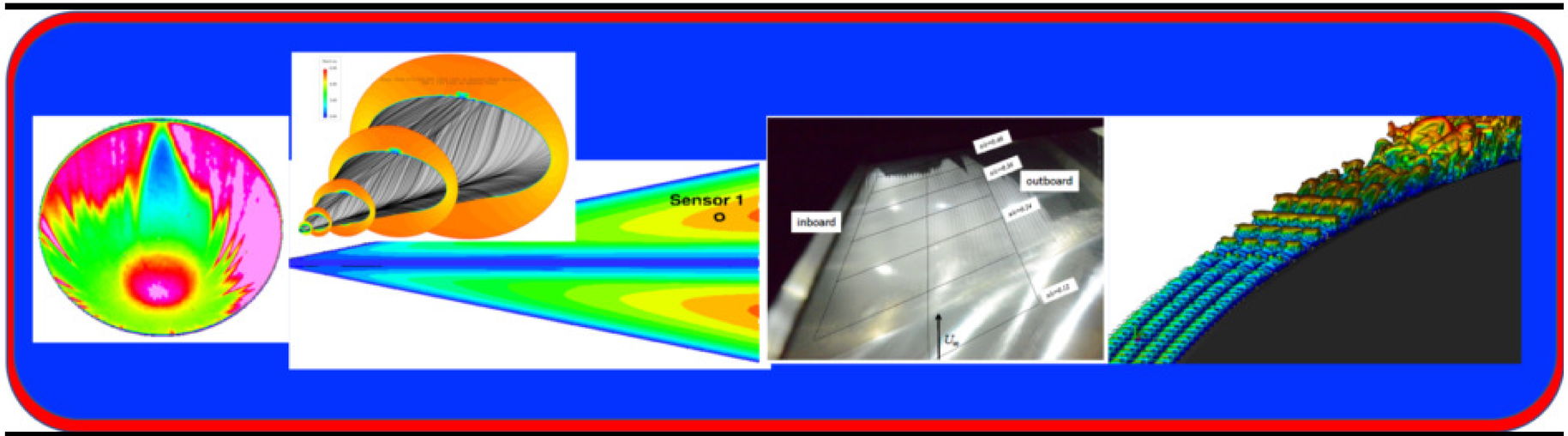
Transition Modeling and CFD Vision 2030

AIAA Transition Modeling Workshop



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AIAA Transition Modeling Workshop-I

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IST ULisbon, MARIN

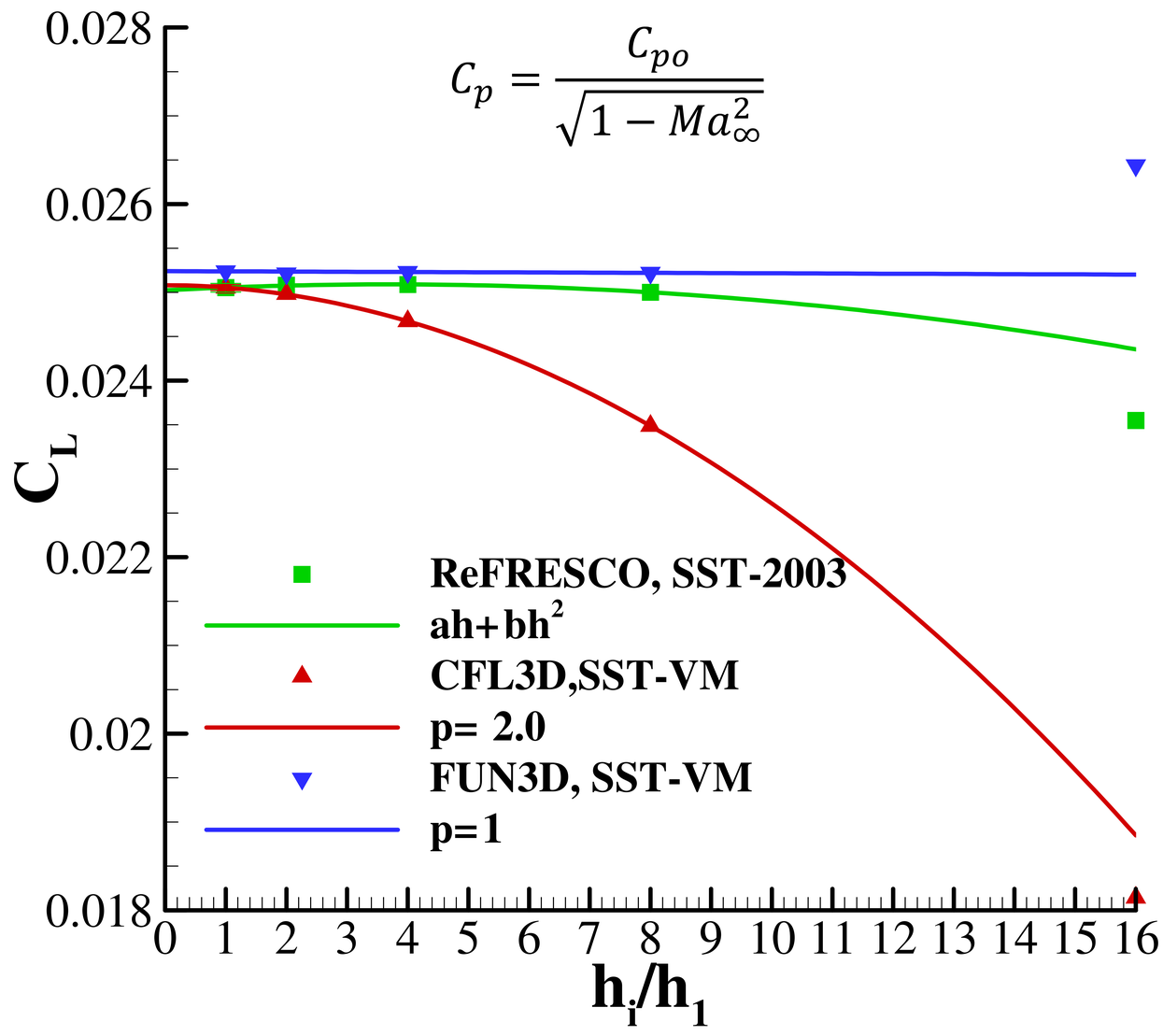
Contents:

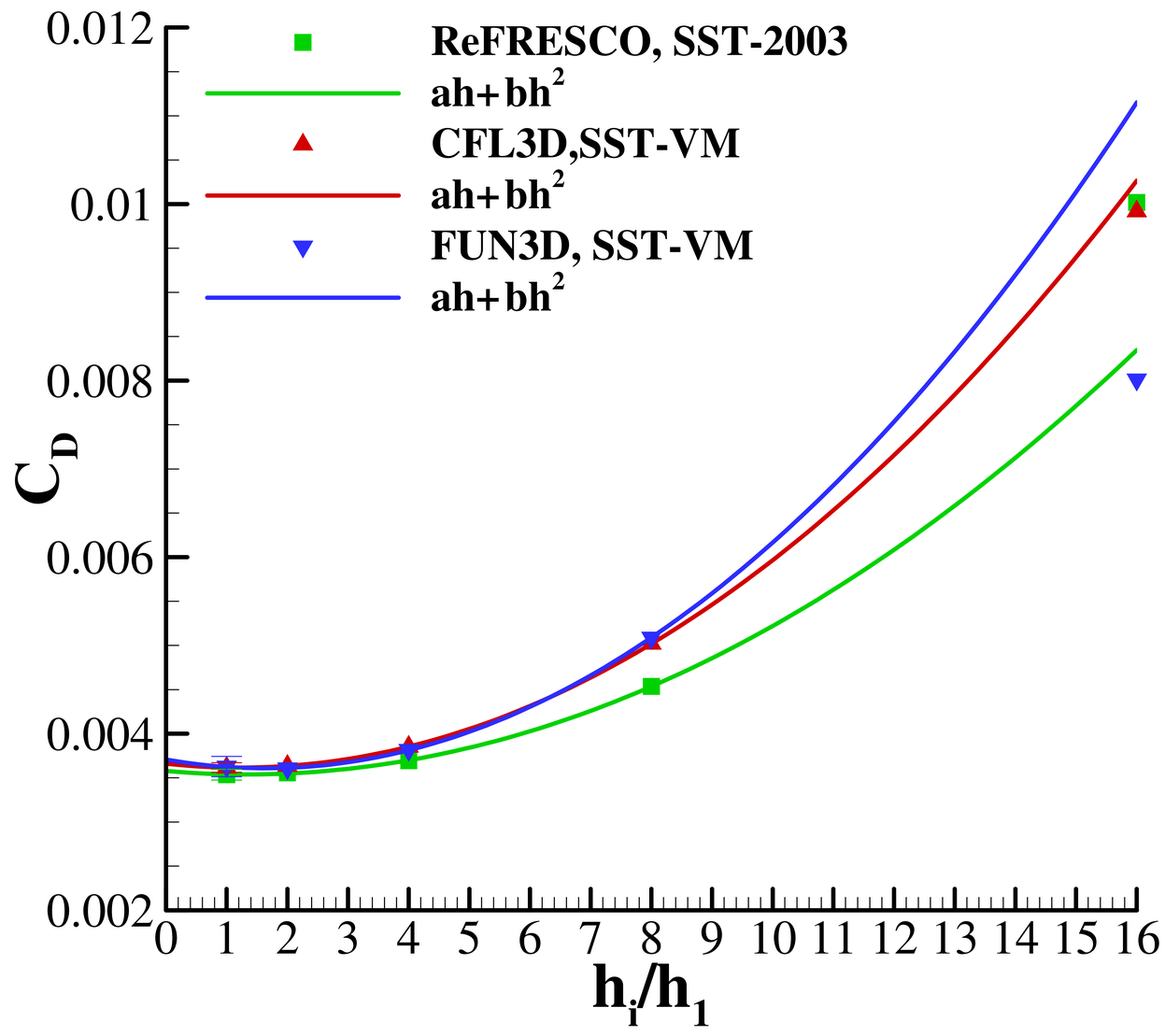
- Case 0
- Cases 1A, 1B and 1C;
- Cases 2A and 2B:
  - Influence of domain size;
  - Estimation of numerical uncertainty;
  - Estimation of sensitivity coefficients for I and ν_t/ν at the inlet.
- Case 3:
  - Specification of inflow conditions.

Mathematical Models and Flow Solver

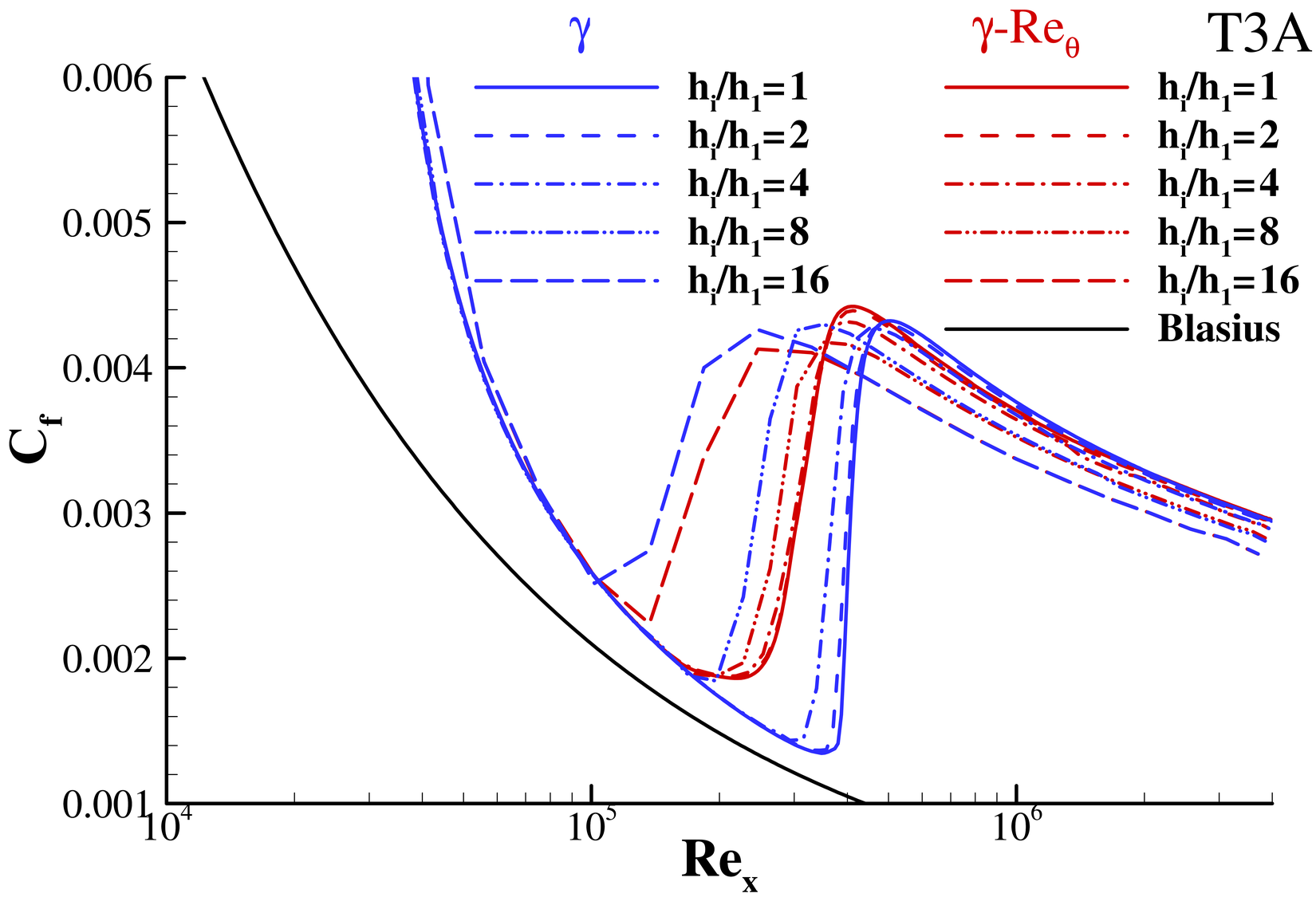
- Reynolds-Averaged Navier-Stokes equations for an incompressible fluid (**Ma=0**) supplemented with the $k-\omega$ SST 2003 combined with the following transition models:
  - $\gamma - Re_\theta$ (Langtry and Menter 2009);
  - γ (Menter et al. 2015);
  - AFT (Coder 2017a).
- Cases 0 and 1 were simulated in the provided grids.
- Cases 2 and 3 were simulated with our own multiblock structured grids.

Case 0 – 3D Bump in channel





Case 1 – Zero pressure gradient flat plate



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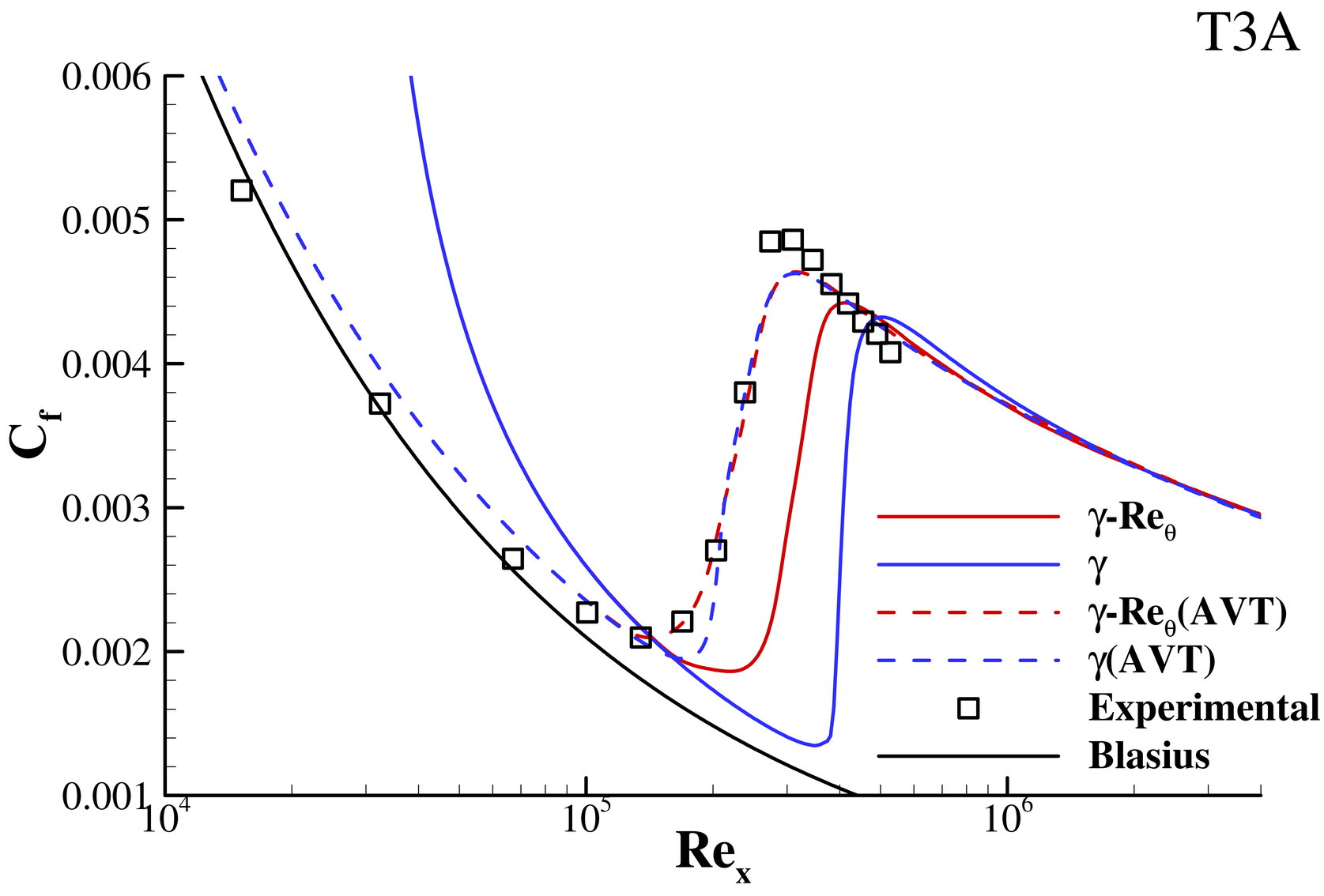

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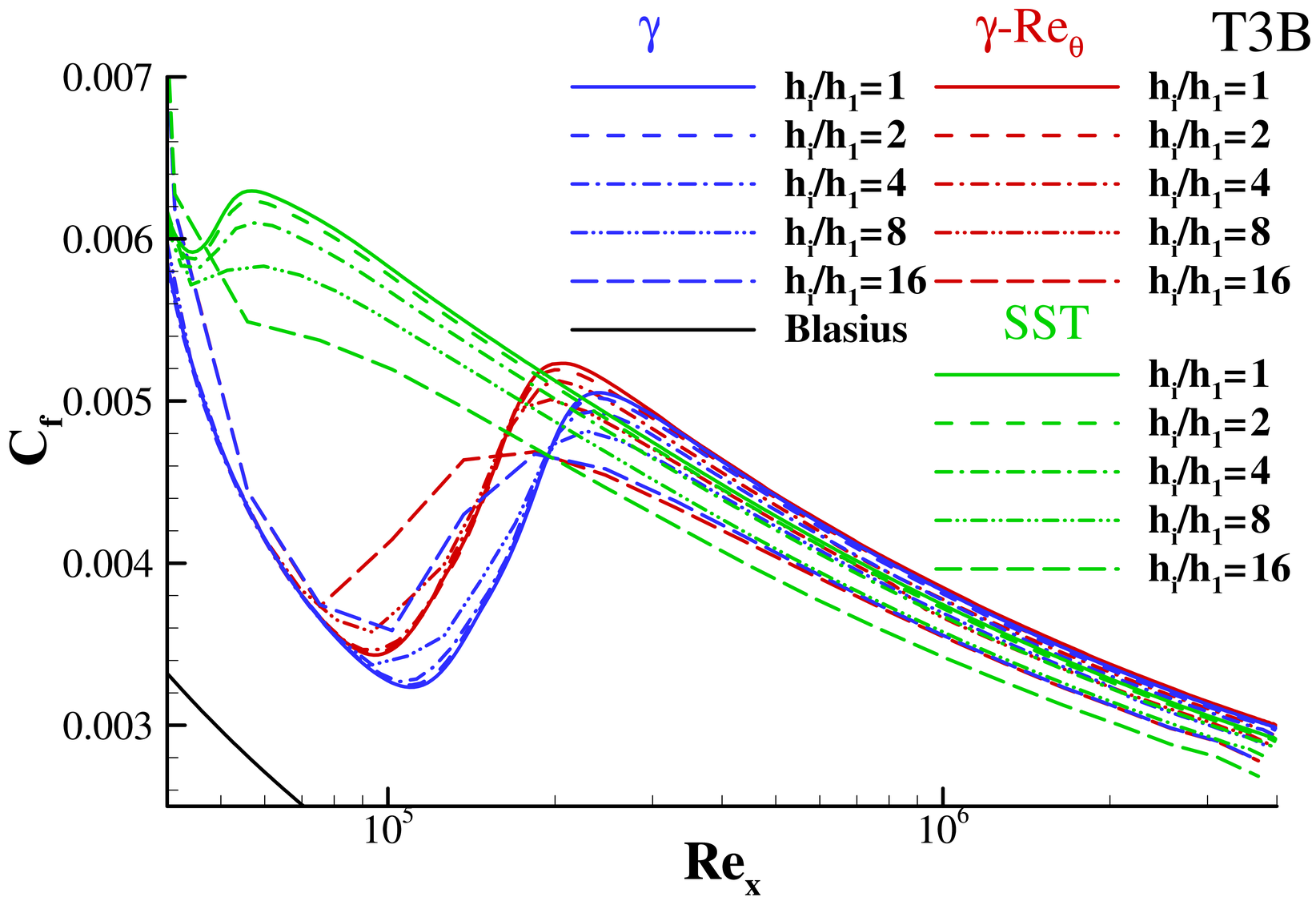

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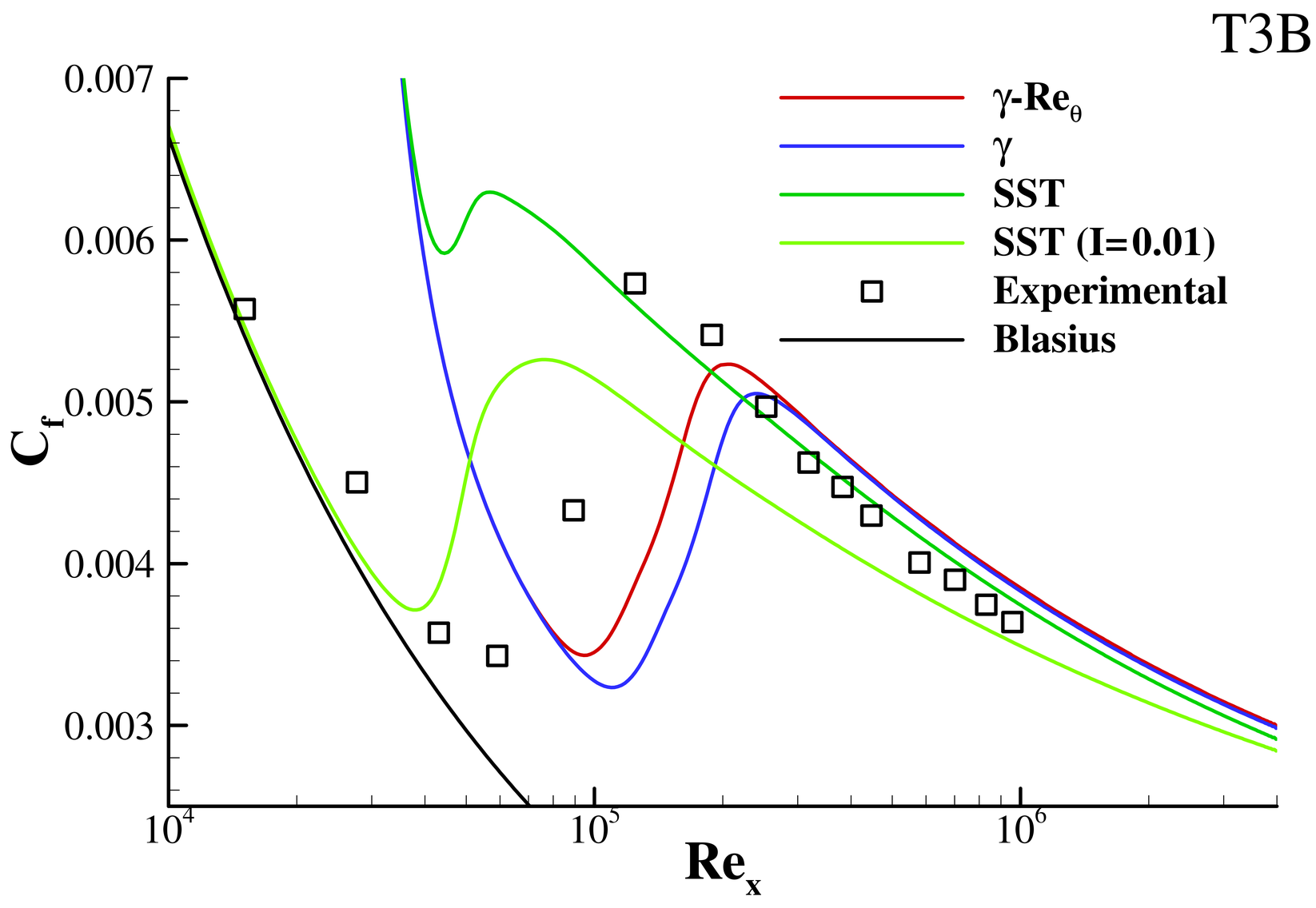
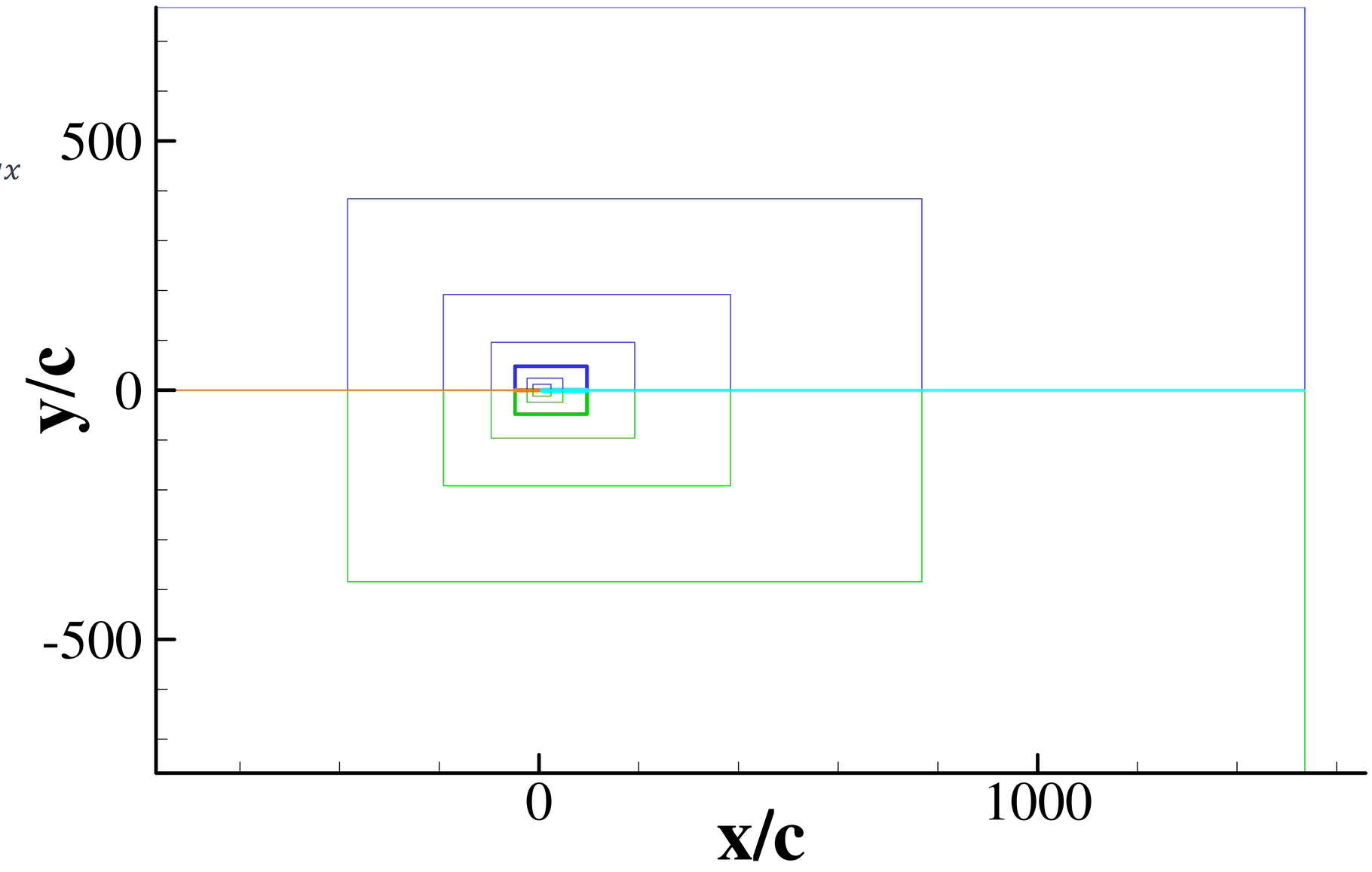


Case 2 – NLF(1)-0416 airfoil

Study of size of the computational domain
$\lambda = 1536c/L_y = 2304c/L_x$

Selected domain
$\lambda = 16$
$L_x = 144c, L_y = 96c$

- V_∞ aligned with x;
- Free slip at top and bottom boundaries;
- Pressure imposed at the outlet.



