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Assessment of RANS-based Transition Models based on Experimental Data of the Common Research Model with Natural Laminar Flow

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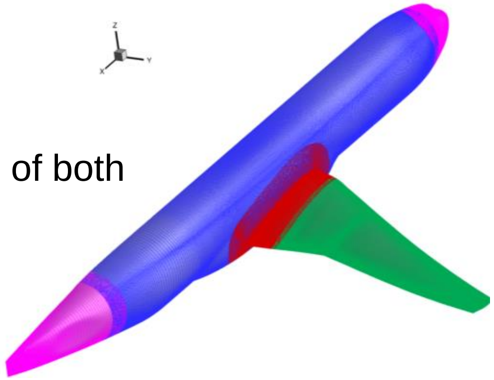
Objectives

- Detailed assessment of the existing RANS-based transition models in NASAs OVERFLOW CFD Flow solver towards developing improved models
  - Focus on data obtained from NASA's recent experiments on the Common Research Model with Natural Laminar Flow (CRM-NLF)*
  - Evaluate performance of transition models when multiple transition mechanisms are at work and when the speed regime is higher than the data used to calibrate them

CRM-NLF

- Built upon CRM legacy
- The CRM-NLF wing has been designed such that the overall amplification of both TS and CF instabilities are reduced
- https://Commonresearchmodel.larc.nasa.gov/crm-nlf/



* Lynde, M. N., Campbell, R. L., and Viken, S. A., "Additional Findings from the Common Research Model Natural Laminar Flow Wind Tunnel Test," AIAA Paper 2019-3292, 2019.

The NASA OVERFLOW Code (Ver 2.3b)

- Implicit structured overset grid Navier-Stokes solver
- Several options for spatial and temporal discretization

- RANS-based transition models (studied in this work)
  - Langtry-Menter (LM) 2009 and 2015 models are implemented upon SST-2003 model
  - Amplification Factor Transport (AFT) model implemented upon SA turbulence model

1. LM2009

   Can model natural, bypass and separation-induced transition scenarios

2. LM2015

   Accounts for stationary crossflow instability through a correlation based on surface roughness levels

3. AFT 2017b version

   Accounts for TS instabilities alone and no crossflow

Nichols, R. H, and Buning, P. G., "User's Manual for OVERFLOW 2.3, Version 2.3," NASA Langley Research Center, Hampton, VA, Oct 2019.

Flow Conditions and Computation Details

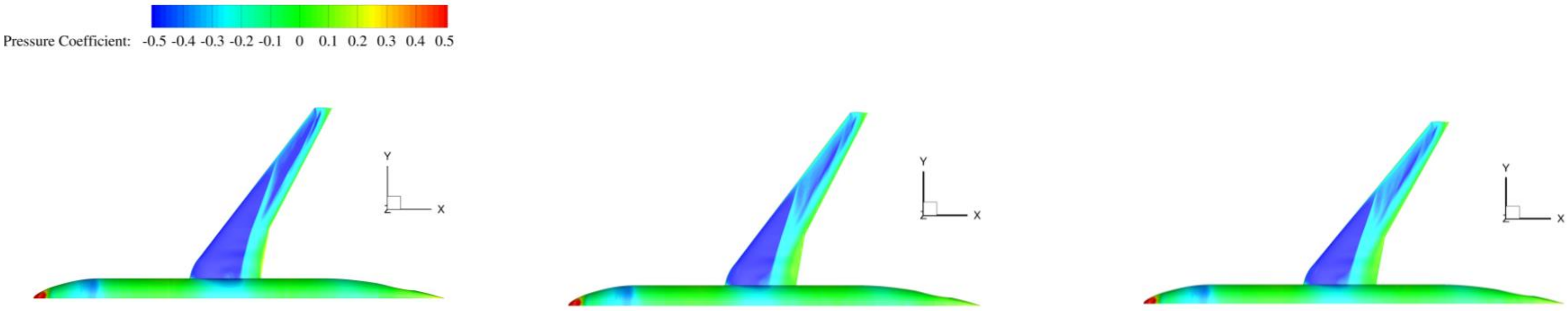
Condition	**AOA (deg.)**	**Mach No.**	**T_∞ (K)**	**Re_{MAC}**
1	1.448 ± 0.001	0.856 ± 0.001	241.7	14.84M
2	1.980 ± 0.001	0.856 ± 0.001	242.0	14.81M
3	2.937 ± 0.001	0.856 ± 0.001	243.0	14.72M

