Analysis and Design of the Federal Aviation Administration Fire Test Burner

Particle Image Velocimetry Applied to Fire Safety Research

Presented to: International Aircraft Materials Fire Test Working Group – Köln, Germany

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Federal Aviation Administration

Outline

- Motivation
- Objectives of Study
- Explanation of PIV
- Acquired Data
- Summary and Future Work

Motivation

- **The FAA utilizes a modified oil burner to simulate the effects of a post-crash fuel fire on an aircraft fuselage and interior components**
  - The specified burner is a typical home heating oil burner
  - Burner uses JP8 or Jet A jet fuel
- **Burner flame characteristics scaled directly from measurements made from full scale pool fire testing**
  - Heat flux
  - Temperature
  - Material burn-through times
- **The burner is used to measure the fire worthiness of aircraft materials**
  - Seats, thermal-acoustic insulation, and cargo liners

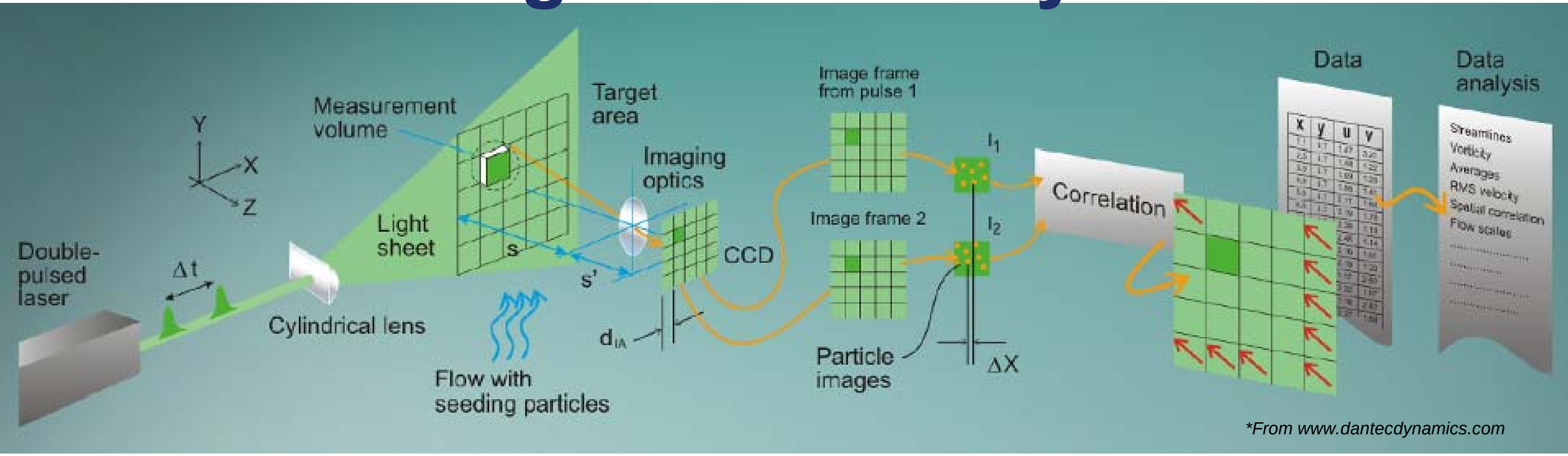
Objectives of Current Investigation

- **Develop a re-designed NexGen burner**
  - Independent of previous components that have limited availability
  - Produces similar flame and test results
  - Increased accuracy and consistency
- **Must investigate original burner**
  - Determine parameters that most influence burner output
  - Study each parameter individually then combinations of parameters
  - Develop new components and configurations

Methodology

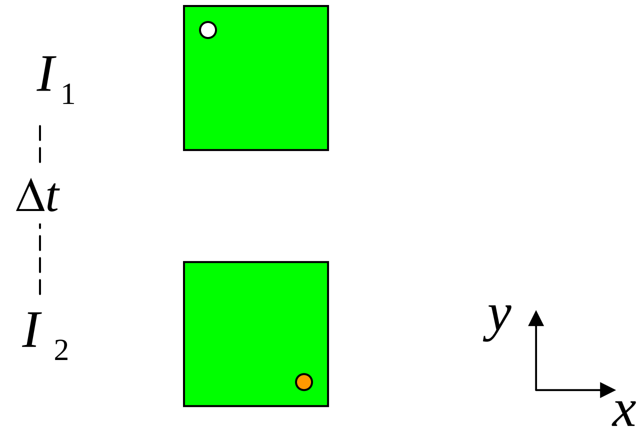
- **Utilize flow measurement techniques to study the operation of the burner and assess each component or parameter**
- **Selection of a technique:**
  - Hot Wire Anemometry
  - Laser Doppler Anemometry
  - Particle Image Velocimetry
- **PIV was chosen as the most robust method for this study**
  - Instantaneous, non-intrusive, planar velocity measurements in 2-D with capabilities for 3-D
  - Hot and cold flows (reacting and non-reacting)
  - Capabilities for particle sizing (spray characterization)

Particle Image Velocimetry



*From www.dantecdynamics.com

- **Particle Image Velocimetry (PIV)**
  - Fluid flow measurement technique
  - Measures the displacement of small particles entrained in the flow over a short period of time and calculates the velocity at discrete points
- **Key Advantages**
  - Non-intrusive measurement of flow
  - Whole-field measurement; can resolve wide range of flow field areas ($\mu m^2 \rightarrow m^2$)



PIV for Fire Safety

- **Fire test methods**
  - Oil burner
- **Sprays**
  - Water mist
  - Extinguishment agent
- **CFD model validation**
  - Smoke transport

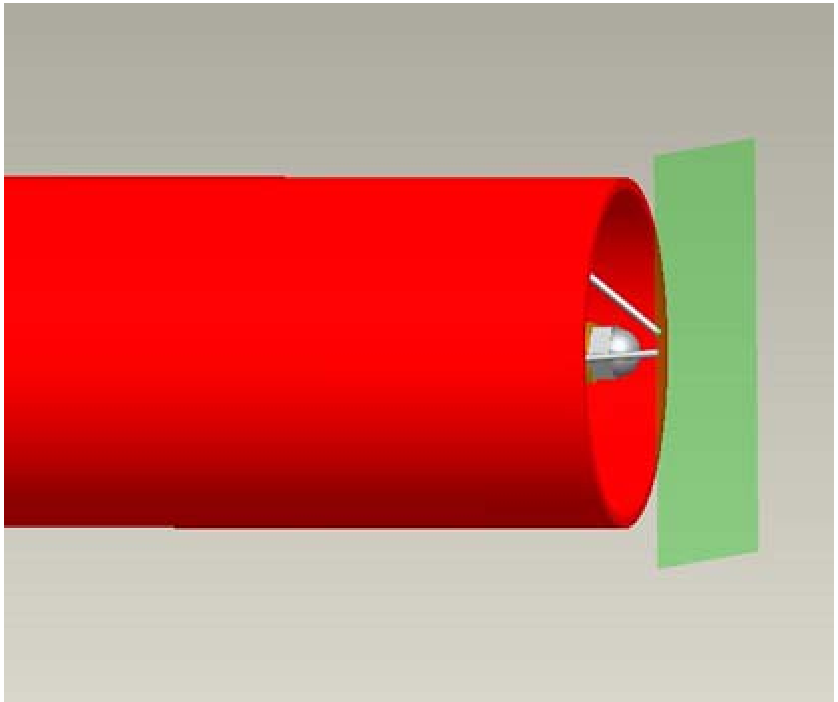
Fire Safety's PIV Laboratory

- **Dantec Dynamics 3D PIV system**
  - 2 FlowSense 2M cameras
  - SOLO PIV 120XT laser
  - PC with Dynamic Studio software for analyzing PIV images
  - Scheimpflug Camera Mounts
  - Beam Splitter
  - Traverse System
  - Precision Powder Seeder
- **Current status**
  - Laboratory is on-line

Recently Acquired Data

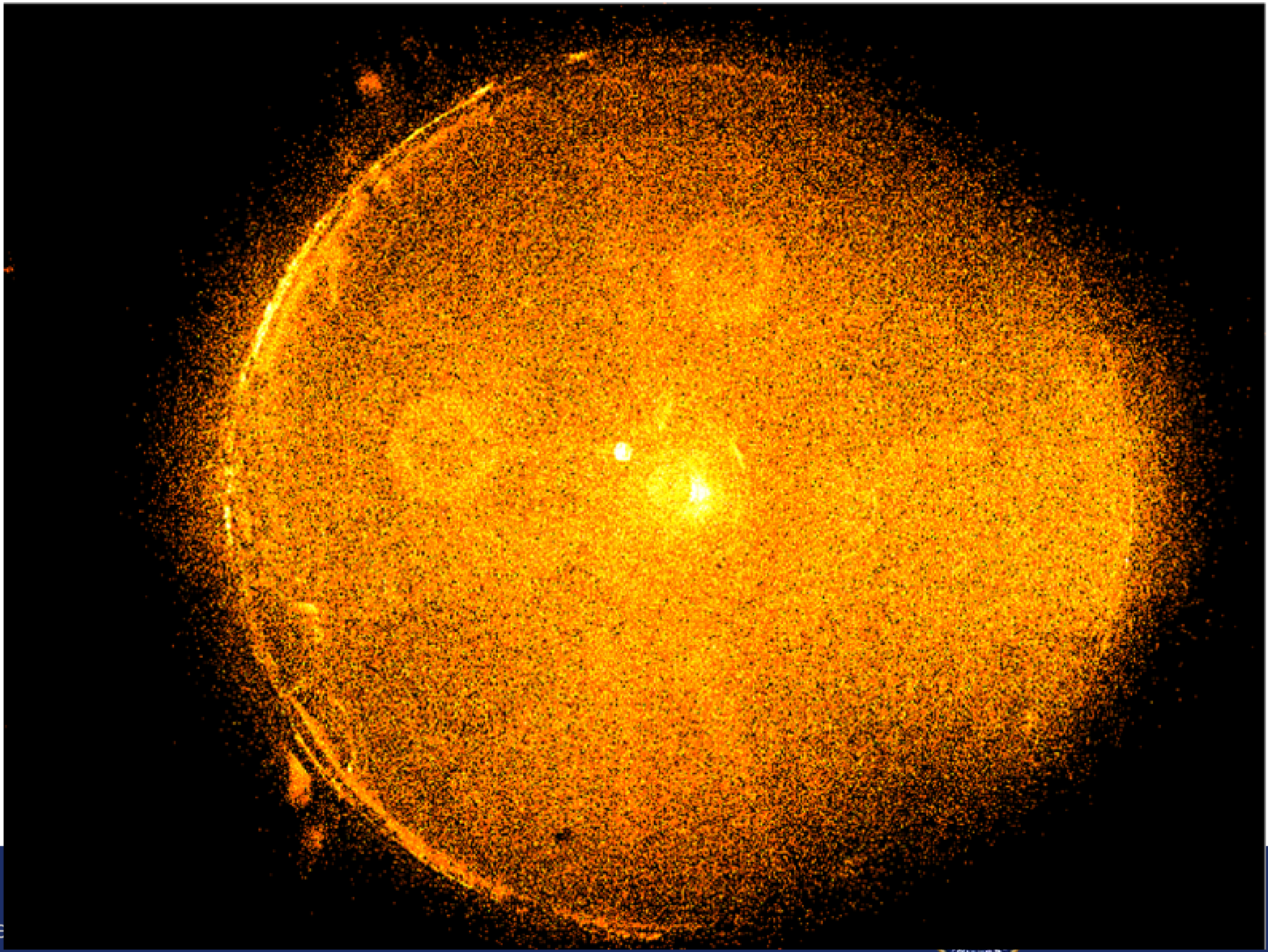
Burner Air Flow

Exit Air Flow from Draft Tube (Turbulator Removed)

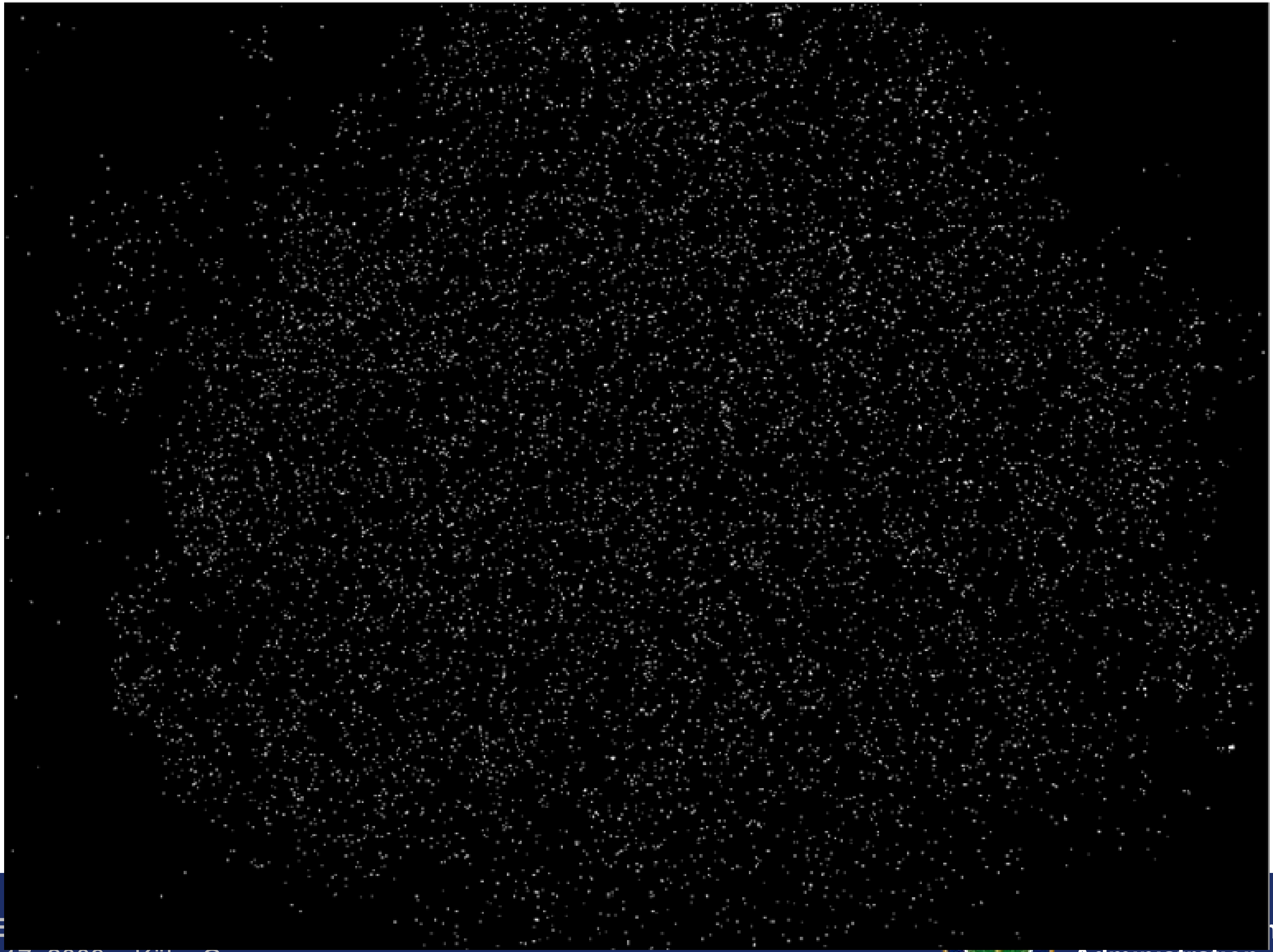


- **Measurement plane is 1" from draft tube exit plane**
- **Flow is seeded with Aluminum Dioxide particles, ~15 micron**
- **Δt=100μs**

