

Steady Supersonic/Hypersonic — Blottner Case

Geometry: Sphere

Flow: Laminar

Constant Wall Temperature

Scheme

- Block structured
- 2nd-order FV
- Limiter: Yee's STVD
- Numerical Flux: Roe's + Harten's entropy fix
- Solver: line relaxation

Stagnation and integrated heat flux

		Stagnation qw [W/cm^2]	Stagnation qw [unitless]	Integrated wall heat flux [W]	Integrated wall heat flux [unitless]	Total iterations [#]	Final L2 norm	Work unit [CPU hours]
Blottner-Original	Coarse	11.296	1336.716	1133.572	5.295E+02	5,000	1.02E-16	-
	Medium	11.150	1319.439	1127.721	5.267E+02	6,000	6.61E-18	120
	Fine	10.975	1298.731	1126.603	5.262E+02	10,000	3.08-18	480
		Stagnation qw [W/cm^2]	Stagnation qw [unitless]	Integrated wall heat flux [W]	Integrated wall heat flux [unitless]	Total iterations [#]	Final L2 norm	Work unit [CPU hours]
Blottner-Adapted (3 times)	Coarse	11.1340	1317.546	1134.101	5.297E+02	6,000	1.24E-17	-
	Medium	11.0526	1307.914	1126.588	5.262E+02	9,000	9.73E-17	180
	Fine	10.9267	1293.015	1125.667	5.258E+02	15,500	1.16E-16	480

$T_w = 98.9 [K]$

$T_\infty = T_w/1.308 = 75.61 [K]$

$\rho_\infty = 8.767 \times 10^{-2} [kg/m^3]$

$V_\infty = 874.1 [m/s]$

$k_\infty = 1.236 \times 10^{-10} \rho_\infty V_\infty^3 [kg/sec - K]$

$= 7.24 \times 10^{-3} [kg/sec - K]$

$= 7.10 \times 10^{-2} [W/m - K]$

$Radius := R = 0.0635 [m],$

$\mu_{Sutherland} = \frac{s_1 T^{3/2}}{T + s_2}, \quad s_1 = 0.1458205 \times 10^{-5}, \quad s_2 = 110.333333$

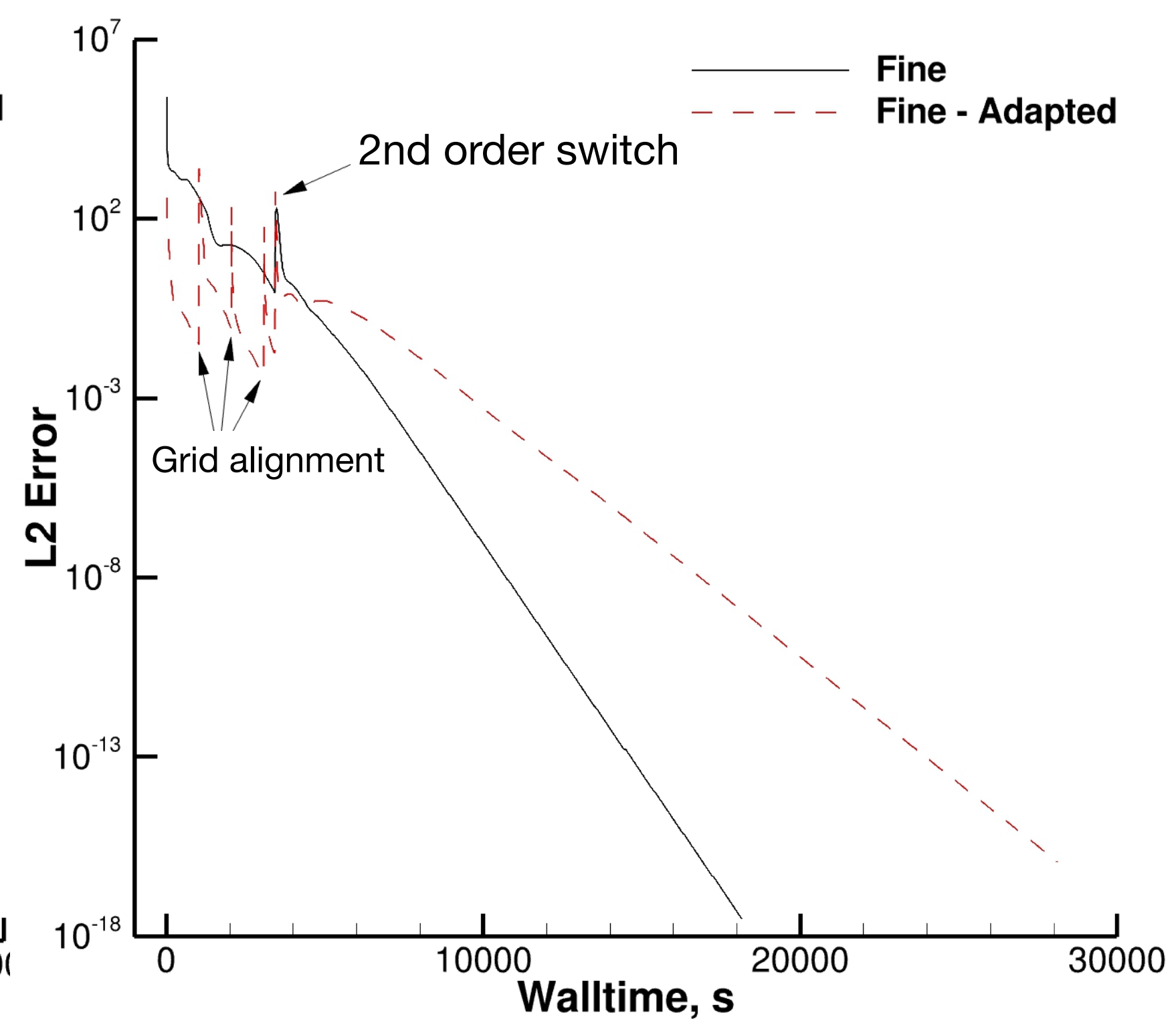
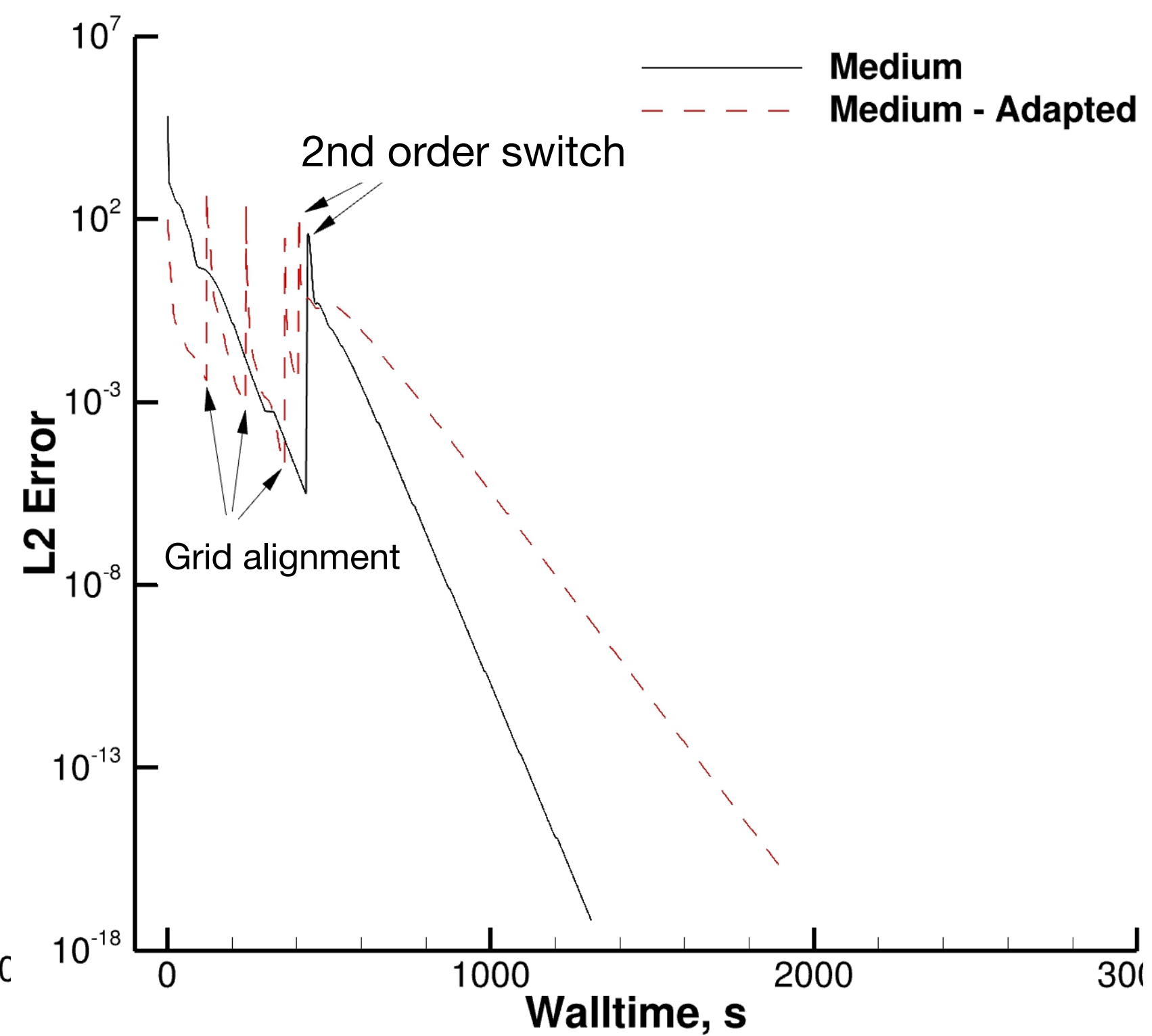
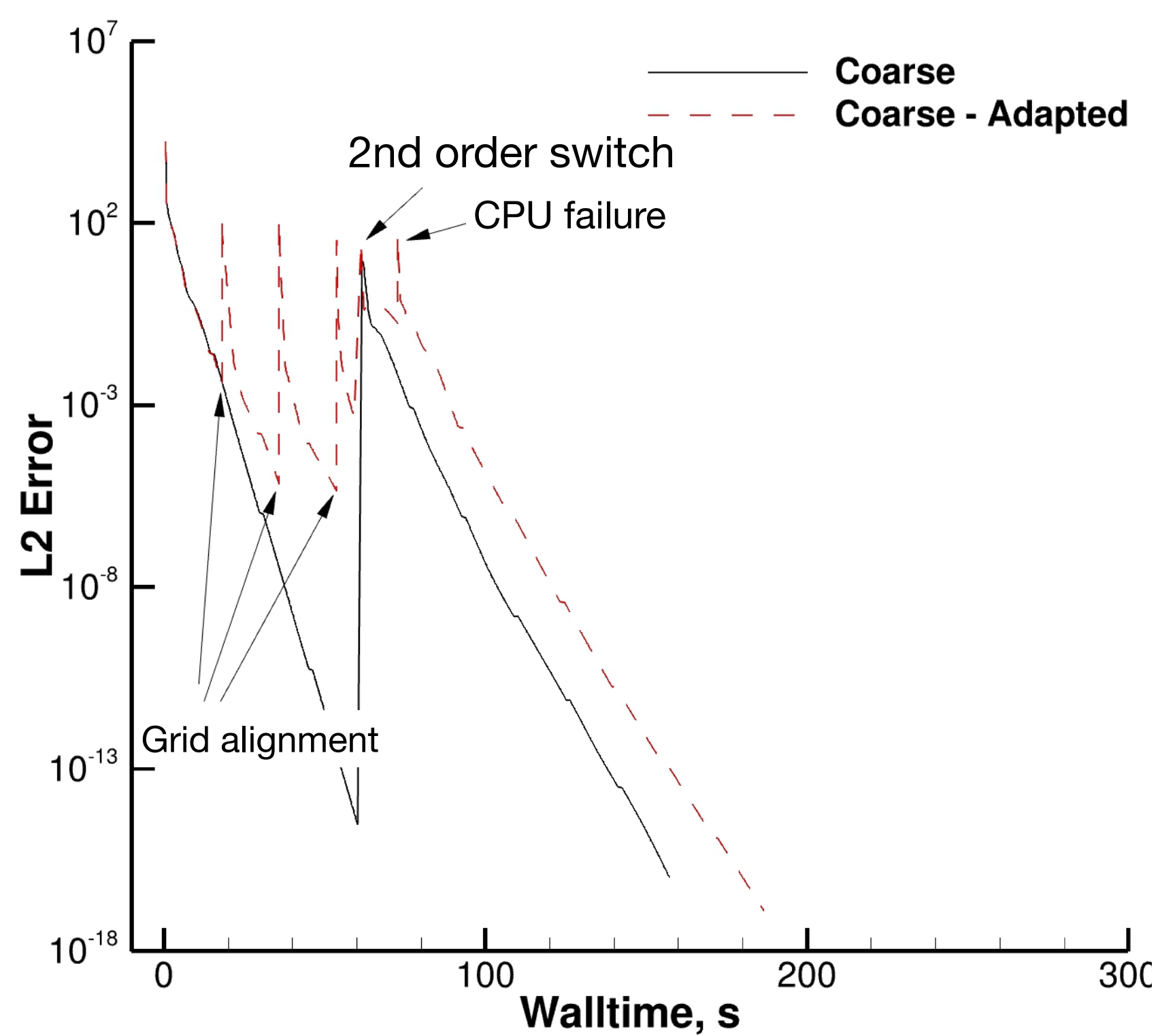
• The unitless wall heat flux is evaluated as:

$$q_w [unitless] = \frac{q_w [W/cm^2]}{T_\infty k_\infty / R} \times 10^4$$

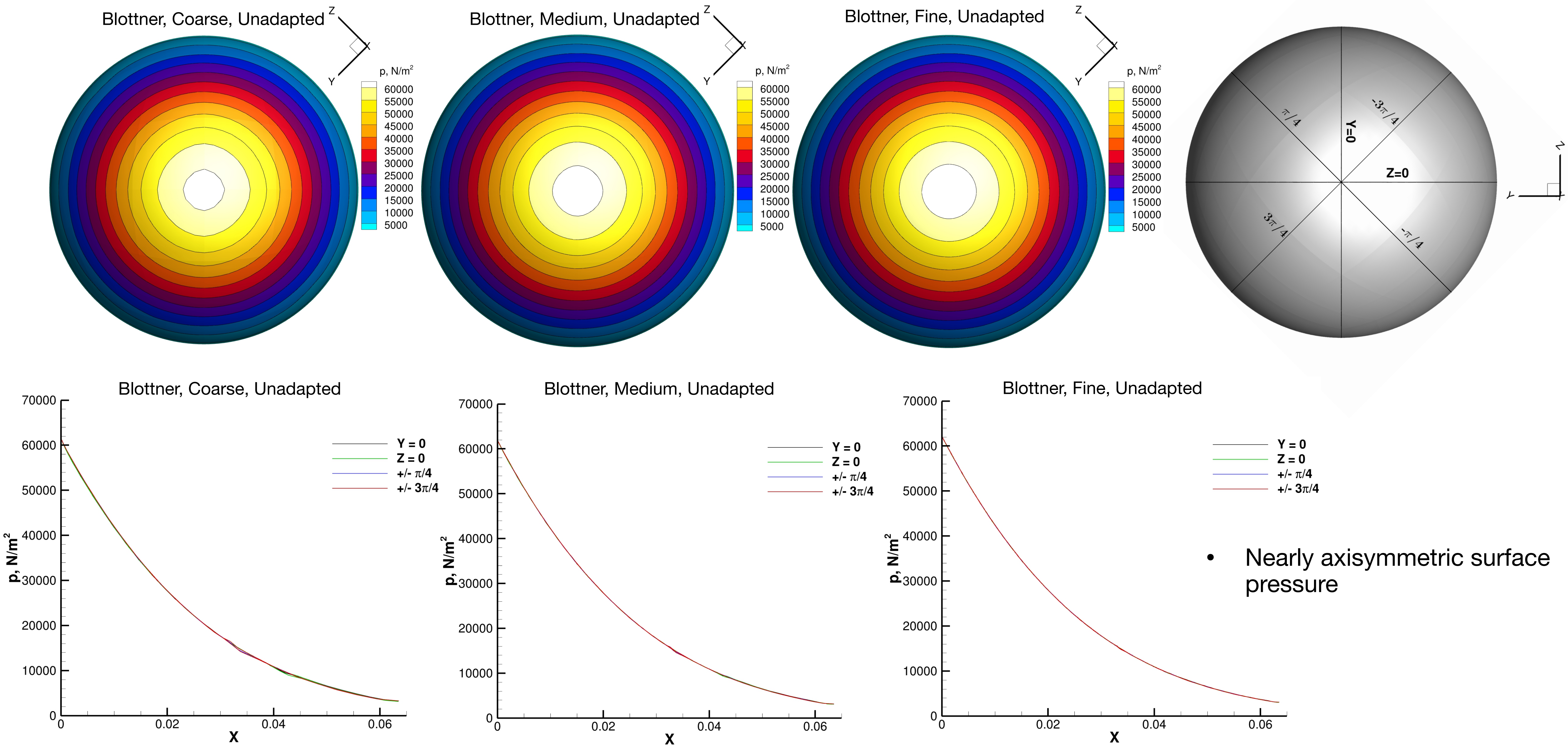
• The unitless integrated wall heat flux is evaluated as:

$$\int q_w dS [unitless] = \frac{\int q_w dS [W]}{(2\pi R^2) T_\infty k_\infty / R} = \frac{\int q_w dS [W]}{2\pi T_\infty k_\infty R}$$

