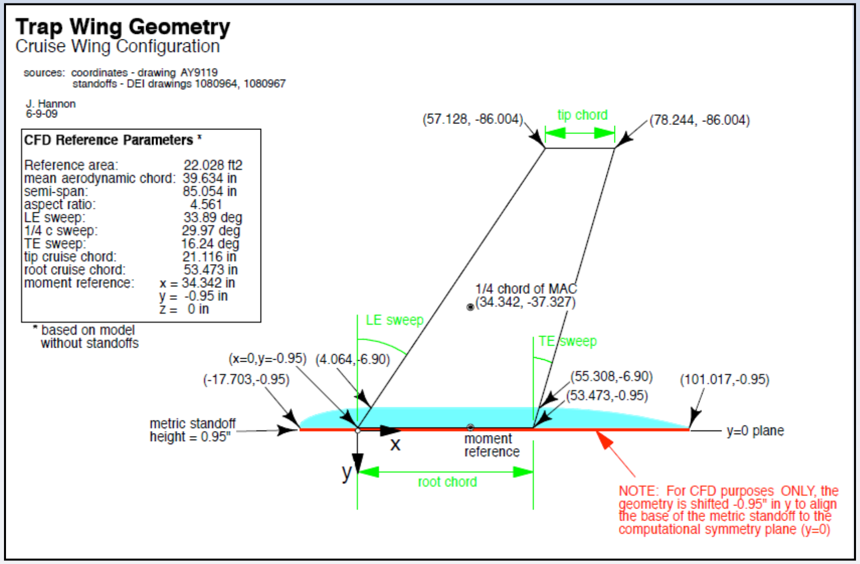
The NASA Trap Wing Model

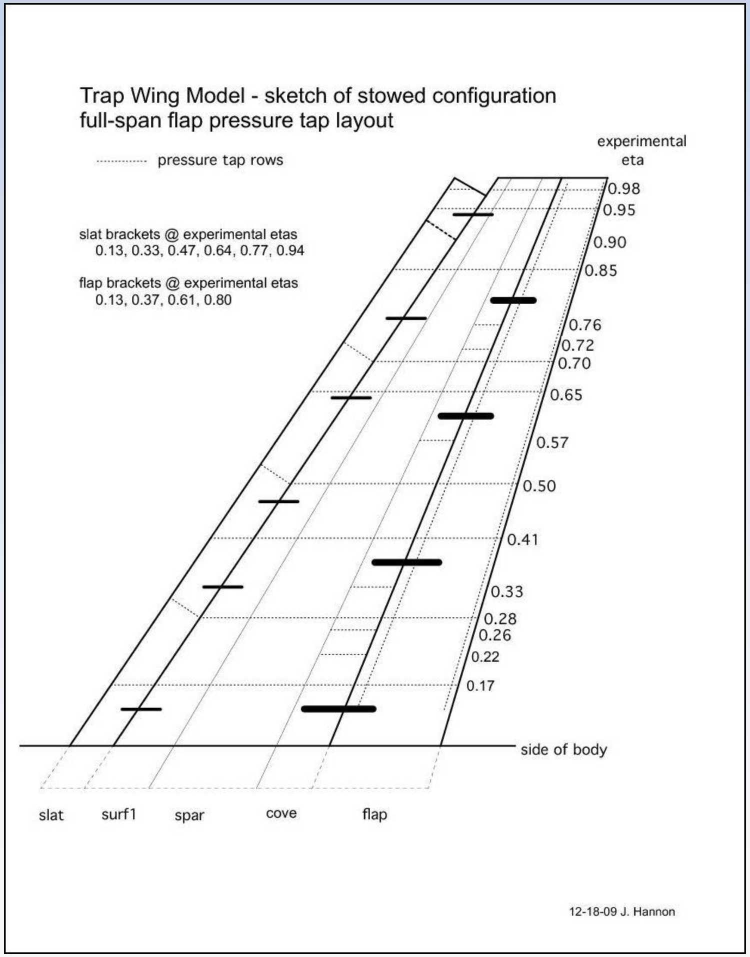
HiLiPW-1 Trap Wing Model

- **Ideal test case for industrial application of transition model**
- **Low Reynolds number**
  - 1e6 → transition will be a factor
- **Complex 3D wing**
  - Opportunity for multiple, interacting transition mechanisms
  - Changes in flow topology can lead to large scale effect
- **Difficult problem**
  - Known difficulty capturing stall
    - Could transition help?
- **Validation**
  - Good experimental data available
- **Sharing and feedback**
  - Excellent venue for gaining feedback from expert users



