

Ahmed Bluff Body OpenFOAM Validation Study: Mesh and Reynolds Number Sensitivity Studies

Caesar Wiratama, M.S.^{1,a)}

¹PT Tensor Karya Nusantara

^{a)} wiratama@pt-tensor.com

Abstract. This report documents an OpenFOAM validation of the classic Ahmed bluff body at 25° slant angle. A production baseline (CFD) was established at $U_\infty = 40$ m/s, followed by a three-level grid-independence study (GIT) and a three-point Reynolds-number sensitivity analysis. Force coefficients C_d and C_l are compared with experimental targets ($C_d = 0.299$, $C_l = 0.345$ at $Re\ 2.78 \times 10^6$). The medium mesh (~ 0.70 M cells) yields C_d and C_l errors within about 1% and 2% of experiment, respectively. The fine mesh shows incomplete steady convergence of C_l . Reynolds-number sweeps on the medium mesh recover the expected mild decrease of C_d with Re .

1. INTRODUCTION

The Ahmed body [1] is a simplified, geometric vehicle model widely recognized as a benchmark in automotive aerodynamics for replicating the airflow characteristics of real passenger cars. Developed by S.R. Ahmed, G. Ramm, and G. Faltin in 1984, this generic bluff body features a sharp, slanted rear end that triggers complex three-dimensional flow structures, including massive flow separation and highly sensitive trailing vortices.

Validating an OpenFOAM template for this specific case is critical because it forms a foundational element of tensorCFD [4], an open-source initiative by PT Tensor aimed at delivering production-ready, industry-grade simulation templates. Specifically, this validated setup will serve as the core engine for tensorXFV, a dedicated template designed for evaluating external flow over road vehicles. Because the 25° slant angle creates a highly unstable flow regime that sits right at the edge of the critical aerodynamic threshold, rigorously verifying this OpenFOAM template against trusted experimental data [2, 3] ensures that tensorXFV provides engineers with a highly reliable, mesh-independent, and Reynolds-number-accurate baseline for commercial automotive development.

2. NUMERICAL METHODS

2.1 Solver and Turbulence Model

Incompressible steady RANS was solved with simpleFoam using the consistent SIMPLE algorithm. Turbulence closure is kOmegaSST. Kinematic viscosity is $\nu = 1.5 \times 10^{-5}$ m²/s. Force coefficients use $A_{ref} = 0.115032$ m², $l_{ref} = 0.470$ m, and freestream density $\rho_\infty = 1$ (incompressible convention).

2.2 Geometry and Boundary Conditions

The 25° Ahmed body STL occupies a domain $x \in [-5, 15]$, $y \in [-4, 4]$, $z \in [0, 8]$ m. Inlet velocity is uniform U_∞ ; outlet pressure is fixed; the lower wall is a moving ground at freestream speed; upper and side walls are slip; the body is no-slip. Inlet turbulence intensity is about 1%, with $k \propto U_\infty^2$ and $\omega \propto U_\infty$ when Re is varied.

2.3 Mesh Generation

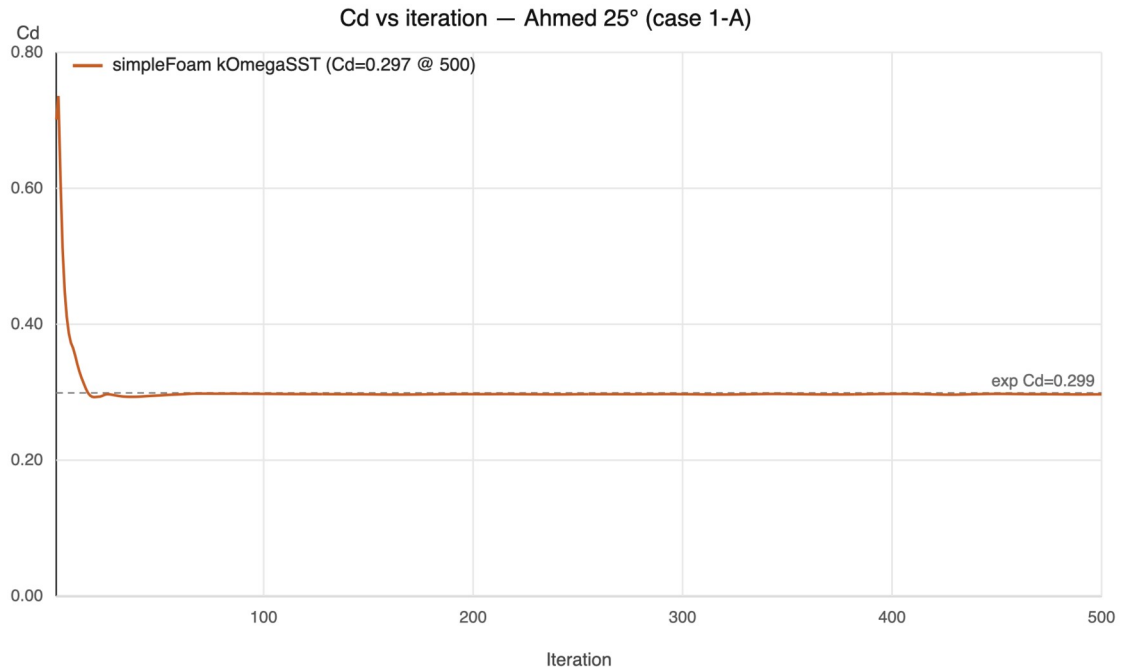
Background grids are generated with blockMesh and body-fitted hex-dominant meshes with snappyHexMesh (castellate, snap, layers). Feature edges are extracted with surfaceFeatureExtract. Parallel meshing uses eight ranks (hierarchical $4 \times 2 \times 1$). The baseline (mesh02 / CFD) has approximately 695,463 cells after layer addition.

