PIV MEASUREMENTS OF CHEVRONS ON F400 TACTICAL AIRCRAFT NOZZLE MODEL

Presented by James Bridges
Contributions of Mark Wernet (PIV acquisition)
& Franco Frate (CFD)
Acoustics Technical Working Group
28 April 2010, Cleveland, Ohio

Previous talks at this meeting have covered our collaborative work on high-energy jets such as present in tactical aircraft (those with supersonic plumes). The emphasis of this work is improving our understanding of flow physics and our prediction tools. In this presentation we will discuss recent flow diagnostics acquired using Particle Image Velocimetry (PIV) made on an underexpanded shocked jet plume from a tactical aircraft nozzle. In this presentation we show cross-sectional and streamwise cuts of both mean and turbulent velocities of an F404 engine nozzle with various chevron designs applied. The impact of chevron penetration, length, and width are documented. The impact of the parameters is generally nonlinear in measures considered here, a surprising result given the relatively smooth behavior of the noise to variations in these chevron parameters.

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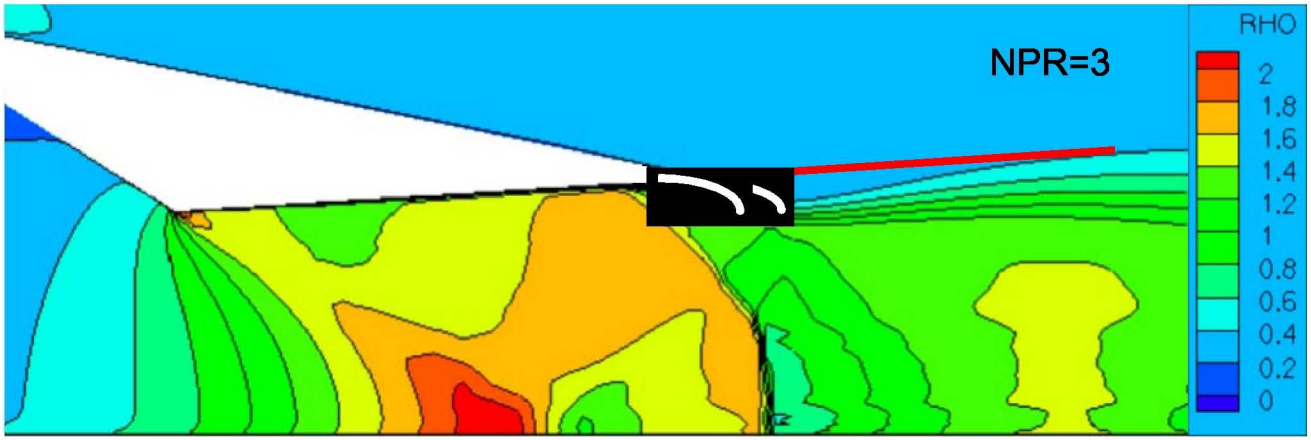
Application of chevrons to C-D nozzle

- Investigate jet noise reduction from chevrons for tactical aircraft
- Collaboration with NAVAIR, GE
- Big Picture:
  - How can chevrons reduce jet noise in overexpanded nozzles?
  - Do current aeroacoustic tools apply?
- NASA Tasks
  - CFD design of chevrons
  - Far-field model-scale acoustic testing
  - **PIV diagnostics**
  - Model- and Full-scale phased array measurements
  - Parametric modeling of acoustic impacts of chevrons

Primary Issues

- Tactical aircraft have actuated C-D nozzles with area ratios tied to throttle
  - Area ratio at takeoff appropriate for cruise pressure ratio
  - Nozzle flow strongly overexpanded at takeoff
- How does overexpansion of flow in C-D nozzle impact design of chevrons?
  - Flow leaves nozzle surface at or near exit and curves inward
  - Chevrons may have to penetrate further to create vorticity.

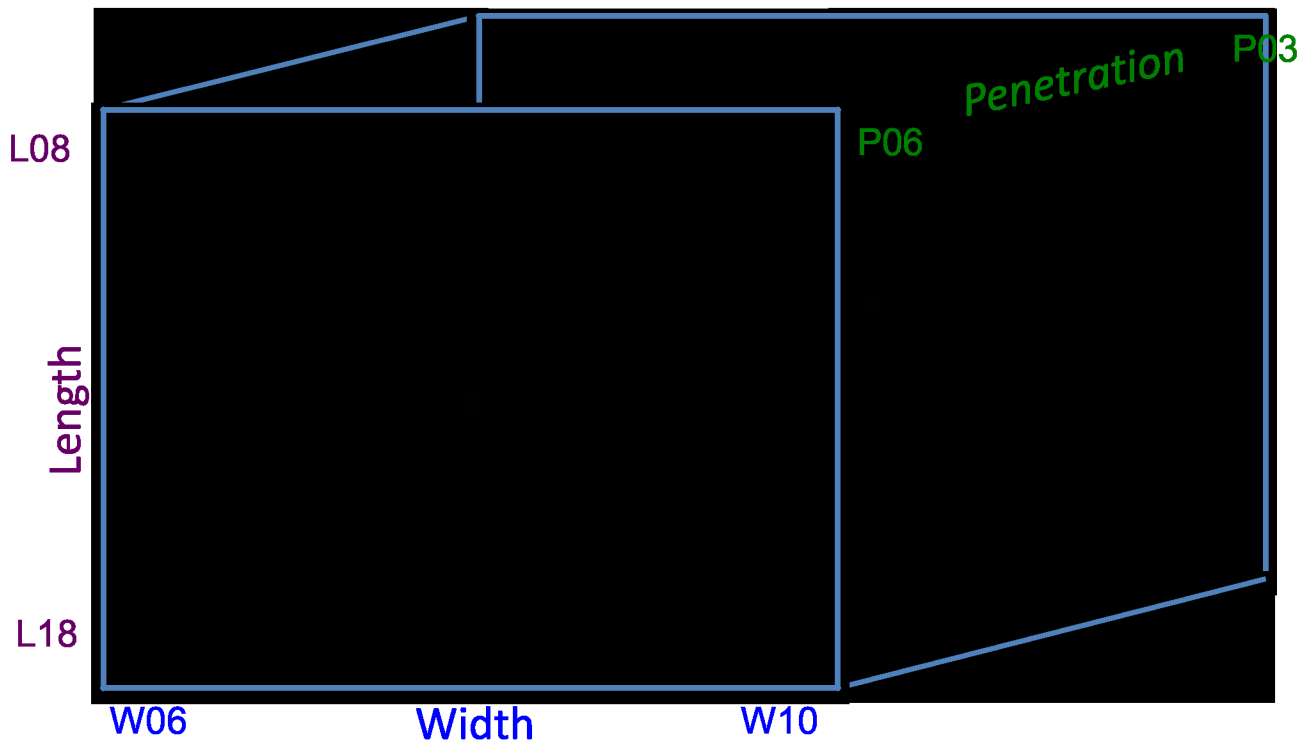


Test details

- GE F400-series model
  - One convergent + three divergent sections
    - Md=1.3, 1.5, 1.65
  - Faceted—12 flaps/seals
  - 4.454” throat diameter

