Active Flow Control, From Fluidic Oscillators to Future Applications.

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1.- Passive versus Active flow control.
2.- Devices used is AFC Advantages/disadvantages.
3.- Application of AFC using steady blowing/suction.
4.- Application of AFC using periodic forcing.
5.- Possible future applications.

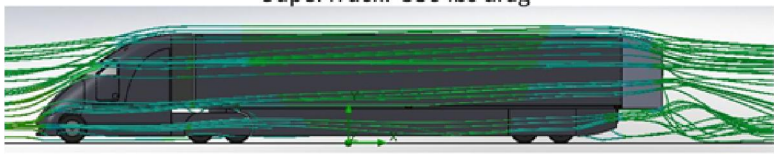
Passive versus Active Flow Control



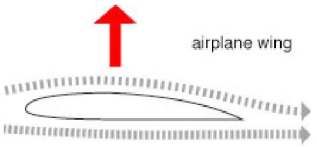


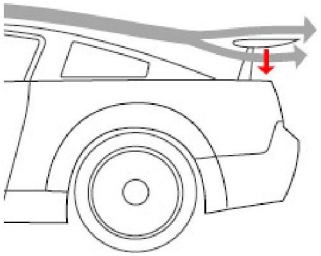




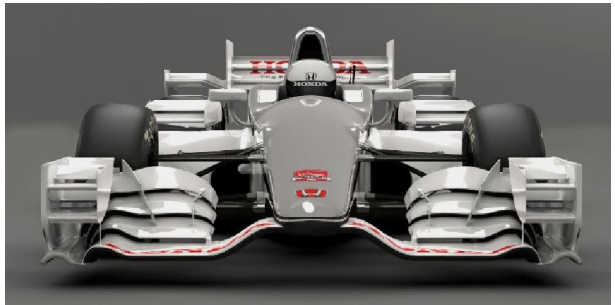


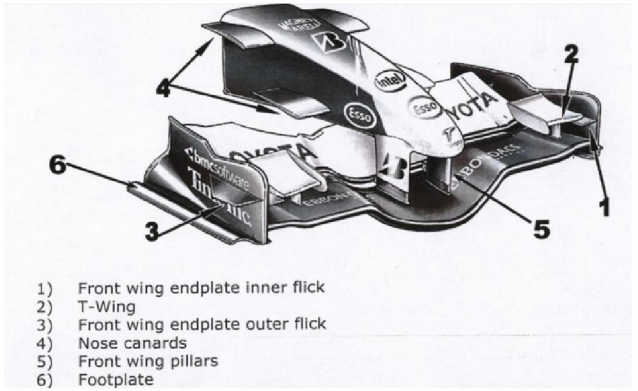




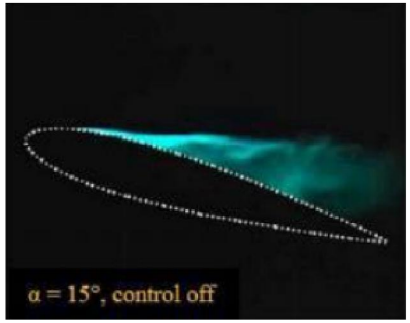


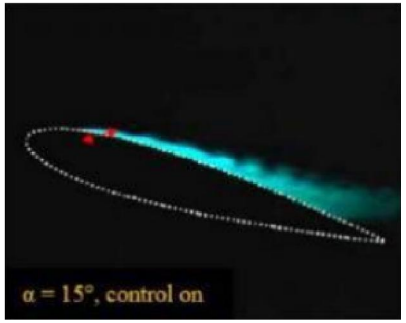


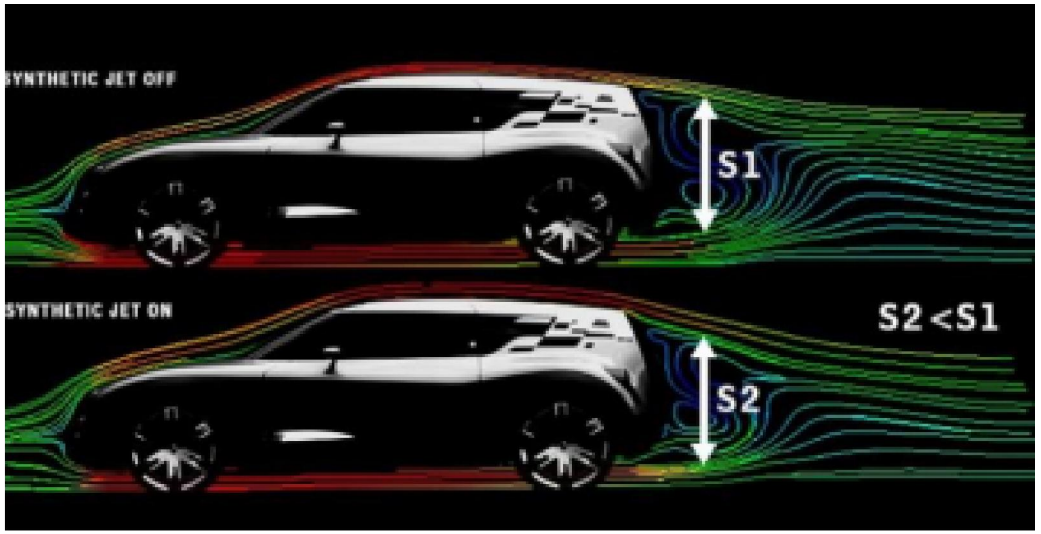


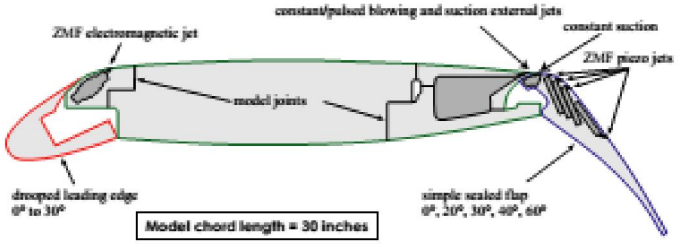


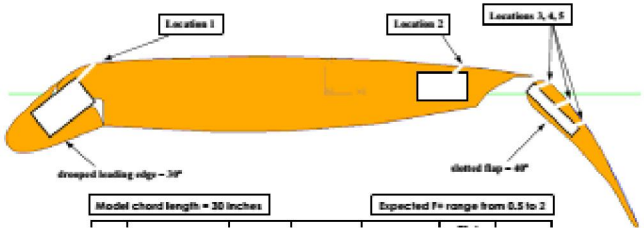
Passive versus Active Flow Control

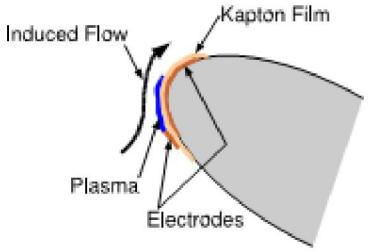


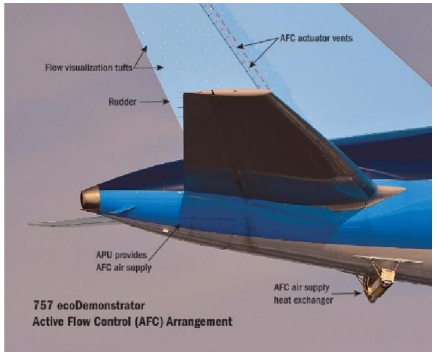


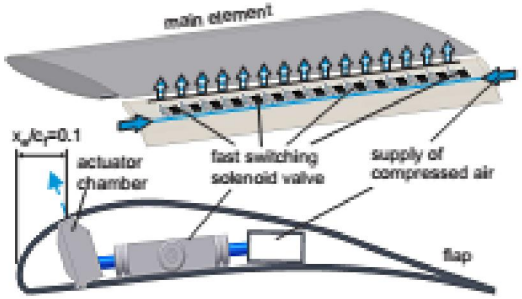


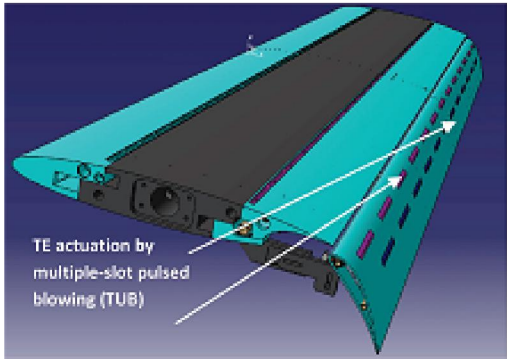


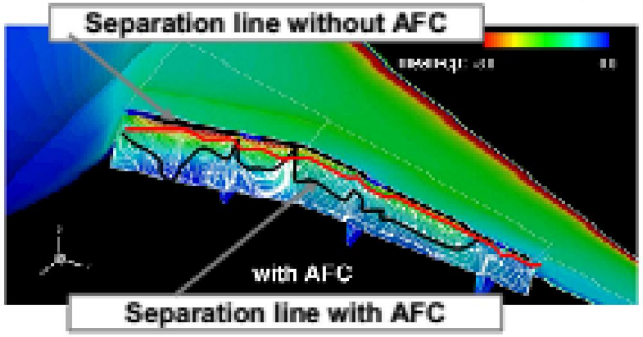












Different existing actuators

ZNMF (zero net mass flow)