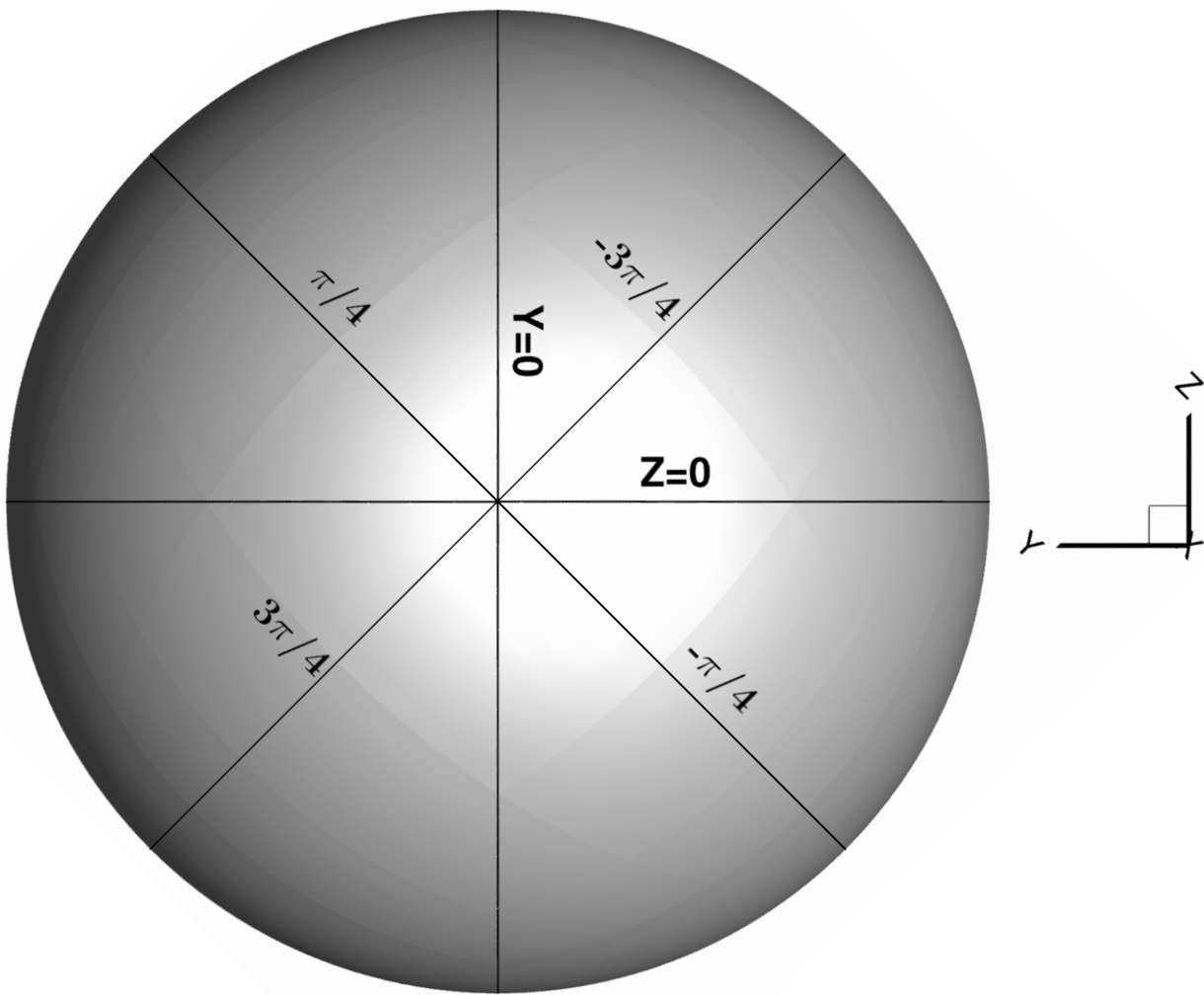
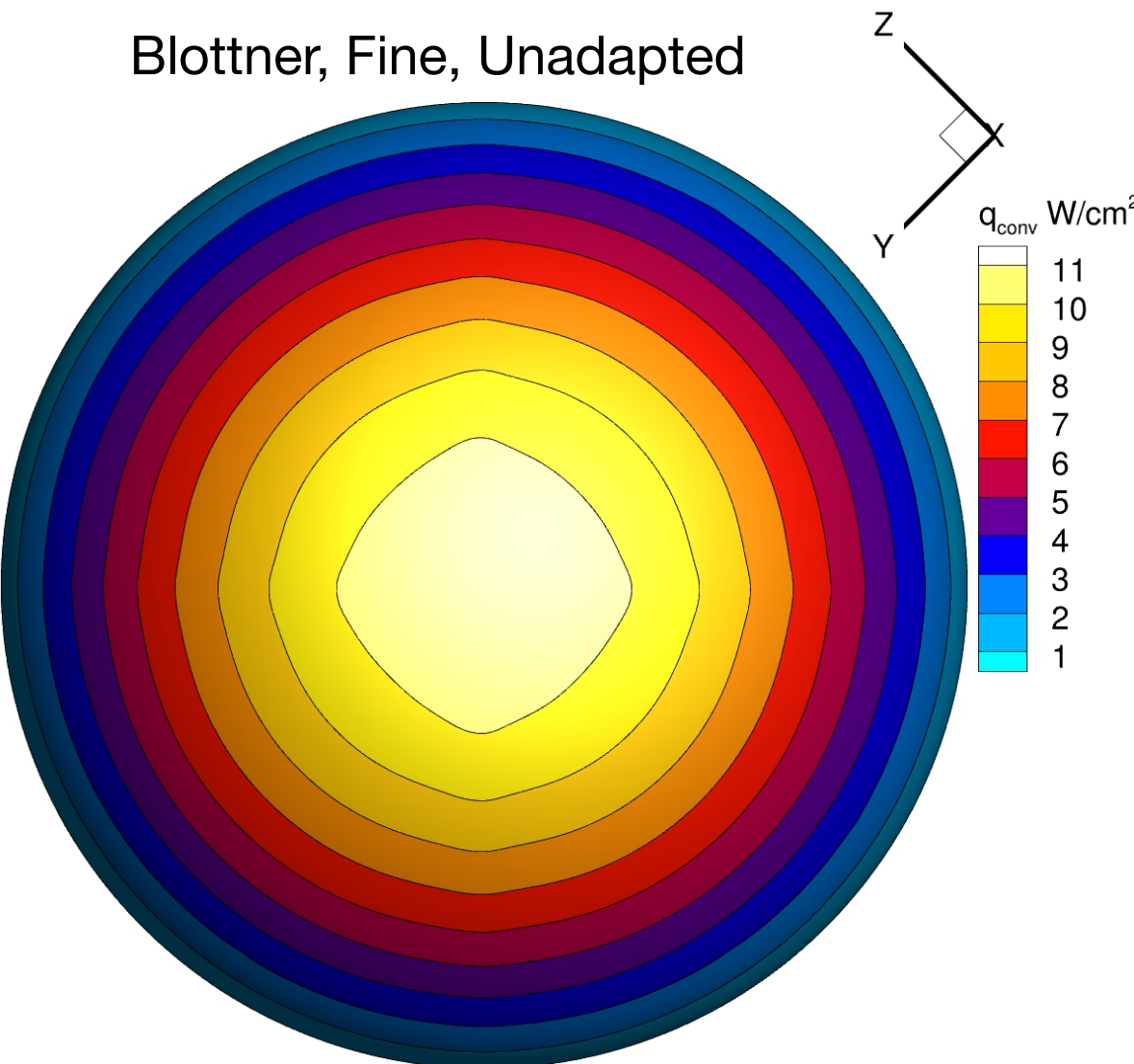
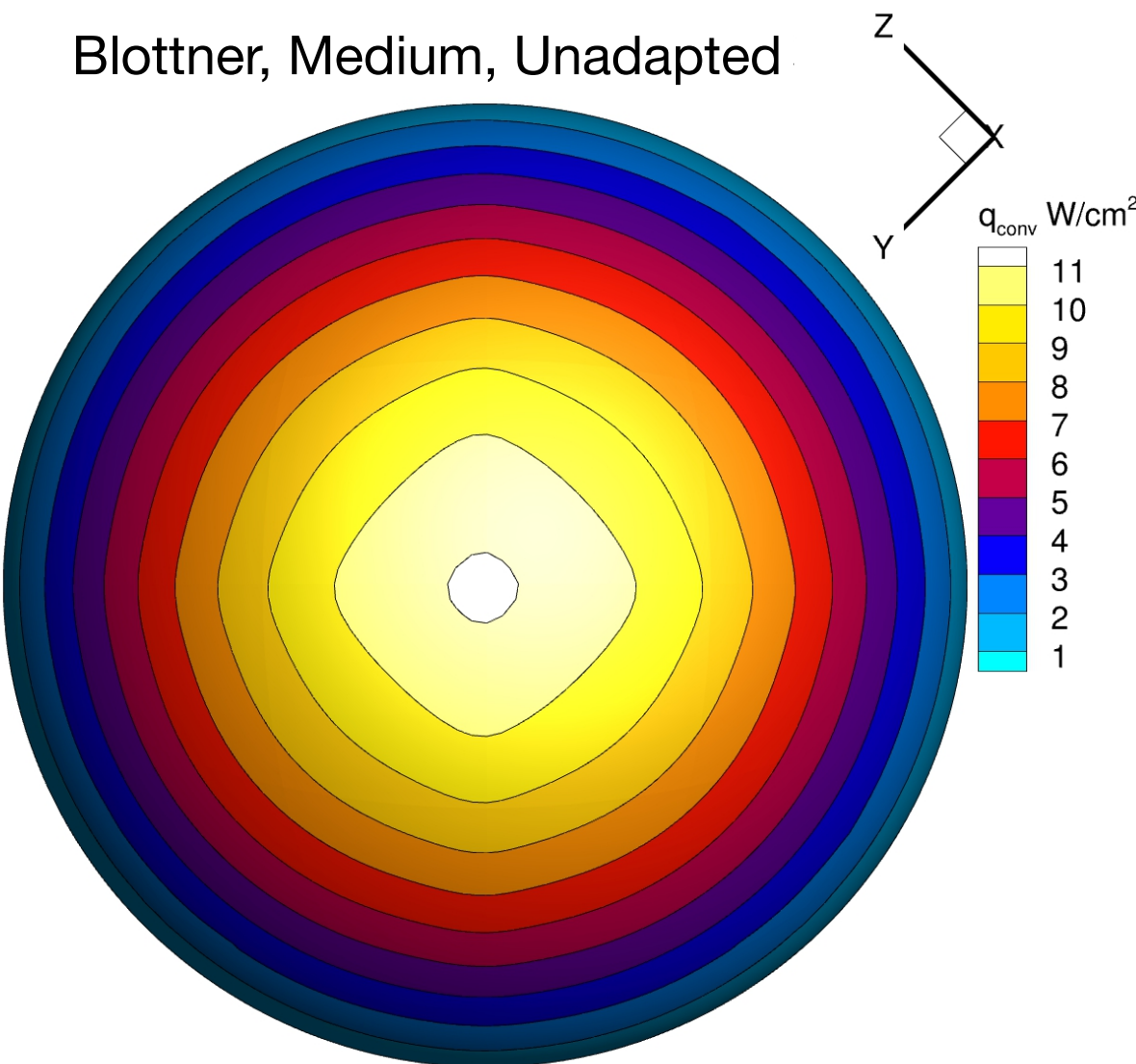
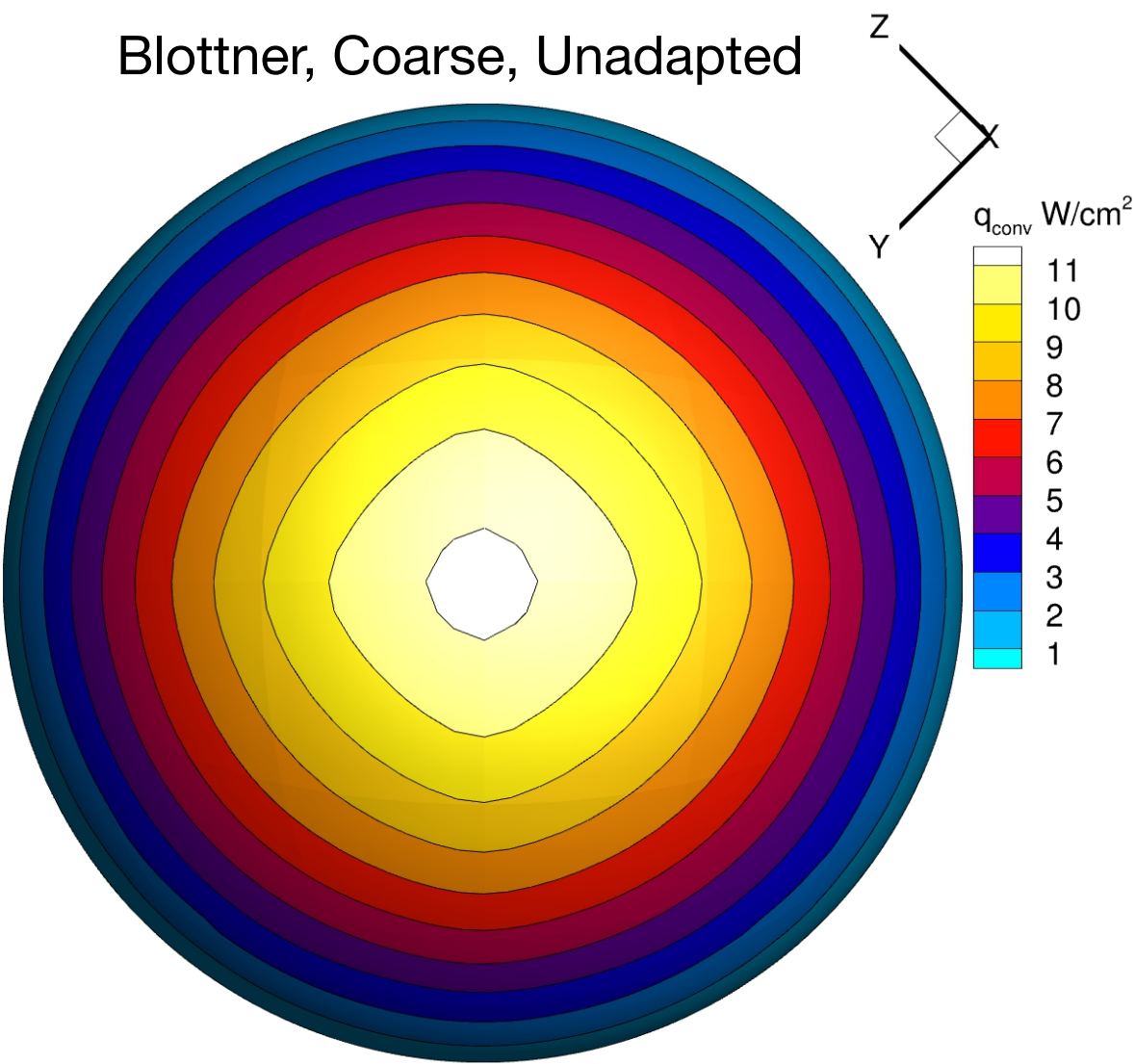
Convergence plots