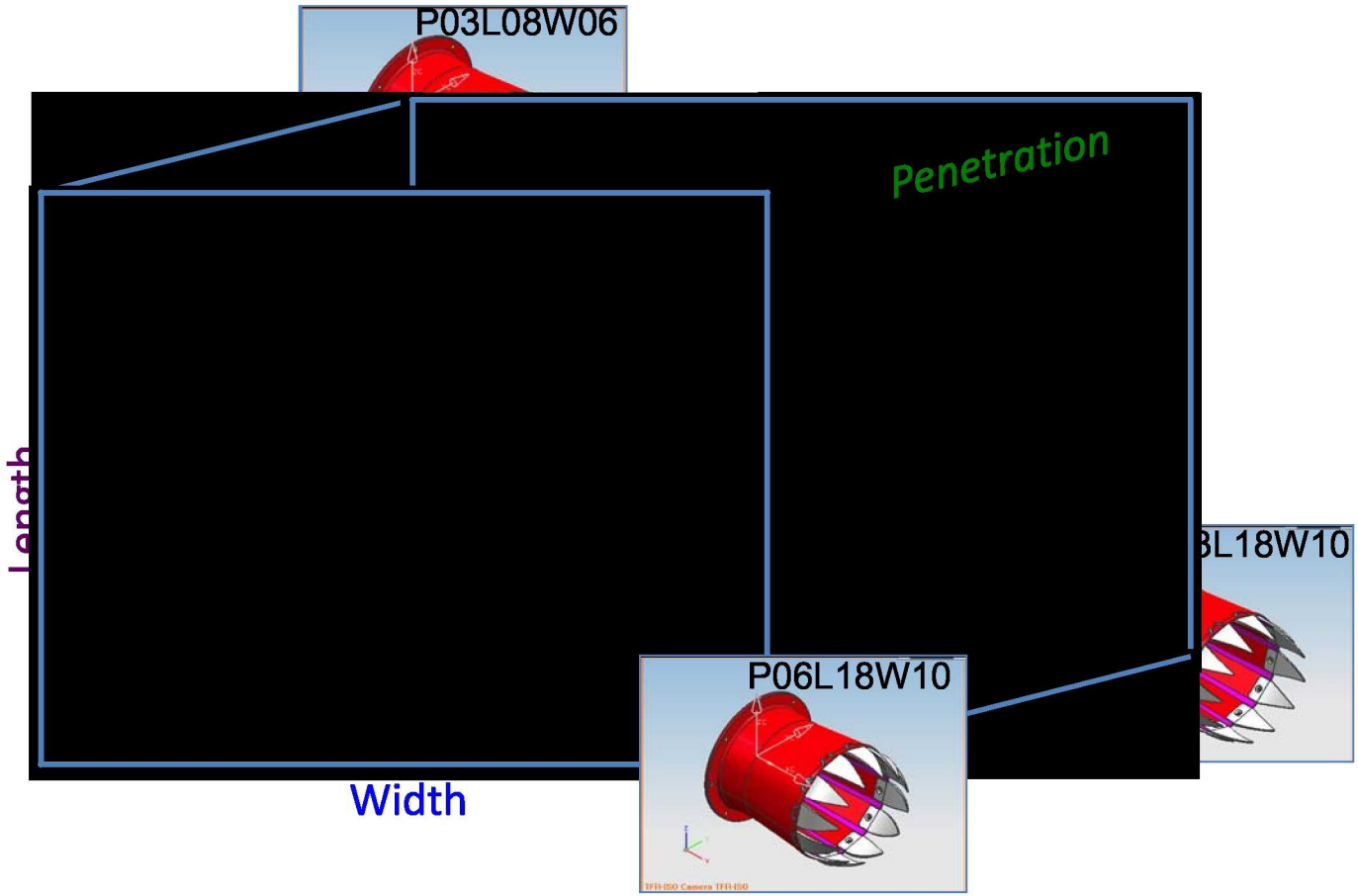
Chevron designs

- NASA MDOE parametric matrix: Penetration, Length, Width



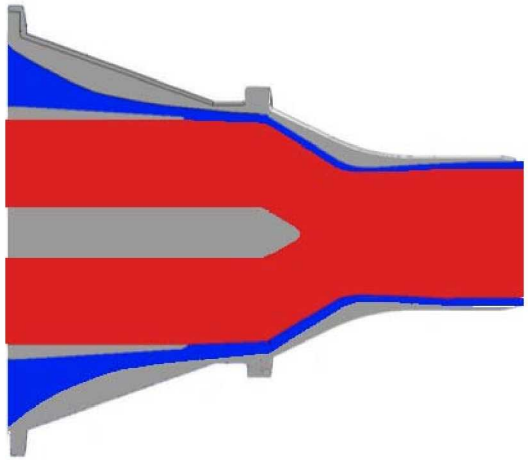
Chevron designs

- NASA MDOE parametric matrix: Penetration, Length, Width
- Subset of configs for PIV study



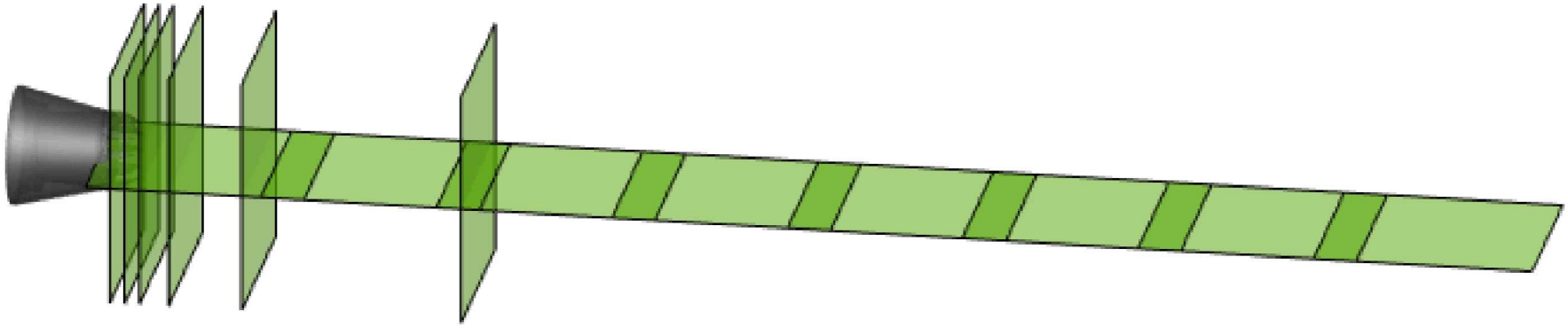
Facility details

- NATR with jet rig in internally mixed configuration
  - Axisymmetric splitter with area ratio 0.2:1
  - Typical BPR = 0.3



