AE 801: M.Tech Seminar

Numerical Investigation of Flow Over Bluff Bodies: Effect of Seam & Rotation on Swing Force & Magnus Force on a Cricket Ball

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(Computational Fluid Dynamics Lab)

Contents

Introduction

- Cricket balls at highest-level games are made up of four pieces of leather with two larger hemispheres are joined with six rows of stitches that form the **‘seam’**
- Orientation at an angle creates asymmetry in the flow resulting in force imbalance
- Seam acts as a Boundary Layer Trip
- Aerodynamics plays a prominent role in the flight of a cricket ball
- Lateral Movement of the ball in air
- **The Objective is to investigate the effect of seam orientation and rotation on Swing Force and Magnus Force**

Fig.1: Red Cricket Ball | Kookaburra
https://www.kookaburrasport.com.au/

Conventional Swing & Reverse Swing

- ❑Lateral force in the direction of seam
- ❑Lateral force in the opposite direction of seam

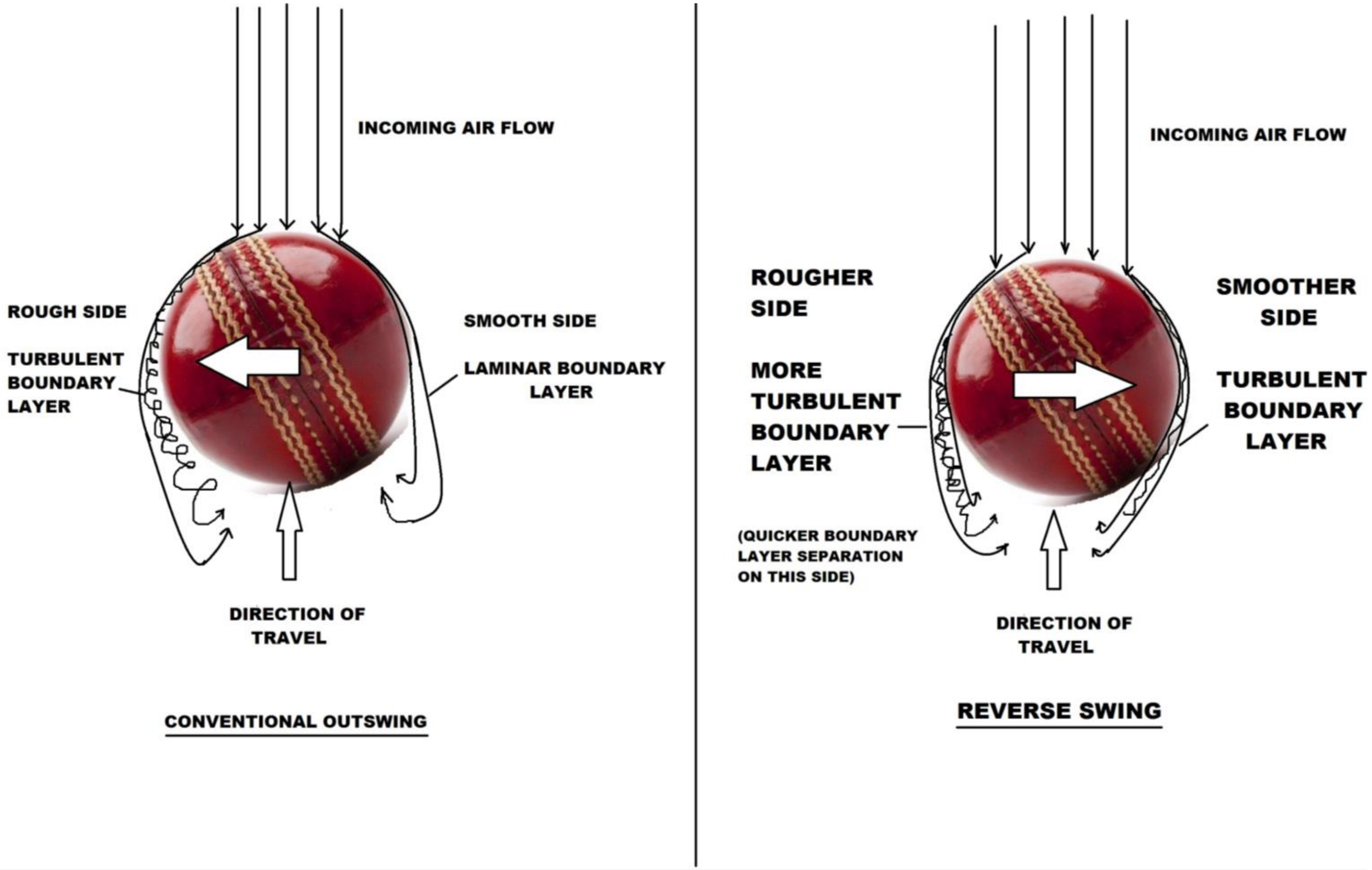

Fig.2: Comparison of Conventional and Reverse Swing[1]
https://www.computationalfluiddynamics.com.au/

