

# AS1-LES of the transitional flow around an infinite cylinder at $Re=3900$

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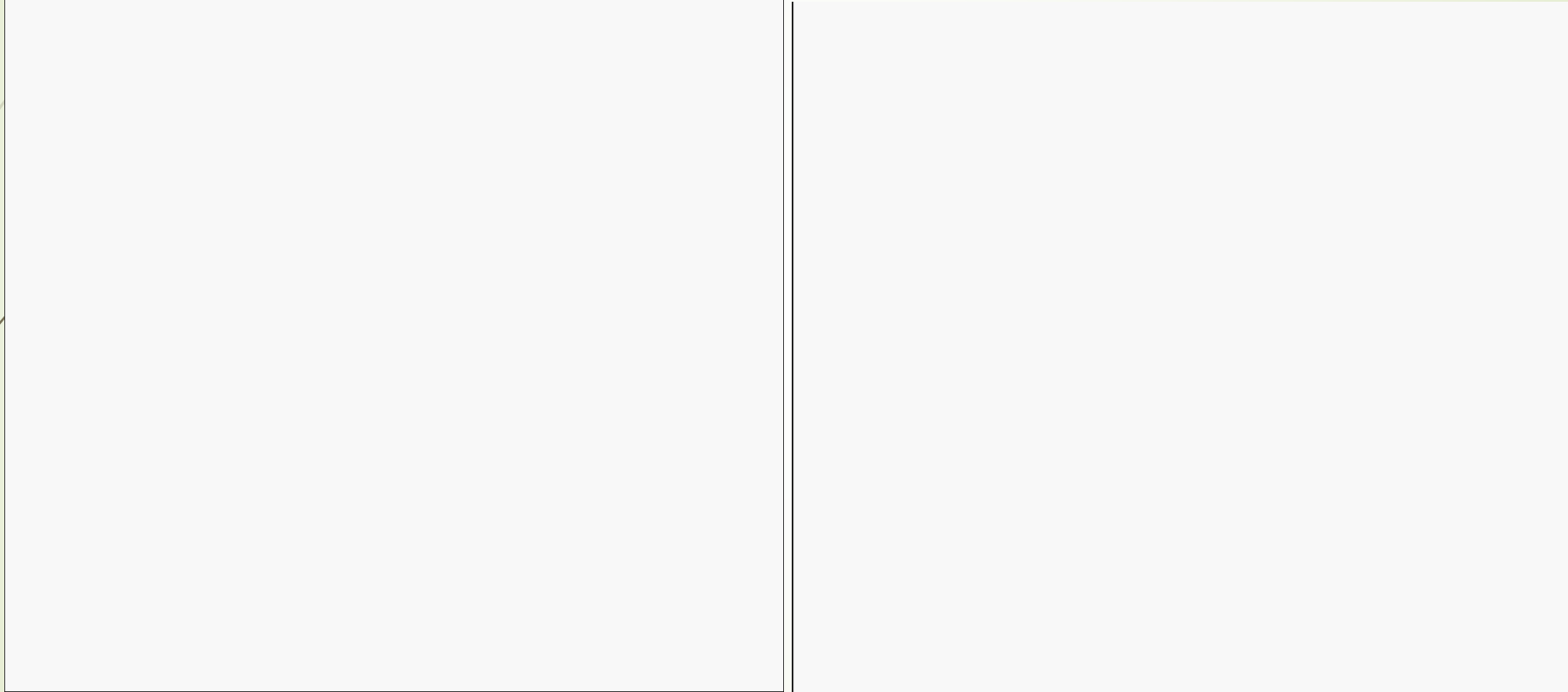
# Main Features of KU's hpMUSIC Code

- Object-oriented hp-adaptive MULTiphysics Simulation Code with hanging nodes
- FR/CPR formulations solving inviscid, laminar, LES and RANS (SA model) equations
- Capable of handling mixed 2D and 3D elements including triangles, quadrilaterals, tetrahedrals, hexahedrals, prisms and pyramids
- Support dynamic moving grids
- Explicit and implicit time integration schemes (Runge-Kutta, LU-SGS, GMRES with various preconditioners)
- Limiters and artificial viscosity for shock-capturing



# Rectangular Wing

30x more thrust generated by flapping + pitching



Flapping only

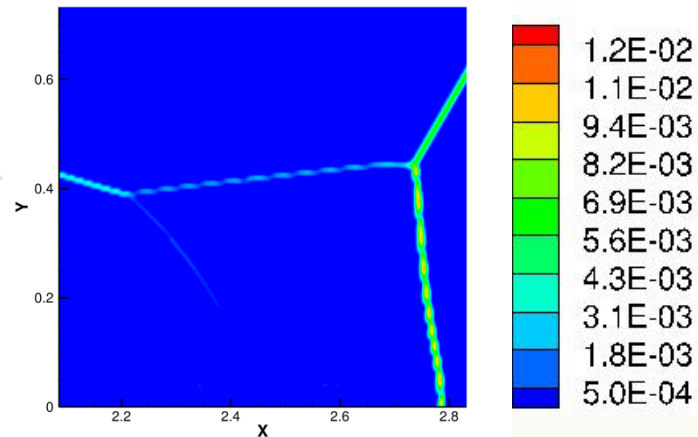
Flapping + pitching

# Double Mach Reflection

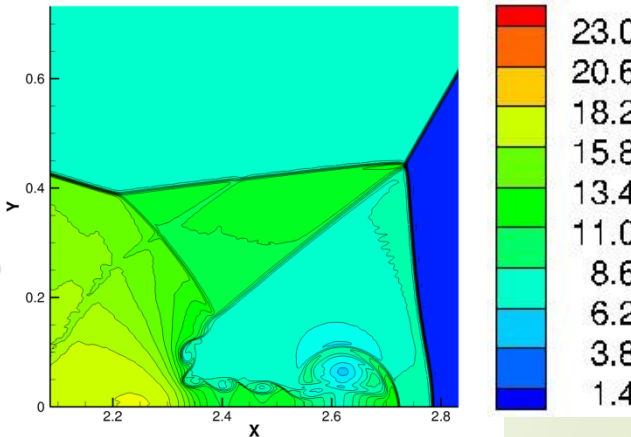
Density



Artificial  
viscosity  
at  $t=0.2s$



Density  
at  $t=0.2s$

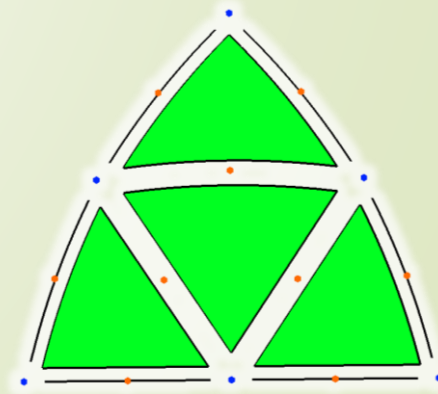


$Ma = 10$ ,  $P^3$  reconstruction (4<sup>th</sup> order),  $t \in [0, 0.2s]$

Computational domain  $[0, 4] \times [0, 1]$ ,  $816 \times 204$  elements

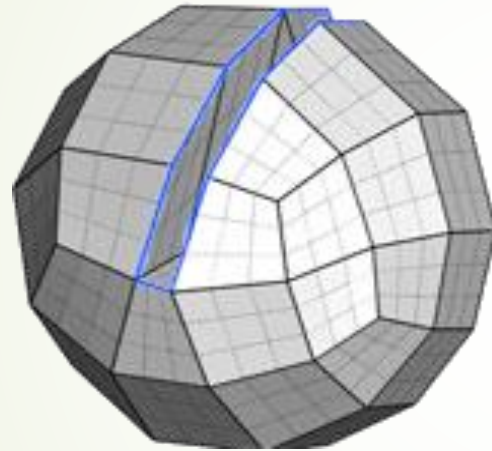
# KU's meshCurve Code – without CAD

- Covert linear meshes into high-order meshes in CGNS format.
- Automatically detect geometrically important features (sharp edges and corners)
- Least-squares based surface reconstruction to recover curved geometries
- Curve interior elements to remove negative Jacobians

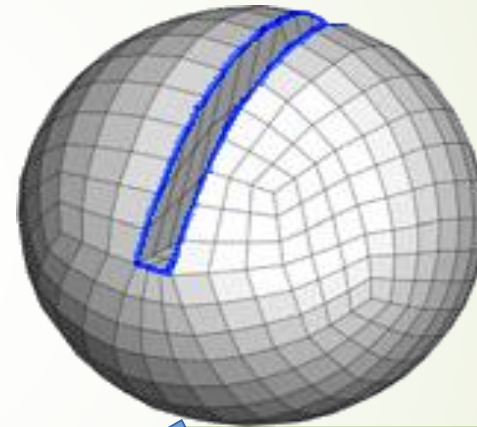


# The Mission

For high-order CFD simulations, we need to



change this



to this

without smoothing away edges.



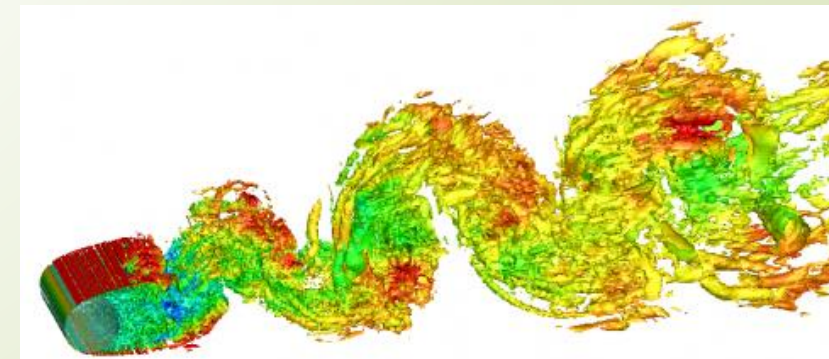


# Two minute demo

- [https://documents.ku.edu/users2/ibjeremy/meshCurve\\_animations/meshCurve\\_demo.html](https://documents.ku.edu/users2/ibjeremy/meshCurve_animations/meshCurve_demo.html)
- Go to: zjwang.com for the link