Trap Wing Model



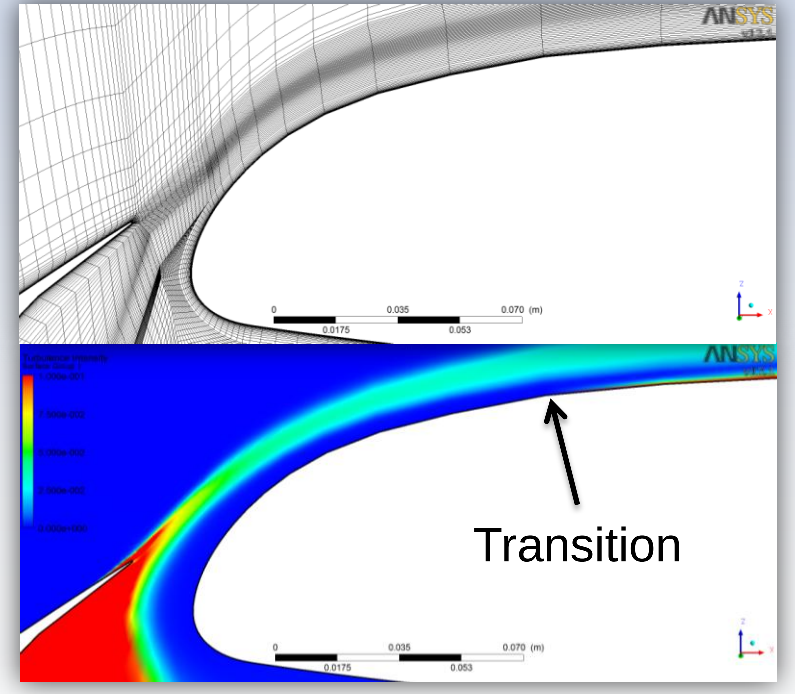


Model, Grids and Operating Conditions

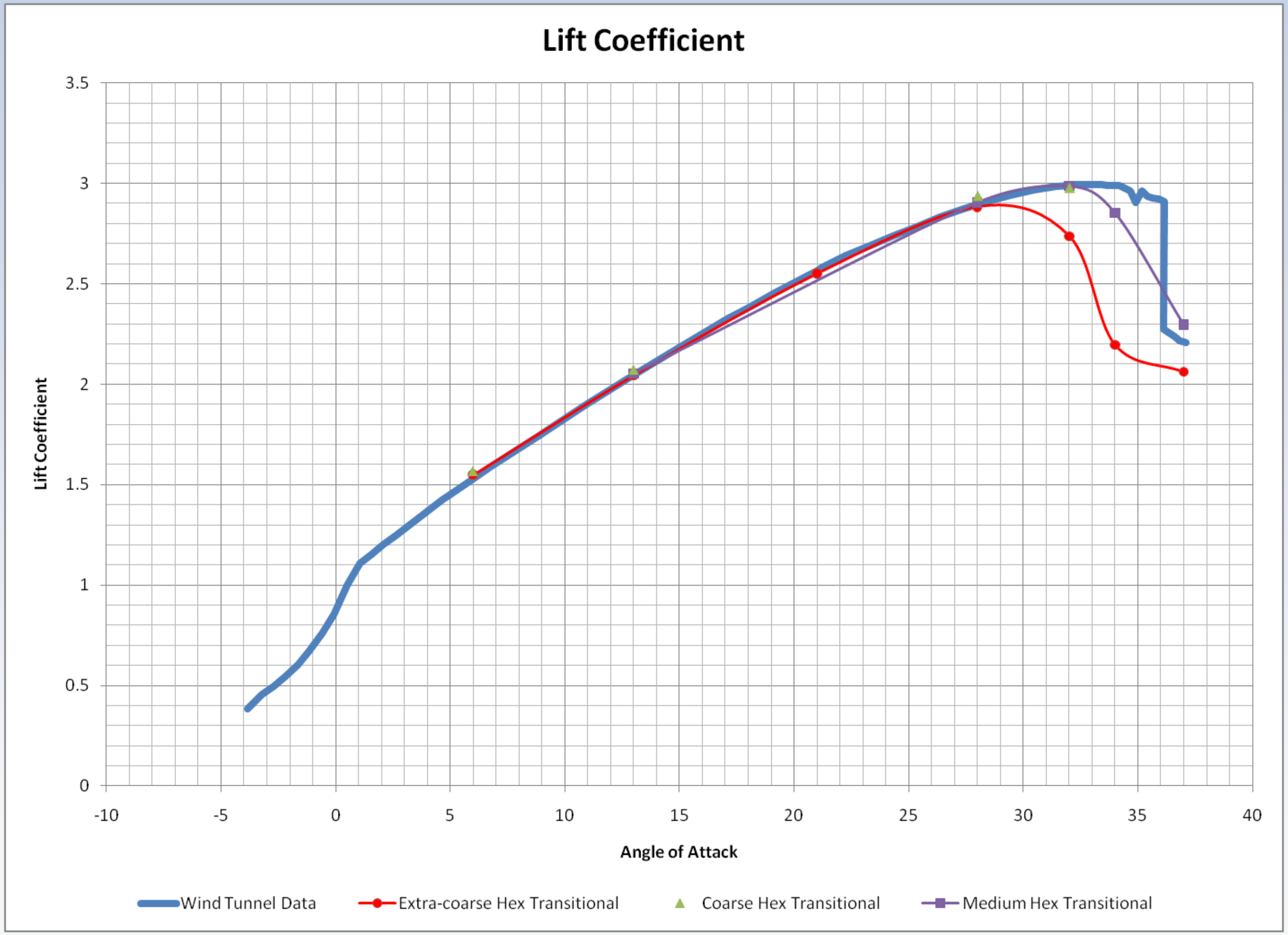
- **Workshop grid**
  - Configuration 1
  - Hex A-v1
- **Operating Conditions**
  - Mach = 0.2
  - Reynolds number = 4.3 million
    - based on mean aerodynamic chord
  - Reference Temperature = 288.89 K (530 R)
- **Y+ < 1**

	α						
	6	13	21	28	32	34	37
Extra-coarse	●	●	●	●	●	●	●
Coarse	●	●		●	●		
Medium		●		●	●	●	●

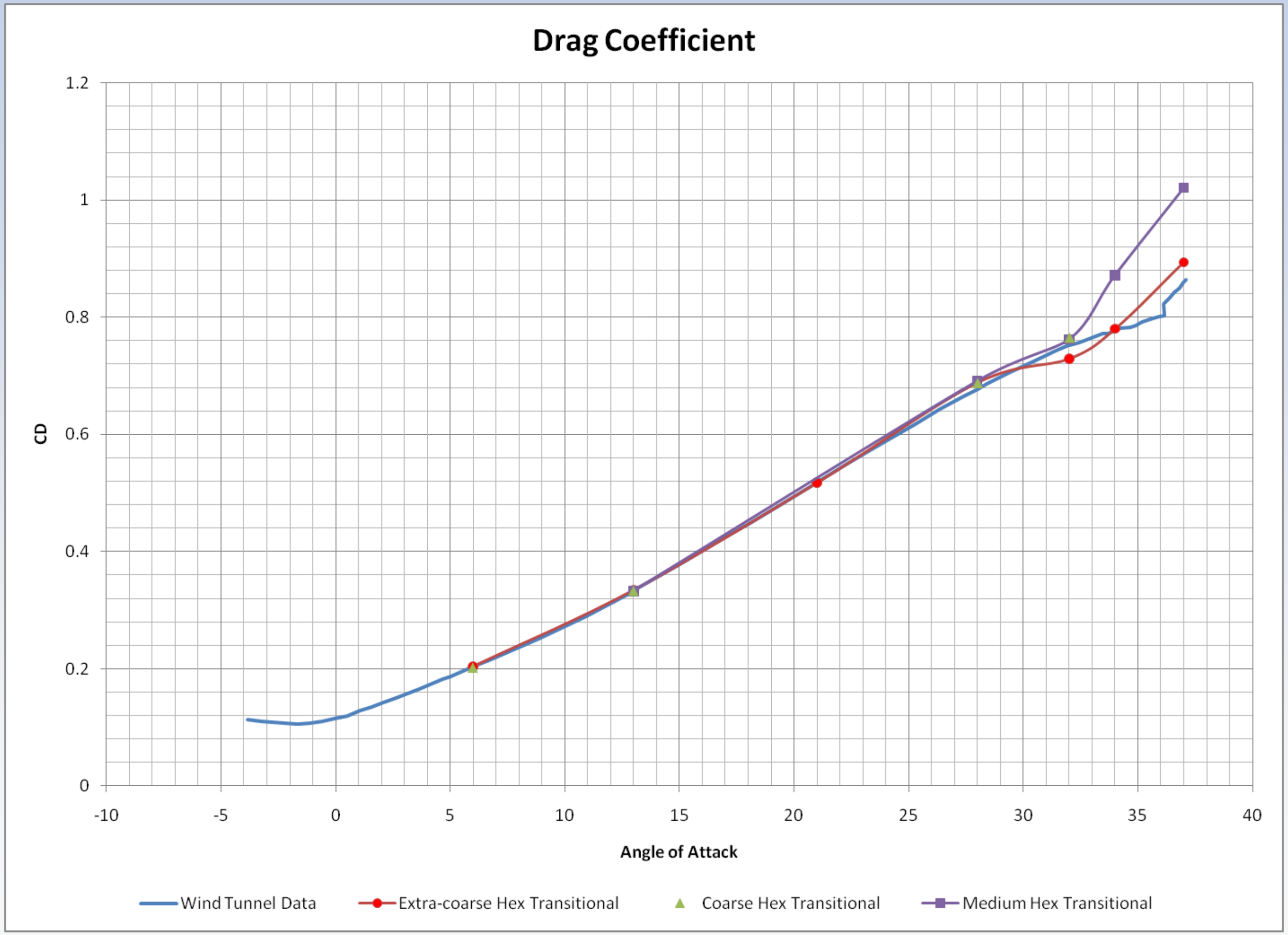
	Nodes	Elements
Extra-coarse	6,068,737	5,957,632
Coarse	20,356,741	20,107,008
Medium	48,104,801	47,661,056
Fine	161,853,985	160,856,064



