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 – Niagara Falls, NY

By: Robert Ian Ochs

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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

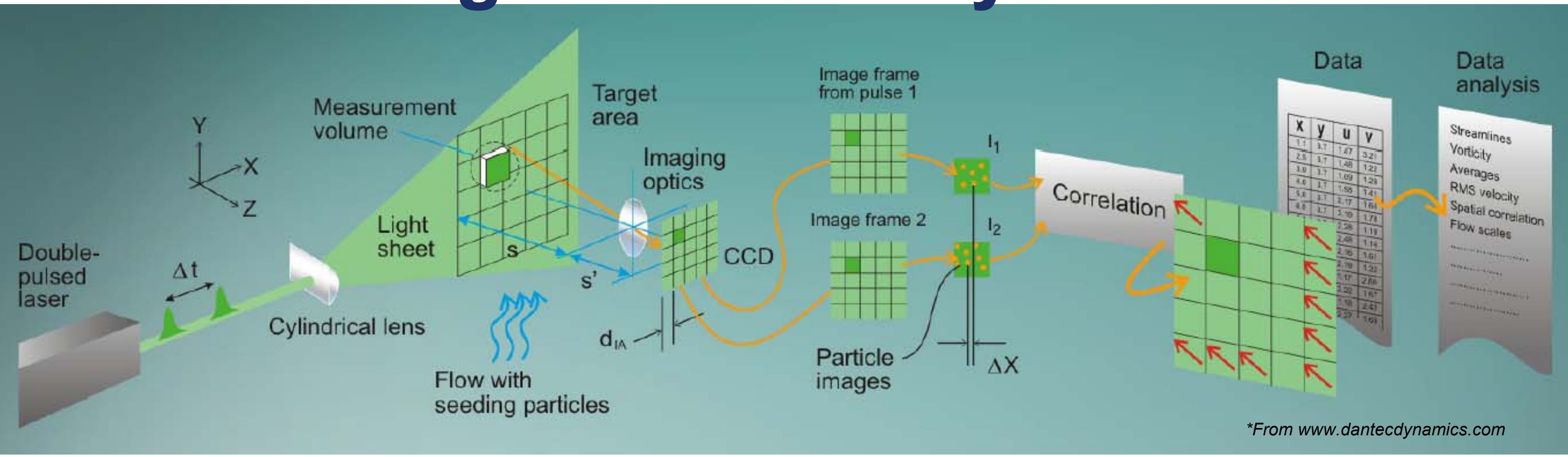
Objectives

- **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

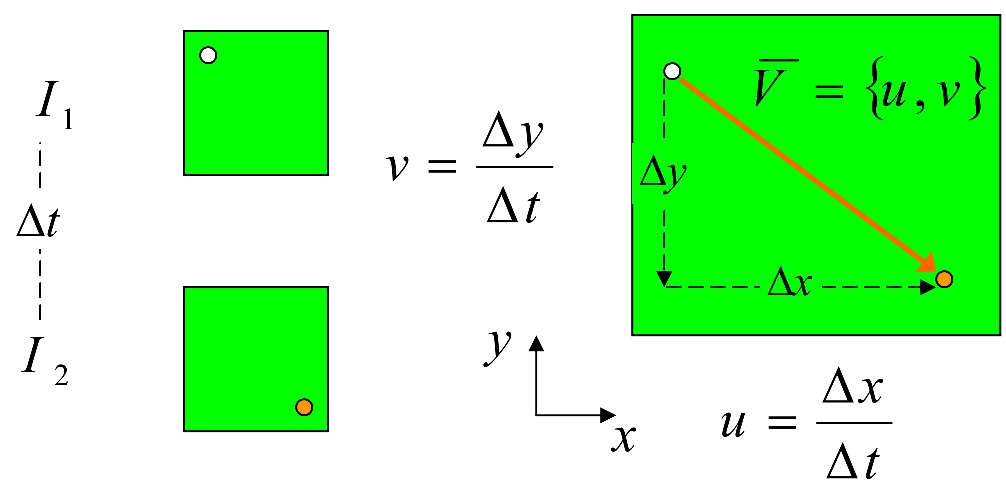
- **Utilize flow measurement techniques to study the operation of the burner and assess each component or parameter**
- **Selection of a technique:**
  - Hot Wire Anemometry
  - Laser Doppler Anemometry
  - Particle Image Velocimetry
- **PIV was chosen as the most robust method for this study**
  - Instantaneous, 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



*From www.dantecdynamics.com

- **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

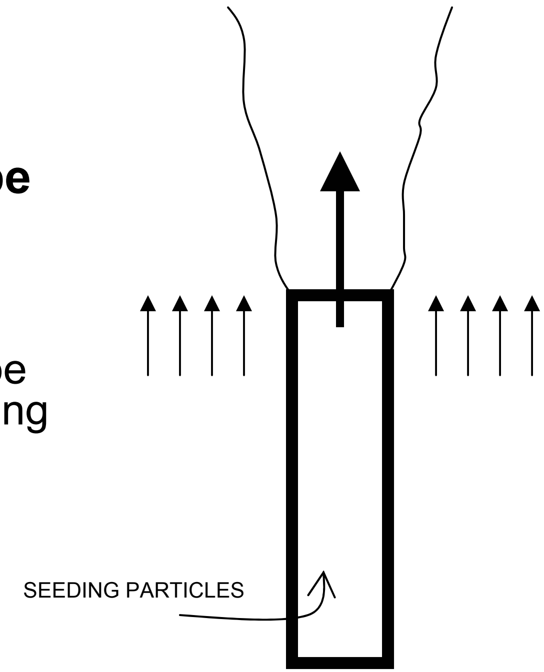
- **Material fire test methods dependent upon accuracy of test methods**
  - Fire test methods involve burners
    - Burners are driven by fluid-thermal processes
    - Test results are completely dependent upon these processes
    - Insight into the fundamental burner parameters will lead to optimization 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**
  - FlowSense 2M camera
  - SOLO PIV 120XT laser
  - PC with Dynamic Studio software for analyzing PIV images
- **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