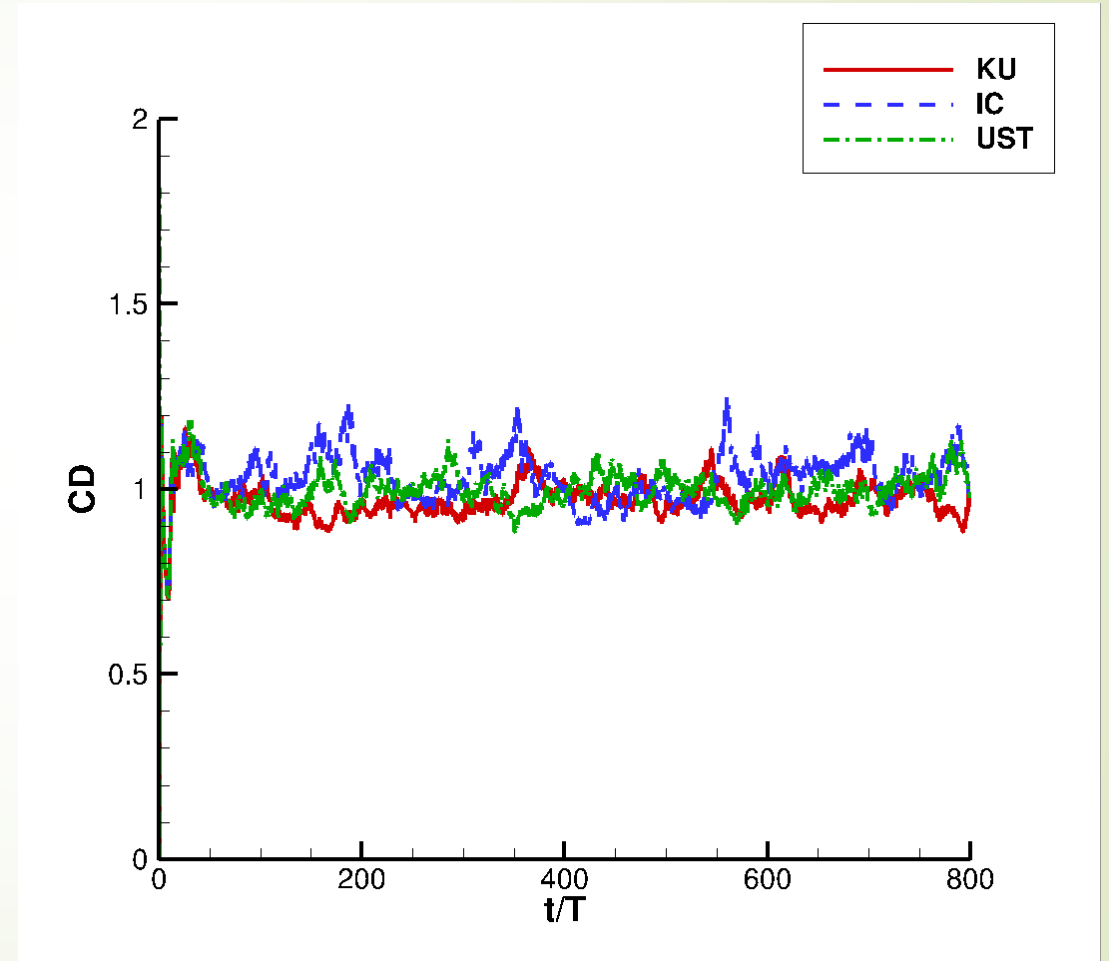
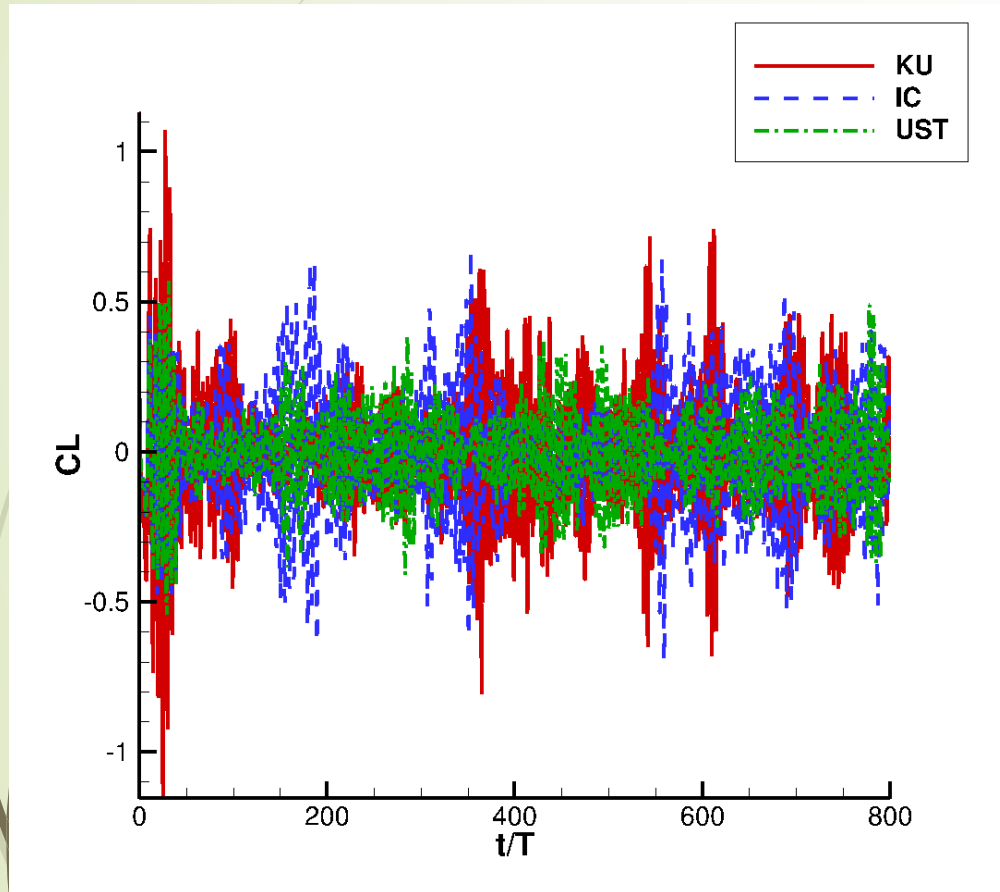
# Main Characteristics of the Problem

- Infinitely smooth geometry and initial conditions
- Non-symmetric initial conditions in the span-wise and circumferential directions so that the path to non-symmetric flow pattern is not due to round-off error
- CL and CD errors at  $t = 1$  used as an error indicator
- Transitional and turbulent flow



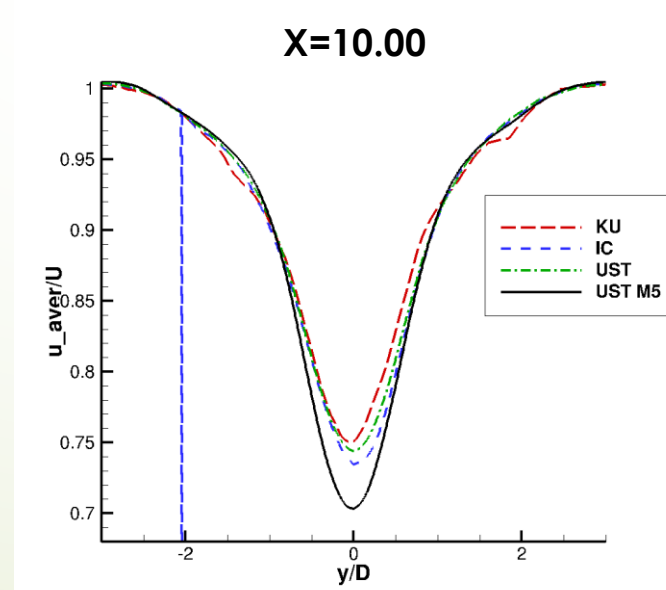
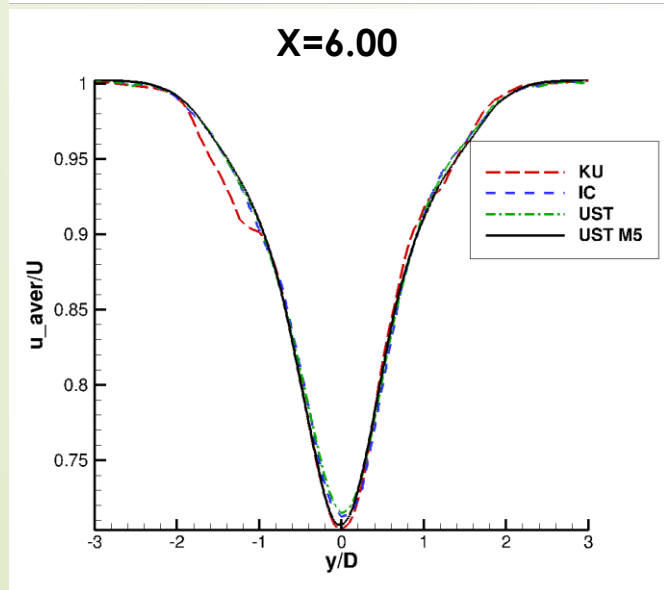
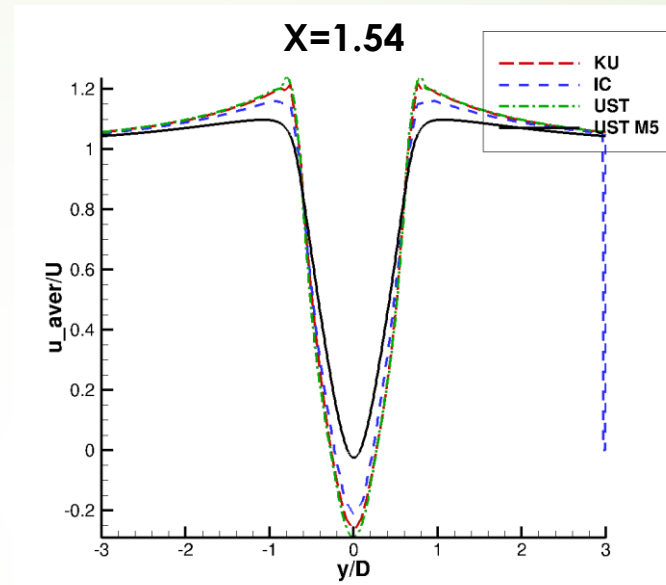
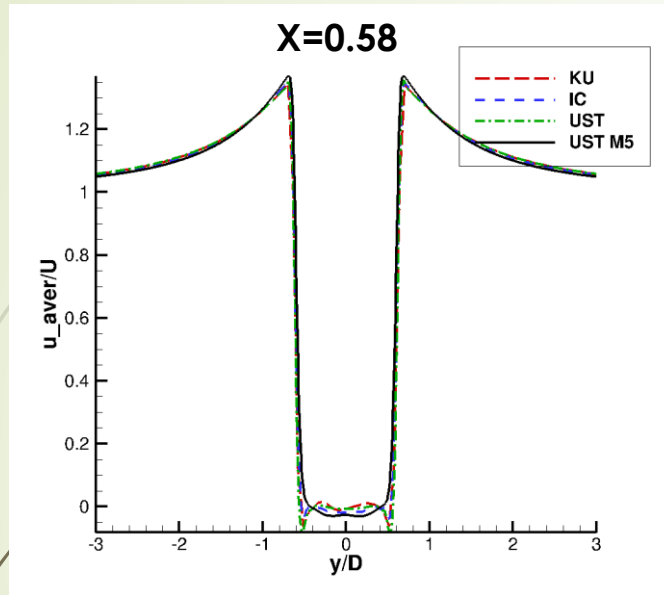


# Coefficient of lift and drag history – p2

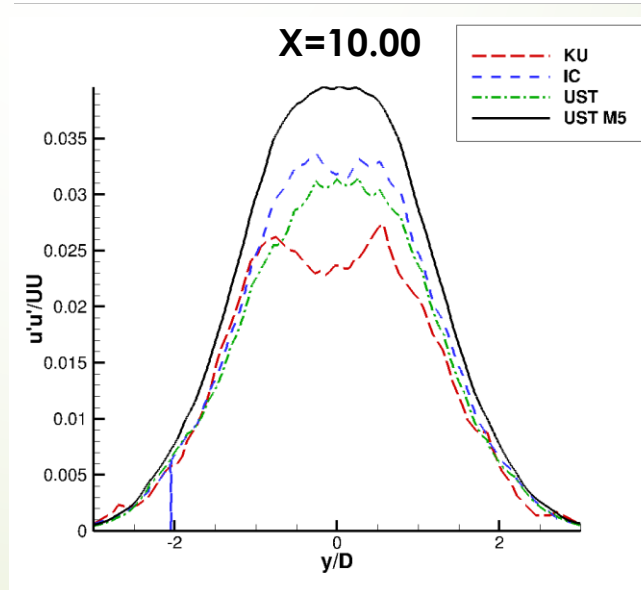
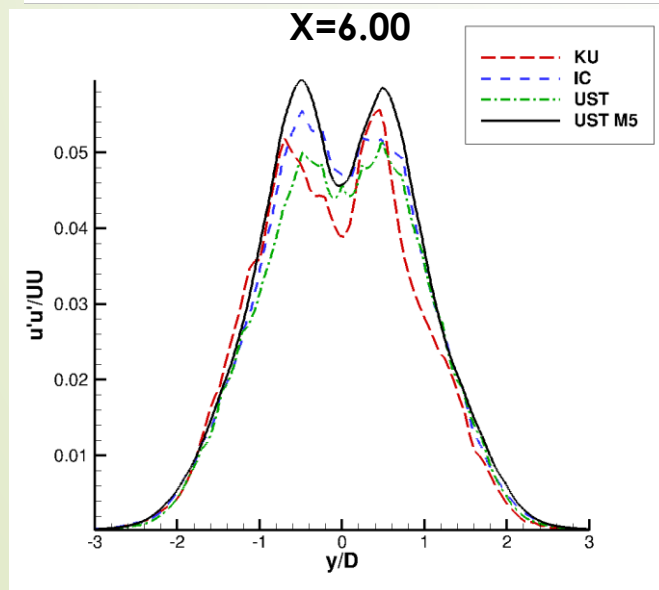
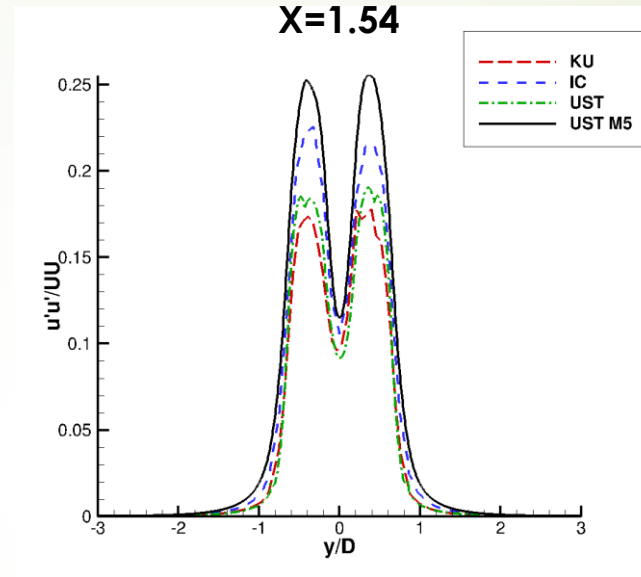
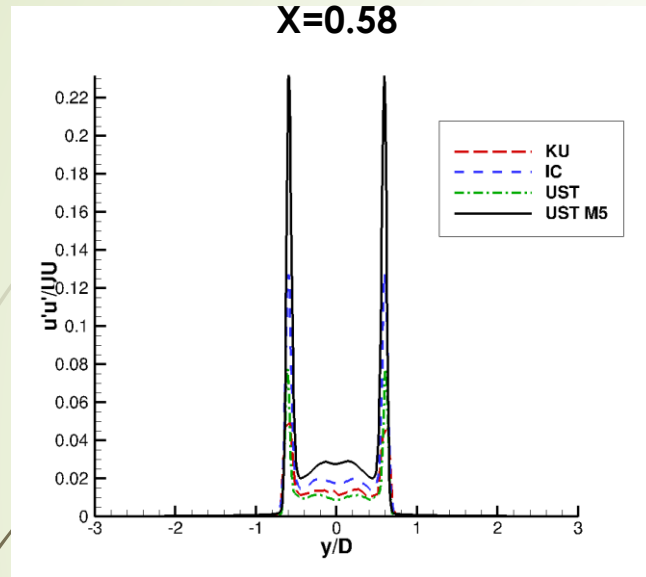


