中国航空学会 Chinese Society of Aeronautics and Astronautics
IAGA INTERNATIONAL ASSOCIATION FOR GREEN AVIATION
ICGA 2026 2026 INTERNATIONAL CONFERENCE ON GREEN AVIATION
XI' AN,CHINA NOV.1-3, 2026

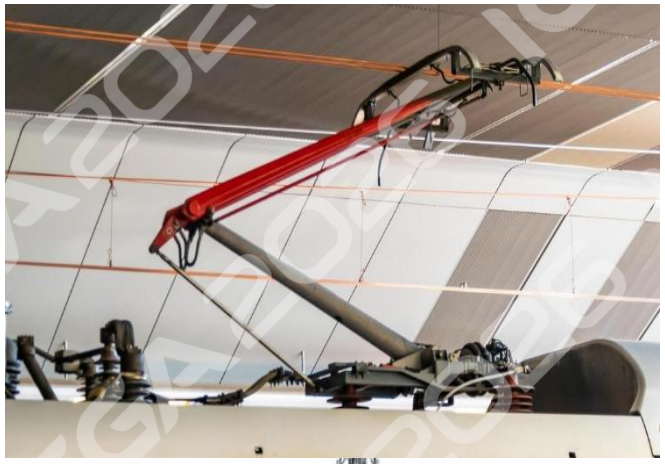
Drag Reduction using Asymmetric Corner Modification of Square Cylinder

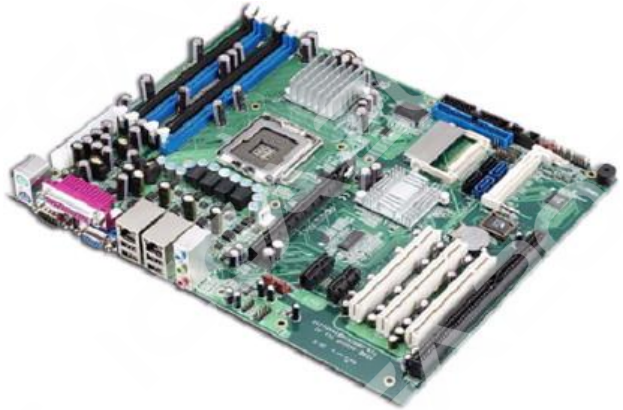
Presenter: *Engr. Dr. Muhammad Yamin Younis*

COMAC-BUAA Large Aircraft Innovation Center

International Innovation Institute of Beihang University (H3I), Hangzhou, China

Introduction















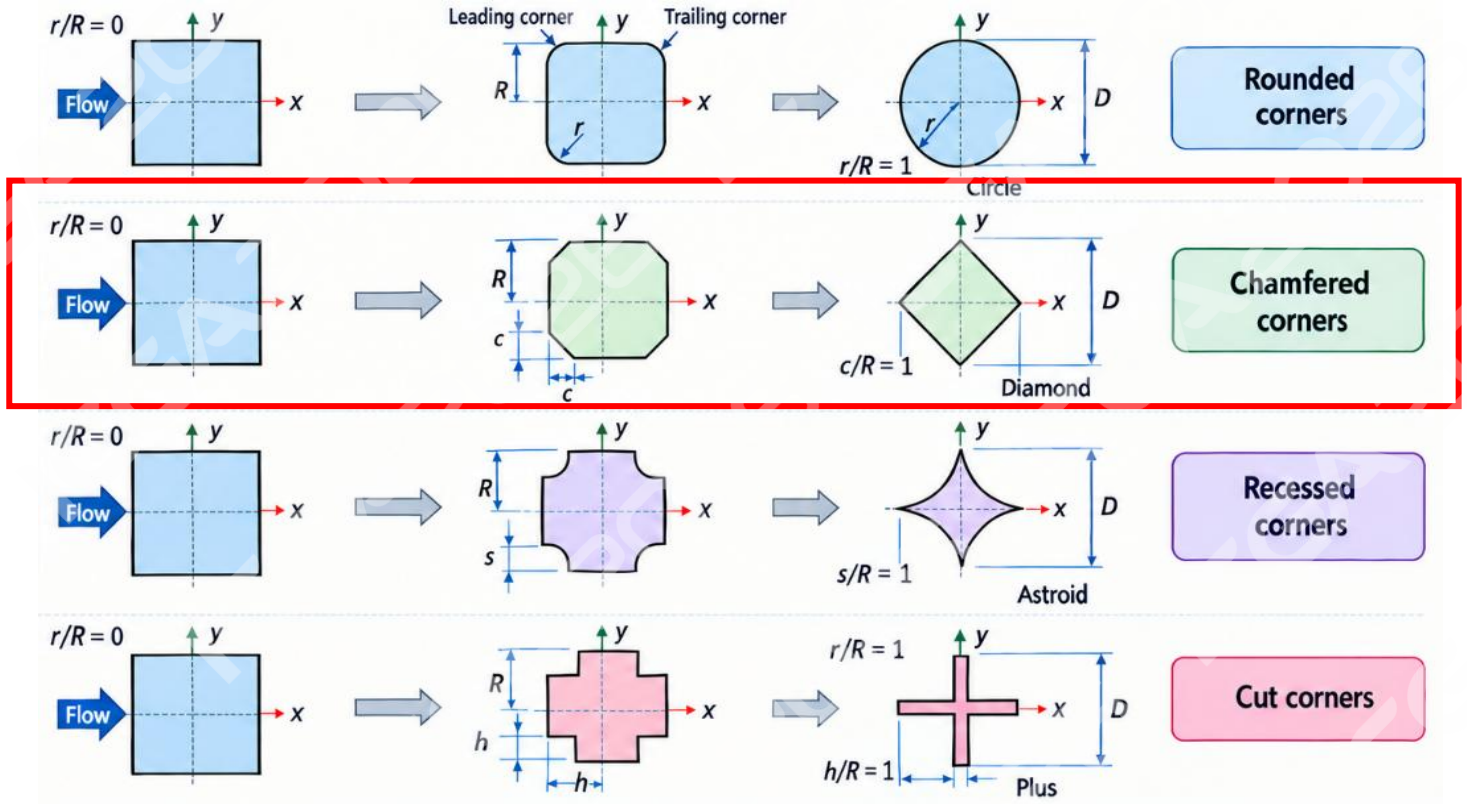
Introduction

- Flow separation and vortex formation influence aerodynamic forces.
- Pressure fluctuations and vortex shedding produce fluctuating aerodynamic loads.
- Fluid motion controls convective heat transfer from engineering surfaces.
- Surface geometry influences flow distribution, recirculation, and thermal performance.
- Aerodynamic design improves lift-to-drag performance of a system.
- Controlling the wake reduces resistance and improves energy efficiency.

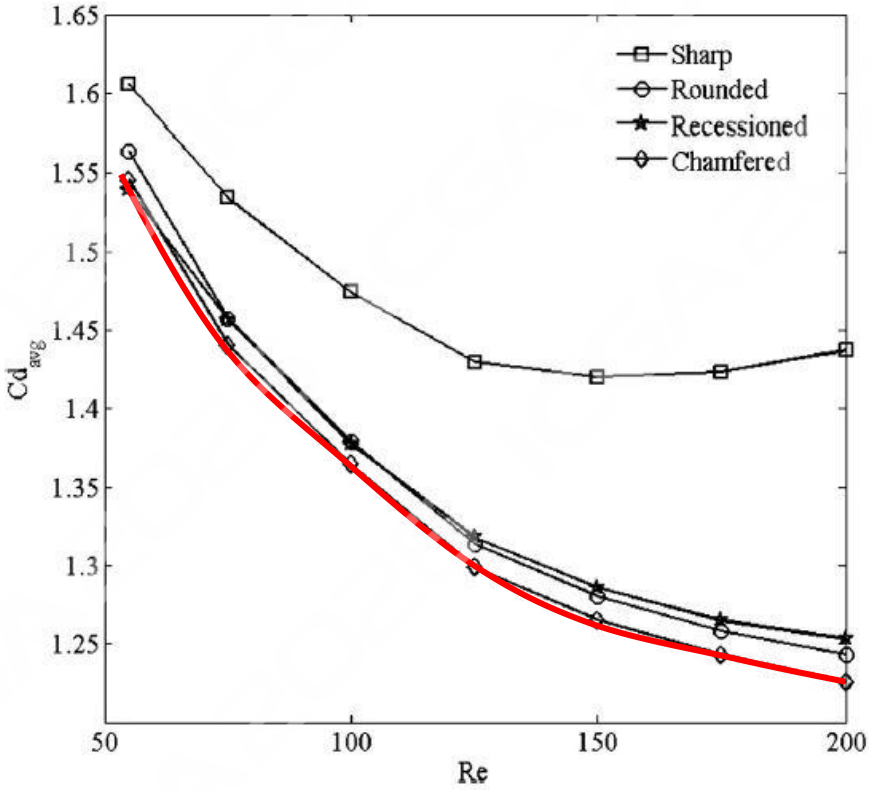
Introduction

- Square cross section is commonly observed in both micro and macro level engineering applications.
- Flow around sharp corners exert strong fluctuating and mean forces, which affects the structural health and heat transfer characteristics.
- Control measures reduce the adverse effects thus are necessary to optimize the engineering design.

