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A Novel Airfoil Circulation Augment Flow Control Method Using Co-Flow Jet

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Objective:

- Develop a new circulation control method:

1) Augment lift (L, L/D)

2) Increase aircraft maneuverability (AoA range)

3) Be energy efficient (overall airframe-propulsion system)

Review:

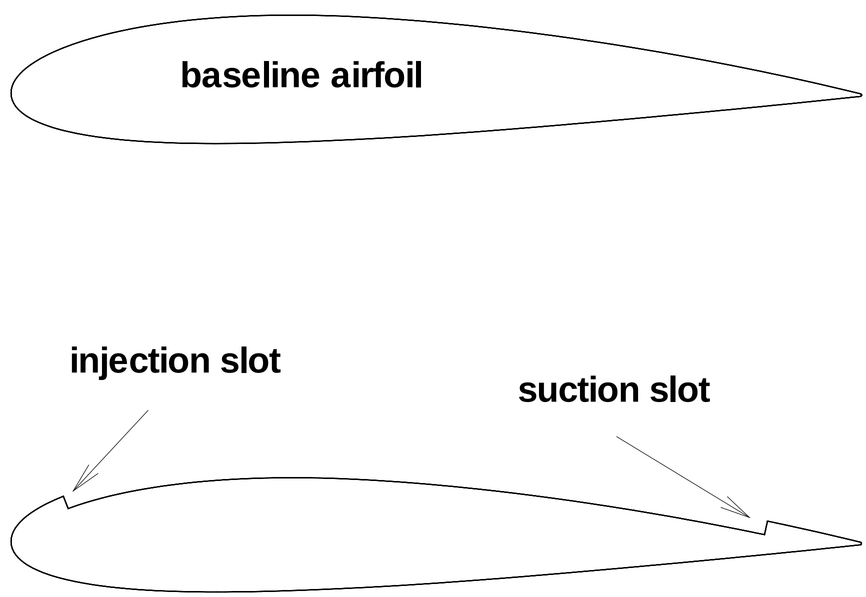
- Conventional circulation control increase lift significantly and reduce noise
- Most effective for large LE and TE radius
- Large drag at cruise and for high speed aircraft
- Hinged flap have thin TE, the complexity of the mechanical control system increased.
- Mass flow blowing penalize propulsion system efficiency
- Maneuverability reduced due to reduced AoA range
- More suitable for taking off and landing, may not used for cruise

New Circulation Control Method

- Use co-flow jet on airfoil suction surface
- Blow near LE, sucking same amount flow near TE, enhanced Coanda effect
- Turbulence mixing transfer energy from jet to mainflow
- Energized flow augment circulation
- Re-circulate jet reduce energy expenditure
- Do not need large LE or TE radius
- Can apply to low or high speed aircraft

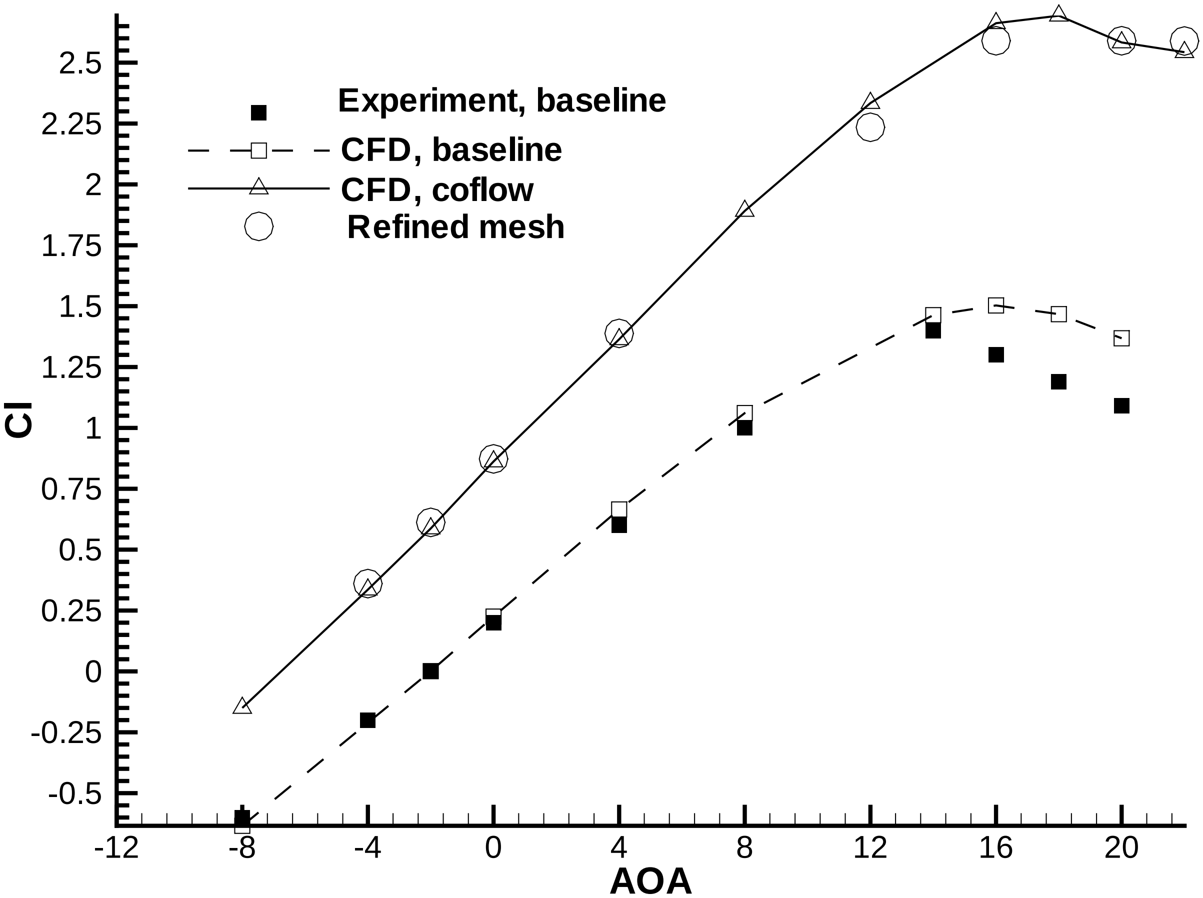
Co-Flow Jet Airfoil

NACA 2415: slot inlet at 6.72%C, outlet at 88.72%C, suction surface lowered by 1.67%C, inlet area = 1.56%C, outlet area = 1.63%C.