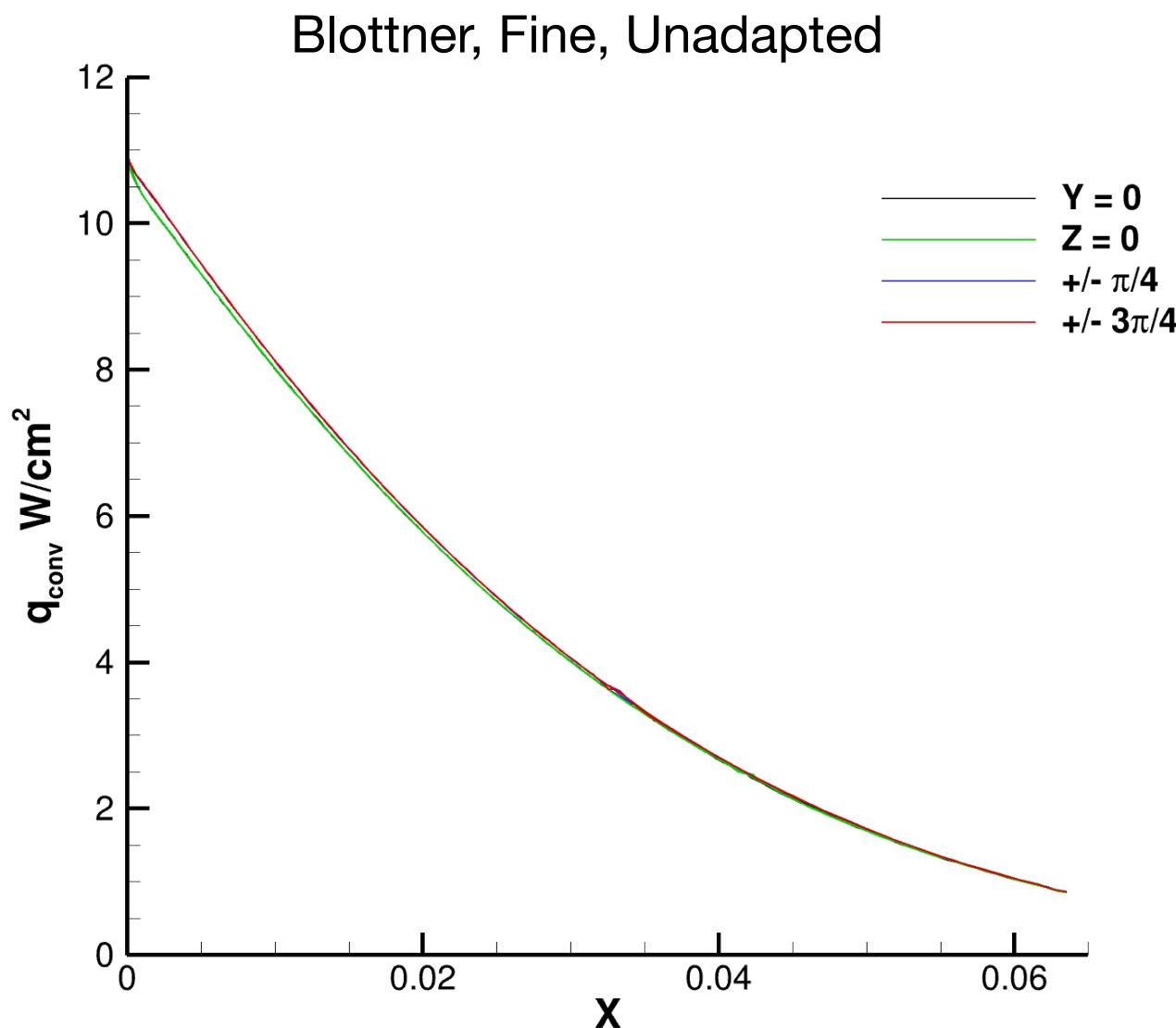
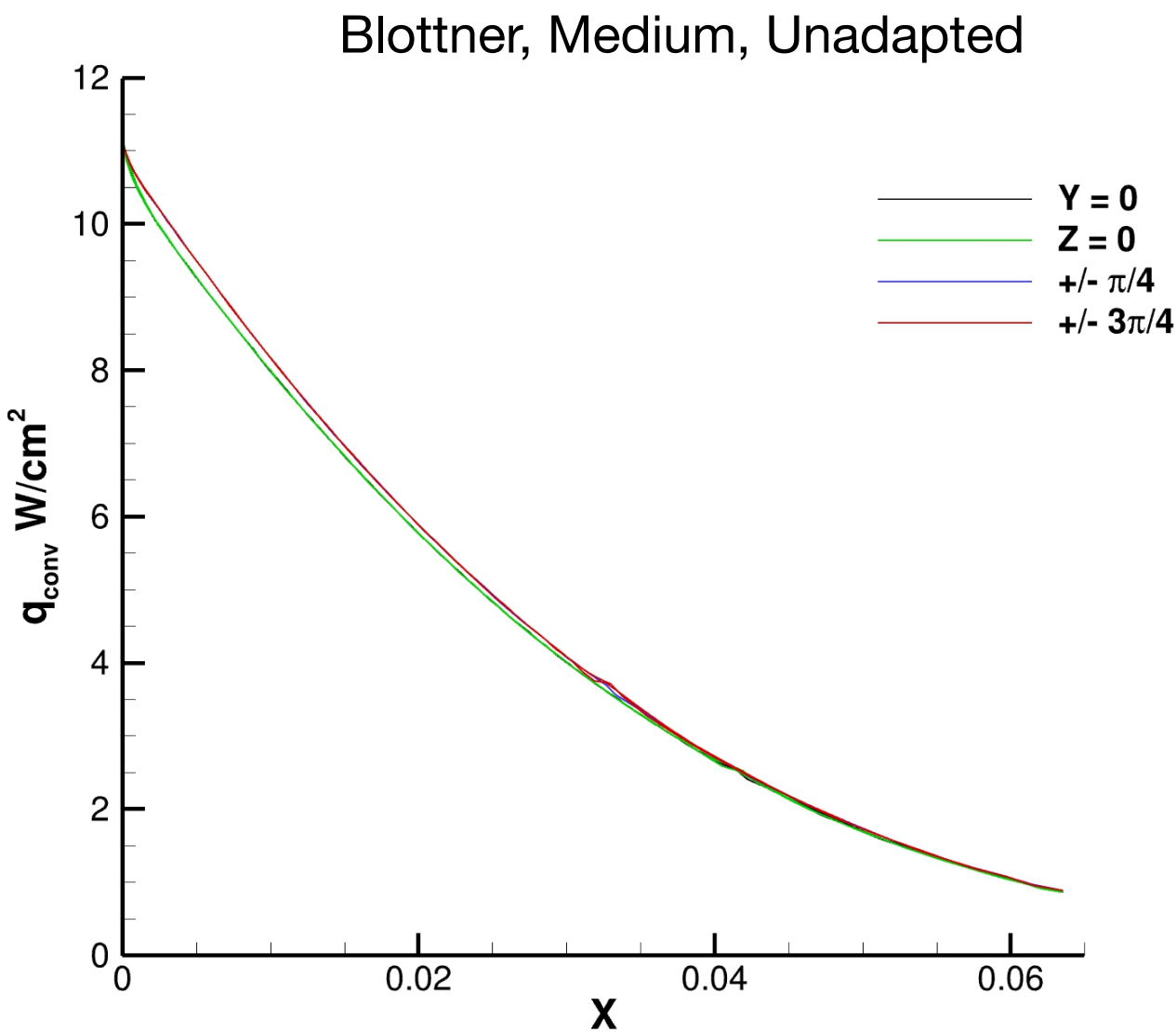
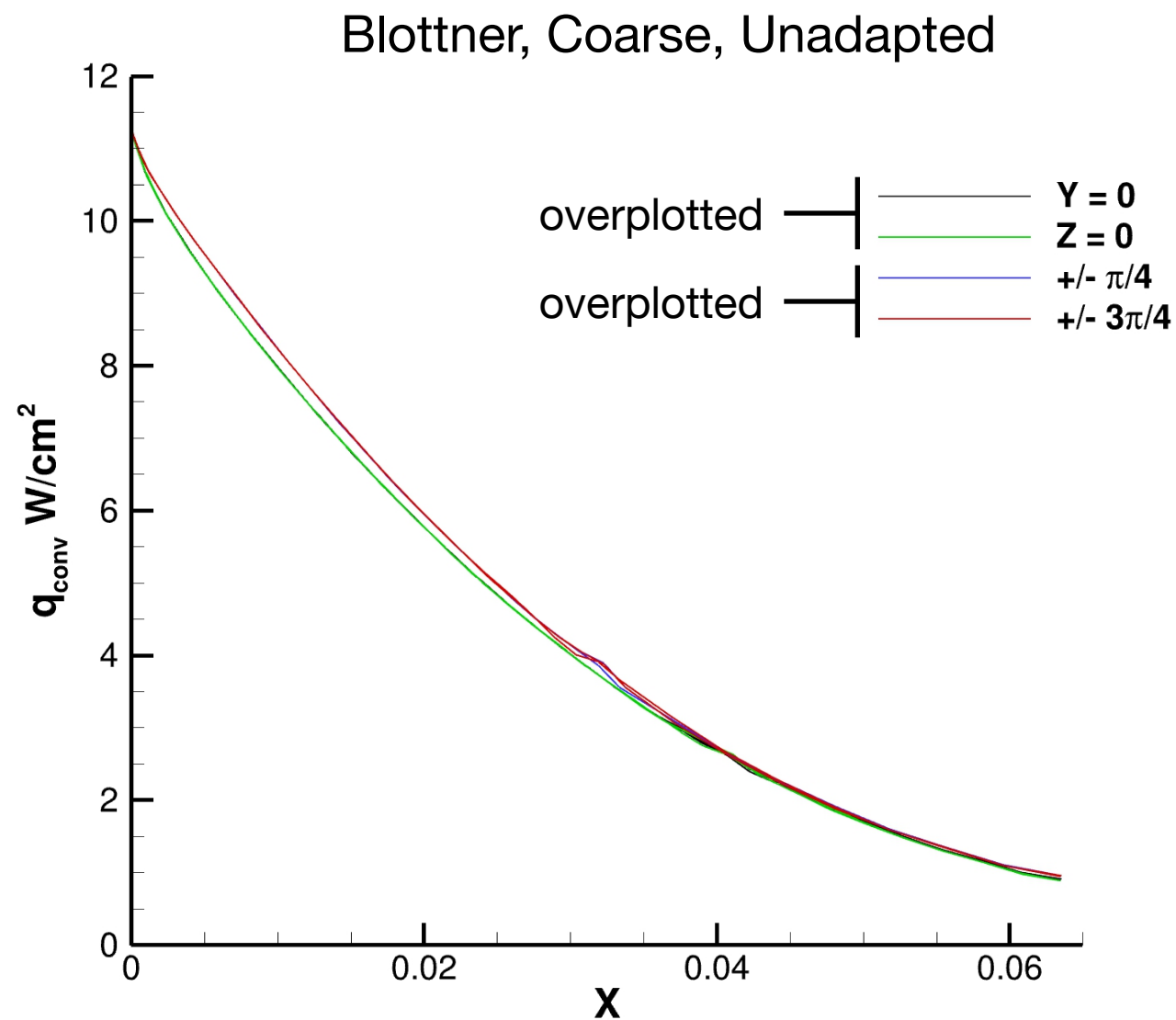
Unadapted Solutions — Coarse, Medium, Fine



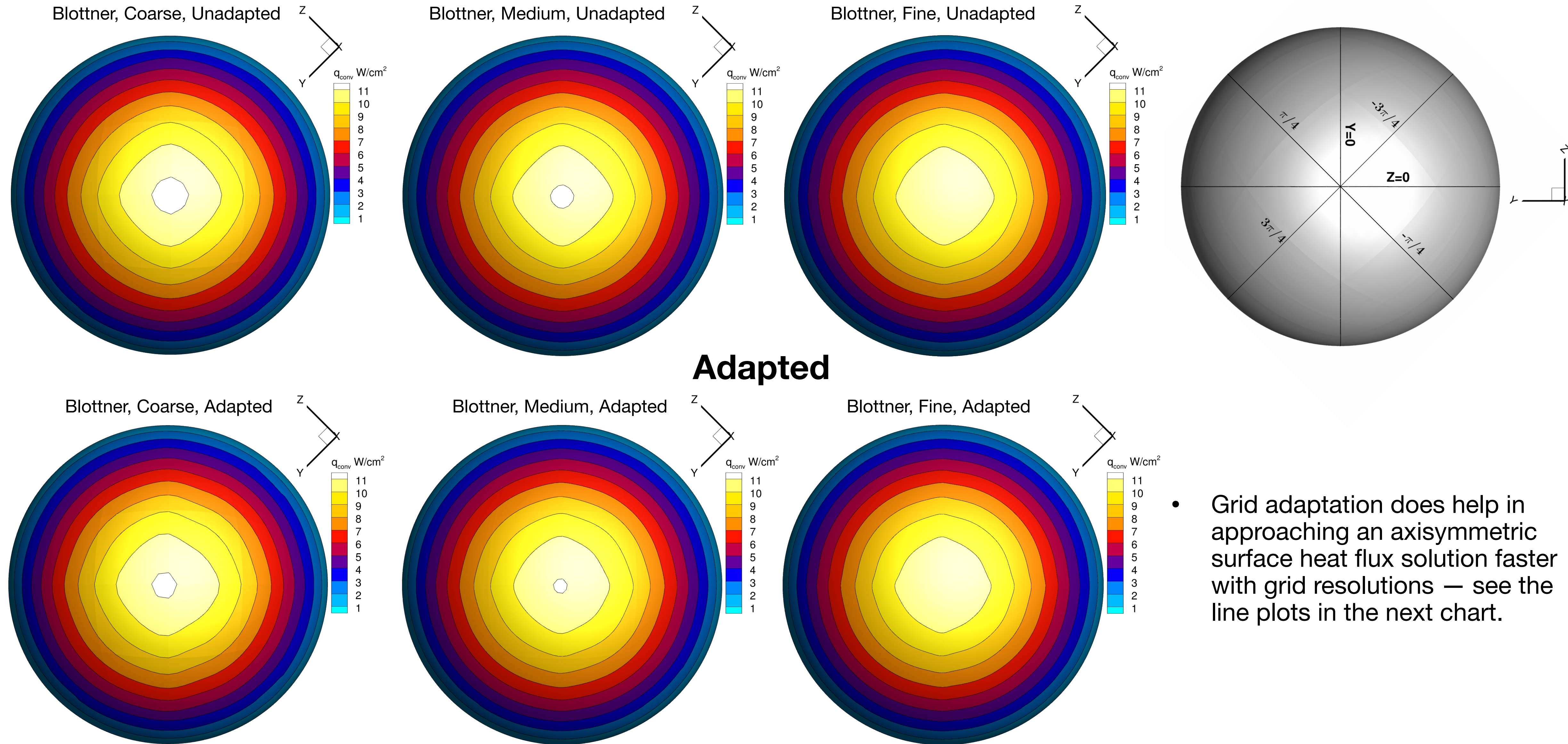
Unadapted Solutions — Coarse, Medium, Fine



- Predicted surface heat flux is not axisymmetric.
- Surface heat flux approaches an axisymmetric solution with further grid resolutions.
- Surface heat flux is symmetric along the intersections of the wall and $Y=0$ and $Z=0$ planes (see overplotted lines).
- Surface heat flux is symmetric along the intersections of the wall and 45/135 rotations of the $Y=0$ and $Z=0$ planes (see overplotted lines).