IC, UST, KU have the same converged  $CL$  and  $CD$  at  $t = 1$

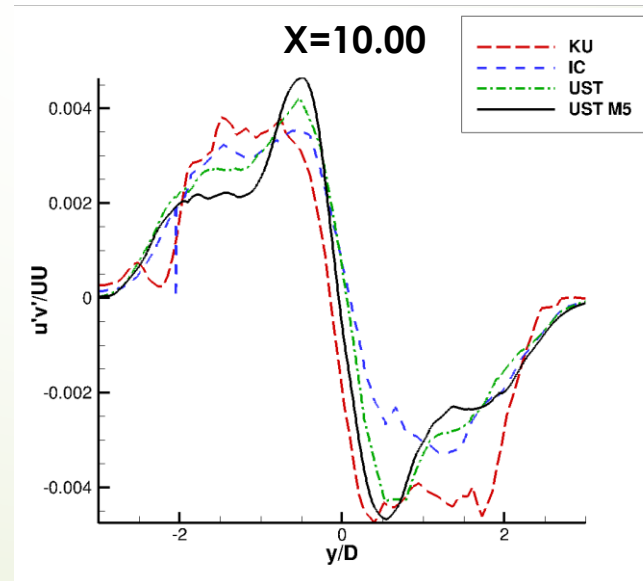
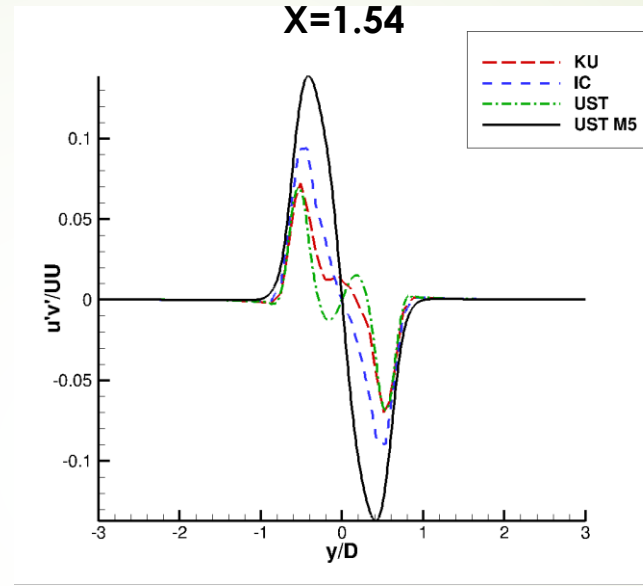
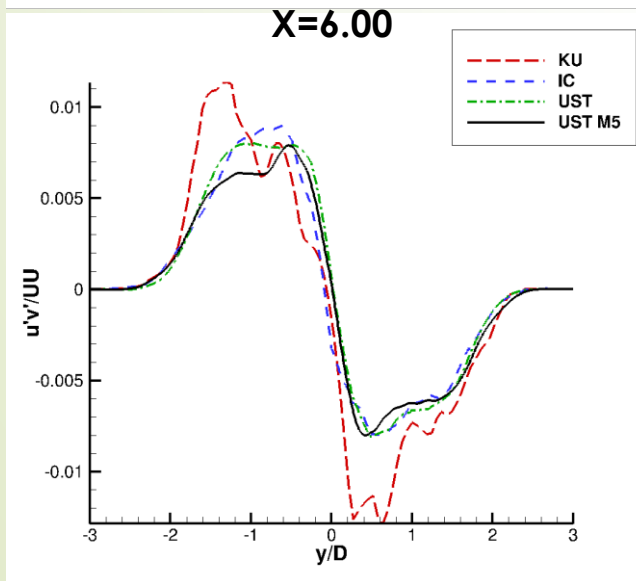
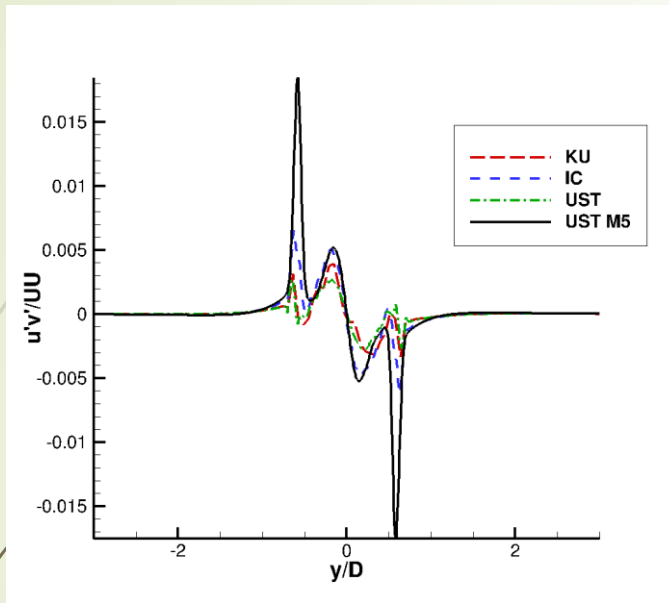
# Streamwise mean velocity



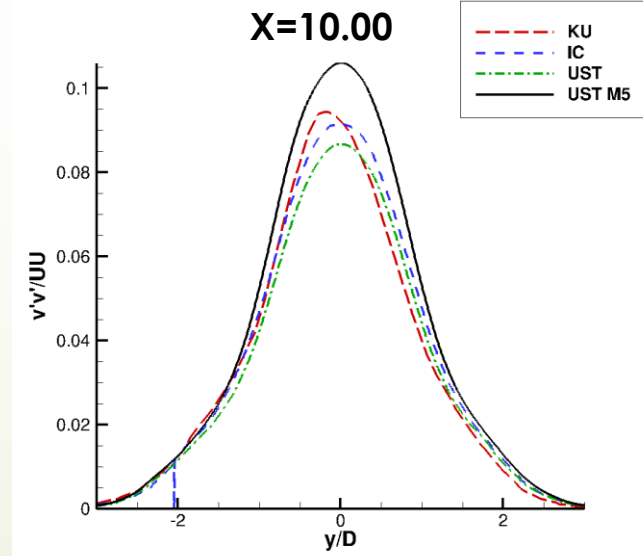
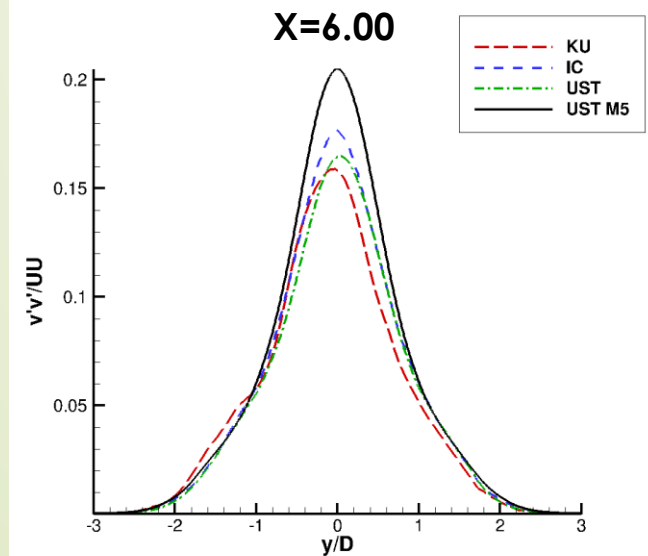
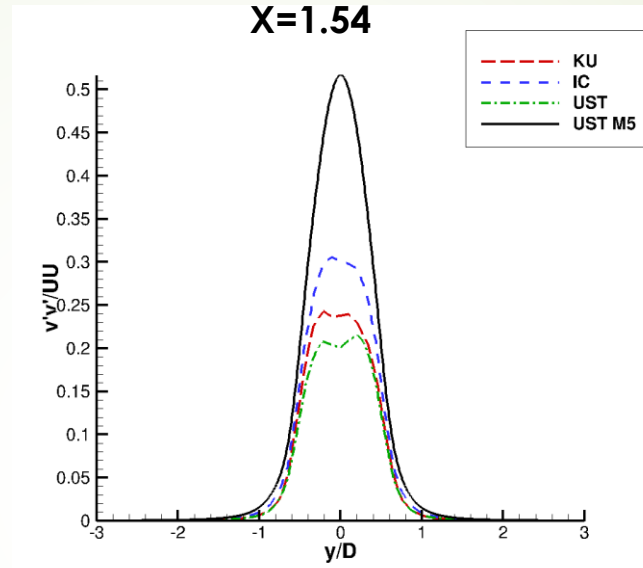
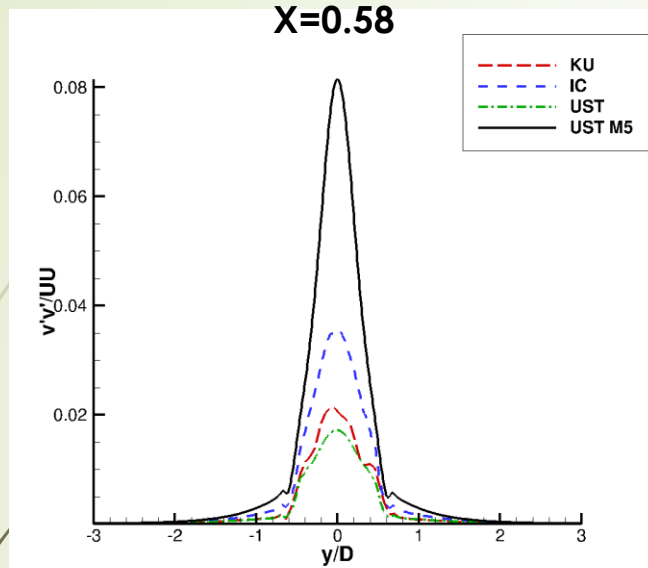
# Reynolds stress $u'u'/U^2$



