EMBEDDED LES USING PANS [2]

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PANS LOW REYNOLDS NUMBER MODEL [3]

$$\frac{\partial k_u}{\partial t}+\frac{\partial(k_u U_j)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(\nu+\frac{\nu_u}{\sigma_{ku}}\right)\frac{\partial k_u}{\partial x_j}\right]+(P_u-\varepsilon_u)$$

$$\frac{\partial \varepsilon_u}{\partial t}+\frac{\partial(\varepsilon_u U_j)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(\nu+\frac{\nu_u}{\sigma_{\varepsilon u}}\right)\frac{\partial \varepsilon_u}{\partial x_j}\right]+C_{\varepsilon 1}P_u\frac{\varepsilon_u}{k_u}-C^*_{\varepsilon 2}\frac{\varepsilon_u^2}{k_u}$$

$$\nu_u=C_\mu f_\mu\frac{k_u^2}{\varepsilon_u},\, C^*_{\varepsilon 2}=C_{\varepsilon 1}+\frac{f_k}{f_\varepsilon}(C_{\varepsilon 2}f_2-C_{\varepsilon 1}),\, \sigma_{ku}\equiv\sigma_k\frac{f_k^2}{f_\varepsilon},\, \sigma_{\varepsilon u}\equiv\sigma_\varepsilon\frac{f_k^2}{f_\varepsilon}$$

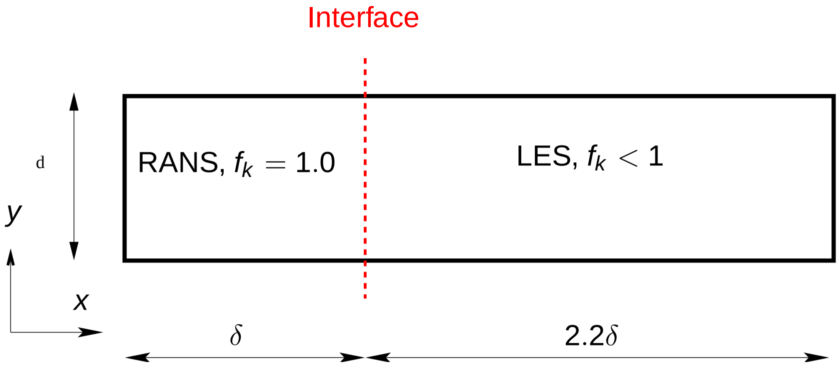
$C_{\varepsilon 1}$, $C_{\varepsilon 2}$, σ_k, σ_ε and C_μ same values as [1]. $f_\varepsilon=1$. f_2 and f_μ read

$$f_2=\left[1-\exp\left(-\frac{y^*}{3.1}\right)\right]^2\left\{1-0.3\exp\left[-\left(\frac{R_t}{6.5}\right)^2\right]\right\}$$

$$f_\mu=\left[1-\exp\left(-\frac{y^*}{14}\right)\right]^2\left\{1+\frac{5}{R_t^{3/4}}\exp\left[-\left(\frac{R_t}{200}\right)^2\right]\right\}$$

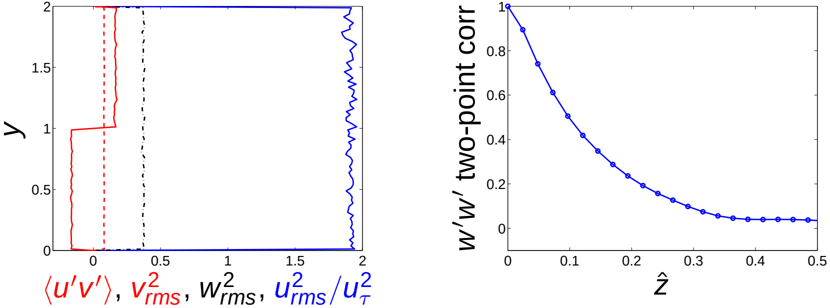
- Baseline model: $f_k=0.4$. Range of $0.2<f_k<0.6$ is evaluated

Channel flow: Domain



- Interface: Synthetic turbulent fluctuations are introduced as additional convective fluxes in the momentum equations and the continuity equation
- $f_k = 0.4$ is the baseline value for LES [3]

INLET FLUCTUATIONS



- Anisotropic synthetic fluctuations, u', v', w',
- Integral length scale $\mathcal{L} \simeq 0.13$ (see 2-p point correlation)
- Asymmetric time filter $(\mathcal{U}')^m = a(\mathcal{U}')^{m-1} + b(u')^m$ with $a = 0.954, b = (1 - a^2)^{1/2}$ gives a time integral scale $\mathcal{T} = 0.015$ $(\Delta t = 0.00063)$