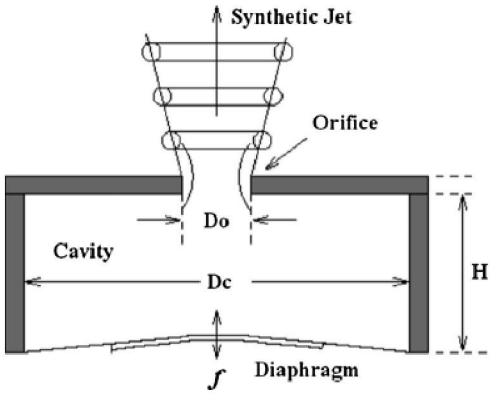
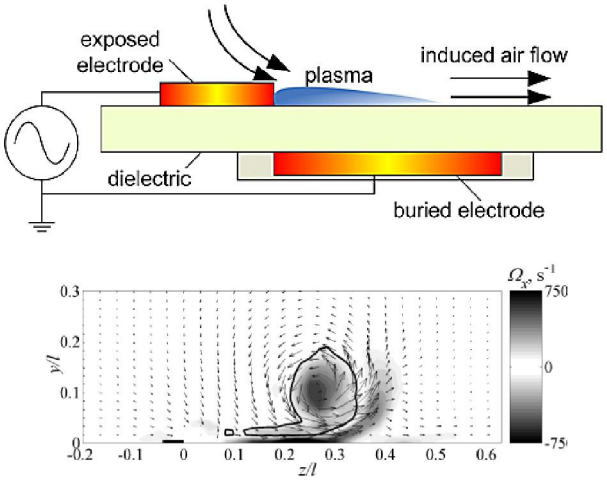
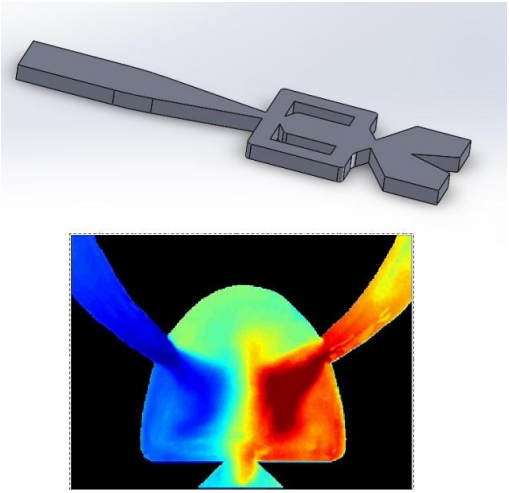


Fig. 1. Schematic representation of an SJA.

Plasma actuators

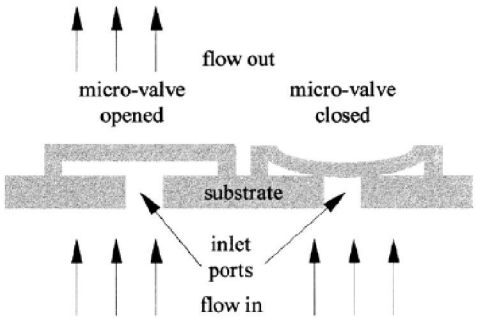


Fluidic oscillators

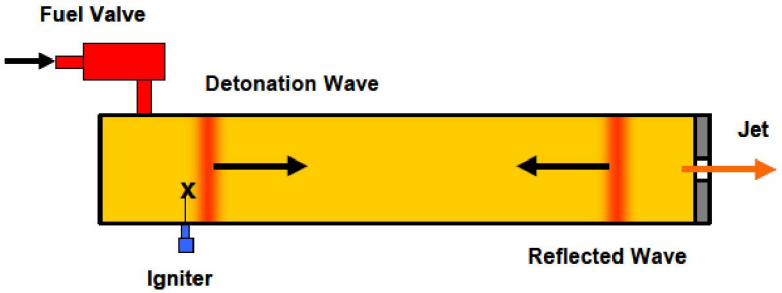


Steady Blowing
Steady sucking

MEMS (Micro-Electro-Mechanical Systems),



Combustion driven jet actuators



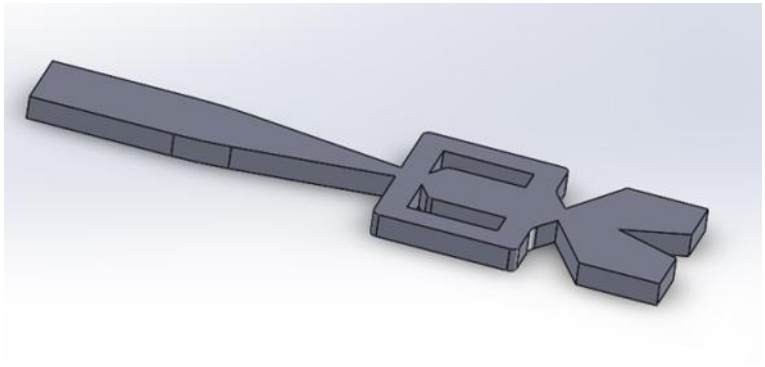
Why periodic actuation instead of simple blowing/suction

Periodic forcing acts on flow natural instabilities. Joseph et al (2012)

Downstream vortex shedding frequency.

Shear layer flapping instability frequency. (shear layer natural frequency)

Shear layer natural Kelvin Helmholtz instability



Parameters to be considered.

a.- Frequency

b.- Amplitude

c.- Momentum coefficient (C_μ)

$$St = \frac{f\ L}{V_\infty}$$

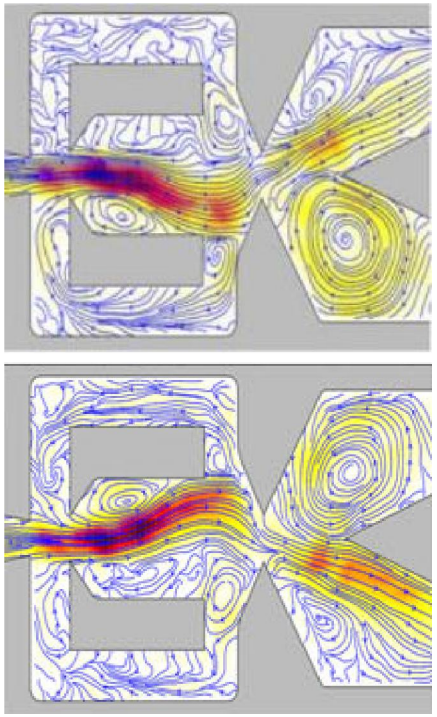
$$C_\mu = \frac{\rho_j\ W\ V_j^2}{\frac{1}{2}\rho\ V_\infty^2\ C}$$

d.- Velocity ratio (Steady blowing/suction) $\frac{V_{jet}}{V_\infty}$

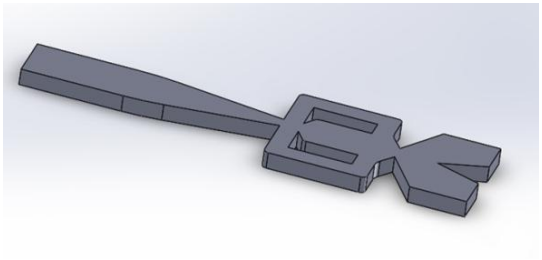
e.- Groove width

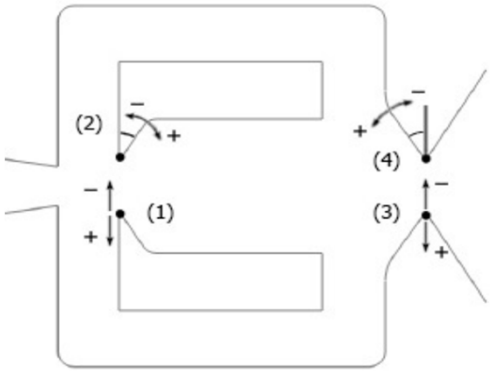
f.- Groove position

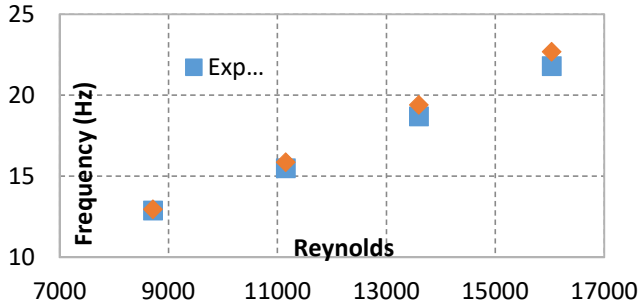
g.- jet angle

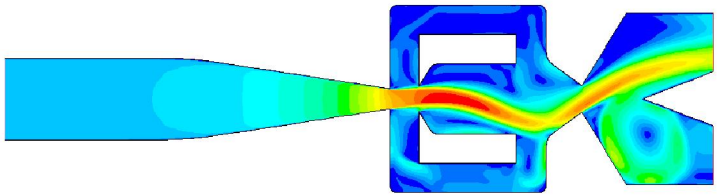


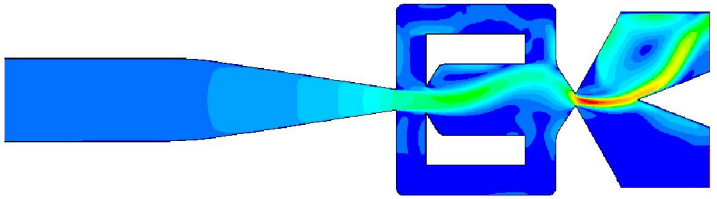
Fluidic actuators particularities.