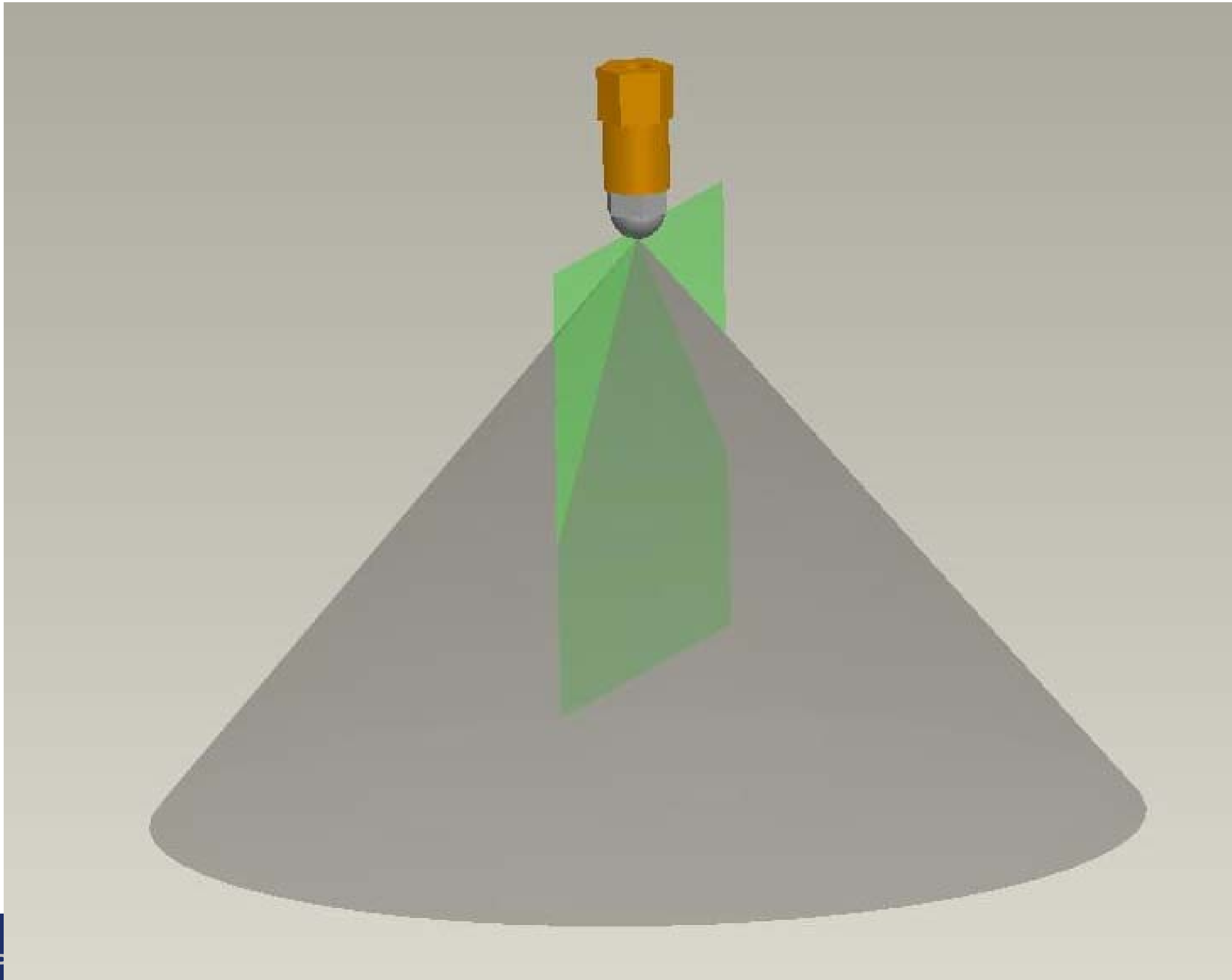
PIV System Validation

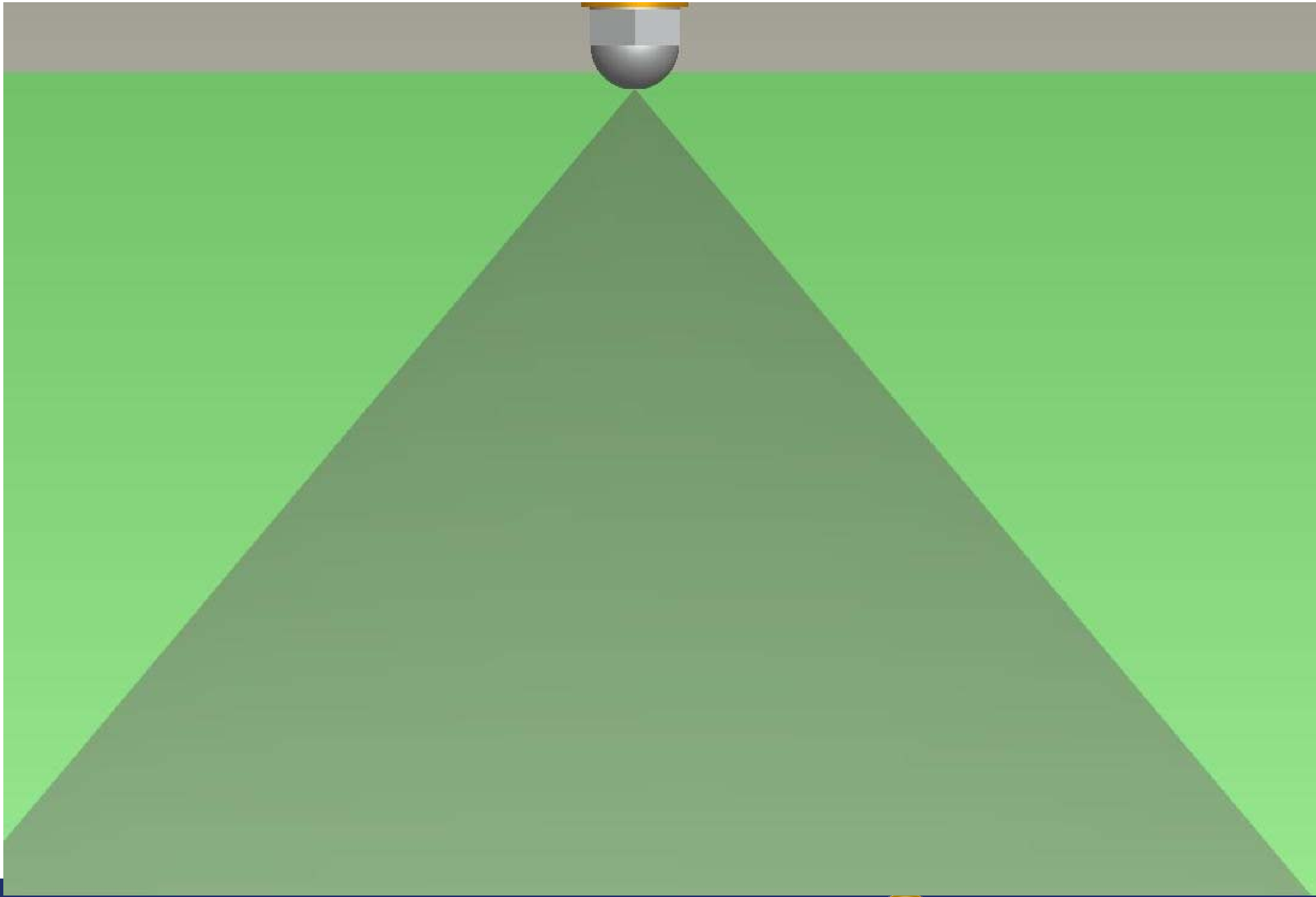
- **Validation measurements must be performed initially**
  - Simple, widely studied experiments
  - Results obtained will be compared to pre-existing published data
- **Jet**
  - Non-reacting flow
  - Reacting flow
- **Jet is similar to a Bunsen burner**
  - Bunsen burner is also an FAA fire test method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

