LAMINAR FLAME SPEED ANALYSIS USING PIV (PARTICLE IMAGE VELOCIMETRY)

OPERATIONAL PROCEDURES

Venue: Project Room, Hopkinson Lab, CUED
Experimental date: 25 March 2008
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Content

1.0 Introduction

This document describes the operational procedures of measuring laminar flame speed of methane-acetone-air mixture using PIV system in the Project room of Hopkinson lab.

2.0 Objectives

The objectives of the experiment are as follows:

(a) To determine the velocity field of laminar flame.
(b) To familiarize with PIV and FID measurement technique.

3.0 Procedure descriptions

3.1 Room preparation

The project room layout is shown in Appendix 1. The room has one entrance door and an emergency exit door. The front door has an electronic lock that requires access password. Once the experimental apparatus is set up, follow the steps below:

1. The operator is to wear a CO detector at all times.
2. Check methane pressure gauge is at set point from previous run. If there is significant pressure drop, perform leak testing.
3. Turn on the exhaust fan.
4. Ensure that the entrance and fire exit door are not blocked.
5. Make sure flammable liquid and materials are placed at safe spot.
6. Test the emergency stop solenoid to ensure that it is in fine working condition.
7. On the methane line, close ball valve, followed by bottle valve (To enable leak test).
8. Make sure laser safety goggle is worn when PIV system is initiated.
9. Make sure the laser interlock system is working.

3.2 Experimental set-up

The experimental apparatus is shown in Figure 1. The air flow is supplied by an air compressor while the methane is supplied from a compressed cylinder. The air flow is split into 2 lines, one is used to bubble the acetone to saturate the air, and another line is for seeding purposes with one bypass line. Aerosil Amorphous Silica R812 S is chosen as the particles to be seeded with air flow because they are good light scatterer with average particle size of 7 nm. The seeded air flow will mix with the corresponding amount of methane and acetone-saturated air to achieve the desired mixture before being burnt at the burner at laminar condition. The acetone-saturated air line is heated with *Omega* rope heater that is wrapped around the PTFE tube to prevent condensation. The particles in the flame will be illuminated by the double-pulsed laser sheet. A co-flow of nitrogen is provided to shroud the mixture to prevent perturbation from surrounding. The flame is impinged onto a ceramic plate held by a water cooling system. The light source of PIV is

Nd:YAG 120 mJ, New Wave Gemini, with second harmonic generating crystals used to create a Q-switched laser output at 532 nm. The laser beam will go through a combination of spherical-cylindrical lenses to give a planar laser sheet. Two successive flame image will be recorded with a 135 mm Nikkon lens (f:1/28) through a high resolution CCD camera with the array of 2044 x 2044 pixels.