TABLE 1. Baseline numerical setup

Item	Setting
OpenFOAM	v2406 / run host v2512
Solver	simpleFoam (steady RANS)
Turbulence	RAS kOmegaSST
U_∞ (baseline)	40 m/s
$Re_L = U_\infty L / \nu$, $L = 1.044$ m	2.78×10^6
ν	1.5×10^{-5} m ² /s
Exp. C_d / C_l ($Re\ 2.78 \times 10^6$)	0.299 / 0.345
Decomposition	8 ranks, hierarchical (4 2 1)
End time (iterations)	500

3. BASELINE CFD RESULTS

The production baseline at $U_\infty = 40$ m/s on the medium mesh converges to $C_d \approx 0.2971$ and $C_l \approx 0.3381$ (mean of the last 200 iterations), corresponding to relative errors of about -0.65% and -2.0% versus experiment.

**FIGURE 1.** Baseline CFD: C_d versus iteration ($U_\infty = 40$ m/s).

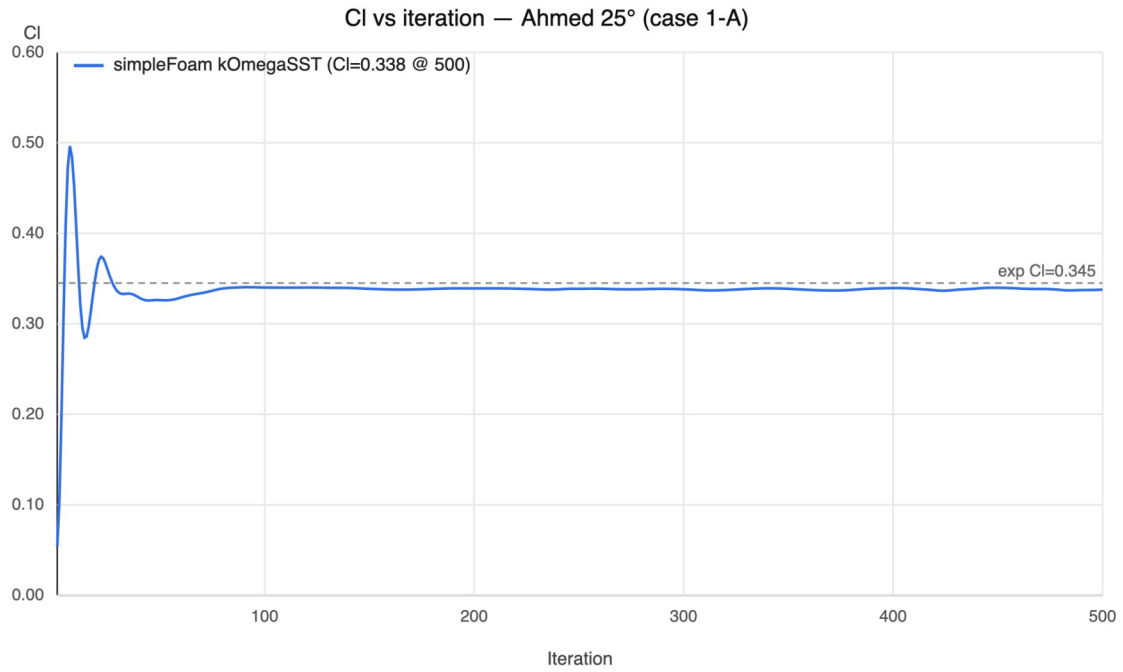


FIGURE 2. Baseline CFD: CI versus iteration ($U_\infty = 40$ m/s).

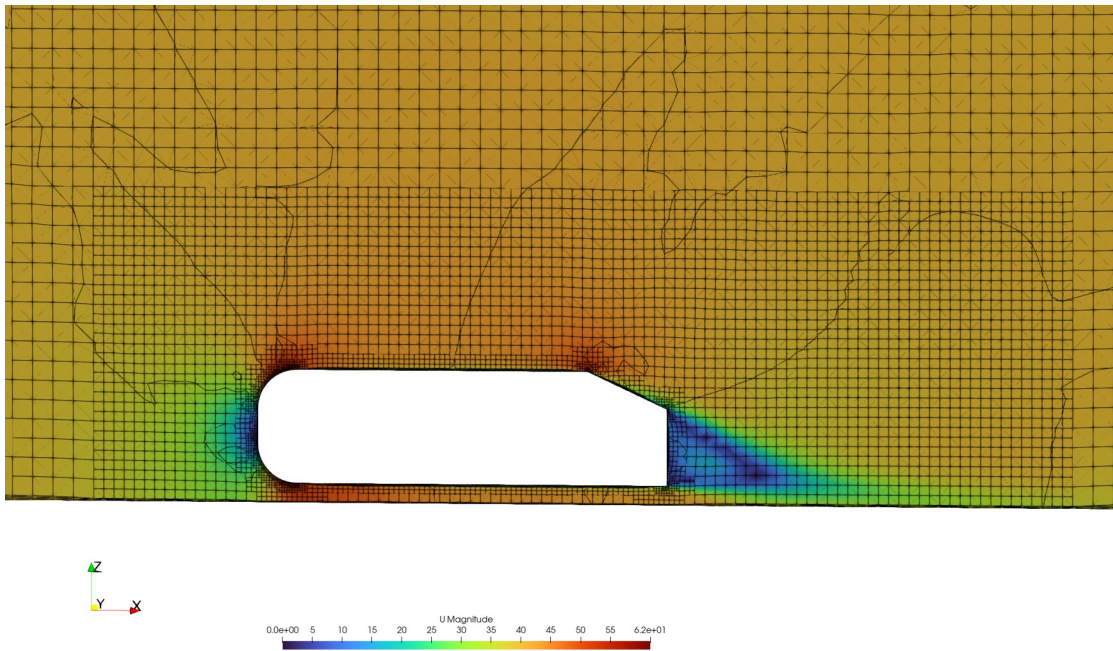


FIGURE 3. Baseline velocity magnitude on the symmetry plane (mesh02 / CFD, $U_\infty = 40$ m/s).