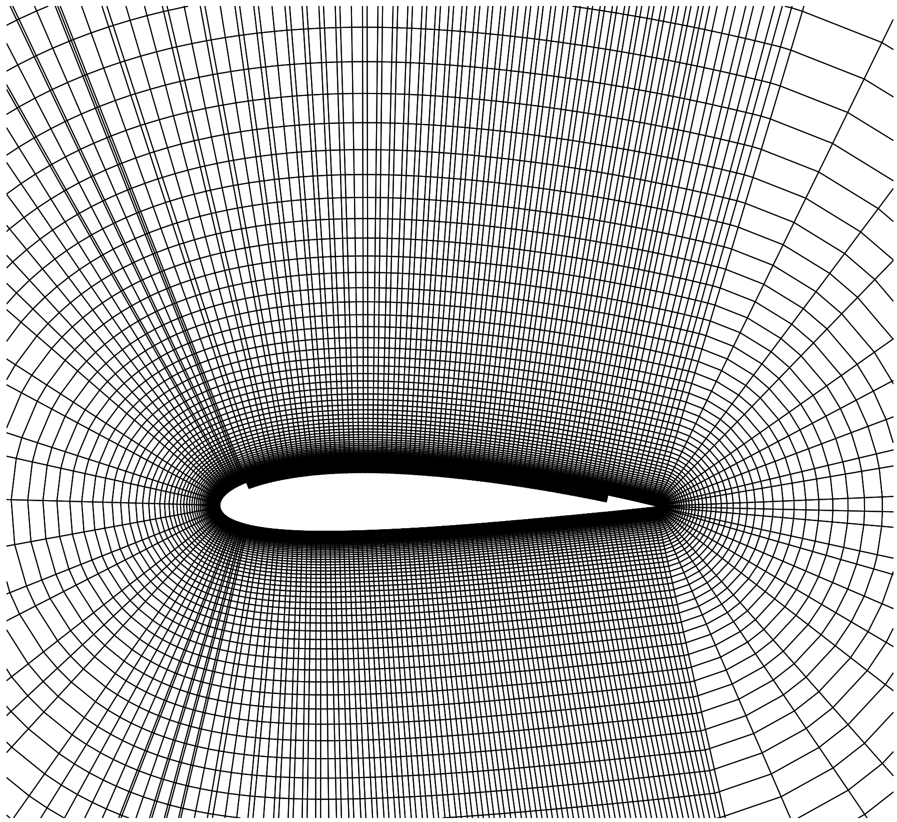


CFD Simulation

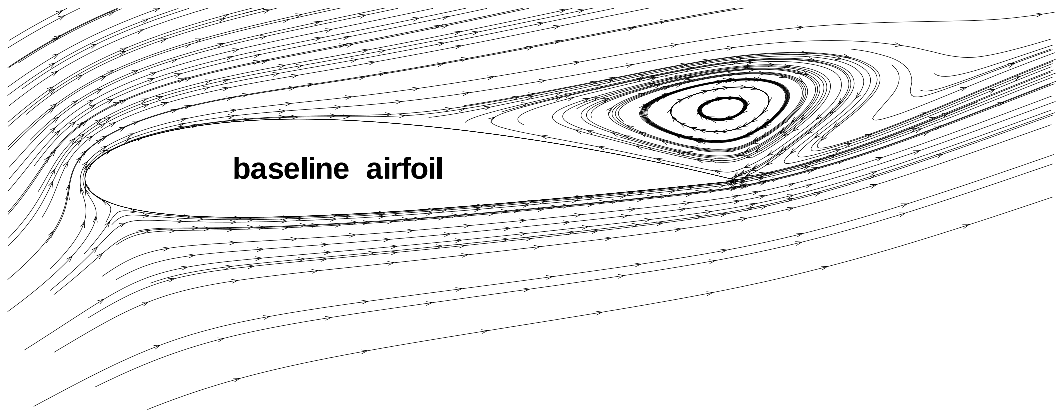
$Re = 1.9 \times 10^6,\ M_\infty = 0.3,\ Pt_{jetinlet} = 1.315 Pt_\infty$

