

PIV Measurements on a Delta Wing with Periodic Blowing and Suction

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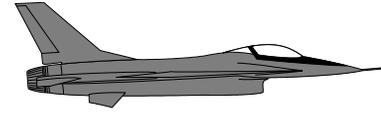
Stefan Siegel

Thomas McLaughlin

Julie Morrow

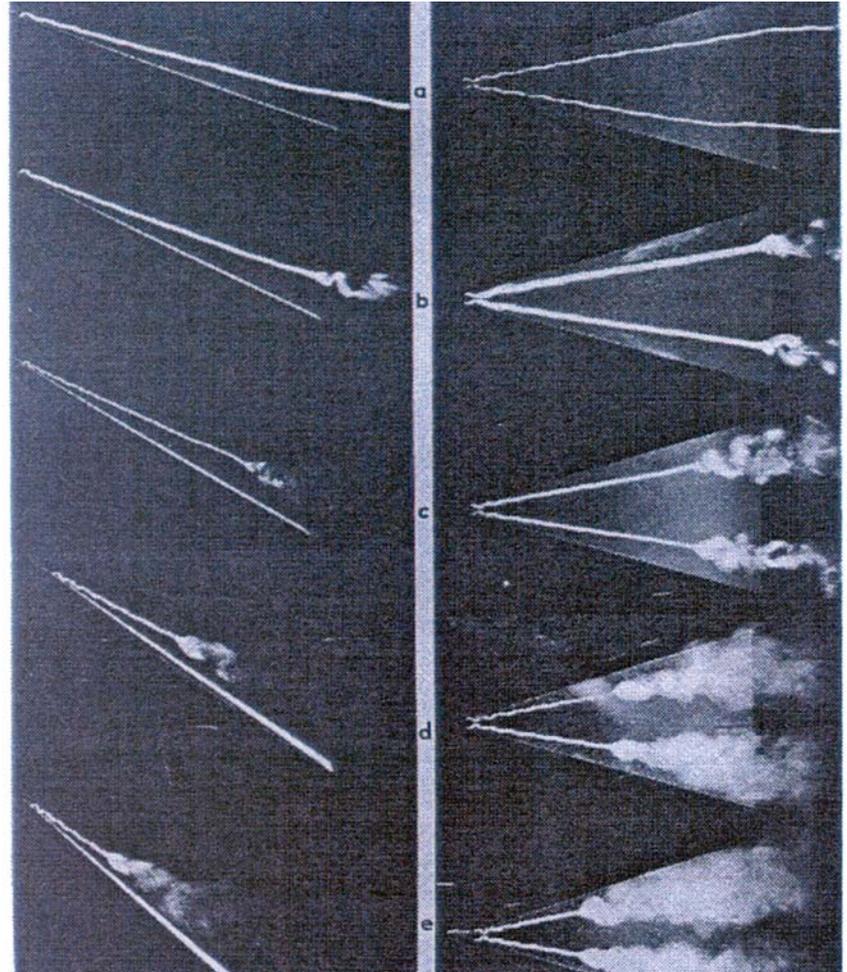
US Air Force Academy, Colorado Springs, CO

Sponsored by AFOSR, Dr. Steve Walker



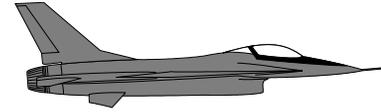
- **F/A 18 Vortex Breakdown**

Photo by NASA Dryden



- **Delta Wing Vortex Breakdown**

Photo by Werle



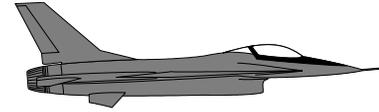
Guy, Morrow, McLaughlin 1999:

- **Lift increase by up to 38% using blowing and suction**
- **Stall Angle increased by 10° AOA**
- **Delay of Vortex Breakdown by 35% Chord**

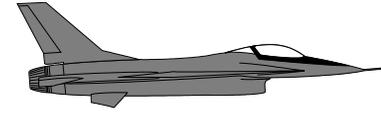
Research Objective

- **Investigate mechanism by which lift is increased, vortex breakdown delayed**
- **Further improve forcing**

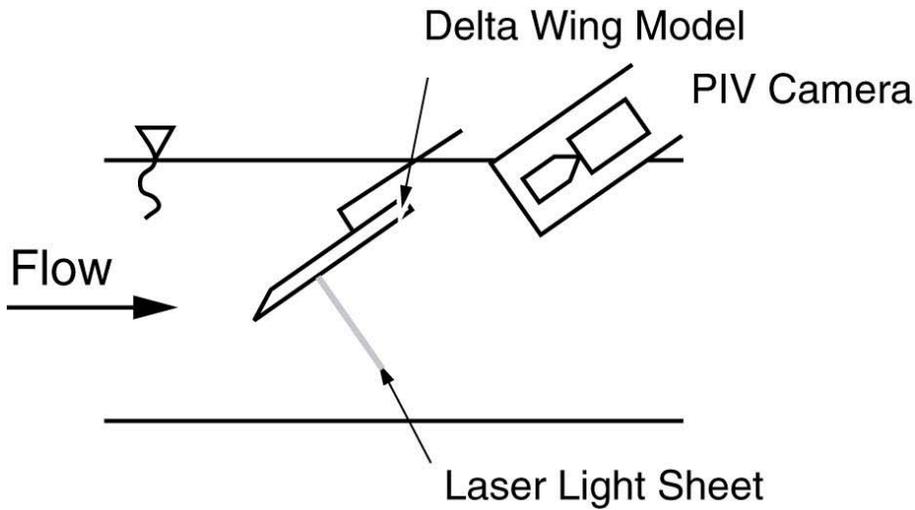
Experimental Parameters



- **70° Delta Wing**
- **Water Tunnel Experiments**
- **2D PIV Measurements**
- **AOA = 35°**
- **Re_C = 25k**
- **Periodic Blowing and Suction forcing parallel to wing surface, normal to and along entire leading edge.**
- **u'(t) = sin(ωt)**
- **Forcing Parameters:**
 - **F+ = 1.75** $F+ = (f C_r) / U_{inf}$
 - **C_μ = 0.004** $C_{\mu} = 2(H / C_r)(\langle u' \rangle / U_{inf})^2$