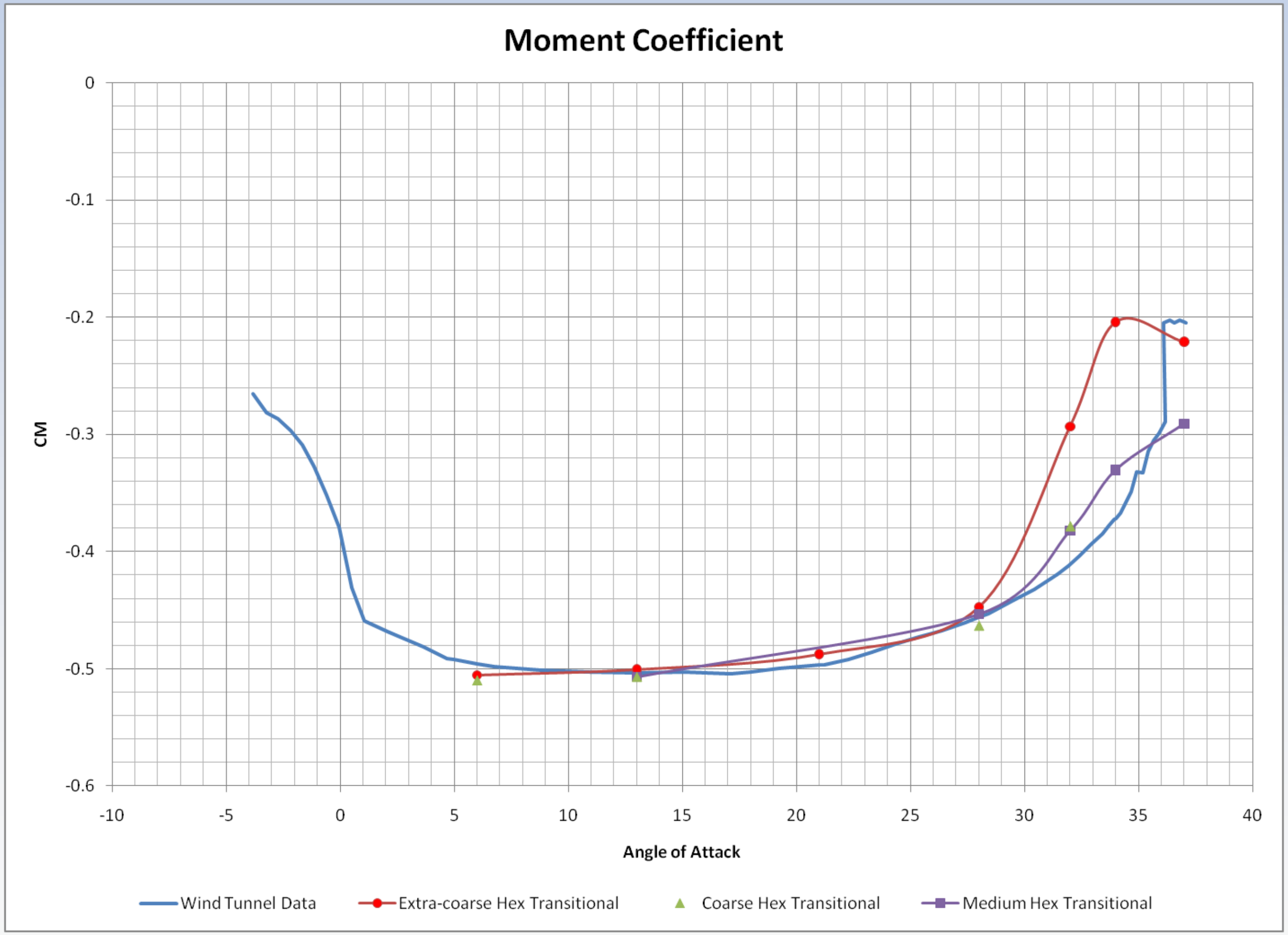
SST γ-R_θ Transition Results
Lift Coefficient



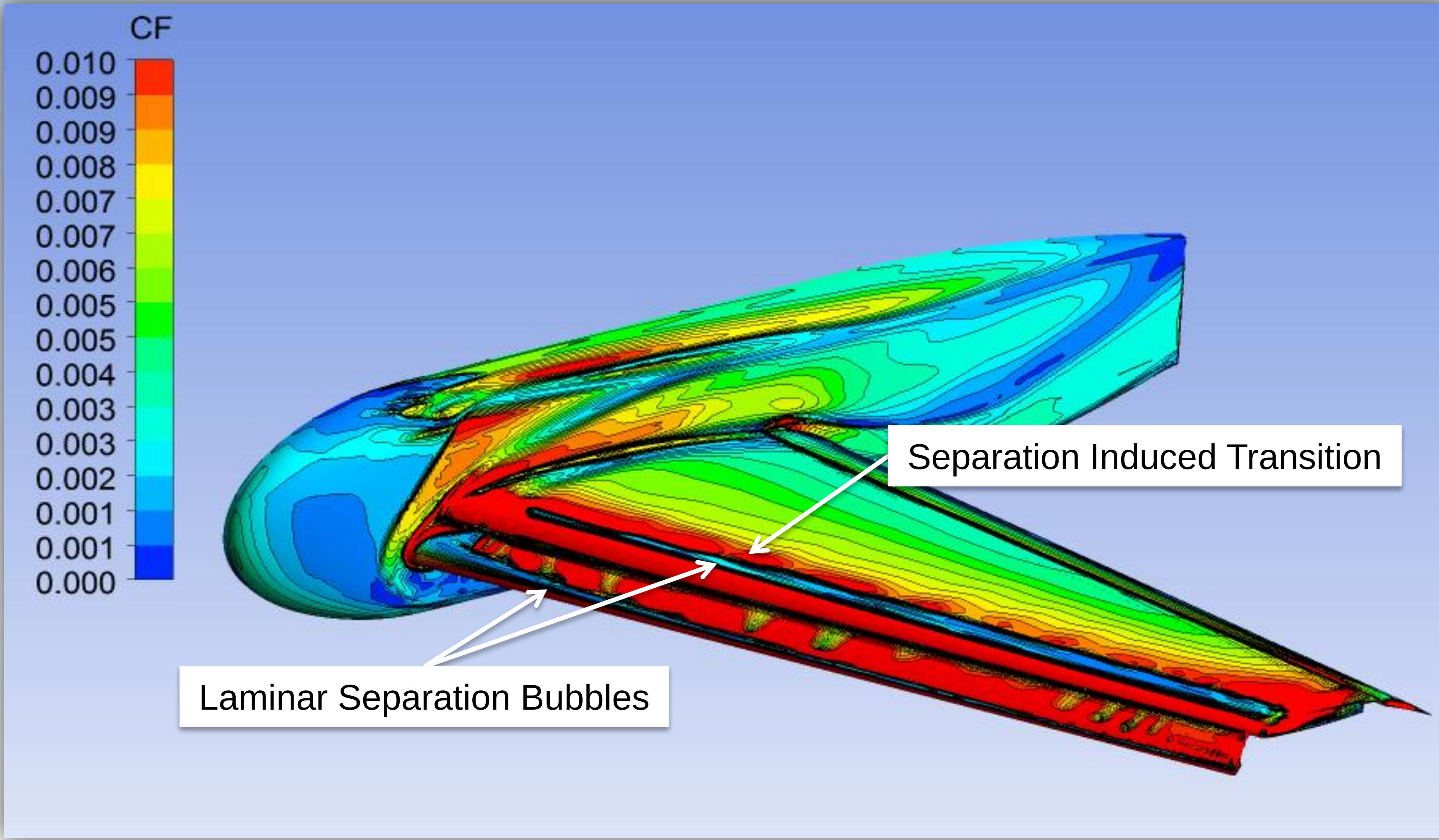
SST γ-R_θ Transition Results
Drag Coefficient