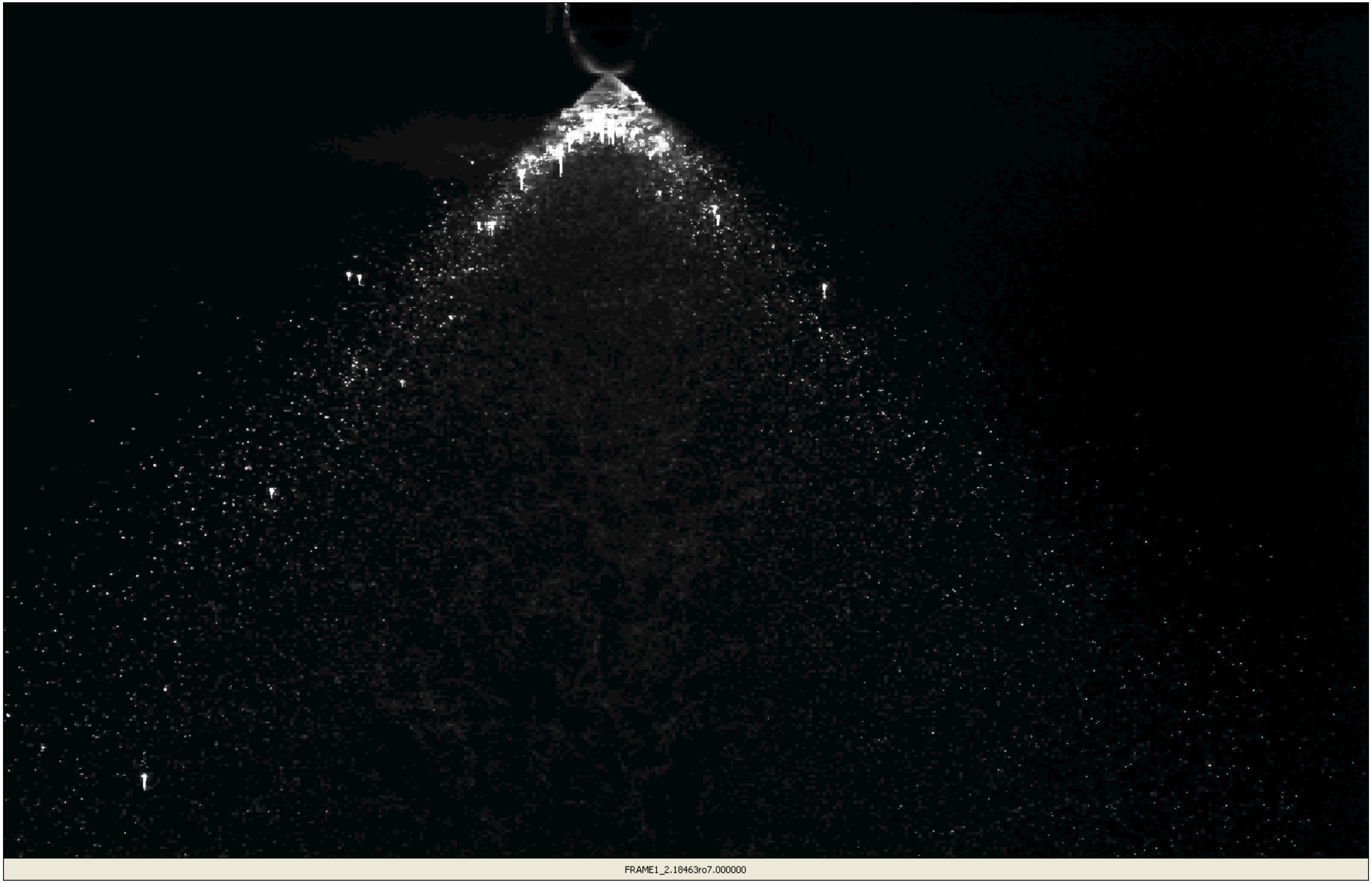


Acquired Data – Fuel Nozzle

- 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



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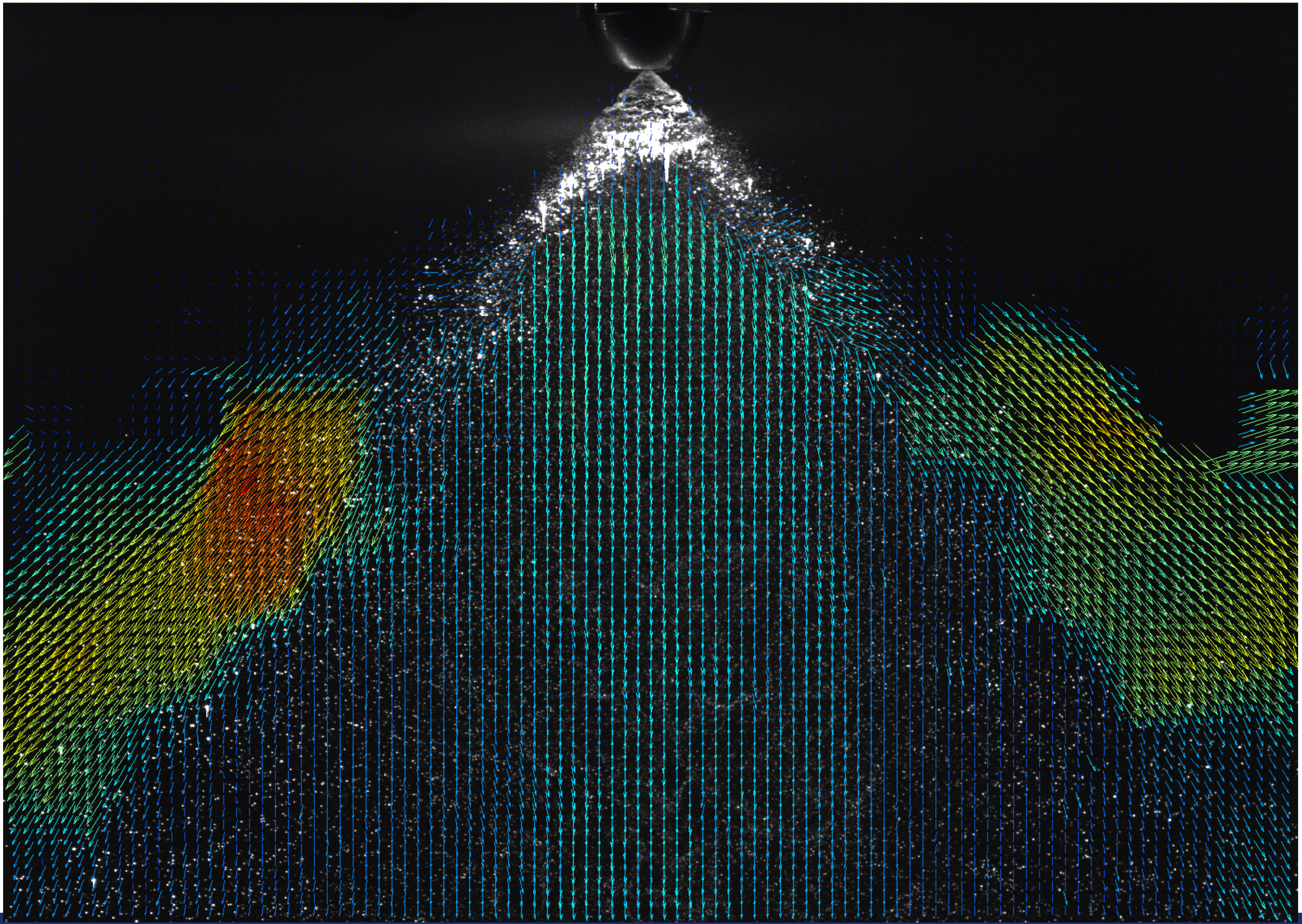