- Freestream Turbulence Intensity (FSTI) = 0.24% (NTF tunnel characterization);
- Surface roughness = 0.9 μinch (based on CRM-NLF)

<u>CFD Computation Details:</u>

- Steady-State computations using 3rd order Roe Upwind Scheme and the unfactored successive symmetric overrelaxation (SSOR) implicit solution algorithm
- SST-2003 model with option to sustain turbulence was used to enforce appropriate FSTI (*Spalart & Rumsey (2007)*)
- In-house generated fine grid (120 million near-body grid points, $y^+ \sim 0.5$) – See paper for details

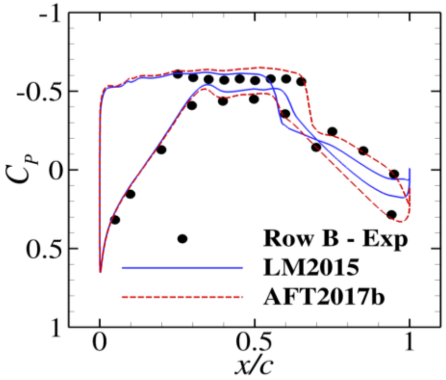
Transitional Flow computations at AOA = 1.44 deg.

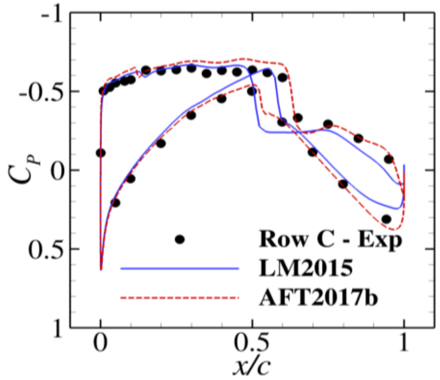


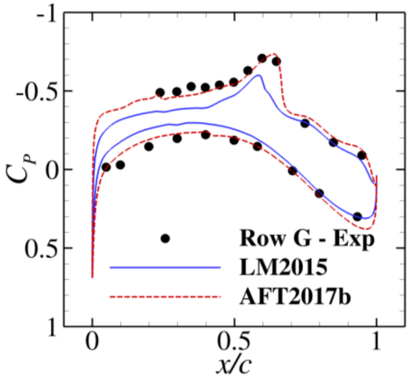
SA-AFT2017b

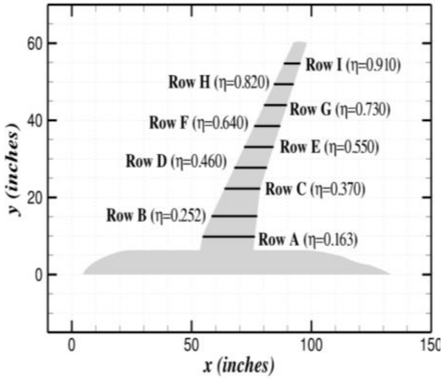
SST-2003-LM2009

SST-2003-LM2015



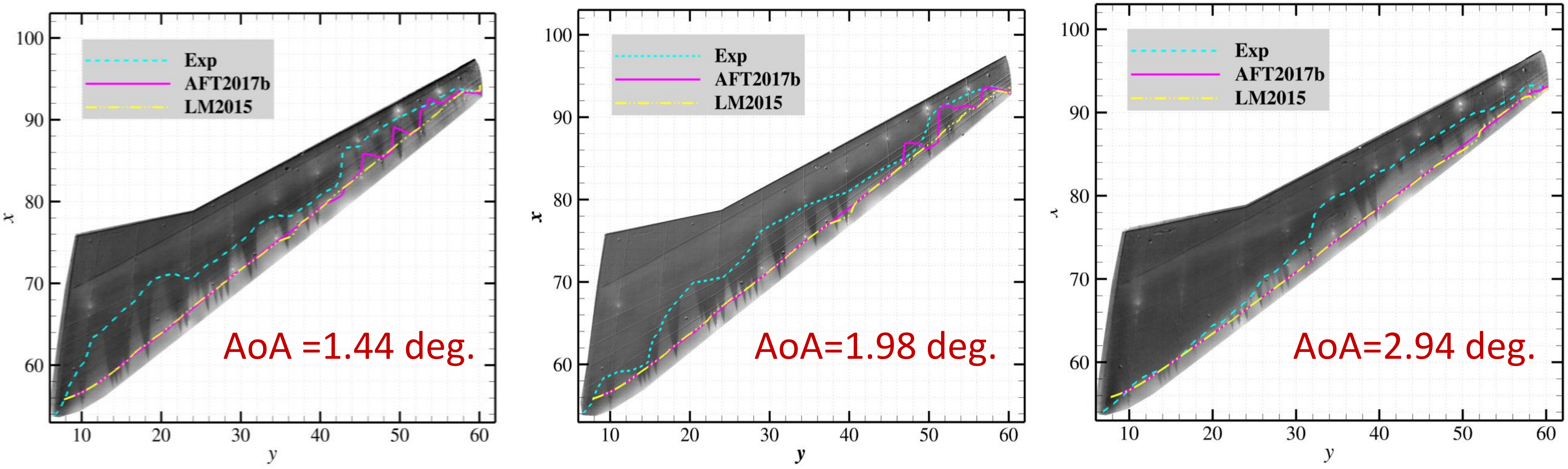






- Double shock system across span of wing
- SA-based AFT model gives best match against measured pressure data
- SST-2003 based LM models predict incorrect surface pressure distribution
- Pressured distribution from LM2009 and LM2015 were similar
- Similar trend at different AoA

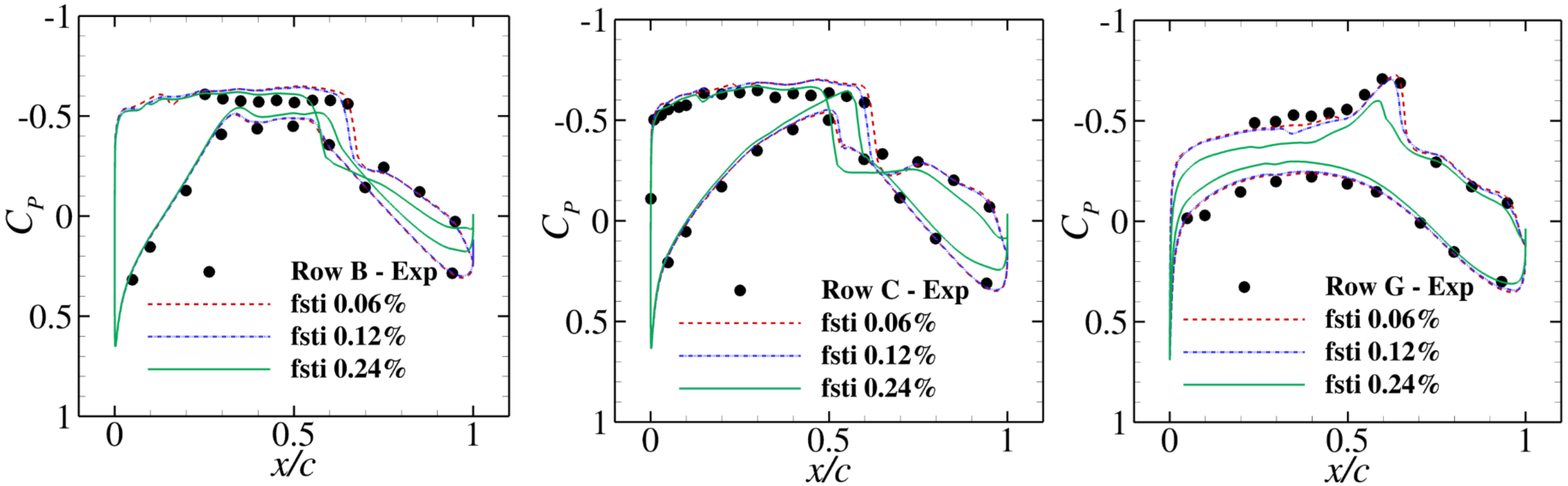
Transition front at different flow conditions (AoA)