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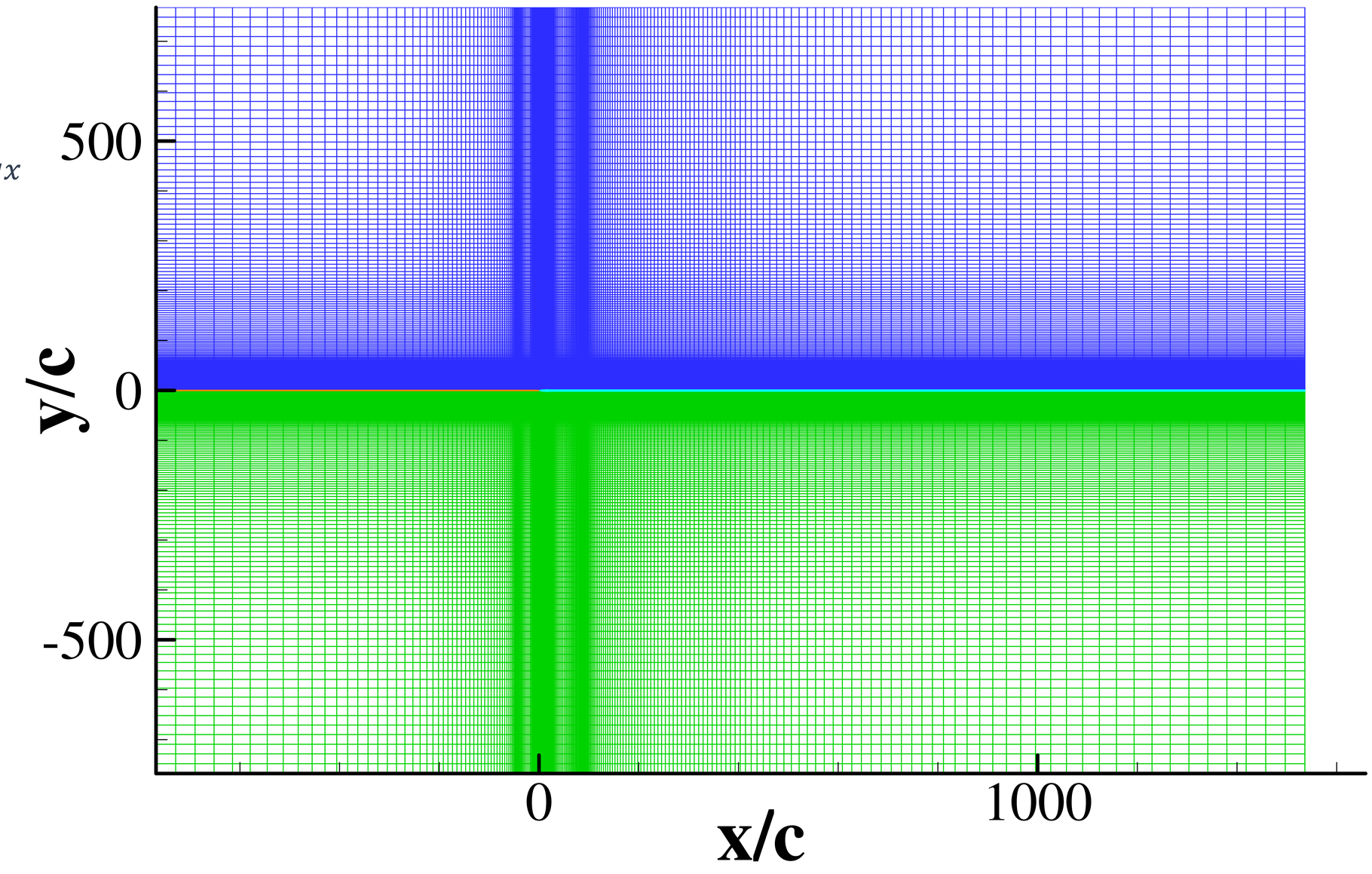
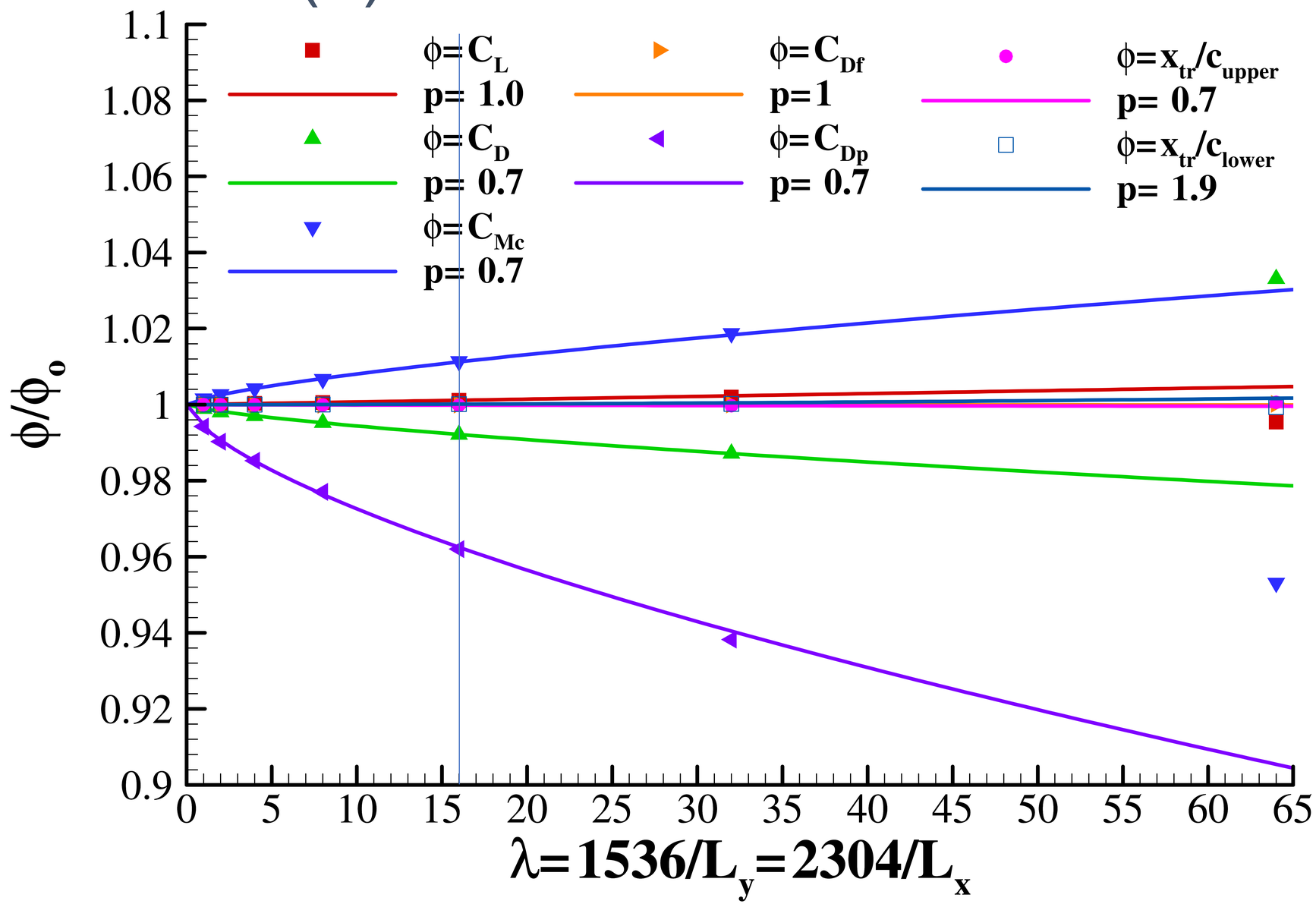


Case 2 – NLF(1)-0416 airfoil



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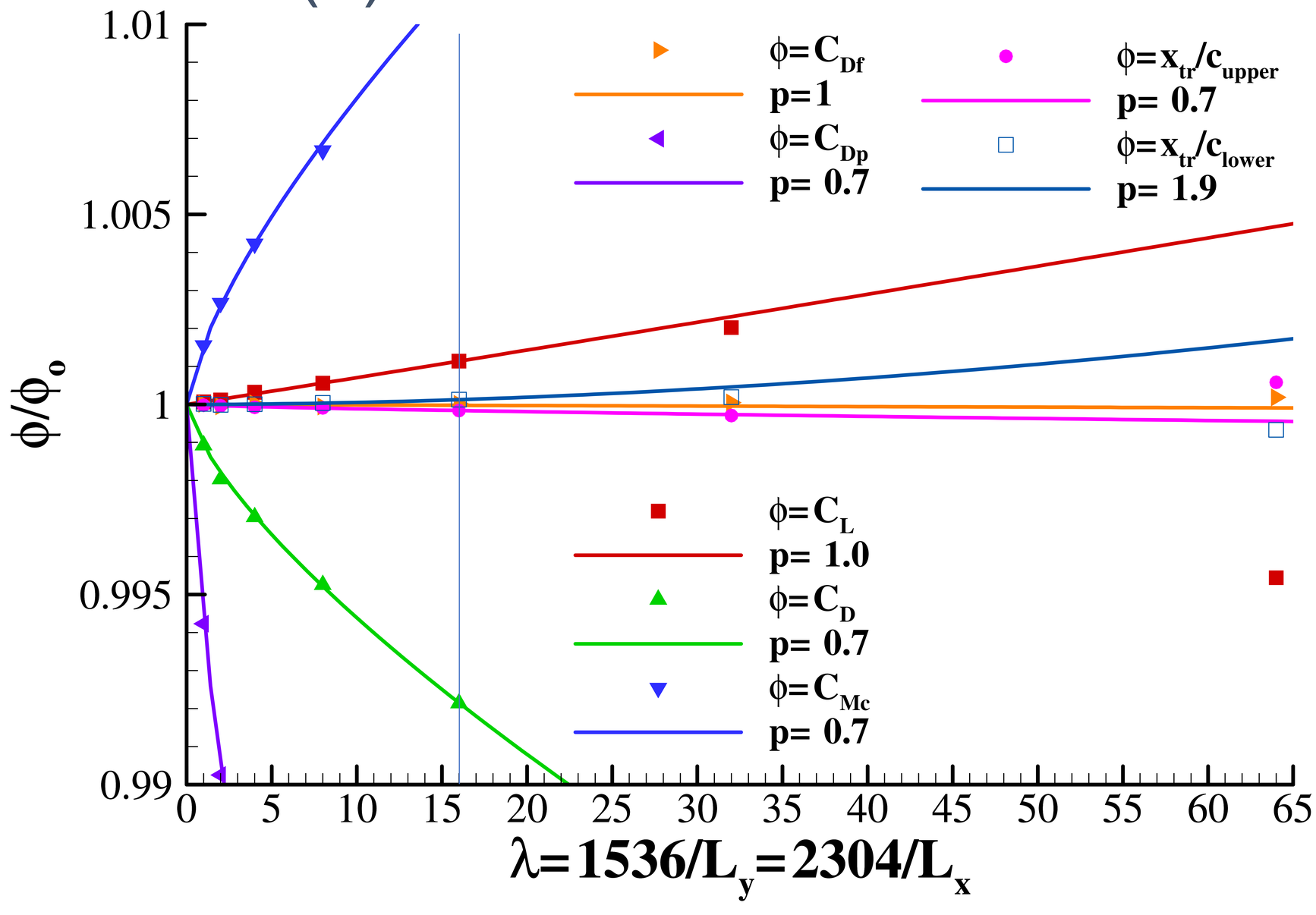

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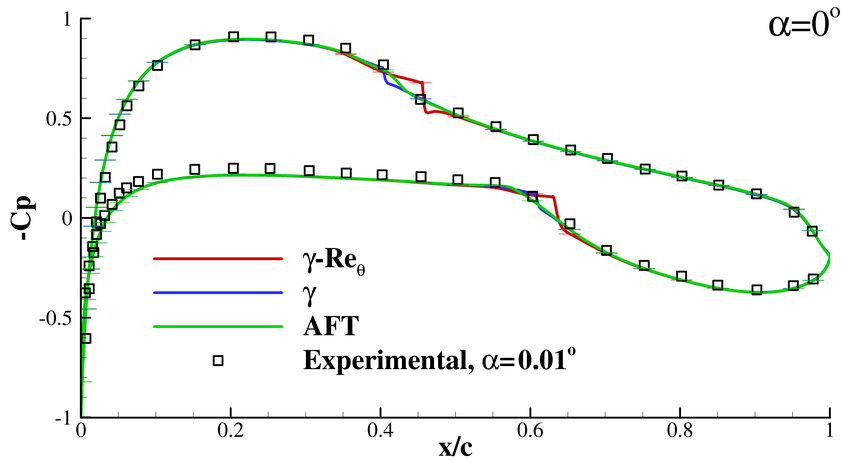
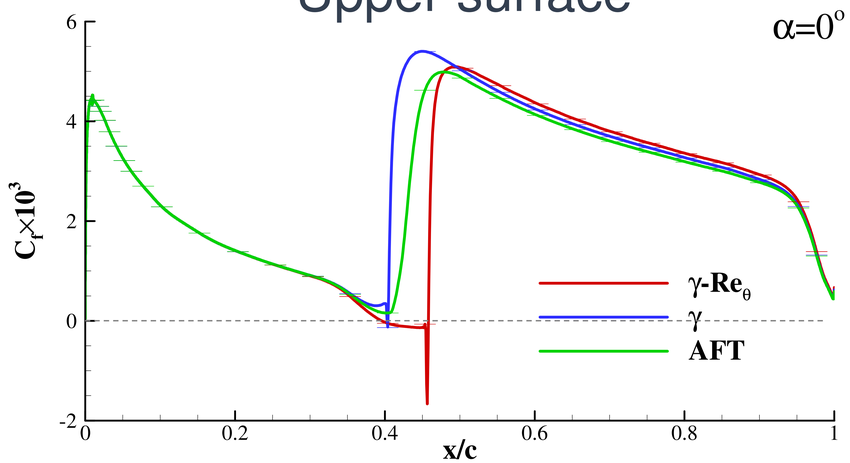
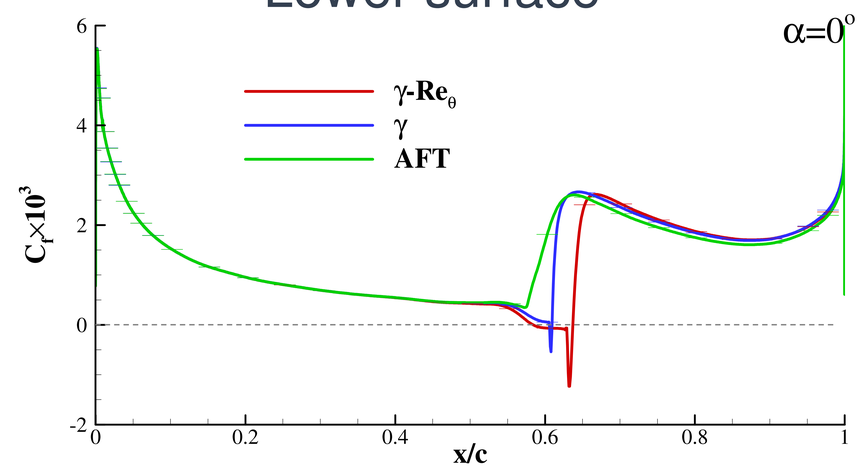
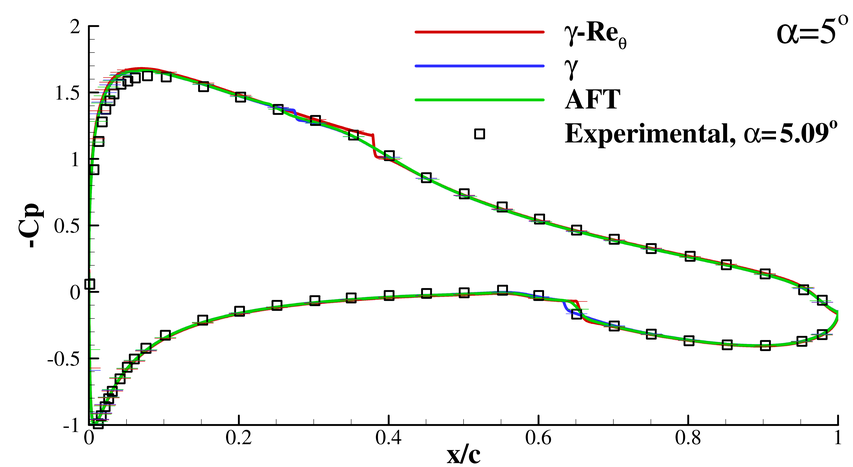


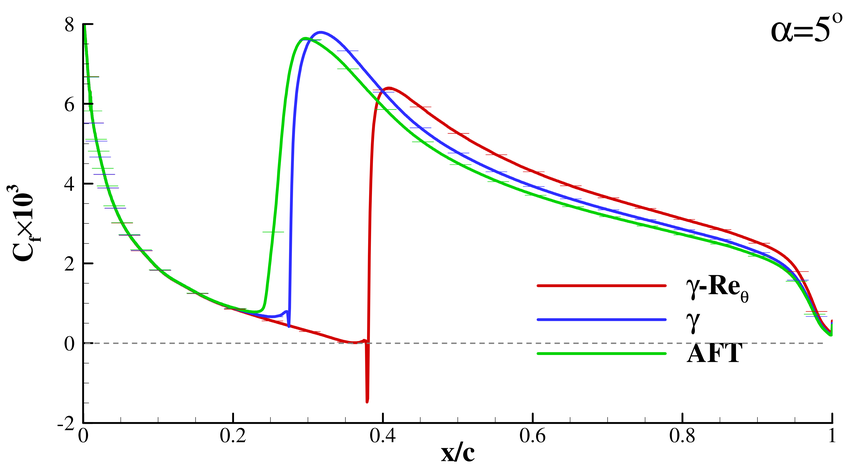
Upper surface

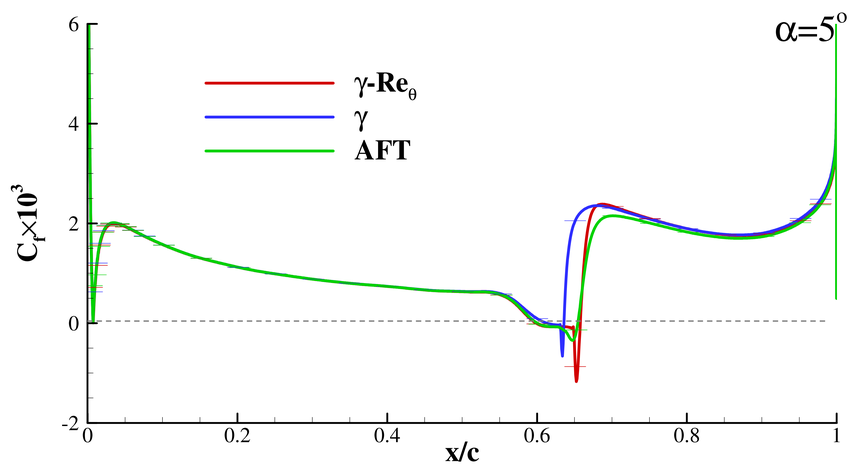


Lower surface





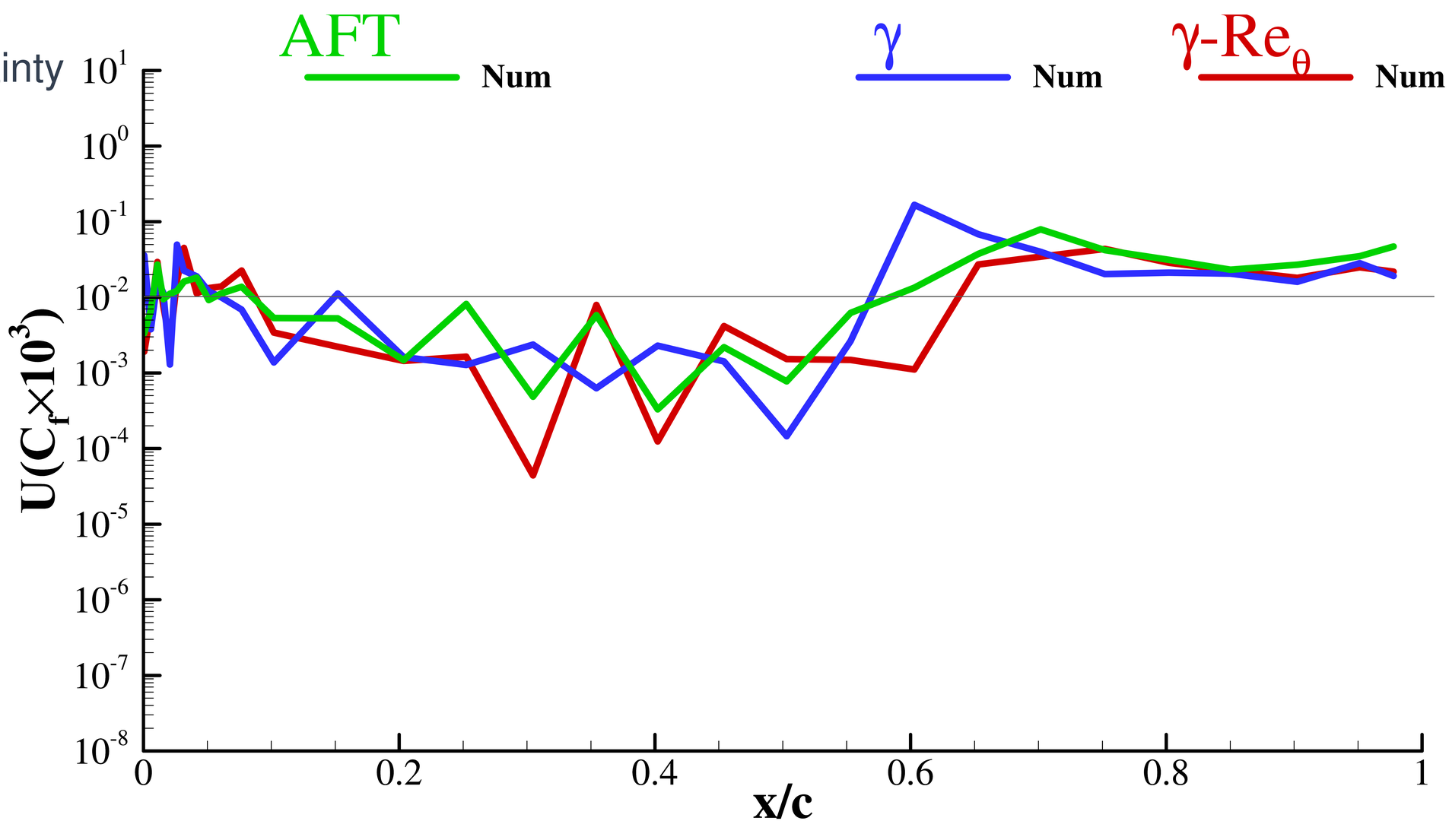




Case 2 – NLF(1)-0416 airfoil

Lower surface, $\alpha = 0^o$

Num
Numerical Uncertainty

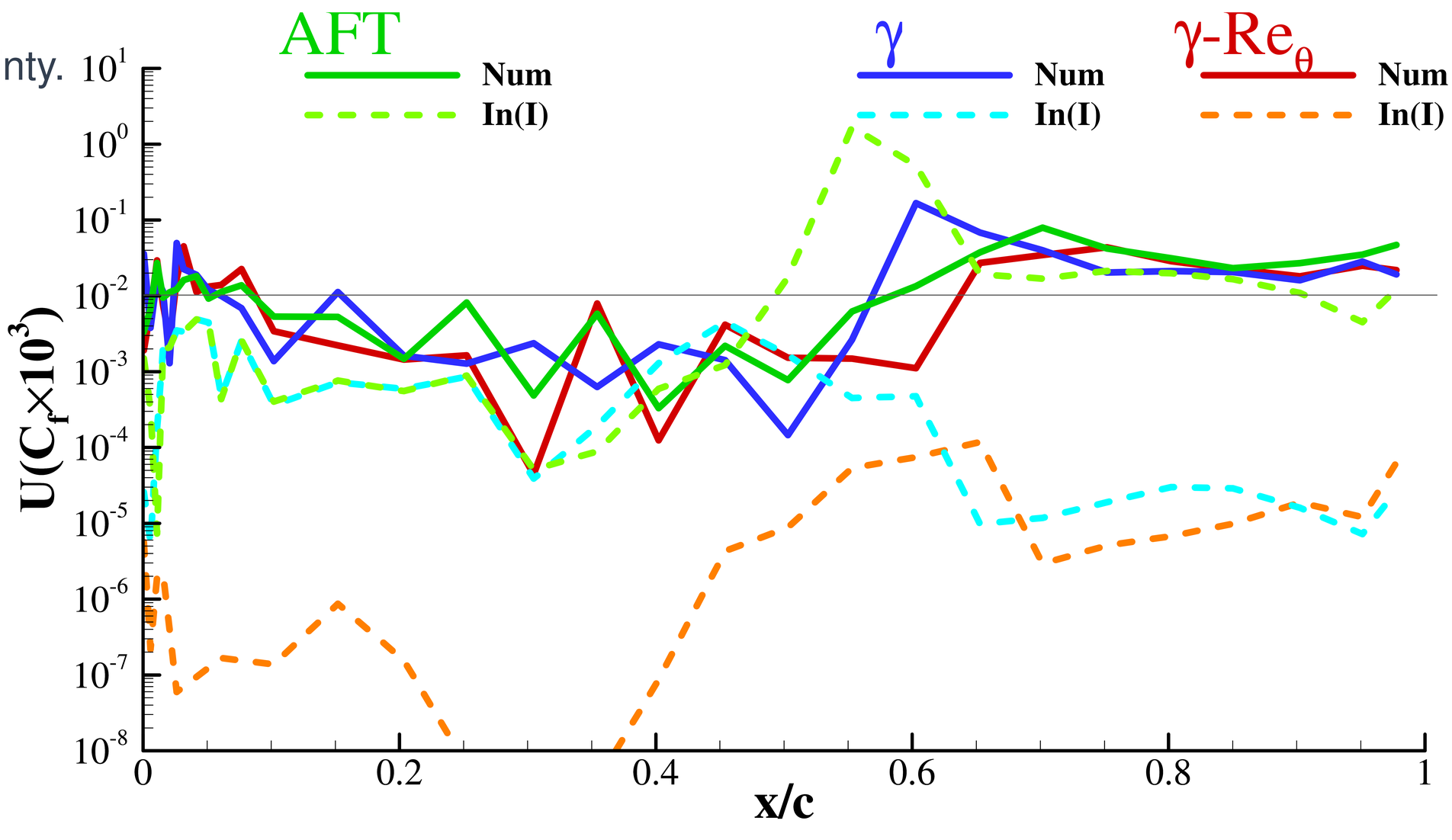


Case 2 – NLF(1)-0416 airfoil

Lower surface, $\alpha = 0^o$

Num
Numerical uncertainty.

In(I)
Input uncertainty from 5% uncertainty in I at the inlet.



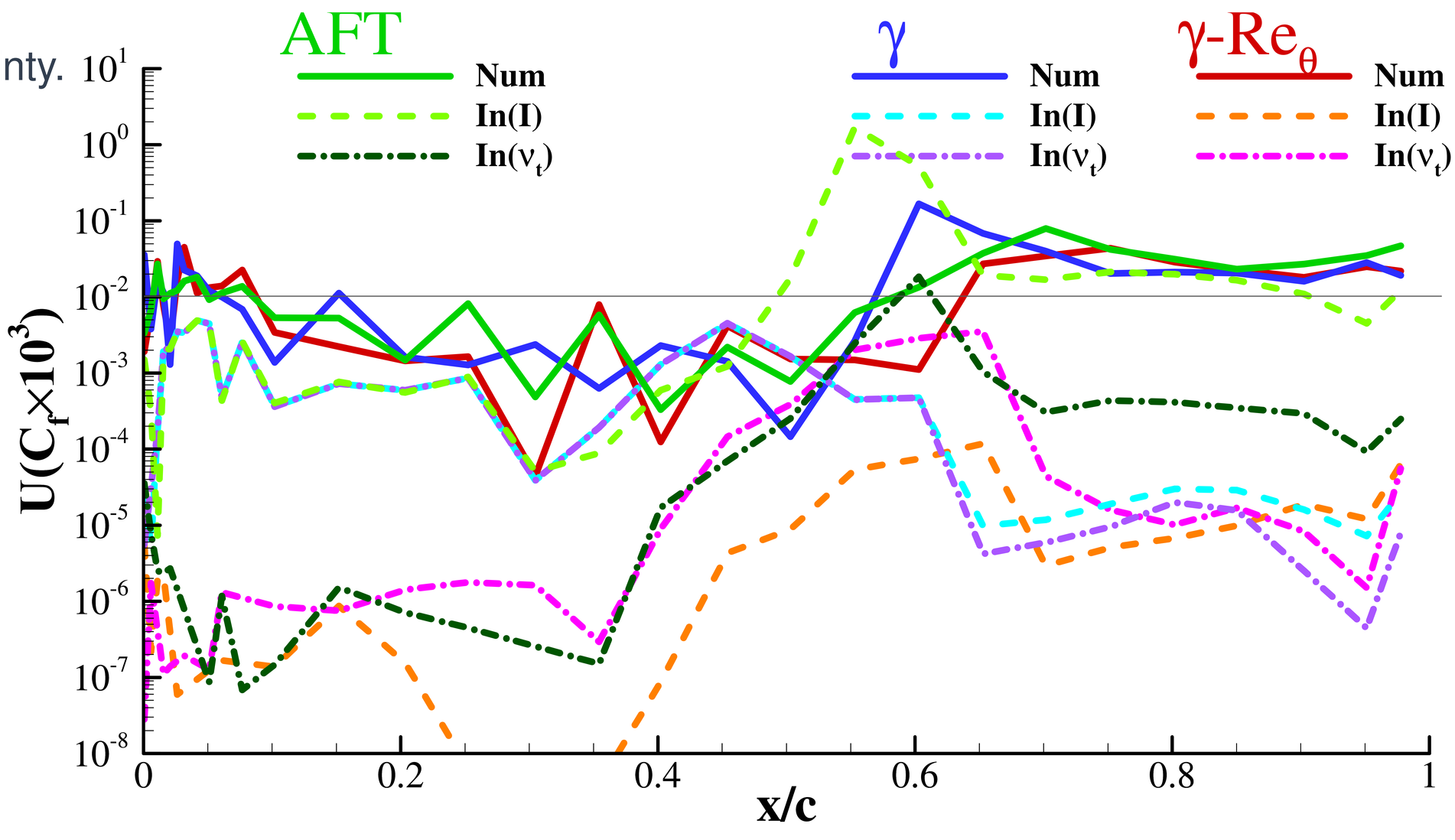
Case 2 – NLF(1)-0416 airfoil

Lower surface, $\alpha = 0^o$

Num
Numerical uncertainty.

In(I)
Input uncertainty from 5% uncertainty in I at the inlet.

