Contribution to HiLiftPW-3

Jim Coder[1], Tom Pulliam[2], Jeff Slotnick[3], David Yeh[3]

[1]University of Tennessee, Knoxville, [2]NASA Ames Research Center,

[3]The Boeing Company

PID 005

3rd High Lift Prediction Workshop
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Summary of cases completed: OVERFLOW 2.2

Case	Alpha=8, Fully turb, grid study	Alpha=16, Fully turb, grid study	Other
1a (full gap)	no	no	
1b (full gap w adaption)	no	no	
1c (partial seal)	no	no	
1d (partial seal w adaption)	no	no	
Other	-	-	

(copy this page if submitting multiple code, grid series, or turbulence model results)

Case	Polar, Fully turb	Polar, specified transition	Polar, w transition prediction	Other
2a (no nacelle)	yes	yes	yes	Transition predicted with AFT2017b model
2b (no nacelle w adaption)	no	no	no	
2c (with nacelle)	yes	yes	yes	Transition predicted with AFT2017b model
2d (with nacelle w adaption)	no	no	no	
Other	-	-	-	

Case	2D Verification study	Other
3	no	
Other	-	

Summary of Code and Numerics Used

- OVERFLOW 2.2
  - Structured, overset, finite-difference solver
  - Non-time-accurate
  - 3rd-order MUSCL scheme with Roe fluxes
  - Implicit Pulliam-Chaussee scalar pentadiagonal algorithm
    - Recommended values of artificial dissipation
  - Quadratic constitutive relationship (2000 version)
    - $C_{NL1} = 0.3$
  - Spalart-Shur rotation/curvature correction
  - Spalart-Allmaras eddy-viscosity model
    - Fully turbulent: SA-**noft2**-RC-QCR2000
    - Transition prediction: SA-RC-QCR2000-**AFT2017b**
    - Prescribed transition: SA-**Ia**-RC-QCR2000
  - Free-stream turbulence: Tu = 0.16%, $\mu_t/\mu = 2.8 \times 10^{-7}$

Transition Modeling Strategy

- SA-RC-QCR2000-AFT2017b model
  - Based on Spalart-Allmaras eddy-viscosity model

$$\frac{D\tilde{\nu}}{Dt} = c_{b1}\left(1 - f_{t2}\right)\tilde{S}\tilde{\nu} - \left(c_{w1}f_w - \frac{c_{b1}}{\kappa^2}f_{t2}\right)\left(\frac{\tilde{\nu}}{d}\right)^2 + \frac{1}{\sigma}\left\{\frac{\partial}{\partial x_j}\left[\left(\nu + \tilde{\nu}\right)\frac{\partial \tilde{\nu}}{\partial x_j}\right] + c_{b2}\frac{\partial \tilde{\nu}}{\partial x_j}\frac{\partial \tilde{\nu}}{\partial x_j}\right\}$$

  - With two additional transported scalars

$$\frac{\partial\left(\rho\tilde{n}\right)}{\partial t} + \frac{\partial\left(\rho u_j \tilde{n}\right)}{\partial x_j} = \rho\Omega F_{crit}F_{growth}\frac{d\tilde{n}}{dRe_\theta} + \frac{\partial}{\partial x_j}\left[\left(\mu + \sigma_n \mu_t\right)\frac{\partial \tilde{n}}{\partial x_j}\right]$$

$$\frac{\partial\left(\rho\tilde{\gamma}\right)}{\partial t} + \frac{\partial\left(\rho u_j \tilde{\gamma}\right)}{\partial x_j} = c_1\rho S F_{onset}\left[1 - \exp\left(\tilde{\gamma}\right)\right] - c_2\rho\Omega F_{turb}\left[c_3\exp\left(\tilde{\gamma}\right) - 1\right] + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\gamma}\right)\frac{\partial \tilde{\gamma}}{\partial x_j}\right]$$

  - Coupling takes place through

$$f_{t2} = c_{t3}\left[1 - \exp\left(\tilde{\gamma}\right)\right]$$

Transition Modeling Strategy

- AFT equation
  - Based on model of Coder and Maughmer (2014) and Coder (2017)

$$\frac{\partial(\rho\tilde{n})}{\partial t}+\frac{\partial(\rho u_j\tilde{n})}{\partial x_j}=\rho\Omega F_{crit}F_{growth}\frac{d\tilde{n}}{dRe_\theta}+\frac{\partial}{\partial x_j}\left[(\mu+\sigma_n\mu_t)\frac{\partial\tilde{n}}{\partial x_j}\right]$$

$$H_L=\frac{d^2}{\nu}\left[\nabla(\rho\vec{u}\cdot\nabla d)\cdot\nabla d\right] \qquad H_{12}=0.3770+\sqrt{\frac{H_L+2.4534}{0.6532}}$$

$$F_{crit}=\begin{cases}0, & Re_V<Re_{V,0}\\ 1, & Re_V\geq Re_{V,0}\end{cases} \qquad \frac{Re_{V,0}}{Re_{\theta,0}}=0.2462H_{12}{}^2-0.1418H_{12}+0.0089 \qquad Re_V=\frac{\rho S d^2}{\mu+\mu_t}$$

$$F_{growth}=\frac{H_{12}}{0.5482H_{12}-0.5185}\left(1+m(H_{12})\right)\frac{l(H_{12})}{2}$$

- $l(H_{12})$, $m(H_{12})$, $Re_{\vartheta,0}$, and $d\tilde{n}/dRe_\vartheta$ are functions of H_{12}, and their definitions are in the above references

Transition Modeling Strategy

- Intermittency equation
  - Based on the Menter 2015 transition model

$$\frac{\partial(\rho\tilde{\gamma})}{\partial t}+\frac{\partial(\rho u_j\tilde{\gamma})}{\partial x_j}=c_1\rho S F_{onset}\left[1-\exp(\tilde{\gamma})\right]-c_2\rho\Omega F_{turb}\left[c_3\exp(\tilde{\gamma})-1\right]+\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\gamma}\right)\frac{\partial\tilde{\gamma}}{\partial x_j}\right]$$

$$F_{onset,1}=\min\left(\frac{\tilde{n}}{N_{crit}},2\right) \qquad F_{onset,2}=\max\left[1-\left(\frac{\mu}{3.5\mu_t}\right)^3,0\right] \qquad F_{onset}=\max\left[F_{onset,1}-F_{onset,2},0\right]$$

$$N_{crit}=-8.43-2.4\ln\left(\frac{Tu(\%)}{100}\right) \qquad F_{turb}=\exp\left[-\left(\frac{\mu}{2\mu_t}\right)^4\right]$$

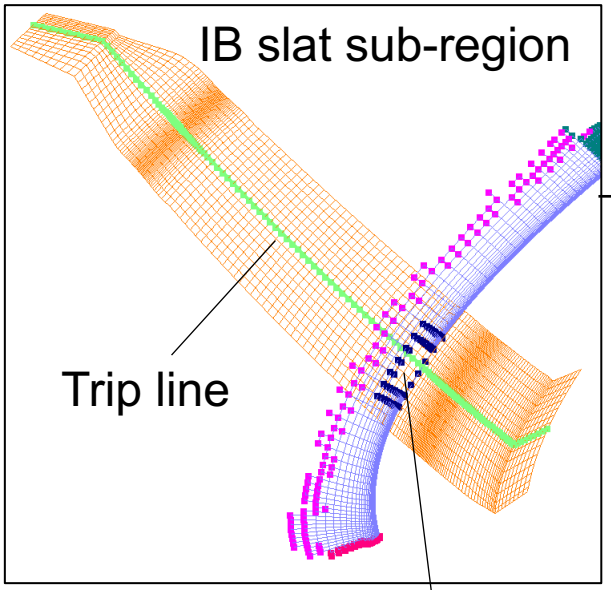
  - with c_1 = 100, c_2 = 0.06, c_3 = 50, σ_γ = 1

  - Maps to “true” intermittency (binary logic) as

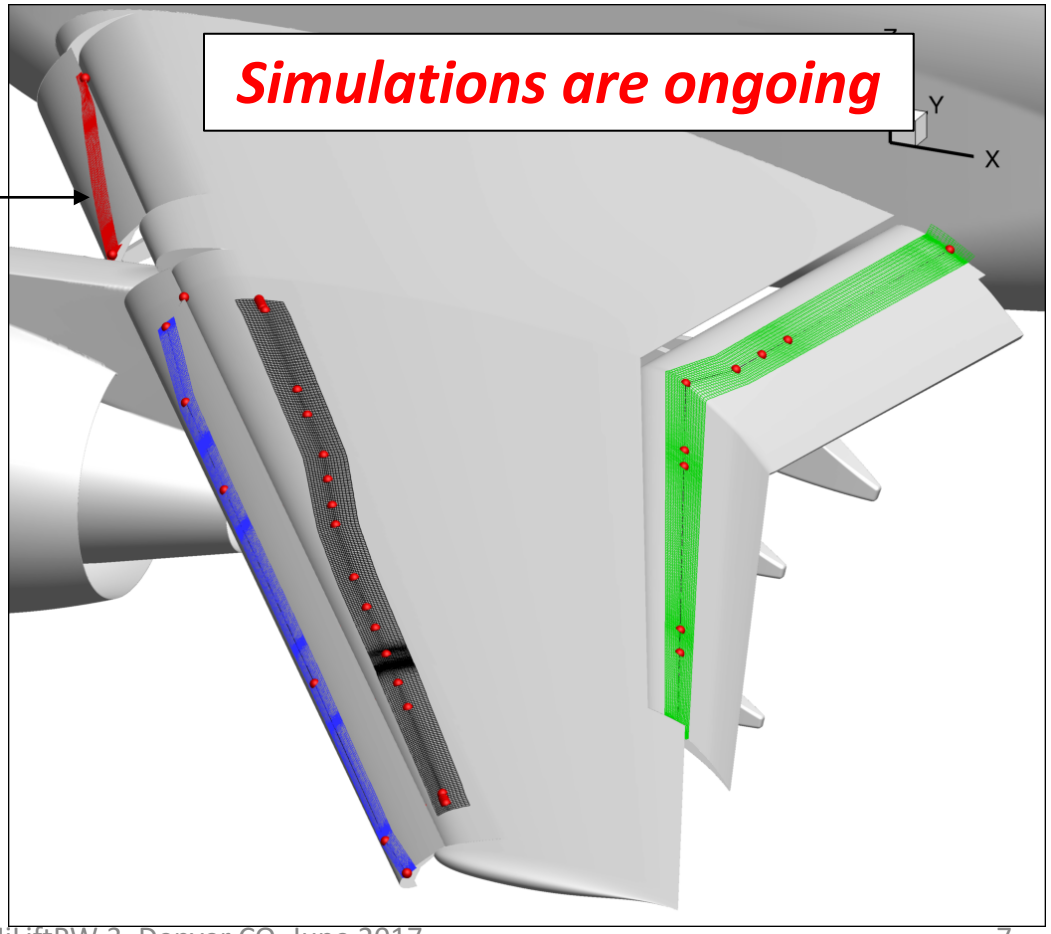
$$\gamma=\exp(\tilde{\gamma})$$

Prescribed Transition Strategy

- SA Trip Line method of Yeh and Slotnick (2017)
  - Specify transition line segments in sub-regions
  - Try to specify the transition in other regions using the existing grid lines