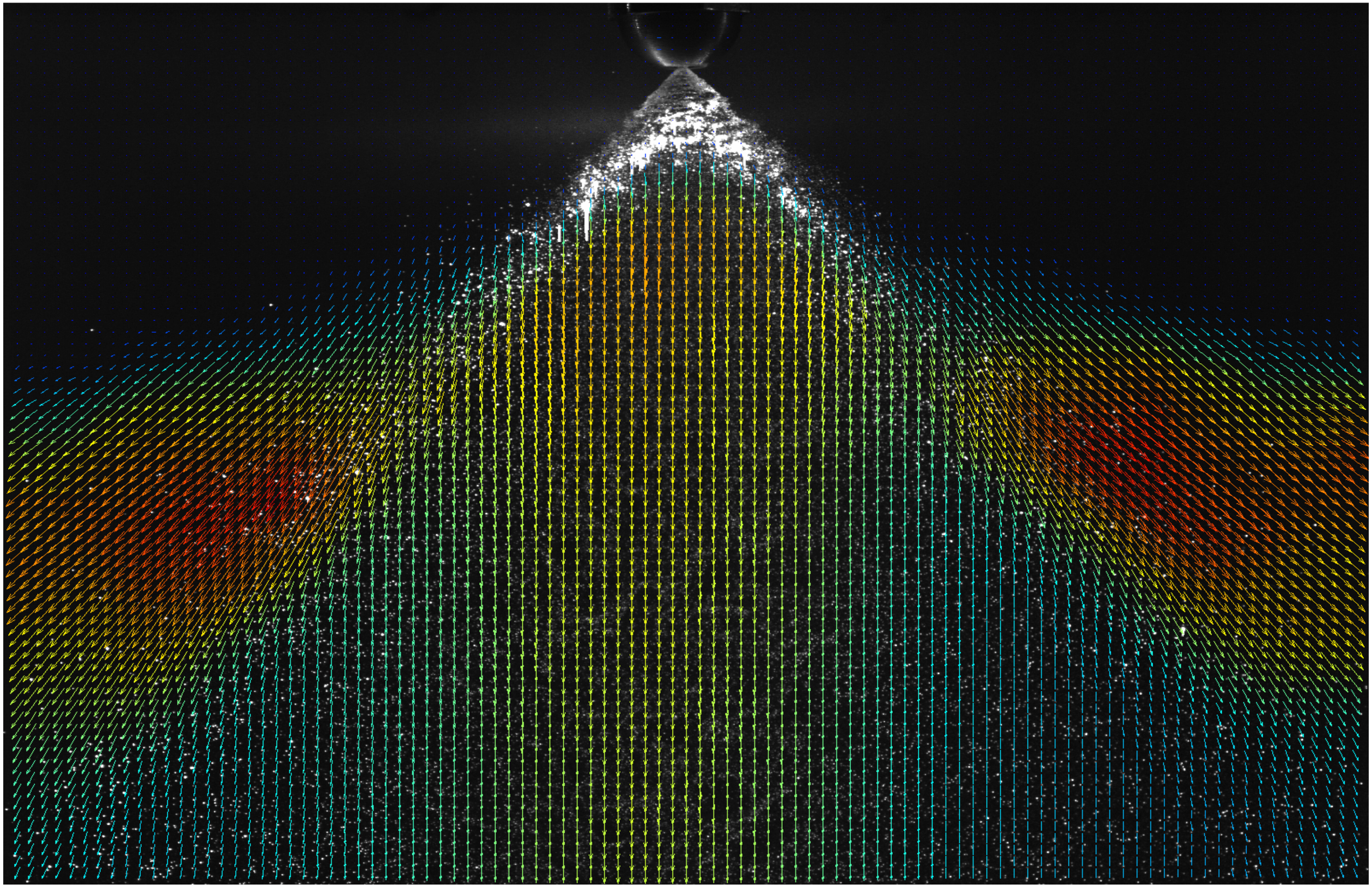

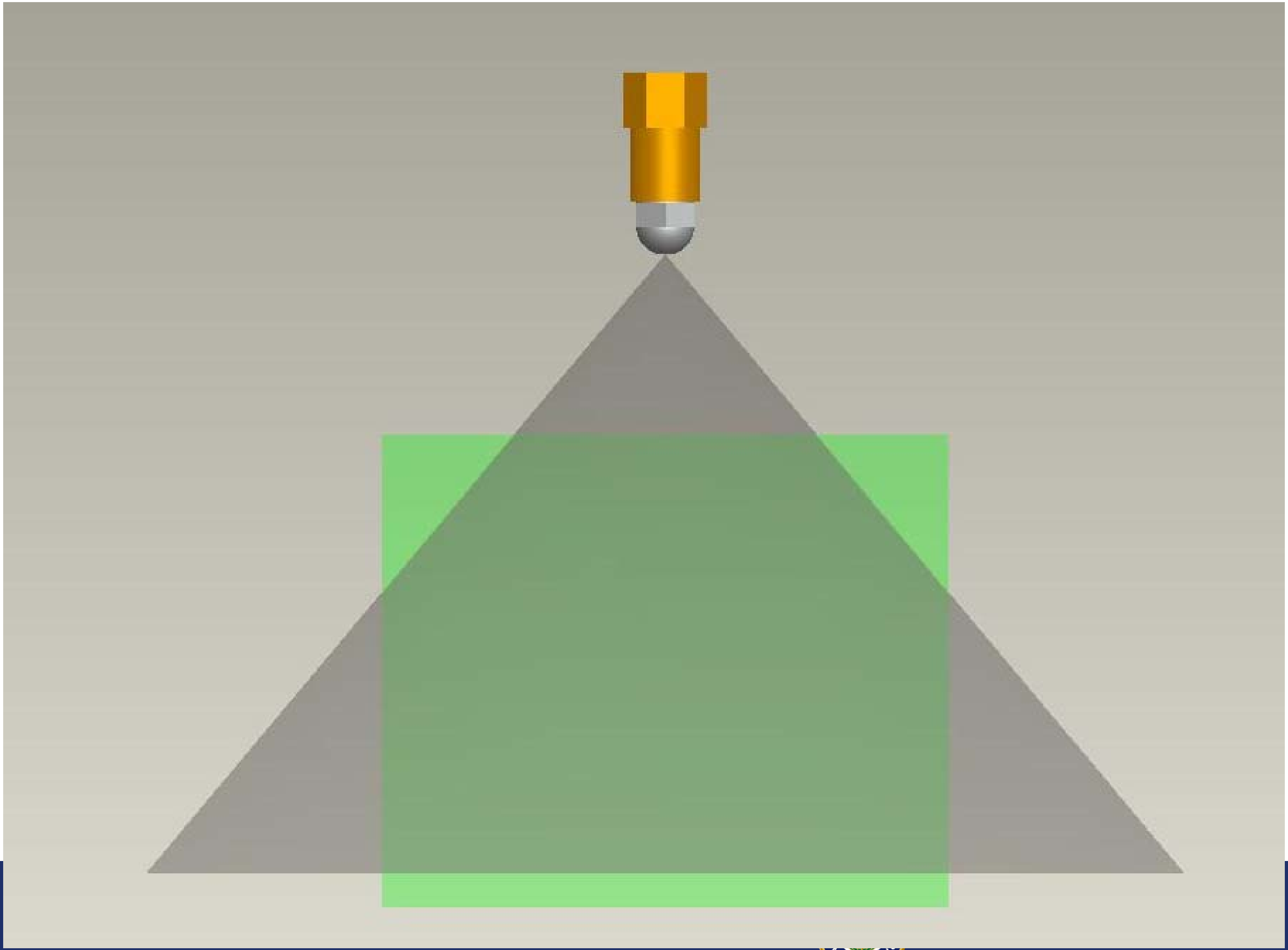