In(ν_t)
Input uncertainty from 5% uncertainty in ν_t at the inlet.



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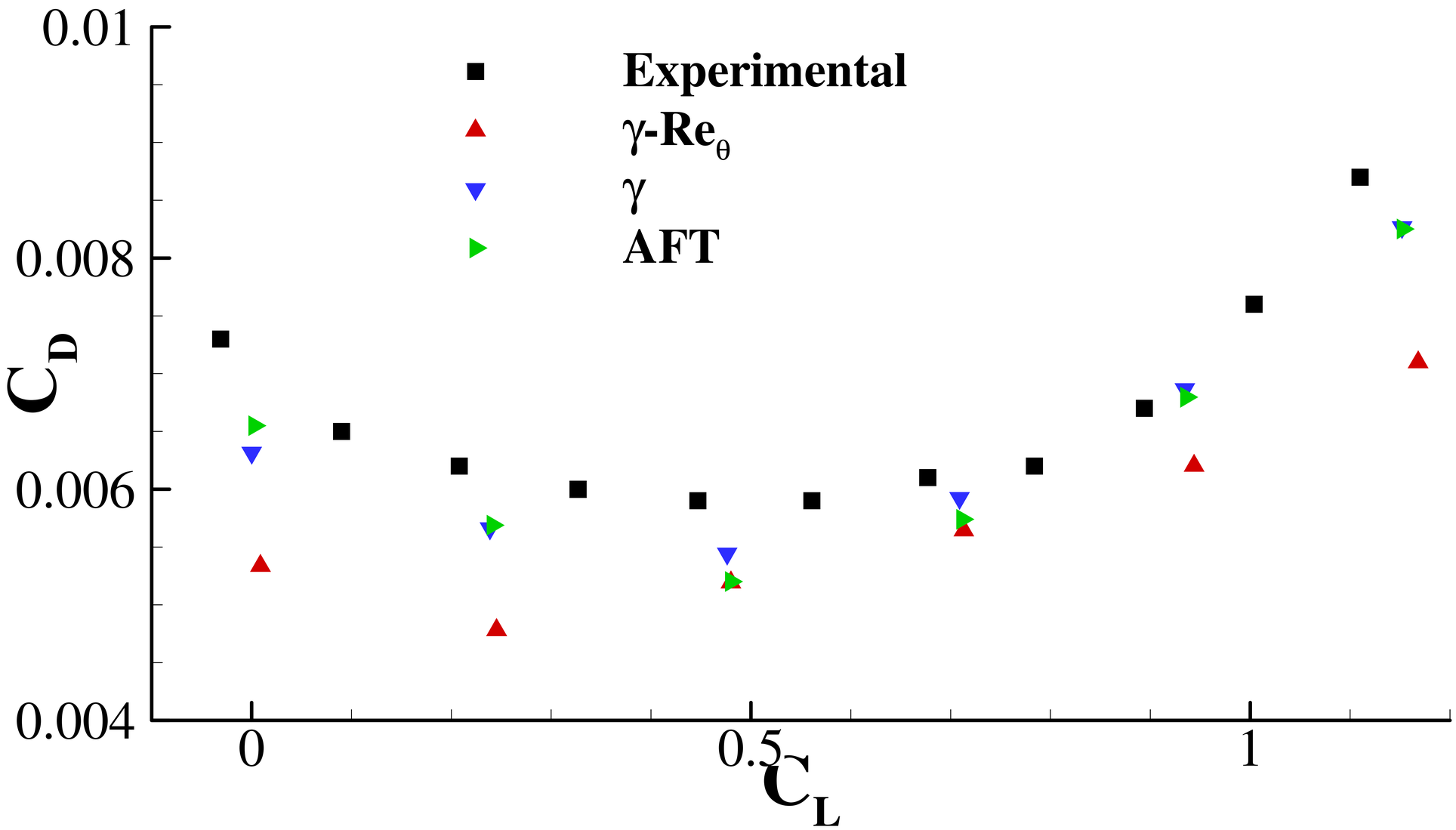
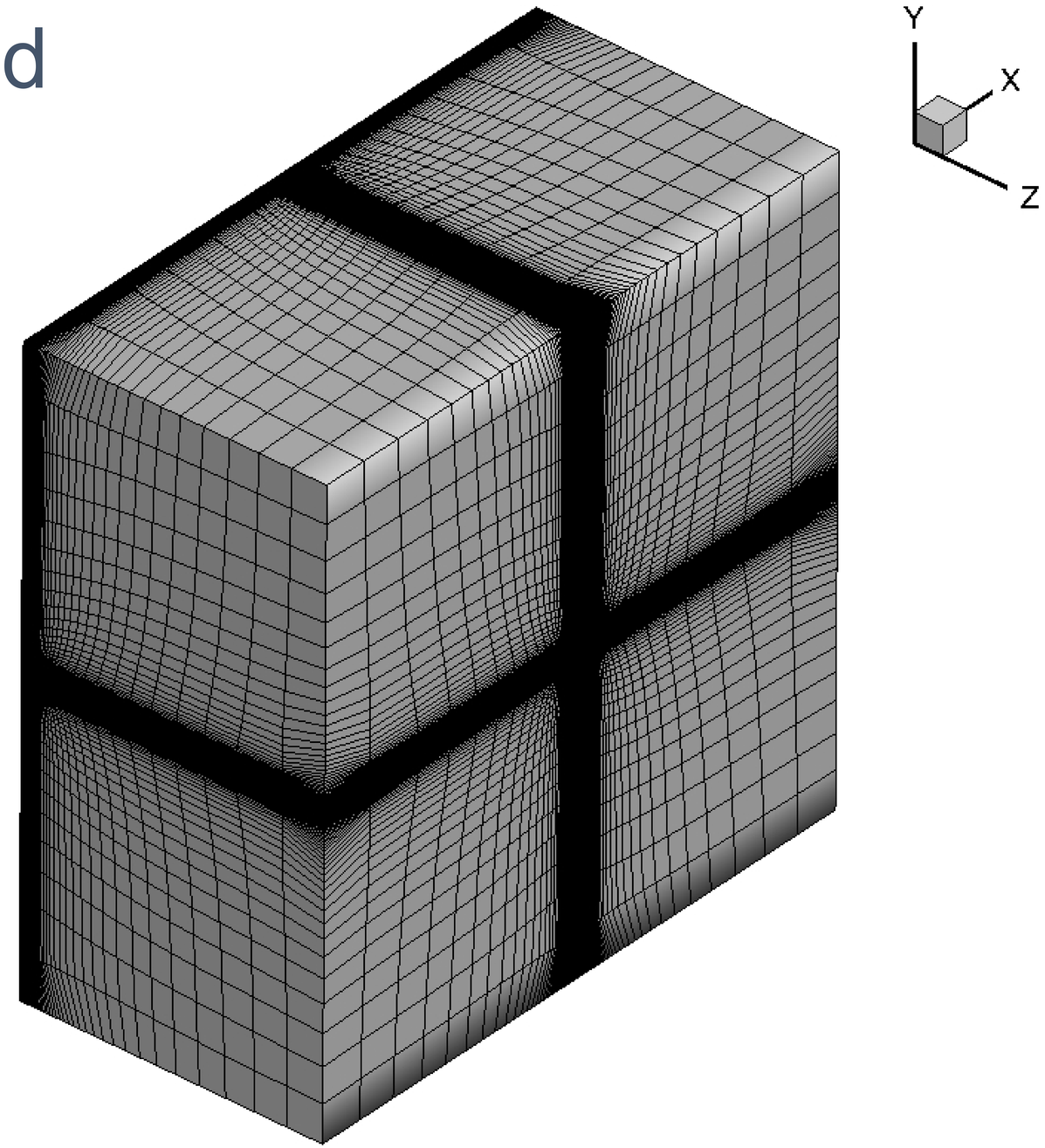


Case 3 – 6:1 Prolate Spheroid

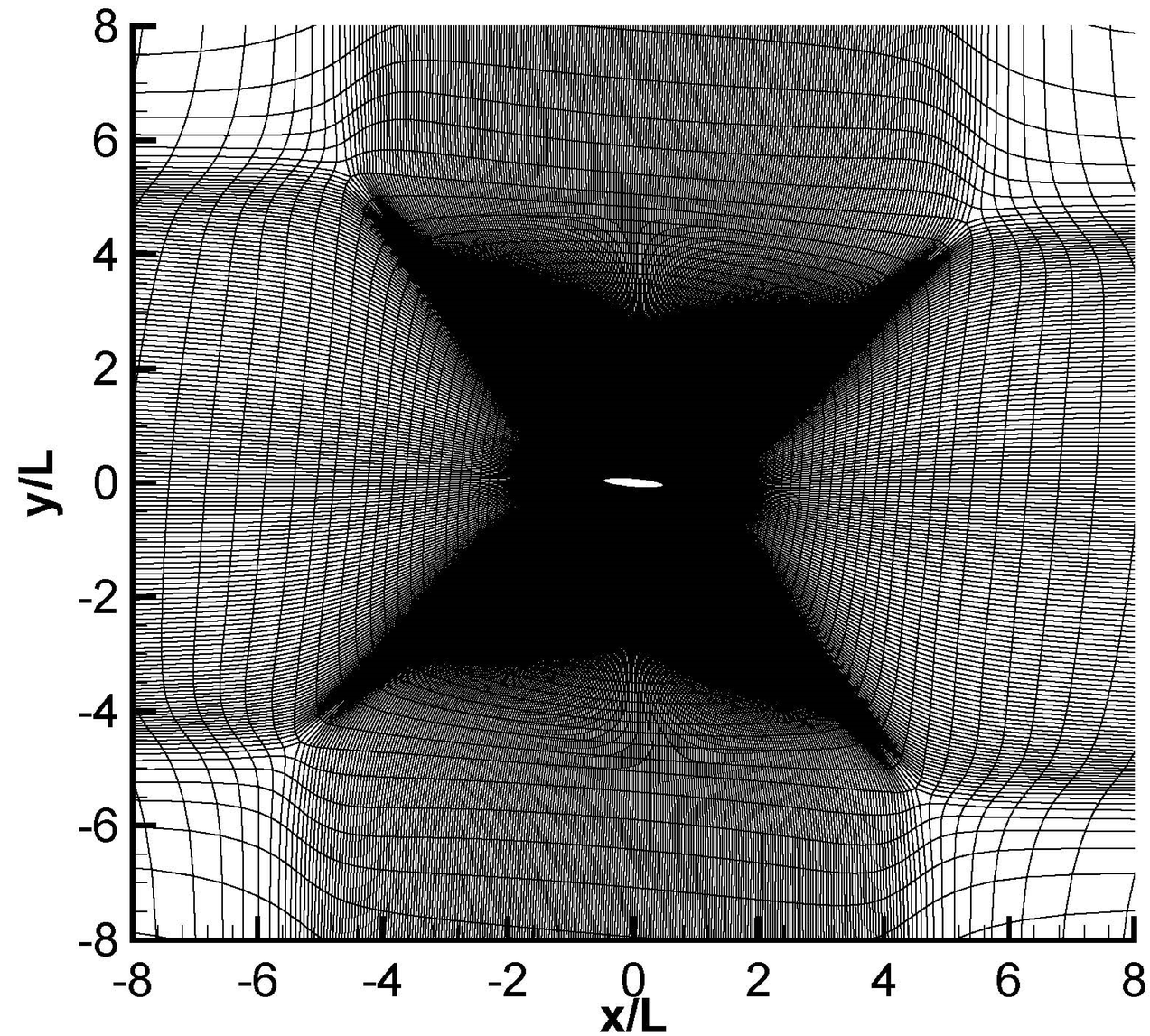
Computational Domain

- Follows workshop guidelines:
- Boundaries at $\frac{X}{L} = \pm 100$, $\frac{Y}{L} = \pm 100$ and $\frac{Z}{L} = +100$;
- Symmetry plane at the spheroid $\left(\frac{Z}{L} = 0\right)$;



Case 3 – 6:1 Prolate Spheroid

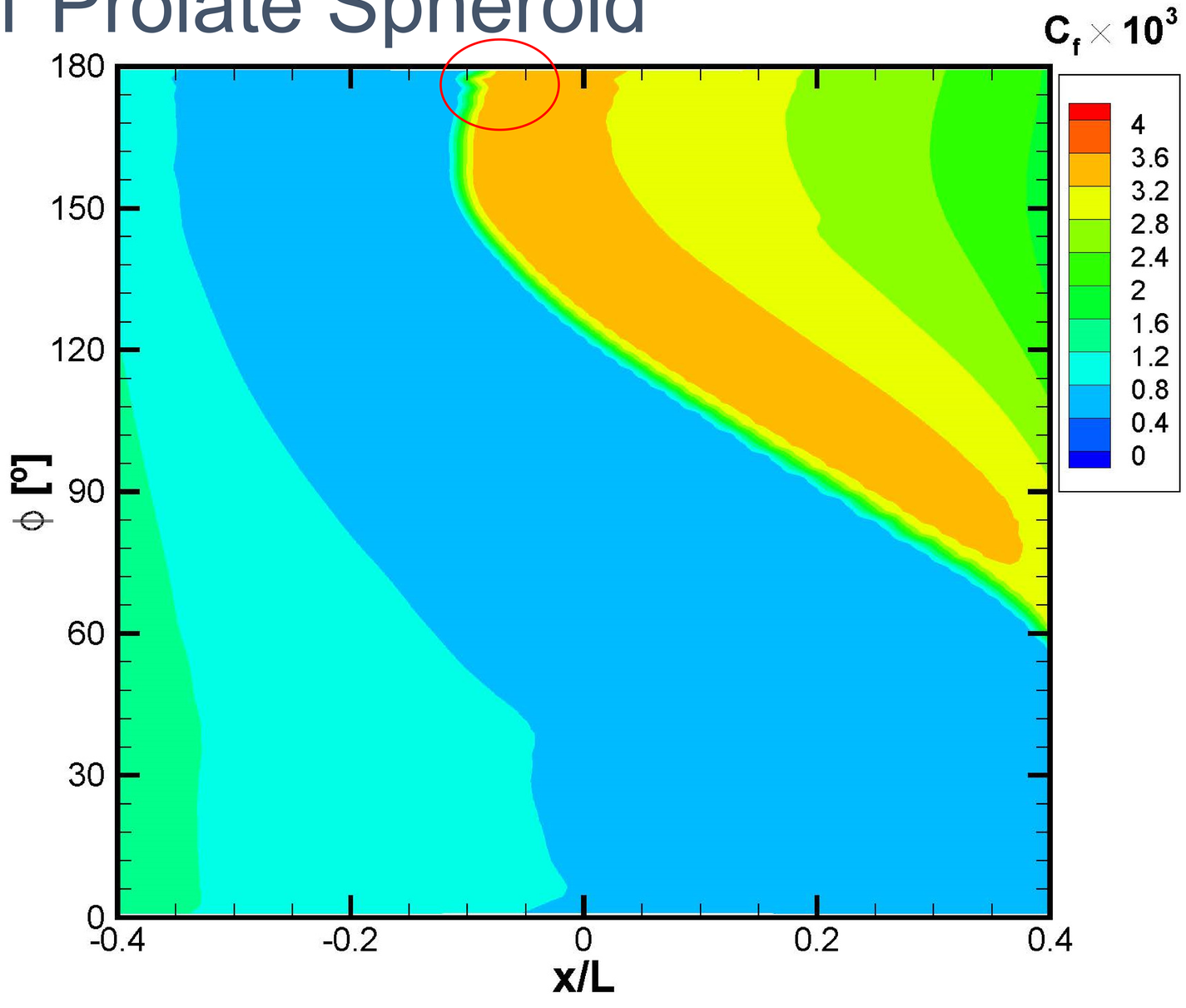
Grids	$r = \frac{h_i}{h_1}$	$N_{surface}$	N_{cells}
1	1	126,016	42.6M
2	1.14	95.816	28.3M
3	1.33	70,884	17.9M
4	1.61	48,750	10.3M
5	2	31,504	5.3M



Case 3 – 6:1 Prolate Spheroid

Boundary Conditions

- $I = 0.1917\%$;
- $\frac{\mu_t}{\mu} = 5.2$;
- $X_F = -1.5L$;
- Matches guideline for $I = 0.15\%$ at the nose of the spheroid.

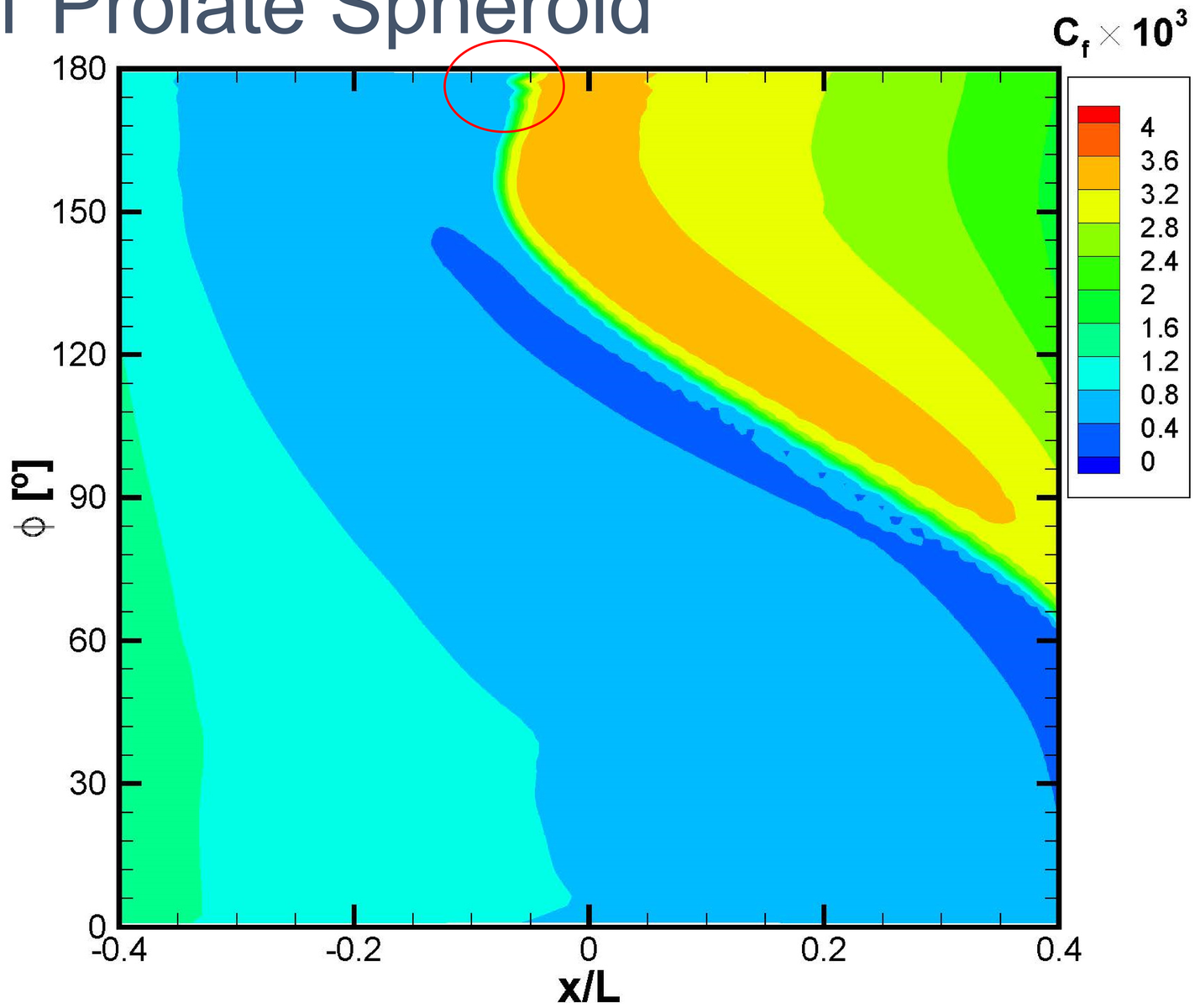


- $\alpha = 5º$
- Grid 5;
- $\gamma - Re_\theta$;

Case 3 – 6:1 Prolate Spheroid

Boundary Conditions

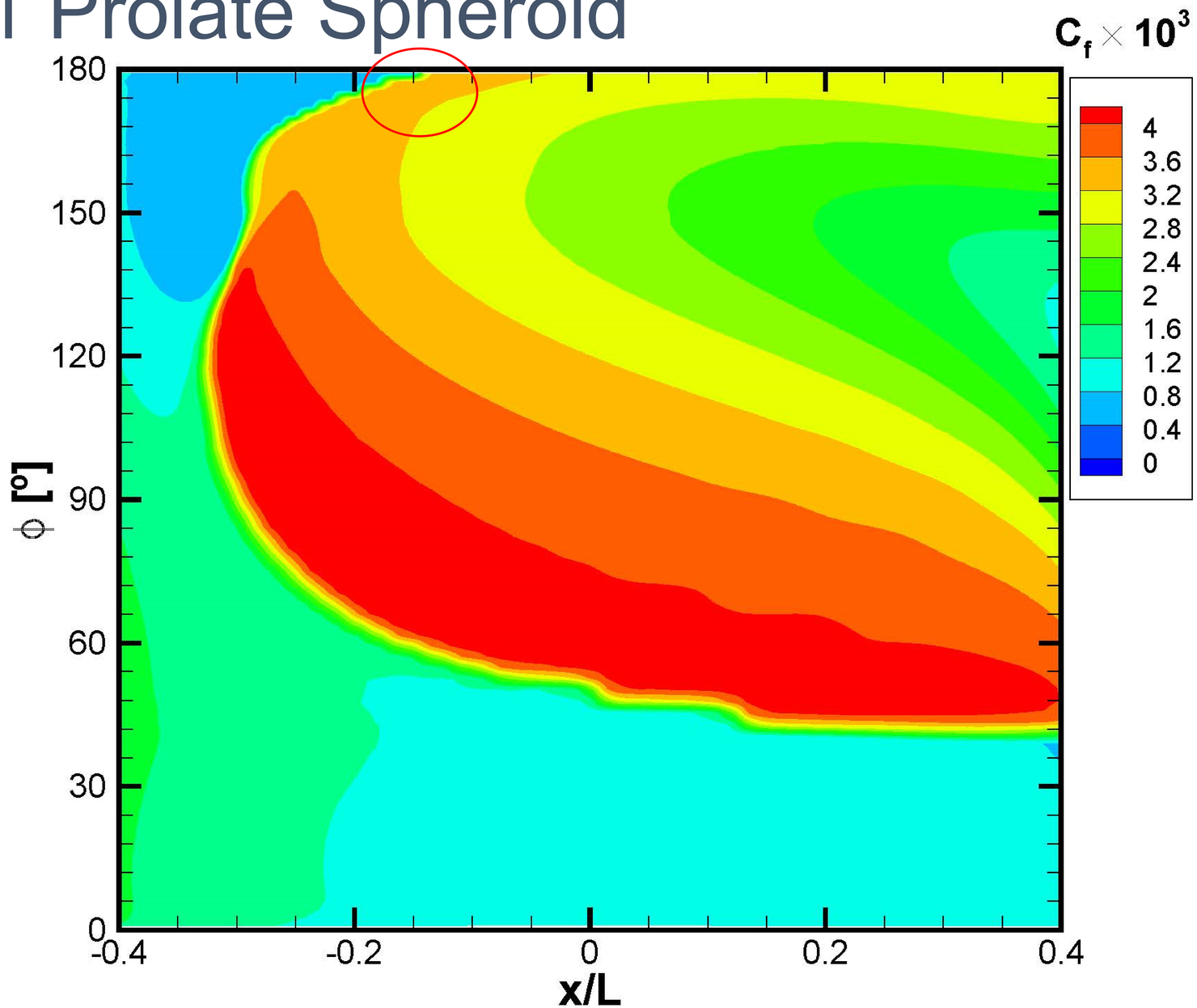
- $I = 0.5\%$;
- $\frac{\mu_t}{\mu} = 250$;
- X_F not used;
- Matches guideline for $I = 0.15\%$ at the nose of the spheroid.



- $\alpha = 5^{\underline{o}}$
- Grid 5;
- $\gamma - Re_\theta$;

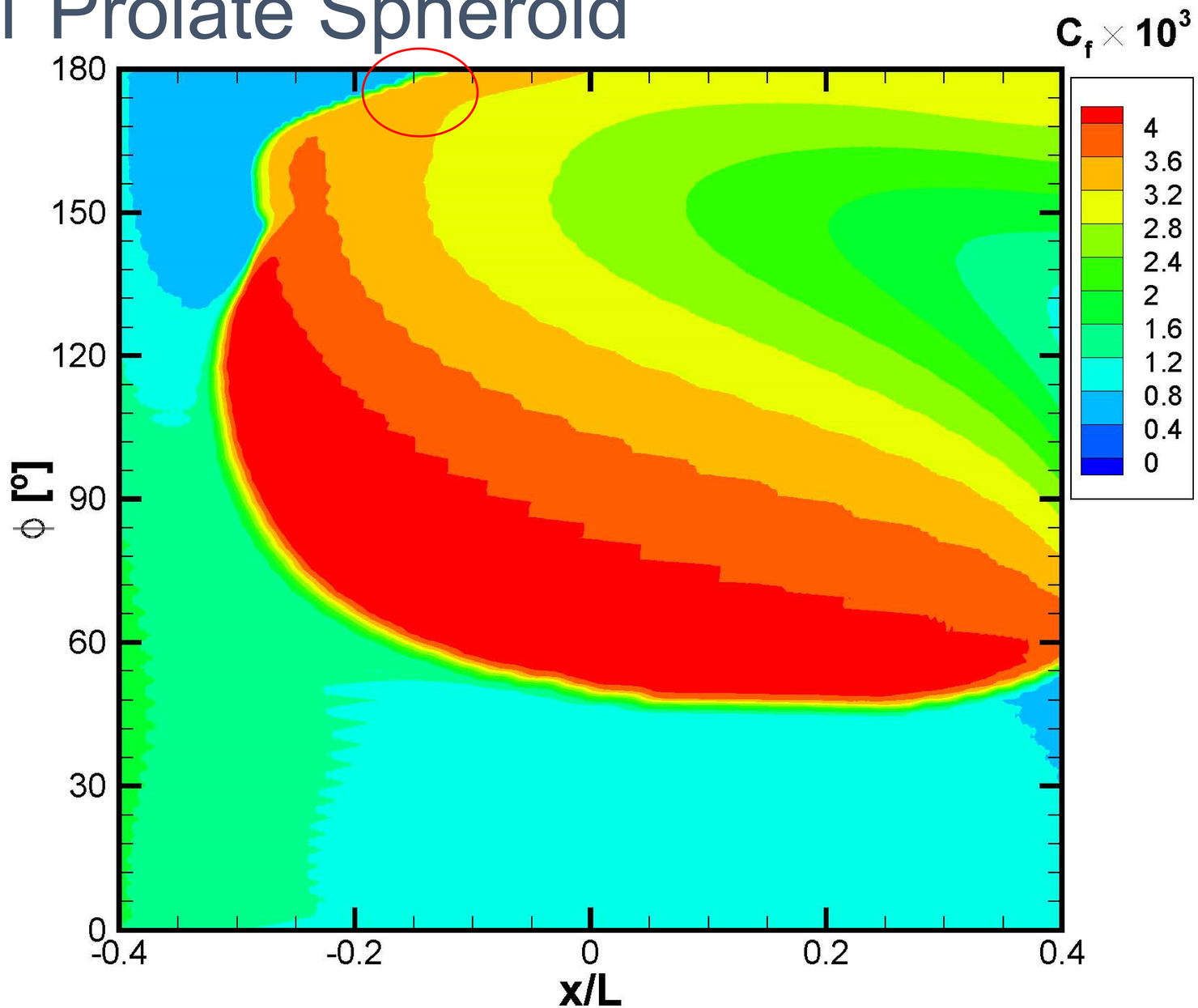
Case 3 – 6:1 Prolate Spheroid

- $\alpha = 10º$
- Grid 5;
- $\gamma - Re_\theta$ - CFHE;



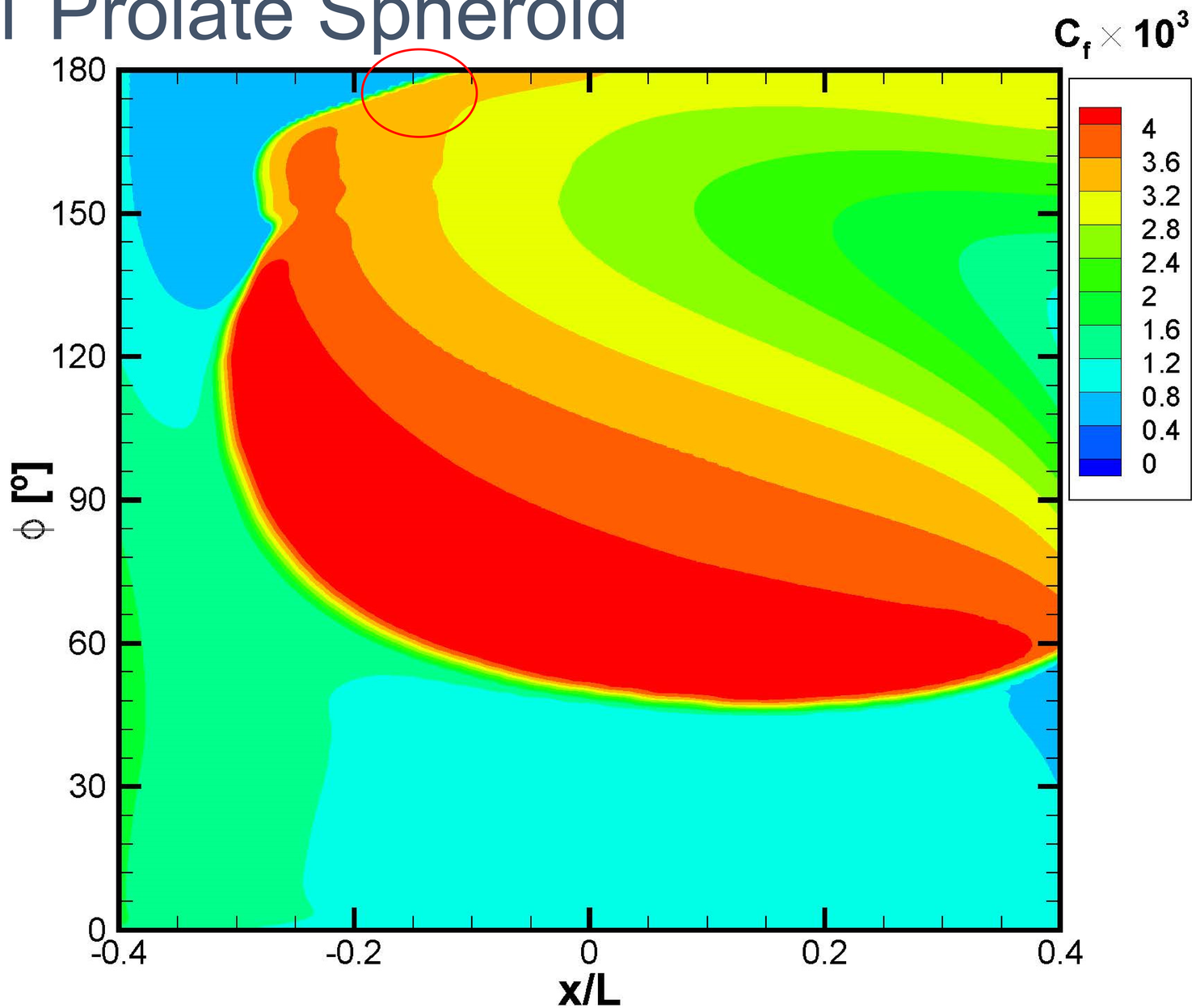
Case 3 – 6:1 Prolate Spheroid

- $\alpha = 10º$
- Grid 3;
- $\gamma - Re_\theta$ - CFHE;