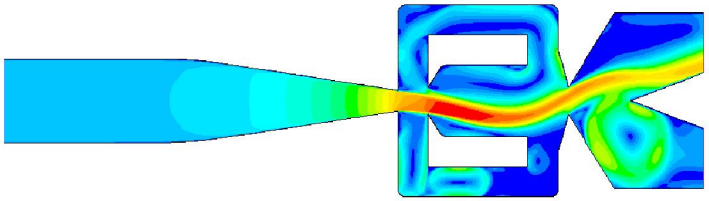


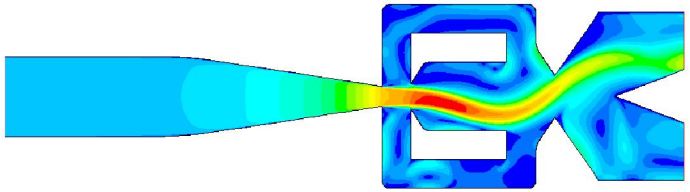


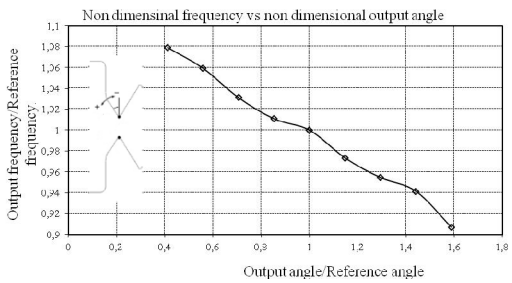


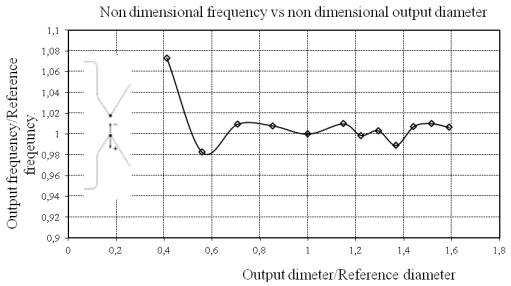












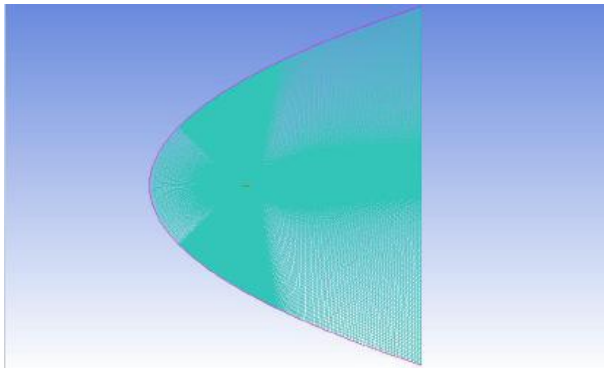
How to implement AFC.

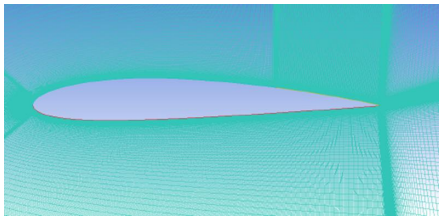
NACA 2412

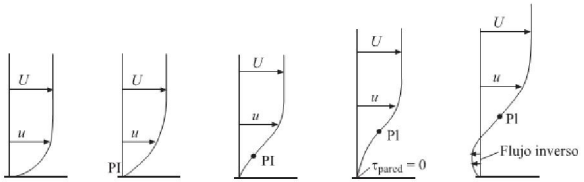
$Re = 3.1 * 10^6$

Steady state

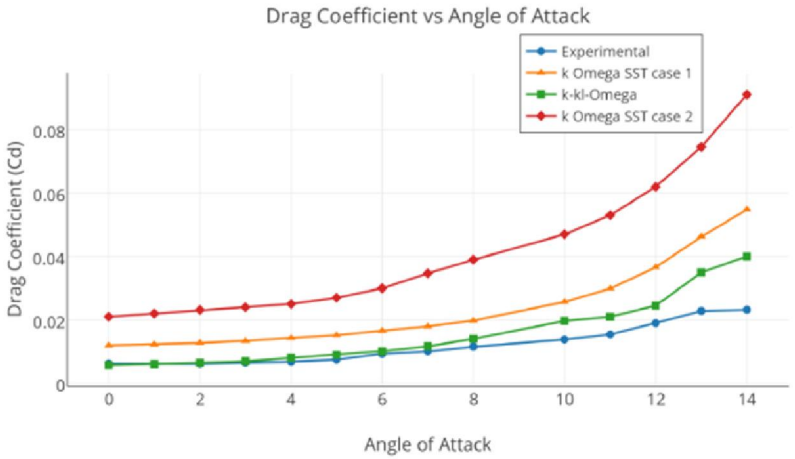
Steady blowing and suction.

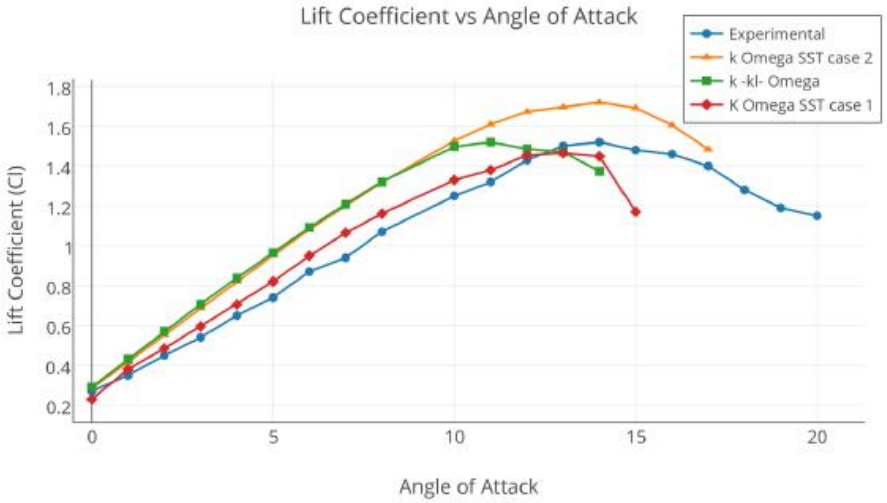






$$Y^+ = \frac{Y\,V_\tau}{\nu};\; V_\tau = \sqrt{\frac{\tau_{wall}}{\rho}}$$

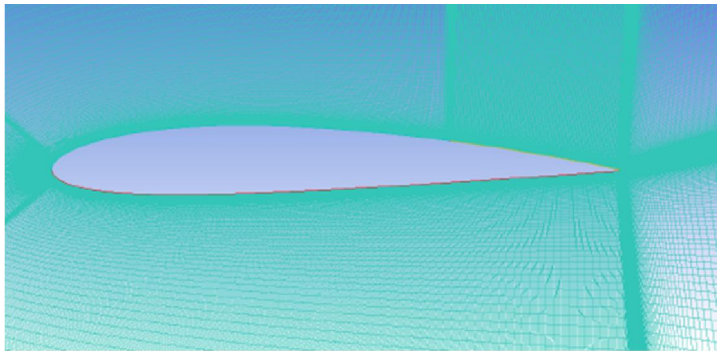


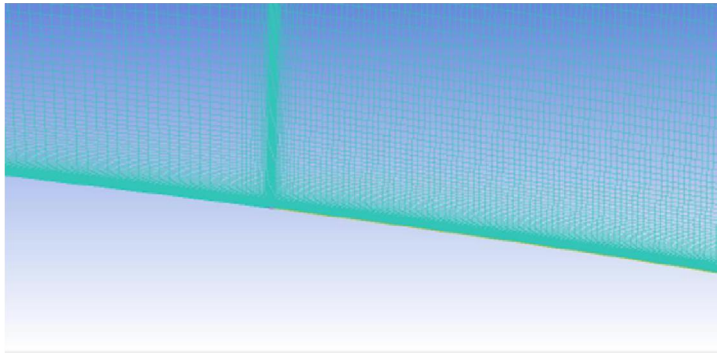


Separation point at angle of attack =12º is located at 82%C.

AFC implementation.

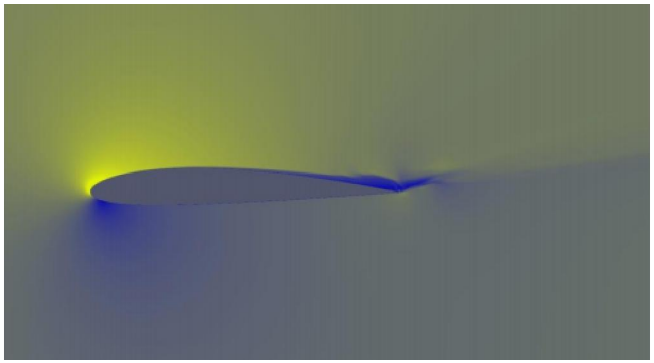
Angle of attack 12deg.
Steady suction.
Steady blowing.

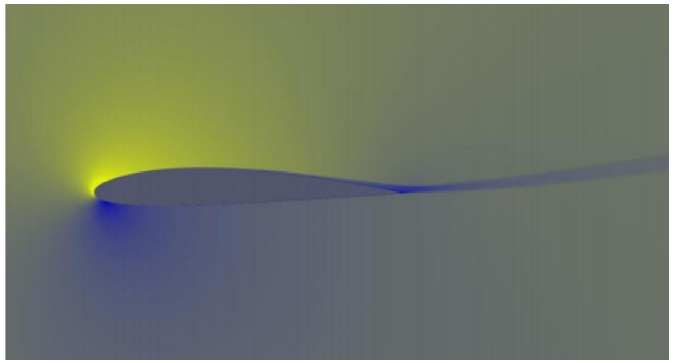




Parameters evaluated.