Domain Specification

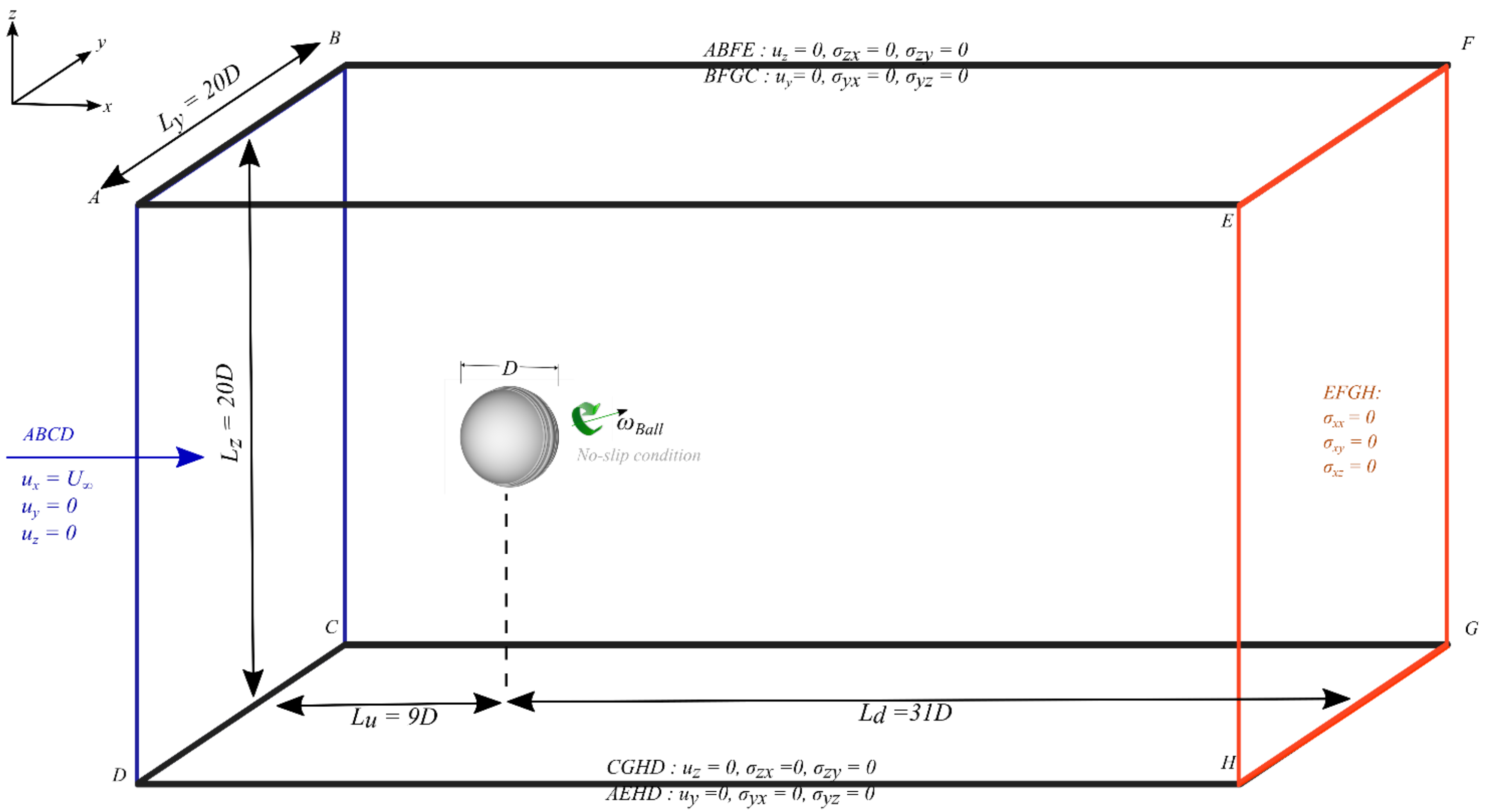

Fig. 3: Computational Domain

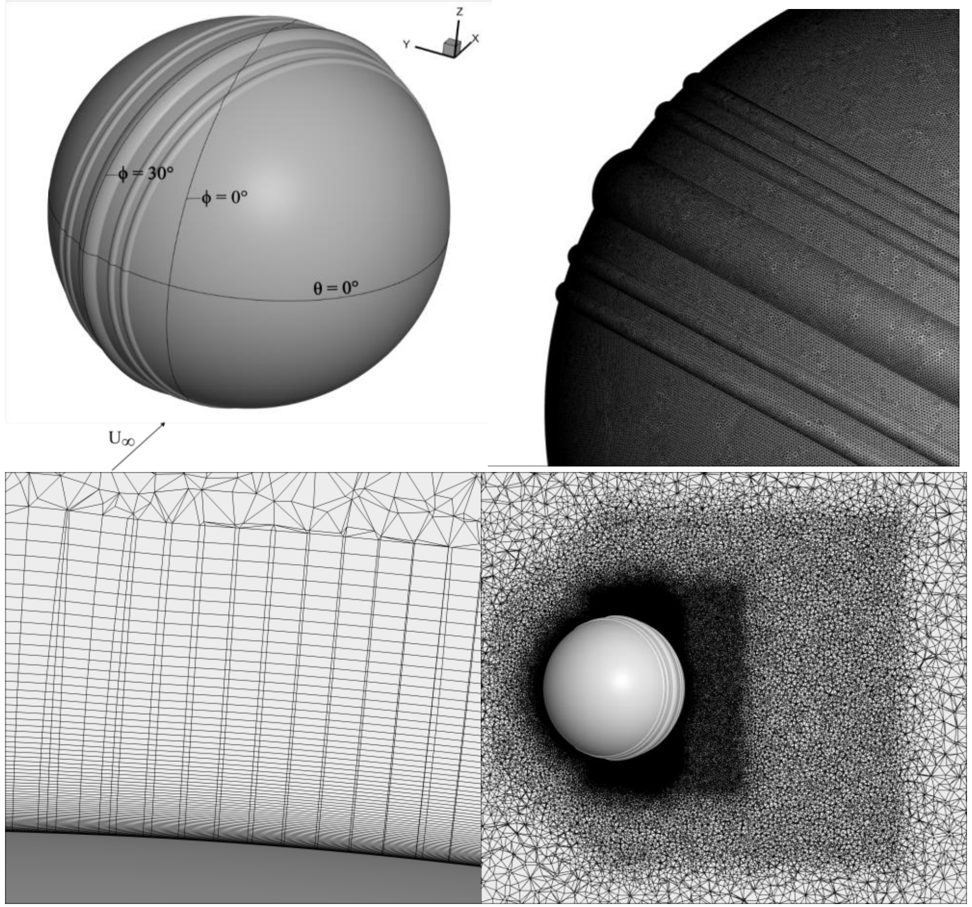

Fig.4: Geometry and Mesh [2]

Table 1: Geometry and Mesh Specifications

Diameter of Ball	Major Trip Height	Minor Trip Height	Total Elements	Total Nodes
0.5	0.014D	0.0049D	81.9 Million	30.2 Million

Overview of Regimes

1. **Region of No Swing:** Up to Re = 5×10^4, the swing is approximately zero, suggesting that the seam does not affect the flow until here.
2. **Region of Delayed Laminar Separation:** Swing for ($7.5 \times 10^4 \leq Re \leq 1.7 \times 10^5$) is caused by delayed separation upto 89° of the laminar boundary layer on the seam side
3. **Swing due to LSB on Seam Side:** LSB along with an SV on seam side for Re = 2×10^5 while the LSB at Re = 3×10^5 is smaller and without an SV marking an end of CS regime
4. **Reverse Swing due to LSB on Non-Seam Side:** At Re = 4.5×10^5, unlike the laminar separation on the non-seam side, the boundary layer transitions to a turbulent state

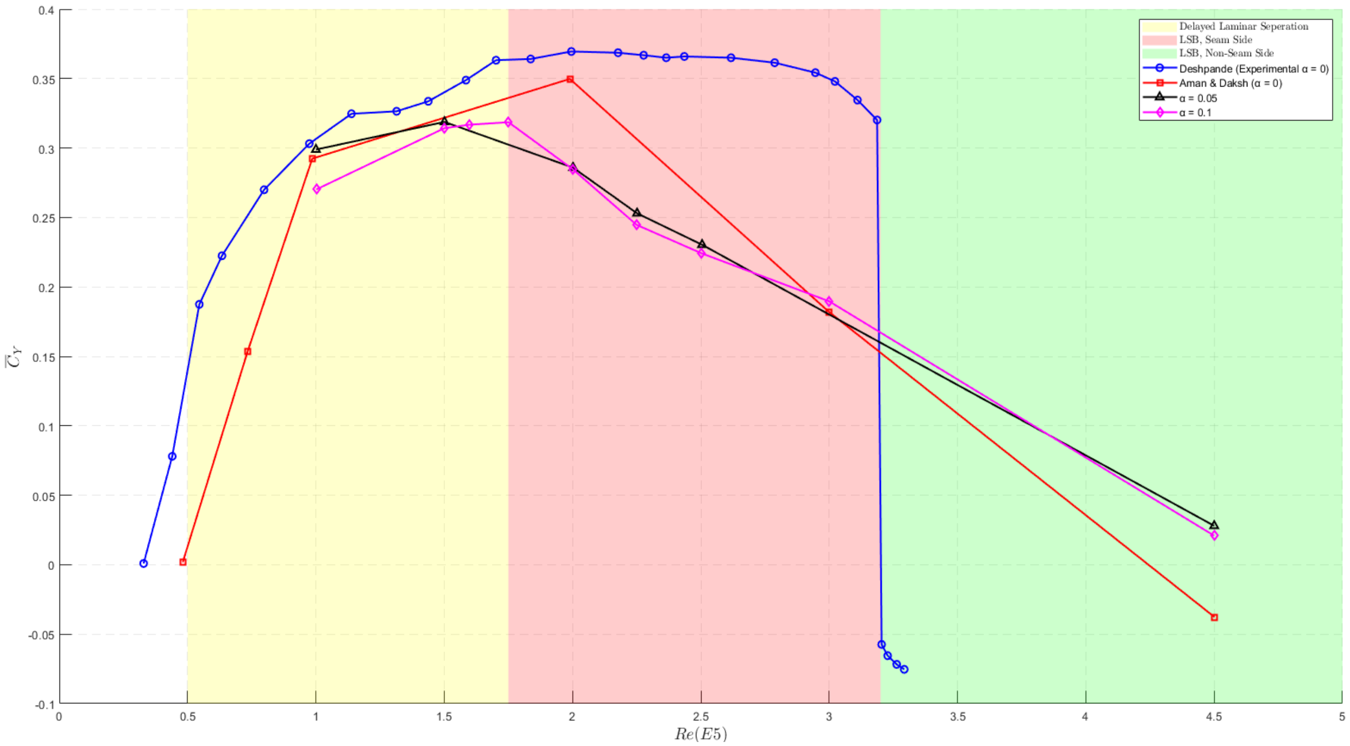

Fig. 5: C_Y vs Re comparison for various Alpha [2] [4]
(Previous work by Rahul Deshpande, Aman & Daksh, Yash Srivastava and Lawprakash Gupta)

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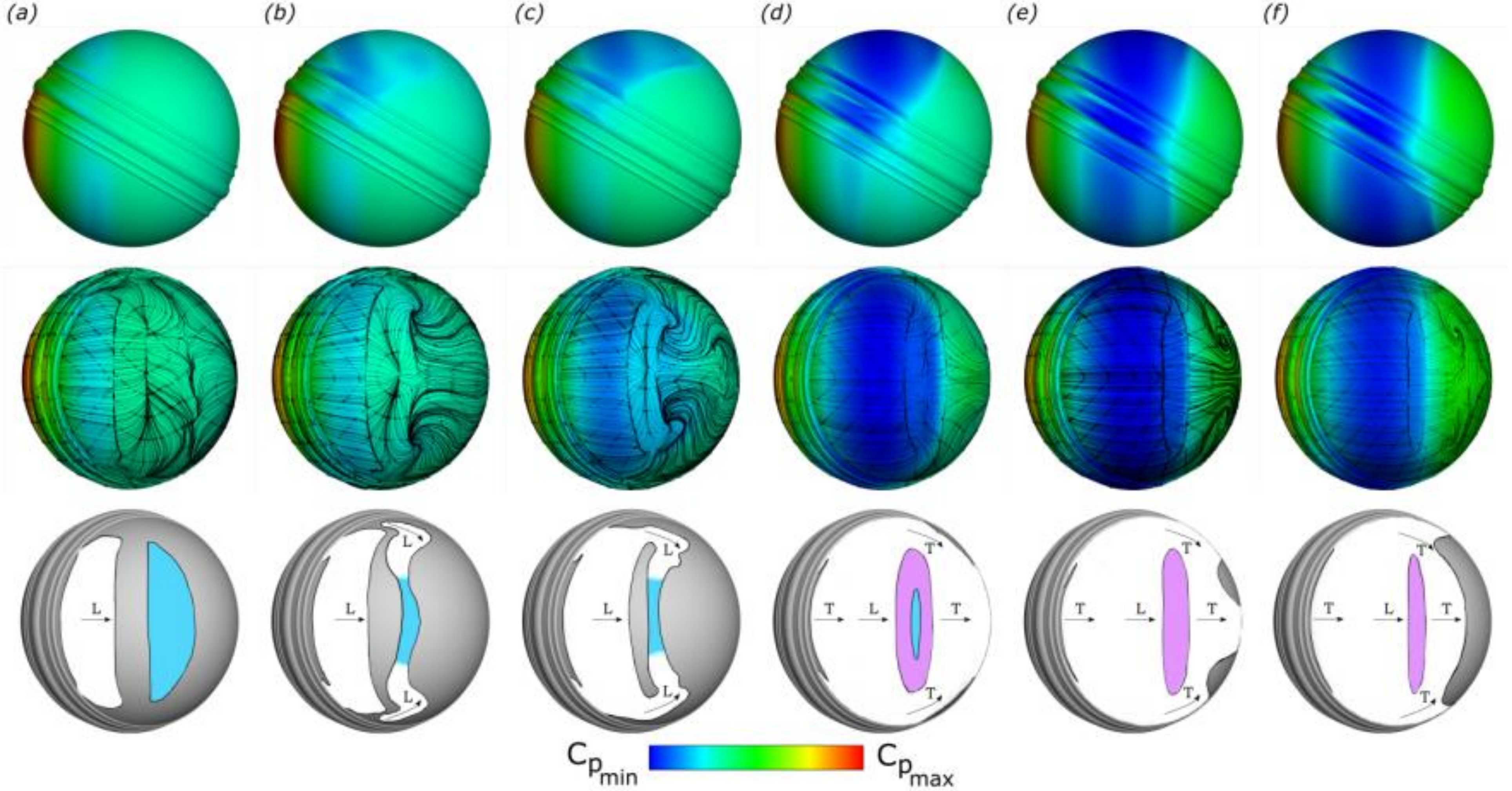