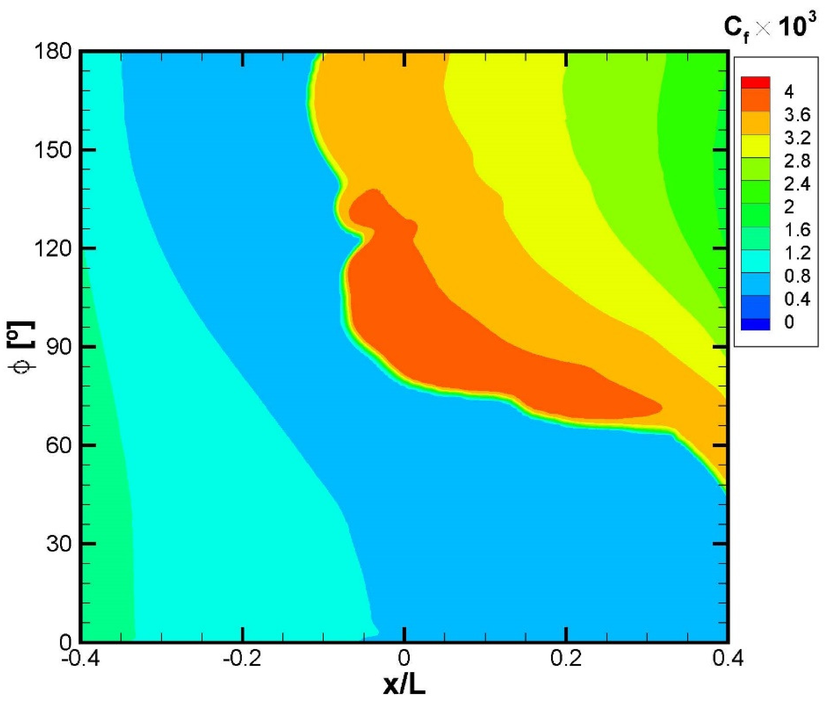
Case 3 – 6:1 Prolate Spheroid

- $\alpha = 10º$
- Grid 1;
- $\gamma - Re_\theta$ - CFHE;

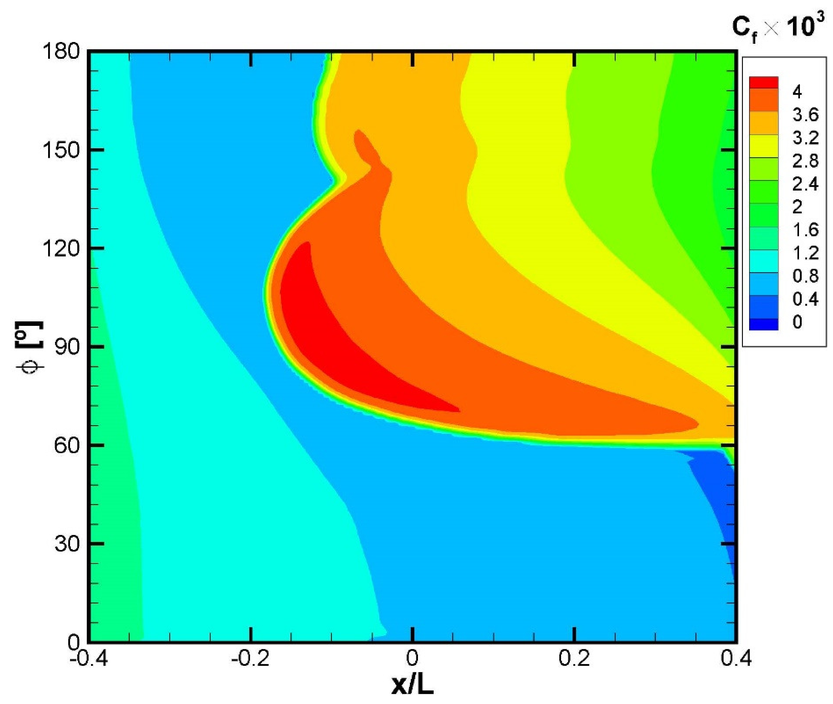


Case 3 – 6:1 Prolate Spheroid

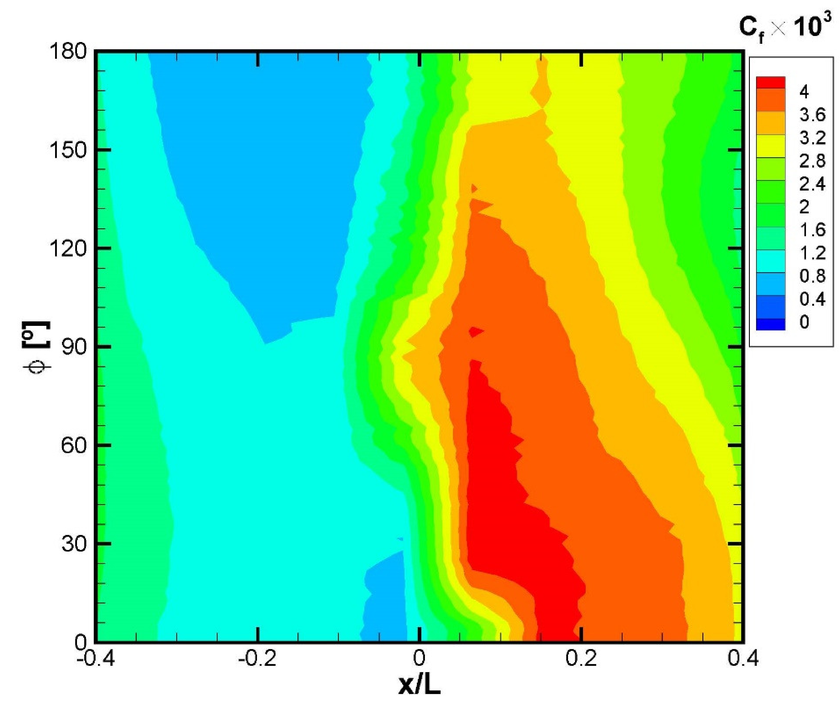
- $\alpha = 5º$



$\gamma - Re_\theta$ - CFHE



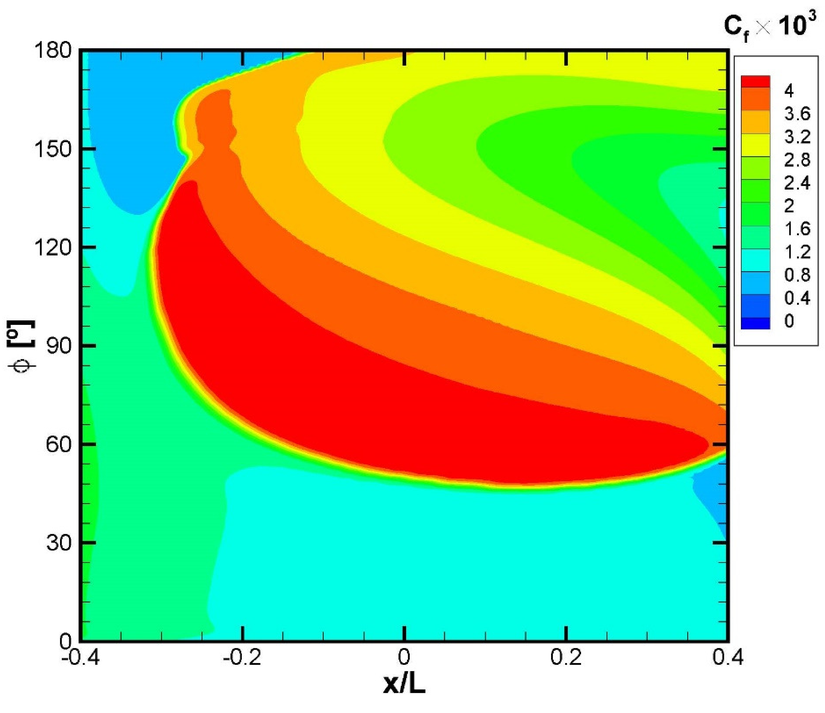
$\gamma -$ CFHE



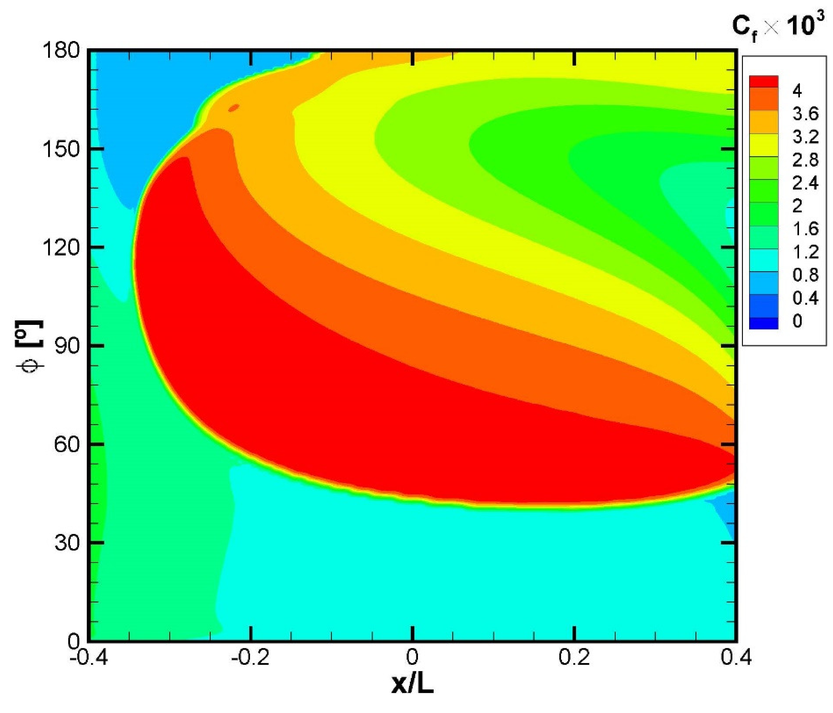
Exp.

Case 3 – 6:1 Prolate Spheroid

- $\alpha = 10º$



$\gamma - Re_\theta$ - CFHE



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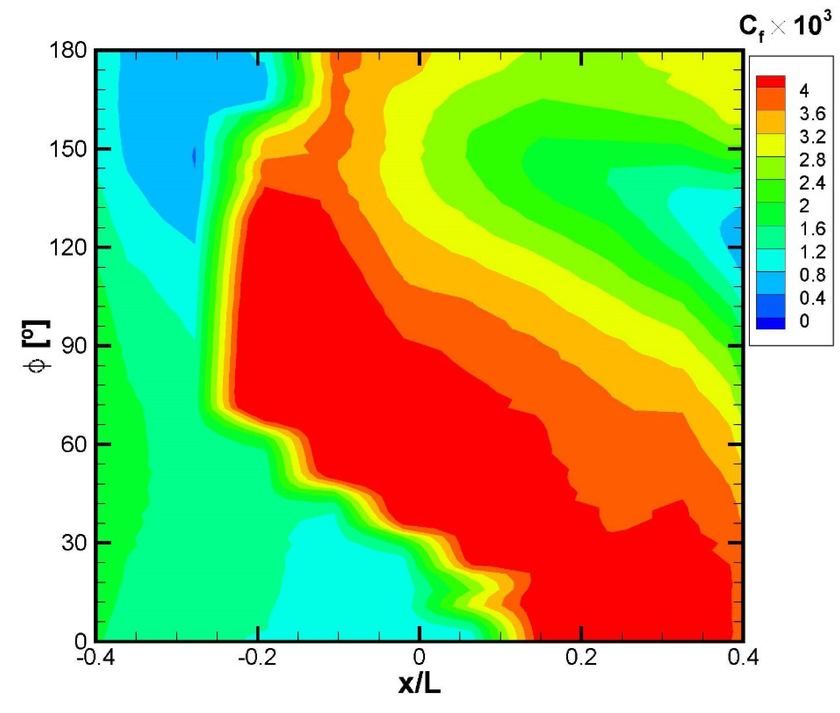
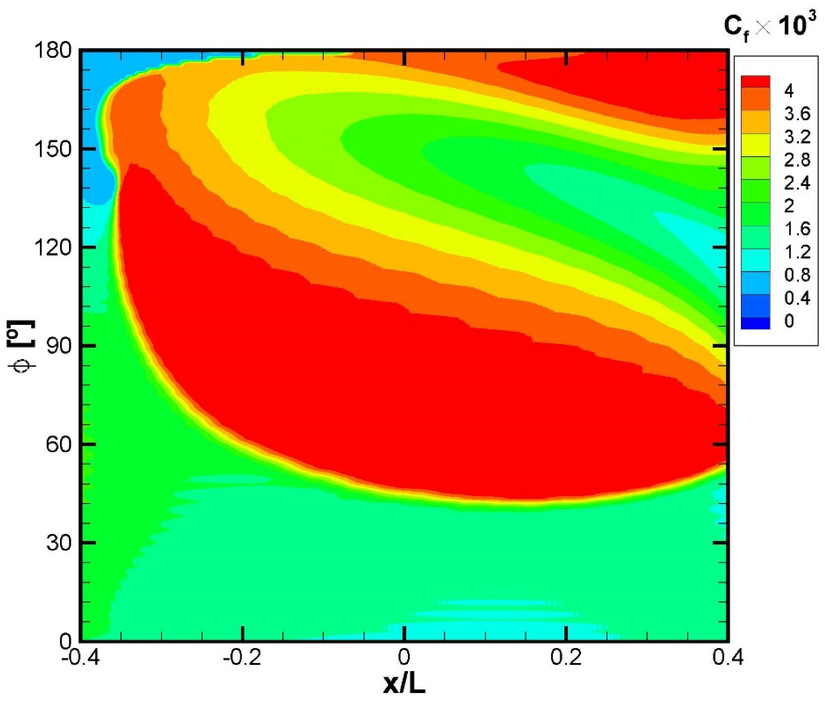


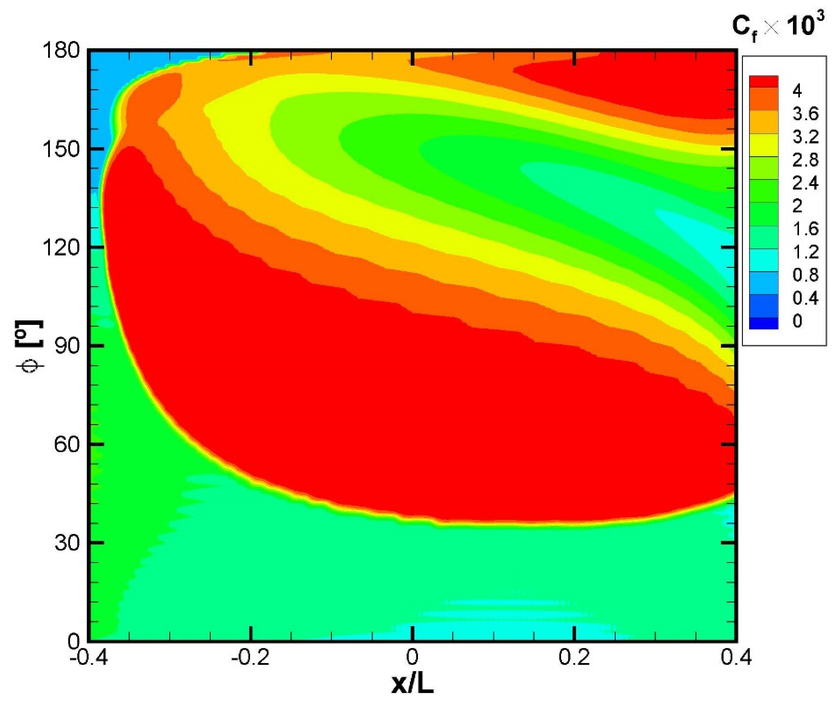
Exp.

Case 3 – 6:1 Prolate Spheroid

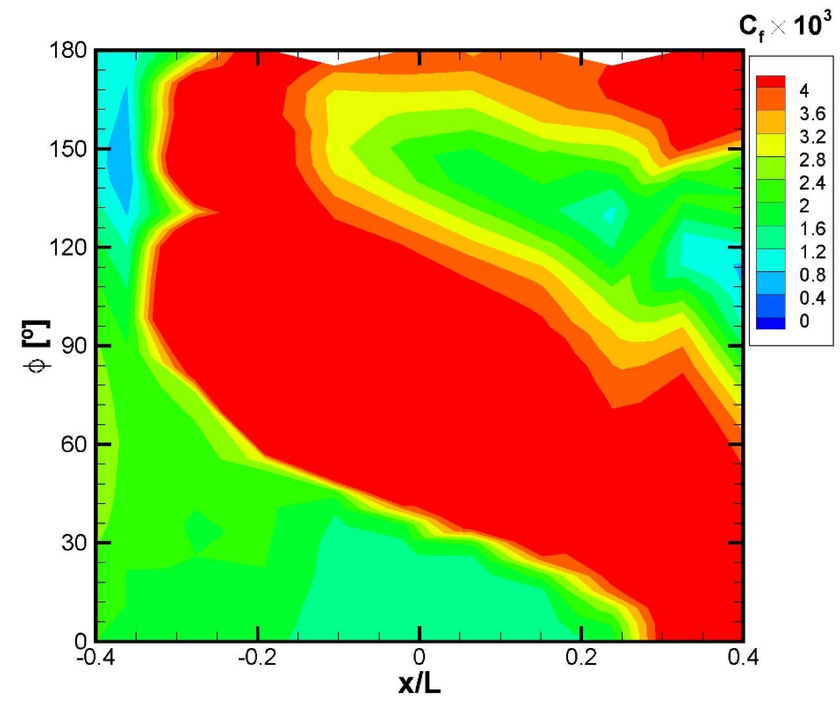
- $\alpha = 15º$



$\gamma - Re_\theta$ - CFHE



$\gamma -$ CFHE



Exp.

Final Remarks

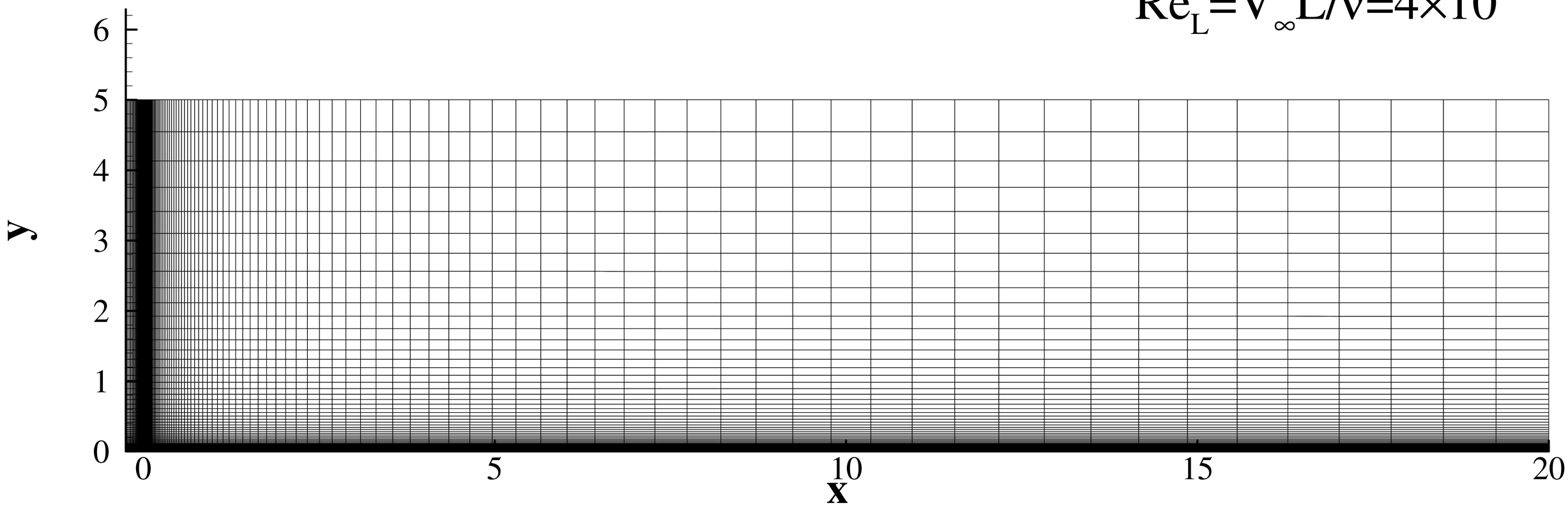
- Complete specification of inlet boundary conditions is essential for simulations performed with transition models at low Reynolds numbers. Specifying only turbulence intensity at the leading edge is insufficient.
- Reliable comparison with experimental data depends on knowledge of complete inflow conditions and domain size (wind tunnels are not infinite domains).
- Simple test cases are essential to perform Solution Verification studies and Code to Code comparisons.

Backup Slides

Case 1 – Zero pressure gradient flat plate

Inlet – Everything specified except the pressure;
Bottom – Symmetry and no slip/impermeability conditions;
OP-TO – Pressure at the outlet and zero normal derivatives at the top;
OP-TS – Pressure at the outlet and symmetry at the top;
OO-TP– Zero streamwise derivatives at the outlet and pressure at the top.

$$Re_L = V_\infty L/\nu = 4\times10^6$$



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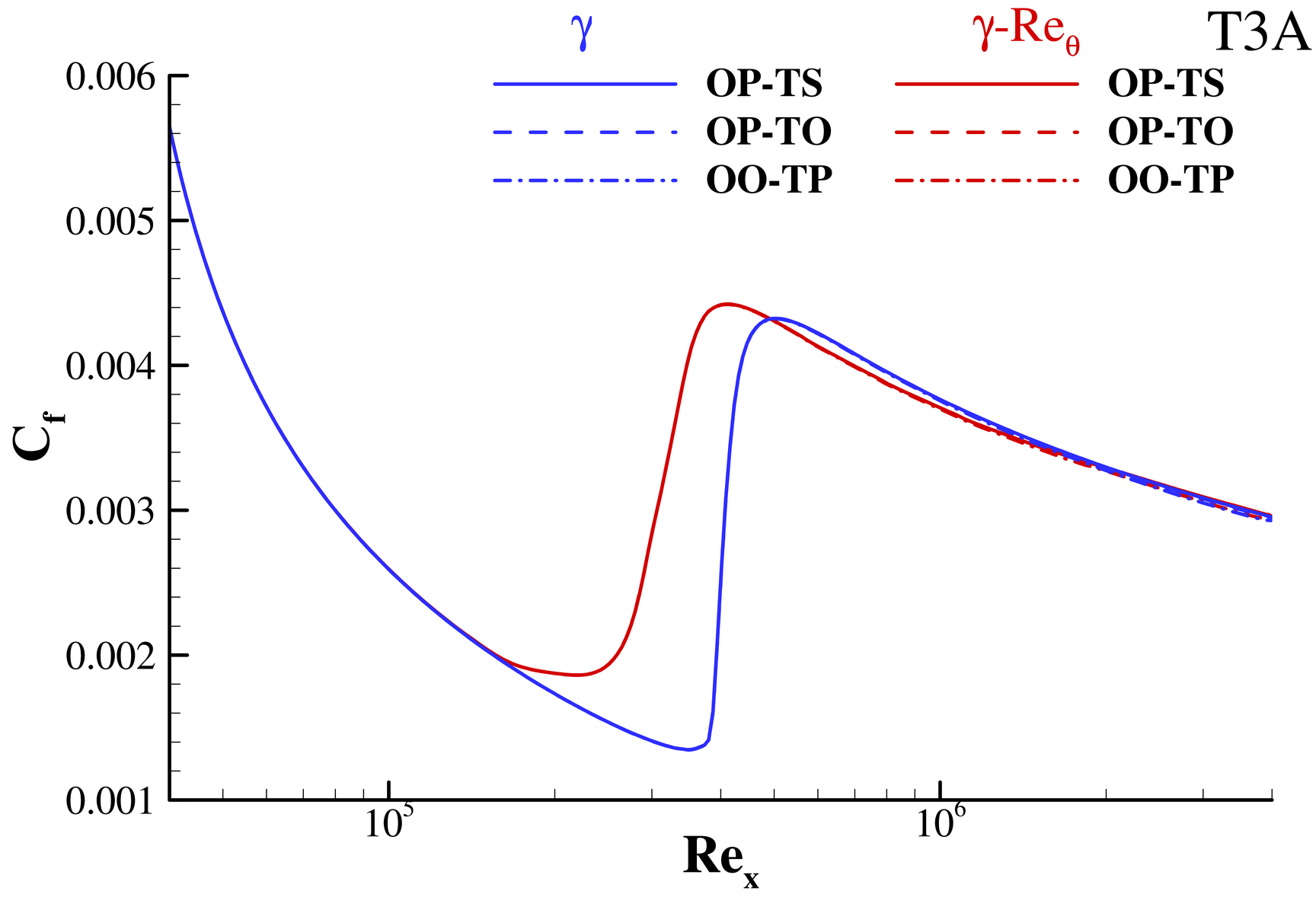

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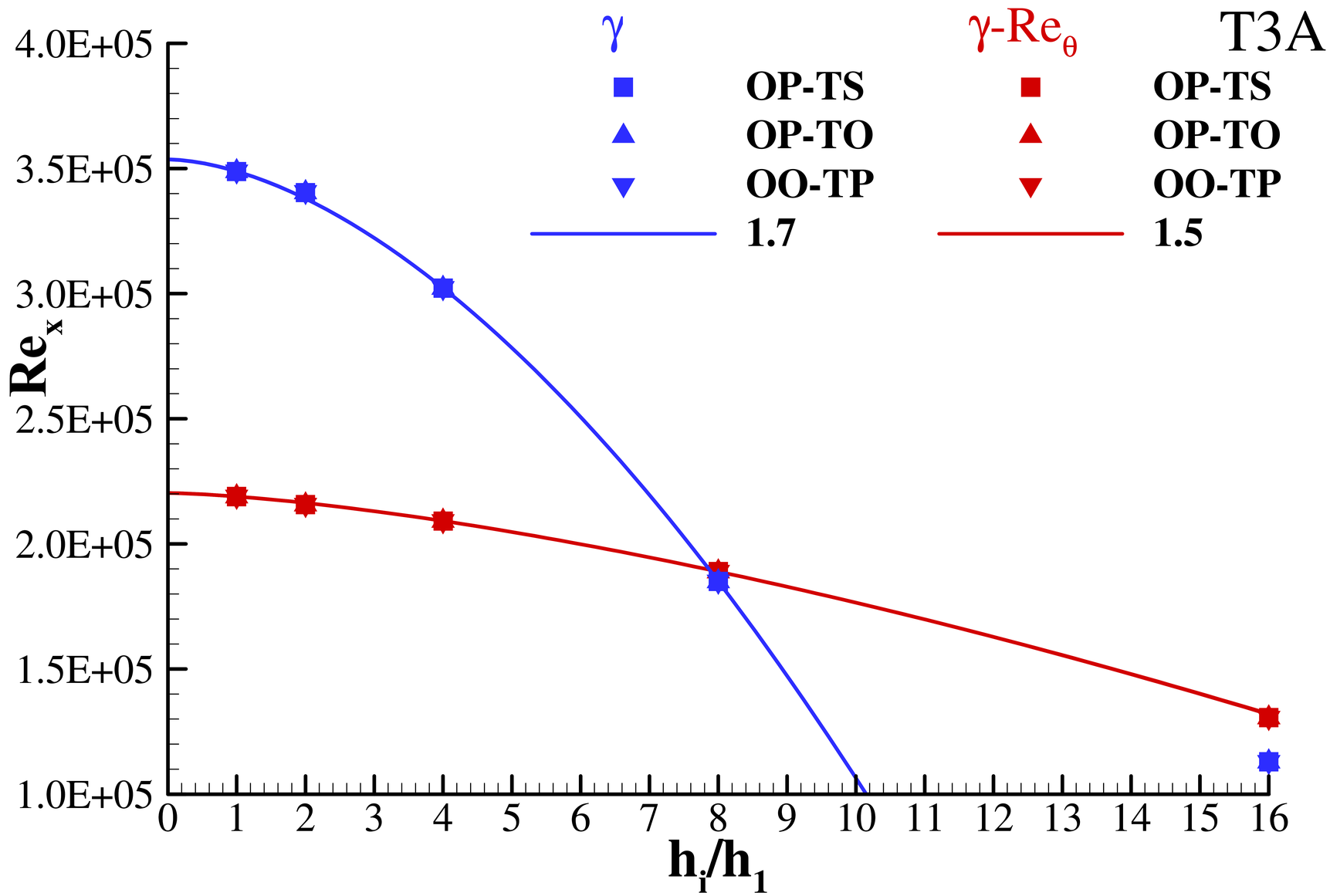