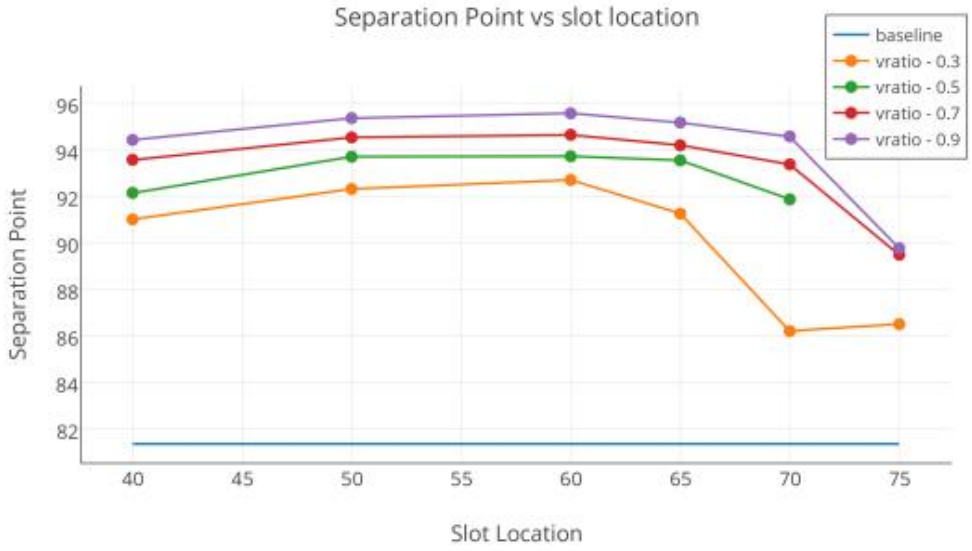
1.- Velocity ratio $\frac{V_{jet}}{V_{\infty}}$
2.- Slot location.
3.- Slot width.
4.- Injection/suction angle.