Introduction



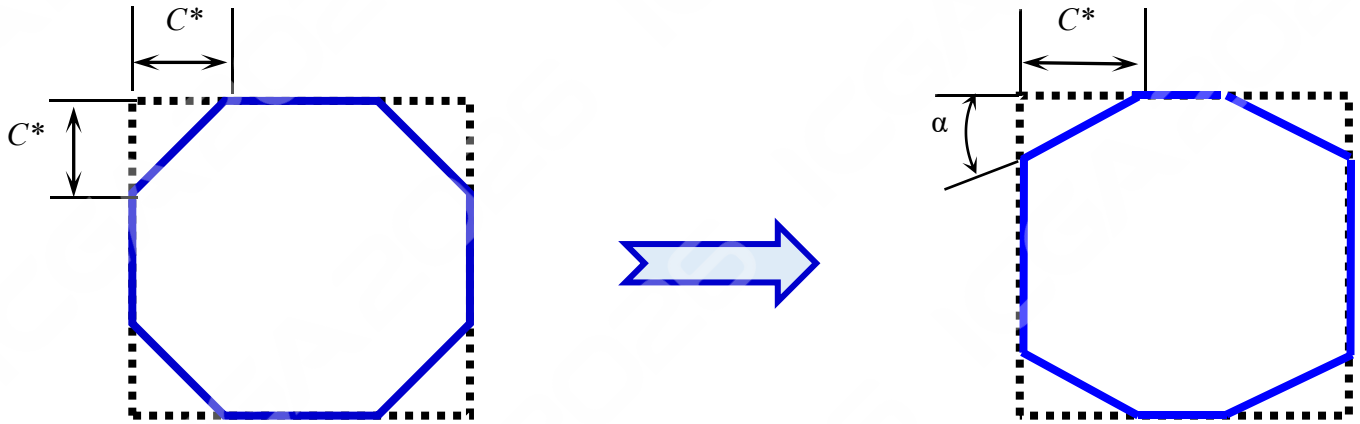
Corner Modified Square Cylinder (Alam 2022)



Corner Modified Square Cylinder (Ambreen et al, 2018)

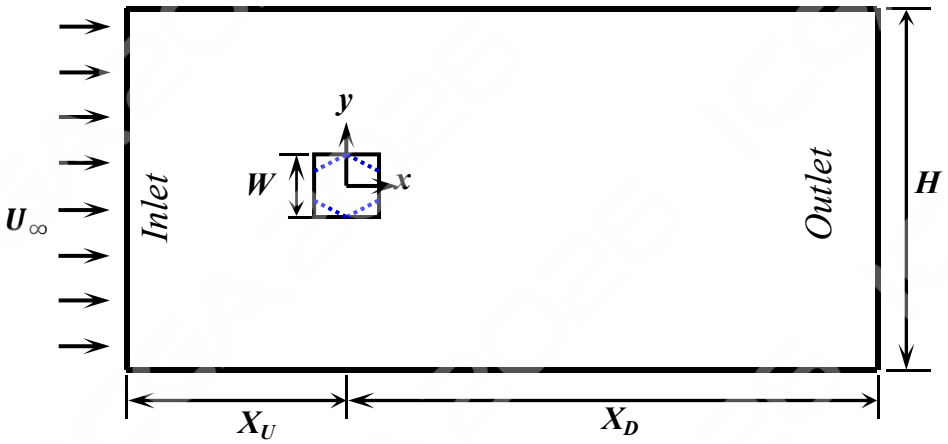
Introduction

- Four major symmetric corner modifications—rounding, chamfering, recession, and cut corner, that have been explored to control wake dynamics and improve aerodynamic performance.
- Does symmetric corner modification provide optimal aerodynamic and heat-transfer performance?
- What happens when the corners are modified asymmetrically, and how does this affect the aerodynamic and heat-transfer performance?

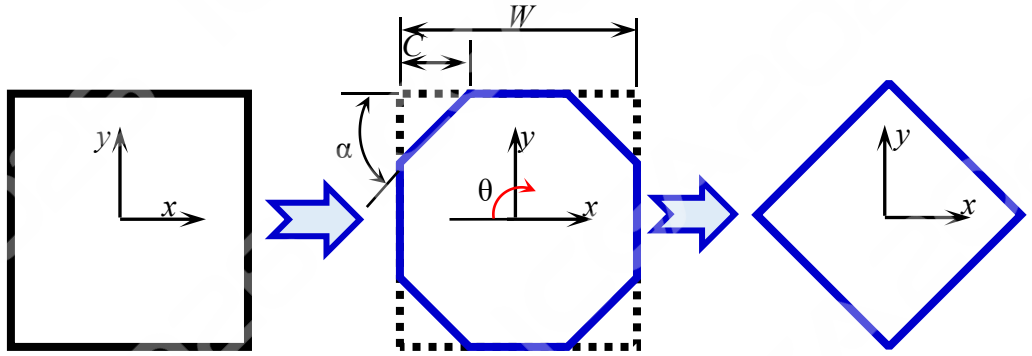


Methodology

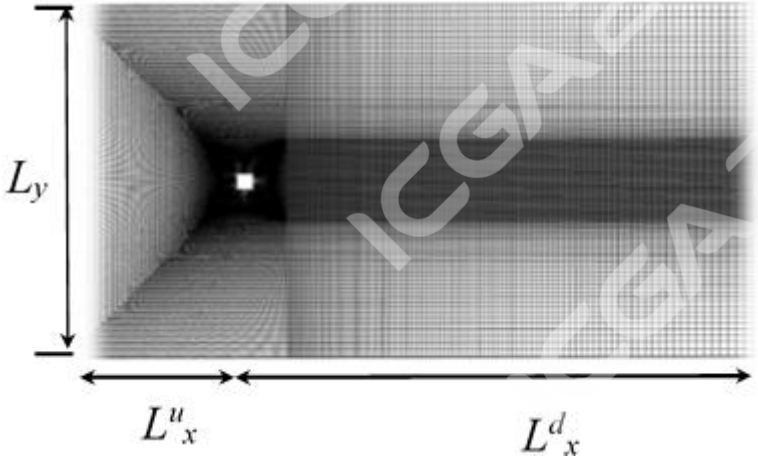
Flow Domain

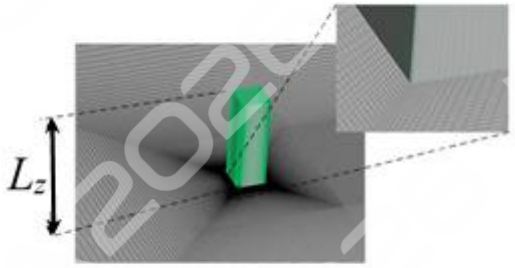


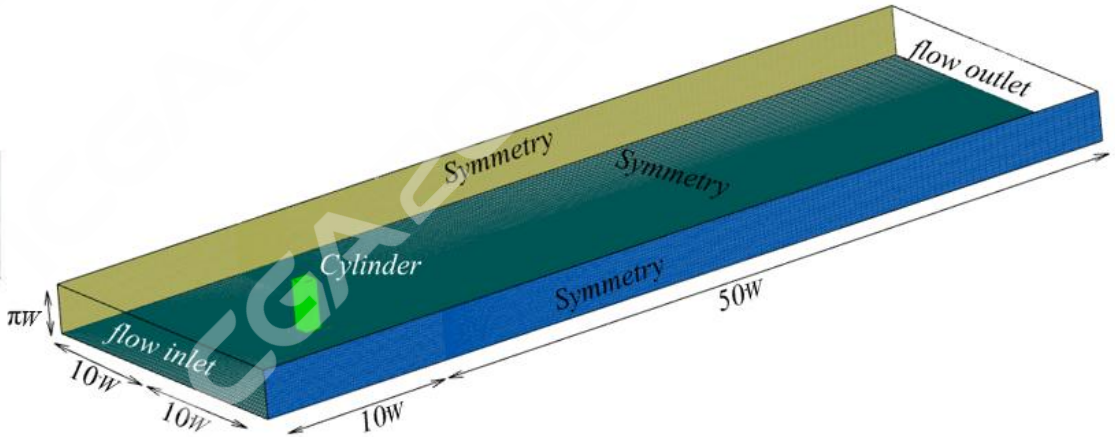
Asymmetric Chamfered Square Cylinder
($0 \le \alpha \le 45°$ and $0 \le C^* \le 0.5$)



