WALL MODELING
FOR IMMERSED BOUNDARY METHOD

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BRINKMAN PENALIZATION METHOD

\[ \begin{aligned}
\frac{\partial Q_\eta}{\partial t} + \nabla \cdot F(Q_\eta) + \frac{1}{\eta} \chi \begin{pmatrix}
0 \\
\rho_\eta (u_\eta - u_B) \\
\rho_\eta (u_\eta - u_B) + E_\eta - \rho \varepsilon_B \vee 0
\end{pmatrix} = \frac{1}{\text{Re}} \nabla \cdot F_v(Q_\eta), \quad x \in \Omega_f, \ t > 0
\end{aligned} \]

\[ Q_\eta(x,0) = Q_0(x), \quad x \in \Omega_f \]

\( \eta \ll 1 \) - penalty parameter

\( \chi(x) = \begin{cases} 
1, & x \in \Omega_b \\
0, & x \in \Omega_f
\end{cases} \) - mask function

Boiron O., et al. (Comp.& Fluids, 2009)
Abgrall R., et al. (JCP, 2014)
WALL FUNCTION FOR HIGH REYNOLDS NUMBER FLOW (1)

Wall functions: motivated by the universal nature of the flat plate boundary layer

Reichardt’s wall law

\[ u^+ = f_w(y^+) = \frac{1}{k} \log(1 + ky^+) + 7.8 \left( 1 - e^{\frac{y^+}{11}} - \frac{y^+}{11} e^{-0.33y^+} \right) \]
WALL FUNCTION FOR HIGH REYNOLDS NUMBER FLOW (2)

Implementation of the wall law using Brinkman penalization

The wall function adjusts the velocity field after penalization step.

- Consider interface point $P1$.
- Point $P2$ is found, along the normal-to-the-wall direction, at distance $d$, for instance, equal to *twice the largest distance from the wall to the interface points*.
- Velocity at $P2$ ($U_2$) is found by interpolation on the surrounding points.
- Using $U_2$ and wall law, the friction velocity is calculated.
- Using the friction velocity and wall law, the tangential velocity at $P1$ is calculated.

- interface point
- fluid point
- body point

Re = $1e+06$

$M = 0.2$

IBC, m1 – immersed boundary method using coarse mesh m1 with near-wall dy = 1e-02
IBC, m2 - immersed boundary method using fine mesh m2 with near-wall dy = 1e-05
BF – body-fitted approach using mesh with near-wall dy = 1e-05
FLAT PLATE (2)

No-slip boundary condition vs Wall-function (WF)

IBC, m1 – immersed boundary method with WF using coarse mesh m1 with near-wall dy = 1e-02
BF – body-fitted approach with No-Slip using mesh with near-wall dy = 1e-05

d – distance from the wall to interpolation point P2
Work in progress

• Investigate the robustness and efficiency issues in more detail.

• Review and implementation alternative wall modelling approaches applicable with penalty immersed boundary method.

• To use the Characteristic-Based Volume Penalization method instead of Brinkman Penalization? The mathematical ground can be provided.