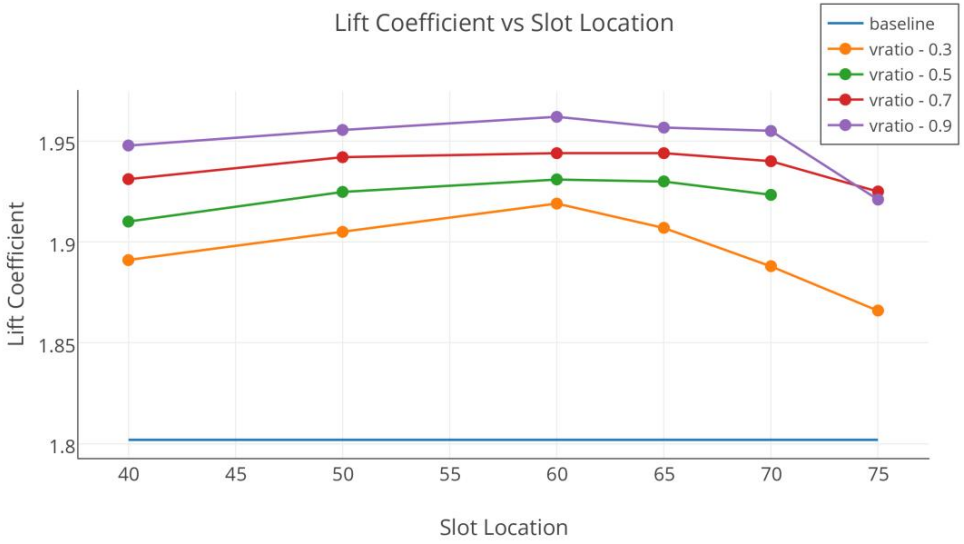


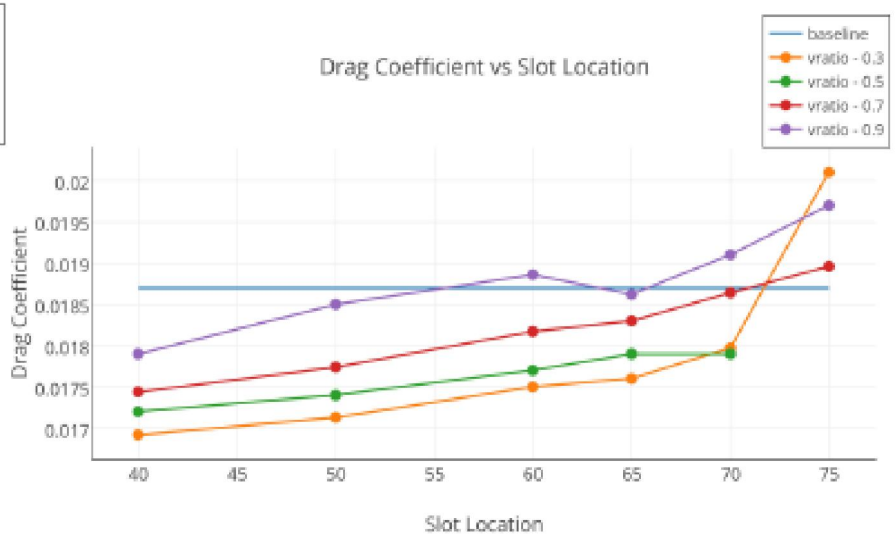


Results – Suction - Slot location

Slot =1.5 mm
Suction angle = 90º
Angle of attack = 12º

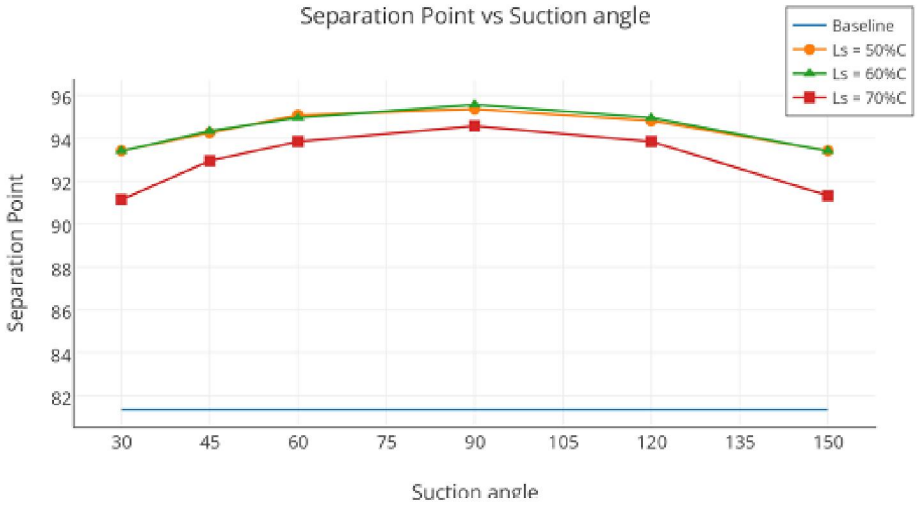


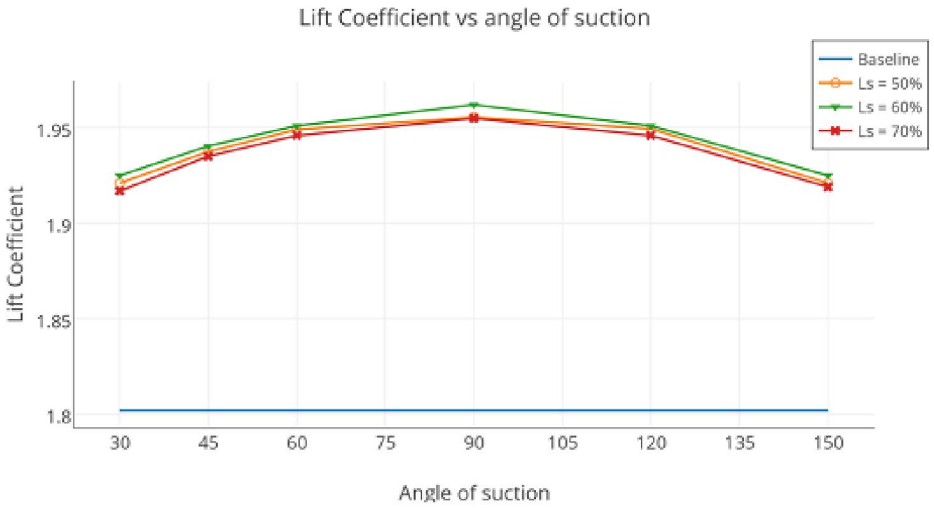


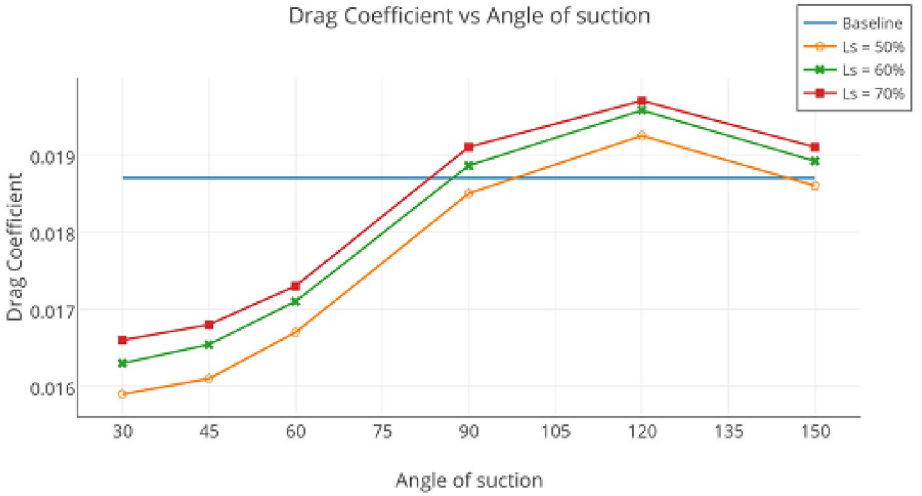


Slot =1.5 mm
Velocity ratio = 0.9
Angle of attack = 12º
Slot location 60%C

Results – Suction – Inclination angle

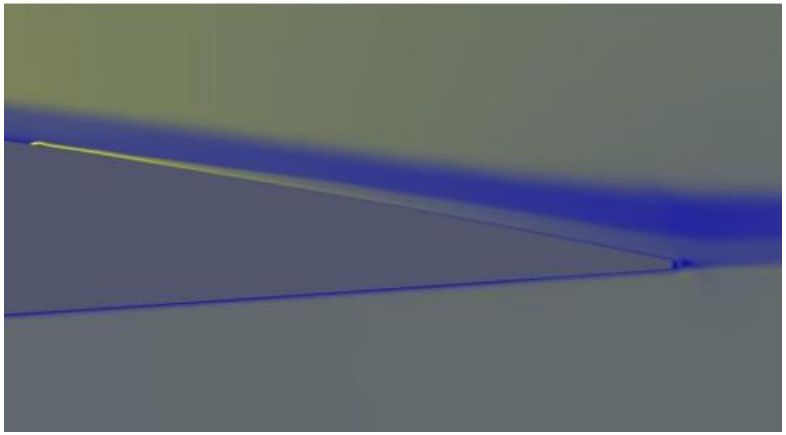


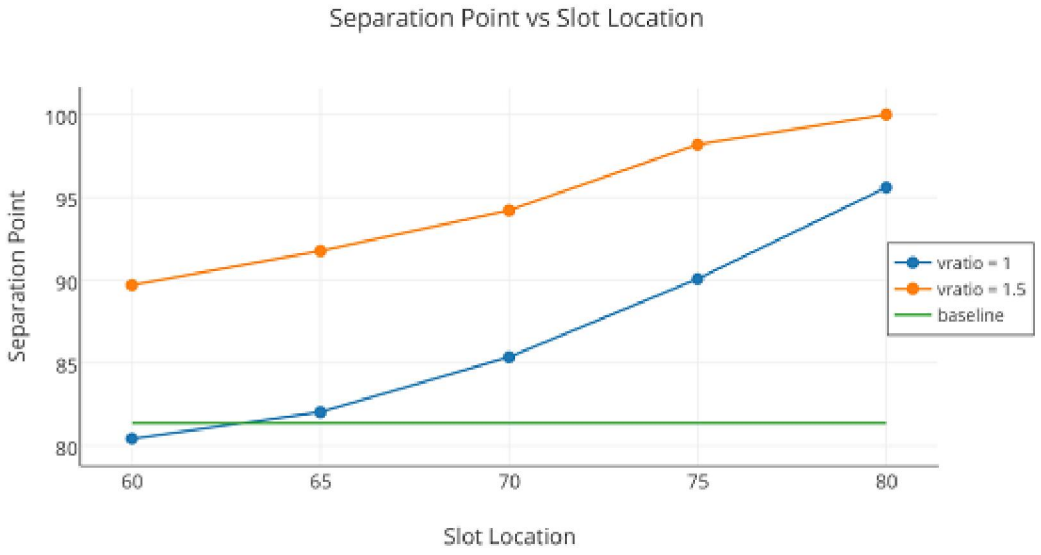


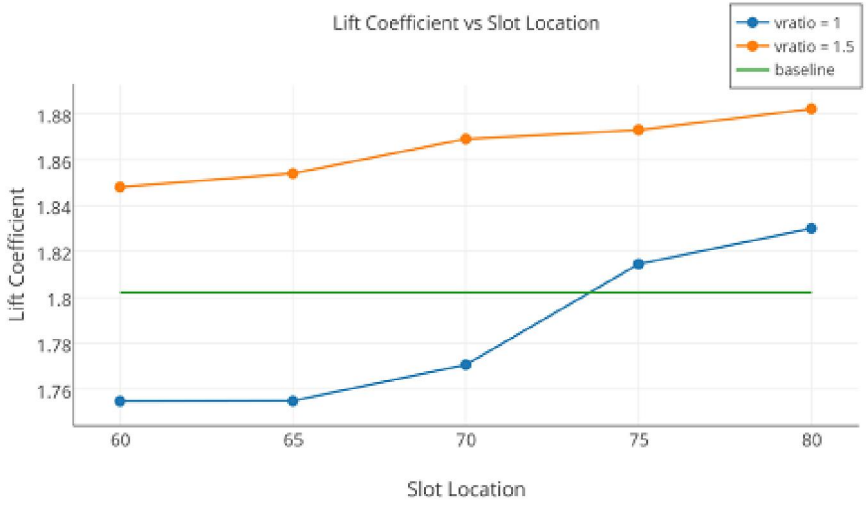


Slot =1.5 mm
Blowing angle = 30º
Angle of attack = 12º

Results – Blowing - Slot location



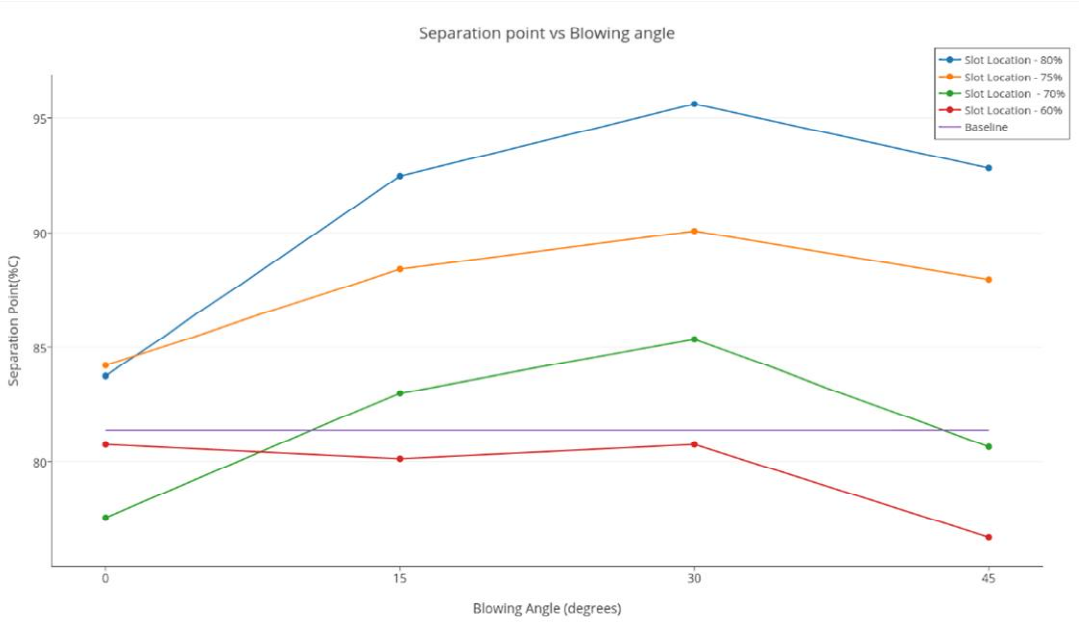


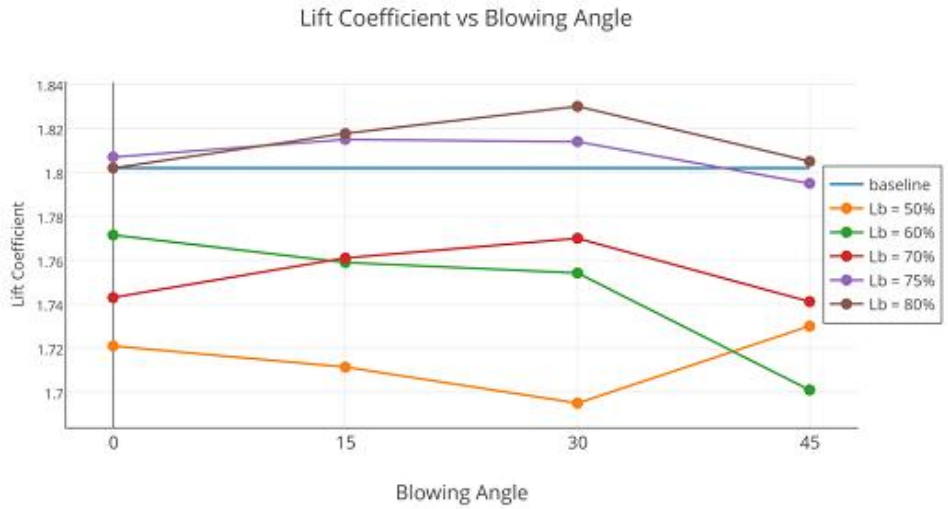


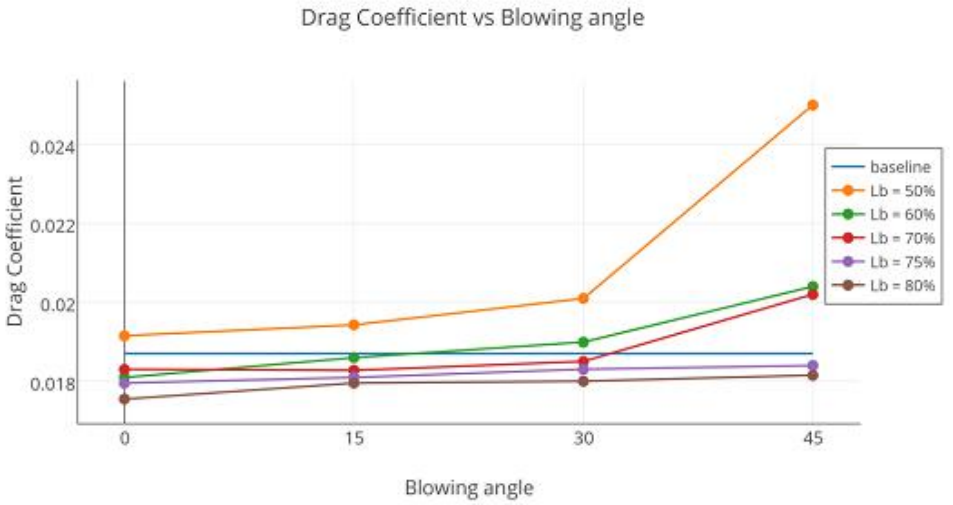


Slot width =1.5 mm
Velocity ratio = 1
Angle of attack = 12º

Results – Blowing – Injection angle



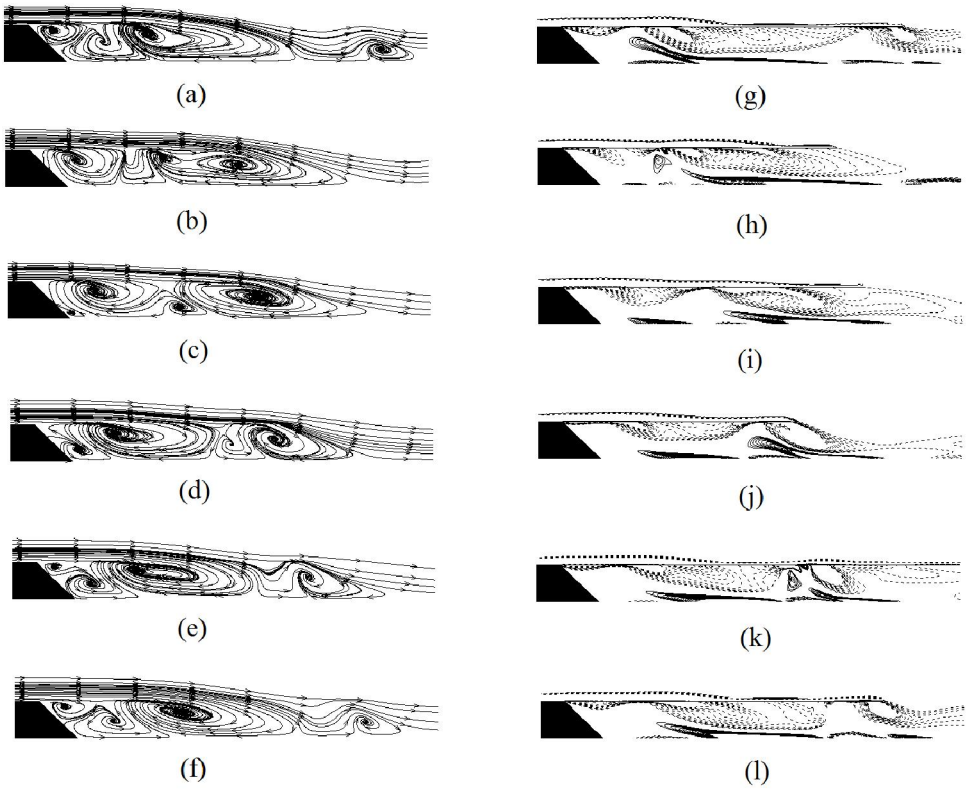


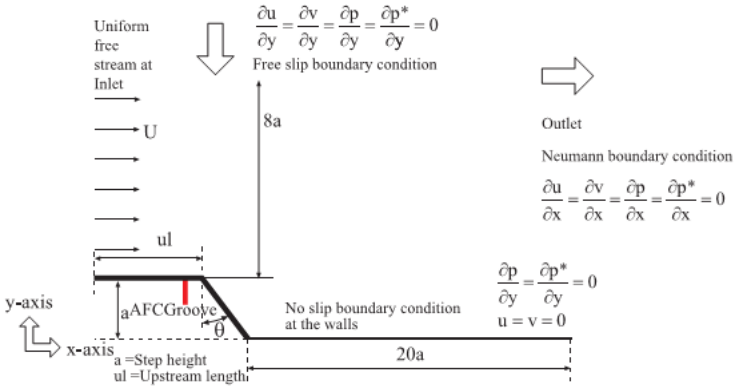


Conclusions Steady blowing/suction

	Suction(Optimal case)	Blowing (Optimal case)
Slot Location	60%	75%
Velocity ratio	0.5	1.5
Angle	90	30
Slot Width	1.5	1.5
Separation Point	16.23%	20.67%
