Measurement and Simulation of Suppression Effects in a Buoyant Turbulent Line Fire

James P. White

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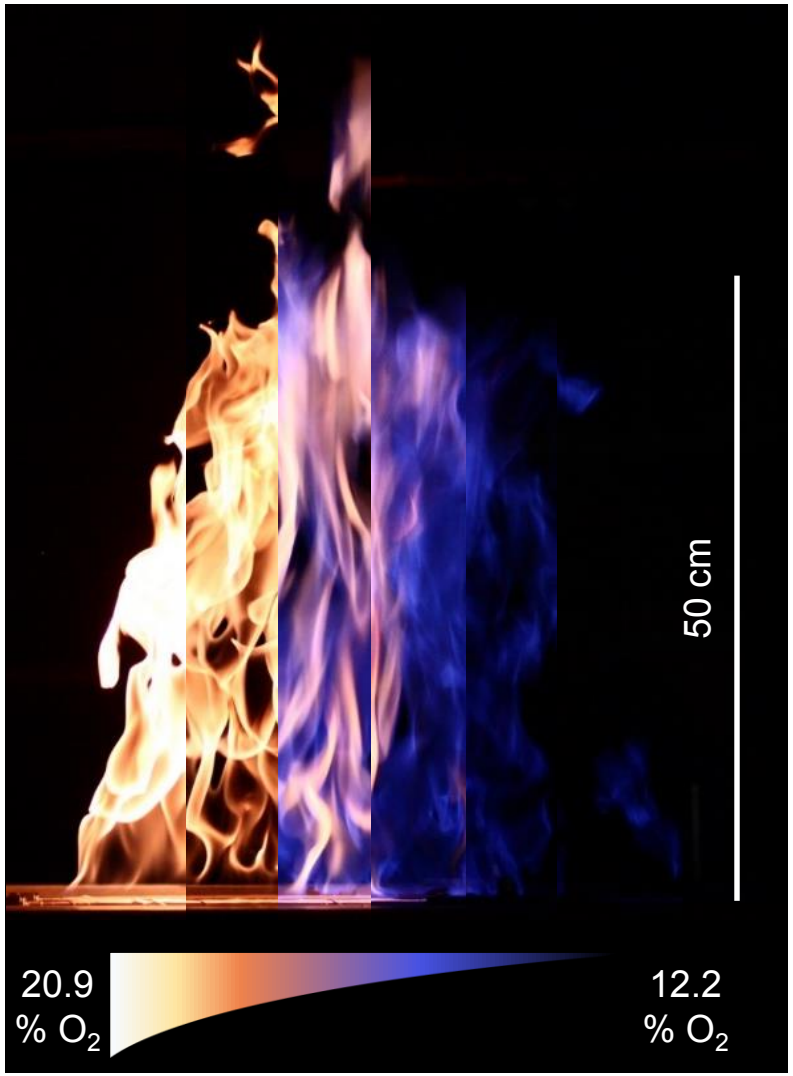
Introduction: Motivation

- How to establish performance-based design of fire suppression systems?
  - Primary issues
    - Full and scaled experiments can be prohibitively costly, with limited utility
    - Complexity of suppression phenomena hinders model development
  - Currently, no validated analytical framework to predict suppression performance
    - Limited accuracy of practical CFD treatments
    - Limited data for model validation

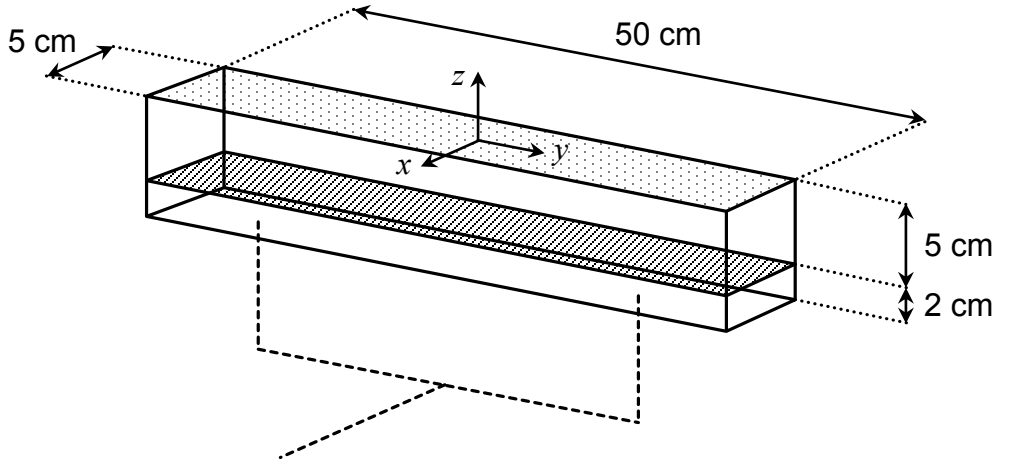
Introduction: Objective

- Experiment (Turbulent Line Burner, TLB)
  - Develop a canonical lab-scale facility for the investigation of fire suppression phenomena
  - Provide detailed and well-characterized measurements to support the development and validation of suppression models
- Simulation (FDS, FireFOAM)
  - Assess the performance of current suppression models via comparison with measurements
  - Identify recommendations for model improvement