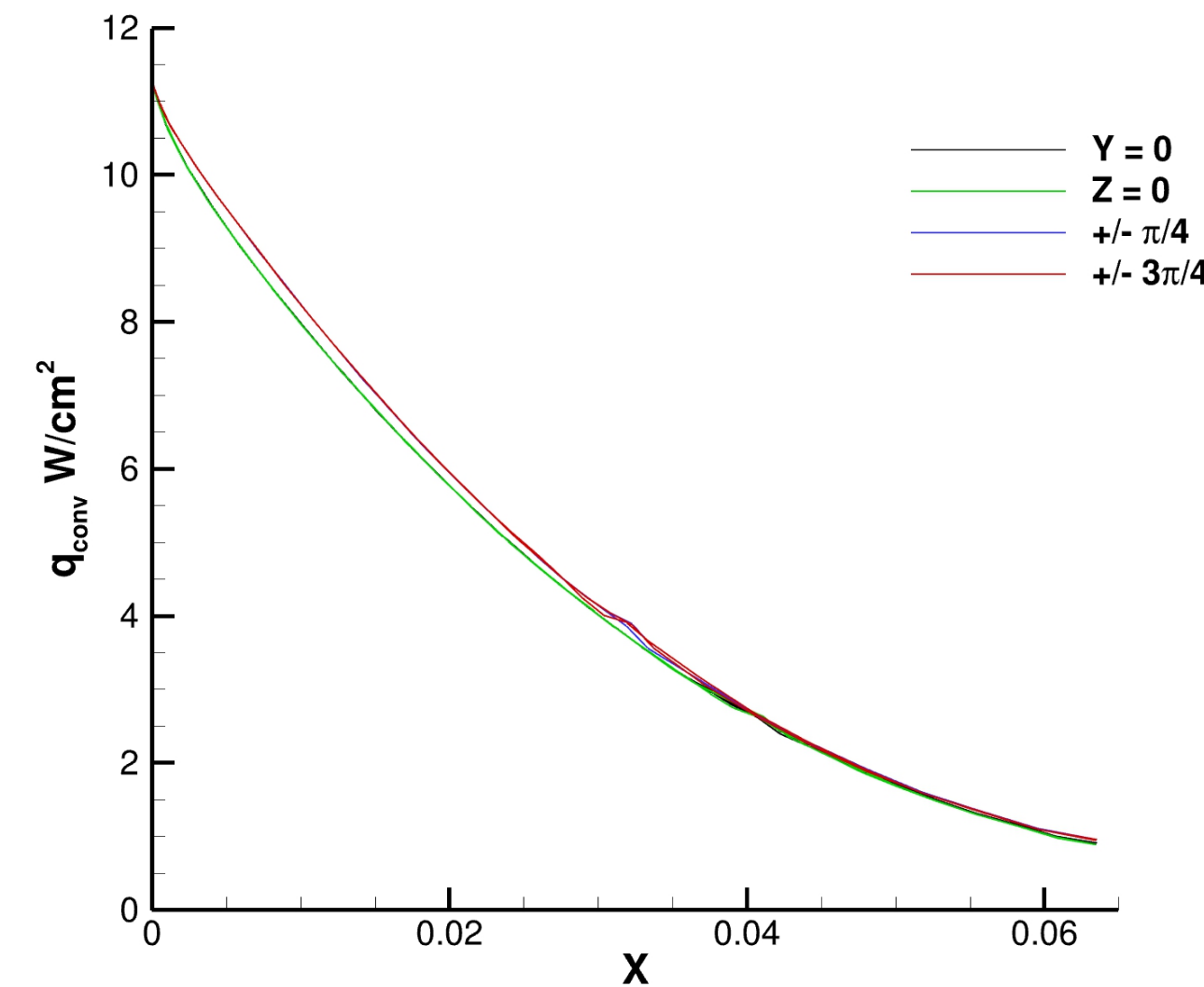


Unadapted vs Adapted Solutions — Coarse, Medium, Fine

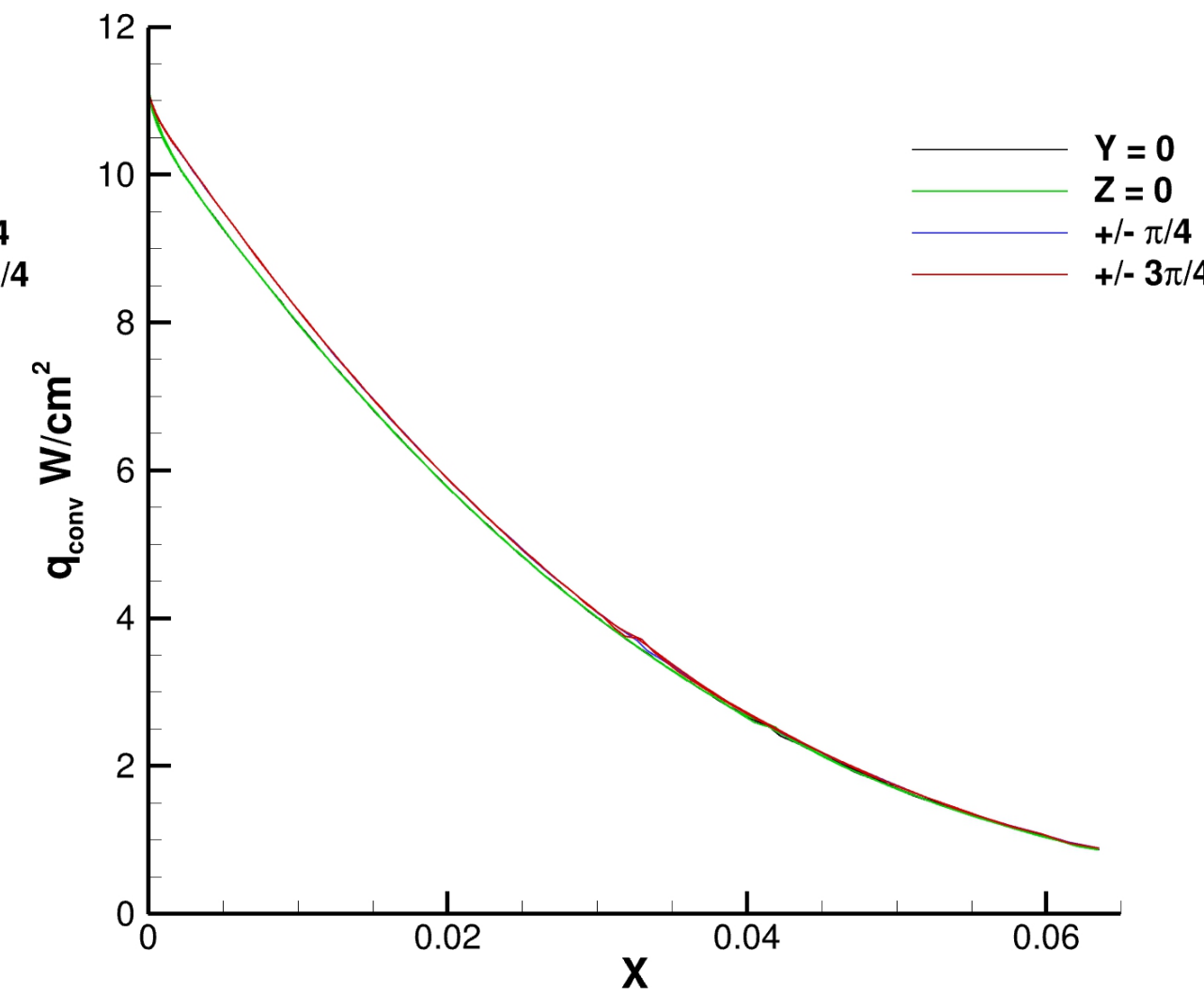


Unadapted vs Adapted Solutions — Coarse, Medium, Fine

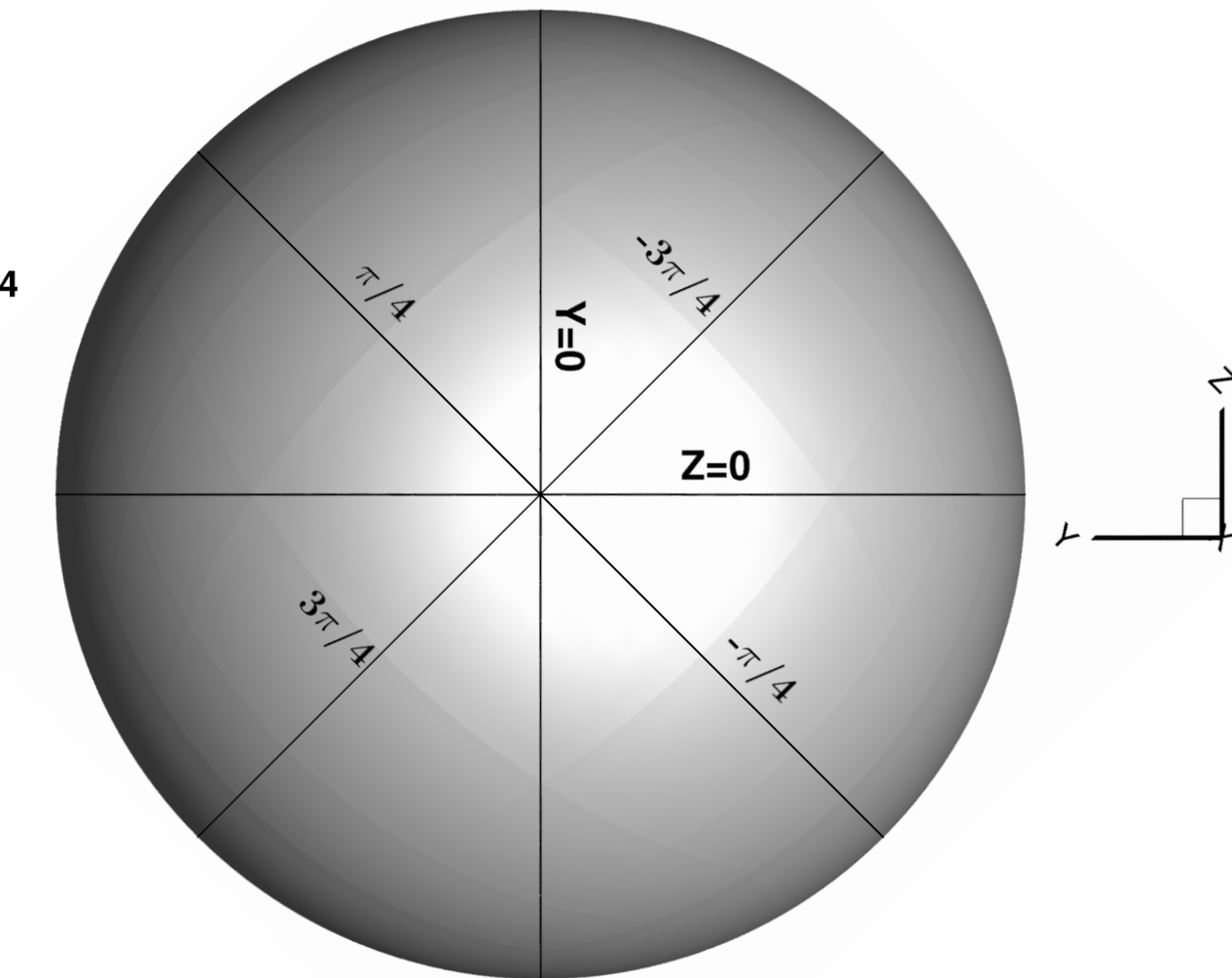
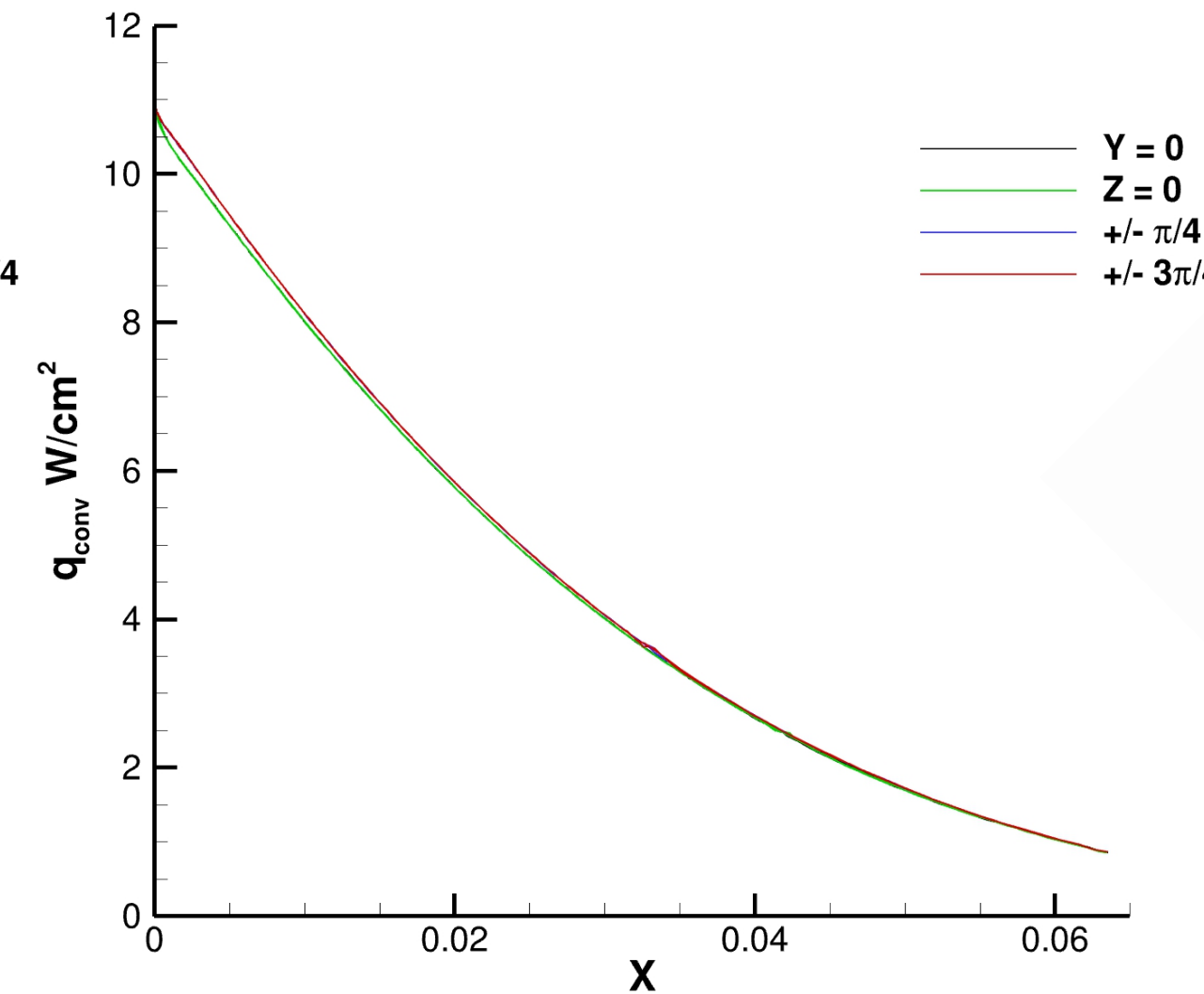
Blottner, Coarse, Unadapted



Blottner, Medium, Unadapted

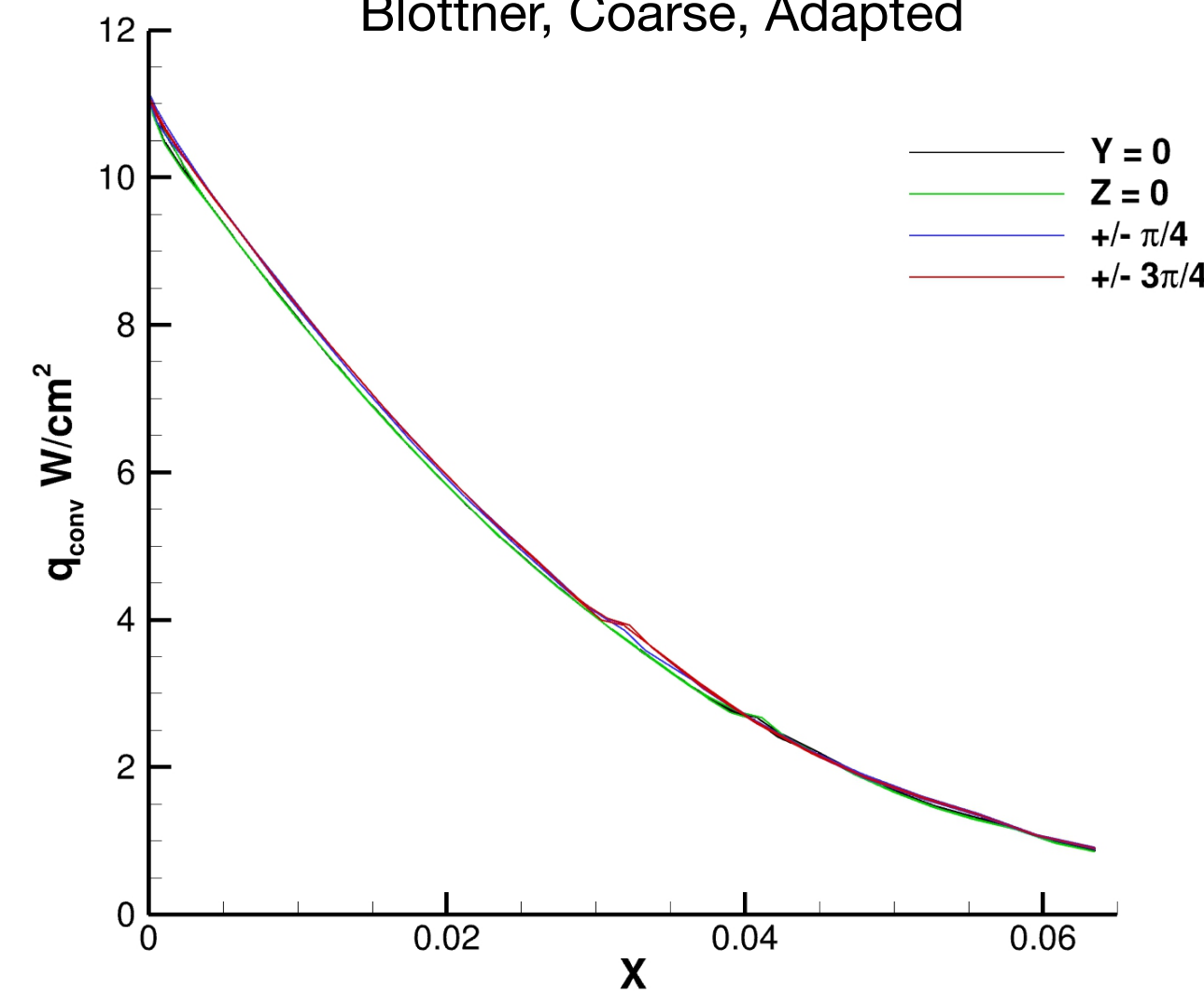


Blottner, Fine, Unadapted

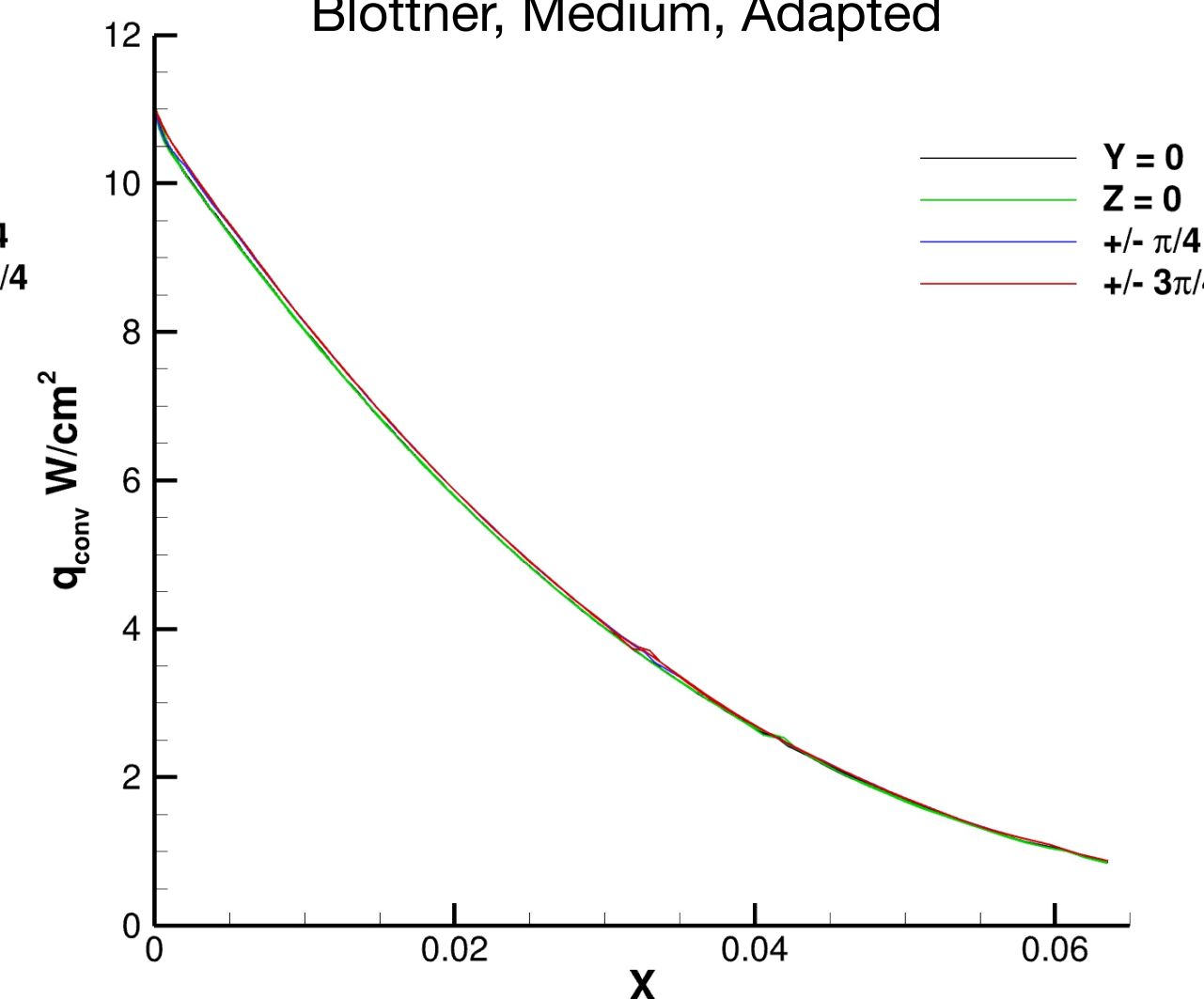


- Adaptation brings closer heat flux solutions along the intersections of the surface with $y=0/z=0$ plane and their 45/135 degree — toward an axisymmetric surface heat flux solution.