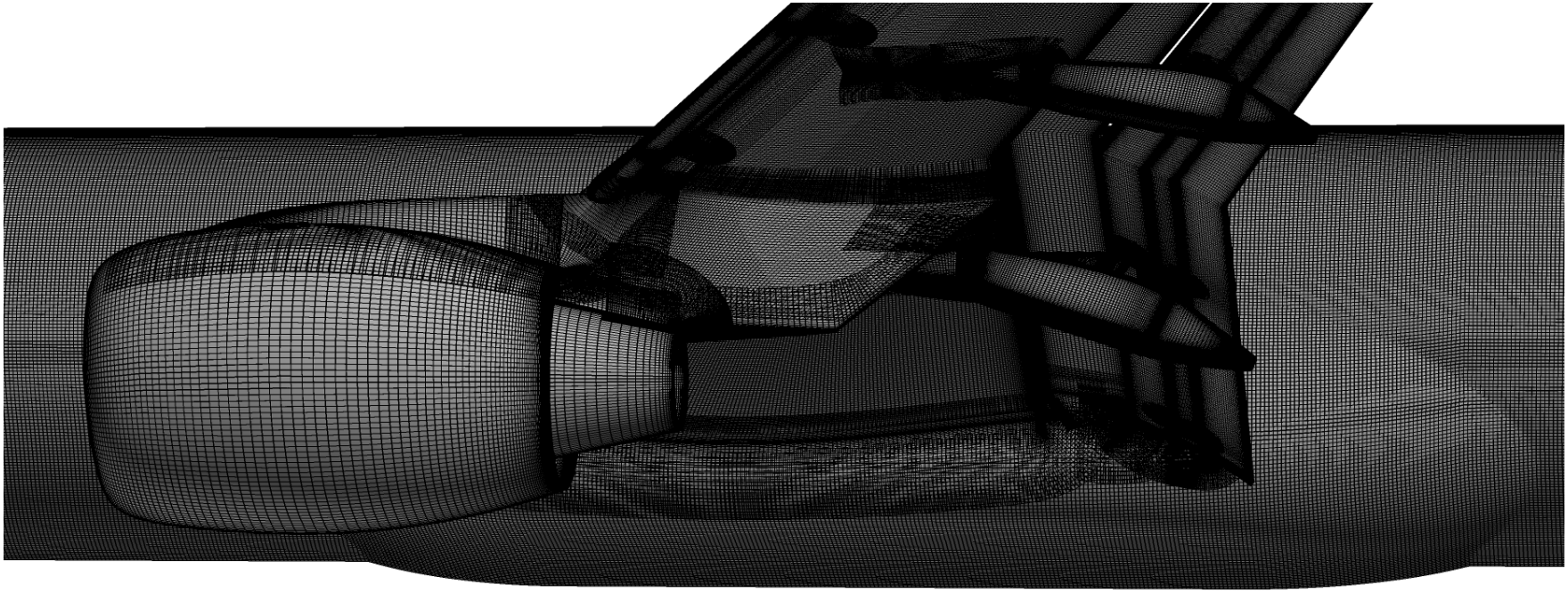


Holes are created in grids overset with the sub-region



Grid Systems

Grid System	Case(s)	If committee grid, report any problems/issues If user grid, reason for generating grid system
Committee (Grid name)	2a, 2c	No issues, just very large
User (Grid type/description)	-	
Other	2a, 2c	Committee-provided grids modified to include trip zone for prescribed transition



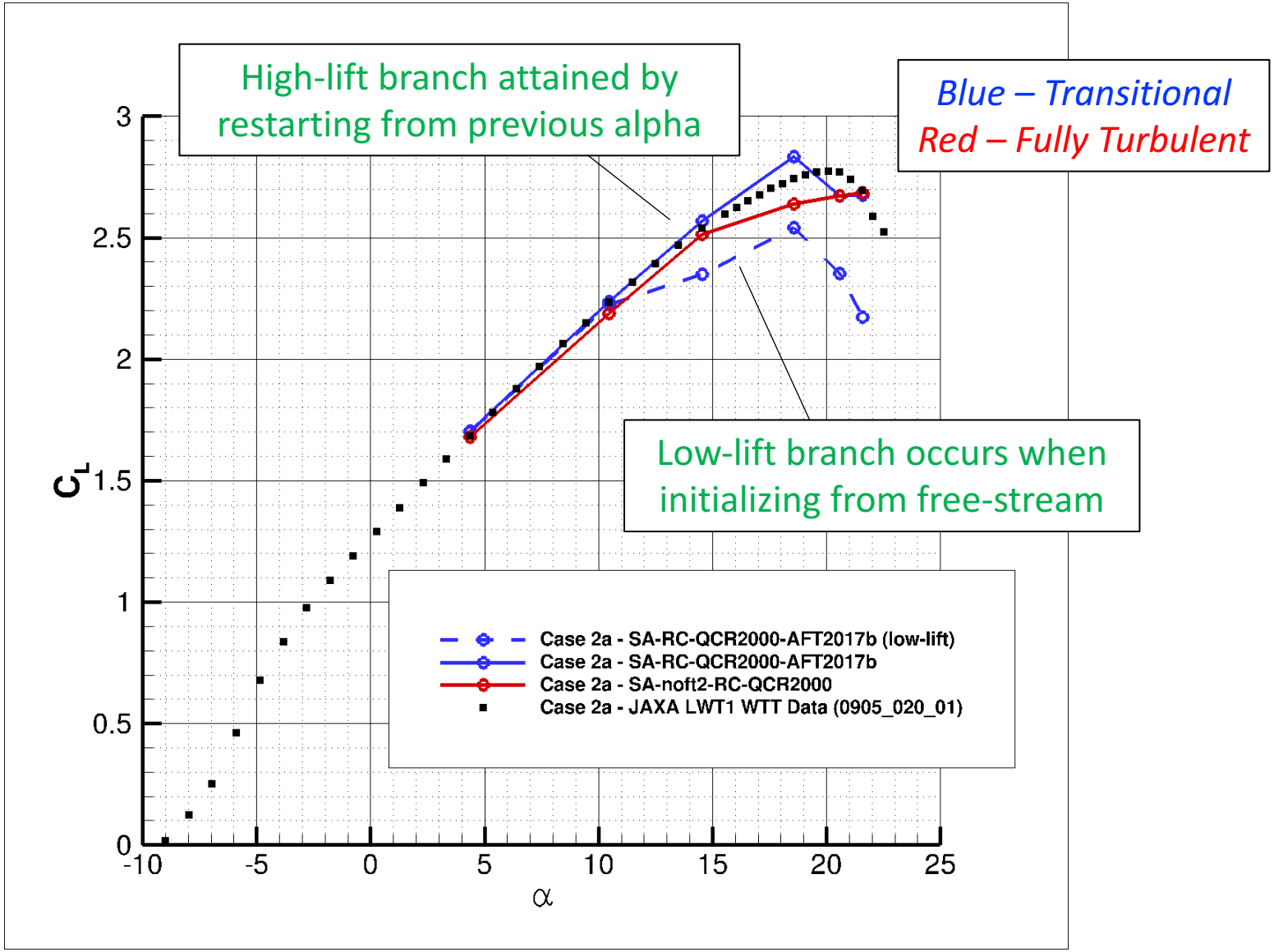
Summary of JSM Results

- JSM simulated fully turbulent and with transition prediction
  - N_{crit} = 7 (consistent with reported FSTI)
  - Goal is to determine the impact of transition on predicted forces and moments

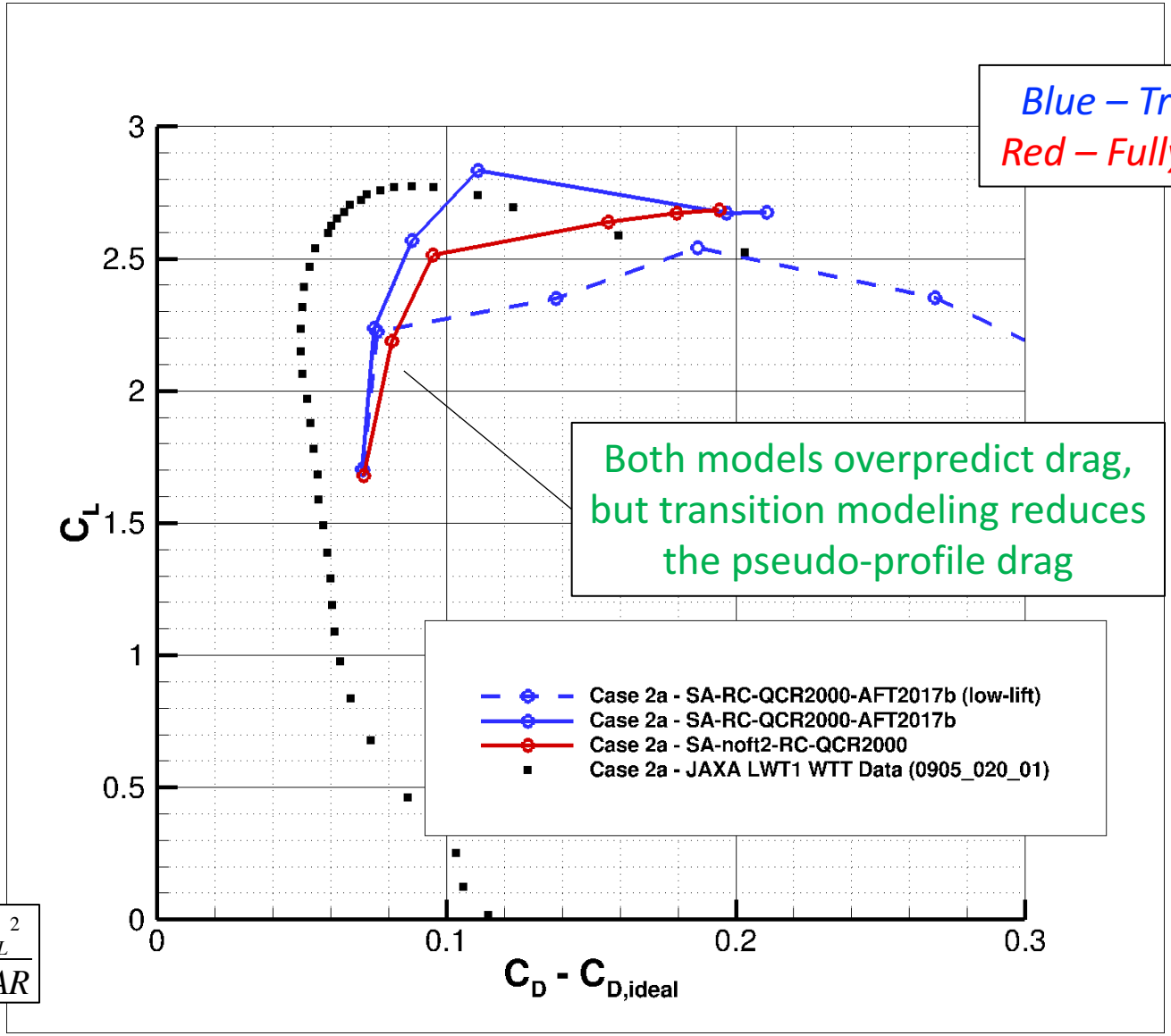
- Initialization from free-stream as well as previous angle-of-attack considered
  - Free stream → low-lift branch
  - Previous alpha → high-lift branch
  - Bifurcation happens between 10 and 14 degrees