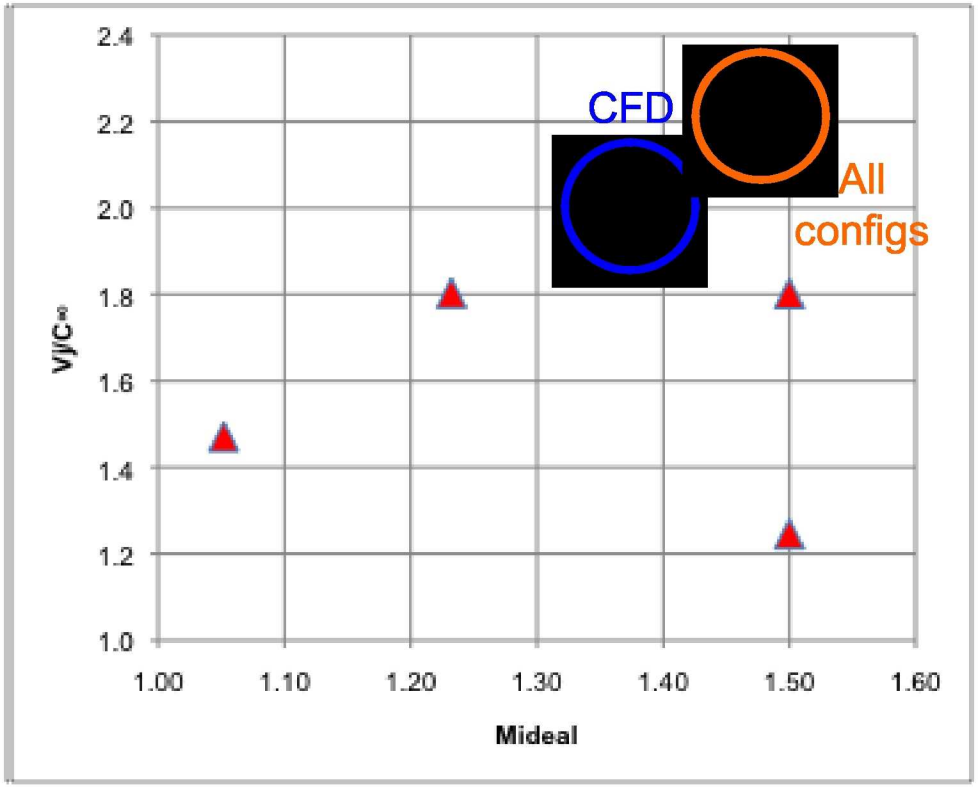
PIV setup in two modes

- Streamwise, two velocity components on plane including centerline
- Cross-stream, three velocity components on plane cutting centerline



Test matrix

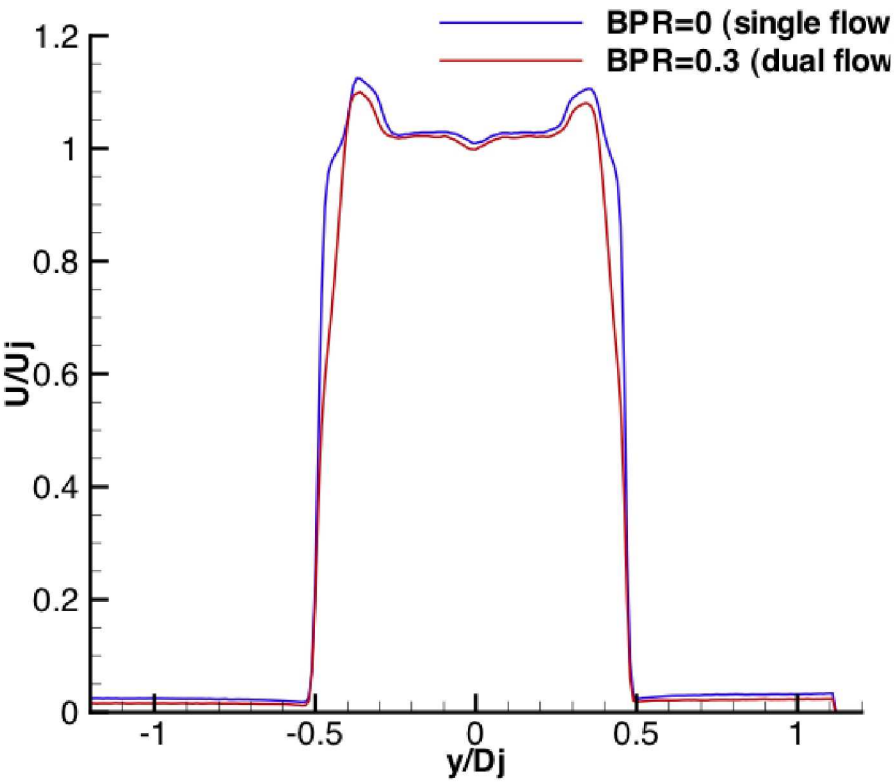
- Explore impact of expansion ratio/NPR for baseline and a single chevron design
- Explore impact of chevrons at one point.

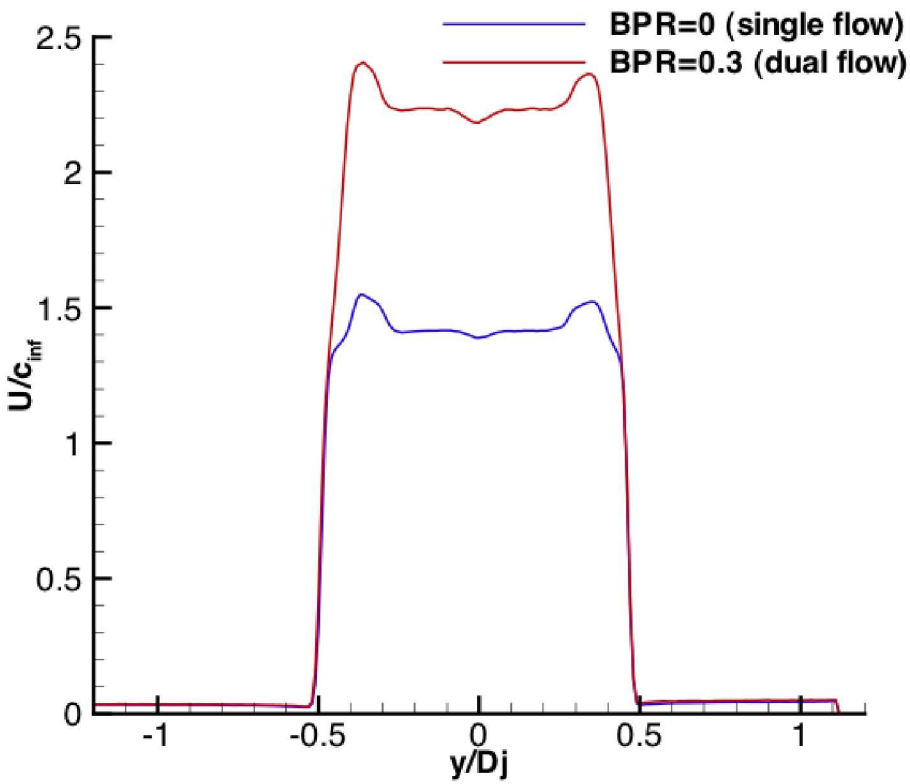


Exit velocity profiles—dual vs single flow

- Baseline nozzle (M_d = 1.65) operated at M_{ideal} = 1.5
  - Both streams cold vs streams pressure matched, Ttr_{core} = 3.2
- Cooling flow results in only slightly thicker boundary layer

