AIAA Paper 2006-1060, 01/11/2006

Numerical Simulation of Co-Flow Jet Airfoil Flows

Gecheng Zha
Wei Gao
Craig Paxton
Dept. of Mechanical and Aerospace Engineering
University of Miami
Coral Gables, FL 33124
E-mail: Gzha@miami.edu

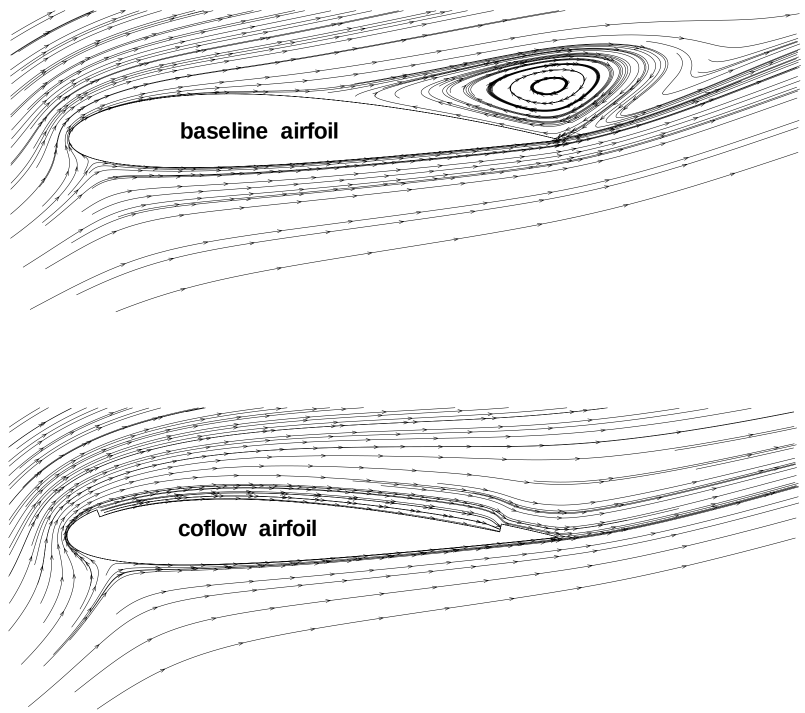
Overview of Airfoil Flow Control

- Rotating Cylinder at LE and TE
- Circulation Control Airfoil, Coanda Effect (IBF)
- Synthetic Jet, Pulsed Jet
- Externally Blown Flaps
- Upper Surface Blowing
- Co-Flow Jet Airfoil

Co-Flow Jet(CFJ) Airfoil

• AIAA Book Series, 2006, AIAA J. of Aircraft, 2006

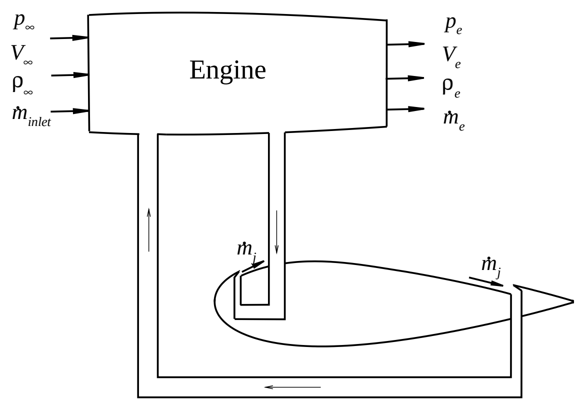
• AIAA Paper: 2004-2208,2005-1260, 2006-1060, 2006-0102, 2006-1061, NASA/CP-2005-213506, 2005



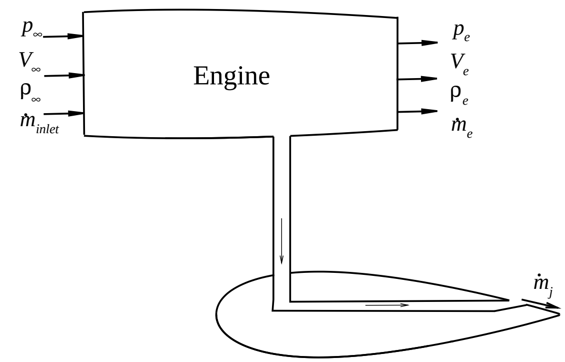
CFJ Airfoil

- **Highly Effective**: High Lift, Low Drag, High Stall Margin
- **Energy Efficient**: Small Penalty to Propulsion System
- **Easy Implementation**

Objectives: Develop a CFD simulation strategy for CFJ airfoil design and analysis

