# S-ZDES: Zonal Detached Eddy Simulation coupled with steady RANS in the wall region

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# DES — DETACHED-EDDY SIMULATIONS

- Problem:
  - the flow in the RANS region is highly unsteady (i.e. URANS)
  - this means that RANS turbulence models (developed for steady flow) are not accurate

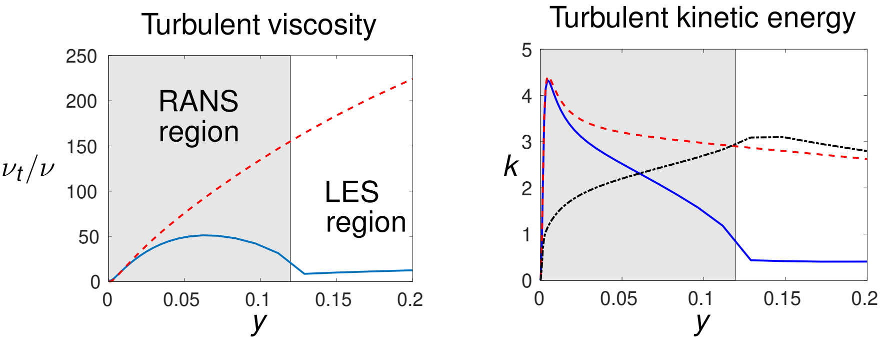



FIGURE: ——— : DES; – – ; 1D steady RANS; — · — : DES resolved $k$.

# DES — Detached-Eddy Simulations

- Problem:
  - the flow in the RANS region is highly unsteady (i.e. URANS)
  - this means that RANS turbulence models (developed for steady flow) are not accurate
- Solution:
  - solve the steady equations in the RANS region

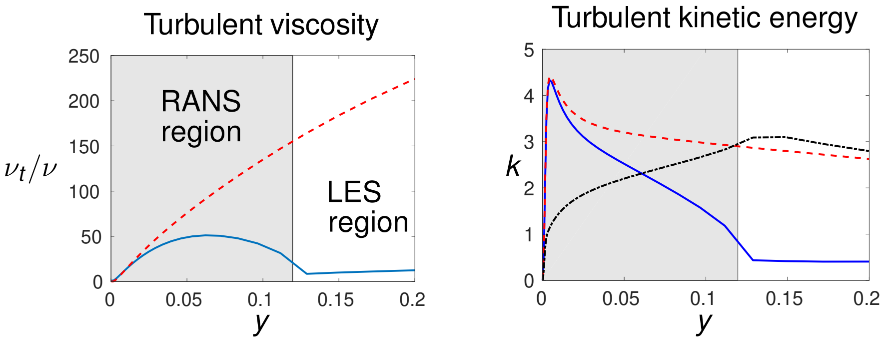



FIGURE: —— : DES; - - ; 1D steady RANS; - · - : DES resolved $k$.

# TWO SOLVERS IN THE ENTIRE DOMAIN

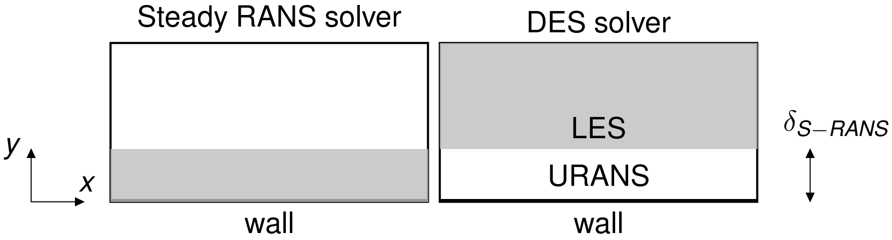
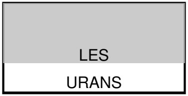



FIGURE: Grey color indicates the solver that drives the flow

# DRIFT TERMS ARE ADDED IN WHITE REGIONS

Steady RANS solver

DES solver




$$S_i^{RANS} = \frac{\langle v_i^{LES}\rangle_T - v_i^{RANS}}{\Delta t} \qquad S_i^{LES} = \frac{v_i^{RANS} - \langle \bar{v}_i^{LES}\rangle_T}{\Delta t},$$