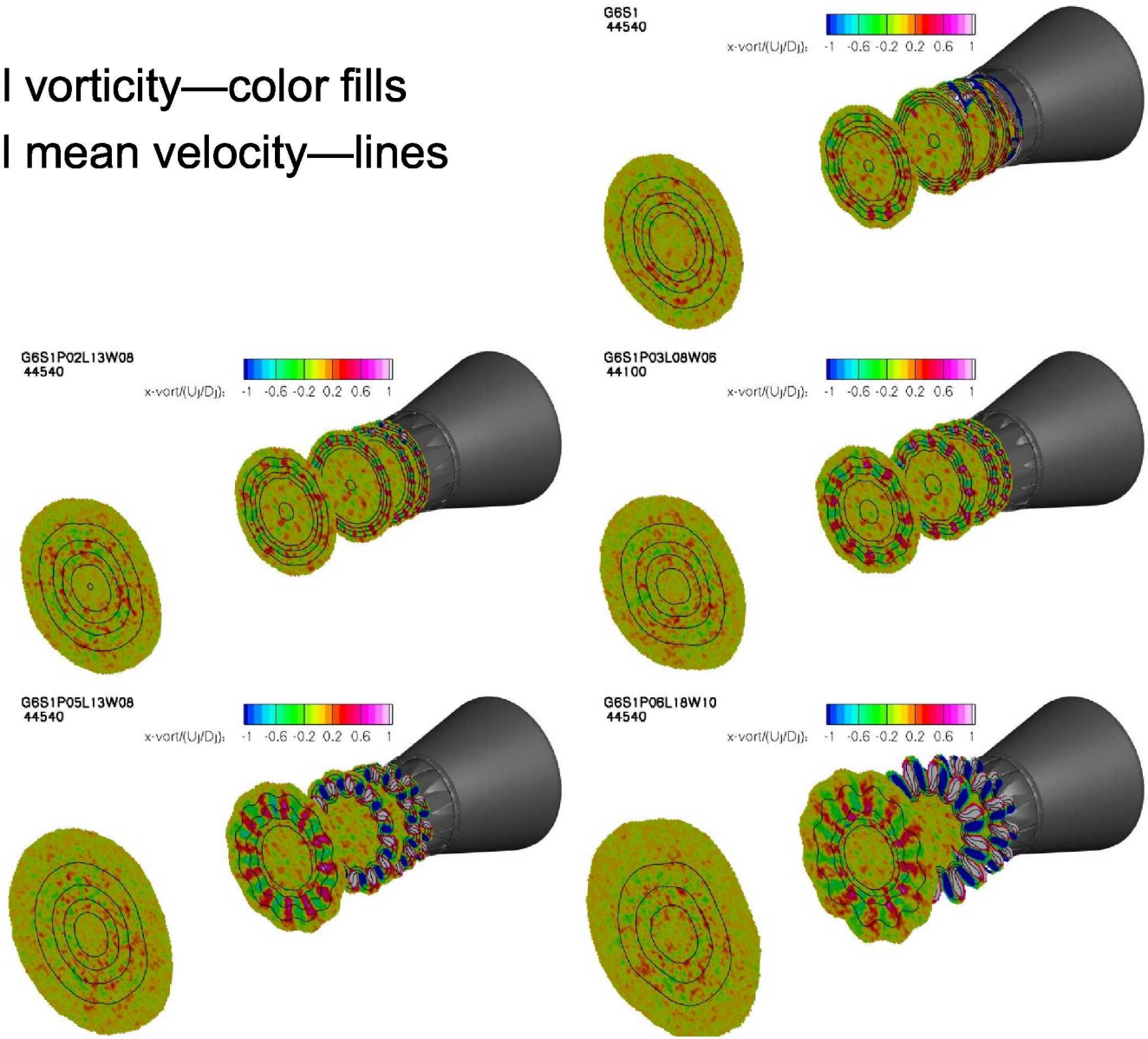
Mean axial velocity, x/Dj = 0.07





Impact of chevrons—Overview

- Axial vorticity—color fills
- Axial mean velocity—lines



Impact on mean velocity

- U/Uj of M_d=1.65 running at M_{ideal}=1.48

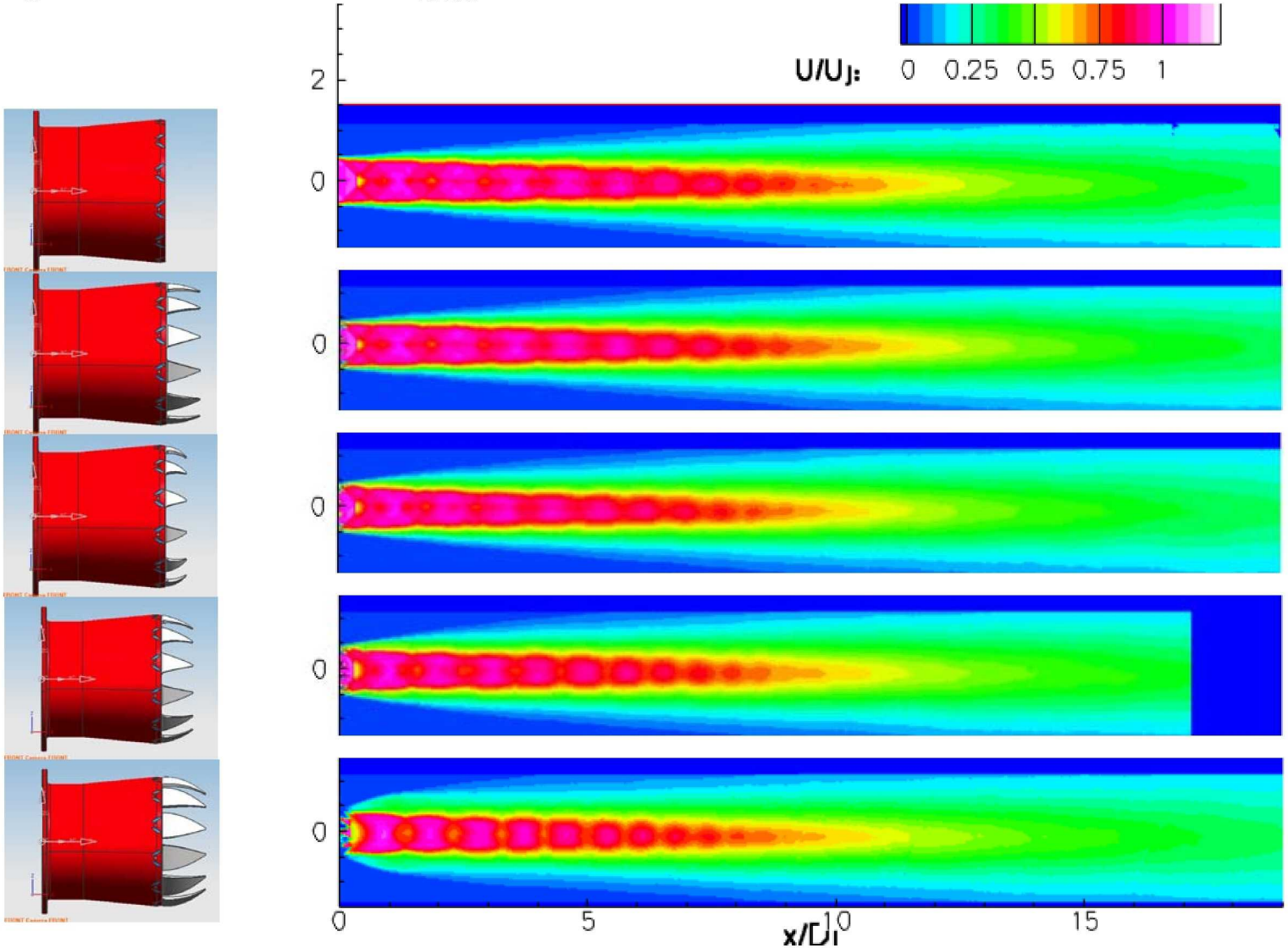
BASELINE

P02L13W08

P03L08W06

