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and Technology

Advanced Wall Treatment Method for Turbulent Flow CFD Simulations

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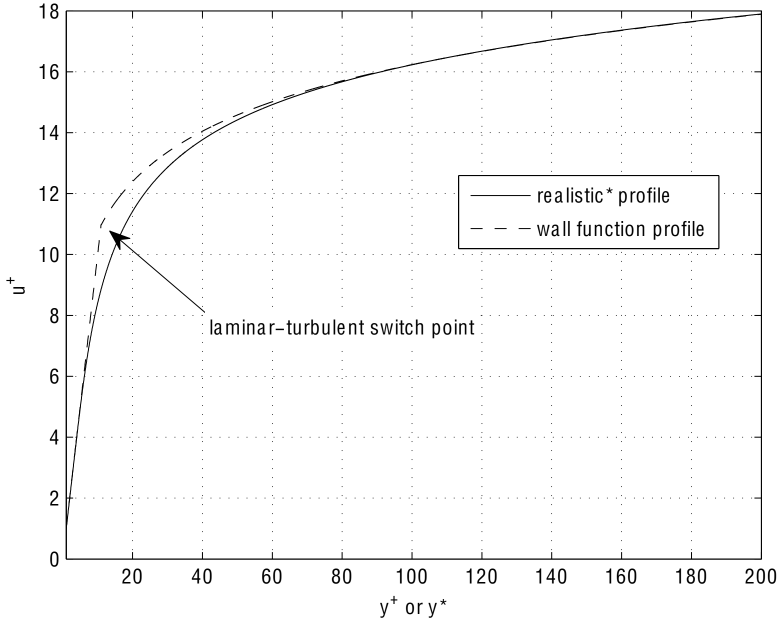
NEAR WALL HEAT AND MOMENTUM TRANSFER

✓**Difficult to measure or simulate**

✓**Enormous gradients (T, U)**

✓**Strong variation of (ρ, μ, κ, cp) with T**

✓**Anisotropic near wall turbulence**



HEAT (MOMENTUM) TRANSFER IN CFD

✓<u>Direct Numerical Simulation (DNS)</u>

→ Accurate but too heavy for most engineering simulations

✓<u>Large Eddy Simulation (LES)</u>

→ Still too heavy for accurate near wall modeling

✓<u>Reynold Averad Navier-Stokes (RANS)</u>

→ Economical but inaccurate with standard methods

NEAR WALL RANS MODELING OPTIONS

✓ <u>**Low-Re/Two-layer models**</u>
→ **require extensively fine mesh**

✓ <u>**High-Re models with wall functions**</u>
→ **huge property variations, e.g. ρ(T), impair accuracy**

✓ <u>***Advanced wall treatment/turbulence model***</u> →
→ **Less restrictions, high accuracy!!!**

ADVANCED WALL TREATMENT/ TURBULENCE MODEL

- ✓ Based on a Low-Re k-ε turbulence model
- ✓ Relevant profiles discretized in wall adjacent cells, integrated numerically
- ✓ Discretization ADAPTIVE to local conditions!!!
- ✓ Accounts for grad(T) induced property variations (ρ, μ, k, cp)

