



Surface and Flow Field Measurements on the FAITH Hill Model

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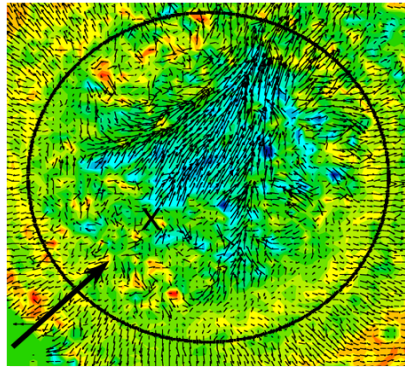


- **Objective:** To generate an experimental database with well-documented inlet and boundary conditions that will enable an assessment of our ability to predict complex flow behavior in the separated region over a model with simple geometry.
- **Approach:** Use a variety of experimental techniques (PSP, PIV, Skin Friction, Cobra Probe, Oil Flow Vis.) to thoroughly document flow around an axisymmetric wall-mounted hill model immersed in subsonic flow.
- **Results and Impact:** Detailed surface and flow field data capture the complexity of the separated flow. Database will facilitate basic understanding of complex separated flows and help develop/validate CFD techniques.

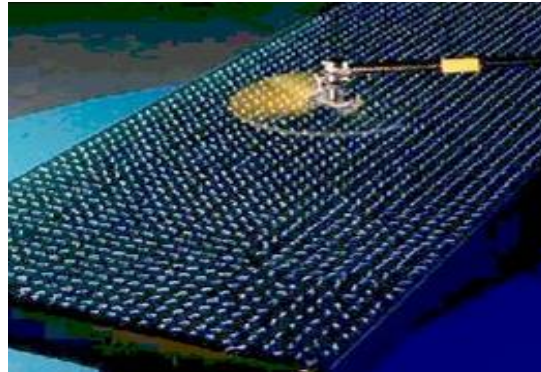
FAITH Measurement Techniques



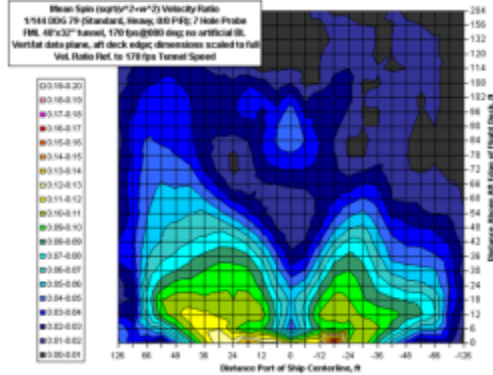
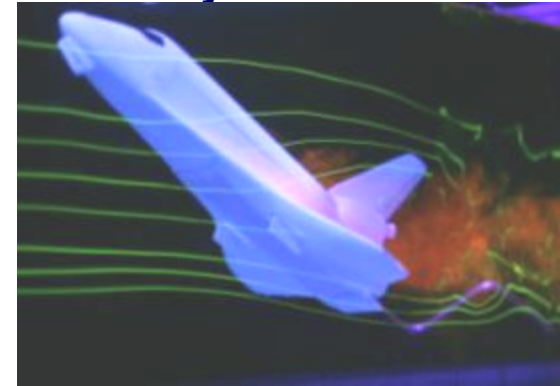
PIV



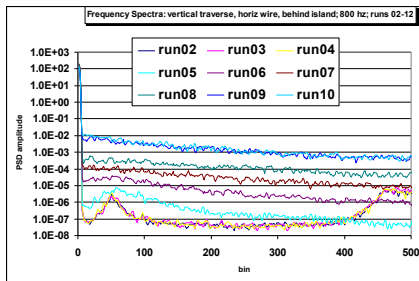
Mini Tufts



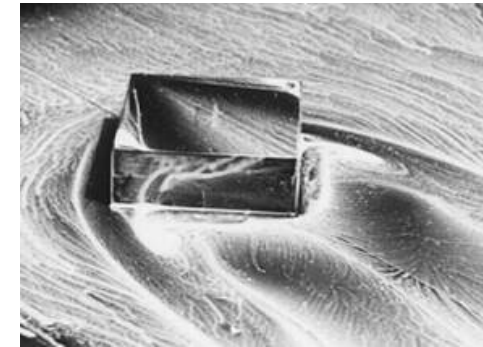
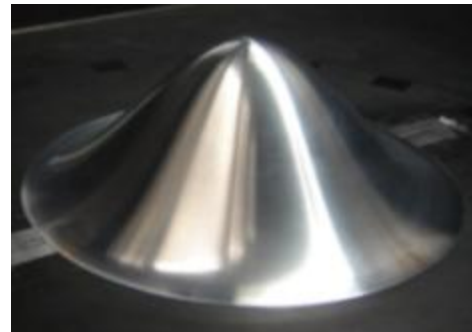
Dye Flow Viz



Cobra Probe

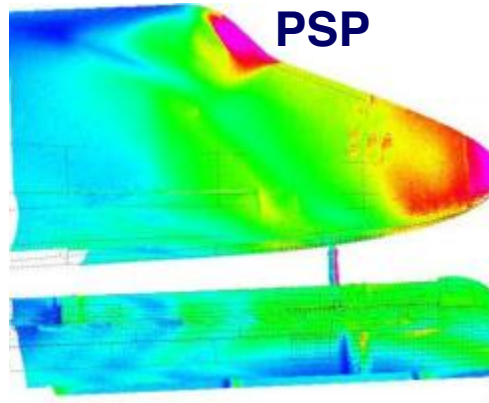


Fundamental Aeronautics Program
Subsonic Fixed Wing Project

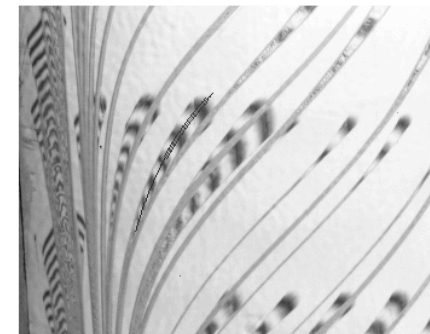


Oil Flow

PSP



FISF



FAITH Model

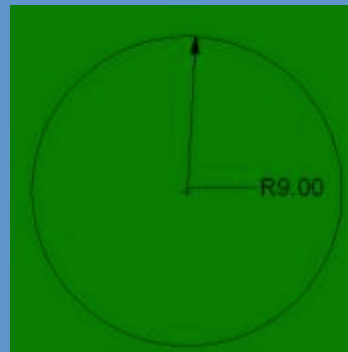
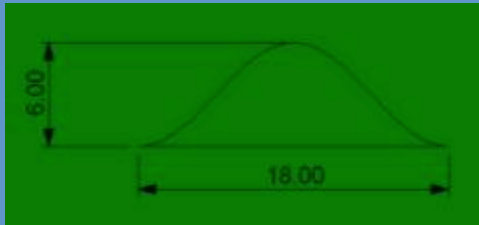


- 3D, Axisymmetric, Cosine Curve
- $H/\delta = 3$; $\delta = 2$ in. at centroid

$$h = 3 \cdot \cos\left(\frac{\pi}{9}x\right) + 3$$



Wind Tunnel Speed ~ 165 ft/sec
Re No based on height = 500,000

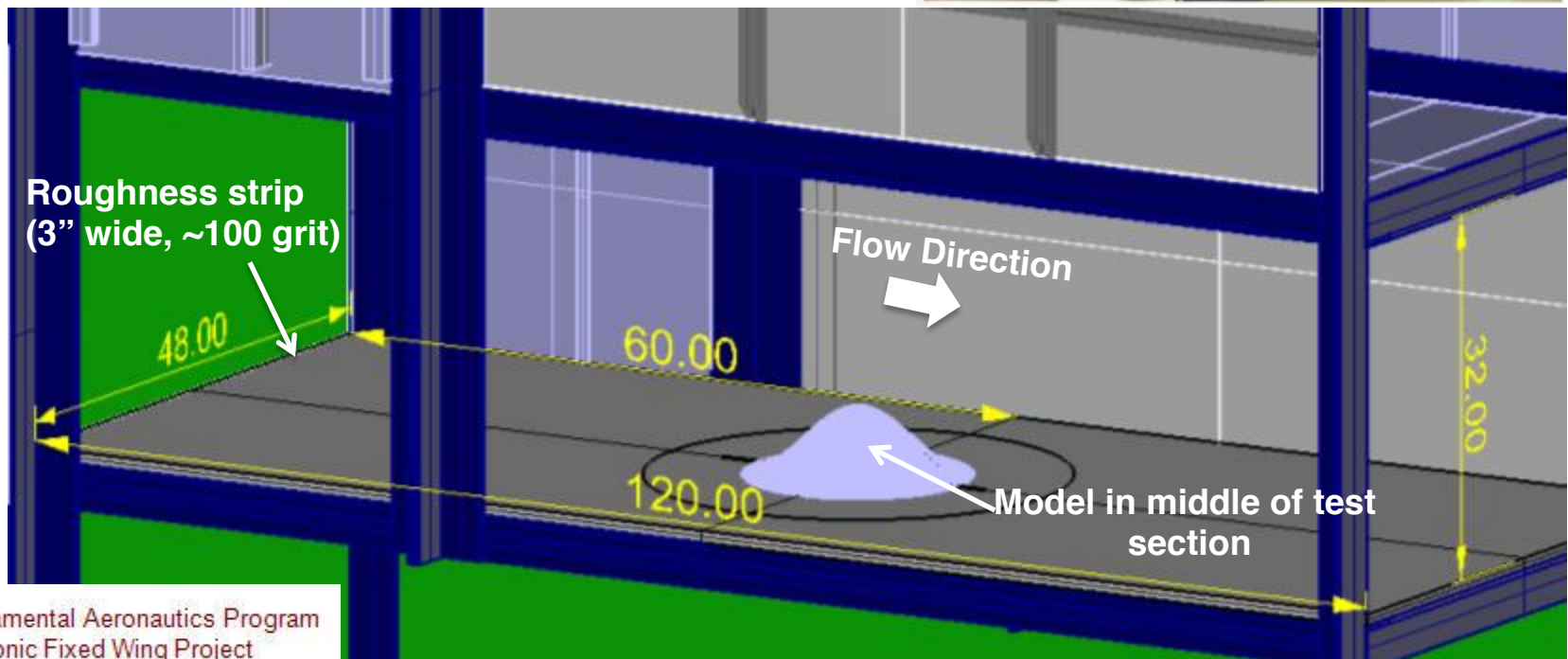


FAITH Experimental Facilities



Indraft Wind Tunnel

- Test Section: 48" X 32", 10 ft long
- Speed Range: 40 - 170 f/s
- Turbulence Intensity Level: 0.1%
- Roughness strip upwind
- Oil Flow, Cobra Probe, FISF, PSP, PIV



Summary of FAITH Techniques



- **Water Channel Flow Vis**
- **Surface Oil Flow Vis**
- **Pressure Sensitive Paint (PSP)**
- **Fringe Imaging Skin Friction (FISF)**
- **Cobra Probe**
- **Particle Image Velocimetry (PIV)**

FAITH Flow Visualization

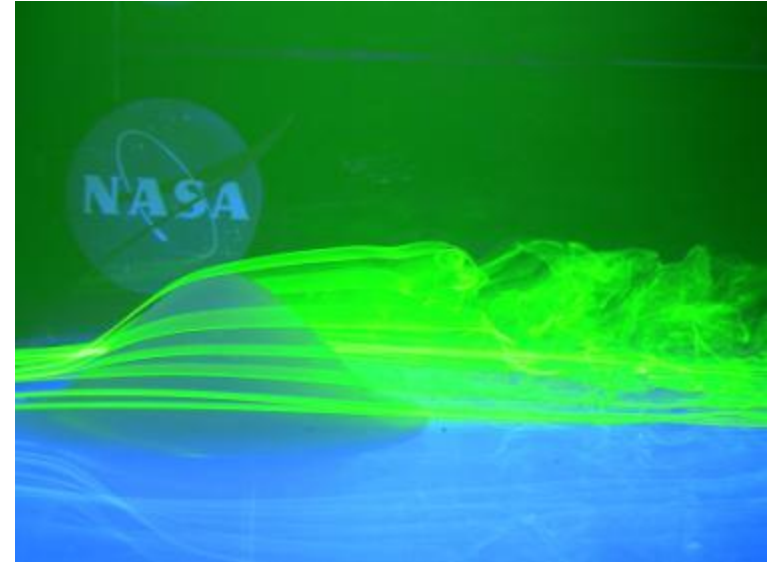


Water Channel



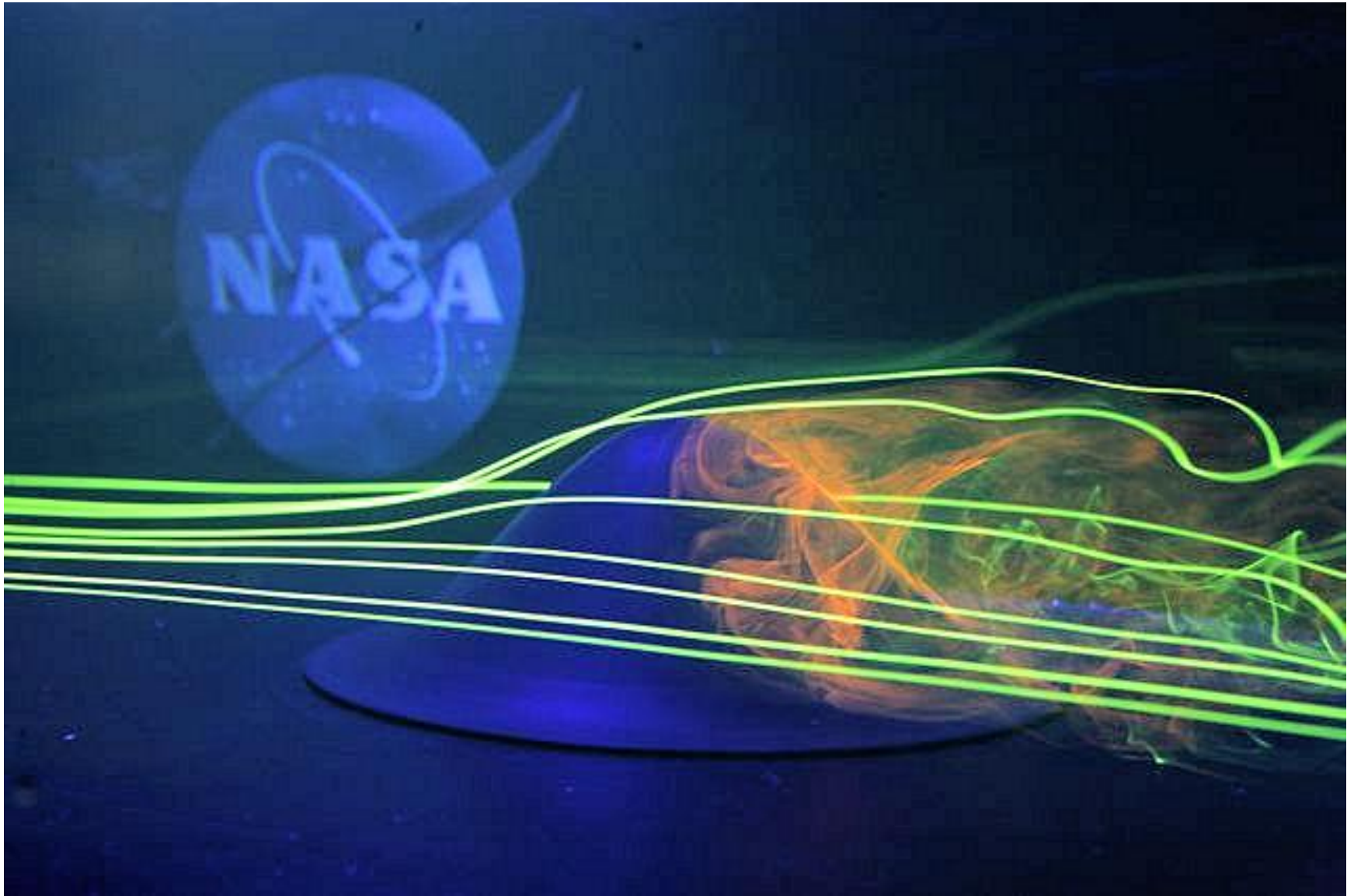
Test Section: 17" X 11", 8 ft long
Speed Range: 1 – 4 in/s
UV lamps and fluorescent dye