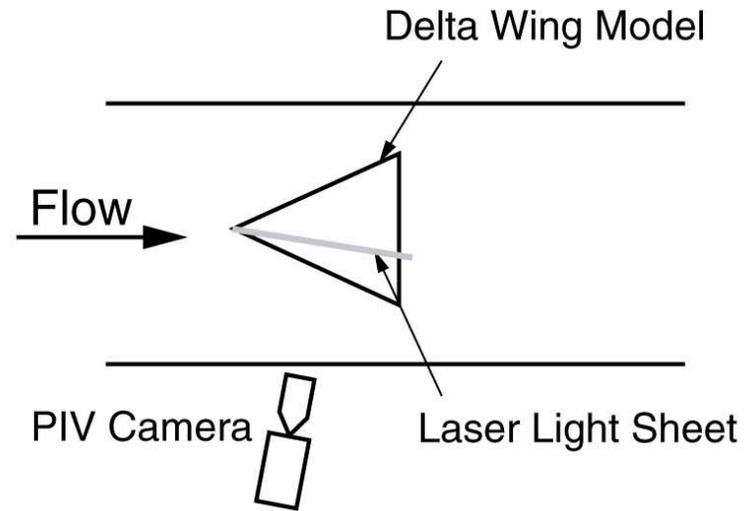


Measurements across vortex core



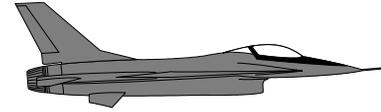
Side View of Test Section

Measurements along vortex core



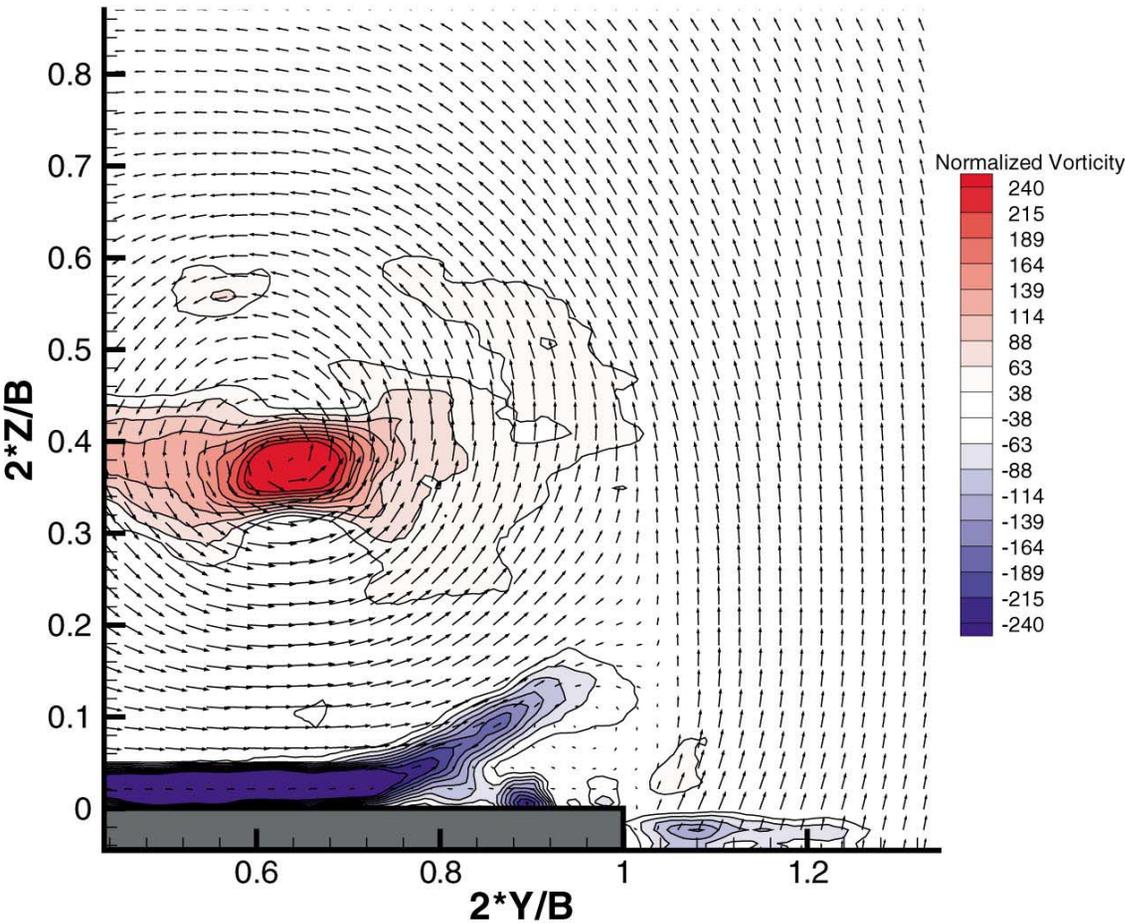
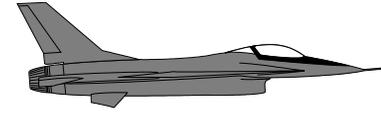
Top View of Test Section

PIV Measurement Procedure



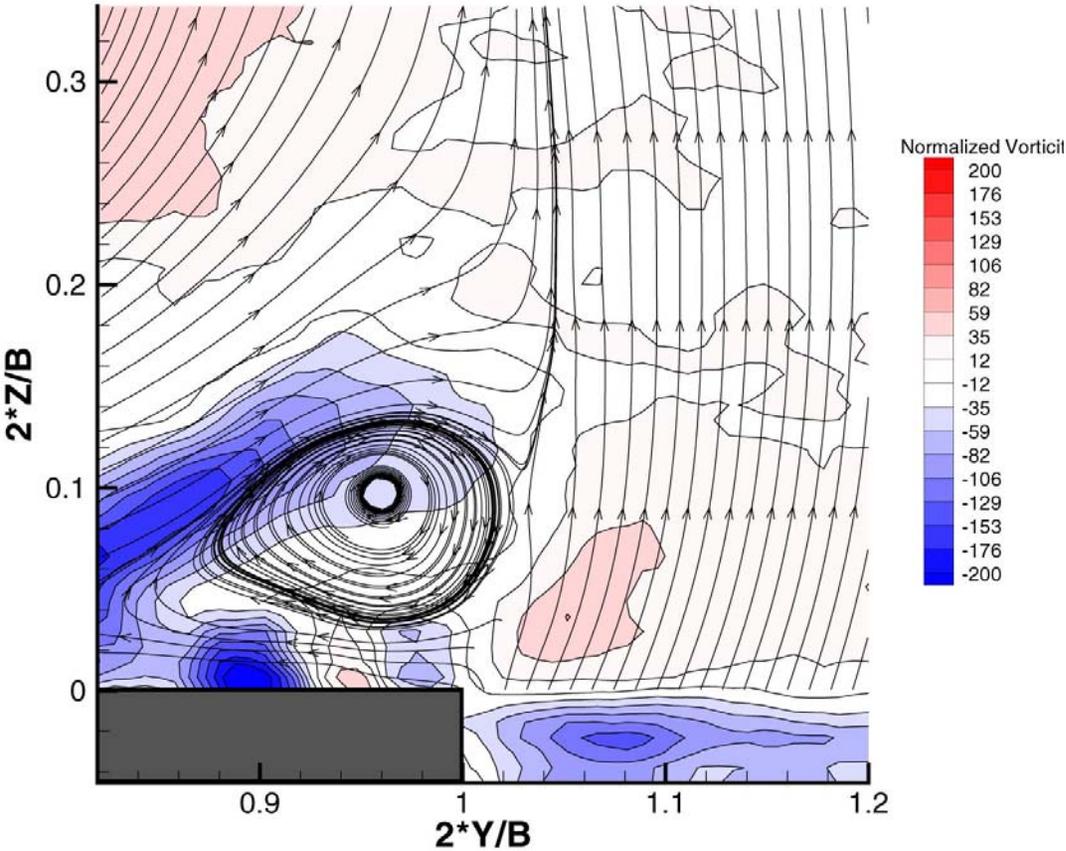
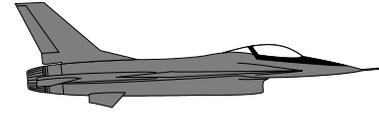
- **32x32 pixel interrogation area**
- **(Phase) Averaging over ten data sets**
- **Spatial averaging in a 3x3 vector area**
- **Forced data acquisition phase locked to forcing input**
- **Reference quantities for normalization are the freestream velocity, and the root chord**