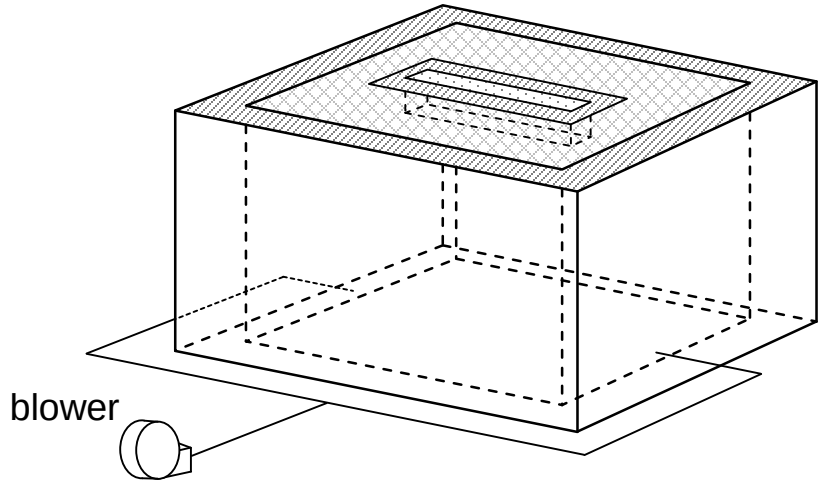
Experiment: Configuration

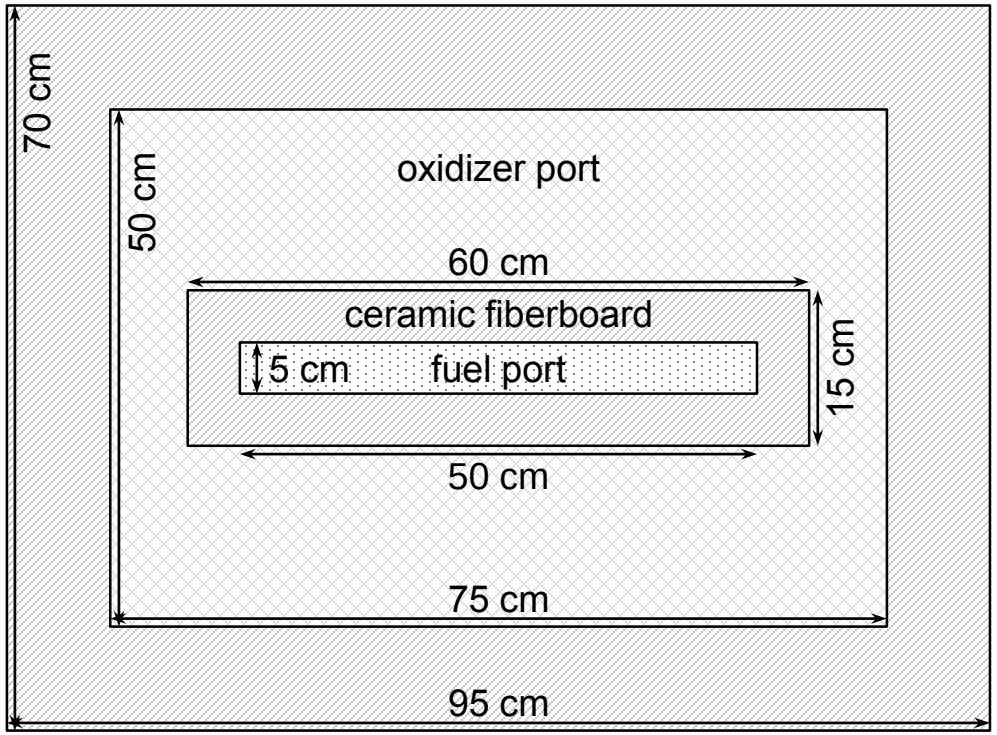
- Turbulent Line Burner (TLB)
  - Desired flame characteristics:
    - Line-fire geometry
    - Buoyancy driven
    - Fully turbulent
  - Fuel
    - Methane (CH_4) 1.00 g/s (6.0 cm/s)
  - ~ 50 kW total heat-release rate



Experiment: Configuration

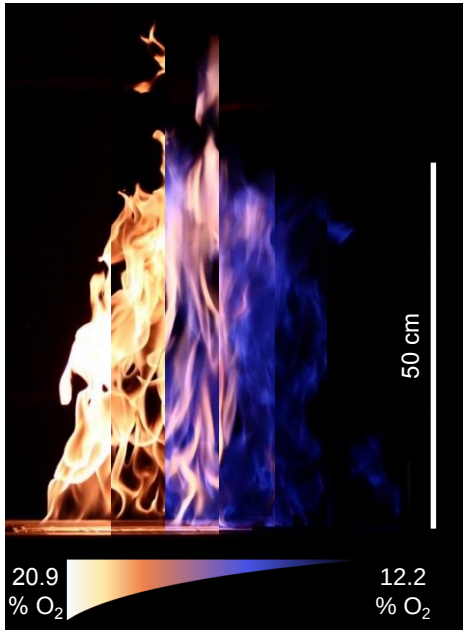
- Co-flowing Oxidizer
  - Desired oxidizer characteristics:
    - Steady, uniform flow
    - Controlled suppressant delivery
    - Minimally impact flame entrainment
  - Total flow 55-85 g/s (16-25 cm/s)
  - Ceramic fiberboard blockage around fuel port

