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

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°

CFJ0025-065-196 airfoil, AoA=43°
Control Volume AIAA Paper 2006-0102, Zha and Gao
$F_{xcf\_j}$: duct reaction force in x-direction

$$
F_{xcf\_j} = (m_{j1}u_{j1} + (p_{j1}A_{j1})_x) - \gamma(m_{j2}u_{j2} + (p_{j2}A_{j2})_x)
= (m_{j}V_{j1} + p_{j1}A_{j1})\cos(\theta - \alpha) - \gamma(m_{j}V_{j2} + p_{j2}A_{j2})\cos(\theta + \alpha)
$$

(1)

$$
D = R'_x - F_{xcf\_j} = \int_{h}^{b} \rho V_e (V_\infty - V_e) dy
$$

(2)

or

$$
C_D = C_{Drake}
$$

(3)
Lift

\[ L = R' - F_{y_{cfj}} \]  \hspace{1cm} (4)

\( R_y' \): Surface pressure and shear stress integral in y-direction

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

\[ = (\dot{m}_j V_{j1} + p_{j1} A_{j1}) \sin(\theta_1 - \alpha) + \gamma(\dot{m}_j V_{j2} + p_{j2} A_{j2}) \sin(\theta_2 - \alpha) \]  \hspace{1cm} (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 $C_\mu$
- Suction: Iterate p, matching $\dot{m}_j$
2D Mesh
Computed Injection Momentum Coefficient

![Graph showing computed injection momentum coefficient versus AoA. The graph includes data from Experiment, CFJ0025-065-196-w/trip-1.27 and CFD, CFJ0025-065-196, wind tunnel.]
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

![Graph showing computed CFJ airfoil wake profiles at different AoA.](image-url)
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.