Transition Analysis for the CRM-NLF Wind Tunnel Configuration

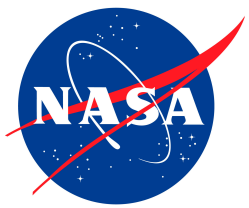
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AIAA Scitech 2021
APA-54, Transonic Aerodynamics
1:00PM-2:15PM, January 19, 2021



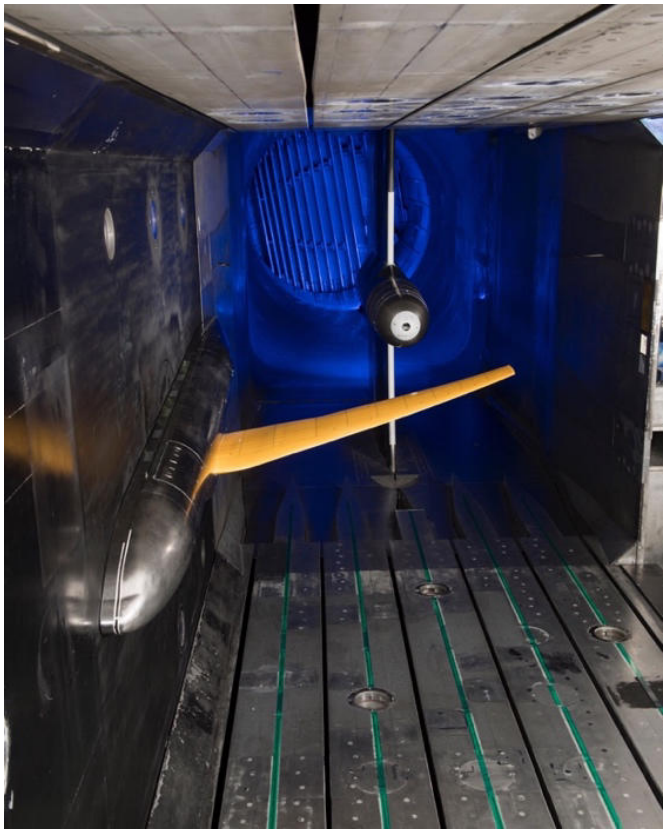


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Outline

1. Motivation
2. Results
   - Mean flow solution
   - Instability Characteristics
3. Summary and Concluding Remarks

Common Research Model - Natural Laminar Flow[1]



- CRM is an open geometry representation of a generic transport vehicle
- CRM-NLF includes wing designed for extended natural laminar flow by controlling
  - attachment line contamination and instability
  - crossflow (CF) instability
  - Tollmien-Schlichting (TS) instability
- `https://commonresearchmodel.larc.nasa.gov/crm-nlf`

[1] R.L. Campbell and M. Lynde. *Expanding the natural laminar flow boundary for supersonic transport*. AIAA Paper 2016-4327. 2016.

Objectives

- Examine the effects of simplifying approximations in both basic state computations and stability analysis on N-factor correlations:
  - basic state computed by using full Navier-Stokes equations with OVERFLOW 2.3b[2]
  - LST and PSE stability analysis performed by using a nonorthogonal coordinate system with LASTRAC.3d[3]
  - effects of surface curvature and nonparallel mean flow included in PSE
- Evaluate the dual $N_{TS} - N_{CF}$ criterion[4]
- Provide guidance to improve the physical basis of existing transition models
  - **Venkatachari et al., AIAA 2021-0000, APA-54, Jan 19, 1:00 pm**

[2] H Nichols and PG Buning. *User's manual for OVERFLOW 2.3*. 2019. URL: https://overflow.larc.nasa.gov/home/users-manual-for-overflow-2-3/.

[3] C.-L. Chang. *LASTRAC.3d: Transition Prediction in 3D Boundary Layers*. AIAA Paper 2004-2542. 2004.

[4] D. Arnal. "Boundary layer transition: Prediction based on linear theory". In: *Special course on Progress in Transition Modeling. AGARD. R-793*. 1994, pp. 1–62.