Predicted transition fronts overlaid on TSP images from the experiment

- ➢ Significant underprediction of laminar extent across all angles of attack by both AFT and LM models (suction side)
- ➢ In the inboard portion (up to the break), TS effects are expected to be important (*Lynde et al. (2019), Paredes et al. (2021)*) and yet both AFT and LM models fail here
- ➢ No difference observed in results from LM2009 and LM2015
    - o Crossflow effects were only deemed to be important in a small region around the break and near the wing-tip

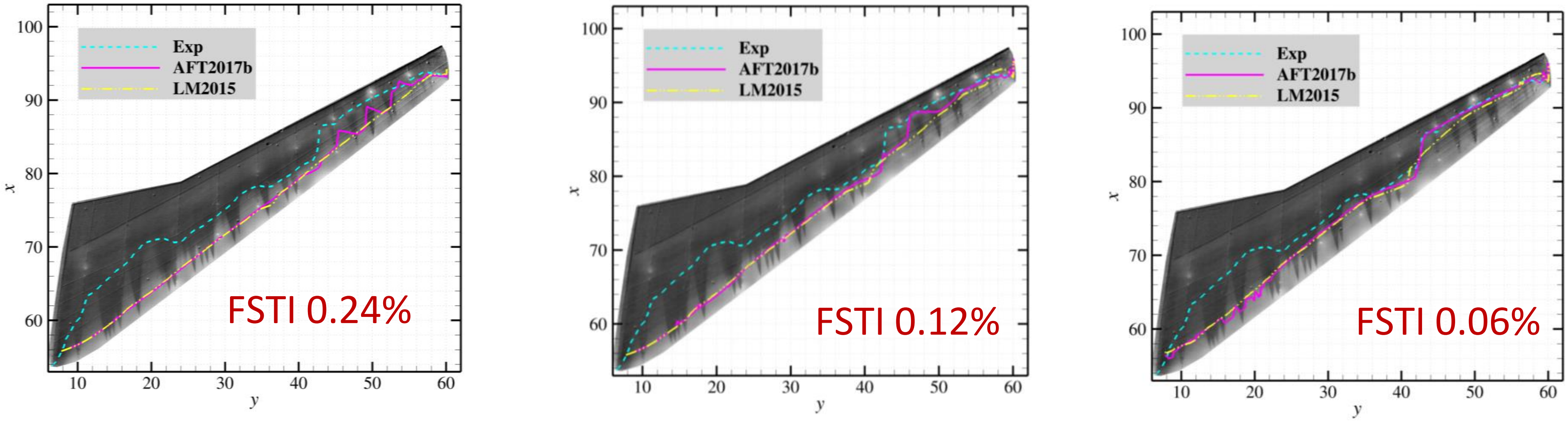
Influence of FSTI (AOA = 1.44 deg.)



SST-2003-LM2015 Results

- Predicted pressure distribution of SST-2003-LM2009/LM2015 model improved significantly with reduction in FSTI
  - Possible impact of using turbulence sustaining terms to enforce FSTI
  - Need to explore alternate mechanism to specify FSTI (*Langel et al. (2014), Halila et al. (2018)*)