4. GRID INDEPENDENCE STUDY (GIT)

Three meshes were constructed by changing background resolution, surface/feature refinement, volume boxes, and prism layers. Physics and boundary conditions match the CFD baseline. mesh02_medium is identical in intent to CFD (~0.70 M cells).

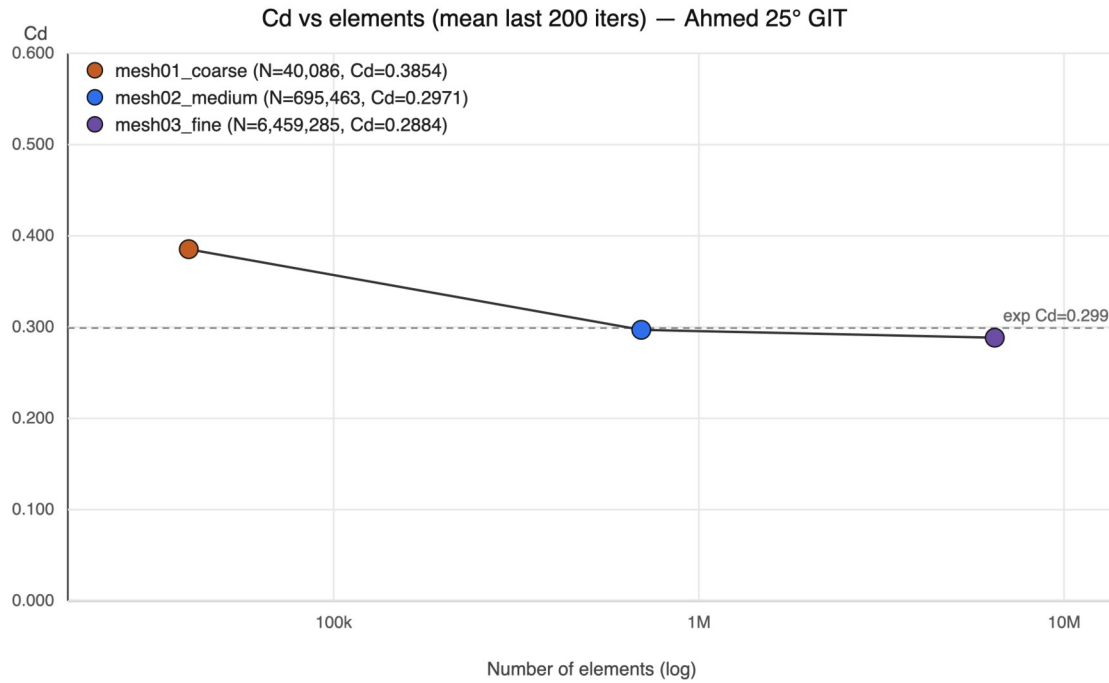
TABLE 2. Mesh ladder settings

Case	blockMesh	Surface level	Volume boxes	Body layers	Cells
mesh01_coarse	(16 8 8)	(4 5)	2 / 3 / 4	6	40,086
mesh02_medium	(24 10 10)	(5 6)	3 / 4 / 5	10	695,463
mesh03_fine	(36 14 14)	(6 7)	4 / 5 / 6	12	6,459,285

TABLE 3. GIT results versus experiment (averaged last 200 iterations to accommodate transient data)

Mesh	Cells	Cd	Cd err %	CI	CI err %
mesh01_coarse	40,086	0.3854	+28.90%	0.3737	+8.33%
mesh02_medium	695,463	0.2971	−0.65%	0.3381	−1.99%
mesh03_fine	6,459,285	0.2884	−3.54%	0.3124	−9.46%

The coarse mesh over-predicts drag substantially. The medium mesh is closest to experiment. The fine mesh does not improve CI agreement: CI exhibits a large limit-cycle oscillation in the last 100 iterations (range ≈ 0.16), so the steady RANS mean is not a fully converged steady answer. Finer grids reduce numerical dissipation and expose the intrinsic unsteadiness of the 25° Ahmed wake.