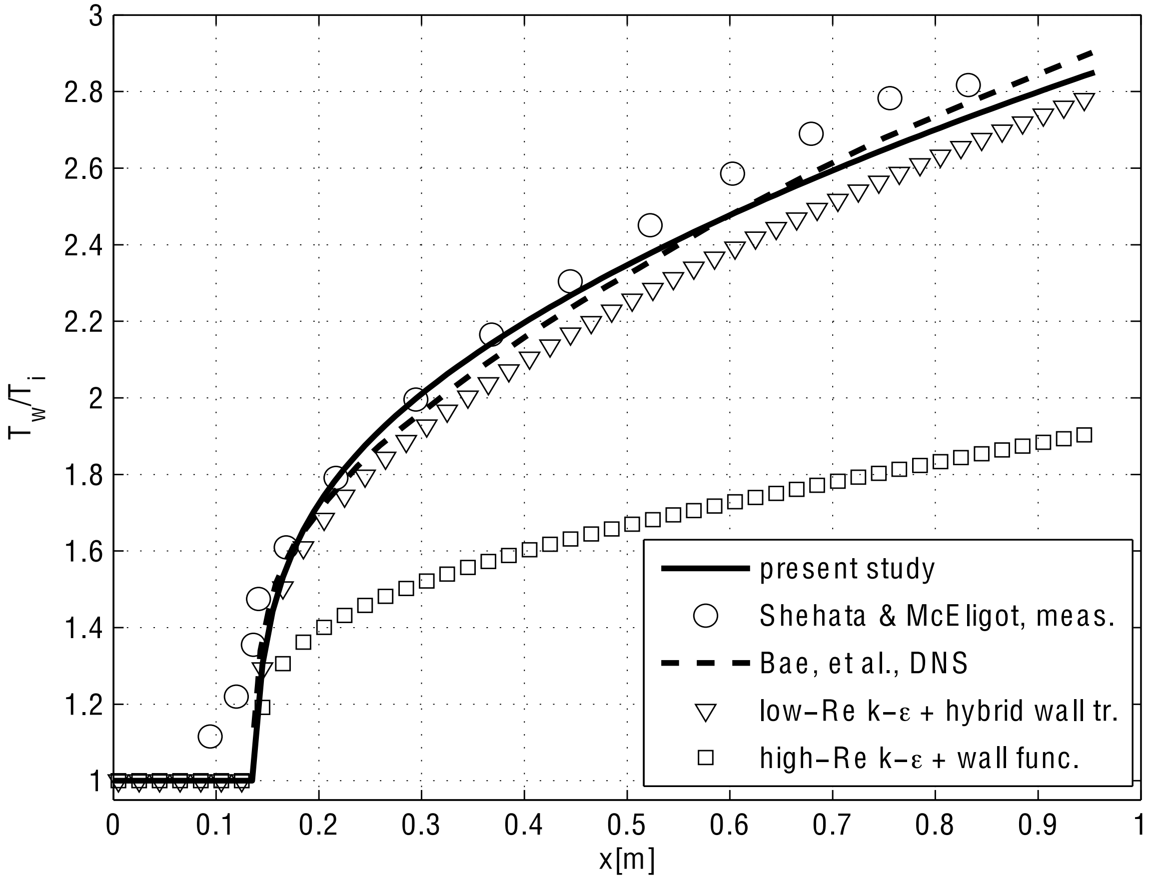
ADVANCED WALL TREATMENT/ TURBULENCE MODEL

- ✓ **Enhanced accuracy in near wall turbulence source computation with any resolution (utilizing the discrete profiles)**