Fig. 6: Distribution of the time-averaged pressure coefficient on the surface of ball (top and front views, as seen in the x-y planes and x-z planes respectively in top and middle rows) at Re = (a) 5 $\times 10^4$, (b) 7.5 $\times 10^4$, (c) 1 $\times 10^5$, (d) 2 $\times 10^5$, (e) 3 $\times 10^5$ and (f) 4.5 $\times 10^5$. (C_{Pmin} , C_{Pmax}) is (-1,1) for (a)-(c) and (-1.2,1.2) for (d)-(f). Surface streamlines for the time-averaged flow are overlayed on the pressure distribution in the middle row. The schematic of the flow for each Re is shown in the bottom row. The state of the boundary layer is indicated by L (laminar) and T (turbulent). Also shown is the secondary vortex (SV) in cyan and laminar separation bubble (LSB) in magenta color. The region of separated flow is marked in gray. [2]

(From **Parekh, A., Chaplot, D., and Mittal, S.** (2024), Journal of Fluid Mechanics)

Computation (Re = 4.5 × 10^5, α = 0.05)

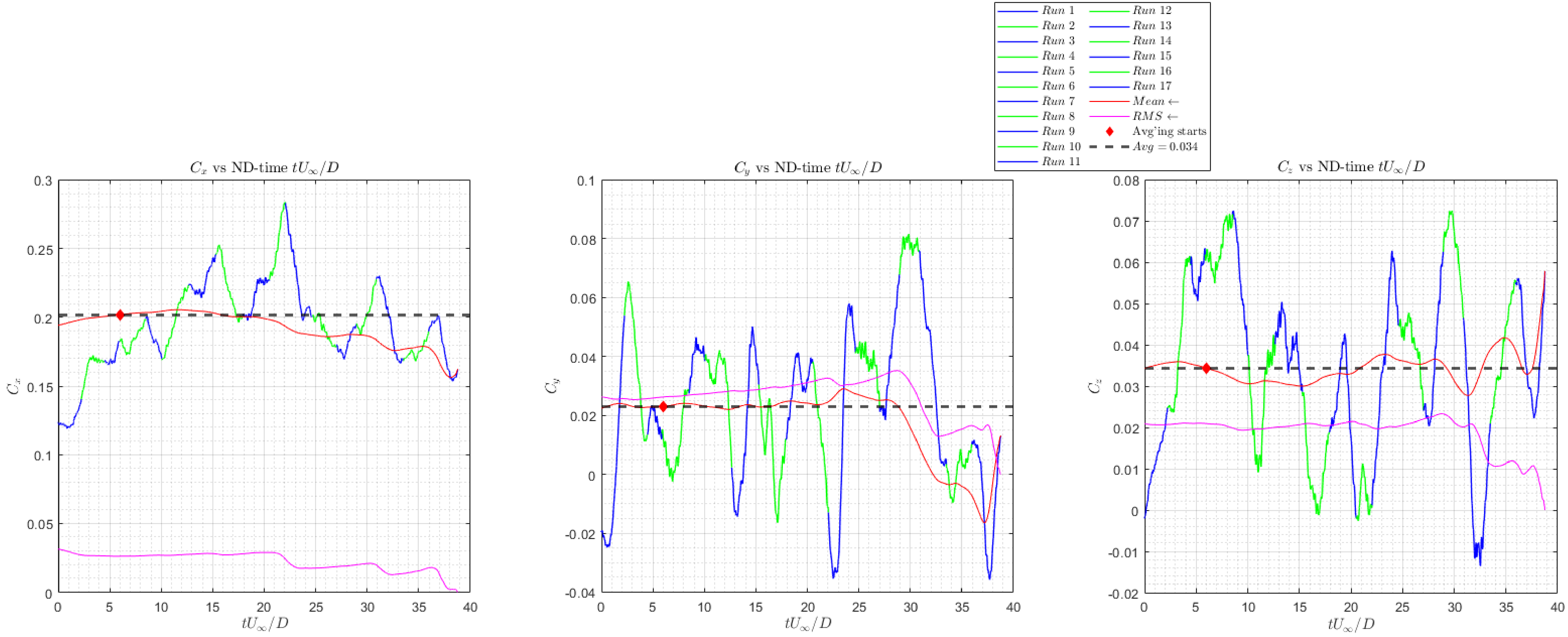


Fig.6: Time History for **4.5 × 10^5, α = 0.05** to show variation of Drag, Swing & Magnus Coefficients with multiple computations along with the Mean and RMS curves

Post Processing

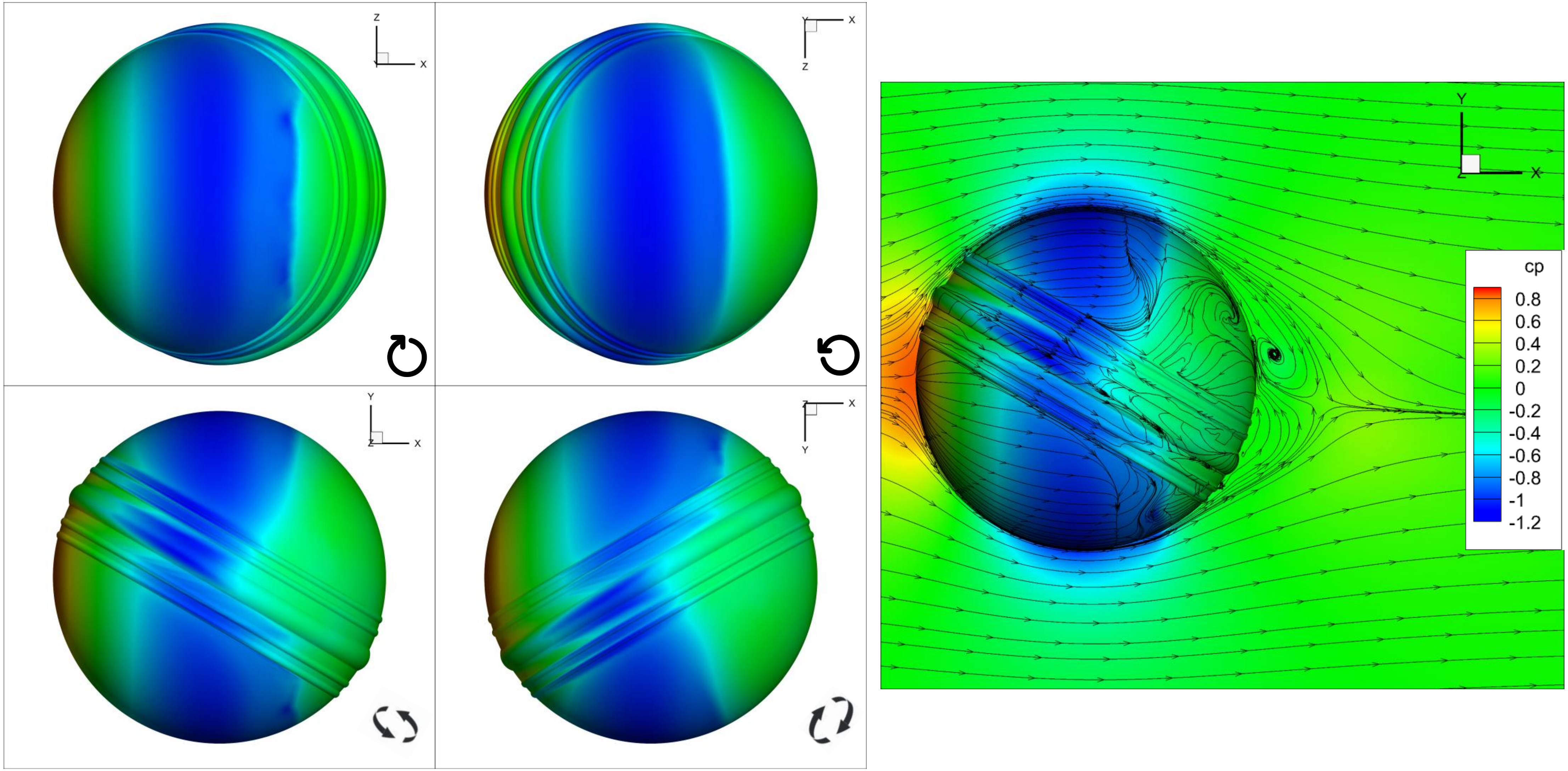
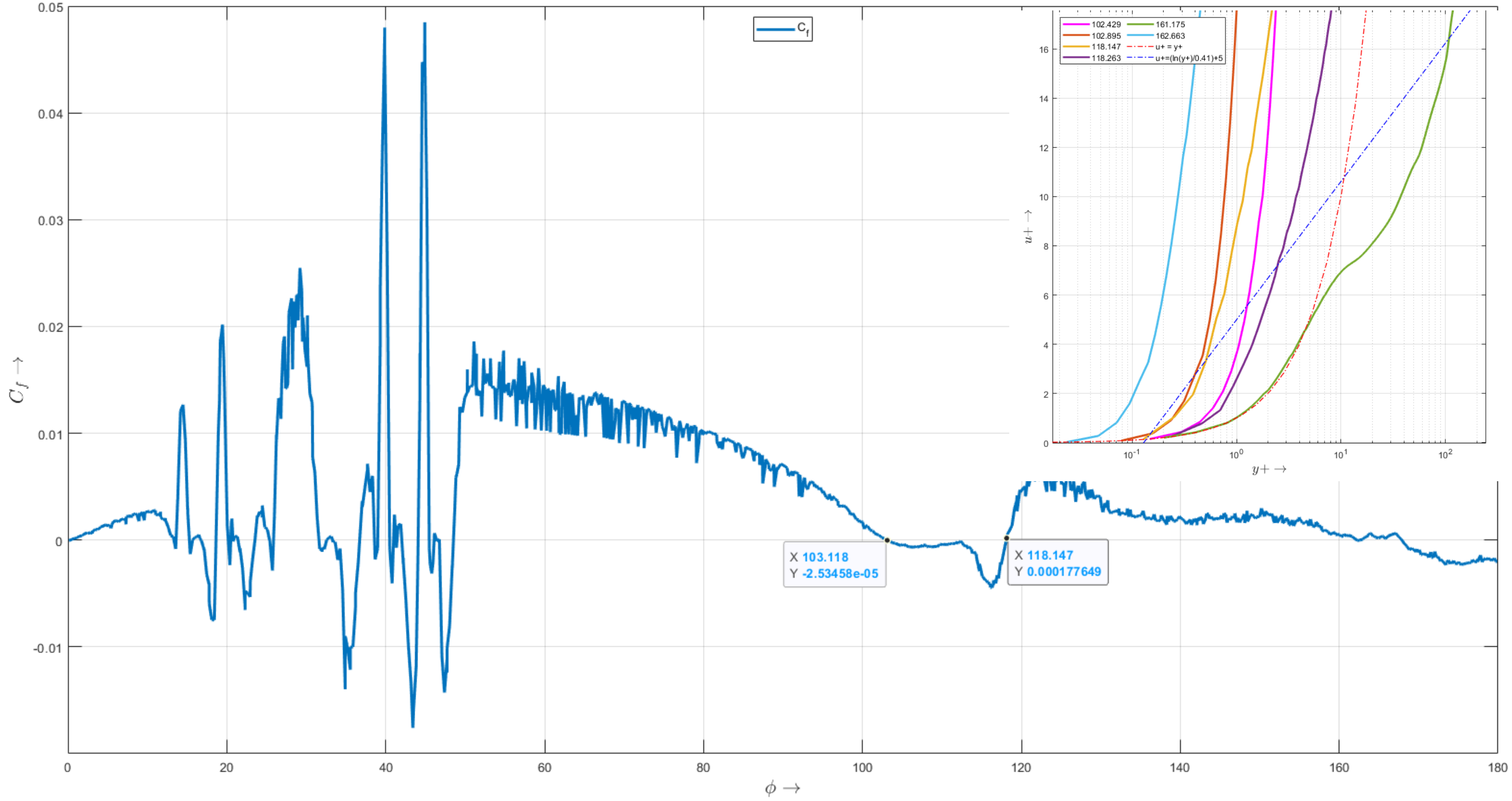
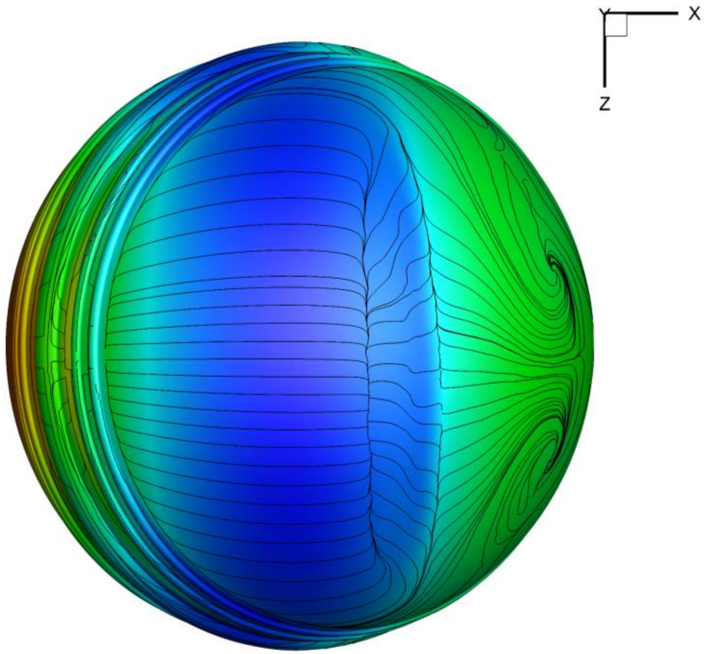


