WMLES of K-Type and Bypass Boundary-Layer Transition

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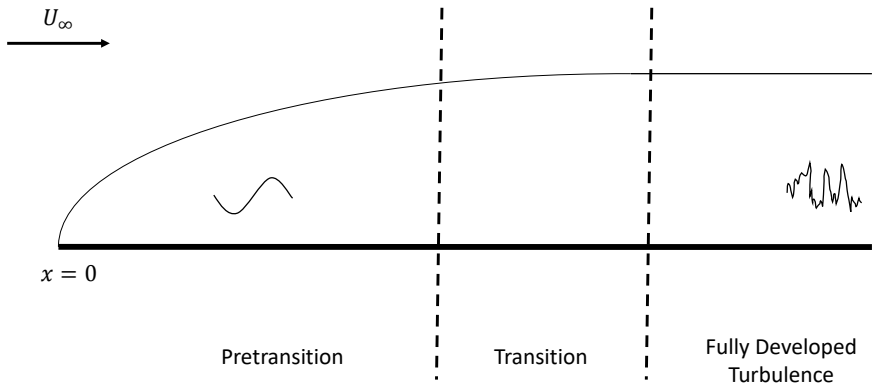
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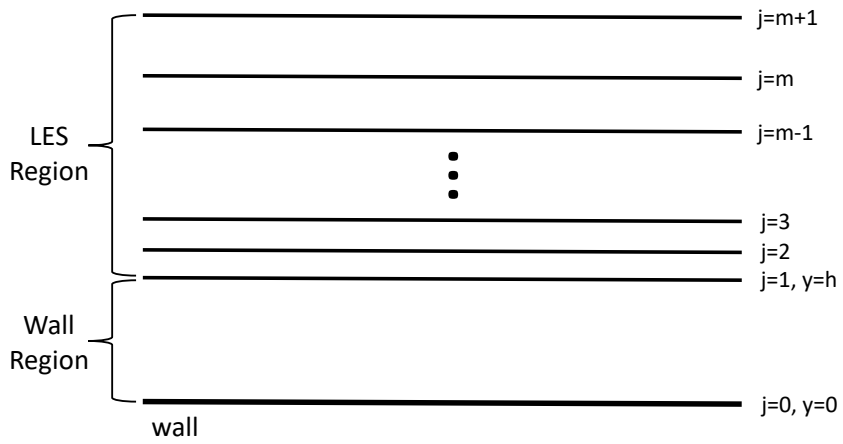
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Transition Mechanisms



1. Extension of WMLES to transitional flows would play an important role in enabling reliable predictions of separated flows, $C_{L_{\max}}$, etc.
2. Mechanisms
   (a) Resonant triads: H-type (previous work, 2021), K-type (present work).
   (b) Bypass (present work).
3. Three regions: Pretransition, transition, fully-developed turbulence.
4. Previous work includes: Klebanoff et al., 1962, Rist and Fasel, 1995, Wu and Moin, 2009, 2010 (DNS), Bodart and Larsson, 2012 (WMLES), Sayadi and Moin, 2012 (WRLES), Sayadi, Hamman and Moin, 2013 (DNS), Park and Moin, 2014 (WMLES), Lozano-Duran et al., 2018 (DNS, LES, PSE). Also Jimenez et al., 2010 (DNS).

Wall Modeling



Pretransition model:

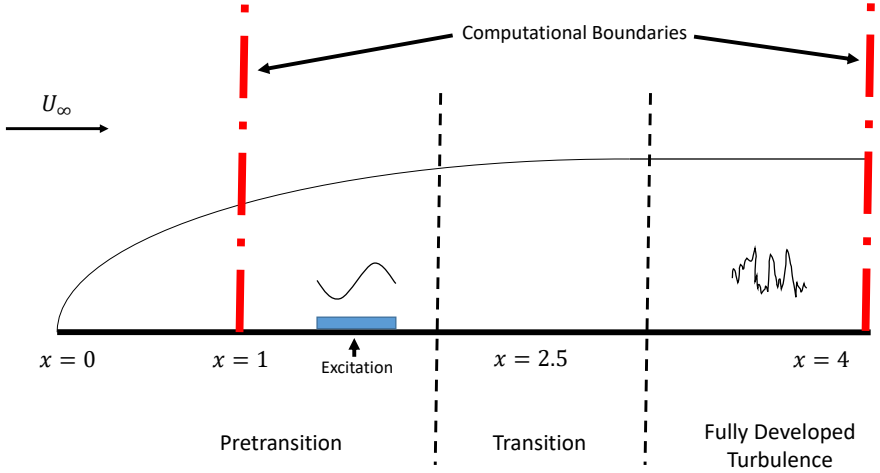
1. Accurate simulation of disturbances without DNS-like wall-normal resolution: larger min cell size implies larger time step (Bodart and Larsson, 2012; Park and Moin, 2014; Lozano-Duran et al., 2018).
2. Not turbulence modeling.
3. Builds on traditional wall modeling concepts (Cabot and Moin, 2000): thin-layer equations (limitations), algebraic equilibrium models.
4. Maintains "equilibrium" nature of model (model computation at each point on wall independent of other points) for computational efficiency.
5. Polynomial algebraic equilibrium model fits LES velocity profile (least square) and satisfies no-slip bc at wall.

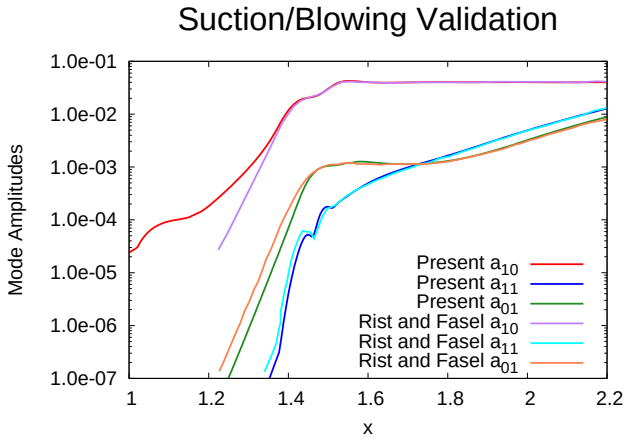
Wall Modeling (Cont.)

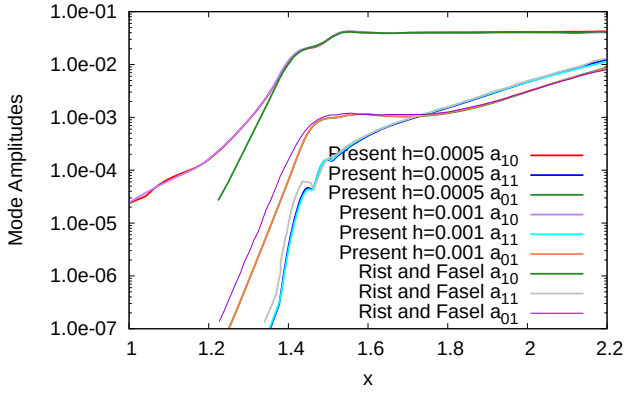
1. Fully developed turbulence wall model: algebraic model based on mean velocity profile.
2. Transition region model: $u_y = (1 - \lambda)u_{y\mathrm{pre}} + \lambda u_{y\mathrm{turb}}$.
3. Transition sensor λ (based on streamwise position).
4. No subgrid-scale model.
5. Solve incompressible Navier-Stokes equations with fourth-order finite-difference and spectral discretizations in space, time splitting.

K-Type Transition

1. Experiment: Klebanoff, Tidstrom and Sargent (1962).
2. Tollmien-Schlichting wave triad.
3. Vibrating ribbon in experiment.
4. Suction and blowing in computations:
   $v_b = A_{10} f_1(x) \sin(\omega t) + A_{01} f_0(x) \cos(2\pi z/\beta)$.
5. Suction and blowing vis a vis wall model: $\frac{C_b v_b}{h}$.