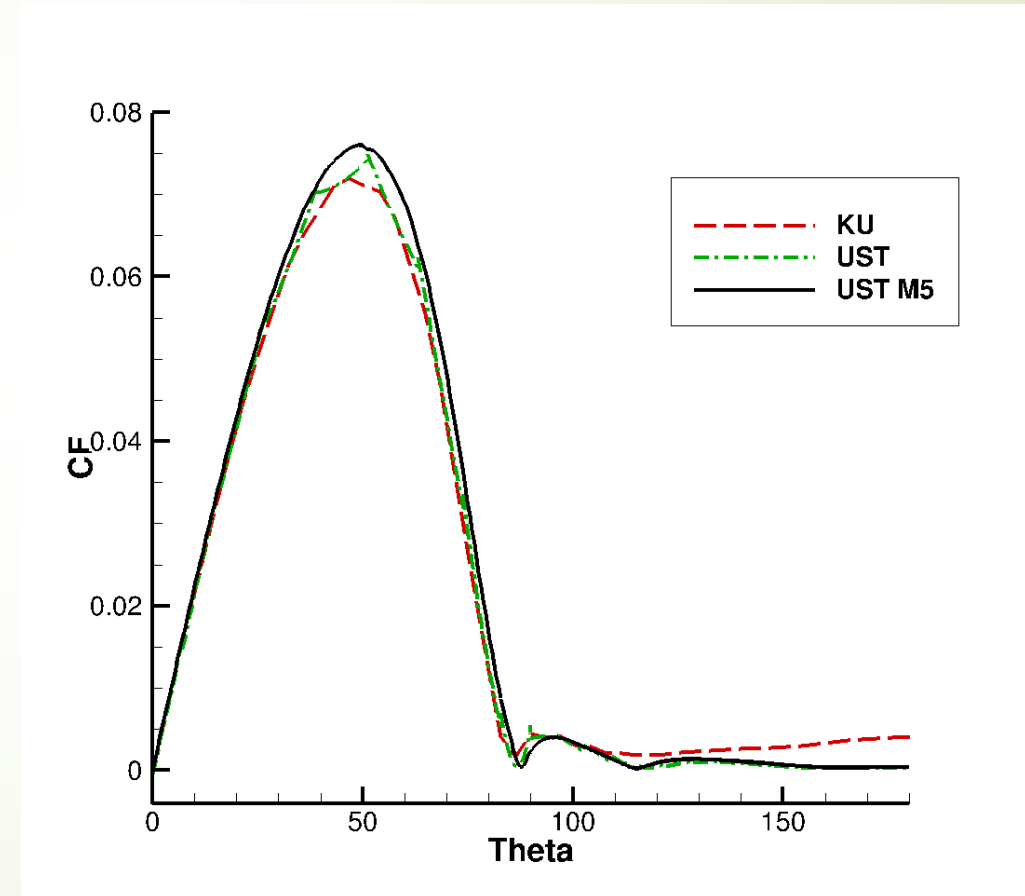
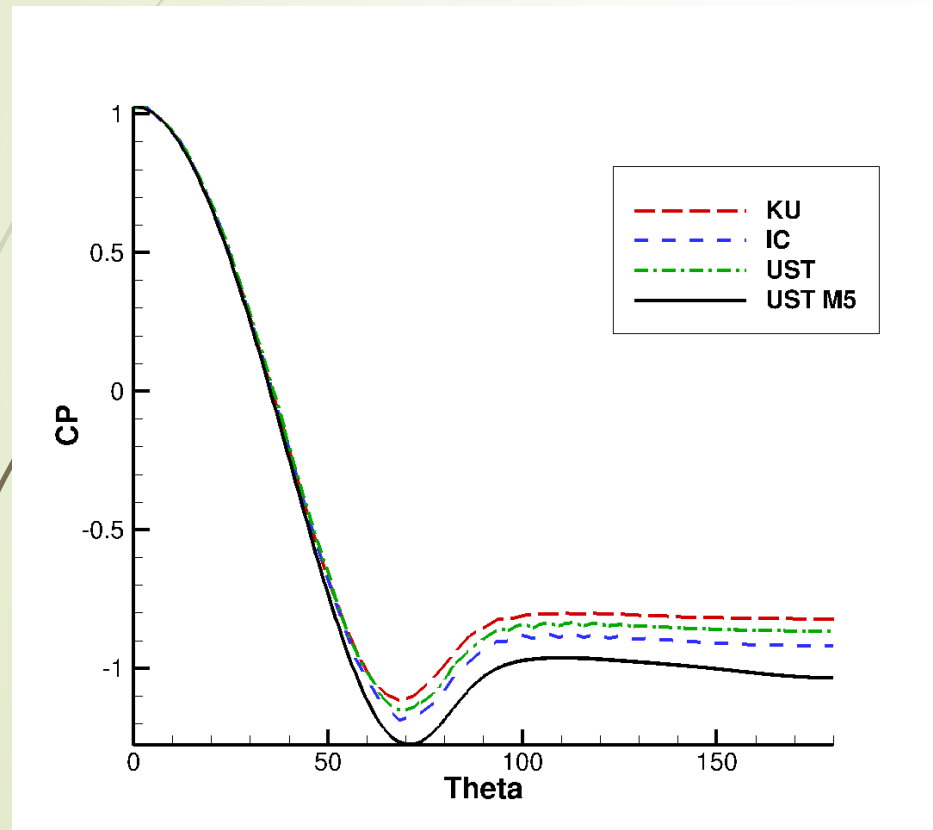
# Reynolds stress $u'v'/U^2$



# Reynolds stress $v'v'/U^2$

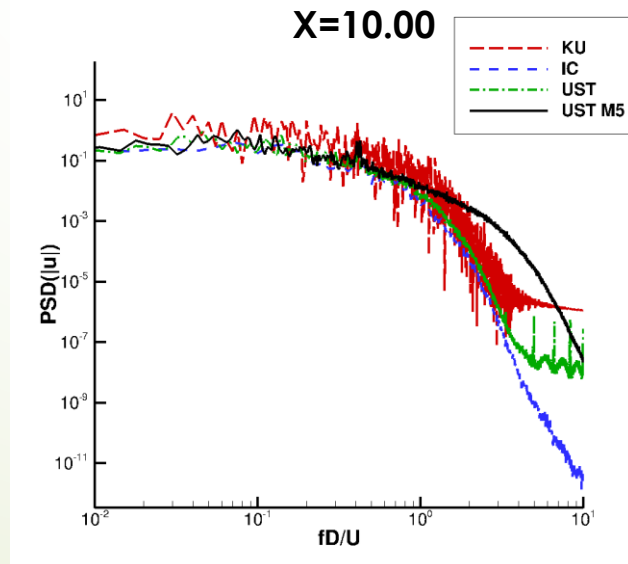
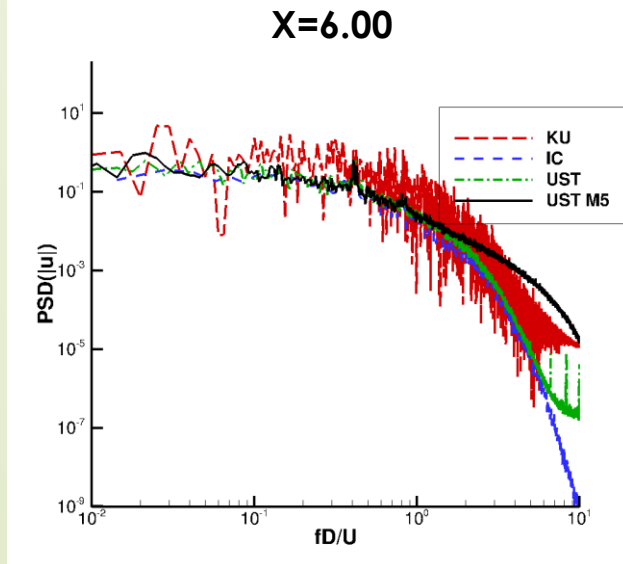
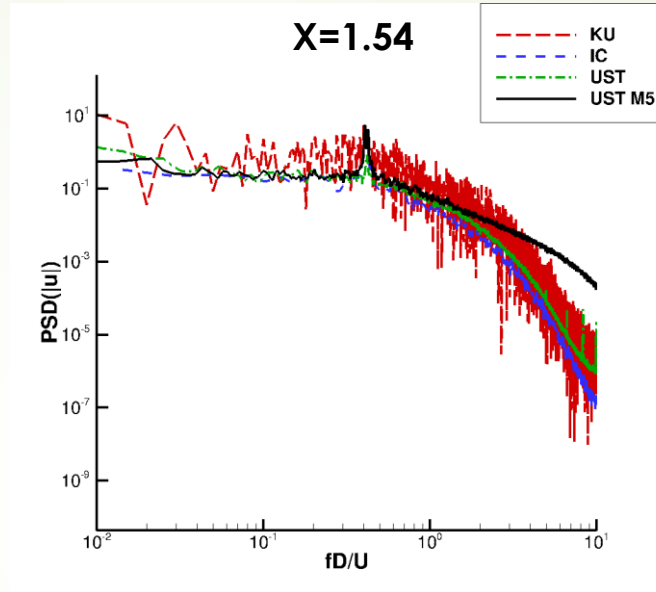
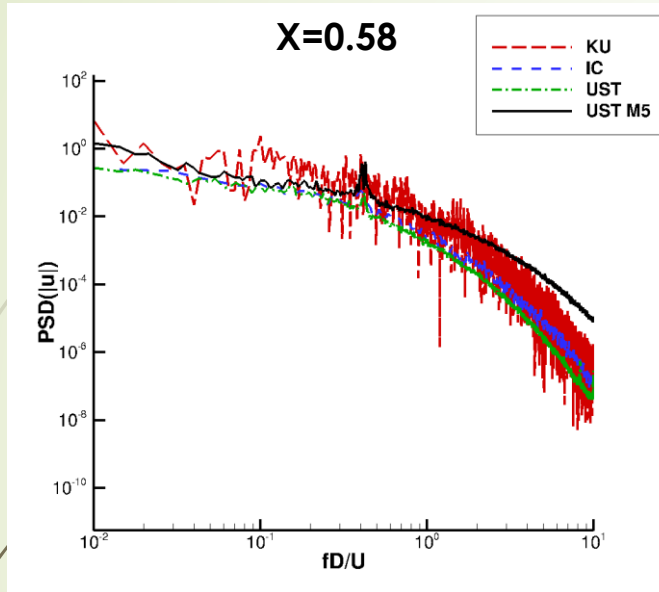