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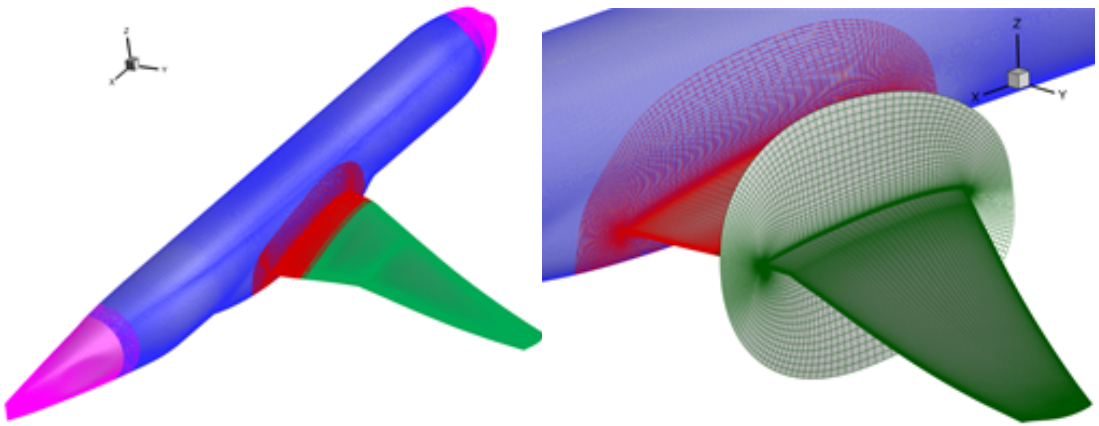
3 Summary and Concluding Remarks

Flow Conditions and Computational Details

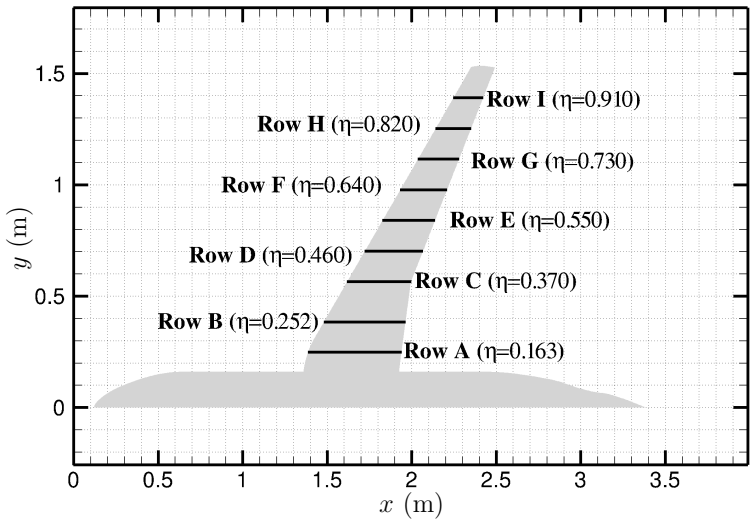
- NASA's OVERFLOW 2.3b solver[5]: NS solver for structured, overset grids
- Fully turbulent (FT) and imposed transition (IT) solutions with SA RANS model
- Flow conditions given by the AIAA Transition Modeling and Prediction workshop
- Adiabatic wall and constant $M_\infty = 0.8565$.

Case	AoA (°)	Re_{MAC} (10^6)	Re_∞ (10^6 m^{-1})
I	1.448	14.979	41.101
II	1.448	17.473	48.039
III	1.980	14.946	41.028

- Surface and wing grid (120×10^6 total points)