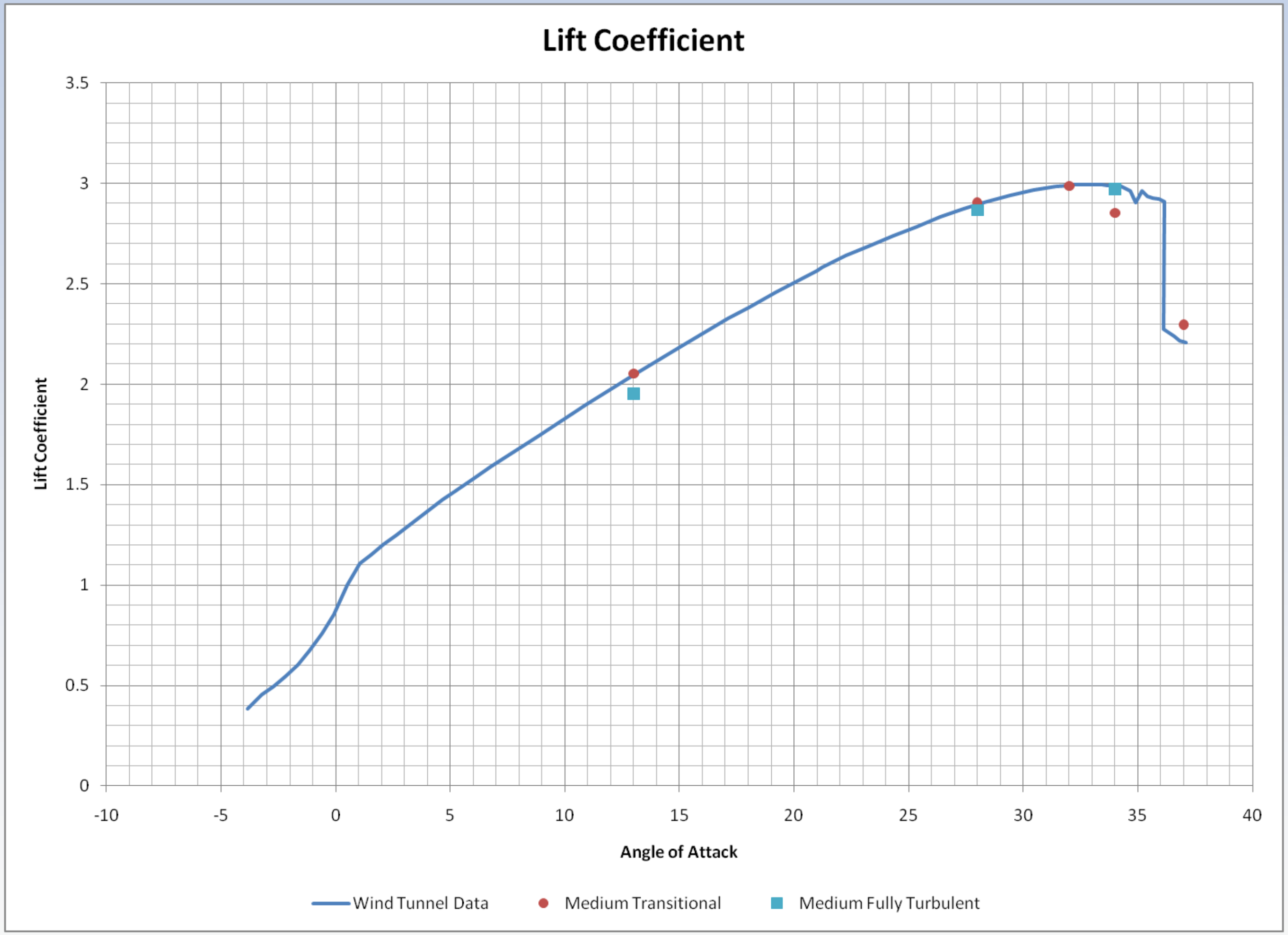
SST γ-R_θ Transition Results
Moment Coefficient



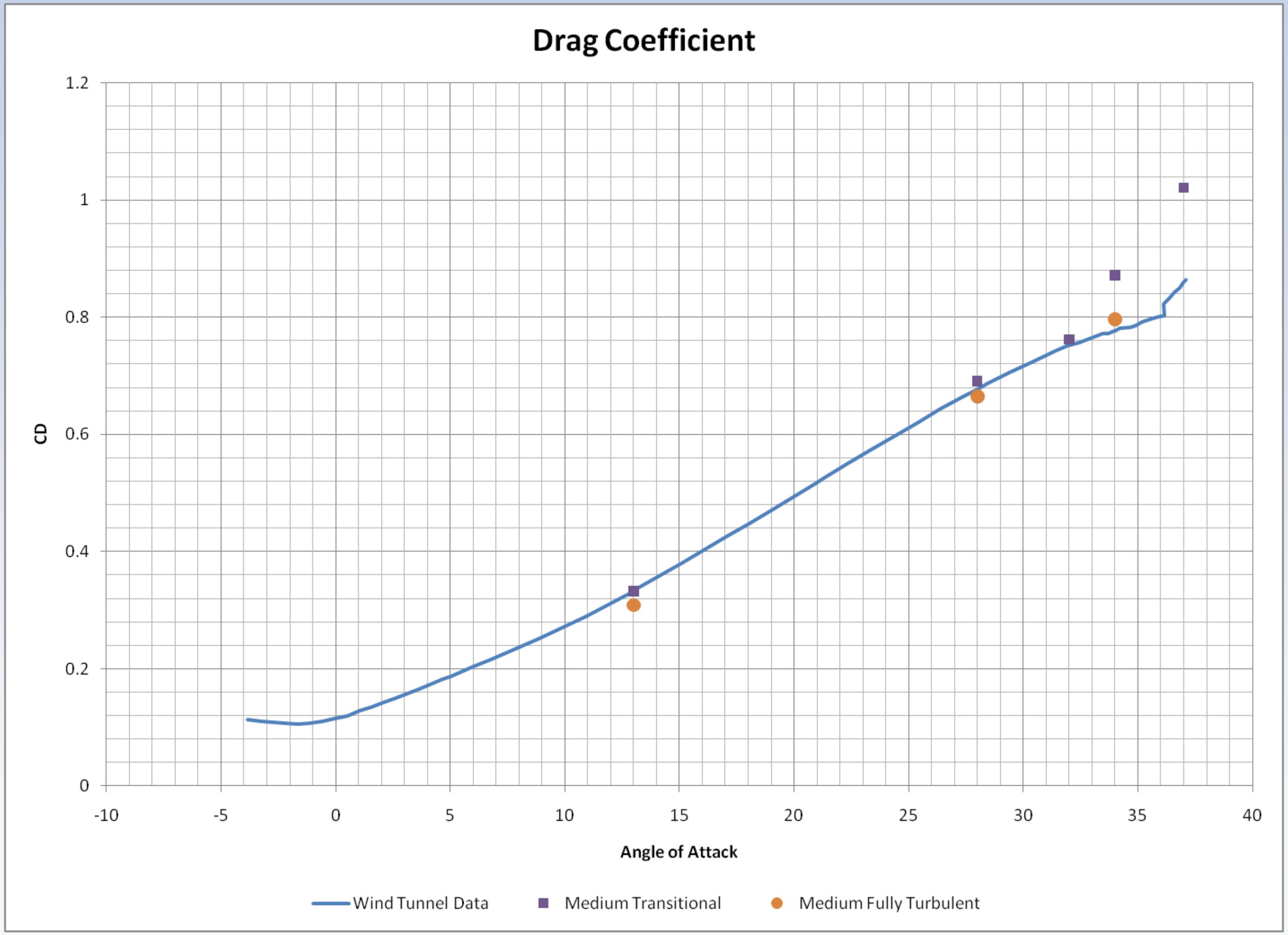
SST γ-R_θ Transition Results
Skin Friction @ α=28°