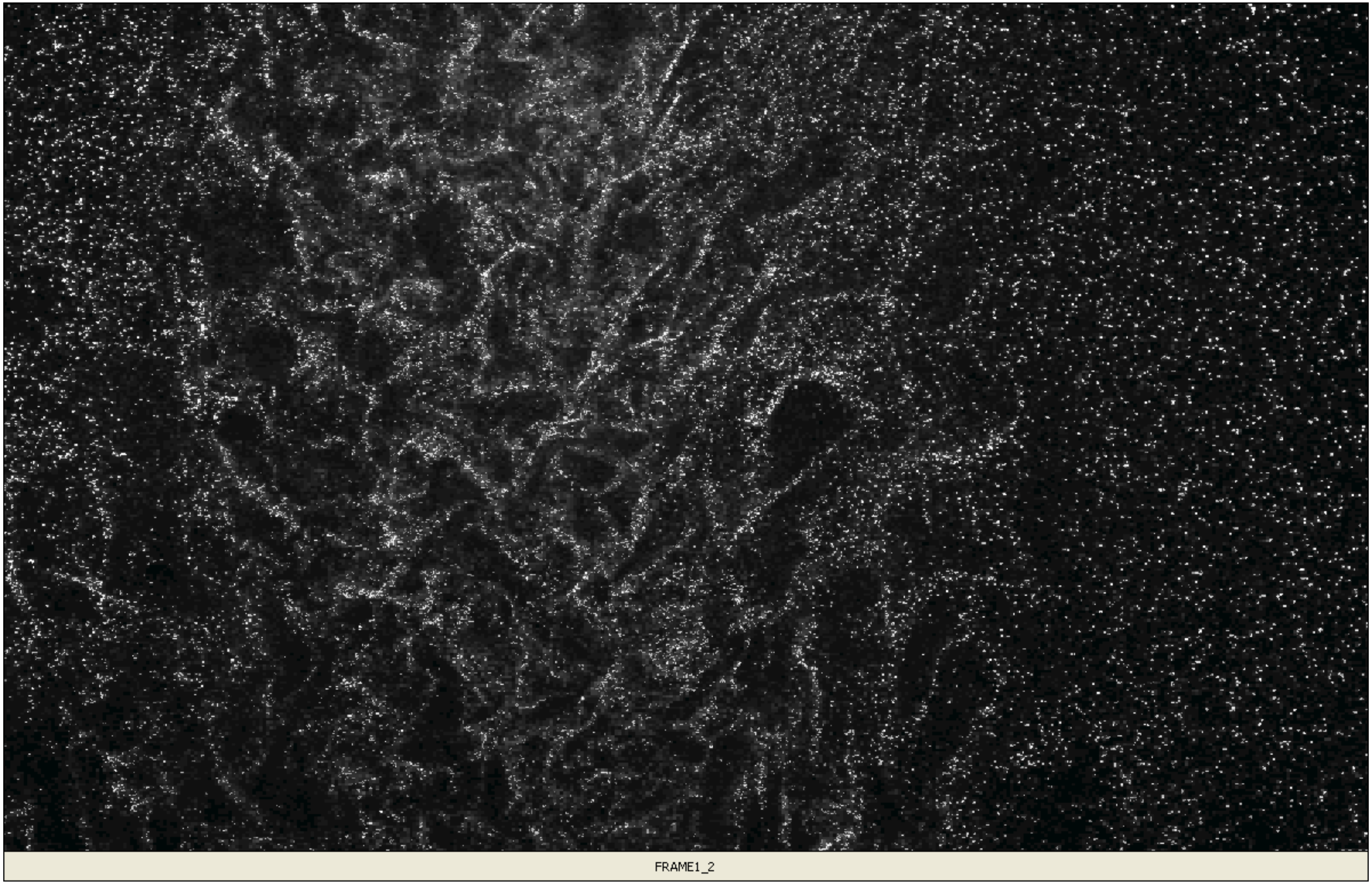
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