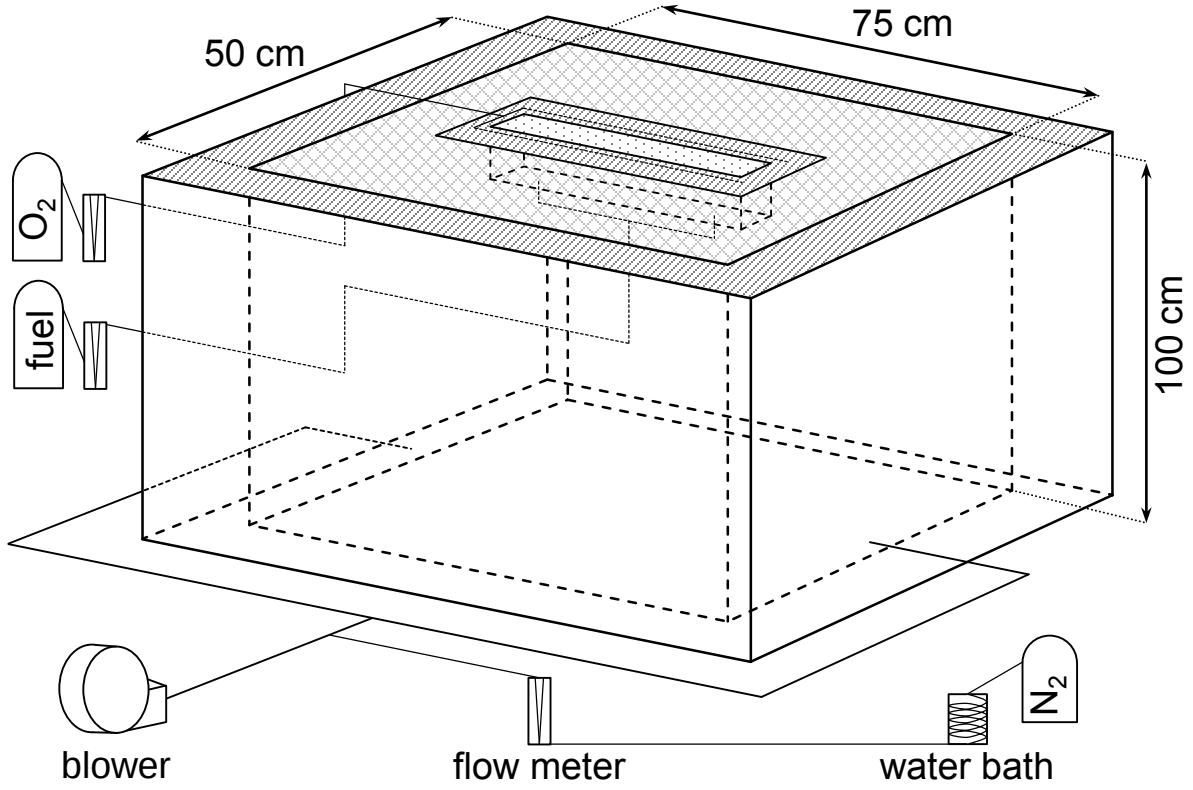




N_2 Suppression: Configuration

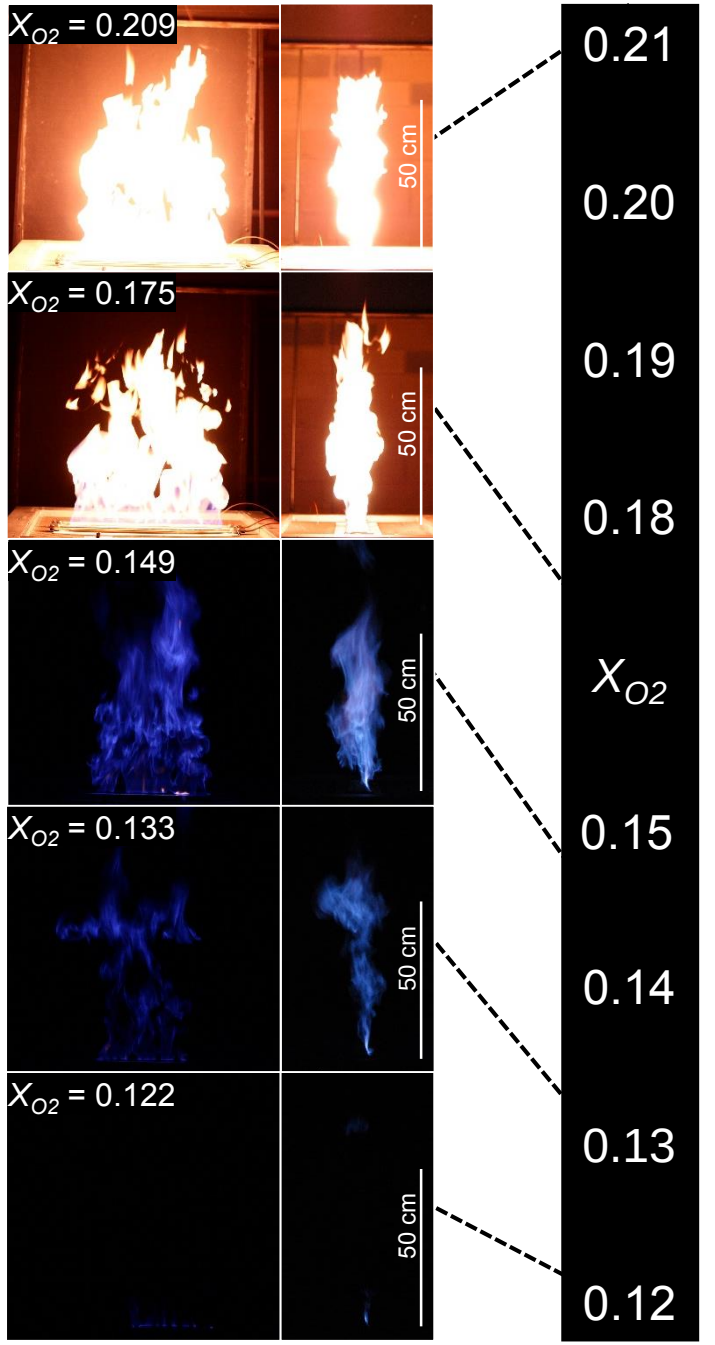
- Nitrogen Suppression
  - N_2 gas via pressurized Dewar
  - 0-40 g/s N_2 (X_{O_2} : 0.21-0.11)
  - Oxygen anchor
    - 0.08 g/s O_2 (~ 2% combustion)
    - Prevents liftoff extinction