- Solutions were run until apparent force/moment convergence
  - Residual unsteadiness persisted
  - Fully turbulent solutions showed less oscillation than transitional solutions

JSM Nacelle/Pylon OFF Forces & Moments



JSM Nacelle/Pylon OFF Forces & Moments

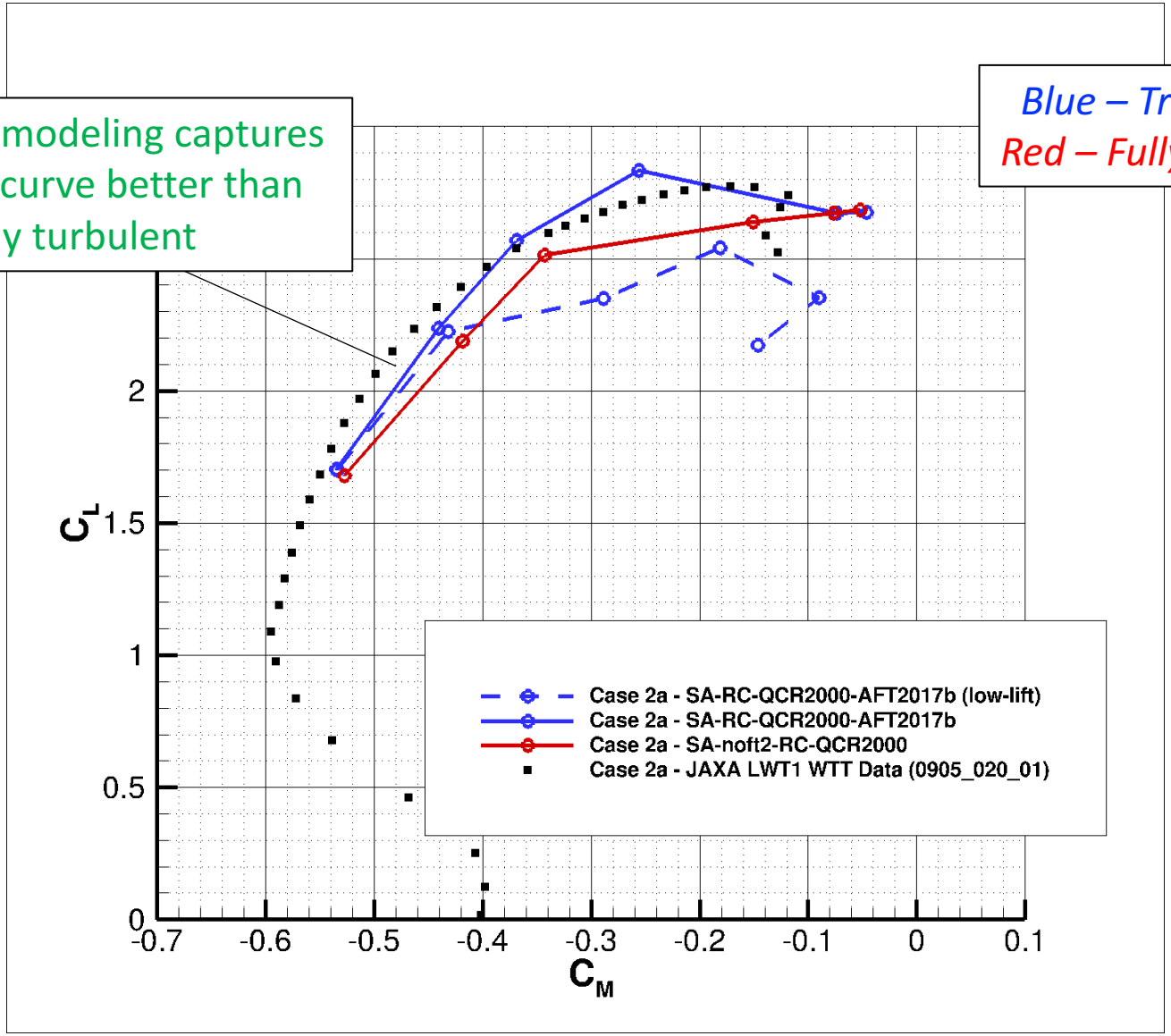


$$C_{D,ideal} = \frac{C_L^{\,2}}{\pi AR}$$

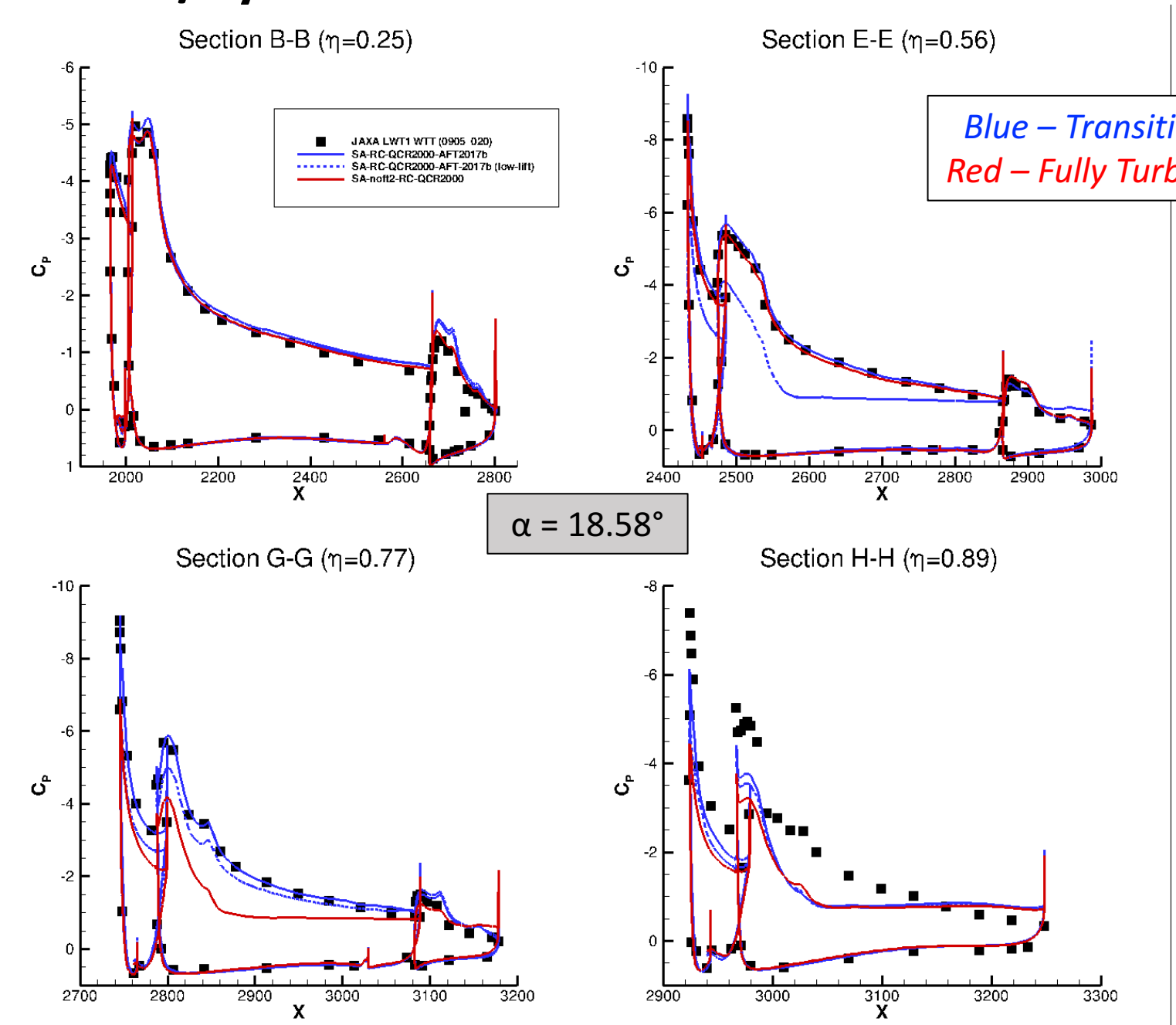
JSM Nacelle/Pylon OFF Forces & Moments

Transition modeling captures moment curve better than fully turbulent

Blue – Transitional
Red – Fully Turbulent