Meshing of the Computational Domain

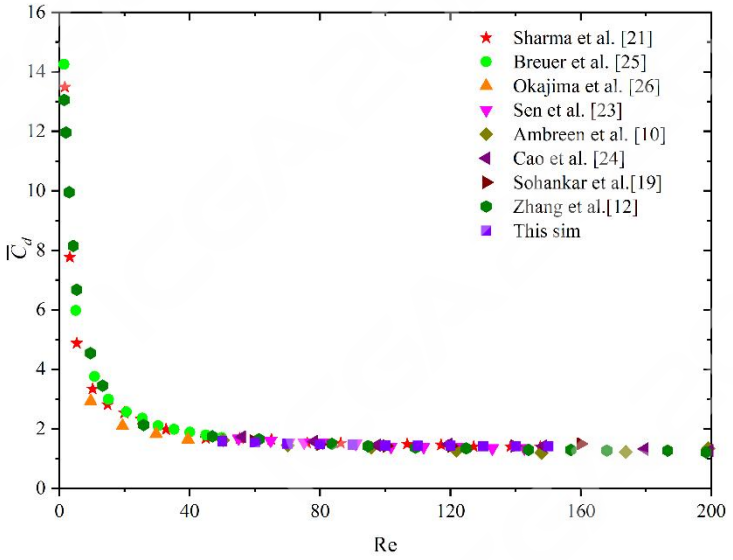






Methodology and Validation

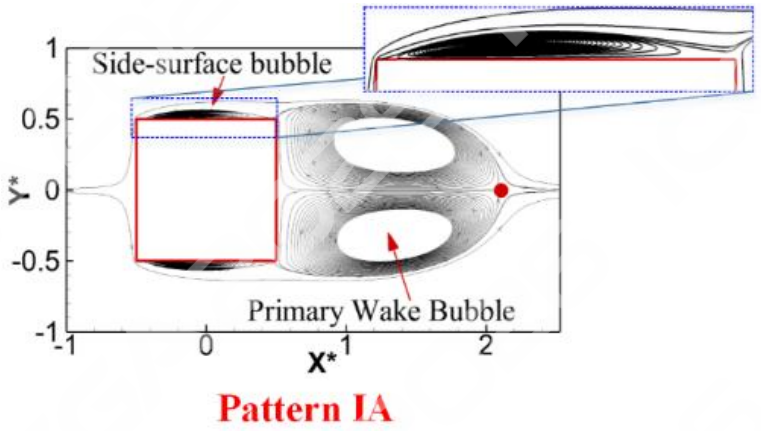
Study	Re	St	C_l'	$\overline{C}_d$	$\langle \overline{N}_u \rangle$
Zafar, F. and M.M. Alam [11]	150	0.154	0.270	1.49	4.77
Sohankar, A., C. Norberg [19]	150	0.138	-	1.46	-
Saha, A.K., G. Biswas, [20]	150	-	0.274	-	-
Sharma, A. and V. Eswaran [21]	150	0.158	0.274	1.33	-
Ranjan, R., A. Dalal,[22]	150	0.130	0.338	1.43	4.82
Ambreen, T. and M.-H. Kim [10]	150	0.162		1.28	5.58
Saha, A.K., G. Biswas, et. al [23]	150	0.166		1.35	
Cao, S., Y. Ge, and Y. Tamura [24]	150	0.163		1.40	
Kamran et al. (Phy. Of Fluids 2025)	**150**	**0.152**	**0.28**	**1.43**	**4.79**



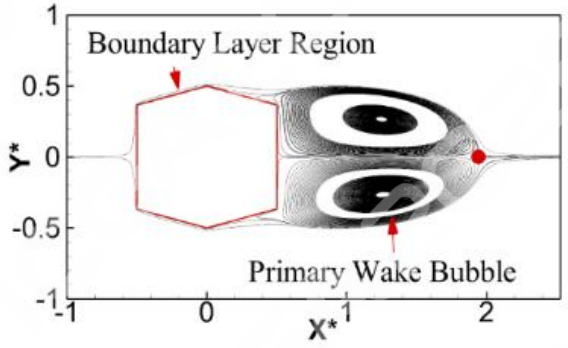
Computational Parameter	Setting
2-D Analysis [Kamran et al. (Phy. Of Fluids 2025)]	
Solver type	Pressure-based
Model	Laminar
Pressure–Velocity coupling	SIMPLE
Gradient interpolation	Least squares cell-based
Pressure discretization	Second order
Momentum equation discretization	Second order upwind
Time integration	Second-order implicit

3-Dimensional Analysis	
Solver type	Pressure-based
Turbulence model	LES, Smagorinsky–Lilly
Pressure–Velocity coupling	SIMPLEC
Gradient interpolation	Least squares cell-based
Pressure discretization	Second order
Momentum equation discretization	Bounded central differencing
Time integration	Second-order implicit

