# 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 – Atlantic City, NJ

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# 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

- **Identify key parameters**
  - Burner operation is known to be dependent upon many factors
  - All relevant factors must be identified and ranked in order of their impact on burner performance
    - Fuel spray
    - Air flow
    - Burner geometry
    - External effects
    - etc, etc, etc…
- **Improve design**
  - Burner is no longer manufactured or available for purchase
  - An equivalent burner must be made available to industry for certifying materials and designs
  - The overall performance, repeatability, and reproducibility of the burner should be improved
  - The burner should be specified such that it can be easily manufactured from readily available materials
  - Optimization of the burner by manipulating the key parameters to provide for an overall better burner design

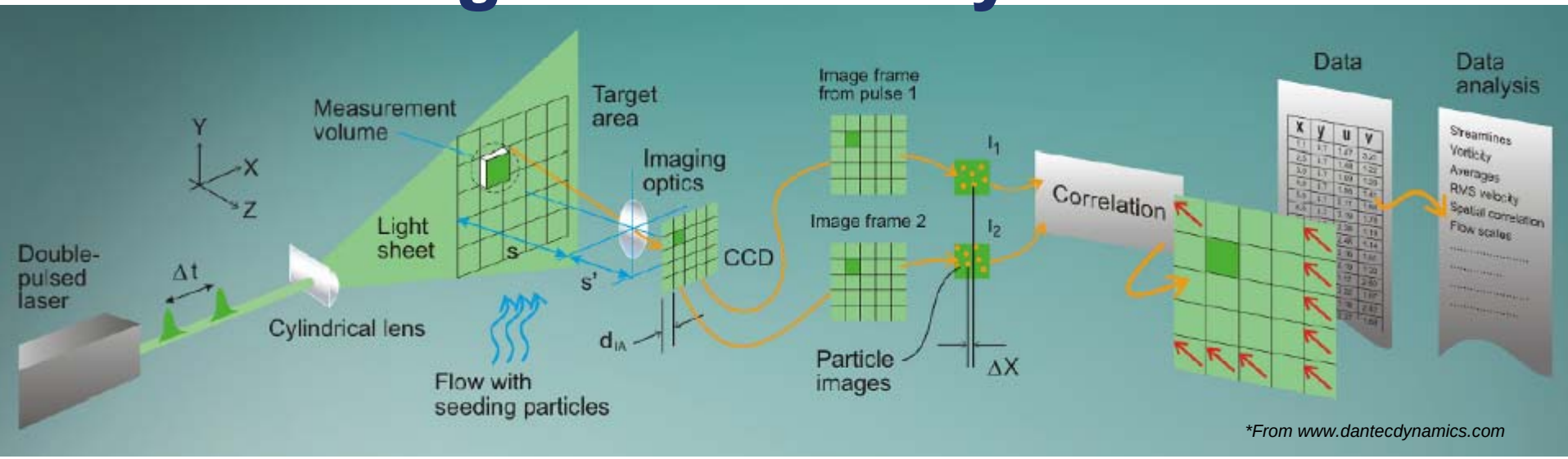
# Methodology

- **Utilize flow measurement techniques to study the operation of the burner and assess each component or parameter**

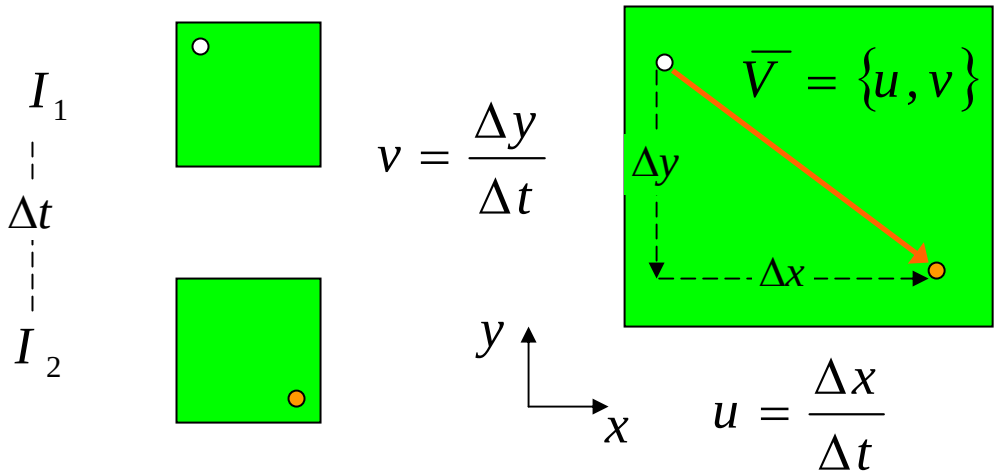
- **Selection of a technique:**
  - Hot Wire Anemometry
  - Laser Doppler Anemometry
  - Particle Image Velocimetry

- **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




- **Particle Image Velocimetry (PIV) is a whole-flow-field visualization technique that provides instantaneous velocity vector measurements in a cross-section of a flow**



# PIV Methodology

- **PIV relies on laser light scattered by particles following a flow**
  - Any particle that follows the flow satisfactorily and scatters enough light to be captured by the camera can be used (particles ~ 5-100 µm)
  - Particle density is critical to achieving a good measurement – anywhere from 10-25 particles per interrogation area window is satisfactory
  - Some flows require seeding to be entrained in the flow (air) while other flows require no seeding (sprays)
- **Resolution and range dictated by particle velocity**
  - Within an interrogation window, particles should move a distance of approx 25% of the window length
  - If a particle moves too far, it will leave the interrogation window and correlation will be lost
  - Pulse width must be timed as to “freeze” the flow
    - Narrow pulse width leads to lack of scattered light
    - Wide pulse width leads to streaking of particles
  - All of these parameters must be optimized to obtain a good measurement

# PIV for Fire Safety

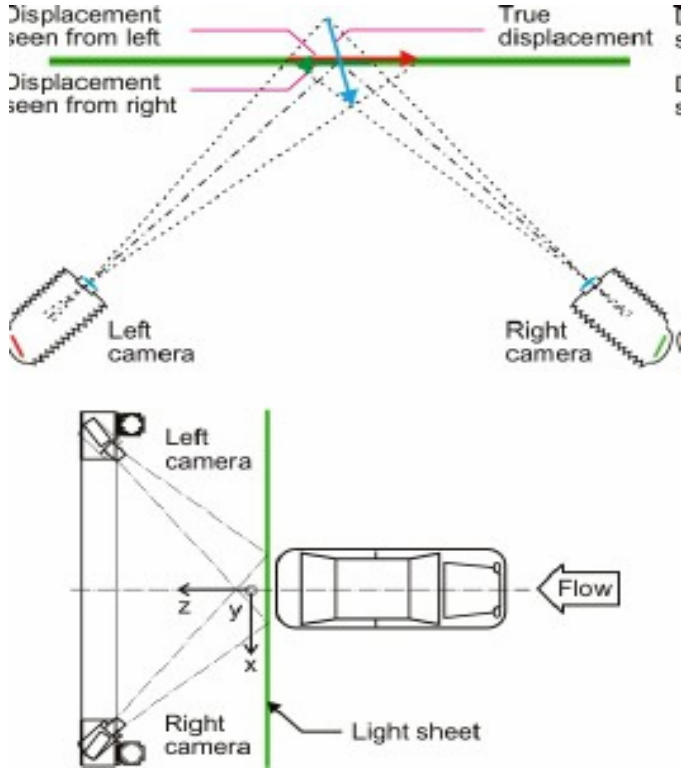
- **Material fire test methods dependent upon accuracy of test methods**
  - Fire test methods involve burners
    - Burners are driven by fluid-thermal processes
    - Test results are completely dependent upon these processes
    - Insight into the fundamental burner parameters will lead to optimization of these parameters
    - Optimization leads to increased level of accuracy and increased confidence in the burner's repeatability and reproducibility
    - With modern materials processing technology and increased levels of industrial quality control, a more clearly defined level of failure is desired so that manufacturers can design to a specific level of safety
  - Analysis of post-crash fuel fires
    - Visualization of the flow field created by a pool fire
    - Analysis of flame impingement on a fuselage
- **Other uses**
  - Visualization of fluid flow within an enclosure
    - Smoke spread from a fire in a cargo compartment or cabin
    - Extinguishment agent propagation for fire suppression
    - Nitrogen dispersion in a partitioned fuel tank or in cabin
  - Sprays
    - Water mist
    - Extinguishment agent sprays