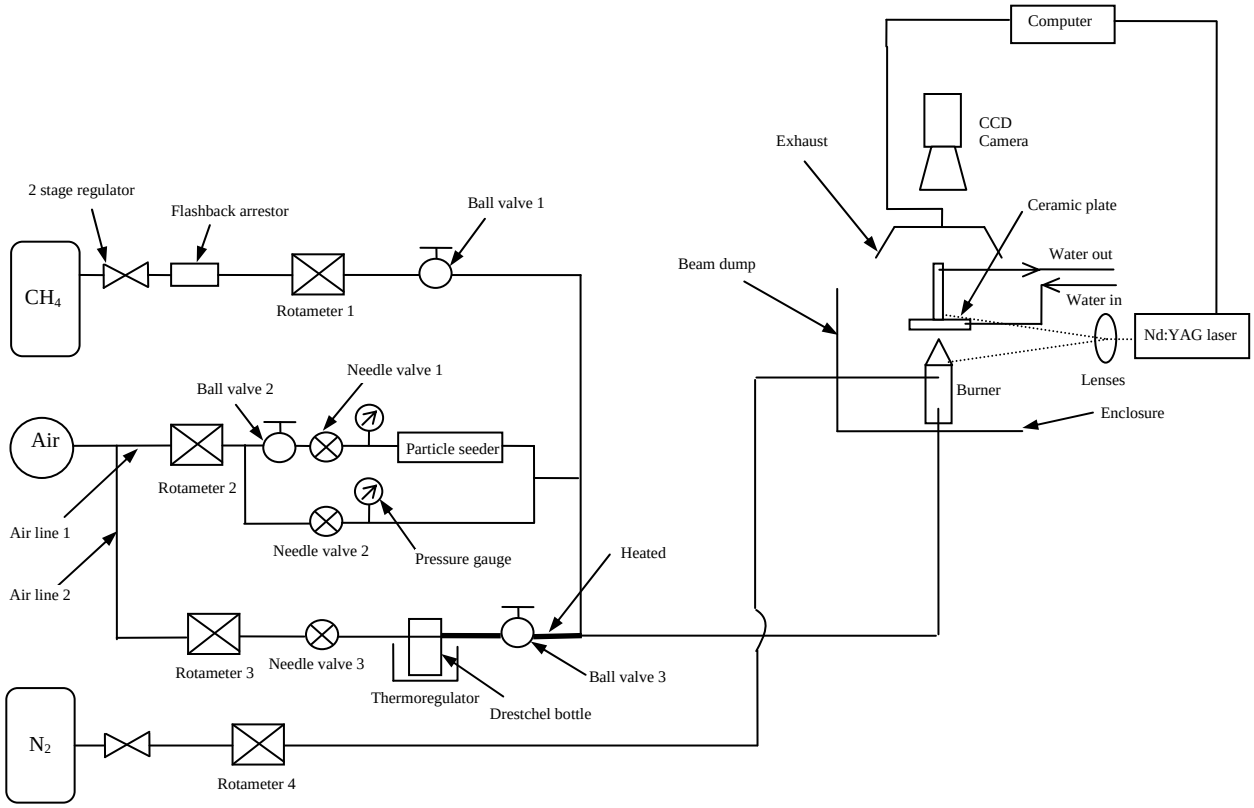


Figure 1: Experimental set-up

3.3 Experimental procedures

3.3.1 Seeder test

1. Turn on the exhaust fan and wear face mask.
2. Make sure rotameter 1 and 3, two stage regulator of methane and nitrogen are closed.
3. Open the ball valve 2 and needle valve 1.
4. Adjust the air pressure regulator to 1 bar.
5. Regulate rotameter 2 to flow rate of 20 l/min.
6. Slowly close the bypass line by regulating needle valve 2 while open needle valve 1 slowly.
7. Observe the seeded flow from the burner outlet.
8. The adjustment is tuned until a steady uniform of visible particle stream is obtained.

9. Once a steady flow is obtained, maintain the setting of needle valve 1 and 2.
10. In order to shut the system, close ball valve 2, let the air purge the system for 2 minutes.
11. Regulate rotameter 2 to zero.
12. Close the pressure regulator of air.

3.3.2 Burner testing

1. Turn on the exhaust fan, CO detector and wear face mask.
2. Turn on the water pump.
3. Open ball valve 1.
4. Check every connection to make sure it is properly secured with no leakage.
5. Adjust the pressure regulator of methane to 0.5 bar.
6. Regulate rotameter 1.
7. Light the burner with a lighter.
8. Use the leak detector to check for leakage at connections.
9. Regulate rotameter 1 to zero.
10. Close the pressure regulator of methane and valve 1.
11. Open valve 2.
12. Regulate rotameter 2.
13. Regulate needle valve 1 and 2 to ensure a smooth stream of particles.
14. Use leak detector to check for leakage at connections.
15. Adjust the pressure regulator of methane to 0.5 bar.
16. Regulate rotameter 1. (refer Appendix 2)
17. Check the seeding is flowing uniformly and regulate needle valve 1, 2 if necessary.
18. Light the burner with a lighter.
19. The flame is observed for its stability.
20. Adjust the pressure regulator of nitrogen tank to 0.5 bar.
21. Regulate rotameter 3 to provide co-flow for the flame,
22. Observe the flame stability.
23. Repeat the experiment with different flow rate. (Refer Appendix 2 for different flow rate)
24. To shut the system, regulate the methane flow rate (rotameter 1) to zero.
25. Close ball valve 1, then close methane tank valve. (To enable leak test)
26. Close ball valve 2.
27. To shut the nitrogen flow, regulate rotameter 3 to zero.
28. Close the nitrogen tank valve.
29. Vent the pressure from the regulator.
30. Let the air run to purge the system for a minute.
31. Regulate rotameter 2 to zero.
32. Turn the knob of the regulator back to zero.
33. Close the valve of the compressed air and turn the pressure regulator back to zero.
34. Turn off the pump.

