Buoyant Jet Mole Fraction Measurements using Rayleigh scattering Technique

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INTRODUCTION

- In flow studying, it is very important to obtain the most possible information about the flow physical behavior.
- Rayleigh scattering technique has the advantage of measuring the density, temperature and velocity without any disturbances to the flow and there is also no need to seed the flow with particles (PIV) or gas phase tracer e.g. acetone (PLIF).
- This technique involves the elastic interaction of the incident laser light with the gas molecules which results the scattered light and the laser to have the same central wavelength.

Rayleigh scattering geometry

\[ I_0 = 1.0NLS\frac{d\sigma}{d\Omega} \]

\( I_0 \) ≡ Rayleigh scattering signal intensity \([W.m^{-2}]\), \( I_0 \) ≡ incident laser intensity \([W.m^{-2}]\), \( N \) ≡ species number density \([m^{-3}]\), \( L \) ≡ length of probe volume \([m]\), \( \Omega \) ≡ solid angle for detection \([Sr]\), \( \frac{d\sigma}{d\Omega} \) = differential Rayleigh scattering cross section species mixture \([m^{2}.Sr^{-1}]\).

METHODOLOGY

- Raw image definition (Clemens, N. T. (2002)): \( S(I, j, t_e, t_w) = w(I, j)|L(I, j) (S_{\text{Ray}}(I, j) + S_{\text{back}}(I, j, t_w)) + S_{\text{dark}}(I, j, t_w) \)

With \( S \) ≡ total detected Rayleigh scattering signal \([pixel - count]\), \( L(I, j) \) ≡ vertical and horizontal pixel locations, \( t_e \) ≡ exposure time, \( t_w \) ≡ array readout time, \( w(I, j) \) ≡ white-field response function, \( L(I, j) \) ≡ Laser intensity distribution, \( S_{\text{Ray}} \) ≡ the actual jet and coflow Rayleigh scattering signal \([pixel - count]\), \( S_{\text{back}} \) ≡ background signal \([pixel - count]\), \( S_{\text{dark}} \) ≡ camera dark current \([pixel - count]\).

- Shot-to-shot correction: using photodiode and oscilloscope to capture each laser pulse (total 500 pulses).

- Background and dark current correction:

\[ \text{Background}(I, j) = \text{Background}_{\text{Ray}}(I, j) - \left( \frac{\frac{d\sigma_{\text{Ray}}}{d\Omega}}{\frac{d\sigma_{\text{Ray}}}{d\Omega} - \frac{d\sigma_{\text{back}}}{d\Omega}} \right) \left( \text{Background}_{\text{Ray}}(I, j) - \text{Background}_{\text{Ray}}(I, j) \right) \]

EXPERIMENTAL SETUP

- Beam dump / power meter
- Camera on moving stage
- sCMOS Zyla 5.5
- Cylindrical lens
- Beam splitter
- 532nm mirror
- MFC

RESULTS + UNCERTAINTY ANALYSIS

- Uncertainty analysis:

\[ I_s = R \frac{P_{\text{EL}}}{T F^2} \Rightarrow T = R \frac{T F^2}{P_{\text{EL}}} \]

\[ \Delta T = \left( \frac{\Delta T F}{T F^2} \right)^2 + \left( \frac{\Delta P}{T F^2} \right)^2 + \left( \frac{\Delta E}{E} \right)^2 \]

\[ \Delta N = \left( \frac{\Delta N}{N} \right)^2 + \left( \frac{\Delta N}{N} \right)^2 \]

- Filtered Rayleigh scattering (FRS) is the atomic/molecular vapor filter which is placed in front of camera and will improve qualitative flow visualizations.
- FRS will be used to remove more precisely the wall/dust reflections from Rayleigh scattering signal to improve accuracy of the image analysis for flow temperature measurements.

Future Work