Contribution to HiLiftPW-3

Jim Coder\textsuperscript{1}, Tom Pulliam\textsuperscript{2}, Jeff Slotnick\textsuperscript{3}, David Yeh\textsuperscript{3}

\textsuperscript{1}University of Tennessee, Knoxville, \textsuperscript{2}NASA Ames Research Center, \textsuperscript{3}The Boeing Company

PID 005

3\textsuperscript{rd} High Lift Prediction Workshop
Denver, CO June 3-4, 2017
# Summary of cases completed: OVERFLOW 2.2

## Case

<table>
<thead>
<tr>
<th>Case</th>
<th>Alpha=8, Fully turb, grid study</th>
<th>Alpha=16, Fully turb, grid study</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a (full gap)</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>1b (full gap w adaption)</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>1c (partial seal)</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>1d (partial seal w adaption)</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

## Case

<table>
<thead>
<tr>
<th>Case</th>
<th>Polar, Fully turb</th>
<th>Polar, specified transition</th>
<th>Polar, w transition prediction</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a (no nacelle)</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>Transition predicted with AFT2017b model</td>
</tr>
<tr>
<td>2b (no nacelle w adaption)</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td>2c (with nacelle)</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>Transition predicted with AFT2017b model</td>
</tr>
<tr>
<td>2d (with nacelle w adaption)</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

## Case

<table>
<thead>
<tr>
<th>Case</th>
<th>2D Verification study</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
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-\texttt{noft2}-RC-QCR2000
    • Transition prediction: SA-RC-QCR2000-\texttt{AFT2017b}
    • Prescribed transition: SA-\texttt{la}-RC-QCR2000
  • Free-stream turbulence: $Tu = 0.16\%, \frac{\mu_t}{\mu} = 2.8 \times 10^{-7}$
Transition Modeling Strategy

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

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

• With two additional transported scalars

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

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

• Coupling takes place through

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

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

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

\[
H_L = \frac{d^2}{v} \left[ \nabla (\rho \tilde{u} \cdot \nabla) \cdot \nabla \right] \quad H_{12} = 0.3770 + \sqrt{\frac{H_L + 2.4534}{0.6532}}
\]

\[
F_{\text{crit}} = \begin{cases} 
0, & Re_v < Re_{v,0} \\
\frac{Re_{v,0}}{Re_{\theta,0}} = 0.2462 H_{12}^2 - 0.1418 H_{12} + 0.0089, & Re_v \geq Re_{v,0}
\end{cases}
\]

\[
Re_v = \frac{\rho S d^2}{\mu + \mu_t}
\]

\[
F_{\text{growth}} = \frac{H_{12}}{0.5482 H_{12} - 0.5185 (1 + m(H_{12})) \frac{l(H_{12})}{2}}
\]

• \(l(H_{12}), m(H_{12}), Re_{\theta,0},\) and \(d \tilde{n}/d Re_{\theta}\) 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

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

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

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

- with \( c_1 = 100, c_2 = 0.06, c_3 = 50, \sigma_\gamma = 1 \)

- 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

Simulations are ongoing

Holes are created in grids overset with the sub-region
# Grid Systems

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

![Grid System Image]
Summary of JSM Results

• JSM simulated fully turbulent and with transition prediction
  • $N_{\text{crit}} = 7$ (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 $\rightarrow$ low-lift branch
  • Previous alpha $\rightarrow$ 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
High-lift branch attained by restarting from previous alpha

Low-lift branch occurs when initializing from free-stream

Blue – Transitional
Red – Fully Turbulent
Blue – Transitional
Red – Fully Turbulent

Both models overpredict drag, but transition modeling reduces the pseudo-profile drag

\[ C_{D,\text{ideal}} = \frac{C_L^2}{\pi AR} \]

HiLiftPW-3, Denver CO, June 2017
Transition modeling captures moment curve better than fully turbulent
JSM Nacelle/Pylon OFF Pressure Distributions

Section B-B ($\eta=0.25$)

Section E-E ($\eta=0.56$)

Section G-G ($\eta=0.77$)

Section H-H ($\eta=0.89$)

Blue – Transitional
Red – Fully Turbulent

$\alpha = 18.58^\circ$
Surface vorticity magnitude with surface streamlines

\[ \alpha = 14.54^\circ \]
JSM Nacelle/Pylon OFF Surface Flow Patterns

\[ \alpha = 18.58^\circ \]
JSM Nacelle/Pylon OFF Surface Flow Patterns

$\alpha = 21.57^\circ$

SA-noft2-RC-QCR2000

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

HiLiftPW-3, Denver CO, June 2017
Transition modeling captures lift curve well, but still stalls early.

Similar modeling differences as nacelle/pylon OFF case.

**Blue – Transitional**

**Red – Fully Turbulent**
Both models still overpredict pseudo-profile drag

Blue – Transitional
Red – Fully Turbulent
Transition modeling still captures moment curve better than fully turbulent

HiLiftPW-3, Denver CO, June 2017
JSM Nacelle/Pylon ON Pressure Distributions

Section B-B ($\eta=0.25$)

Section E-E ($\eta=0.56$)

Section G-G ($\eta=0.77$)

Section H-H ($\eta=0.89$)

$\alpha = 18.58^\circ$

Blue – Transitional
Red – Fully Turbulent
Lift-offset captured well with transition modeling at low alphas

Much larger $\Delta C_{L,\text{max}}$ predicted than measured (for both models)
JSM Nacelle/Pylon ON Surface Flow Patterns

\[ \alpha = 18.58^\circ \]

HiLiftPW-3, Denver CO, June 2017
JSM Nacelle/Pylon ON Transition Comparisons

$\alpha = 4.36^\circ$

Spalart’s Turbulent Index

HiLiftPW-3, Denver CO, June 2017
JSM Nacelle/Pylon ON Transition Comparisons

\[ \alpha = 4.36^\circ \]
JSM Nacelle/Pylon ON Transition Comparisons

$\alpha = 10.47^\circ$
JSM Nacelle/Pylon ON Transition Comparisons

\[ \alpha = 10.47^\circ \]
α = 18.58°
$\alpha = 18.58^\circ$
JSM Nacelle/Pylon ON Transition Comparisons

\[ \alpha = 18.58^\circ \]
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