Unforced Flow, 40% Chord



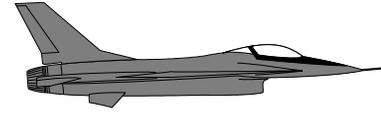
- Slice normal to Wing Surface
- Main Vortex Location at 65% spanwise, 38% wing normal
- Secondary vortex at wing surface
- Flow is steady in time

Unforced Wing Tip Detail

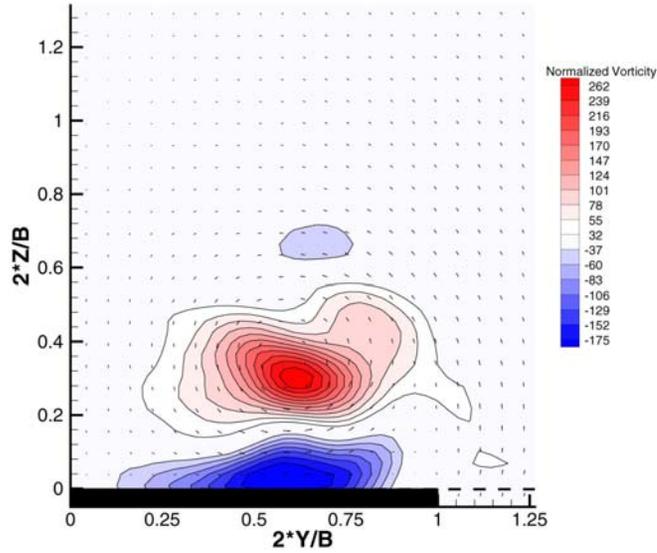


- **Closeup of Wing tip**
- **Center of Rotation without associated Vorticity**

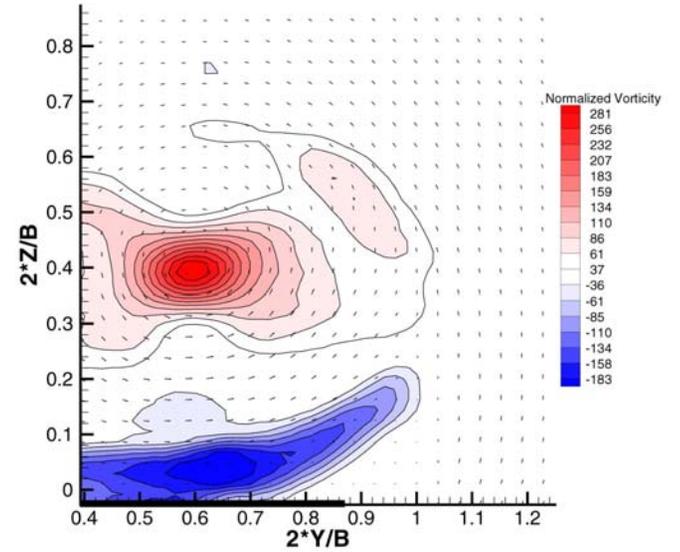
Unforced Streamwise Dev.