Cl	7.18%	3.9%
Cd	-5.22%	-2.3%
Cl/Cd	13.1%	6.8%

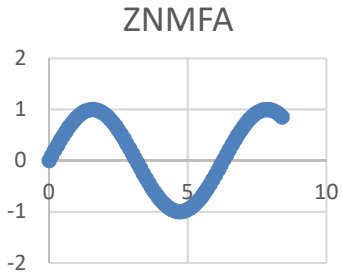
AFC Periodic forcing BFIS Re = 500; 800

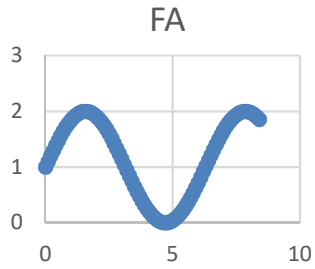




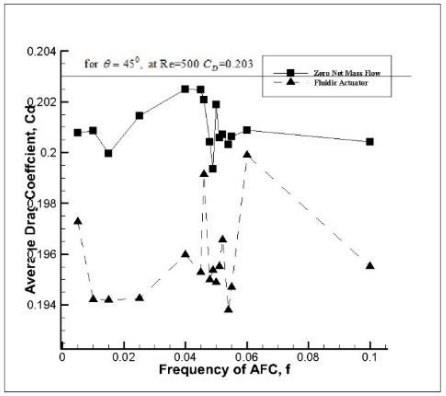
Streamline and corresponding Vorticity plots of vortex shedding cycle in the wake of backward facing inclined Step at Re=500, for $\theta=45^0$: (a, g) T/6; (b, h) T/3; (c, i) T/2; (d, j) 2T/3; (e, k) 5T/6; (f, l) T.
No AFC is applied

ZNMFA and FA main differences. St=0.05

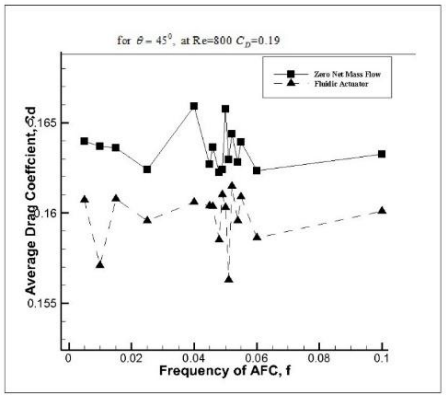




Parameters considered.
Groove location
Groove width
Forcing Frequency
Forcing amplitude
Momentum coefficient
ZNMFA and FA were evaluated

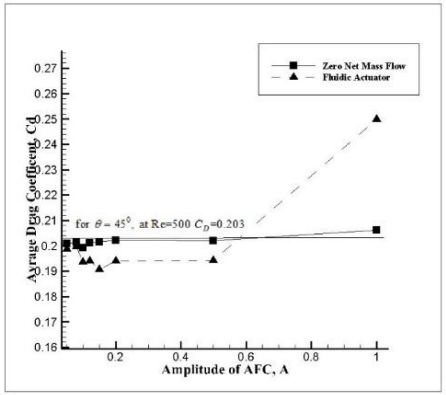


(a)

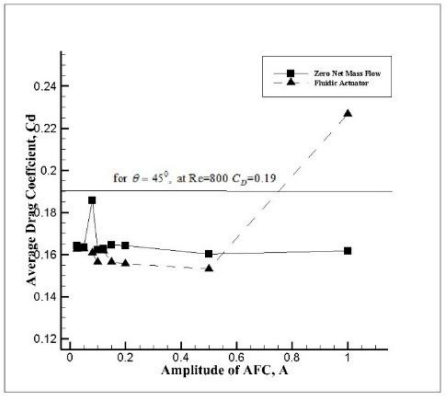


(b)

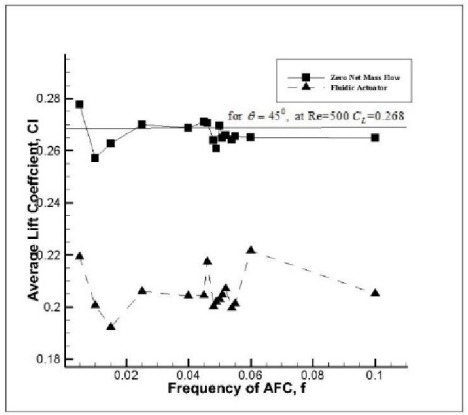
Average Drag coefficient versus frequency.
(a) Re=500, A=0.1
(b) Re=800, A=0.1,
Average drag coefficient versus Amplitude.
(c) Re=500, f=0.049 for ZNMFA and f=0.054for FA,
(d) Re=800, f=0.048 for ZNMFA and f =0.051 for FA.
For all cases x=0.193a, w= 0.023



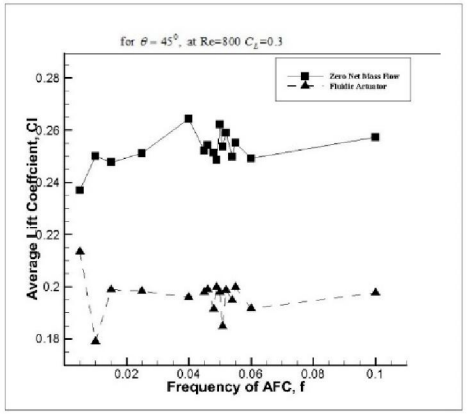
(c)



(d)