Fig.7: Surface C_P contours and flow streamtraces at Z=0 slice

1. LSB on the Seam Side





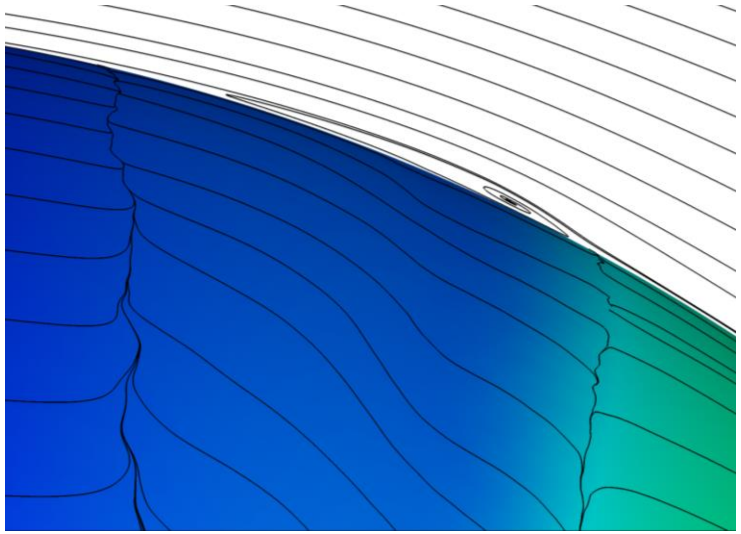


Fig.8: Skin Friction Coefficient with velocity profiles and LSB footprint along with zoomed view of the LSB on Seam Side

2. LSB on the Non-Seam Side :

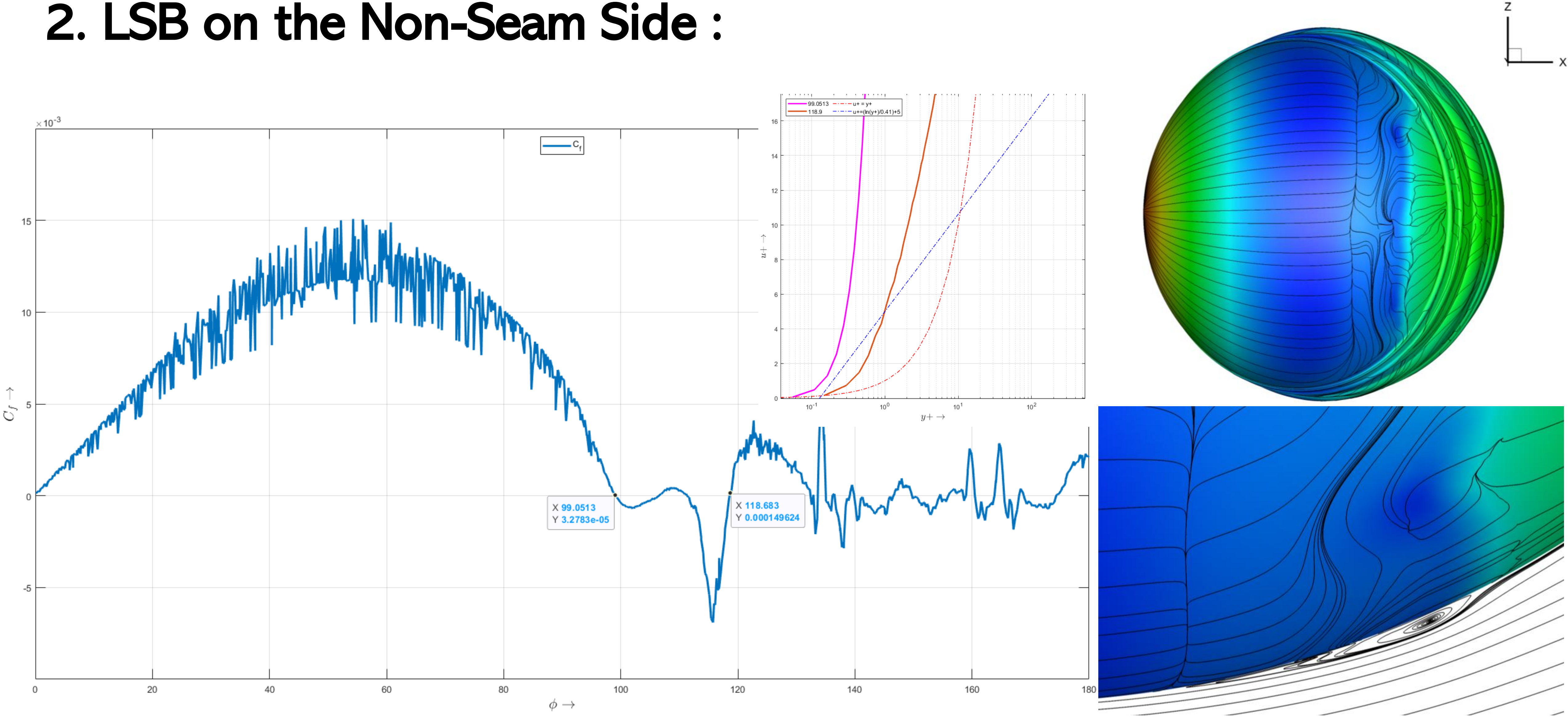


Fig.9: Skin Friction Coefficient with velocity profiles and LSB footprint along with zoomed view of the LSB on Non-Seam Side