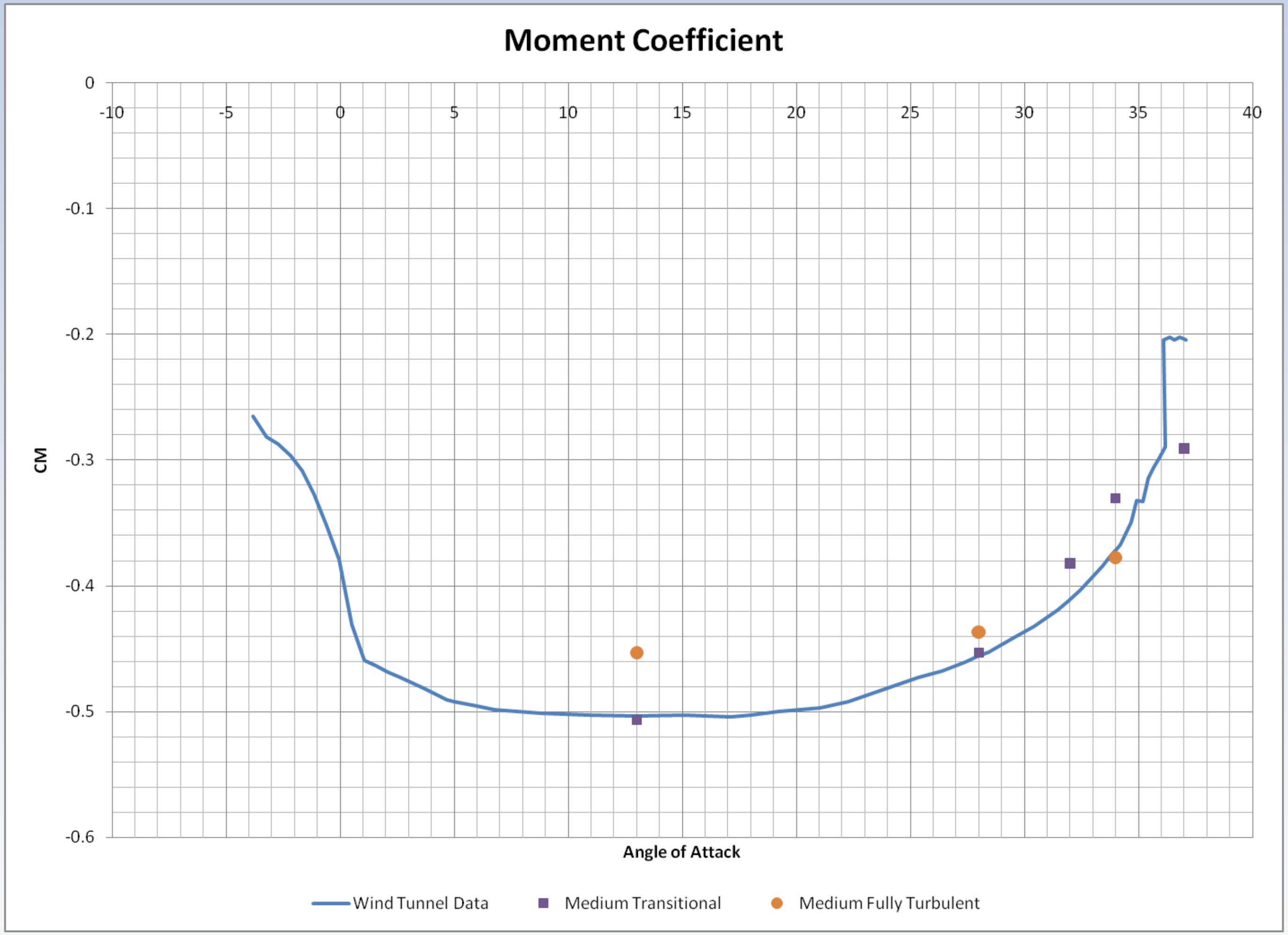
Comparison to SST Fully Turbulent SST Lift Coefficient



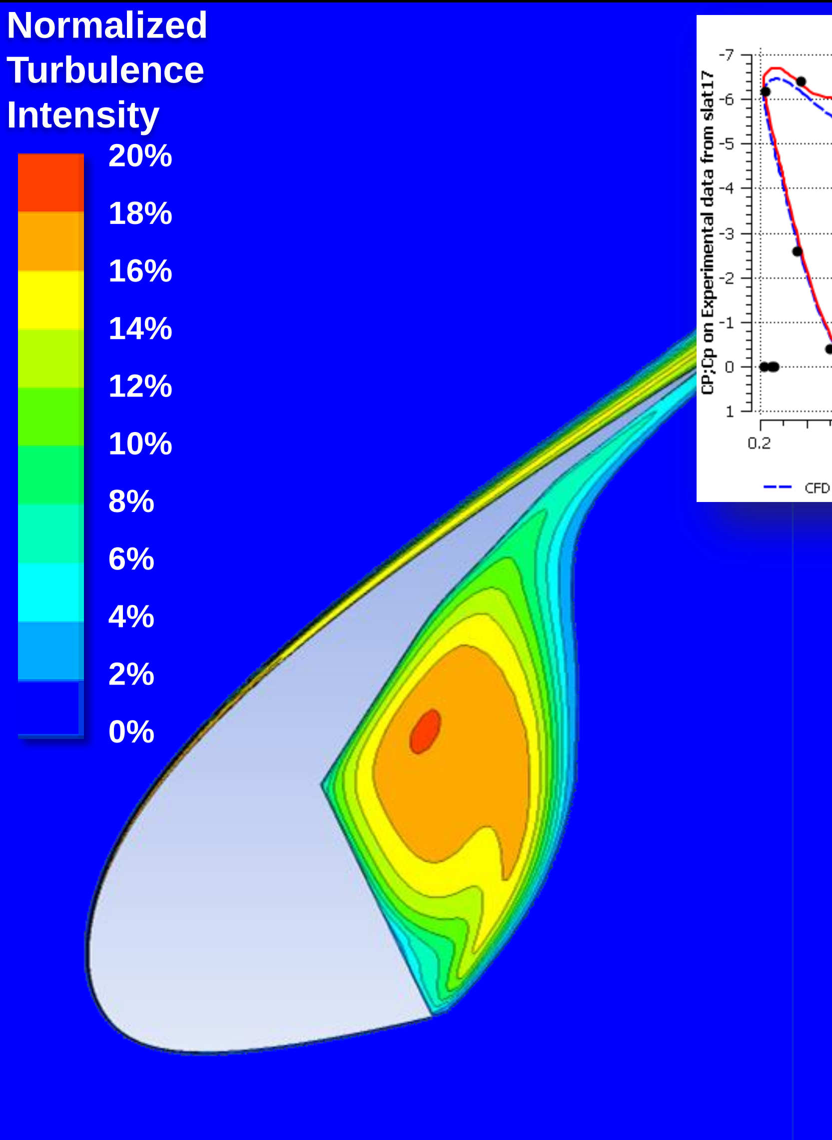
Comparison to SST Fully Turbulent SST Drag Coefficient