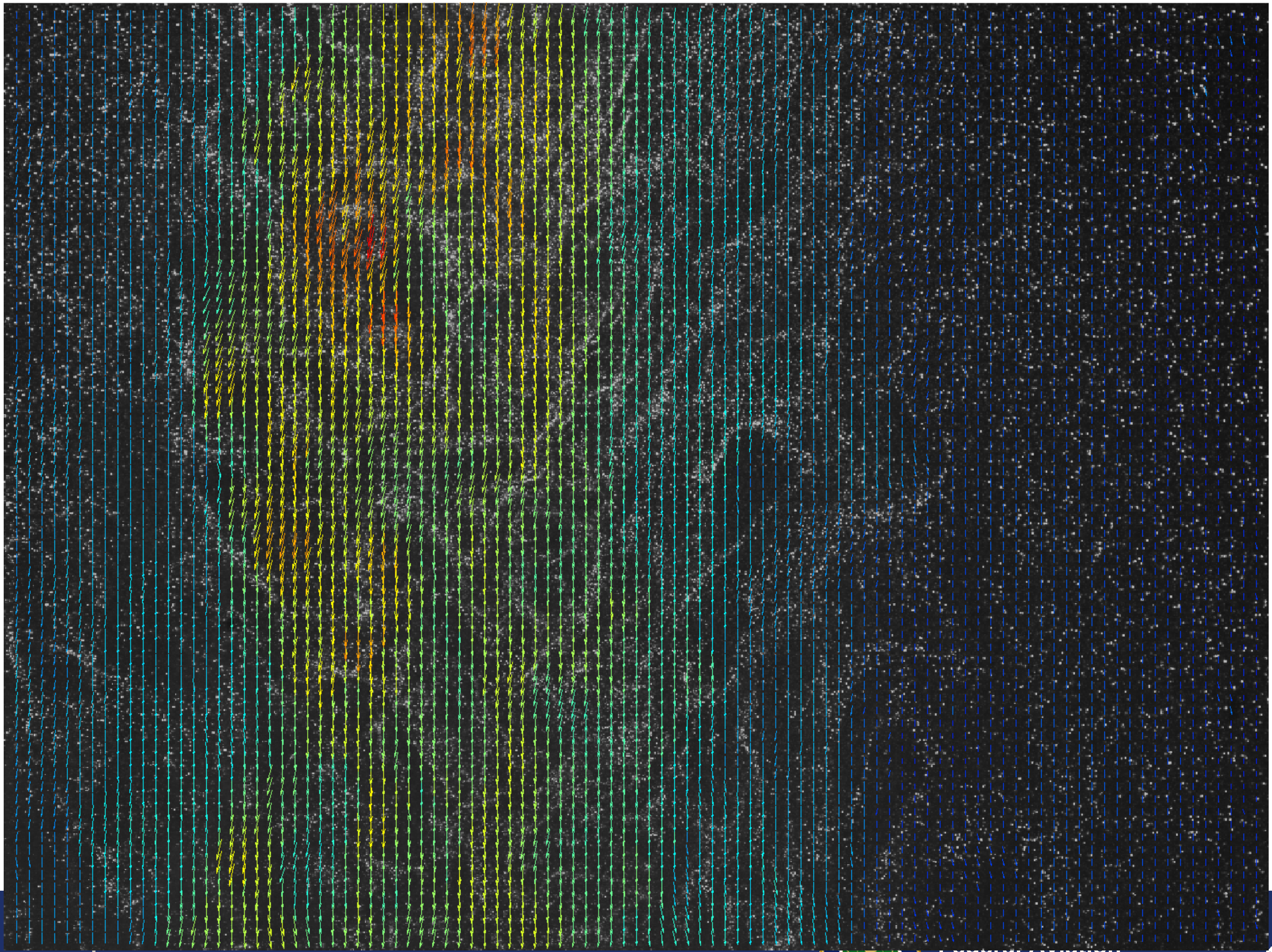
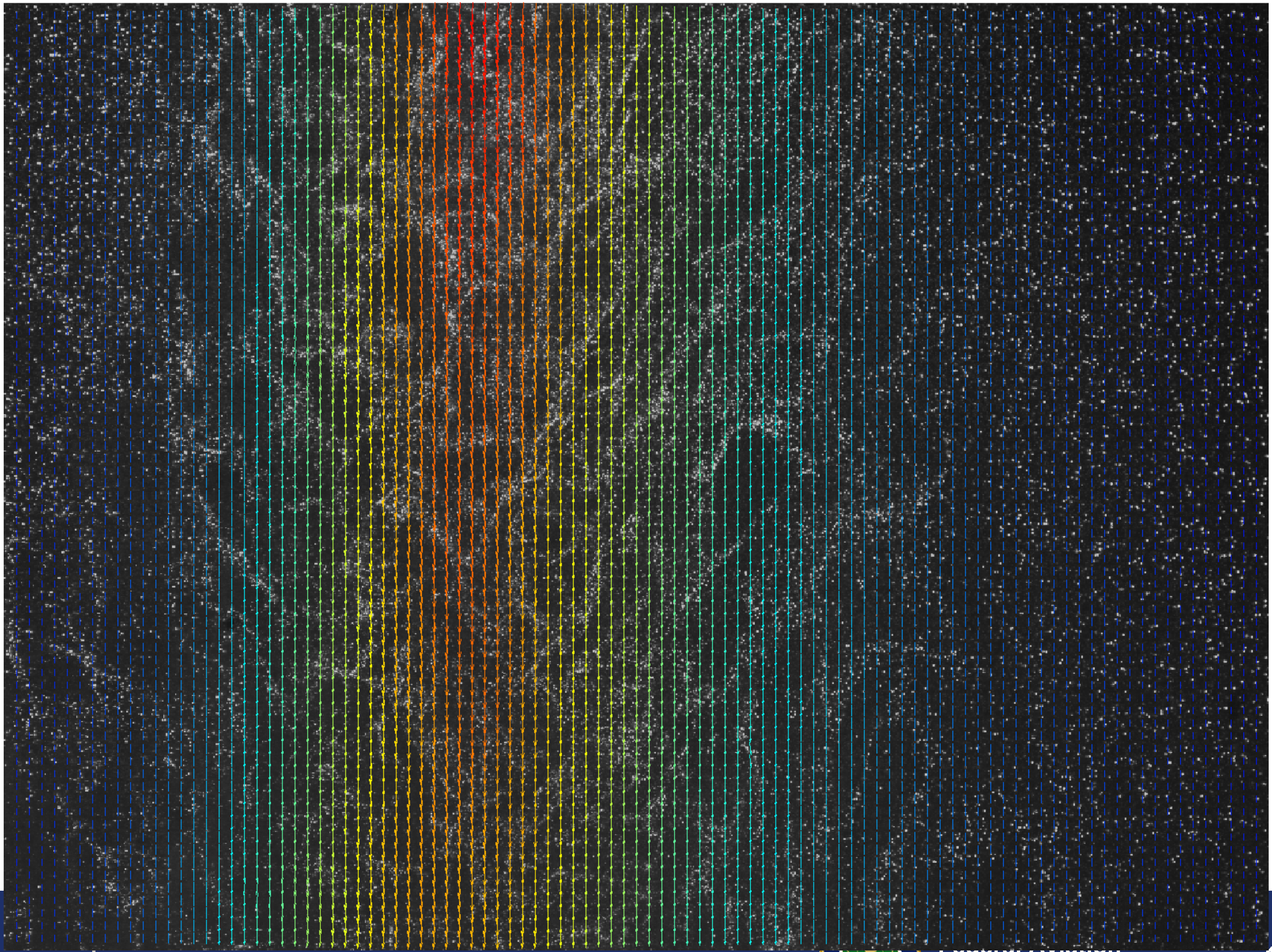
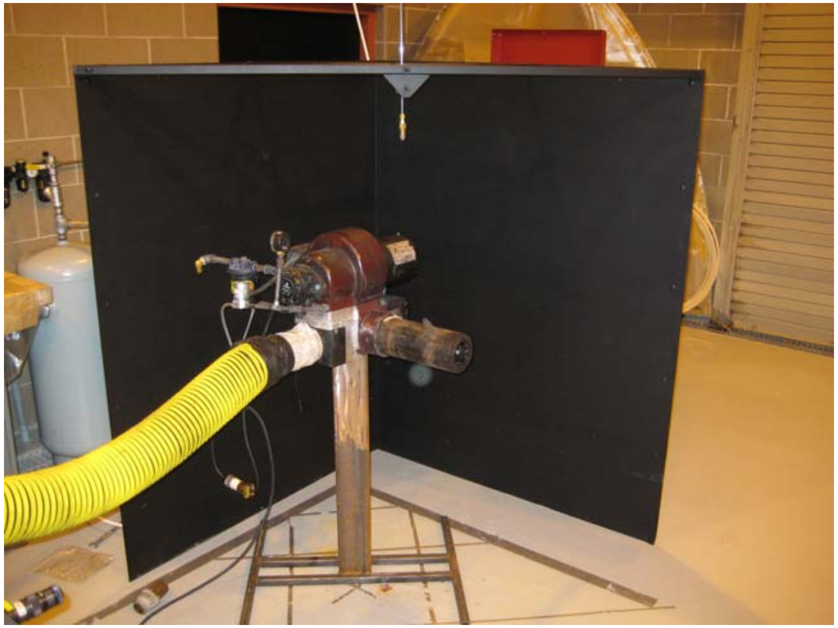