**FIGURE 4.** Cd versus number of elements (GIT), with experimental Cd = 0.299.

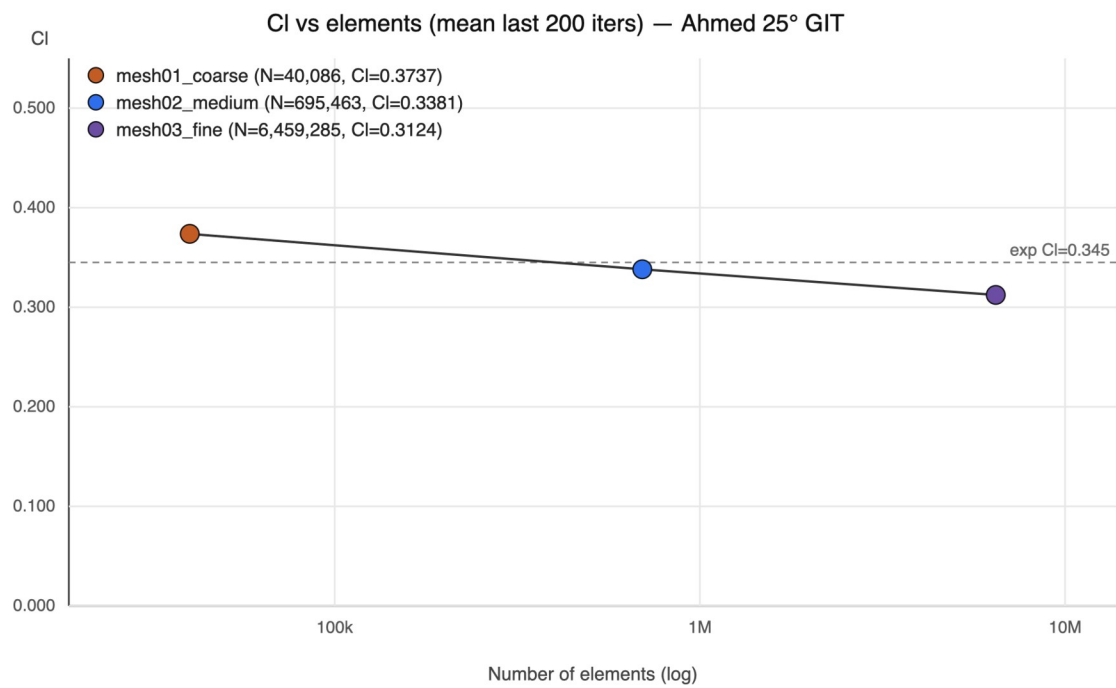


FIGURE 5. CI versus number of elements (GIT), with experimental CI = 0.345.

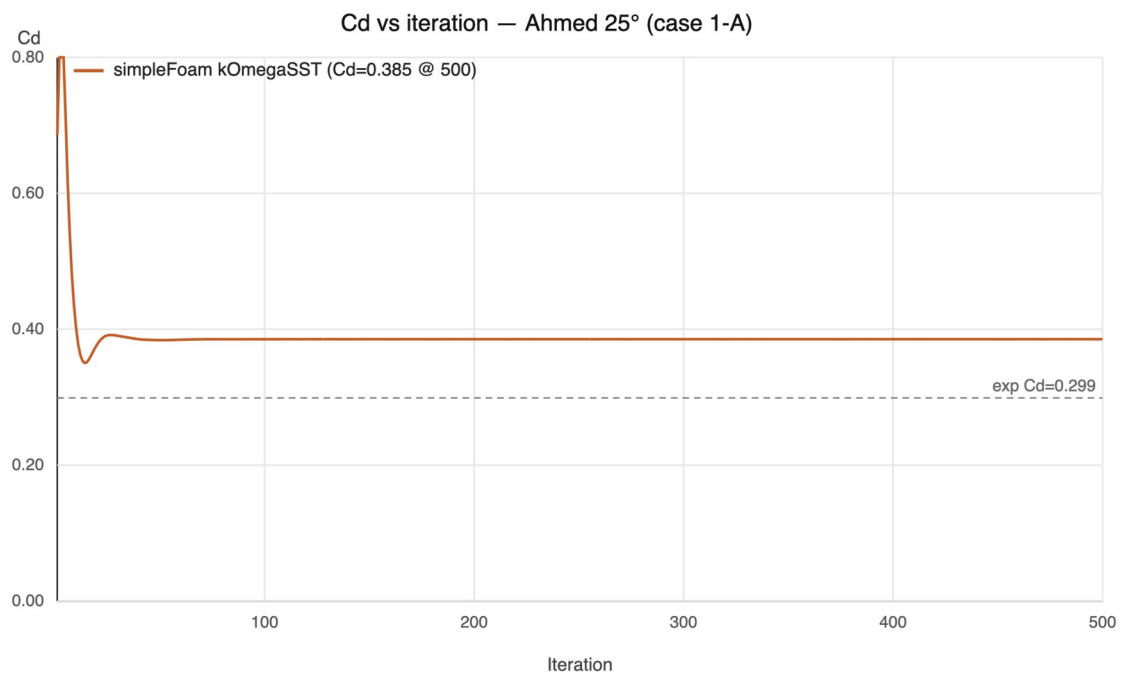


FIGURE 6. mesh01_coarse: Cd versus iteration.

