Experimental and numerical studies of fuel and hydrodynamic effects on piloted turbulent premixed jet flames

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Abstract

An experimental and numerical investigation of fuel and hydrodynamic effects is performed on piloted premixed jet flames. The investigation is carried out at a constant laminar flame speed, varying heat losses, jet Reynolds number, fuel molecular weight, and fuel chemical classification. Large Eddy Simulations are performed in an attempt to reproduce the behaviors observed experimentally. Simulations are compared against well-characterized boundary conditions, well-resolved two-dimensional velocity fields from particle image velocimetry, and line-of-sight CH^* profiles. Experimental results indicate that small amounts of heat losses may play a significant role on the jet reactivity as the flame heights scale with the heat loss from the jet. However, differences between flames with different fuels can still be seen in the absence of heat losses and these differences are magnified at higher Reynolds numbers. Particularly, methane flames are consistently taller and ethylene flames consistently shorter while other fuels present approximately the same flame height. LES reproduce the experimentally observed trends in global flame heights (effects of heat losses and Reynolds number) but some of the differences between fuels are not captured.

Keywords: premixed turbulence, jet flames, PIV, LES, hydrocarbon fuels

1. Introduction

Though turbulent premixed combustion has been studied widely, few numerical and experimental studies have assessed finite-rate chemistry or fuel effects, especially at high turbulence levels. Figure 1 depicts a Borghi/Peters premixed combustion regime diagram [1, 2] with a representative survey of nearly 140 turbulent premixed flame experiments. Two main observations may be drawn from this survey. First, the vast majority of the experimental investigations have been carried out for either hydrogen or methane flames, with very limited data on heavy hydrocarbons despite their omnipresence in practical combustion engines [3, 4]. Second, there is a scarcity of data for any fuels (and especially for high carbon number fuels) in the thin and broken reaction zone regimes. One of the overarching goals of the present paper is to provide much needed data for heavy hydrocarbons at high Karlovitz numbers corresponding to the thin and broken reaction zone regimes on the Borghi/Peters regime diagram).

Independent of the lack of experimental data for heavy hydrocarbon fuels under high turbulent intensities, such Borghi/Peters diagram highlights one important underlying assumption with respect to the modeling of turbulent premixed flames. The use of only two laminar flame properties, namely the laminar flame speed, S_L and the laminar

Fig. 1: Borghi diagram showing experimentally investigated fuels [5–13]. Present work is shown indicated by red crosses.

flame thickness, δ_F , makes the implicit assumption of no significant chemical effects beyond those global properties. Stated differently, the structure of a turbulent flame is the same as that of the one-dimensional freely propagating flame. This assumption is behind a large body of turbulent combustion models [14–16]. This raises an important question: what is the impact of the fuel and its chemistry on the turbulence-flame interaction?

There is experimental evidence that differential diffusion effects, found to be significant in laminar flames [17, 18], are still present in turbulent combustion [6, 19–21]. However, it is not clear if the same correlations apply to high Karlovitz number flows where turbulent transport dominates. There, small eddies can broaden the preheat zone and thicken or even break the reaction zone [22–24]. The impact on the chemical processes is still not well characterized, especially for heavy hydrocarbon fuels. Previous numerical simulations at high Karlovitz numbers using detailed chemistry focused mostly on simple fuels such as hydrogen [25, 26] and methane [27, 28]. Only a few studies considered heavier hydrocarbon fuels such as *n*-heptane. These studies have shown persistent differential diffusion effects in *n*-heptane flames at the transition from the thin to broken/distributed reaction zone regimes [29, 30].

Following these observations, the goal of the paper is to investigate fuel and hydrodynamic effects at high Karlovitz numbers. More precisely, the objectives are two-fold. The first objective is to generate well-characterized experimental data for a variety of fuels from small alkanes/alkenes (methane/ethylene) to large *n*-alkanes (propane and *n*-heptane) to aromatic fuels (toluene). The second objective is to identify possible fuels effects under a fixed and identical S_L . These objectives will be achieved by using a modified piloted premixed jet burner (PPJB) [31, 32] combined with matching Large Eddy Simulations (LES). Any possible fuel effects will be isolated by conducting the experiments with fuel/air mixtures with the exact same S_L and by performing LES with models purposely assuming the same structure as laminar flames.

The document is organized as follows. First, an overview of the experimental setup is provided, followed by a description of the measurements techniques and the modeling strategies used to simulate the turbulent flames. Then,

a detailed comparison of boundary conditions and jet development between experiments and simulations is provided. Finally, the effects of fuel and fluid dynamics are analyzed by considering the height of the turbulent flame.