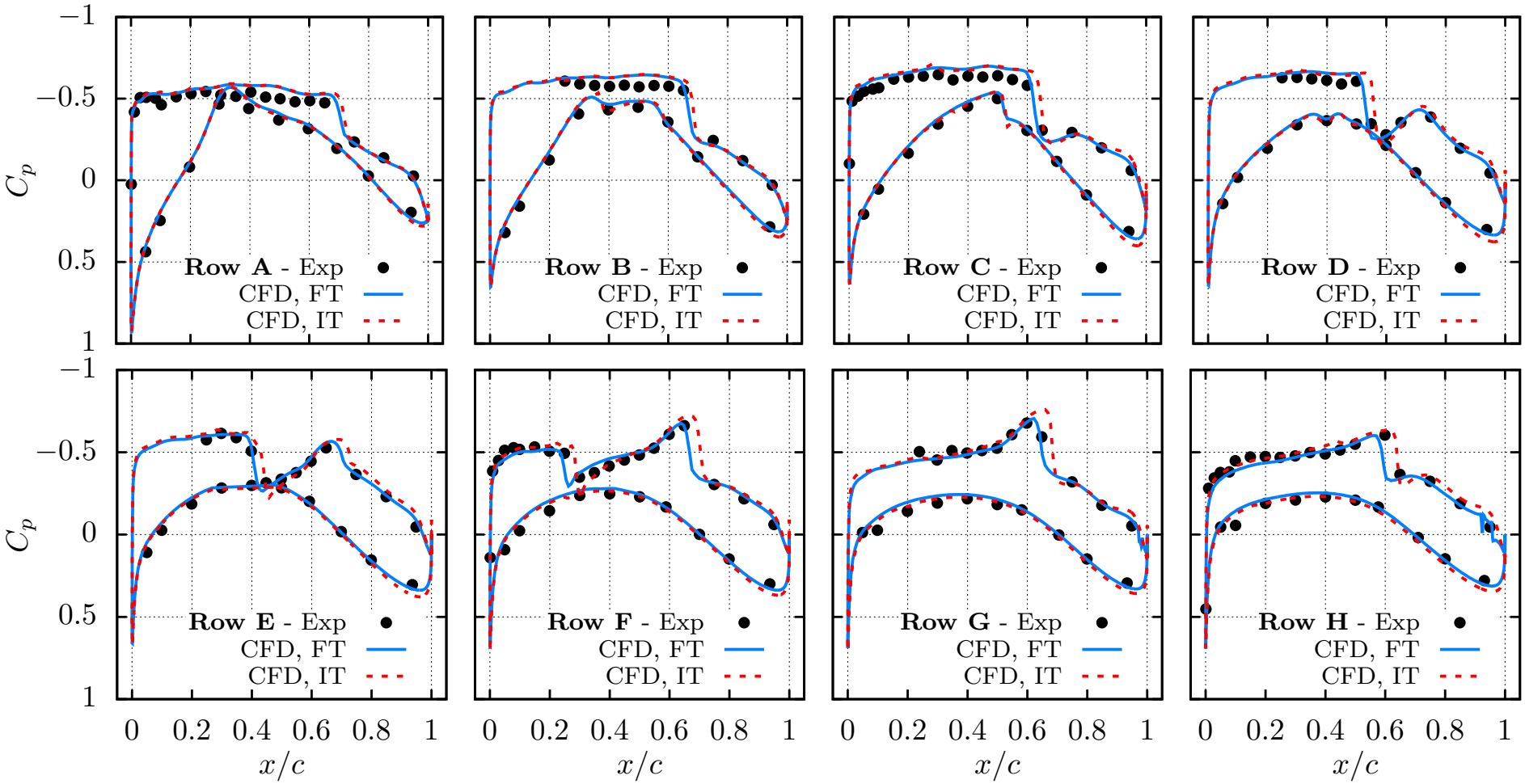
- Span locations of ports



[5] H Nichols and PG Buning. *User's manual for OVERFLOW 2.3*. 2019. URL: https://overflow.larc.nasa.gov/home/users-manual-for-overflow-2-3/.

Pressure Coefficient

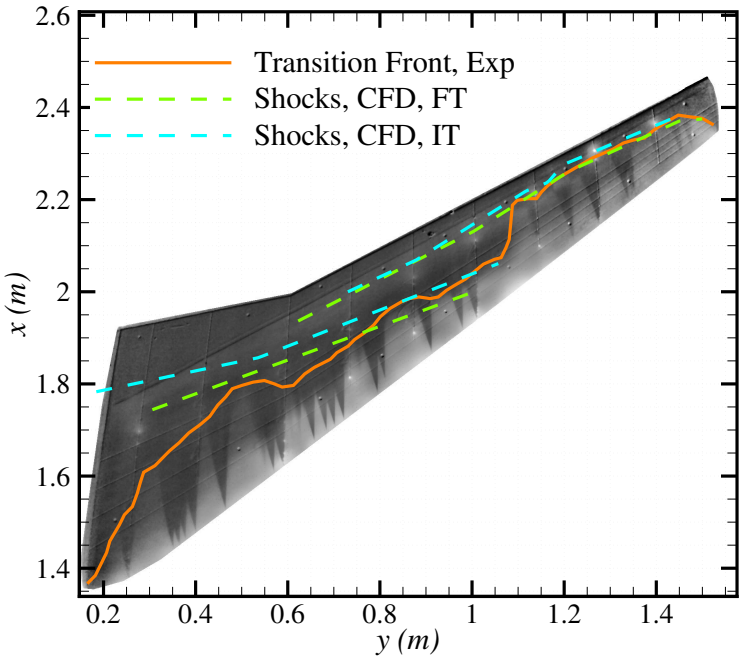
- C_p at selected span locations for case II ($Re_{MAC} = 17.5 \times 10^6$, $AoA = 1.45°$)