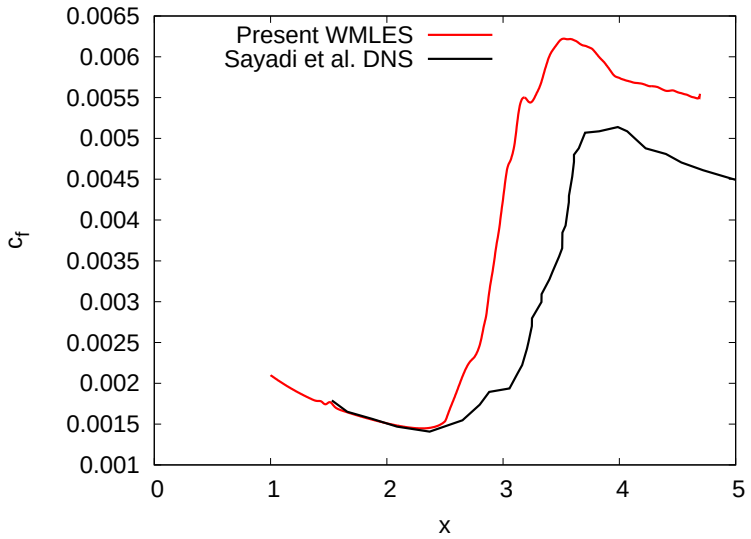


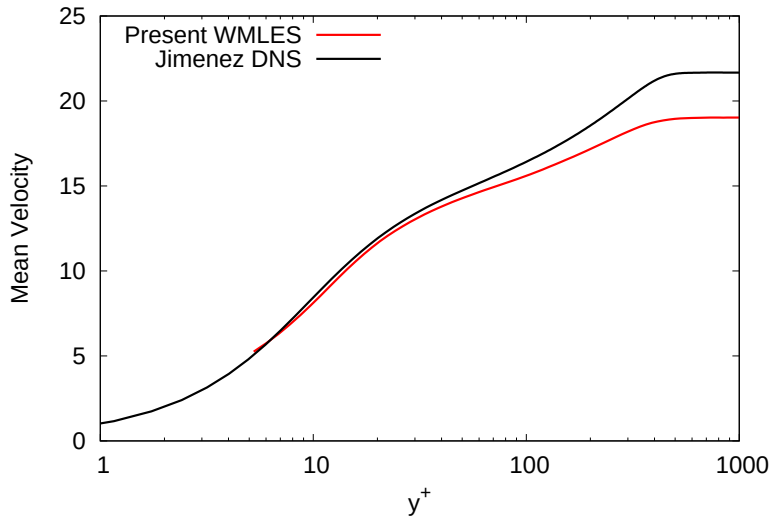




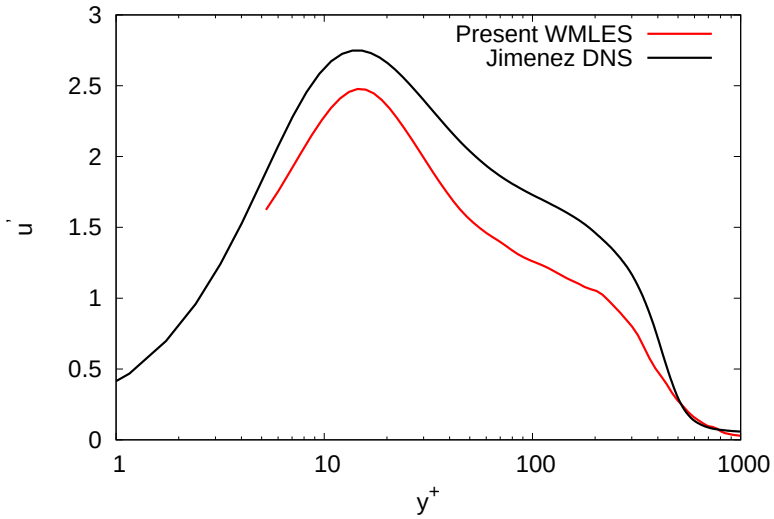
K-Type Transition Results

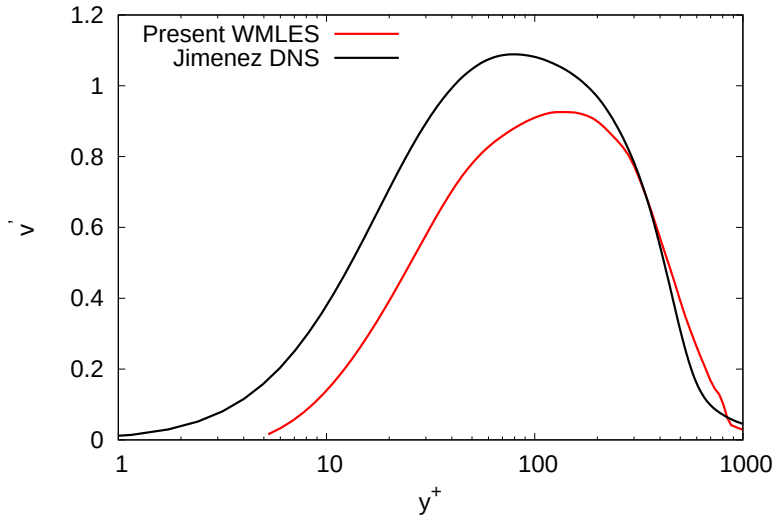
1. $Re = 10^5$
2. Position blending: $\lambda = (x - x_0)/(x_1 - x_0)$, where $x_0 = 2.5$ and $x_1 = 3.0$.