3.3.3 Flame Ionization Detector (FID) testing

FID testing is a separate test to examine the concentration of acetone. The FID is run exclusively from the main system and therefore not included in the Figure 1. The test is conducted prior to the usage of PIV system and HFR500 Fast FID by Cambustion Limited is used.

Starting the analyzer

1. Switch on the service control unit, the vacuum pump and the computer.
2. Turn on the hydrogen-helium, nitrogen-propane gas and air line to 2 bars.
2. Start up the user-interface by double-clicking on the appropriate desktop icon.
3. Click and drag down the pull-down menu and select “On” for Channel 1.
4. If the FID flame lights lit successfully, the sample head will warm up for 10-15 min.

Calibrating and Sampling

1. Select “Options” from the status pull-down menu.
2. Enter correct calibration gas values for span A for HC.
3. Select the output range.
4. Begin calibrating by selecting “Calibration”
5. Once calibrated, the “Gas Select” box will appear green.
6. Place the sample probe at the burner exit.
7. Draw the sample in by clicking the “Sample” button.

Shutting down

1. Switch status indicator from “On” to “Off”.
2. Exit the User-interface program by pressing “Exit”.
3. Switch off service control Unit.
4. Switch off vacuum pump.
5. Shut the Computer.
6. Switch off power supply to the computer.
7. Switch off power supply source to the cabinet.
8. Shut off all gas supplies at source.

3.3.4 Burner with PIV system

1. Turn on the exhaust fan, CO detector and wear face mask.
2. Check every connection to make sure it is properly secured with no leakage.
3. Fill the Drestchel bottle with acetone and connect to the tube.
4. Adjust the pressure regulator of methane to 0.5 bar.
5. Open ball valve 1.
6. Regulate rotameter 1.
7. Light the burner with a lighter.

8. Turn the compressed air regulator to 1 bar.
9. Regulate rotameter 2.
10. Check the seeding is flowing uniformly and regulate needle valve 1 and 2 if necessary.
11. Regulate the rotameter 3 to bubble the acetone.
12. Turn on the water pump for the cooling system.
13. The flame is observed for its stability.
13. WEAR laser safety goggle before turning on the Nd:YAG laser.
14. Ensure that the enclosure is accessible with no blockage.
15. Activate the laser interlock system.
16. Turn on the Nd:YAG laser by following the standard procedure described in section 4.1.
17. Check the sheet formation with a white card.
18. Check for light scattering from the metallic part of the burner.
19. Take the flame images with the CCD camera.
20. Repeat procedure 6, 8-11 for different flow rates as shown in Appendix 2.

4.0 Nd:YAG laser operational procedures

4.1 Starting the laser

1. Close the shutter of the laser head.
2. Connect the laser power cord with appropriate single phase power source. Place the power switch on the AC entry module to ON position.
3. Turn the power supply key switch clockwise to the ON position.
4. Rotate the Flashlamp Voltage knob counter clockwise to the minimum at START position.
5. Press START/STDBY mode button on the control panel until the power supply INTERLOCK LED is off and the control panel LASER EMISSION LED is on.
6. After the LASER EMISSION LED is illuminated, there is an eight seconds delay before laser firing can occur.
7. Use the trigger selection switch to select the desired operation mode.
8. Open the shutter to begin operation.
9. Press the Fire button on the control panel to initiate laser firing. Pressing the Fire button in 1 Shot mode will fire one shot. Pressing the Fire button in Variable or Fixed mode will fire the laser at the set repetition rate.
10. Rotate the Flashlamp Voltage knob clockwise until the desired relative energy is achieved.

4.2 Alignment for PIV

1. Remove the smaller optics head cover to provide access to the beam combining optics and second harmonic generator. Install the interlock defeat mechanism.