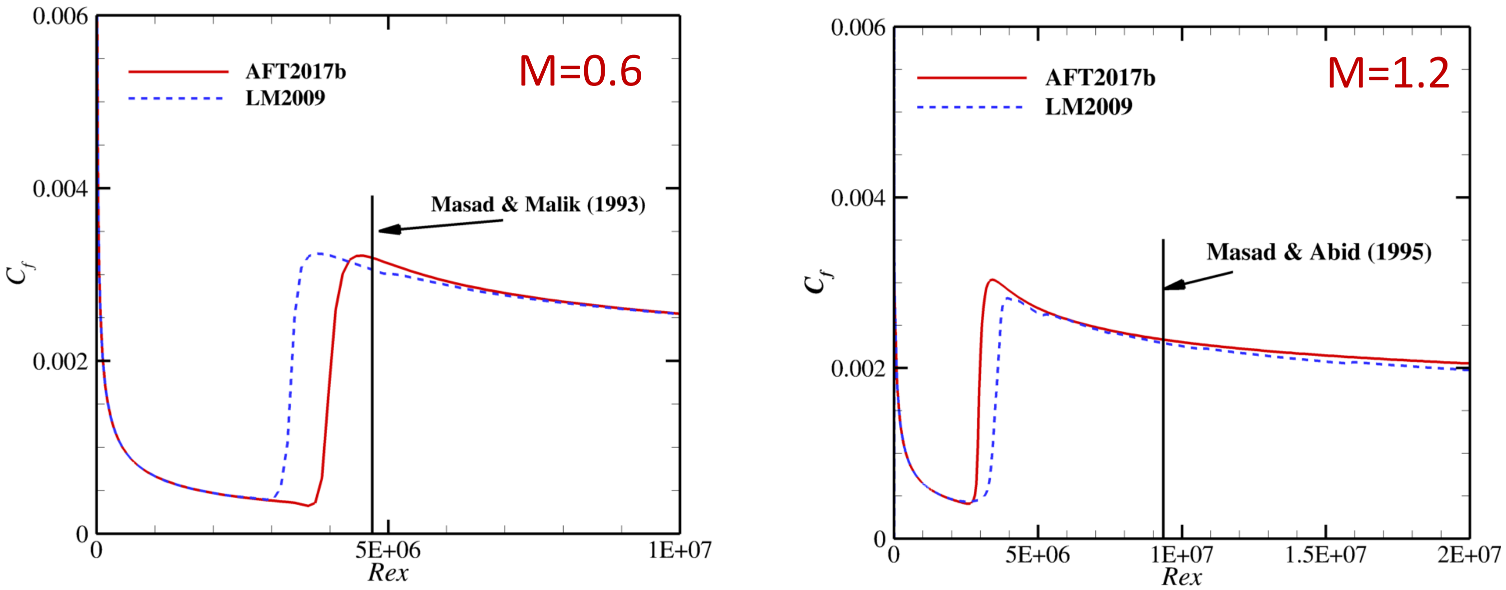
Influence of FSTI (AOA = 1.44 deg.)



Influence of FSTI on predicted transition front overlaid on TSP image from the experiment

- ➢ Predicted laminar front improves with decrease in FSTI
  - o Predicted transition front within the inboard region remains far upstream of measured front
  - o Outboard of break, transition front is likely shock-limited (AFT2017b does well here)
  - o LM2015 predicts slightly earlier transition in the most outboard region (crossflow effects : *Lynde et al. (2019) and Paredes et al. (2021)*)

Influence of Compressibility - RANS-based Transition Models



Influence of Mach number on transition locations for a flow over an adiabatic flat plate

- AFT and LM models do not account for stabilizing influence of compressibility (up to Mach < 2.0)
  - Rely upon transition correlations derived from limited set of low-speed and low unit Reynolds number flow experiments
- *Ströer et al. (2020) & Pascal et al. (2020)* address this aspect in LM models) through new correlations and additional transport equations

Summary

Assessment of transition models in OVERFLOW 2.3b carried out with focus on CRM-NLF

- SA-AFT2017b gave the best match and the SST-2003-LM2009/LM2015 the worst, in terms of measured chordwise pressure distribution across the span of the wing at intended levels of FSTI
- All the investigated models significantly underpredicted laminar flow extent across the span of the wing (irrespective of dominant instability mechanisms)
- Predicted transition front improved with reduction in FSTI for all the investigated models, but only marginally on the inboard portion
- Stabilizing effect of compressibility effects on boundary layer missing from these models, thereby underpredicting laminar extent at transonic speeds