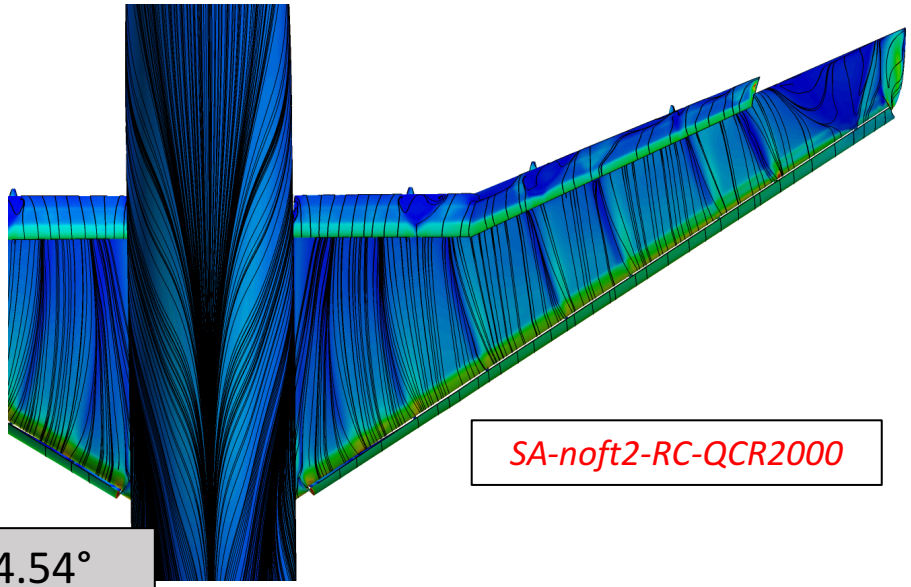


JSM Nacelle/Pylon OFF Pressure Distributions



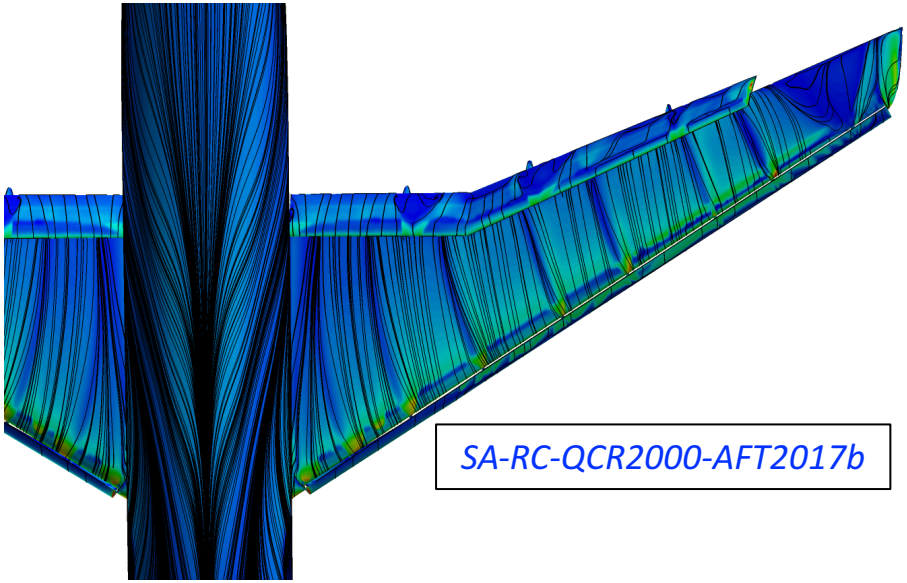
JSM Nacelle/Pylon OFF Surface Flow Patterns

Surface vorticity magnitude with surface streamlines

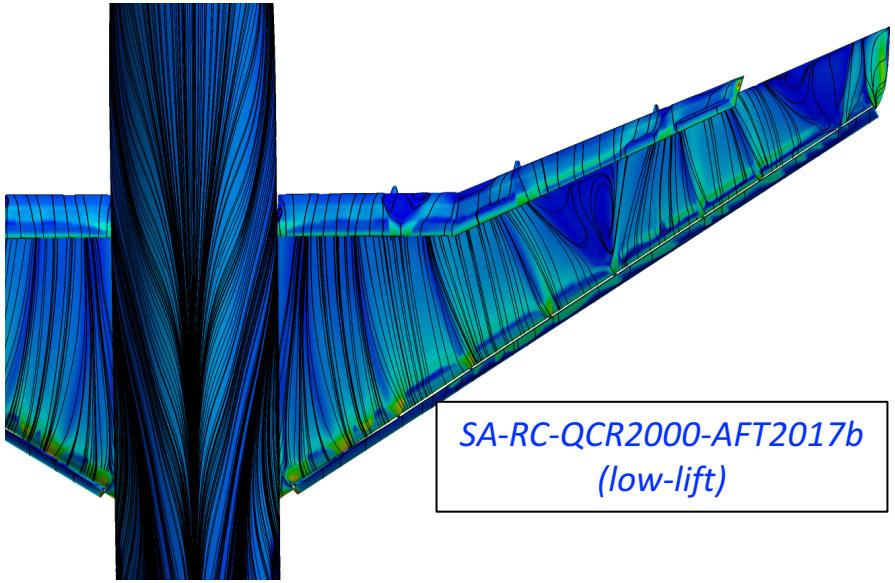


SA-noft2-RC-QCR2000

α = 14.54°

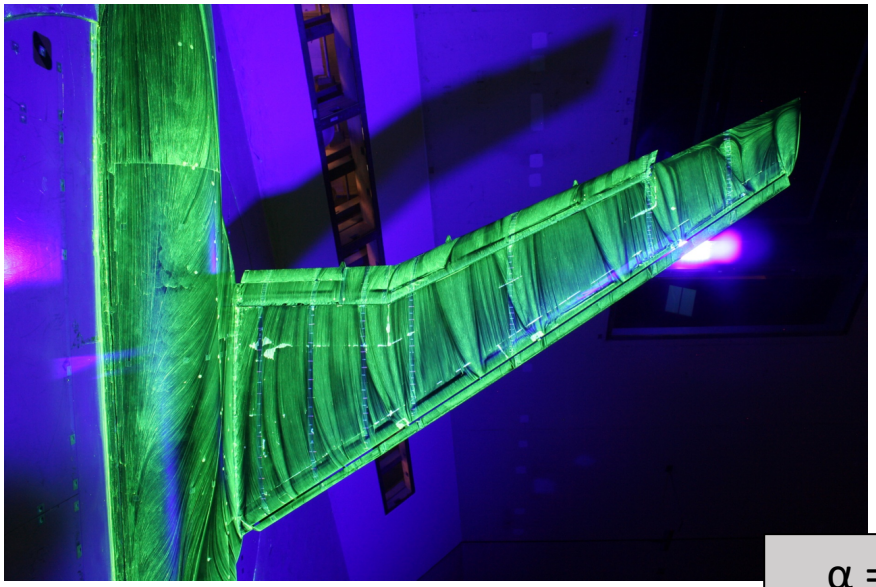


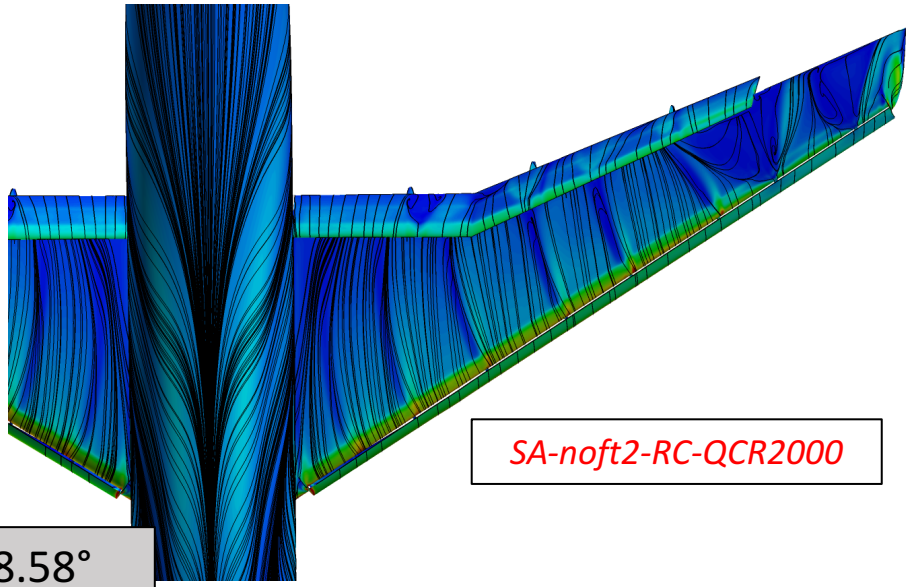
SA-RC-QCR2000-AFT2017b



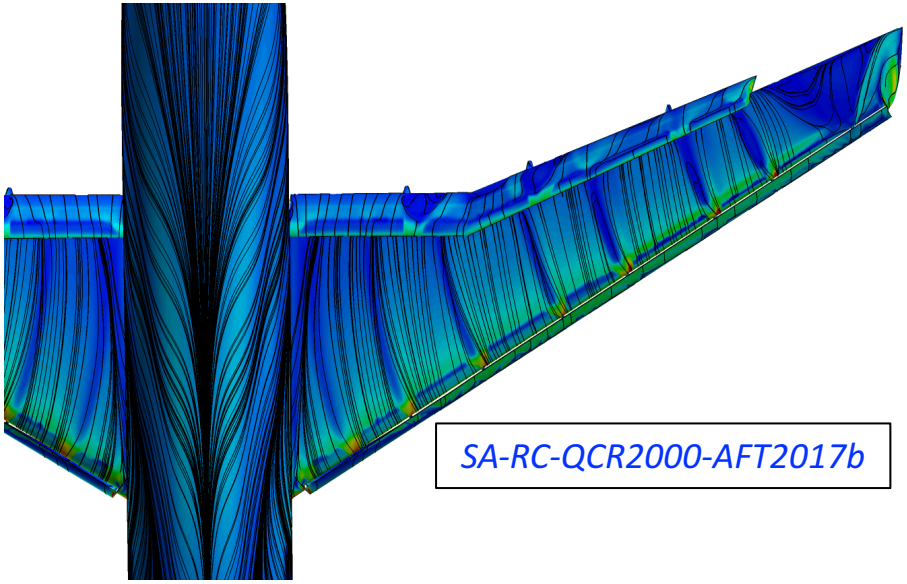
SA-RC-QCR2000-AFT2017b (low-lift)

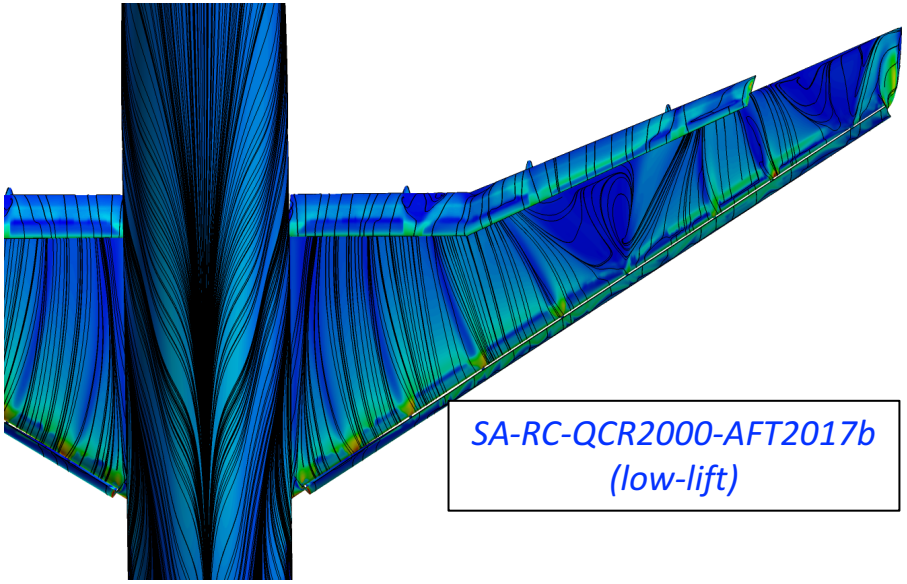
JSM Nacelle/Pylon OFF Surface Flow Patterns