2. Put both lasers into standby mode with the flashlamp voltage just above threshold for generating second harmonic light.
3. Observe the overlap of the two beams at the point where PIV measurement will be made. Adjust the polarizer assembly mount to optimize the overlap of the two beams. Note that the top adjustment screw on the mirrors controls vertical beam motion.
4. Observe the overlap of the two beams from the measurement area to the laser. The alignment is finished if the beams overlap the entire distance.
5. Fire laser #1 and observe the position of the visible beam on the folding mirror immediately after the second harmonic generator.
6. Fire laser #2 and note the position of the beam on the mirror, relative to the beam from laser #1. Adjust the fold mirror #1 to overlap the two visible beams immediately after the second harmonic generator.
7. Observe the overlap of the two beams at a point 1-2 meters away from the laser head.
8. Adjust the polarizer assembly mount to optimize the overlap of the two beams.
9. Repeat steps 5-8 to get the optimal overlap between the beams from laser #1 and laser #2. The overlap can be observed between the beams from laser #1 and laser #2. The overlap can be observed along the beam line from the laser head exit for several meters.
10. Turn off both lasers and reinstall the secondary head cover. Check the alignment with both lasers operating at a desired energy.

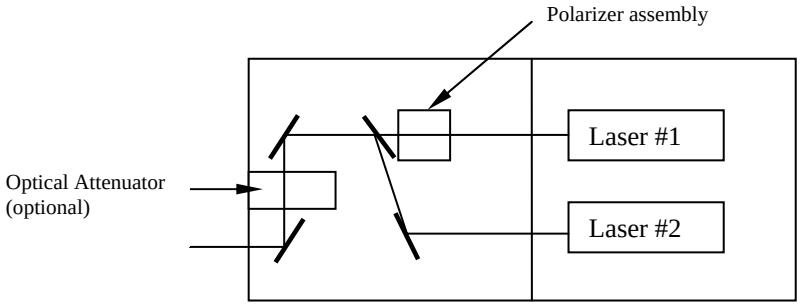


Figure 2: Gemini PIV Beam overlap adjustment

4.3 Turning off the laser

The laser can be turned off automatically by interrupting the interlock. The standard way to turn off the laser is as follow:

1. Rotate the energy knob to the minimum.
2. Press the OFF button.
3. Turn the power supply key switch to the OFF position.

4. Turn off the AC power line switch
5. Close the laser head shutter.

5.0 Safety procedures

5.1 Laminar burner

1. Wear face mask.
2. Ensure that the tubing is free from defects such as cracks.
3. Ensure there are no flammable materials near the burner.
4. The burner is securely placed underneath the exhaust hood.
5. Implement the procedures from 1 to 34 of section 3.3.2.
6. Stand at an arm length distance to light the burner with a lighter.

5.2 Gas cylinder

1. Only use specific equipment with the compressed cylinder, i.e two stage regulators. Contact gas supplier if in doubt.
2. Keep away from ignition sources (including static charges).
3. Refer to supplier's handling instructions.
4. Keep the gas cylinder below 50^{o}C in a well ventilated place.
5. After finishing the experiment, close the cylinder valve. Vent the gas in the regulator and purge the system with excessive air.
6. Make sure all cylinder tanks are strapped to a holding panel with chains.

5.3 Acetone

1. Use HPLC high grade acetone.
2. Keep the bottle in a secured, dry cabinet.
3. Ensure that the bottle is tightly closed.
4. Keep away from ignition sources (including static charge)
5. Wear face mask when handling acetone.
6. Place the acetone bottle in a cool dry place away in store before running the experiment.
7. Dispose excessive acetone in a labeled bottle.
8. Contact Chief Technician Mike Underwood if there is any doubt.
9. Refer to supplier's handling instructions.

5.4 Particle seeder

1. The particle seeder has an emergency 3-bar valve.
2. Ensure that face mask and hand gloves are worn at all time.
3. Make sure that exhaust is turned on at all time.

5.5 HFR500 Fast FID

1. Always ensure that the pump is located in the base of the cabinet before sliding out the control unit on the shelf.
2. The sample heads and sample probes become very hot under normal conditions and must be cooled down before handling.
3. Never attempt to fuel the analyzer with pure hydrogen.
4. If the pump is an oil-filled vacuum pump, make sure the pump is filled with oil to the correct level.
5. When fitting the control unit, make sure another person is present to steady the cabinet and help position the control unit.
6. Make sure the switches are correctly set before connecting these units to main power.
7. In connecting the heated sample probe to the remote sampling head, it is important that the probe is pushed fully into the calibration adaptor to avoid unnecessary voids remaining in the sample flow path which will cause slow response time.
8. Care should be taken when fitting or removing the sample probe as mishandling of the sample probe can fracture the inner capillary.
9. Always refer to HFR500 Fast FID Hydrocarbon Measurement System User manual of Cambustion Limited 2004.