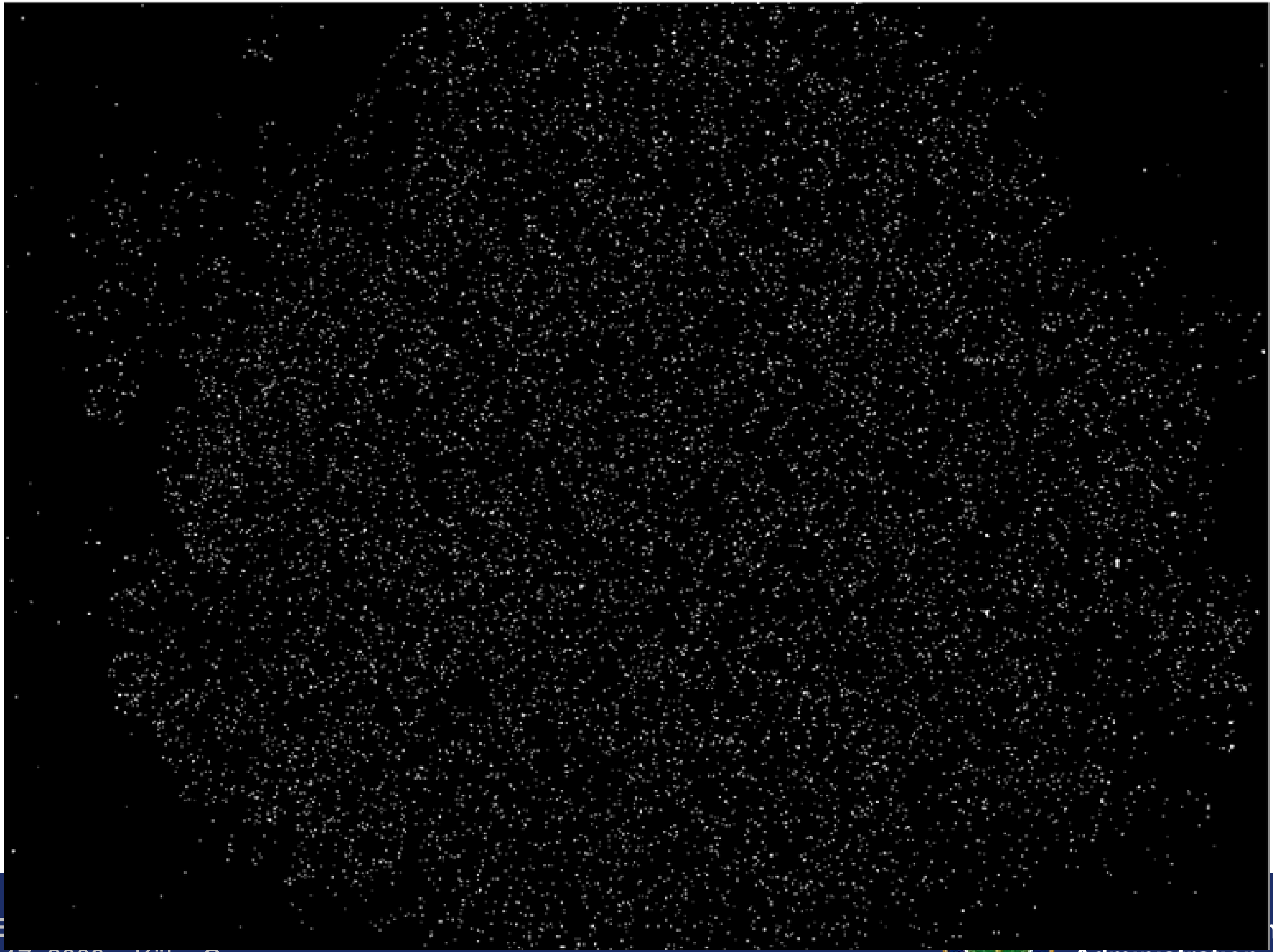
Mean Image – False Color



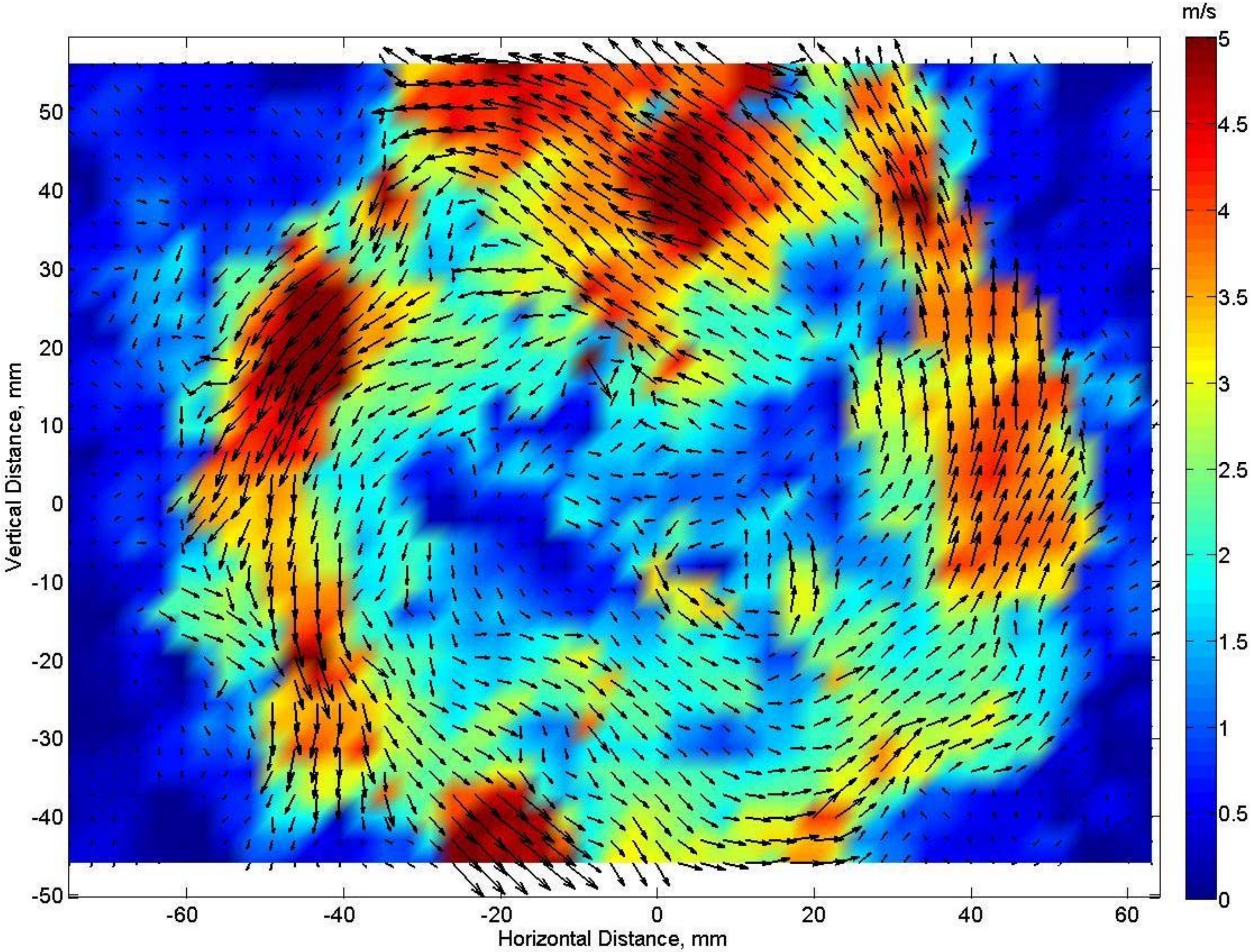
Raw Data Frame 1, t=0



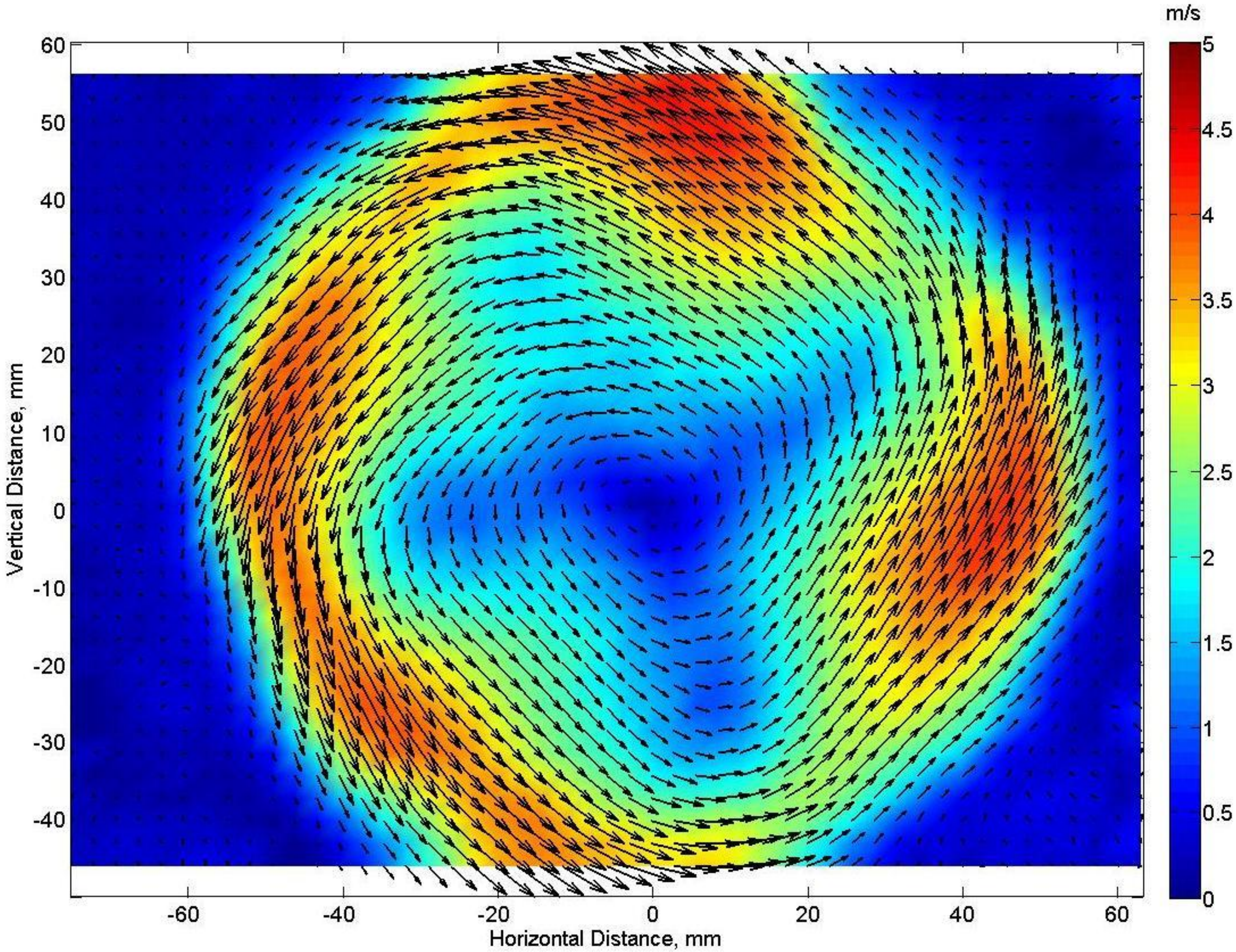
Raw Data Frame 2, t=100μs



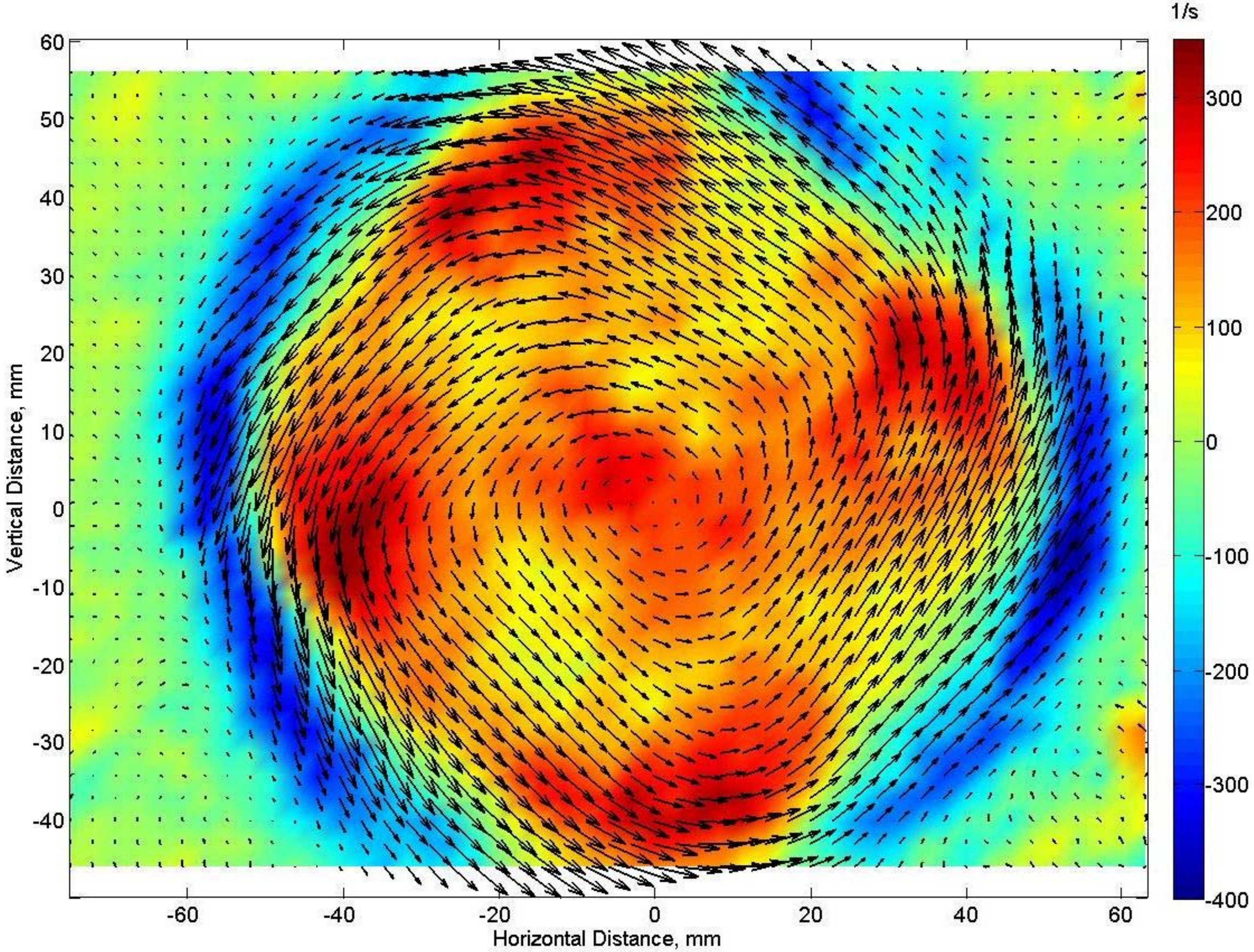
Instantaneous Velocity Field



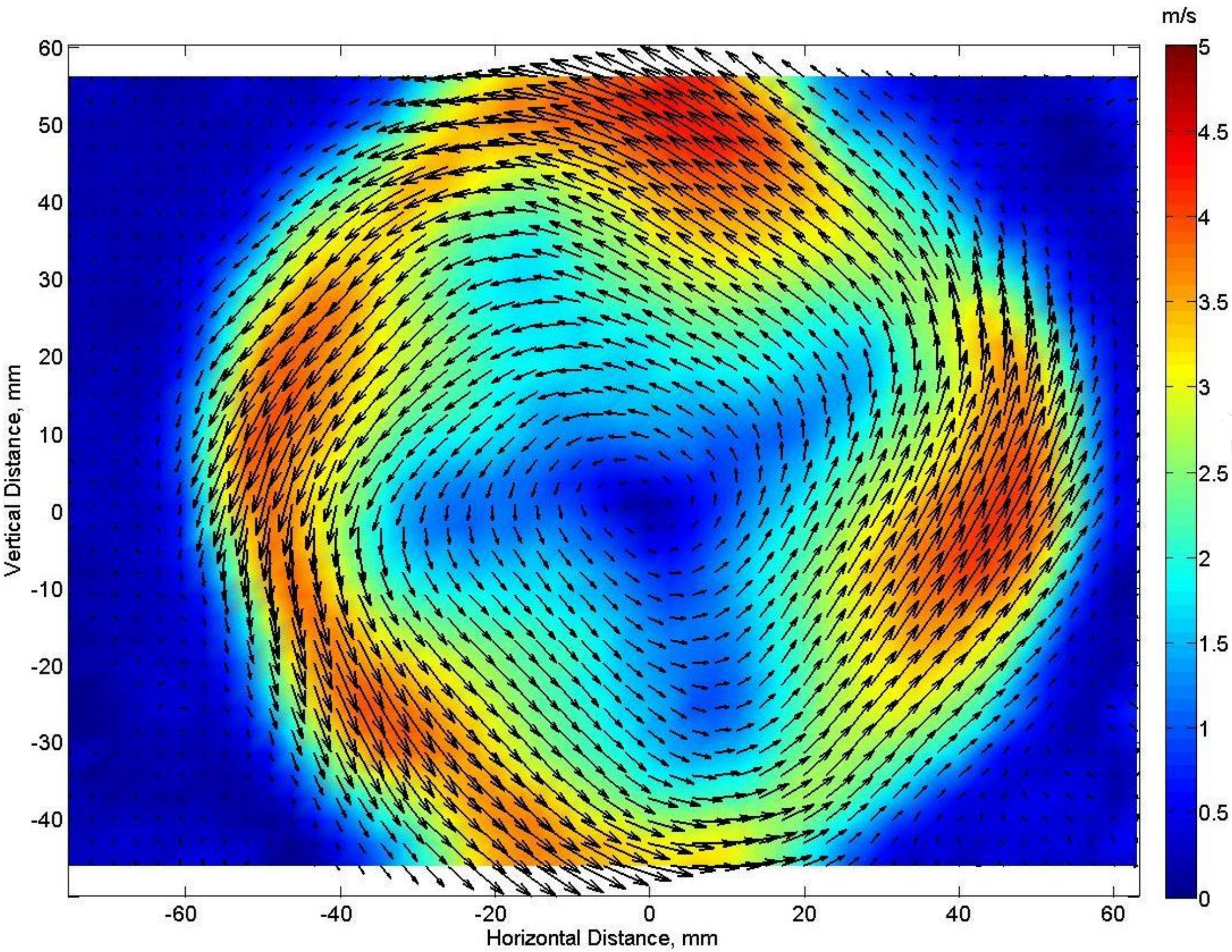
Mean Velocity Field



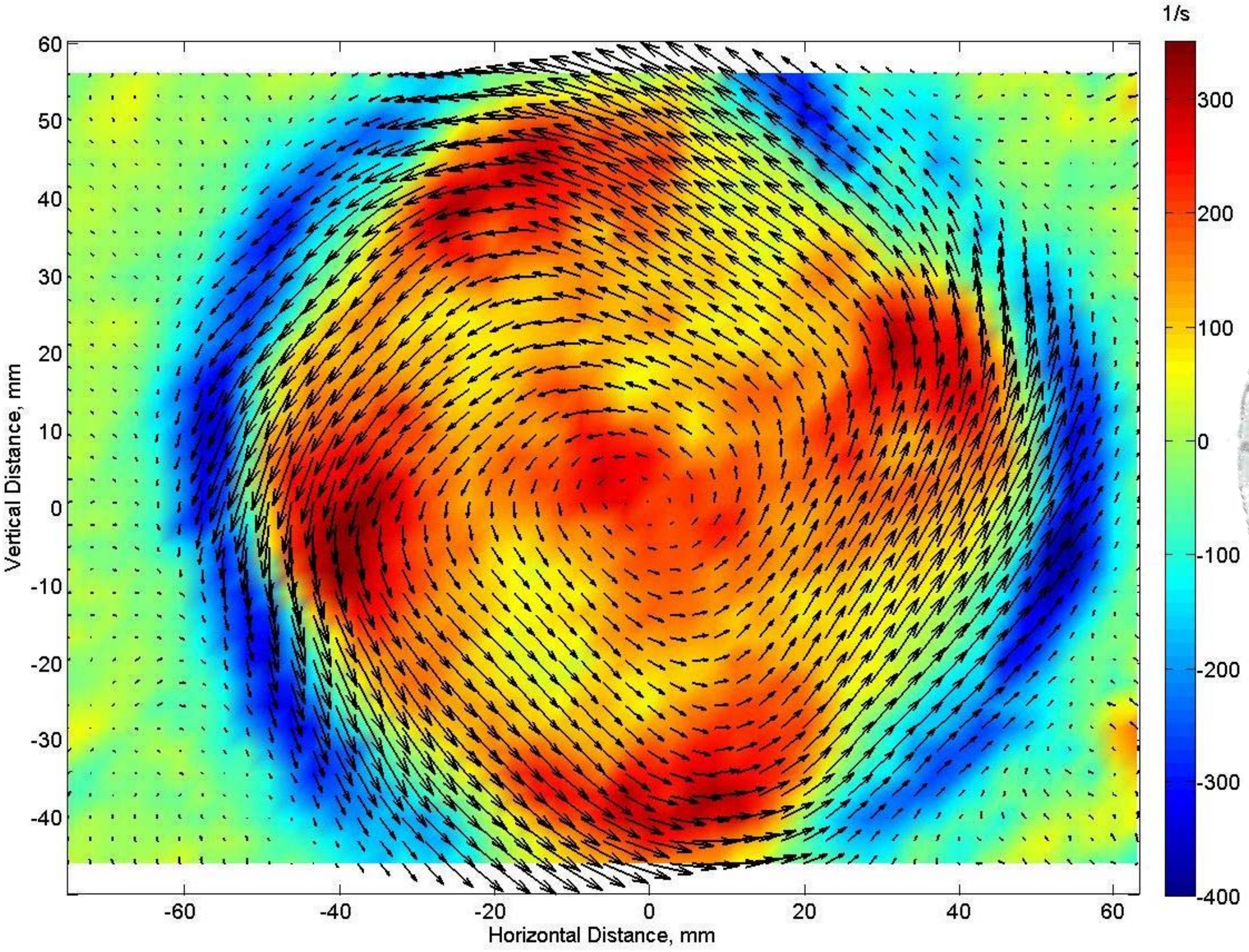
Mean Velocity and Vorticity Field



Mean Velocity



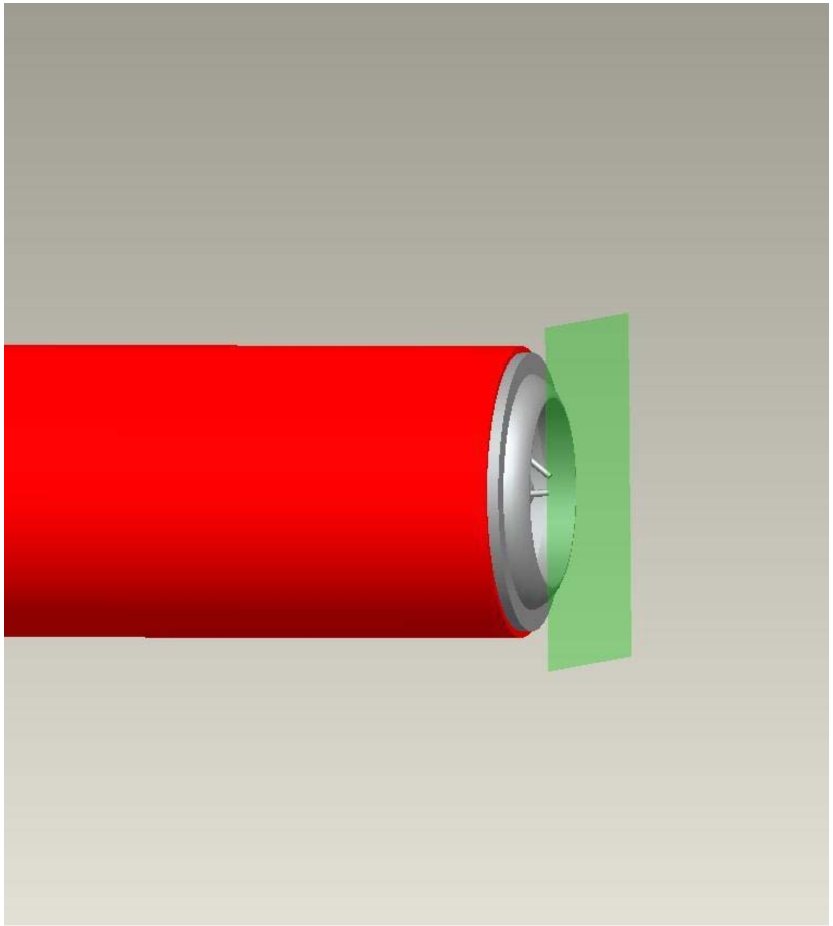