# Fire Safety's PIV Laboratory

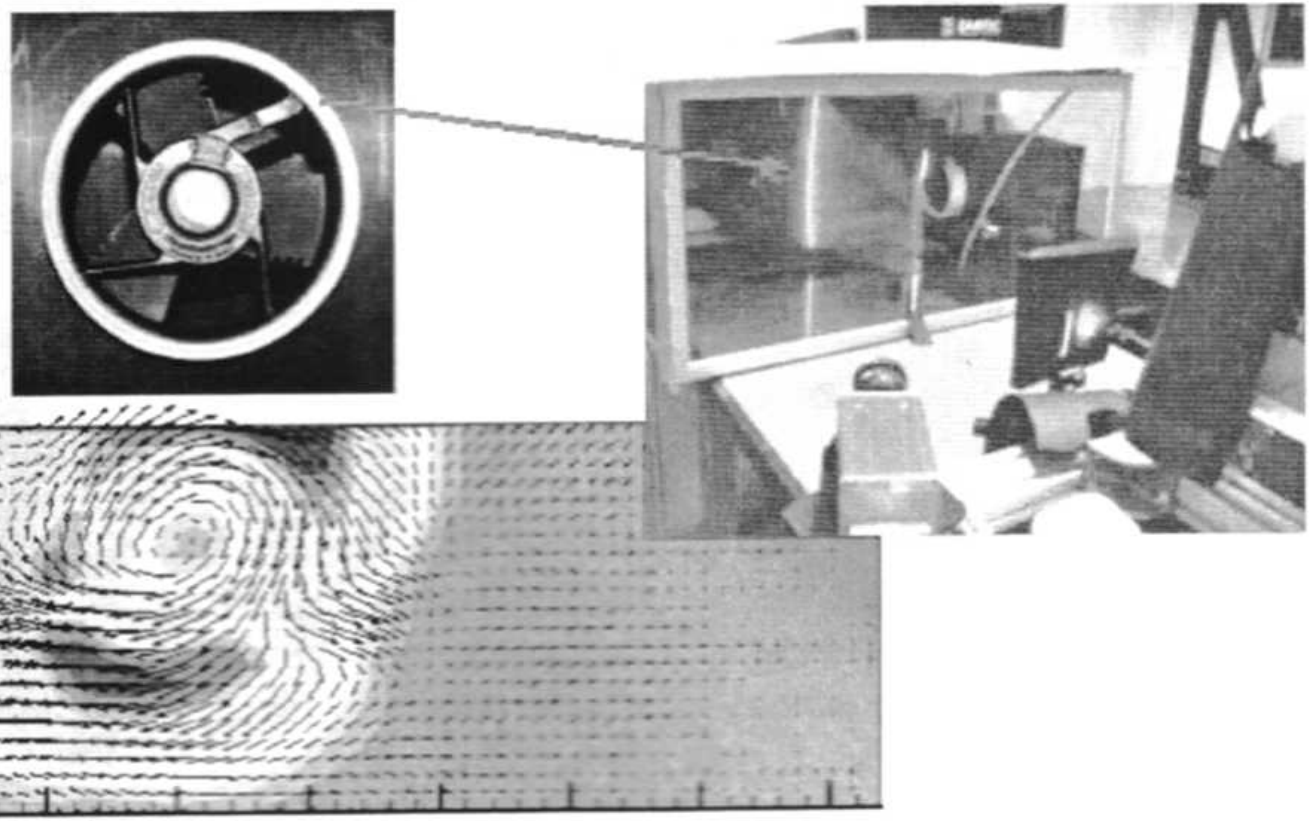
- **Dantec Dynamics 2D PIV system**
  - 2 FlowSense 2M cameras
  - SOLO PIV 120XT laser
  - PC with Dynamic Studio software for analyzing PIV images
  - Scheimpflug Camera Mounts
  - Beam Splitter
- **Current status**
  - Laboratory is on-line
- **Planned activities**
  - Analysis of oil burner
    - Nozzle spray
      - Identify key features of nozzle flow
      - Volume mapping of a nozzle spray, identify symmetry or asymmetry
      - Compare nozzles of same type and of different type
      - Determine optimal nozzle type, manufacturer, or seek to develop a new nozzle
    - Air flow
      - Visualization of the burner exit flow field in different planes
      - Identify the parameters that lead to a more uniform flow field
    - Combined air and fuel flow
      - Determine optimal setting for air-fuel droplet mixing
    - Analysis of flame
      - Determine if flame is seeded with enough soot particles for good PIV measurements
      - Measure flame velocity field and determine if optimal burner settings lead to optimal flame

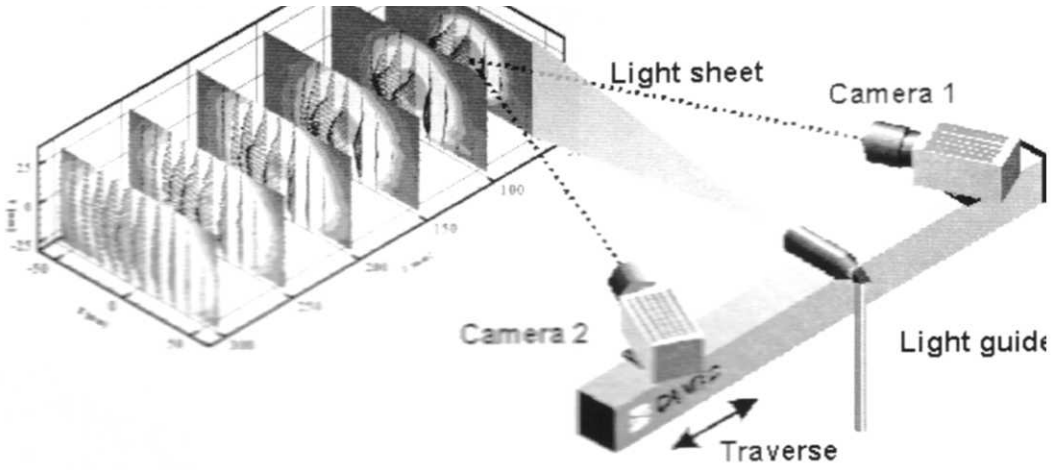
# Stereoscopic 3D PIV

- Based on same fundamental principle as human eyesight
  - "When we look at a given object, our left and right eyes see two similar but not identical images. The brain compares the two images and interprets the slight variations to rebuild the three dimensional information of the object observed."
    - 2 cameras → 2 eyes
    - Computer and software → brain
- We use this technique to obtain the out-of-plane velocity component (z)
- This is used to fully characterize the flow in a plane, and can give information on the swirl of the flow