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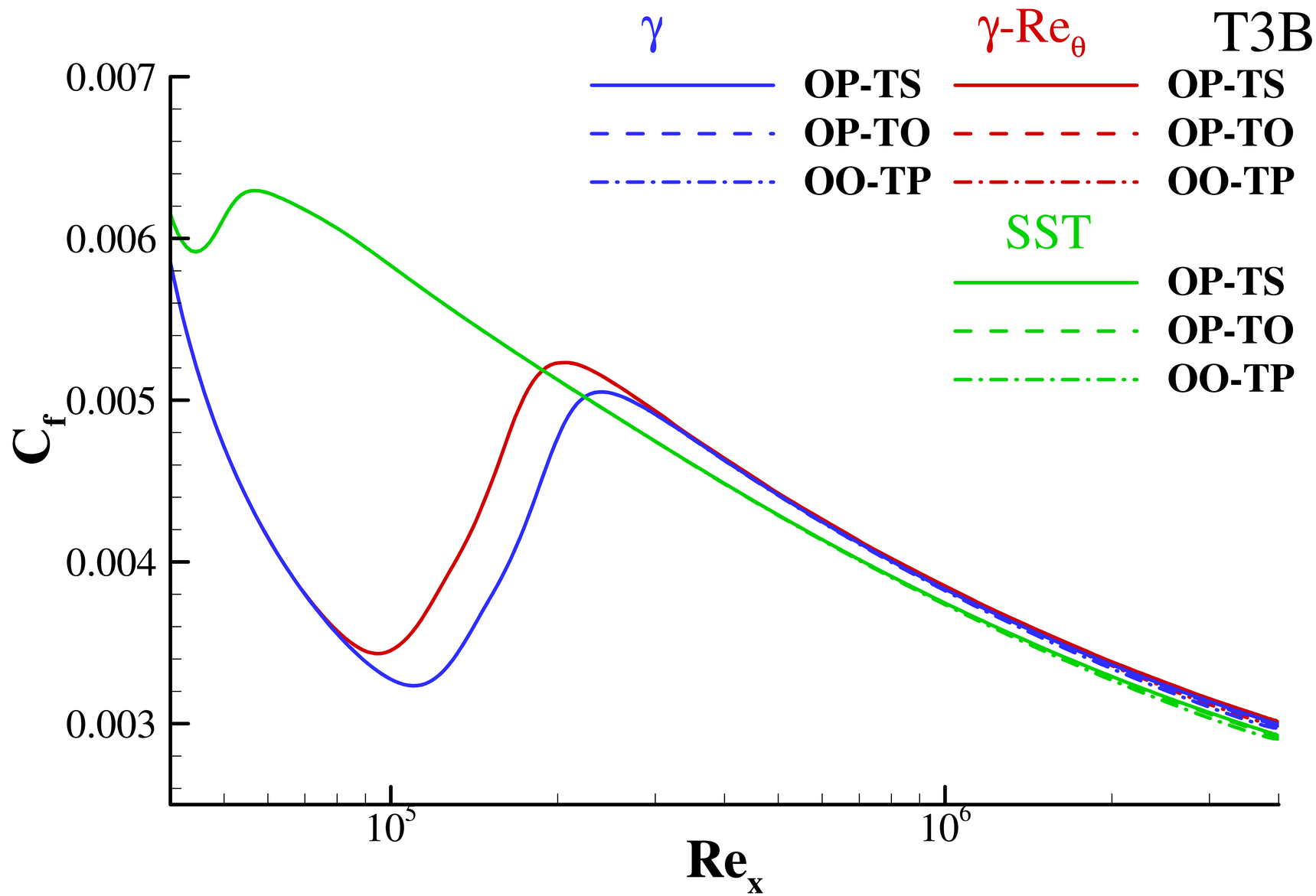

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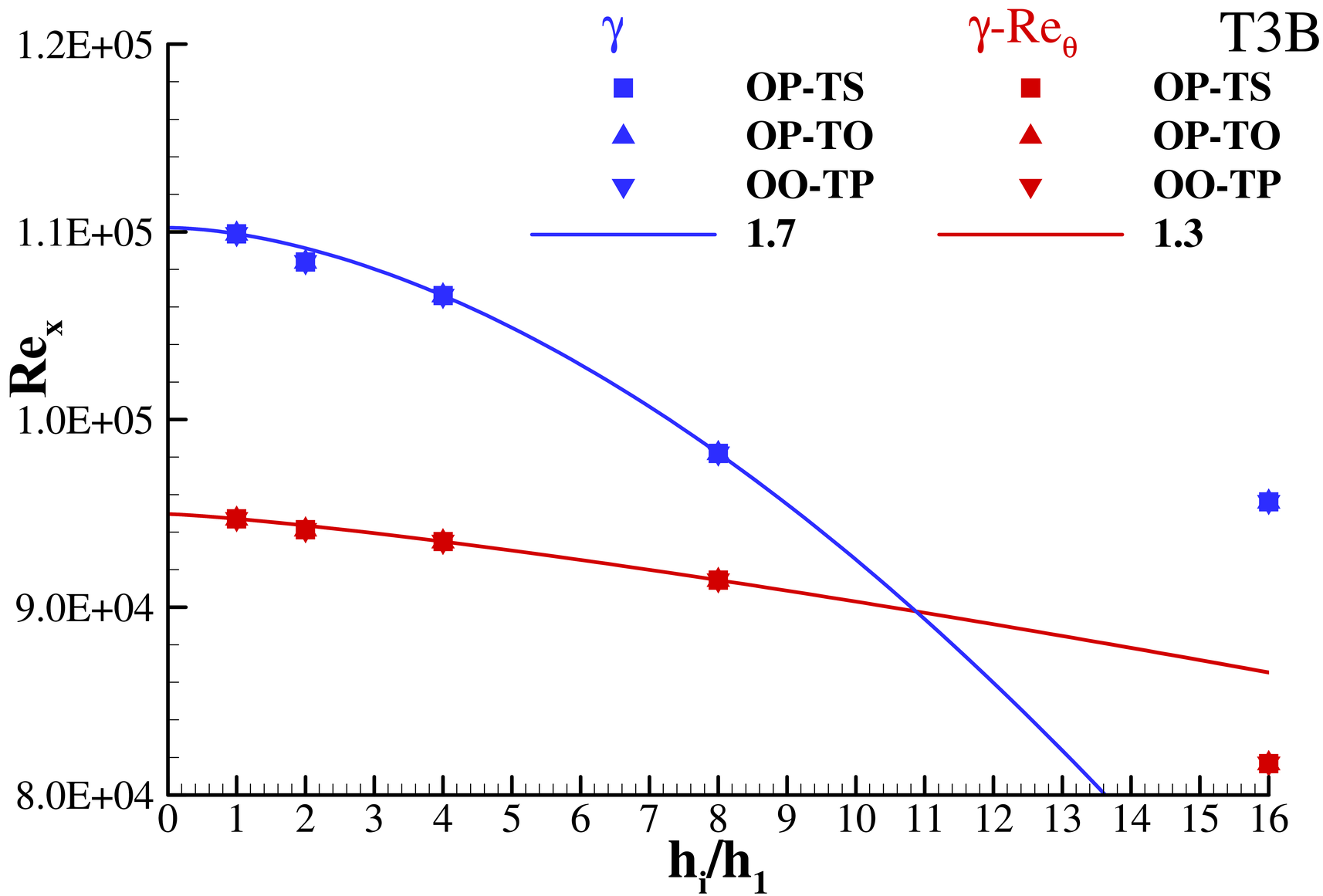

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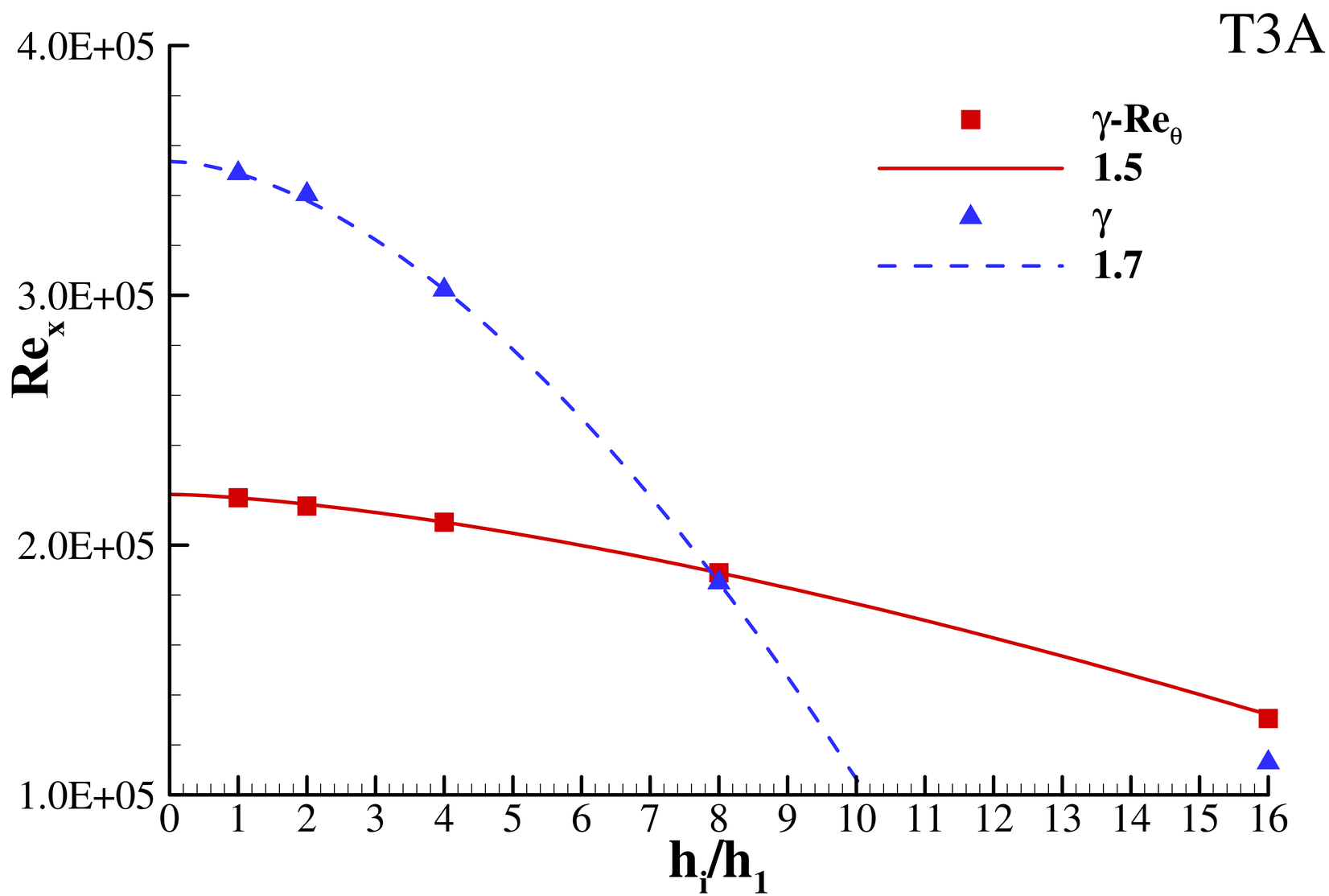

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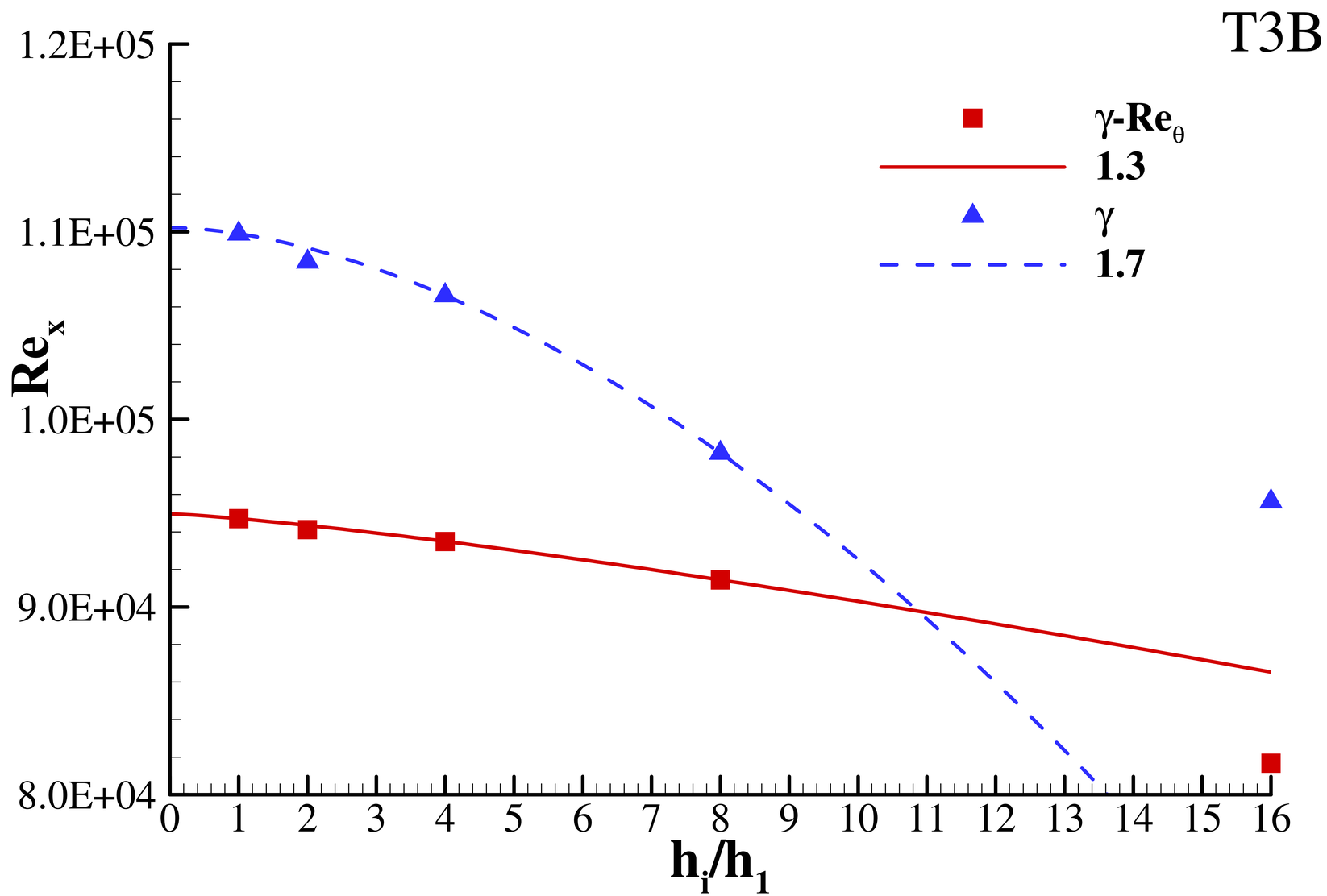
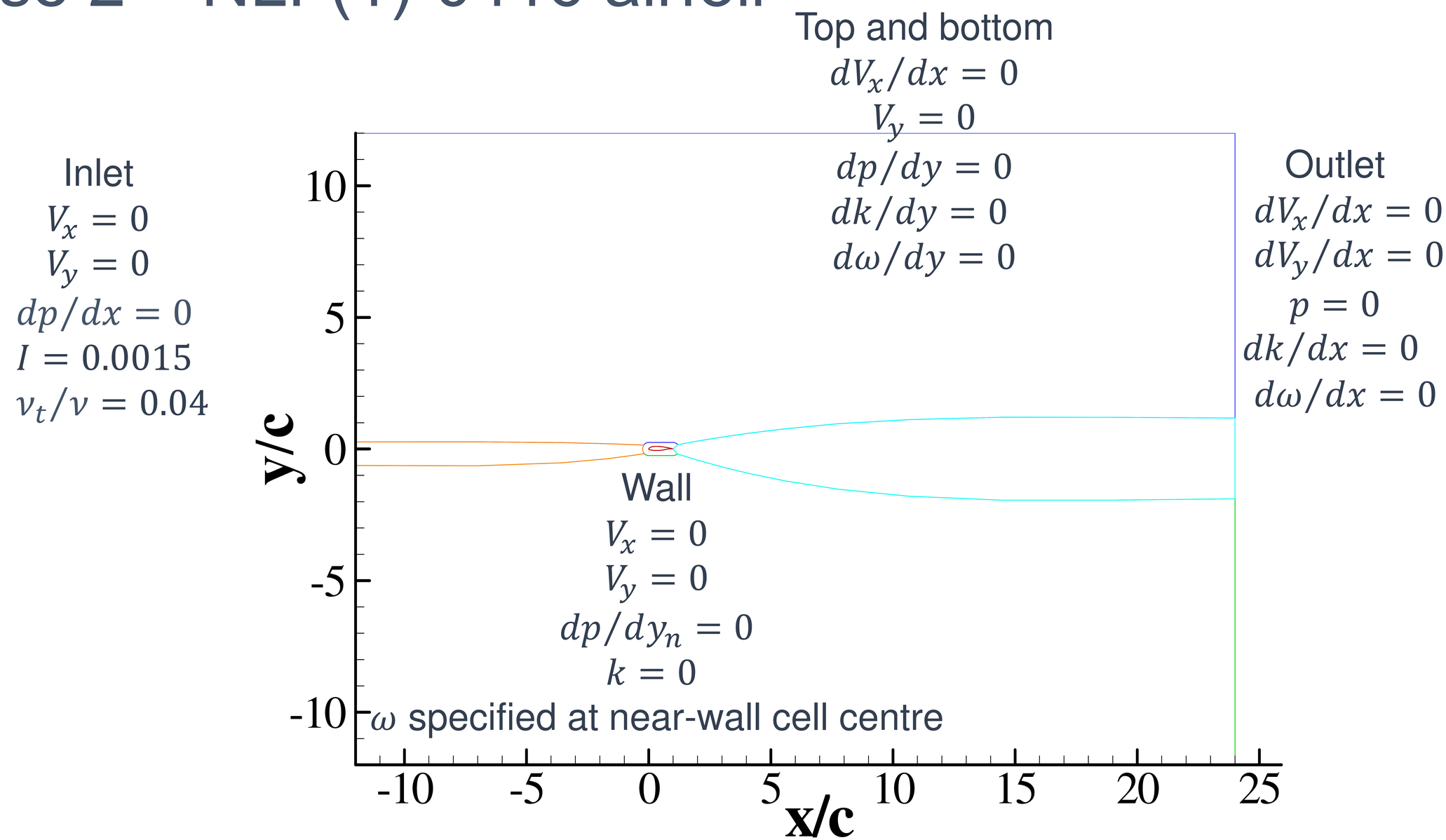


Case 2 – NLF(1)-0416 airfoil

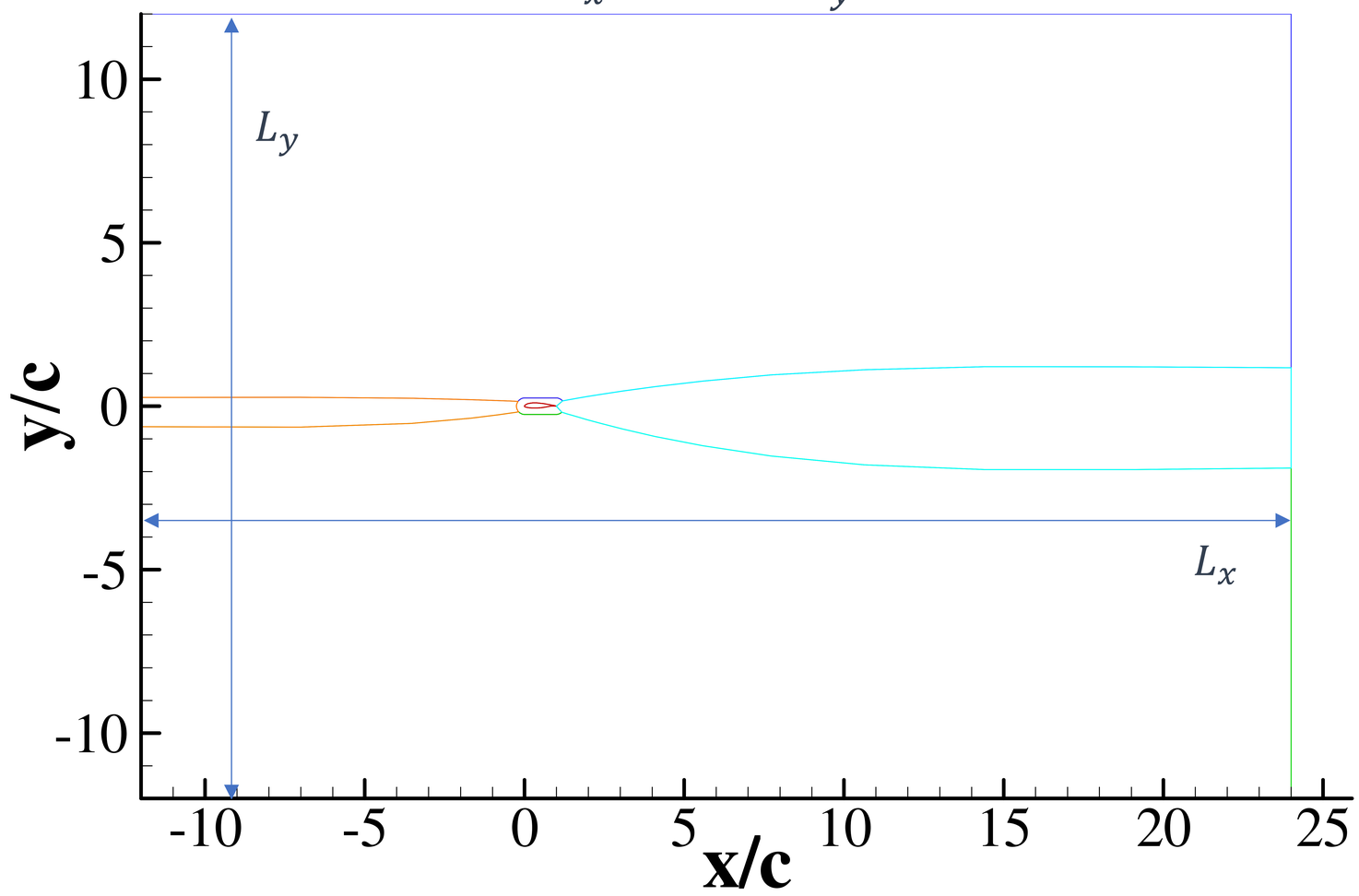


Case 2 – NLF(1)-0416 airfoil

Size of the computational domain

$$\lambda = 1536c/L_y = 2304c/L_x$$

$$\lambda = 64 \Rightarrow L_x = 36c \wedge L_y = 24c$$



Case 2 – NLF(1)-0416 airfoil

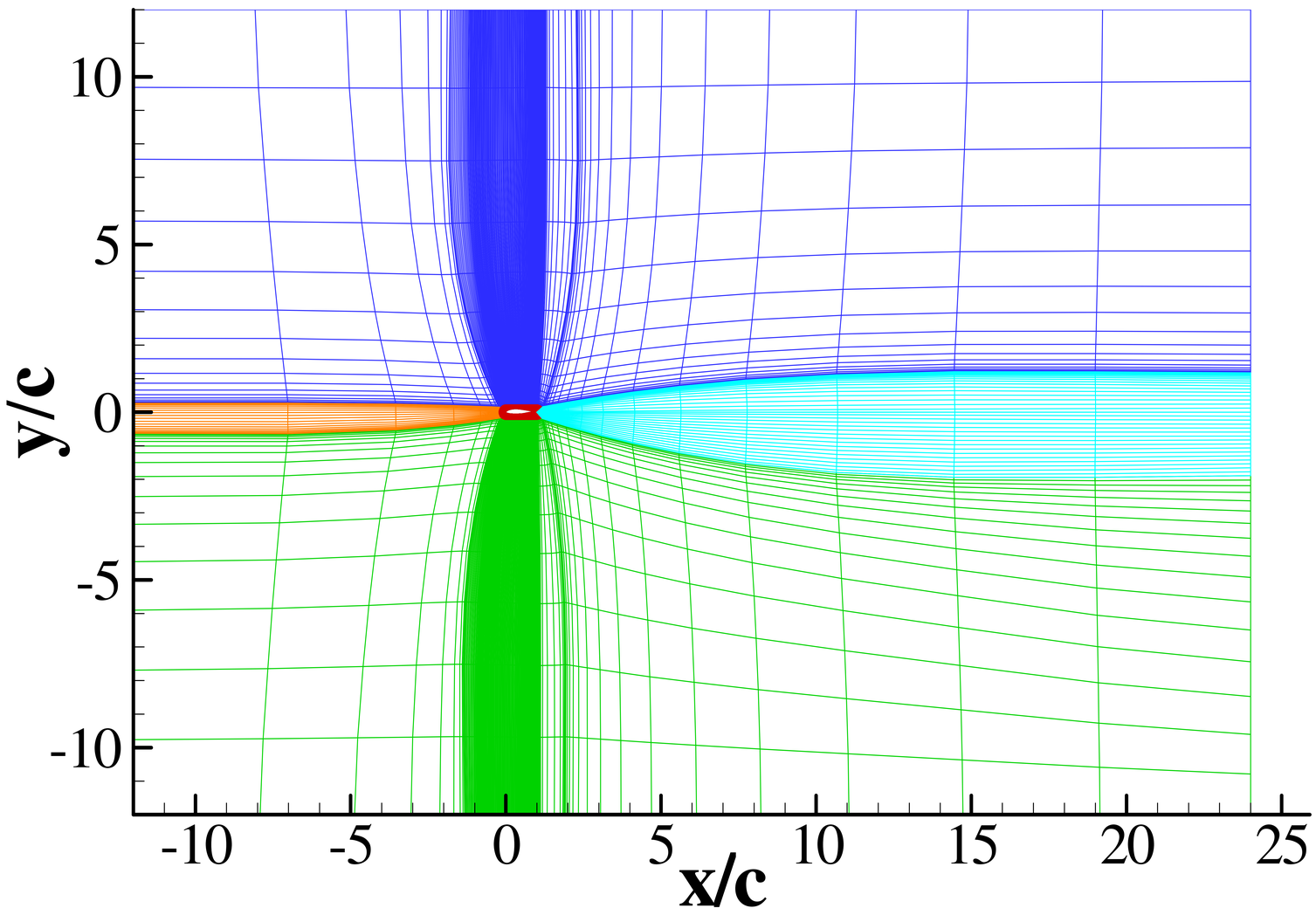
Size of the computational domain
$\lambda = 1536c/L_y = 2304c/L_x$

5 Multiblock Structured Grids
Grids are coincident in the overlapping parts of the domain

Grids	$r = \frac{h_i}{h_1}$	N_{foil}	$N_{cells}(\lambda)$						
			64	32	16	8	4	2	1
1	1	3072	3,520512		3,874752				
2	1.2	2560	2,444800		2,690800				
3	1.5	2048	1,564672		1,722112				
4	1.714	1792	1,197952		1,318492				
5	2	1536	880128	908784	968688	1,032048	1,098864	1,169136	1,242864

Case 2 – NLF(1)-0416 airfoil

Computational domain for $\lambda = 16 \Rightarrow L_x = 72c \wedge L_y = 48c$



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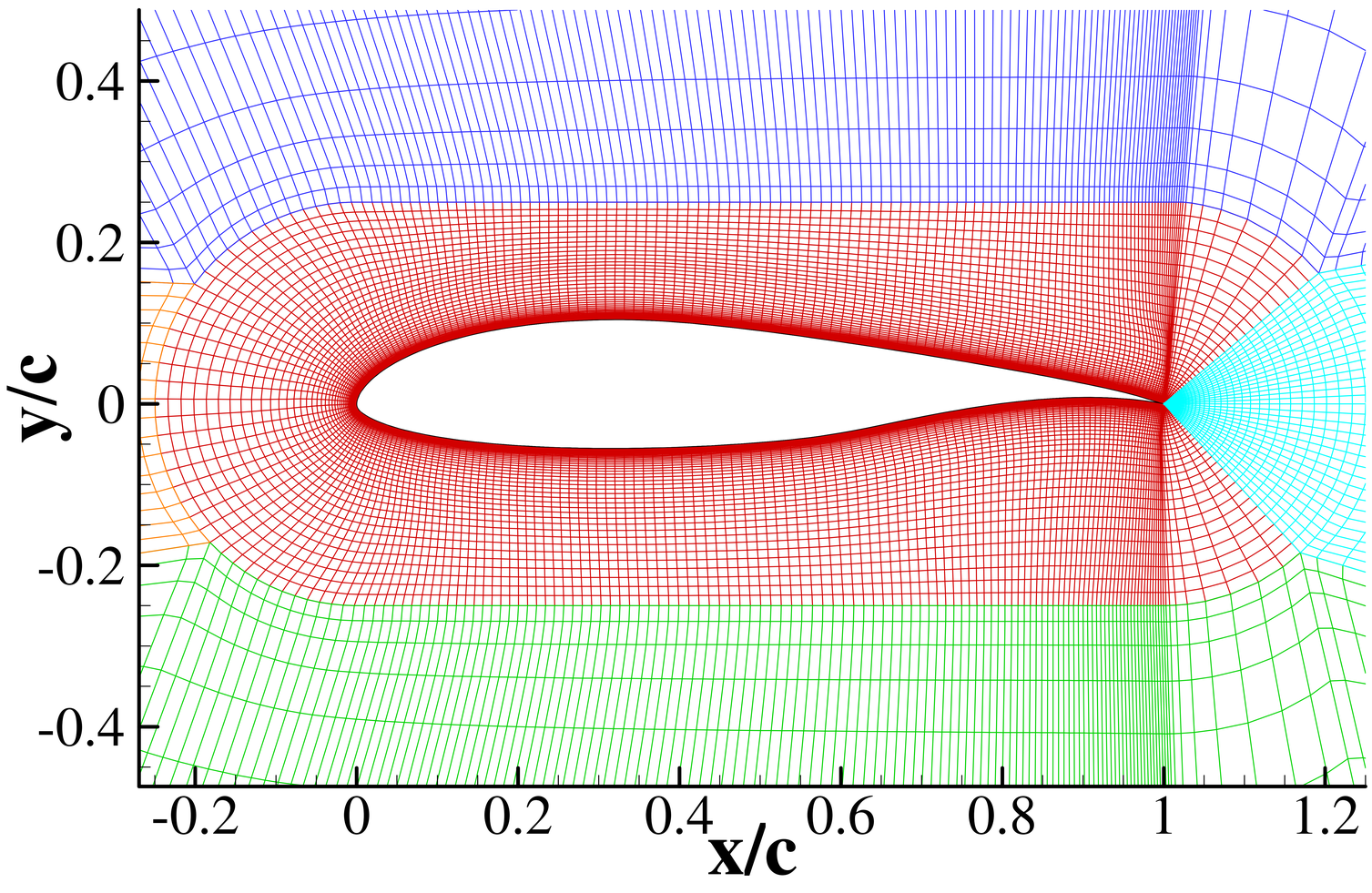