# Coefficients of pressure and skin friction on cylinder surface

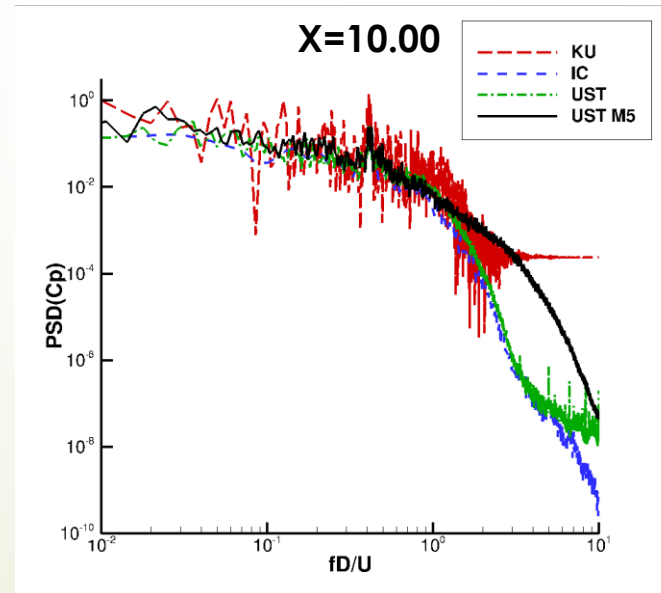
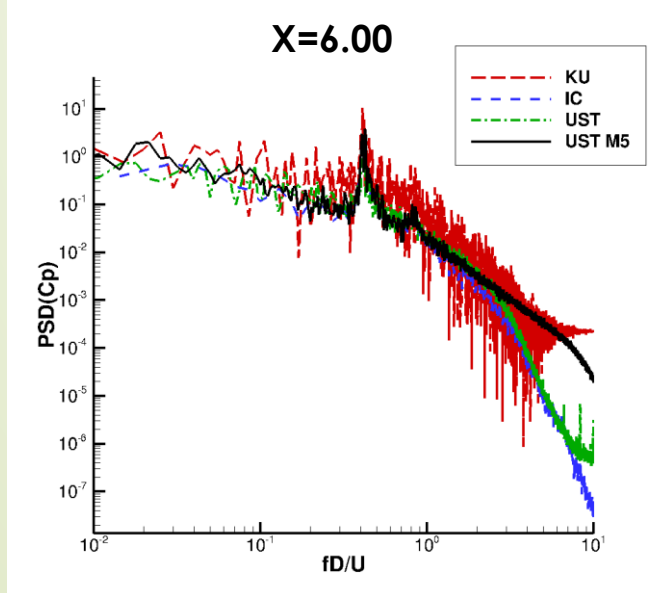
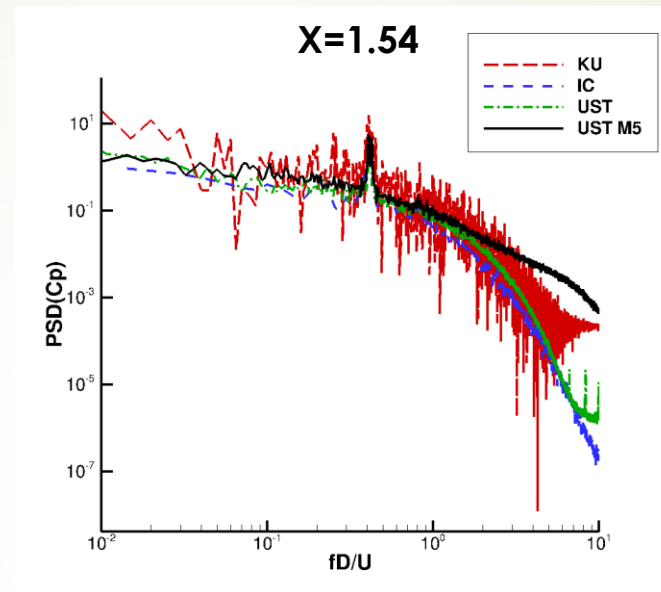
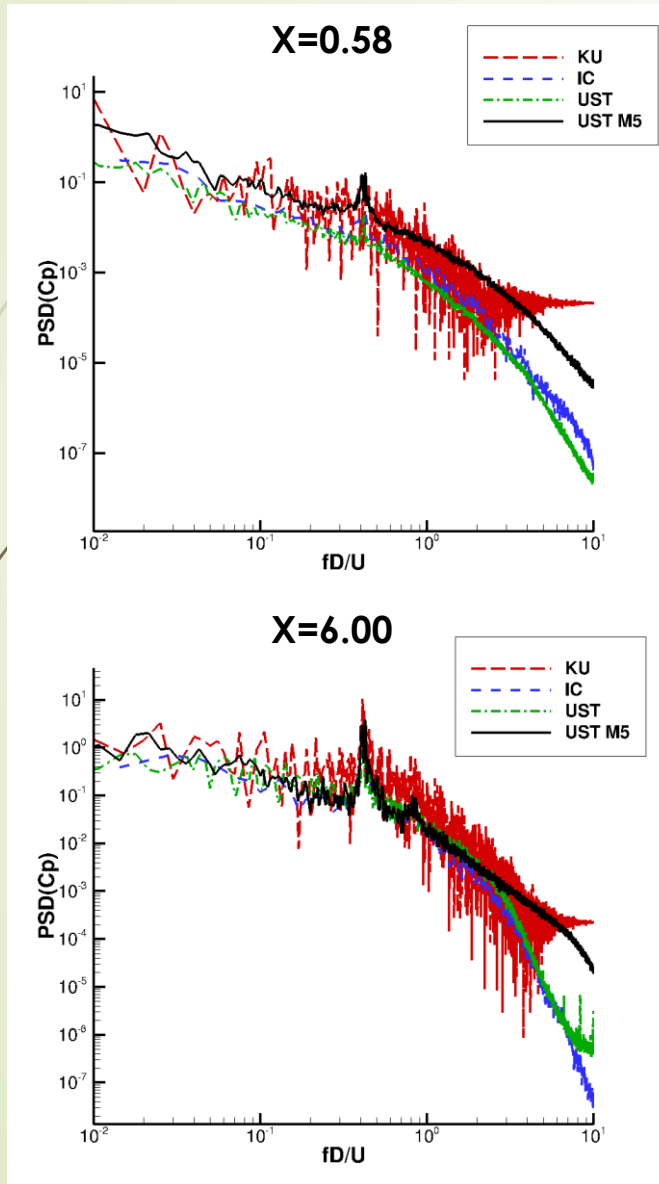




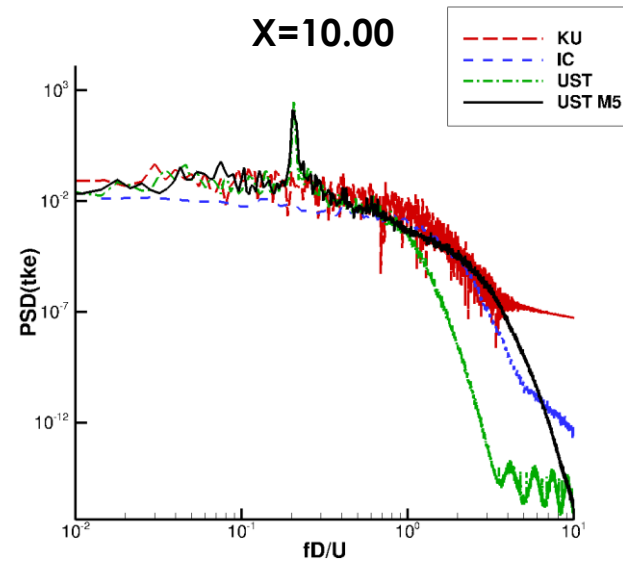
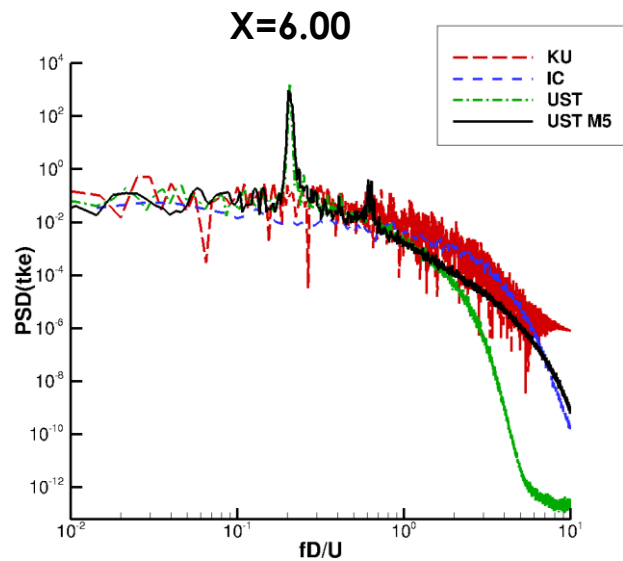
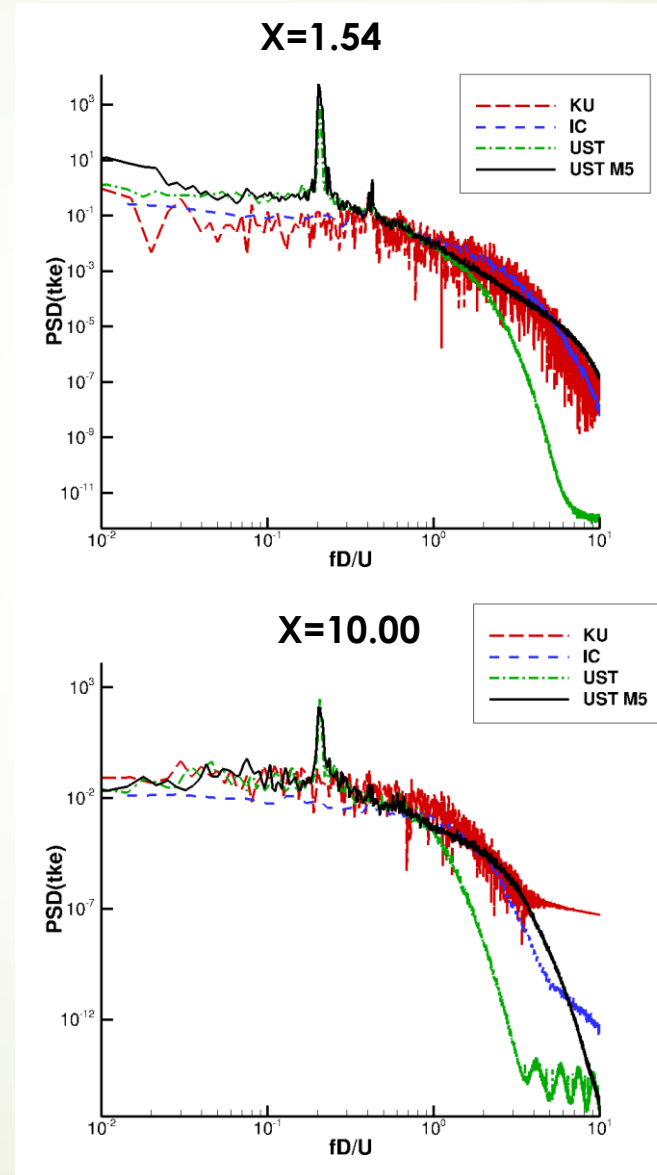
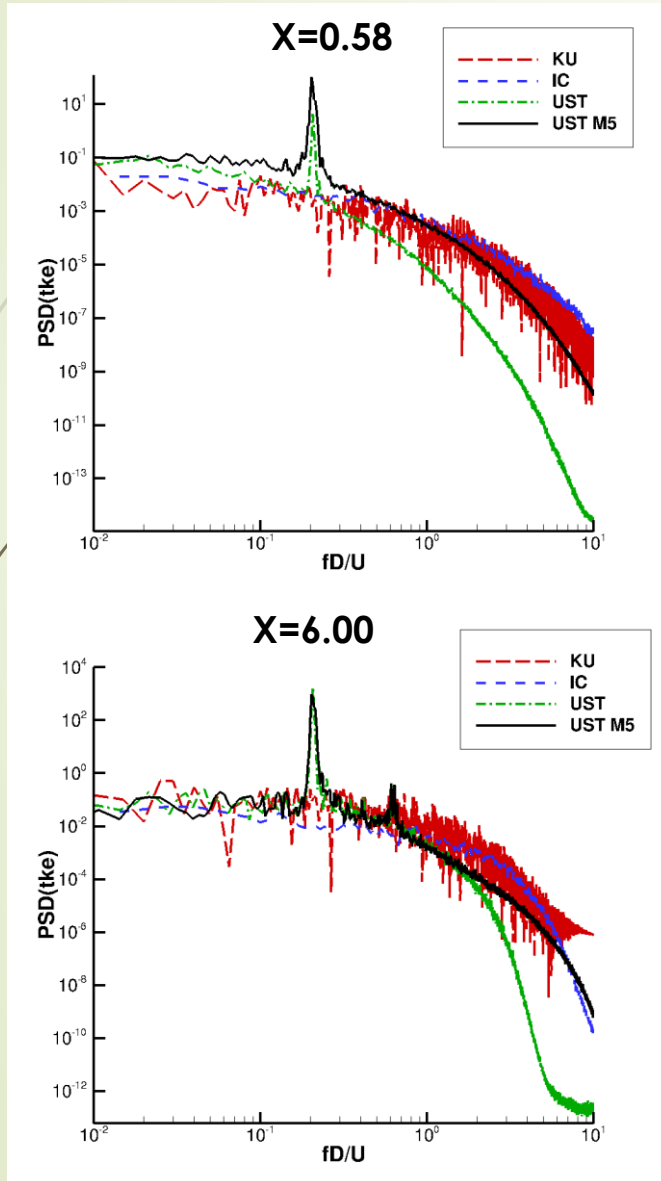
# Power spectral density of | velocity |