Smaller Water Channel Model

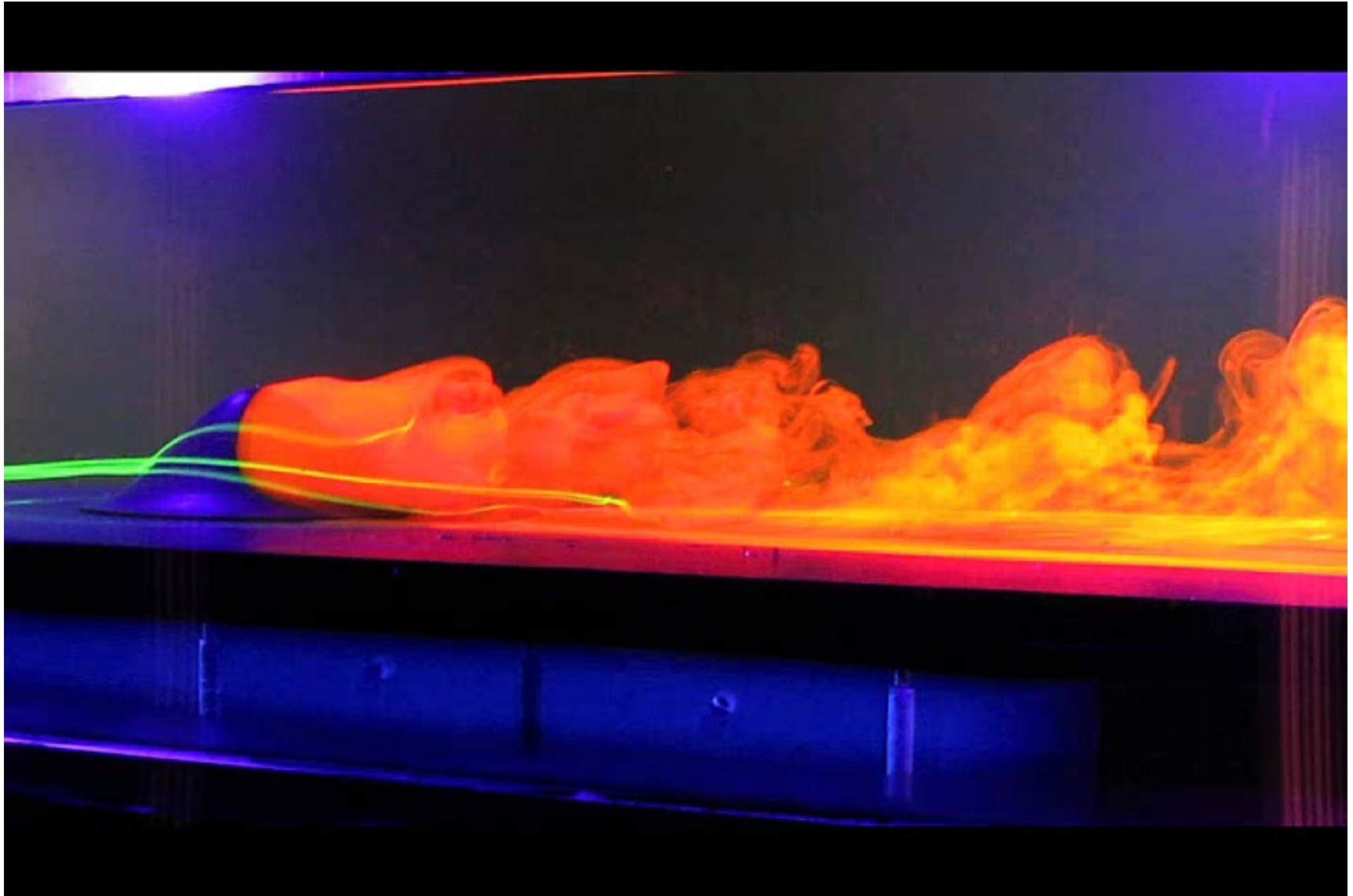


6 inch diameter, 2 inch height
Water Channel Speed: 1 inch/sec
Re No = 1250

FAITH Flow Visualization Studies



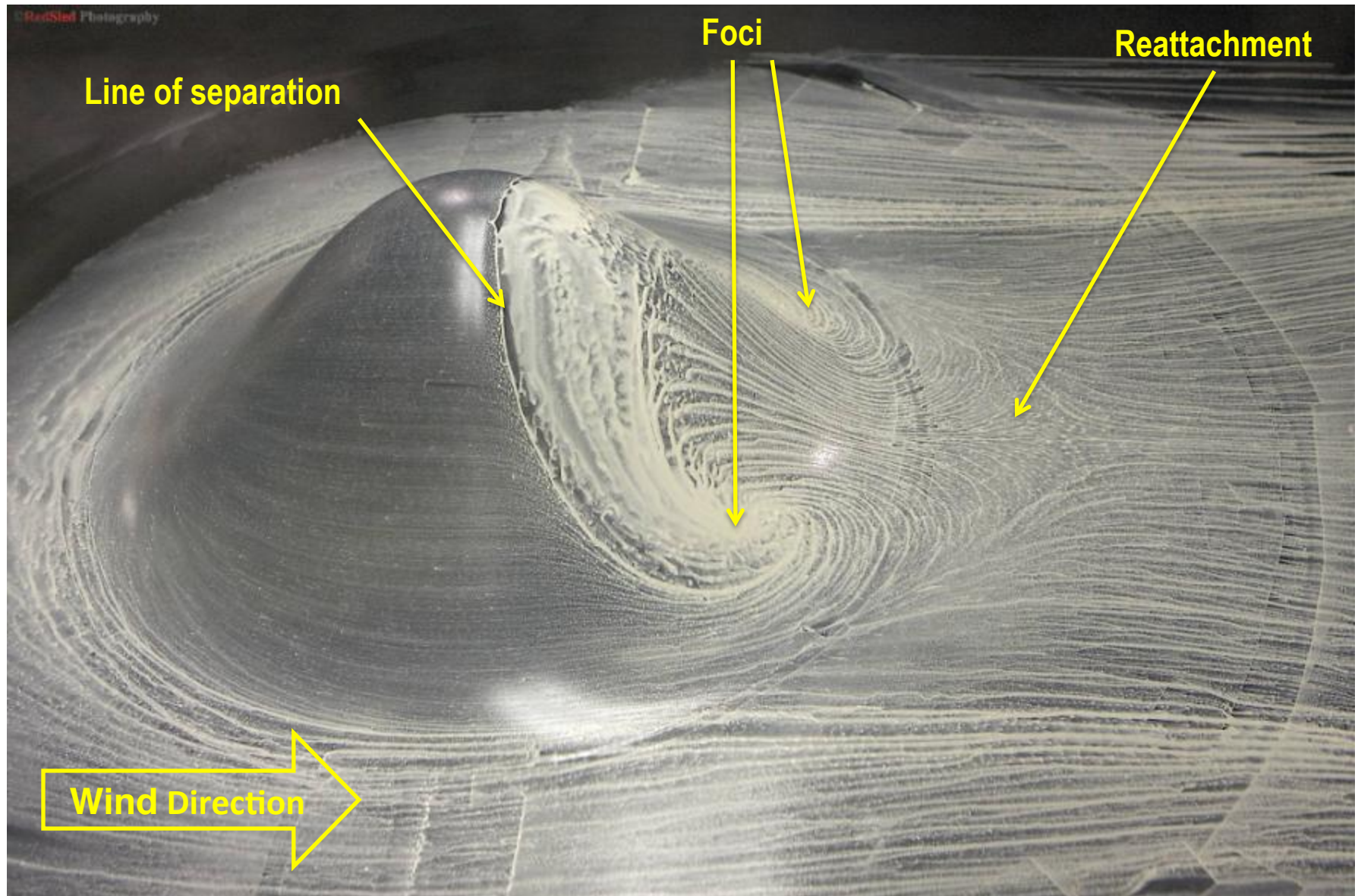
FAITH Flow Visualization Studies



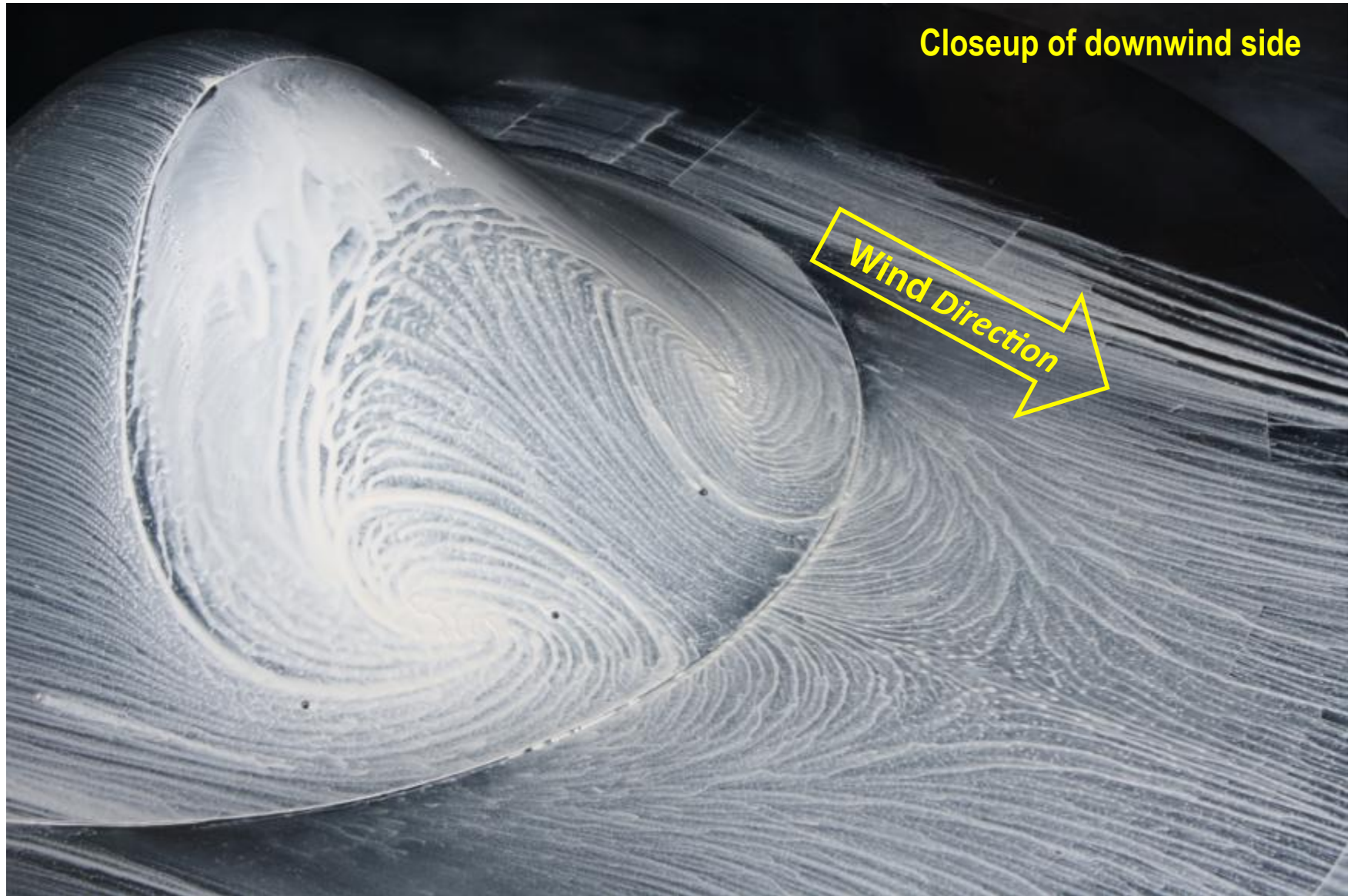
Centerline Cut Using Laser Sheet



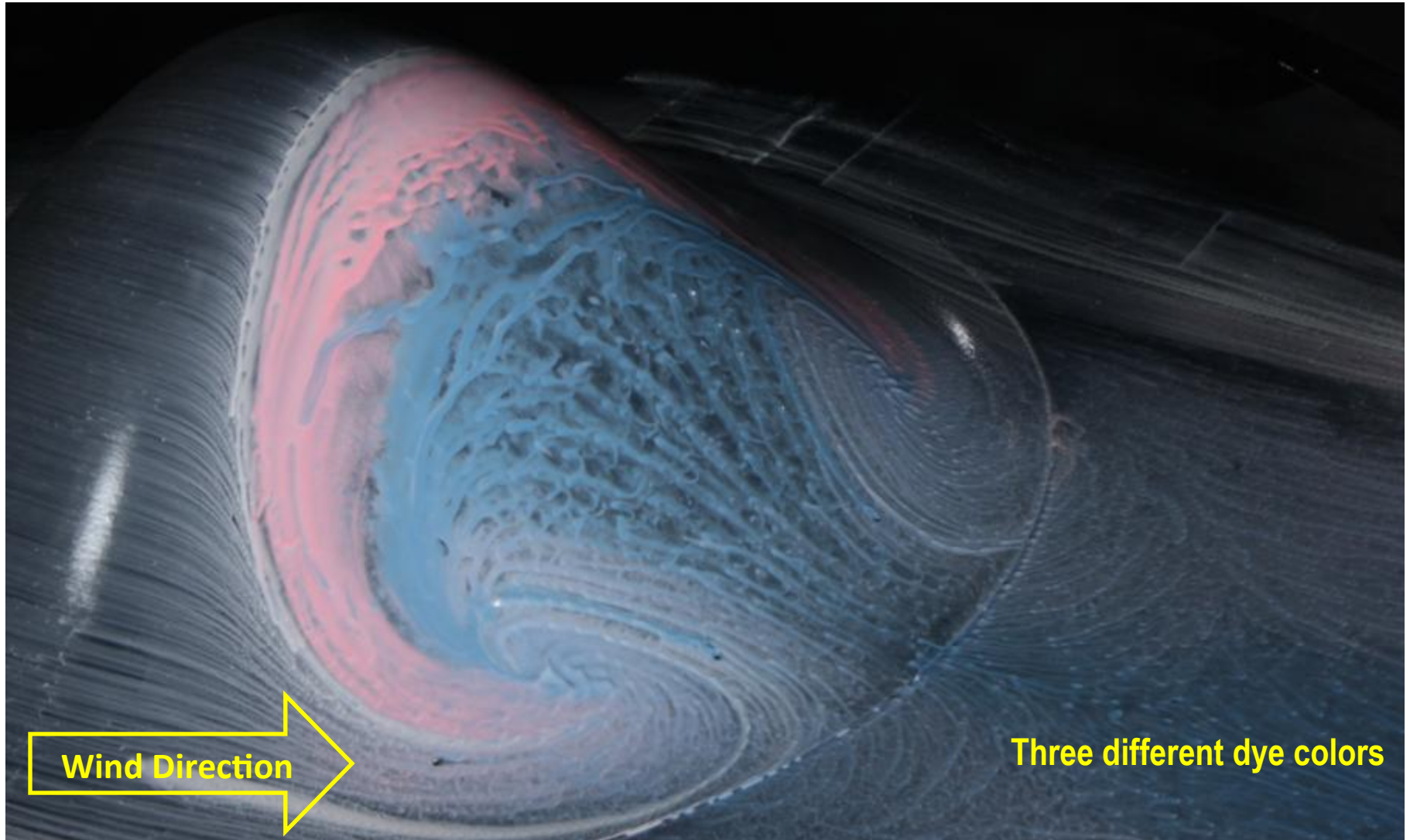
FAITH Surface Oil-Flow Visualization Studies



FAITH Surface Oil-Flow Visualization Studies

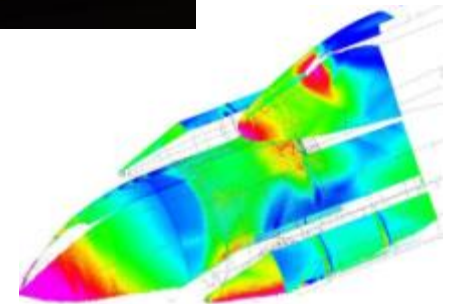
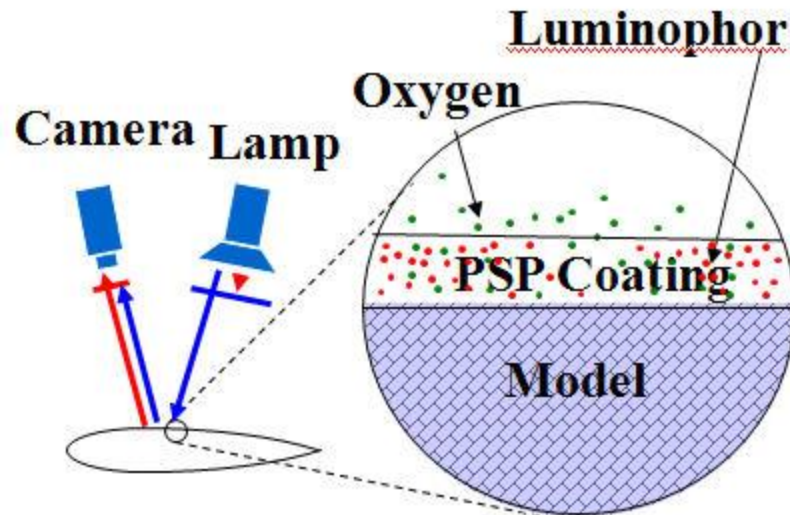


FAITH Surface Oil-Flow Visualization Studies

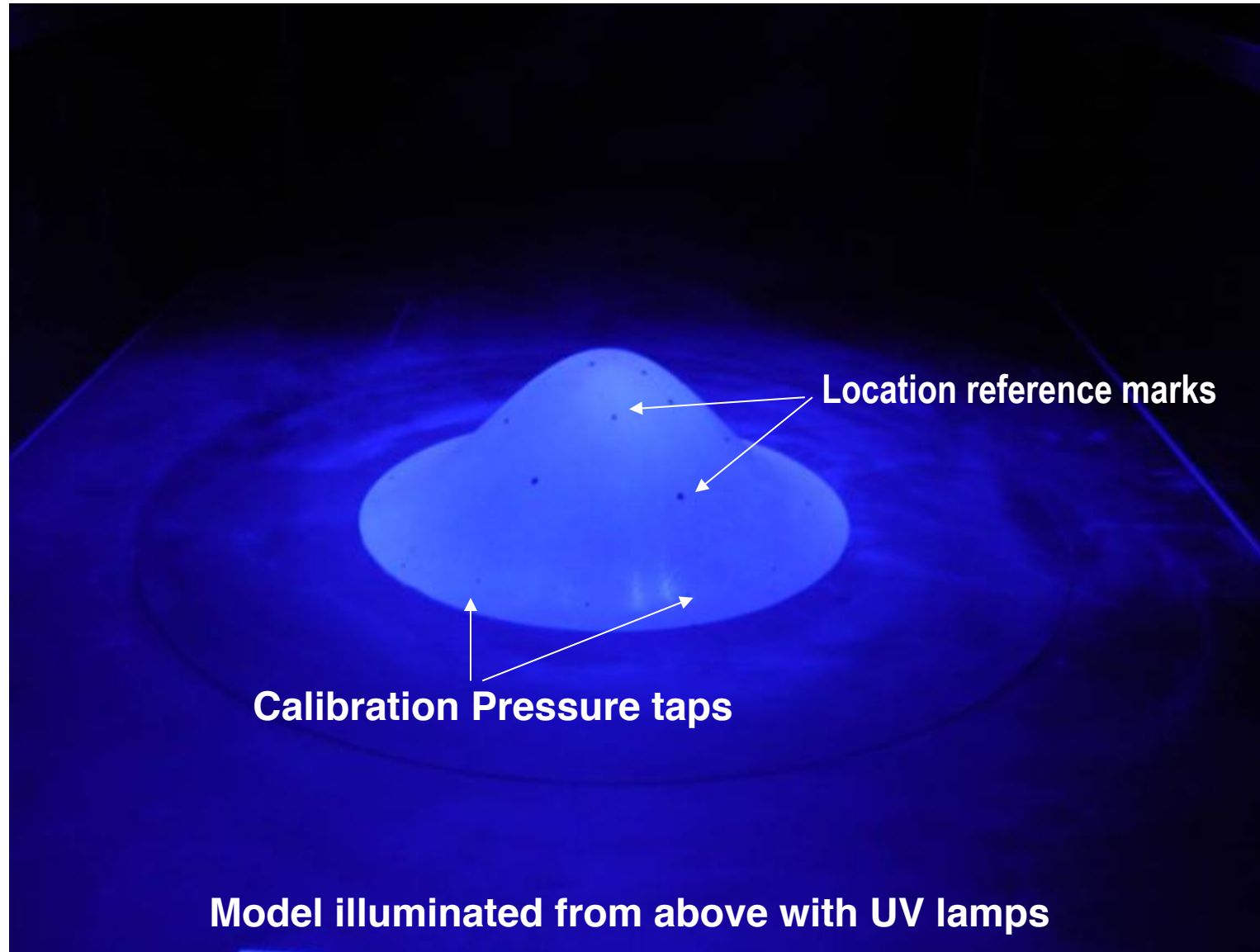


Pressure Sensitive Paint (PSP) Technique

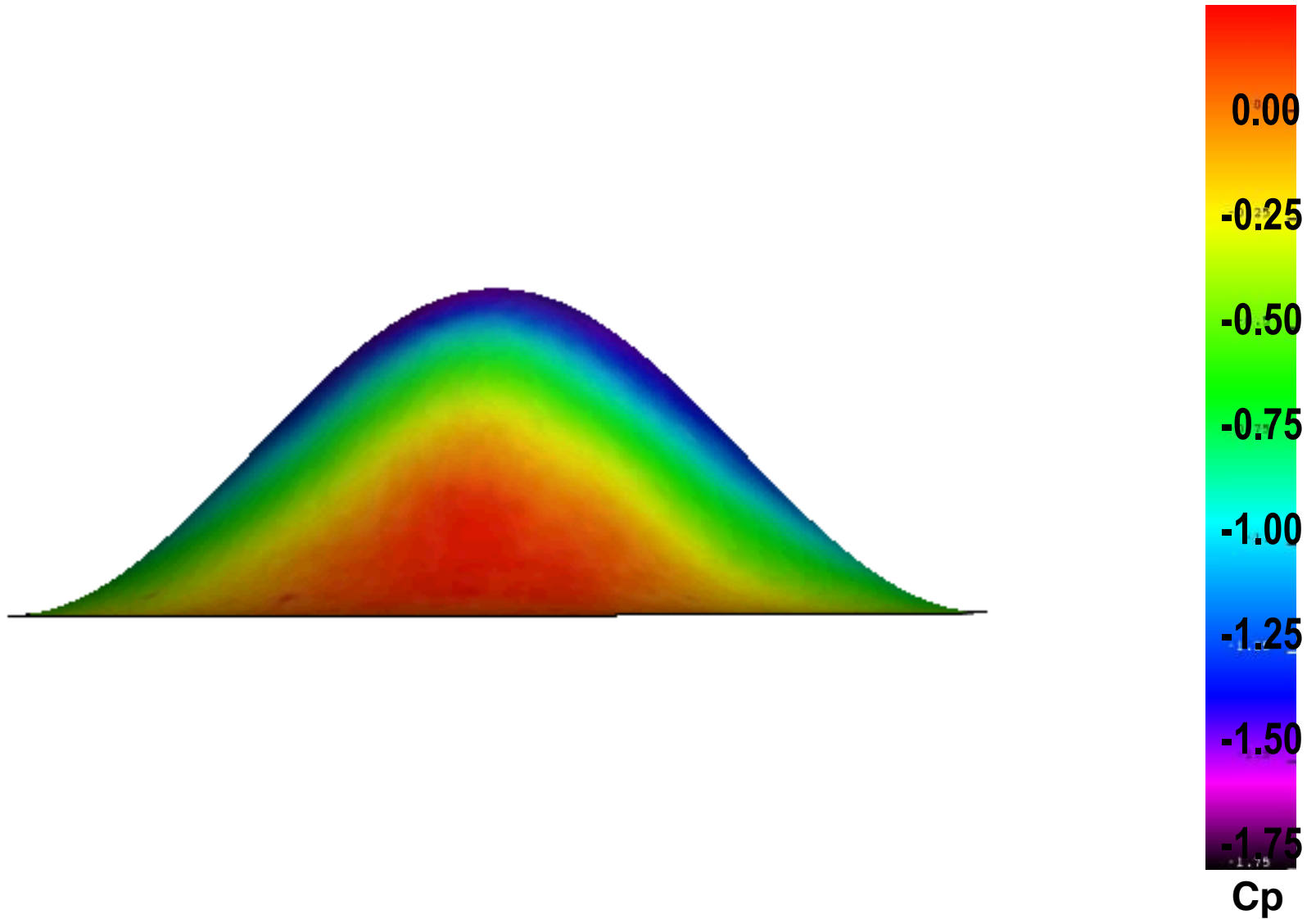
- Model Covered with Pressure Sensitive Paint
- PSP Excited with UV Light
- Excited PSP Molecules Return to Base State via Oxygen Quenching
- Higher Pressure (more oxygen) = More Quenching = Less Luminescence



FAITH PSP Set-Up



FAITH PSP Measurements

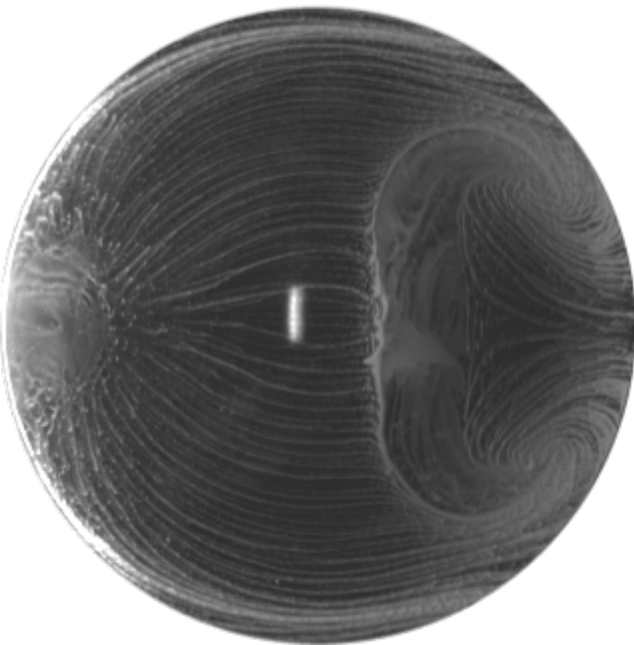


FAITH Oil Flow Visualization and PSP Data

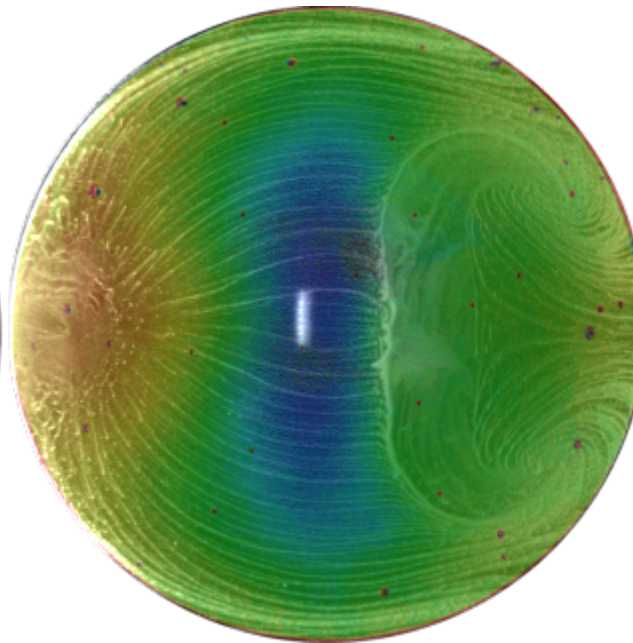


Flow topology critical points vs pressure extrema

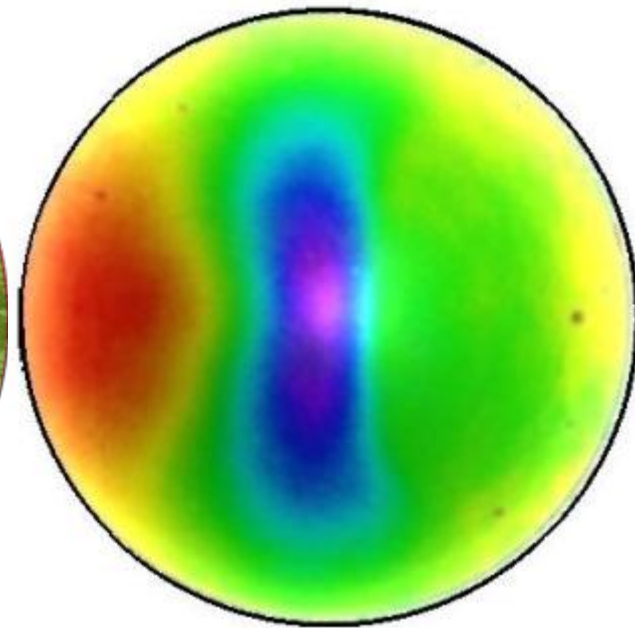
Flow



Oil Flow



Overlay of Oil Flow on top PSP



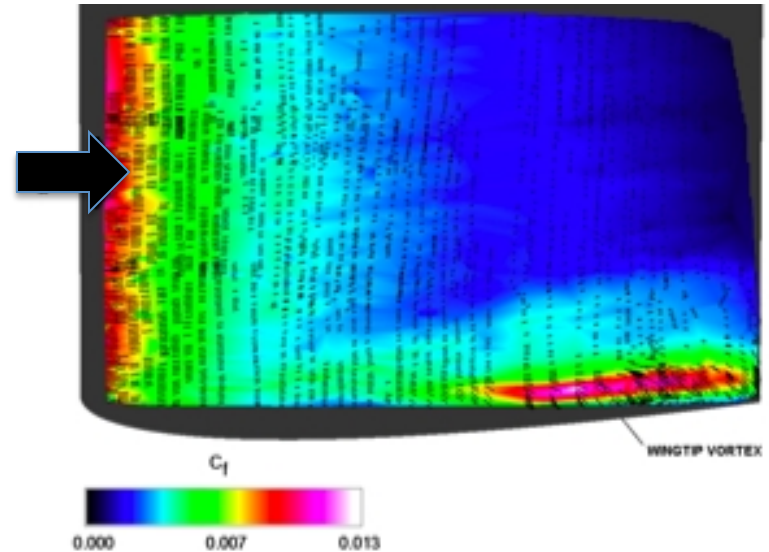
PSP

Fringe Imaging Skin Friction (FISF)