N_2 Suppression: Results

- Flame Images



N_2 Suppression: Results

- Combustion Efficiency

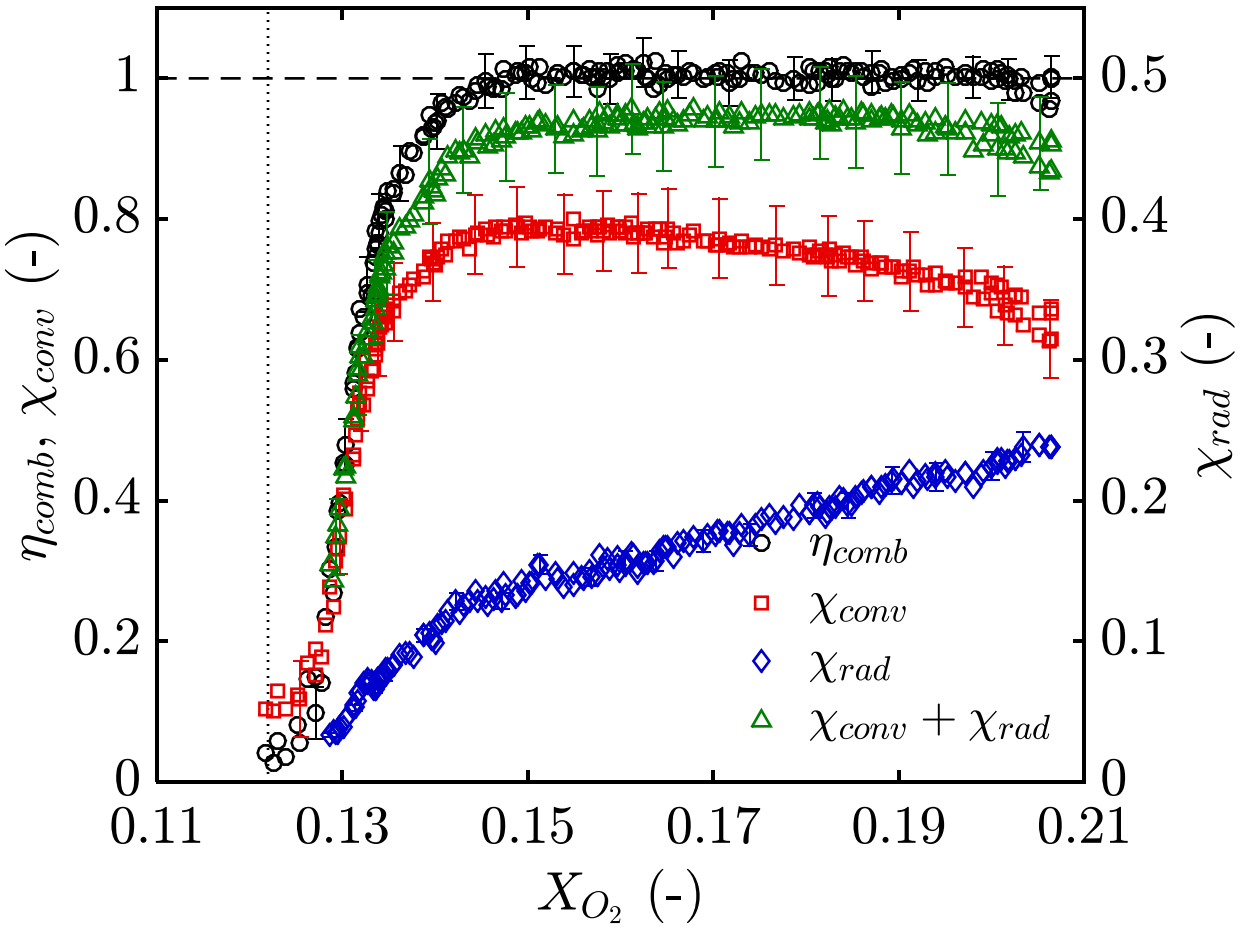
$$\eta_{comb} = \frac{\dot{Q}}{\dot{m}_{fuel}\Delta h_{comb}}$$

$$\chi_{rad} = \frac{\dot{Q}_{rad}}{\dot{m}_{fuel}\Delta h_{comb}} \approx \frac{\dot{q}''_g F_{mp}}{\dot{m}_{fuel}\Delta h_{comb}}$$

$$\chi_{conv} = \frac{\dot{Q}_{conv}}{\dot{m}_{fuel}\Delta h_{comb}} \approx \frac{\dot{m}_e c_{p,e}\Delta T_e}{\dot{m}_{fuel}\Delta h_{comb}}$$