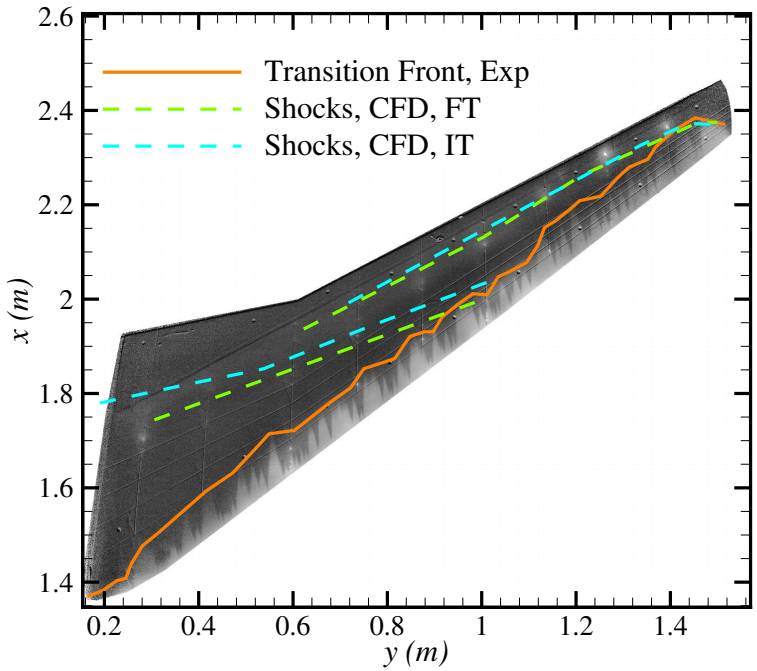
- Reasonable agreement between CFD solutions and experimental measurements
- IT solution shows delayed shock locations w.r.t. FT and Exp

Transition and Shock Fronts

- Transition location extracted from TSP image[6]
- Shock location extracted at strong C_p gradient
- Case I ($Re_{MAC} = 15$M, $AoA = 1.45°$)



- Case II ($Re_{MAC} = 17.5$M, $AoA = 1.45°$)

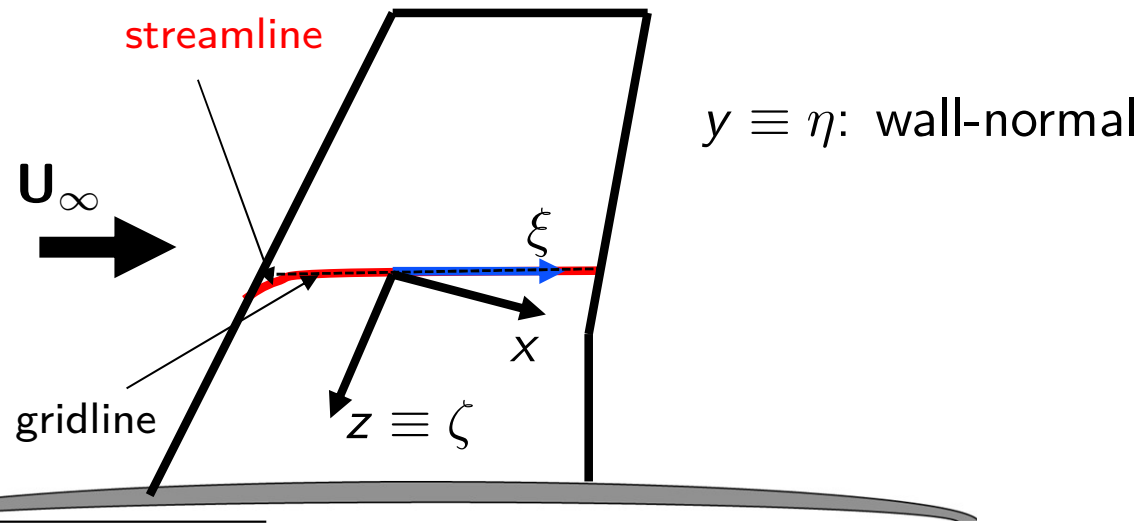


- Shocks upstream of transition front for FT solution
- Large number of wedges in case II deemed to influence early transition
- FT and IT differences due to strong viscous-inviscid interactions