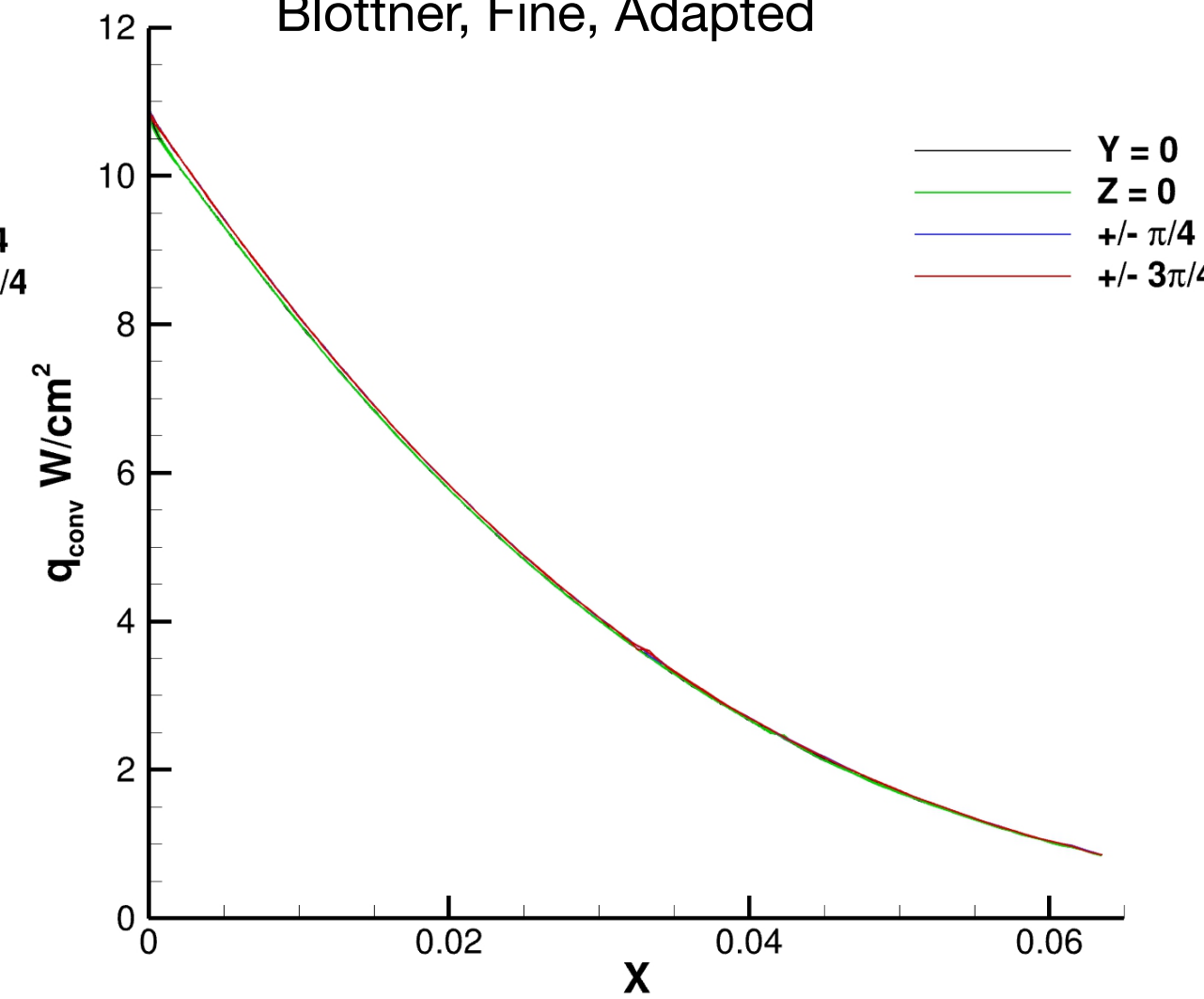
Blottner, Coarse, Adapted



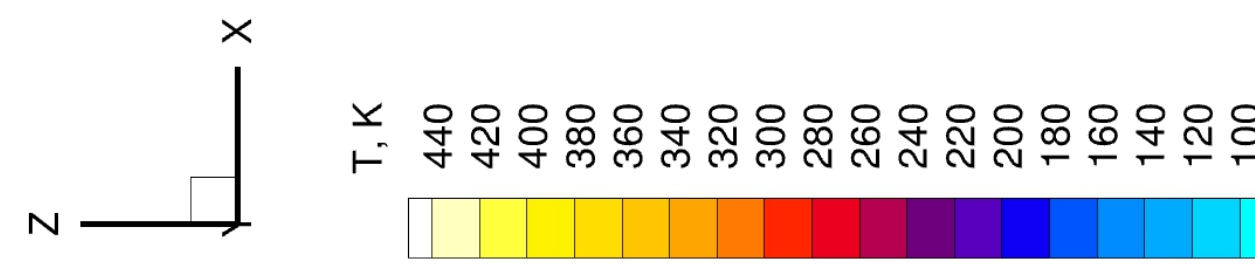
Blottner, Medium, Adapted



Blottner, Fine, Adapted

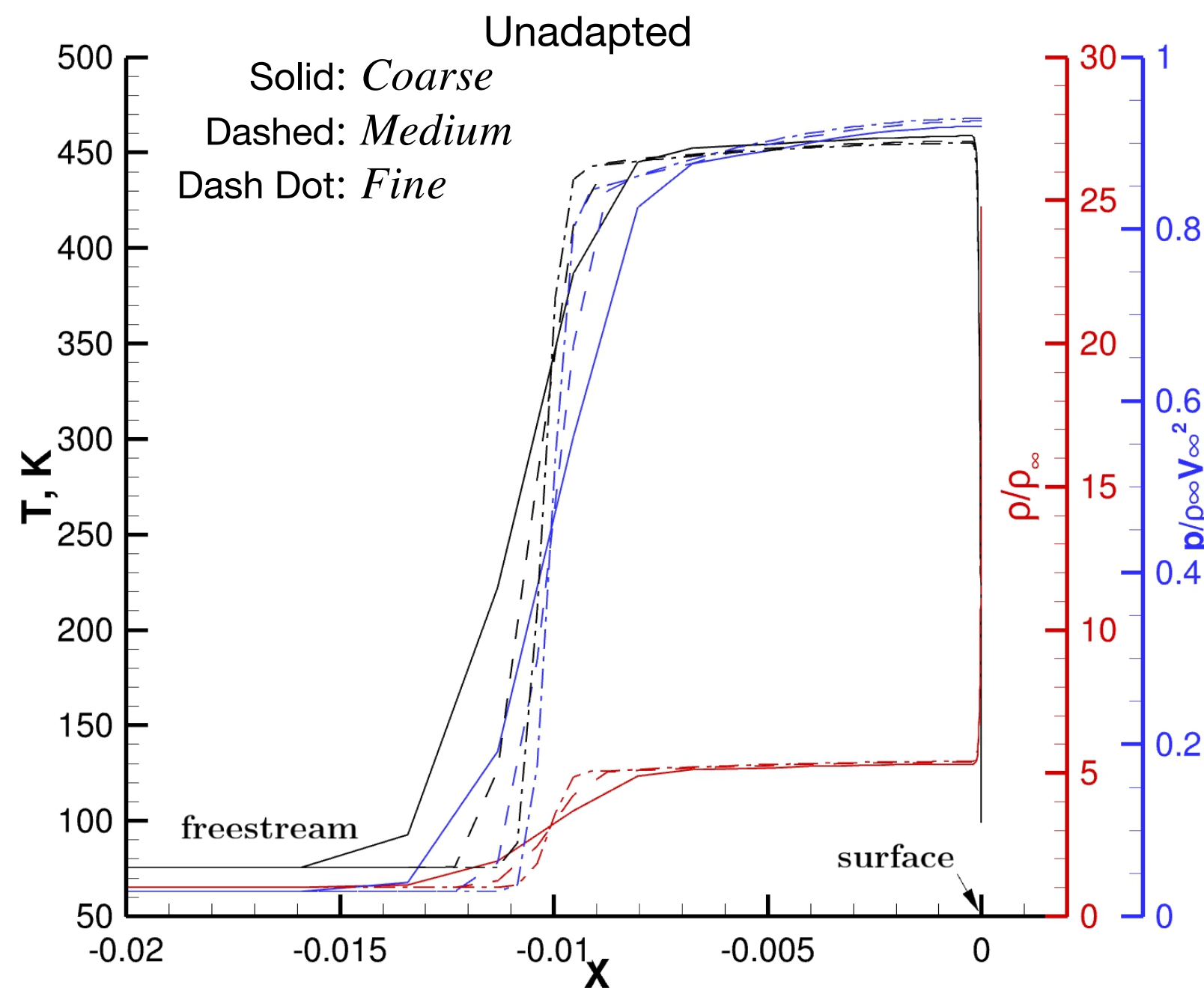


Stagnation profiles



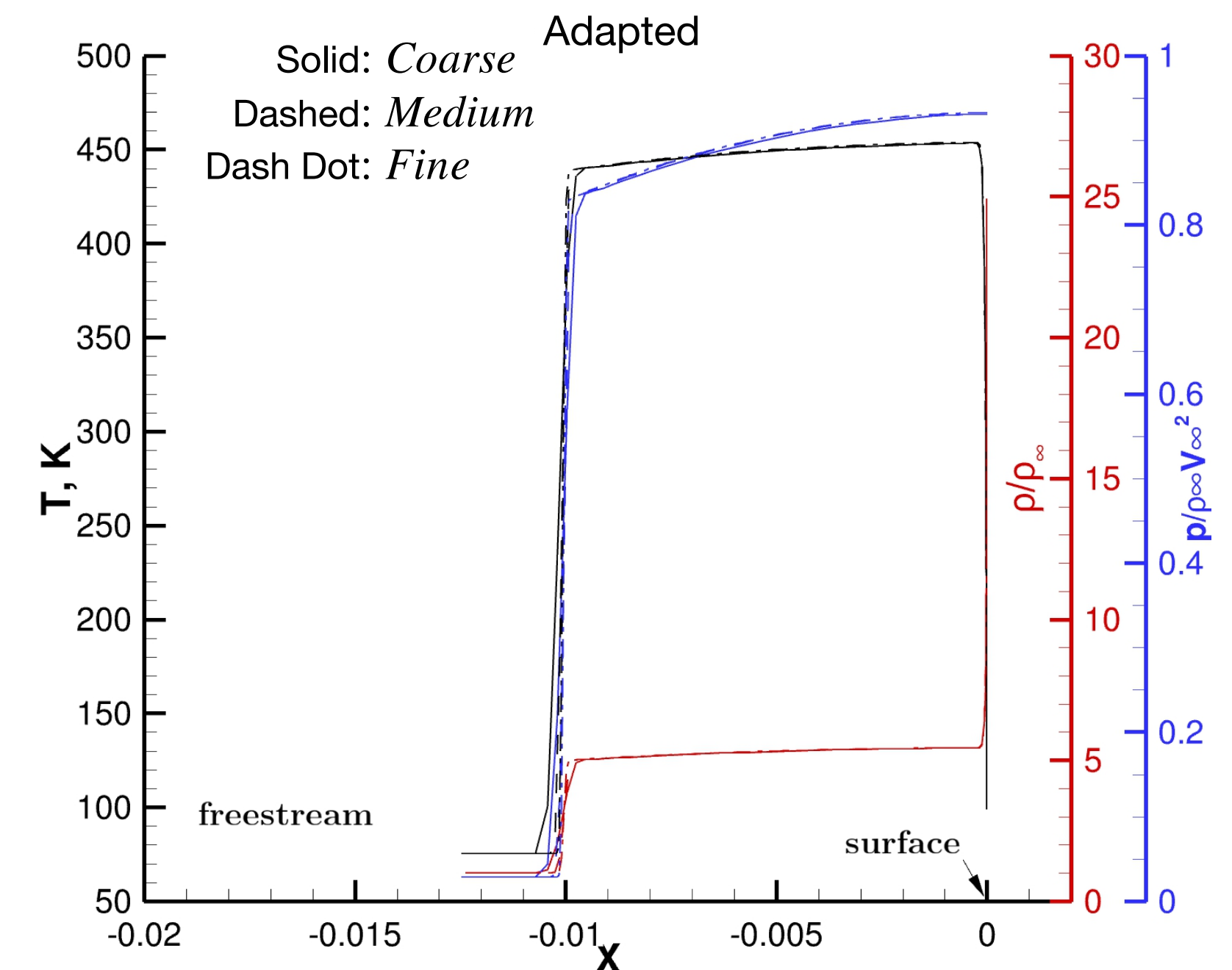
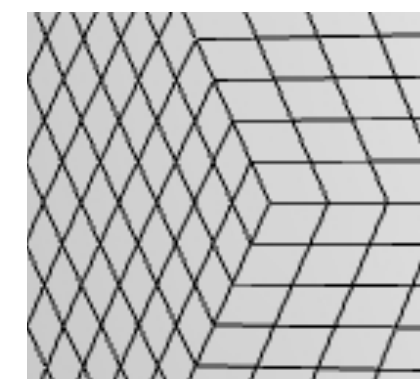
Fine, Unadapted

Coarse, Adapted (3 times)



- Predicted flow profiles on the coarse grid + 3 grid alignments are comparable with the solution predicted on the fine grid without adaptation.

- On grid quality: the best practice in aerothermodynamics applications is to ensure the grids are nearly normal to the block boundaries and surfaces with grid stretching ratio not greater than 1.2. The grids provided by the workshop are generally not used for NASA applications; e.g.,



Steady Supersonic/Hypersonic — HiFIRE1 Case

Flow: Turbulent

Constant Wall Temperature

Scheme

- Block structured
- 2nd-order FV
- Limiter: Yee's STVD
- Numerical Flux: Roe's + Harten's entropy fix
- Turbulence model: SA-Catris*
- Solver: line relaxation

* : Catris, S., and Aupoix, B., "Density Corrections for Turbulence Models", Aerospace Sci. Tech., (4) 2000, pp. 1-11

Stagnation and integrated heat flux

		Stagnation qw [W/cm^2]	Stagnation qw [unitless]	Integrated wall heat flux	Total iterations	Final L2 norm	Work unit [CPU hours]
Blottner-Original	<i>Coarse</i>	922.545	26379.338	276011.3	42,000	1.52E-17	348
	<i>Medium</i>	950.287	27172.595	279436.5	98,000*	1.56E-15	5456*

*: The actual number of iterations and work unit are unknown due to repeated runs because of disk failures on the cluster.

- The unitless wall heat flux is evaluated as:

$$q_w [unitless] = \frac{q_w [W/cm^2]}{T_\infty k_\infty / R} \times 10^4$$

$$T_w = 296.61289 [K]$$

$$T_\infty = T_w / 1.279 = 231.91 [K]$$

$$\rho_\infty = 6.9458 \times 10^{-2} [kg/m^3]$$

$$V_\infty = 2198. [m/s]$$

$$\alpha = 2 [deg]$$

$$k_\infty = 2.862 \times 10^{-10} \rho_\infty V_\infty^3 [kg/sec - K]$$

$$= 2.11 \times 10^{-2} [kg/sec - K]$$

$$= 2.07 \times 10^{-1} [W/m - K]$$

$$Radius := R = 0.137275 [m],$$

$$\mu_{Sutherland} = \frac{s_1 T^{3/2}}{T + s_2}, \quad s_1 = 0.1458205 \times 10^{-5}, \quad s_2 = 110.333333$$

- **A note on minor inconsistency between the provided Reynolds number and freestream density values:**

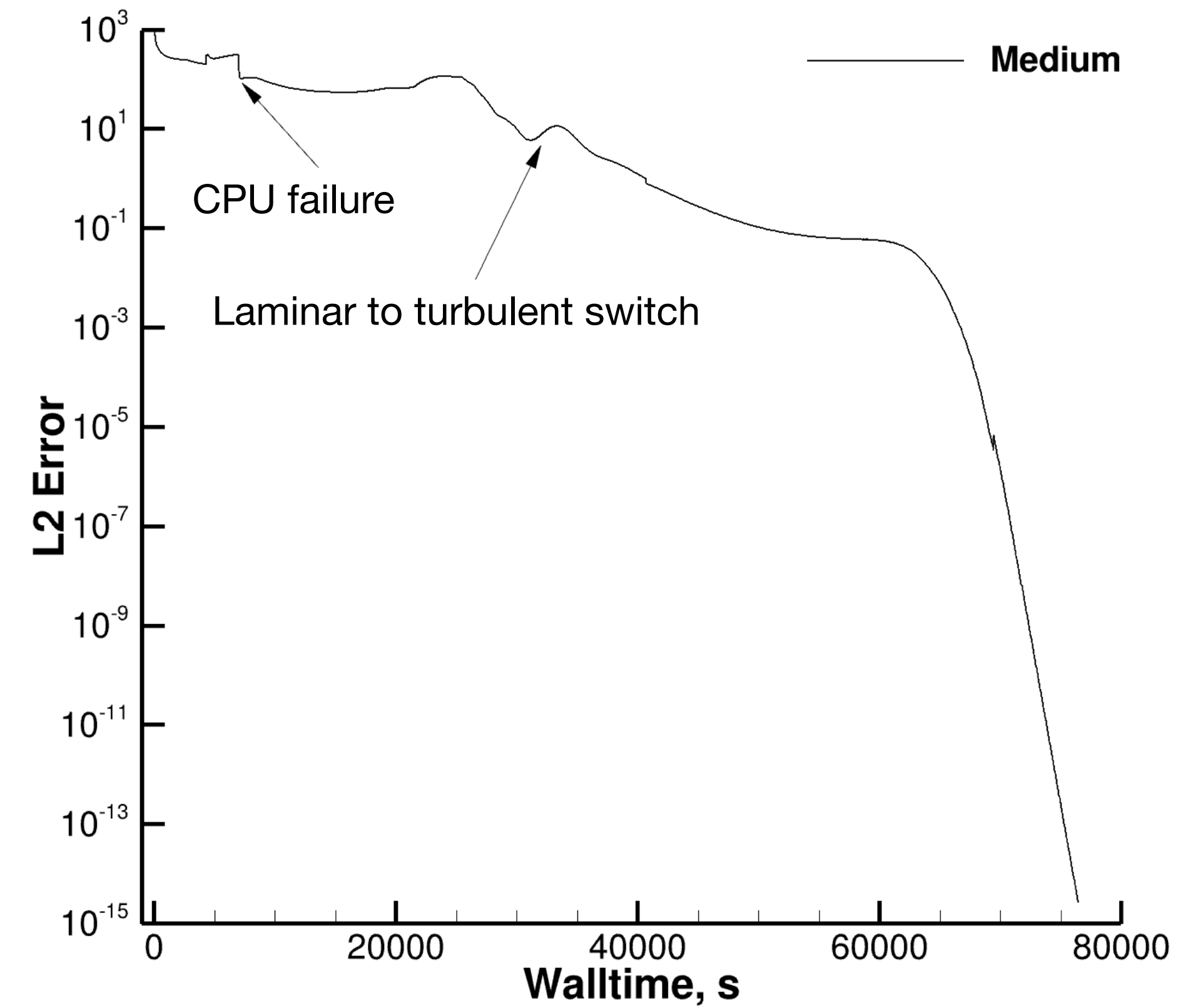
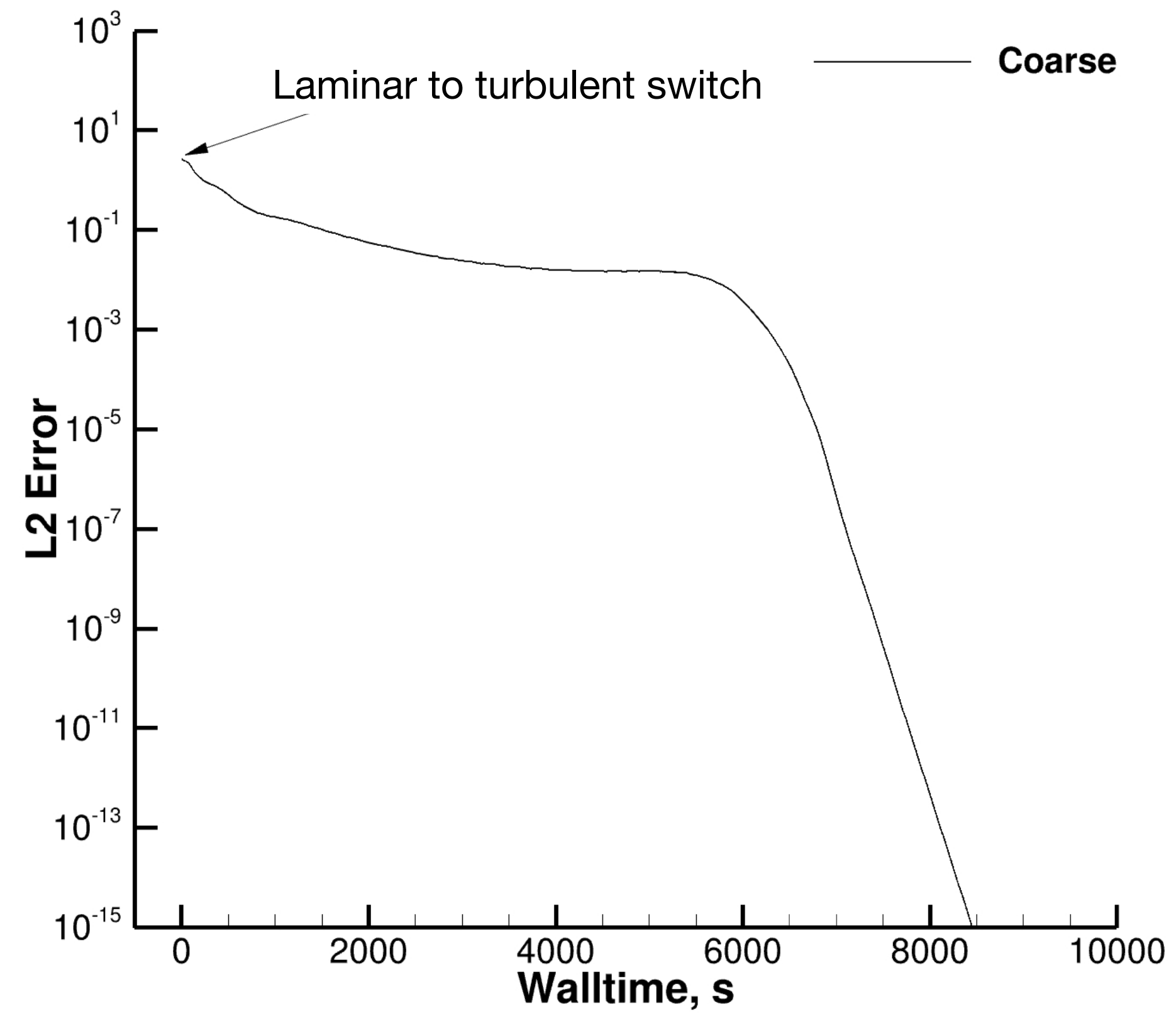
$$\mu_\infty^{Sutherland} + Re_\infty^{provided} (= 10.123 \times 10^6) \rightarrow \rho_\infty = 0.069295 [kg/m^3]$$

$$\mu_\infty^{Sutherland} + \rho_\infty^{provided} (= 0.069458) \rightarrow Re_\infty = 10.15 \times 10^6$$