2. Description of the Piloted Premixed Jet Burner

The present work relies on the original PPJB burner design [31, 32] with modifications to allow studies of fuels with a wide range of molecular weights. A schematic of the burner design used in experiments is shown in Fig. 2. The burner consists of two co-annular premixed flames surrounding and stabilizing the high exit velocity central jet.

The main jet consists of a straight stainless steel tube with an internal diameter of $D=5.84$ mm and an external diameter of 6.35 mm. Keeping S_L constant, the main jet exit velocity U_{jet} and fuel are varied to investigate finite-rate chemistry and fuel effects.

The main jet is surrounded by a pilot flow coming out of a co-annular tube with internal diameter of $D_{\text{pilot}}=22.9$ mm and outer diameter of 24.1 mm. The nozzle edge of the jet is located 0.6mm above the pilot nozzle. A small step (0.5 mm thick) located 11 mm from the burner exit is used to hold a 5 mm thick brass perforated plate. This plate is composed of 52 holes (1.52 mm in diameter) and serves as anchor for the stoichiometric premixed methane/air flames. The pilot tube has an unburnt exit velocity of 0.75 m/s before the step. The pilot tube is 70 mm in length and externally conical in shape with a 32.4 diameter base.

Finally, the outermost co-axial coflow uses hot products to insulate thermally the jet. Hydrogen/air flames at an equivalence ratio $\phi=0.44$ and 0.51 are used to provide a coflow temperature (T_{coflow}) of 1400K and 1500K respectively. A fuel mixture of 20% hydrogen and 80% ethylene by mole with air at $\phi=0.55$ is used to provide a temperature of $T_{\text{coflow}}=1600\text{K}$. The coflow flames are stabilized on a perforated plate (outer diameter of 203 mm) with 1800 x 1.52 mm holes. The cold flow exit velocity before the plate is 0.7 m/s. All three streams are at the controlled laboratory air temperatures of 298K before being subsequently burned. The total heat release of the PPJB apparatus varies from 44 to 58 kW depending on the fuel and Reynolds number.

Experiments and simulations are performed at various unburnt jet Reynolds numbers, $\text{Re}_{\text{jet}} = U_{\text{jet}}D/\nu=25,000$, 37,500, 50,000, and 75,000 for five different fuels: methane, ethylene, propane, *n*-heptane, and toluene. The unburnt temperature was 298 K in all cases and the equivalence ratio of the main jet was varied to enforce the same laminar flame speed, $S_L=11.3$ cm/s. The methane flame has $\phi=0.60$ with an adiabatic flame temperature $T_{\text{ad}}=1666\text{K}$; ethylene $\phi=0.48$, $T_{\text{ad}}=1543\text{K}$; propane $\phi=0.56$, $T_{\text{ad}}=1623\text{K}$; *n*-heptane $\phi=0.56$, $T_{\text{ad}}=1629\text{K}$; and toluene $\phi=0.58$, $T_{\text{ad}}=1720\text{K}$. Table 1 provides a summary of the conditions investigated. The laminar flame thickness of methane/air is used in Table 1 since less than 7% variation was observed between the different fuels. These turbulent premixed flames are characterized by large turbulent intensities and high Karlovitz numbers. The flames are expected to fall

Fig. 2: Piloted premixed jet burner (PPJB) cutaway with dashed lines showing the lower bounds of the computational domain. All measurements are in mm.

either in the thin reaction zone regime or in the broken reaction zone regime.

U_{jet} (m/s)	Re_{jet}	$\frac{u'}{S_L}$	u' (m/s)	$\tau_t = \frac{u'}{L_{int}}$ (ms)	$\frac{L_{int}}{\delta_f}$	L_{int} (mm)	$\tau_\eta = \sqrt{\frac{L_{int}\nu_u}{u'^3}}$ (ms)	$Ka = \frac{\tau_f}{\tau_\eta}$	$Da = \frac{\tau_t}{\tau_f}$	$Re_t = \frac{u' L_{int}}{\nu_u}$
68.5	25000	65	8	0.88	7.1	6.6	0.0153	524	0.0314	3037
100	37500	104	12	0.48	6.7	6.2	0.0071	1132	0.0173	4564
133	50000	157	18	0.32	6.3	5.8	0.0039	2079	0.0115	6405
200	75000	252	29	0.18	5.5	5.1	0.0018	4533	0.0063	9074

Table 1: Conditions of the experiments and simulations performed. Re_t is the turbulent Reynolds number, Ka is the Karlovitz number, and u' is the peak turbulent intensity at $x/D=15$. The integral length scale L_{int} is evaluated in the shear layer at $x/D = 15$. All values are calculated based on the kinematic viscosity of the unburnt mixture but the turbulent properties of the flow, i.e. L_{int} and u' used in Re_t are measured with the flame ignited. S_L and thermal flame thickness $\delta_f = ((T_b - T_u))/|\nabla T|_{max}$, were calculated using PREMIX [33]. Flame properties of methane/air are used.