FIGURE: Subscript $T$ indicates integration over time $T$

$$\langle\phi(t)\rangle_T = \frac{1}{T}\int_{-\infty}^{t}\phi(\tau)\exp(-(t-\tau)/T)d\tau \Rightarrow$$

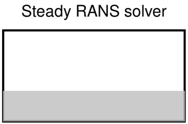
$$\langle\phi\rangle_T^t \equiv \langle\phi\rangle_T = a\langle\phi\rangle_T^{t-\Delta t} + (1-a)\phi^t$$

$$a = \exp(-\Delta t/T).$$

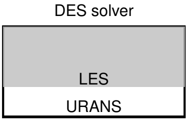
# Previous Work

- The present method is similar to those in [1, 2, 3]. The main differences are that
  - In [1, 3] they use one additional drift terms in the LES momentum equations to control resolved Reynolds stresses
  - They include drift terms also in the $k$ and $\varepsilon$ equations [1] or the $k$ equation [3].
  - In [1, 3] they include five tuning constants in all drift terms. I have one ($T$).

# Turbulence Models




- EARSM (Explicit Algebraic Stress Model) [4] coupled to Wilcox $k - \omega$ model [5]




- DES $k - \omega$ model
- Lengthscale in dissipation term of the $k$ eq.is taken from the IDDES model [6, 7]

FIGURE: RANS and DES turbulence models

# Numerical Method: CALC-LES & CALC-BFC

- CALC-LES [8]: DES solver
  - Incompressible finite volume method
  - Pressure-velocity coupling treated with fractional step
  - Central differencing scheme for momentum eqns
  - Hybrid $1^{st}$ order upwind/$2^{nd}$ order central scheme $k$ & $\omega$ eqns.
  - $2^{nd}$-order Crank-Nicholson for time discretization
- CALC-BFC [9]: RANS solver, called every $10^{th}$ timestep
  - Incompressible finite volume method
  - SIMPLEC
  - MUSCL: 2nd order bounded upwind scheme for momentum eqns
  - Hybrid $1^{st}$ order upwind/$2^{nd}$ order central scheme $k$ & $\omega$ eqns.

# First Test Case: Channel flow

- Reynolds number is $Re_\tau = 5\,200$.
- A $32 \times 96 \times 32$ mesh is used
- $x_{max} = 3.2$, $z_{max} = 1.6$, 15% stretching in $y$ direction

# Channel flow: Velocity

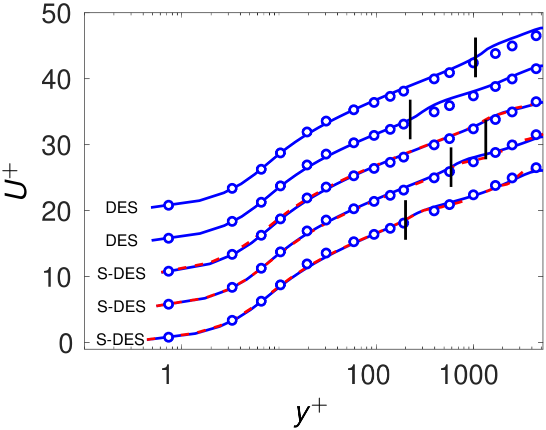



Figure: $T = 10\delta/U_b$ ——— : DES; – – : RANS; ∘: DNS. Vertical black lines show locations of $\delta_{S-RANS}$.

