LiteratureReviews Documentation

Release 0.0.1

Sayop Kim

January 27, 2015

Contents:

CHAPTER 1

Flow Turbulence Combustion

1.1 Tyliszczak et al. (2014): LES/CMC of blow-off w/ swirled spray flame

Title

LES/CMC of Blow-off in a Liquid Fueled Swirl Burner

(Flow Turbulence Combust (2014) 92:237–267)

Authors

Artur Tyliszczak, Davide E. Cavaliere, Epaminondas Mastorakos

Summary

1.2 Cavaliere et al. (2013): Blow-Off behaviour of spray flames

Title

A Comparison of the Blow-Off Behaviour of Swirl-Stabilized Premixed, Non-Premixed and Spray Flames

Authors

Davide E. Cavaliere, James Kariuki, Epaminondas Mastorakos

Summary

This work examines the dynamics of blow-off for premixed, non-premixed, and spray flames. The same burner was used for three combustion regimes.

- Test conditions

For premixed, flames, `methane` was fully premixed with air. For the non-premixed flames, the bluff body was modified to feed the `methane` by a central pipe. For the spray flame, liquid fuel of `n-heptane` was used due to its quick evaporation.

For each of combustion regimes, three equivalence ratios were set and two conditions were investigated: stable, stable but just prior to the blow-off event.

See Table 1.

- How to achieve blowoff??

1. Premixed: fixing the air flow rate and decreasing the fuel flow rate.

2. Non-premixed, and spray flames: Fix the fuel flow rate and then gradually increase the air flow rate every 20 seconds until blow-off occured.

- Stability limits:

1. Premixed: As expected, It is evident that the blow-off velocity increases with equivalence ratio
2. Non-premixed: The air velocity at extinction increases with fuel jet velocity.
3. Spray flame: Air velocity increases with increasing fuel flow rate, but levels-off at high fuel flows, so that above a certain value, U_{BO} becomes independent of fuel flow rate

- Flame structure approaching blow-off

1. Premixed: At conditions far from blow-off, high OH emision is observed near the walls and along the boundary of the wake above the bluff body. Strong OH emission is also observed in the smaller wake at the sudden expansion. However, as the blow-off condition is approached, emission at the sudden expansion wake disappears and both the length and thickness of the flame brush increase. At conditions close to the blow-off, the flame brush has moved closer towards the centerline of the bluff body. (See Fig. 7 a-b)
2. Non-premixed, spray flame: Contrary to the premixed flame, these flames show OH only in thin regions at the sides of the RZ. (See Fig. 7 c-f)
3. For the non-premixed flame, the flame intermittently lifts-off the bluff body. The absence of OH in the central part of the flow (i.e. flame only along the shear layer) is consitent with the quick mixing of the fuel jet.

- Lift-off height statistics

The lift-off height is quantified only for non-premixed and spray flames. A wide PDF is observed with a long positive tail. (See Fig. 10)

1. The average lift-off height increases as the air velocity decreases.
2. The spray flame is lifted much less compared to the gaseous case. The average lift-off depends less on the operating conditions. (See Fig. 10)

- Blow-off transient

1. Premixed: The average reaction zone is located near the downstream end of the RZ. Low chemiluninescence is observed near the anchoring region.
2. Non-premixed: The flame shrinks on the bluff-body.
3. Spray flame: Towards the end of the blow-off process, flame fragments seem to remain aligned with the spray cone.

1.3 Marinov et al. (2012): Extinction limit for KERO and Methane flames

Title

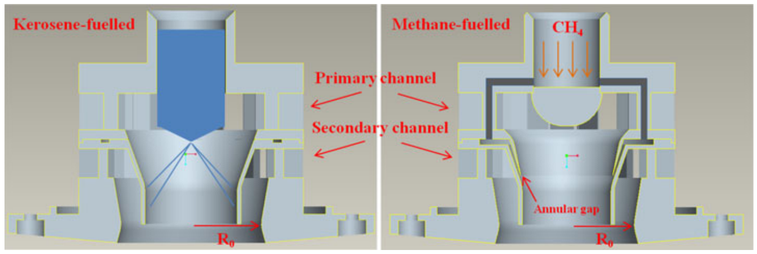
Similarity Issues of Kerosene and Methane Confined Flames Stabilized by Swirl in Regard to the Weak Extinction Limit

Authors

Svetoslav Marinov, Matthias Kern, Nikolaos Zarzalis, Peter Habisreuther, Antonio Peschiulli, Fabio Turrini, O. Nuri Sara

Summary

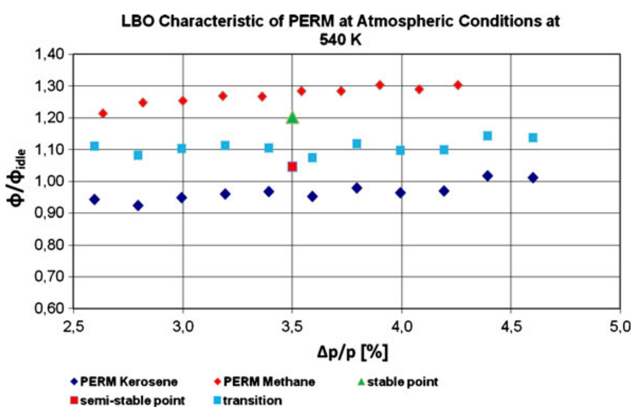
- Experimental approach: Using identical hardware and different fuels to provide more insights in the stabilization mechanisms of non-premixed confined swirl flames.



- Determination of the LBO: the gas analyzer was used for global CO concentration measurements on the center line at the exit of the chamber. While the combustion air mass flow rate is kept constant, kerosene mass flux is gradually decreased.
- Flame stability: Two reference operating points for KERO: `stable` and `semi-stable` regimes

Φ_{idle}: Normalized parameter that represents the equivalence ratio at blowout of the spray flame at this consistent condition.