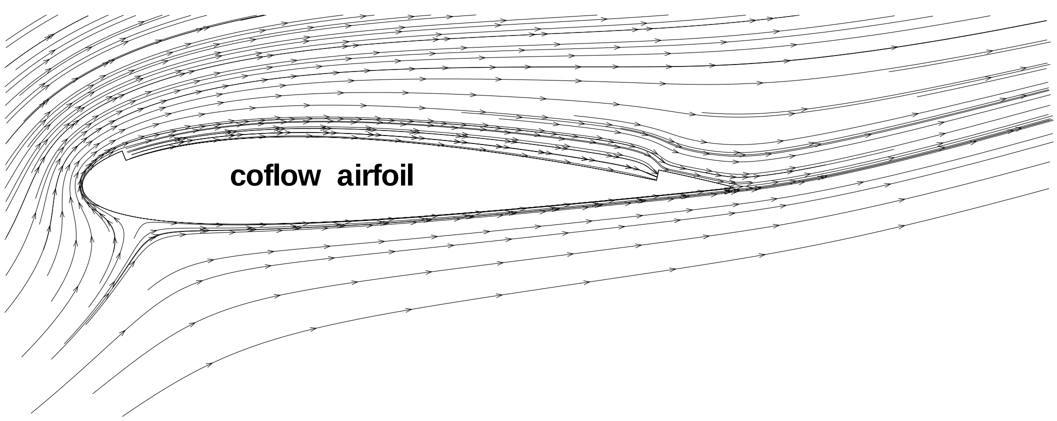


Zoomed Mesh

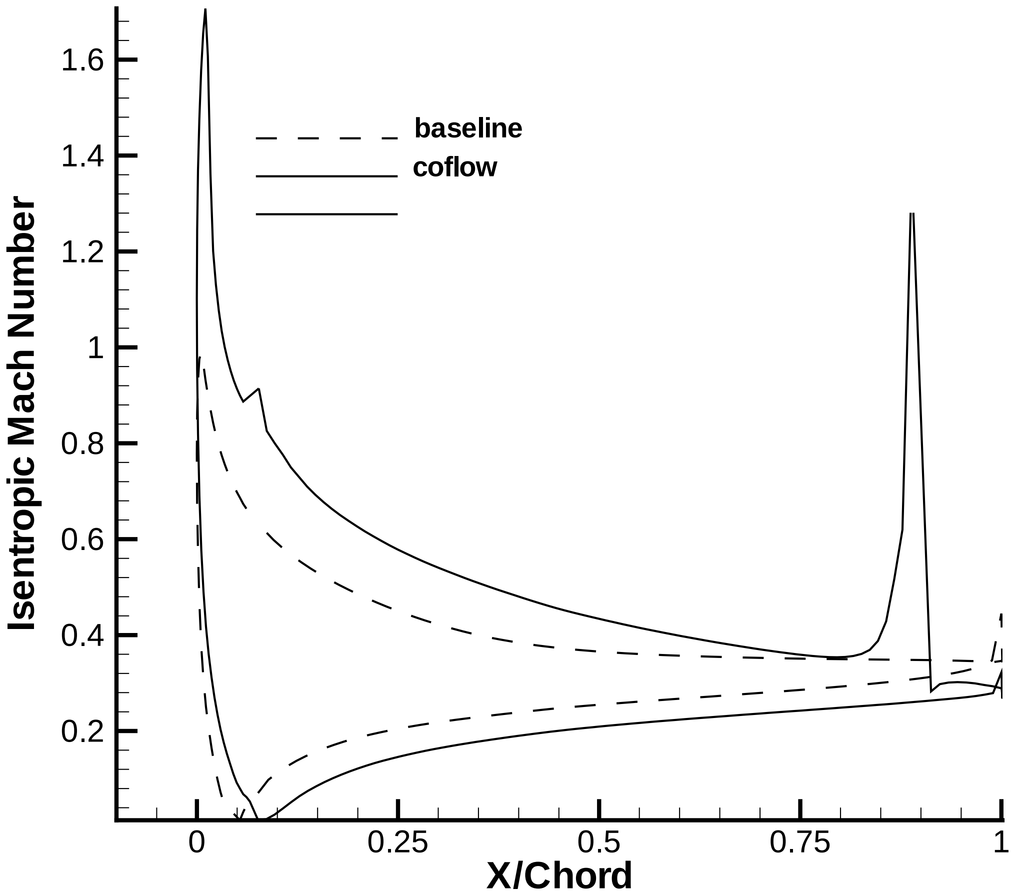


Streamlines at $AoA = 20°$