Interface Conditions for k_u and ε_u

- For k_u & ε_u we prescribe "inlet" boundary conditions at the interface.
- First, the usual convective and diffusive fluxes at the interface are set to zero
- Next, new convective fluxes are added. Which "inlet" values should be used at the interface?
  - $k_{u,int} = f_k k_{RANS}(x = 0.5\delta)$, $\varepsilon_{u,int} = C_\mu^{3/4} k_{u,int}^{3/2}/\ell_{sgs}$, $\ell_{sgs} = C_s \Delta$, $\Delta = V^{1/3}$
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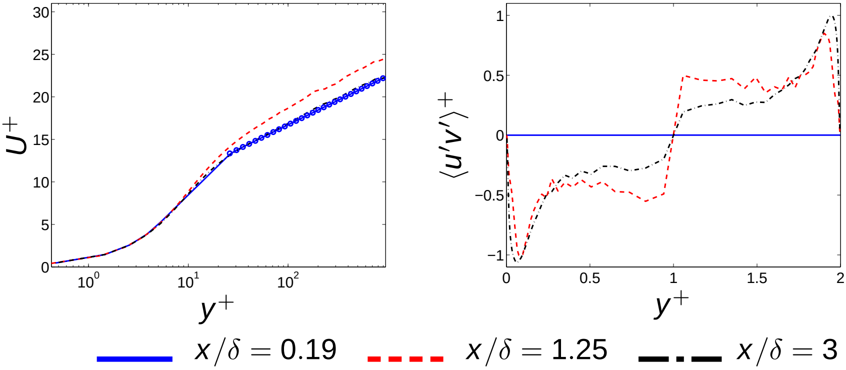
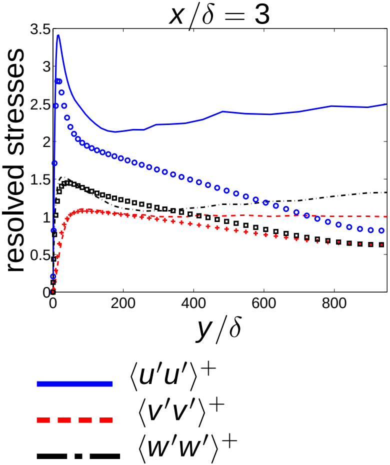
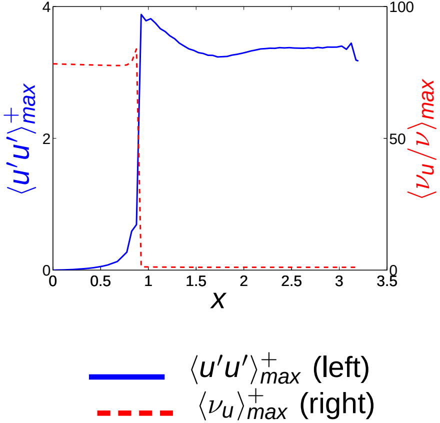
  - Baseline $C_s = 0.07$; different C_s values are tested

Channel Flow: Velocity and Shear Stresses



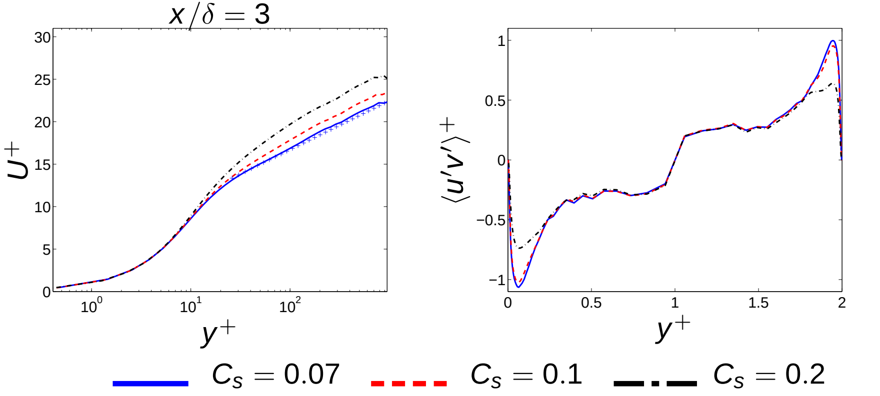
CHANNEL FLOW: STRESSES AND PEAK VALUES VS. x