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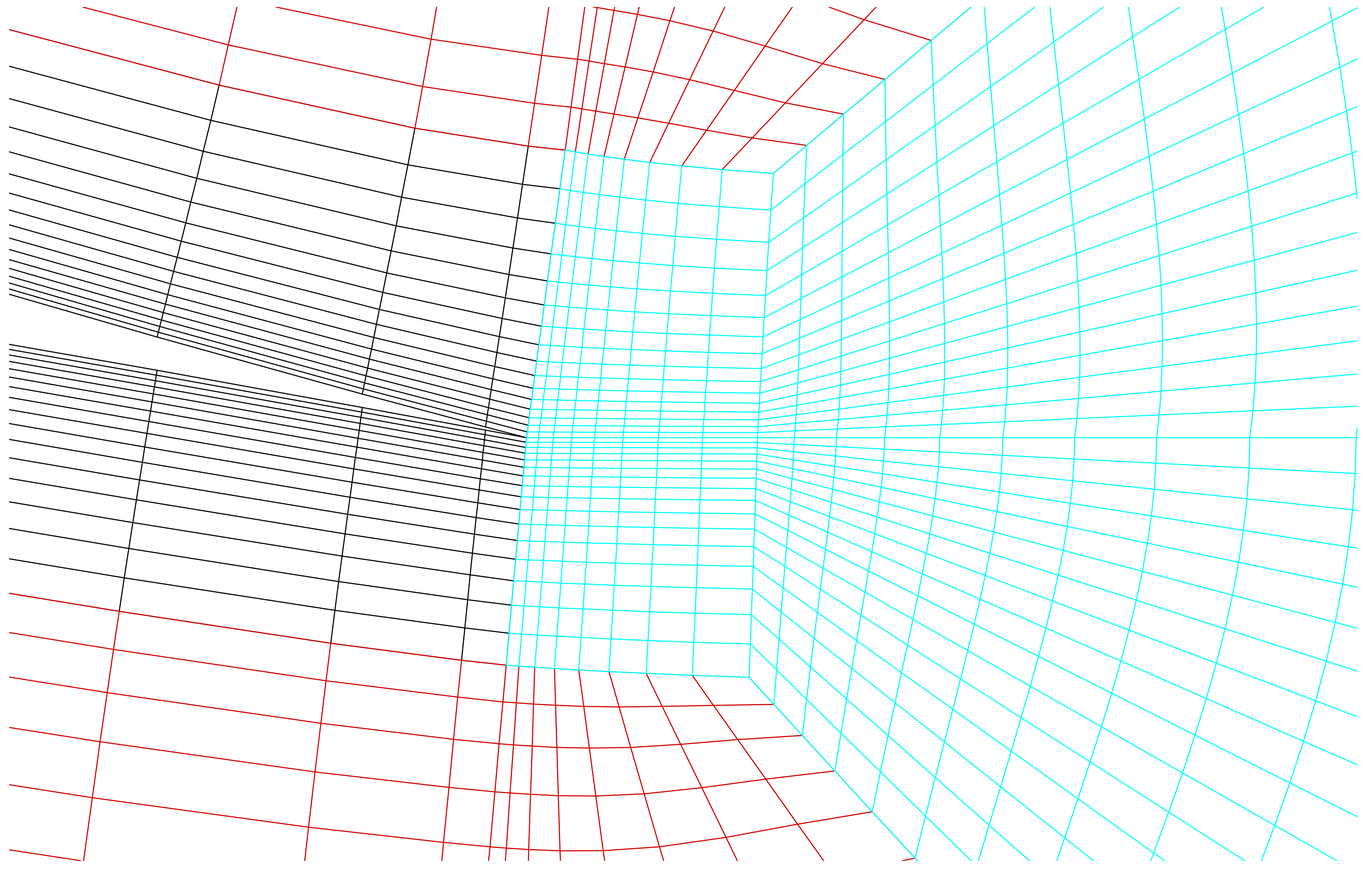
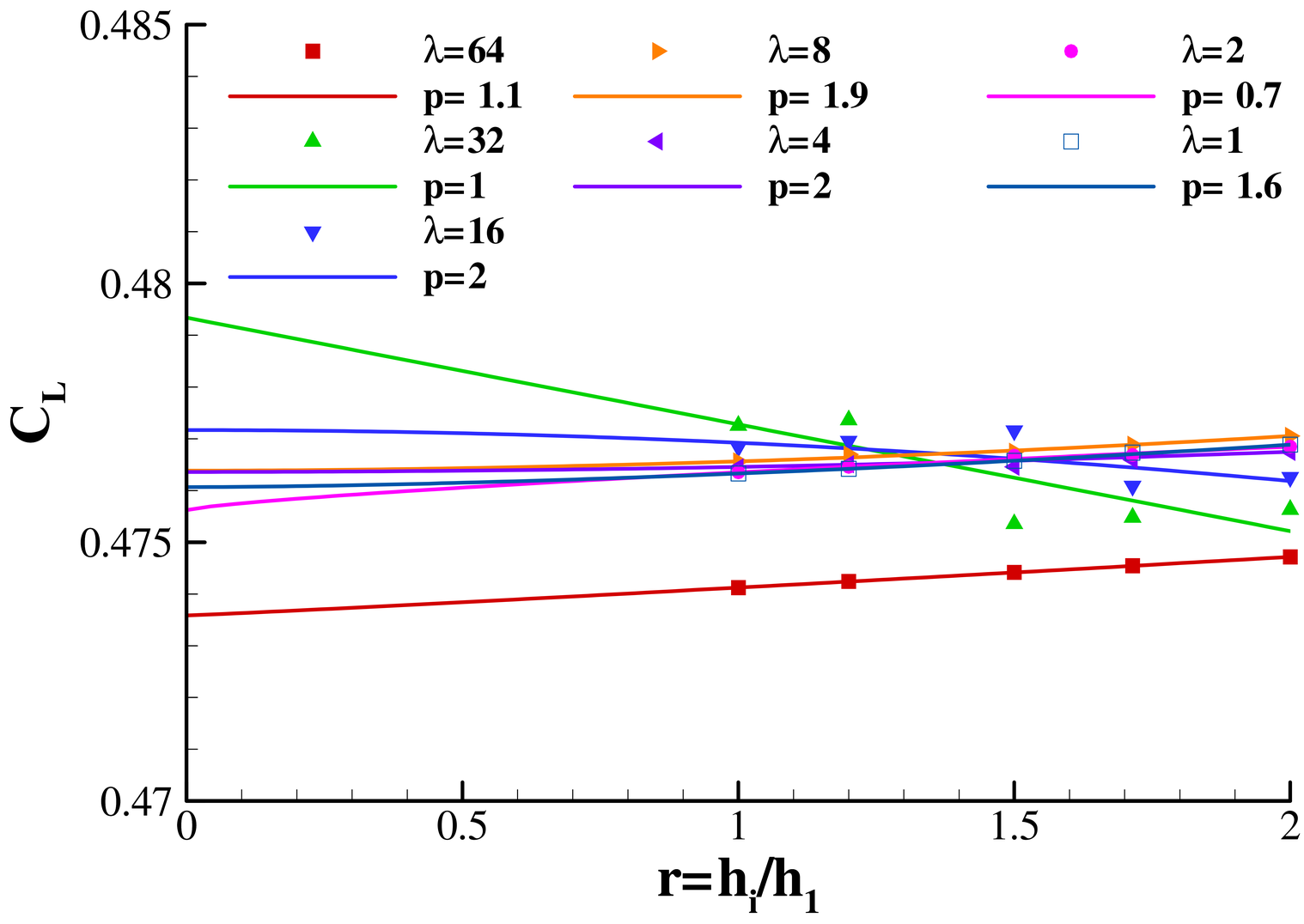


Case 2 – NLF(1)-0416 airfoil

Simulation of the flow at $\alpha = 0^o$ for $\lambda = 64,32,16,8,4,2,1$



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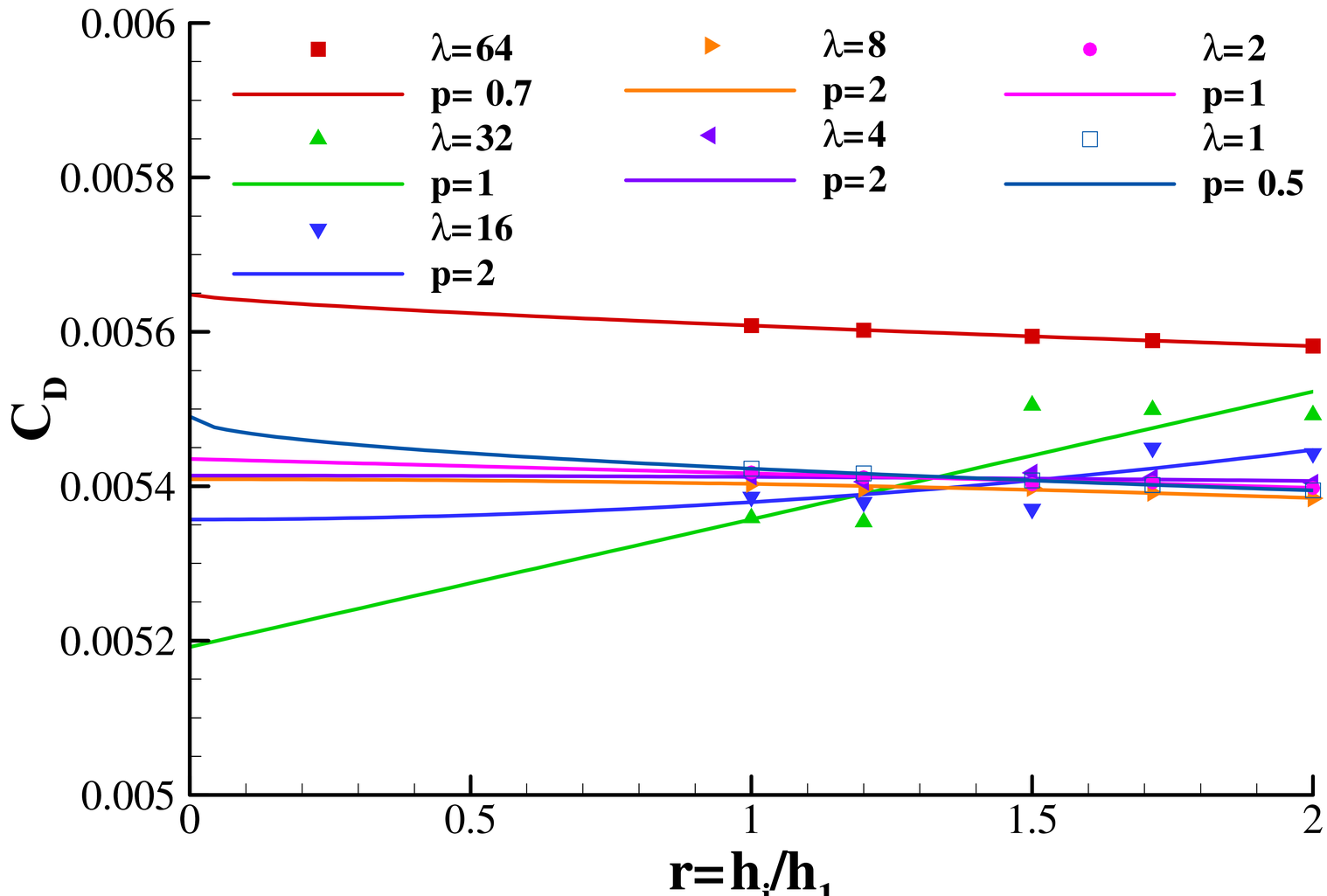

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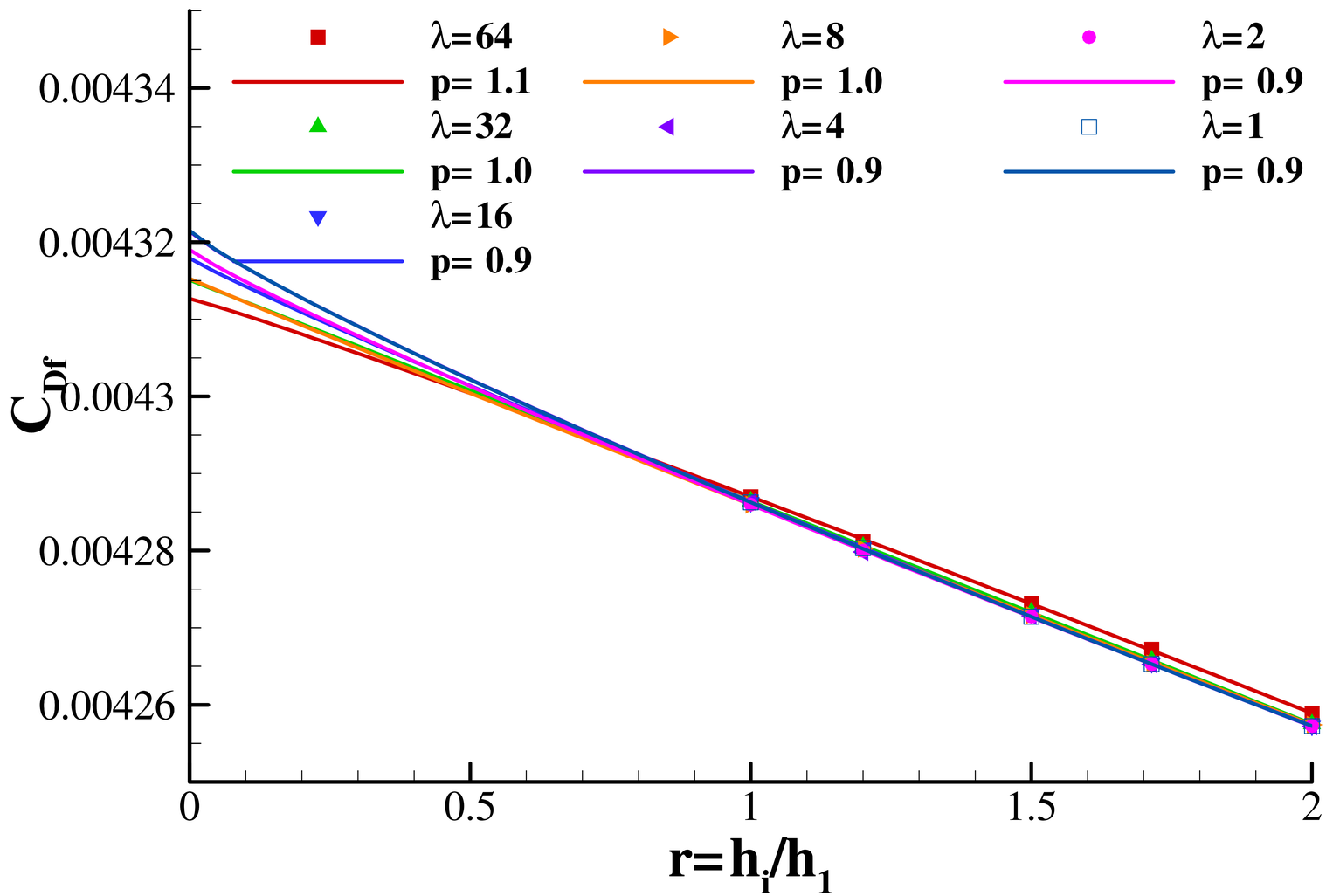

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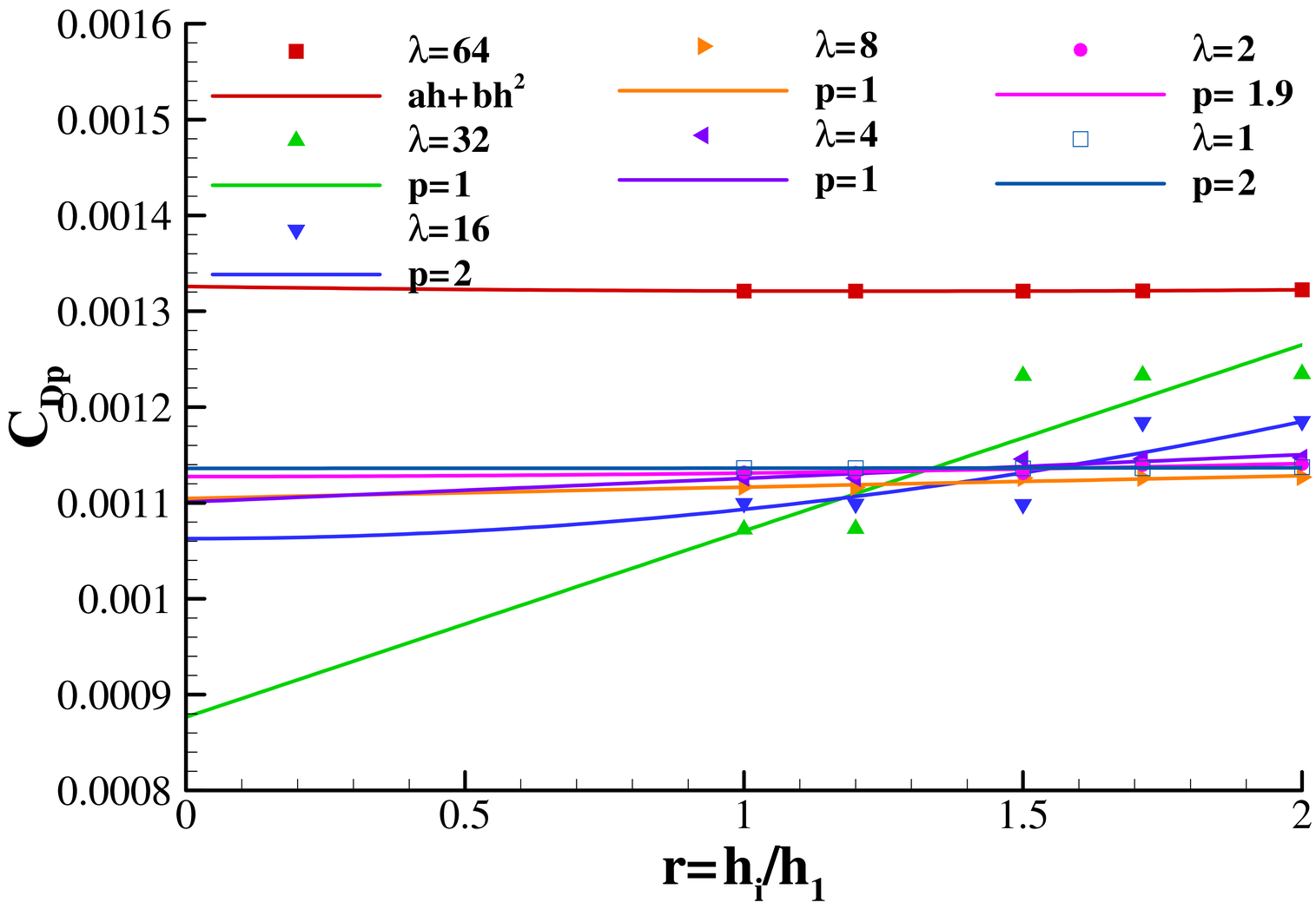

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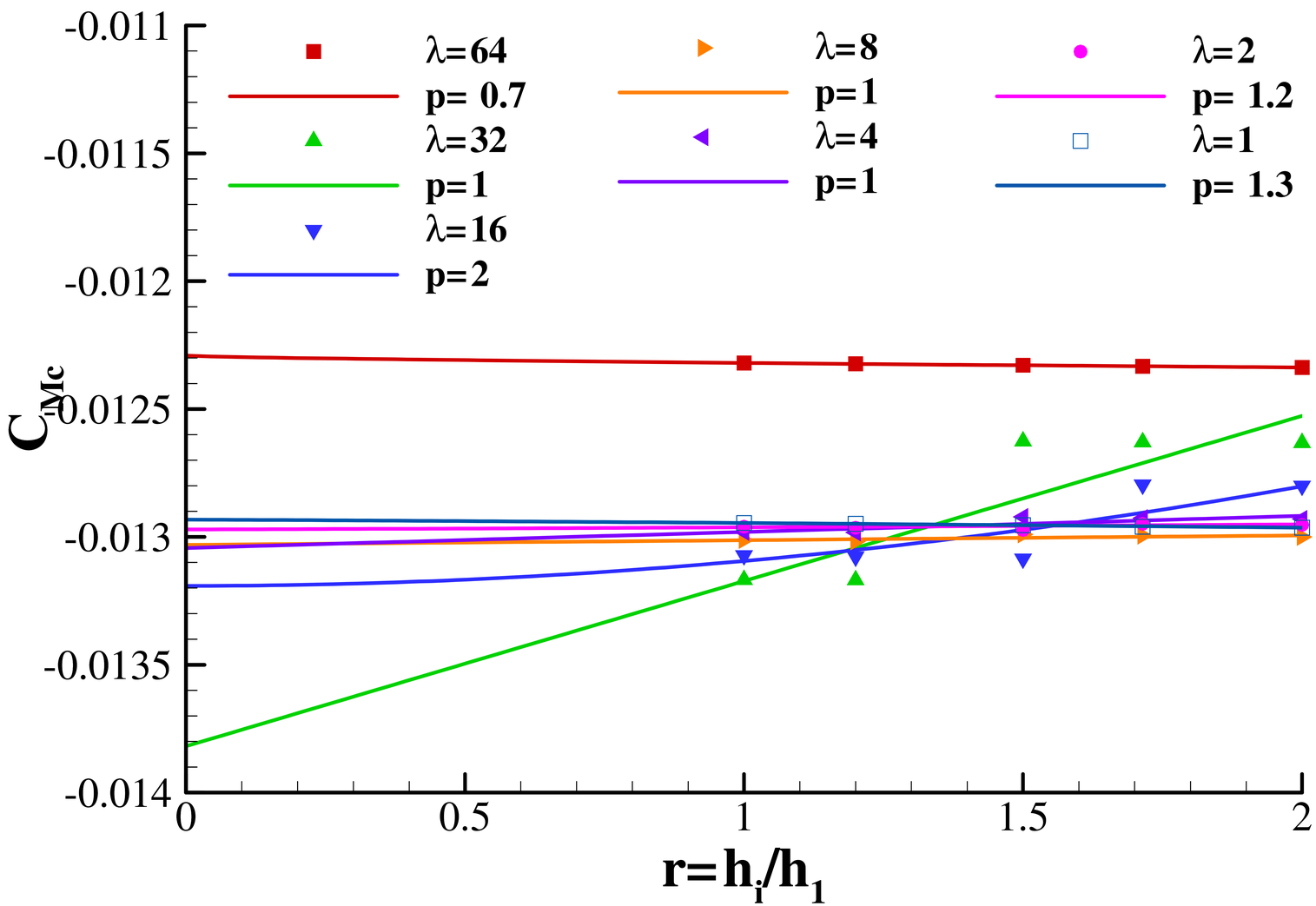

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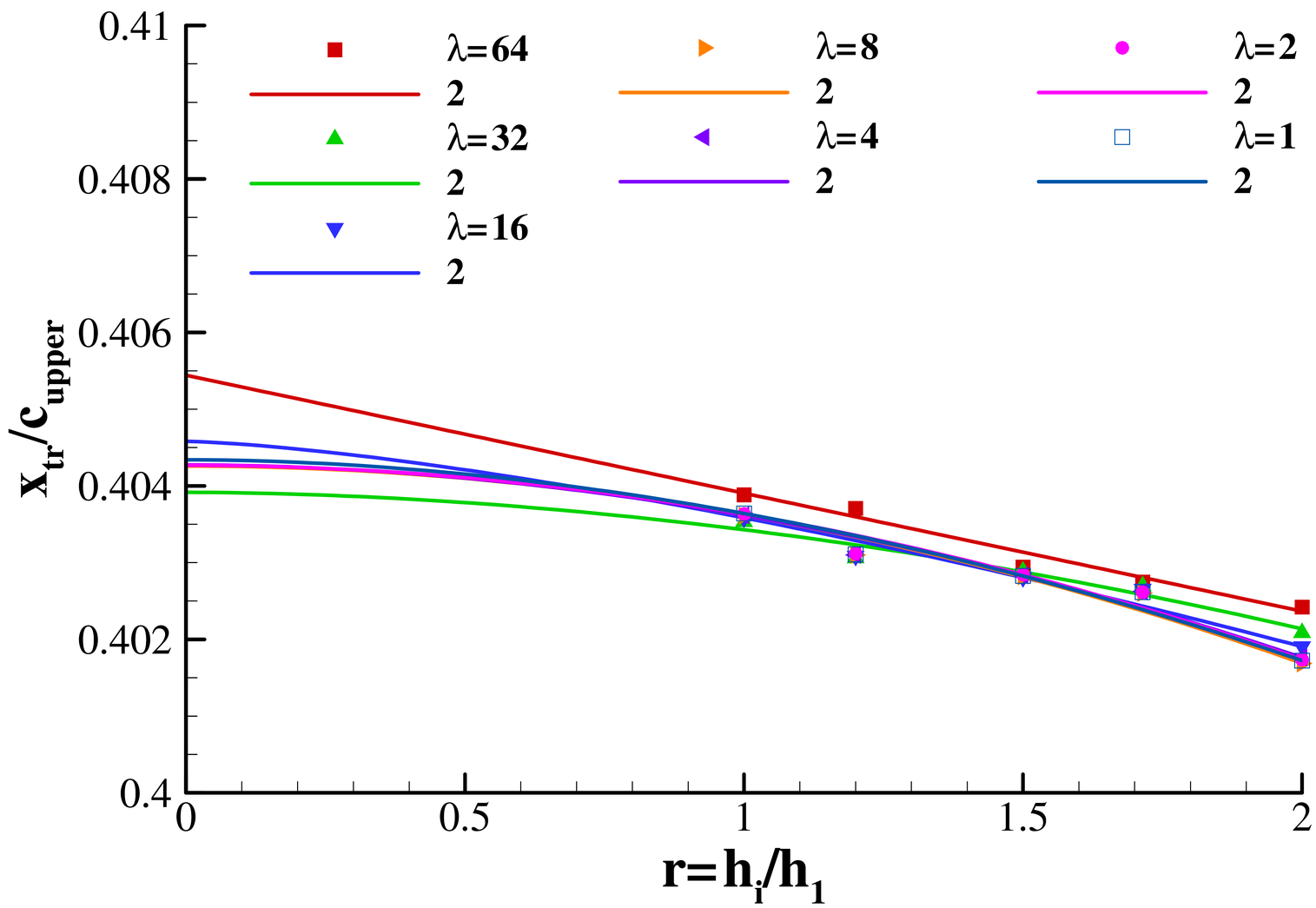

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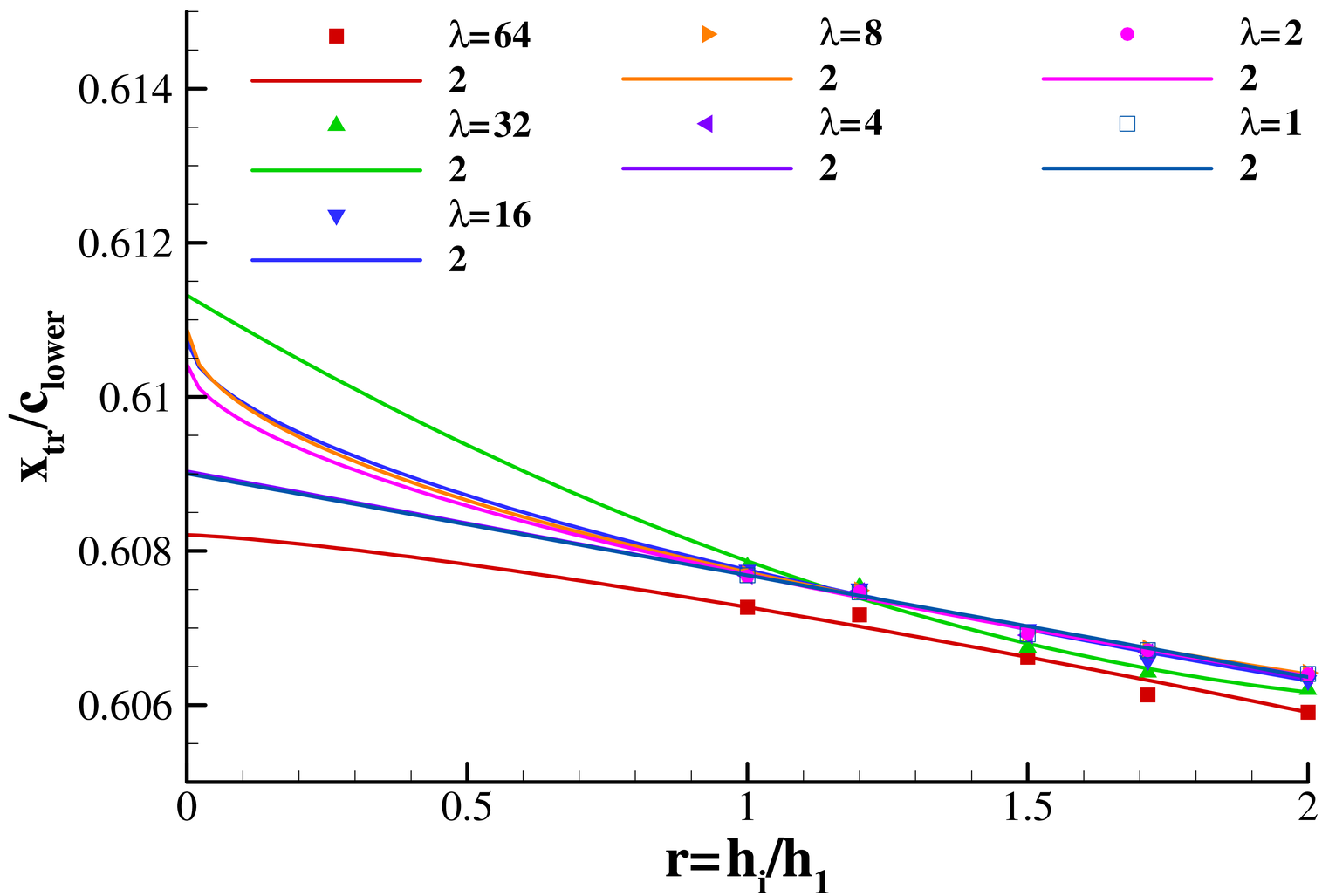