Future Work

1. Accounting for effect of Mach number and unit Reynolds number on RANS-based transition models

2. Computations for CRM-NLF with fixed CL instead of fixed angle of attack

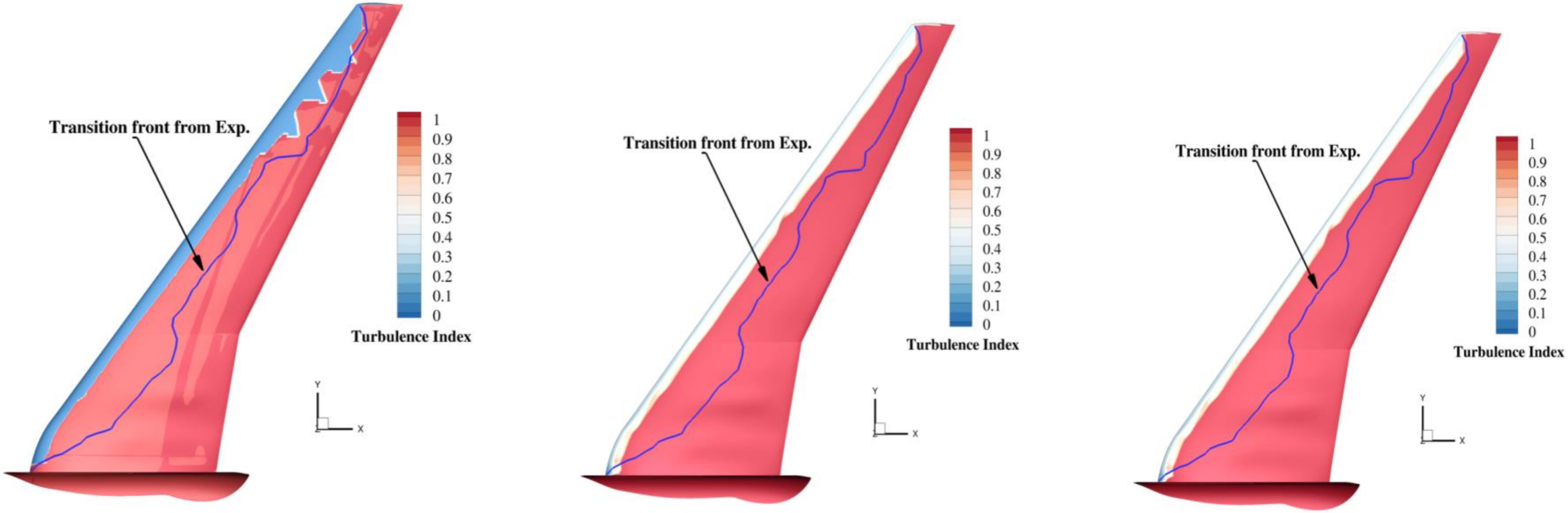
3. Incorporate lessons from accompanying stability analysis study by *Paredes et al. (2021)* (APA-54, Jan 19, 2021 1.00 PM)

Back up slides

Additional details in paper

- Details about mesh and grid convergence of results
- Comparisons of pressure coefficient and integrated force coefficients with measured data for the different flow conditions
- Detailed discussion on the predicted transition fronts for the different flow conditions
- Influence of Kato-Launder limiter on the SST-2003-LM model
- Influence of small variations in Mach number and angle of attack on predicted front and pressure distribution
- Influence of freestream turbulence intensity on integrated force coefficients

Transitional Flow computations at AOA = 1.44 deg.



SA-AFT2017b

SST-2003-LM2009

SST-2003-LM2015

Turbulence index contours (0:Laminar; 1: Turbulent)

- All models significantly underpredict laminar extent across the span of the wing (suction side)
- In the inboard portion (up to the break), TS effects are expected to be important (*Lynde et al. (2019), Paredes et al. (2020)*) and yet both AFT and LM models fail here
- No difference in results from LM2009 and LM2015
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