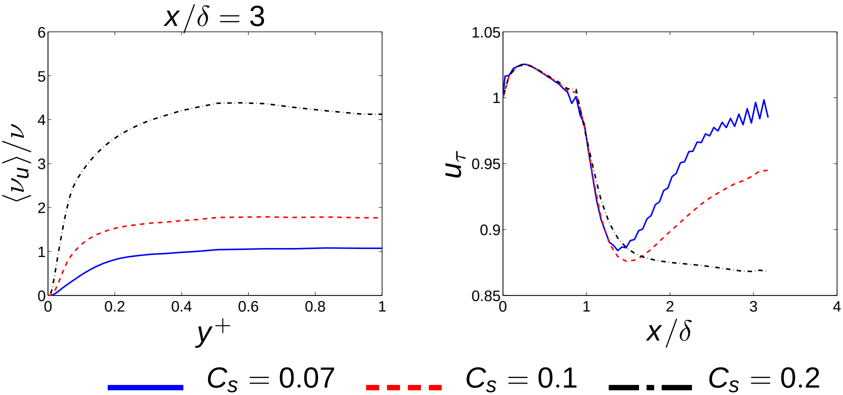


Channel Flow: different C_s value for $\varepsilon_{interface}$

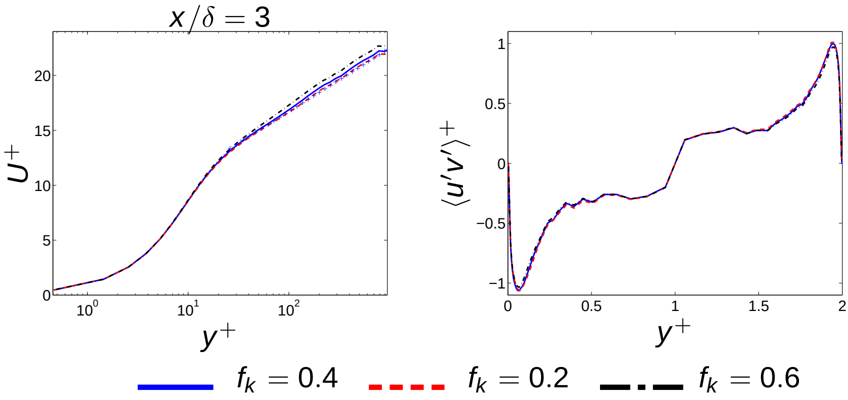
- $k_{u,int} = f_k k_{RANS}$
- $\varepsilon_{u,int} = C_\mu^{3/4} k_{u,int}^{3/2} / \ell_{sgs}$, $\ell_{sgs} = C_s \Delta$



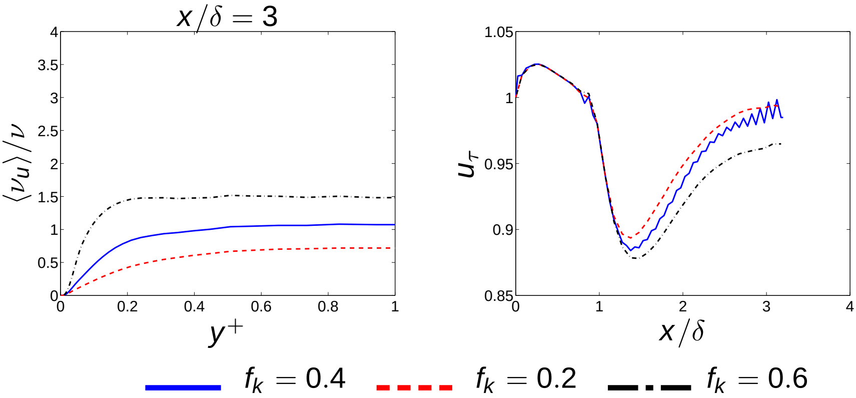
CHANNEL FLOW: DIFFERENT C_s VALUE FOR $\varepsilon_{interface}$



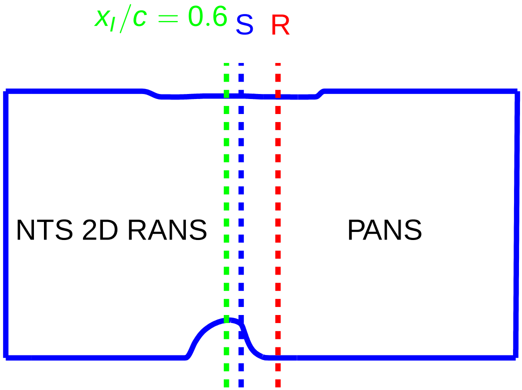
Channel Flow: different f_k values



CHANNEL FLOW: DIFFERENT f_k VALUES

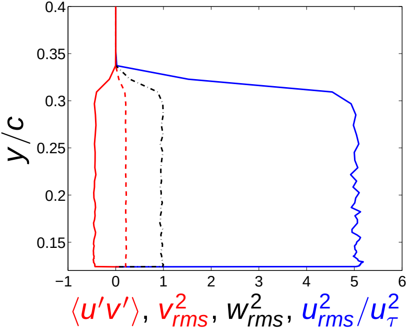


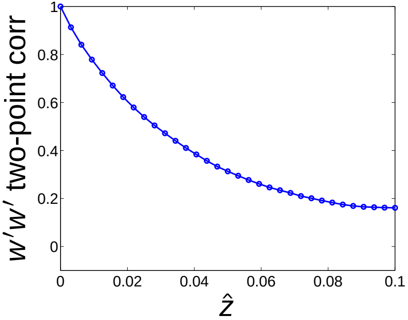
HUMP FLOW



- Inlet, Separation $x_S/c = 0.65$; reattachment $x_R/c = 1.1$
- $Re_c = 936\,000 \frac{U_{ij} c}{\nu}$ $(U_{in} = c = \rho = 1,\ \nu = 1/Re_c$
- $H/c = 0.91,\ h/c = 0.128,\ x/c = [0.6, 4.2]$
- Mesh: $312 \times 120 \times 64,\ Z_{max} = 0.2c$ (baseline)