3. Q Isosurface at Q = 0.5

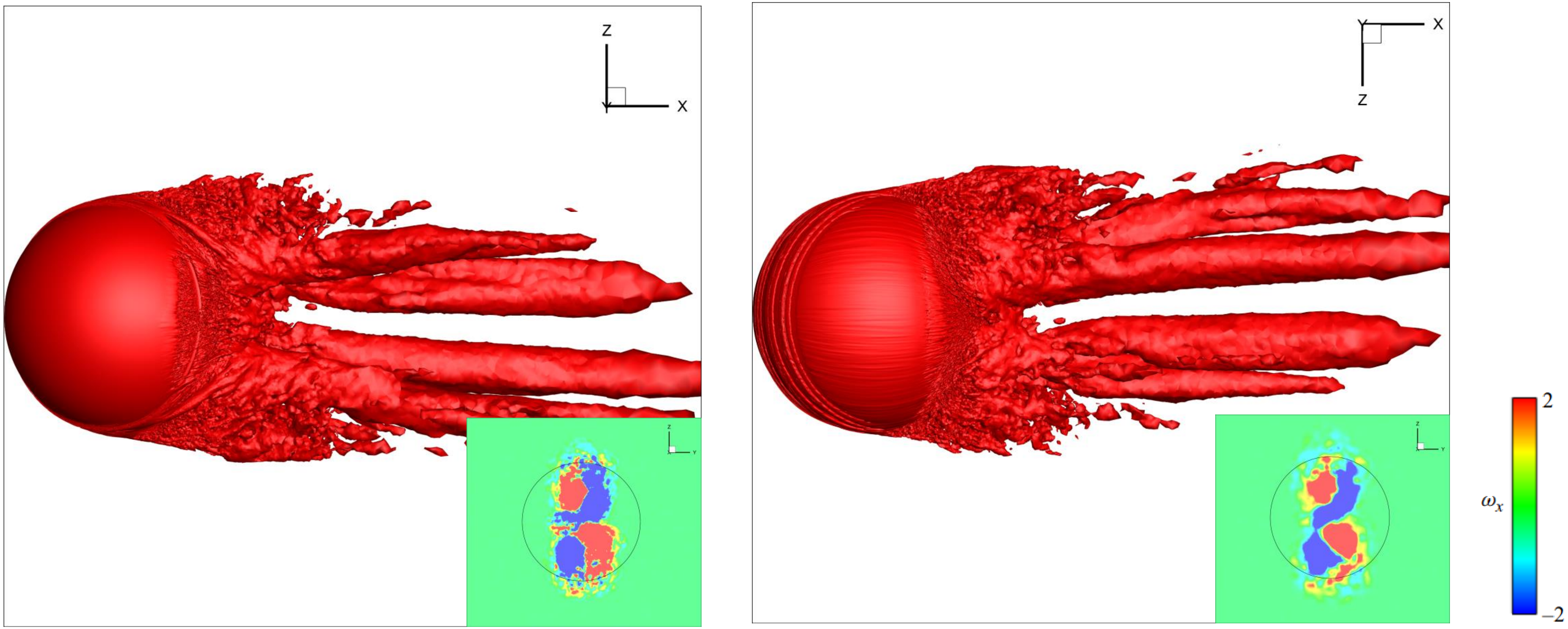


Fig.10: Q Isosurface at Q = 0.5 and Streamwise component of vorticity (ω_x) on the y-z plane at x = 0.7D and 1D

- The Q-criterion is the second invariant of the velocity gradient tensor. It's a measure of the excess rotation rate relative to the strain rate

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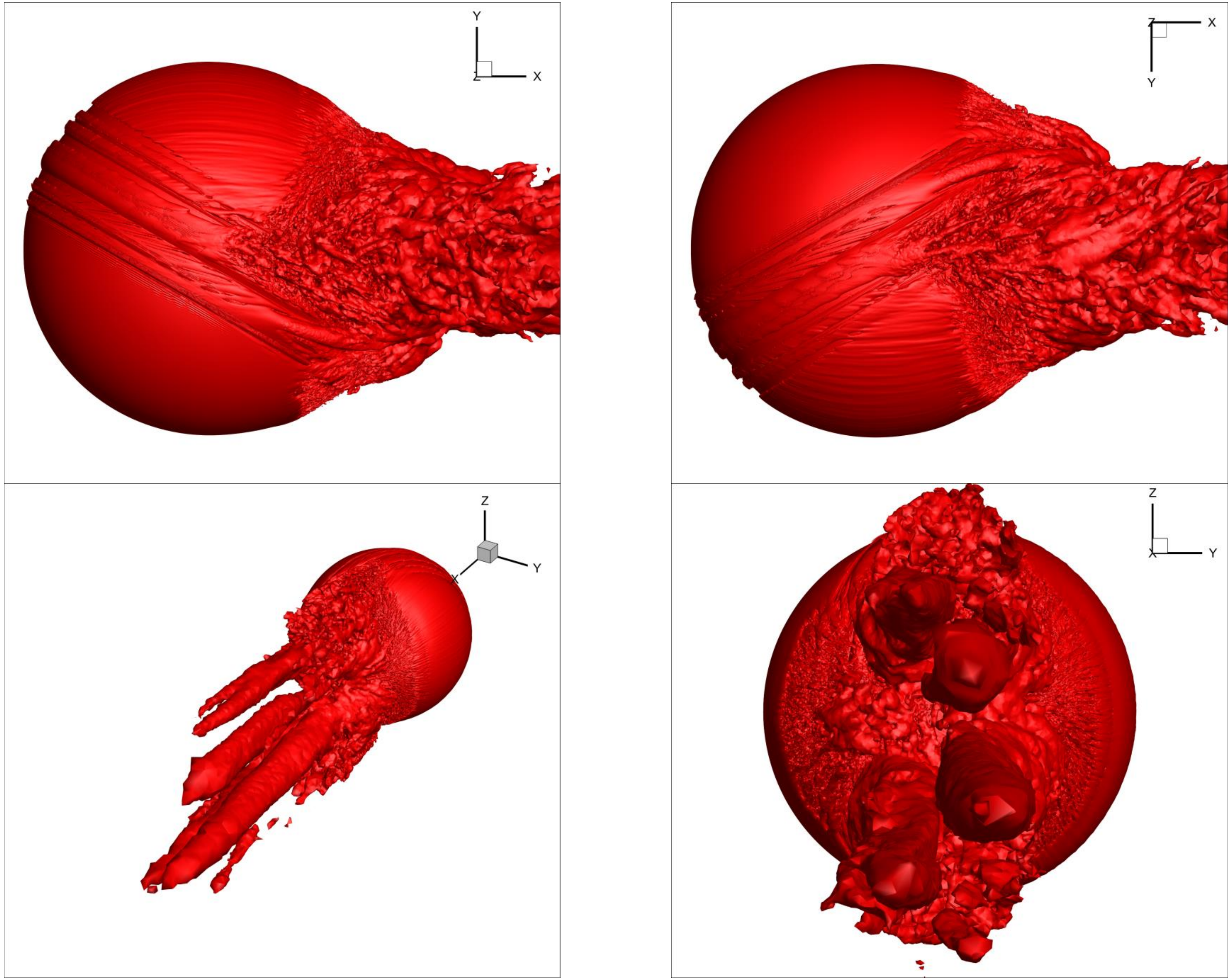


Fig.11: Q Isosurface at Q = 0.5

Computation (Re = 4.5 × 10^5, α = 0.1)

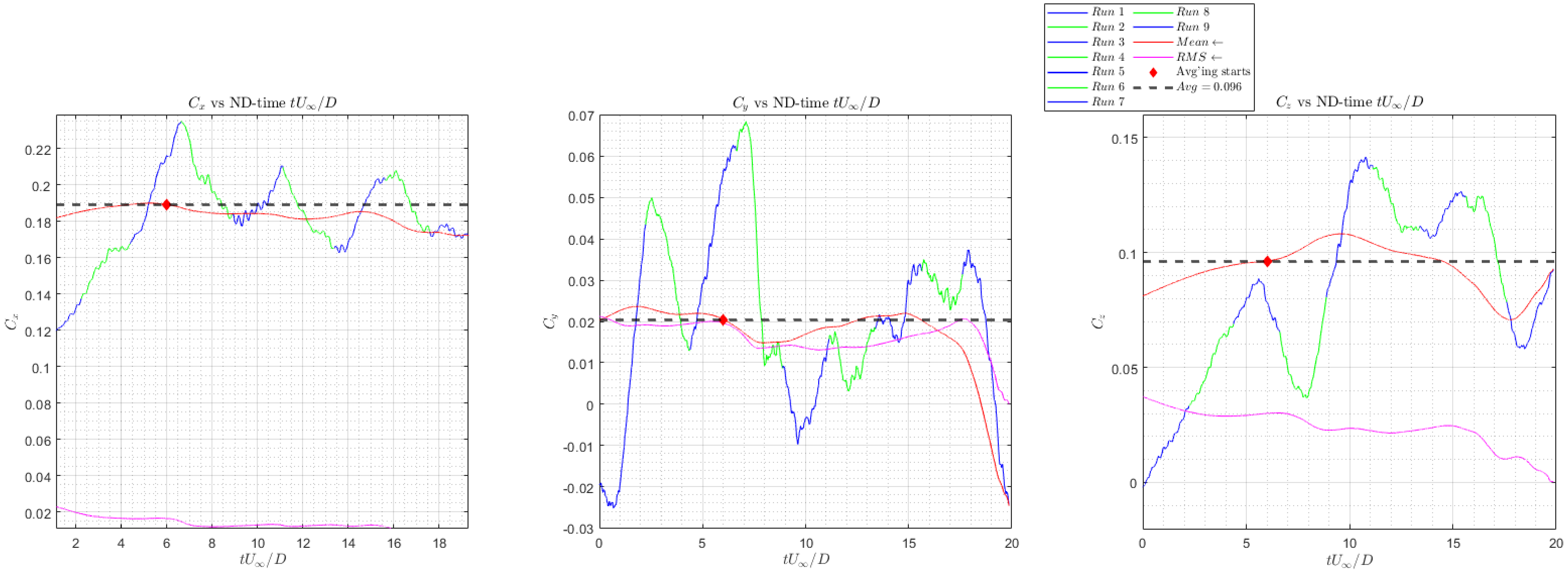


Fig.12: Time History for **4.5 × 10^5, α = 0.1** to show variation of Drag, Swing & Magnus Coefficients with multiple computations along with the Mean and RMS curves