5.6 Laser equipment

Please refer to the laser risk assessment form and local rules.

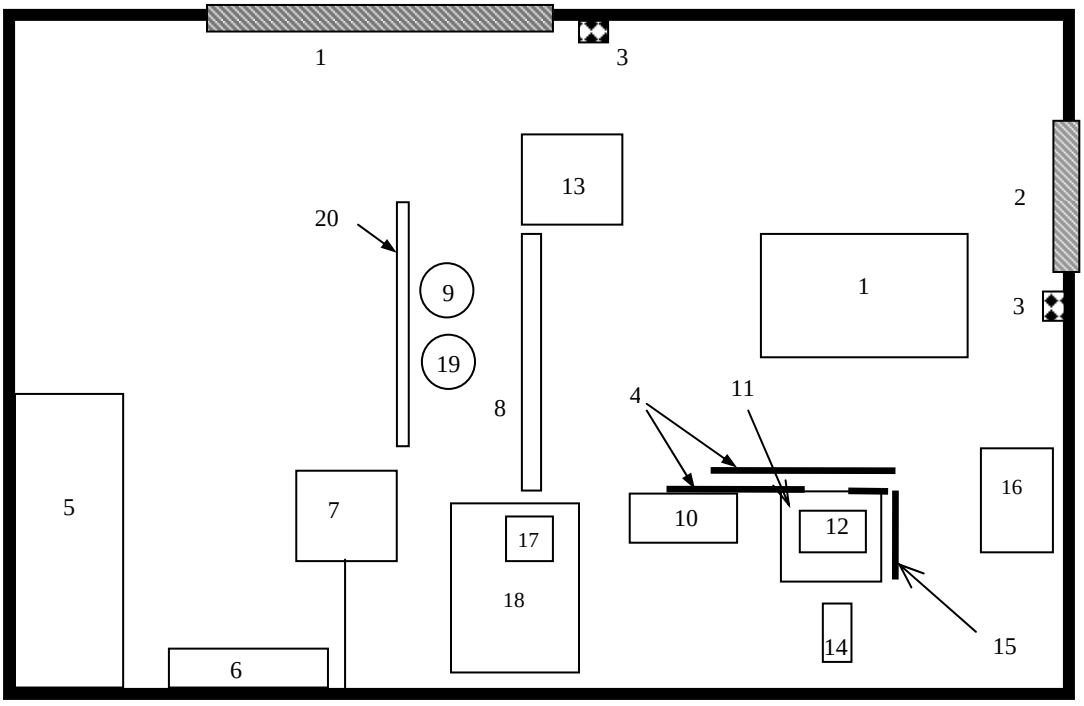
6.0 Related documents

1. New Wave research Inc. – Operator's manual for Tempest and Gemini PIV Nd:YAG Lasers, October 2000
2. Dantec Flowmap PIV manual
3. Local rules for Project Room of Hopkinson Lab
4. Laser risk assessment form
5. Risk Assessment form
6. Control of Substances Hazardous to Health (COSHH) forms
7. HFR500 Fast FID Hydrocarbon Measurement System User manual of Cambustion Limited 2004.
8. HFR500 Fast FID Simplified Operating Instructions of Cambustion Limited 2004.

7.0 Appendix

7.1 Appendix 1

Plan view of Project Room



1. Front entrance
2. Emergency exit
3. Emergency button
4. Partitions
5. Storage cabinet
6. Air compressor
7. Exhaust fan
8. Rotameter panel
9. N_2 gas cylinder
10. Nd:YAG laser
11. Exhaust fan
12. Burner set up
13. Table
14. CCD camera
15. Beam dump
16. Water tank
17. Thermoregulator
18 Table
19 Methane gas cylinder
20 Gas cylinder holding panel