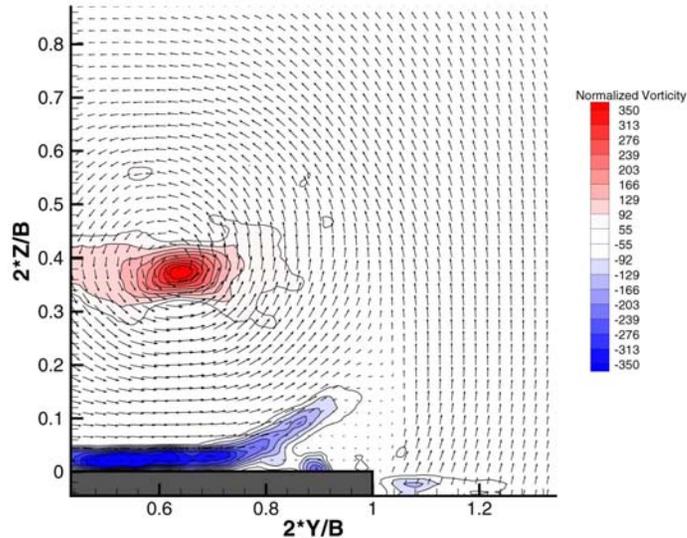
20%



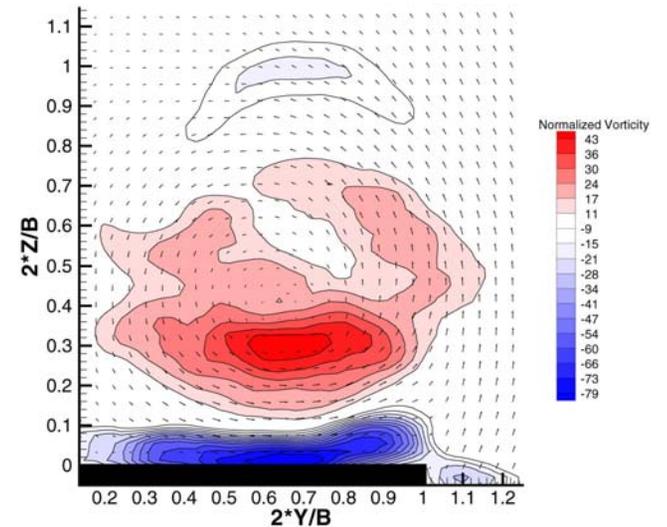
30%



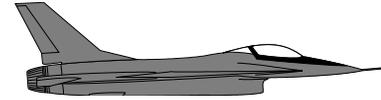
40%



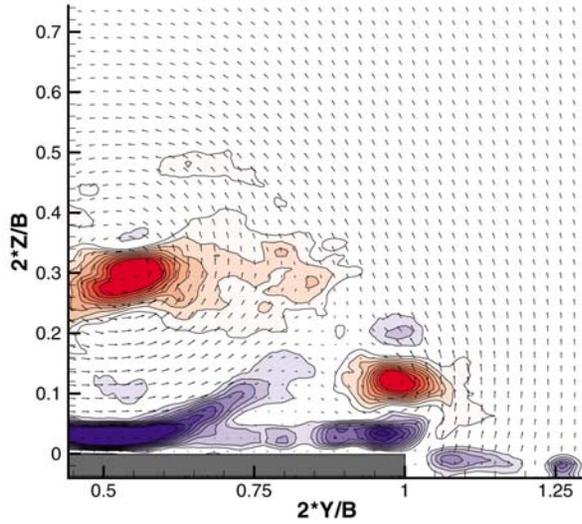
50%



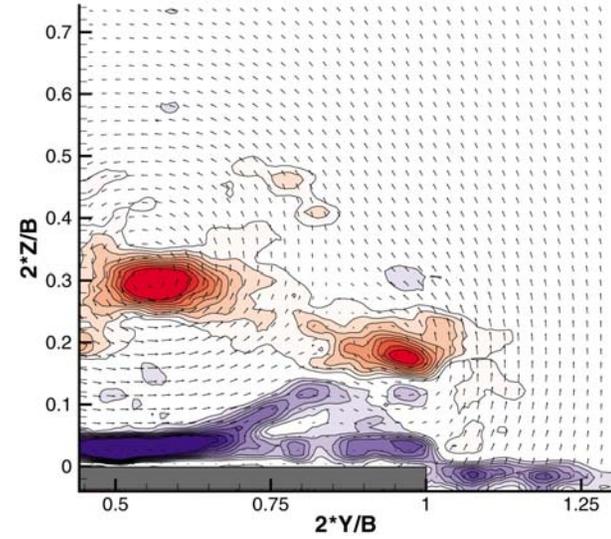
Forced Flow 40%Chord



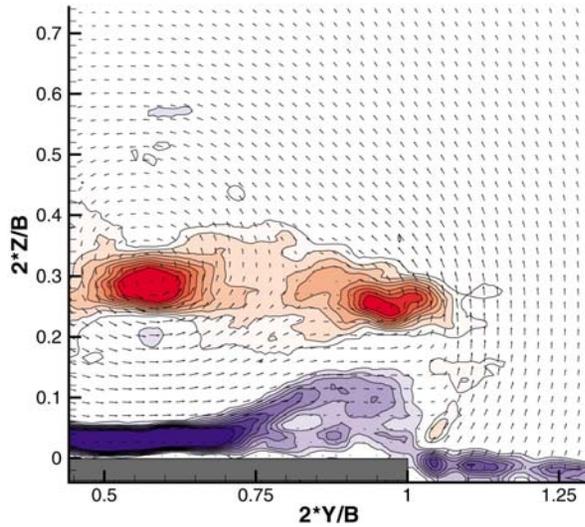
100°



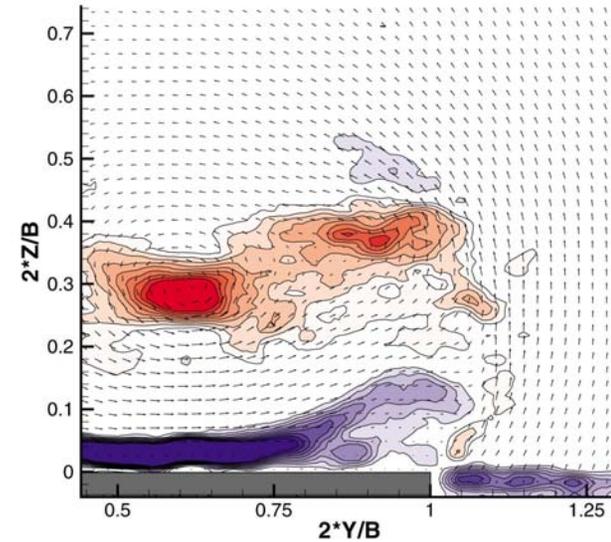
110°



120°