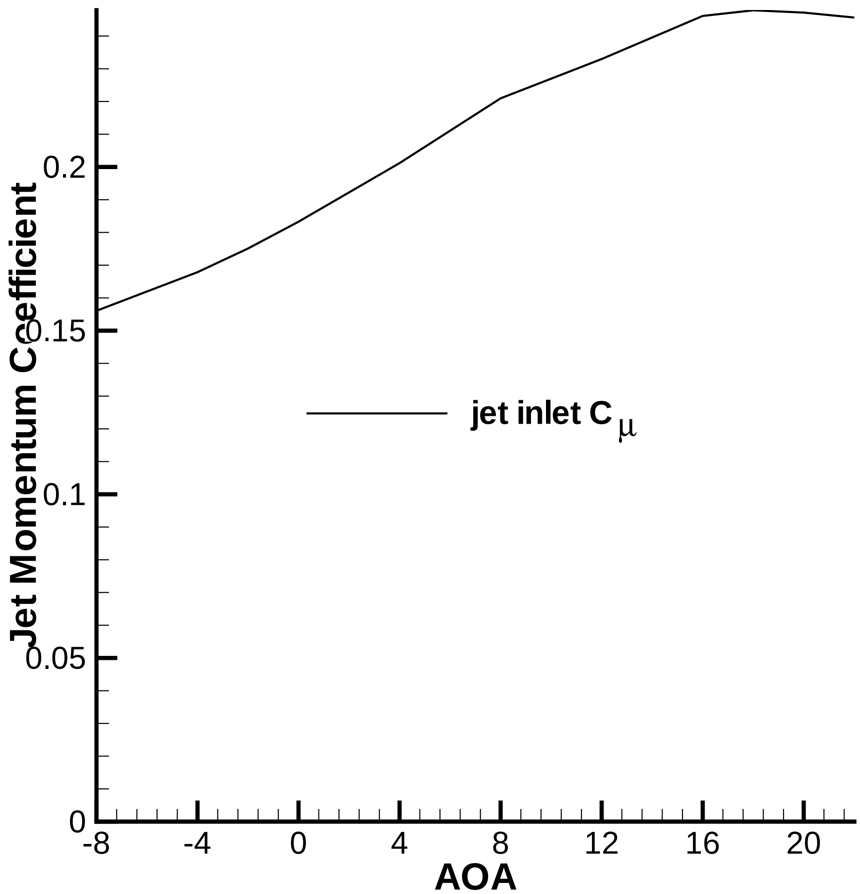




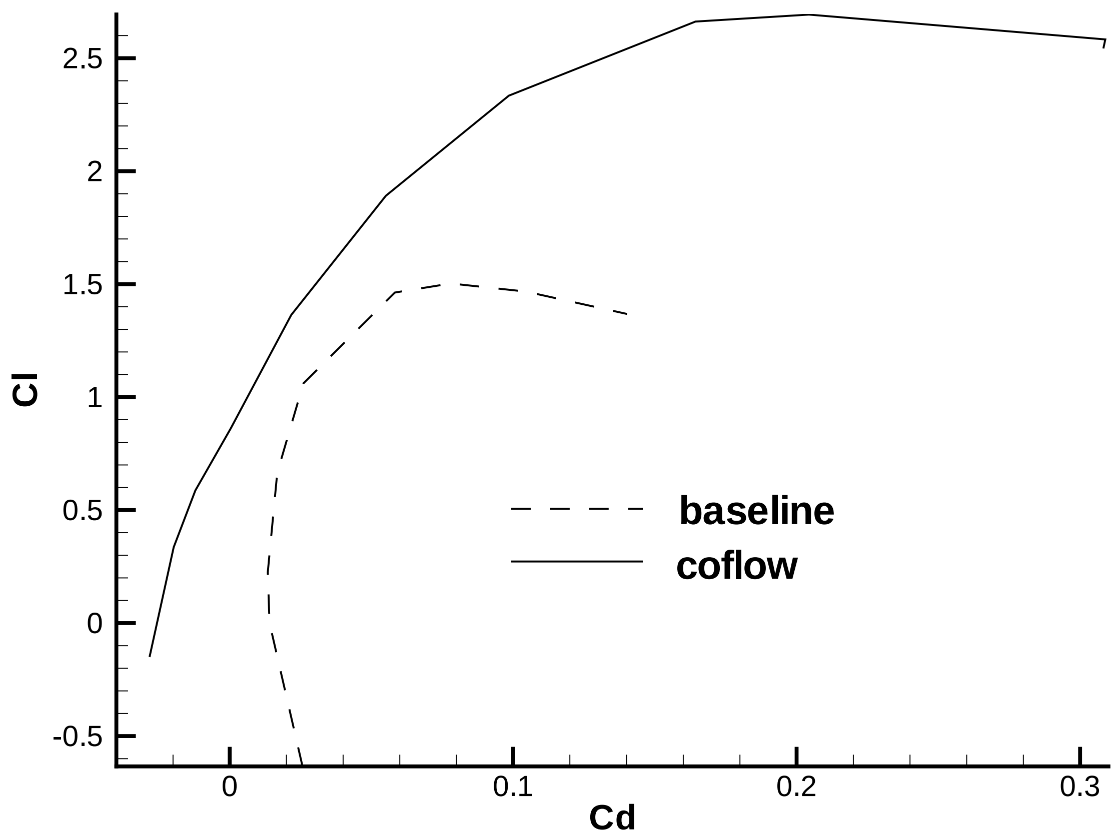
Surface Isentropic Mach Number at AoA=20°