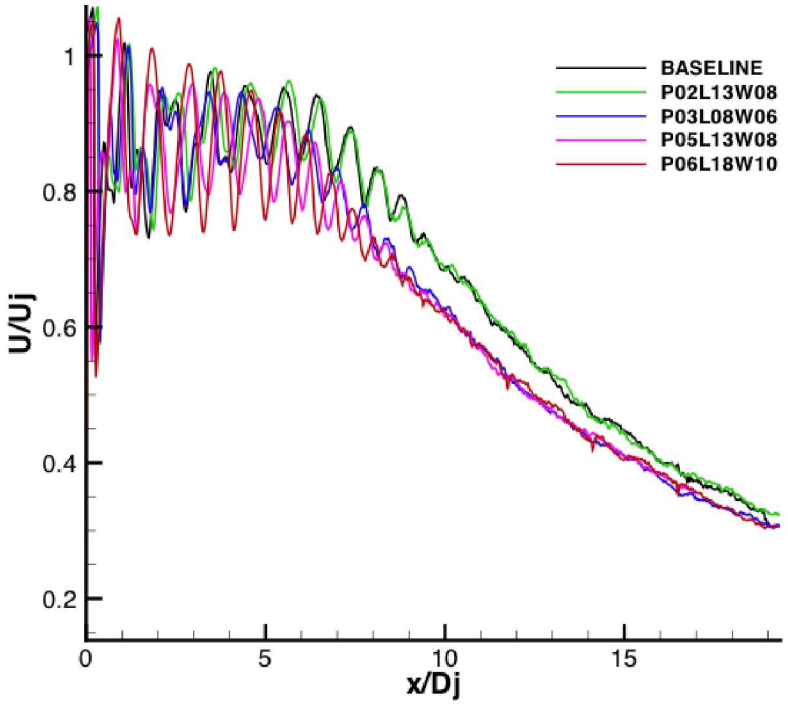
P05L13W08

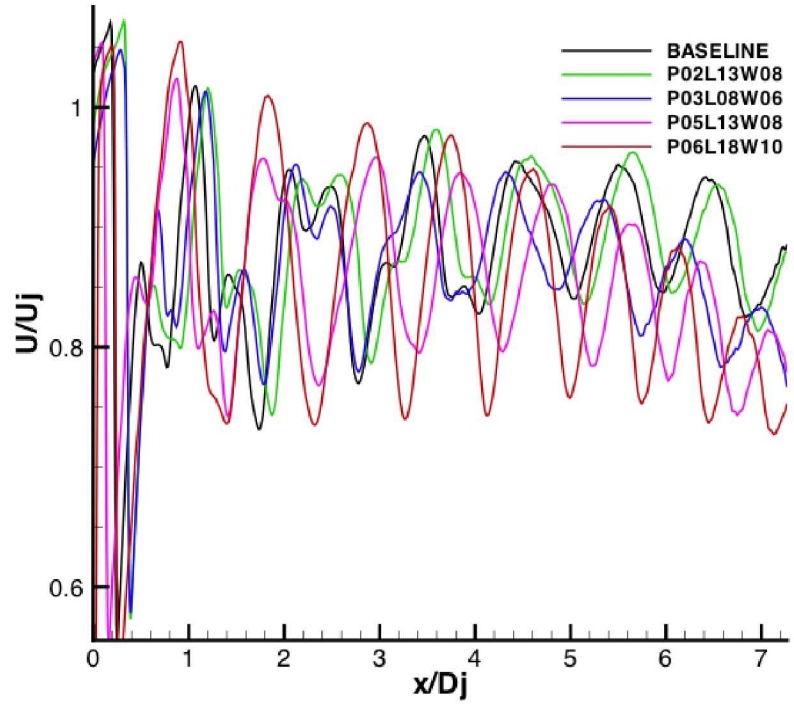
P06L18W10



Impact on mean velocity on centerline

- Impact on centerline decay
- Impact on shock structure





Impact on turbulence distribution

- U_{rms}/U_j of M_d=1.65 running at M_{ideal} = 1.48

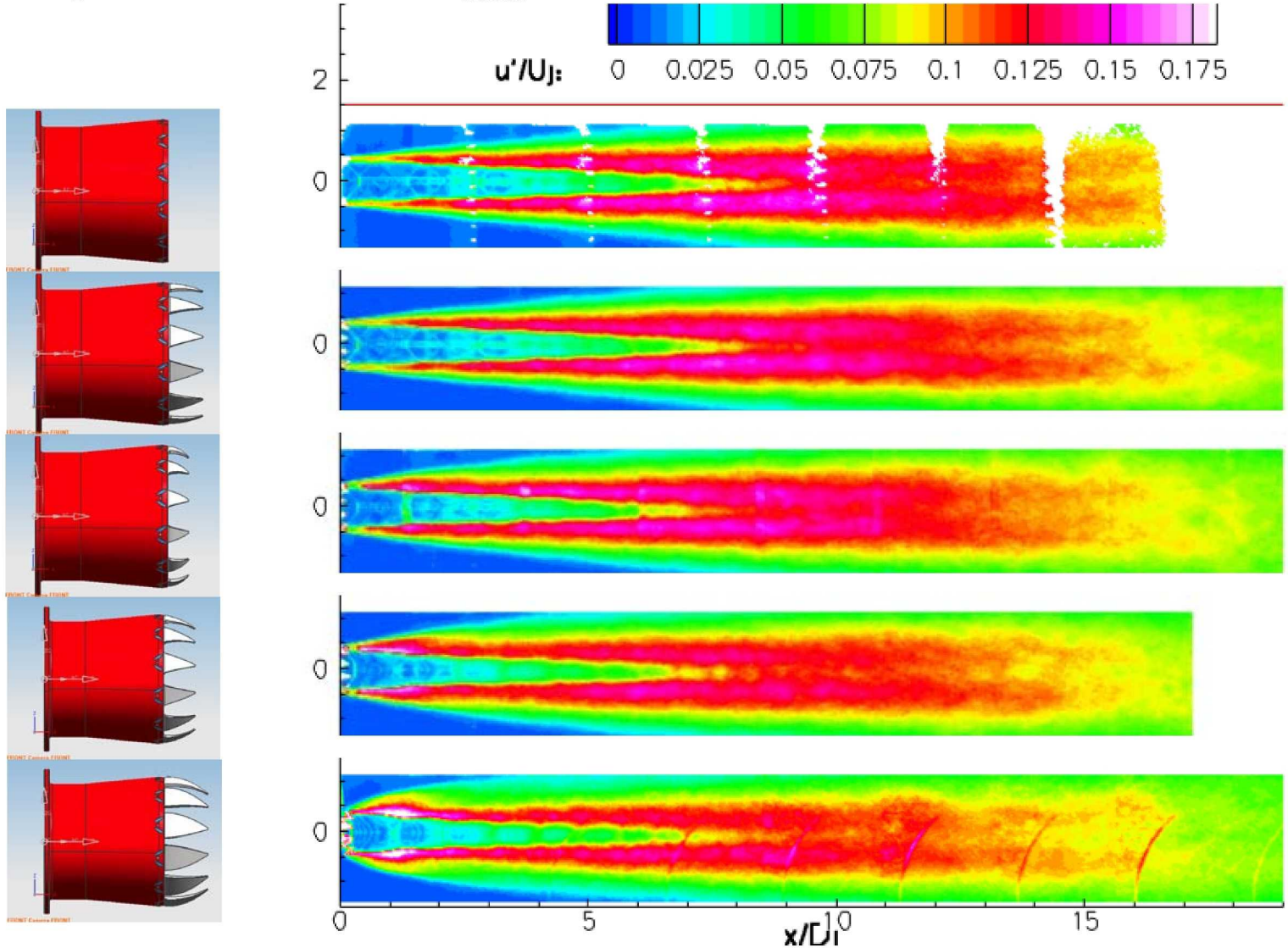