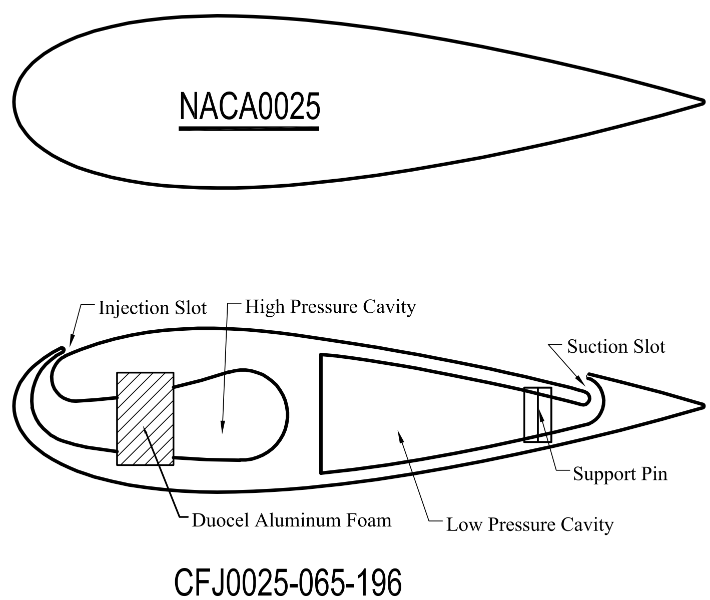


CFJ Airfoil, injection-suction



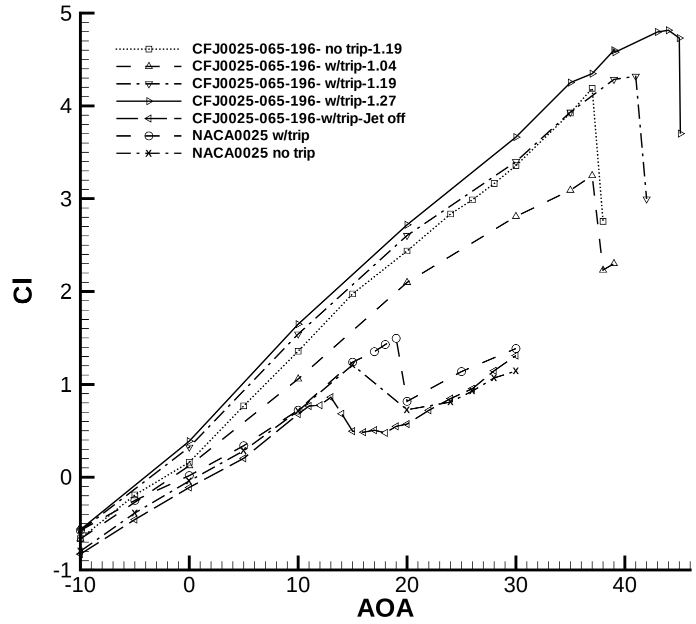
CC Airfoil, injection only

CFJ Airfoil Geometry

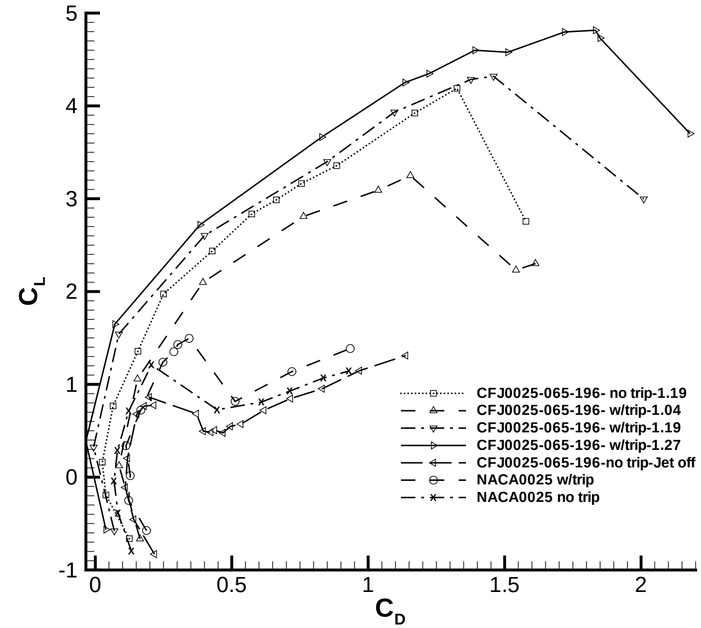


Baseline NACA0025, CFJ0025-065-196,

Wind Tunnel Test Results, CFJ0026-065-196 airfoil

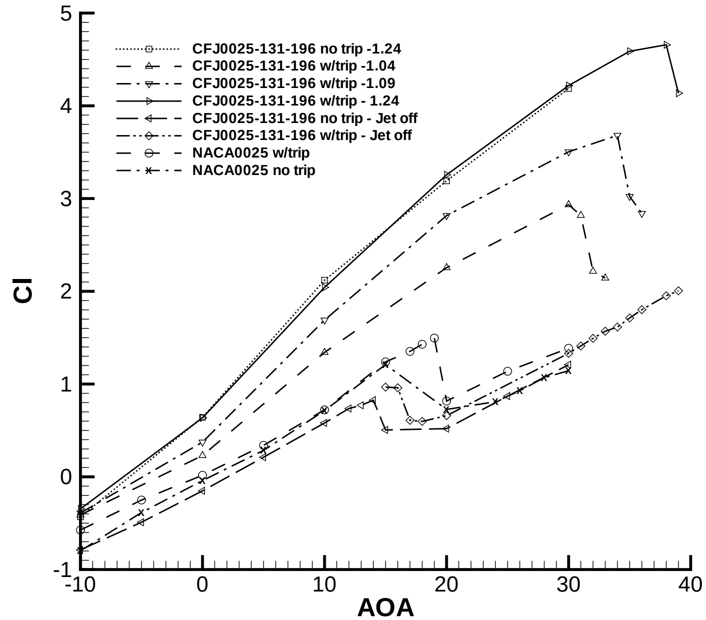


Measured Lift vs AoA

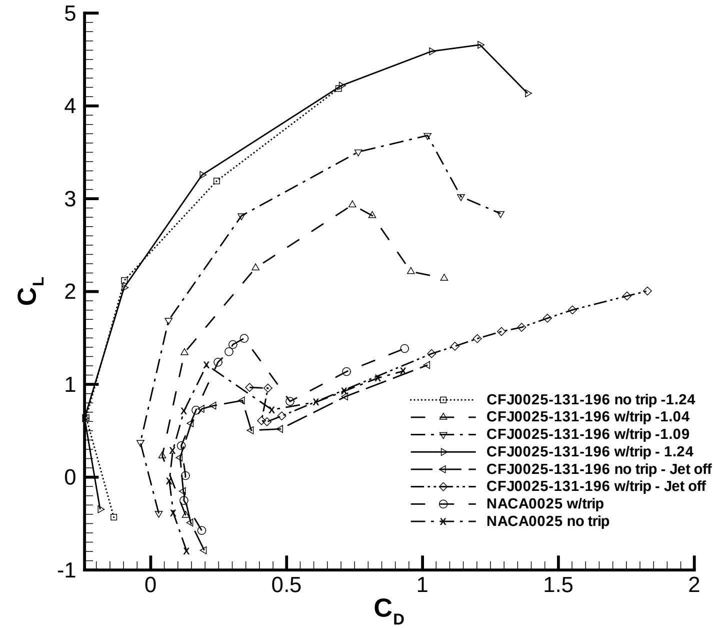


Measured Drag Polar

Wind Tunnel Test Results, CFJ0026-131-196 airfoil

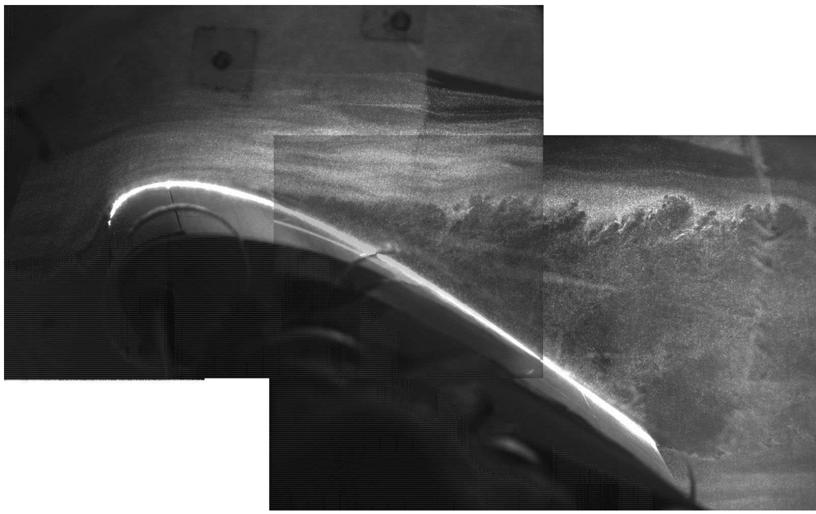


Measured Lift vs AoA

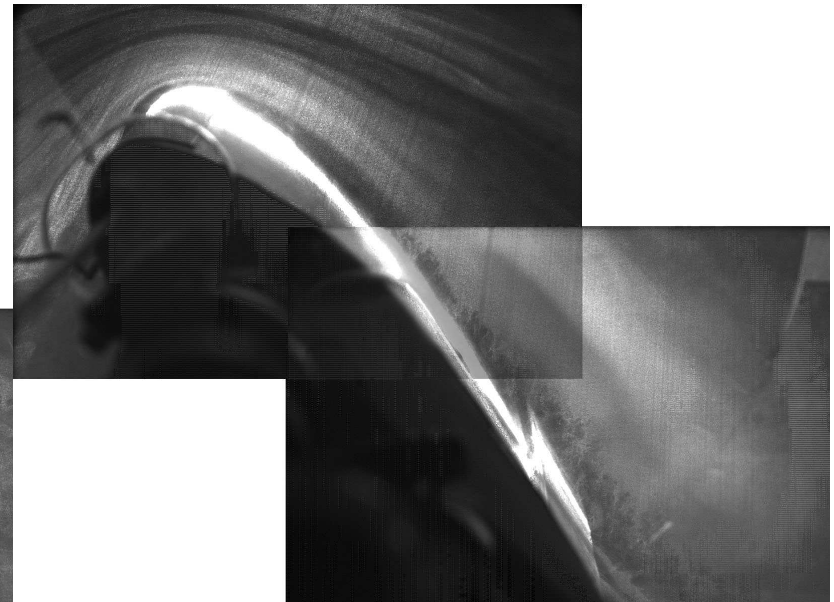


Measured Drag Polar

Wind Tunnel Test Results

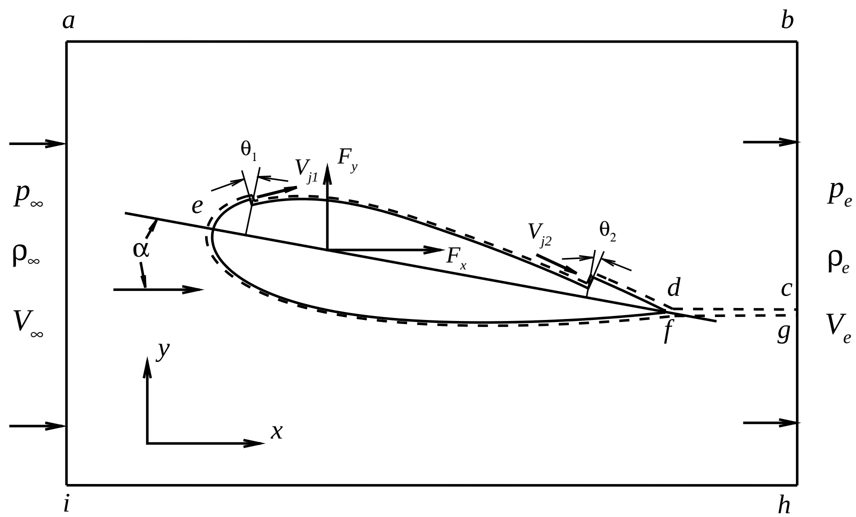


baseline airfoil, AoA $=20^0$



CFJ0025-065-196 airfoil,
AoA$=43^0$

Control Volume AIAA Paper 2006-0102, Zha and Gao



F_{xcfj}: duct reaction force in x-direction