[6] M.N. Lynde, R.L. Campbell, and S.A. Viken. *Additional findings from the common research model natural laminar flow wind tunnel test*. AIAA Paper 2019-3292. 2019.

Nonorthogonal parabolized stability equations (PSE)

- NASA's LASTRAC.3d solver[7]: instability analysis with LST and PSE
- Orthogonal LST (x, y, z):
  - infinite-span-wing approximation (planar waves are oblique w.r.t. streamline)
  - neglects surface curvature and nonparallel mean flow effects
- Nonorthogonal PSE (ξ, η, ζ):
  - allows clear distinction between stationary CF and planar TS waves
  - includes surface curvature and nonparallel mean flow effects

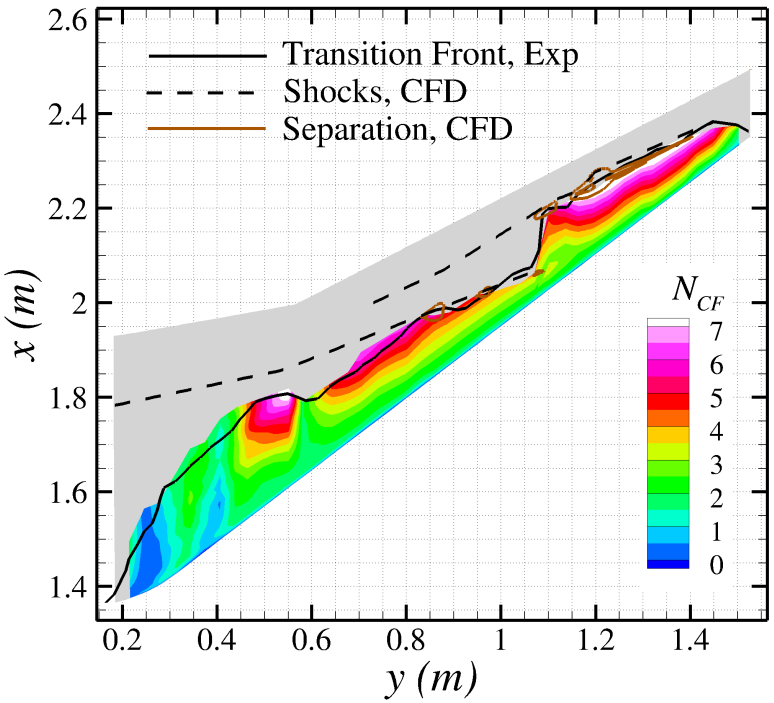


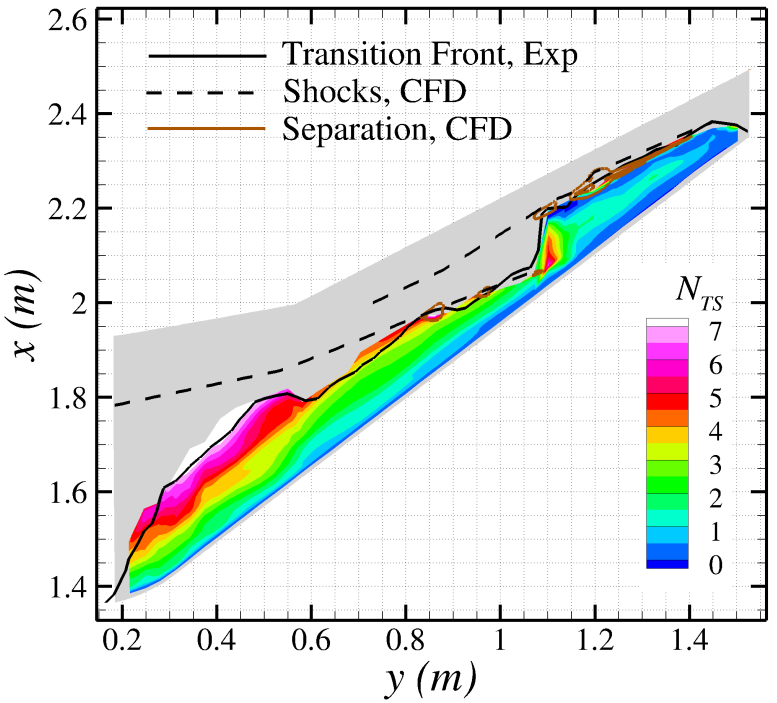
[7] C.-L. Chang. *LASTRAC.3d: Transition Prediction in 3D Boundary Layers*. AIAA Paper 2004-2542. 2004.