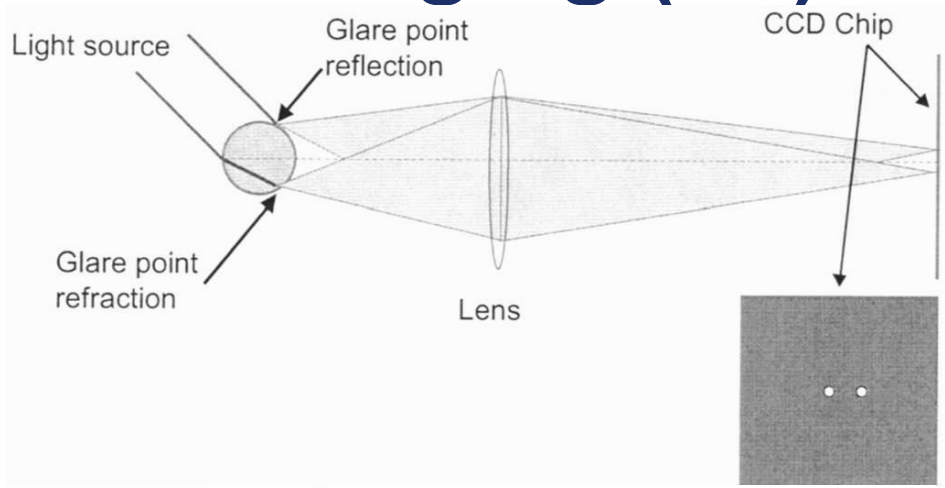
# Stereoscopic 3D PIV

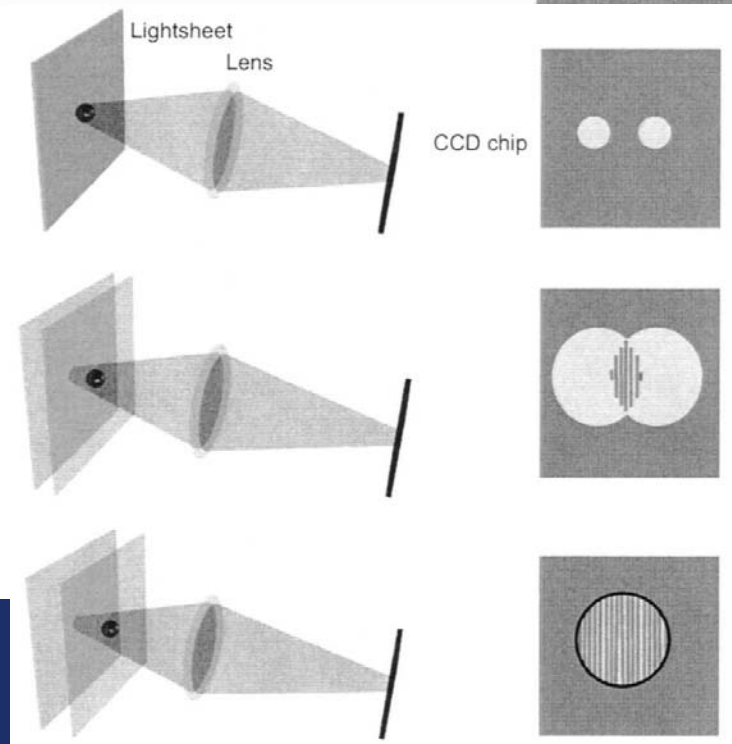


# Interferometric Particle Imaging (IPI)

- Based on the interference of the relection and refraction glare points from an illuminated transparent particle
- 2 cameras see the same image, one is focused, the other defocused
- As the degree of defocusing increases, the two glare points merge into one single unified image with interference fringes
- It is possible to determine the distance between the glare points, or the size of the particle, from the frequency of the interference fringes in the defocused image.



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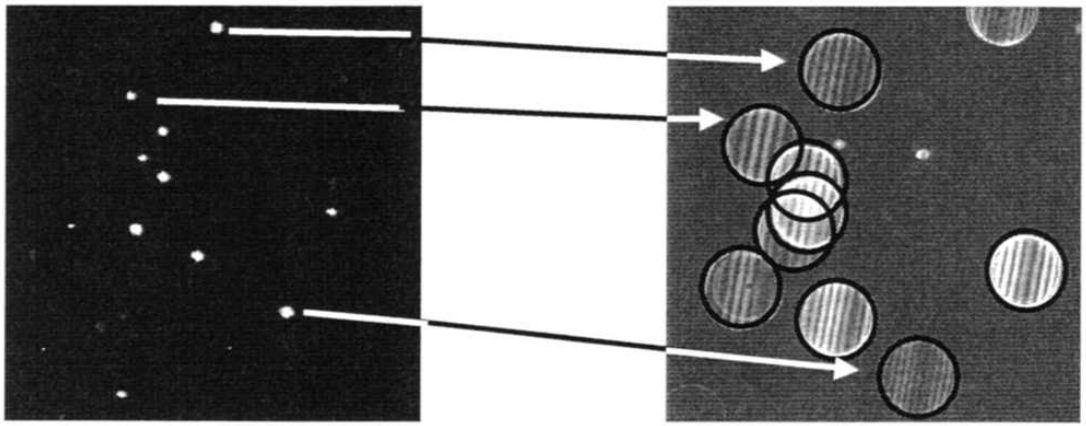
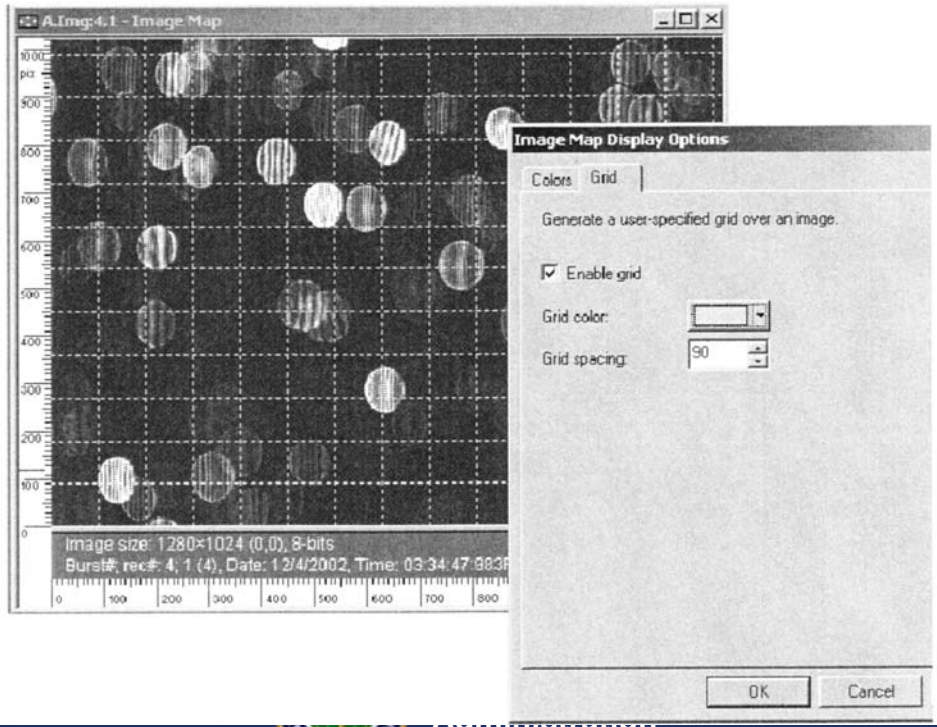
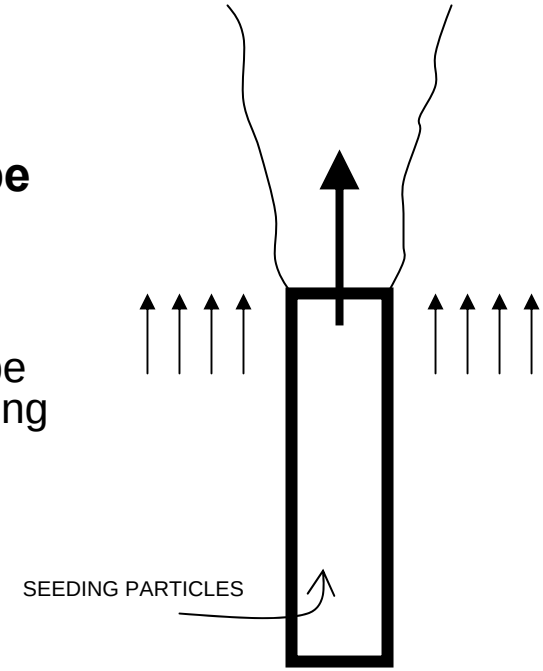