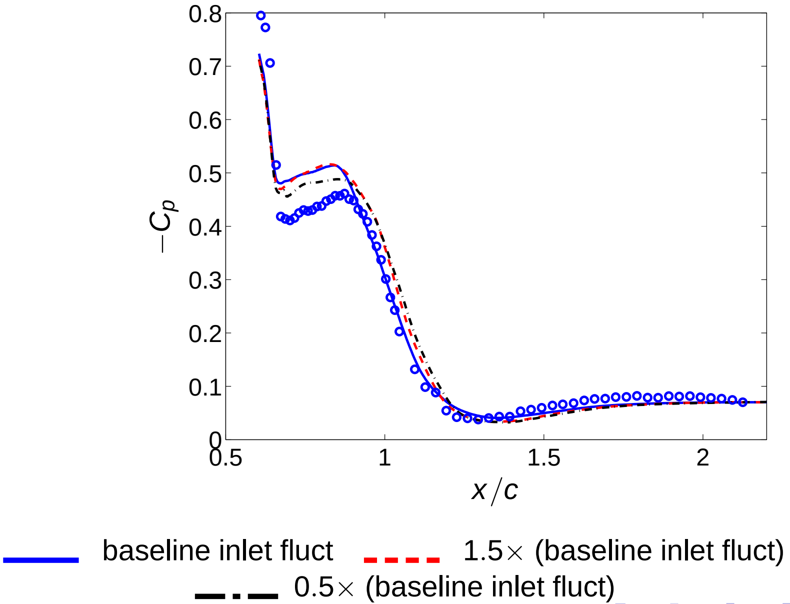
Baseline Inlet fluctuations



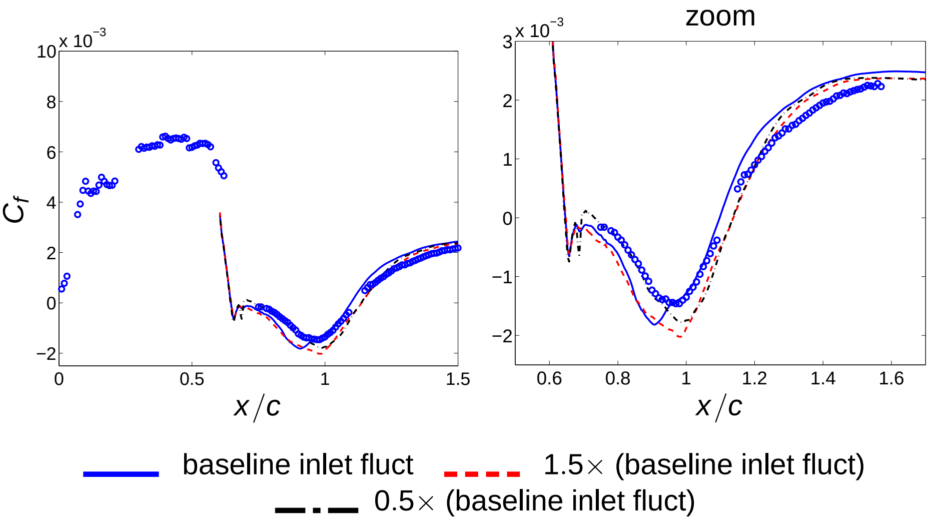


- Integral length scale $\mathcal{L} \simeq 0.04$ (see 2-p point correlation)
- Asymmetric time filter $(\mathcal{U}')^m = a(\mathcal{U}')^{m-1} + b(u')^m$ with $a = 0.954, b = (1 - a^2)^{1/2}$ gives a time integral scale $\mathcal{T} = 0.038$
- $\Delta t = 0.002$. $7500 + 7500$ time steps (100 hours one core)
- Fluctuations multiplied by $f_{bl} = \max\{0.5[1 - \tanh(y - y_{bl} - y_{wall})/b], 0.02\}$, $y_{bl} = 0.2$, $b = 0.01$.