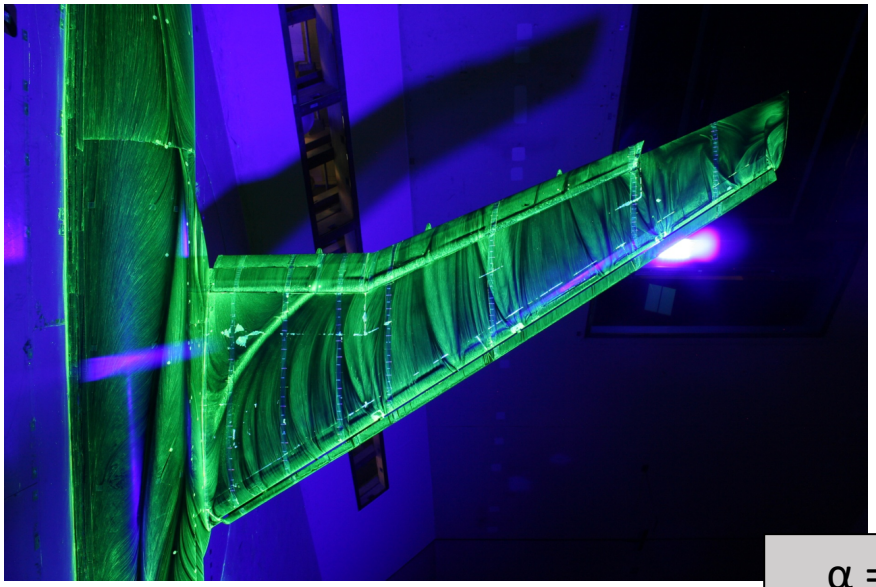


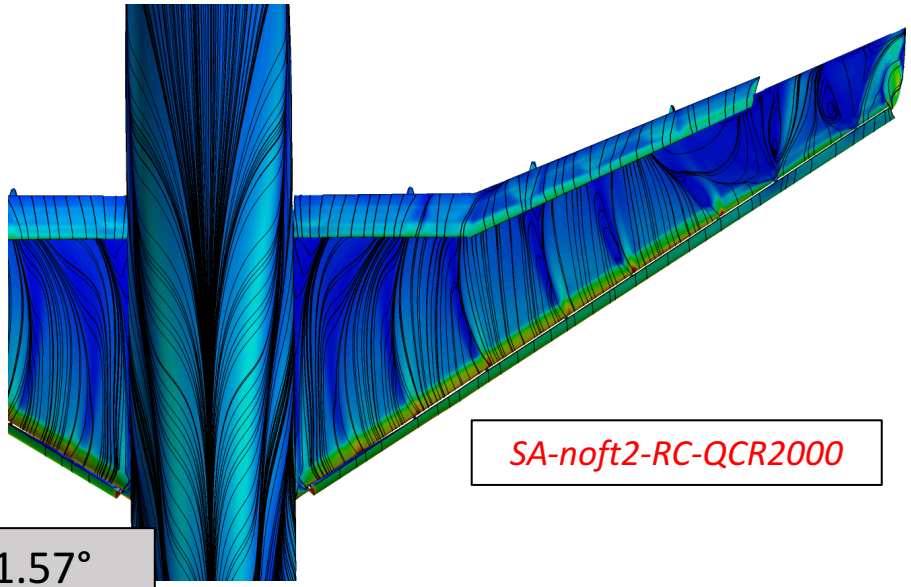
α = 18.58°



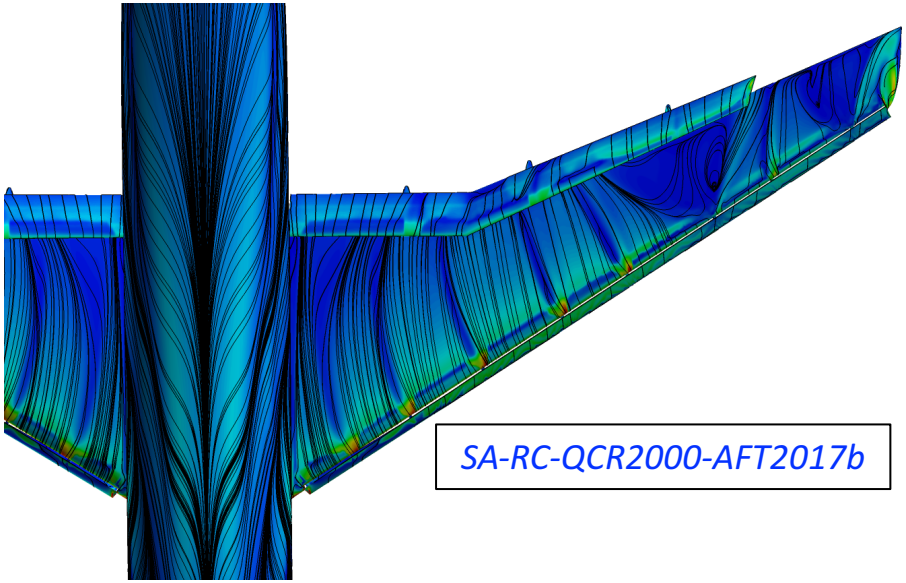


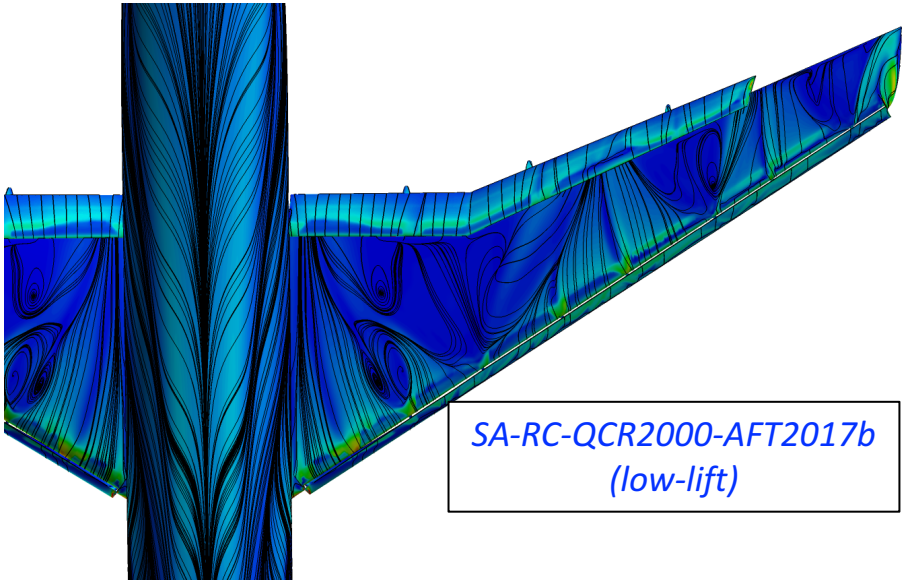
JSM Nacelle/Pylon OFF Surface Flow Patterns