- **FISF**
 - Nickel Plating to allow for maximum reflectivity
 - Apply Oil (Drops/Lines) of Known Viscosity (multiple viscosities?)
 - Run Wind Tunnel to Create Fringes (reflection off oil and model surfaces)
 - Measure Fringe Direction and Spacing to get C_f Vector

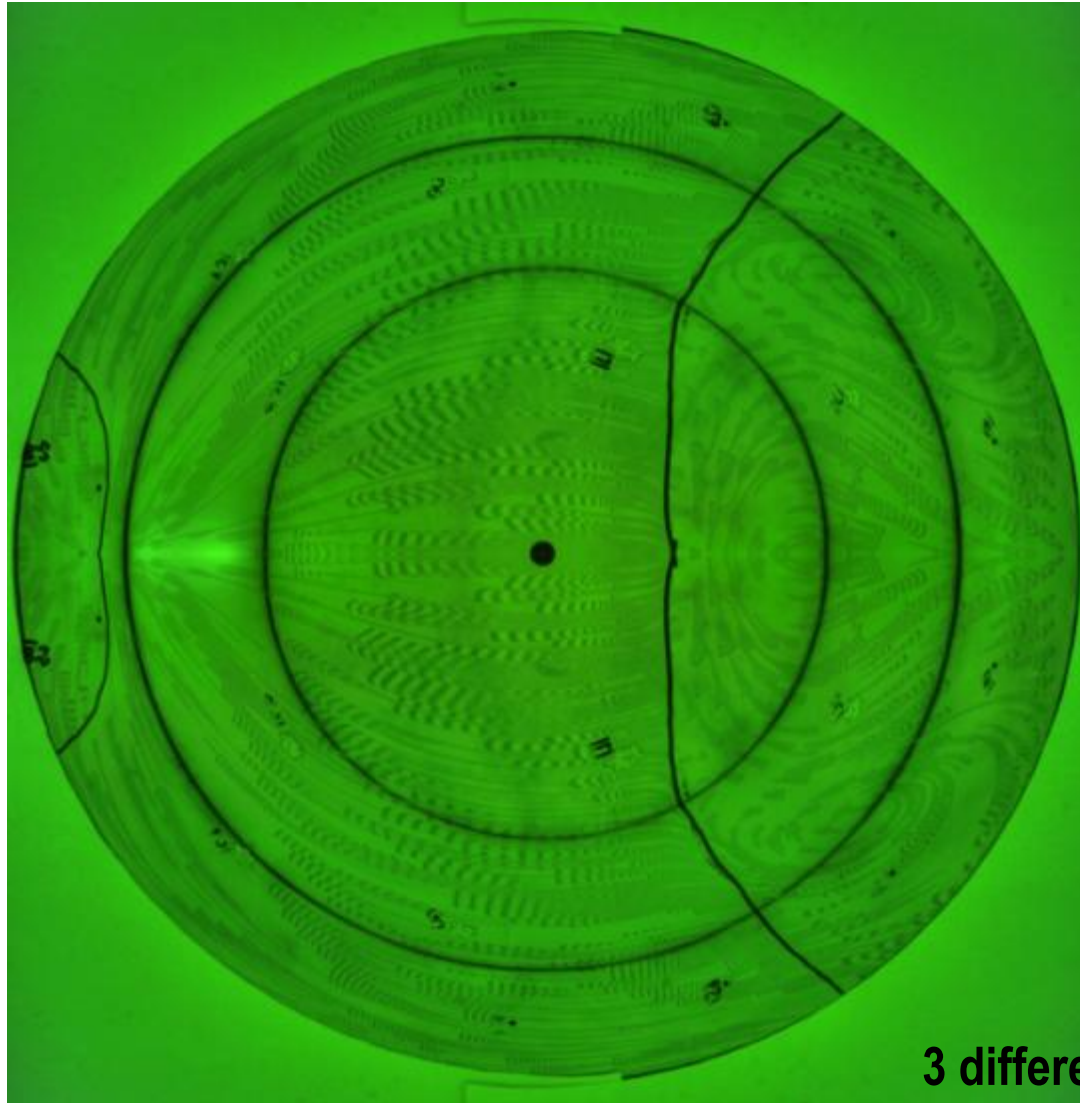


Oil Film Fringes



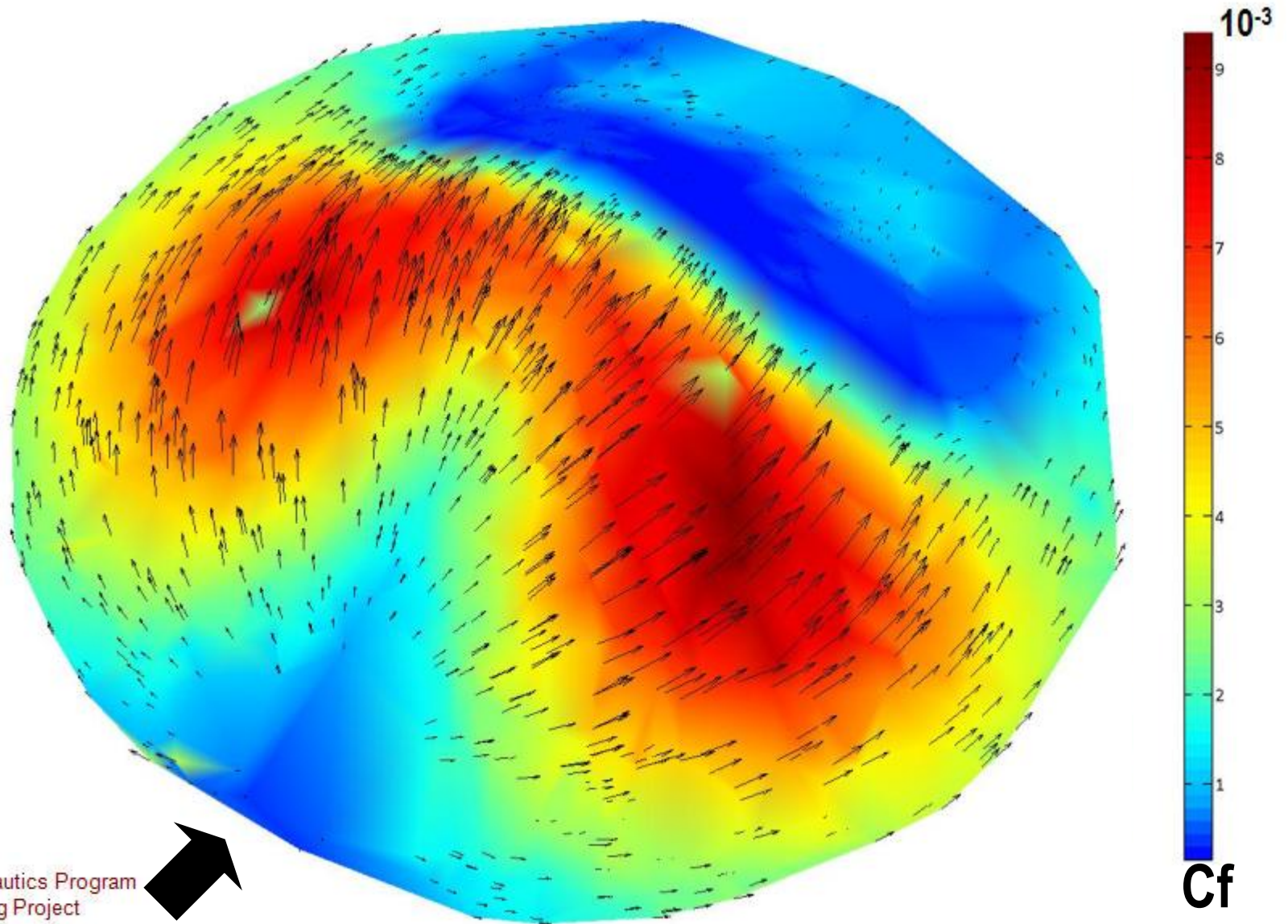
False-colored image of a wing tip model showing the skin friction (C_f) distribution

FAITH: Oil Fringe Pattern

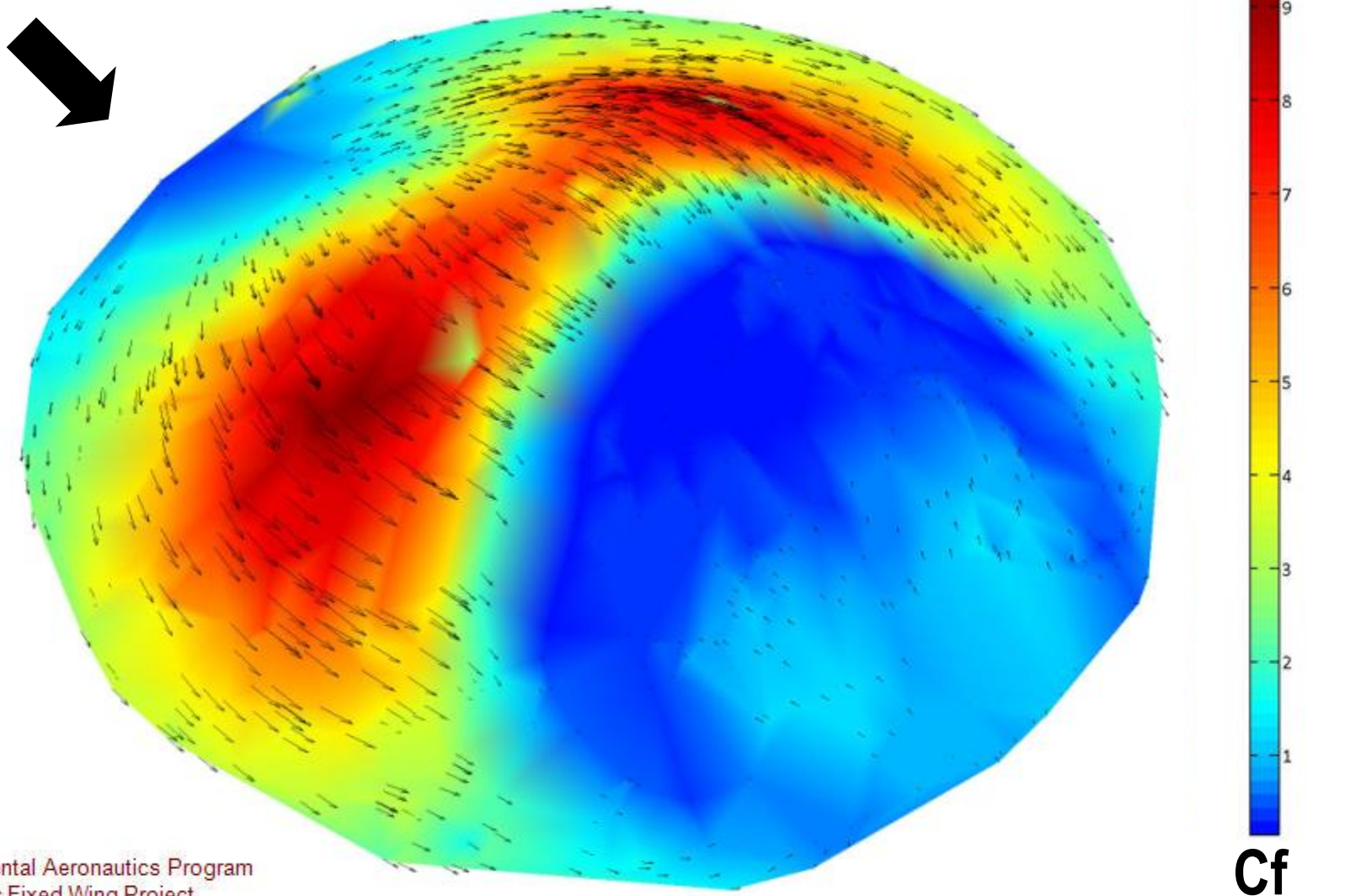


3 different oil viscosities

FAITH: Skin Friction Distribution

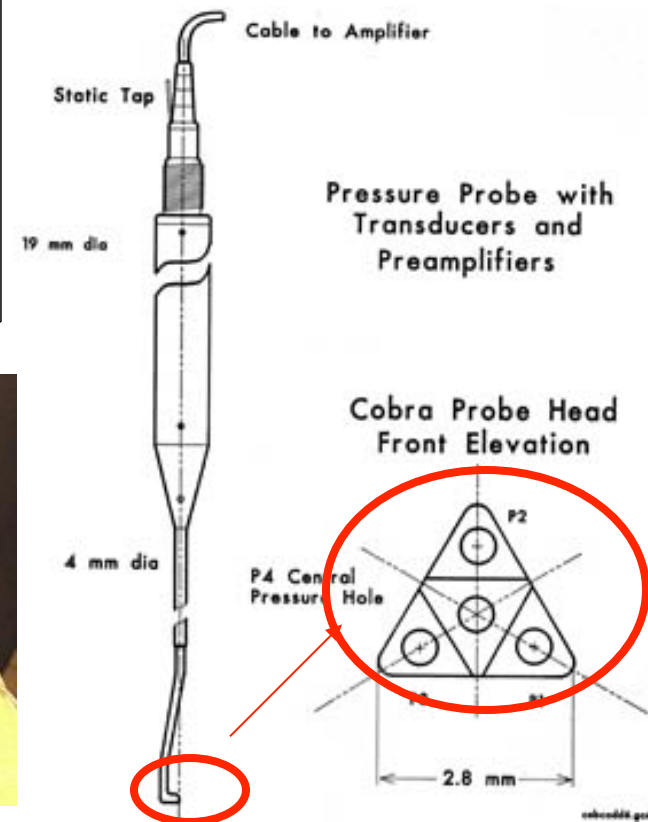
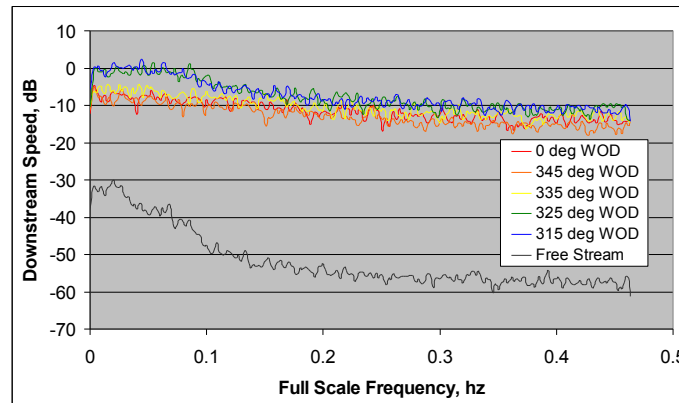
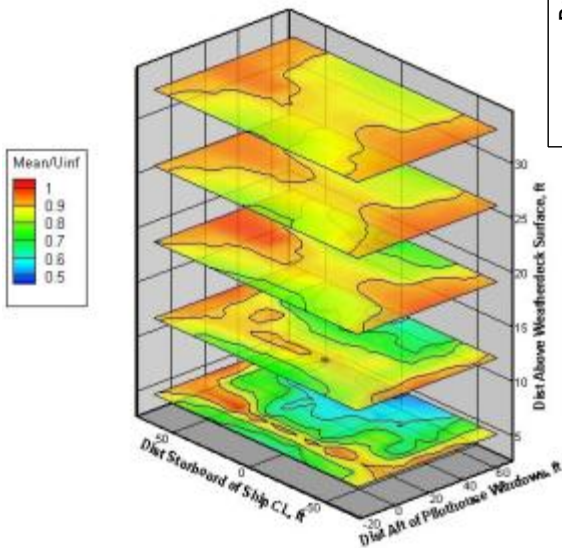