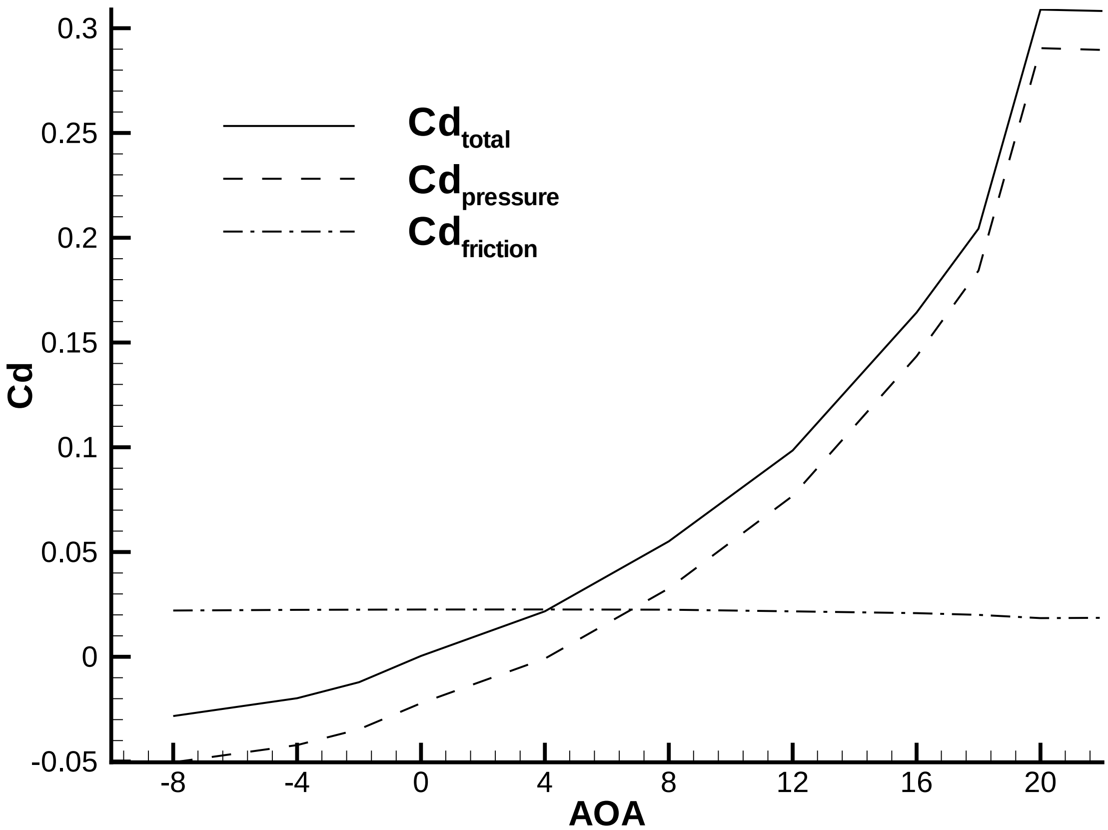
Momentum Coefficient vs AOA



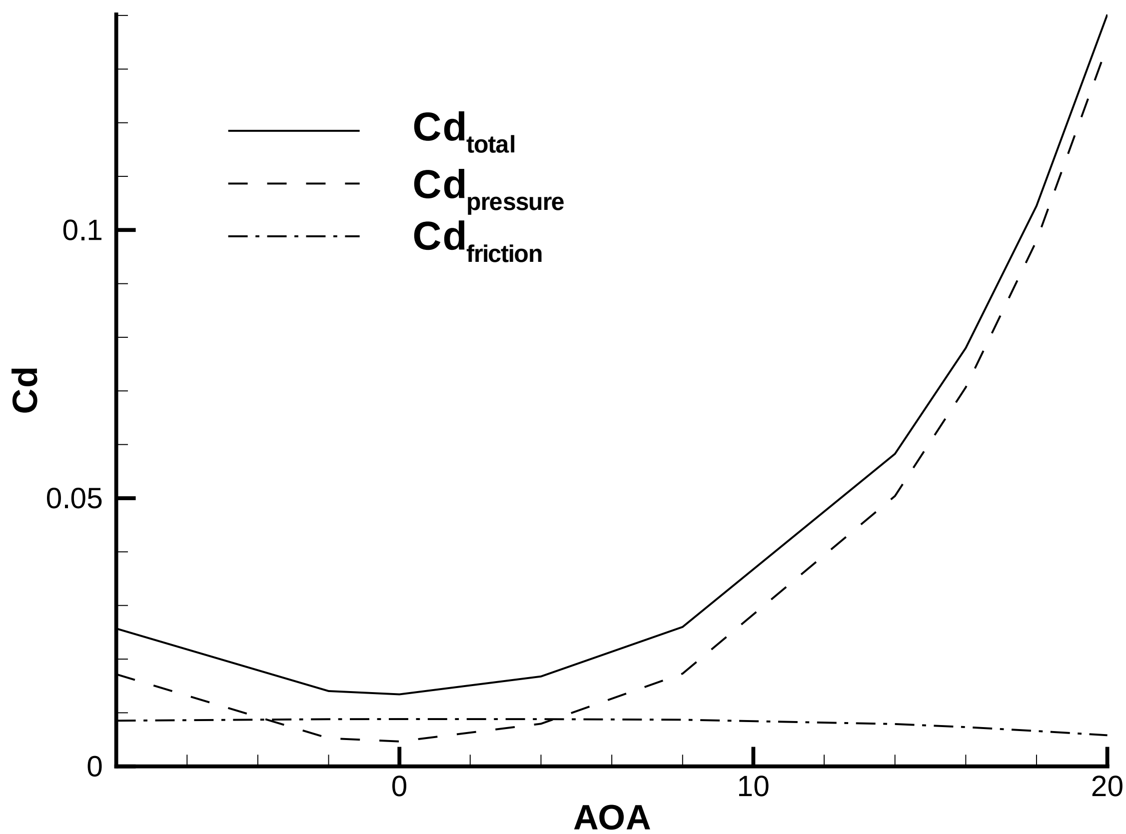
Drag Polar



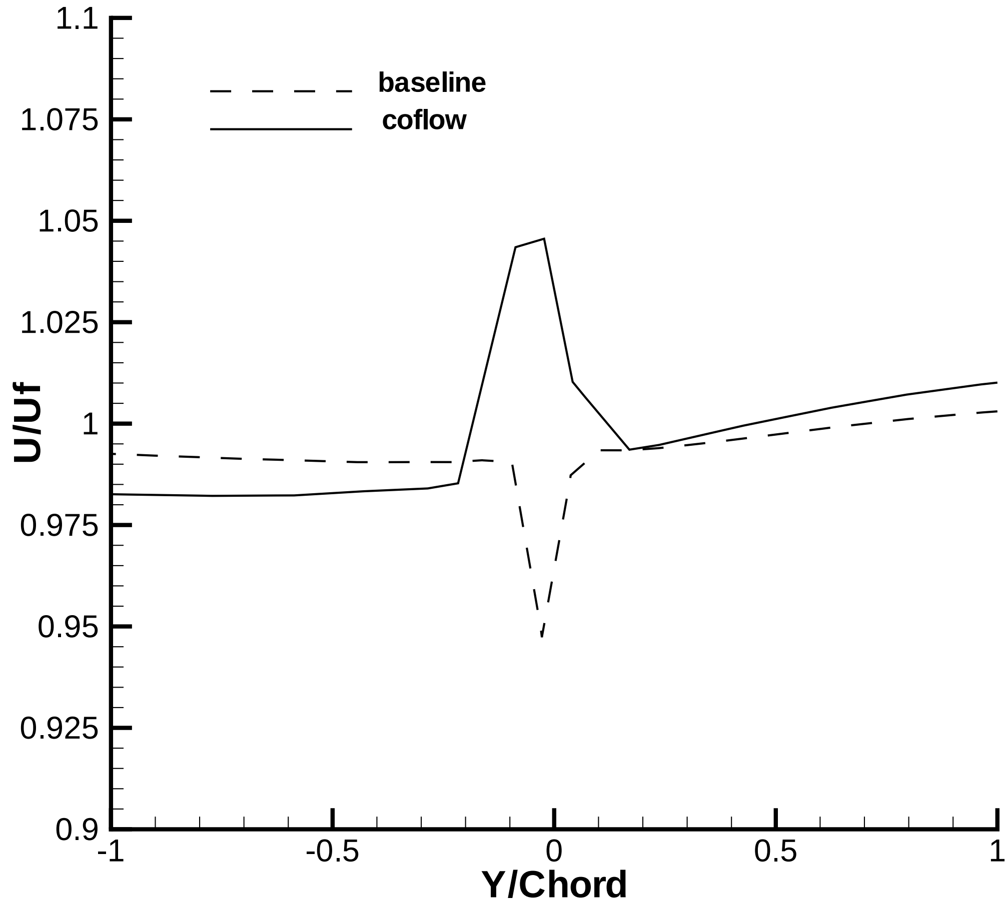
Drag vs AOA for Co-Flow Jet Airfoil



Drag vs AOA for Baseline Airfoil



Wake Profile at AOA=0°



Work required to energize jet

$$
\begin{aligned}
W_{isentropic} &= Cp(T_{02} - T_{01}) \\
&= CpT_{01}((P_{02}/P_{01})^{\frac{\gamma-1}{\gamma}} - 1) \qquad (1)
\end{aligned}
$$