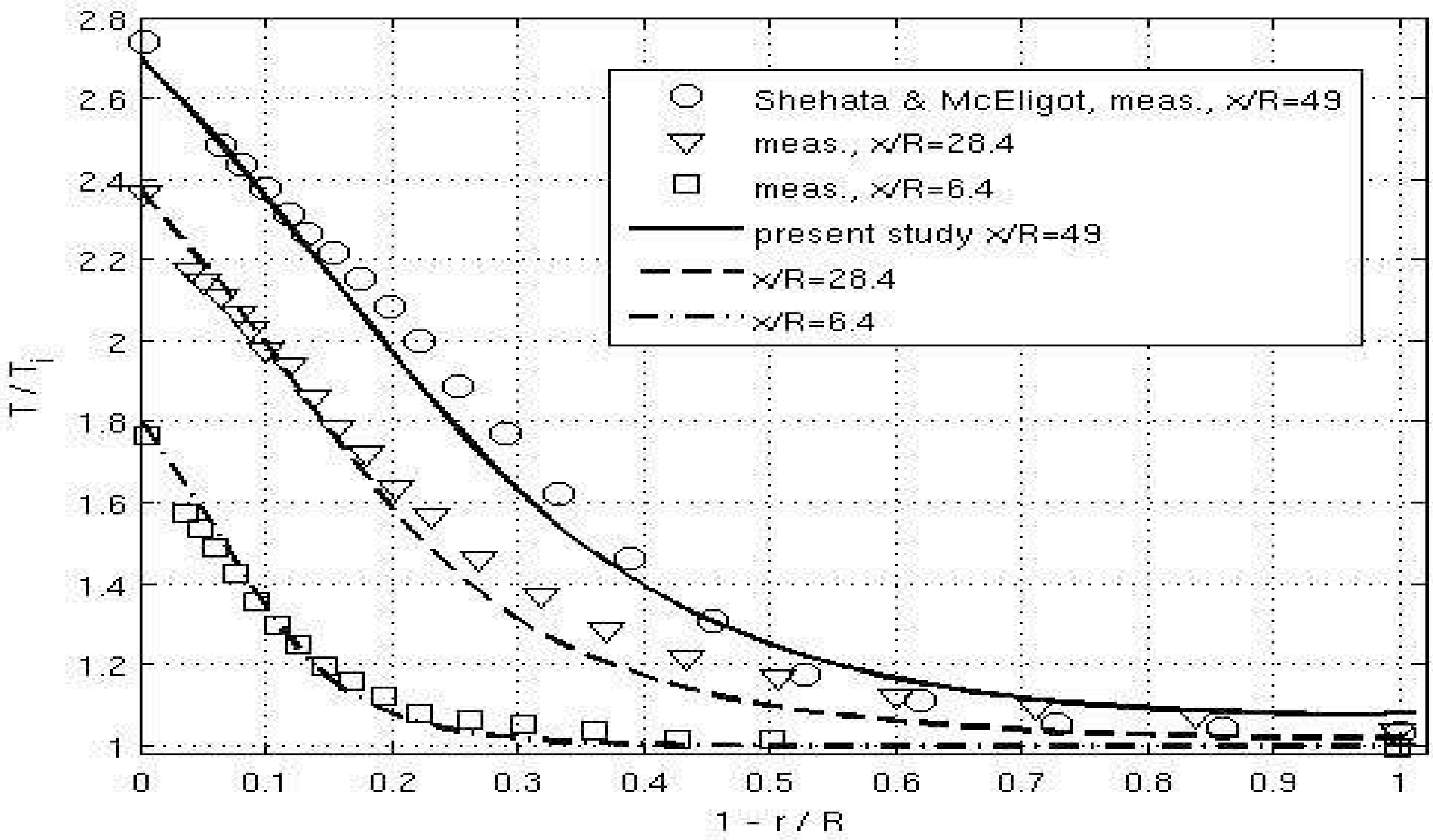
- ✓ **Free from the usual High/Low Re model grid spacing requirements**

VALIDATION AGAINST MEAS. AND DNS-DATA, WALL TEMPERATURE

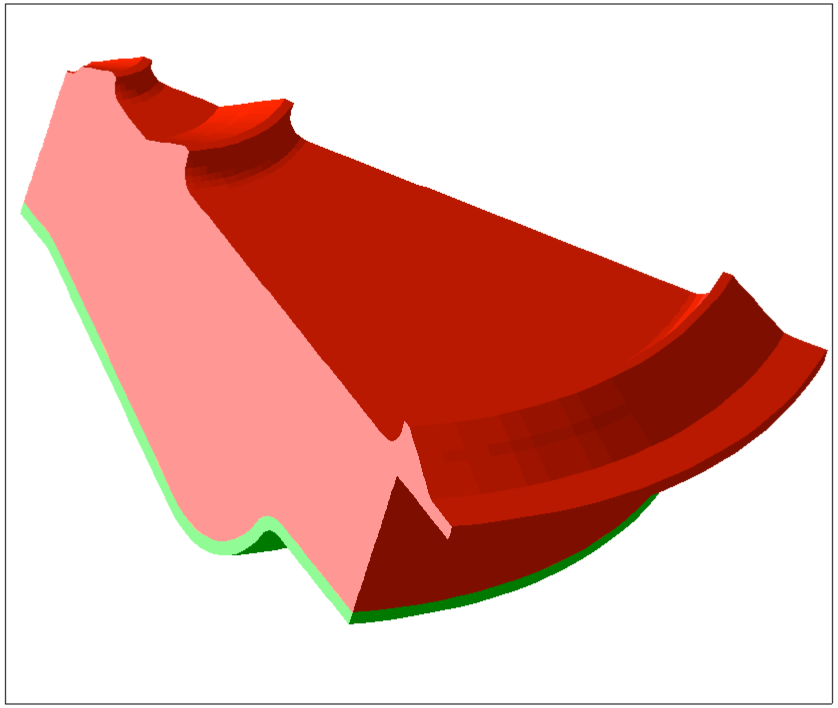
- Pipe Flow
- Re=4300
- D=27.4mm
- L=0.96m
- q=3980W/m^2
- y+<1