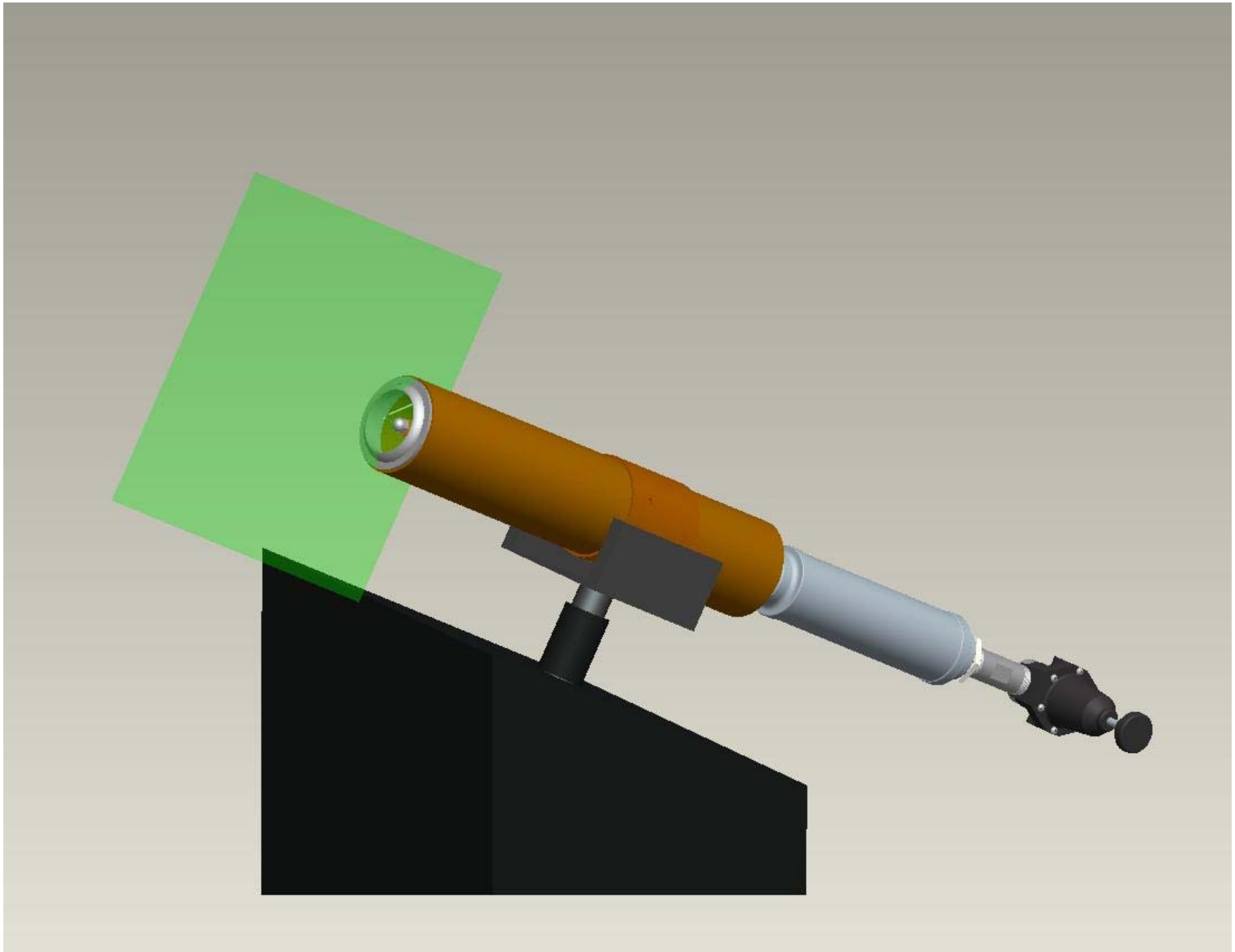
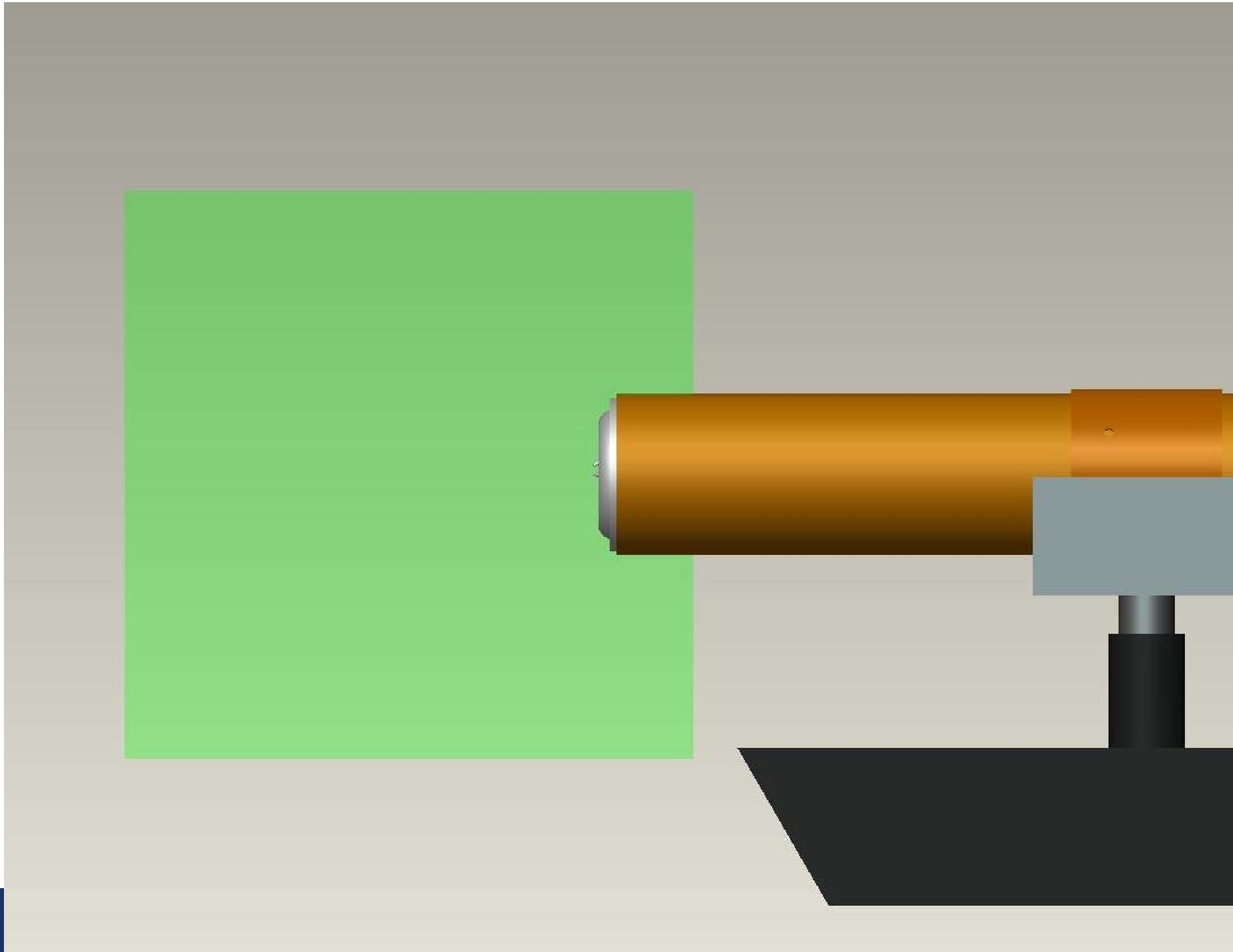