$$W = W_{isentropic}/\eta \qquad (2)$$

If the flow control system has the same efficiency for blowing only and recirculation, the work ratio

$$
\begin{aligned}
W_R &= \frac{W_{rec}}{W_{blow}} \\
&= \frac{((P_{02}/P_{01})^{\frac{\gamma-1}{\gamma}} - 1)_{recirculation}}{((P_{02}/P_{01})^{\frac{\gamma-1}{\gamma}} - 1)_{blowonly}} \qquad (3)
\end{aligned}
$$

Assume a very conservative case:

$$\eta_{recirculation} = 0.5\eta_{blow} \qquad (4)$$

$$W_R = 2\frac{((P_{02}/P_{01})^{\frac{\gamma-1}{\gamma}} - 1)_{recirculation}}{((P_{02}/P_{01})^{\frac{\gamma-1}{\gamma}} - 1)_{blowonly}} \qquad (5)$$

The P_t ratio of recirculation is smaller and hence the work required to energize the jet is less than the blowing only.

Penalty to Propulsion due to disposed jet flow

Assume test an engine on the ground and the nozzle expand to ambient,

The thrust is:

$$F = m_{nozzle} V_{nozzle} \tag{6}$$

The disposed jet flow will directly decrease thrust.

Total Efficiency of propulsion system:

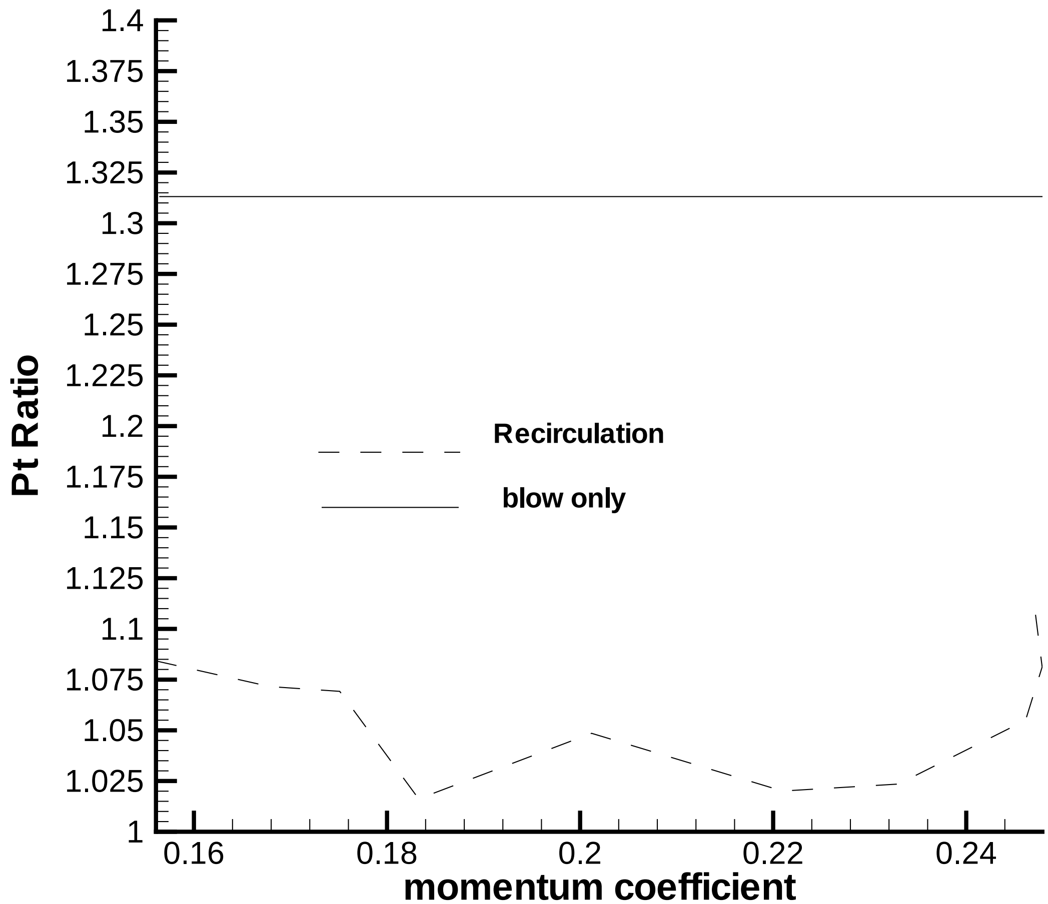
$$\eta = \frac{C_\infty m_{nozzle}(C_{nozzle} - \frac{m_{nozzle}}{m_{inlet}} C_\infty)}{Q} \tag{7}$$

If assume Q is the same, $\frac{m_{nozzle}}{m_{inlet}} \approx 1$, then η is proportional to m_{nozzle}.