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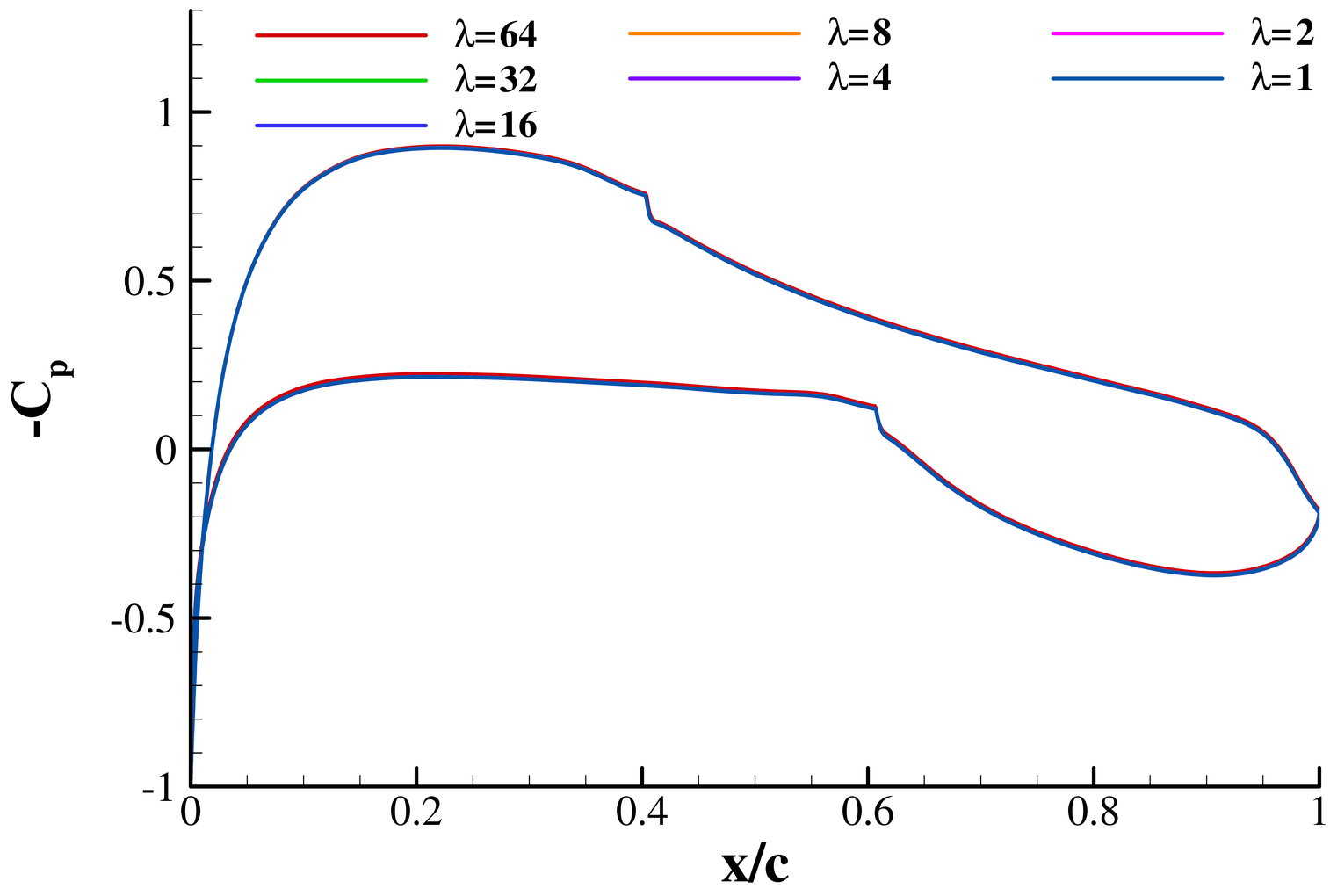

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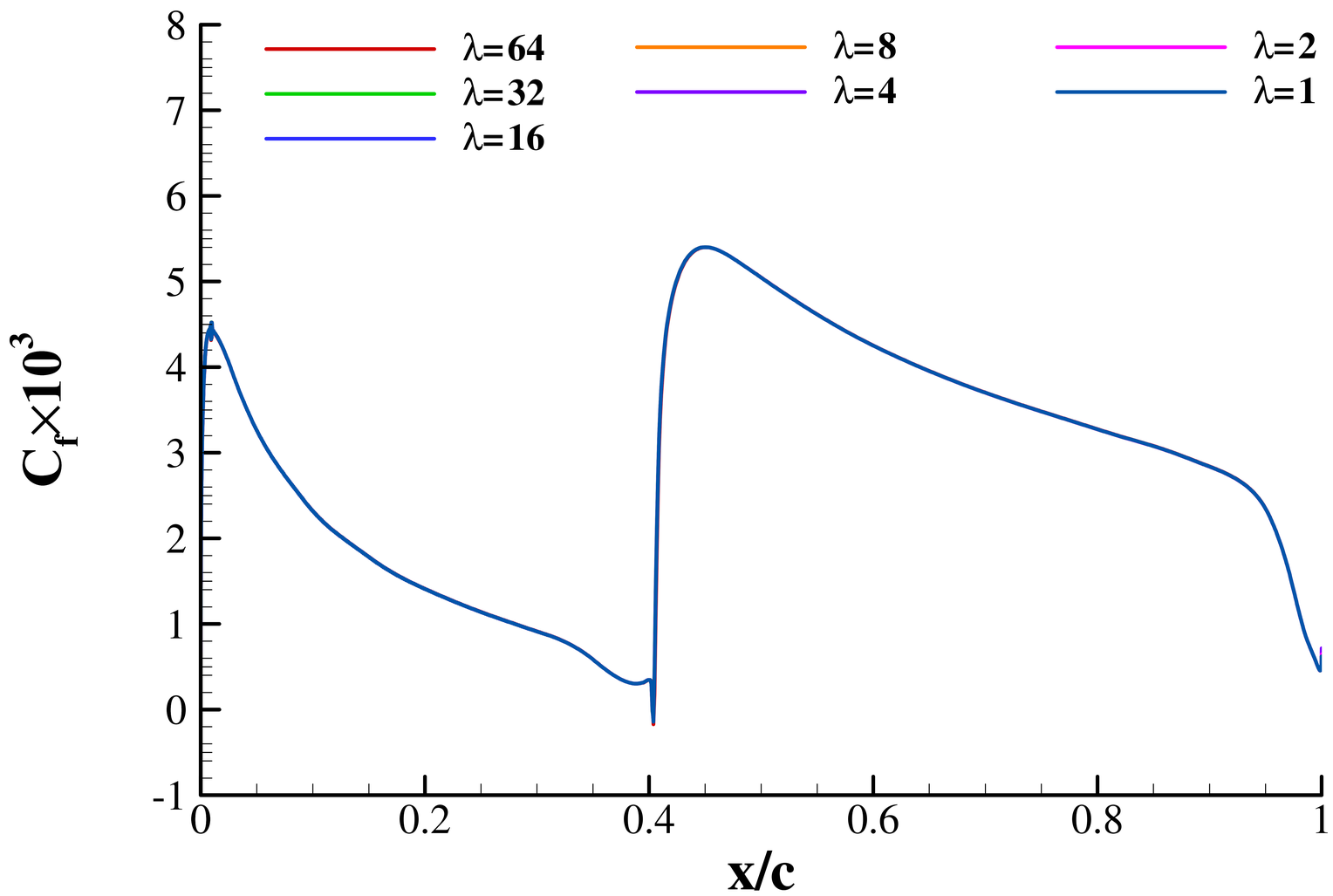

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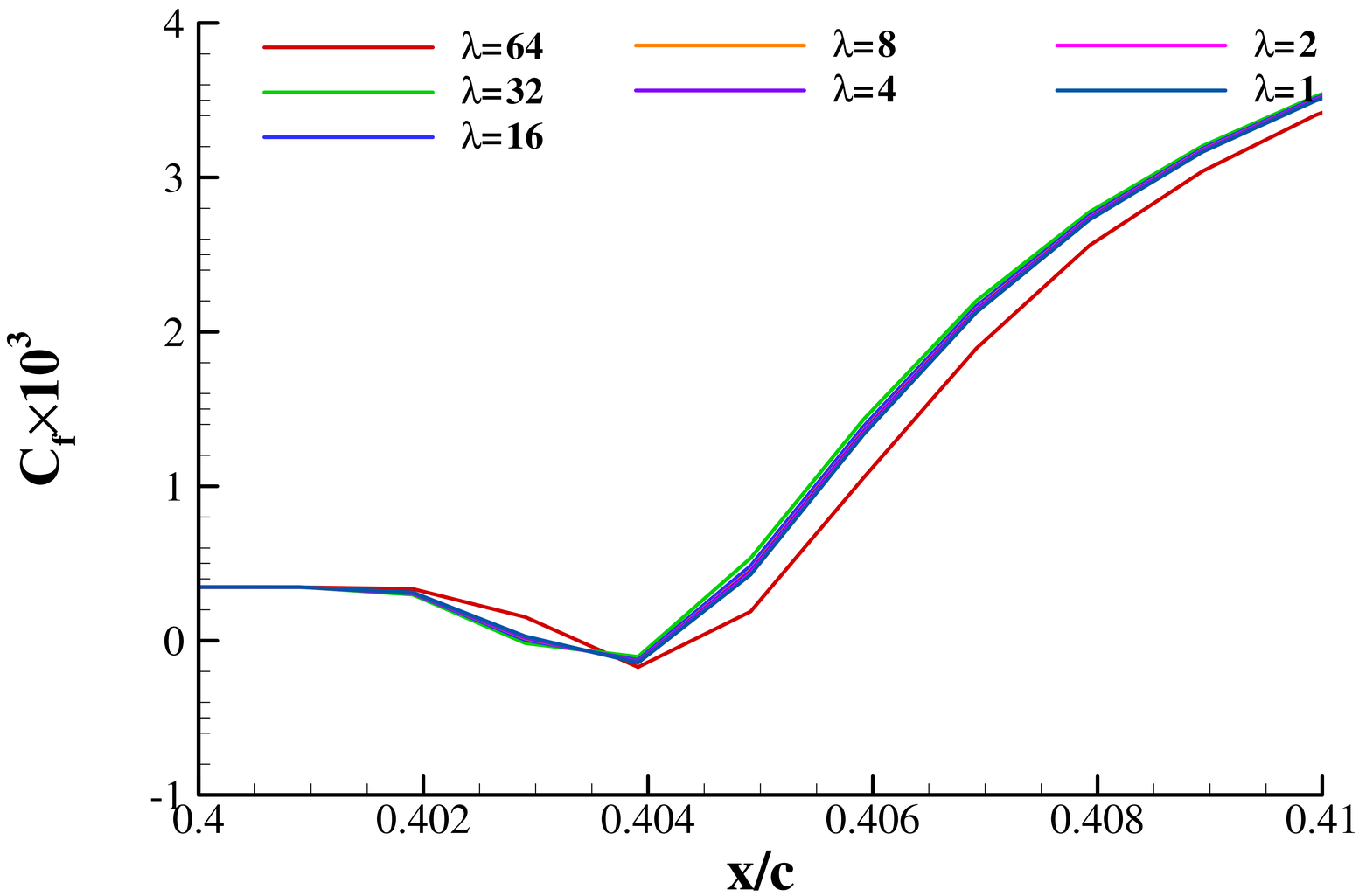

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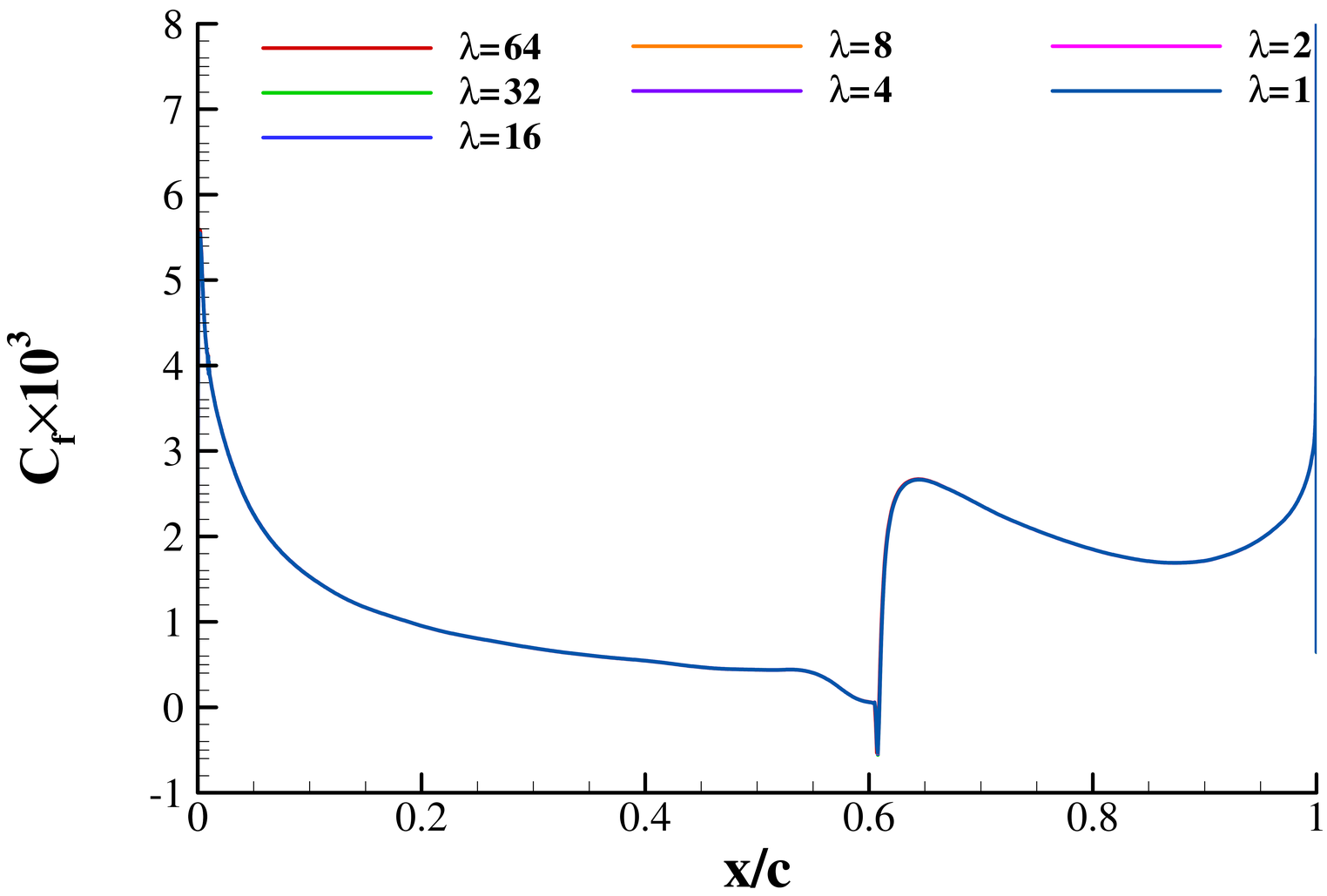

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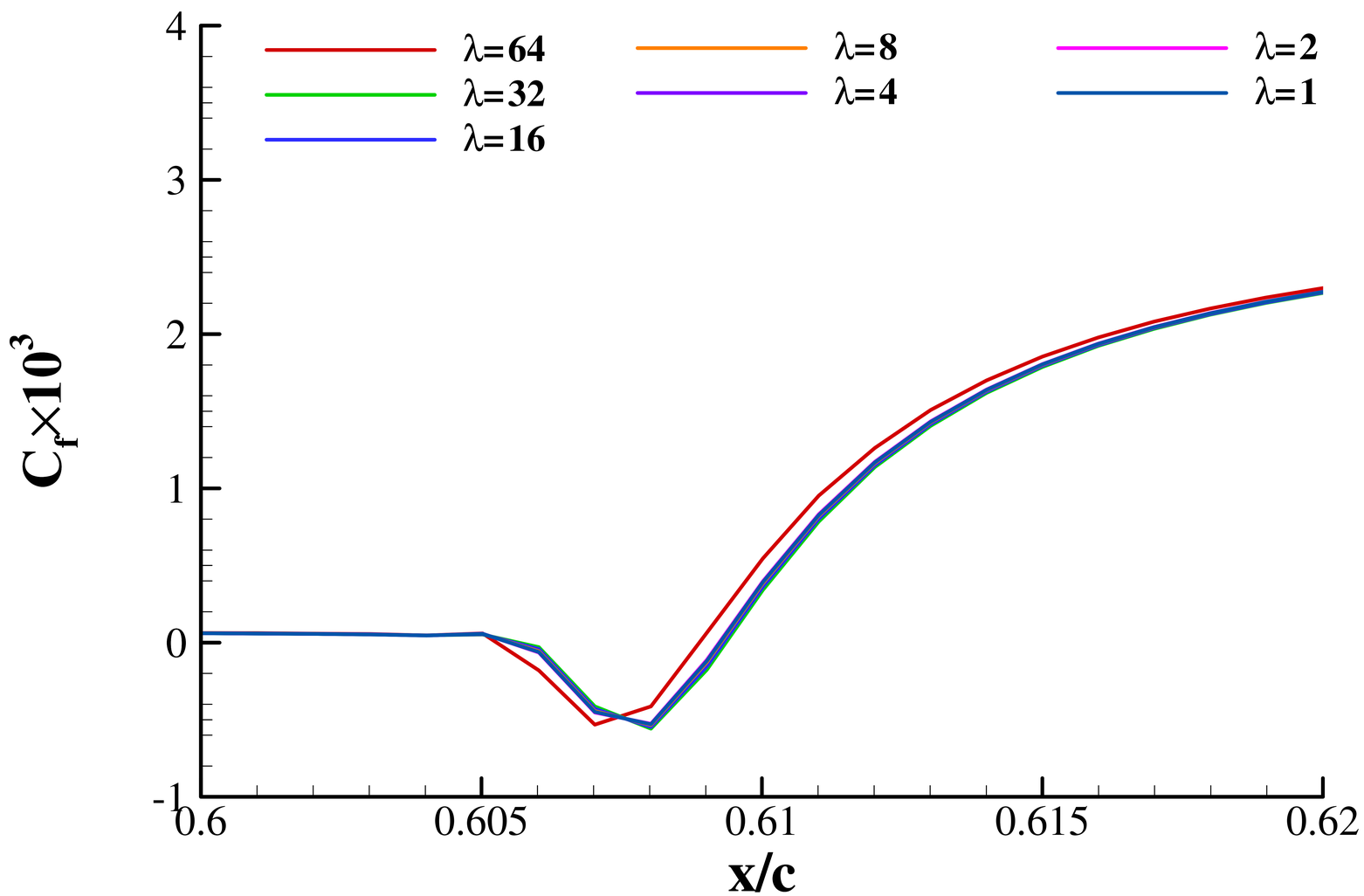

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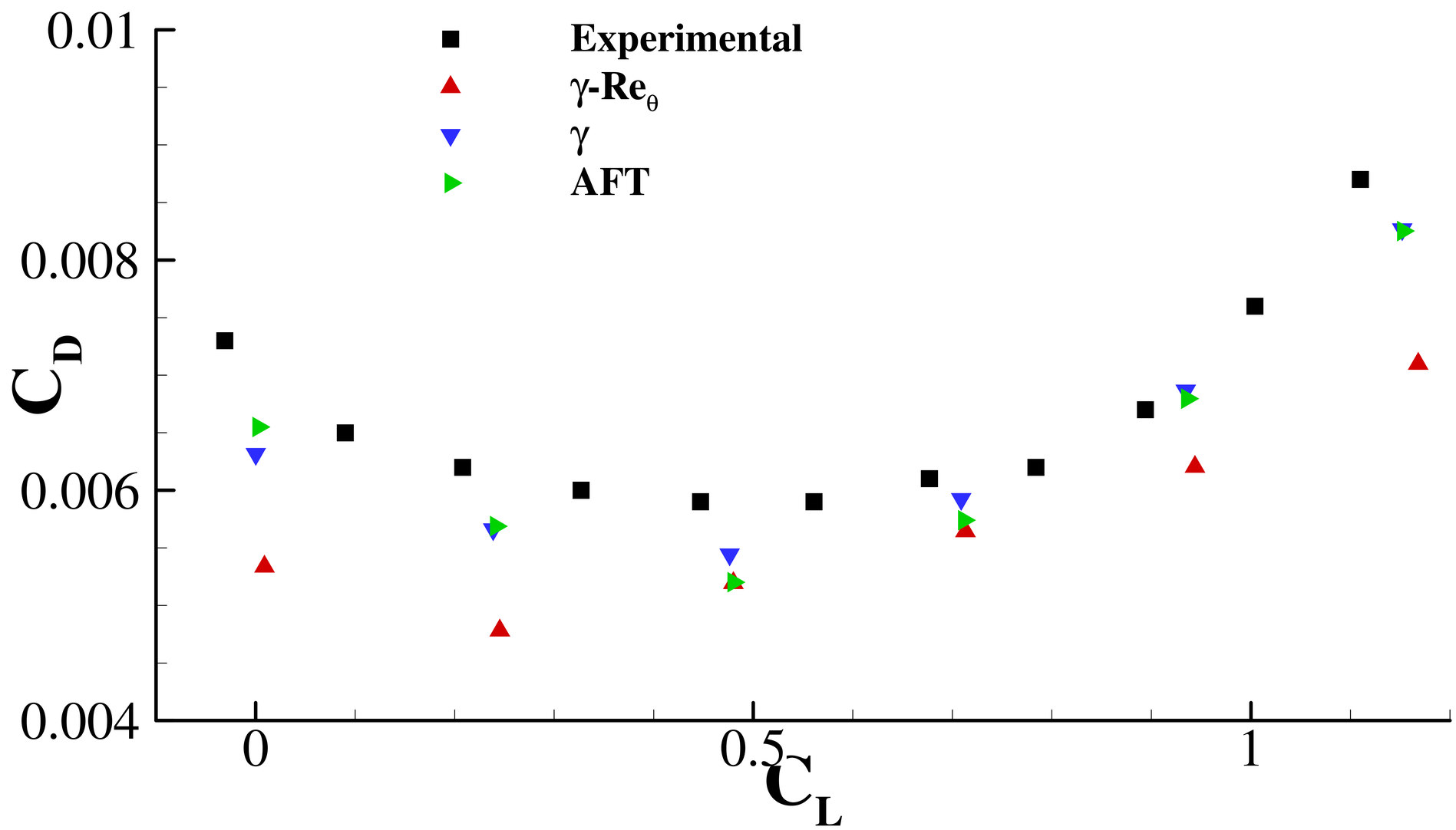

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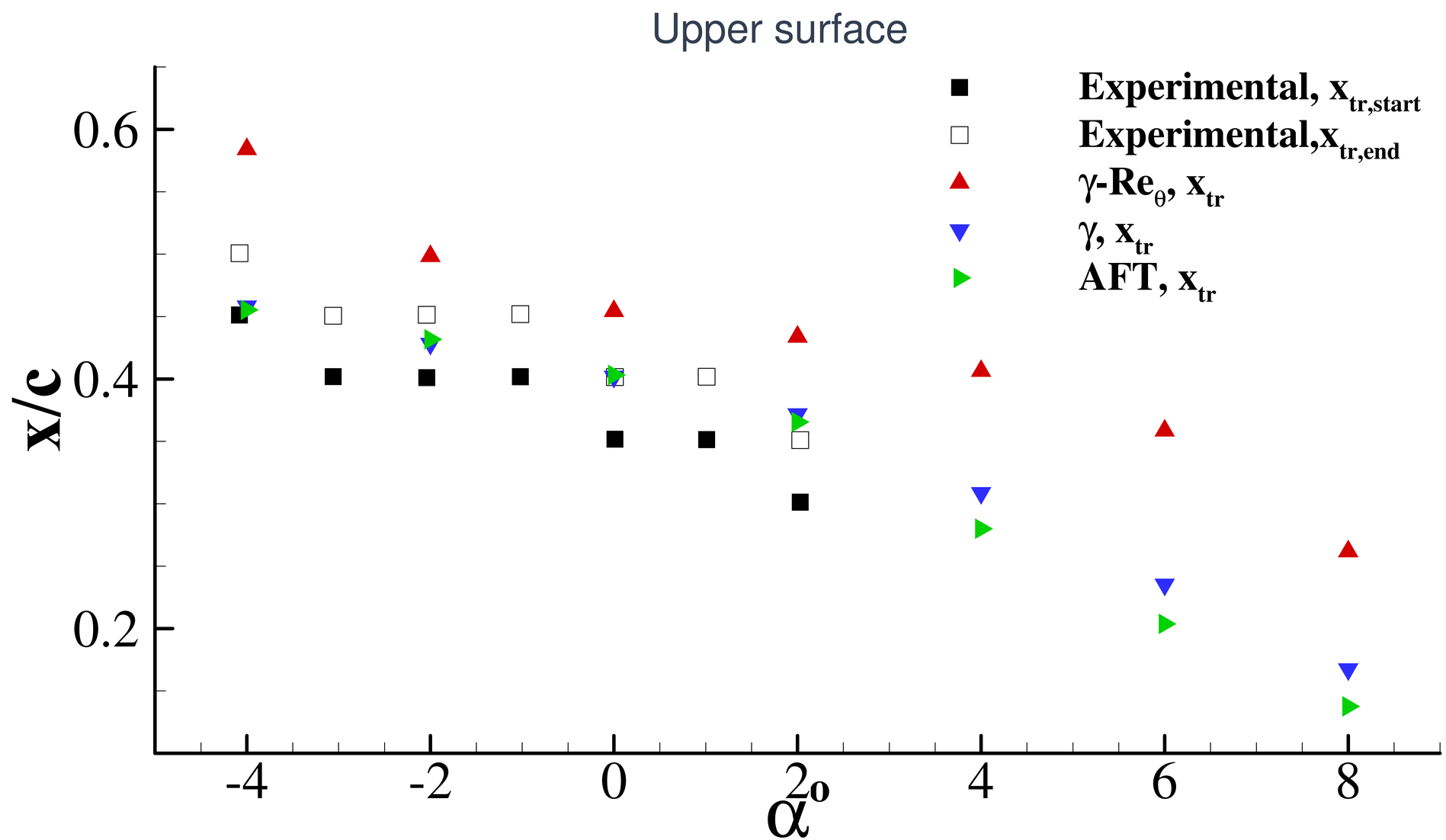