Linear amplification of CF and TS

Case I ($Re_{MAC} = 15$M, $AoA = 1.45°$)

- N-factors computed with nonorthogonal PSE
  - N_{CF} ($\omega = 0$)
  - N_{TS} ($\beta = 0$)



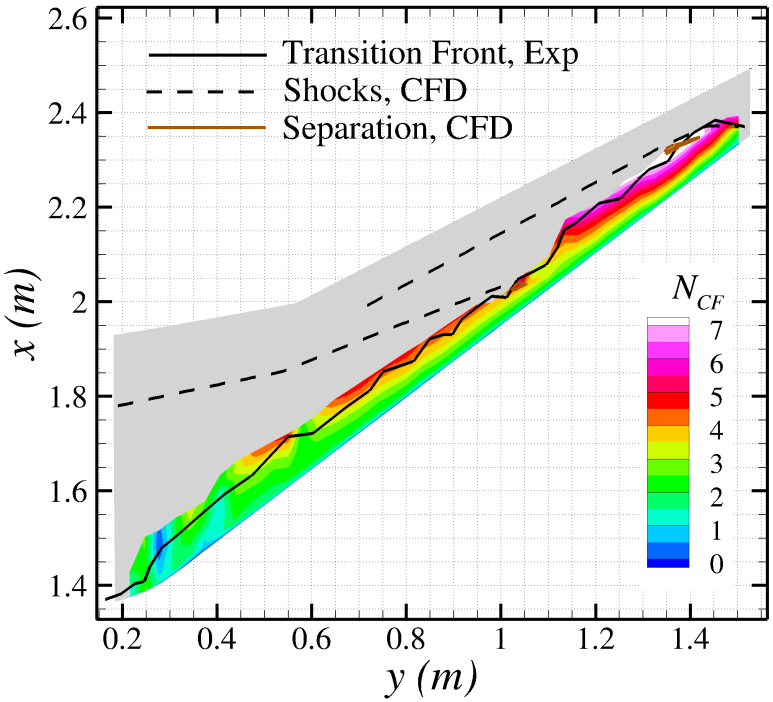


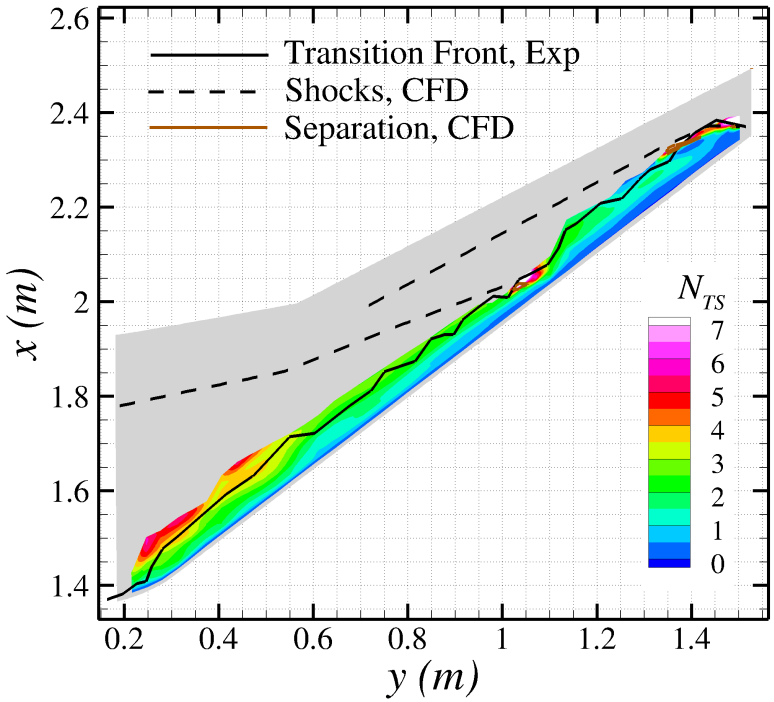
- Large values of N_{CF} in midspan and outboard regions but shock limited
- Region inboard of Yehudi break mainly dominated by TS with $N_{TS} \approx 7$