FAITH: Skin Friction Distribution

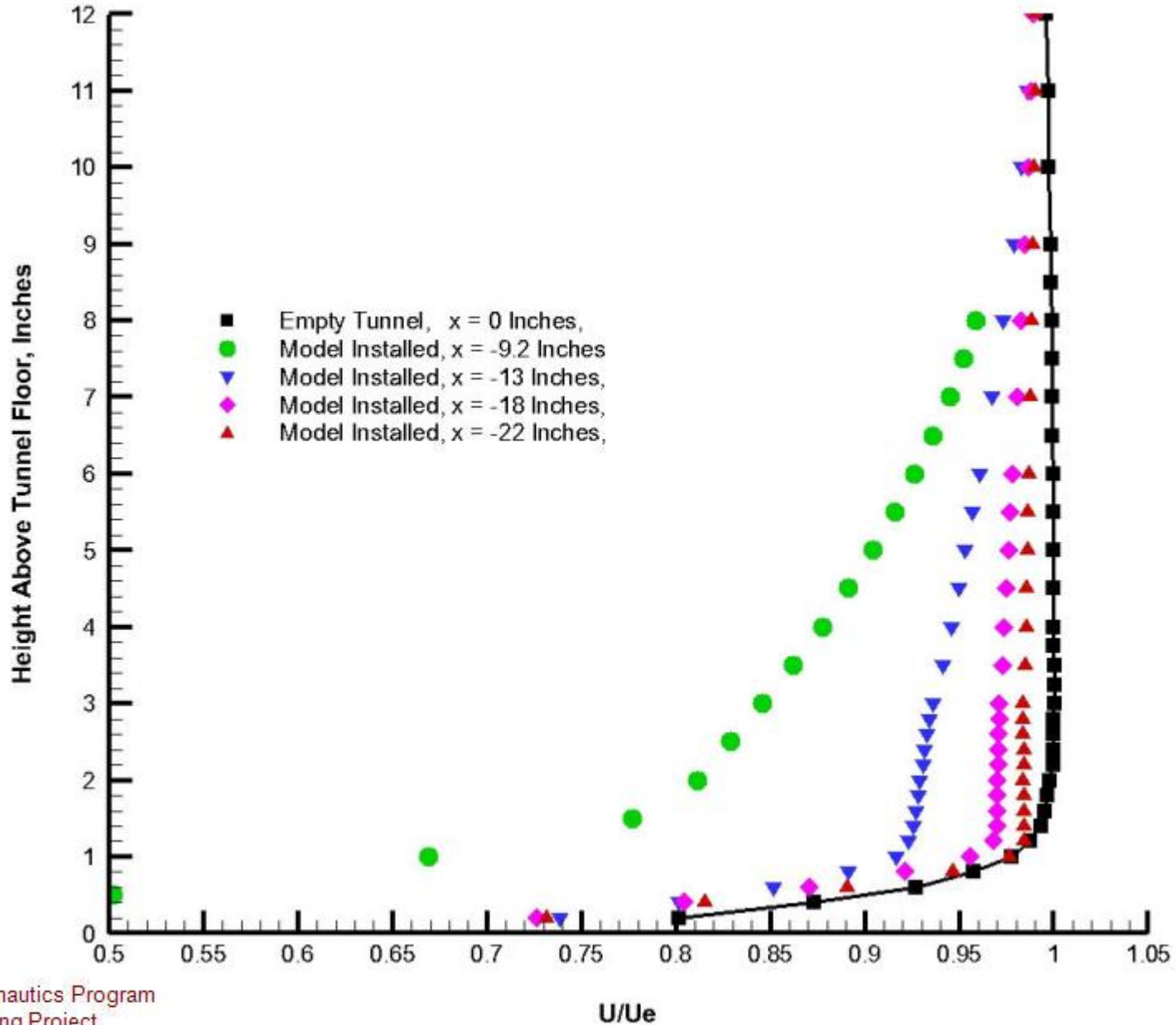


Multi-Hole “Cobra” Probe

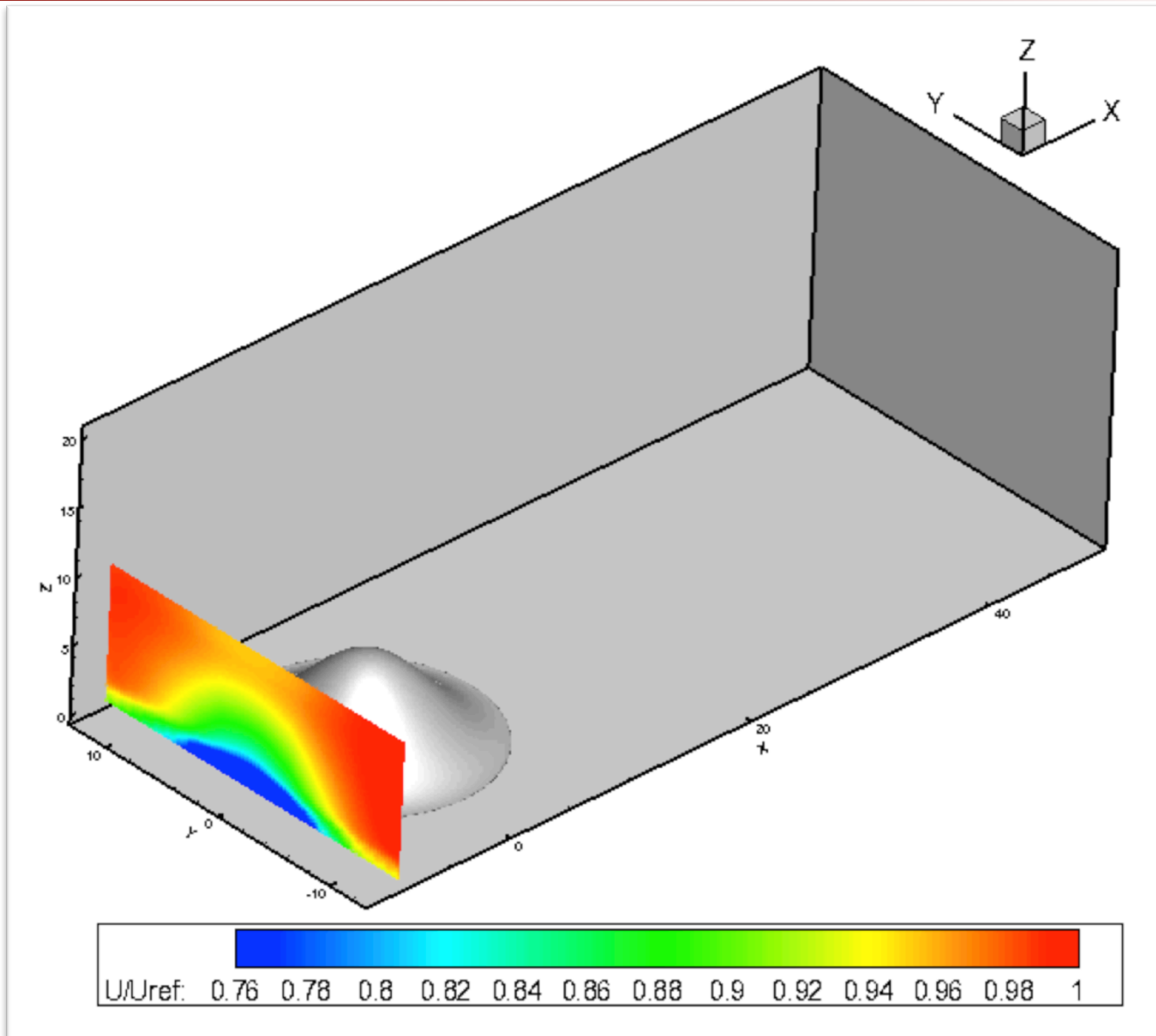
- 4-Hole Unsteady Pressure Probe
- 3-D Unsteady (<1 KHz) Velocity
- Attached to 3-D Traversing Mechanism
- $>2,000$ points



Inlet Mean Streamwise Velocity Profiles



Mean Velocity Measurements at 6 Streamwise Locations



3-D Particle Image Velocimetry (PIV)

- Non-intrusive flow field measurement using lasers, cameras and flow seeding
- Three components of velocity in a plane
- Mean velocities and turbulence measurements

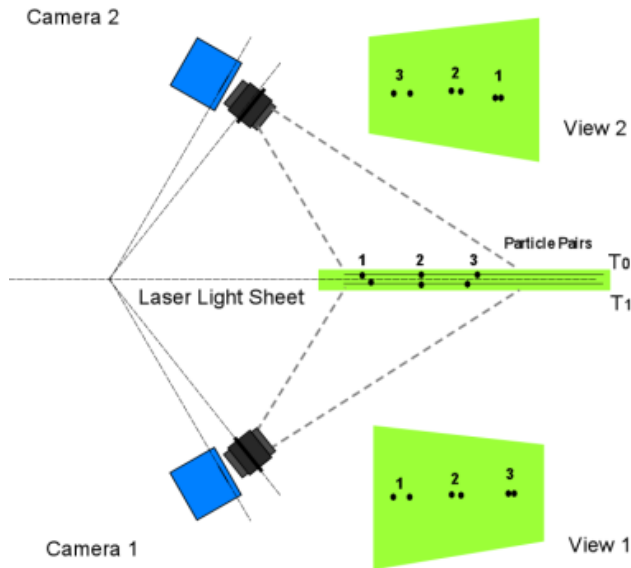
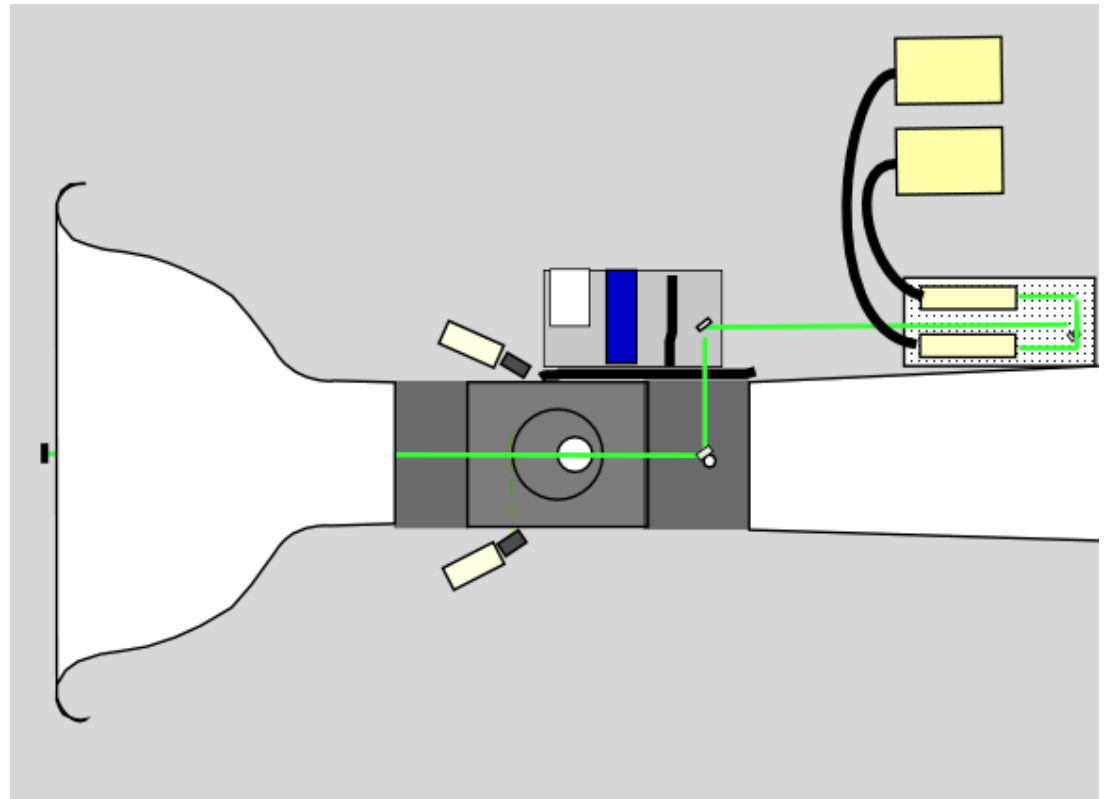


Diagram of StereoPIV Concept

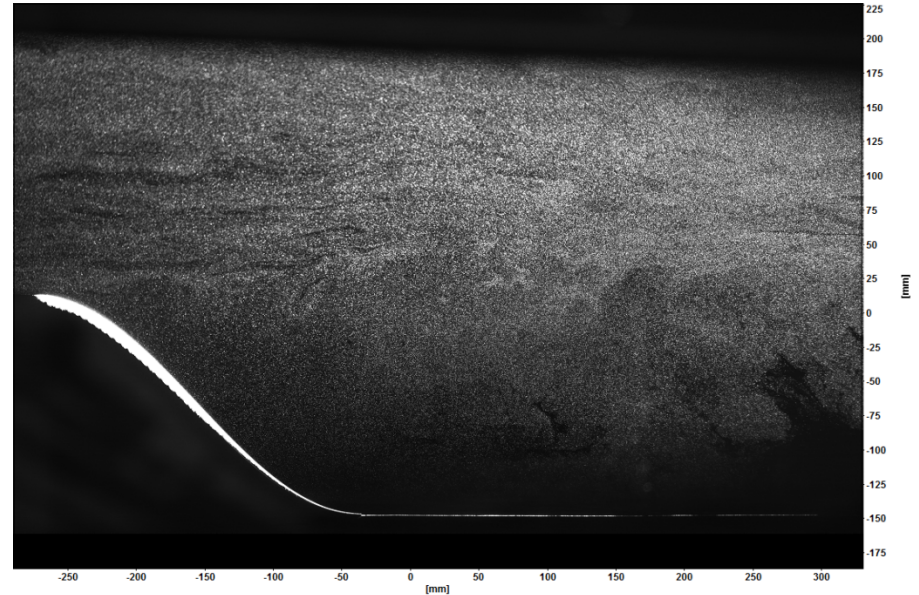


Plan view of HS PIV system for FAITH in 4-foot x 3-foot Tunnel

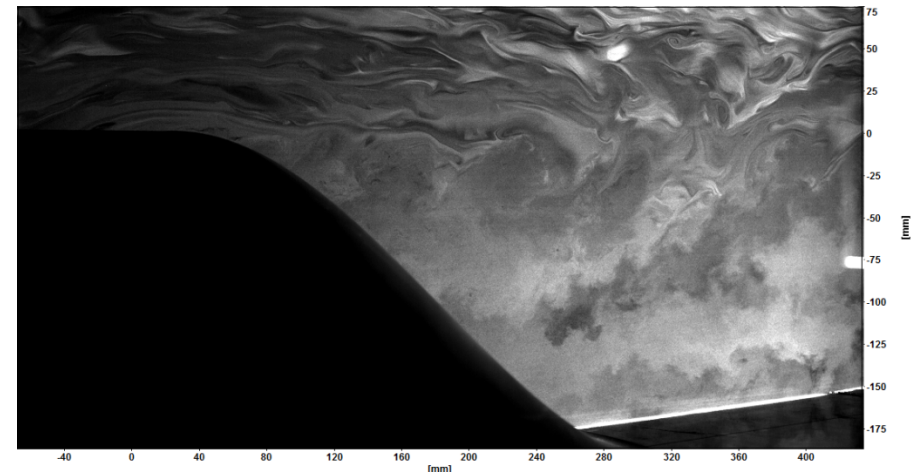
3-D Particle Image Velocimetry (PIV)

Two measurements were made:

- 1.5 Hz ,
44,000 vectors/sample
ROI of 585 mm x 223 mm (23 in x 9 in)
4000 Samples
Originally reported in 2012



- 1000 Hz,
37,000 vectors/sample in
ROI of 480 mm x 200 mm (19 in x 8 in)
4790 Samples
Data not yet released

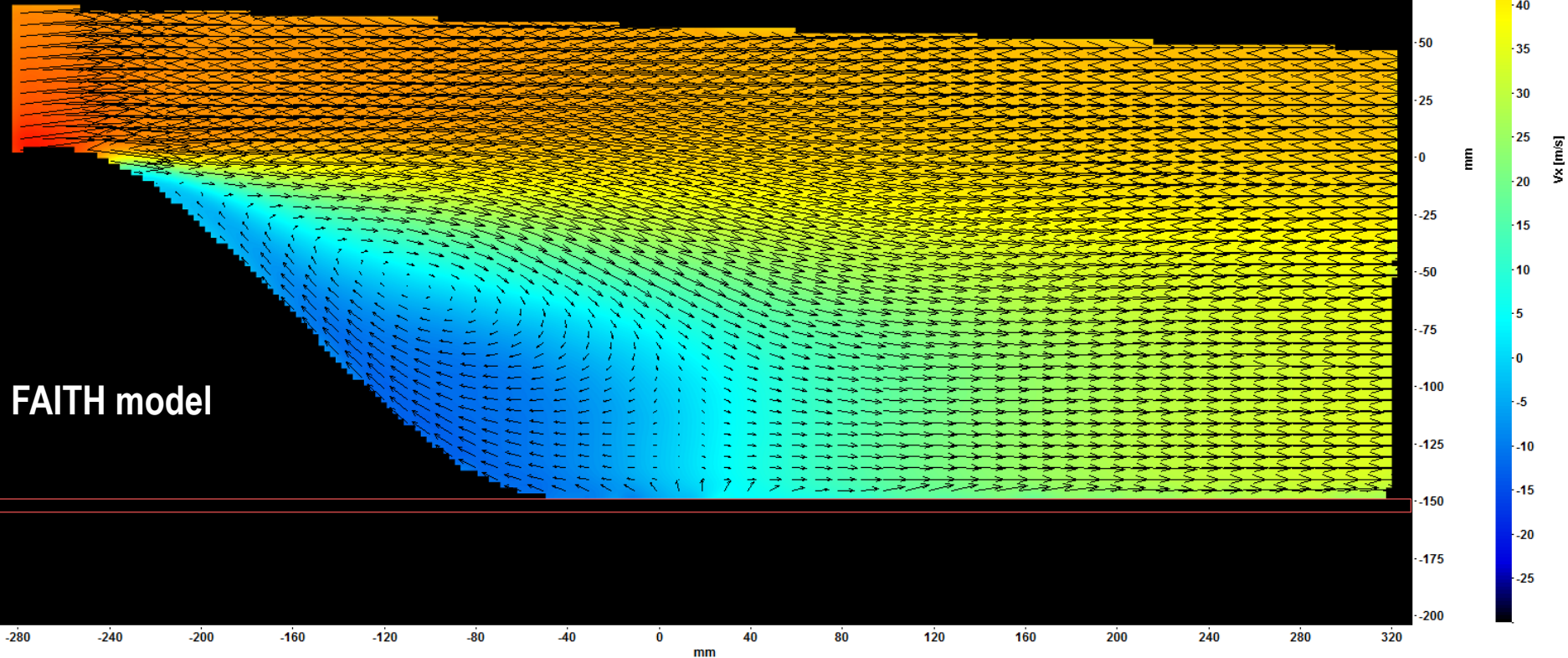


3-D Particle Image Velocimetry (PIV)

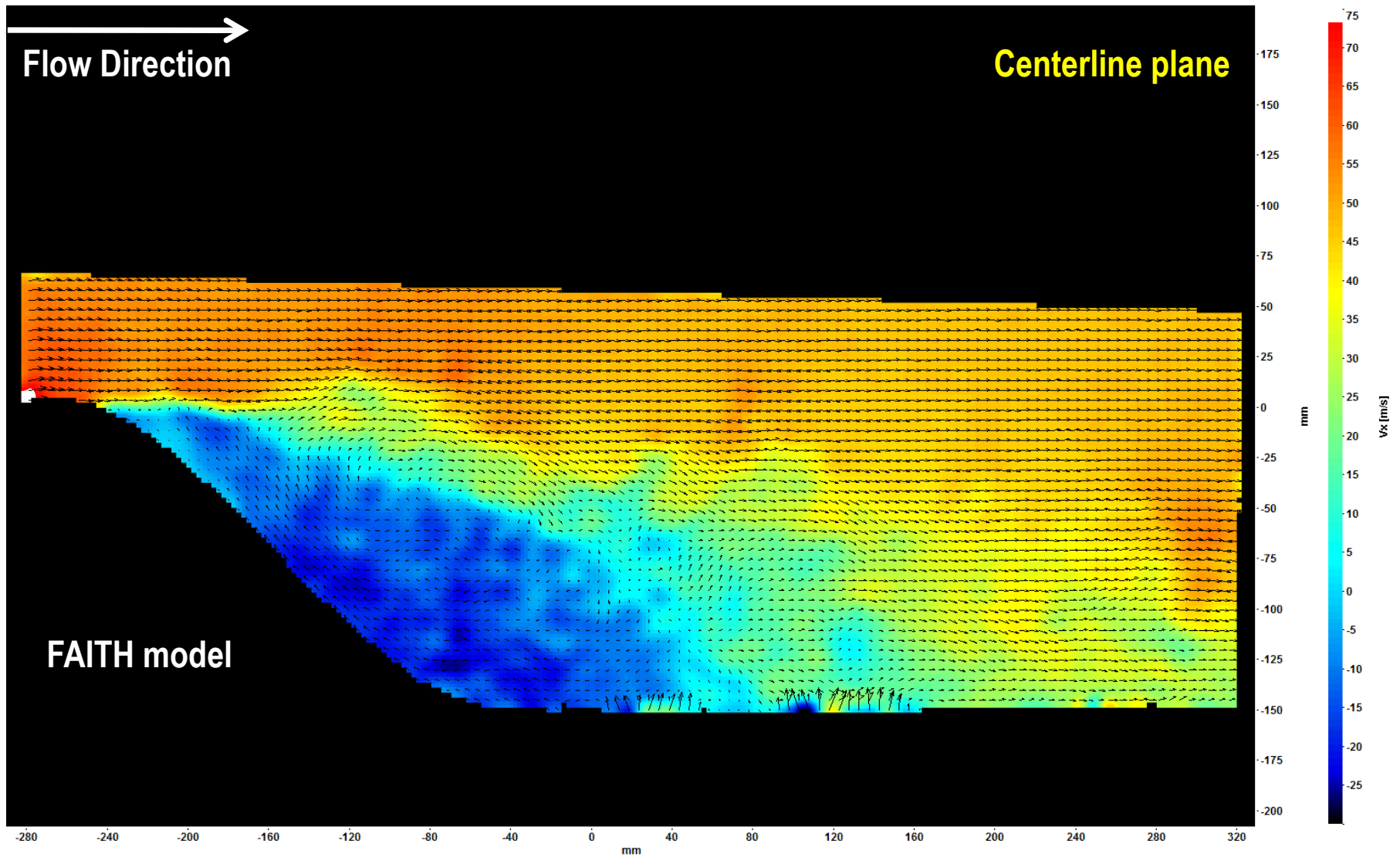
→
Flow Direction

Centerline plane

Mean Velocity
Streamwise Velocity (U) Contours
Vertical (V) and Streamwise (U) Velocity Vectors



3-D Particle Image Velocimetry (PIV)

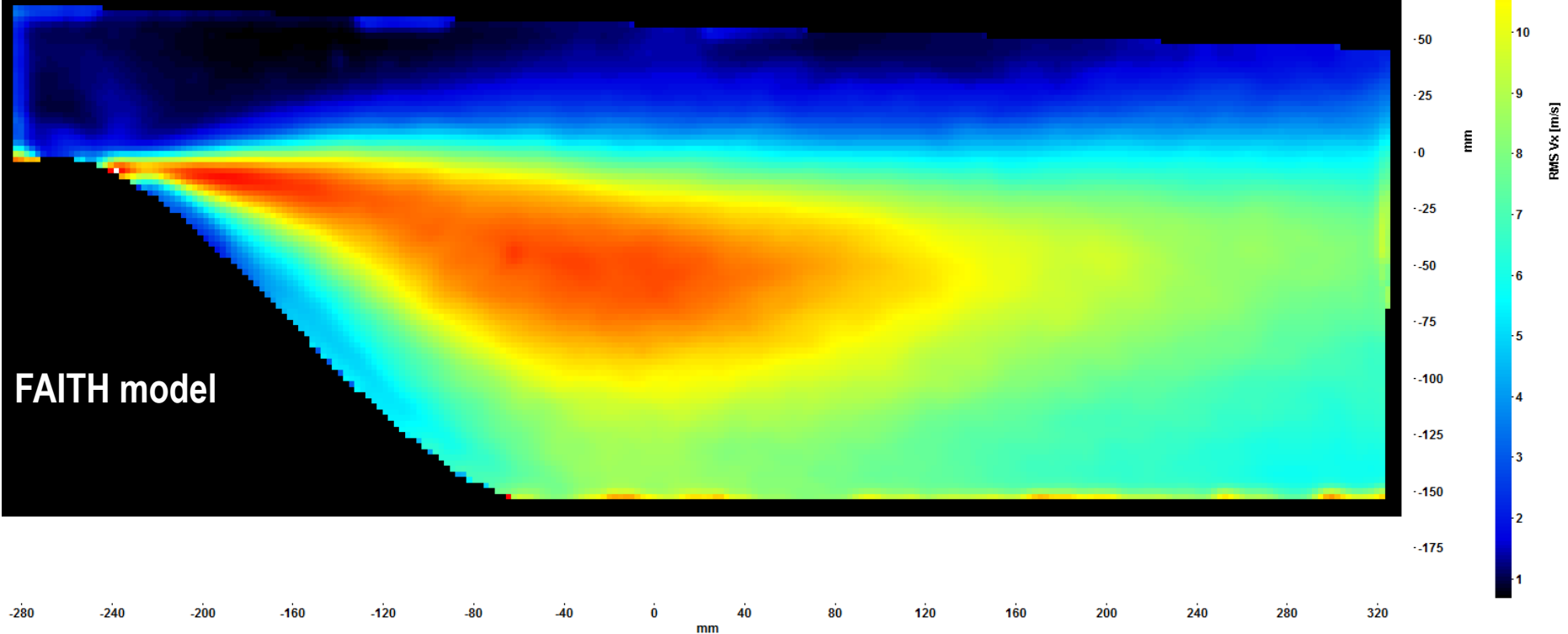


3-D Particle Image Velocimetry (PIV)

Flow Direction →

Centerline plane

Fluctuating Velocity: Streamwise Component (u')