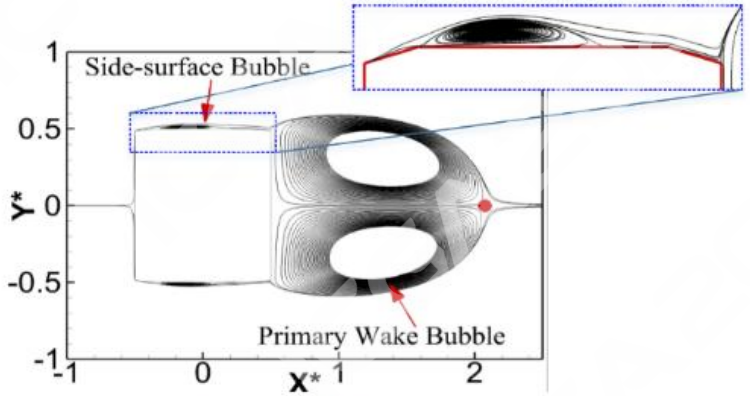
The Waka characteristics



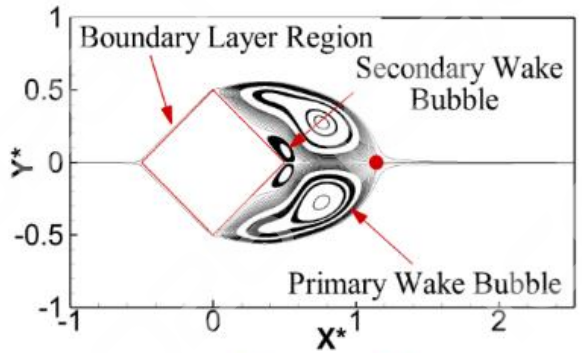
Pattern IA



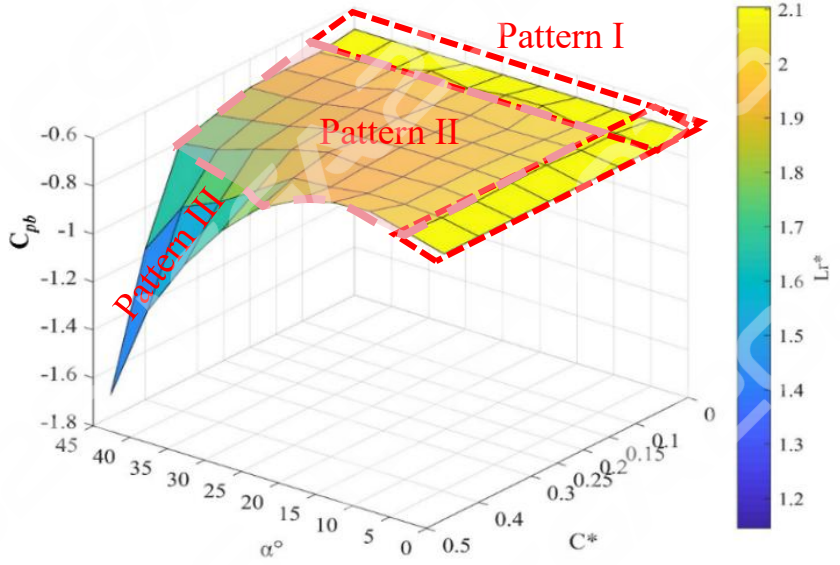
Pattern II

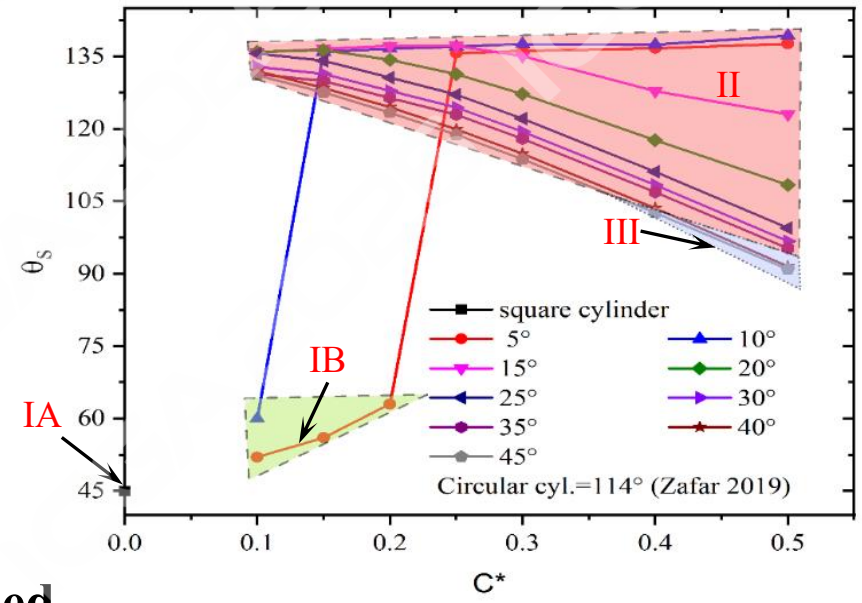


Pattern IB



Pattern III

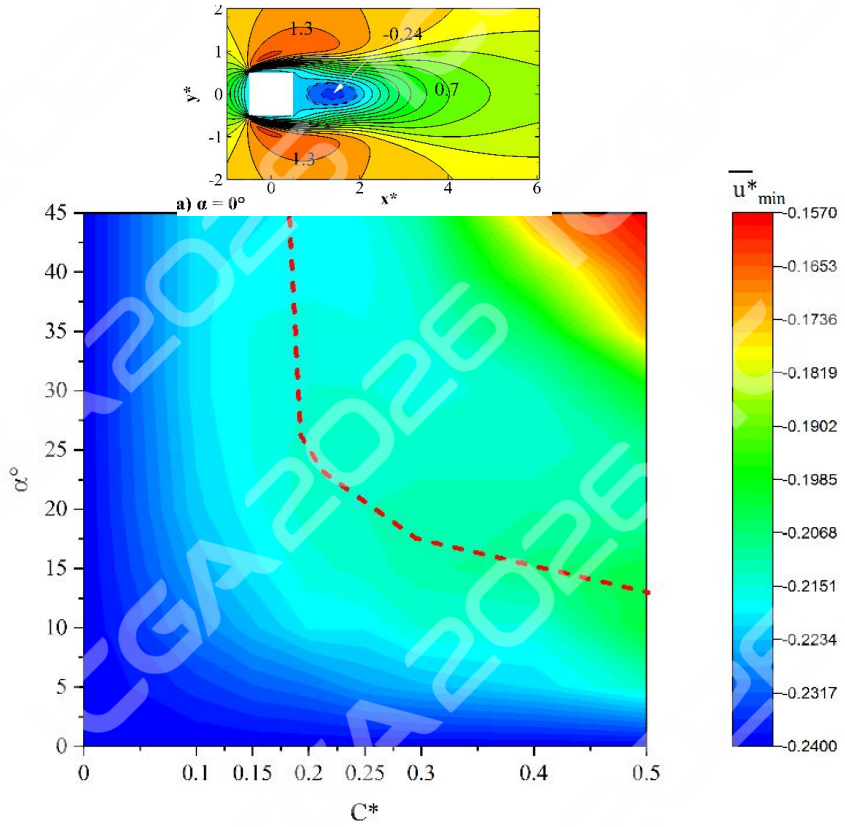


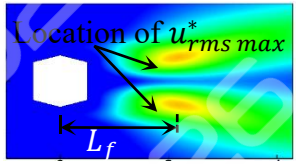


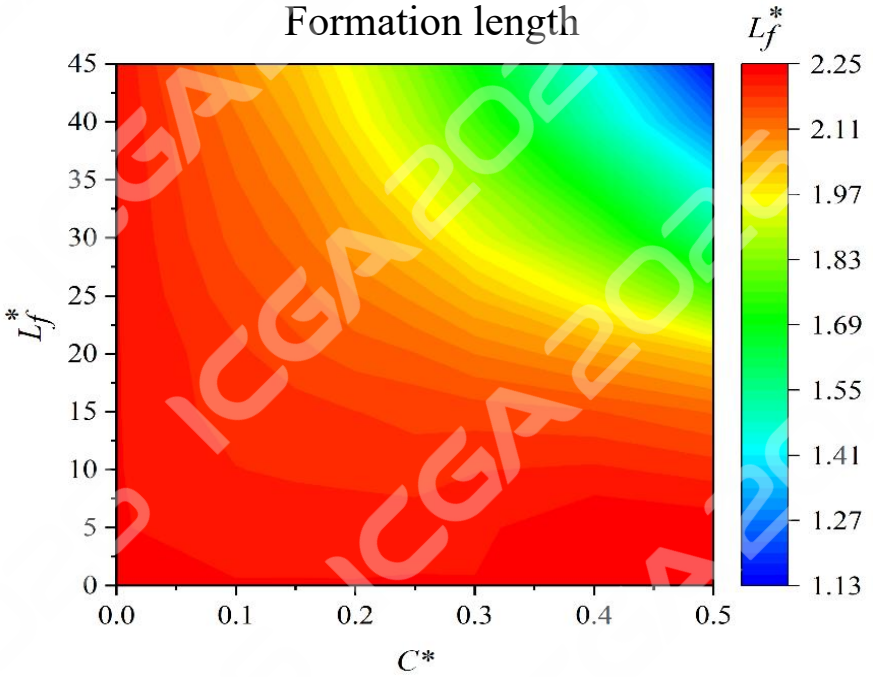
Wake Topology and Flow Separation for different shapes studied

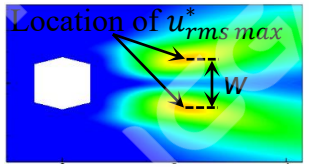
[Kamran et al. (Phy. Of Fluids 2025)]

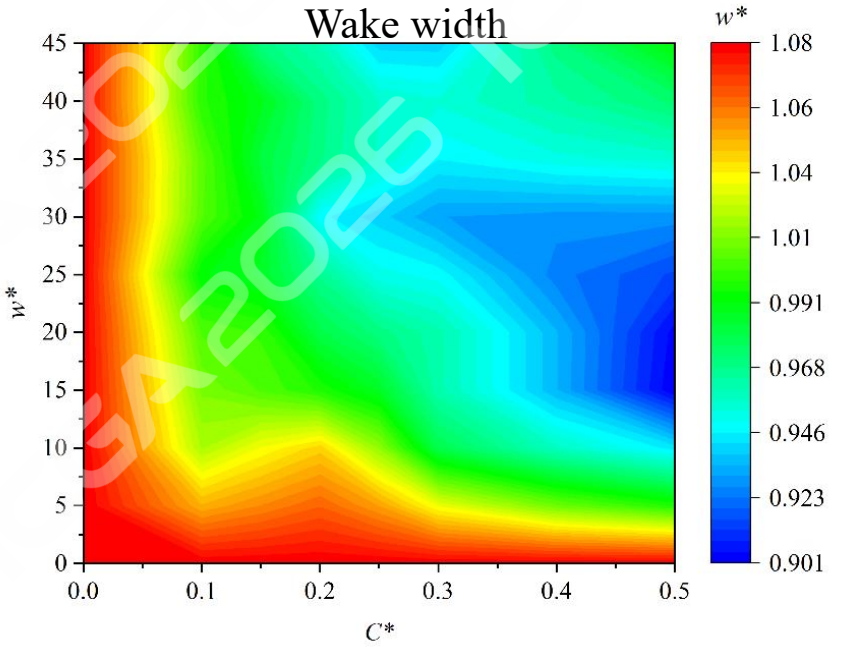
The Wake Characteristics











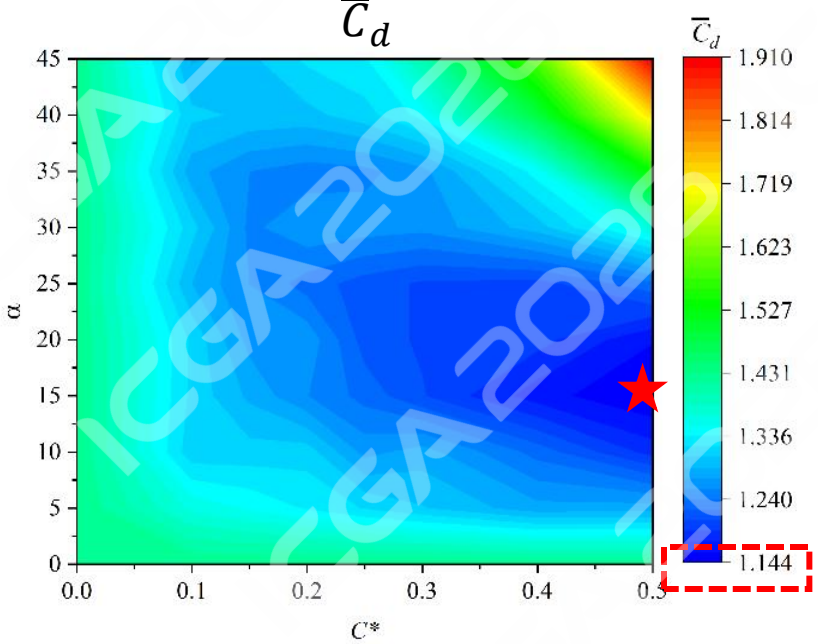
Time Average Wake Strength and Size

[Kamran et al. (Phy. Of Fluids 2025)]