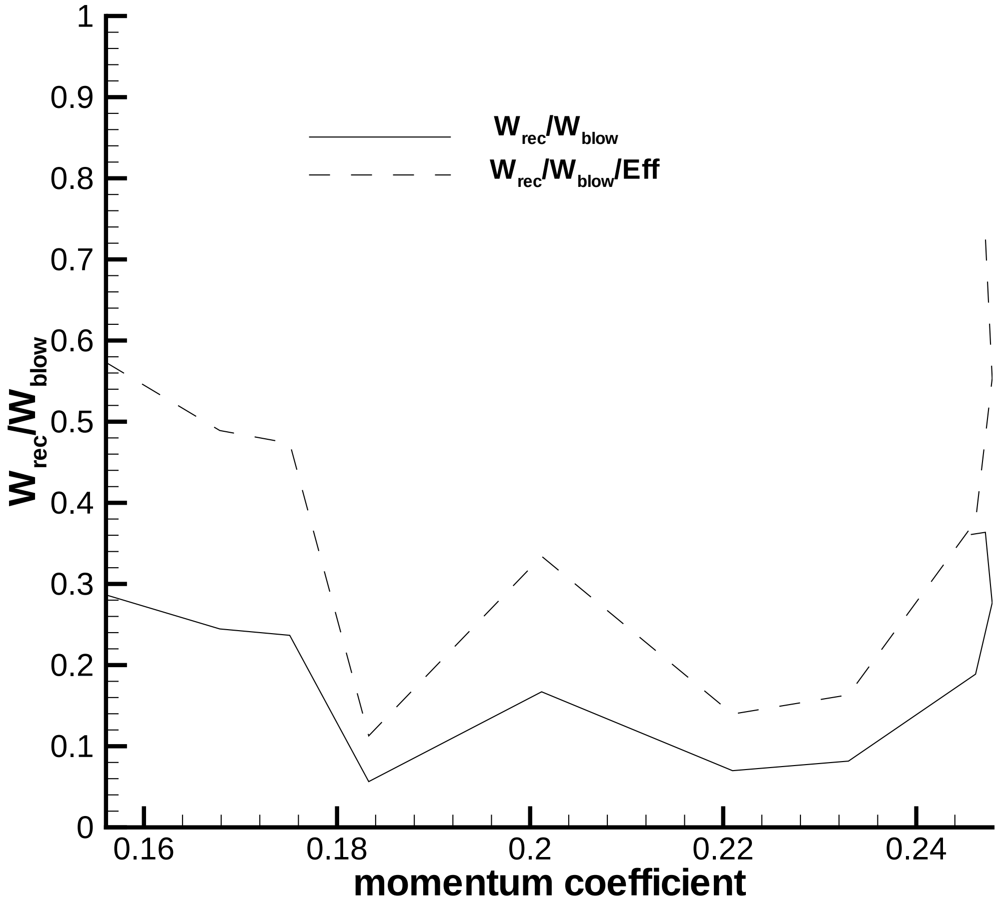
The disposed jet flow will directly reduce the propulsion system efficiency.

The recirculating co-flow jet avoid this penalty.

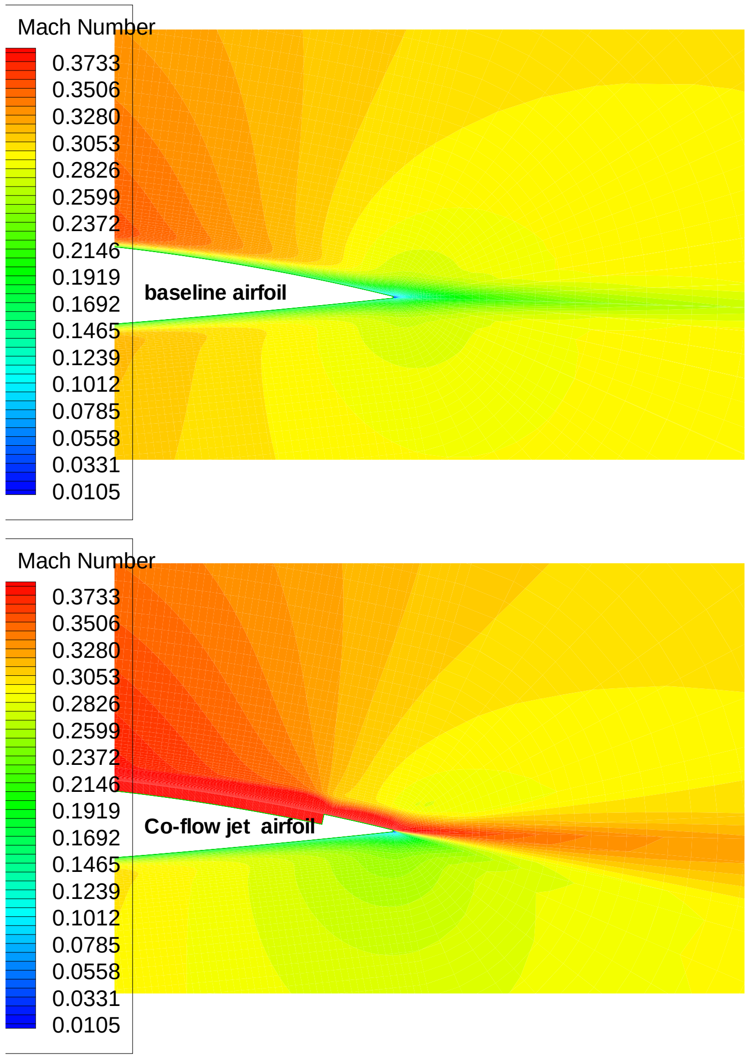
Total Pressure Ratio vs Momentum Coefficient