BASELINE

P02L13W08

P03L08W06

P05L13W08

P06L18W10

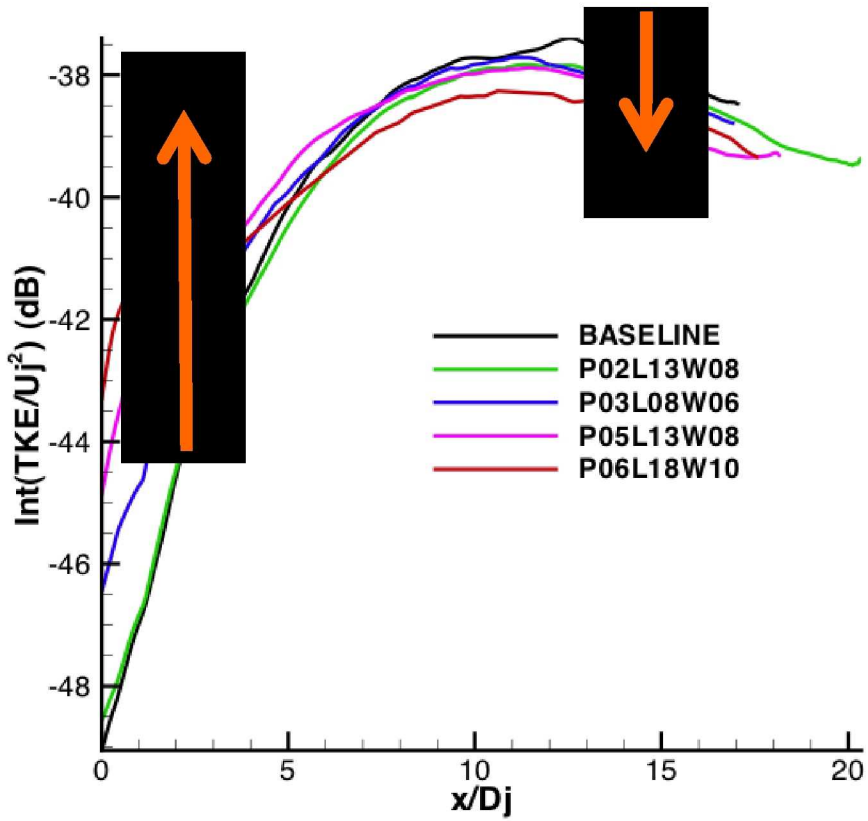


Impact on turbulence

Integrate TKE over jet cross-sections to mimic acoustic source strength

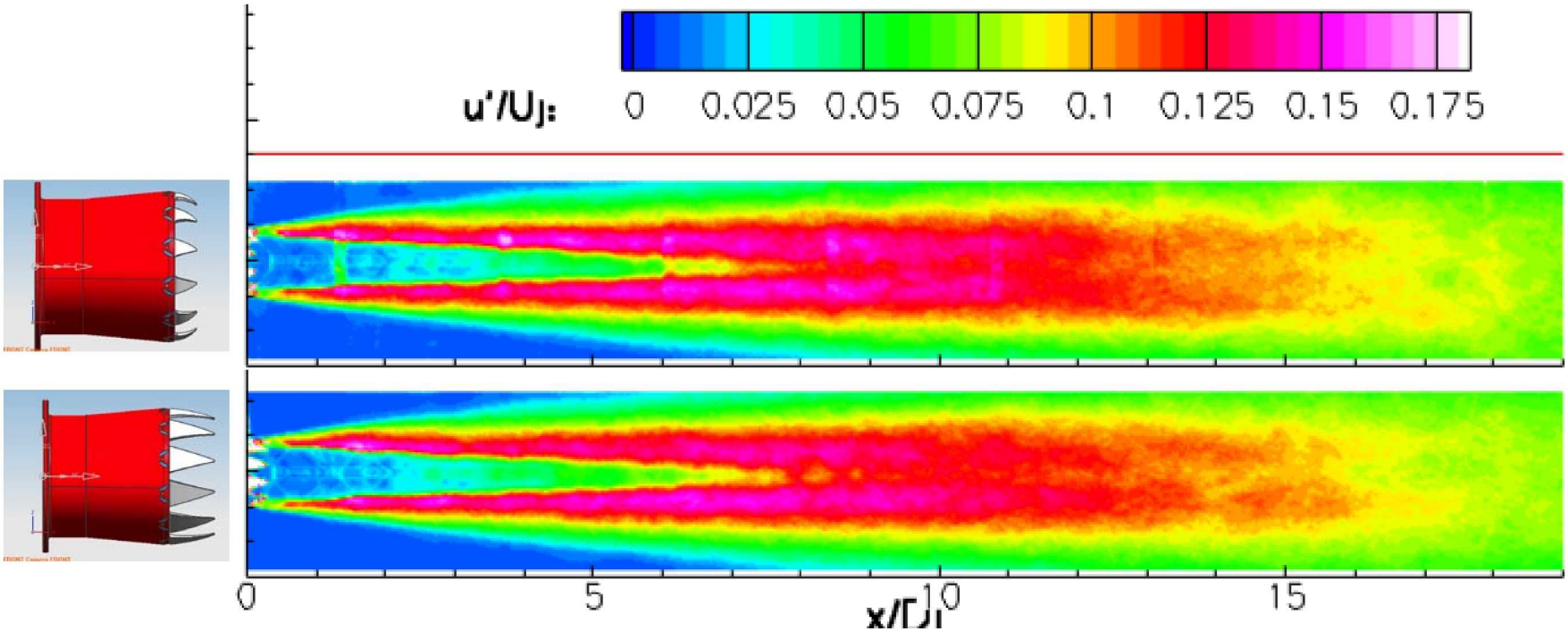
$$10\log\int_A TKE/U_j^2\ dA$$

Trend of increasingly aggressive chevron borne out.