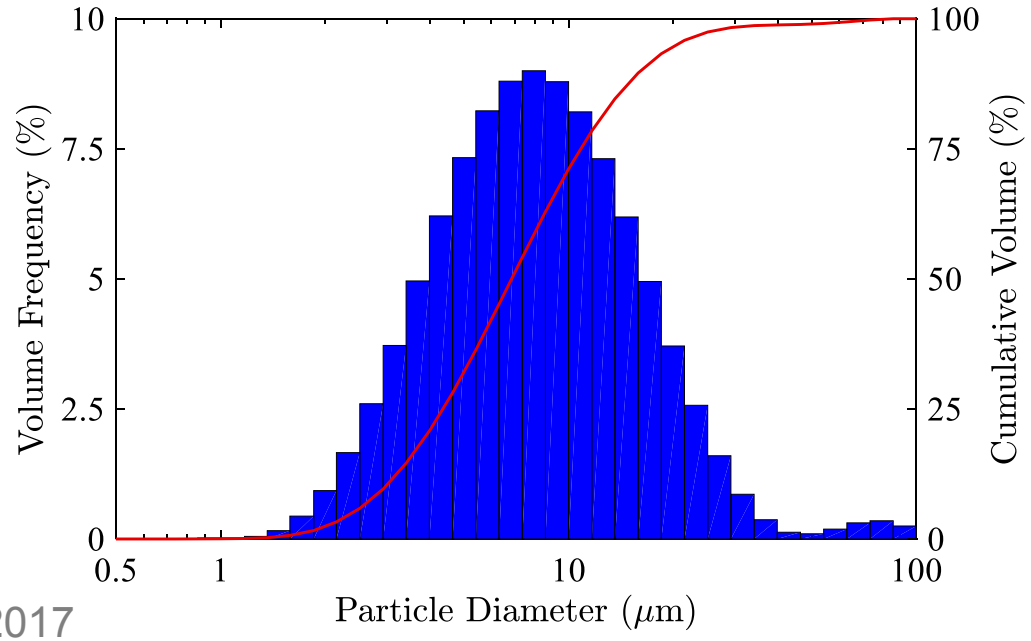
$$\dot{Q} \approx \dot{Q}_{rad} + \dot{Q}_{conv}$$

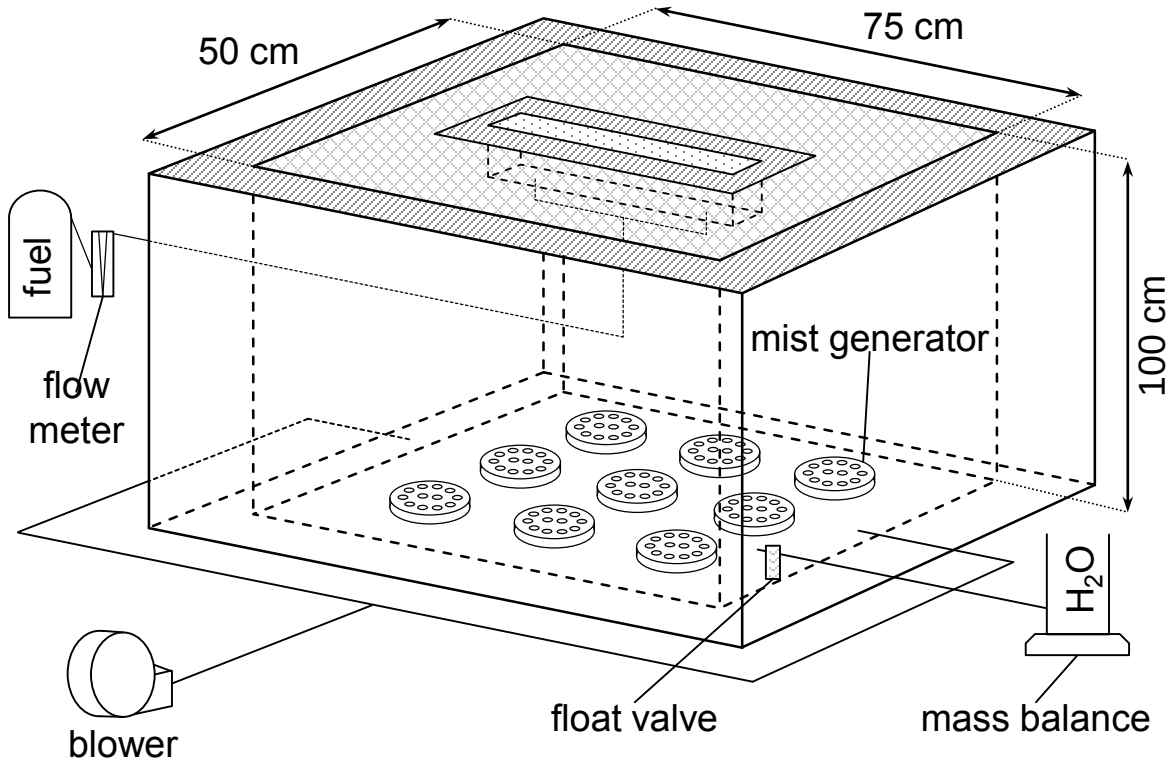
$$\eta_{comb} \approx \chi_{rad} + \chi_{conv}$$