Fluid Forces

Time mean drag coefficient

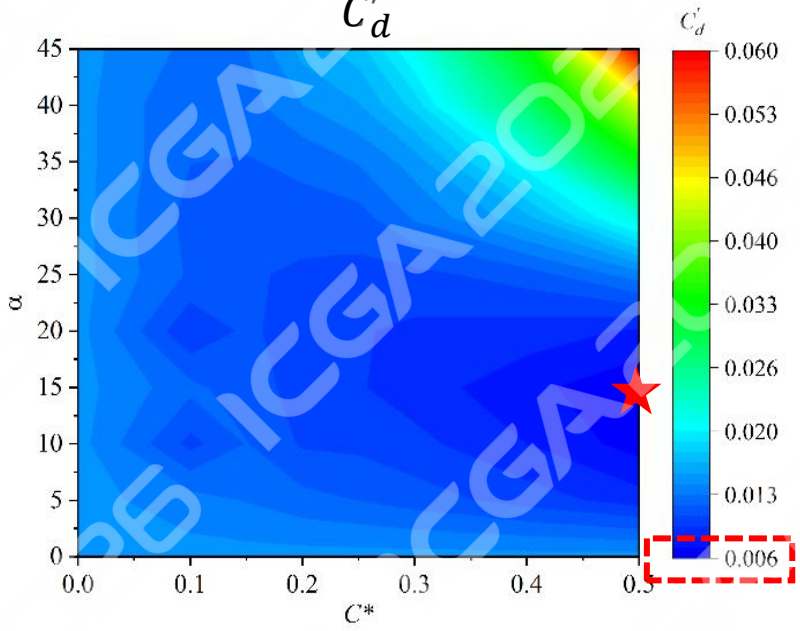
$\overline{C}_d$



$\overline{C}_d$ $(Circle)$= 1.35
(Zafar and Alam 2019)

Fluctuating drag coefficient

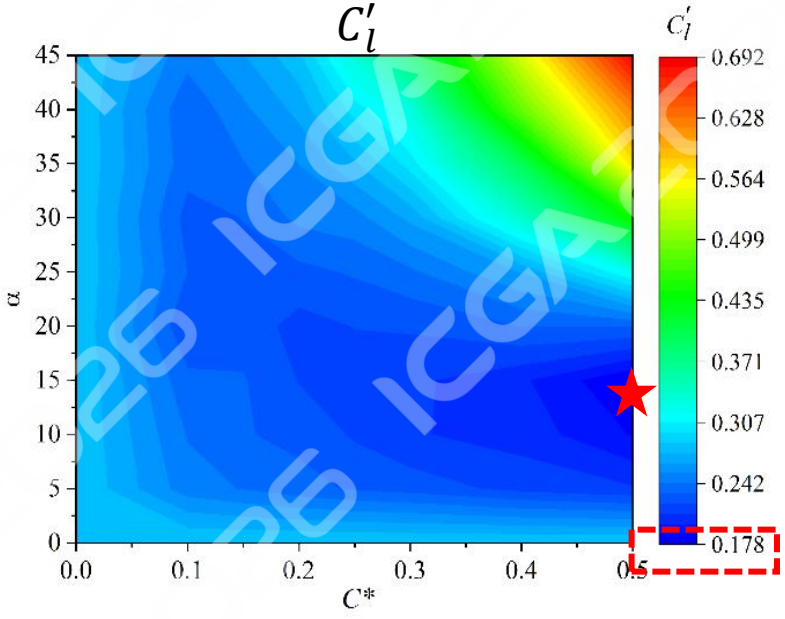
C'_d



$\overline{C}_d$ $(Circle)$= 0.0171
(Zafar and Alam 2019)

Fluctuating lift coefficient

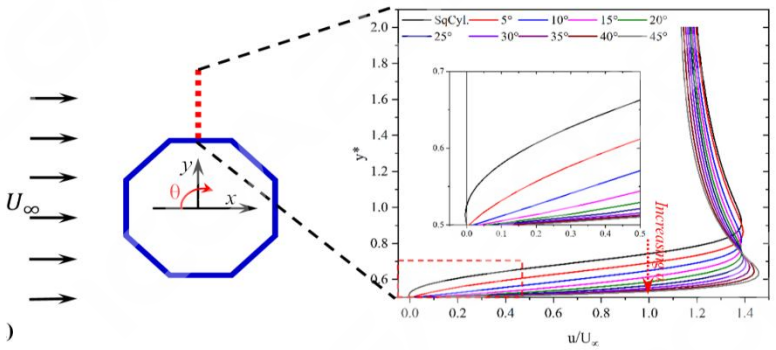
C'_l

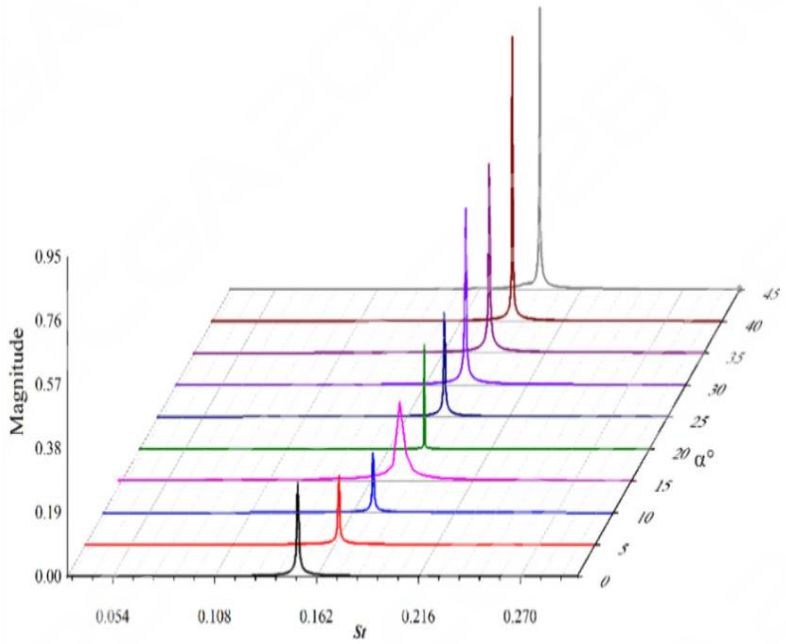


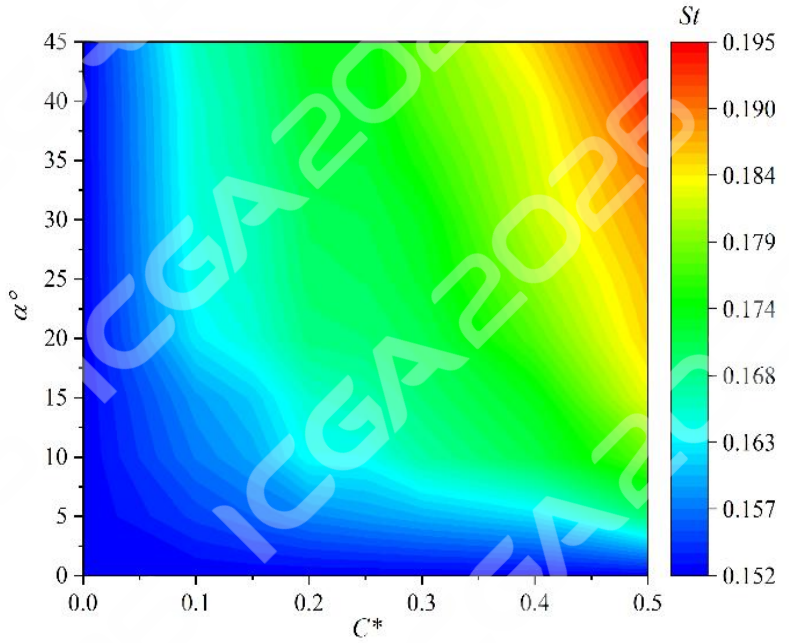
$\overline{C}_d$ $(Circle)$= 0.353
(Zafar and Alam 2019)