Computation (Re = 4.5×10^5, α = 0.2)

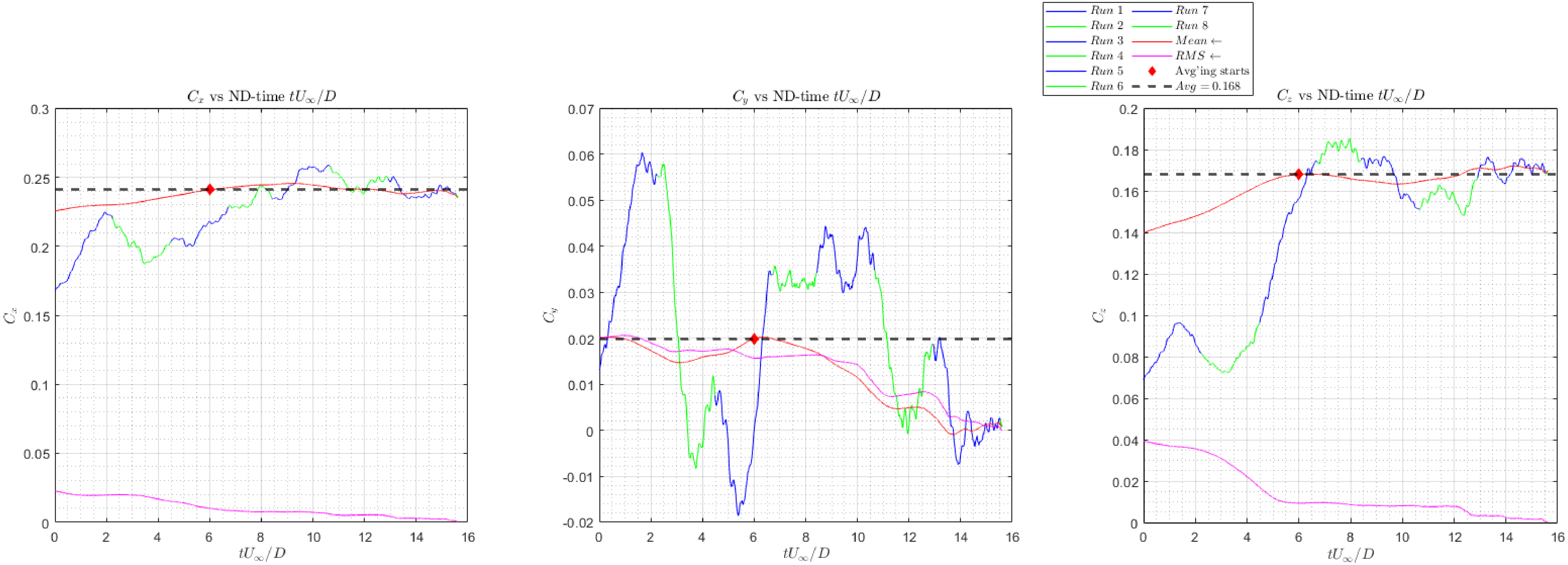


Fig.13: Time History for **4.5×10^5, α = 0.2** to show variation of Drag, Swing & Magnus Coefficients with multiple computations along with the Mean and RMS curves

Scatter Plot of ‘α vs Re’ for Cricket Ball Data

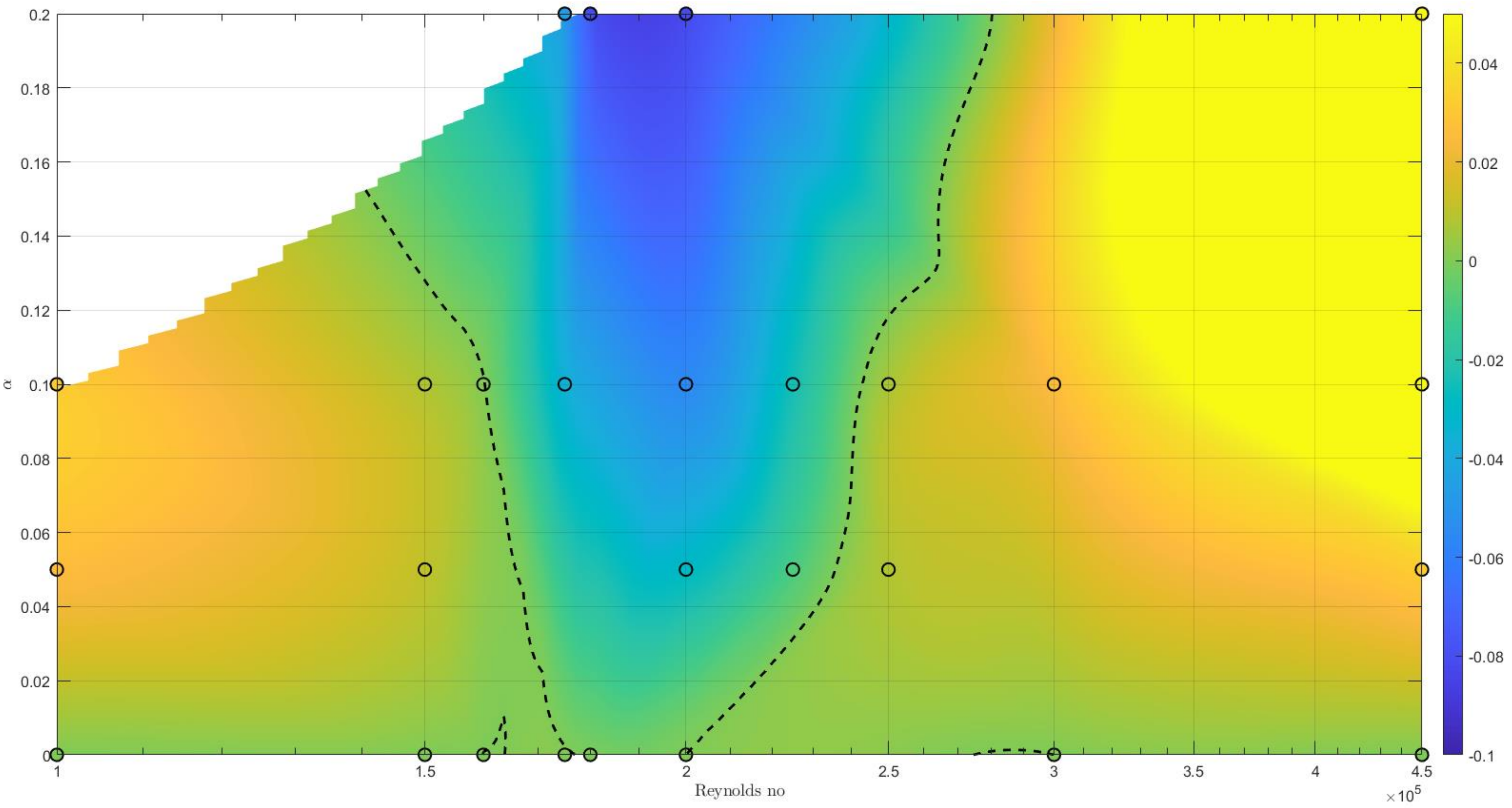


Fig.14: Scatter plot of Magnus & Inverse Magnus Coefficients for Cricket Ball [2] [4]