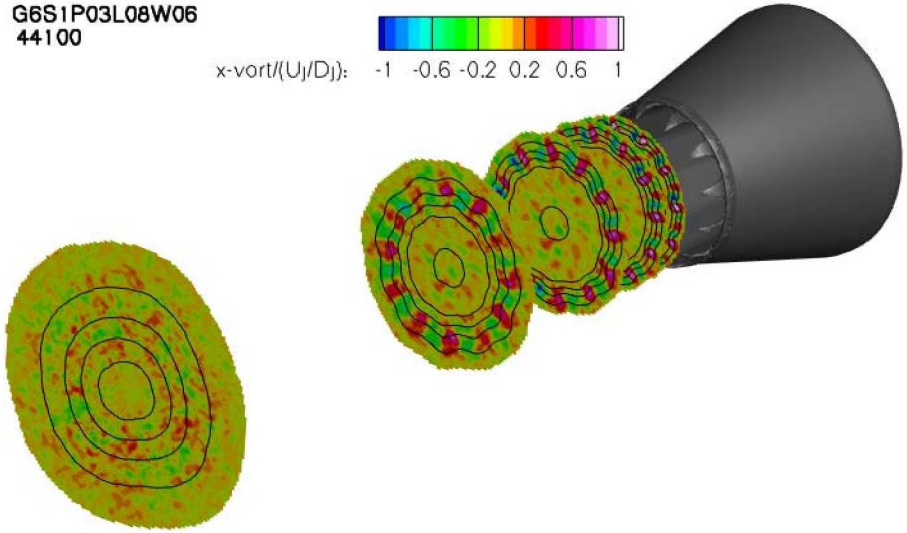
Effect of Length

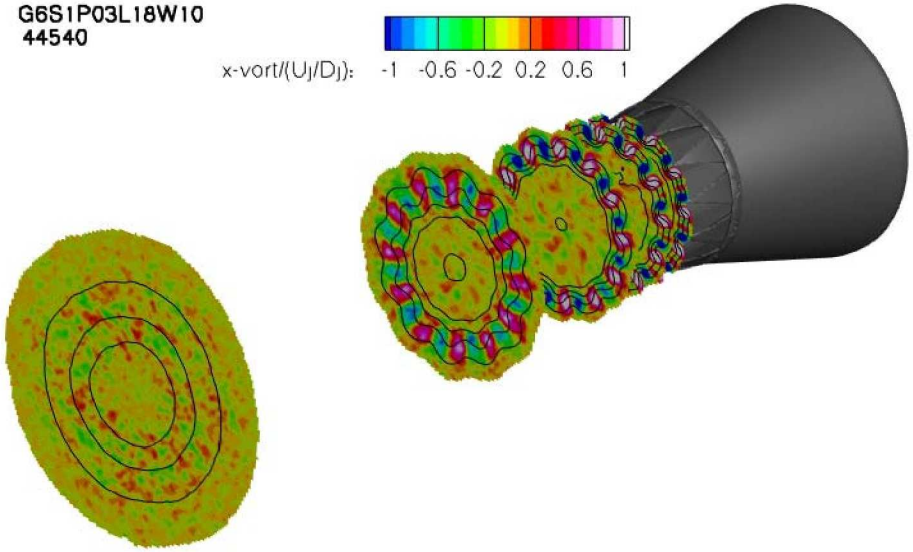
- P03L08W06 vs P03L18W10
- Assume width has small effect
- Longer chevrons better able to impact flow