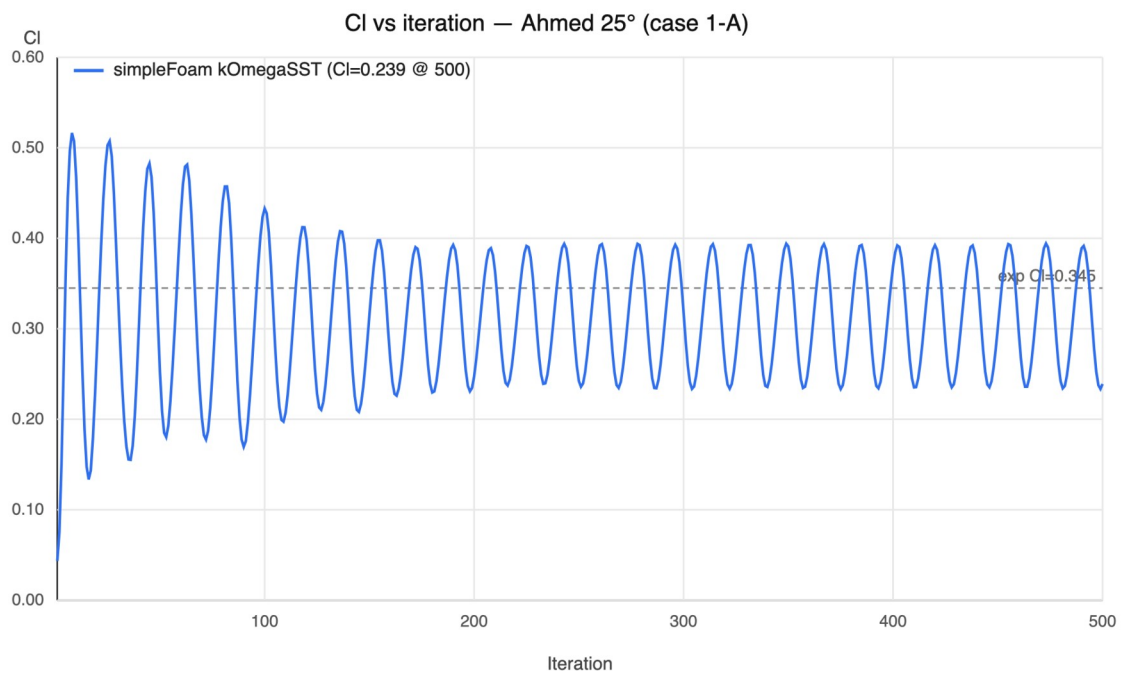


FIGURE 7. mesh03_fine: CI versus iteration (strong late-time oscillation).

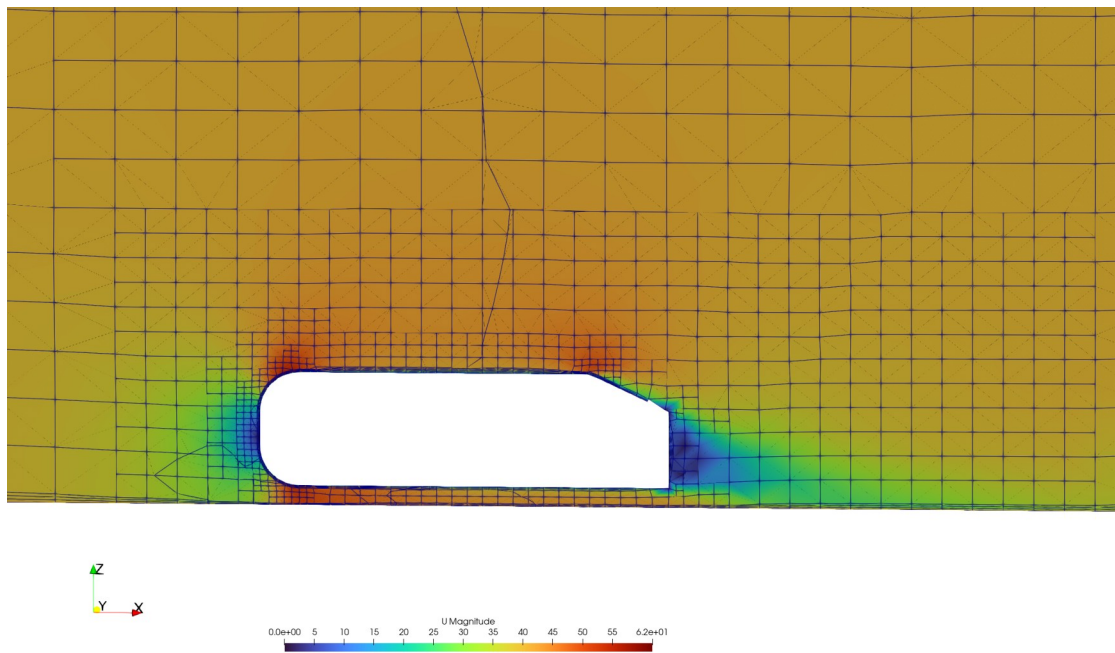


FIGURE 8. Velocity magnitude, mesh01_coarse (symmetry plane).

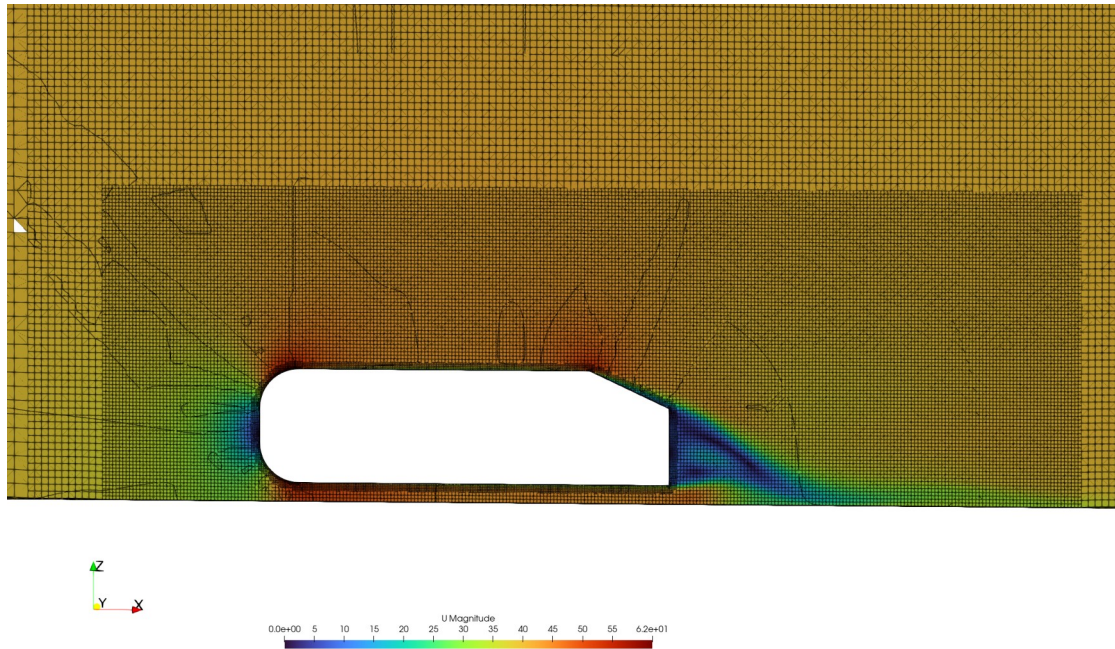


FIGURE 9. Velocity magnitude, mesh03_fine (symmetry plane).