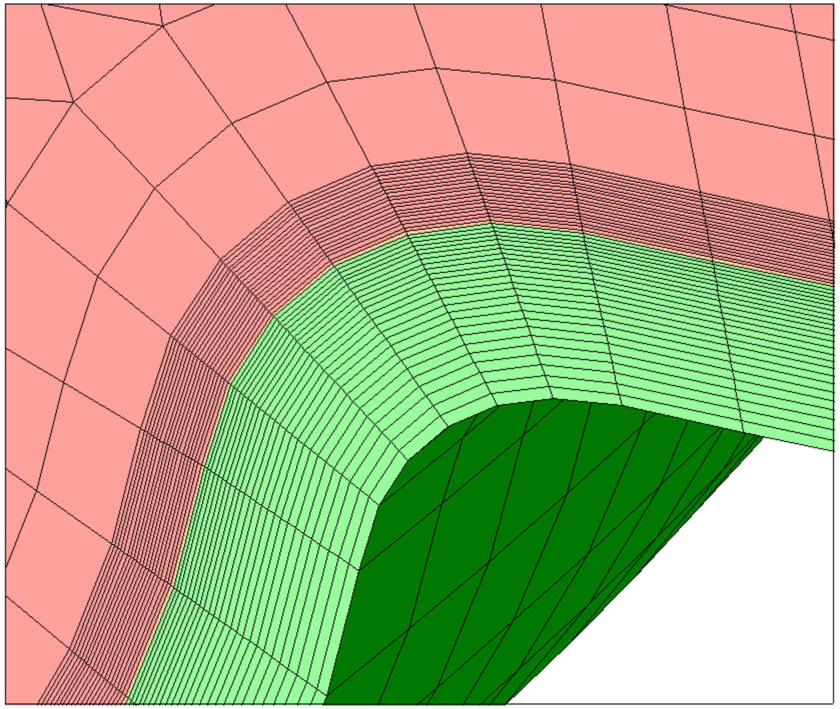


VALIDATION AGAINST MEAS., T(r)



CI ENGINE HEAT TRANSFER SIMULATIONS, 3D GRID





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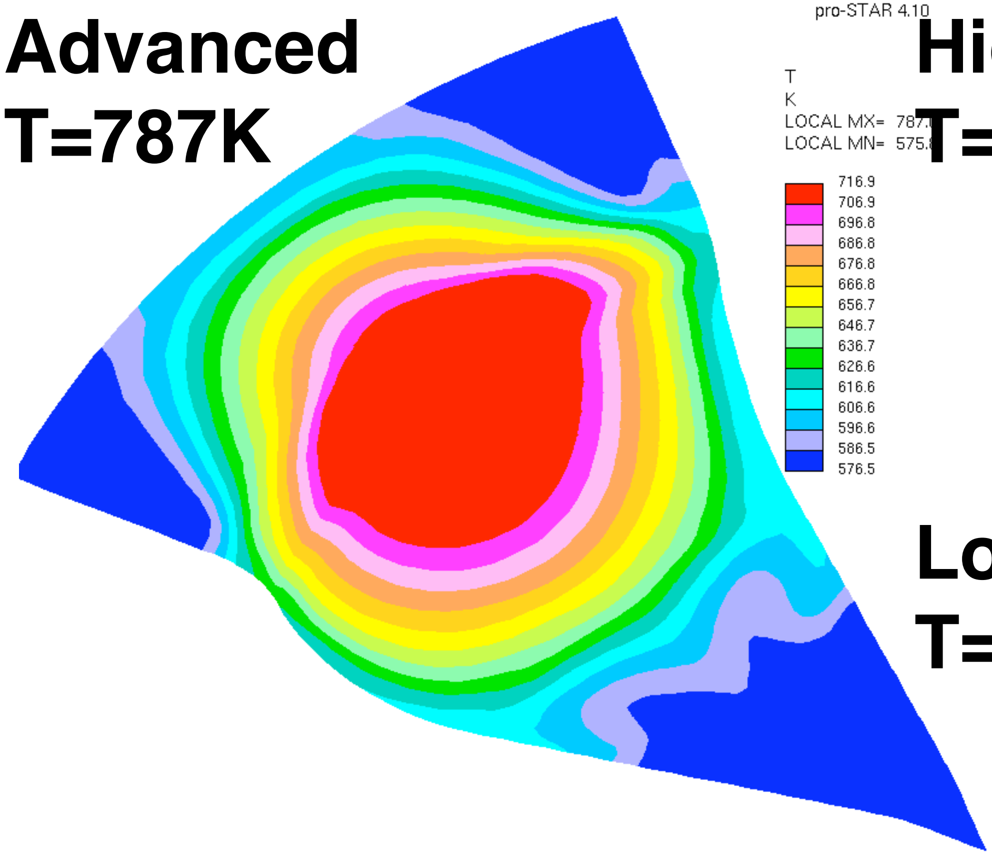
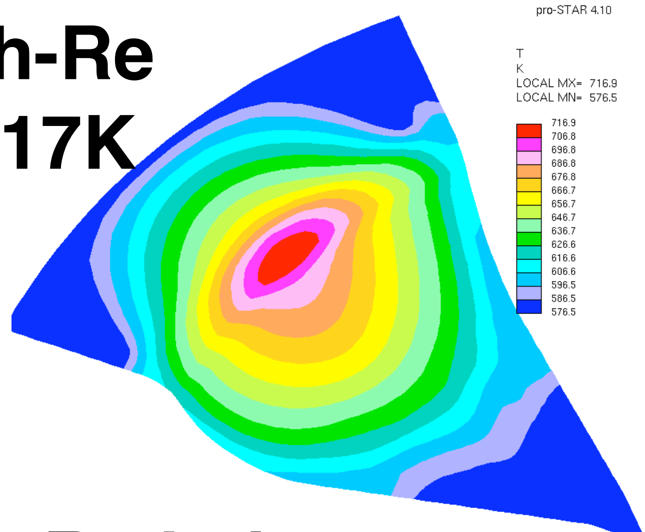
CI ENGINE HEAT TRANSFER SIMULATIONS, SURFACE TEMP.