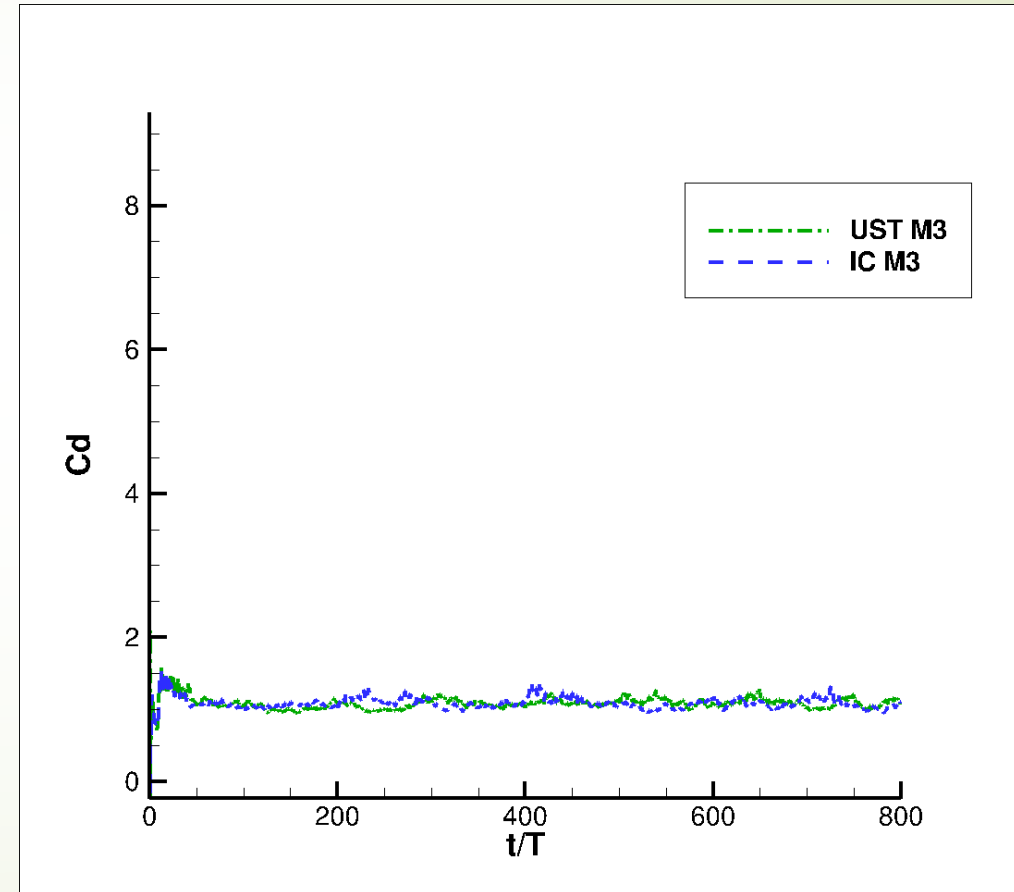
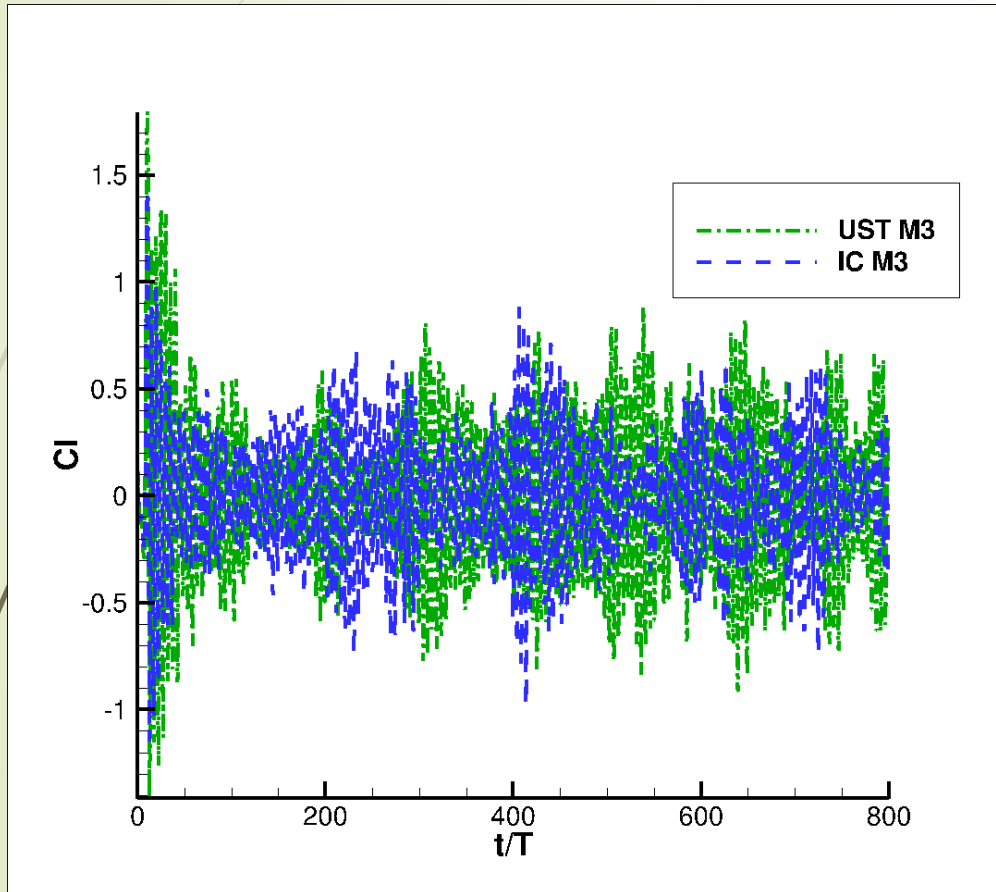
# Power spectral density of $C_p$



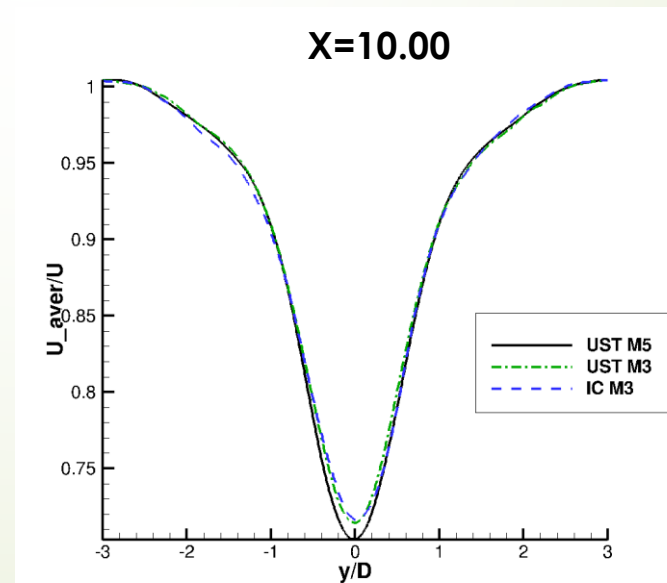
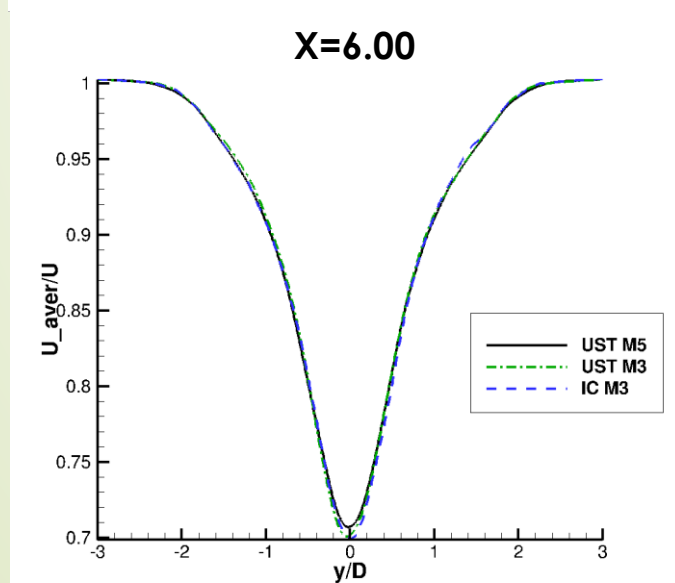
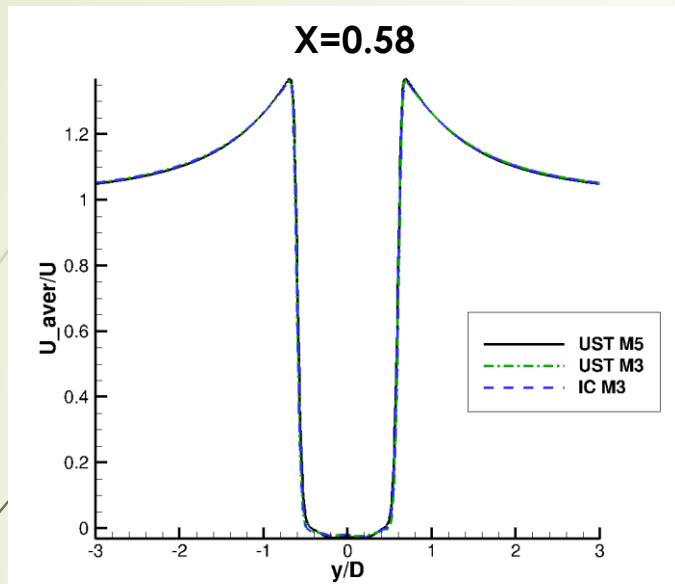
# Power spectral density of tke



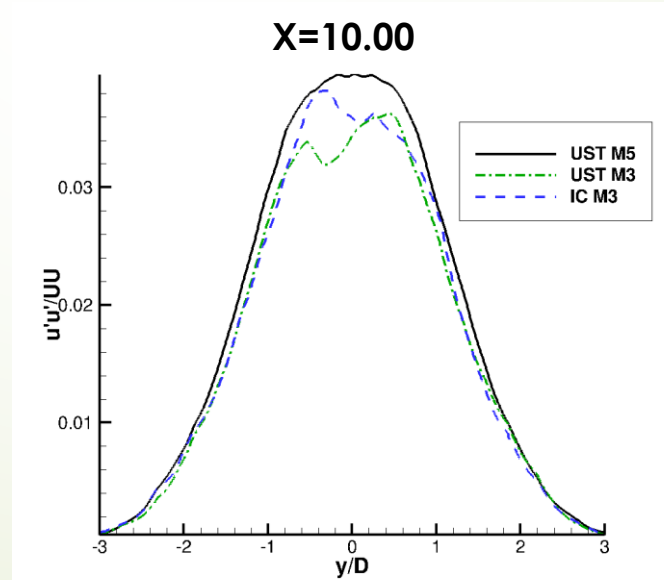
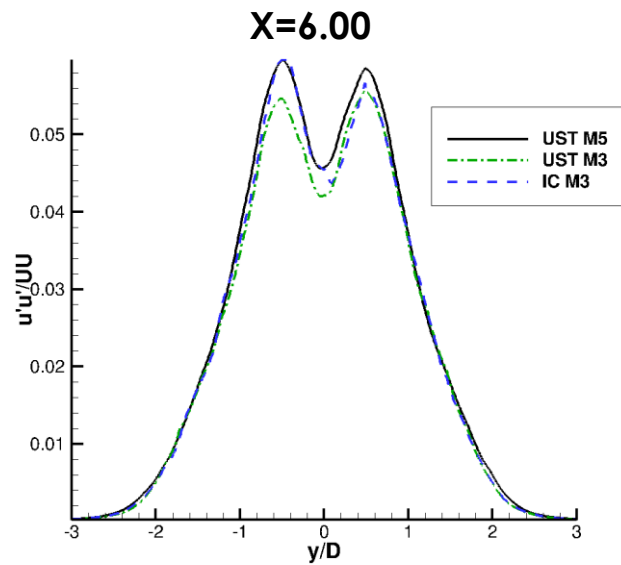
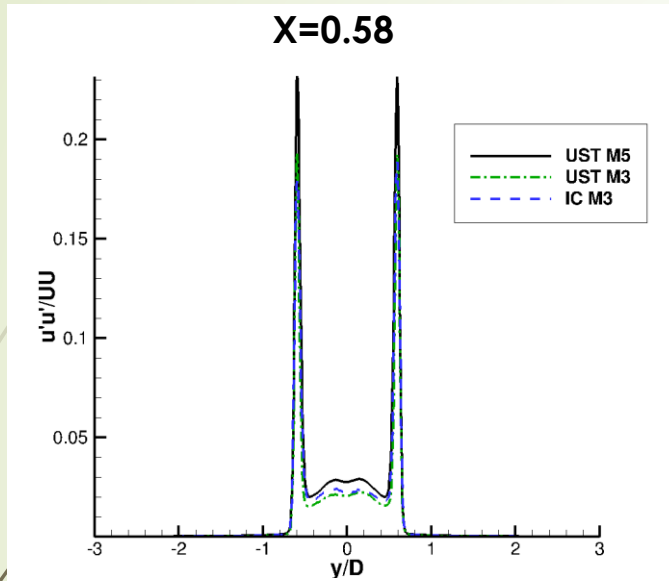
# Coefficient of lift and drag history (p3)