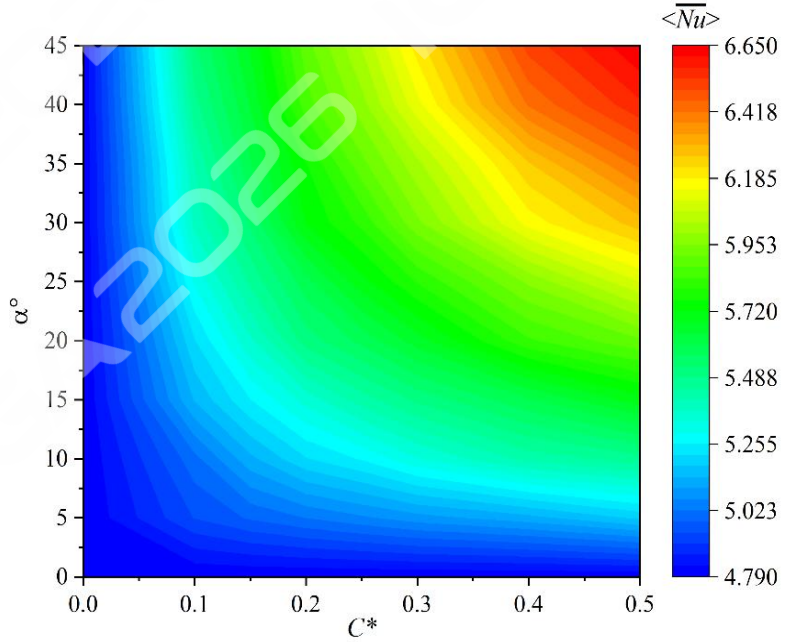
[Kamran et al. (Phy. Of Fluids 2025)]

Heat Transfer Characteristics









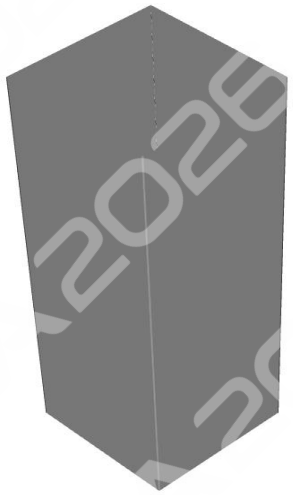
- Increase in near-wall flow velocity, thinner the thermal boundary layer
- Shorter bubble with higher vortex shedding frequencies corresponds to higher heat transfer

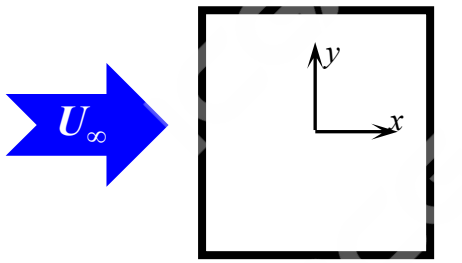
Performance Comparison

Study/Corner modification	Shape	$\overline{C}_D$	C_{Df}	C_{Lf}	St	$\langle \overline{Nu} \rangle$
Present	Square	1.437	0.0146	0.286	0.152	4.793
	Modified Corner	**1.15**	**0.00657**	**0.178**	**0.177**	5.685
	($C^* = 0.5$, $\alpha = 15°$)	**(-20%)**	**(-55%)**	**(-37%)**	**(+16.48%)**	**(+18.53%)**
Alam & Zafar[2019]	Square	1.492	0.0155	0.271	0.154	4.770
(Corner Rounding)	r/d=0.25	1.308	0.011	0.258	0.172	5.118
		(-12.34%)	(-22.6%)		(11.69%)	(7.30%)
	r/d=0.125	1.340	0.012	0.241 (11.07%)	0.169	4.921
Talaat & Alam[2021]	Square	1.492	0.0155	0.271	0.154	4.770
(Corner Rounding)	r/R=0.50	1.308	0.011	0.258	0.172	5.118
		(-12.34%)	(-22.6%)		(11.69%)	(7.30%)
	r/R=0.25	1.340	0.012	0.241 (11.07%)	0.169	4.921
Tehmina Ambreen[2018]	Square	1.421	--	--	0.157	4.815
(Chamfering)	Chamfer	1.265	--	--	0.167	5.590
	c/D=0.125	(-10.97%)			(+6.37)	(+15.45%)

- Asymmetric chamfering with **($C^* = 0.5$, $\alpha = 15°$)** out performed all the other corner modifications in terms of reduction in fluid forces and increasing the thermal performance

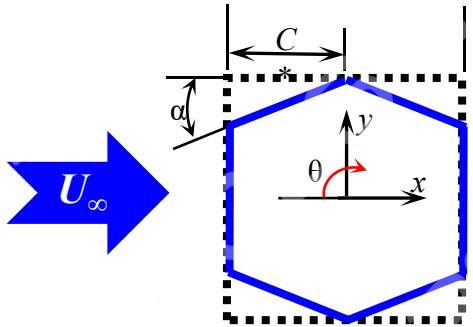
Impact of Reynolds Number





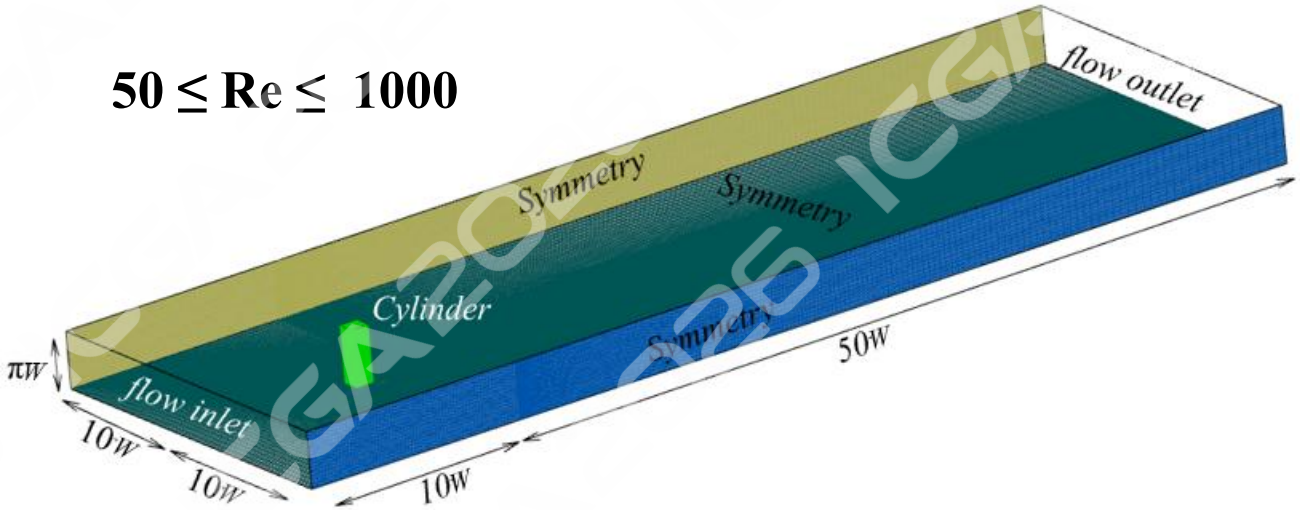
Square Cylinder



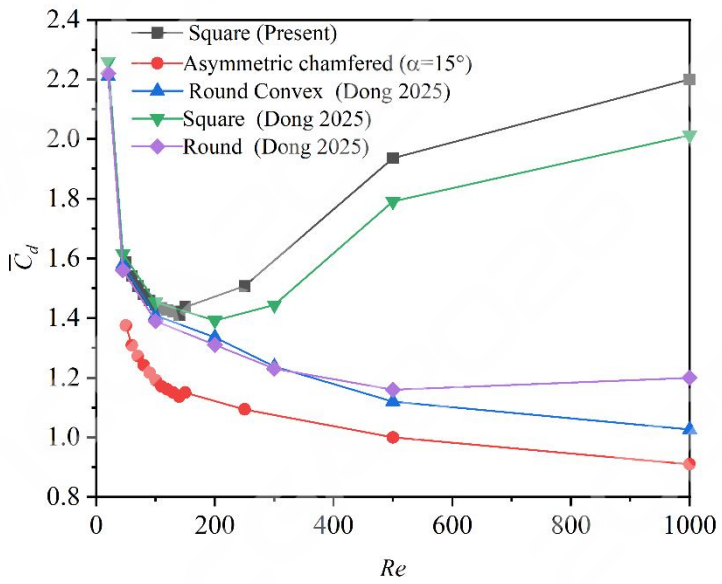


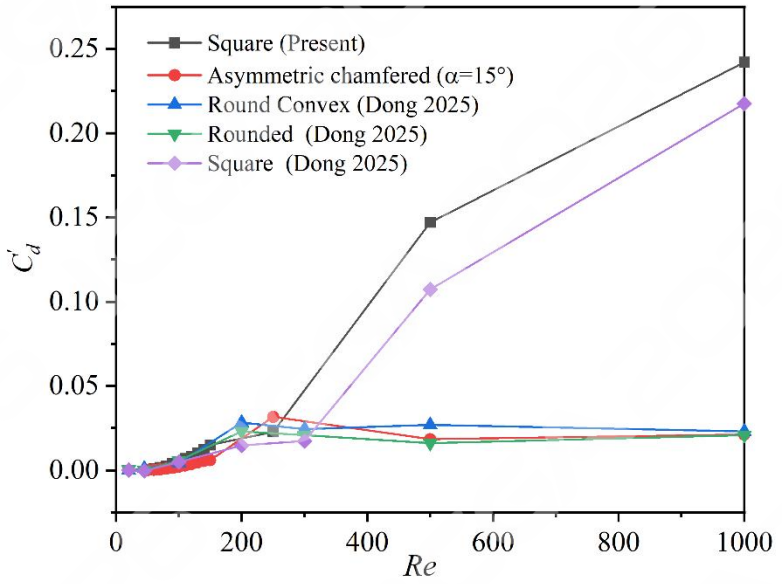
(α = 15° and C^* = 0.5)