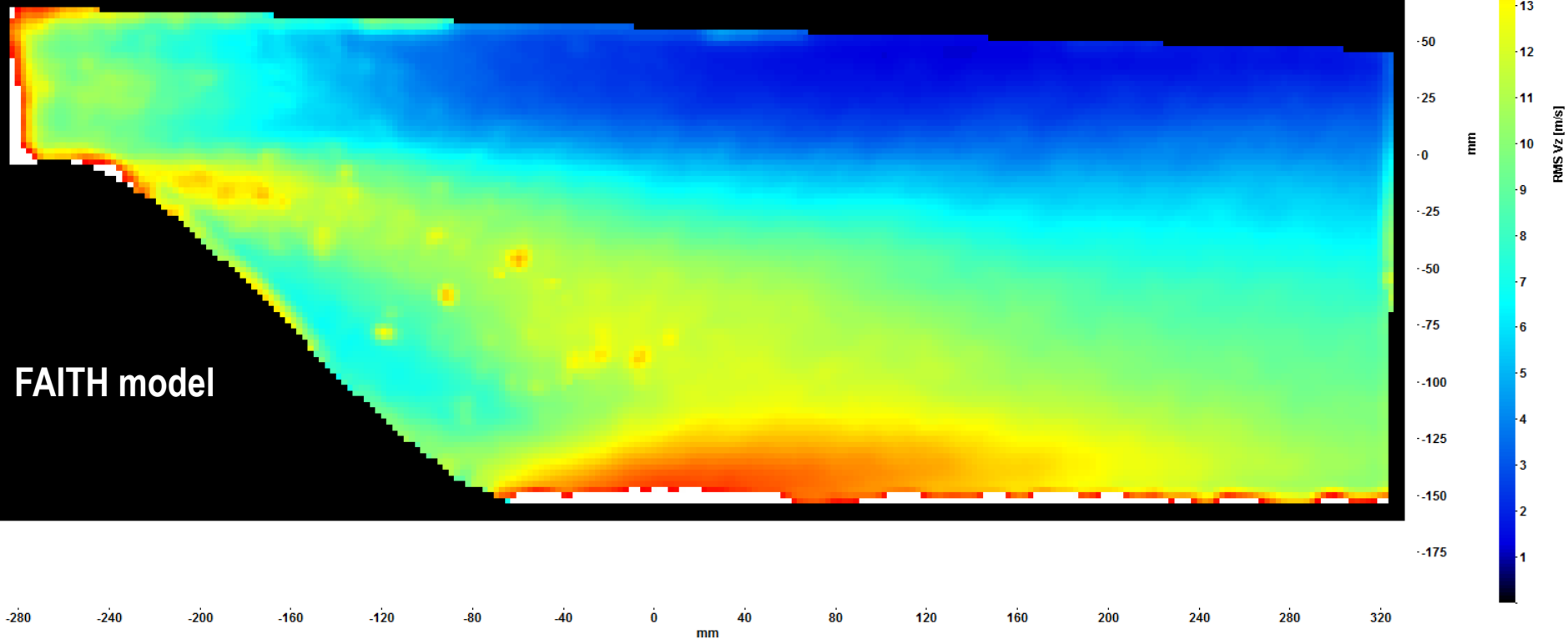


3-D Particle Image Velocimetry (PIV)

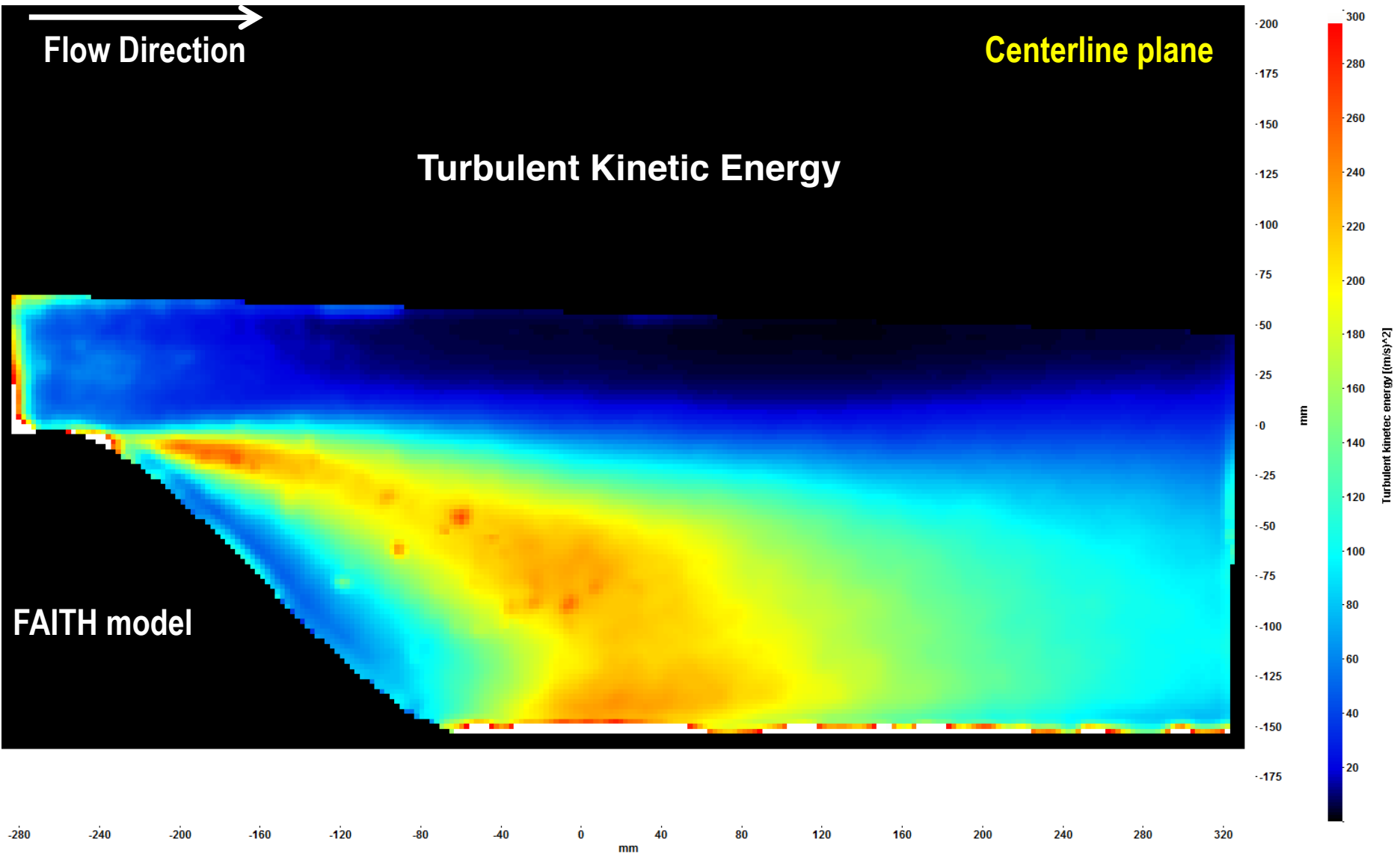
→
Flow Direction

Centerline plane

Fluctuating Velocity: Spanwise Component (w')



3-D Particle Image Velocimetry (PIV)

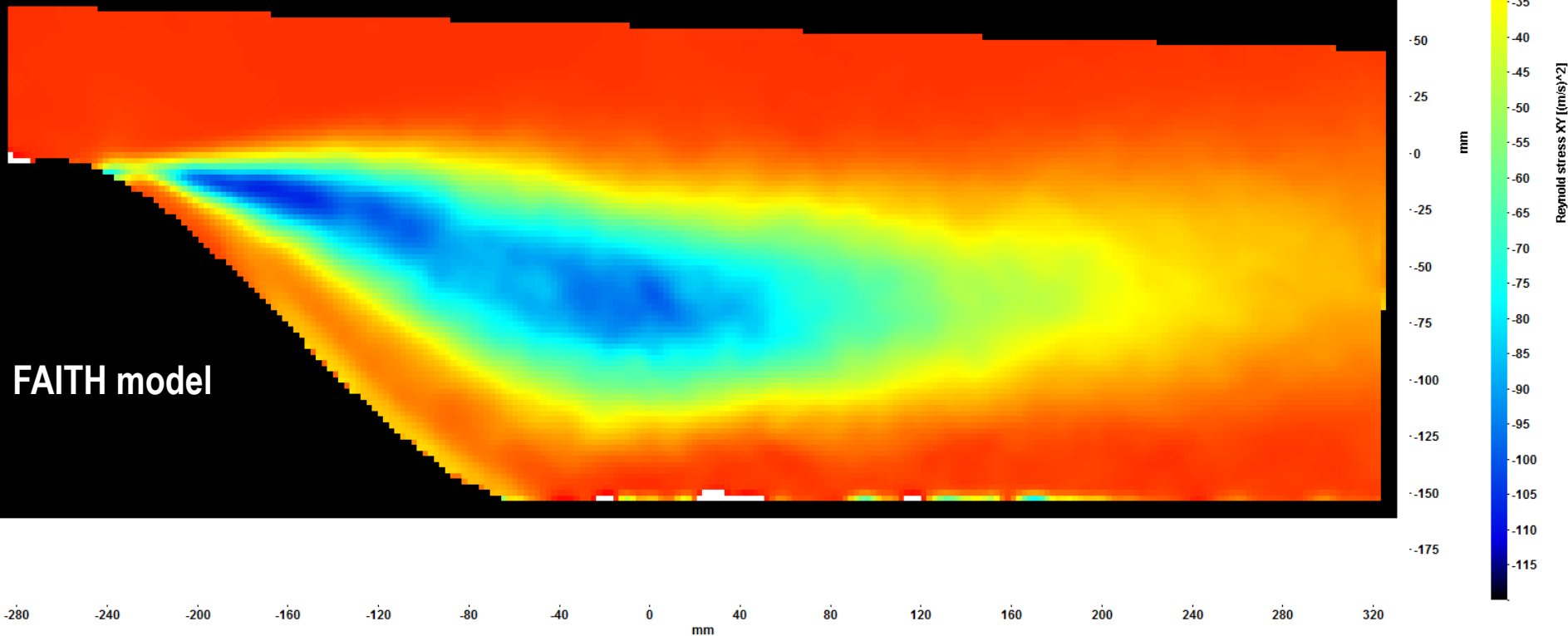


3-D Particle Image Velocimetry (PIV)

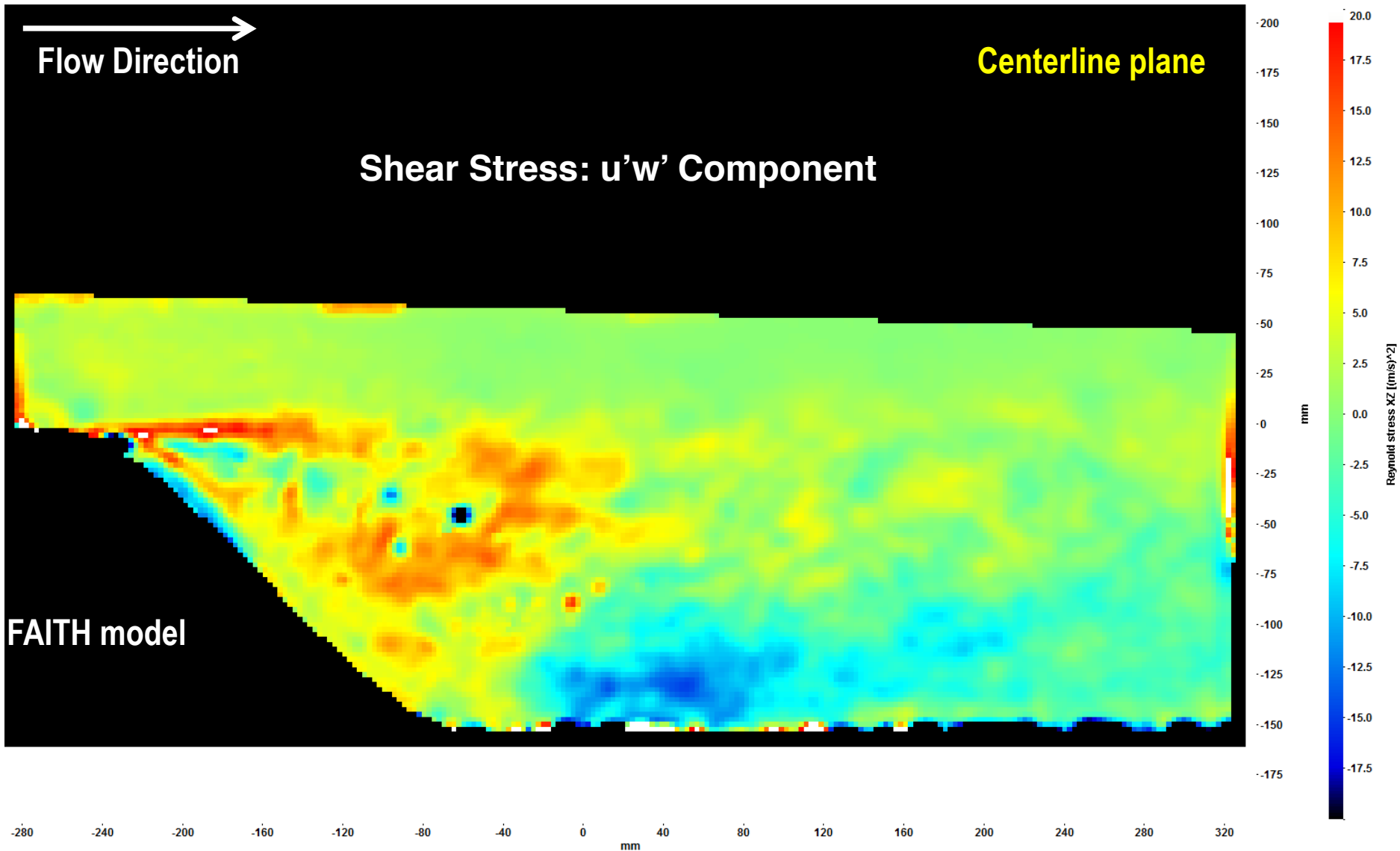
Flow Direction →

Centerline plane

Shear Stress: $u'v'$ Component



3-D Particle Image Velocimetry (PIV)



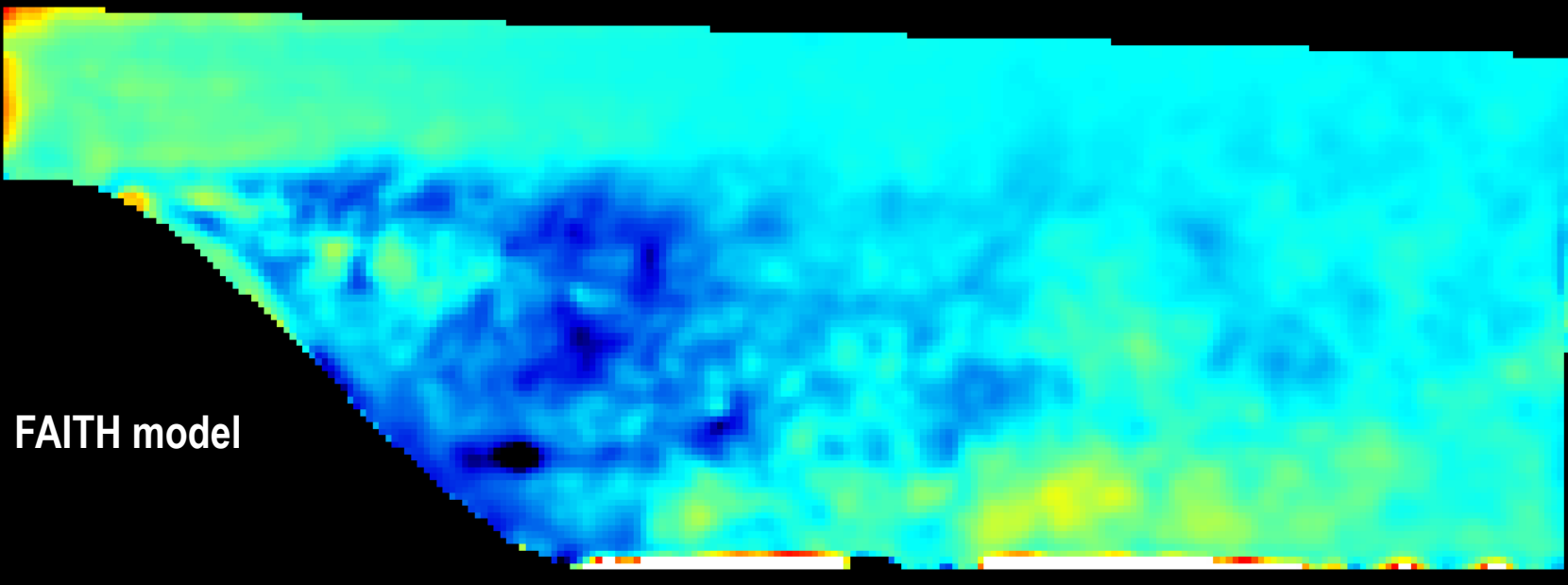


3-D Particle Image Velocimetry (PIV)

→
Flow Direction

Centerline plane

Shear Stress: $v'w'$ Component

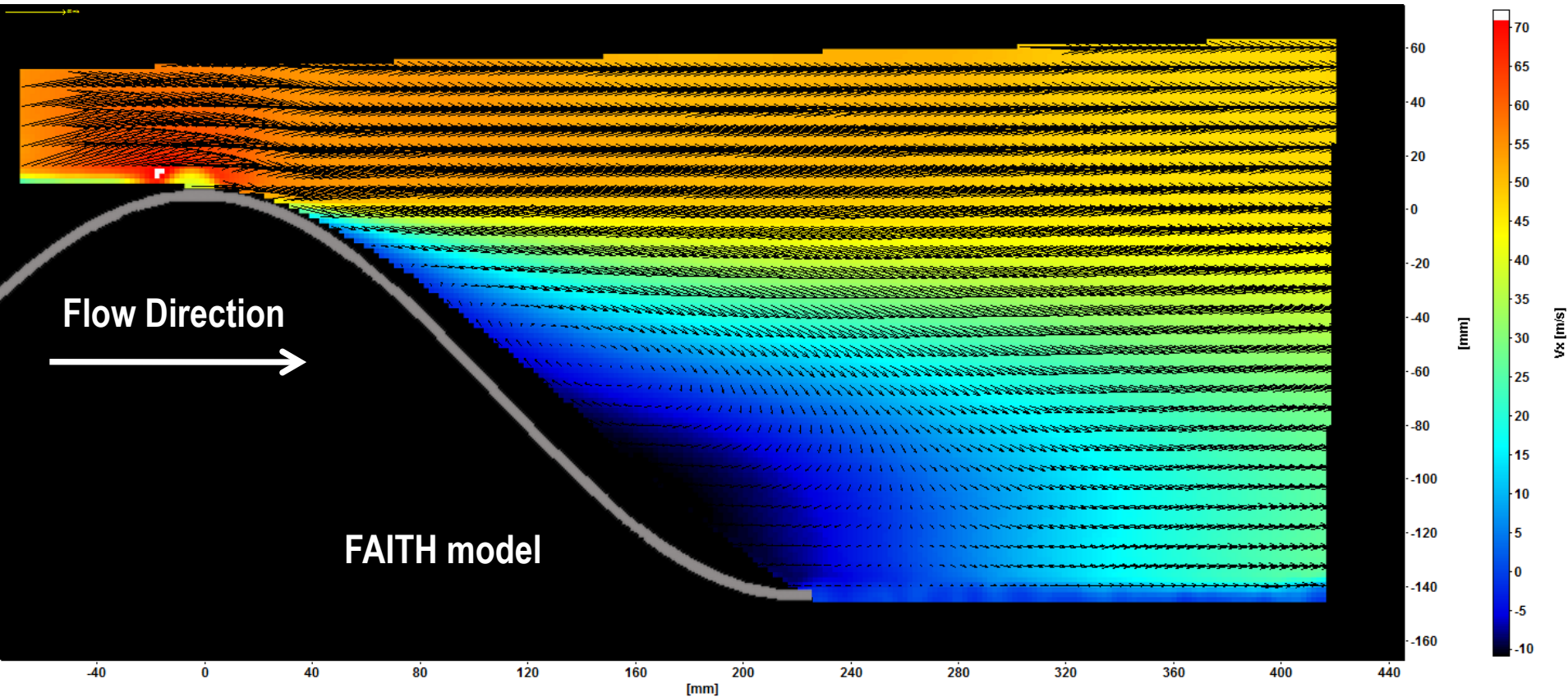


Reynold stress $v'z'$ [(m/s)²]

mm

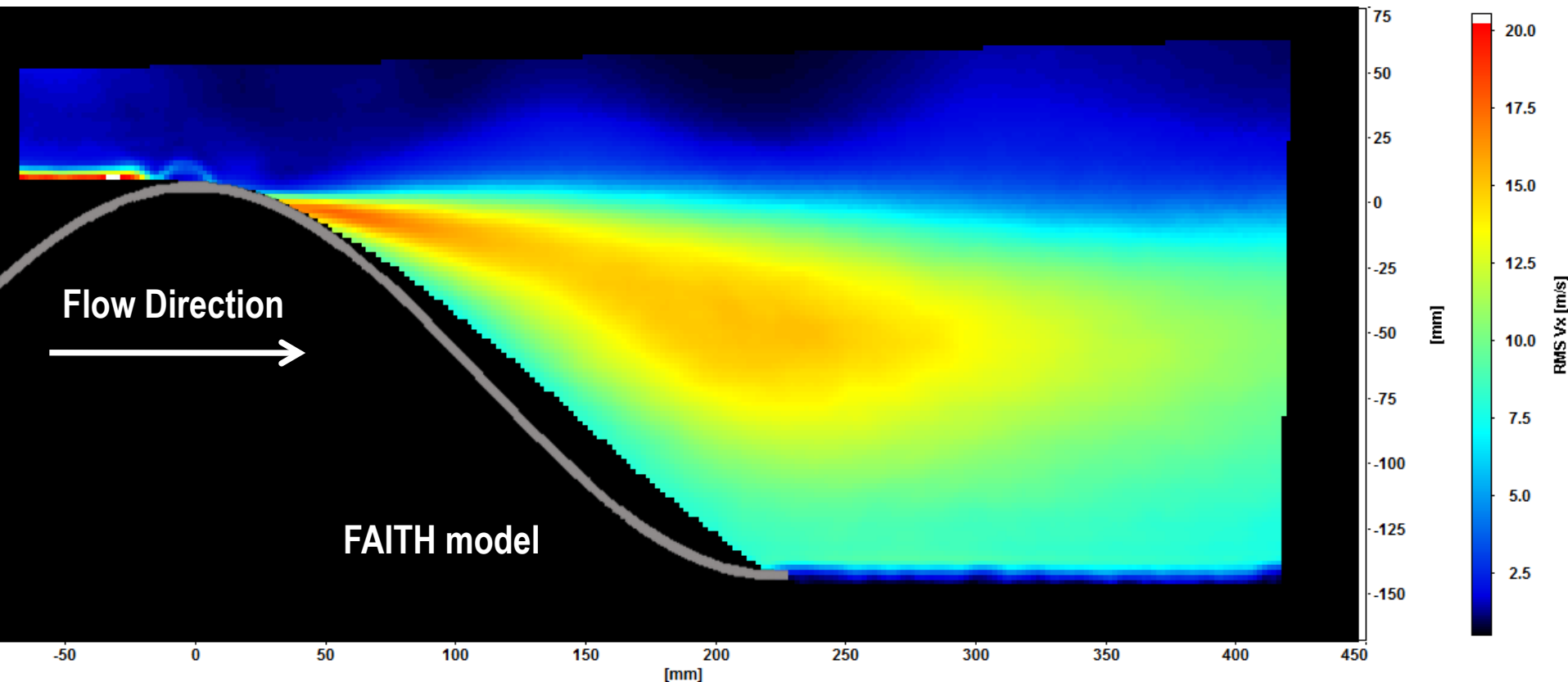
HS 3-D Particle Image Velocimetry (PIV) - 1kHz