- Here, the provided density is used; i.e.,

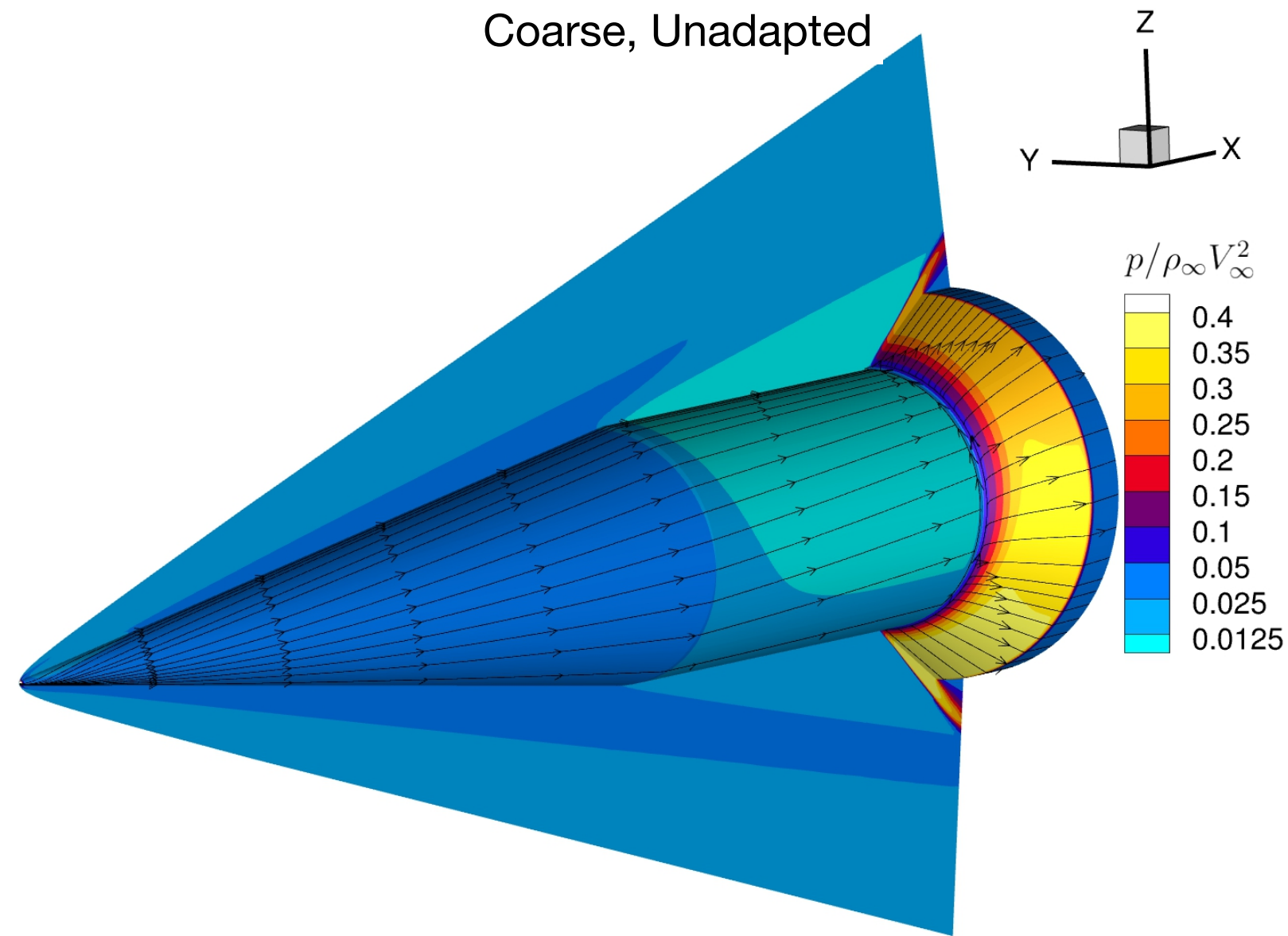
$$\mu_\infty^{Sutherland} + \rho_\infty^{provided} (= 0.069458) \rightarrow Re_\infty = 10.15 \times 10^6$$