5. REYNOLDS NUMBER SENSITIVITY

Using the medium mesh, freestream speed was set to 20, 40, and 60 m/s ($Re_L \approx 1.39 \times 10^6$, 2.78×10^6 , 4.18×10^6). Turbulence intensity and length scale were held fixed by scaling $k \propto U_\infty^2$ and $\omega \propto U_\infty$. Mid-Re experimental anchors ($C_d = 0.299$, $C_l = 0.345$) are from Meile et al. [3]. Low/high C_{d_exp} values are trend estimates informed by the Re dependence reported in [3] and the higher-Re comparison with Ahmed et al. [1], anchored so the mid point matches $C_d = 0.299$; C_{l_exp} is held at 0.345.

TABLE 4. Re sensitivity: CFD versus experiment (mean last 200 iterations)

Case	U_∞	Re_L	C_d	C_{d_exp}	$C_d \text{ err } \%$	C_l	C_{l_exp}	$C_l \text{ err } \%$
re01_U20	20	1.39e6	0.3019	0.3190	-5.36%	0.3278	0.3450	-4.98%
re02_U40	40	2.78e6	0.2971	0.2990	-0.65%	0.3381	0.3450	-1.99%
re03_U60	60	4.18e6	0.2953	0.2970	-0.56%	0.3431	0.3450	-0.56%

CFD recovers a mild decrease of C_d with increasing Re , consistent with published trends. Agreement is best at mid and high Re for the exact/near-anchor targets. The larger low- Re C_d discrepancy partly reflects uncertainty in the estimated experimental C_d at $Re_L = 1.39 \times 10^6$.

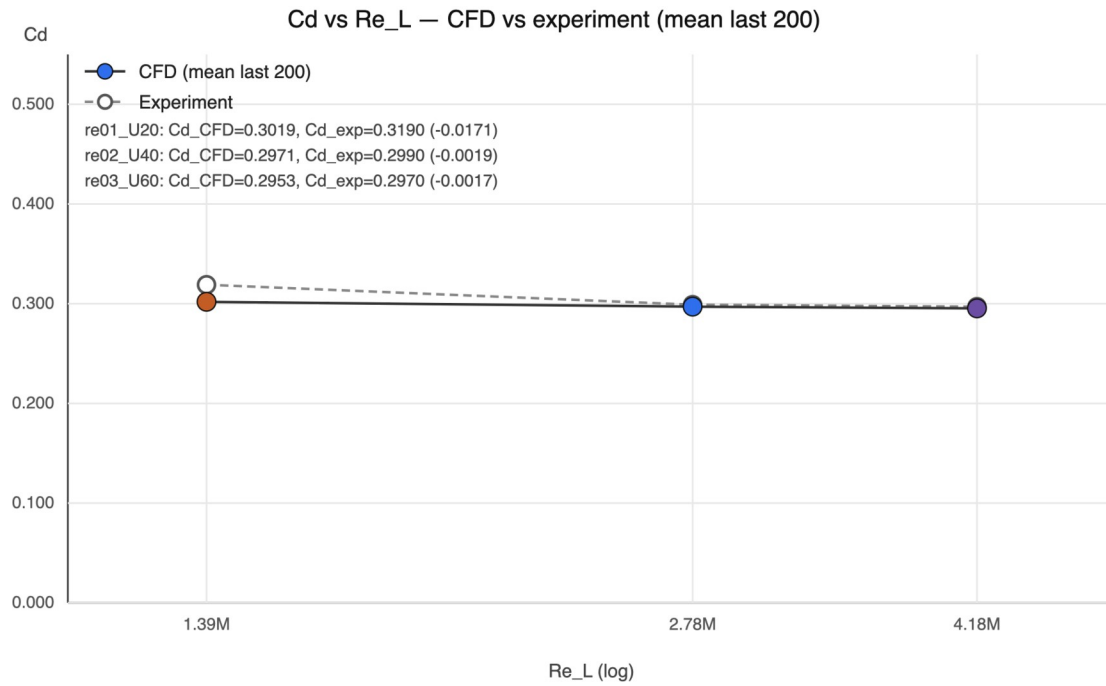


FIGURE 10. C_d versus Re_L : CFD versus experiment.