Mean Vorticity



Analysis

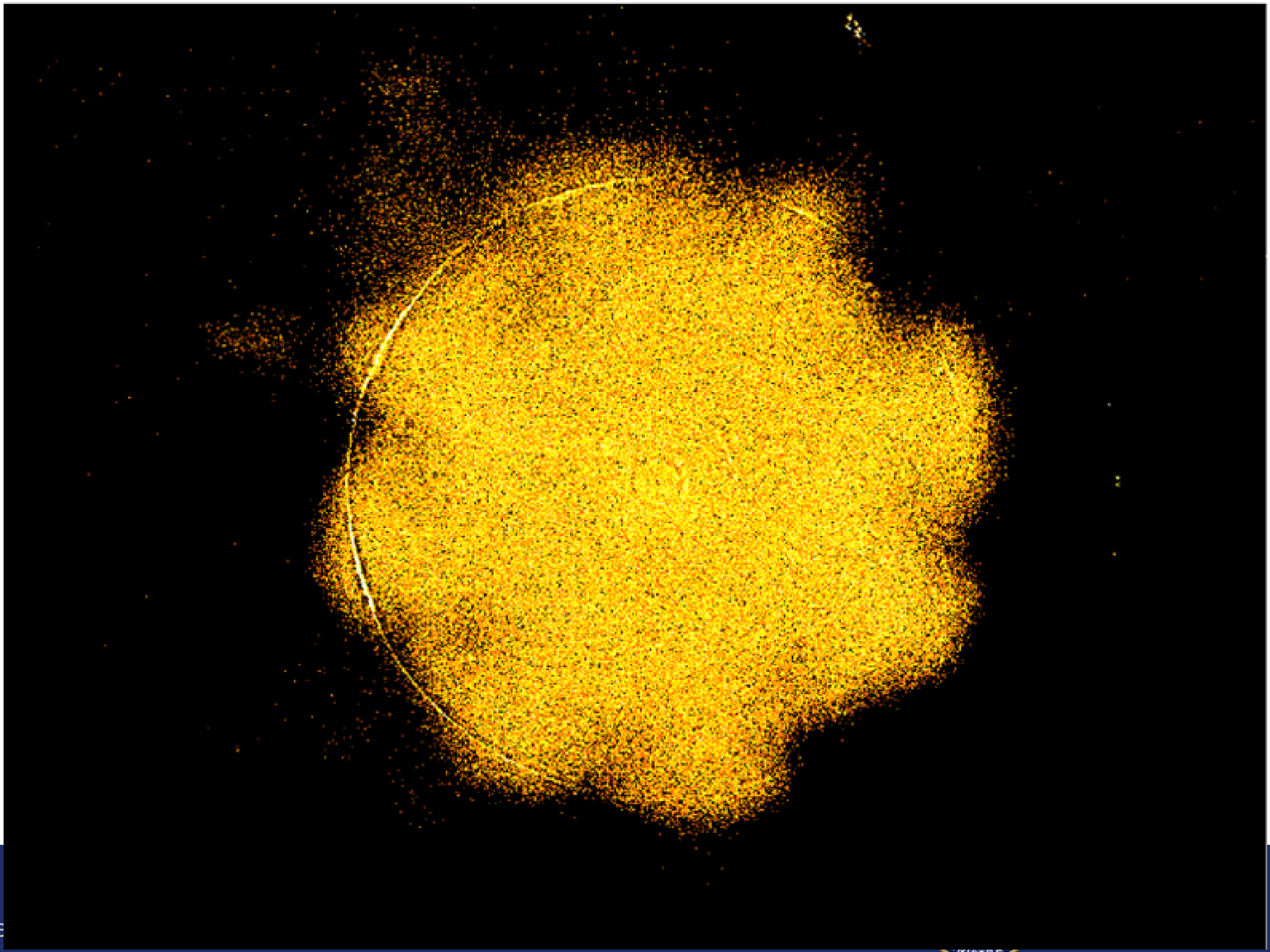
- The effect of the stator is apparent in the measured flow field
- Curved stator vanes are found to convert nearly axial flow to a swirling counterclockwise (positive) flow
- Vorticity is strongest at the stator vane – draft tube boundary, where the imparted tangential velocity is rotated by the curvature of the draft tube
- Flow retains the swirling motion even after exiting the draft tube