3. Wall region: $h = 0.001$ (7% of inflow boundary layer thickness.)
4. Turbulence profiles at $Re_\theta = 800$.

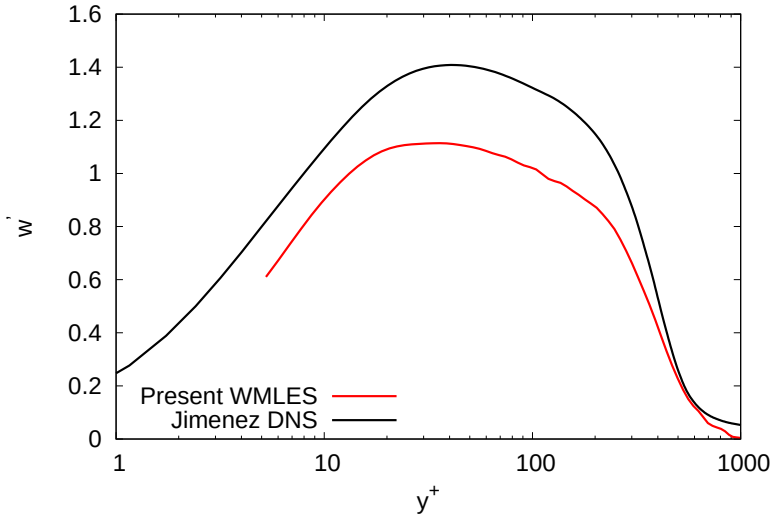


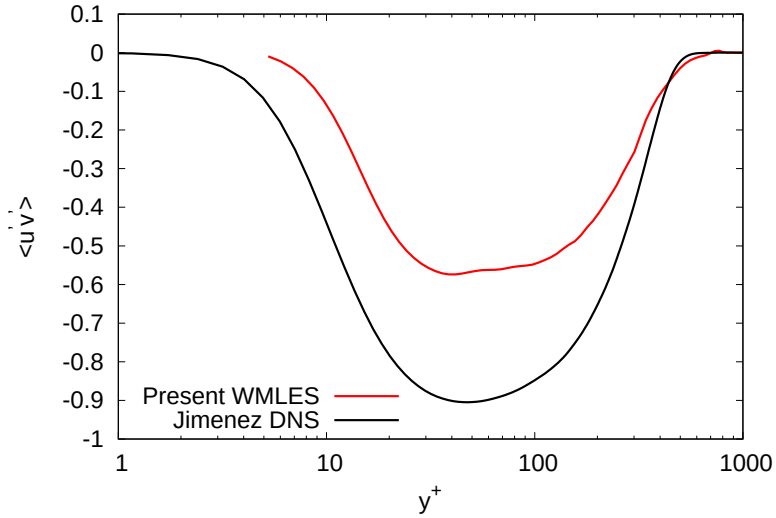


K-Type Transition Results (Cont.)