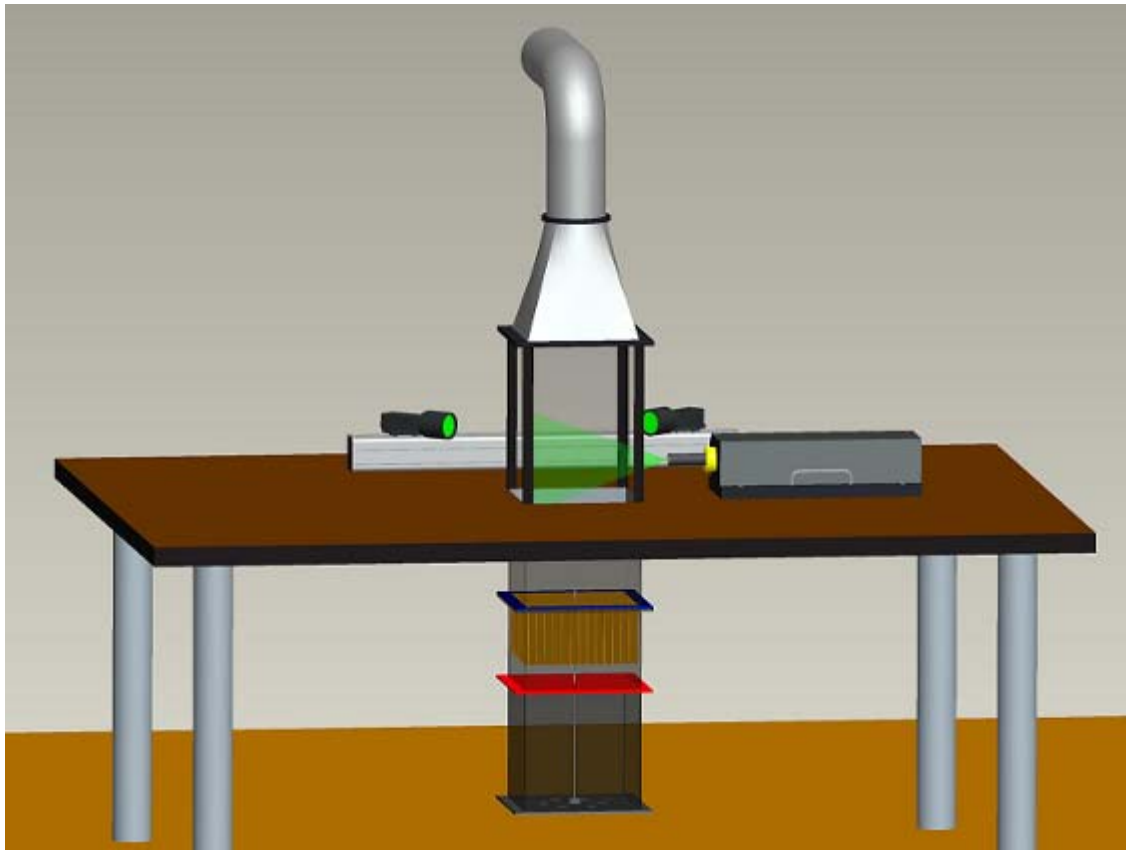


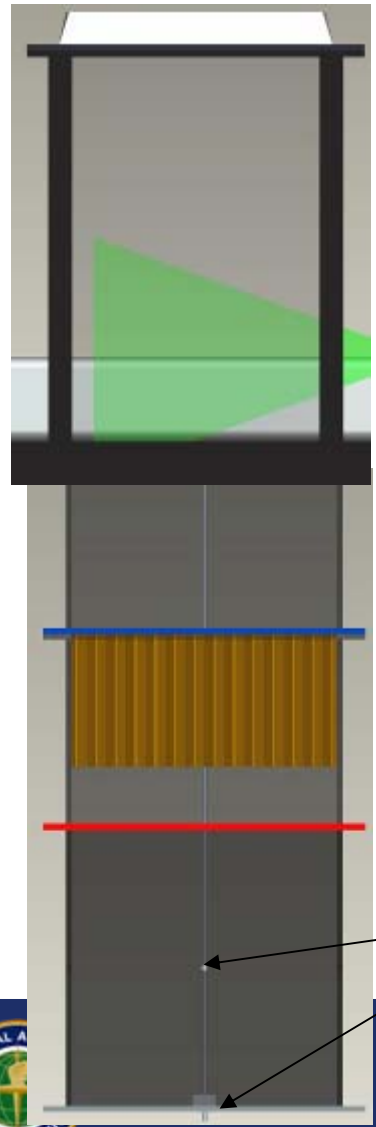
# PIV System Validation

- **Validation measurements must be performed initially**
  - Simple, widely studied experiments
  - Results obtained will be compared to pre-existing published data
- **Jet**
  - Non-reacting flow
  - Reacting flow
- **Jet is similar to a Bunsen burner**
  - Bunsen burner is also an FAA fire test method
  - Results will be useful for system validation and for FAA knowledge