Linear amplification of CF and TS

Case II ($Re_{MAC} = 17.5$M, $AoA = 1.45°$)

- N-factors computed with nonorthogonal PSE
  - N_{CF} ($\omega = 0$)
  - N_{TS} ($\beta = 0$)





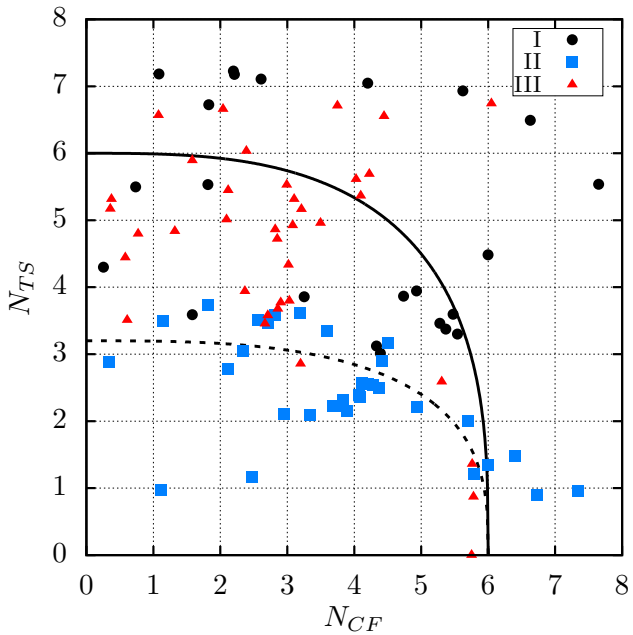
- $N_{CF} \approx 4$ over the midspan and $N_{CF} \approx 6$ in the outboard region
- Moderate $N_{TS} = 3 - 4$ along transition front up to the Yehudi break ($y < 0.6$ m)

The dual $N_{TS} - N_{CF}$ criterion[9]

- Transition onset occurs when a function of N_{TS} and N_{CF} reaches a threshold

$$\left(\frac{N_{TS}}{N_{TS,c}}\right)^{a_{TS}} + \left(\frac{N_{CF}}{N_{CF,c}}\right)^{a_{CF}} = 1$$

- $N_{TS,c} = 6$ based on wing body experiments[8], $N_{CF,c} = 6$, $a_{TS} = a_{CF} = 3$



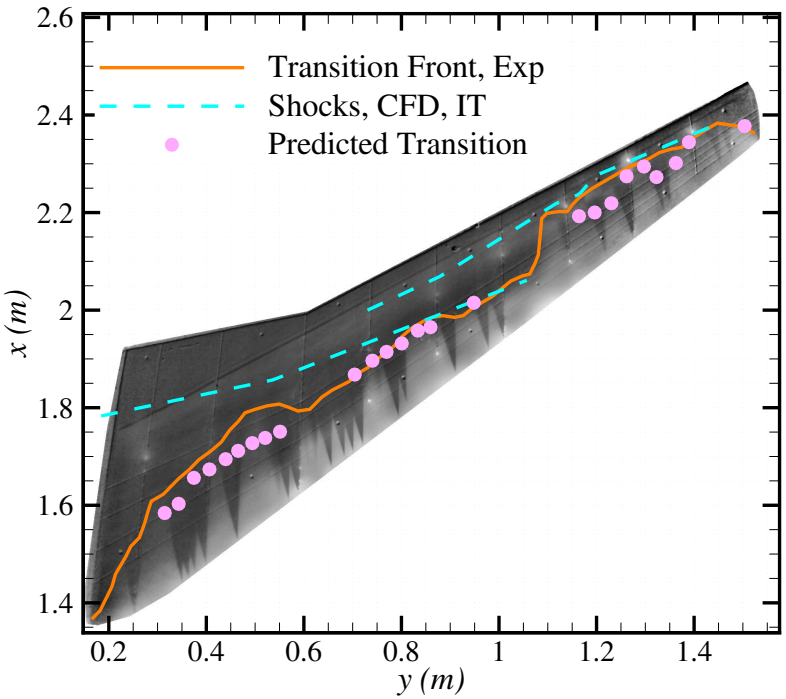
- Large scatter in $N_{TS} - N_{CF}$ data
- Case II data clustered around dashed line with $N_{TS,c} = 3.2$

[8] J. Crouch et al. *Assessment of the National Transition Facility for Natural Laminar Flow Testing*. AIAA Paper 2010-1302. 2010.