3. Experimental approach

3.1. Fuel vaporization system

A new fuel vaporization system was designed based on existing technology developed for heavy hydrocarbon investigations in laminar flames [17, 18]. This system has a much higher flowrate capable of fully vaporizing up to 20 mL/min of liquid fuel with air flow rates of up to 400 SLPM. The system consists of inline heaters that preheat the air which issues into heated stainless steel chambers. The fuel is then injected in a crossflow configuration into the chambers with a fine mist of droplets from the tip of a Meinhardt liquid nebulizer [18]. The fuel is held in a Chemyx syringe and the flow rate controlled with a high accuracy Nexus syringe pump. Special care has been taken in order to avoid hot spots that can cause fuel decomposition and cold spots that can cause fuel condensation throughout the flow system [17]. The gaseous flow rates are controlled accurately using sonic nozzles.

3.2. CH^* luminosity

Flame height H_{fl} is commonly used to compare flames in Bunsen and jet burner configurations and will be the main metric here to compare between fuels. For each flame, 100 images of the CH^* luminosity are taken using a filter centered at 434 nm with a bandwidth of 17 nm to capture the primary emittance band from CH^* which peaks around 431 nm. These images are taken with an Andor Zyla camera using an exposure time of 200 ms and then averaged together. H_{fl} is defined as the location where the line-of-sight chemiluminescence of the flame brush drops to a quarter of the maximum value along the jet centerline, not accounting for the luminosity from the pilot. The error bars on these measurements are $\pm 1D$. A 5% change in the threshold only leads to marginal changes in flame height and would affect all flames similarly. Thus, the observed trends will not be affected.

3.3. Particle Image Velocimetry (PIV)

A high power Q-switched frequency-doubled laser (Quantel Brilliant Twins) generates light at 532 nm and expands using a plano-cylindrical lens (Thorlabs) into a thin sheet through the jet centerline at 10 Hz. The jet is seeded with 0.3-1 μm aluminum oxide particles that survive the flame. 500 statistically independent coupled Mie scattering images are taken with three stitched high resolution SCMOS cameras (Andor Zyla 5.5) focalized with a F85mm/2.8D Nikon lens in order to find the velocity field along the entire height of the jet. A laser-line filter at 532 nm removes the flame luminosity signal. Inter-frame times range between 1 μs -20 μs , depending on U_{jet} and the average velocity at the location of interest. The image couples have a resolution of 57.9 μm /pixel and are post-processed with the Davis Flowmaster software (LaVision Research Inc.) with decreasing interrogation window sizes of 64x64 pixels then 16x16 pixels with 50 percent overlap between windows and then averaged to obtain the mean and RMS velocity profiles. Vectors with a peak ratio of less than 1.05 are removed and the universal outlier detection method is used for spurious vector removal.

PIV measurements at 1 mm above the burner surface (boundary conditions) are taken with a finer resolution of approximately 9 μm /pixel using one SCMOS camera and a F200mm/4D Nikon lens. All three streams are seeded simultaneously with tracer particles. A separate Δt is used for the central jet and the pilot/coflow since the exit velocity of the central jet is significantly greater than the pilot and coflow streams. For this data set, 1000 statistically independent images are averaged.

The PIV uncertainty of the jet is dependent on U_{jet} and is estimated to be $\pm 0.05 U_{jet}$. PIV measurements in the coflow and pilot have a 10% relative uncertainty due to a lower particle seeding density.

3.4. Temperature measurements

Temperature measurements along the centerline are taken with a ceramically-shielded thermocouple (Omega,

Inc) and corrected for radiation. The thermocouple tip, 200 μ m in diameter, is inserted into the flame perpendicular to the incoming flow with approximately 1 mm of the leads exposed. The thermocouple measurements have an uncertainty of ± 50 K everywhere except at the interface between flows. There, the uncertainties reach ± 100 K due to oscillations in the measured temperature values.