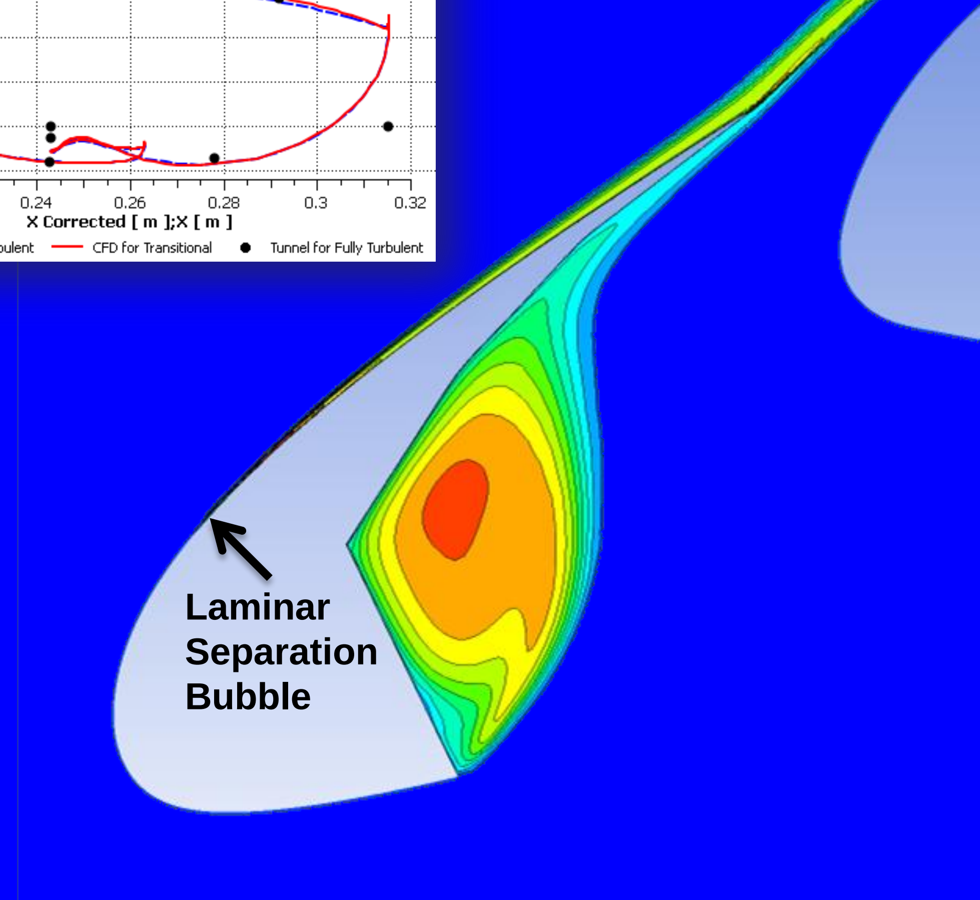


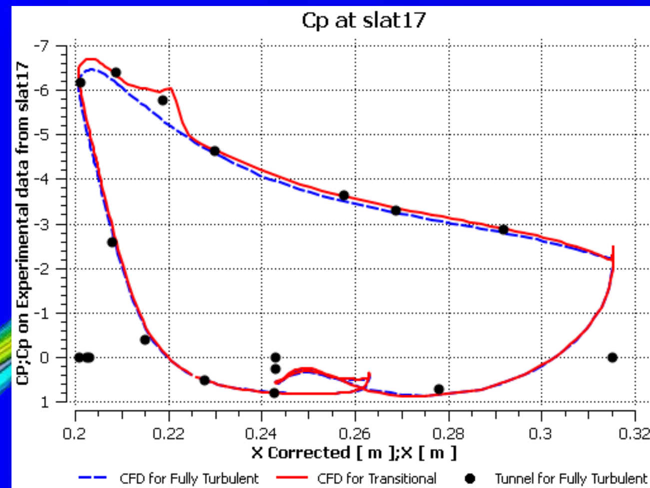
Comparison to SST Fully Turbulent SST Moment Coefficient



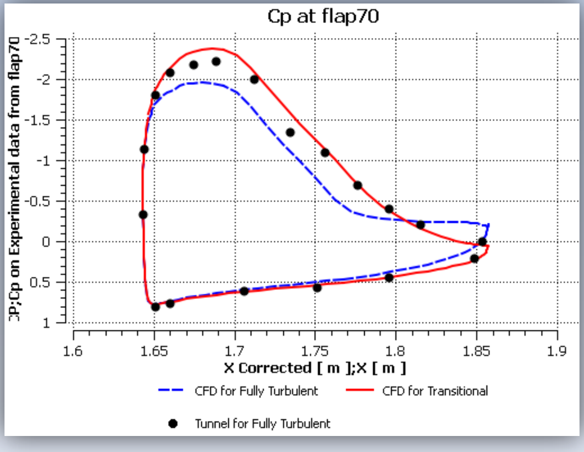
Comparison to SST Fully Turbulent SST Laminar separation on slat

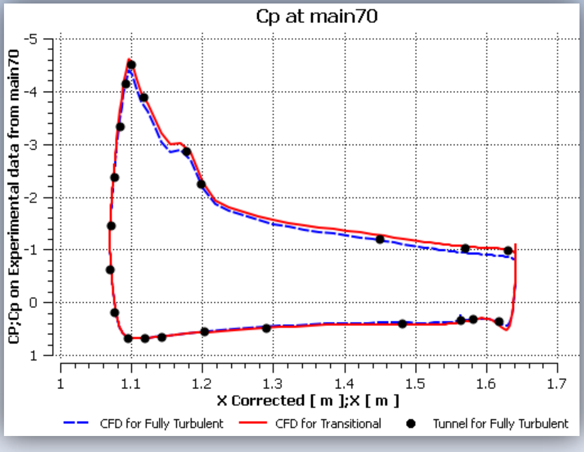


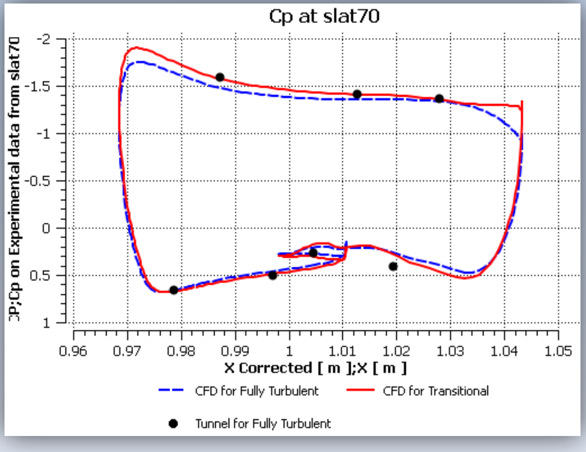




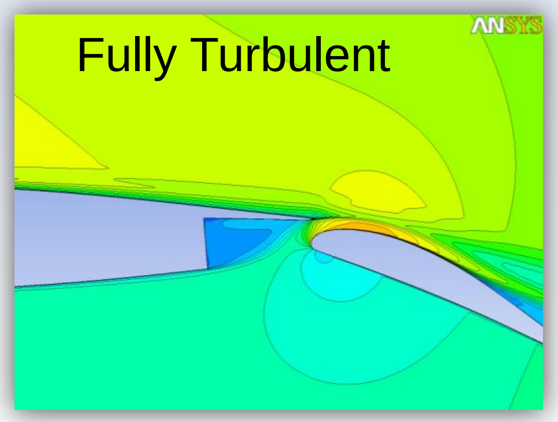
Comparison to Fully Turbulent SST results