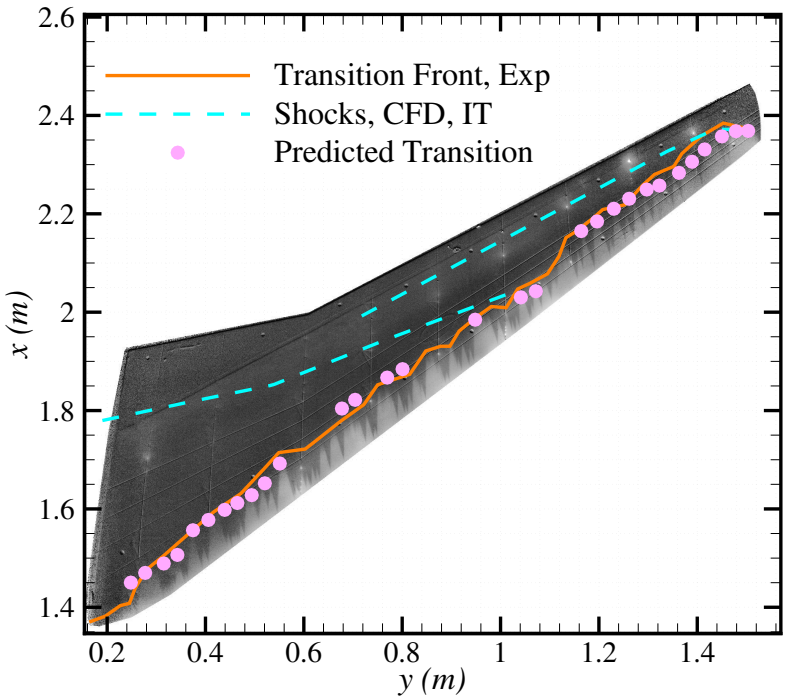
[9] D. Arnal. "Boundary layer transition: Prediction based on linear theory". In: *Special course on Progress in Transition Modeling. AGARD. R-793.* 1994, pp. 1–62.

Prediction of transition onset

- Transition onset predicted at locations where $(N_{TS}/N_{TS,c})^3 + (N_{CF}/6)^3 = 1$
  - Case I ($N_{TS,c} = 6$)



  - Case II ($N_{TS,c} = 3.2$)



- Predicted transition available only at span locations where data reach threshold
- General acceptable agreement with experimental transition fronts

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Summary

- Pressure coefficients of fully turbulent (FT) solution agree well with measured values
- Imposed transition (IT) solution show a consistent downstream shift of the shock location that indicates viscous-inviscid interaction effects
- Instability results agree with previous observations
  - Dominant TS within the inboard region of the wing
  - Dominant CF in the outboard region, but transition onset limited by shocks
- Despite the large scatter in the $N_{TS} - N_{CF}$ pairs, the predicted transition where the stability data reach the critical $N_{TS}(N_{CF})$ value shows a favorable agreement with experimental data.
- Future work:
  - Transition analysis for lower Re configurations and additional angles of attack
  - Computations with fixed lift coefficient instead of fixed angle of attack

Thank you for your attention

- Acknowledgements
  - This research was sponsored by the NASA Transformational Tools and Technologies (TTT) Project of the Transformative Aeronautics Concepts Program (TACP) under the Aeronautics Research Mission Directorate (ARMD)
  - Resources supporting this work were provided by the NASA High-End Computing (HEC) Program through the NASA Advanced Supercomputing (NAS) Division at Ames Research Center and by the LaRC K-Midrange Cluster at Langley Research Center.
  - We thank the CRM-NLF Team, and especially Richard Campbell, Michelle Lynde, and Sally Viken, for sharing details about CRM-NLF experiment and associated computations.