Convergence plots

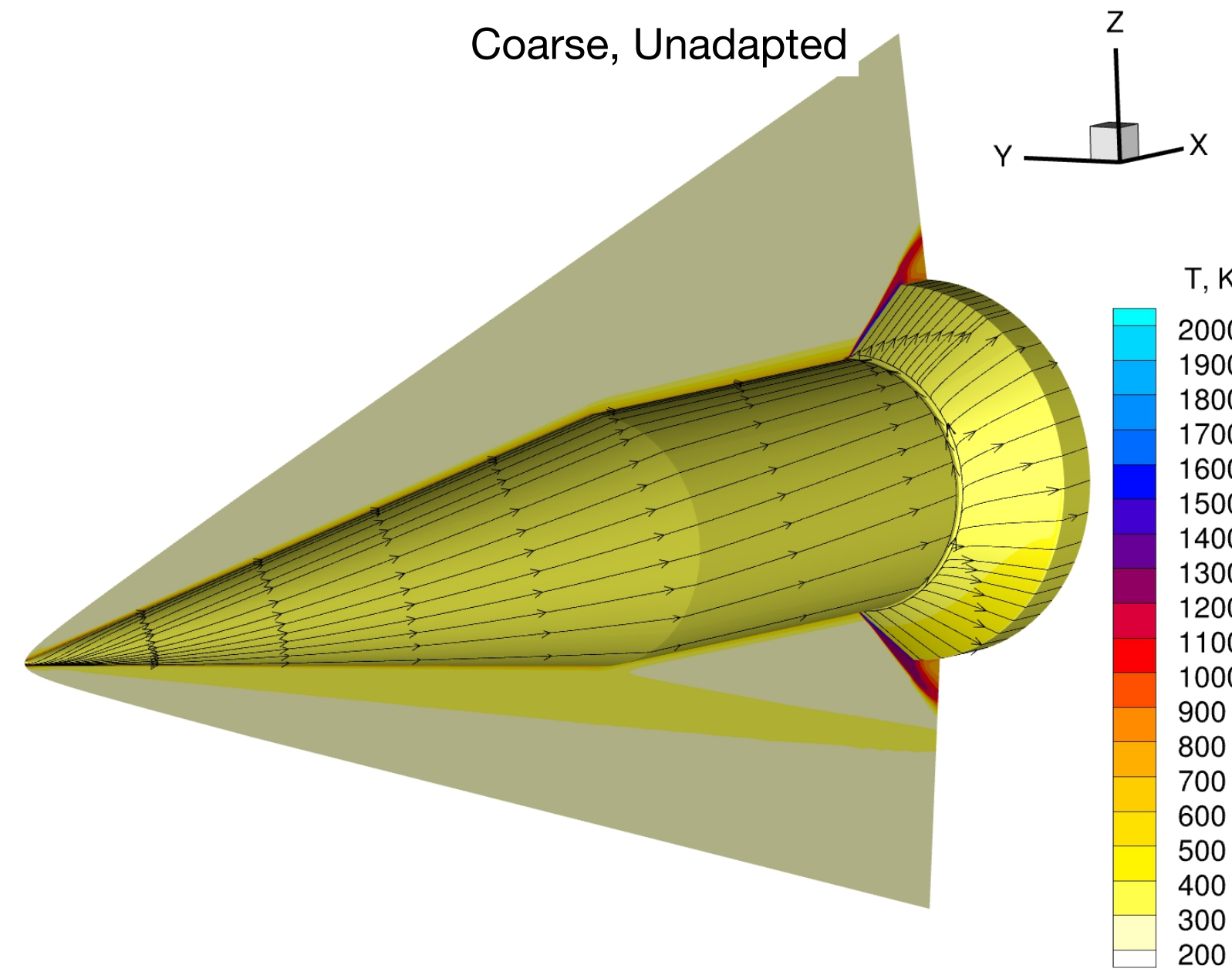


Coarse vs Medium Solutions

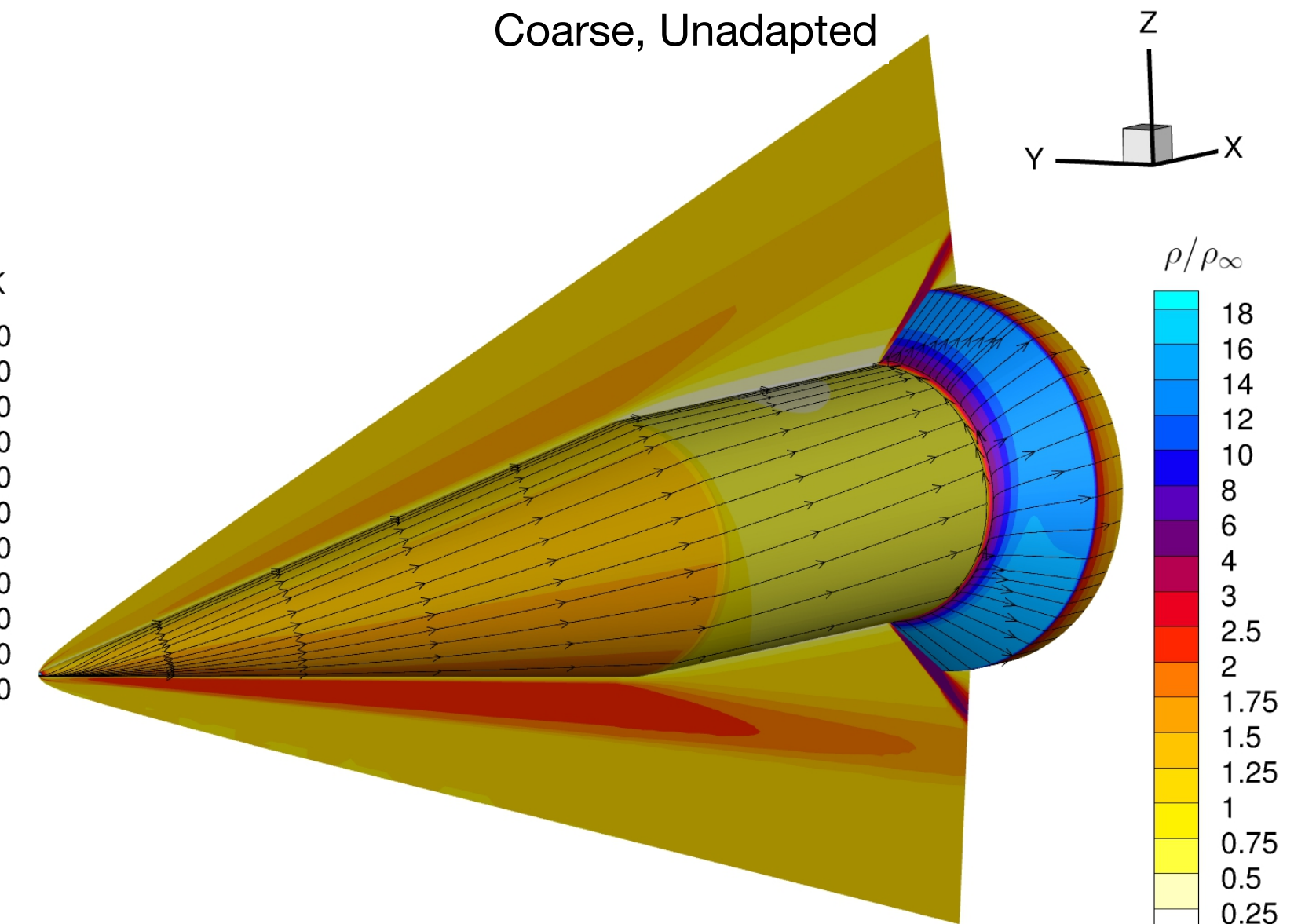
Coarse, Unadapted



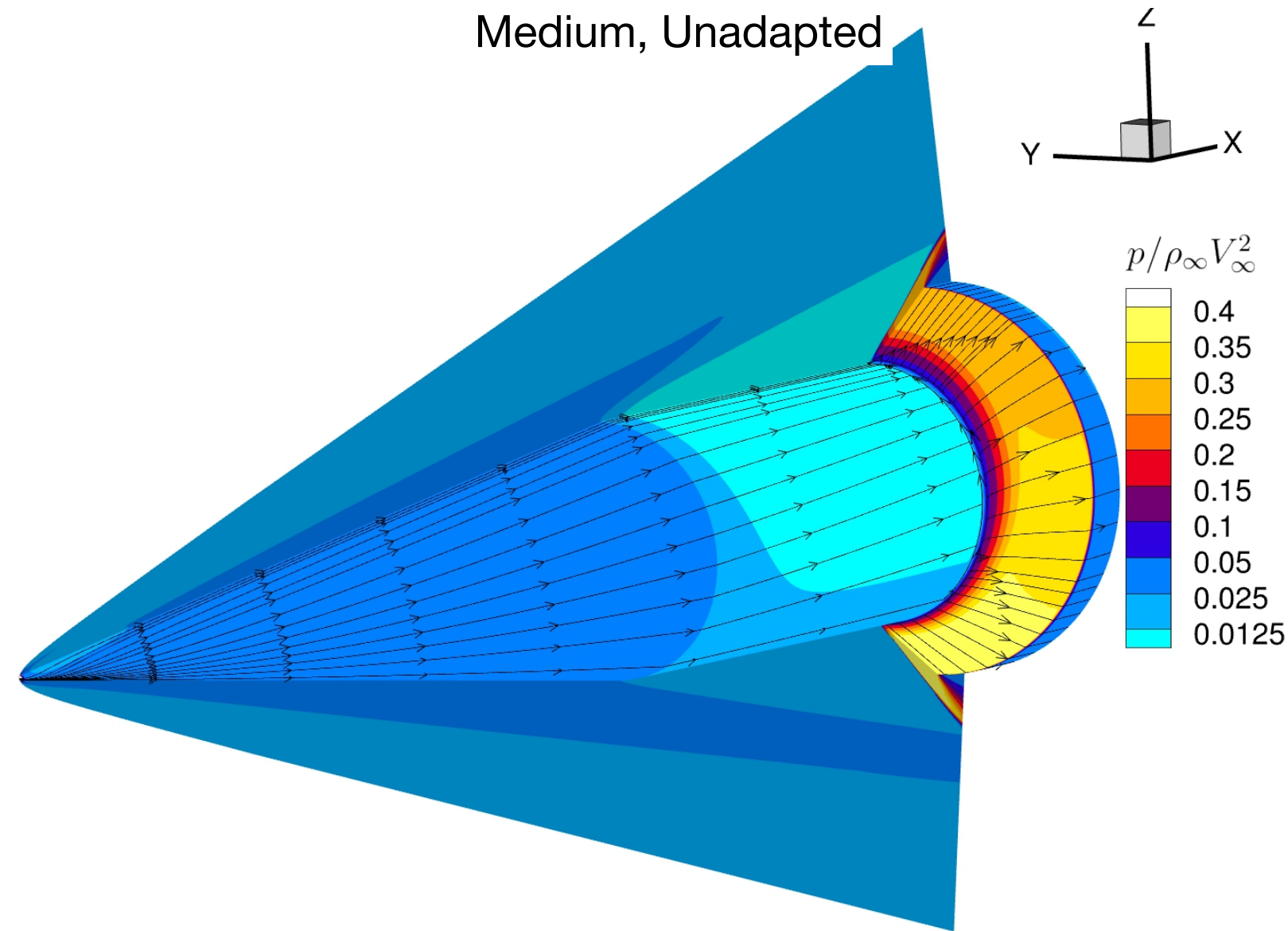
Coarse, Unadapted



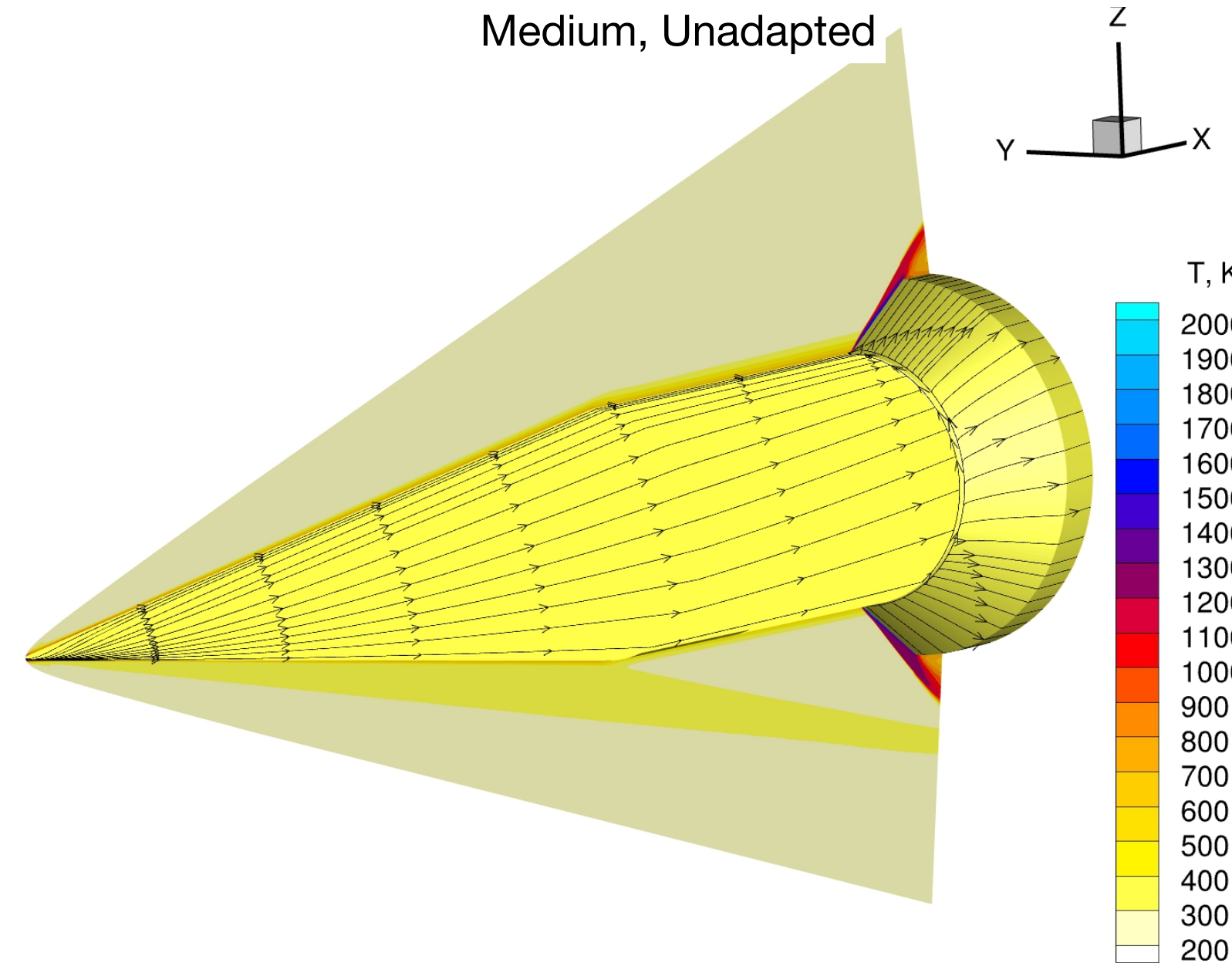
Coarse, Unadapted



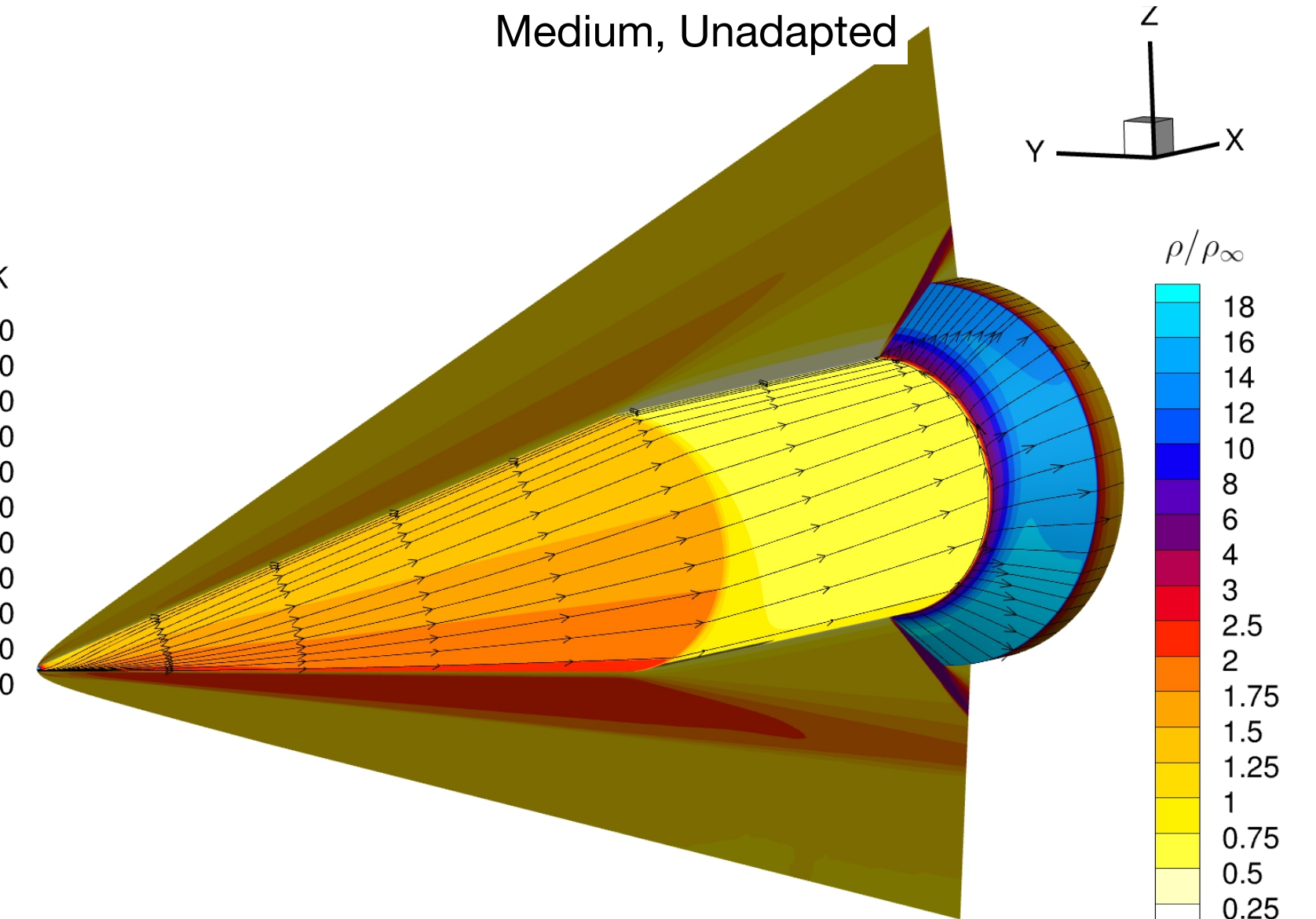
Medium, Unadapted



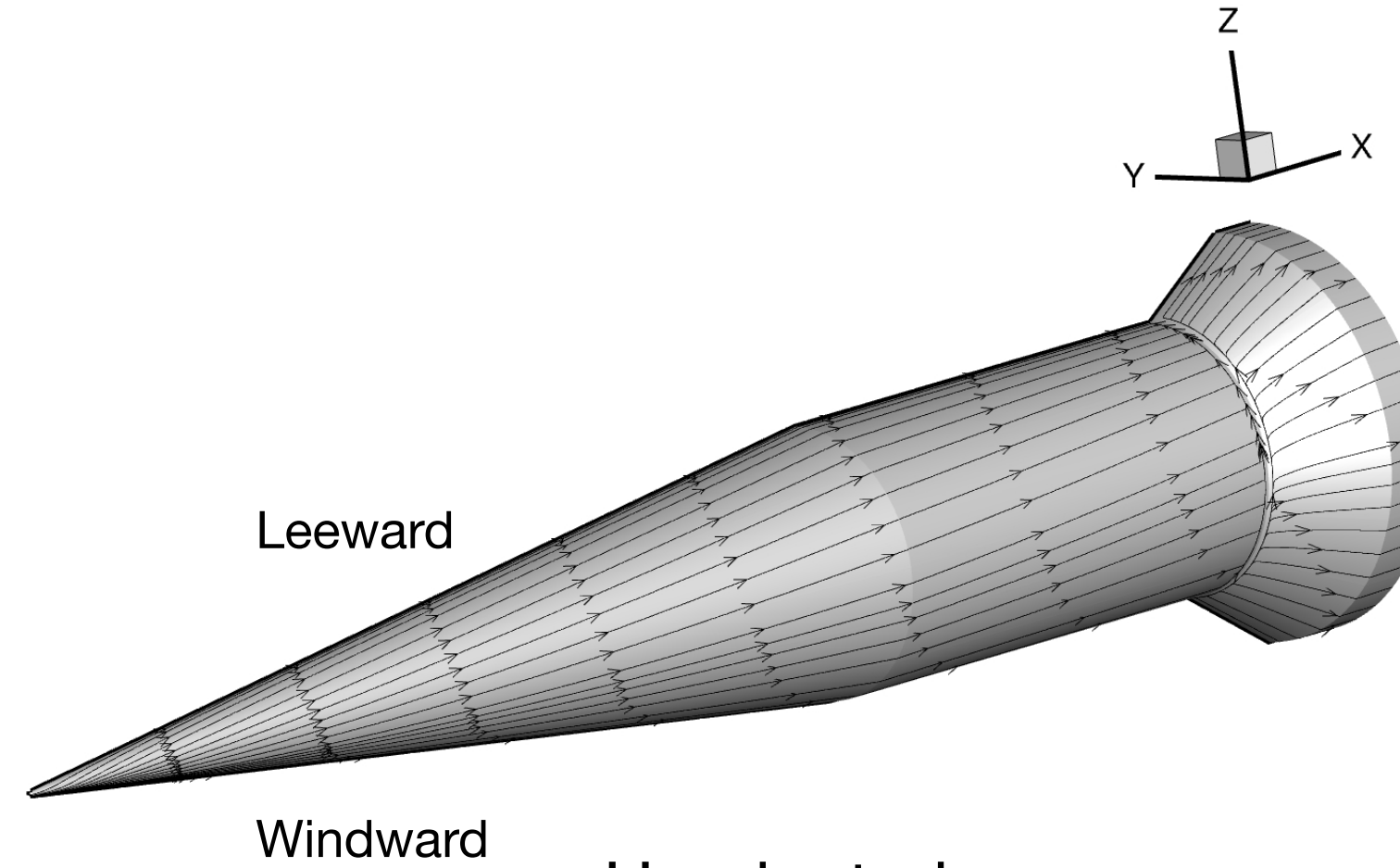
Medium, Unadapted



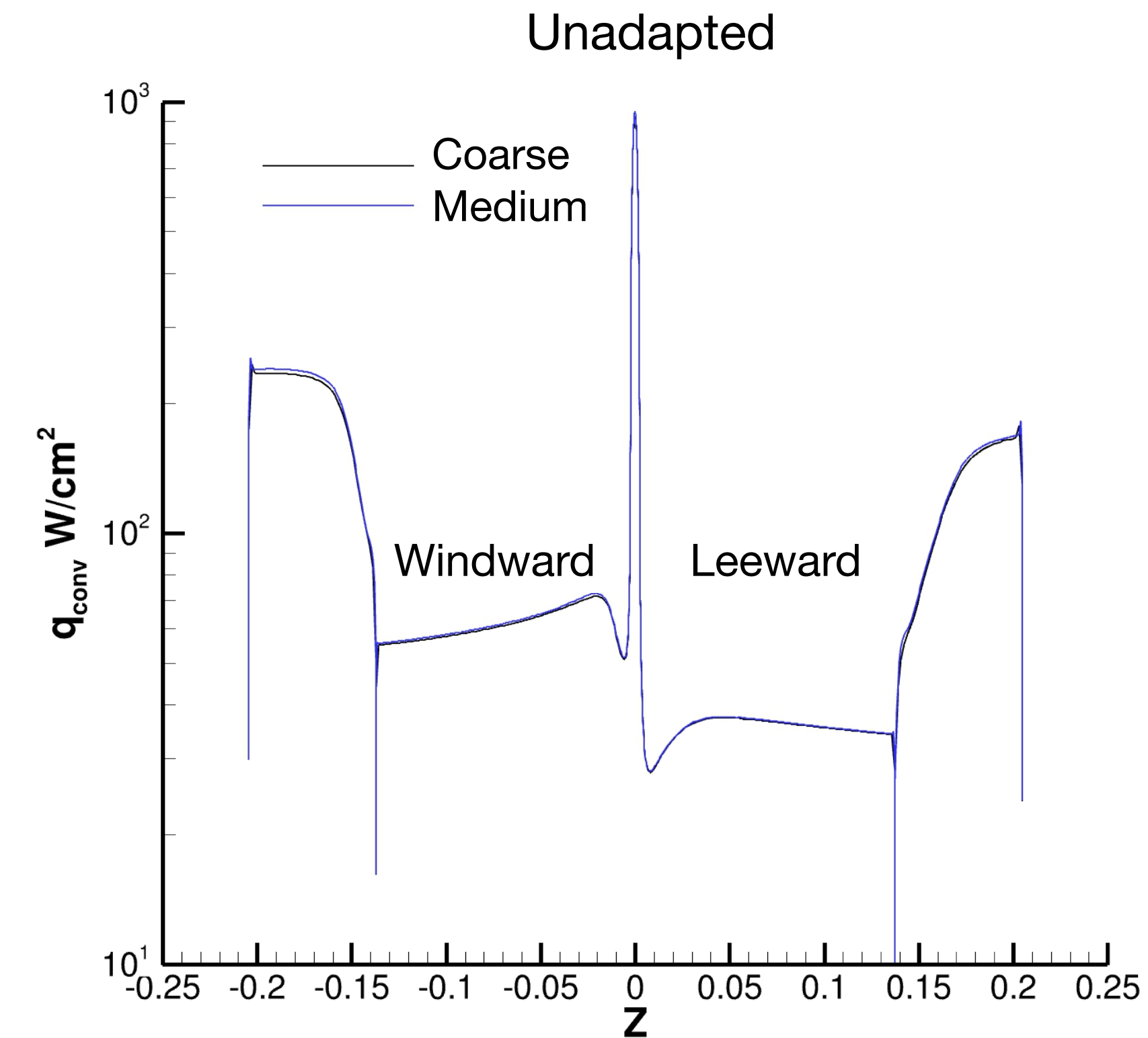
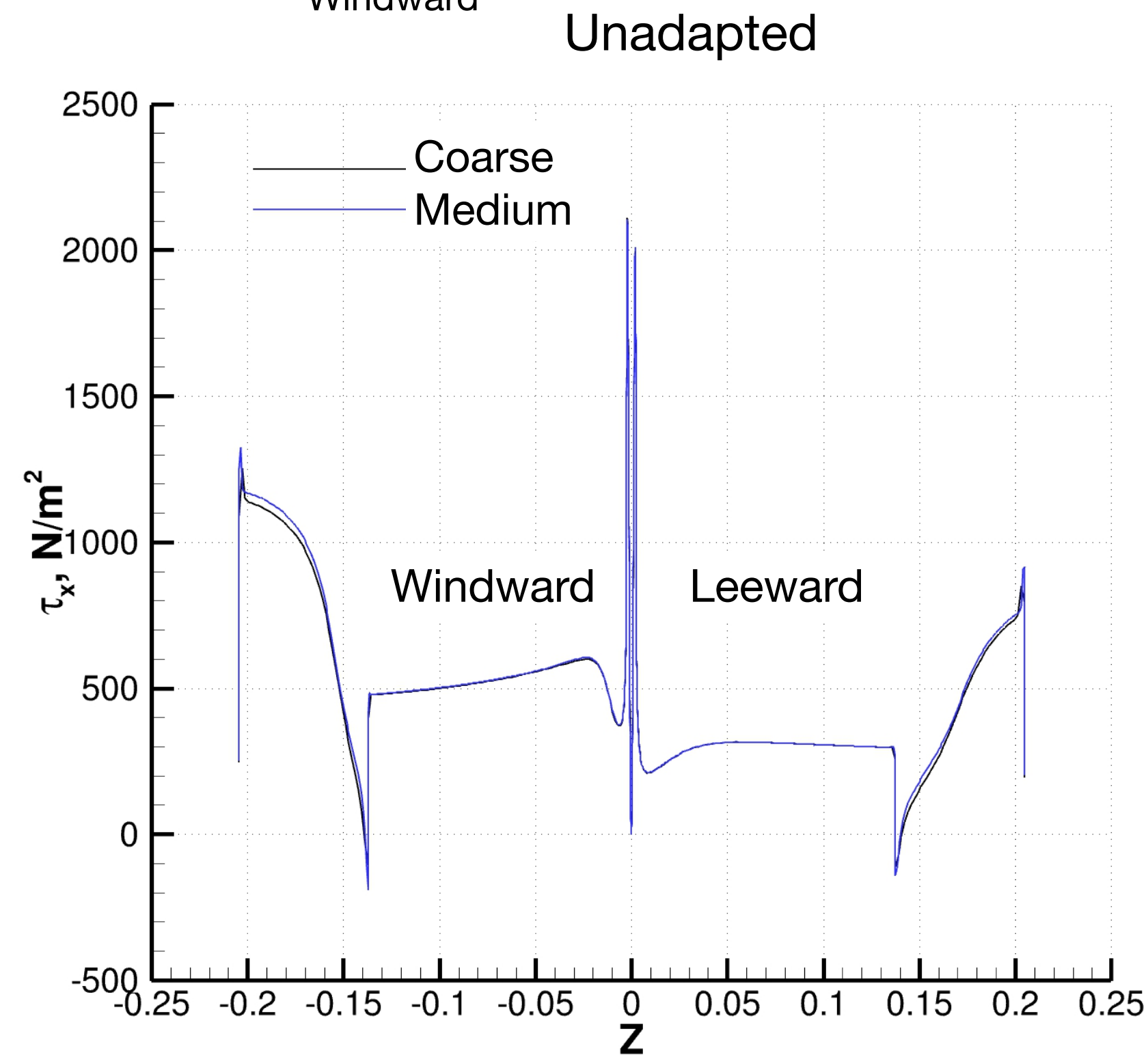
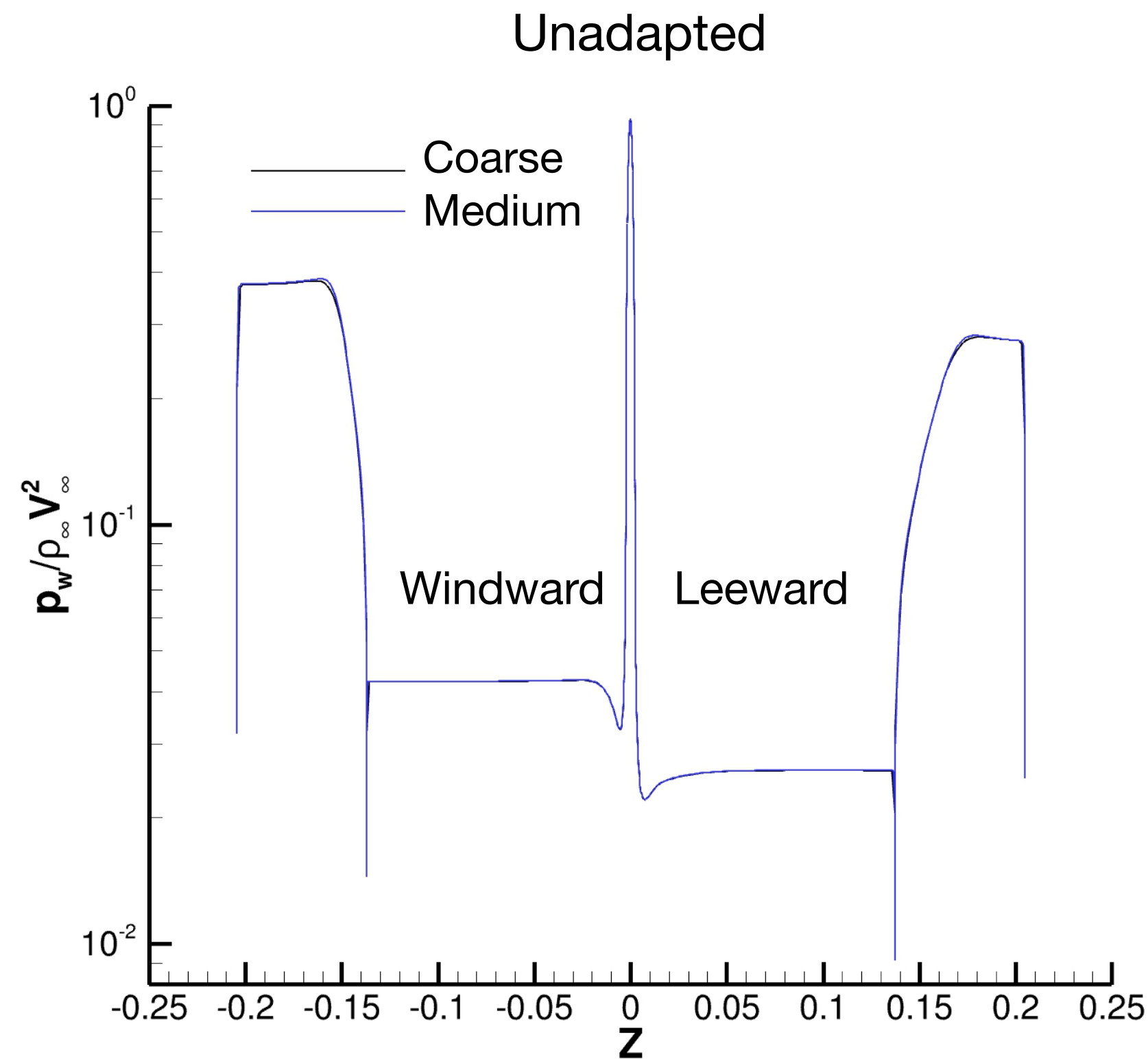
Medium, Unadapted