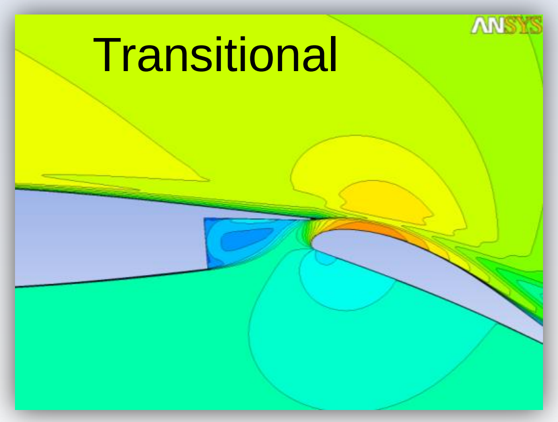




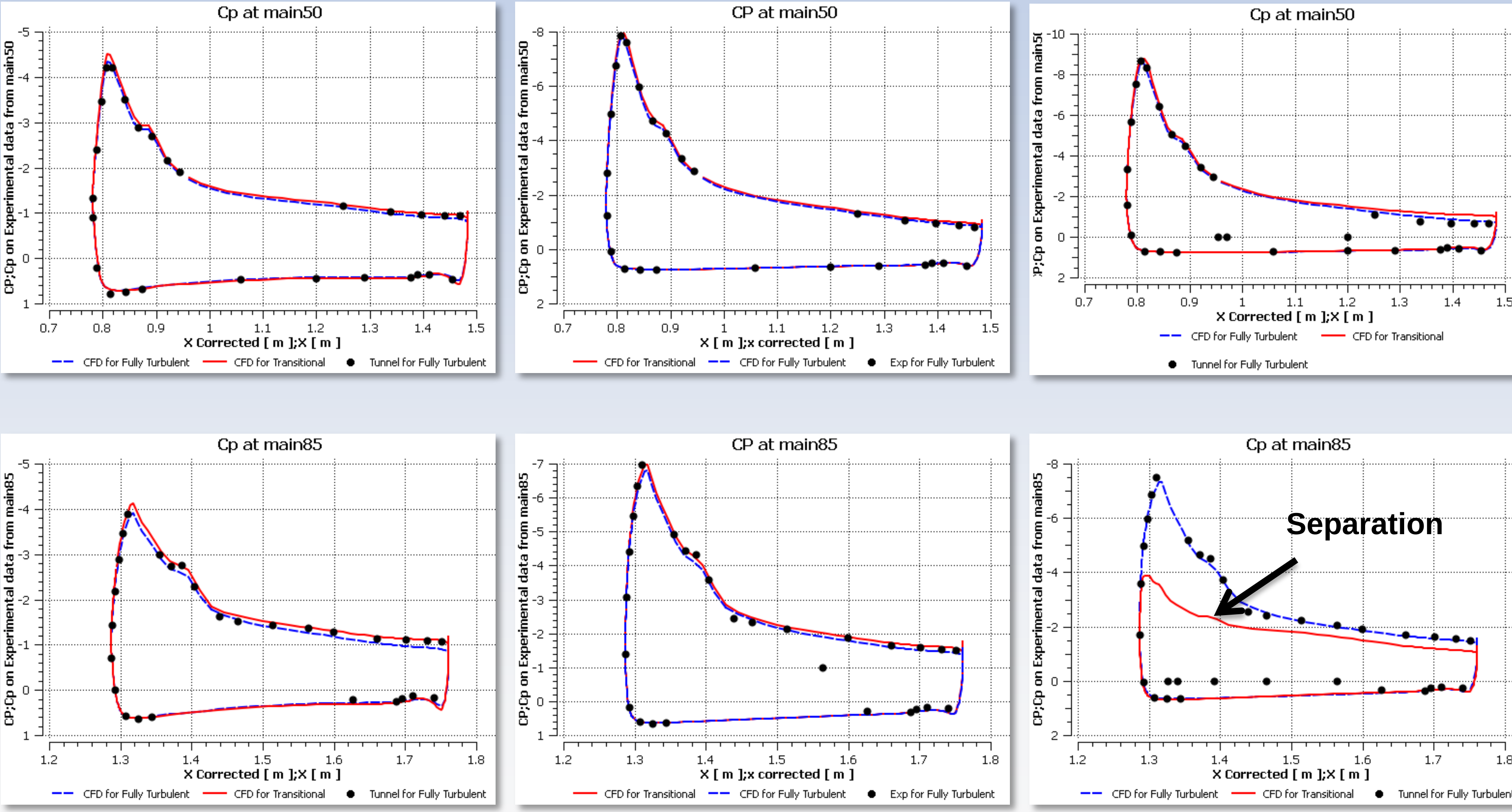


η= 0.70
α=13°





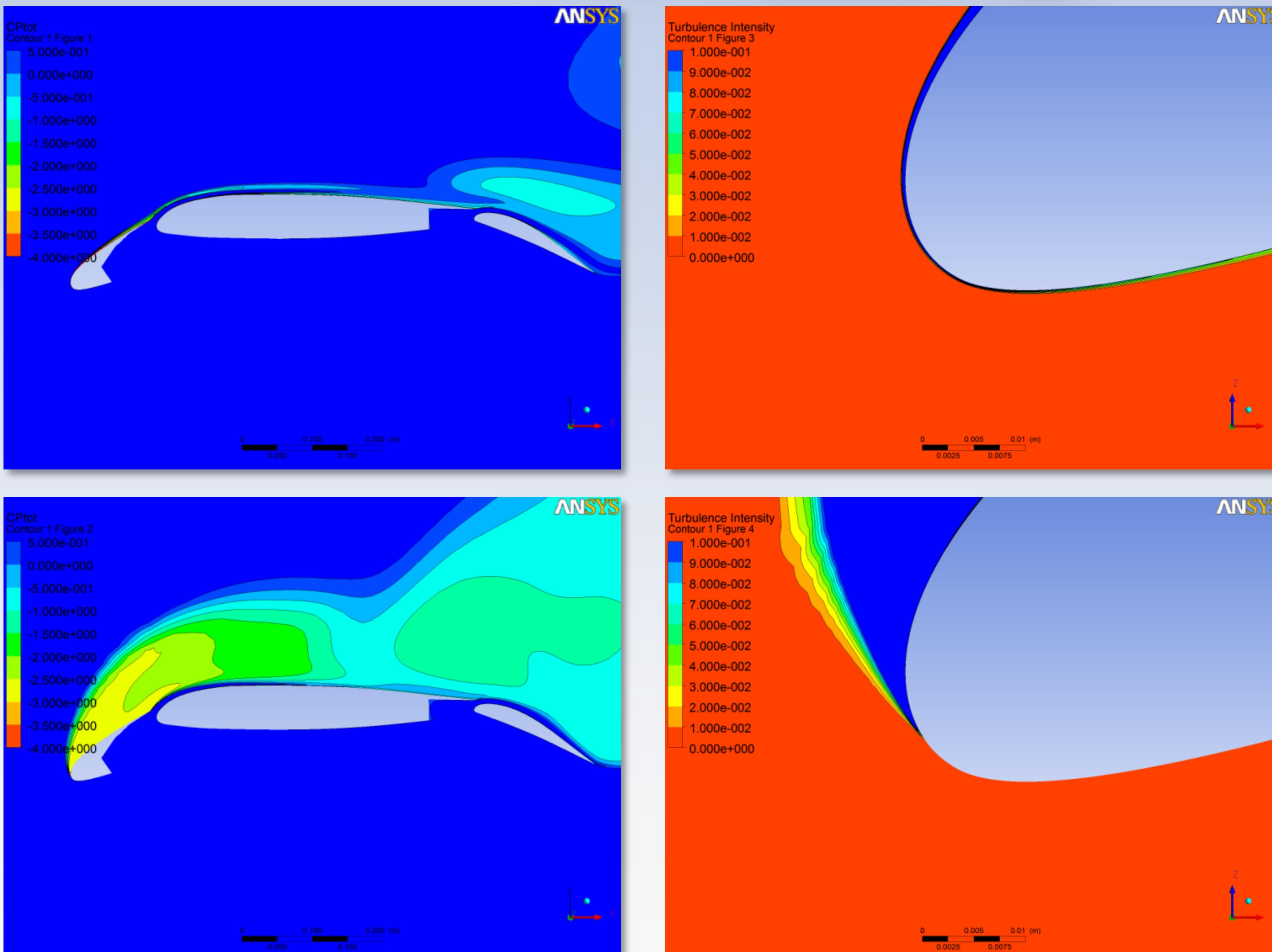
Comparison of Transitional, Fully Turbulent and Experimental values @ α=13°, 28°, 34°



