Laser Diagnostics Two Phase flows

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Outline

+ Particle Image Velocimetry (PIV)
+ Shadowgraph techniques
+ Volumetric PIV and Two Phase flows
+ MicroPIV
Particle Velocimetry

+ Numerous techniques
  - Particle Image Velocimetry (PIV)
  - Particle Tracking Velocimetry (PTV)
  - Volumetric 3-Component Velocimetry
  - Common elements
    - Optically clear Fluid
    - Small tracer particles follow fluid flow
    - Images of particle positions, illuminated by a pulsed laser, are captured at separate times
    - Particle displacements are calculated across dt, the time between laser pulses, to determine velocity
Definition

+ **Particle Image Velocimetry (PIV)**
  • an optical imaging technique to measure fluid or particulate velocity vectors at many (e.g. thousands) points in a flow field *simultaneously*.
  • Typically measurements (2 or 3 components of velocity) made in “Planar slices” of the flow field - Evolving into Volumetric
    - Time Resolved

+ **Accuracy and spatial resolution**
  • can be comparable to LDV and HWA.
PIV Fundamentals

+ PIV measures the displacement of tracer seed particles in a flowfield to determine the 2D velocity field
  • At time $t_1$
    - Pulsed laser sheet illuminates a planar region of the flow
    - Particles are imaged on the camera (Frame A)
  • At time $t_1 + \Delta t$
    - A second image (Frame B) is taken of a second light sheet
  • Statistical (Cross-Correlation) methods are used to determine the particle displacement over the time $\Delta t$, and thus the local velocity
+ One vector represents flow “averaged” over a single cross-correlation interrogation region
  • Need enough particles to build up a good “average”
  • Velocity variation within a single interrogation region should be small
Cross Correlation

+ All particles look alike, so approach is not find the ‘same’ particle in both Frame A and B (as in PTV)
+ Instead, PIV uses a statistical approach to find the most likely displacement of a group of particles
+ Frame A is broken up into a grid of ‘interrogation regions’
+ The group of particles in the interrogation region creates a fairly unique ‘fingerprint’ that we can look for in both frames (PIV)
Impeller Mixing Study

Courtesy of University of Birmingham
Shadowgraphy to measure Particle size and velocity

+ Sparger
Sparge conditions

+ 50 mL / min
+ No applied flow
+ Fine sparger
+ No surfactant added
+ Approximate Field of View: 7 cm x 7 cm
+ 36 image pairs
Sample Raw Images
Processed Images
Size – Velocity Correlation
TIME-RESOLVED PIV MEASUREMENTS OF A 2-PHASE FLOW (BUBBLES AND MEDIA)

PIV system consisted of:

- Dual-head 1000 Hz Nd:YLF pulsed laser with 30 mJ/pulse and fitted with adjustable light sheet optics
- 1280 × 800 pixel CMOS camera operating at 1000 Hz (Model #630083-3GB).
  - The laser illuminated a diffuser placed at the background of the bubbly flow chamber.
  - The camera was with its axis collinear with the laser illumination.
  - A sparger was positioned at the bottom of the flow chamber, and bubbles of approximate size 1-2 mm were formed and were drawn upward through buoyancy forces.
Phase Separation SSA PIV Bubbles
Bubbles and Flow Field

![Diagram showing bubble distribution and flow field with X and Y axes, and a color scale indicating vorticity and diameter in um.](image-url)
Bubble trajectories
Particle Image Velocimetry
3 Component measurements

+ Three Component PIV Measurements
  • Measurement of 3 components of velocity simultaneously
  • Illumination: using a light sheet
  • 3 components of measurements in a plane
# Volumetric PIV systems

<table>
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<tr>
<th>System Type</th>
<th>Characteristics and functions</th>
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| **V3V-TS volumetric PIV system** | • Optimal system with fixed volume size -- 50 mm x 50 m x 30 mm max  
  • Use of three camera configuration with detachable camera arrangement  
  • High resolution cameras up to 29MPixels with frame rate up to 180 fps  
  • High spatial resolution to resolve turbulent flow structure |
| **V3V-CS volumetric PIV system** | • Optimal system with fixed volume size -- 140 mm x 140 m x 100 mm max  
  • Use of three camera configuration with detachable camera arrangement  
  • High resolution cameras up to 29MPixels with frame rate up to 180 fps  
  • Large volume size to capture complete coherent flow structure |
| **4-Camera volumetric PIV system** | • Flexible camera arrangement for optimized measurement volume and spatial resolution  
  • Support of high speed cameras for Time-resolved volumetric measurements with capture rate up to 10kHz  
  • Variety of hardware makes it possible to choose between high temporal or spatial resolution, or both  
  • Upgradeable from single camera PIV, stereo PIV and V3V to the latest configuration |
TAP TV Operation Overview