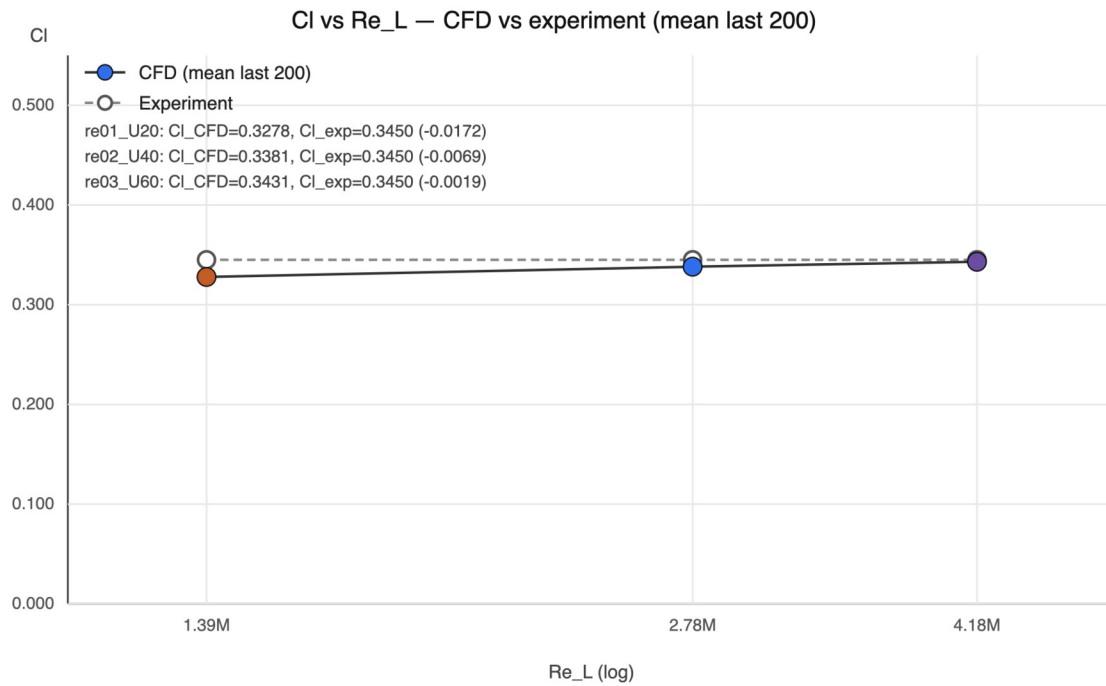


FIGURE 11. Cl versus Re_L : CFD versus experiment.

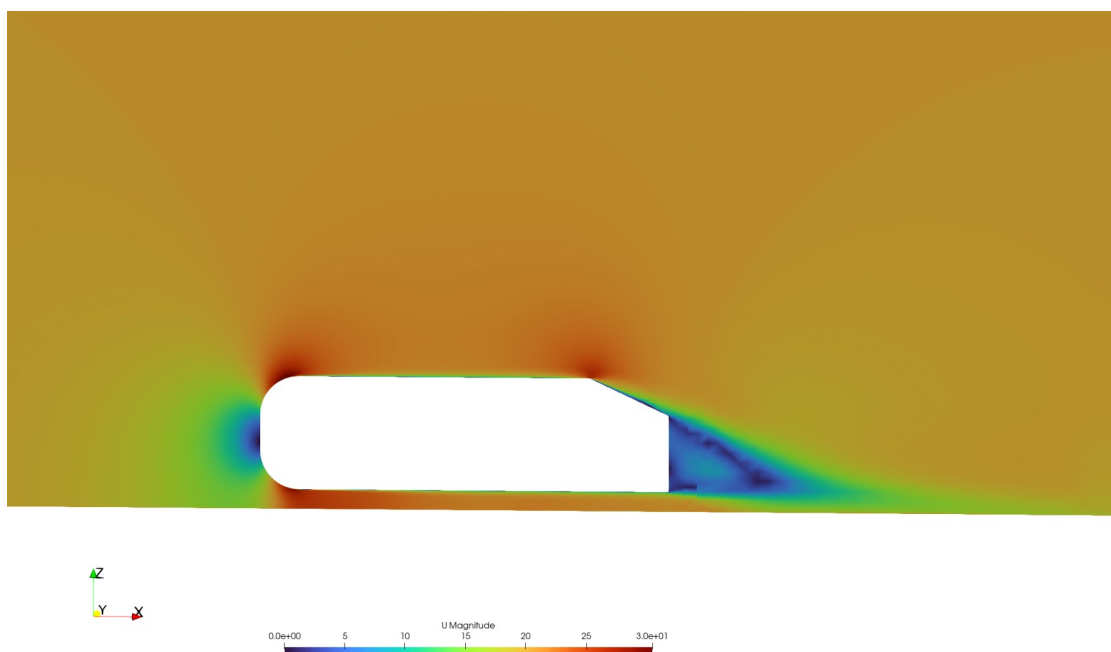


FIGURE 12. Velocity magnitude at $U_\infty = 20$ m/s (re01_U20).

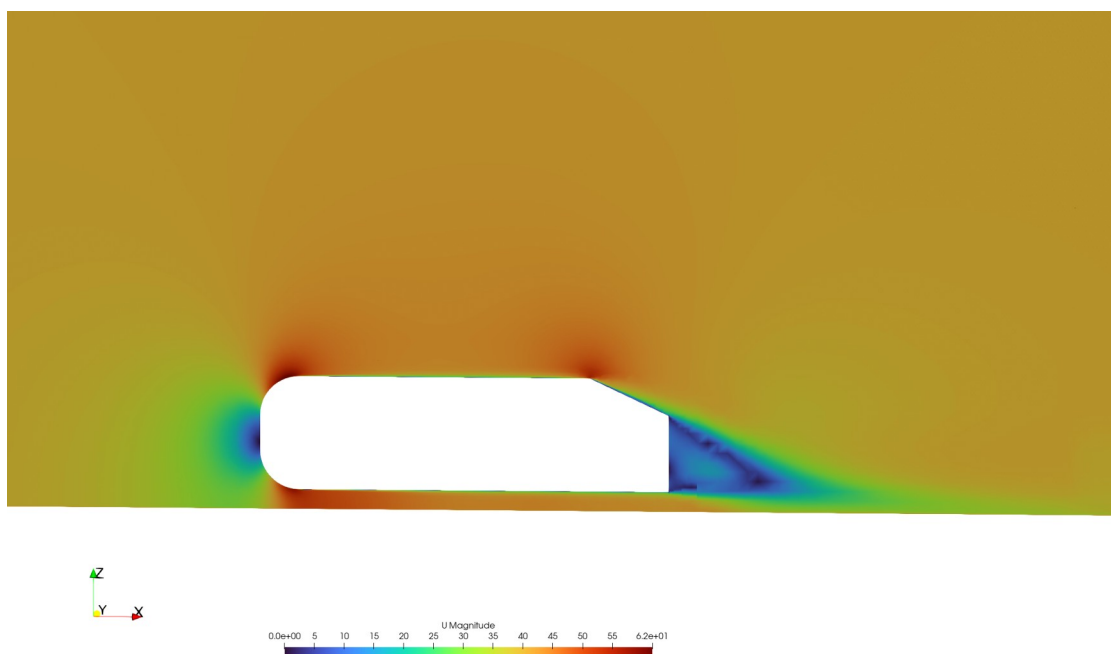


FIGURE 13. Velocity magnitude at $U_\infty = 40$ m/s (re02_U40).