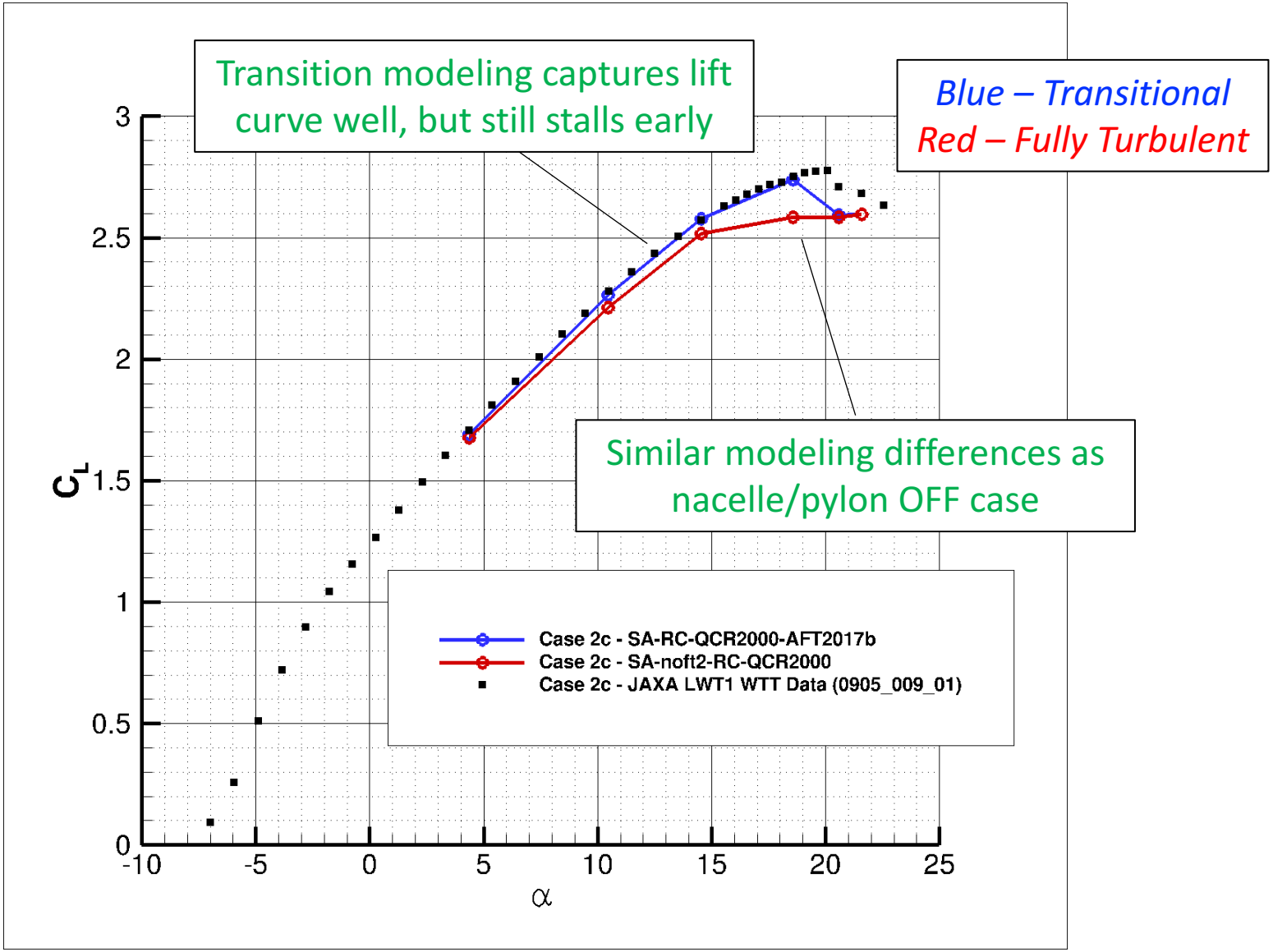


α = 21.57°

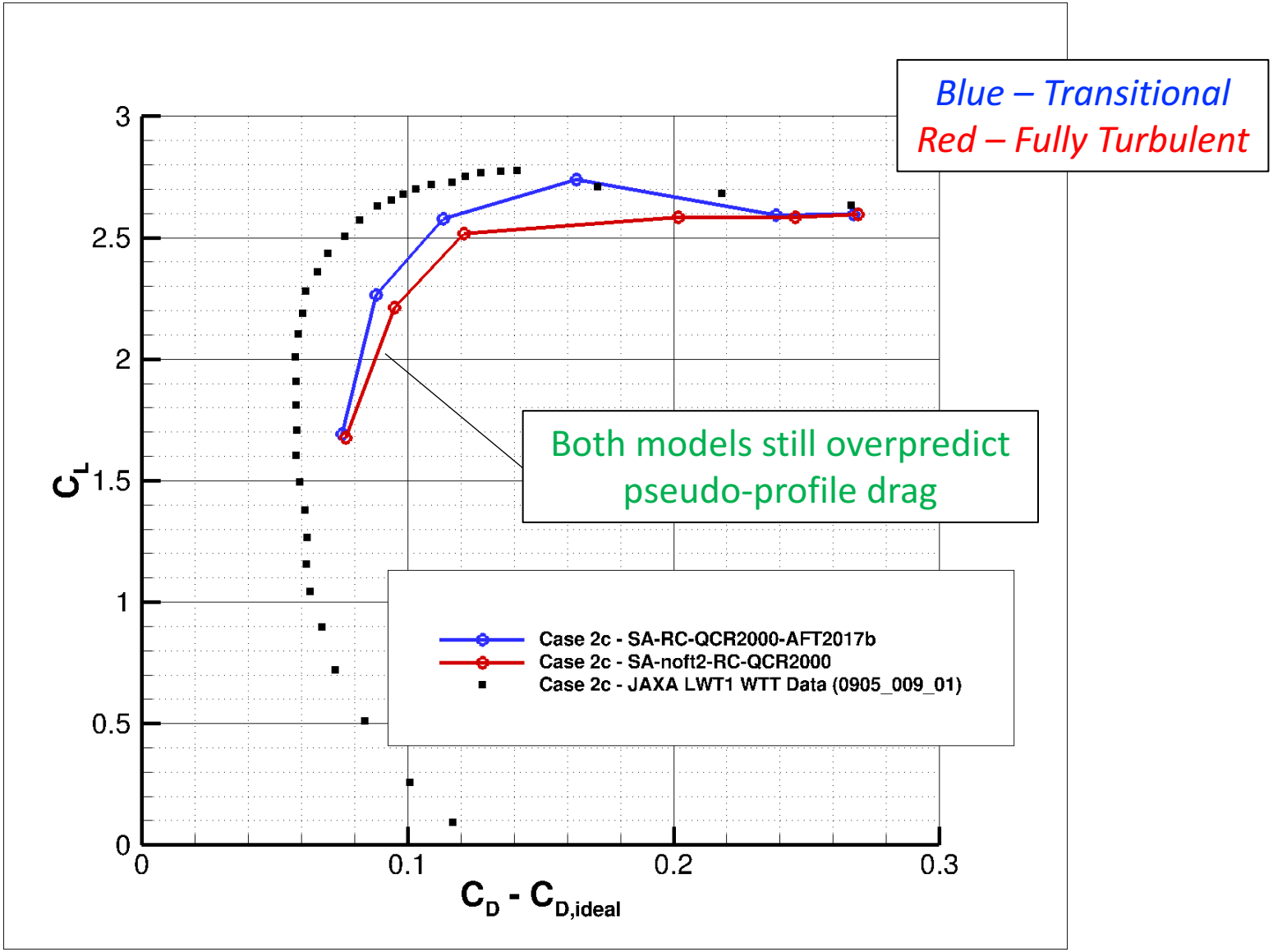




JSM Nacelle/Pylon ON Forces & Moments



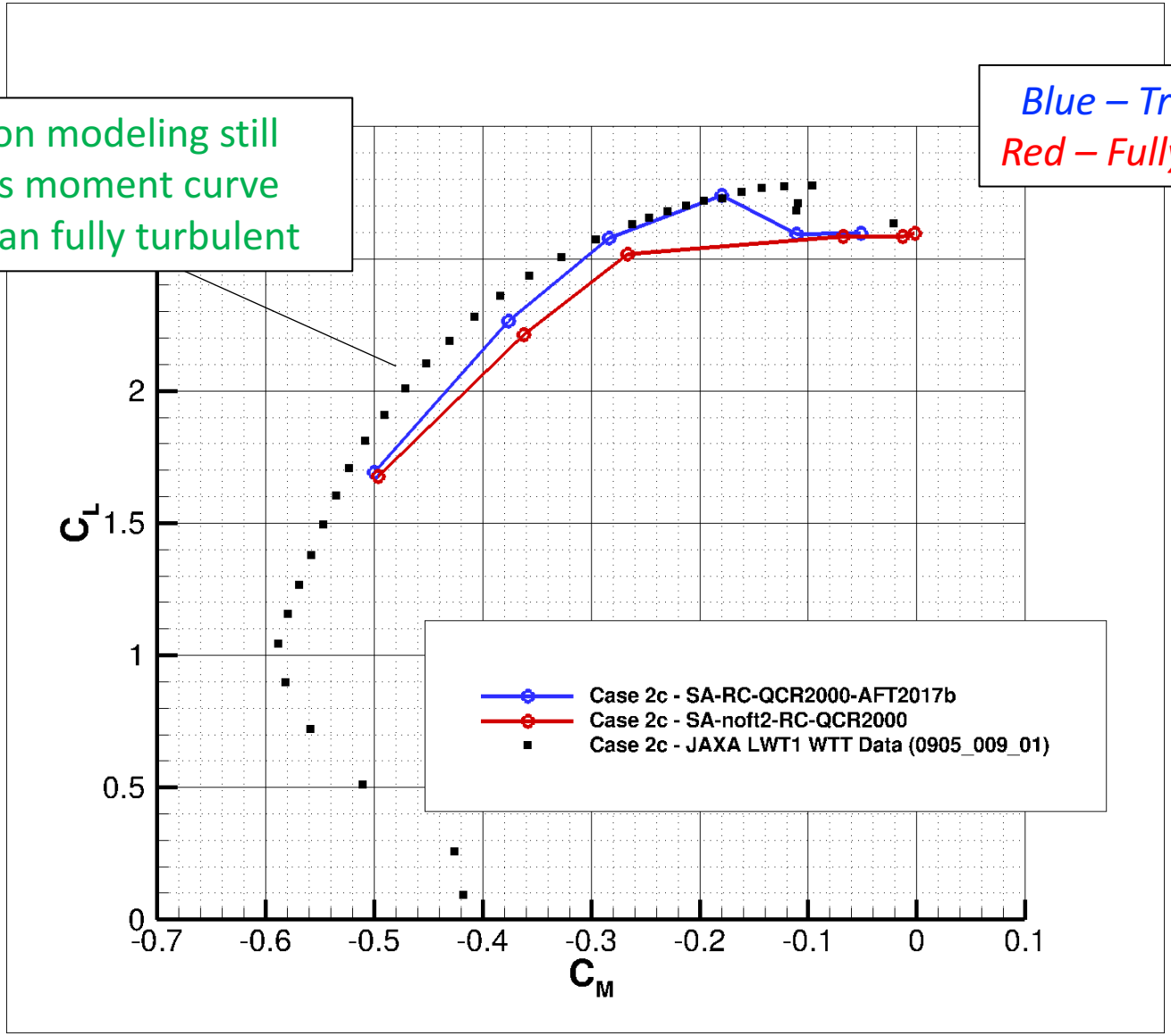
JSM Nacelle/Pylon ON Forces & Moments



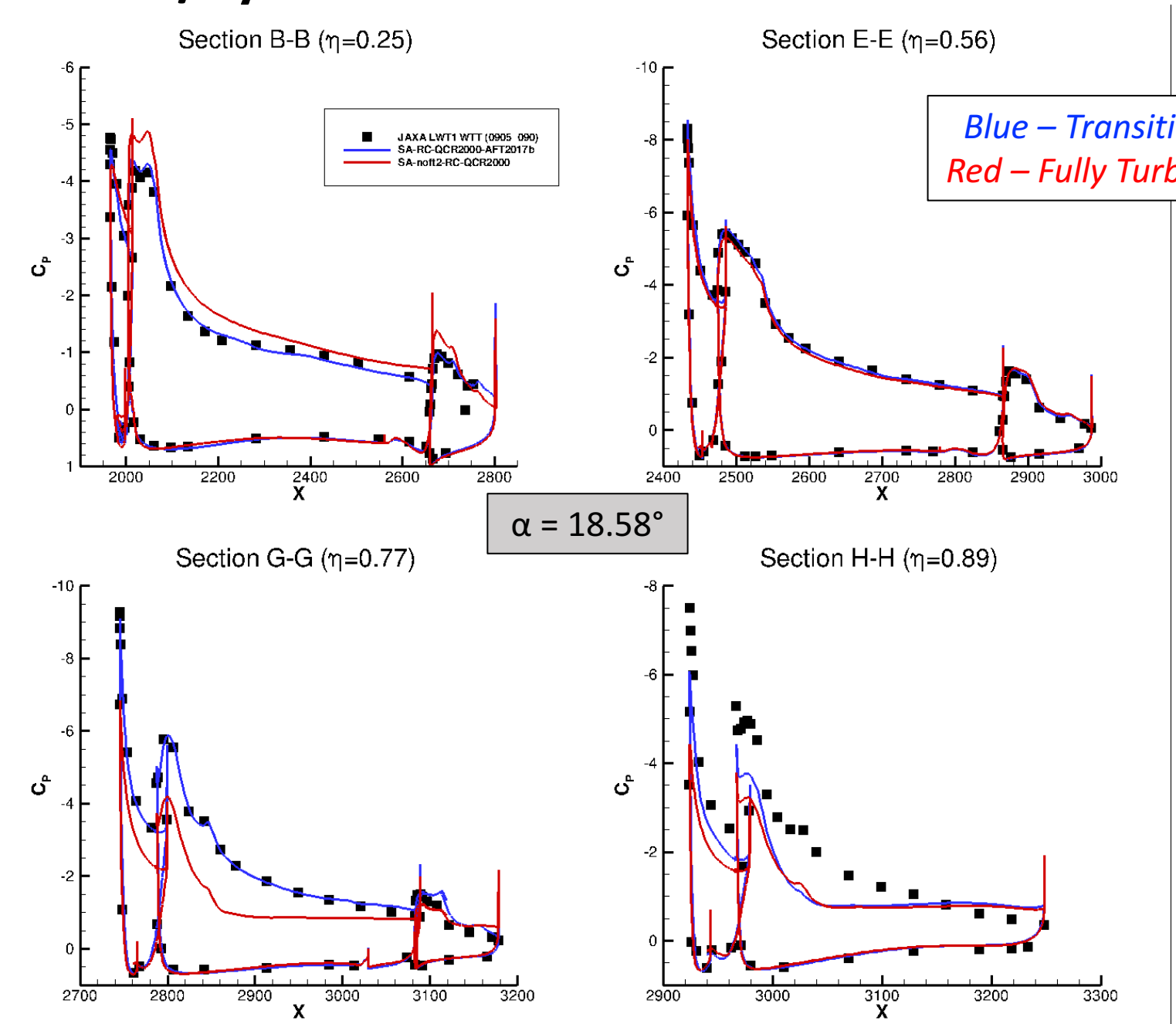
JSM Nacelle/Pylon ON Forces & Moments

Transition modeling still captures moment curve better than fully turbulent

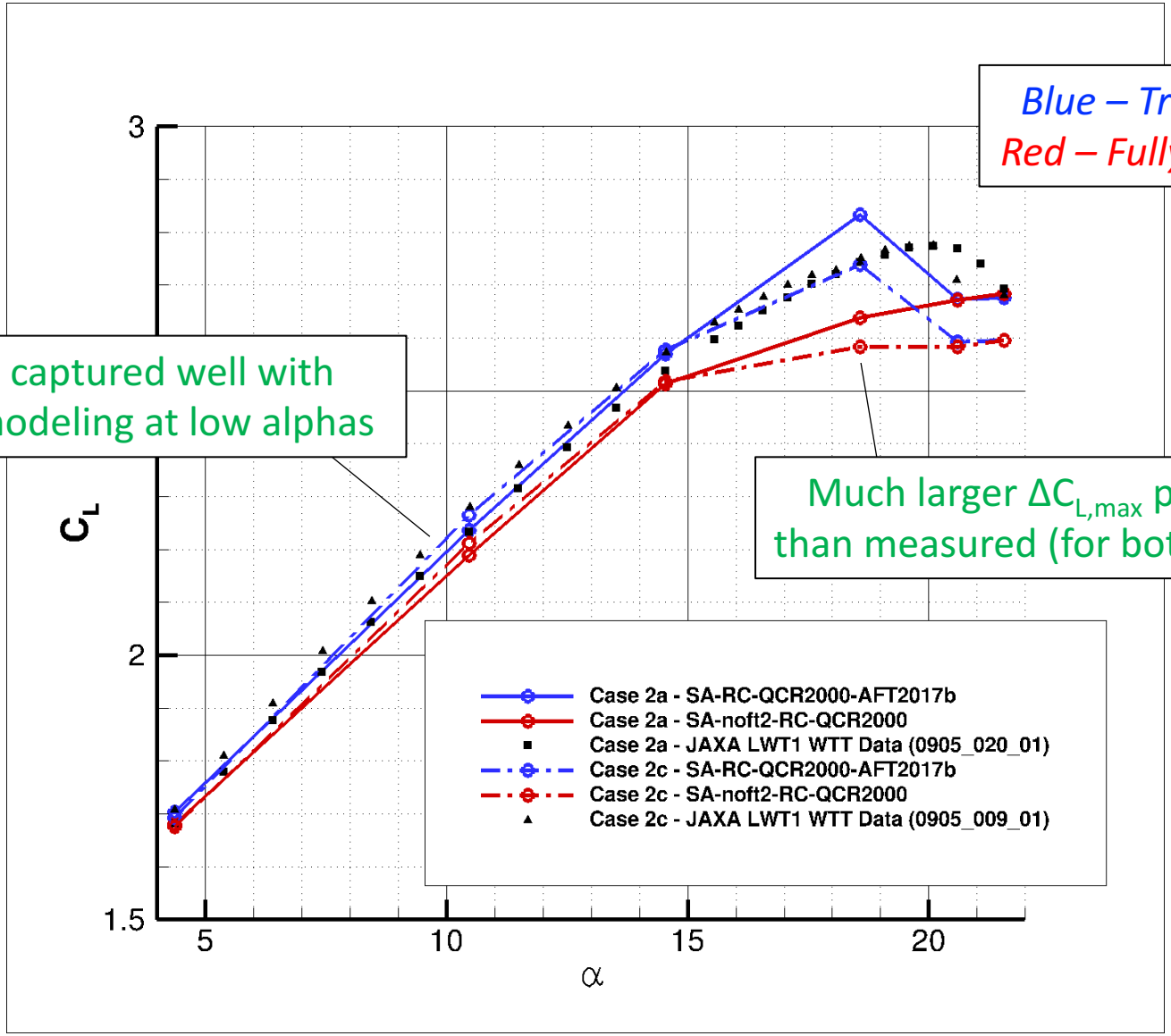