Exit Air Flow from Turbulator

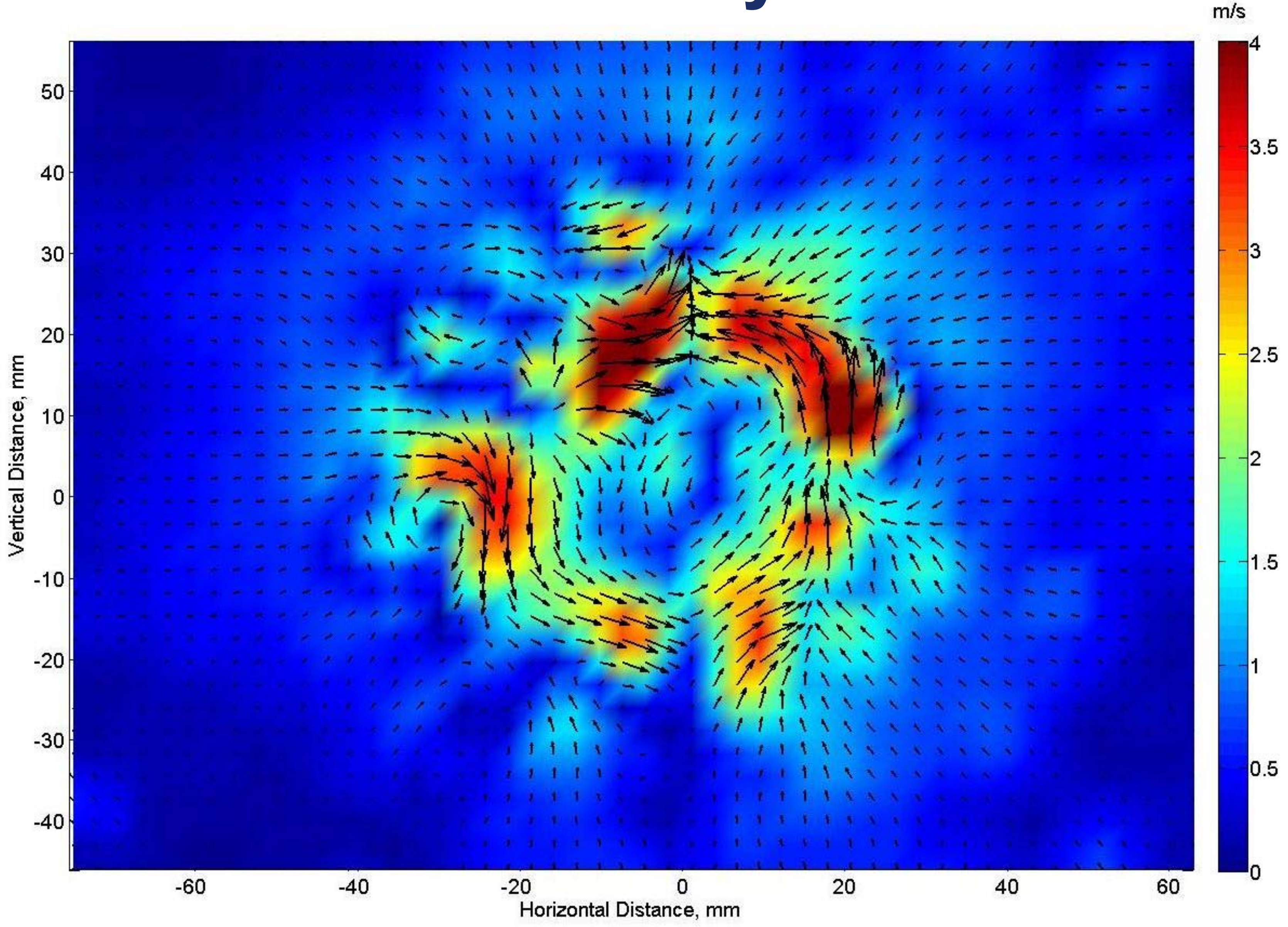


- **Measurement Plane is parallel to the turbulator exit plane, ½” from exit**
- **Flow is seeded with Aluminum Dioxide particles, 15 micron**
- **$\Delta t = 100 \mu s$**