$$F_{xcfj} = (\dot{m}_{j1} u_{j1} + (p_{j1} A_{j1})_x) - \gamma(\dot{m}_{j2} u_{j2} + (p_{j2} A_{j2})_x)$$

$$= (\dot{m}_j V_{j1} + p_{j1} A_{j1}) * cos(\theta_1 - \alpha) - \gamma(\dot{m}_j V_{j2} + p_{j2} A_{j2}) * cos(\theta_2 + \alpha) \quad (1)$$

$$D = R'_x - F_{xcfj} = \int_h^b \rho V_e (V_\infty - V_e) dy \quad (2)$$

or

$$C_D = C_{D rake} \quad (3)$$

Lift

$$L = R'_y - F_{y_{cfj}} \tag{4}$$

R'_y: Surface pressure and shear stress integral in y-direction

$$F_{y_{cfj}} = (\dot{m}_{j1}v_{j1} + (p_{j1}A_{j1})_y) - \gamma(\dot{m}_{j2}v_{j2} + (p_{j2}A_{j2})_y)$$

$$= (\dot{m}_j V_{j1} + p_{j1}A_{j1}) * sin(\theta_1 - \alpha) + \gamma(\dot{m}_j V_{j2} + p_{j2}A_{j2}) * sin(\theta_2 + \alpha) \tag{5}$$

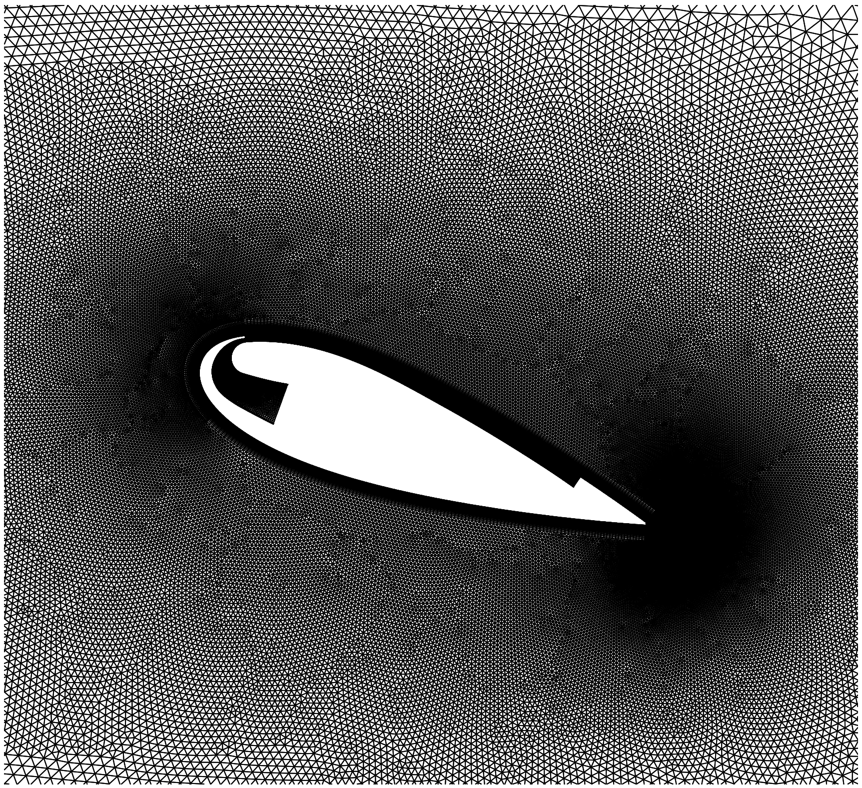
CFD Solver: Fluent

- 2nd Order Upwind Scheme, Pressure Based
- $k - \epsilon$ model integrated to wall, $y^+ \approx 1$
- Structured mesh around airfoil, unstructured mesh far field