Blue – Transitional
Red – Fully Turbulent



JSM Nacelle/Pylon ON Pressure Distributions



JSM Nacelle/Pylon ON vs. OFF

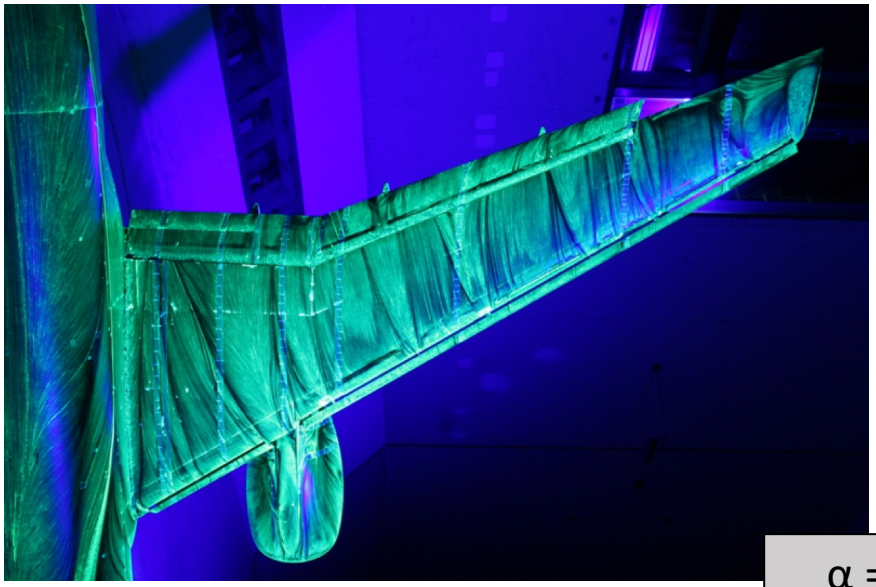


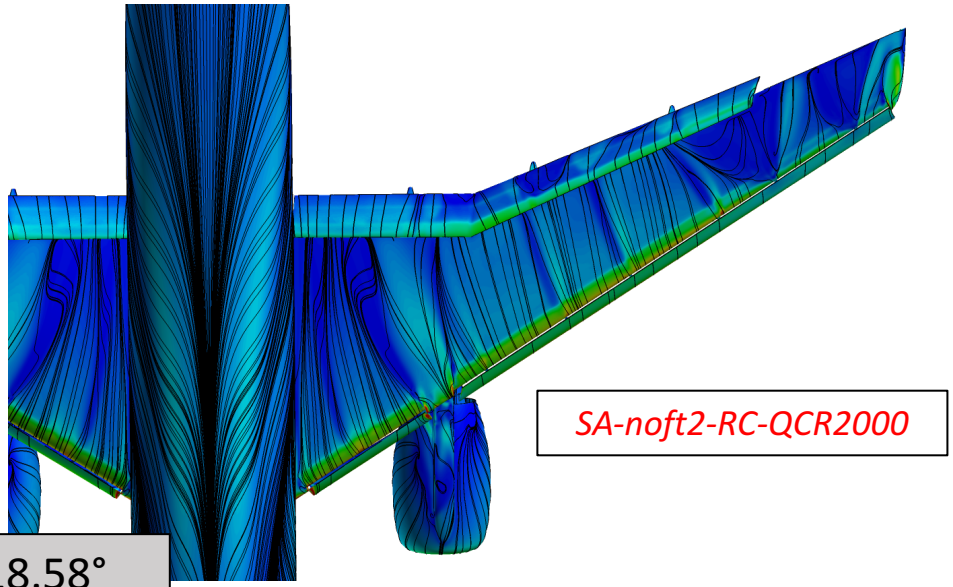
Blue – Transitional
Red – Fully Turbulent

Lift-offset captured well with transition modeling at low alphas

Much larger $\Delta C_{L,max}$ predicted than measured (for both models)