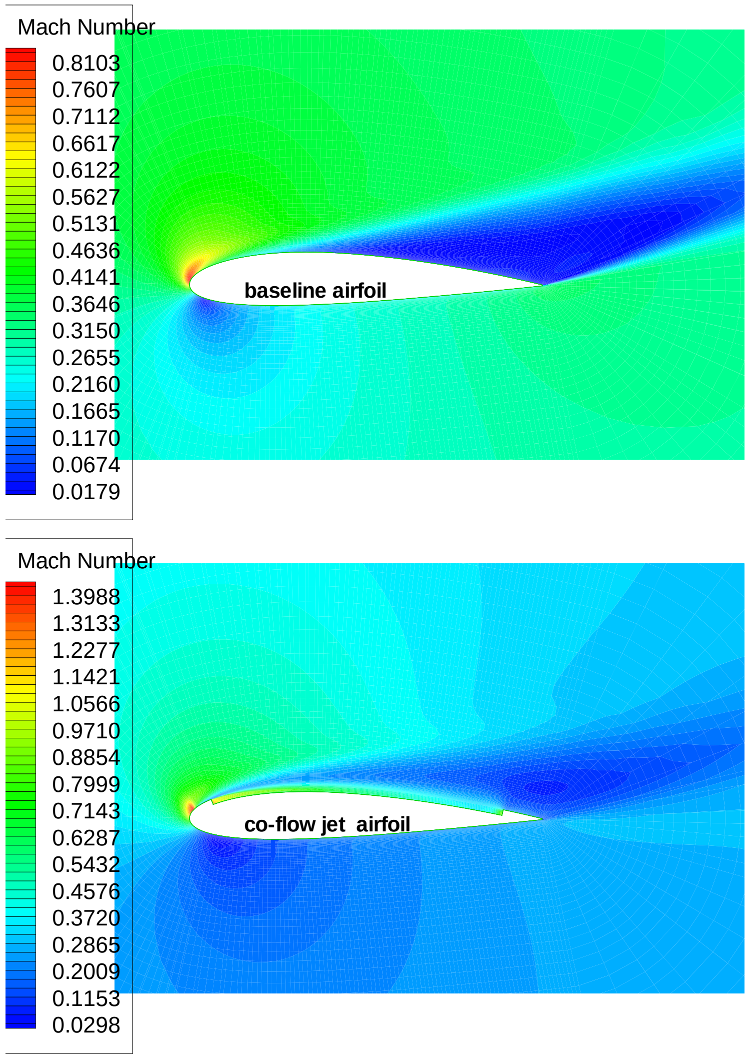
$Work_{recirculate}/Work_{blow}$



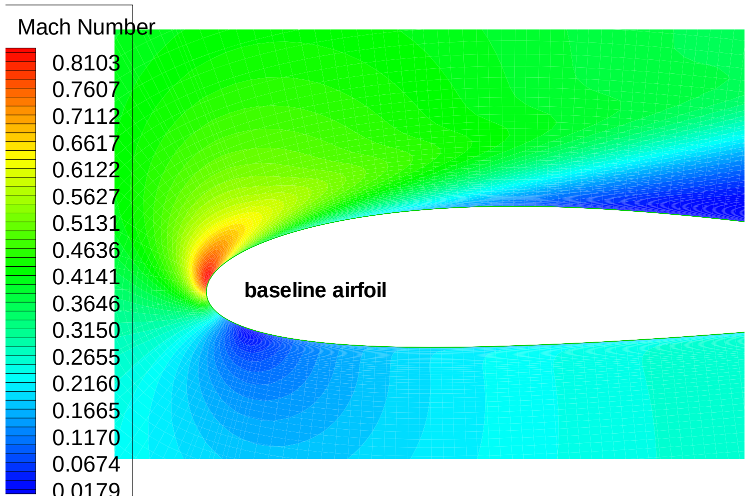
Mach Contours at TE AOA=0°

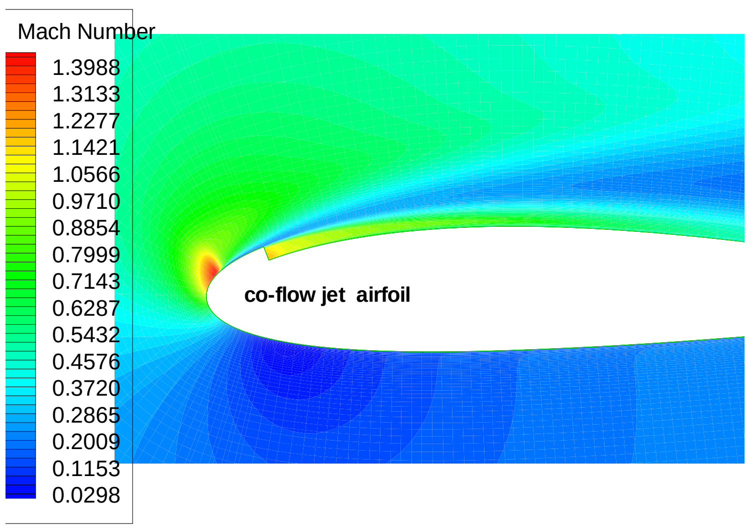


Mach Contours AOA=20°



Mach Contours at LE AOA=20°





Conclusions:

• CFD simulation shows that the lift is significantly increased by co-flow jet.

• Stall margin is greatly enlarged and may increase aircraft maneuverability.

• At cruise, co-flow jet may fill the wake due to surplus momentum and hence reduce drag, or create thrust, the high C_l and low C_d may yield very high aerodynamic efficiency C_l/C_d.

• At high AoA, high lift and high drag may help for short landing and taking off.

• It does not require large LE and TE and hence may be applied to any airfoil (low or high speed).

• Compared with the blowing only flow control, the recirculating co-flow jet may be much more energy efficient.

• Preliminary Experimental results prove the concept, Experiment is in progress thanks to NASA LaRC support.

Perspective Superior Aircraft Performance:

- The CFJ airfoil works for the whole flying mission instead of only taking off and landing
- Economic fuel consumption
- Short distance taking off and landing
- No moving parts are needed and the implementation is not difficult
- Small wing span for easy storage, light weight and reduced skin friction
- Low noise since no high lift flap system is used
- The CFJ airfoil can be used for low and high speed aircraft.