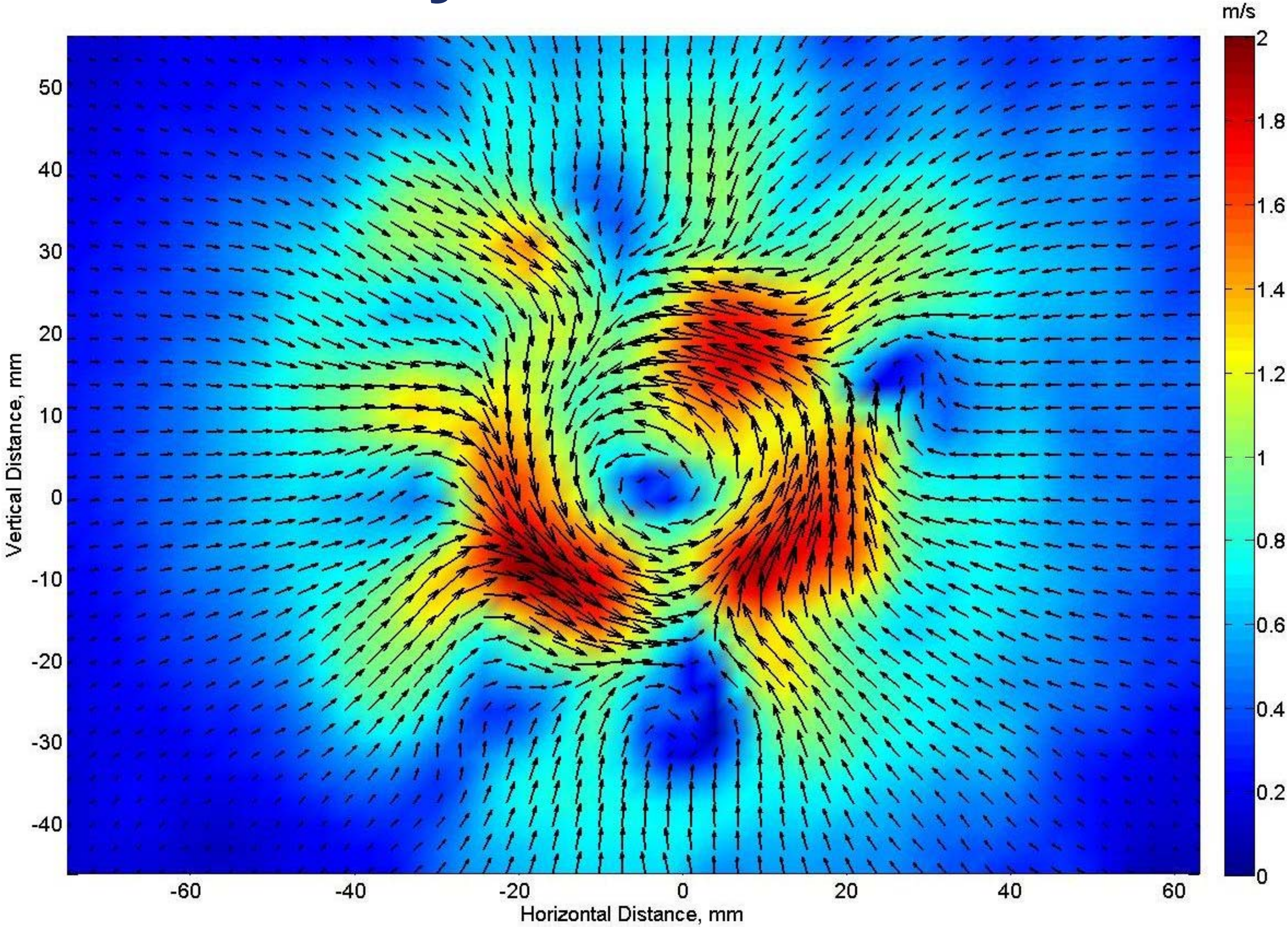
Mean Image – False Color



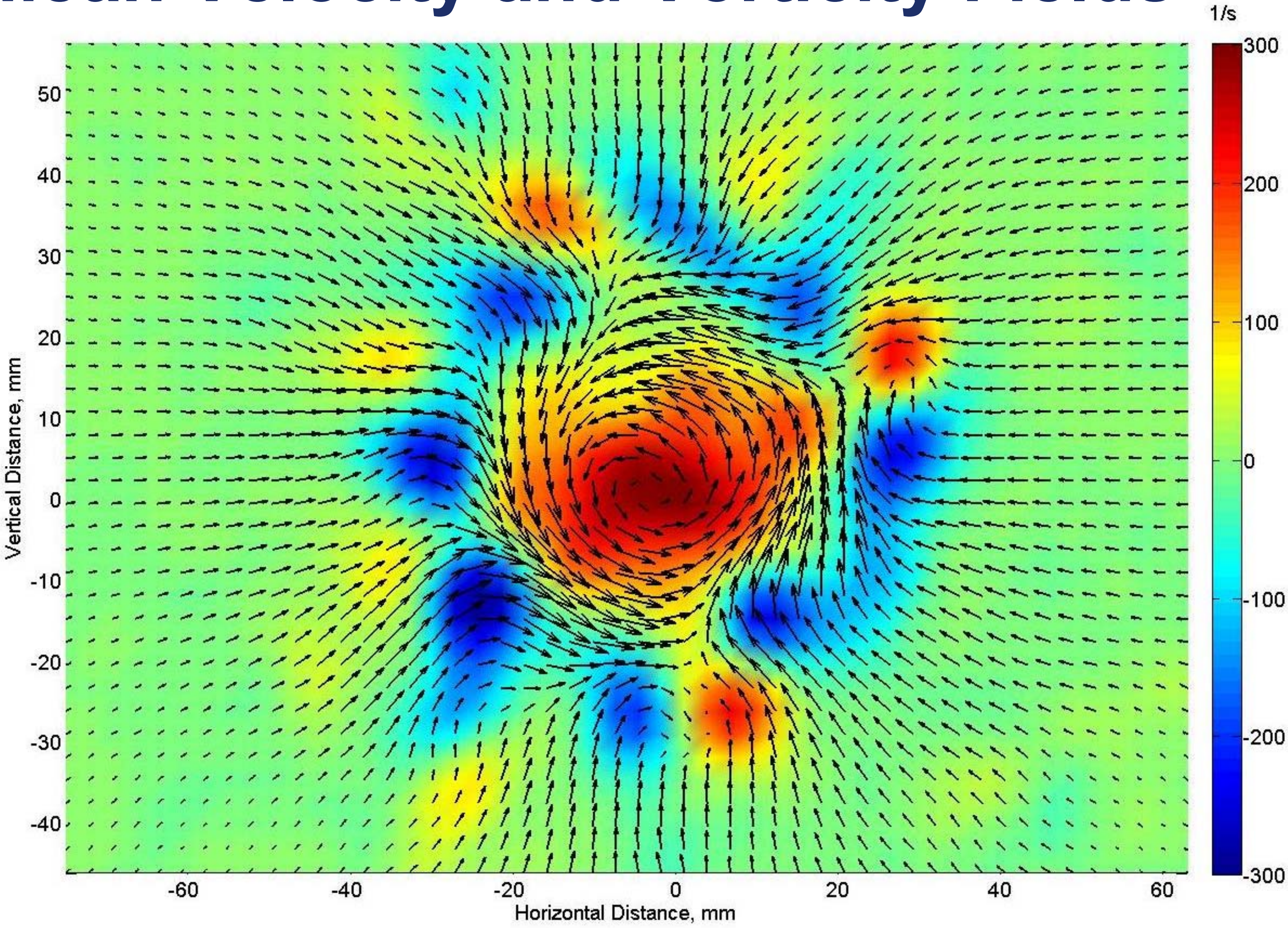
Instantaneous Velocity Field



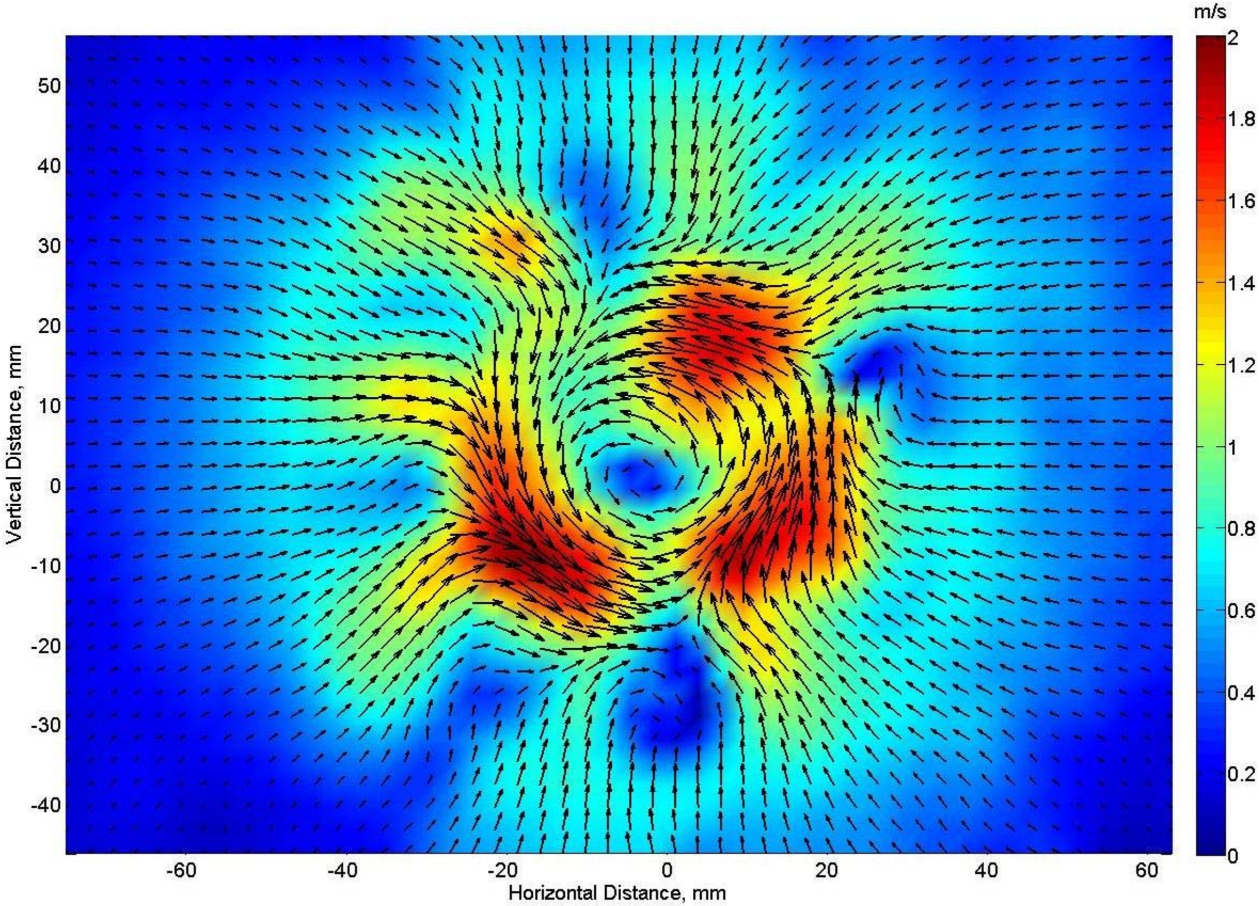
Mean Velocity Field



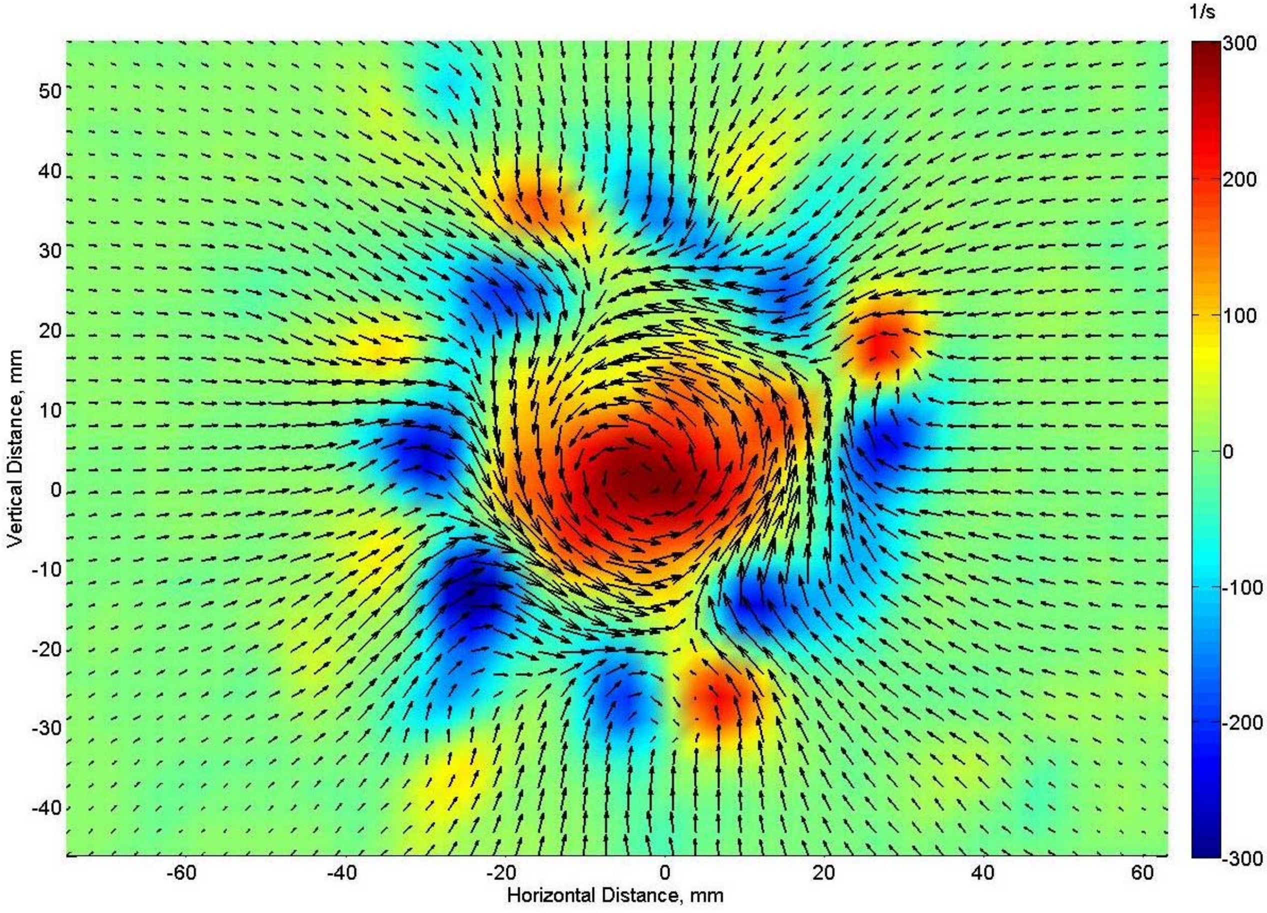
Mean Velocity and Vorticity Fields

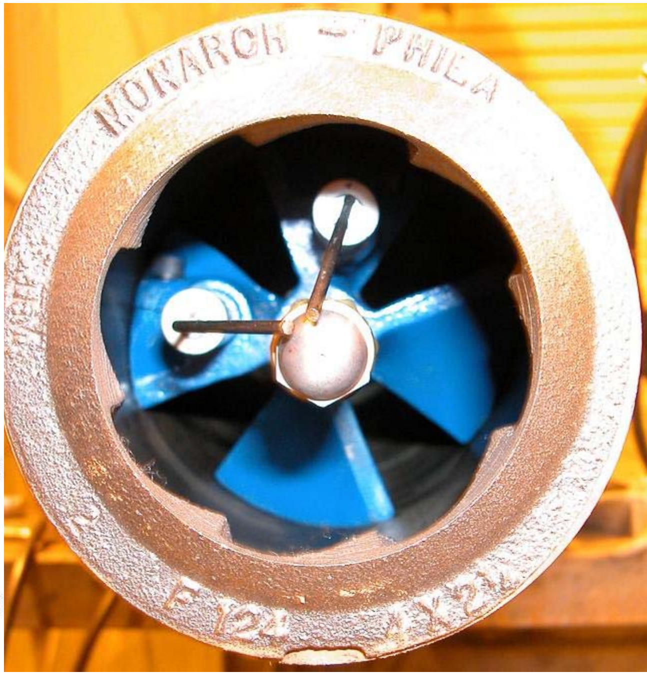


Mean Velocity



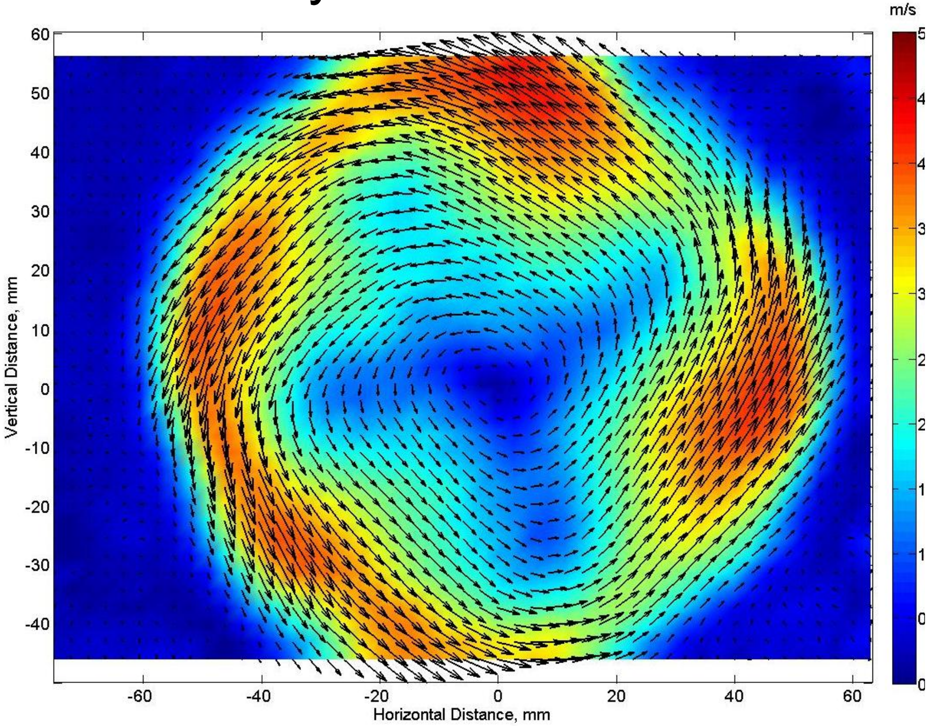
Mean Vorticity



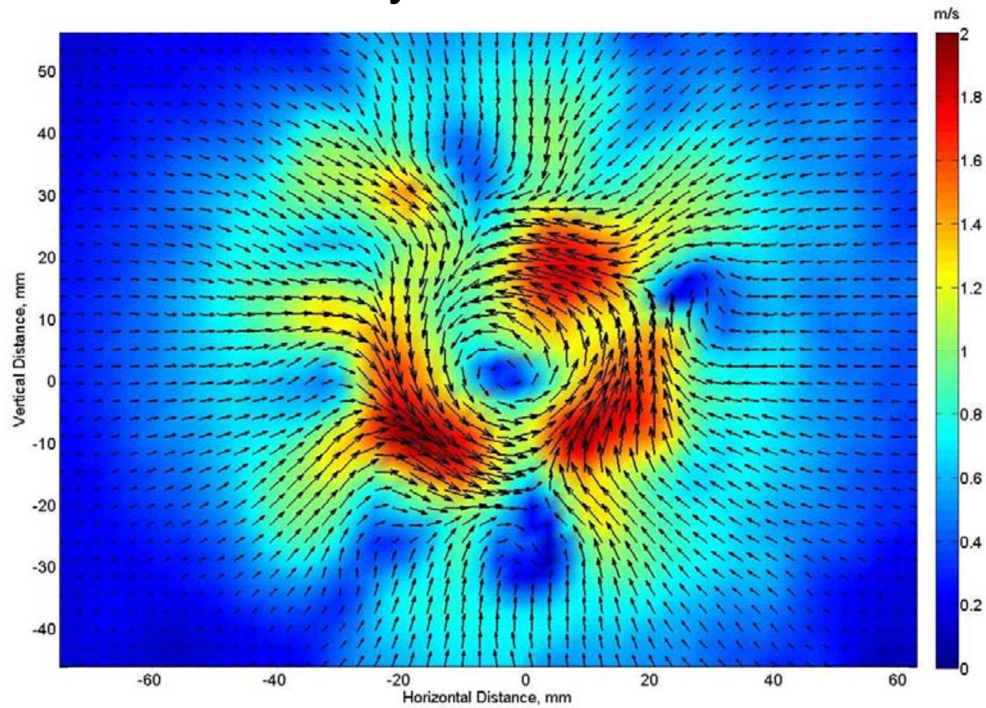


Comparison – Vector Fields

Air Only – Turbulator Off

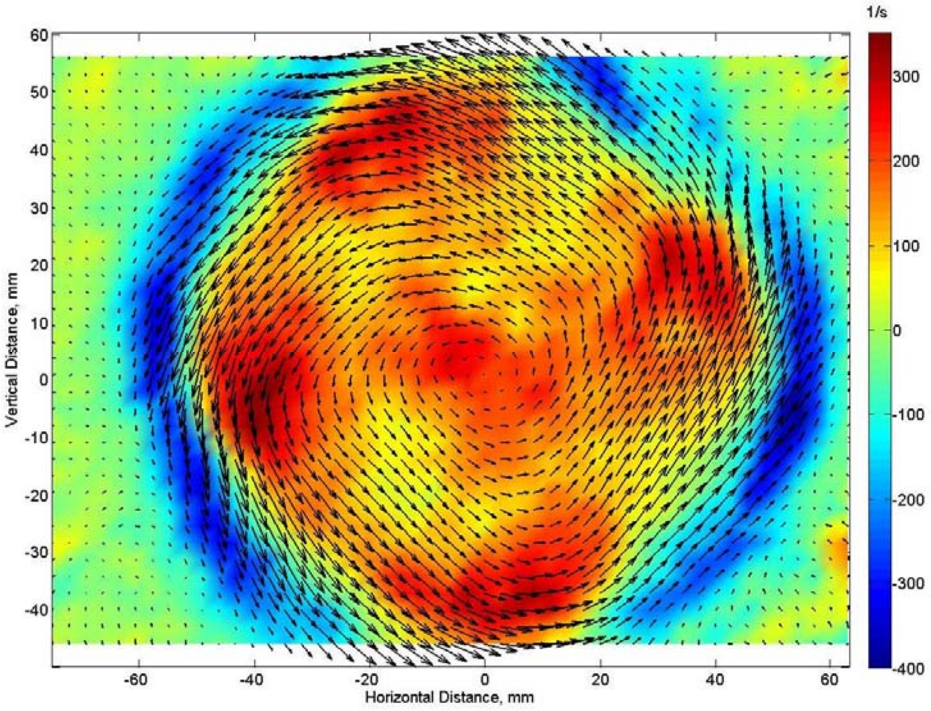


Air Only – Turbulator On

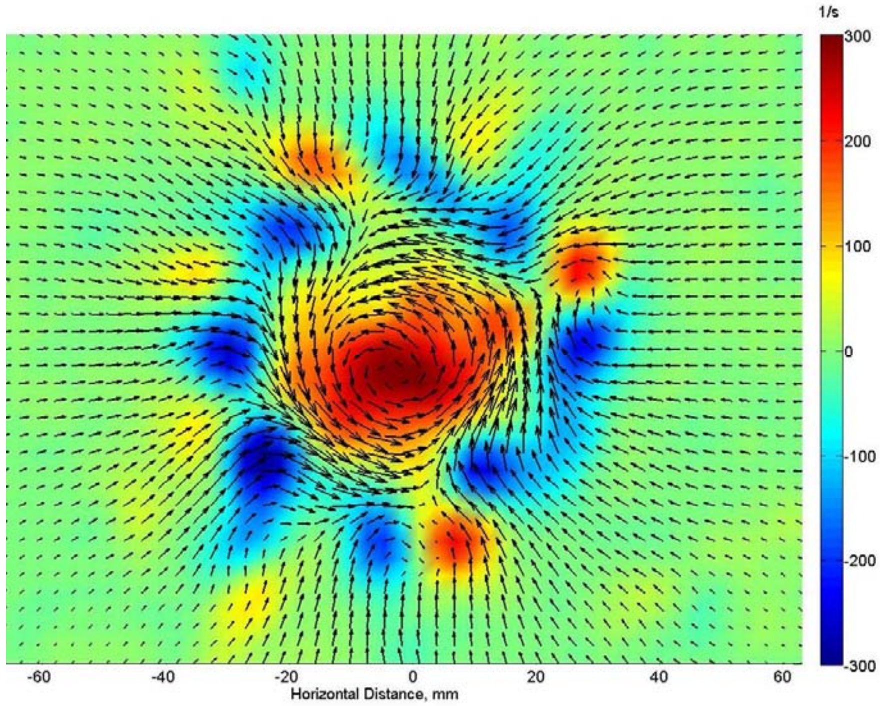


Comparison – Vorticity

Air Only – Turbulator Off



Air Only – Turbulator On



Analysis

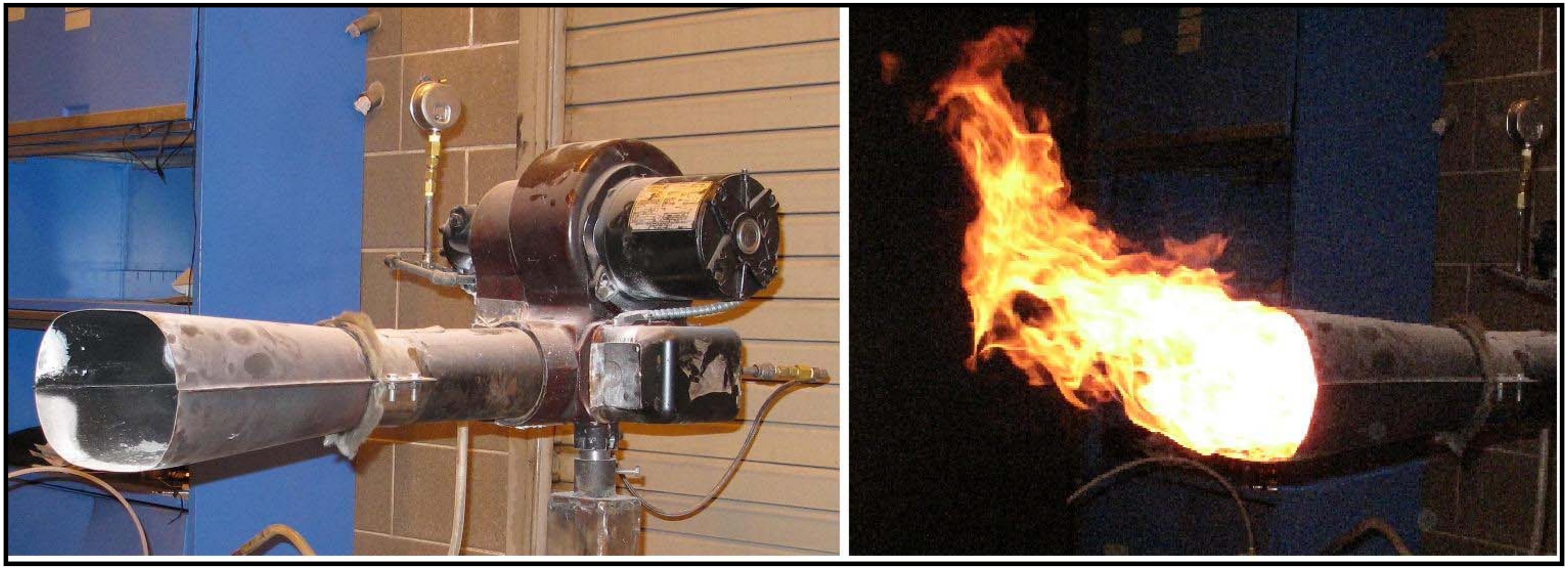
- The effect of the turbulator is apparent in the flow field
- The magnitude of the velocity on the periphery of the flow field is significantly reduced by the action of the turbulator, from ~4 m/s to ~1 m/s
- The regions of strong vorticity on the edges of the flow are compressed into the central region of the flow by the turbulator