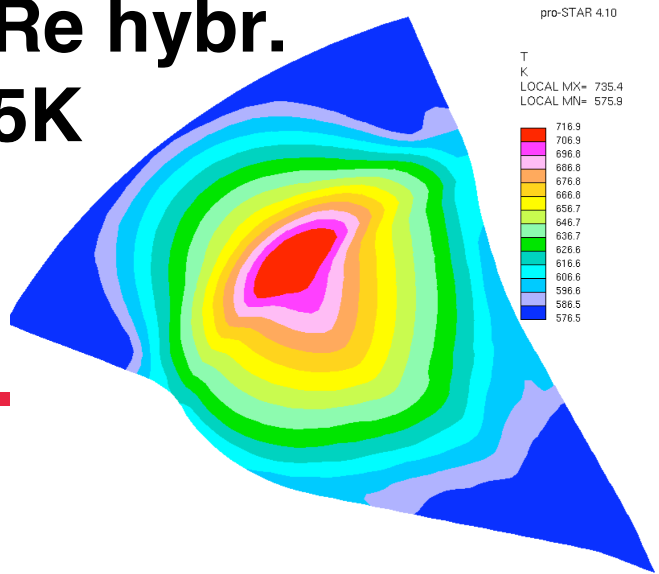
Advanced
T=787K



High-Re
T=717K

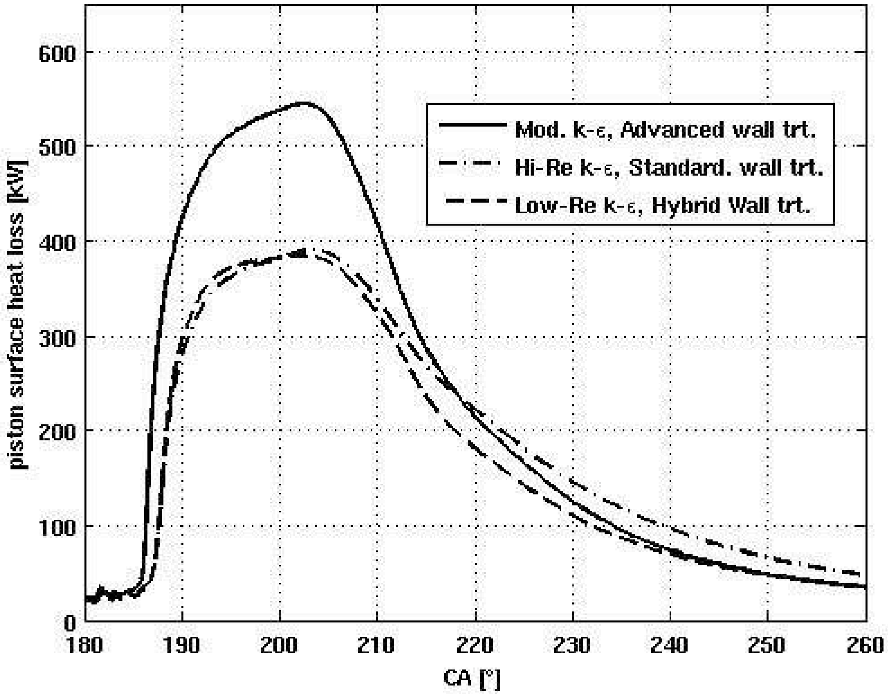


Low-Re hybr.
T=735K

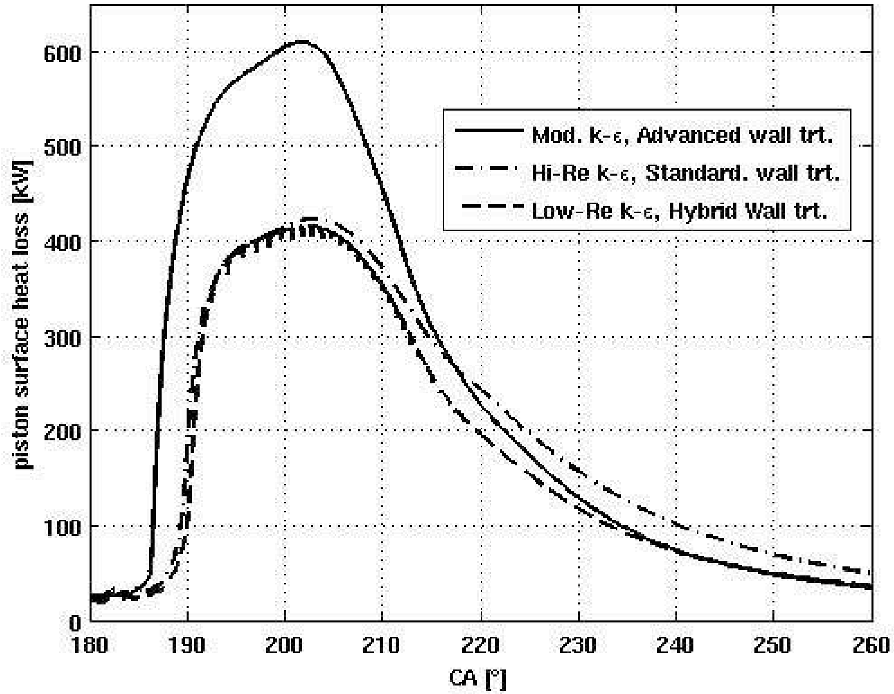


TOTAL PISTON HEAT LOSS

Conjugate Heat Transfer



Const. Temp. B.C.



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CONCLUSIONS & FUTURE GOALS

- ✓ Advanced model consistent with measurements and DNS
- ✓ Advanced model adaptive to grid resolution
- ✓ Advanced model successfully implemented on a commercial CFD code (Star-CD)
- ✓ Goals
  → Further model development
  → Piston temperature measurements

Near wall treatment equations

$$-\mu\frac{\partial^2 k}{\partial y^2} = \mu_t\left(\frac{\partial u}{\partial y}\right)^2 - \rho\varepsilon$$

$$\varepsilon = \tilde{\varepsilon} + \varepsilon_{wall} = \frac{C_\mu^{3/4}k^{3/2}}{\kappa y} + 2\frac{\mu}{\rho}\frac{k}{y^2} =$$

$$\frac{C_\mu^{3/4}k^{3/2}}{\kappa y}\left(1 + \frac{2\kappa C_\mu^{-3/4}}{\mathrm{Re}_y}\right) =$$

$$\tilde{\varepsilon}\left(1 + \frac{\alpha_\varepsilon}{\mathrm{Re}_y}\right)$$

$$(\mu + \mu_t)\frac{\partial u}{\partial y} = \tau_w$$

$$c_p\left(\frac{\mu}{\mathrm{Pr}} + \frac{\mu_t}{\mathrm{Pr}_t}\right)\frac{\partial T}{\partial y} = q_w$$