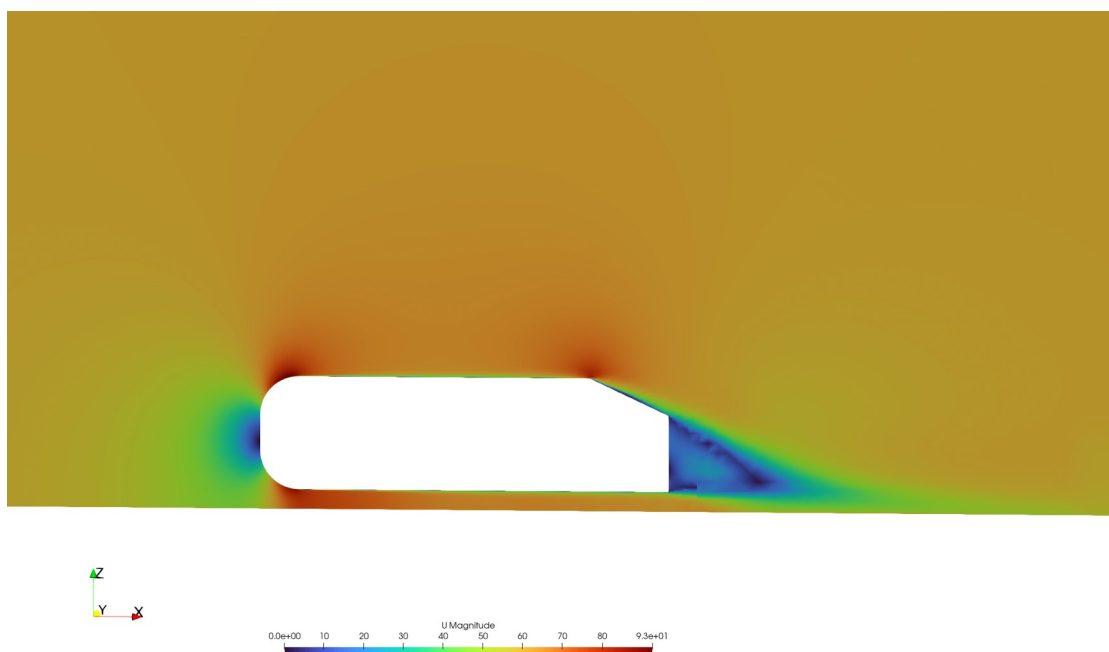


FIGURE 14. Velocity magnitude at $U_\infty = 60$ m/s (re03_U60).

6. CONCLUSIONS

This study successfully established and validated an OpenFOAM v2406 RANS simulation workflow for the 25° Ahmed body against experimental force coefficients at a velocity of 40 m/s. Through a systematic grid independence study, the medium mesh configuration with approximately 0.70 million cells was identified as the most practical optimum for steady RANS calculations. This grid density achieved excellent predictive accuracy, restricting the drag coefficient (C_d) error to approximately -0.65% and the lift coefficient (C_l) error to around -2% .

Interestingly, increasing the grid resolution to a fine mesh of roughly 6.5 million cells did not improve the accuracy of the lift coefficient. Instead, the finer grid exposed transient wake unsteadiness that conflicted with the steady-state iteration constraints. This indicates that a fair evaluation of a highly refined mesh requires shifting to more advanced transient approaches, such as Unsteady RANS (URANS) or Detached Eddy Simulation (DES), coupled with longer time-averaging. Finally, conducting Reynolds-number sweeps on the optimal medium mesh captured a physically consistent trend in how drag changes with the Reynolds number, keeping the results tightly aligned within a few percent of the baseline experimental targets.

ACKNOWLEDGEMENT

PT Tensor for sponsoring this validation study and for their ongoing commitment to advancing the computational fluid dynamics community through the tensorCFD initiative. This work was made possible by their vision of keeping high-fidelity engineering templates accessible, practical, and production-ready for global industrial applications.

In the true spirit of open-source collaboration, the complete case files, mesh configurations, and automated post-processing scripts for this study have been made publicly available. The simulation template can be accessed, cloned, and modified directly via GitHub at: <https://github.com/pt-tensor/AhmedBody-RANS.git>

REFERENCE

1. Ahmed, S. R., Ramm, G., & Faltin, G. (1984). Some Salient Features of the Time-Averaged Ground Vehicle Wake. SAE Technical Paper 840300.
2. Lienhart, H., Stoots, C., & Becker, S. (2000). Flow and Turbulence Structures in the Wake of a Simplified Car Model (Ahmed Model). DGLR Fach-Symposium der AG STAB.
3. Meile, W., Brenn, G., Reppenhagen, A., Lechner, B., & Fuchs, A. (2011). Experiments and numerical simulations on the aerodynamics of the Ahmed body. *CFD Letters*, 3(1), 32–39.
4. PT Tensor. OpenFOAM case templates / tensorCFD. <https://en.pt-tensor.com/openfoam-case-templates/>