- This centralized high rotation region is intended to interact with the high mass, high momentum fuel droplets in the spray cone

Future Measurements

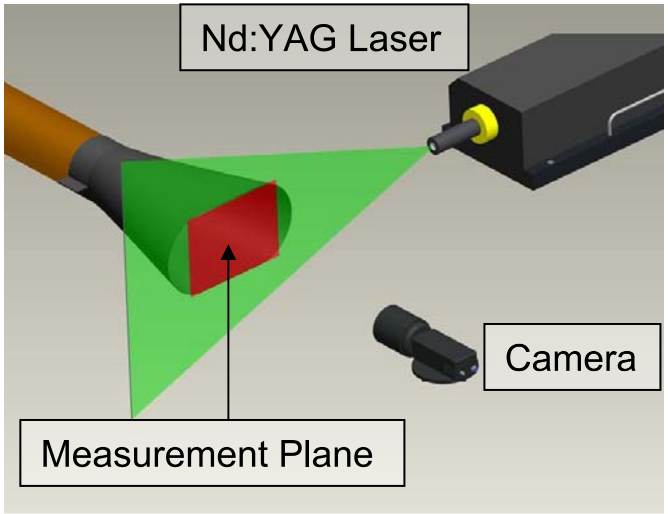
- **Make similar iterative measurements at locations downstream**
  - Study frequency and behavior of flow as a function of axial location
  - This may give insight into optimal location, position of stator and turbulator
- **Perform same measurements, study effect of variables**
  - Air flow rate
  - Air temperature
  - Fuel spray as seeding

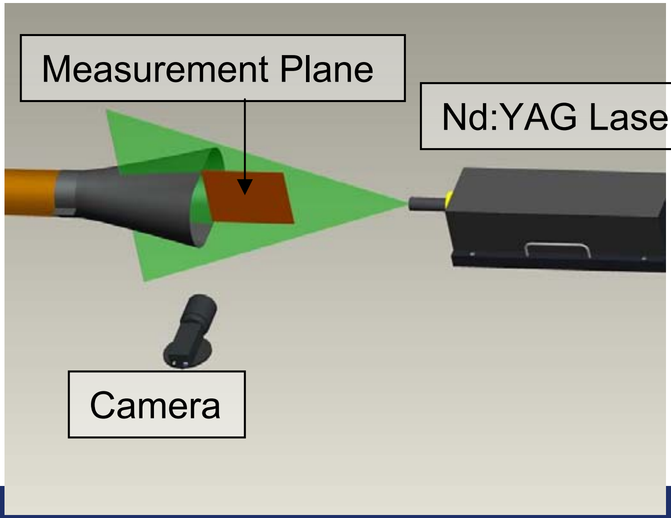
Preliminary Flame Measurements

- Initial measurements were made on the burner flame approx 3 inches from burner cone exit plane
- Narrow band filters were necessary to block all wavelengths except for 532 nm laser light
- Flame is extremely luminous, soot emission at 532 is much stronger than seed particle emission
- An external electro-optic shutter is necessary to avoid over-lightening of the second frame