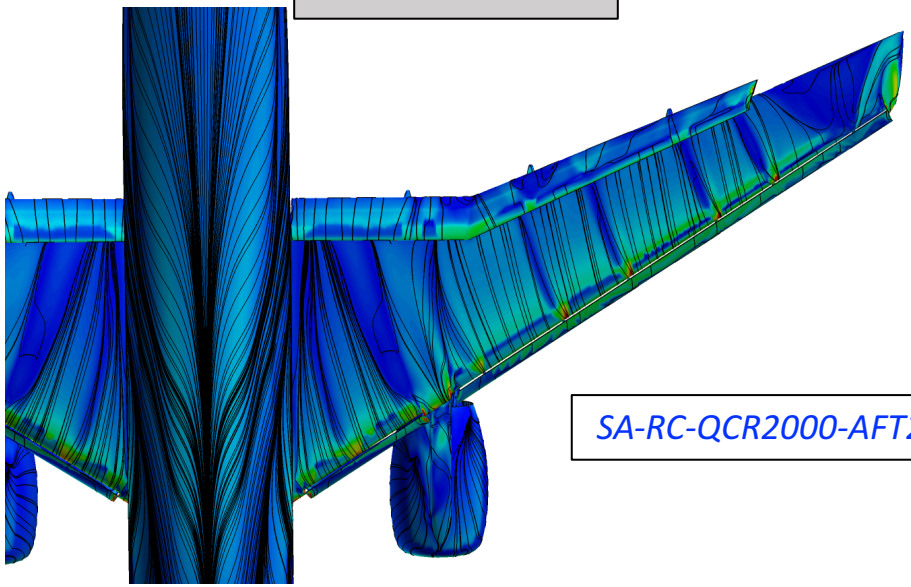
JSM Nacelle/Pylon ON Surface Flow Patterns





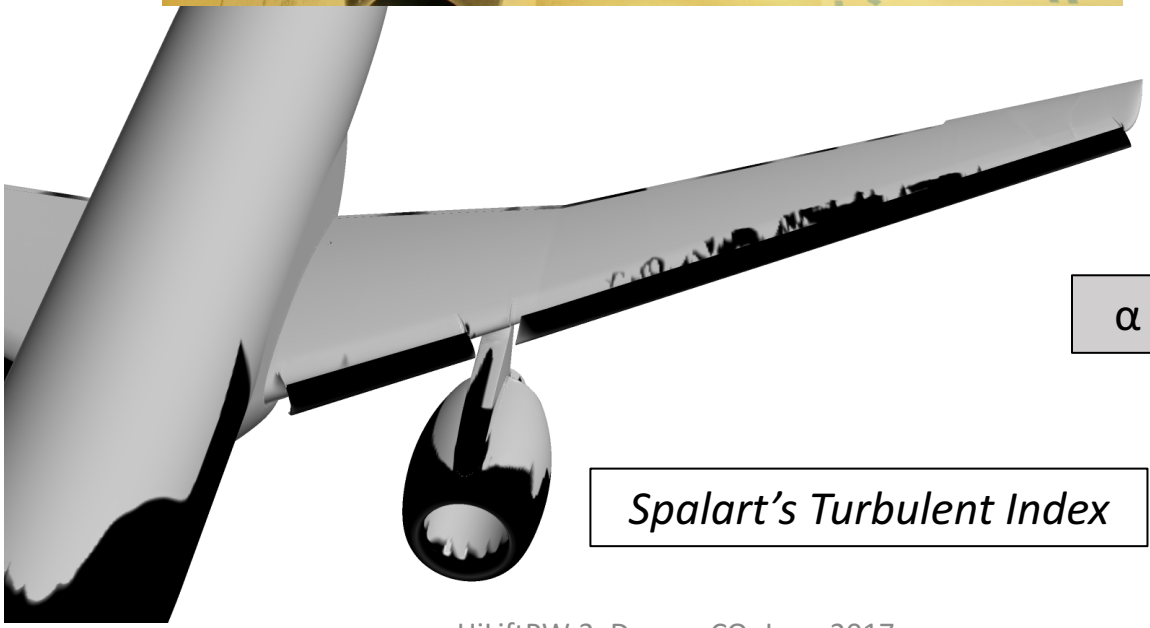
SA-noft2-RC-QCR2000

α = 18.58°



SA-RC-QCR2000-AFT2017b

JSM Nacelle/Pylon ON Transition Comparisons



α = 4.36°

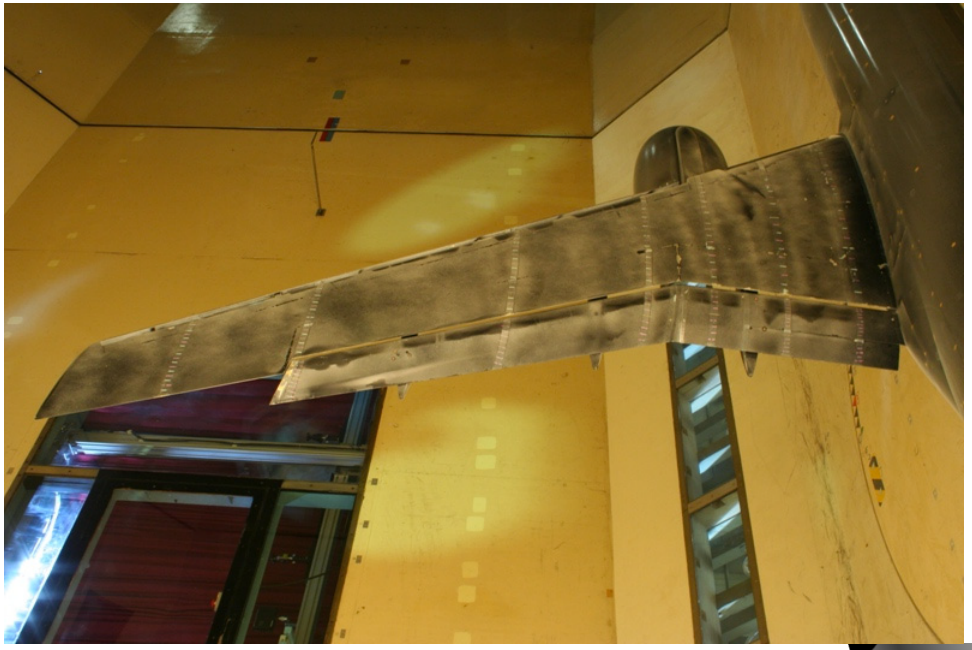
Spalart's Turbulent Index

JSM Nacelle/Pylon ON Transition Comparisons

JSM Nacelle/Pylon ON Transition Comparisons

α = 10.47°

JSM Nacelle/Pylon ON Transition Comparisons



α = 10.47°

JSM Nacelle/Pylon ON Transition Comparisons

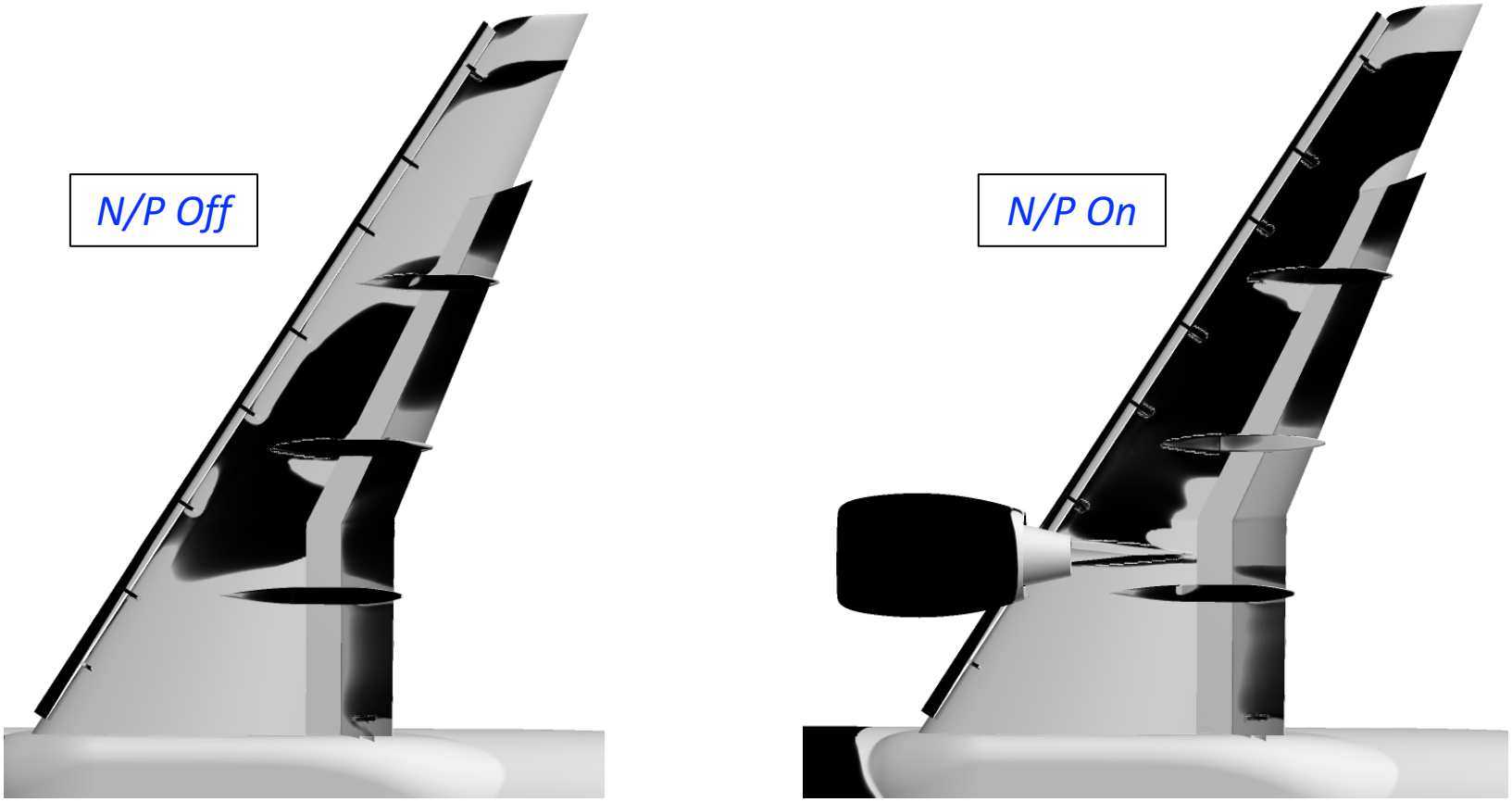
α = 18.58°

JSM Nacelle/Pylon ON Transition Comparisons

JSM Nacelle/Pylon ON Transition Comparisons

$\alpha = 18.58°$

JSM Nacelle/Pylon ON Transition Comparisons



α = 18.58°

Summary

- Transition modeling had a positive impact on predicted forces and moments compared to fully turbulent
  - Overall favorable agreement for transition locations
  - Predicted maximum lift coefficient is more accurate
  - Separation characteristics are more consistent with experiment
  - Better agreement for surface pressure distributions

- High-lift and low-lift branches observed for Case 2a (nacelle/pylon off), but not Case 2c (n/p on)
  - Multiple solutions possible for wing, but nacelle/pylon ”selects” one