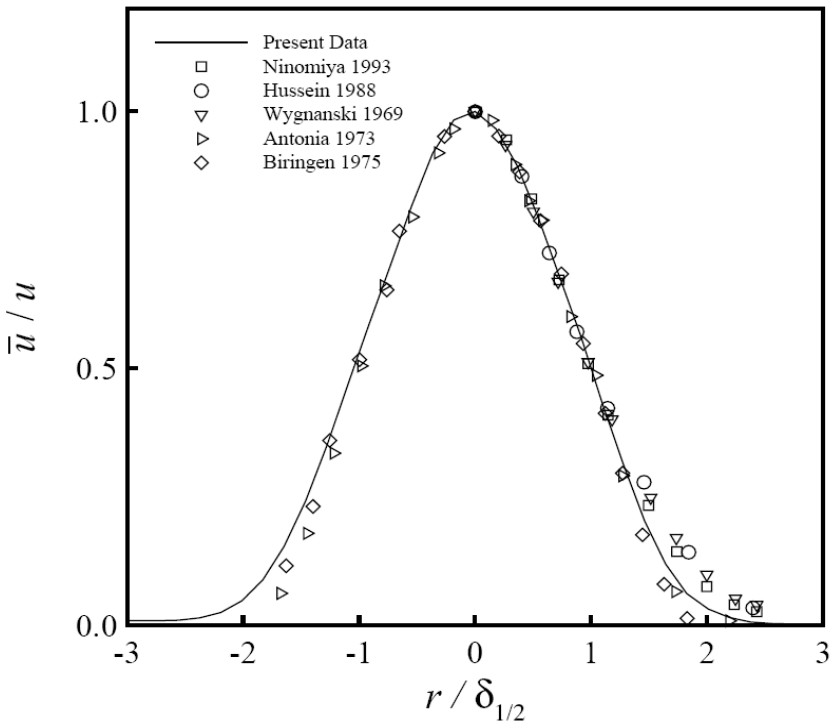



# Co-Flow Facility

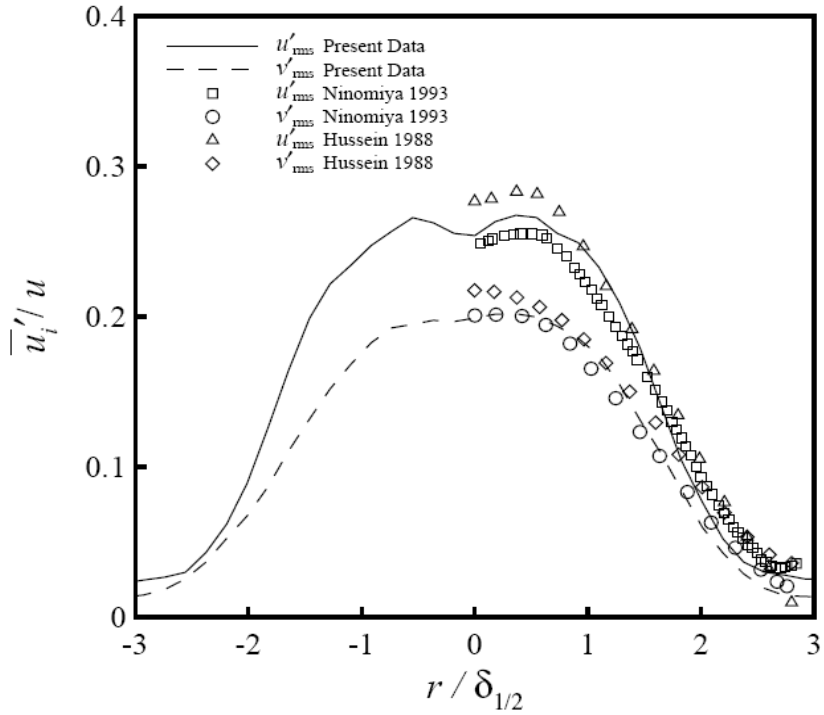




# Validation Data to Acquire




**Mean Streamwise Velocity ($U-U_\infty$)**




**Velocity fluctuations ($u_{rms}$ and $v_{rms}$)**

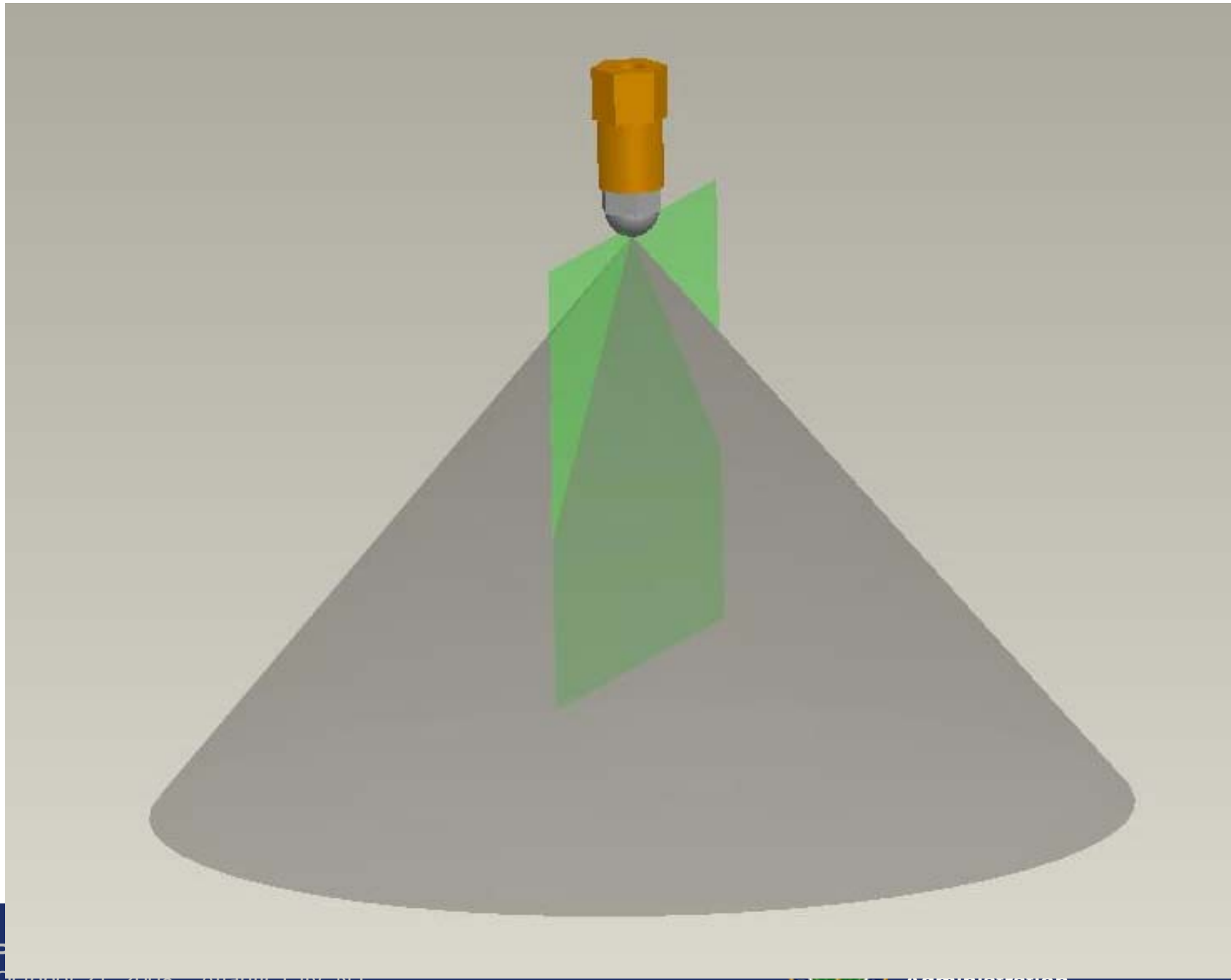
*From Mullin Ph.D. Thesis, U of Mich., 2004*