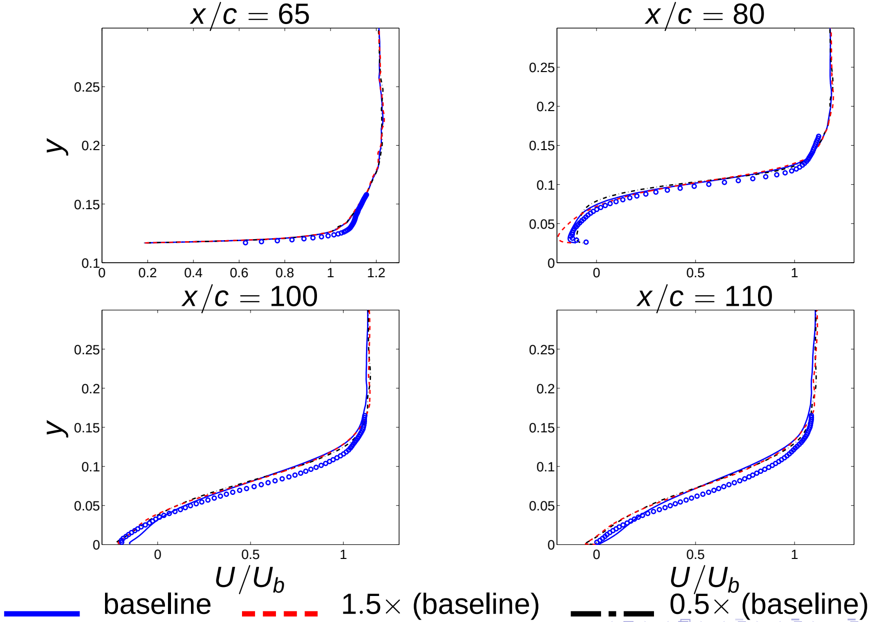
PRESSURE: AMPLITUDES OF INLET FLUCT



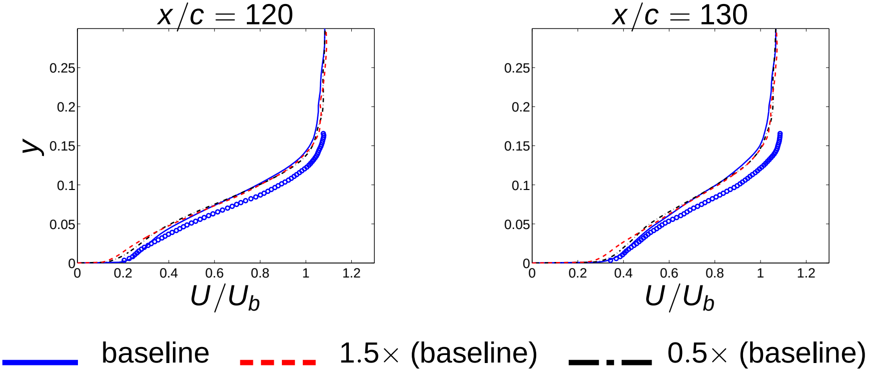
Skin Friction: Amplitudes Of Inlet Fluct