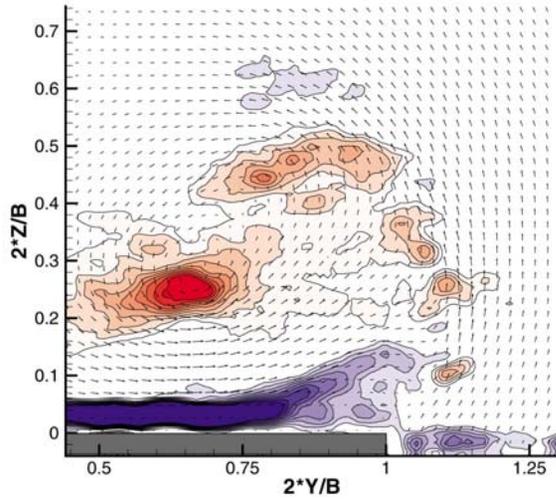
130°



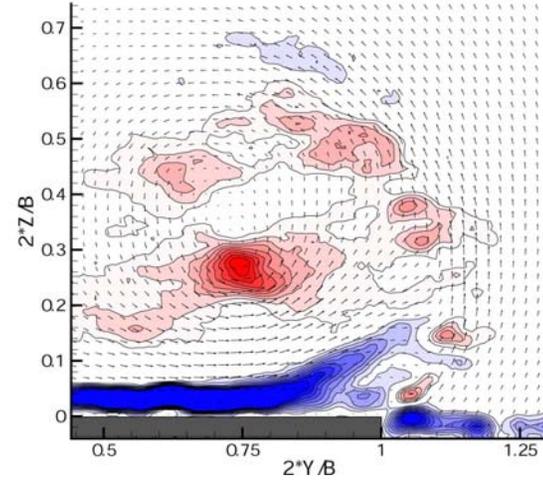
Forced Flow 40% Chord cont'd



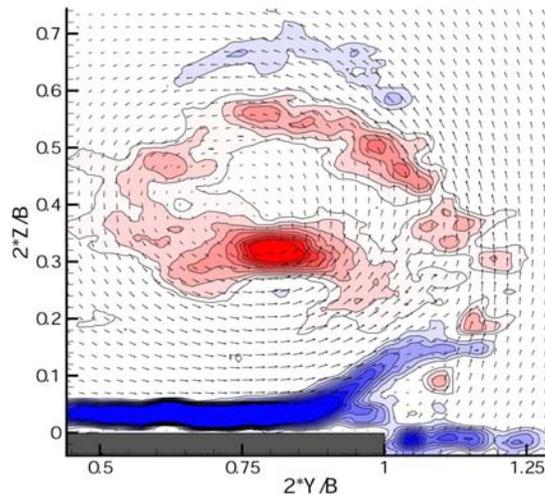
140°



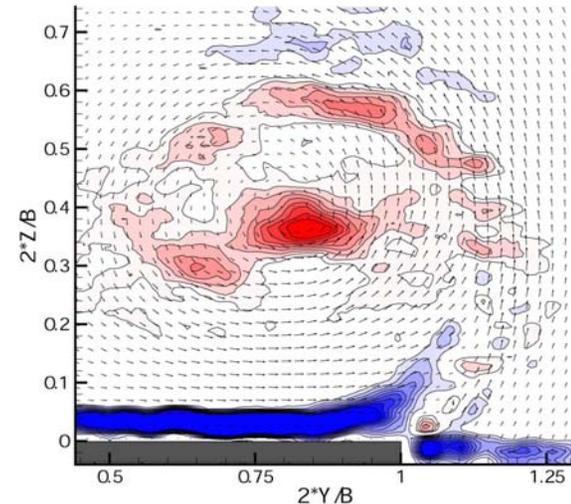
150°



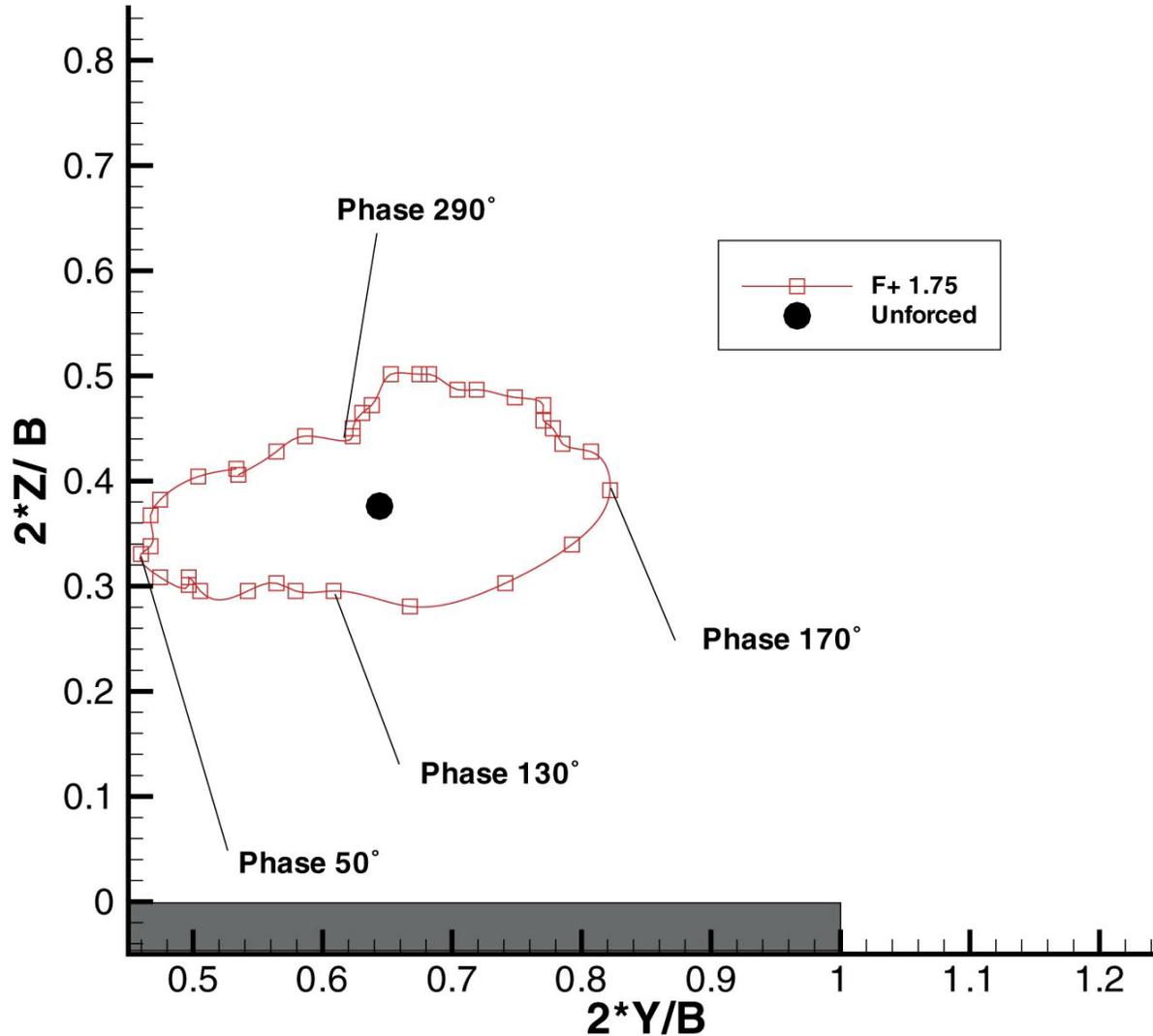
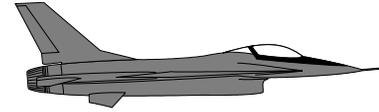
160°

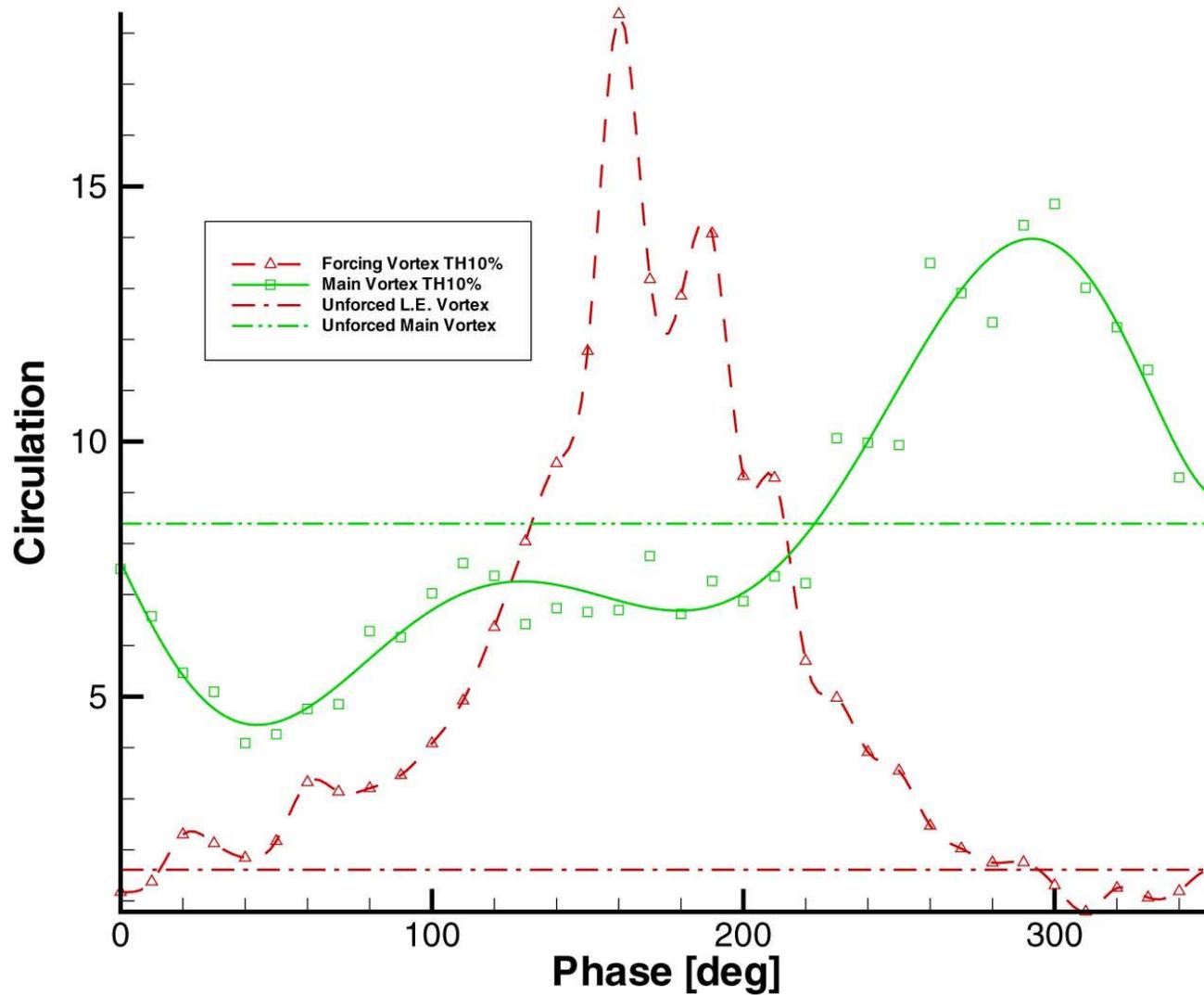
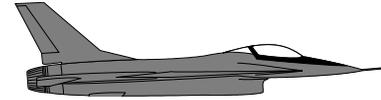