Centerline plane – Average Vectors, contour of Uave



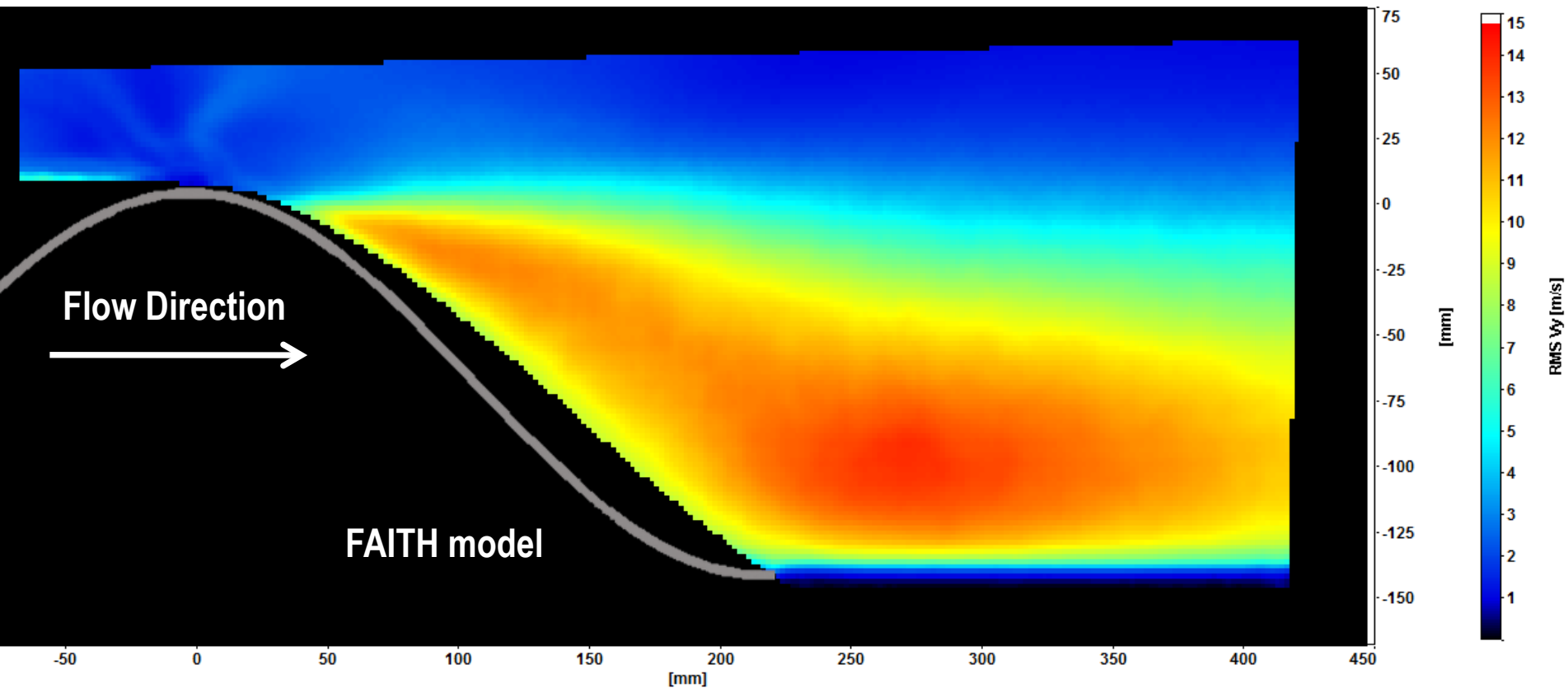
HS 3-D Particle Image Velocimetry (PIV) - 1kHz

Centerline plane – Contour of Urms



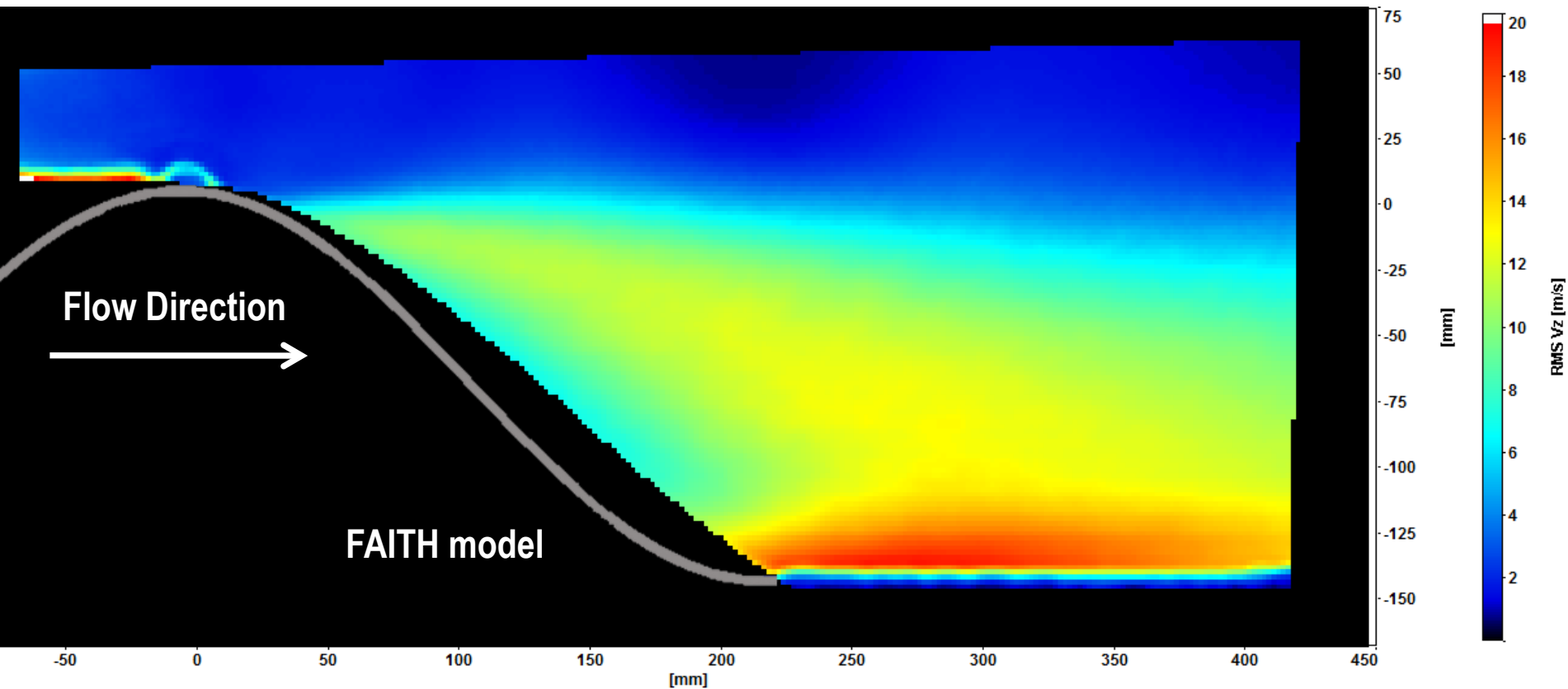
HS 3-D Particle Image Velocimetry (PIV) - 1kHz

Centerline plane – Contour of V_{rms}



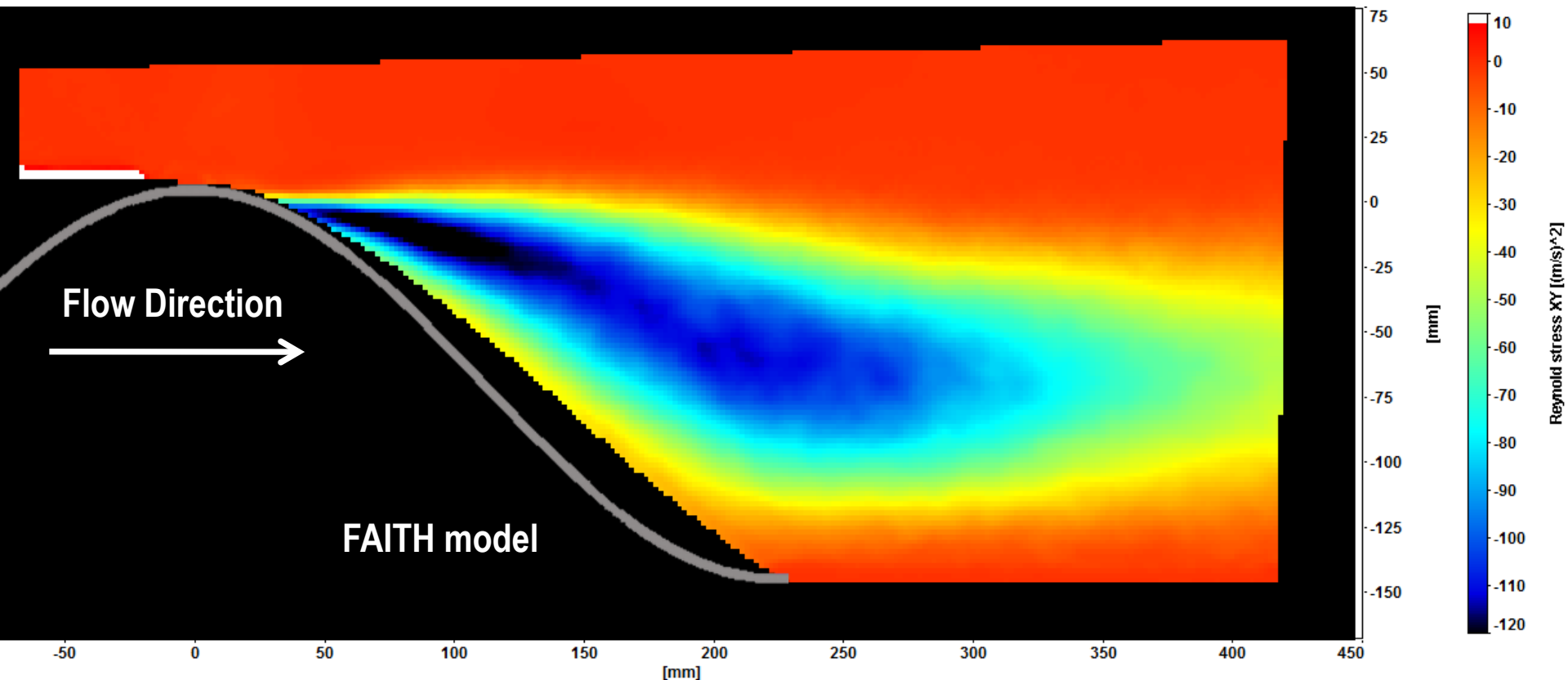
HS 3-D Particle Image Velocimetry (PIV) - 1kHz

Centerline plane – Contour of Wrms



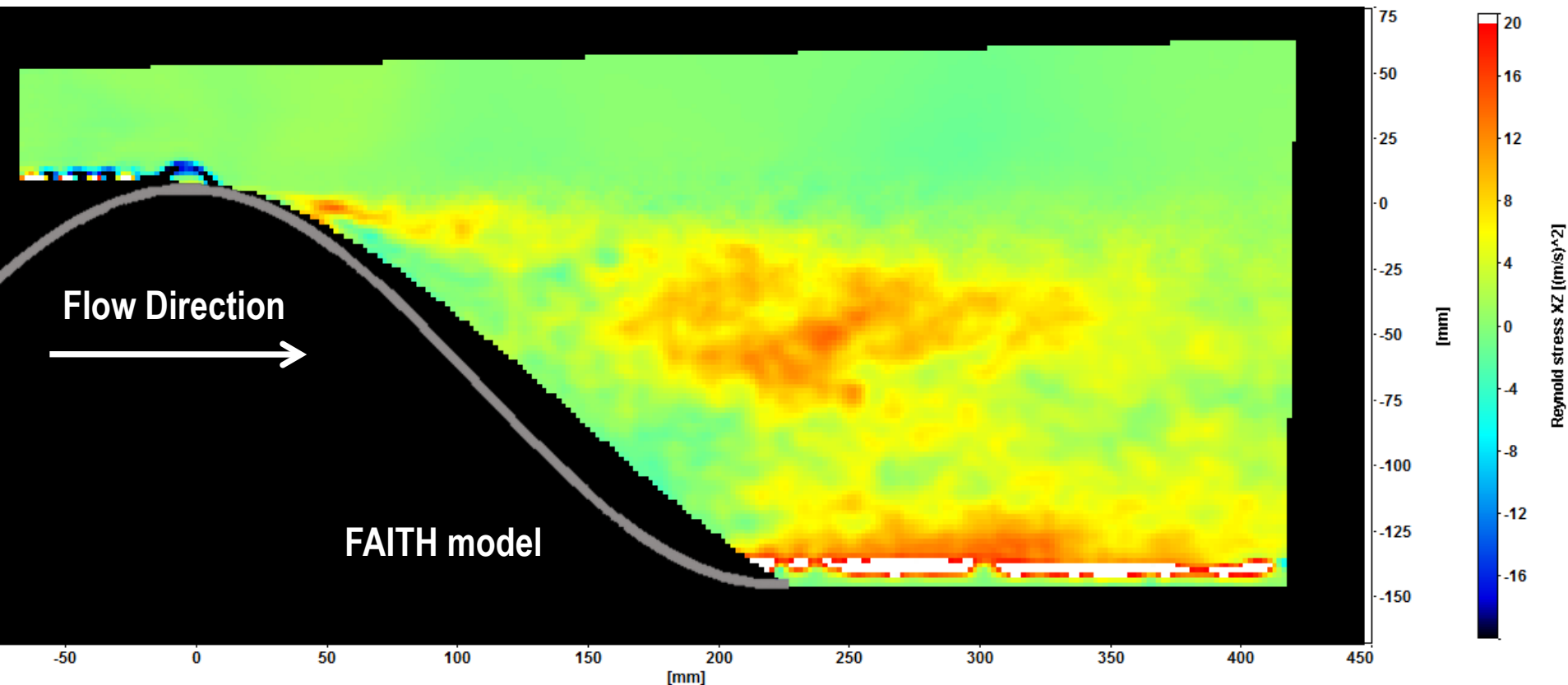
HS 3-D Particle Image Velocimetry (PIV) - 1kHz

Centerline plane – Contour of Re Stress, $U'V'$



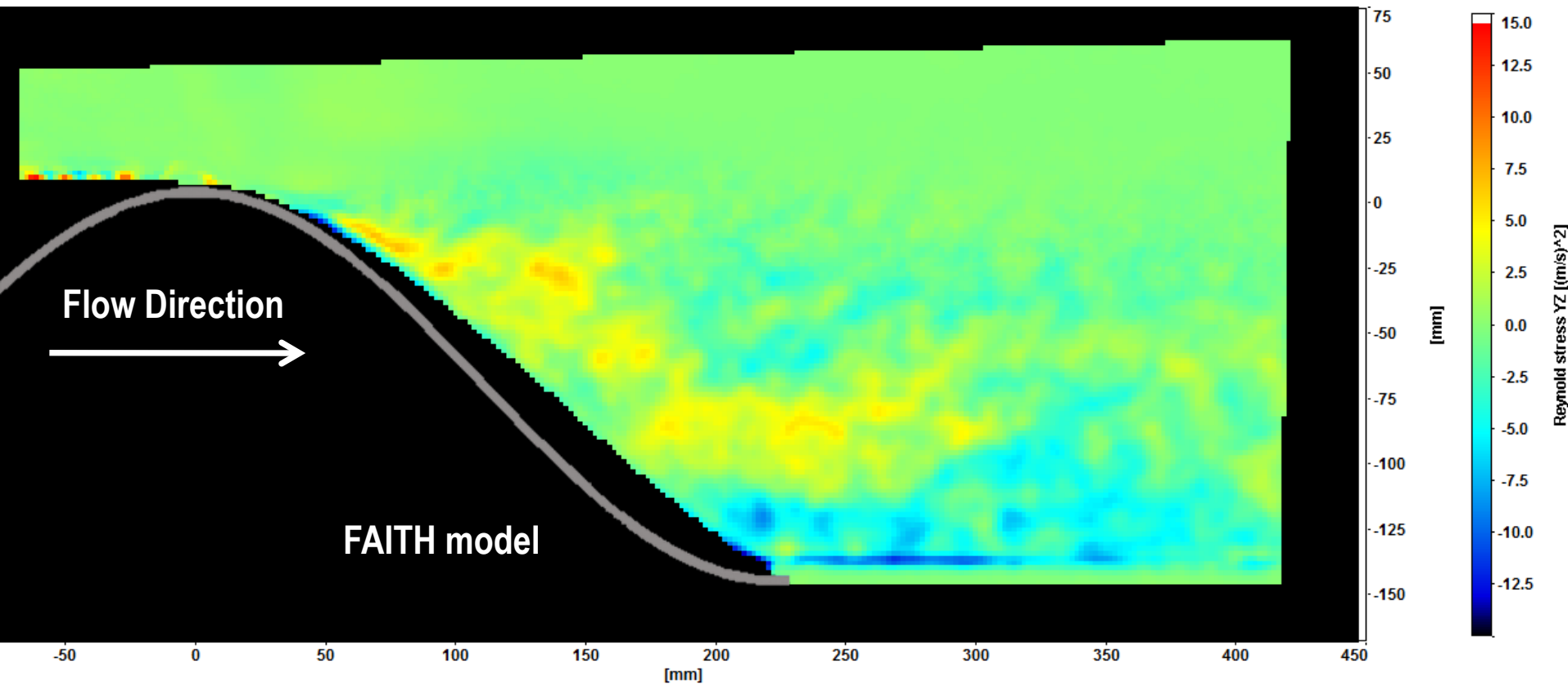
HS 3-D Particle Image Velocimetry (PIV) - 1kHz

Centerline plane – Contour of Re Stress, $U'W'$



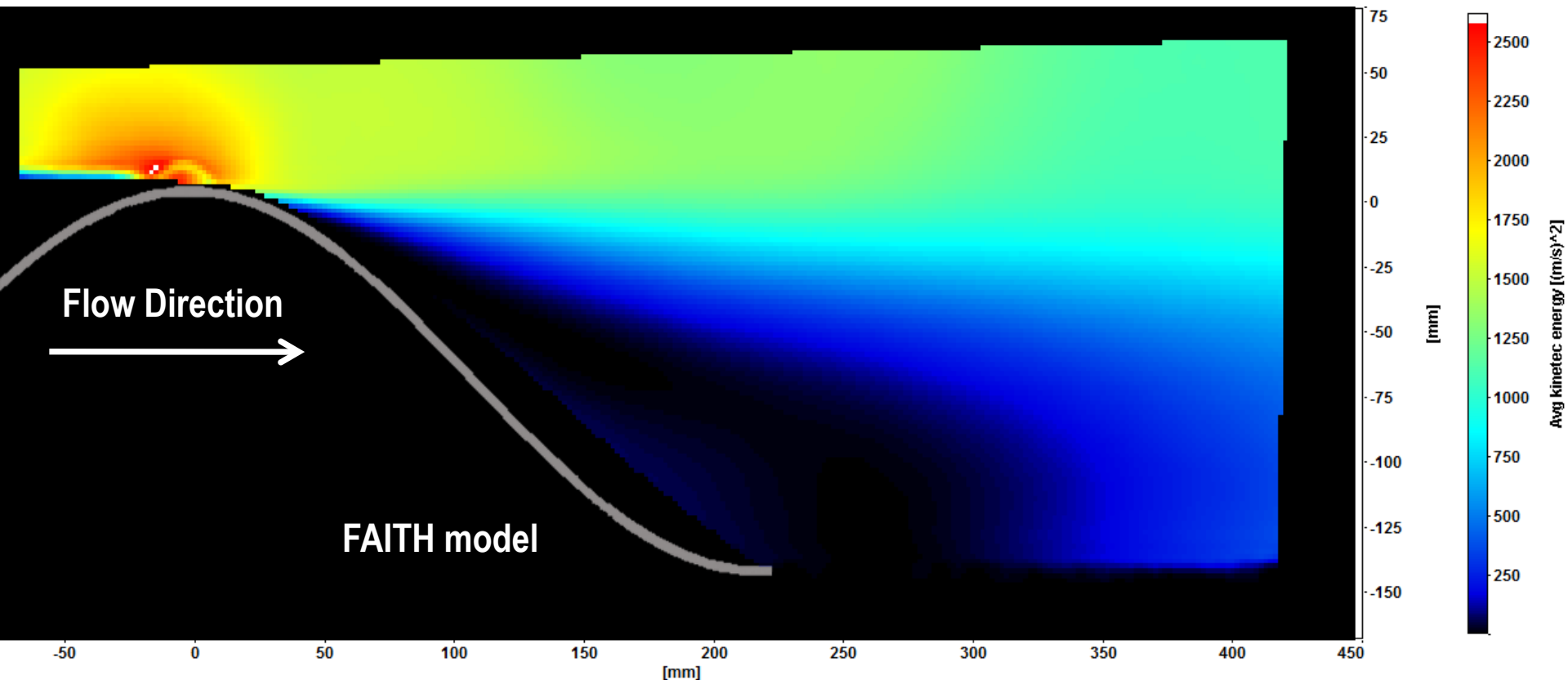
HS 3-D Particle Image Velocimetry (PIV) - 1kHz