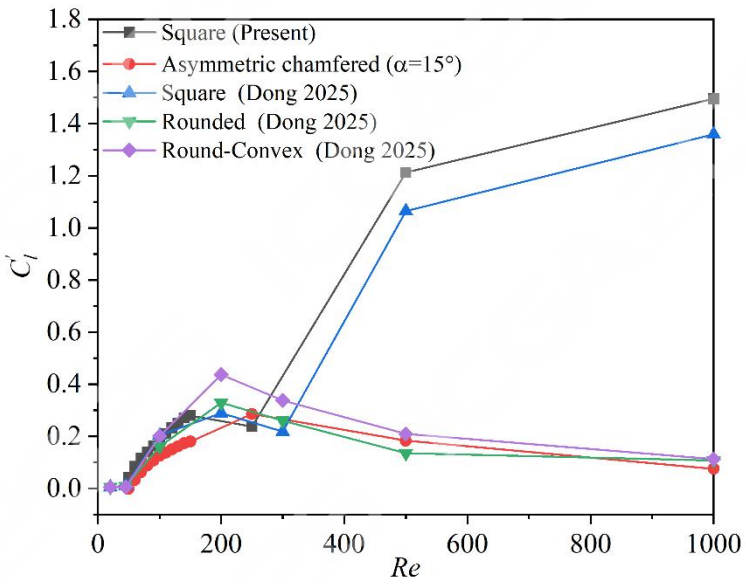
50 ≤ Re ≤ 1000



Impact of Reynolds Number
(Fluid Forces)



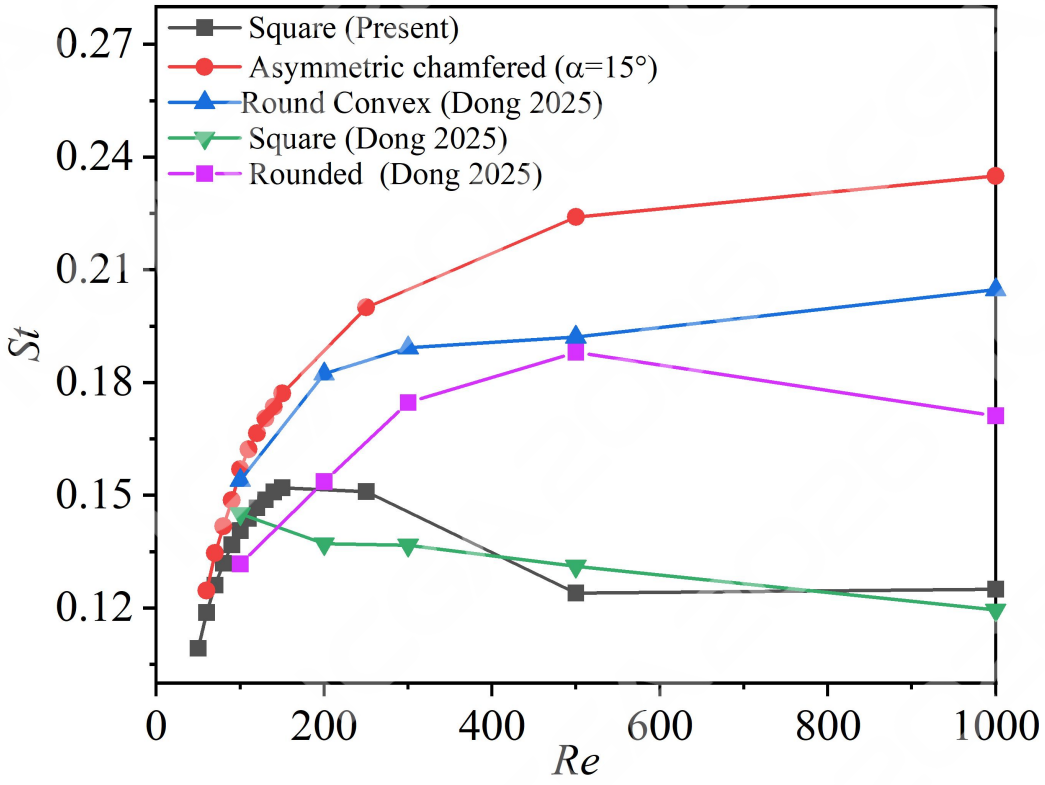


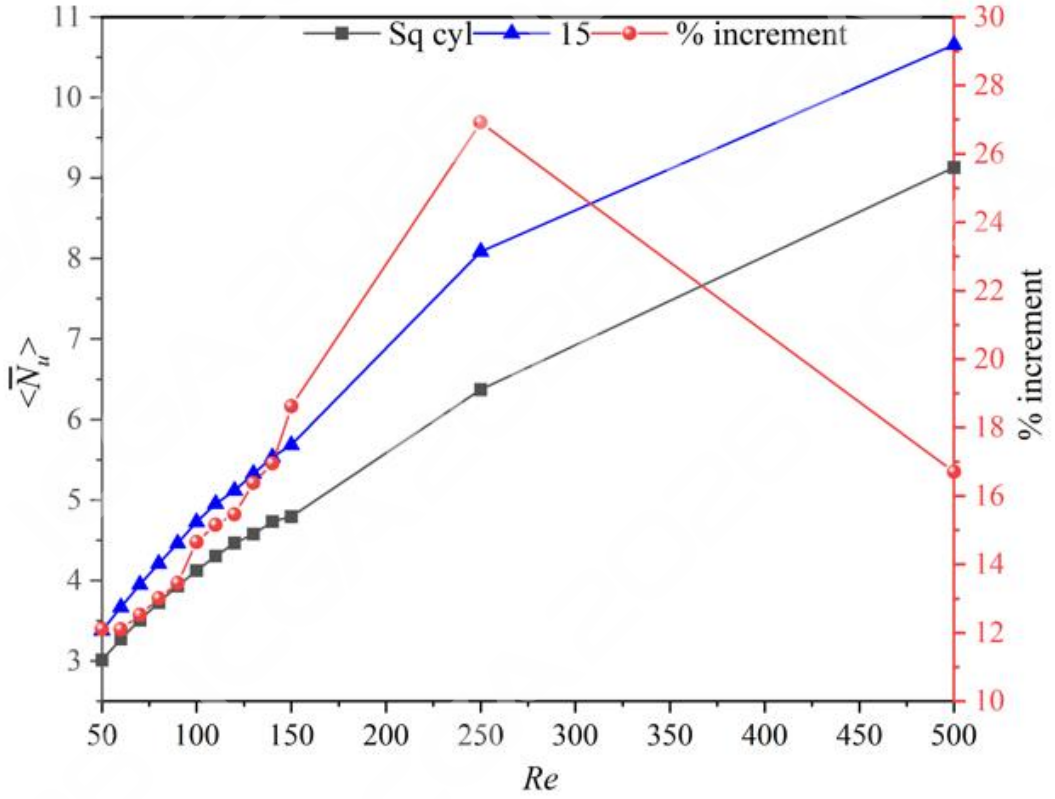


- Asymmetric chamfering with **($C^* = 0.5$, $\alpha = 15°$)** has significantly improved characteristics in terms of fluid forces.