# CHANNEL FLOW: TURBULENT VISCOSITY

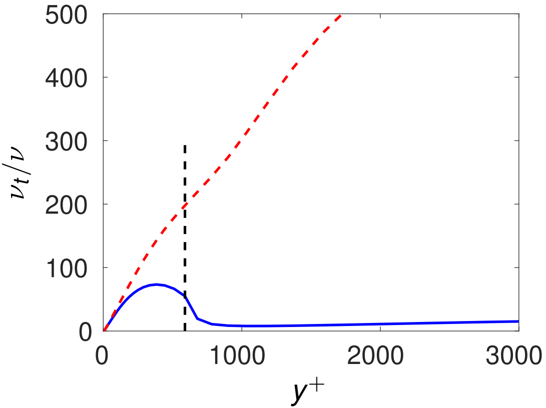



FIGURE: ▬▬ : DES solver; ‒ ‒ : RANS solver. Vertical black lines show locations of $\delta_{S-RANS}$.

# Second Test Case: Hump flow

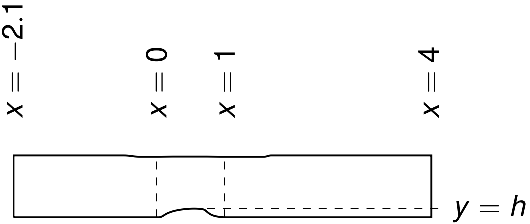
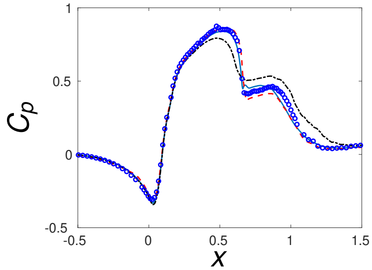



FIGURE: The domain of the hump. $z_{max} = 0.2$.

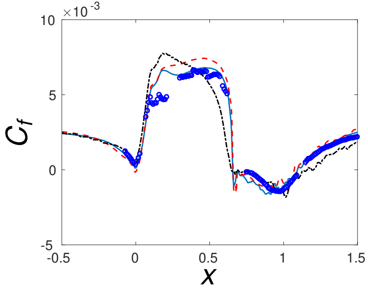
- The Reynolds number of the hump flow is $Re_c = 936\,000$.
- The mesh has $386 \times 120 \times 32$ cells ($x$, $y$, $z$)
- Grid from NASA workshop.[1]
- Inlet is located at $x = -2.1$ and the outlet at $x = 4.0$,

[1] https://turbmodels.larc.nasa.gov/nasahump_val.html

# HUMP FLOW: $C_p$ & $C_f$



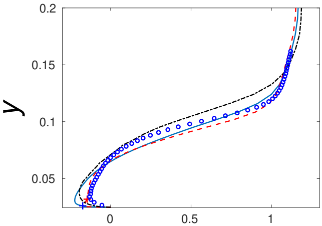

(A) Pressure coefficient.



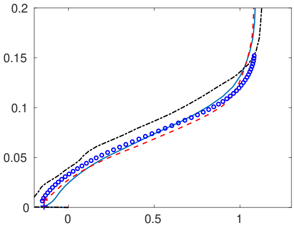

(B) Skinfriction.

FIGURE: $T = 20h/U_{in}$. ——— : S-DES, $j_0 = 33$; – – : S-DES, $j_0 = 53$; – · – : DES

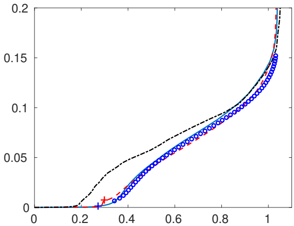
# Hump flow: Velocities



(A) $x = 0.8$



(B) $x = 1.0$



(C) $x = 1.3$

Figure: —— : S-ZDES, $j_0 = 33$; - - : S-ZDES, $j_0 = 53$; -·- : DES; ∘: exp

# CONCLUSIONS

- A new steady RANS coupled to DES (S-ZDES) is proposed.
- Very good results
- Drawback: it is dependent on the lower limit of integration time, $T$ for the hump flow
  - $T = 10h/U_{in}$ too small ($h$ is hump height)
  - $T = 20$ and 50 give indentical results
  - For $T = 100$ we must more than double developing+sampling time to $345 + 345$ ($7.3 + 7.3$ throughflow times)

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