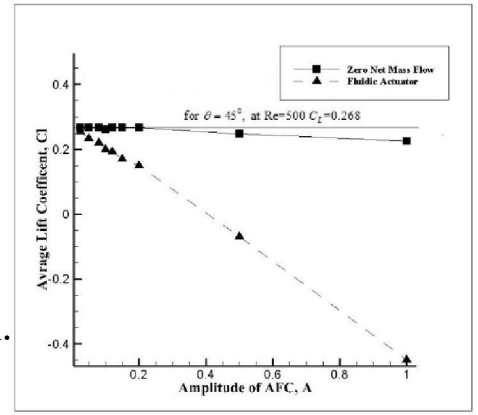


(a)

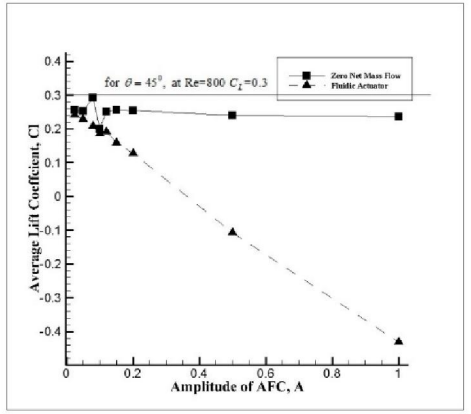


(b)

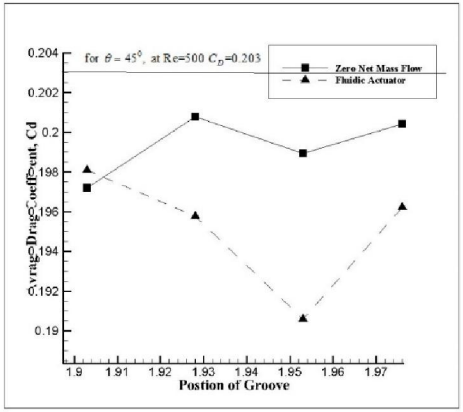
Average Lift coefficient versus frequency.
(a) Re=500, A=0.1,
(b) Re=800, A=0.1,
Average Lift coefficient versus amplitude.
(c) Re=500, f=0.049 for ZNMFA, and f=0.054 for FA,
(d) Re=800, f=0.048 for ZNMFA and f=0.051 for FA.
For all cases x=0.193a, w= 0.023



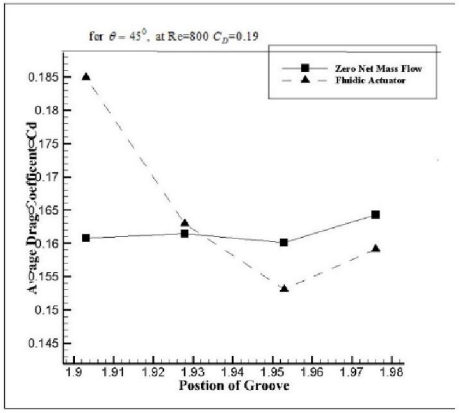
(c)



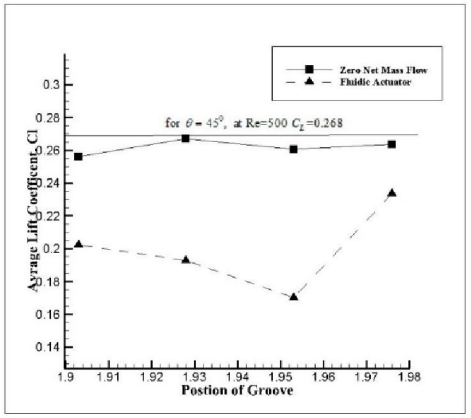
(d)



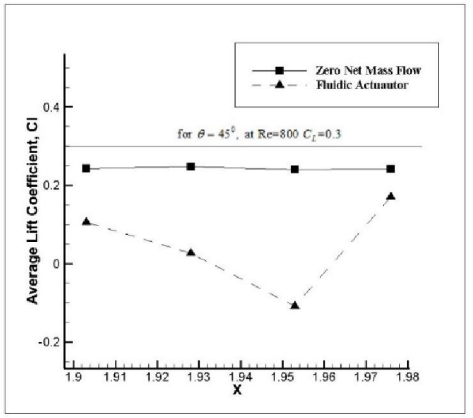
(a)



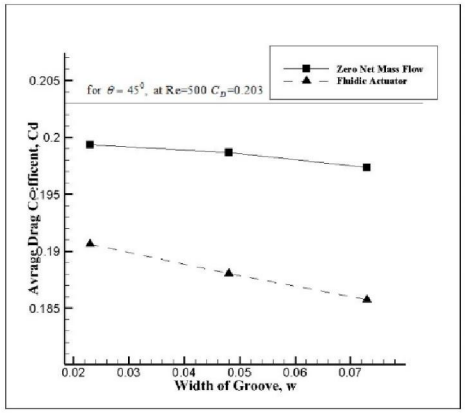
(b)



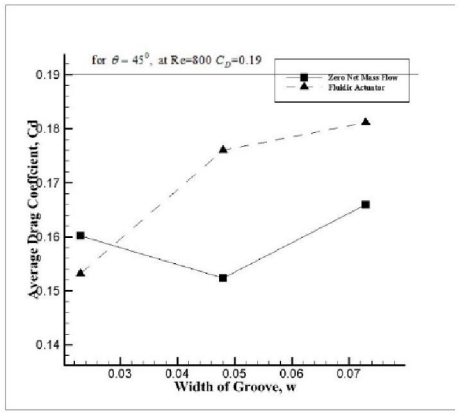
(a)



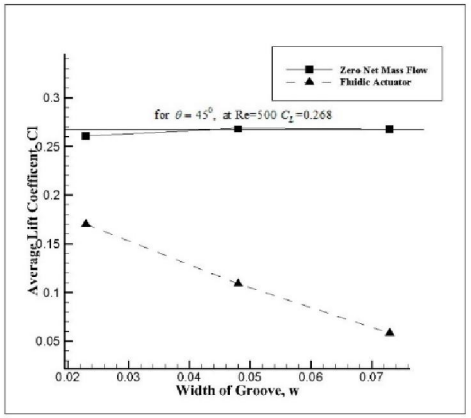
(b)



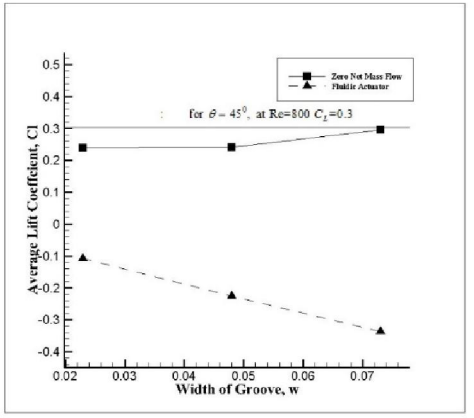
(c)



(d)



(c)



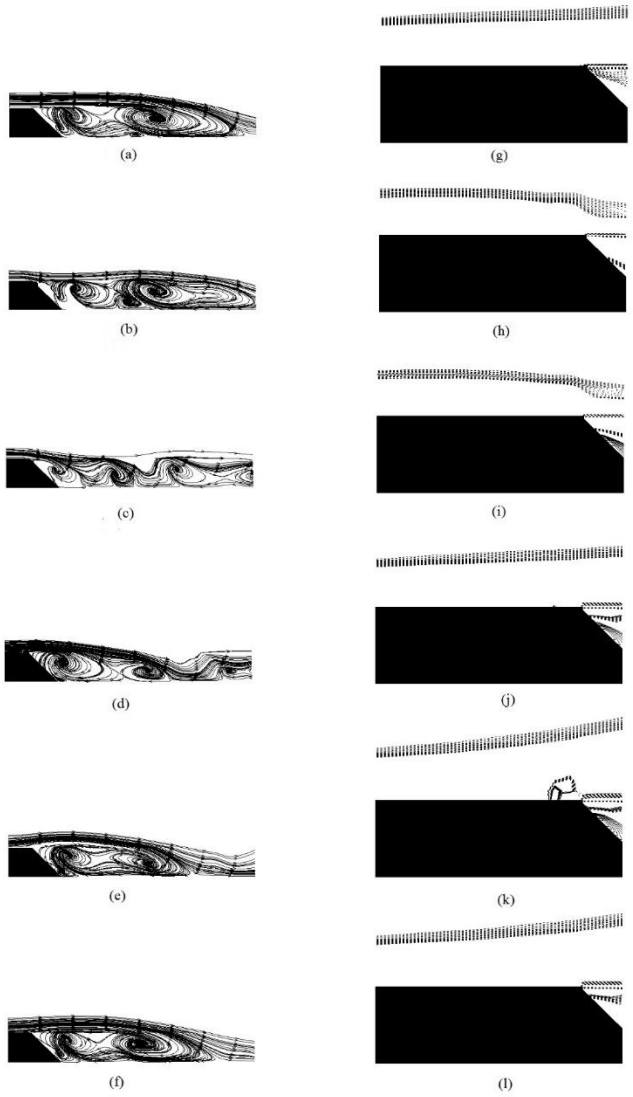
(d)

Average Drag coefficient versus groove position. (a) Re=500, (b) Re=800, groove width remained constant at w=0.023.