# Streamwise mean velocity



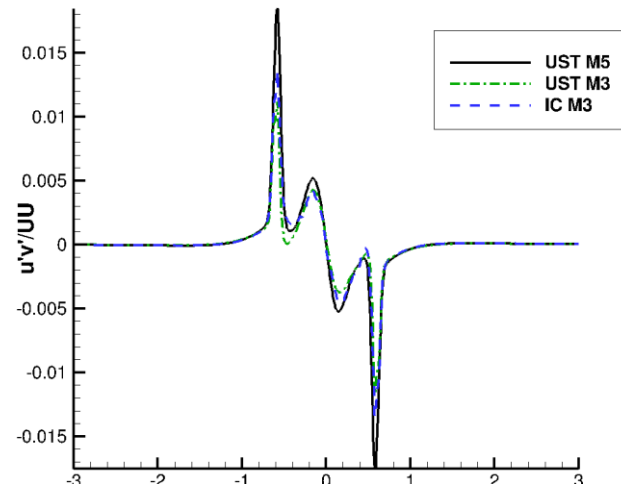
# Reynolds stress $u'u'/U^2$



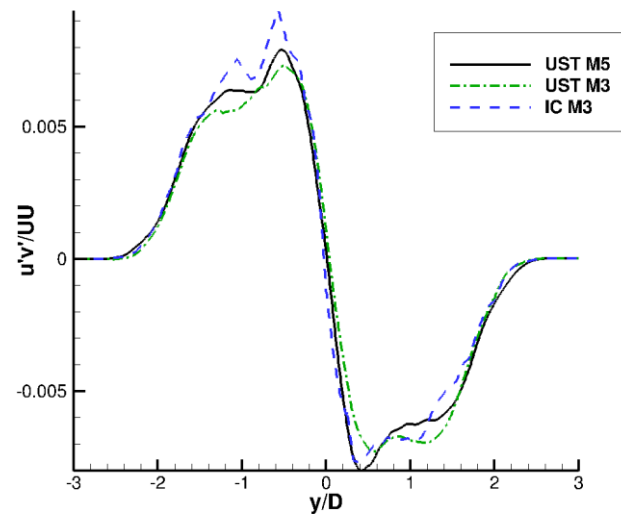


# Reynolds stress $u'v'/U^2$

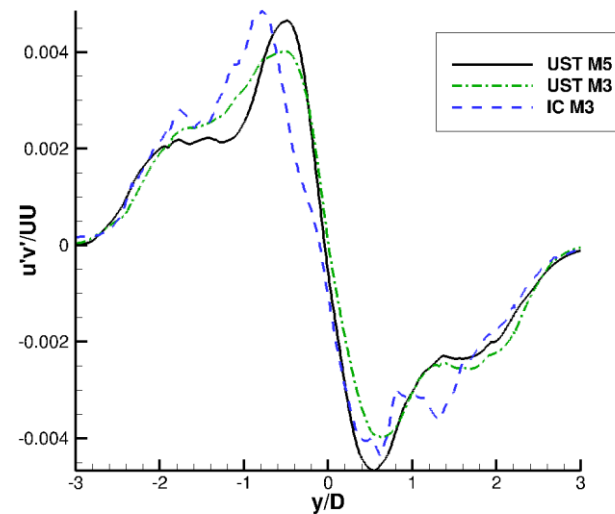
**X=0.58**



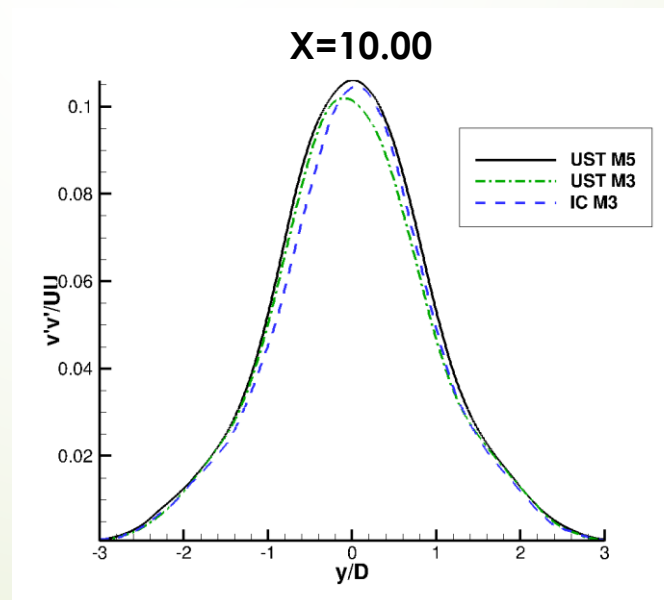
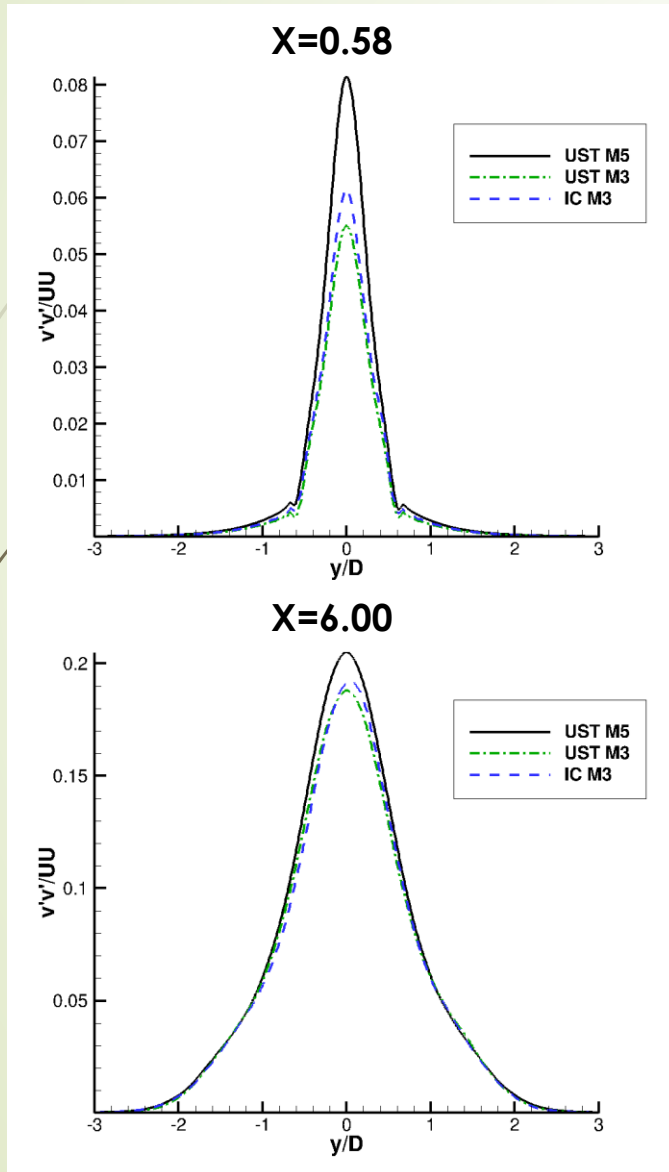
**X=6.00**