170°



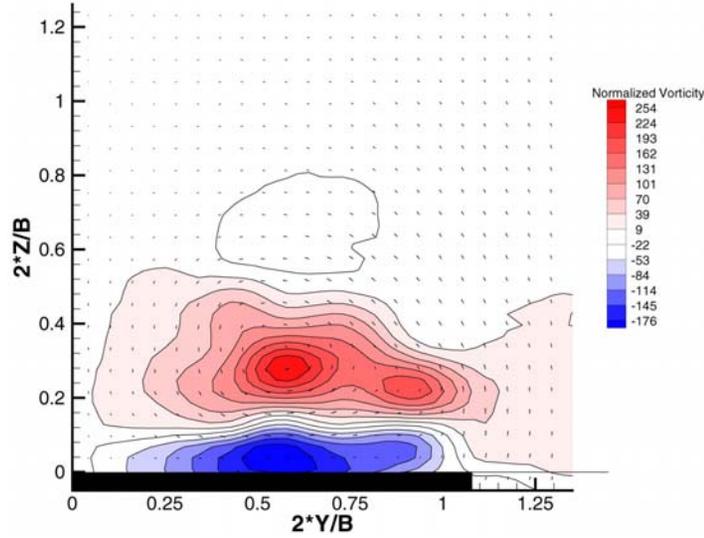
Forced Flow Vortex Movement



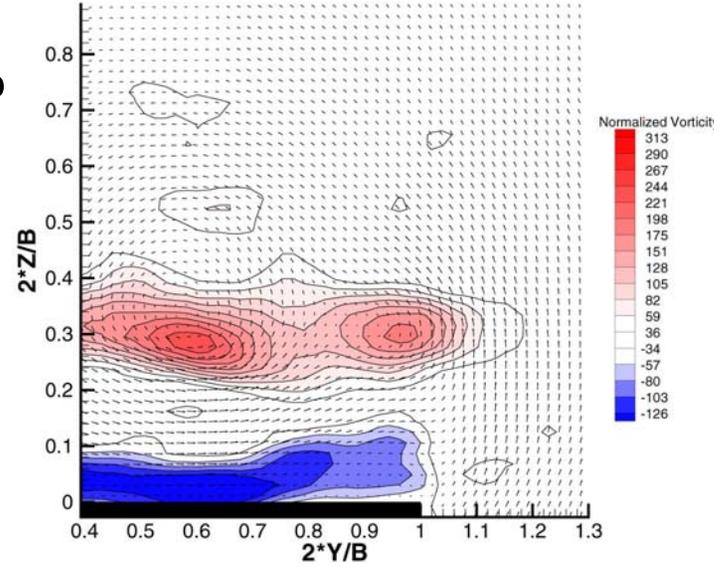




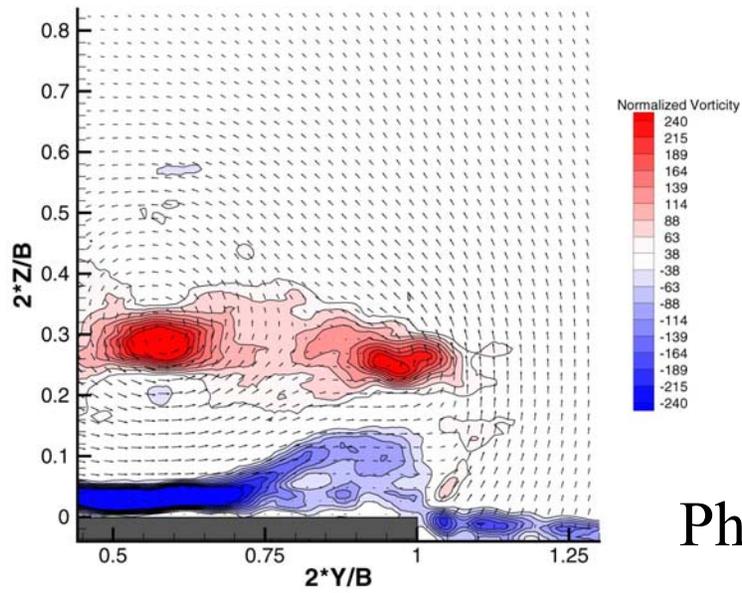
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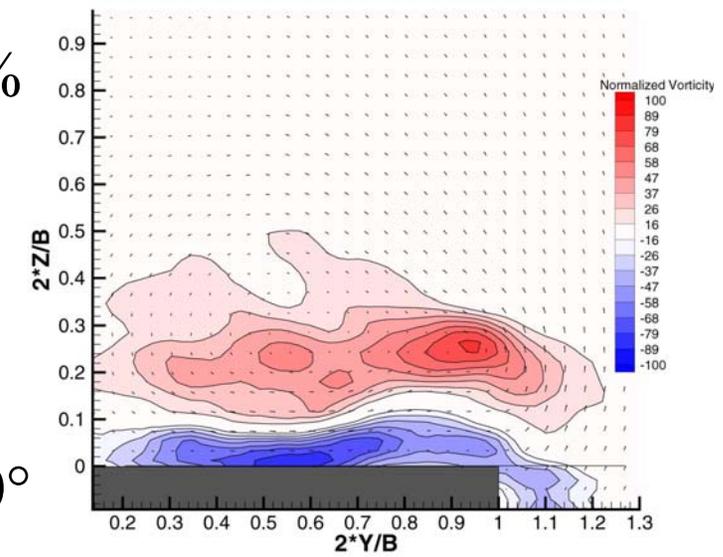
30%