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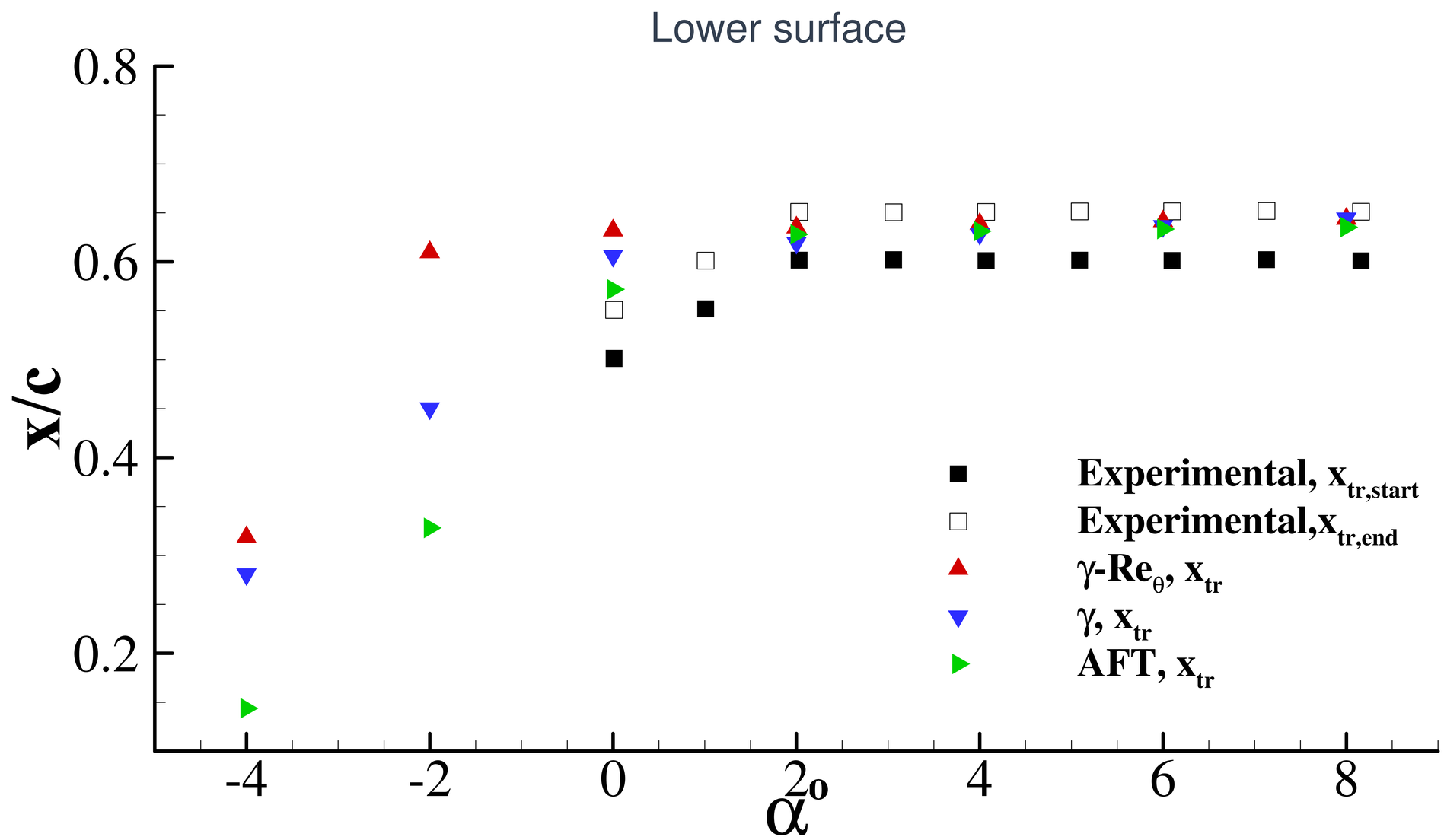
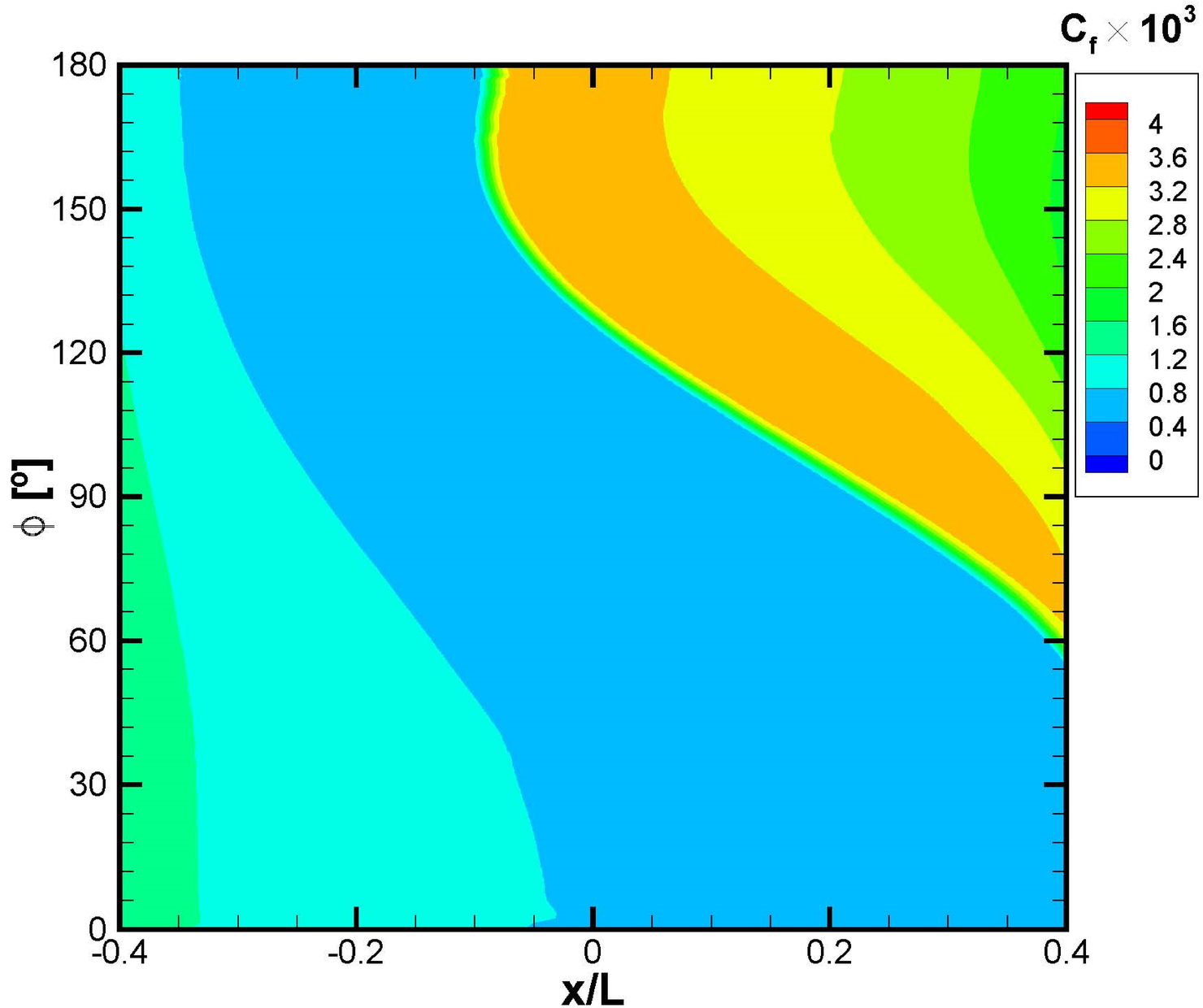
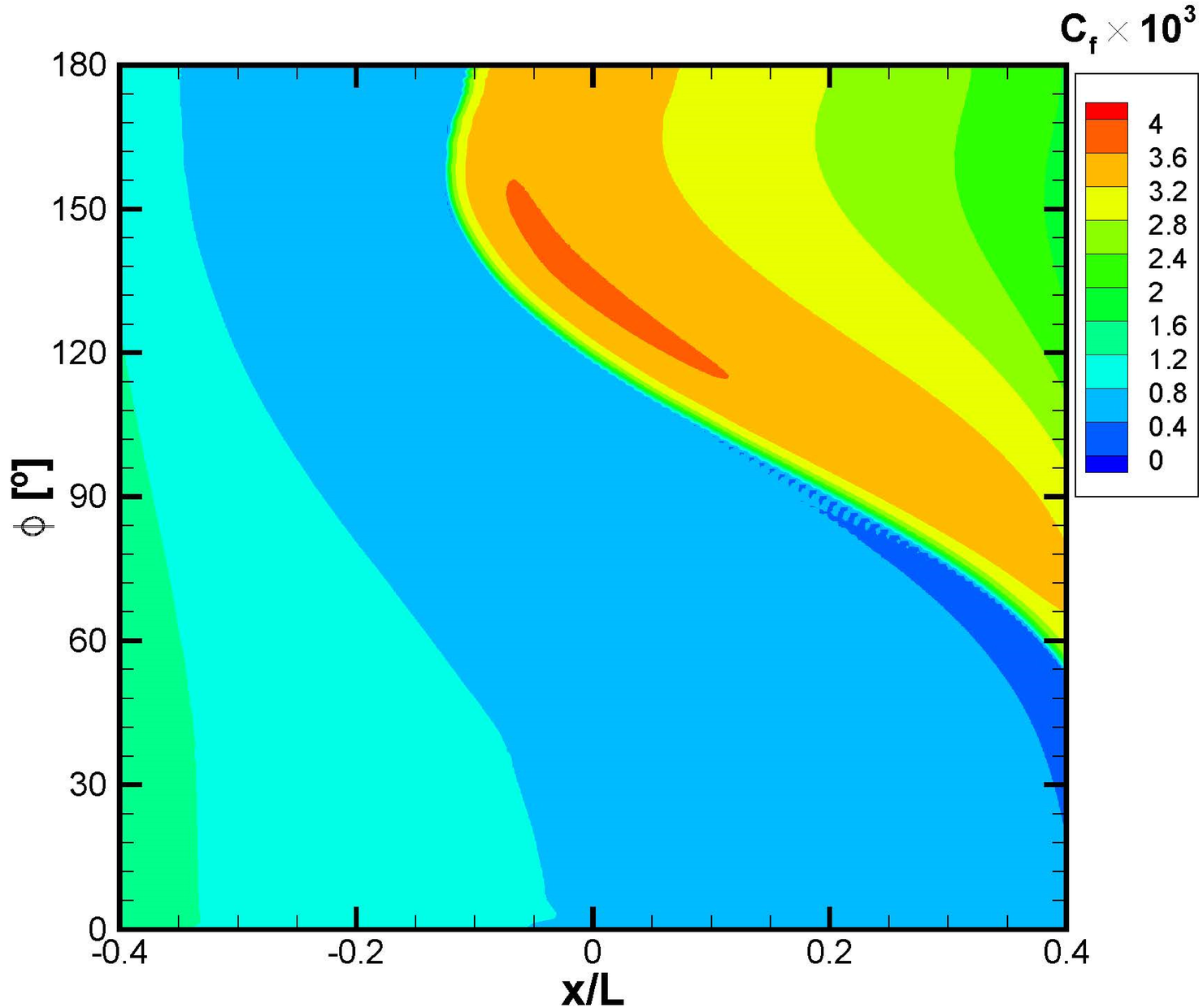


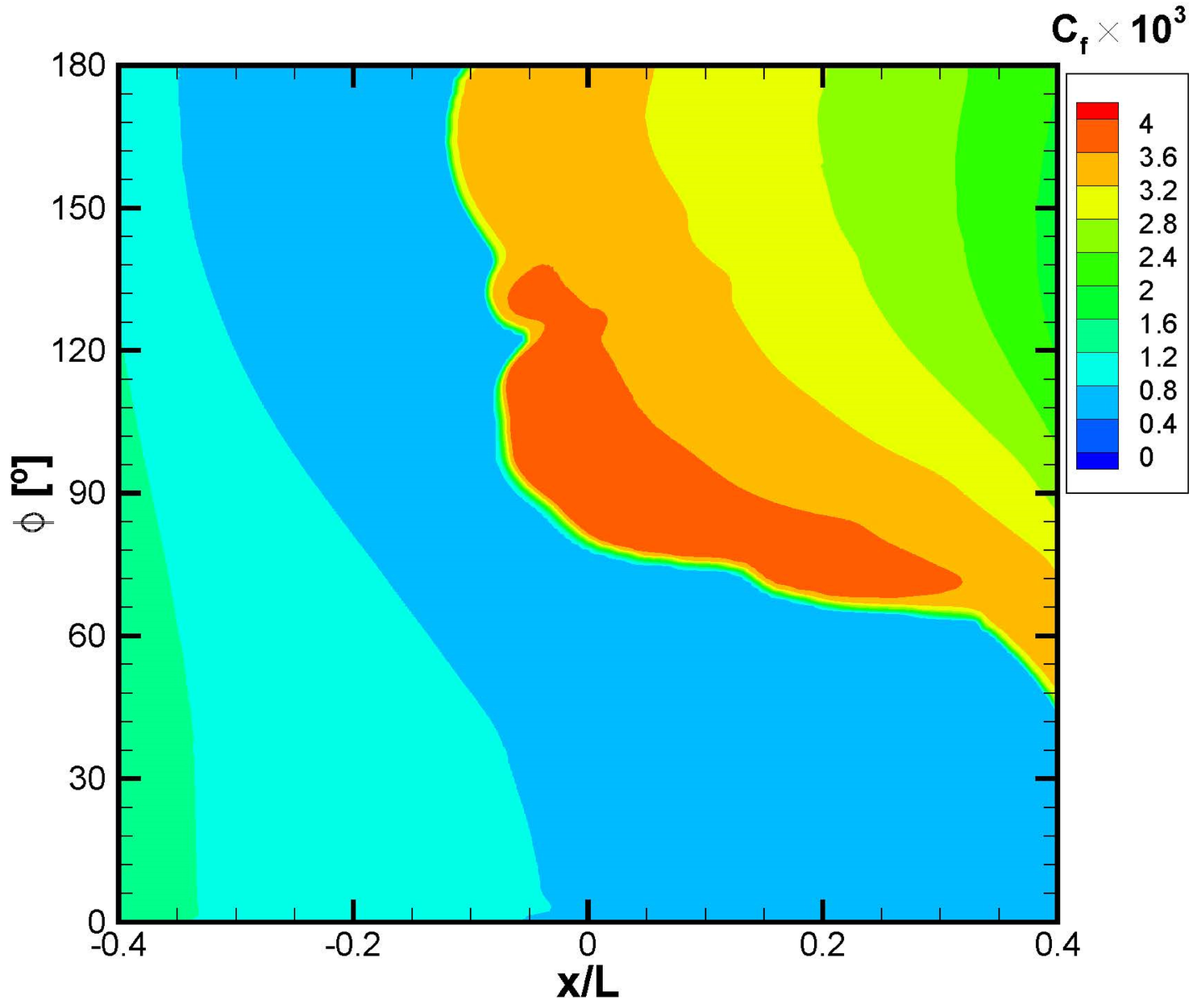
Simulation of the flow at $\alpha = 5^o$ – Grid 1: $\gamma - Re_\theta$



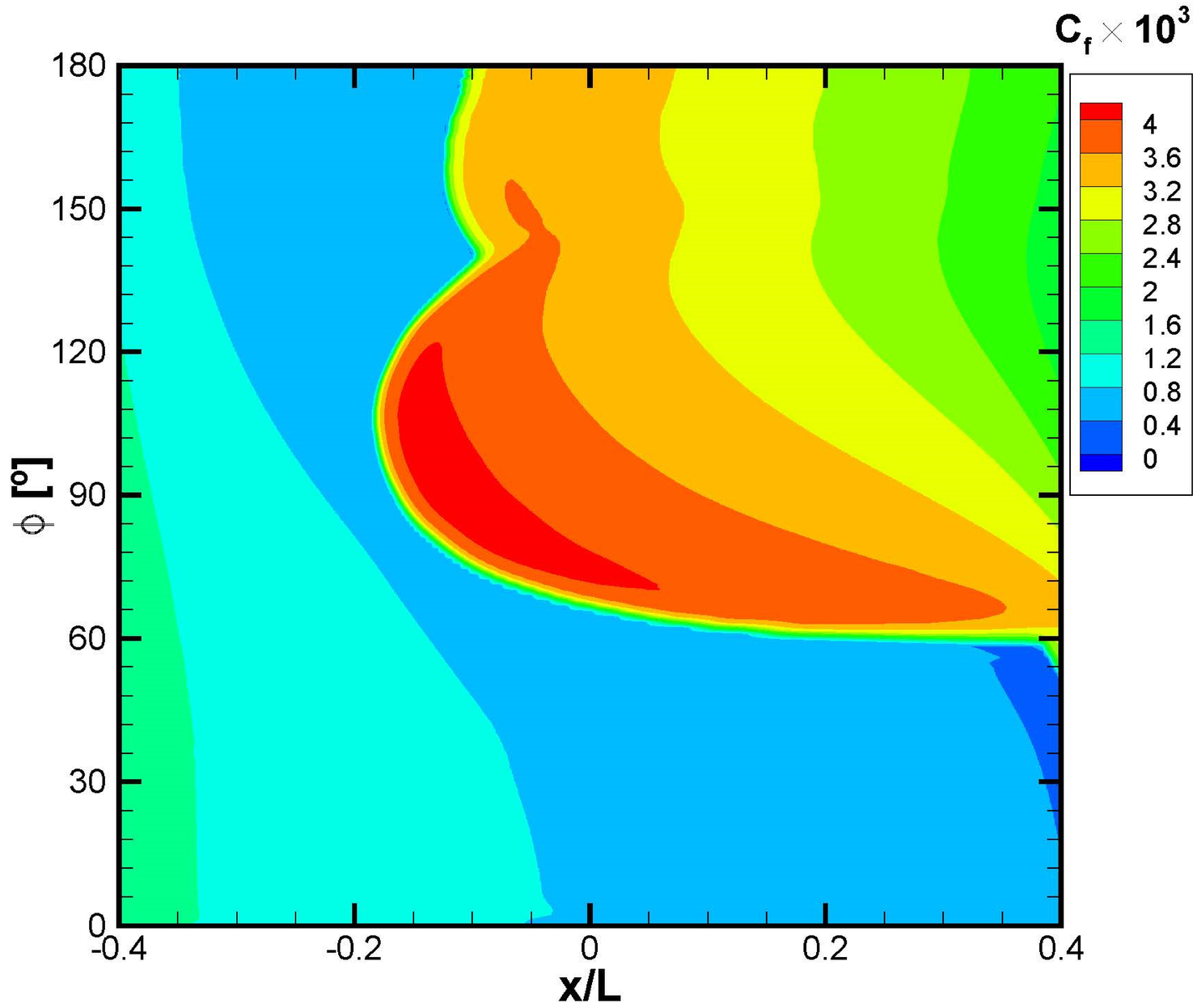
Simulation of the flow at $\alpha = 5^o$ – Grid 1: γ



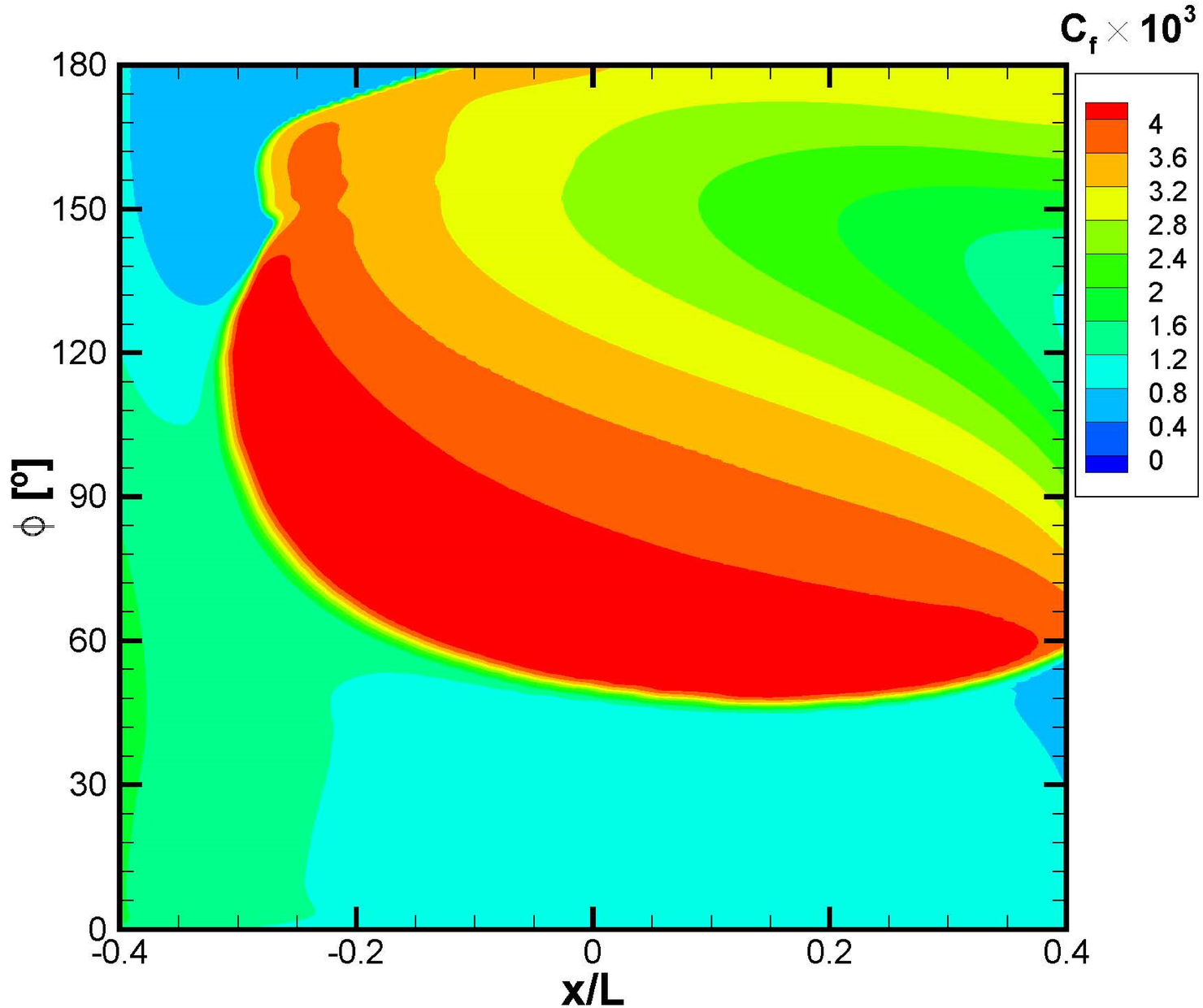
Simulation of the flow at $\alpha = 5^o$ – Grid 1: $\gamma - Re_\theta$ - CFHE



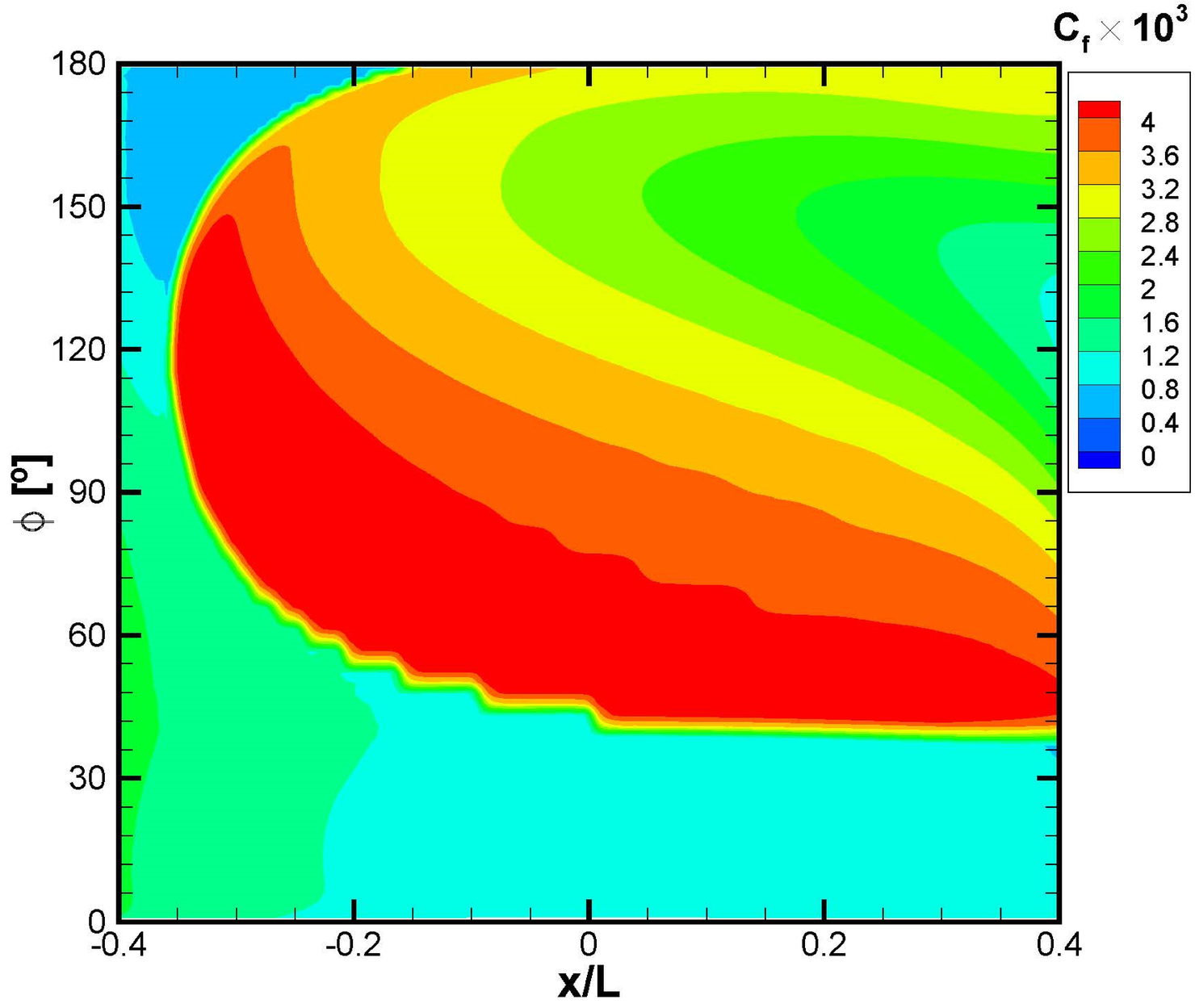
Simulation of the flow at $\alpha = 5^o$ – Grid 1: γ - CFHE



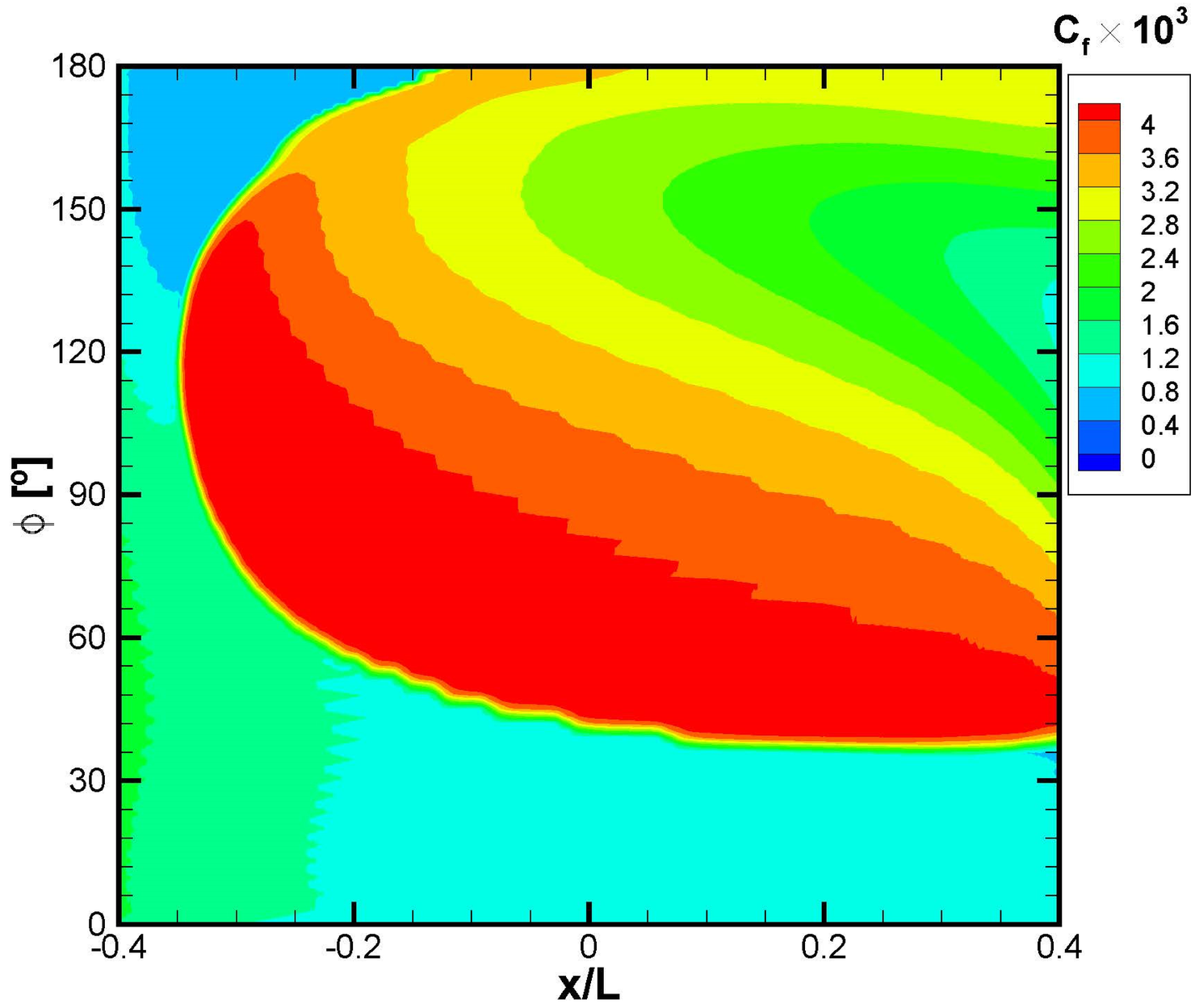
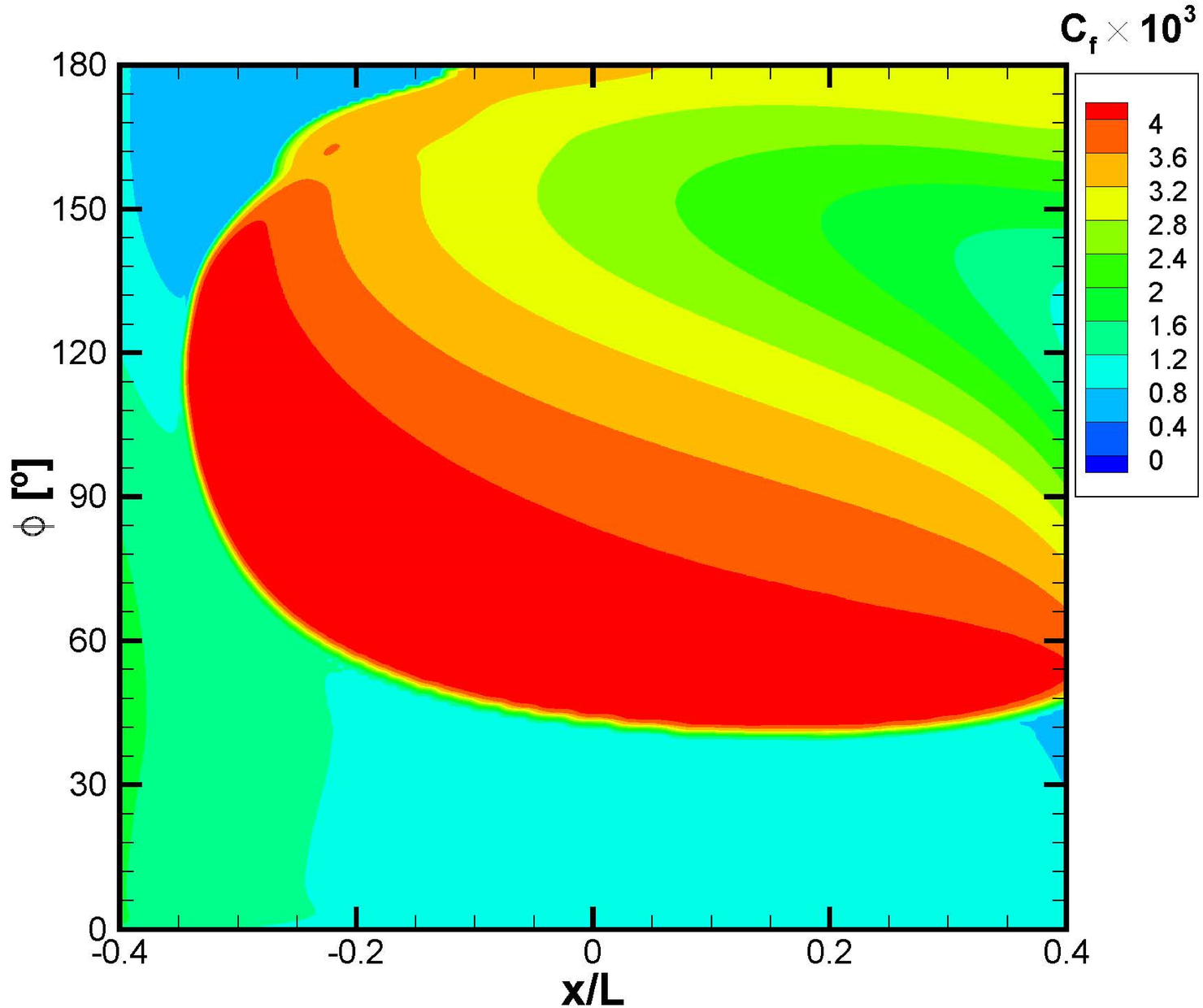
Simulation of the flow at $\alpha = 10^o$ – Grid 1: $\gamma - Re_\theta$ - CFHE



Simulation of the flow at $\alpha = 10^o$ – Grid 5: γ - CFHE



Simulation of the flow at $\alpha = 10^o$ – Grid 3: γ - CFHE



Simulation of the flow at $\alpha = 10^o$ – Grid 1: γ - CFHE