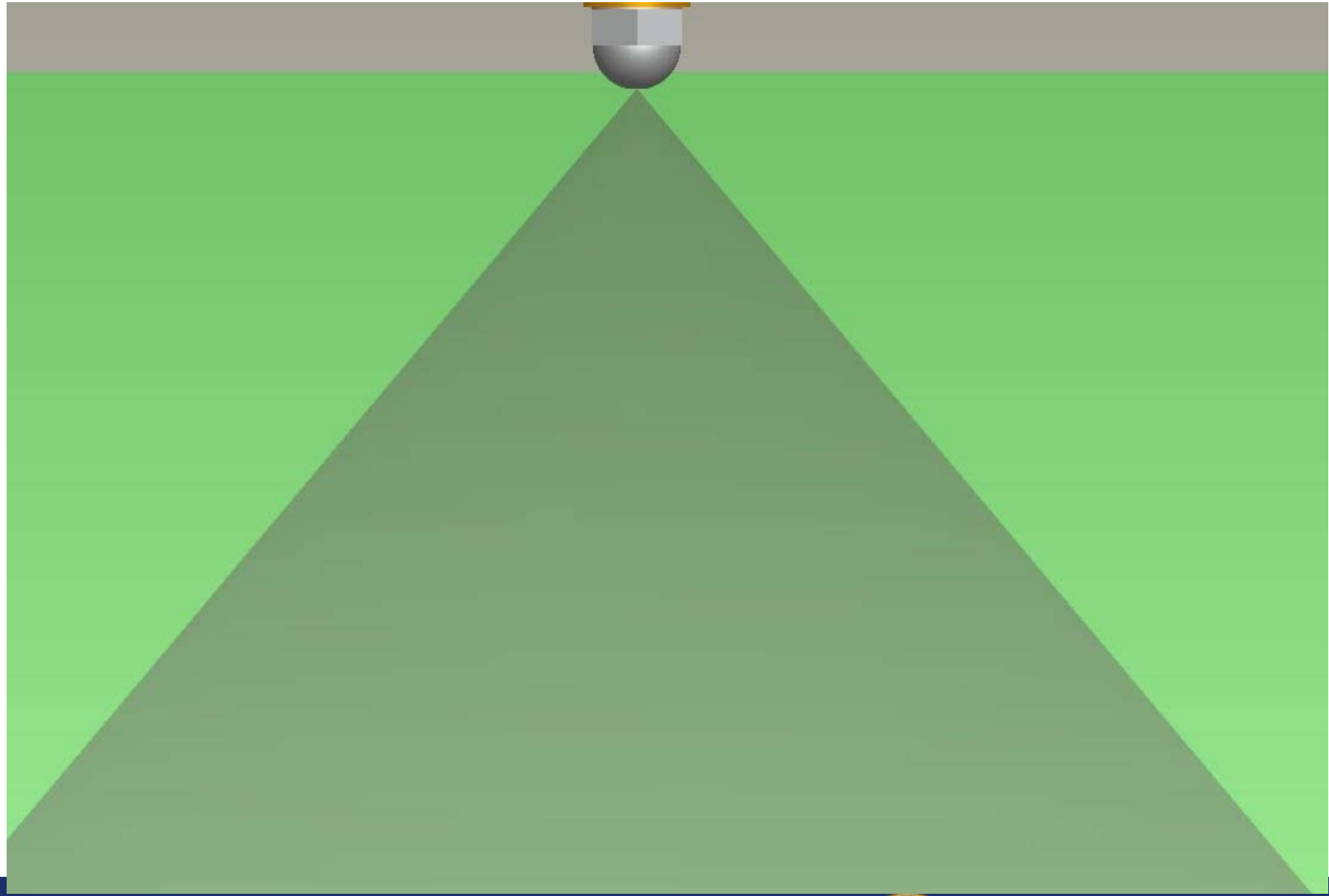
# Validation Data to Acquire

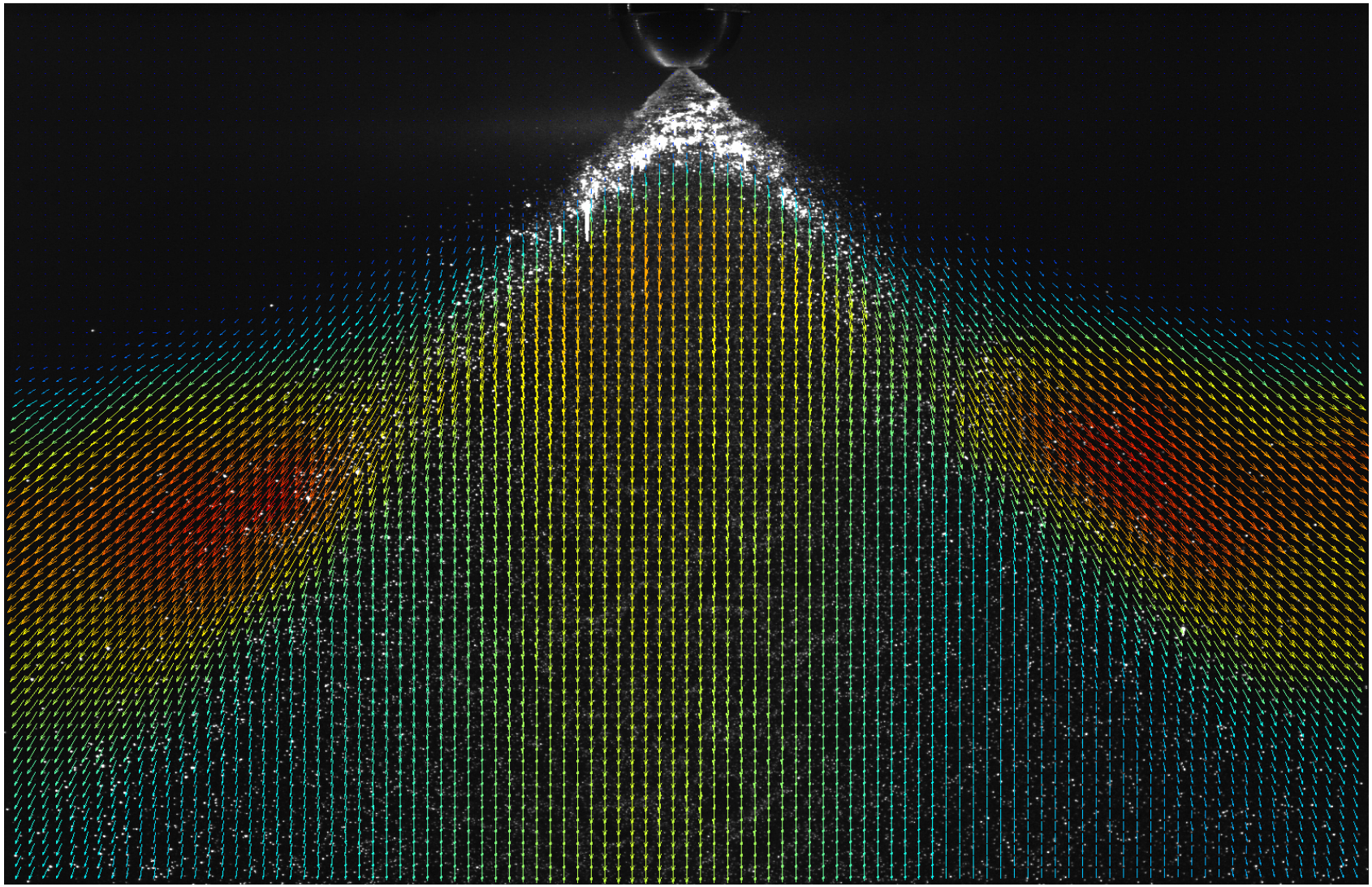
- **Once non-reacting jet has been validated in coflow facility, attempt reacting jet**
  - Hydrogen or Methane flame seeded with particles
  - Take measurements, compare with published reacting jet data
  - This will validate the system for use in reacting flows