Mist Suppression: Configuration

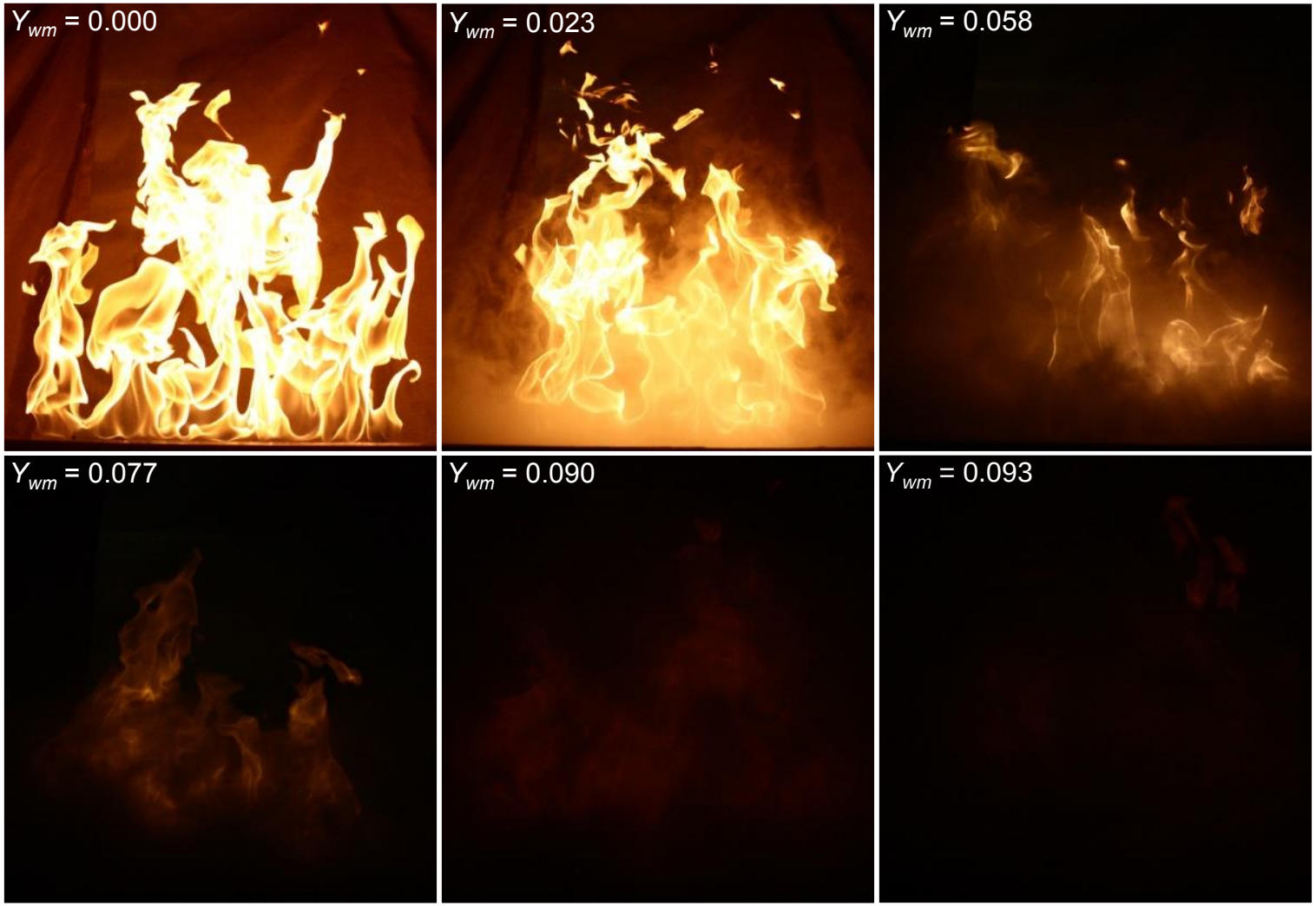
- Mist Suppression
  - Ultrasonic mist generators
  - 0-5.5 g/s mist (Y_{wm} : 0-0.10)
  - Droplet size, SMD = 6.6 μm
  - Negligible injection momentum