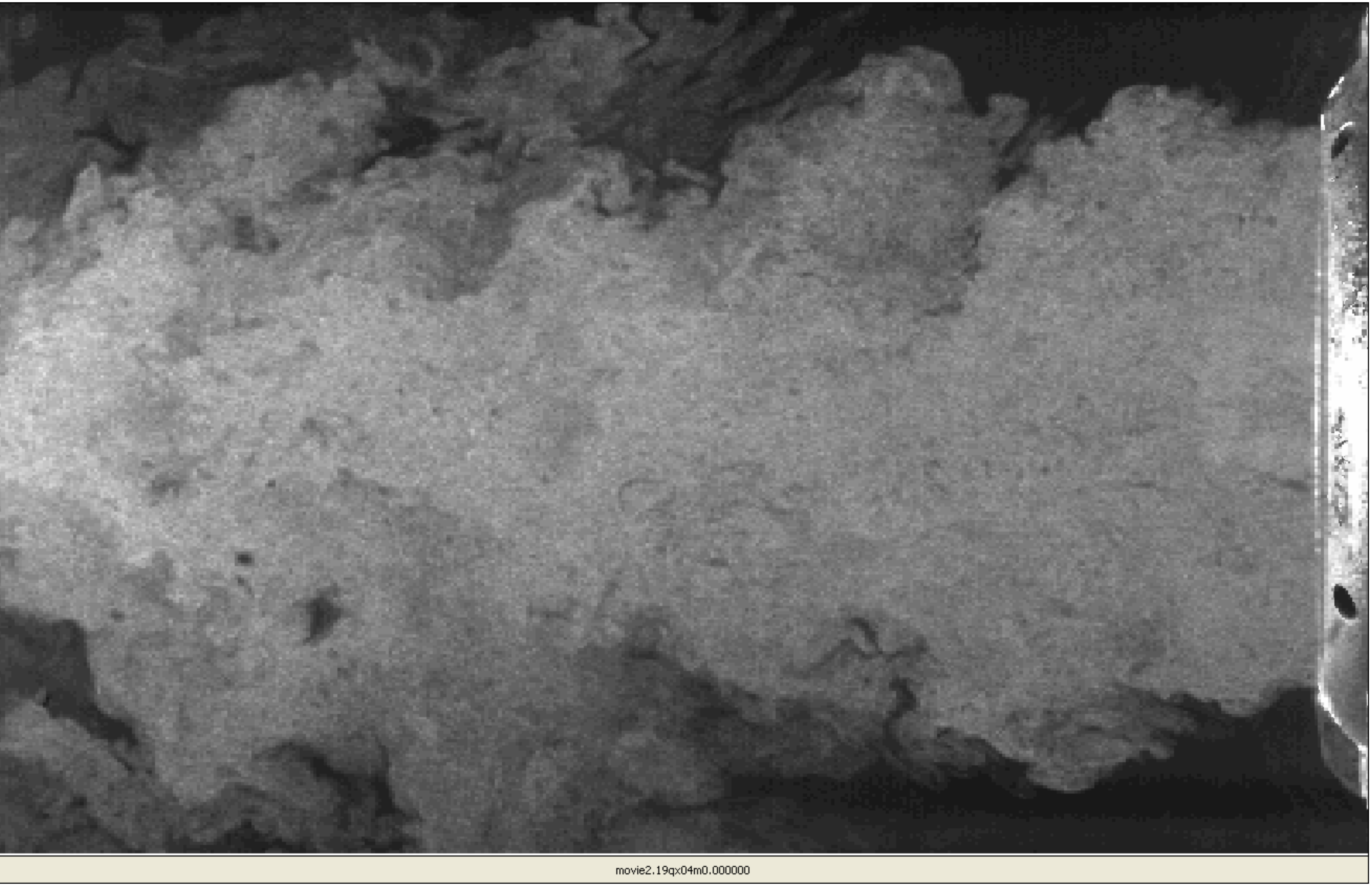


Acquired Data – Burner Air Flow





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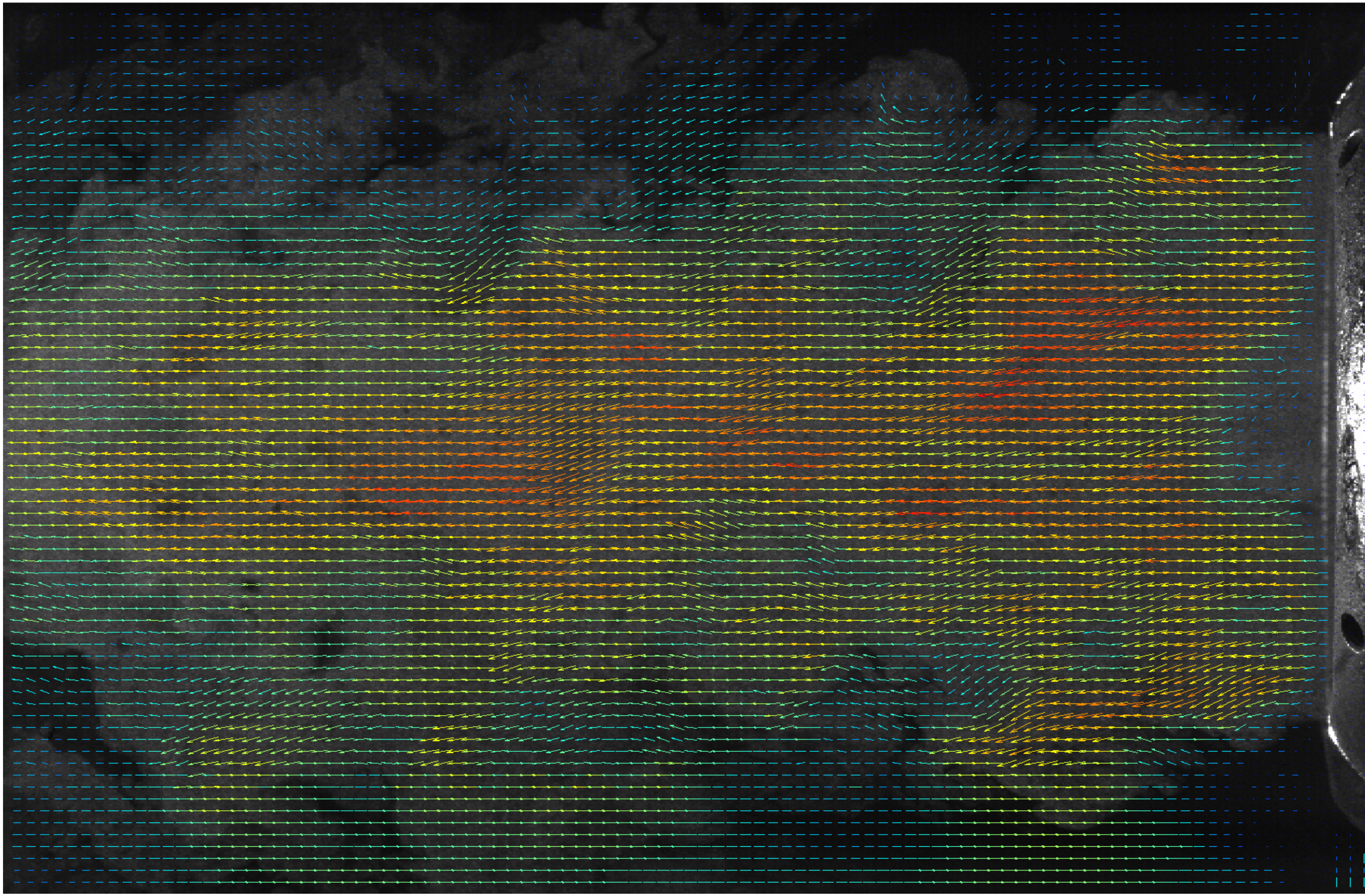

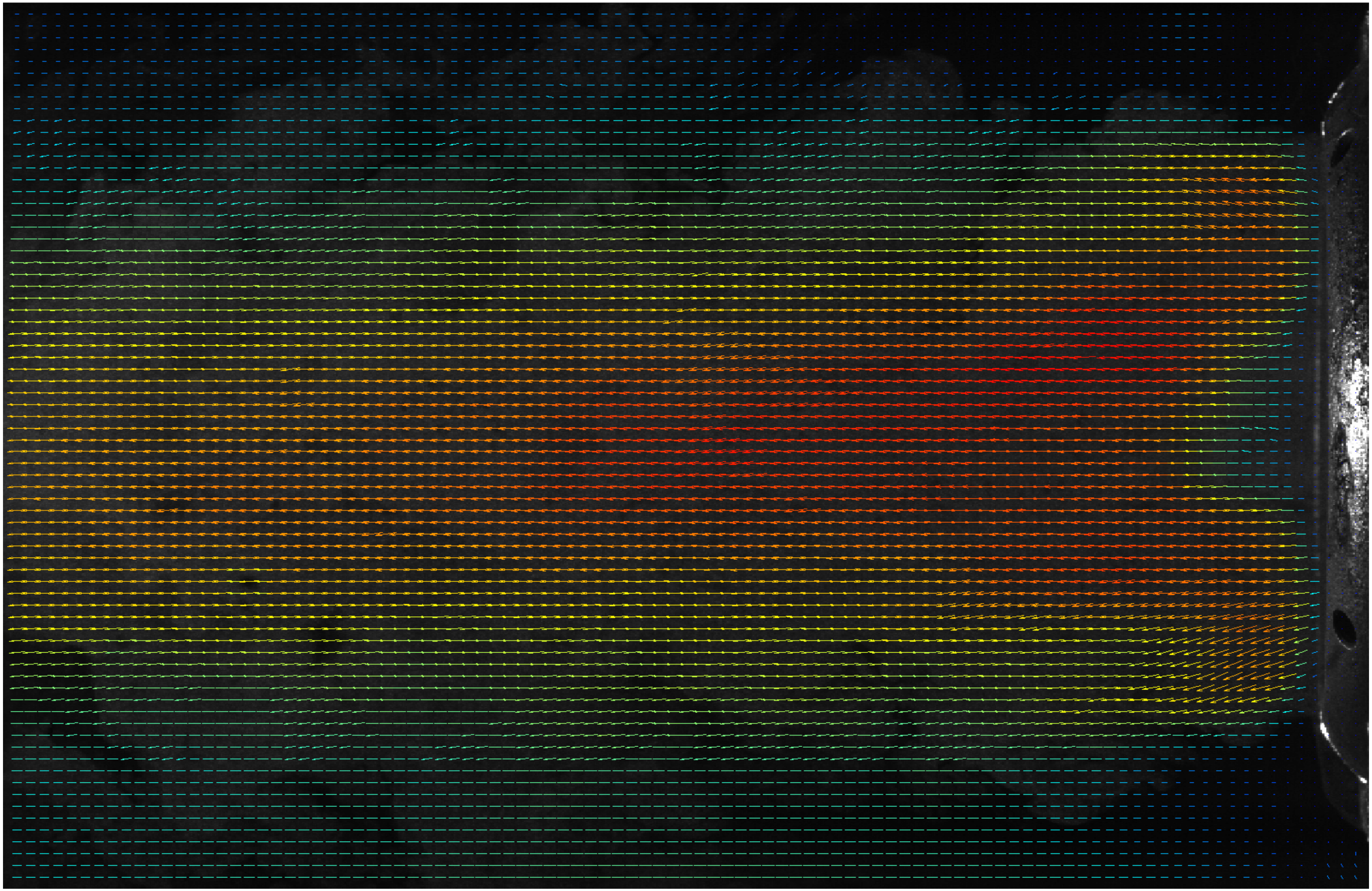

Burner Air Flow

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