4. Numerical approach

The combustion modeling used in the present LES relies on chemistry tabulation of laminar flames with presumed sub-filter PDF. In recent DNS with detailed chemistry [29, 30], it was shown that the mean species and chemical source term profiles (in progress variable space) of high Karlovitz number flames can be well approximated by one-dimensional unstretched premixed flames. The governing equations are described first, followed by the chemistry tabulation.

4.1. Governing equations and LES closure

The filtered (LES) equations are as follows:

$$\frac{\partial \bar{\rho}}{\partial t} + \nabla \cdot (\bar{\rho} \tilde{\mathbf{u}}) = 0, \quad (1)$$

$$\frac{\partial \bar{\rho} \tilde{\mathbf{u}}}{\partial t} + \nabla \cdot (\bar{\rho} \tilde{\mathbf{u}} \tilde{\mathbf{u}}) = -\nabla \bar{p} + \nabla \cdot \bar{\boldsymbol{\tau}} + \nabla \cdot \bar{\boldsymbol{\tau}}_{\mathbf{u}}, \quad (2)$$

$$\frac{\partial \bar{\rho} \tilde{c}}{\partial t} + \nabla \cdot (\bar{\rho} \tilde{\mathbf{u}} \tilde{c}) = \nabla \cdot (\bar{\rho} \tilde{D}_c \nabla \tilde{c}) + \nabla \cdot \bar{\boldsymbol{\tau}}_c + \bar{\rho} \tilde{\omega}_c, \quad (3)$$

$$\frac{\partial \bar{\rho} \tilde{Z}}{\partial t} + \nabla \cdot (\bar{\rho} \tilde{\mathbf{u}} \tilde{Z}) = \nabla \cdot (\bar{\rho} \tilde{D}_Z \nabla \tilde{Z}) + \nabla \cdot \bar{\boldsymbol{\tau}}_Z, \quad (4)$$

where the density, $\bar{\rho}$, velocity vector, $\tilde{\mathbf{u}}$, progress variable, $\tilde{c}$, and mixture fraction, $\tilde{Z}$, are the resolved quantities. All sub-filter stresses ($\bar{\boldsymbol{\tau}}_{\mathbf{u}}$) and scalar fluxes ($\bar{\boldsymbol{\tau}}_{\phi}$) are closed using dynamic Smagorinsky models [34–36] with Lagrangian averaging techniques [37, 38]. The filtered thermochemical quantities $\bar{\rho}$, $\tilde{\nu}$, $\tilde{D}$, $\tilde{\omega}$ are expressed as:

$$\tilde{\phi} = (\tilde{c}, c_v, \tilde{Z}) \quad (5)$$

using a chemistry tabulation approach (Section 4.3).

The governing equations are solved using the energy conservative, finite difference code NGA designed for the simulation of variable density, low Mach number, turbulent flows [39]. The simulations use second-order accurate spatial and temporal discretizations. The third-order Bounded QUICK scheme, BQUICK [40], is used as the

transport scheme for the scalars to ensure they remain within their physical bounds.

4.2. Flow configuration

The size of the computational domain (see Fig. 2) is selected to be $0.35\text{m} \times 0.13\text{m} \times 2\pi$ in the axial, radial, and azimuthal directions, respectively. The grid in the axial direction uses 256 points and is stretched downstream of the burner exit. The radial direction is discretized using 200 non-uniformly distributed grid points concentrated in the shear layers between the different streams. The azimuthal direction is discretized using 64 equally spaced points. This corresponds to a resolution ranging from $\Delta/\delta_F \approx 0.5$ close to the burner exit to $\Delta/\delta_F \approx 4$ far downstream.

The turbulent inlet velocity profile for the fuel stream is extracted from a separate, fully-developed periodic pipe flow simulation. Laminar flat velocity profiles are imposed in the pilot and coflow streams, matching the experimental conditions.

4.3. Chemistry tabulation

As mentioned earlier, all thermodynamic and flame properties are tabulated using the progress variable, c , and mixture fraction, Z , from the solution of one-dimensional, unstretched, laminar premixed flames (i.e. flamelets) [15, 16, 41]. The progress variable is defined as the sum of H_2O , H_2 , CO , and CO_2 mass fractions.