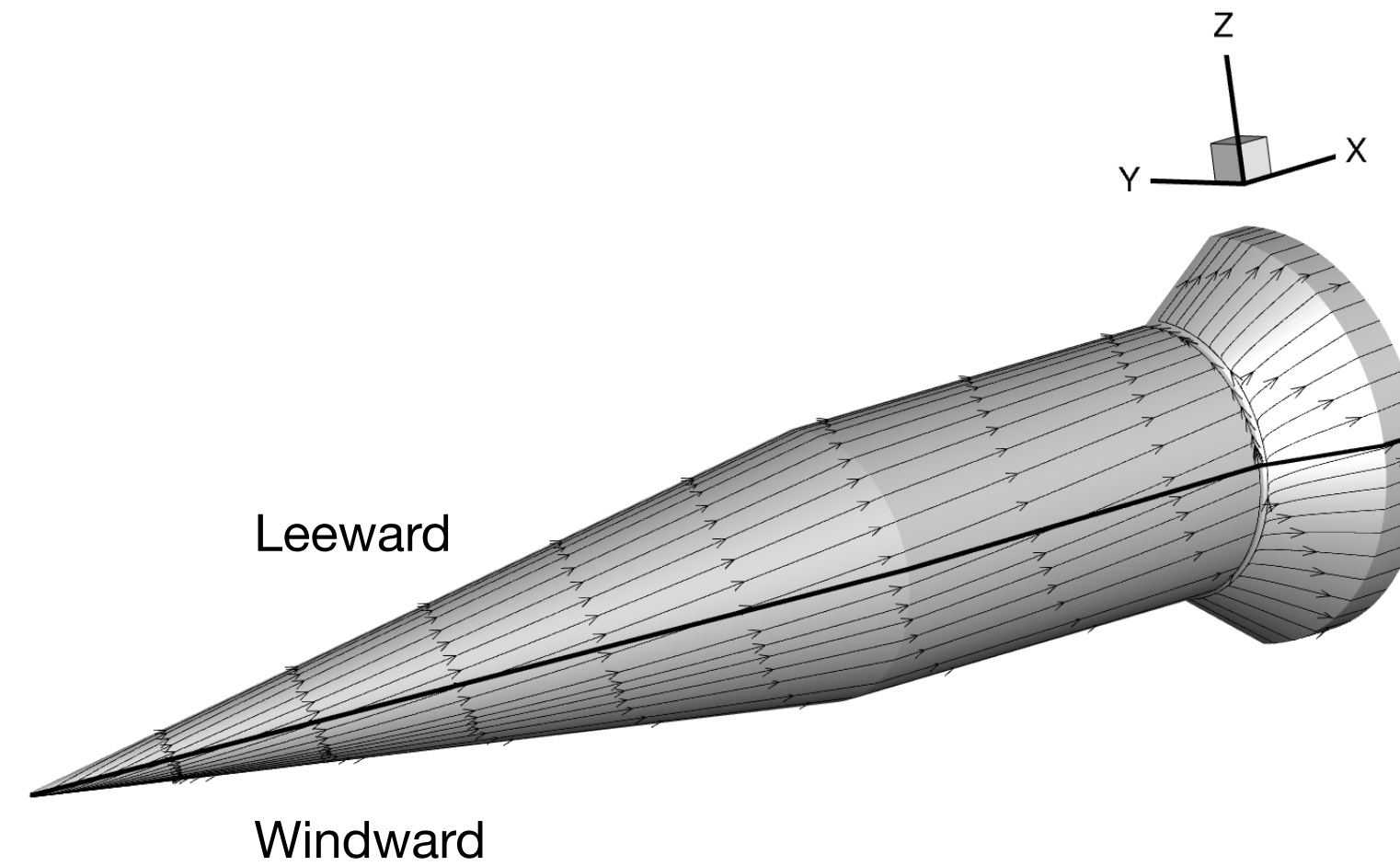
Surface properties along y = 0 plane



- The surface heat fluxes predicted on the coarse and medium grids are different by less than 3%.

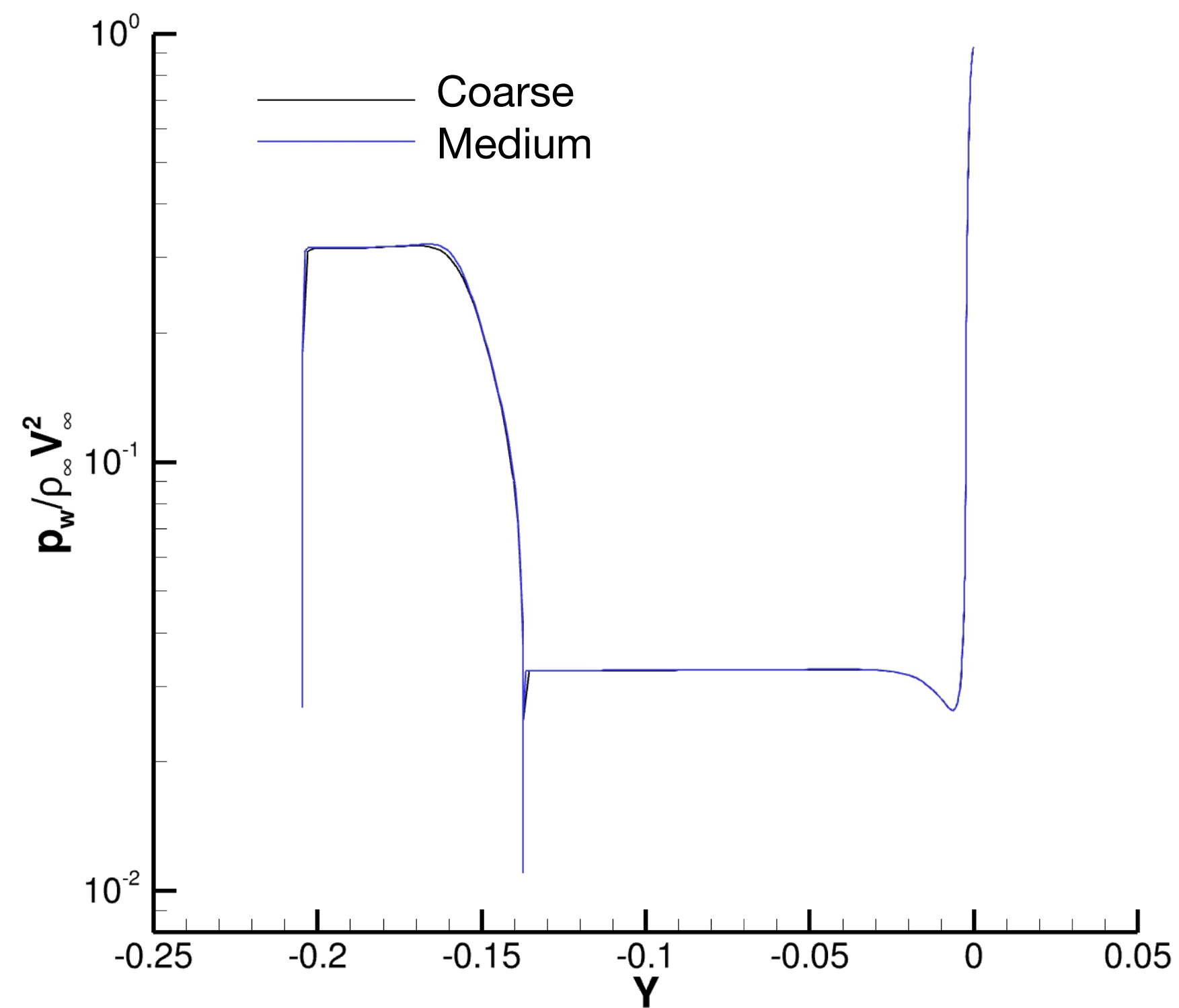


Surface properties along Z = 0 plane

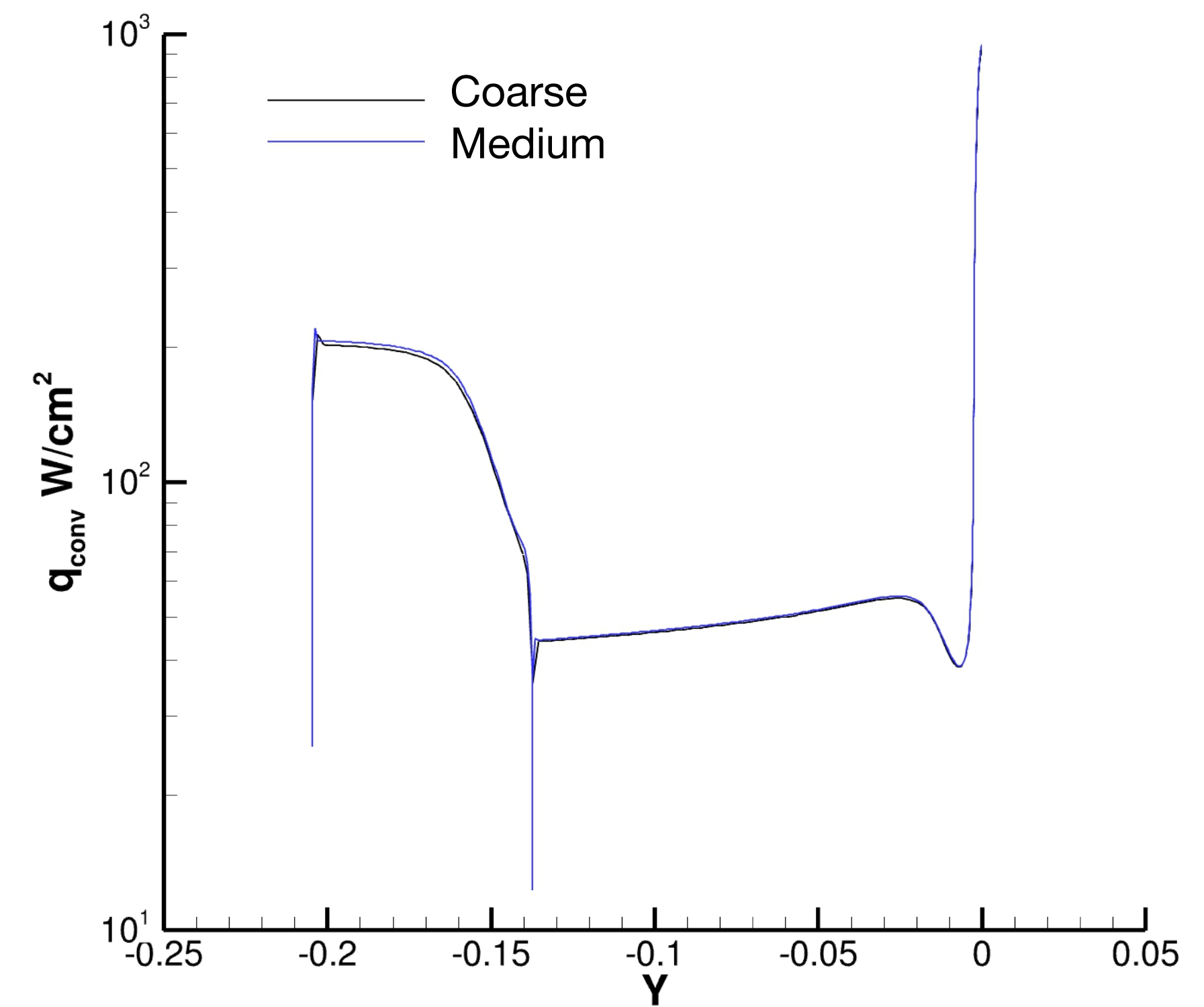


- The surface heat fluxes predicted on the coarse and medium grids are different by less than 3%.

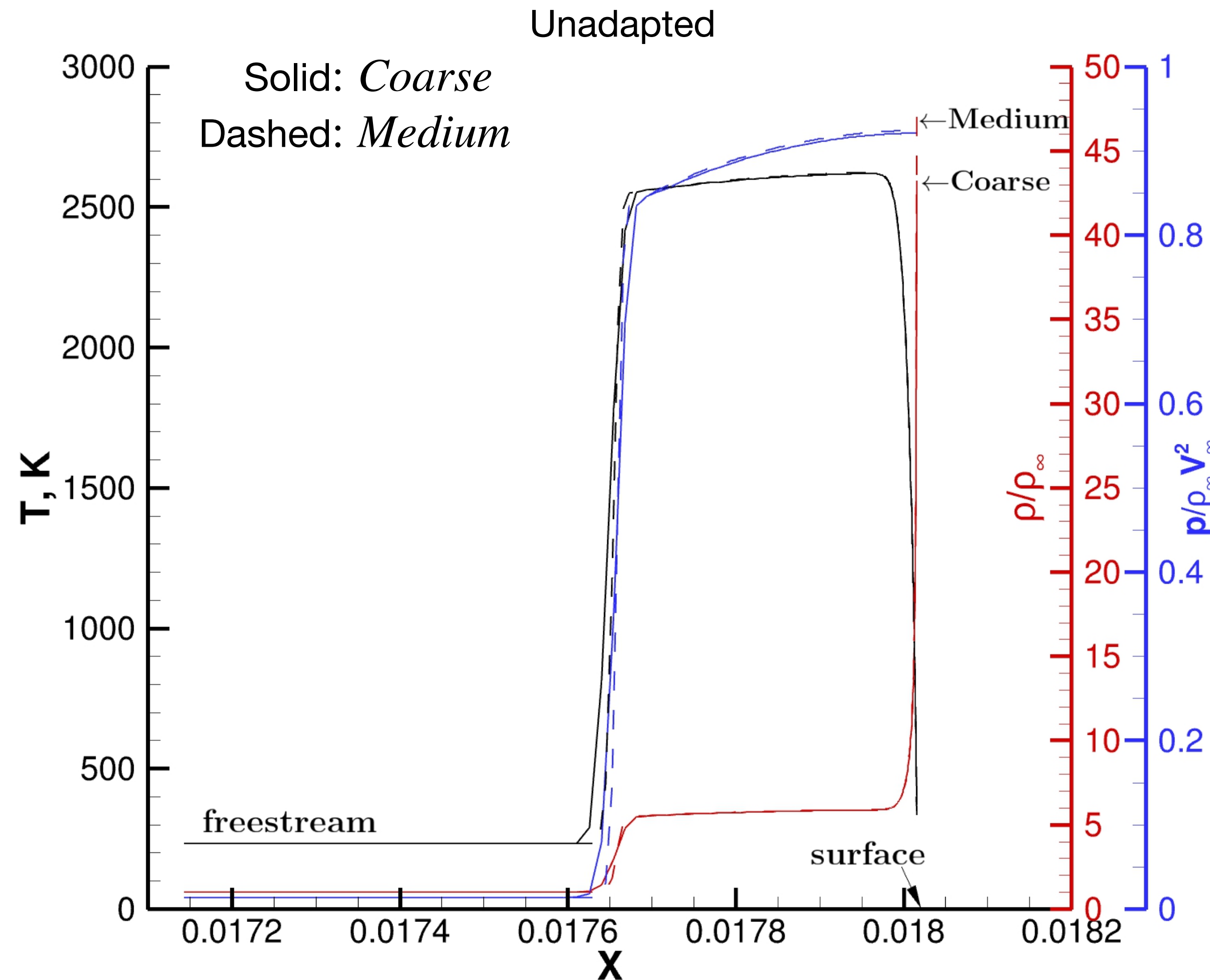
Unadapted



Unadapted



Stagnation profiles



- Improved shock capturing with higher grid resolutions.
- About 8% higher stagnation point density is predicted on the medium grid.
- Grid alignment with the shock on the coarse grid (TBD) is expected to give similar or better solutions in comparison with the predicted solutions on the unadapted medium grid.