- **3D Imaging Technique**
  - Calibrate Camera with a target of known dot-spacing

- **Capture and Identify Particle Images**
  - Laser illuminates tracers in a volume
  - 2 laser pulses (like PIV)
  - Identify 2D particle locations in each image

- **3D Particle Mapping**
  - Map particle images into 3D space using the camera calibration

- **Particle Tracking**
  - Determine individual particle tracks within the volume
  - Velocity = displacement / time

- **Interpolation (Optional)**
  - Interpolate tracks onto a regular grid
V3V System in Operation

Laser (behind)

InsightV3V Software

Flow Tank

V3V Camera

Synchronizer
Rushton Turbine

Rushton Turbine

- $Re = 107,000$
- 295rpm
- Inner Diameter $D=44.3\,\text{cm}$
- Turbine placed at $D/2$
- Water depth $=D$
- Turbine Blade Diameter $D/3$ (tip to tip)
- Volume 120 by 120 by 100mm
- Seeding polycrystalline particles 100 micron
- Average of 250 Phase locked measurements shown
- Spacing 4mm between vectors
Rushton Turbine
Rushton Turbine

- Comparison to PIV

$\lambda_{ci}$
  - Red Solid – V3V
  - Red Dashed – PIV

$\lambda_2$
  - Black – V3V
  - Gray – PIV
Volumetric PIV: Experimental Setup
Volumetric PIV:
Two-Phase Particle Identification

Right Aperture

$x, y (pix)$

Seed Particle Images

Rain Drop Particle Image
Rain drops with flow tracers
Image showing large rain drop
Volumetric PIV: InsightV3V Two-Phase Measurements

Simultaneous seed particle velocity vectors & droplet particles size & velocity vectors. Colored by normalized velocity magnitude.
MicroPIV Motivation

+ Aero-MEMS applications
  • Micron scale supersonic nozzles (MIT)
  • Remote surveillance aircraft (UCLA, Caltech)
  • Micro Air Vehicle (MAV): flapping-wing vehicle < 15 cm in all directions (UCLA)
  • Micro-jet engine (Epstein et al., MIT)

+ Bio-MEMS Applications:
  • Chemical and biological analysis: “lab-on-a-chip” for medical and defense applications
  • Microfabricated needles for drug delivery
  • Flow sorter (Caltech)

+ Complex microfluidic devices:
  • Micro mixers
  • Micro bio-reactors
  • Micro heat-exchangers
Theory of Operation (Schematic)
Details on Micro-flows Measurement

- Flow In
- Flow Out
- Focal Plane
- Flood Illumination
- Microscope Objective
- Laser beam
- Glass Plate

Flow Model
Theory of Operation (Filter cube light path)
Theory of Operation (Similarities and Differentiators with PIV)

+ **Illumination sources:**
  - Dual pulsed – Dual Head Lasers (527 or 532Hz, 15Hz to kHz)
  - CW lasers
  - LED

+ **Volume illumination**
  - Via microscope objectives
  - Measurement plane defined by Depth of Correlation (DOF)

+ **Fluorescent particles**
  - In general working with smaller size particles (0.1 to 3 um)
  - Important to mention:
    - Brownian motion → random thermal vibration of seed particles
    - Saffman force → can become large near boundary
      - External arbitrary forces → hard to account for...
Fluorescent Particles

+ Sizes (0.1 to 3um)
+ Orange
  - (540nm, 565nm)
+ Red
  - (542nm, 612nm)
+ Vendors
  - Molecular probes
  - Thermo
+ Quantum Efficiency (QE):
  - CCD sensors
  - CMOS sensors
  - Intensified cameras
Typical micro PIV system
Typical micro PIV system
Two Colour Micro PIV
Two Colour Micro PIV

- Two Colour laser
- Two Colour fluorescence separator
- Syringe pump
- Inverted Microscope
Details of set up

+ Aqueous phase seeded with 1 μm carboxylate-modified microspheres FluoSpheres® (540/560 nm)
+ Organic phase with 1 μm blue silica microspheres particles Sicastar® (350/440 nm).
+ Rhodamine 6G fluorescent dye (1 ppm) was also added in the aqueous phase to improve the detection of the liquid-liquid interface
Use the velocity fields of both the continuous and dispersed phase in order to understand the two-phase flow droplet formation and to evaluate the effect of interfacial tension and viscosity on the flow.
Averaged velocity profiles using the two-colour PIV (Newtonian fluid)

(a) slug 48% w/w water and 52% w/w glycerol
(b) plug for silicone oil
(c) Dotted rectangle indicates the fully developed laminar flow area ($Q_C = 0.07 \text{ cm}^3/\text{min}$; $Q_D = 0.03 \text{ cm}^3/\text{min}$).
Questions

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