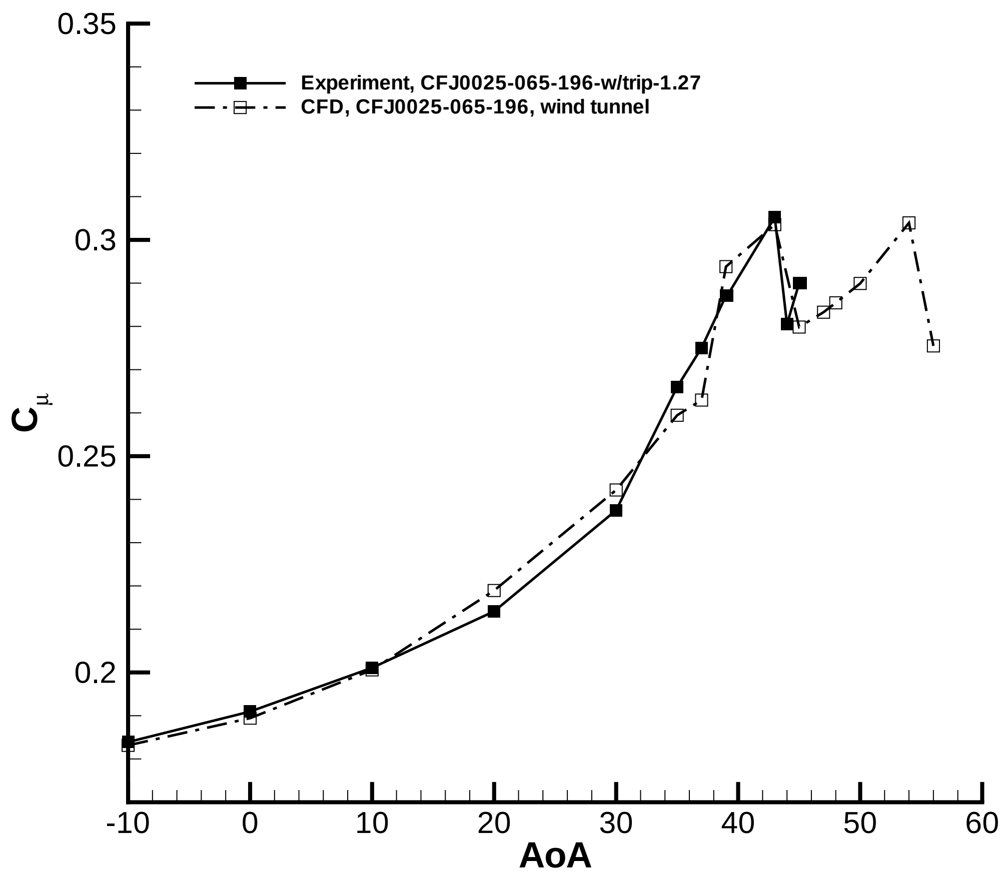
Boundary Conditions

- Far field
- Injection: Iterate P_0, T_0, matching experiment C_μ
- Suction: Iterate p, matching $\dot{m}_j$