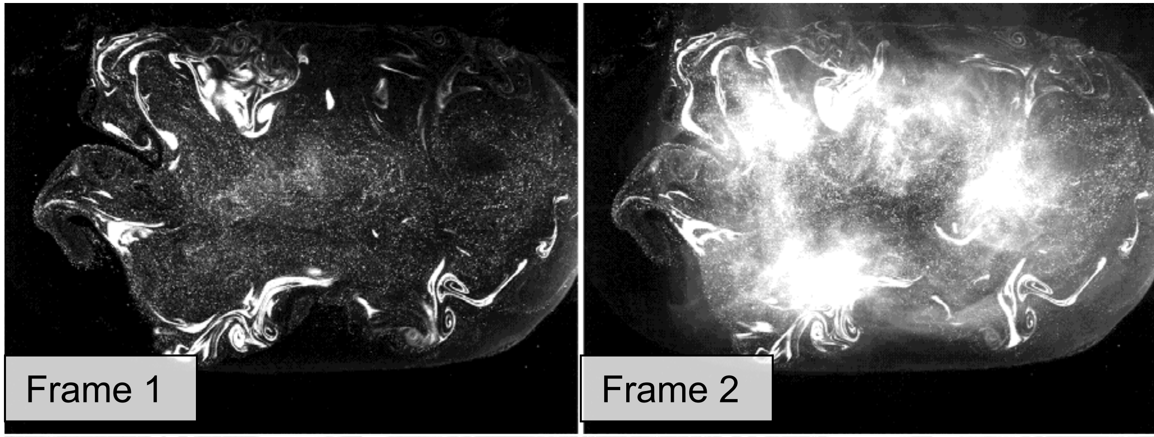


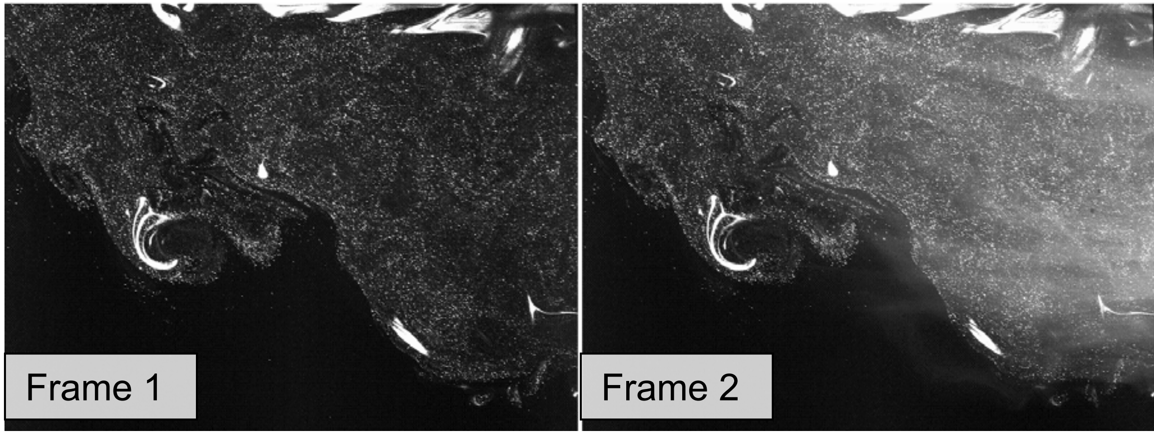
Acquired Images – Single Camera





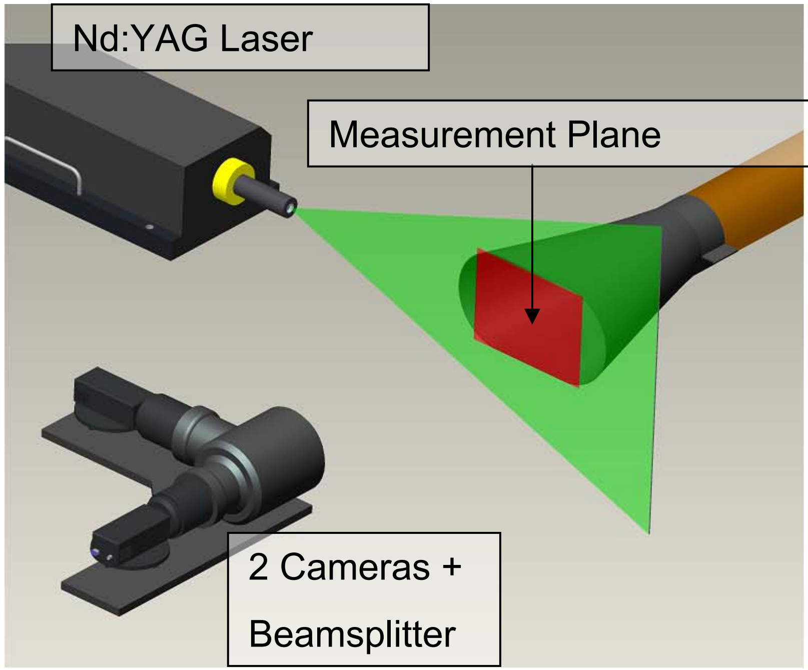
Parallel Plane

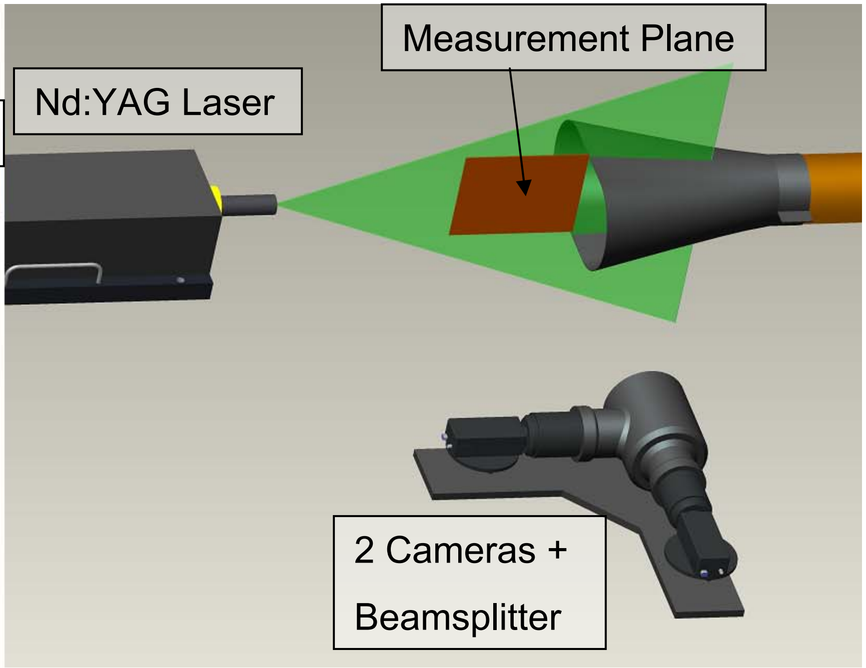




Normal Plane

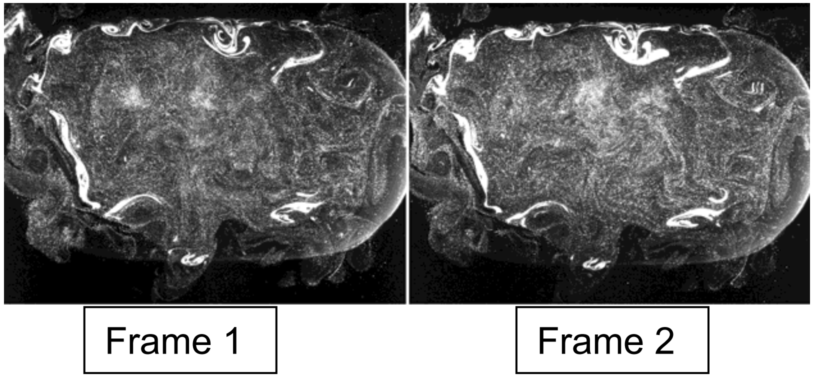
Acquired Images – Dual Camera

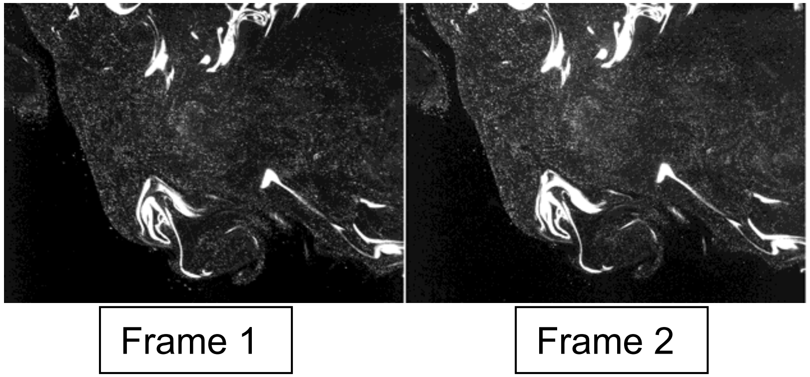




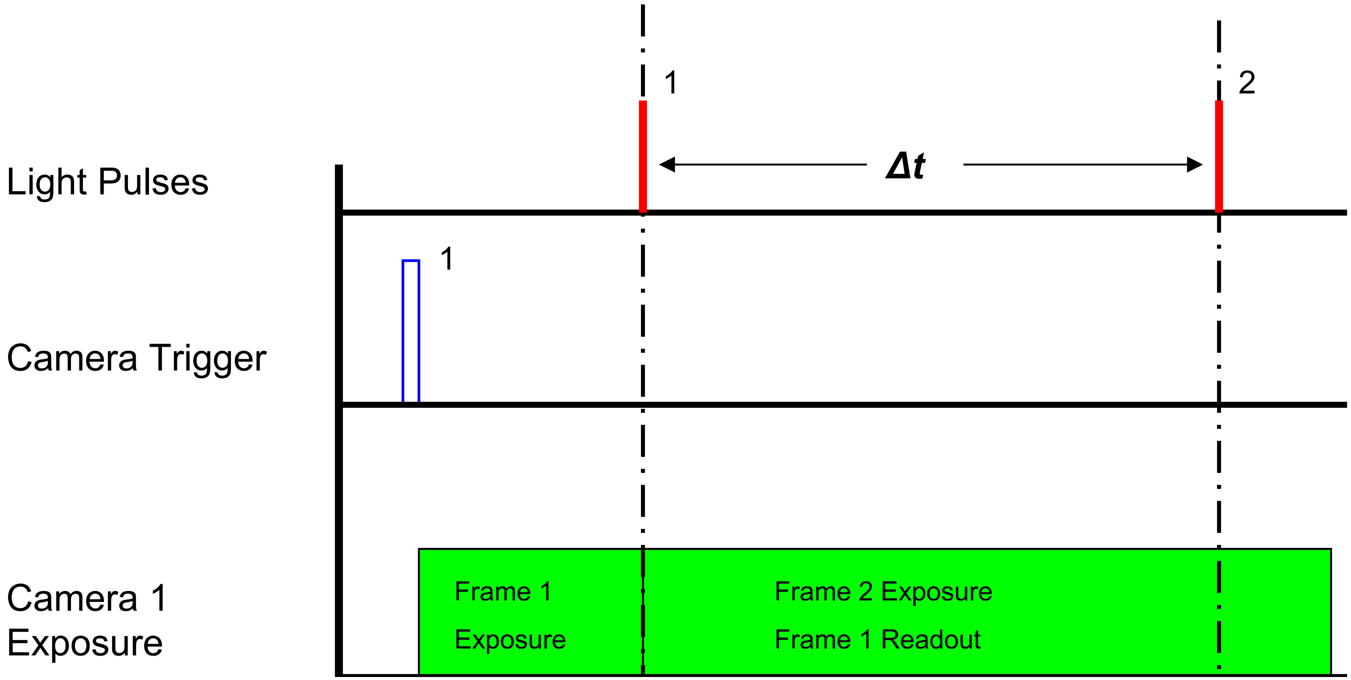
Parallel Plane

Normal Plane

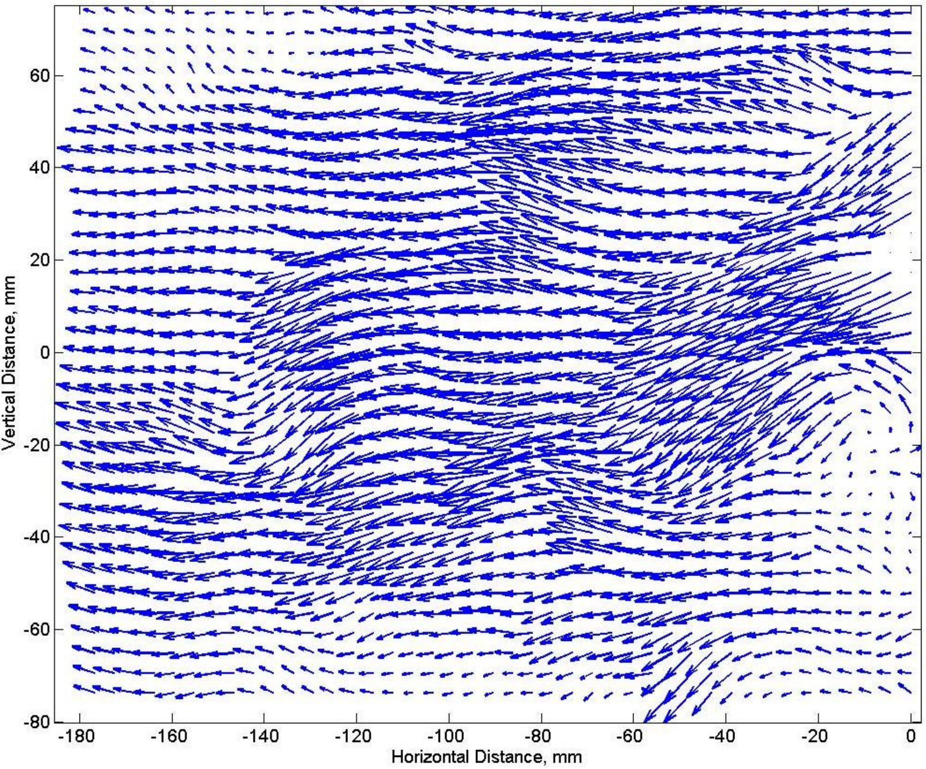




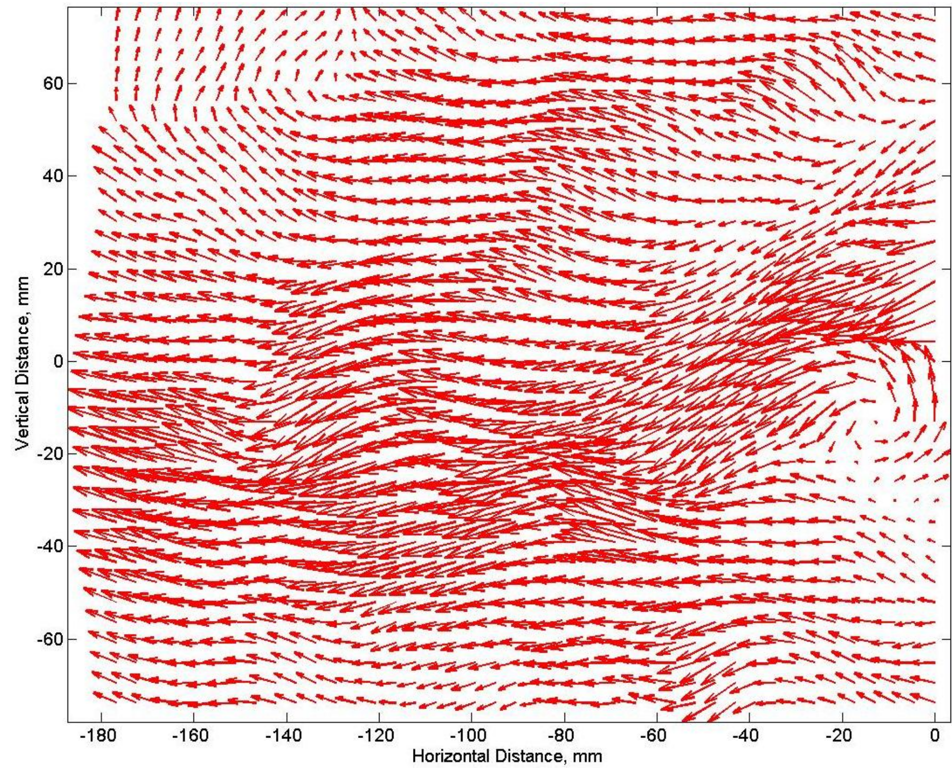
Timing Diagram



Dual Camera Method Validation

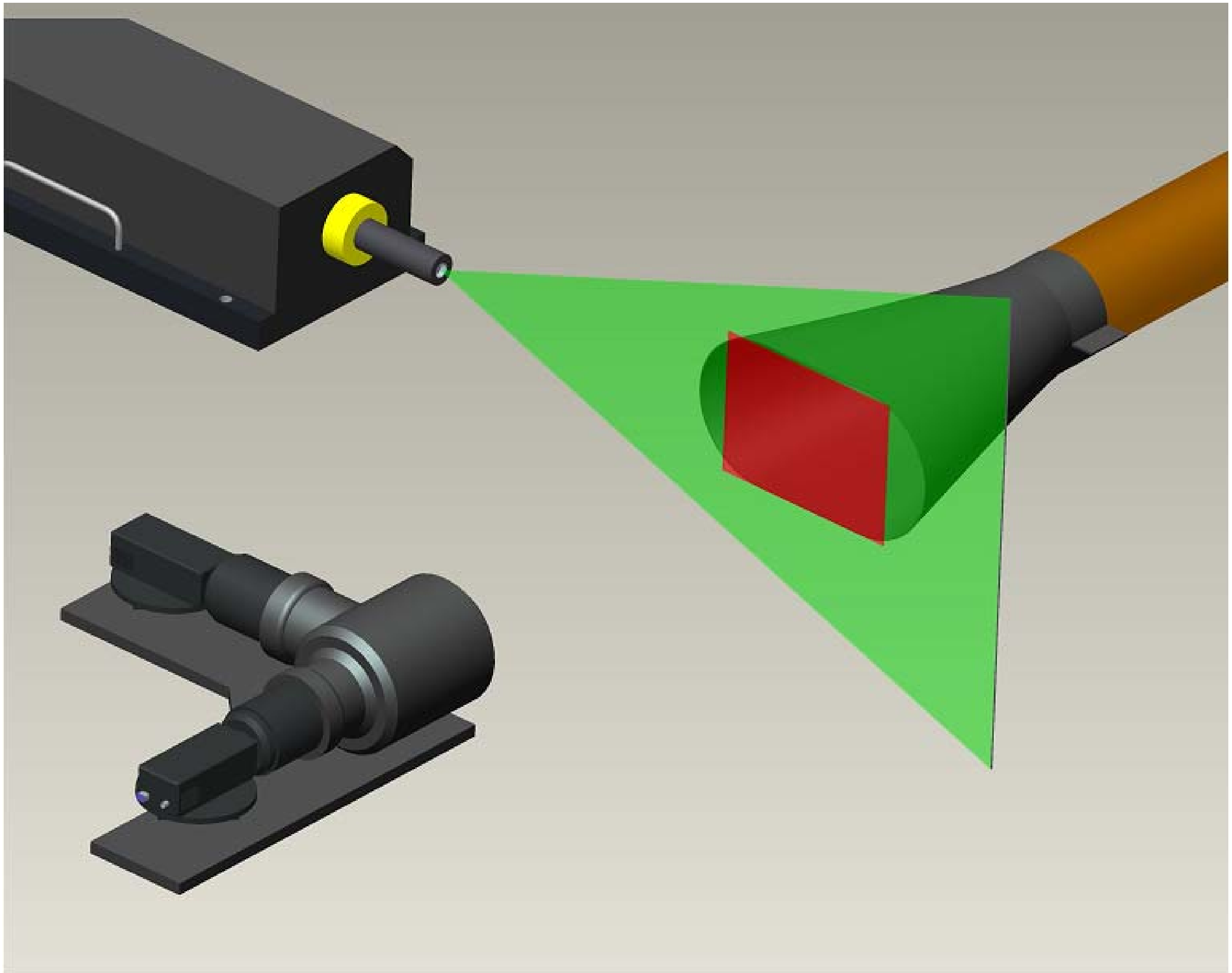


Camera 1 Frames 1 and 2

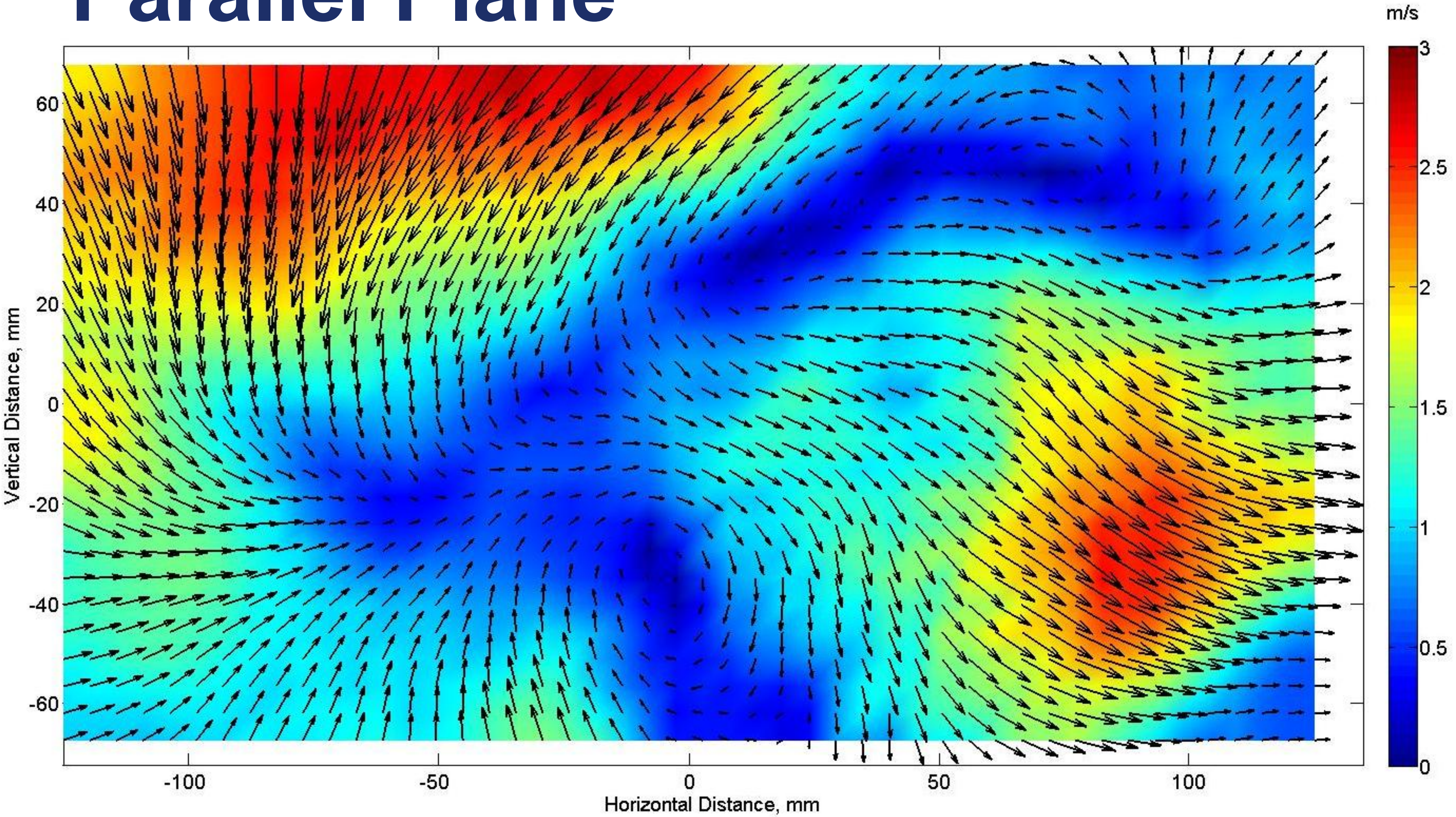


Camera 1 Frame 1 and Camera 2 Frame 1

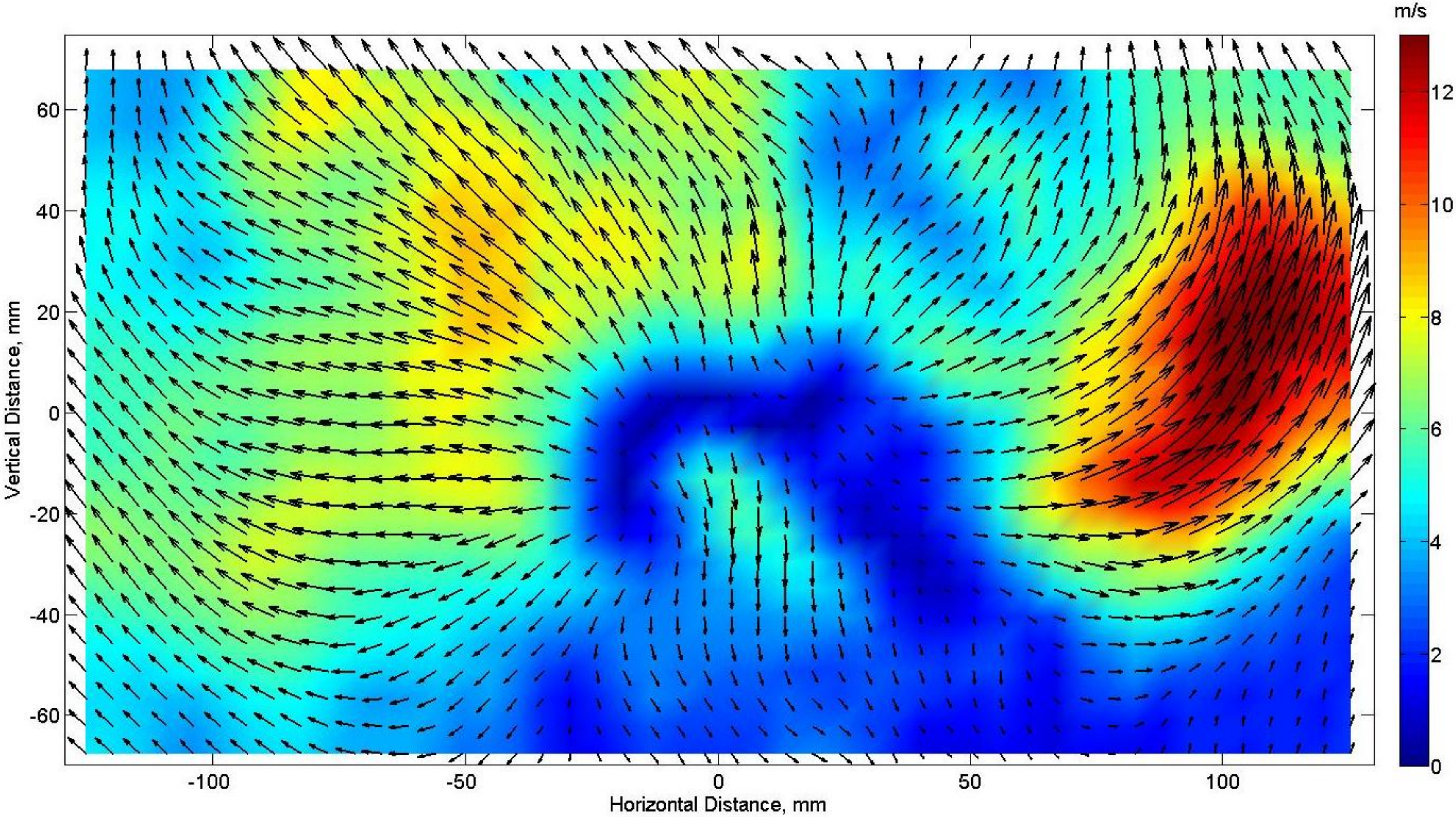
Parallel Plane