A new chemistry table is generated for each fuel considered by combining individual flamelets with various compositions. While the experimental setup involves three different fuels (one for each stream), the present chemistry tables only consider two. The main jet is represented by a fuel/air flamelet at the given equivalence ratio (for instance, n -heptane/air at $\phi=0.56$); the pilot stream is represented by a flamelet of methane/air at stoichiometry; and the coflow is represented by a flamelet of lean fuel/air mixture (same fuel as the main jet) which yields the same burnt temperature as the experimental coflow temperature. The mixture fractions for these three flamelets are evaluated in the unburnt gases using

$$Z = Z_{st} + (1 - Z_{st})(Y_{\text{CH}_4} + Y_{\text{Fuel}}) - Z_{st} \frac{Y_{\text{O}_2}}{0.232} \quad (6)$$

and are used as inlet values for the three corresponding streams. Additional flamelets at intermediate mixture fractions are used to populate the table. These flamelets are computed using FlameMaster [42] and the CaltechMech v2.3 [43]. This chemical model contains 174 species and 1896 reactions (forward and backward counted separately) and has been validated extensively for all present fuels [44, 45].

These flamelets are filtered with different filter widths, and the filtered fields are then tabulated against the filtered progress variable $\tilde{c}$, its variance c_v , and the filtered mixture fraction $\tilde{Z}$ [46–48]. The variance of Z is neglected, and

the variance of the progress variable is obtained using an algebraic model [49, 50]. The resulting flamelet library is discretized with $200 \times 100 \times 200$ grid points in the $\tilde{c}$, c_v , and $\tilde{Z}$ directions, respectively.

5. Experimental/numerical validation

Boundary conditions at the jet exit are discussed first to ensure consistency between experiments and simulations. They are followed by a comparison of the downstream development of the turbulent jet. This is done for the methane/air flame at $Re_{jet}=50,000$ and $T_{coflow}=1500K$.

5.1. Boundary Conditions

Fig. 3: Comparison of experimental and numerical temperature profiles at $x = 1$ mm above the jet exit.

As shown in Fig. 3, thermocouple measurements indicate that the temperature at the burner exit on the centerline stays close to 298K even with the pilot and coflow ignited. The temperature rises sharply in the pilot and peaks around T_{ad} of stoichiometric methane/air at 2250K. The temperature then lowers down to reach a constant value of 1500K in the coflow. The numerical and experimental temperature profiles match reasonably well. The dip in temperature between the pilot and the coflow (missing in the simulations) can be attributed to conduction heat transfer from the hot coflow to the pilot nozzle which was not accounted for in the simulations.

Next, the velocity profiles at the jet exit (1 mm above the exit) are compared in Fig. 4. The measured velocities on the left and right sides of the burner appear to be reasonably symmetric and consistent. The numerical simulations present a flatter profile with a sharper drop-off, suggesting that the experimental pipe flow is not fully turbulent (Fig. 4a). The difference in jet velocity profiles results in different shear layers close to the burner exit. This is consistent with the discrepancies in RMS velocity (u') and entrainment of the pilot (Fig. 4b). However, these differences in inlet boundary conditions do not significantly affect the downstream development of the jet, as shown in Section 5.2.

Fig. 4: Comparison of the velocity profiles measured experimentally and predicted numerically at $x=1$ mm above the jet exit. The vertical dashed line (right) indicates the edge of the pilot.

Fig. 5: Axial (left) and radial (center and right) profiles of mean $\bar{U}$ and rms velocities u' .

5.2. Jet development

With the boundary conditions assessed, the next step is to investigate the downstream evolution of the turbulent reacting jet. This is done first by comparing mean ($\bar{U}$) and RMS velocity (u') profiles along the jet centerline. Figure 5a shows a fairly good agreement between experiment and simulation as the centerline velocity shows the same general decay in mean velocity with a corresponding increase in RMS velocity. This is typical of momentum spreading radially outward as the axial distance increases. The radial profiles of mean and rms velocity upstream show similar jet spreading behavior as seen in Figs. 5b and 5c. The LES mean radial profiles are slightly wider with higher RMS velocity, a behavior which remains consistent further downstream.

6. Global fuel effects

The stability of flames in the original PPJB configuration [32] was observed to be influenced by ϕ , Re_{jet} , and T_{coflow} . In this study, ϕ is adjusted to enforce a constant S_L as baseline for comparison between fuels. Re_{jet} and T_{coflow} are then varied to investigate possible fuel effects on the flame height, H_{fl} . While a single global quantity, H_{fl} encompasses both hydrodynamic and chemical effects.

Fig. 6: Impact of T_{coflow} at a fixed Re_{jet} (left) and Re_{jet} at a fixed $T_{coflow} = T_{ad,jet}$ (center) on the experimentally-measured flame heights. To emphasize the almost linear dependence on Re_{jet} , a linear fit is shown in dashed lines. Comparison of H_{fl} predicted by the LES and measured experimentally at the three different Re_{jet} 's for $T_{coflow}=1500K$ (right).