# Acquired Data – Fuel Nozzle

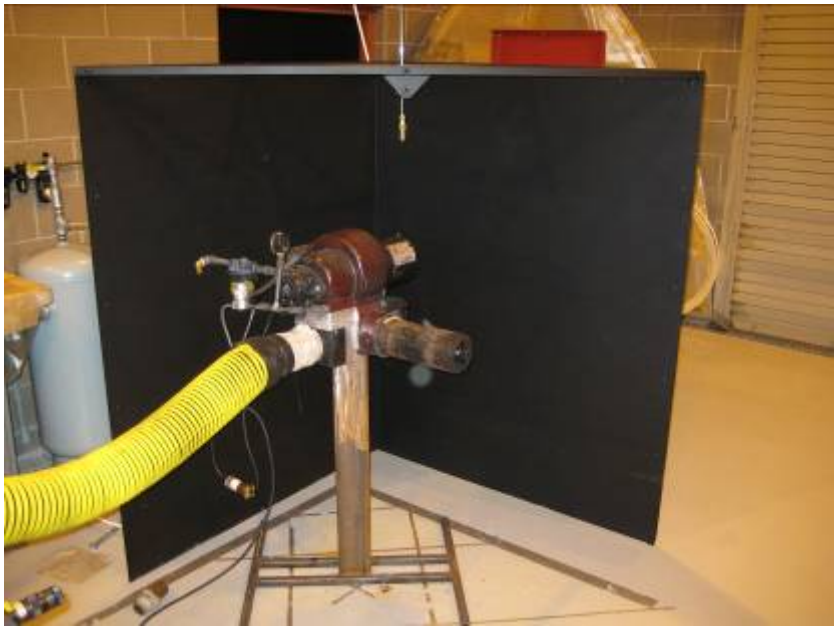
- An apparatus was constructed to hold an oil burner nozzle vertically while spraying down
- Water is used initially as it is easier to work with than jet fuel
- A pressurized tank was filled with water and compressed air to provide pressure
- A catch pan was made to collect all water
- A flat black backdrop was made of sheet metal to absorb stray laser light and provide a black background for easy visualization