40%

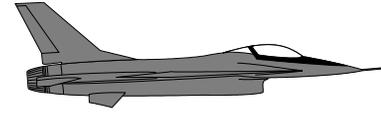


50%

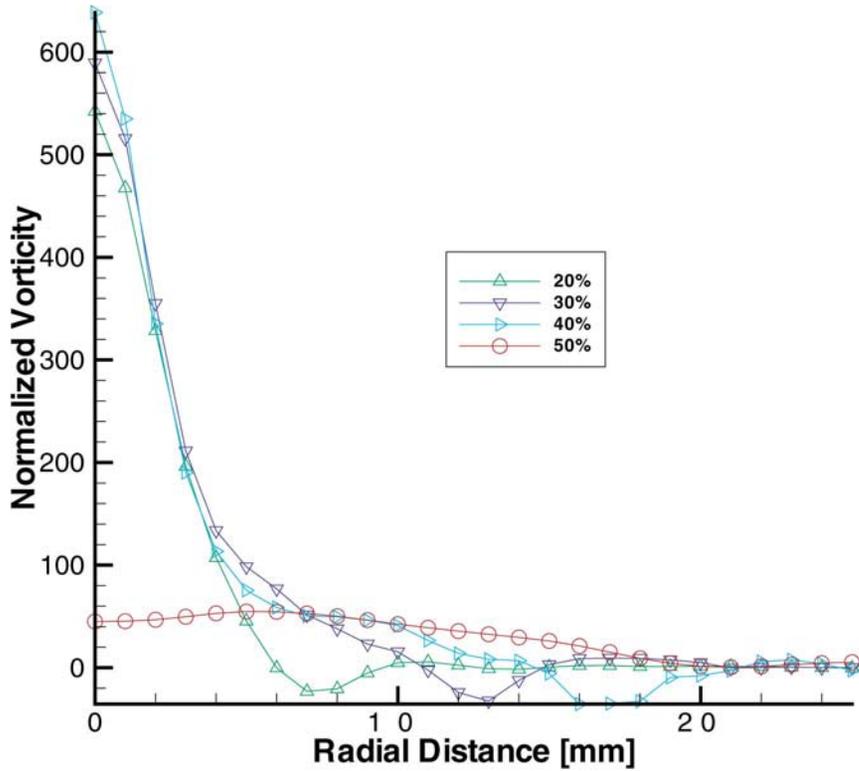


Phase 120°

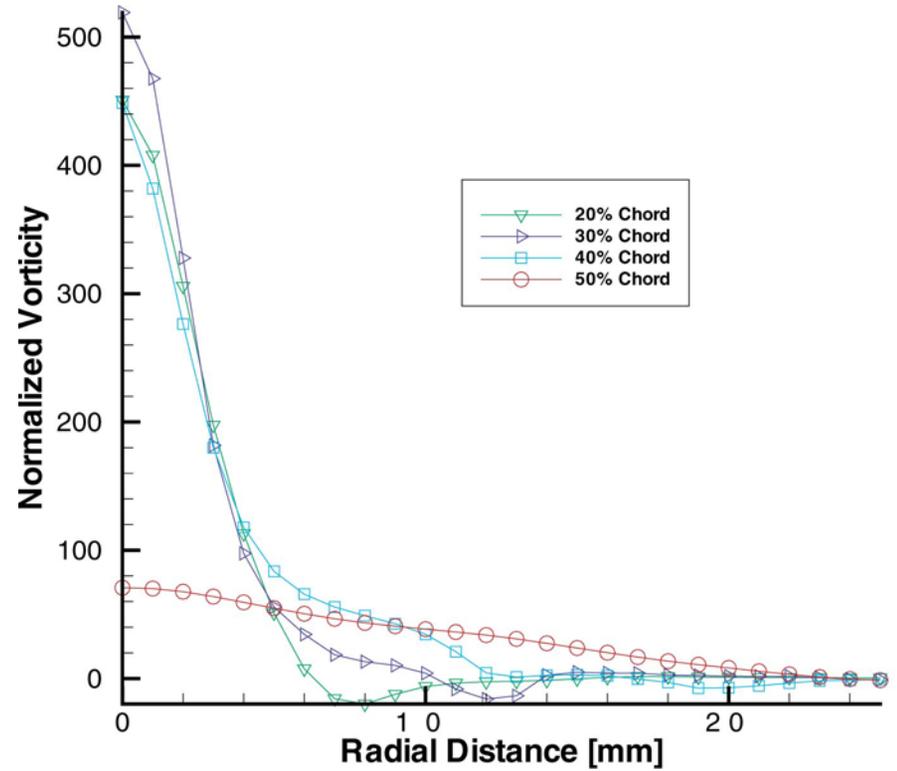
Comparison Forced-Unforced



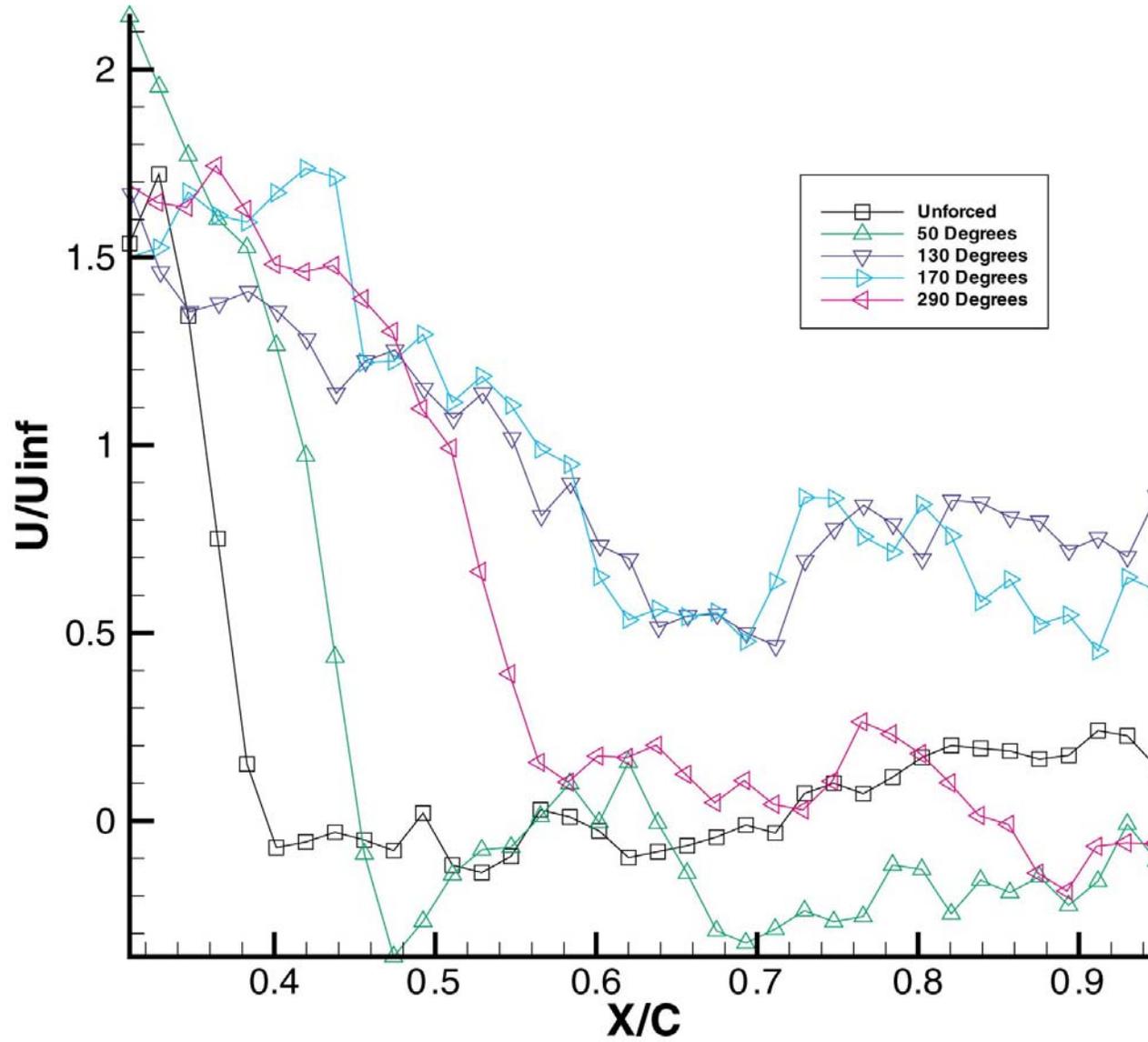
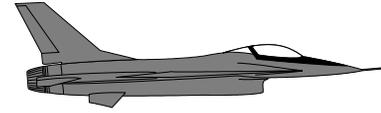
Unforced



