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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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 (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
- $\Delta t=100\mu$s
Mean Image – False Color
Raw Data Frame 1, t=0
Raw Data Frame 2, $t=100\mu s$
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

Frame 1
Frame 2

Normal Plane

Frame 1
Frame 2
Acquired Images – Dual Camera

Nd:YAG Laser

Measurement Plane

2 Cameras + Beamsplitter

Parallel Plane

Frame 1

Frame 2

Normal Plane

Frame 1

Frame 2

Nd:YAG Laser

Measurement Plane

2 Cameras + Beamsplitter
Timing Diagram

Light Pulses

Camera Trigger

Camera 1 Exposure

1 2

Δt

Frame 1 Exposure

Frame 2 Exposure

Frame 1 Readout
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

PIV Explanation and Planned Activities
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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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