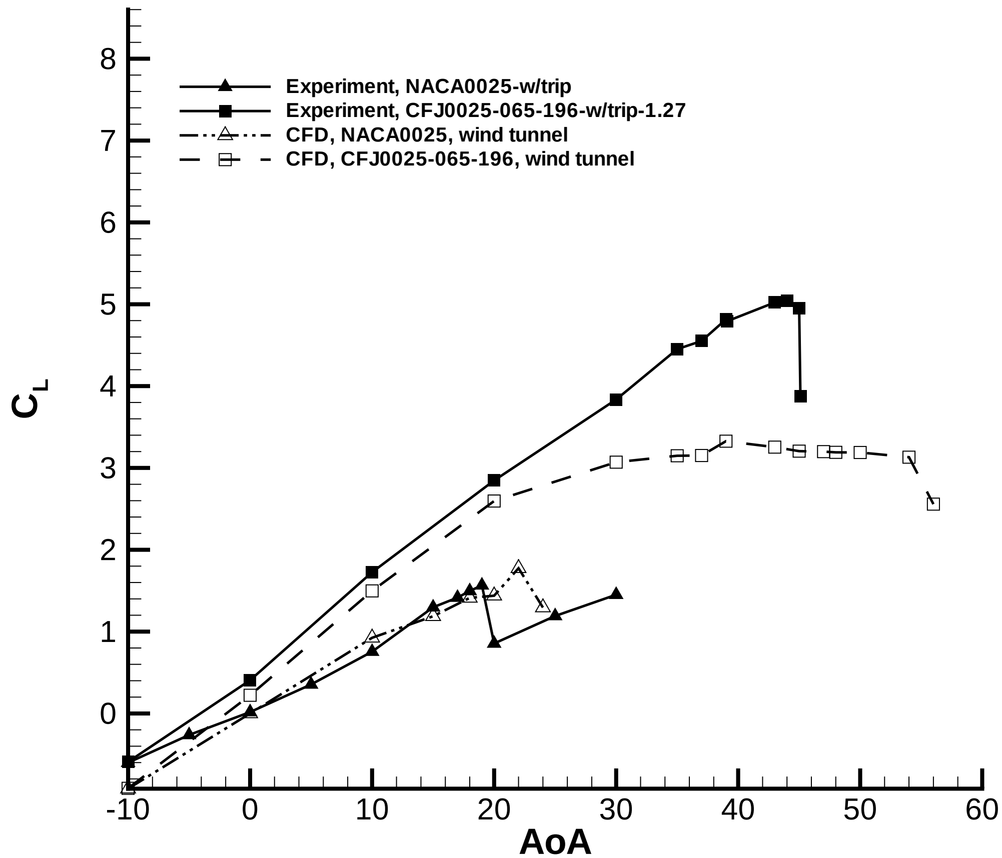
2D Mesh



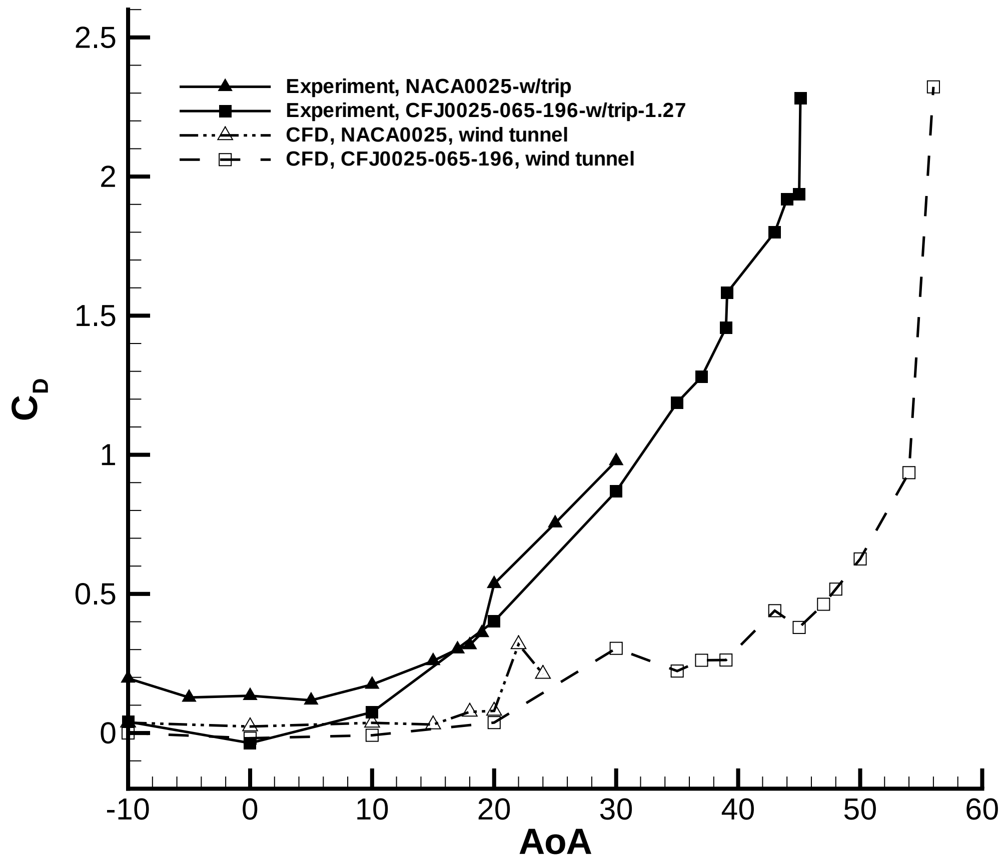
Computed Injection Momentum Coefficient



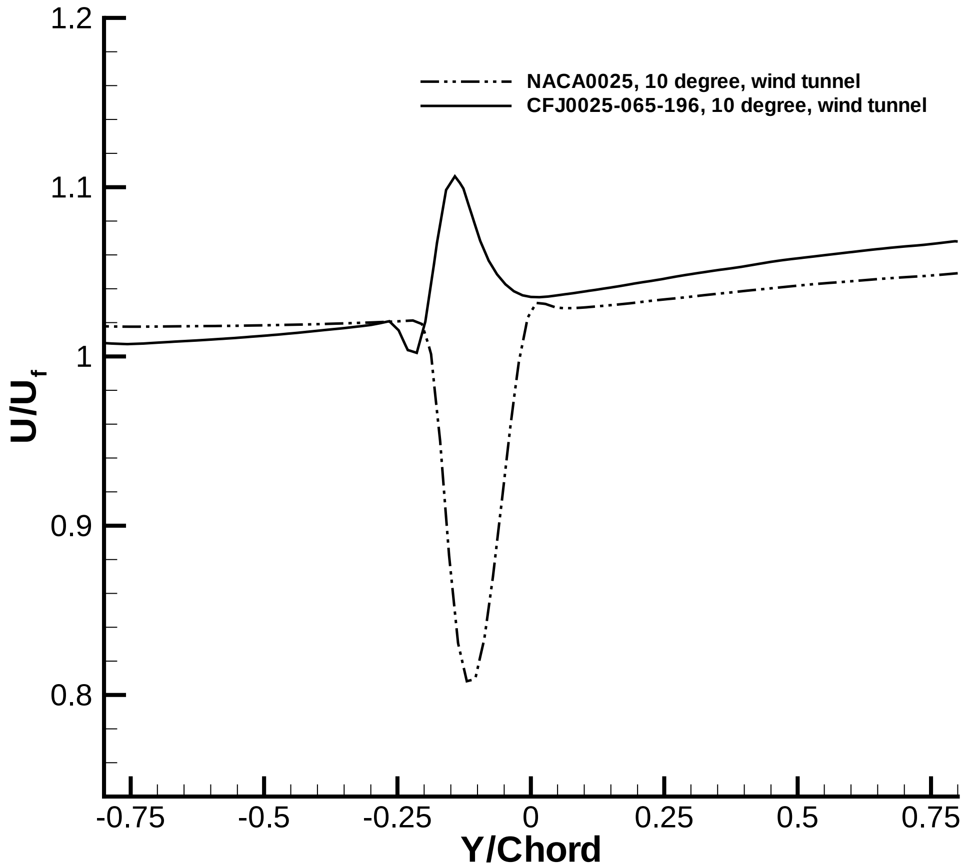
Computed lift coefficient



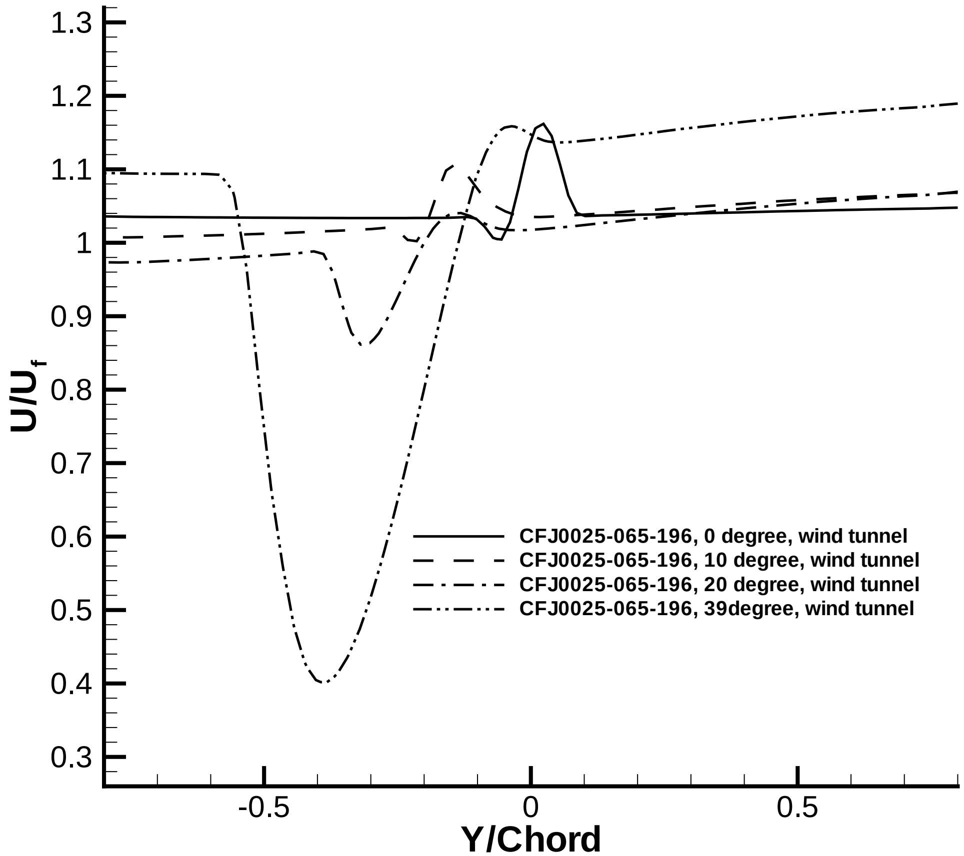
Computed drag coefficient