Smooth Sphere at Re = 1.4×10^5

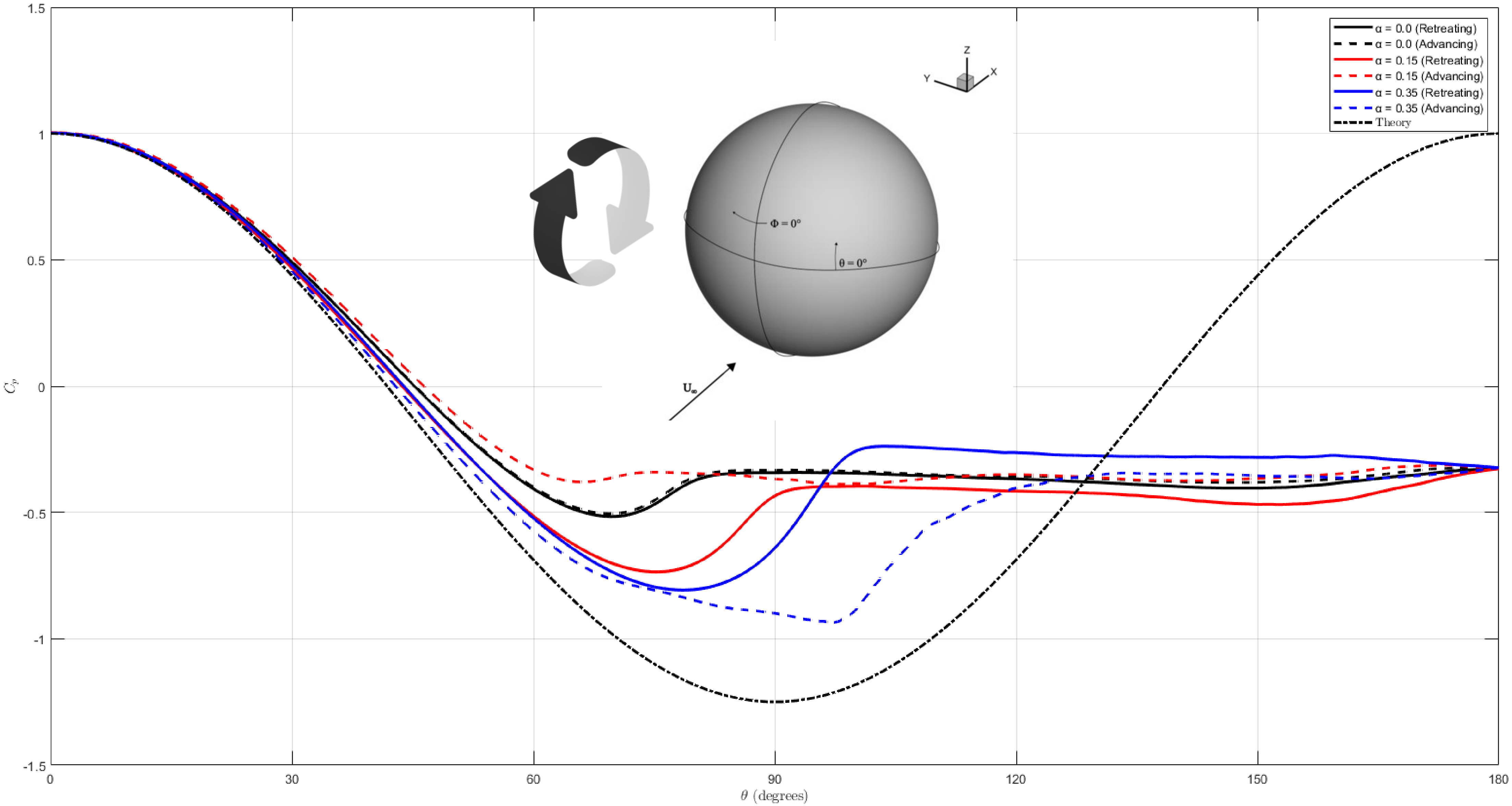


Fig.15: C_p vs Theta plot for Smooth Sphere at Re = 1.4e5 at Y=0 Slice

C_D vs Re for Smooth Sphere

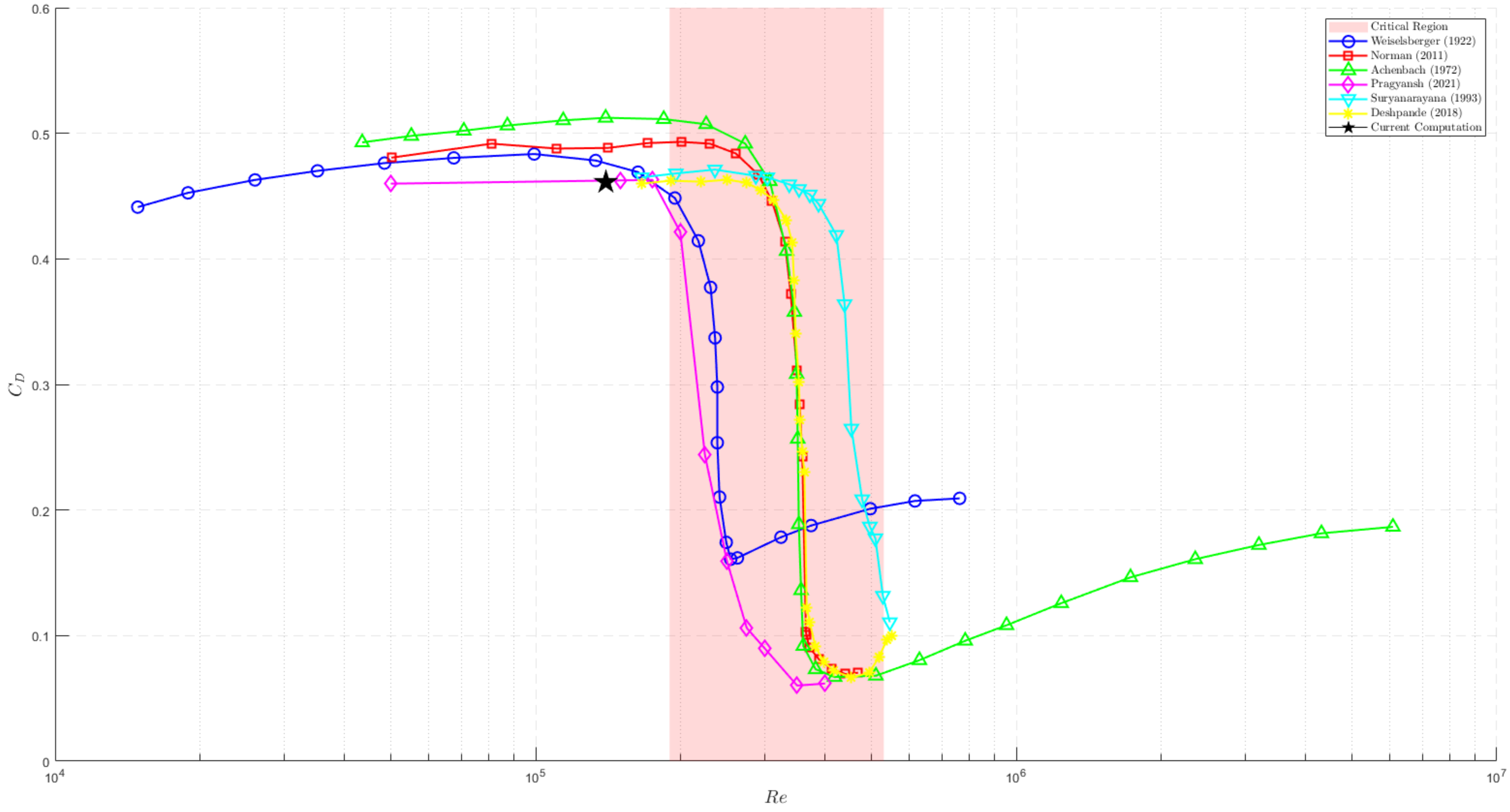
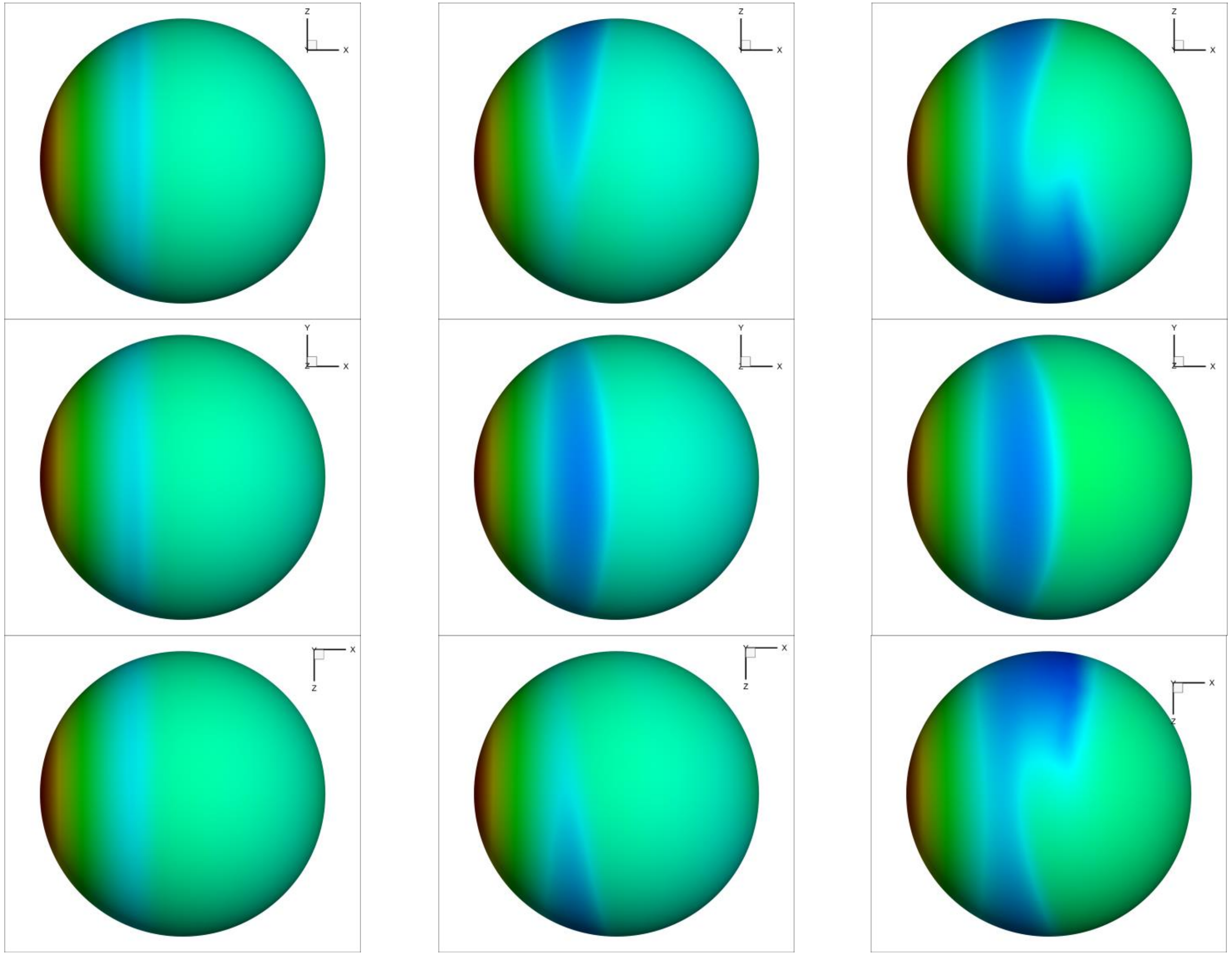