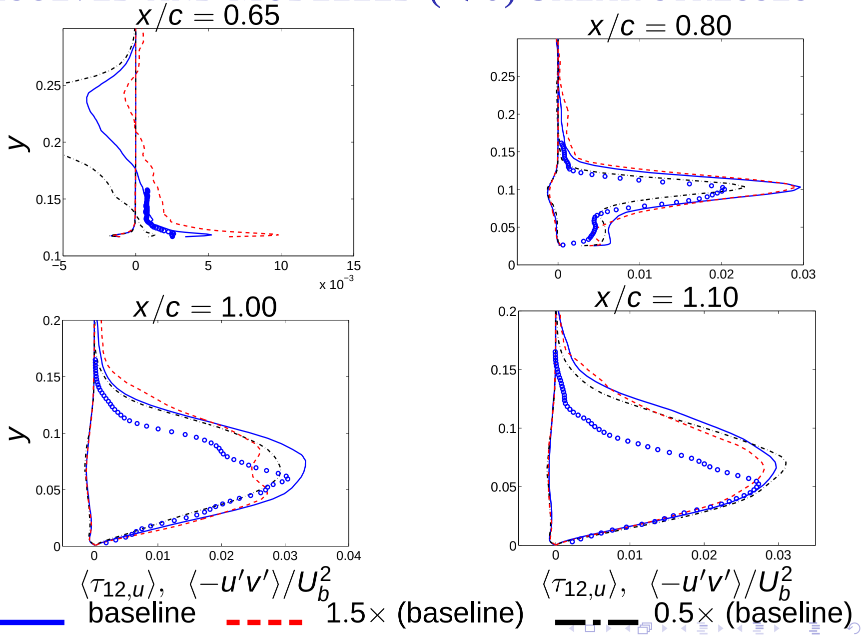
VELOCITIES: AMPLITUDES OF INLET FLUCT



VELOCITIES: AMPLITUDES OF INLET FLUCT

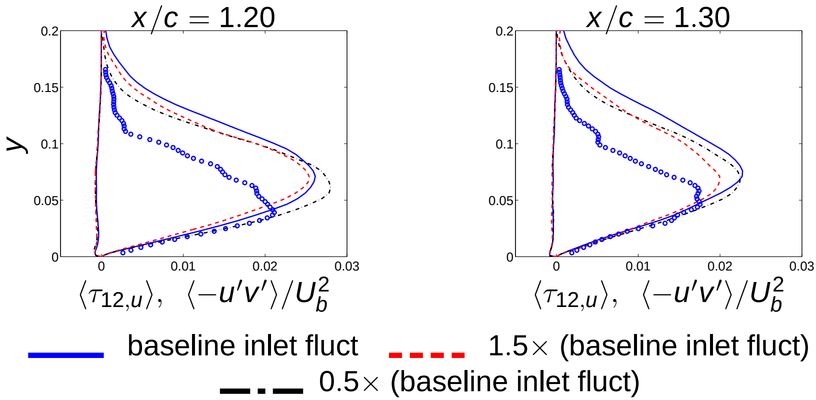


Resolved and Modelled (< 0) Shear stresses

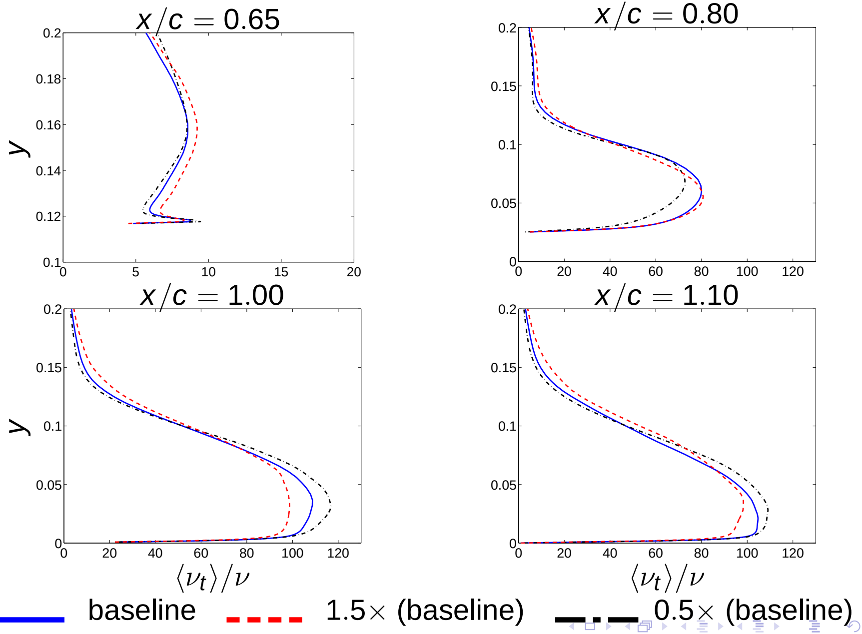


Shear stresses: Amplitudes of Inlet Fluct

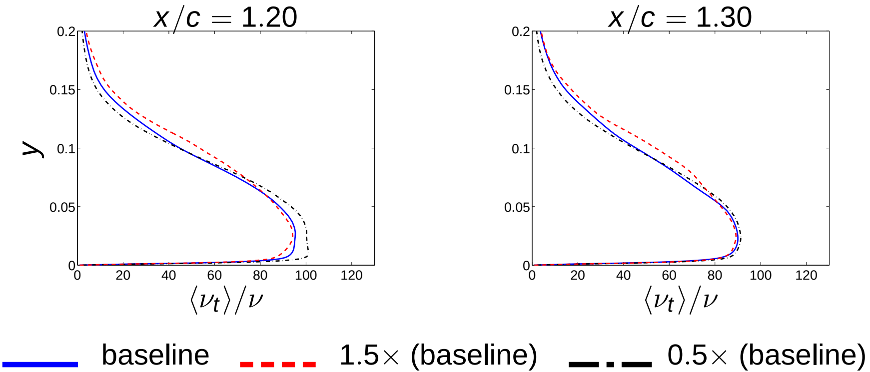
- Resolved and Modelled (<0) Shear stresses



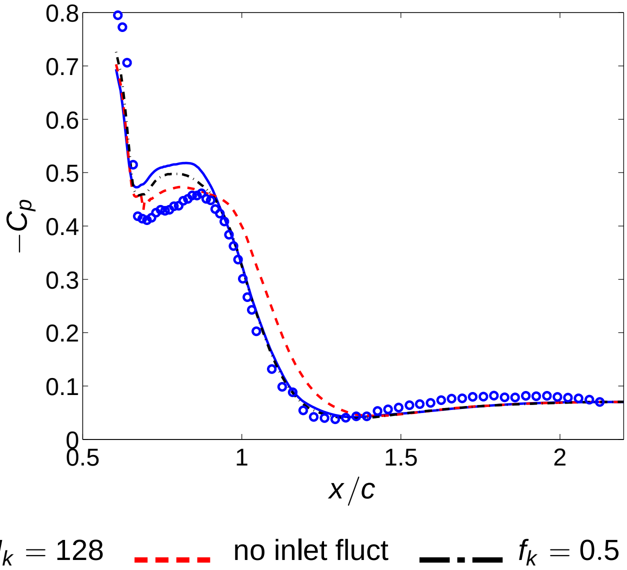
TURB VISCOSITY: AMPLITUDES OF INLET FLUCT



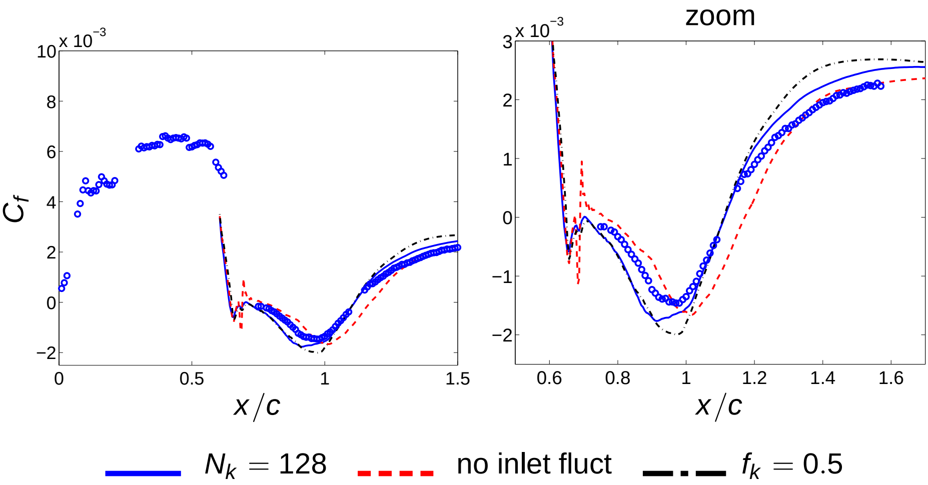
Turb Viscosity: Amplitudes Of Inlet Fluct