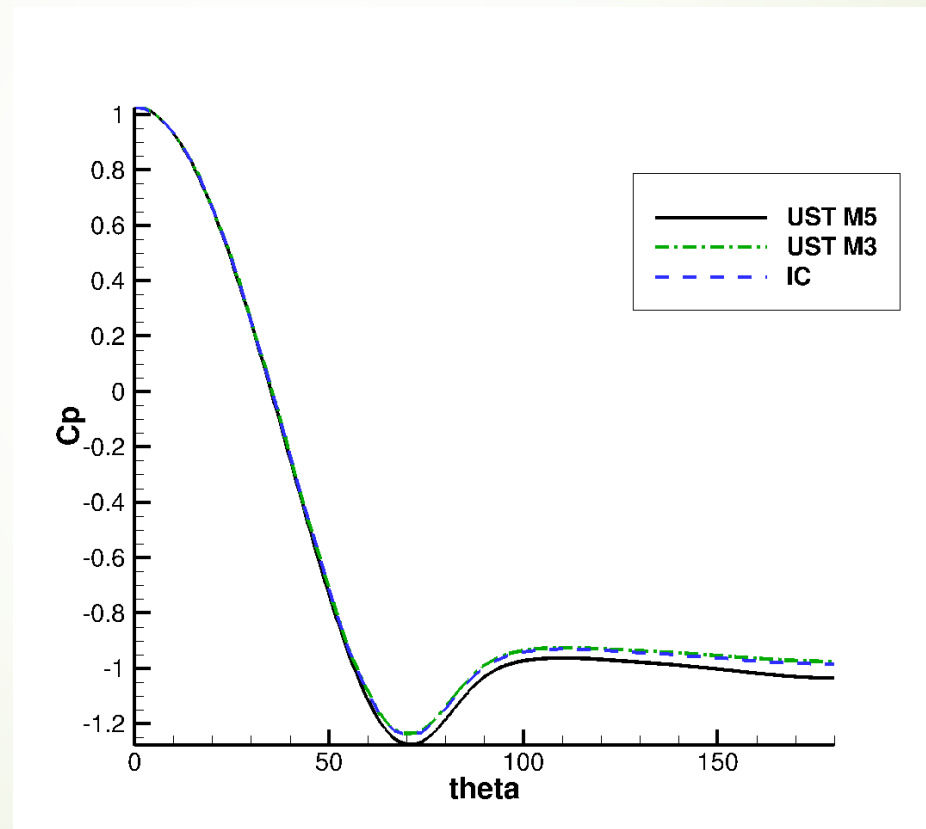
**X=10.00**



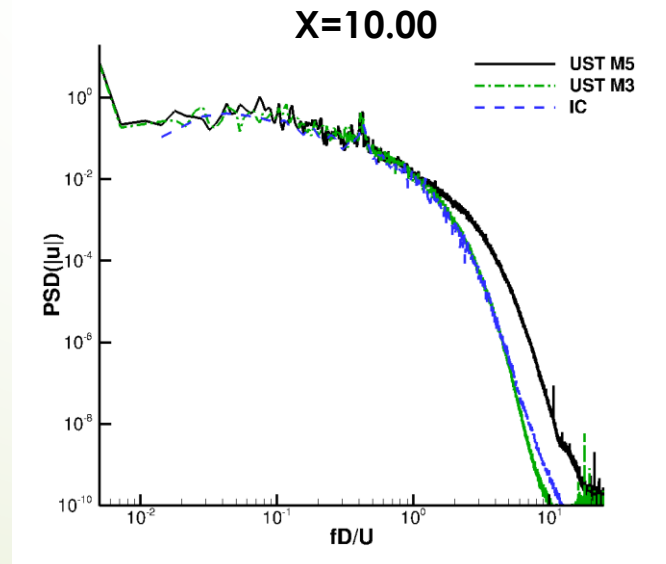
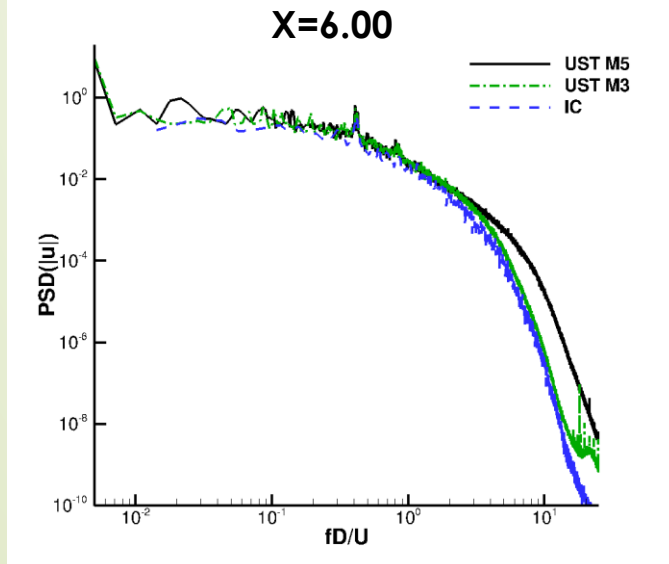
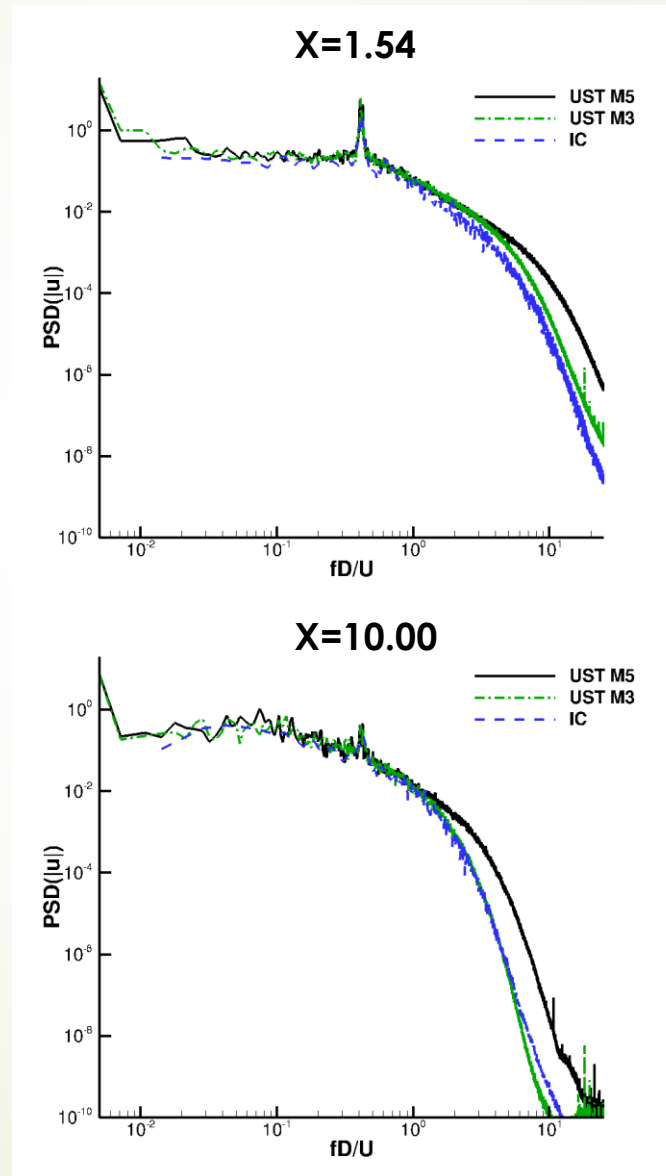
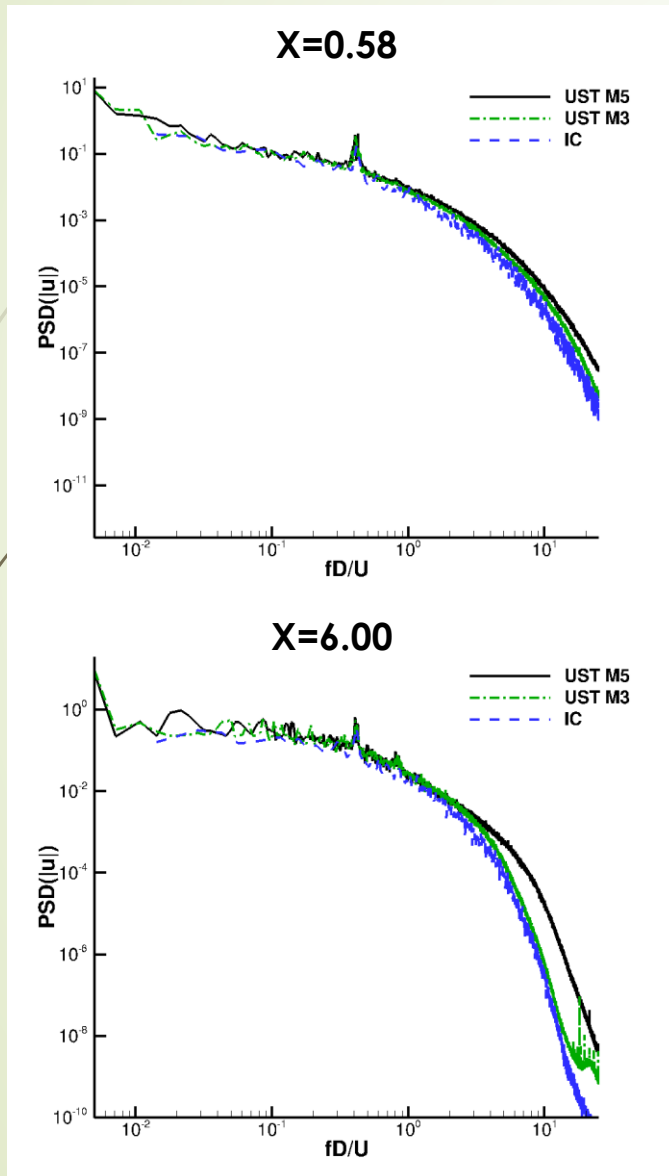
# Reynolds stress $v'v'/U^2$



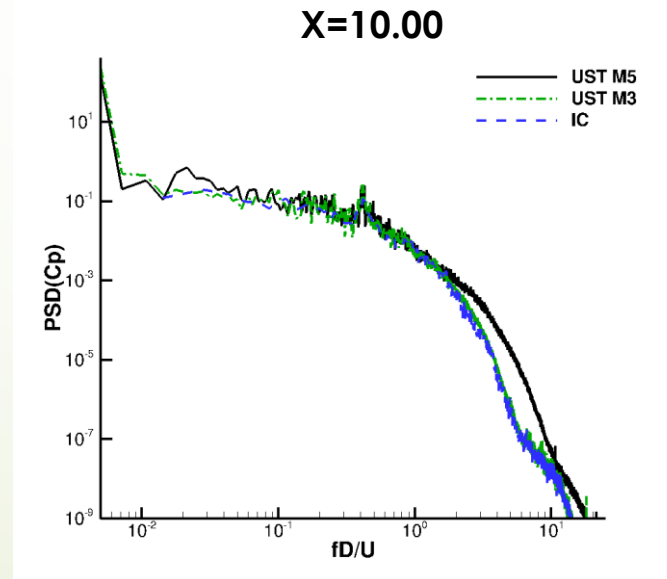
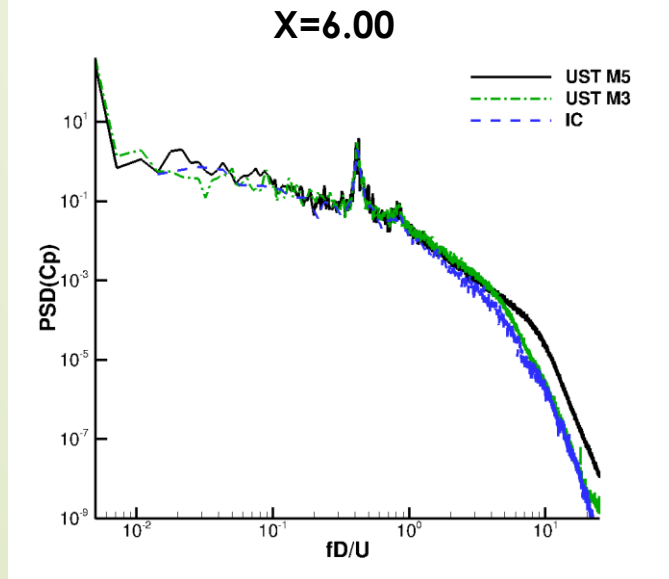
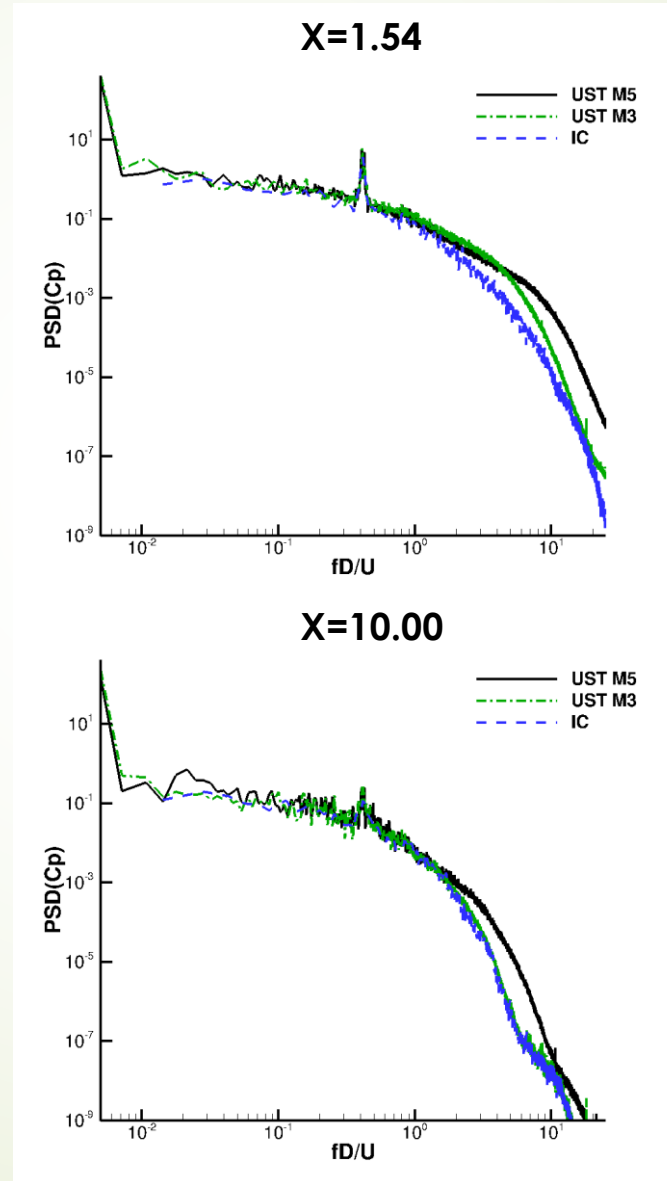
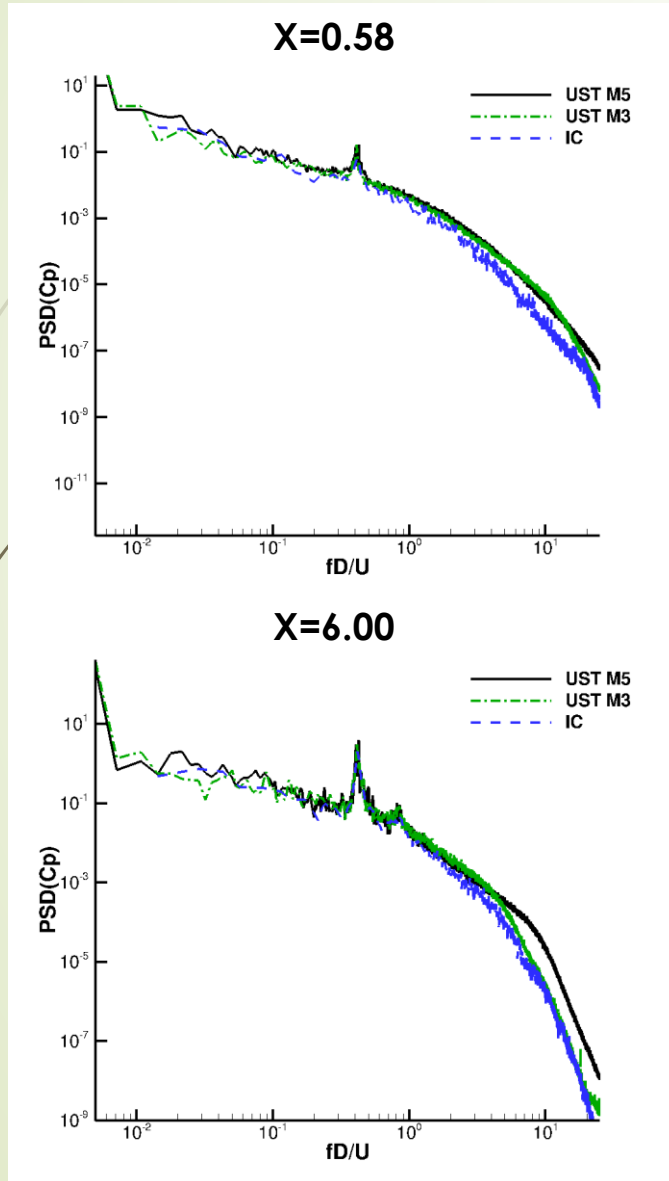
# Coefficients of pressure and skin friction on cylinder surface



# Power spectral density of | velocity |



# Power spectral density of $C_p$



# Power spectral density of tke