Fig. 16: C_D vs Re plot for Smooth Sphere with the highlighted region being the Critical Region

Surface C_P Contours



α = 0.0 α = 0.15 α = 0.35

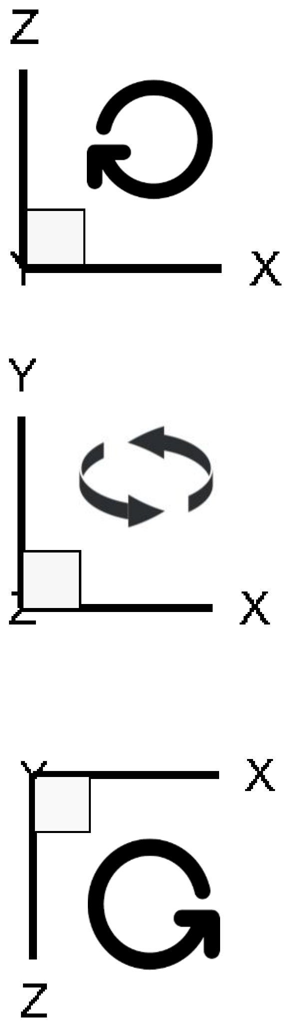


Fig. 17: Surface Cp Contours for various Alpha at Re = 1.4 x 10^5 for a Smooth Sphere

Scatter Plot of ‘α vs Re’ for Smooth Sphere Data

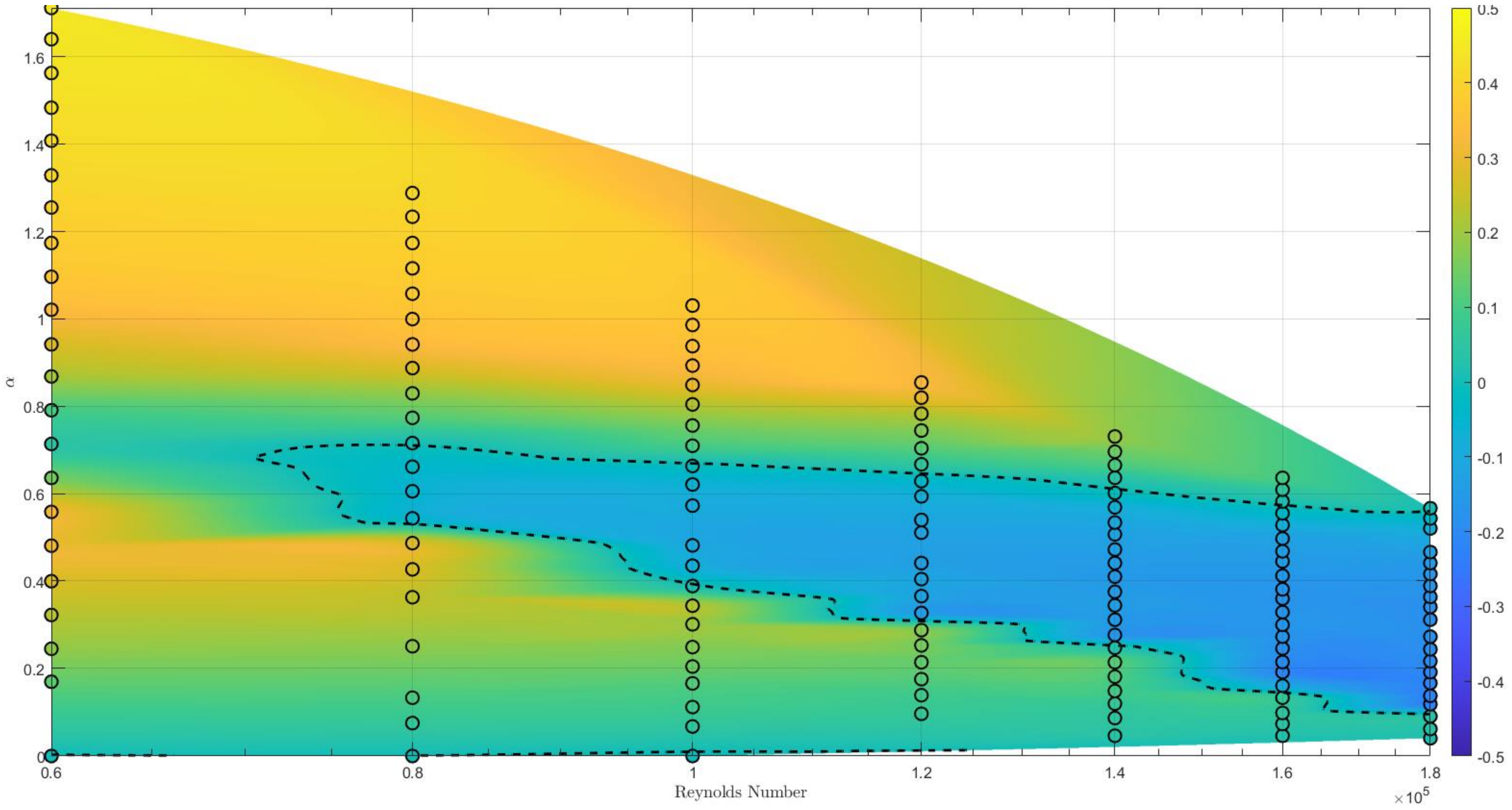


Fig.18: Scatter plot of Magnus & Inverse Magnus Coefficients for Smooth Sphere [5]

Future Work

- Investigating the Effect of Seam Orientation for a Seam Angle of 10°
- Communicating existing data by means of a Research Paper

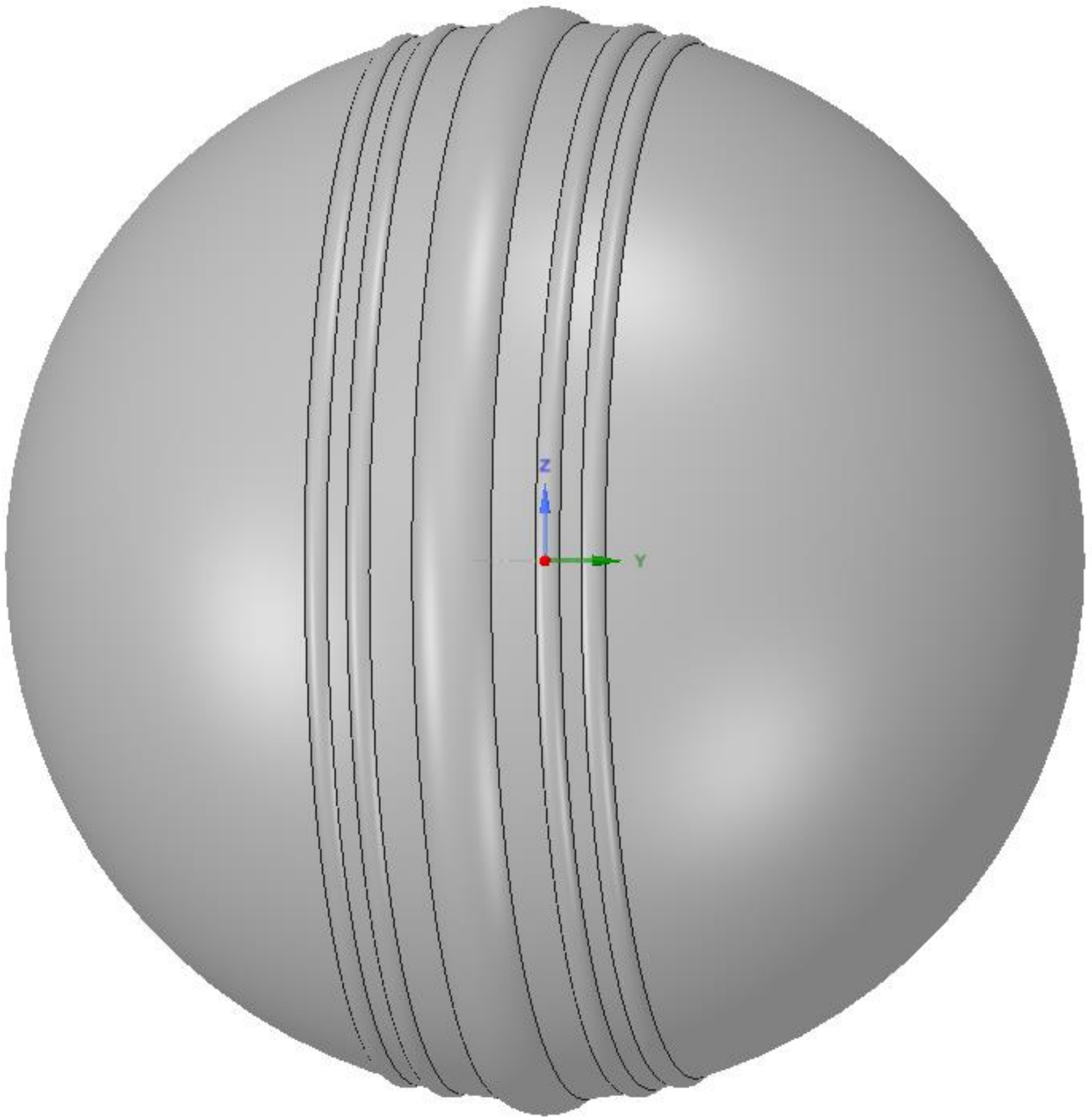


Fig.19: CAD Model of Sphere with five trips (Cricket Ball) at 10° Seam Orientation

References

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Thank You…

Suggestions & Questions are Welcome