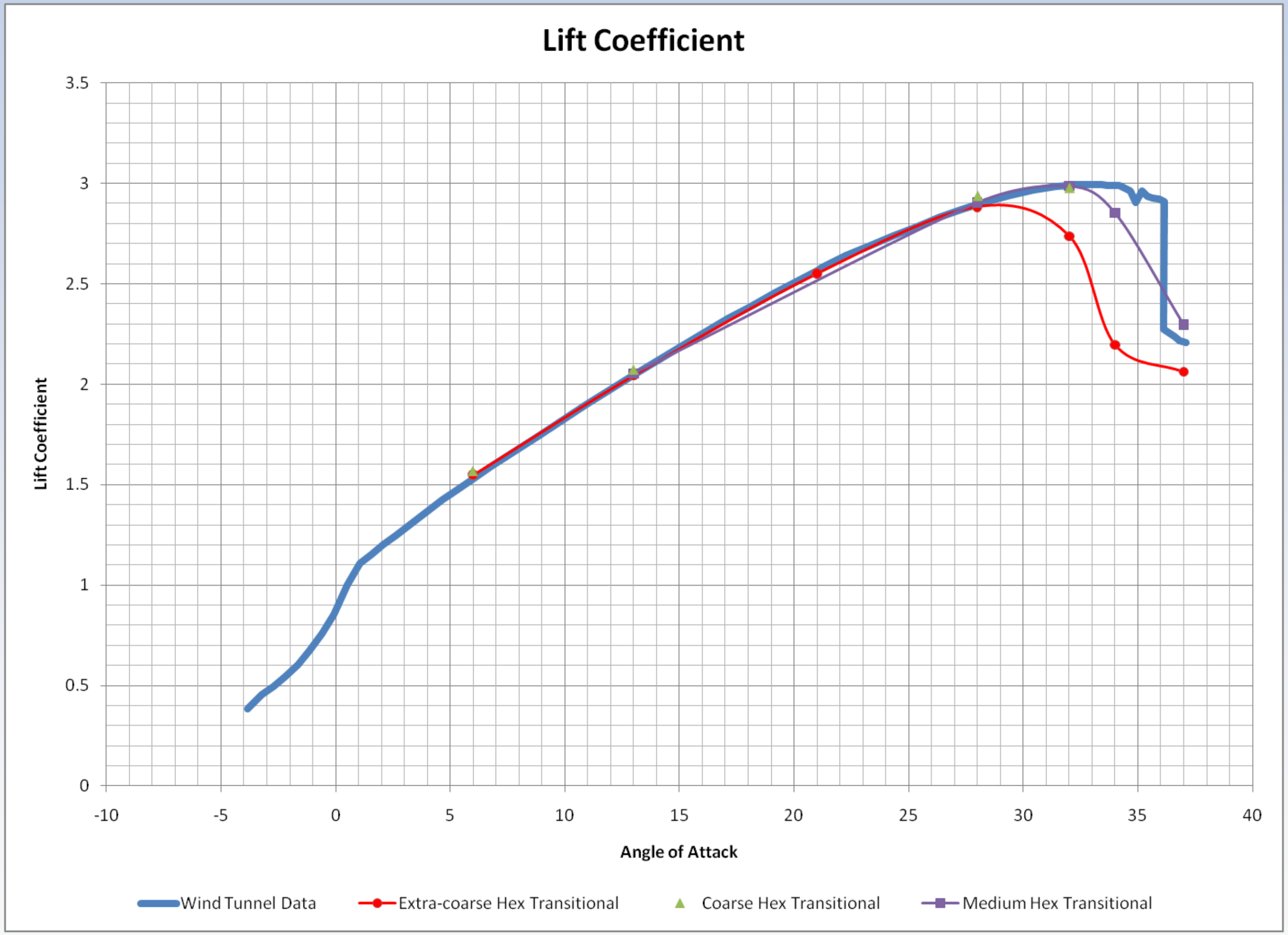
Premature stall @ α=34°

Fully Turbulent

Transitional

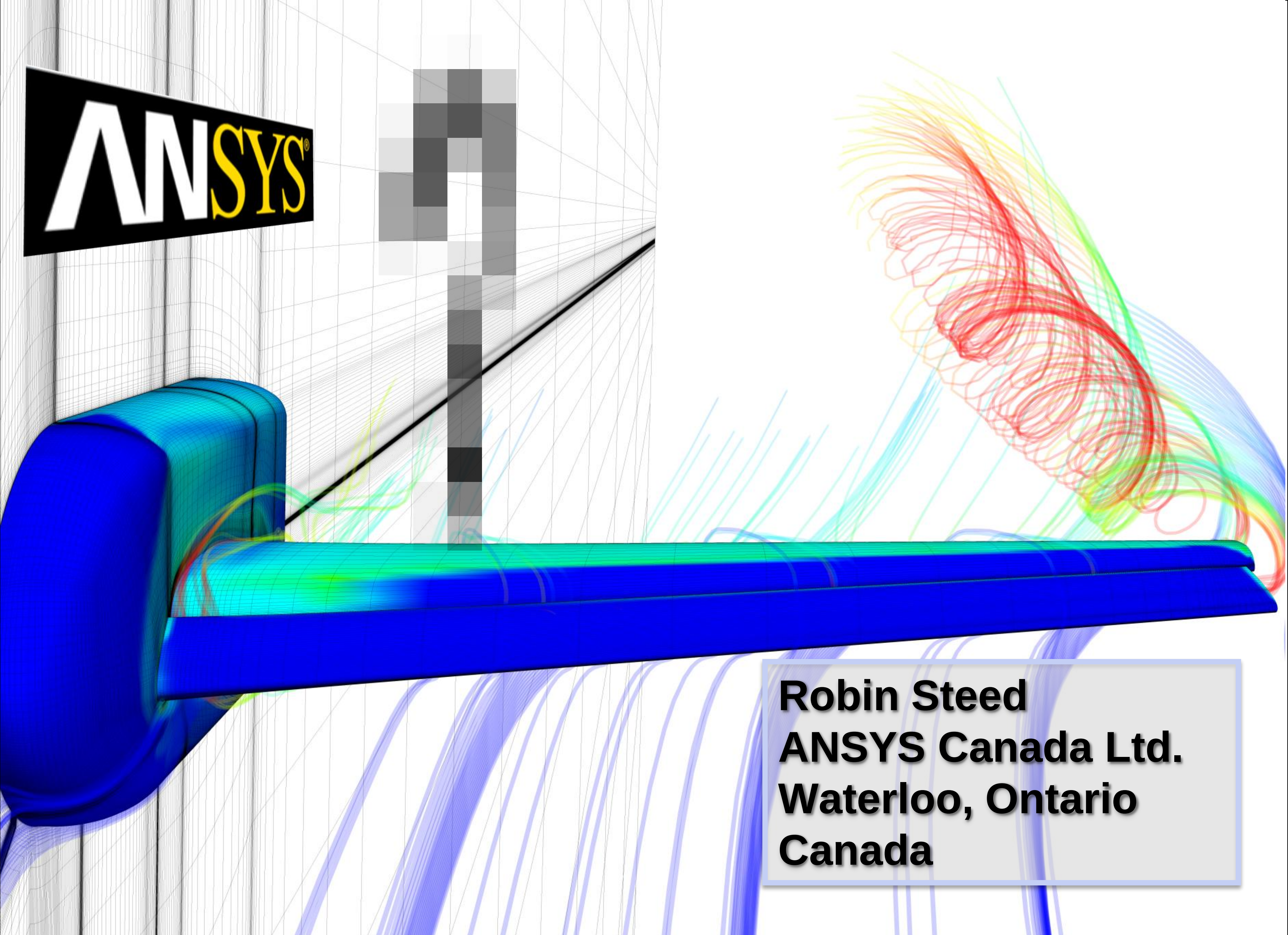


SST γ-R_θ Transition Results
Lift Coefficient



Conclusions and Recommendations

- **Conclusions**
  - SST γ-R_θ transition model agrees well with experimental data at all grid levels and most α
  - Laminar separation leads to premature stall prediction at high α
  - Stall prediction improves with mesh refinement
    - Transition optimized grid may be required
- **Future work**
  - Investigate the influence of grid refinement near transition zones



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