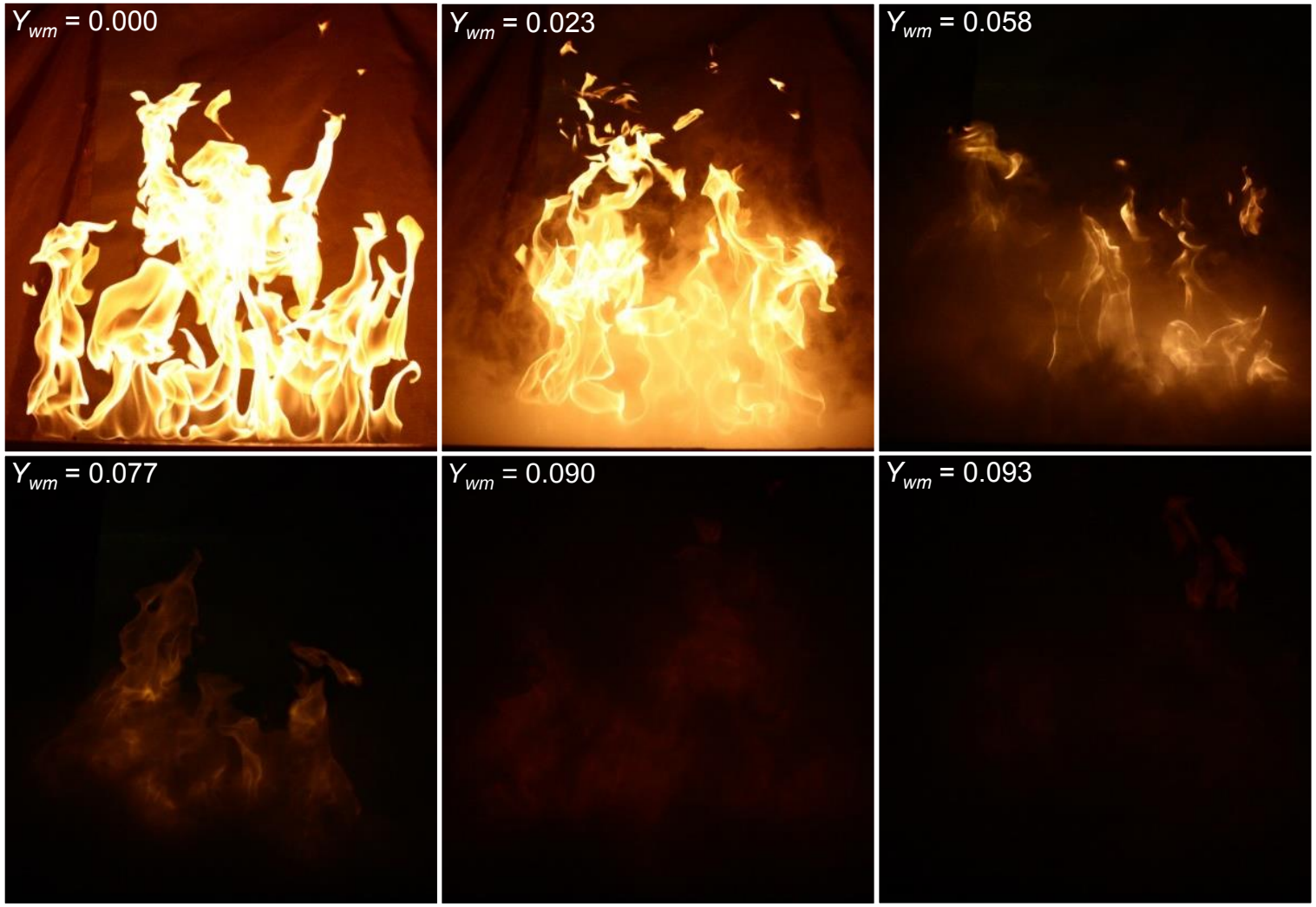
Mist Suppression: Results

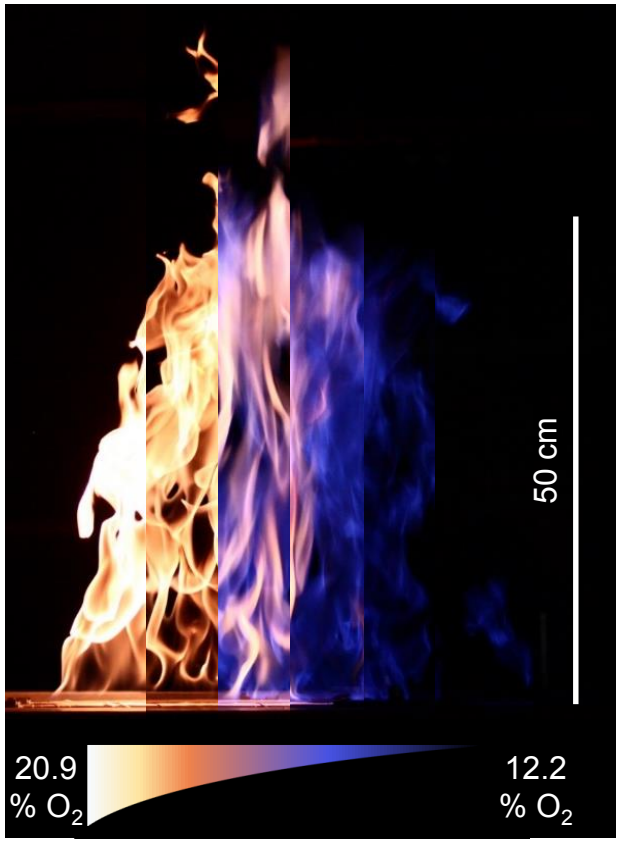
- Flame Images



Mist Suppression: Results

- Flame Images





(N_2 dilution)