Impact of Reynolds Number

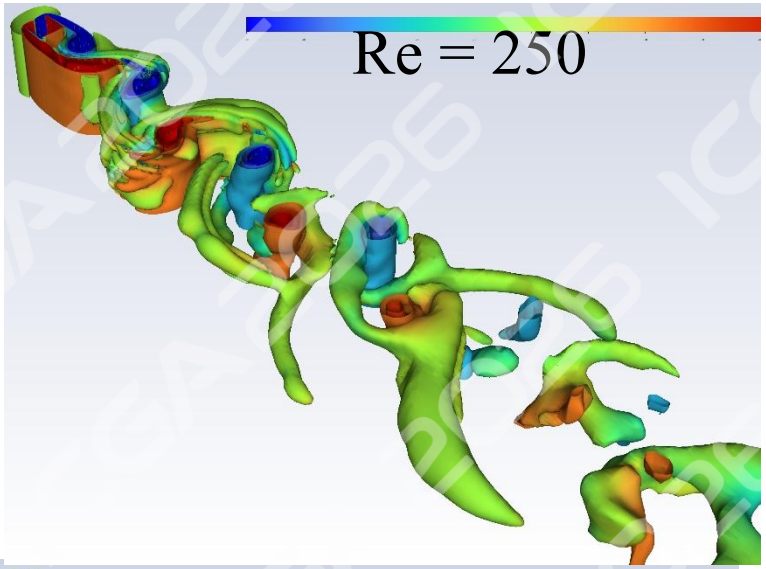
(Vortex Shedding and heat transfer)

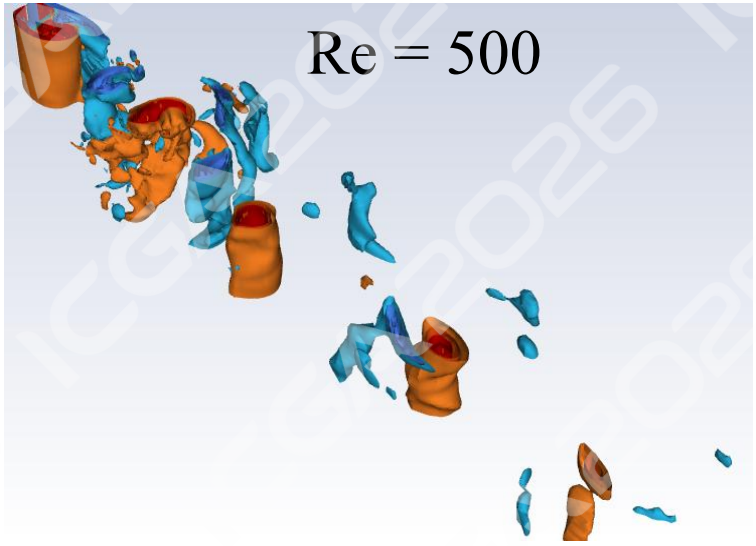


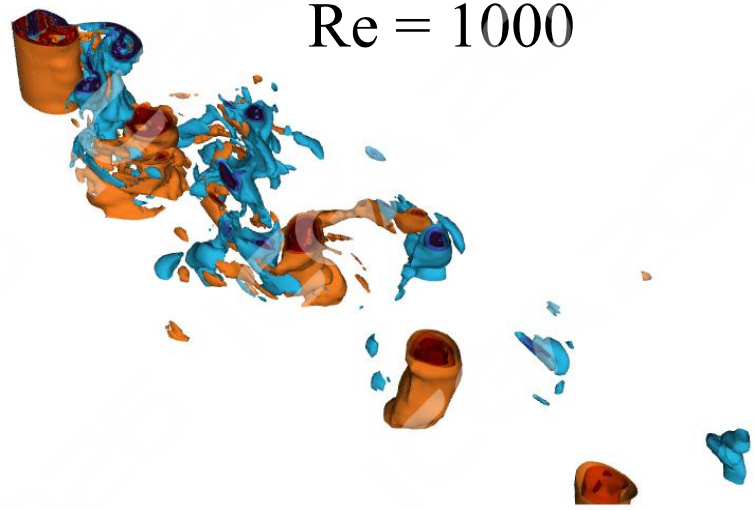


Impact of Reynolds Number
(3-Dimensional instantaneous wake characteristics)

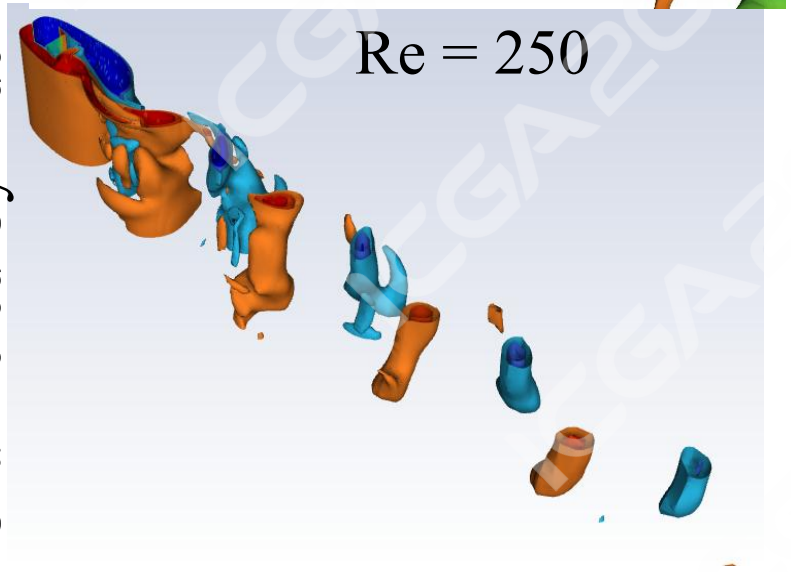
Square Cylinder

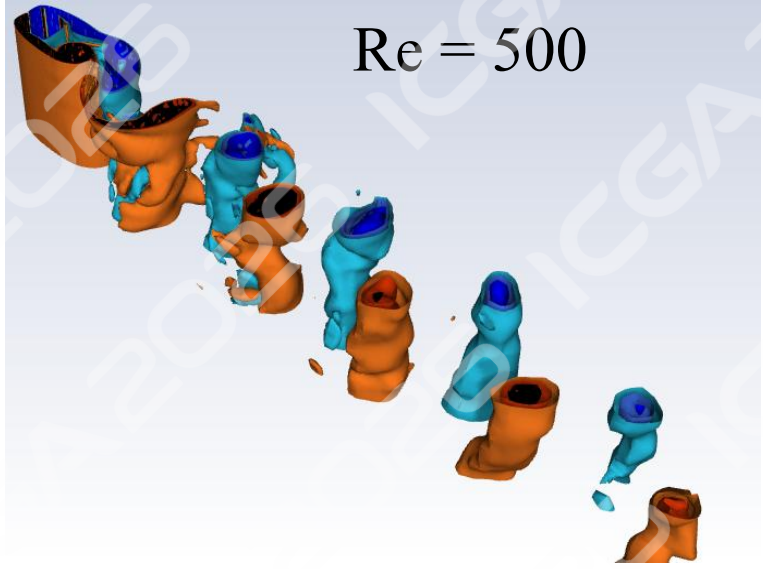


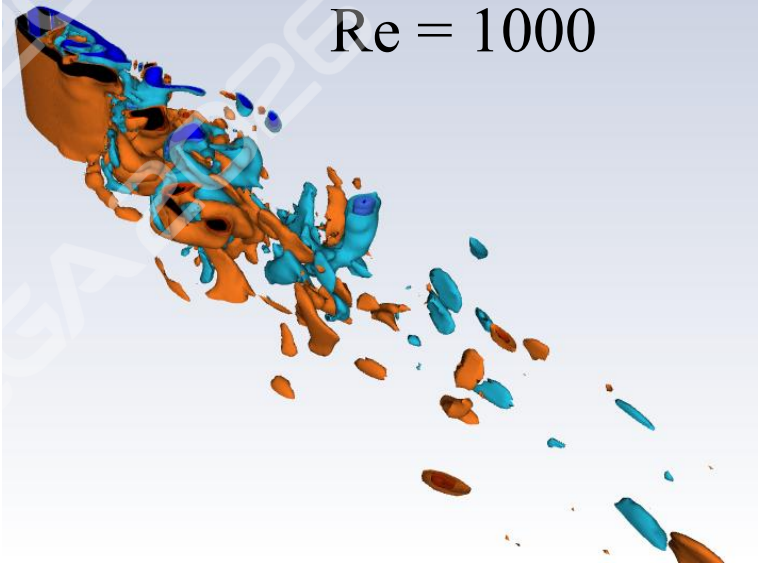




Chamfered Cylinder







Conclusions

- Chamfered cylinder $C^* = 0.5$ and $\alpha = 15°$, outperformer the other corner modifications in terms of reduction in fluid forces with 20%, 55%, and 37%, respectively at Re =150, compared with the square cylinder.
- Heat transfer has been significantly improved based on the delayed flow separation and increased vortex shedding frequency.
- Over the range of Reynolds number $50 \leq Re \leq 1000$, mean and fluctuating drag coefficients decrease continuously with increasing *Re*. The drag-reduction advantage of the chamfered cylinder widens, while the fluctuating-lift difference initially decreases, stabilizes at intermediate *Re* and widens again at *Re* =1000.

The modifications needs to be further investigated for their aero-acoustic and thermo-hydraulic characteristics to be used for thermal management of heat sinks and/or other related applications in aerospace.