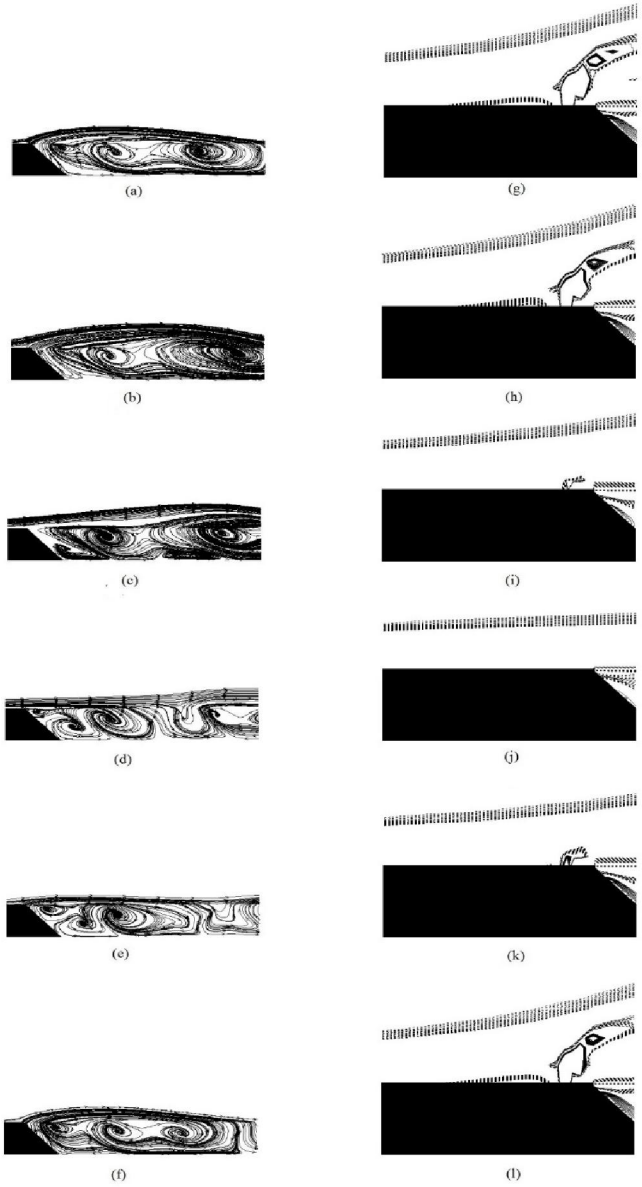
Average Drag coefficient versus groove width w, groove position remained constant at x= 1.953a, (c) Re=500, (d) Re=800. At Re=500, f= 0.049 for ZNMFA and f=0.054 for FA, at Re=800, f=0.048 for ZNMFA and f=0.051 for FA.

Average Lift coefficient versus groove position, (a) Re=500 (b) Re=800, groove width remained constant at w=0.023.

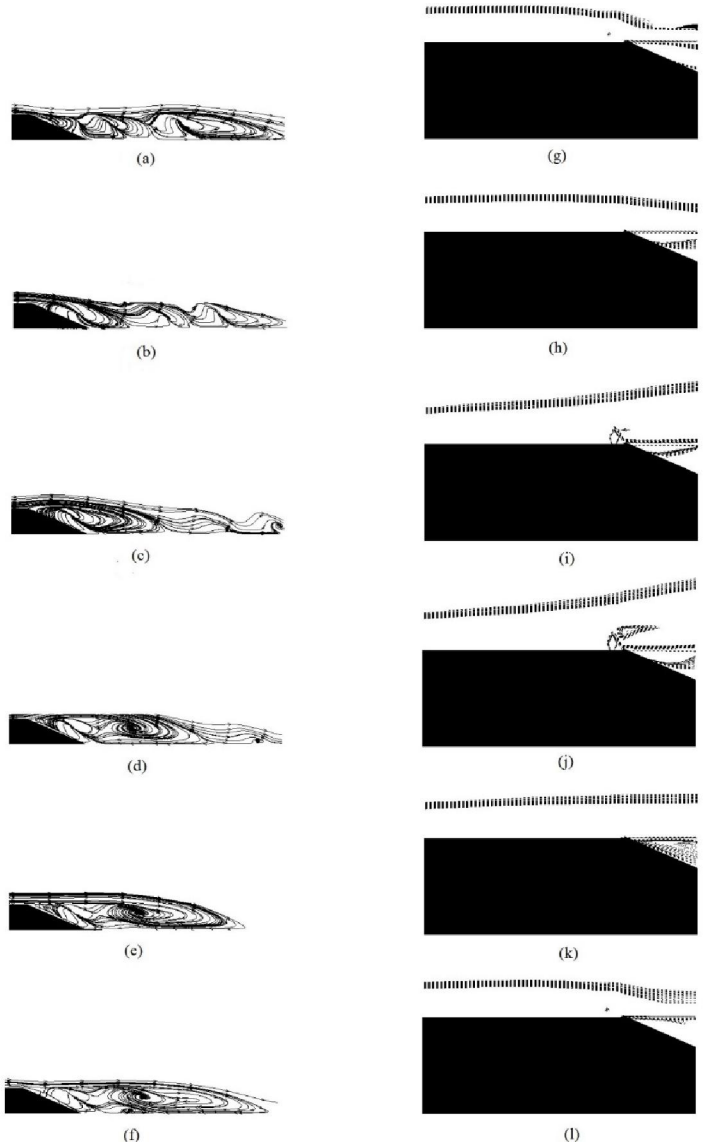
Average Lift coefficient versus groove width, groove position remained constant at x= 1.953a, (c) Re=500, (d) Re=800. At Re=500, ZNMF configuration was f=0.049, A=0.1 and FA configuration was f=0.054, A=0.15 . At Re=800, , ZNMF configuration f=0.048, A=0.5 and FA configuration f=0.051, A=0.5 for FA.



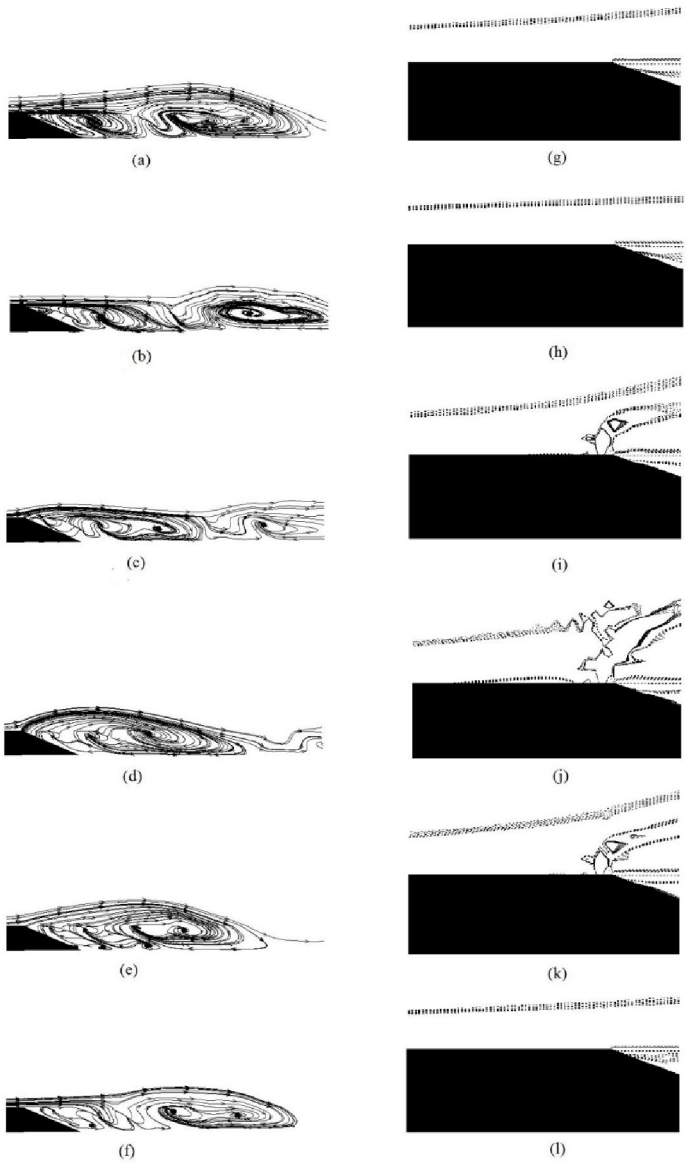
Streamline plots of vortex shedding cycle and corresponding Vorticity plots of AFC on the upstream surface of the inclined step at Re=800, with upstream ZNMF frequency, f=0.048, A=0.5, x = 0.193a and w= 0.073, C_μ=0.0074, θ=45°.



Streamline plots of vortex shedding cycle and corresponding Vorticity plots of AFC on the upstream surface of the inclined step at Re=800, with upstream FA frequency 0.051, amplitude, A=0.5, x = 0.193a, w= 0.073, C_μ=0.0489, θ=45°.



Streamline plots of vortex shedding cycle and corresponding Vorticity plots of AFC on the upstream surface of the inclined step at Re=800, with upstream ZNMF control frequency 0.045, amplitude A=1 for θ=650, x= 0.193a, w=0.023, Cμ=0.0093. (a, g) T/6; (b, h) T/3; (c, i) T/2; (d, j) 2T/3; (e, k) 5T/6; (f, l) T.



Streamline plots of vortex shedding cycle and corresponding Vorticity plots of AFC on the upstream surface of the inclined step at Re=800, with upstream FA flow control frequency 0.045, amplitude A=1 for $\theta=65^0$, x = 0.193a, w=0.023, C_μ=0.0616: (a, g) T/6; (b, h) T/3; (c, i) T/2; (d, j) 2T/3; (e, k) 5T/6; (f, l) T.

Conclusions

C_L and C_D in any bluff body can be via AFC optimized.

Steady blowing/sucking have to be considered.

Periodic forcing requires less energy to modify downstream vortex shedding, and therefore C_L and C_D.

Periodic forcing is more expensive to implement.

Grooves position and width needs to be carefully studied, and depends on the forcing used, Reynolds number, and the bluff body shape.

Pressure coefficients and friction coefficients help to understand the physical phenomena.

Future Applications.
Transport vehicles. Cars, Trucks, Trains etc.
Bluff bodies in general.
Aeroplanes, Windmills, Turbines. Any device using wing profiles.
For general purposes, Multiple groove closed loop systems will be used.