PRESSURE: $f_k = 0.5$; NO INLET FLUCT; $N_k = 128$



SKIN FRICTION: $f_k = 0.5$; NO INLET FLUCT; $N_k = 128$



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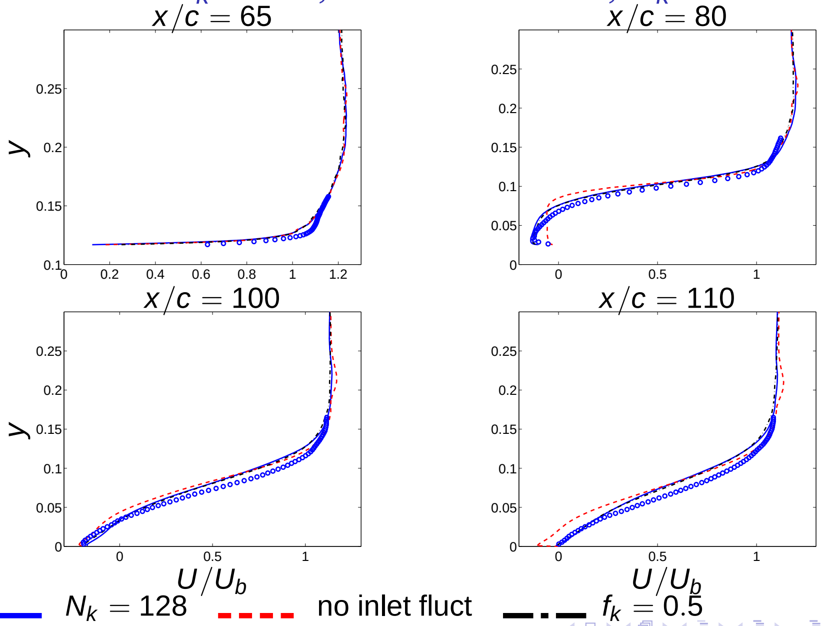
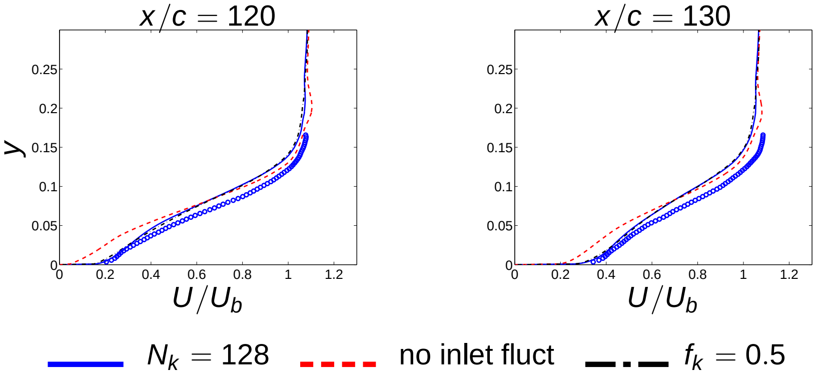
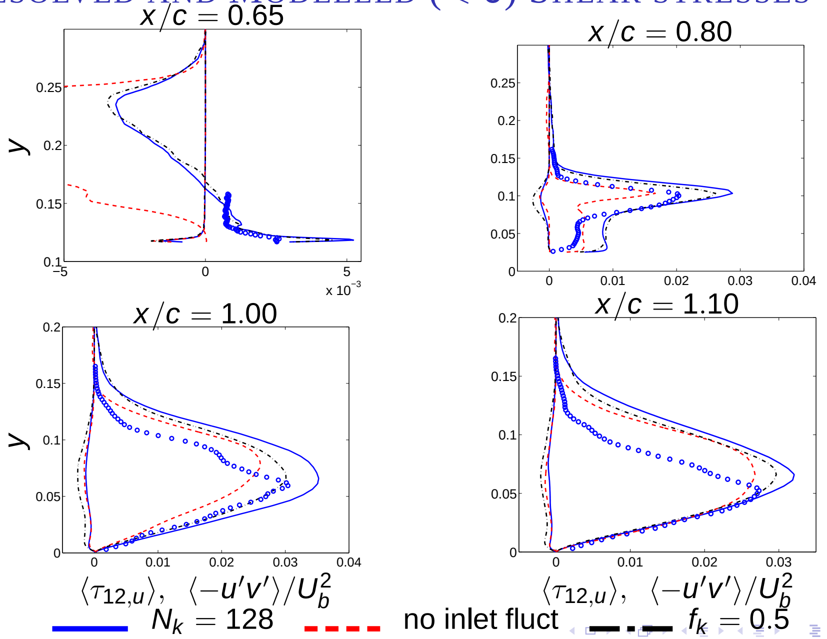