Centerline plane – Contour of Re Stress, $V'W'$



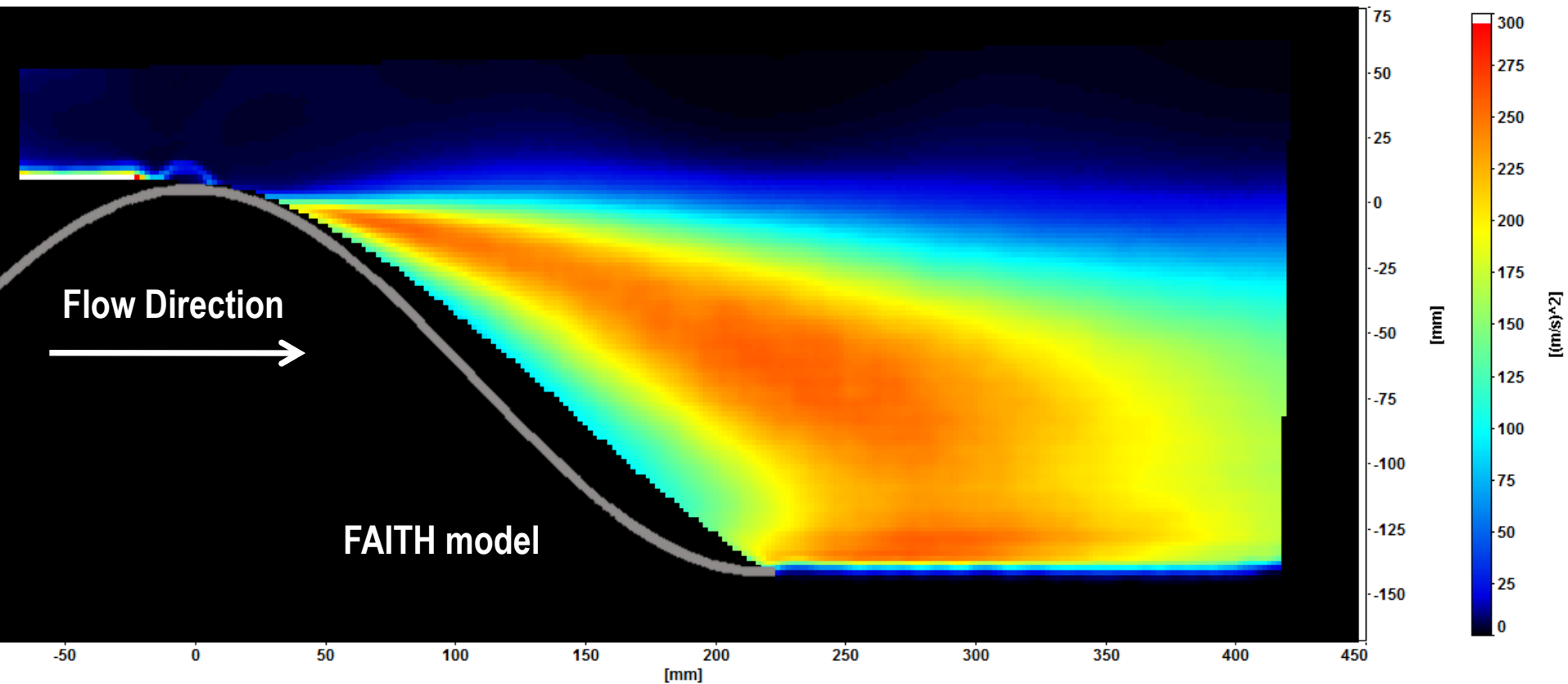
HS 3-D Particle Image Velocimetry (PIV) - 1kHz

Centerline plane – Contour of Average KE



HS 3-D Particle Image Velocimetry (PIV) - 1kHz

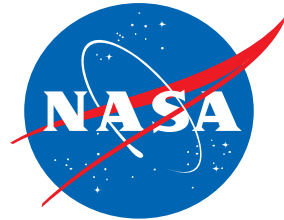
Centerline plane – Contour of Turbulent KE





Summary

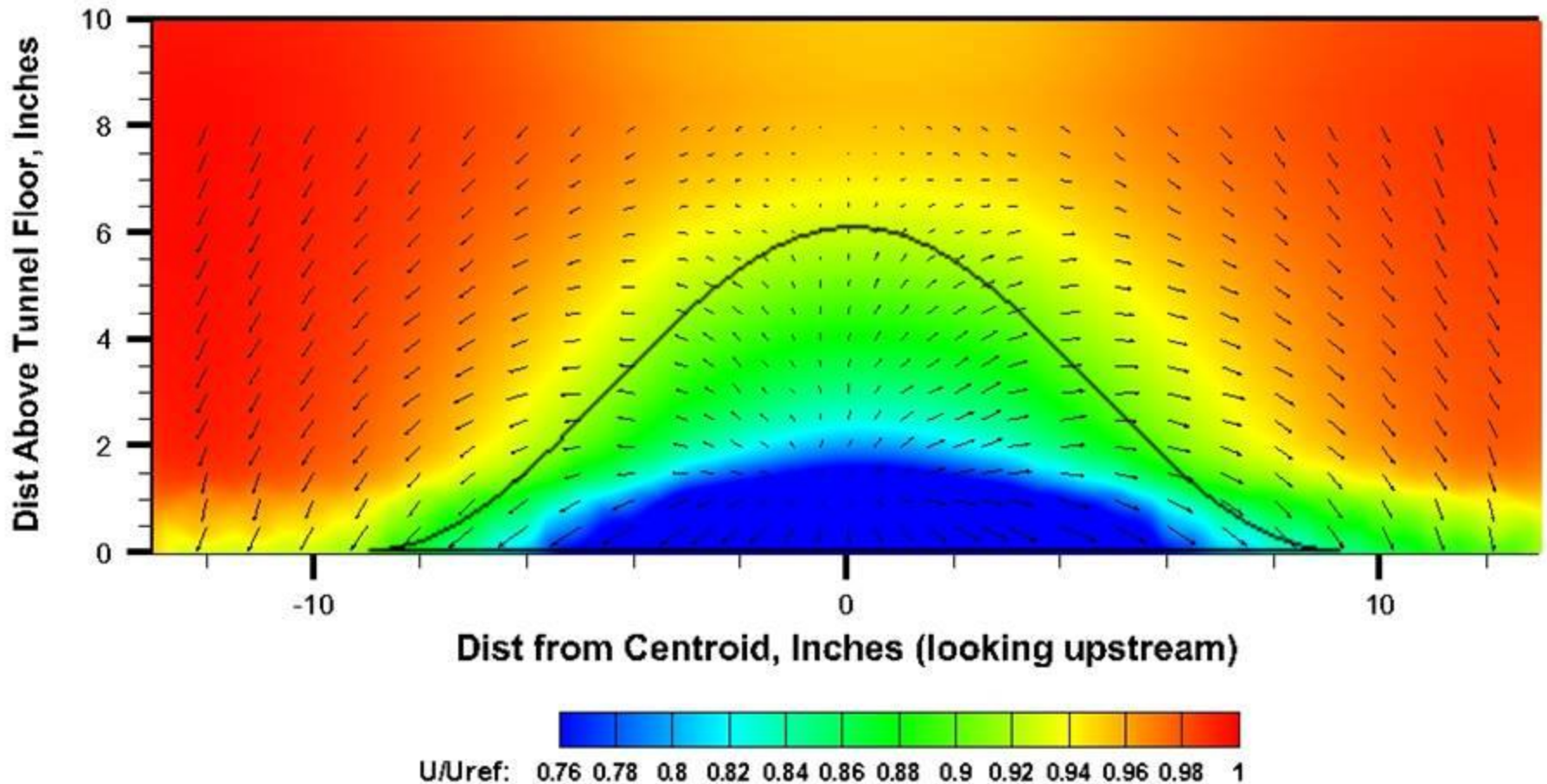
- Generated comprehensive fluid mechanic dataset for a separated flow field about a simple wall-mounted axisymmetric hill in turbulent subsonic flow
 - Water Channel Flow Vis
 - Surface Oil Flow Vis
 - Pressure Sensitive Paint (PSP)
 - Fringe Imaging Skin Friction (FISF)
 - Cobra Probe
 - Particle Image Velocimetry (PIV)
- Data being uploaded to
[http://nspires.nasaprs.com/external/solicitations/summary.do?
method=init&solld=%7b94454604-A9AA-31A5-28B0-37B8332C25DC
%7d&path=open](http://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solld=%7b94454604-A9AA-31A5-28B0-37B8332C25DC%7d&path=open)
- *(Easier: contact me at kurtis.r.long@nasa.gov for emailed link to site)*
- Full dataset available soon



Mean Velocity Measurements



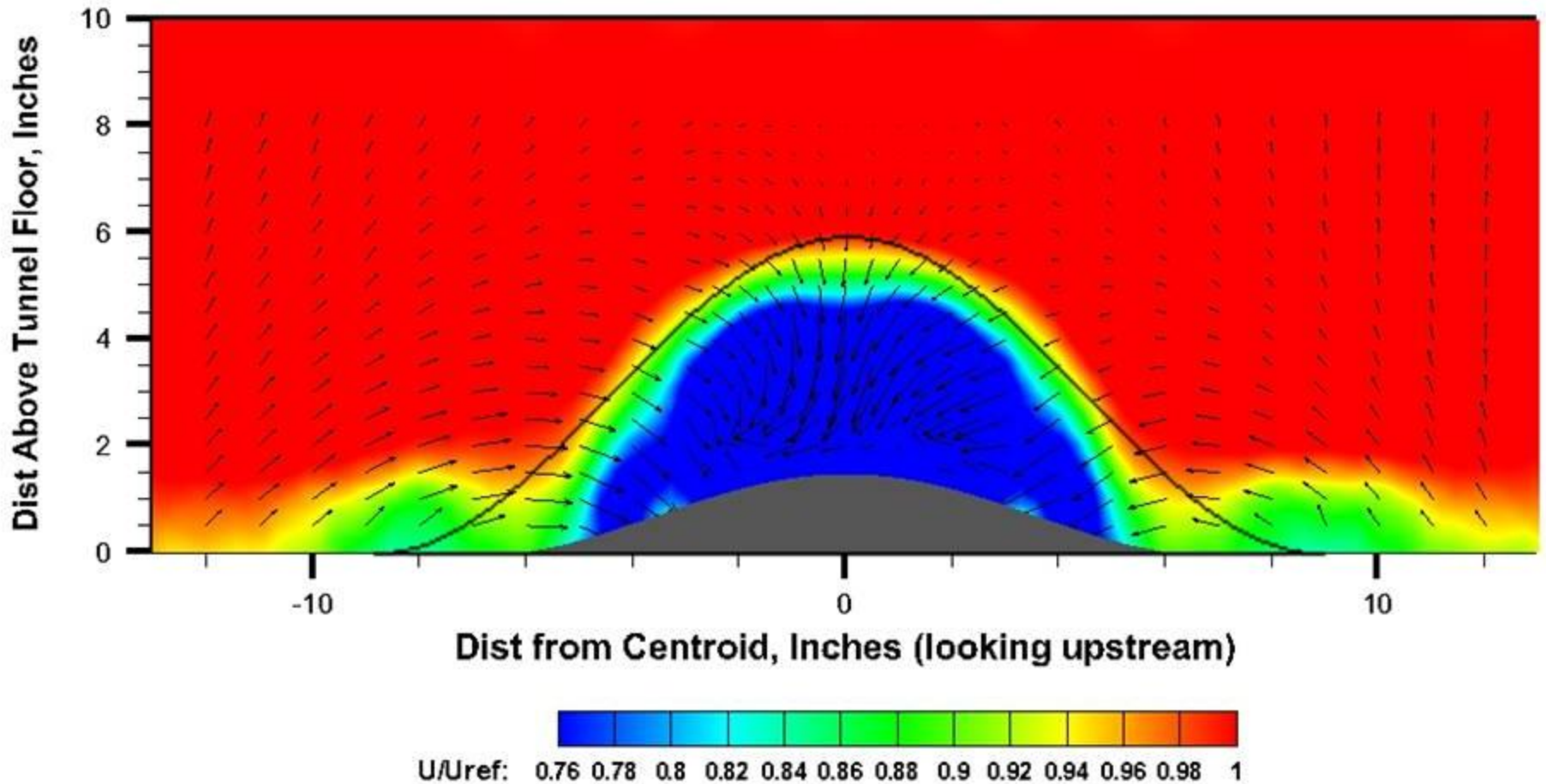
9.2 Inches Upstream of Centroid ($X/H = -1.53$)



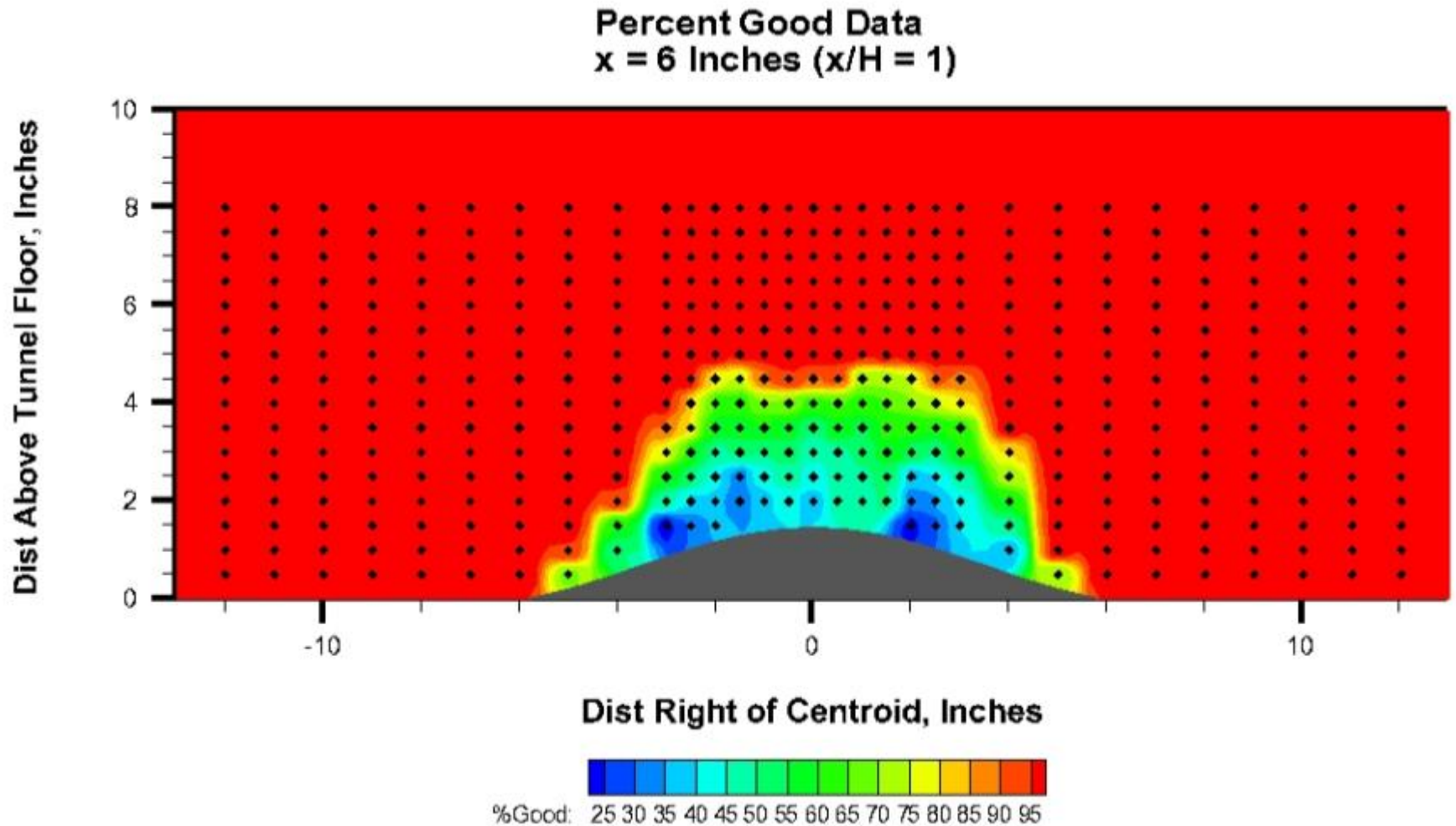
Mean Velocity Measurements



6 Inches Downstream of Centroid ($X/H = 1.0$)



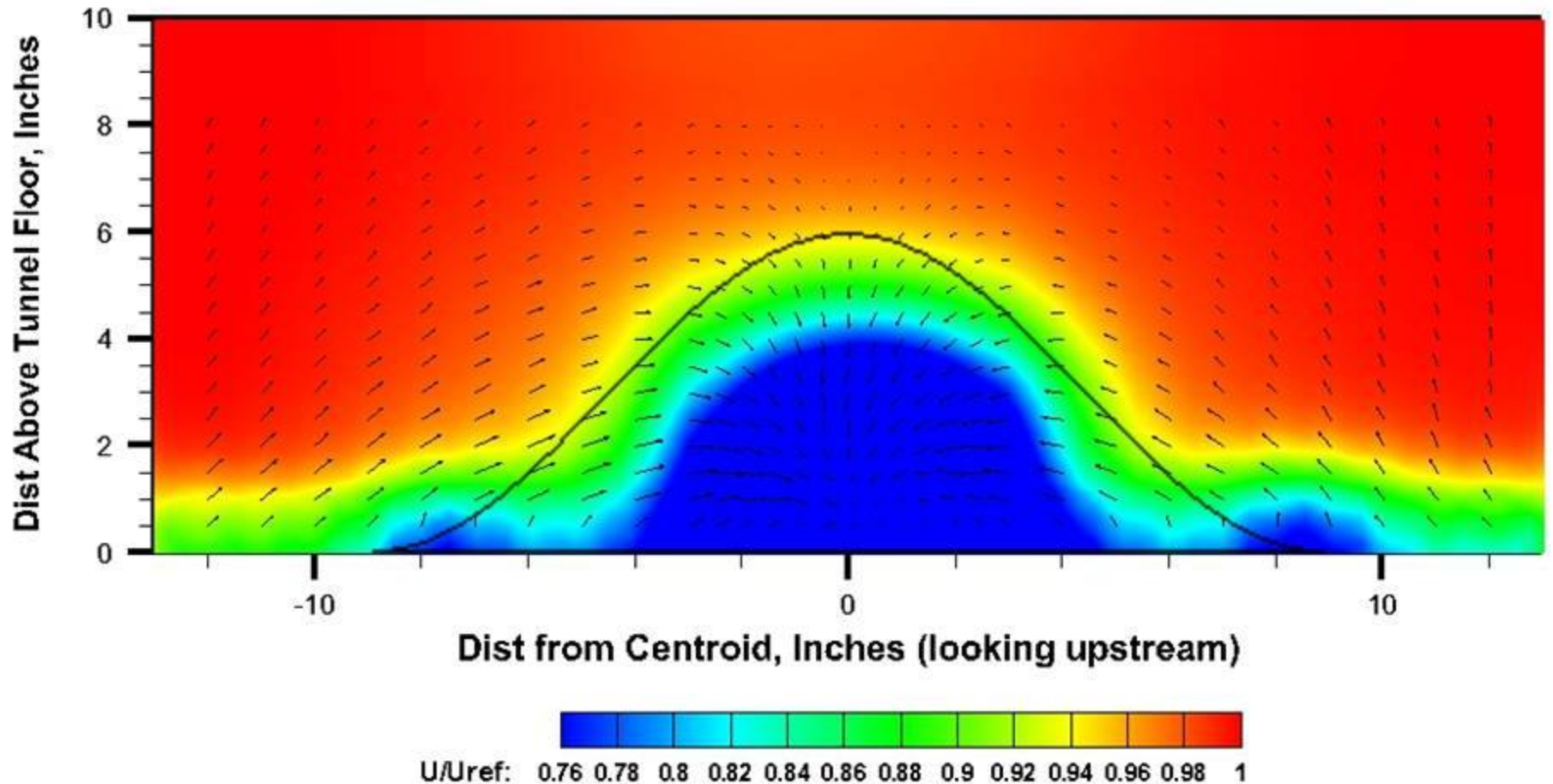
FAITH: Percent “Good” Data at X = 6 In



Mean Velocity Measurements



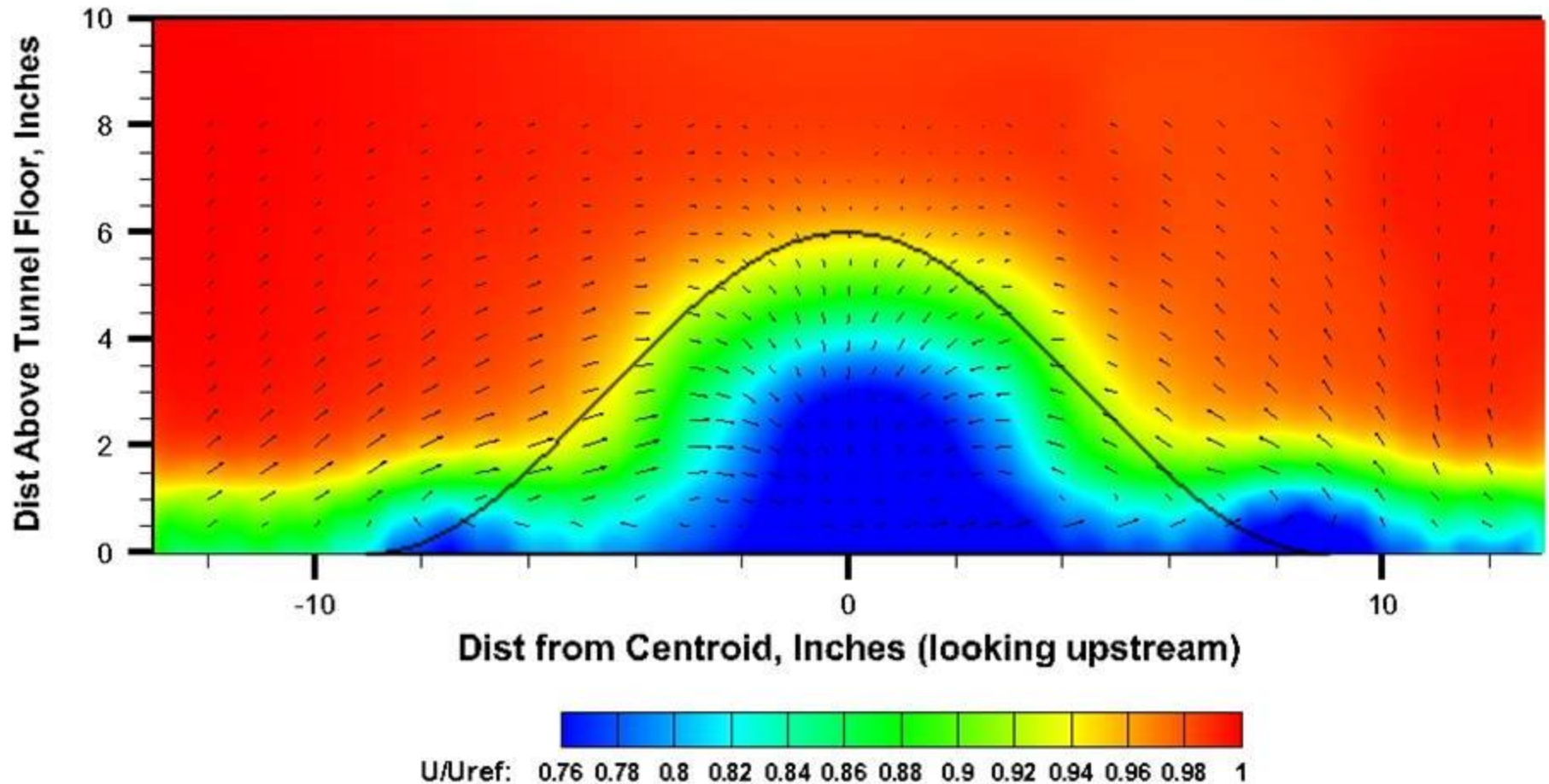
16 Inches Downstream of Centroid ($X/H = 2.7$)