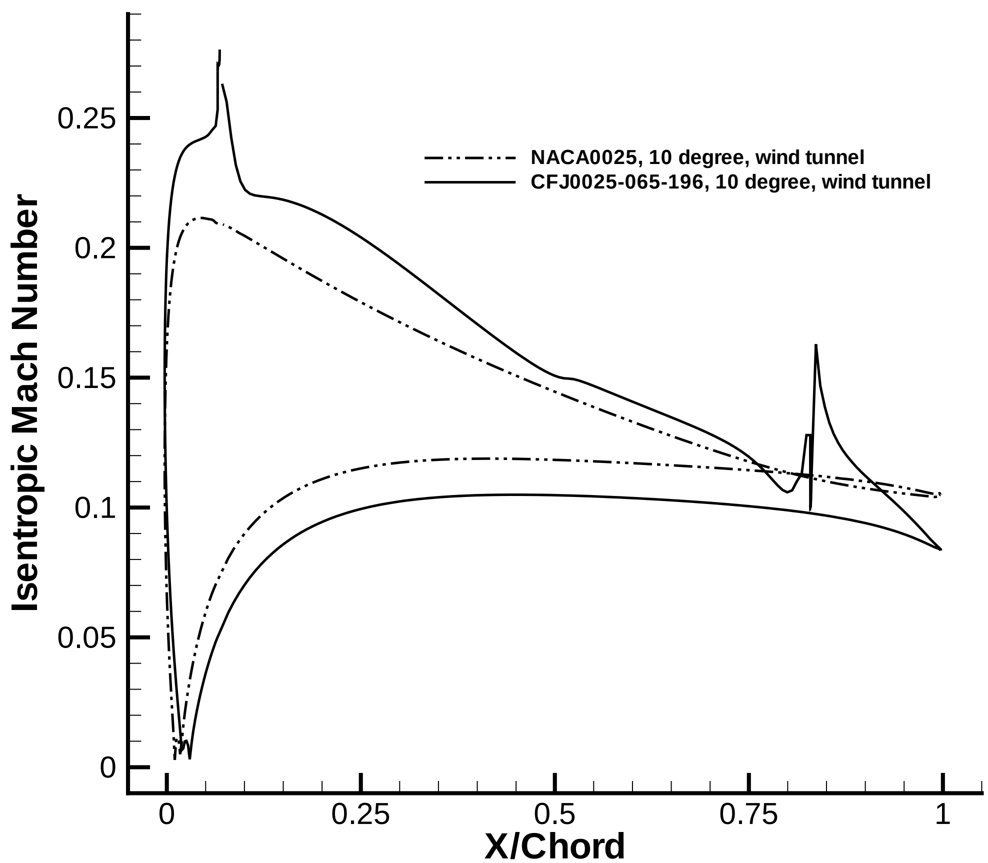
Computed CFJ airfoil wake profile compared with baseline at AoA=10○

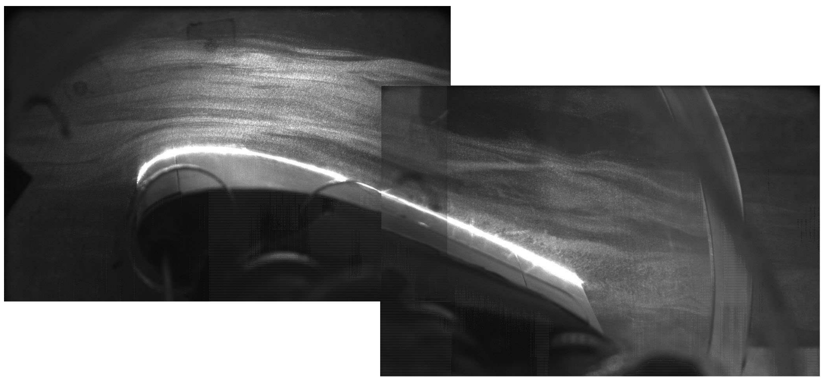


Computed CFJ airfoil wake profiles at different AoA

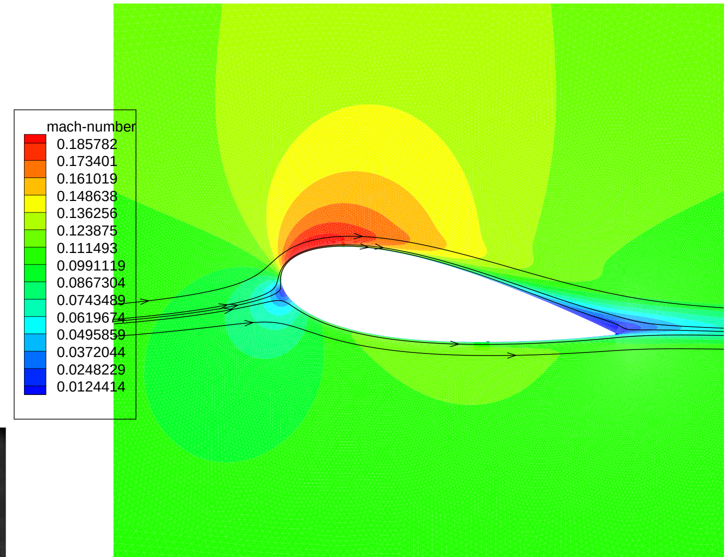


Computed surface isentropic Mach number, AoA=10∘.