$$\mu\frac{\partial^2 k}{\partial y^2} = 2\mu\frac{k}{y^2}\Big|_{y=0}$$

$$\frac{\rho C_\mu k^2 f_{\mu 1}}{\tilde{\varepsilon}}\left(\frac{\partial u}{\partial y}\right)^2 = \rho\tilde{\varepsilon}$$

$$f_{\mu 1} = \left(1 - \exp\left(-\alpha_\mu \mathrm{Re}_y\right)\right)$$

$$y^+ = \frac{\rho_w u_\tau y}{\mu_w}$$

$$u^+ = \frac{u}{u_\tau}$$

$$T^+ = \frac{\rho_w c_{p,w} u_\tau (T - T_w)}{q_w}$$

$$u_\tau = \sqrt{\tau_w / \rho_w}$$

$$\tau_w = \frac{y_c^+}{u_c^+}\mu_w\left\{\frac{u_c - u_w}{y_c}\right\} =$$

$$\alpha^+\mu_w\left\{\frac{u_c - u_w}{y_c}\right\}$$

$$q_w = \frac{y_c^+}{T_c^+}c_{p,w}\mu_w\left\{\frac{(T_c - T_w)}{y_c}\right\} =$$

$$\beta^+ c_{p,w}\mu_w\left\{\frac{(T_c - T_w)}{y_c}\right\}$$

$$\frac{du^+}{dy^+} = \frac{2}{\lambda_1 + \sqrt{\left(\lambda_1^2 + 4\lambda_4\left(\kappa y^+\right)^2 f_{\mu 1}^{3/2}\right)}}$$

$$\frac{dT^+}{dy^+} = \frac{\mathrm{Pr}_w\,\mathrm{Pr}_t}{\lambda_2\,\mathrm{Pr}_t + \lambda_3\,\mathrm{Pr}_w\,\mu^+}$$

$$\mu^+ = \frac{\mu_t}{\mu_w} = \lambda_4\left(\kappa y^+\right)^2 f_{\mu 1}^{3/2}\frac{du^+}{dy^+}$$

Equations cont.

$$y_c^+ = \lambda_{1,c}\left(\frac{\left(y_c^*\right)^2 f_{\mu 1,c}^{1/2}}{\lambda_{4,c}} + \frac{y_c^*}{\lambda_{4,c} f_{\mu 1,c}^{1/2}\kappa}\right)^{1/2}$$

$$P^{wf} = \mu_w \mu^+ \left(\frac{\partial u^+}{\partial y^+}\right)^2 \left\{\frac{y_c^+}{u_c^+}\frac{u_c - u_w}{y_c}\right\}^2$$

$$(\rho\varepsilon)^{wf} = \left[\mu_w \mu^+ + \mu\left(\frac{2\kappa^2}{C_\mu^{1/2}}\right) f_{\mu 1}\right] \times \left(\frac{\partial u^+}{\partial y^+}\right)^2 \left\{\frac{y_c^+}{u_c^+}\frac{u_c - u_w}{y_c}\right\}^2$$

$$P_{avg} = \left\langle \chi_{prod} \right\rangle_{avg} \left\{\frac{u_c - u_w}{y_c}\right\}^2$$

$$\chi_{prod} = \mu_w \mu^+ \left(\frac{y_c^+}{u_c^+}\frac{\partial u^+}{\partial y^+}\right)^2$$

$$(\rho\varepsilon)_{avg} = \frac{\left\langle \chi_{dissip} \right\rangle_{avg}}{\chi_{dissip,c}} (\rho\varepsilon)_c$$

$$\chi_{dissip} = \left[\mu_w \mu^+ + \mu\left(\frac{2\kappa^2}{C_\mu^{1/2}}\right) f_{\mu 1}\right]\left(\frac{\partial u^+}{\partial y^+}\right)^2$$

$$P_{avg,tot} = \left\{P_1 + P_2 - \mu_{t,c}\left(\frac{\partial u_r^t}{\partial n}\right)^2\right\} + P_{avg}$$

$$\frac{\partial u_r^t}{\partial n} = \left\langle \vec{n}, \vec{\nabla} u_r^t \right\rangle = t_i n_j \frac{\partial u_i}{\partial x_j}$$

THANK YOU!

QUESTIONS AND COMMENTS ARE WELLCOME!