VELOCITIES: $f_k = 0.5$; NO INLET FLUCT; $N_k = 128$

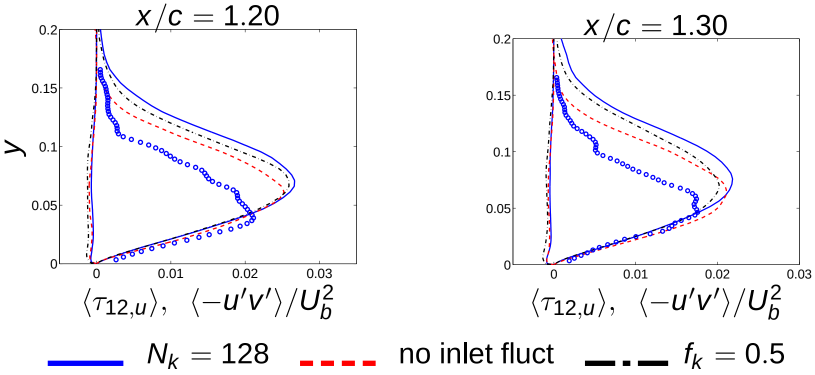


Resolved and Modelled (< 0) Shear stresses

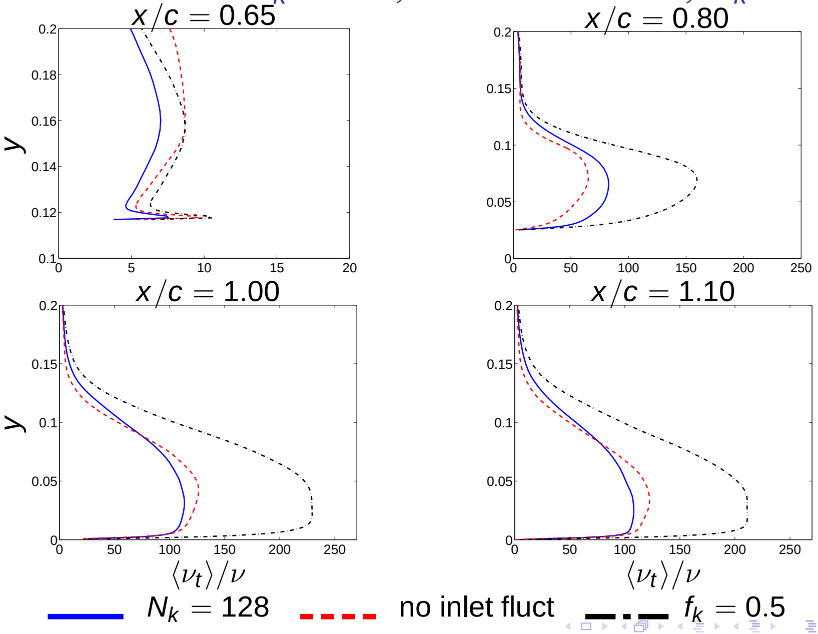


SHEAR STRESSES: $f_k = 0.5$; NO INLET FLUCT; $N_k = 128$

- Resolved and Modelled (< 0) Shear stresses



TURB VISCOSITY: $f_k = 0.5$; NO INLET FLUCT; $N_k = 128$



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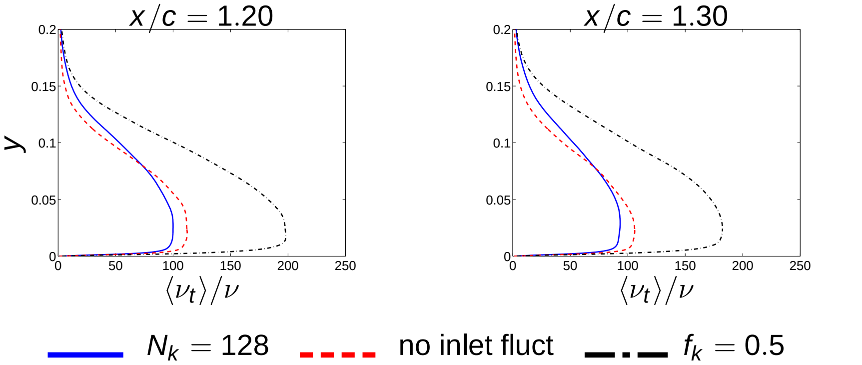

CONCLUDING REMARKS

- LRN PANS has been shown to work well as an embedded LES method
- Channel flow: At two δ downstream the interface, the resolved turbulence in good agreement with DNS data and the wall friction velocity has reached 99% of its fully developed value.
- Channel flow: The treatment of the modelled k_u and ε_u across the interface is important.
- LRN PANS predicts the hump flow well but the recover rate sligtly too slow
- Hump flow: large (small) inlet fluctuations gives a smaller (larger) recirculation

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[3] MA, J., PENG, S.-H., DAVIDSON, L., AND WANG, F.
A low Reynolds number variant of Partially-Averaged Navier-Stokes model for turbulence.
International Journal of Heat and Fluid Flow 32 (2011), 652–669. 10.1016/j.ijheatfluidflow.2011.02.001.