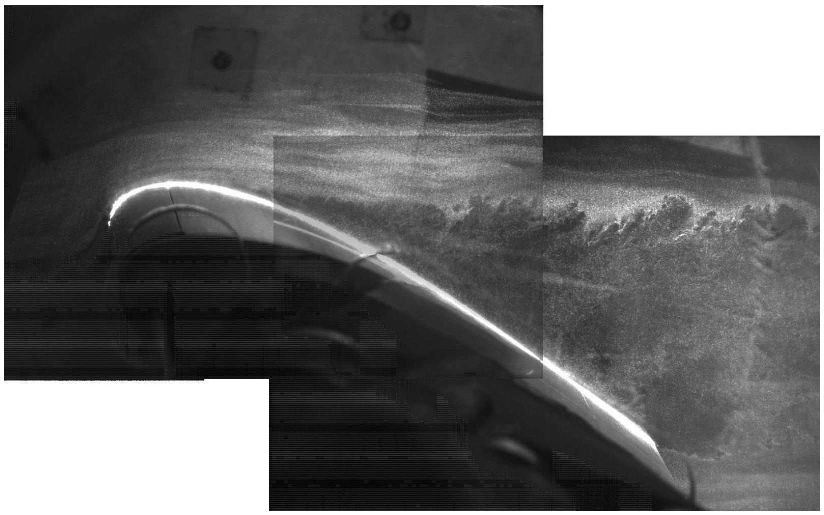


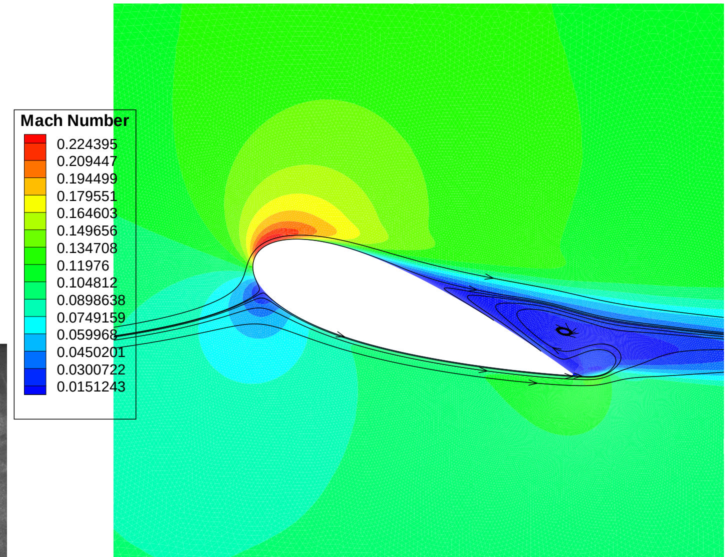


Flow visualization of baseline airfoil, AoA=10°



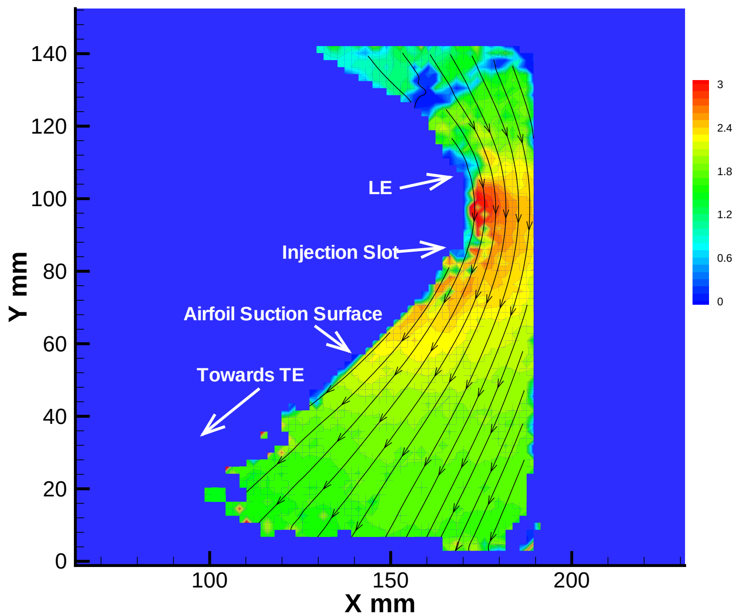
Computed baseline airfoil Mach contours with streamlines, AoA=10°.



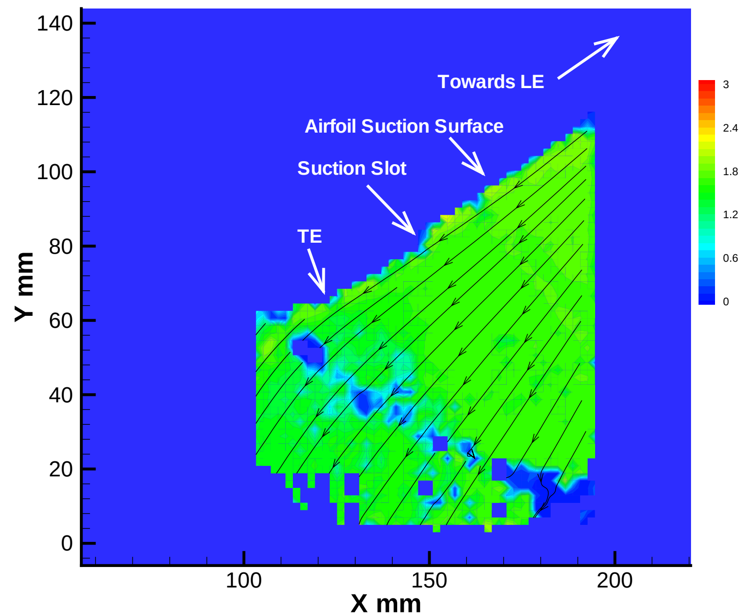


Flow visualization of baseline airfoil, AoA=20°

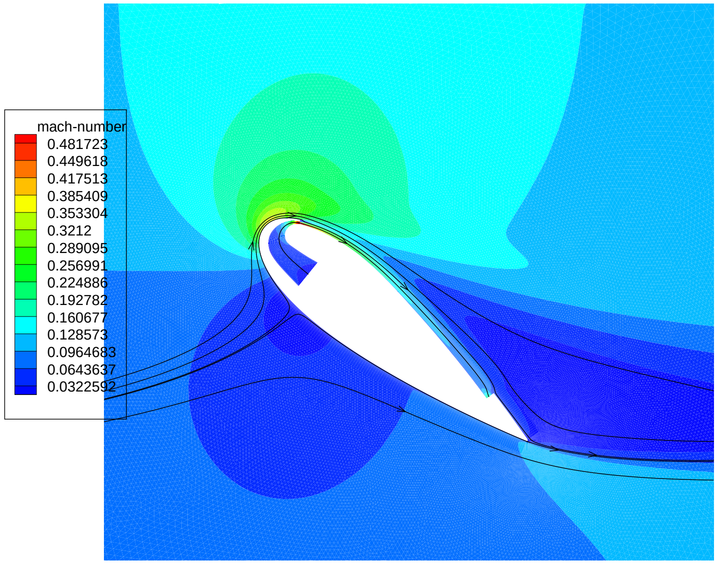
Computed baseline airfoil Mach contours with streamlines, AoA=20°.



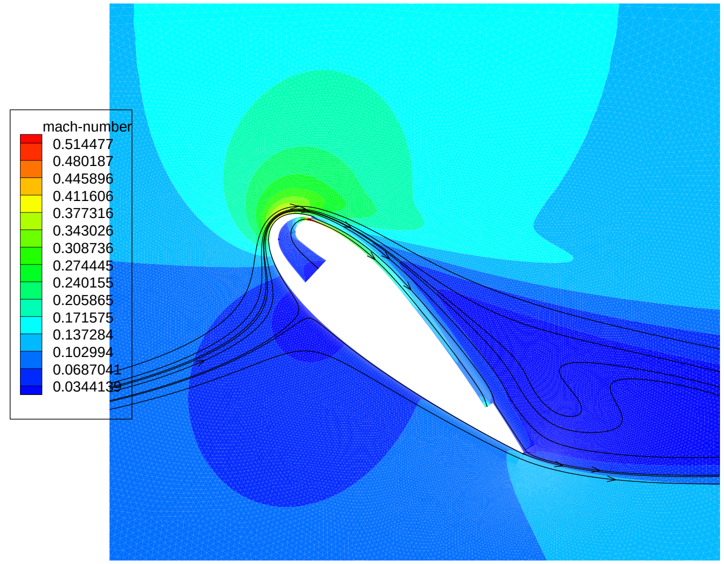
PIV of CFJ airfoil, AoA=43°, front portion