Appendix 2

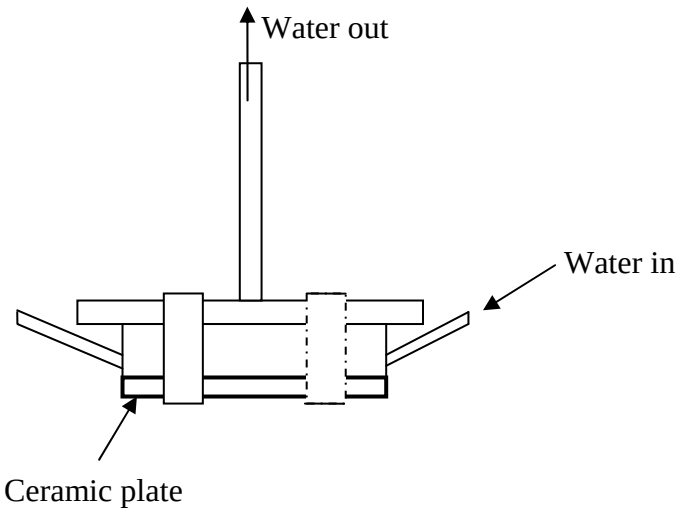
1. Methane and air flow rate

ϕ	$\dot{V}_{air}$ (l/min)	$\dot{V}_{CH4}$ (l/min)	$\dot{V}_{air}$ (l/min)	$\dot{V}_{CH4}$ (l/min)	$\dot{V}_{air}$ (l/min)	$\dot{V}_{CH4}$ (l/min)	$\dot{V}_{air}$ (l/min)	$\dot{V}_{CH4}$ (l/min)
0.60	15	0.95	18	1.13	20	1.26	22	1.39
0.70	15	1.10	18	1.32	20	1.47	22	1.62
0.80	15	1.26	18	1.51	20	1.68	22	1.85
0.90	15	1.42	18	1.70	20	1.89	22	2.08
1.00	15	1.58	18	1.89	20	2.10	22	2.31
1.10	15	1.73	18	2.08	20	2.31	22	2.54
1.20	15	1.89	18	2.27	20	2.52	22	2.77
1.30	15	2.05	18	2.46	20	2.73	22	3.00
1.40	15	2.21	18	2.65	20	2.94	22	3.24
1.50	15	2.36	18	2.84	20	3.15	22	3.47
1.60	15	2.52	18	3.03	20	3.36	22	3.70
1.70	15	2.68	18	3.21	20	3.57	22	3.93
1.80	15	2.84	18	3.40	20	3.78	22	4.16

ϕ	$\dot{V}_{air}$ (l/min)	$\dot{V}_{CH4}$ (l/min)	$\dot{V}_{air}$ (l/min)	$\dot{V}_{CH4}$ (l/min)	$\dot{V}_{air}$ (l/min)	$\dot{V}_{CH4}$ (l/min)
0.60	25	1.58	28	1.76	30	1.89
0.70	25	1.84	28	2.06	30	2.21
0.80	25	2.10	28	2.35	30	2.52
0.90	25	2.36	28	2.65	30	2.84
1.00	25	2.63	28	2.94	30	3.15
1.10	25	2.89	28	3.24	30	3.47
1.20	25	3.15	28	3.53	30	3.78
1.30	25	3.41	28	3.82	30	4.10
1.40	25	3.68	28	4.12	30	4.41
1.50	25	3.94	28	4.41	30	4.73
1.60	25	4.20	28	4.71	30	5.04
1.70	25	4.46	28	5.00	30	5.36
1.80	25	4.73	28	5.29	30	5.67

2. As for Nitrogen co-flow, the testing range will be from 29–35 l/min and will be varied accordingly based on observation.

Appendix 3



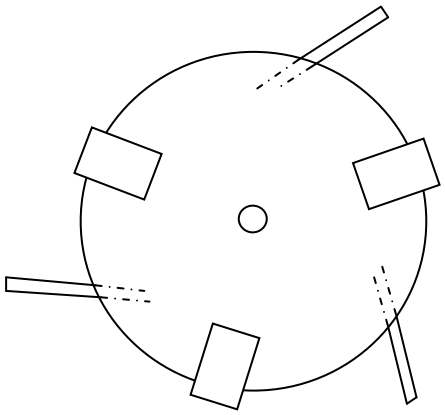


Figure 2: Cooling system and ceramic plate