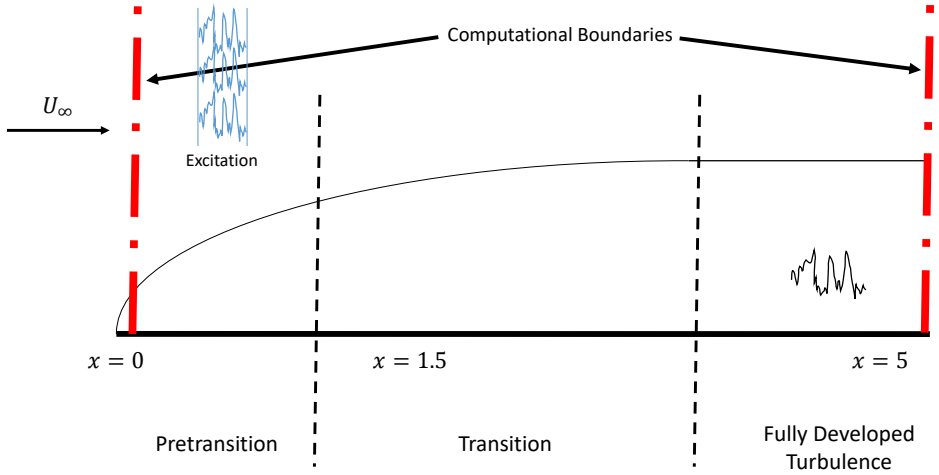


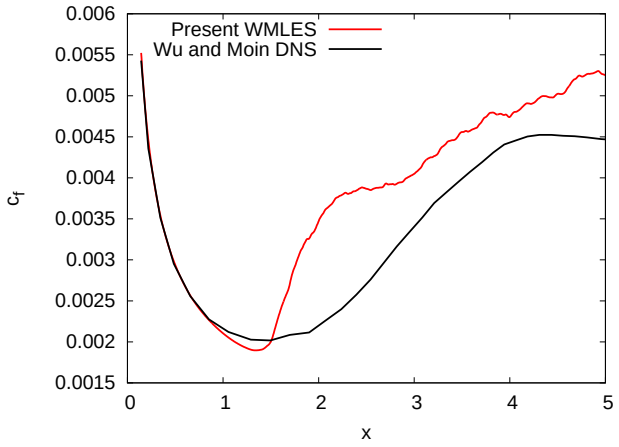




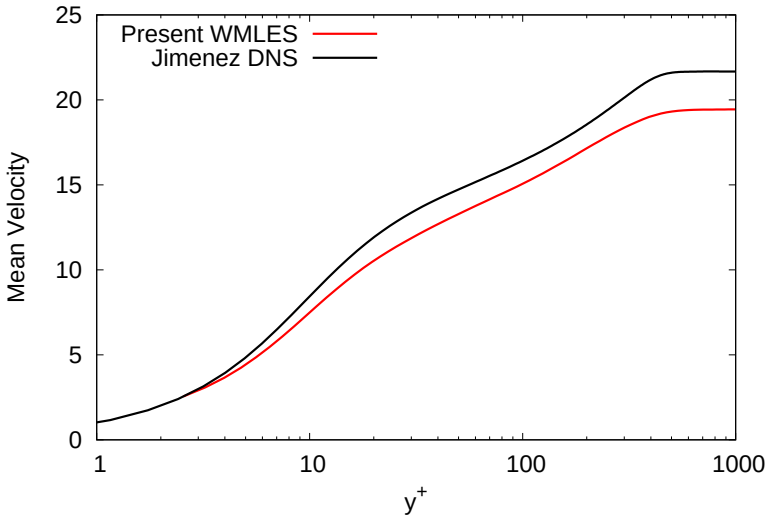
Bypass Transition

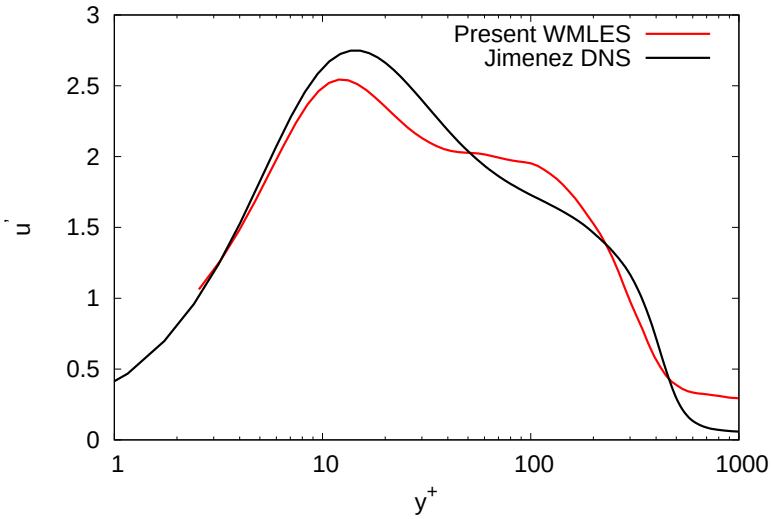
1. Transition initiated by "slabs" of turbulence introduced at inflow boundary.
2. $Re = 10^5$
3. Position blending: $\lambda = (x - x_0)/(x_1 - x_0)$, where $x_0 = 1.5$ and $x_1 = 2.0$.
4. Wall region: $h = 0.0005$ (8% of inflow boundary layer thickness.)
5. Turbulence profiles at $Re_\theta = 800$.