Effect of Length

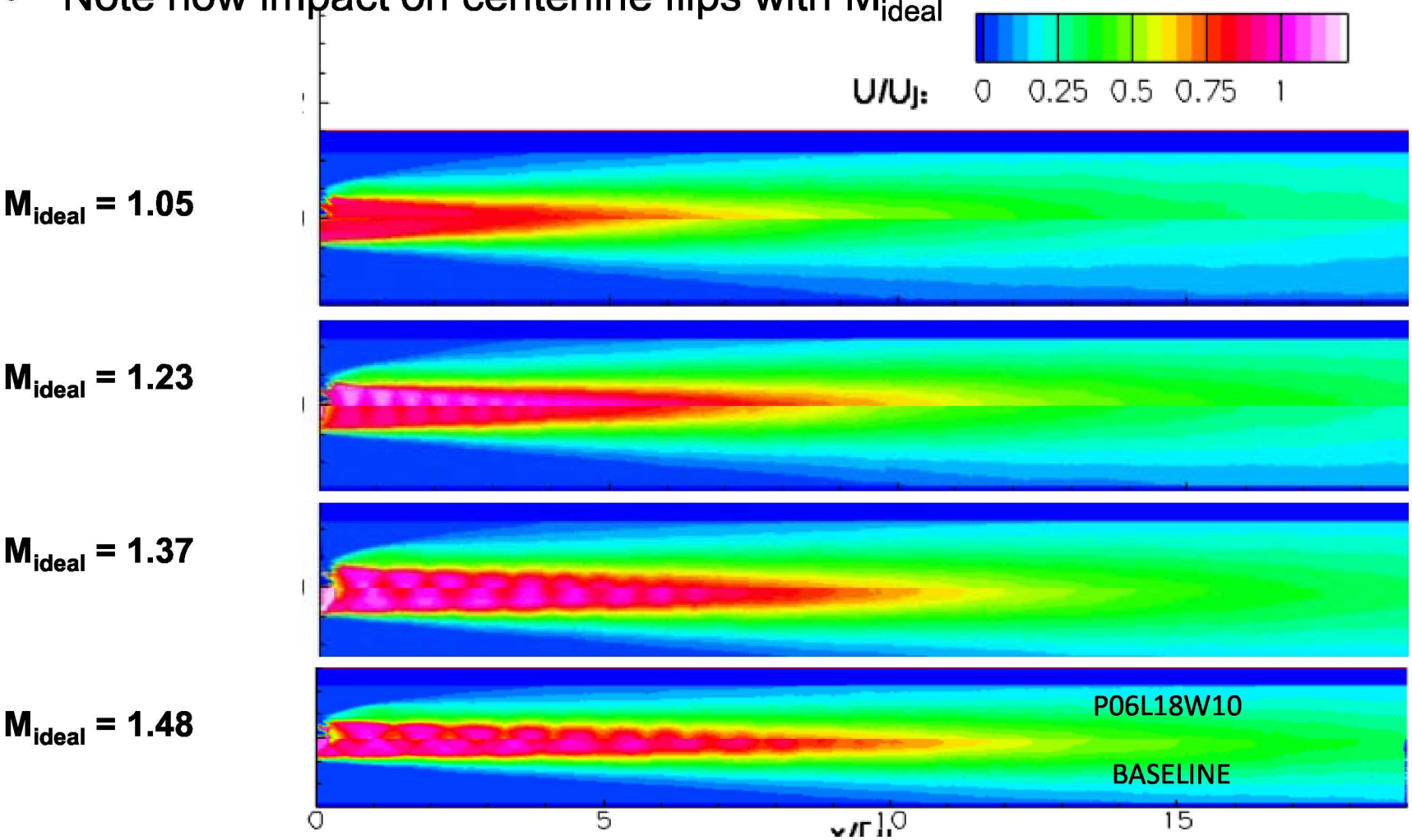
- P03L08W06 vs P03L18W10





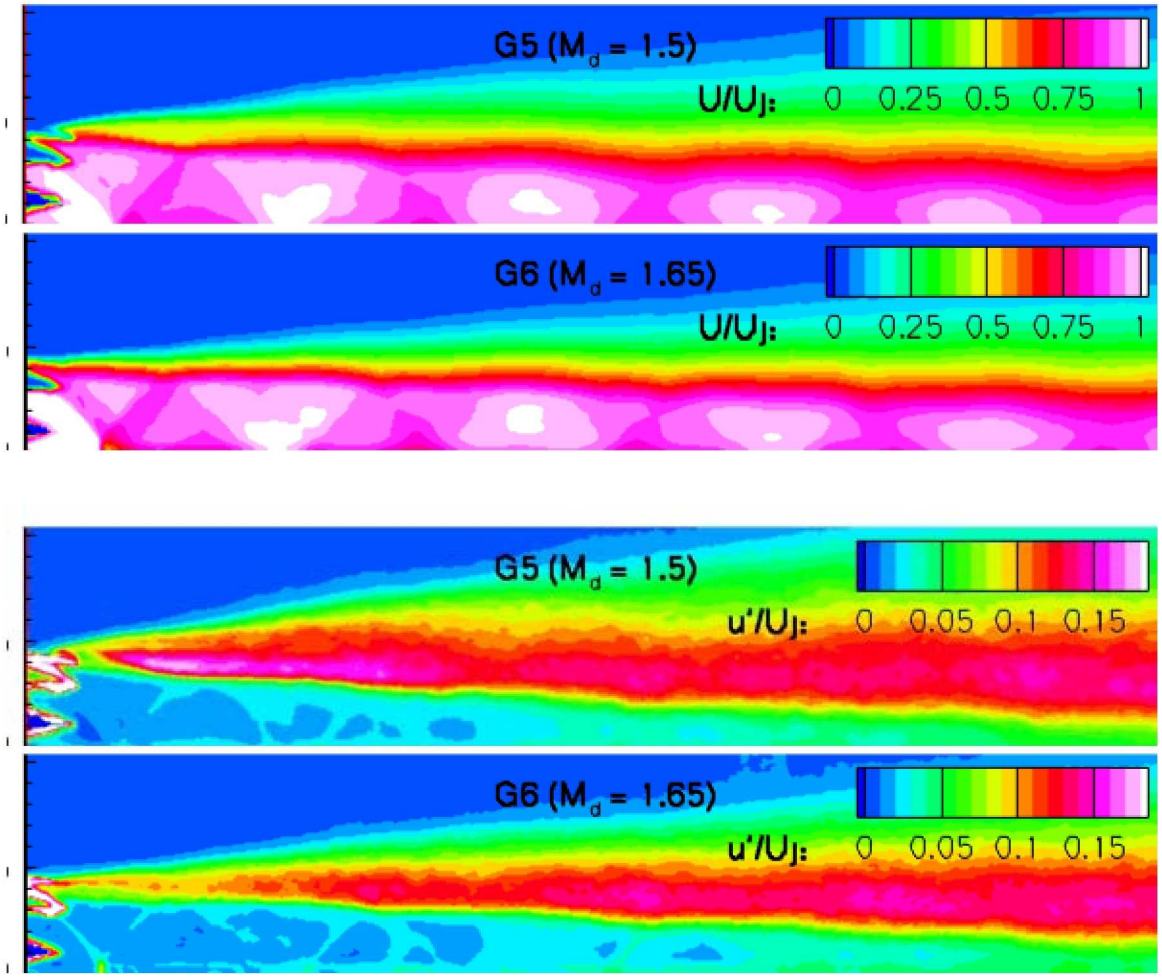
Variation with M

- P06L18W10 chevrons on top, baseline below; M_d = 1.65
- Note how impact on centerline flips with M_{ideal}



Penetration depends on Area Ratio

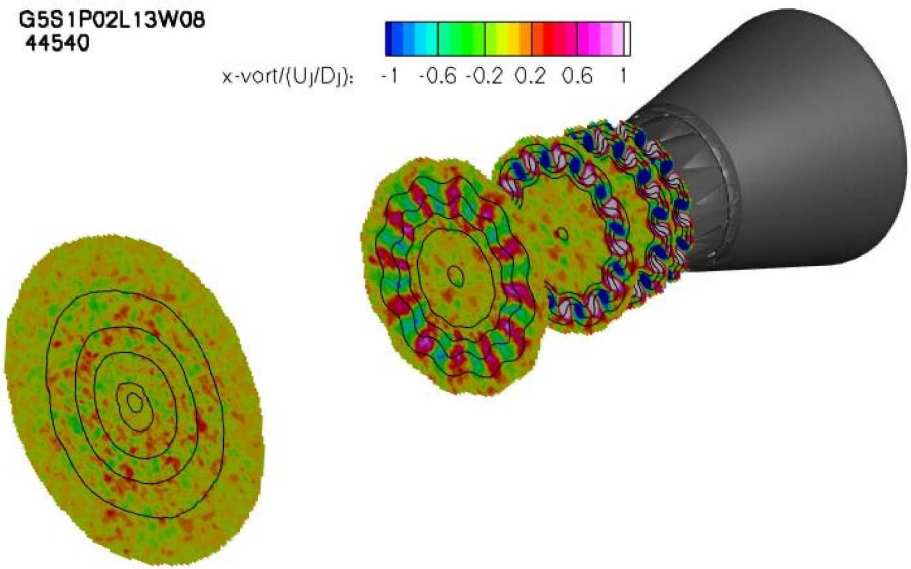
- P02L13W08 on M_d = 1.5 and 1.65 nozzles, run at M_{ideal} = 1.48
- When divergent angle reduced, chevron has impact on flow



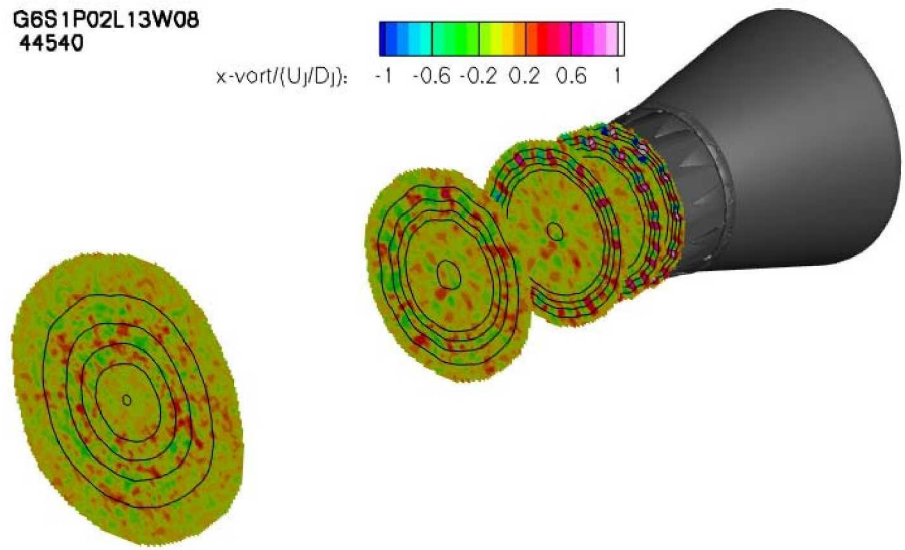
Impact of nozzle divergence angle

- P02L13W08 on M_d = 1.5 v 1.65, run at M_{ideal} = 1.48

M_{ideal} = 1.48, M_d = 1.51



M_{ideal} = 1.48, M_d = 1.65



Summary

- PIV data acquired for chevrons in practical geometry, flow conditions of tactical aircraft
- Cooling flow produces slightly larger boundary layer—significant?
- Impact of chevron design on flow documented:
  - More penetration required on overexpanded flows
  - Penetration/Length key parameters
  - Penetration varies with variable area
  - Impact on potential core length varies with M_{ideal}/M_d
- Impact is generally nonlinear in penetration, length due to complicated interaction with curved, overexpanded shear layer.