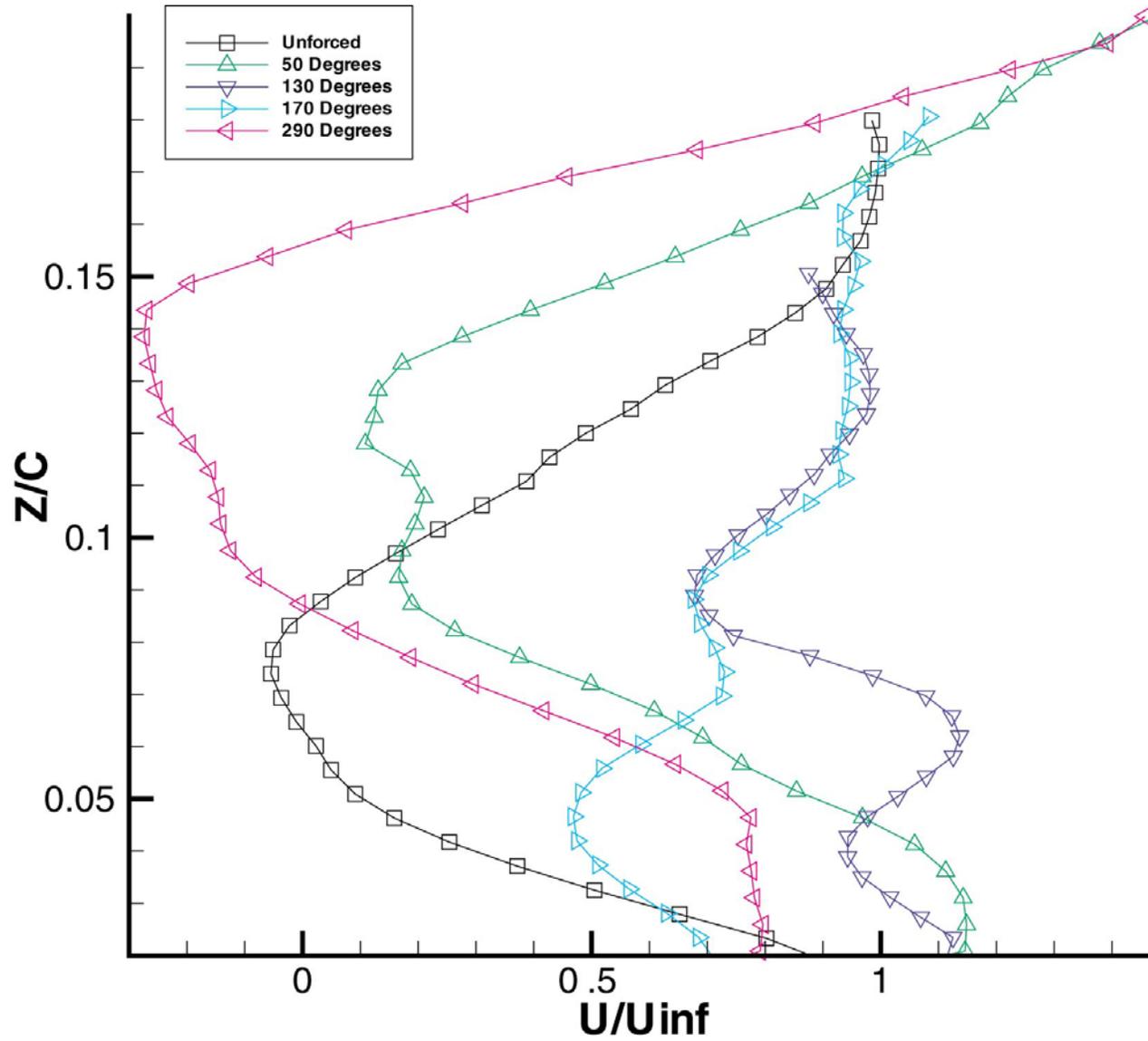
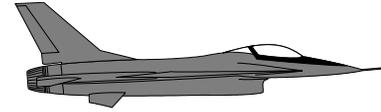
Forced $F+ = 1.75$

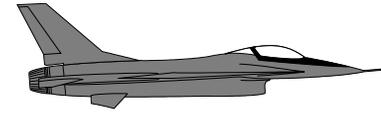


Axial Velocity Profiles

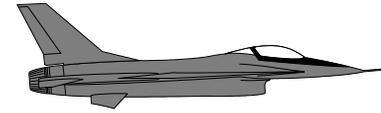


Wing Normal Vel. Profiles

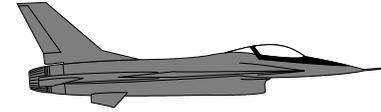




- **Forcing moves vortex in spanwise and wing normal direction along an elliptical path**
- **Forcing generates a strong shear layer vortex that reaches a peak circulation of twice the circulation of the unforced main vortex**
- **Forcing does not significantly change the average circulation of the main vortex**
- **The drop in vorticity does not coincide with the axial velocity drop in the forced case**
- **Forcing does not delay vortex breakdown**



- **Instead, low momentum fluid downstream of vortex breakdown is moved away from wing surface, thus decreasing surface pressure, increasing lift.**
 - **Velocity minimum moved from $Z/C = 0.07$ to $Z/C = 0.11$ at 50° and 290° phase**
 - **Axial Velocity increased from 0 to $0.7 U_{inf}$ at 130° and 170° phase**



- **Investigate partial leading edge forcing**
 - Forcing along the rear half of the wing was found by Dr. Guy to be as effective in increasing lift as forcing along the entire leading edge
- **Alternating blowing and suction to create a curved main vortex, which might break down further downstream**
 - Research at U Washington by Srigrarom et al.