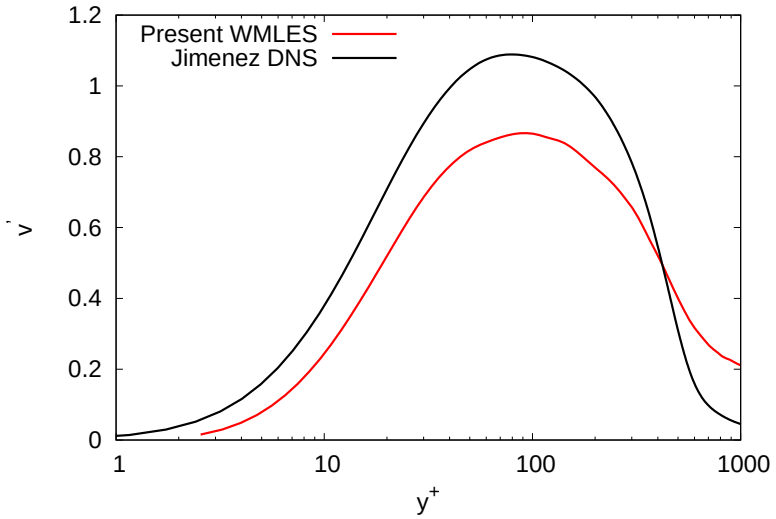


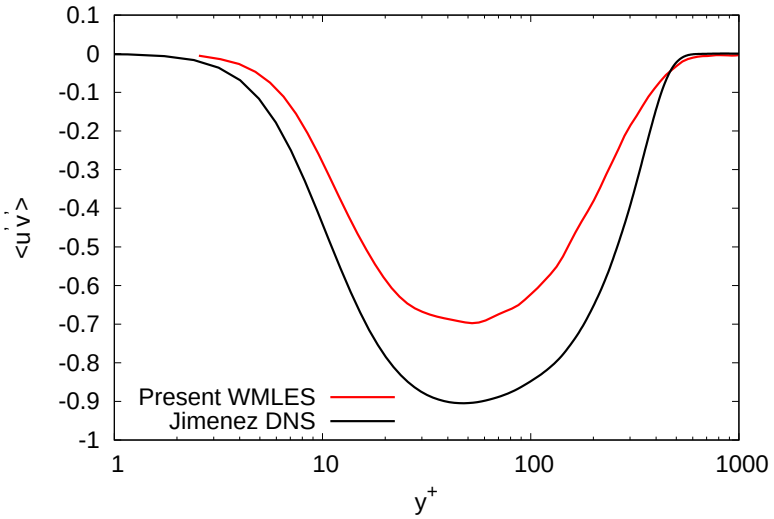


Bypass Transition (Cont.)









Conclusions

1. Pretransition WMLES results compare well with DNS.
   (a) Thin-layer approximation.
   (b) Wall-normal resolution decreased, implying increased numerical time-step.
2. Transition-region WMLES doesn't compare as well as subharmonic transition.
   (a) Excess shear stress in both K-type and bypass simulations.
   (b) Suggests simple blending of wall models inadequate.