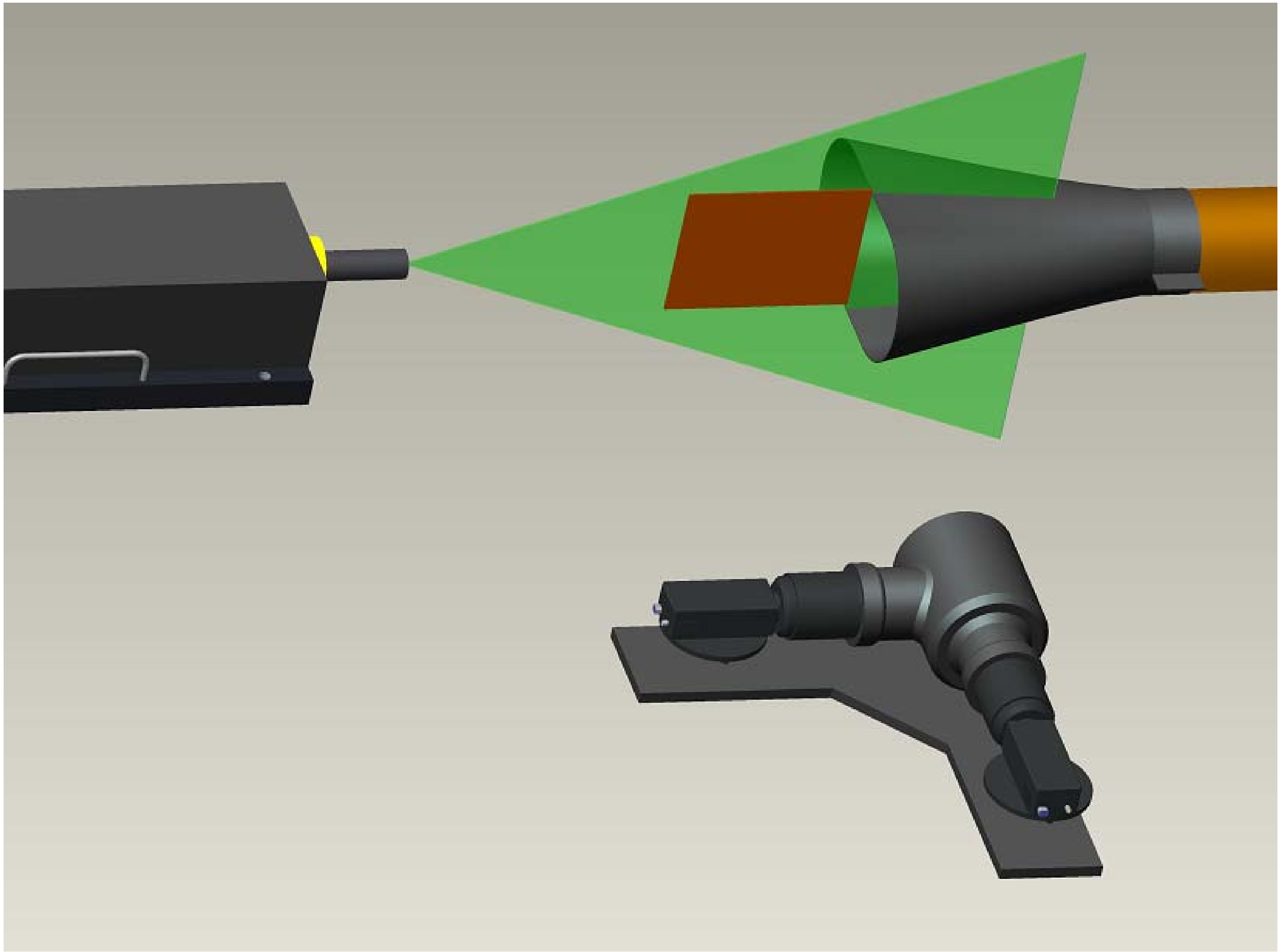
Mean Velocity – Non-Reacting Parallel Plane



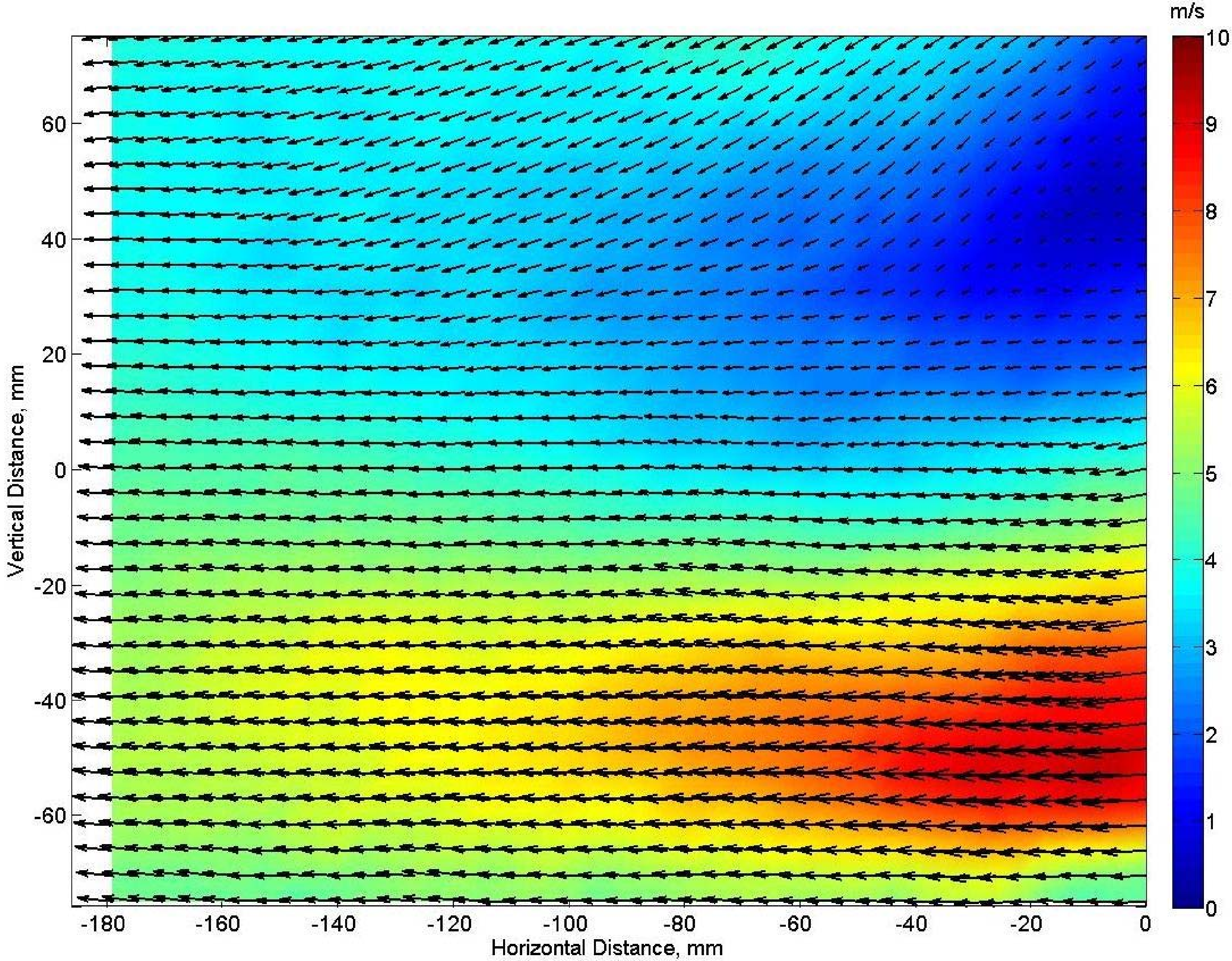
Hot Flow Parallel



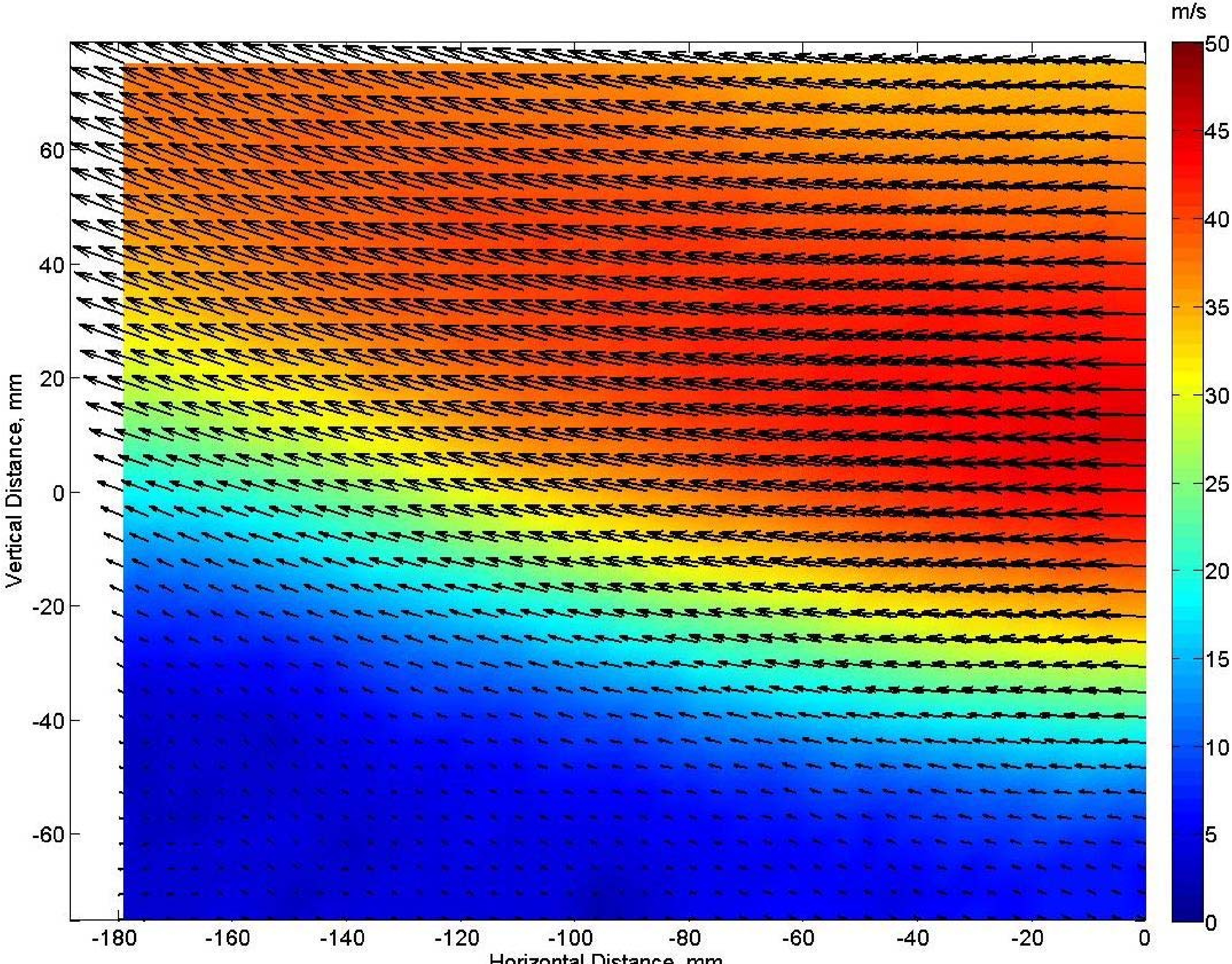
Normal Plane



Cold Flow Normal



Hot Flow Normal



Summary

- PIV can be used to analyze the various components of the FAA Fire Test Burner
- Successful measurements were made of the burner exit air flow
- A dual camera and beam splitter arrangement was successfully used to obtain two frames for performing PIV in a highly sooting, turbulent burner flame

NexGen, Burnthrough, and PIV Task Group

- Discussion of measurements performed
- Measurement suggestions
- Other uses of PIV relevant to Materials Working Group

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