6.1. Experimental T_{coflow} effects on H_{fl}

First, the effects of heat loss/heat gain are investigated by varying T_{coflow} . Three cases are considered: $T_{coflow}=1400K$, $1500K$, and $1600K$. It is important to note that while S_L is kept constant, $T_{ad,jet}$ is different for each fuel. Therefore, the $T_{ad,jet} - T_{coflow}$ difference is not held constant. When T_{coflow} is lower than the adiabatic temperature of the main jet, $T_{ad,jet}$, the flame suffers heat losses (case 1); when T_{coflow} is higher, the flame is super-adiabatically heated (case 2). S_T for the first (resp. second) case is expected to be lower (resp. larger), resulting in a taller flame (resp. shorter flame). Figure 6a shows H_{fl} plotted against the heat loss experienced by the jet, $T_{ad,jet} - T_{coflow}$. The expected behavior is confirmed as H_{fl} increases with increasing $T_{ad,jet} - T_{coflow}$. The flame heights of the heavier hydrocarbon/air flames (propane, *n*-heptane, and toluene) align nicely when plotted against $T_{ad,jet} - T_{coflow}$. However, fuel-dependent differences are observed. Most notably, methane flames are consistently longer while ethylene flames are consistently shorter.

6.2. Experimental Re_{jet} effects on H_{fl}

Next, the effects of Re_{jet} are shown in Fig. 6b. Now, all experiments are performed at adiabatic conditions ($T_{coflow} = T_{ad,jet}$) in order to remove the effects of heat losses. When U_{jet} (equivalently Re_{jet}) is increased at a fixed S_L , the flame is expected to be longer as seen in the original PPJB experiments [32]. Making the crude assumption of a constant turbulent flame speed, S_T , along the time-averaged flame front, the following scaling is expected:

$$\frac{H_{fl}}{D} \approx \frac{U}{2S_T}. \quad (7)$$

This behavior is observed consistently for all fuels, as H_{fl} increases fairly linearly with Re_{jet} . Seemingly, methane has

the largest H_{fl} , ethylene has the smallest H_{fl} , and the rest of the fuels fall somewhere in between. More interestingly, all fuels but methane exhibit the same slope (within experimental uncertainties). One may conclude that, under the present conditions, S_T 's should be very similar for all the fuels investigated but methane.

6.3. Experimental and numerical comparison of H_{fl}

Since differences in H_{fl} were magnified with increasing Re_{jet} , simulations and experiments are compared with one of the highest Re_{jet} cases (but not so high that H_{fl} can no longer be defined). Without surprises, hydrodynamic effects represented by Re_{jet} are well captured in the LES. As shown in Fig. 6c, predicted H_{fl} from the LES are within 10-15% of the experimental values, while the effects of Reynolds number amount to more than 30%. The experimental trends of longer flames for methane and toluene than *n*-heptane and ethylene are reproduced. These results are especially interesting given the assumption behind the combustion models (Section 4.3), namely that the structure of the turbulent flame is the same as that of a laminar flame. With this modeling restriction, the systematic, albeit small, differences between predictions and measurements may be viewed as indirect signs that further modeling development are needed.

7. Conclusions

The present study investigated fuel and hydrodynamic effects on piloted premixed jet flames. This investigation was carried out at a constant laminar flame speed to isolate these effects. The parameters varied include heat losses, jet Reynolds number, fuel molecular weight, and fuel chemical classification. Matching LES were performed of the same experiments and were validated against 2D PIV measurements.

Flame heights defined based on CH* chemiluminescence were used as metric to compare the different flames. Experimental results indicated that small amounts of heat loss may play a significant role on the jet reactivity as the flame heights scaled with the heat loss from the jet. However, differences between flames with different fuels could still be seen in the absence of heat loss, and these differences were magnified at higher Reynolds numbers. Particularly, methane flames were consistently taller and ethylene flames consistently shorter while other fuels had approximately the same height. LES reproduced the experimentally observed trends in global flame heights (effects of heat losses and Reynolds number) but some of the differences between fuels were not captured.

Further work will involve time-resolved data in order to investigate stochastic effects and their influence on the global flame behavior. Furthermore, accurate measurements of mean and local turbulent flame speeds and turbulence intensities will be performed to study the dependence of S_T on turbulence characteristics.

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