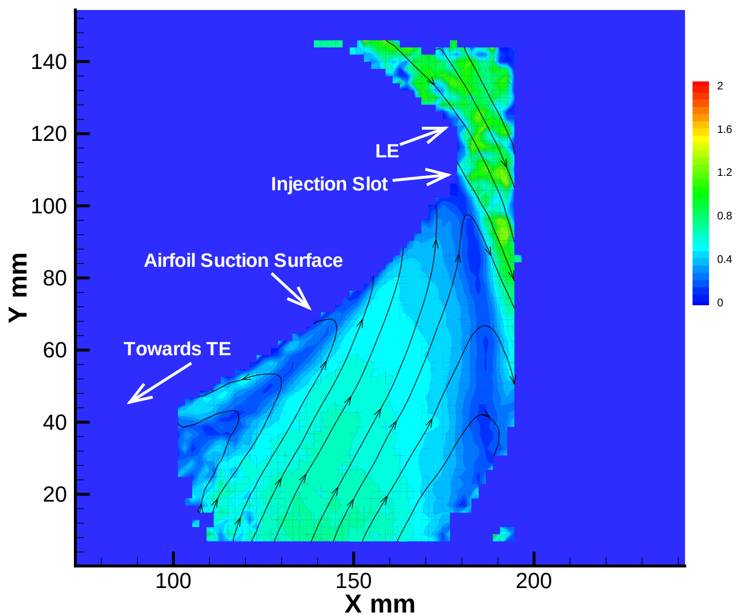
PIV of CFJ airfoil, AoA=43°, rear portion



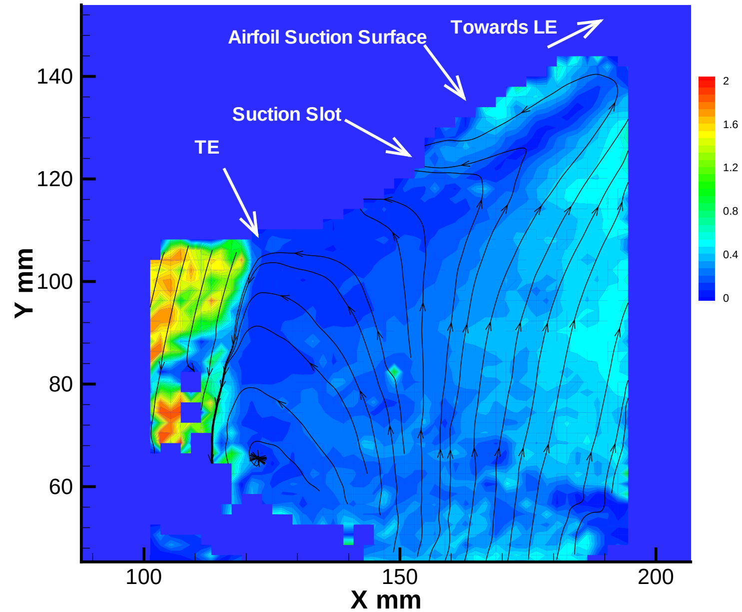
Computed CFJ airfoil Mach contours with streamlines at AoA=39°.



Computed CFJ airfoil Mach contours with streamlines at AoA=43°.

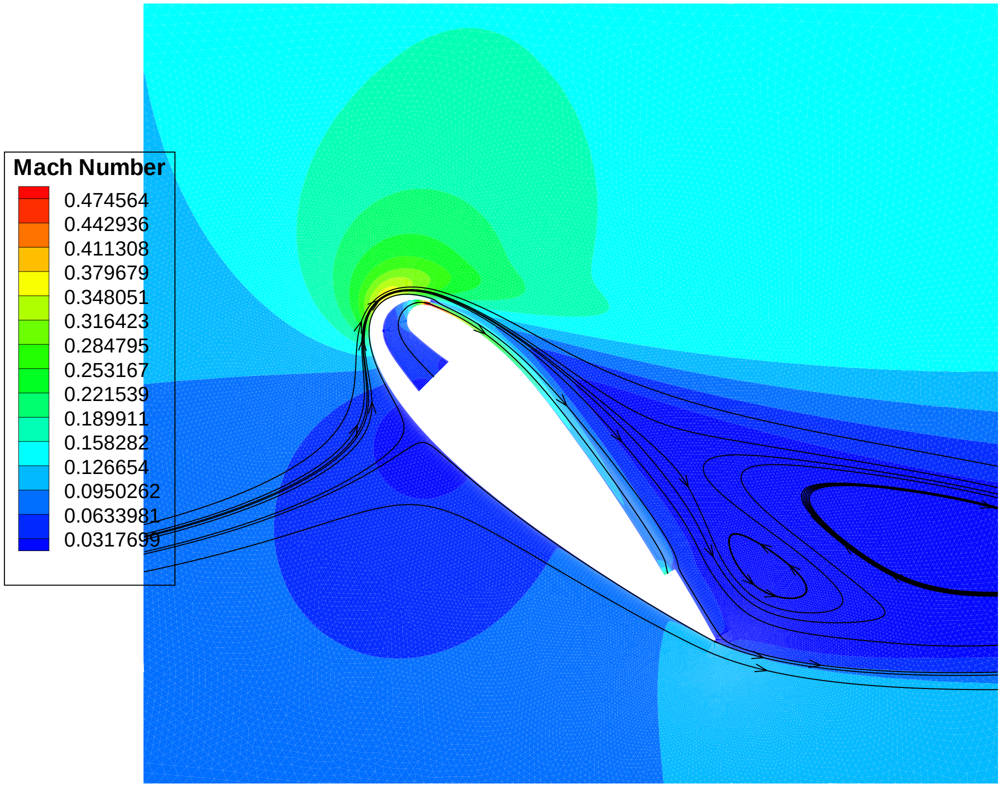


PIV of CFJ airfoil, AoA=46°, front portion



PIV of CFJ airfoil, AoA=46°, front portion

Computed CFJ airfoil Mach contours with streamlines at AoA=46°.



Conclusions

- CFD simulation strategy of CFJ airfoil is developed.
- The baseline lift and drag agree well with experiment, stall AoA 3° larger.
- The jet ducts reaction forces are included in the total lift and drag.
- For the CFJ0025-069-196 airfoil, the computed lift and drag agree well with experiment when AoA¡20°. Both lift and drag are significantly under-predicted when AoA¿20°.
- At low AoA,the reversed wake velocity deficit is predicted, consistent with experiment.
- The stall AoA of CFJ airfoil is predicted well.
- Computation indicate that the CFJ airfoil has higher circulation, lower drag, higher stall margin, consistent with experiment.