Mean Velocity Measurements



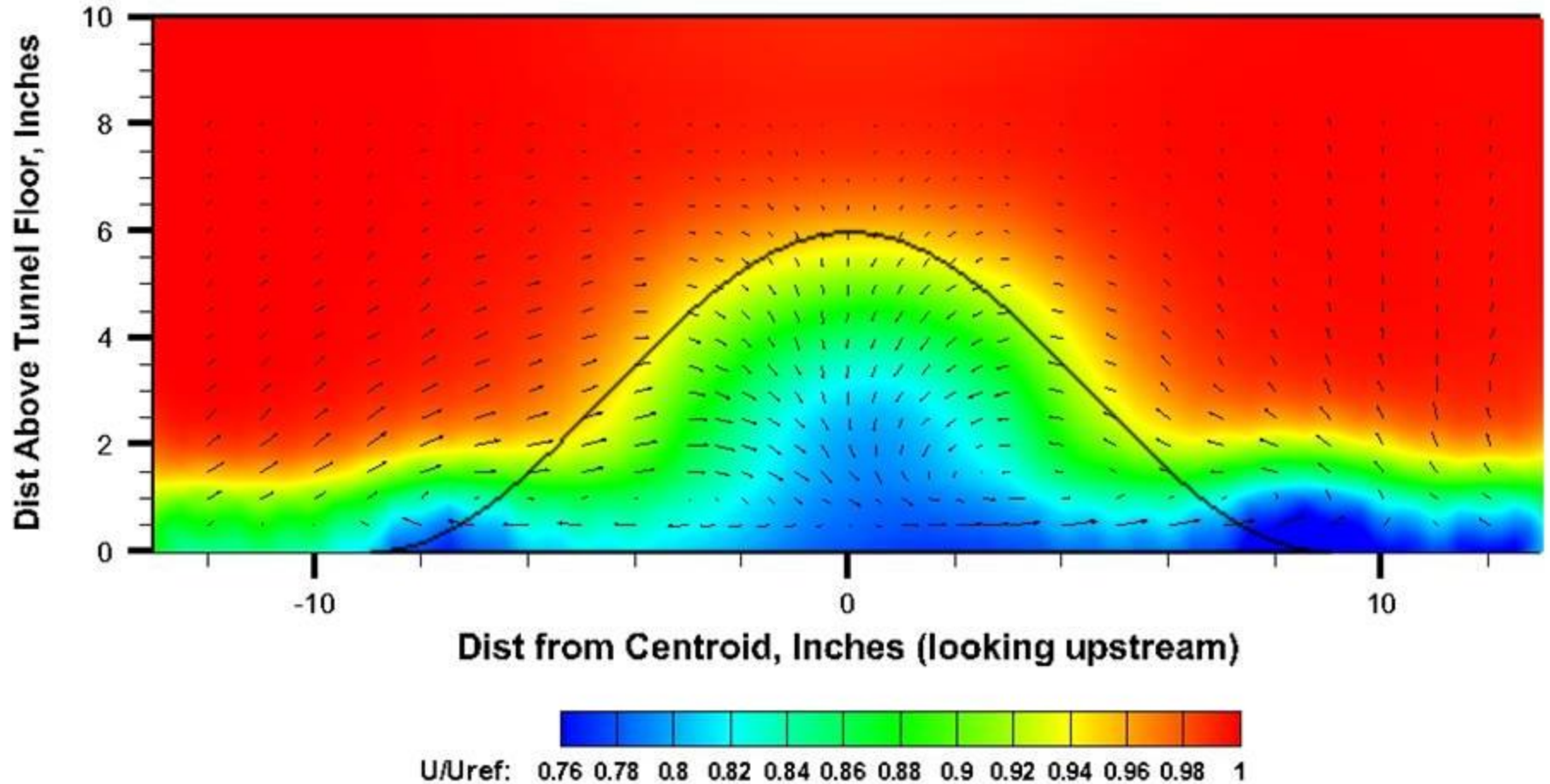
22.2 Inches Downstream of Centroid ($X/H = 3.69$)



Mean Velocity Measurements



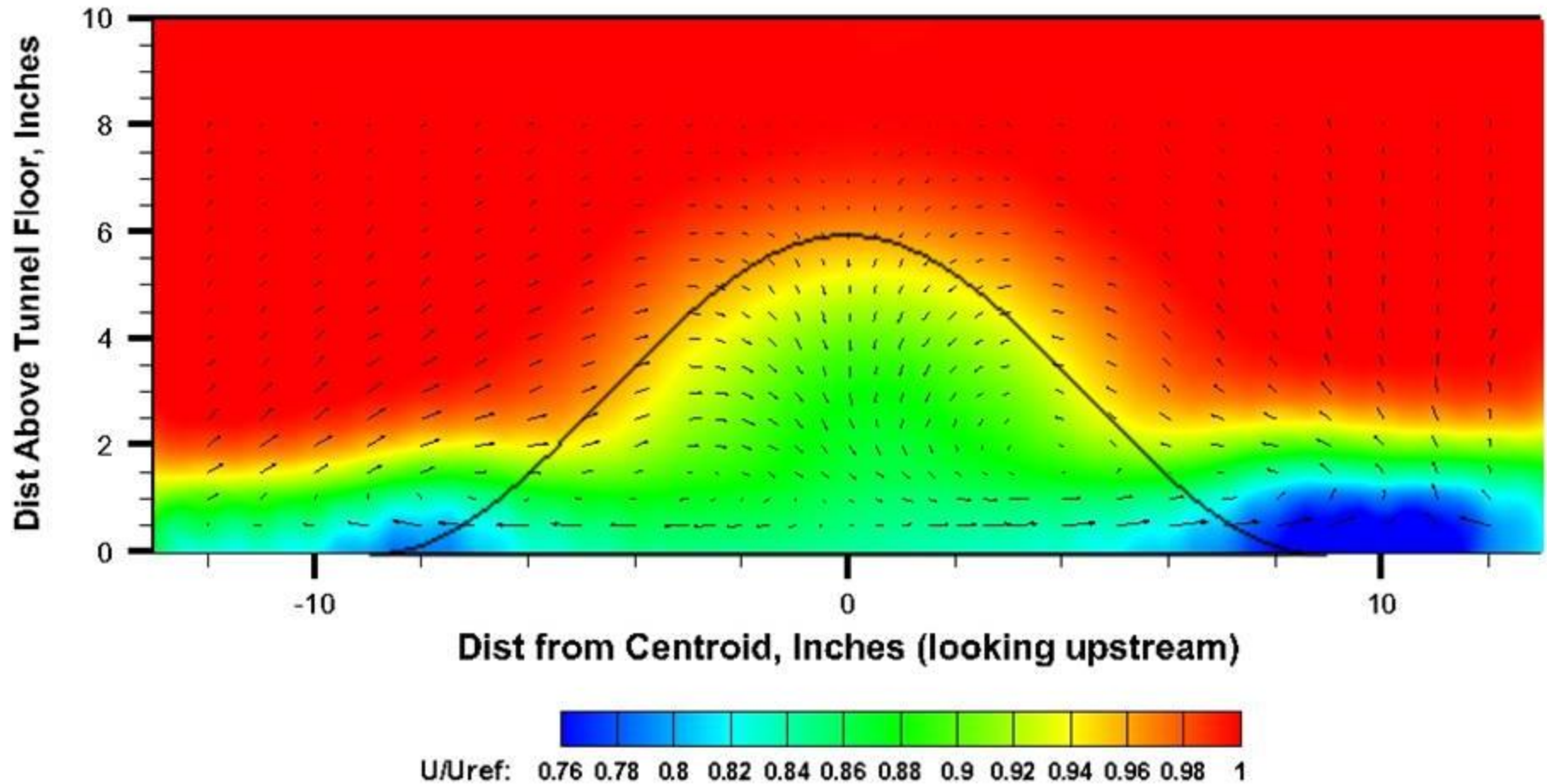
26.8 Inches Downstream of Centroid ($X/H = 4.46$)



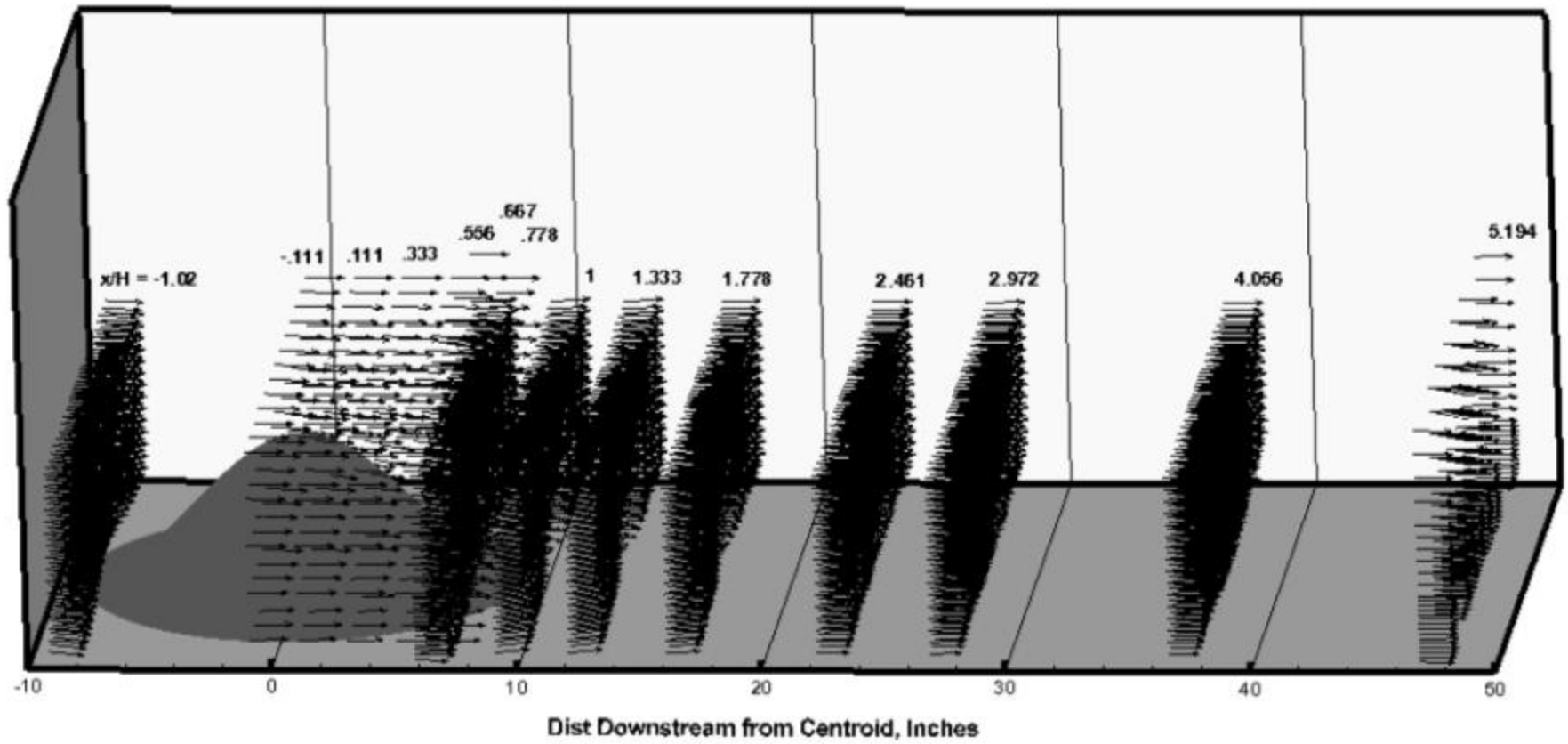
Mean Velocity Measurements



36.5 Inches Downstream of Centroid ($X/H = 6.08$)

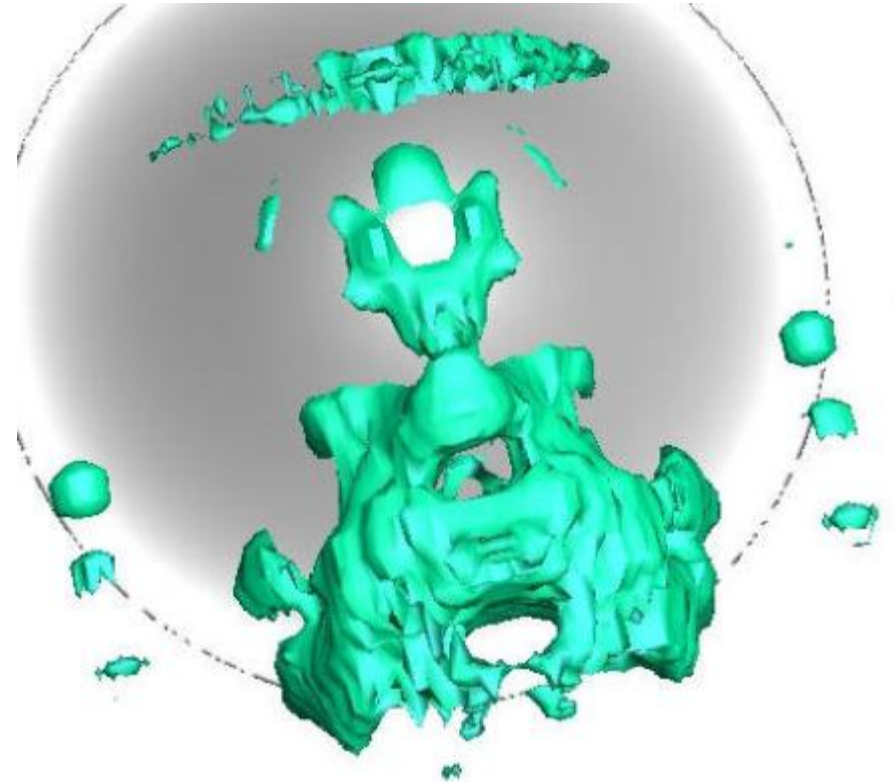
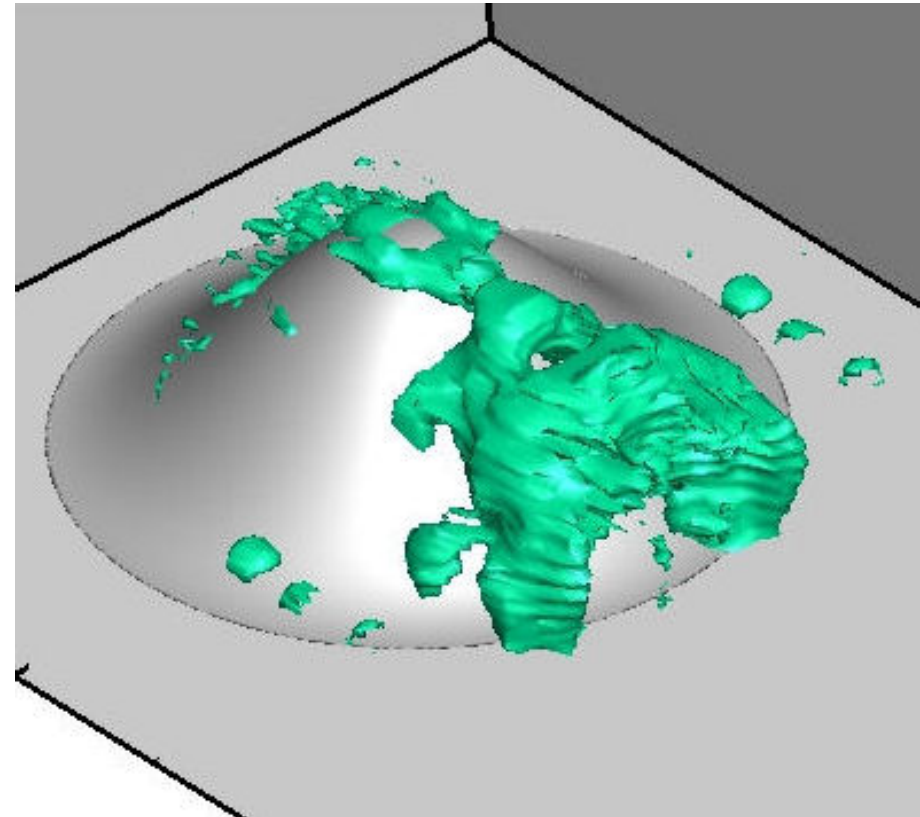


FAITH: Cobra Probe Measurement Grid

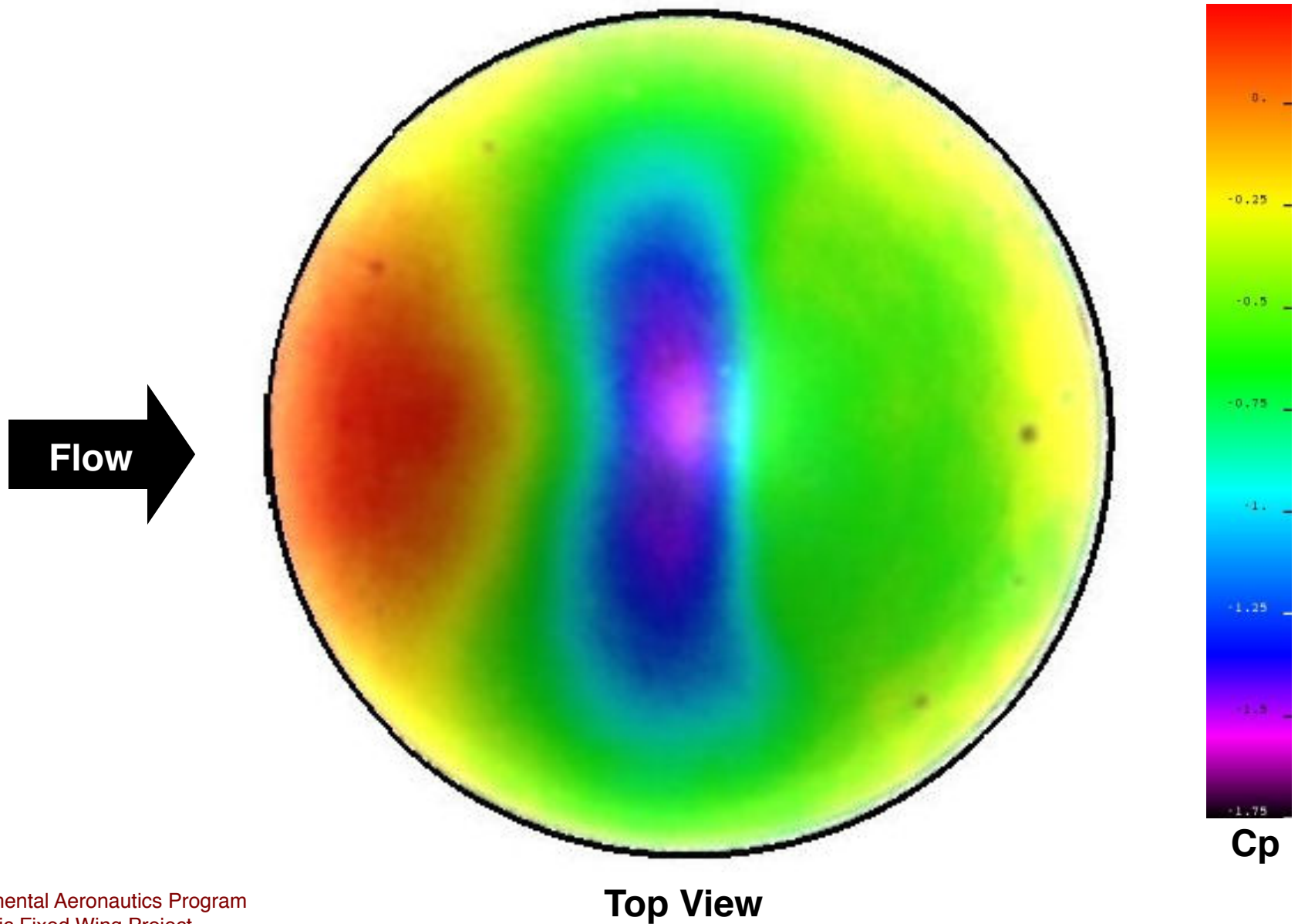


Iso-surface of Vorticity Magnitude

$$\Omega = 0.2$$



FAITH PSP Measurements



FAITH Surface Flow Topology: Murray Tobak