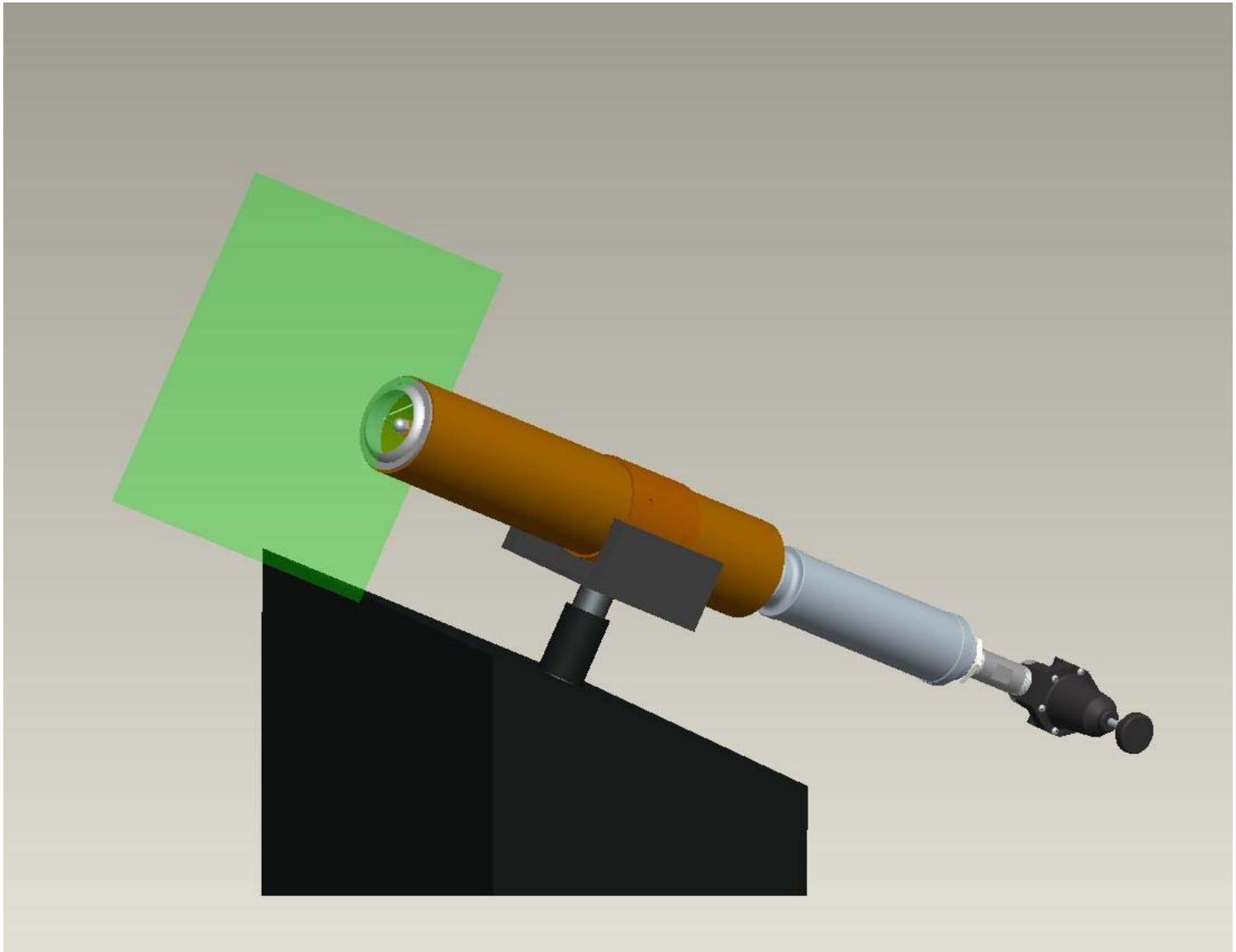


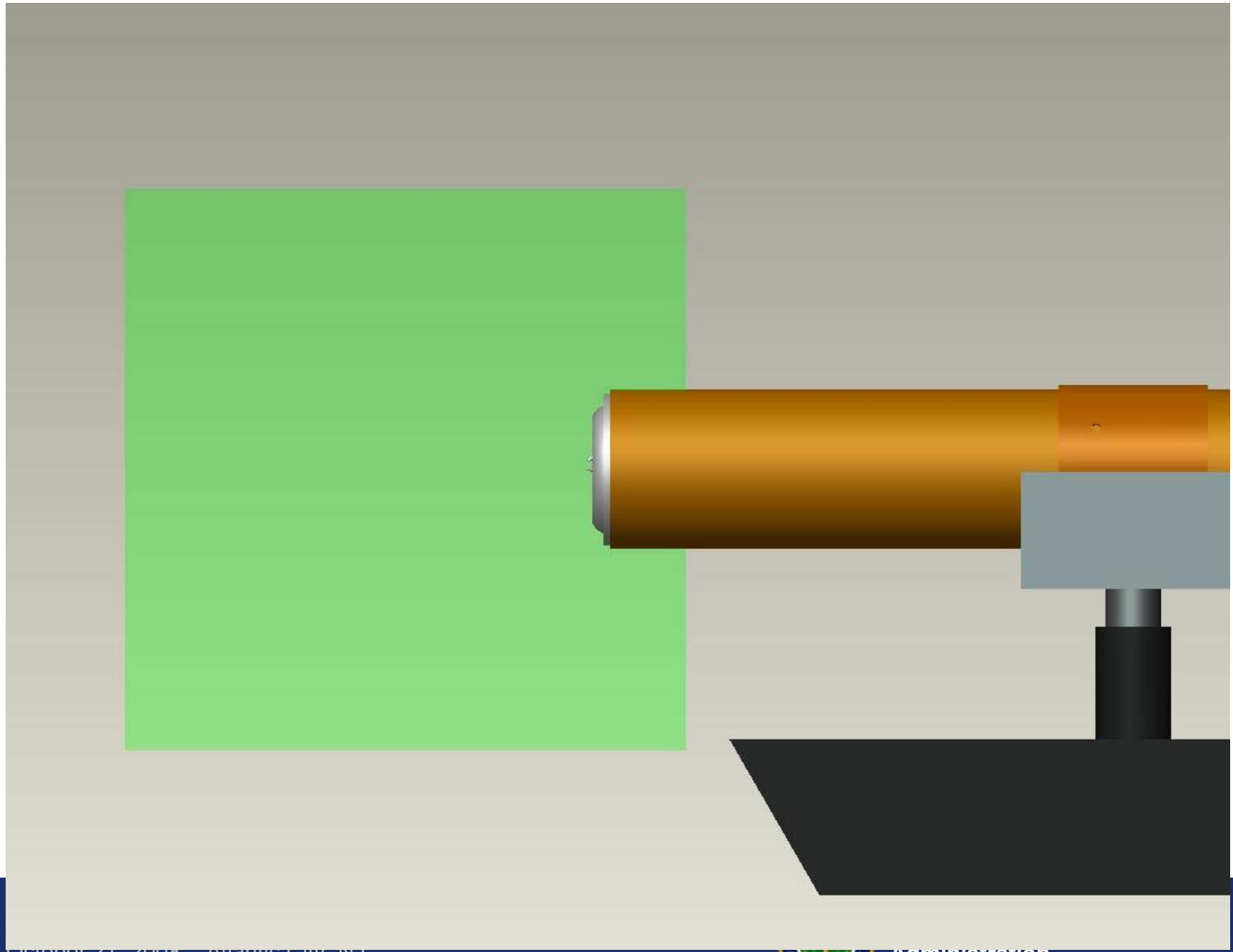


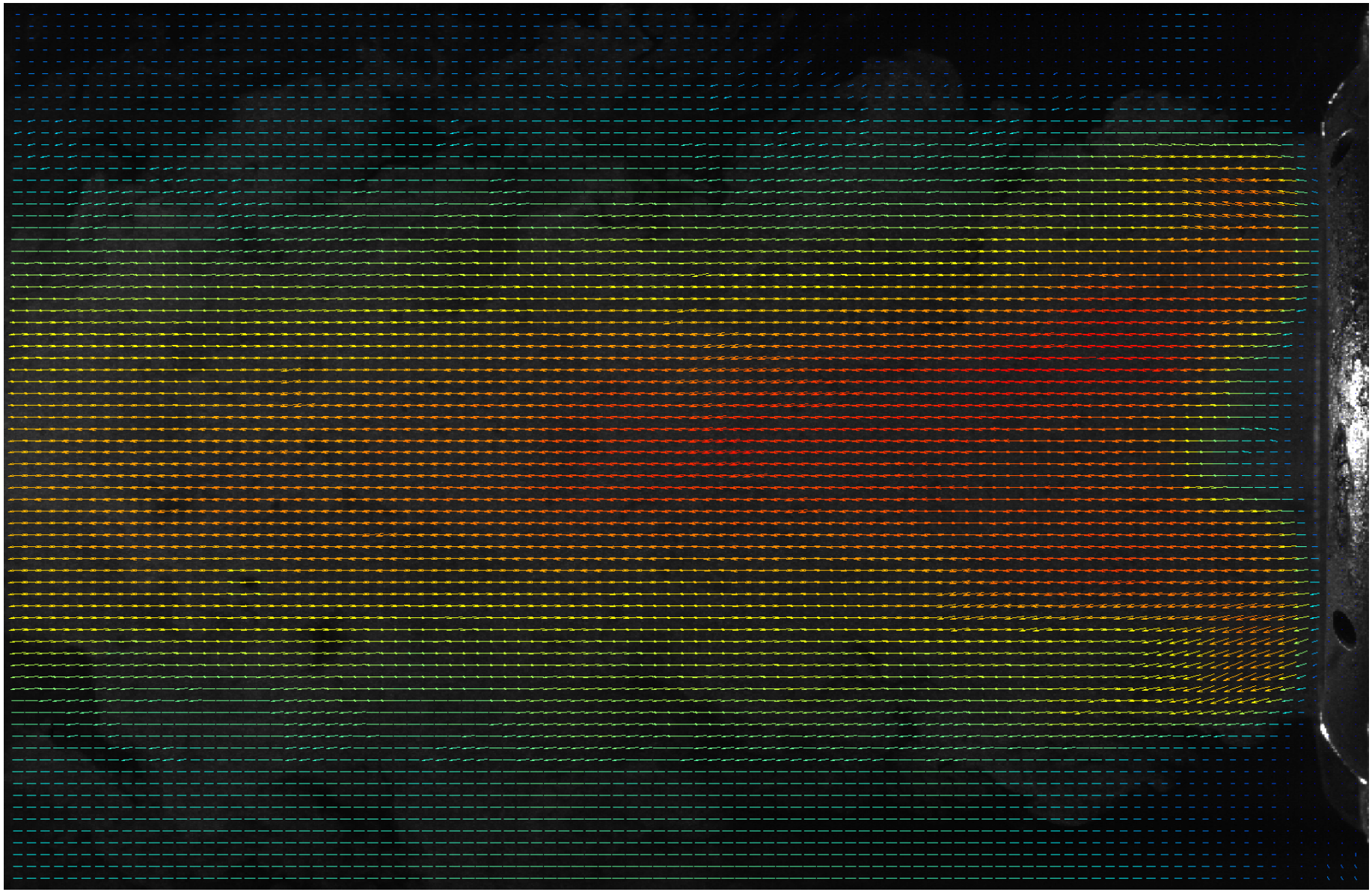


# Acquired Data – Burner Air Flow









# Burner Air Flow

# Future Work

- Refinement of PIV skills
- Create test matrix
- Perform measurements
- Analyze data
- Use knowledge to determine critical burner parameters
- Optimize burner parameters to provide more accurate results