Mist Suppression: Results

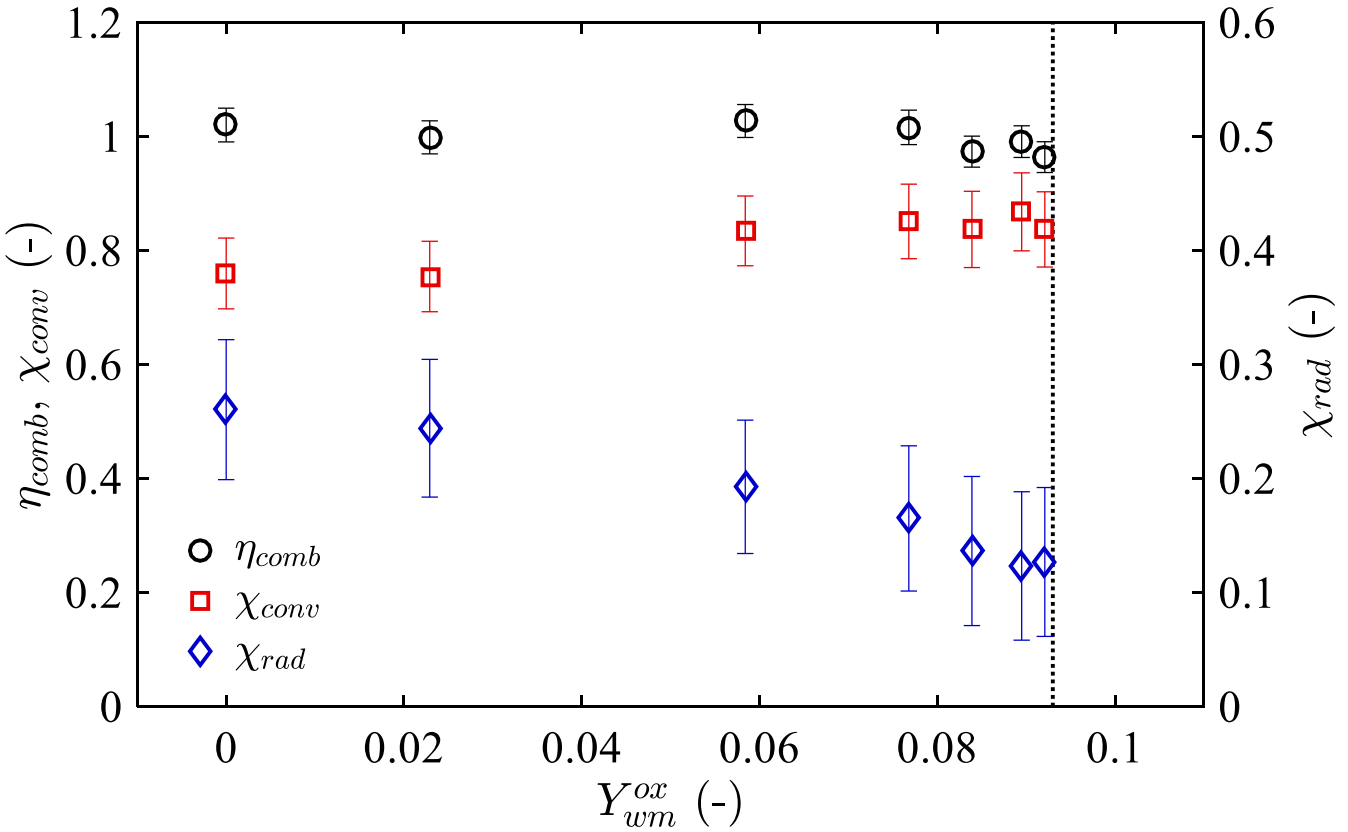
- Combustion Efficiency

$$\eta_{comb} = \frac{\dot{Q}}{\dot{m}_{fuel}\Delta h_{comb}}$$

$$\chi_{conv} = \frac{\dot{m}_e c_{p,e}(T_e - T_\infty) + \dot{m}_{wm}^{vap}\Delta h_{H_2O}^{vap}}{\dot{m}_{fuel}\Delta h_{comb}}$$

$$\chi_{rad} = \eta_{comb} - \chi_{conv}$$

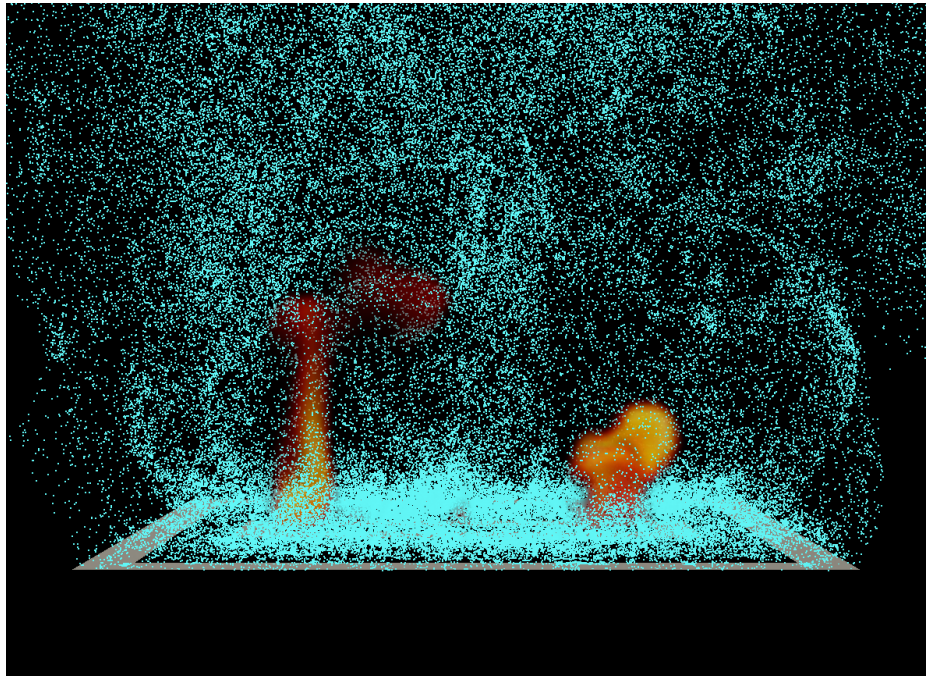
- Extinction Limit
  - $Y_{wm}^{ext} = 0.093 \sim X_{H2O}^{ext} \approx 0.17$
  - From literature*: $X_{H2O}^{ext} \approx 0.27$



* B. Cong & G. Liao. Science in China Series E: Technological Sciences 51 (2008) 1222-1231.

Conclusions

- Highlights
  - Novel and canonical facility for study of turbulent fire suppression phenomena (N_2 & mist)
  - Non-intrusive integral measurements provide insight into suppression processes
  - Measurements available in MaCFP database*
- Future Work
  - Continued fire modeling work on simulating water mist suppression



* http://www.iafss.org/macfp/; https://github.com/MaCFP/macfp-db

Thank You!