The stability range is more extended than in the case of the gas-fuelled burner.



- Observation of flow/flame fields

IRZ closure cannot be seent at `isothermal flow field` (540K), and `semi-stable` condition.

ORZ remains unchanges for all these conditions.

But in the stable reaction case, ORZ is characterized by the low AFR values: ORZ is another flame zone, whereas for the semi-stable condition ORZ is characterized by a high AFR, unfavorable for combustion: This suggests the existence of only one flame zone within IRZ and thus a different flame stabilization mechanism.

- Spray flames:

For the semi-stable combustion, the flame is stabilized in a very narrow region along the center line.

For the stable combustion, the area near the nozzle exit is characterized by the temperature of the preheated air. Further downstream considerable amount of heat is transferred to the main flow by hot gases from IRZ and ORZ, thus the evaporation process is additionally supported. The temprature gradually increases with further spray propagation, i.e. more heat has been transferred into the two-phase flow. Consequently, the KERO vapor fraction increases and more flammable gases are available.

The highest gradients of the CO2 field is in good agreement to the highest temperature gradients: See Fig. 8.

- Comparison between KERO and Methane

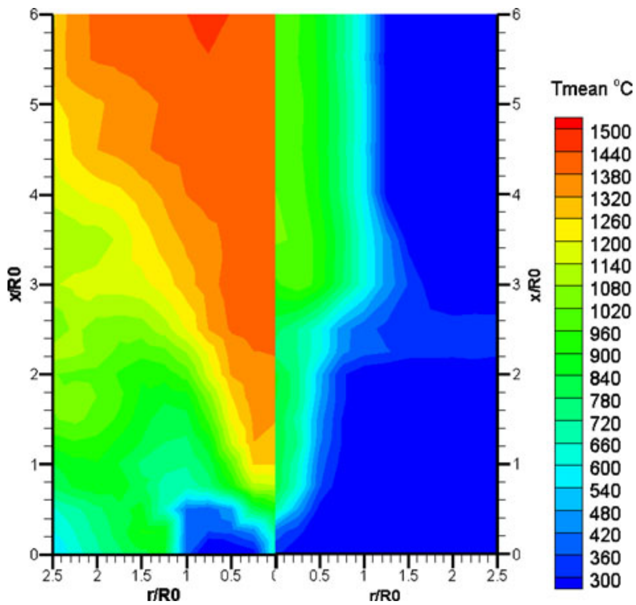


Figure 1.1: mean temperature fields. Stable (left), semi-stable (right)

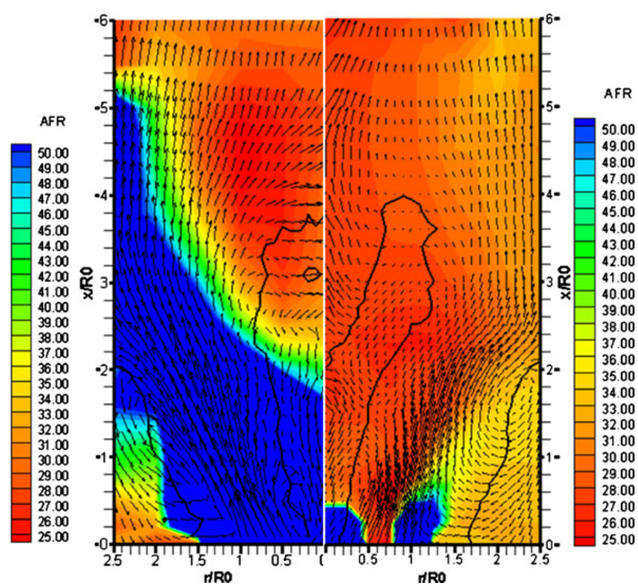


Figure 1.2: reacting flow fields at stable conditions: KERO(left) and CH4(right)

Both fields are considerably similar; in particular the stagnation velocity line around IRZ remains same. Same lengths of both IRZ and ORZ.

CHAPTER 2

Combustoin and Flame

2.1 Rutland and Ferziger (1991): Flame-Vortex interactions

Title

Simulations of Flame-Vortex Interactions

Authors

Christopher J. Rutland and Joel H. Ferziger

Summary

Full numerical simulations to study the interaction of a vortex and a premixed flame as a model problem. The effects of heat release and the importance of the relative length and time scales of the vortex and flames are examined. Changes in the internal structure and overall shape of the flame are studied.

Different approaches are studied to isolate various effects and aid in understand the full interaction.

1. Frozen flame
2. Frozen vortex
3. Full flame-vortex interaction: combination of above two frozen cases

- Non-dimensional parameters:

1. σ: Initial vortex size. Ratio of vortex and flame length scales.
2. Damkohler number (Da): Ratio of time scales. Nondimensional vortex time scale.

- Fronzen flame
  - The frozen flame isolates the effects of the flame on the fluid mechanics. The momentum equation, but not the energy equation, is integrated in time. The temperature and density fields remain fixed as their initial conditions. This approximates high `Damkohler` number flows in which the vortex passes through the flame quickly, experiencing very little turnover.
  - The fluid is assumed to be inviscid.
  - Baroclinic torque acts as a source of vorticity whenever the density gradient and the pressure gradient are not aligned.
  - The density gradient is normal to the flame surface. And the pressure gradient is initially radial from the vortex center.
  - The principal effects appear to be elongation of the vortex in direction normal to the flame surface.

– For high Da, the time scale of the vortex is much longer than the flame: The vortex rotates very little as it passes through the flame. Thus the main effect is expansion of the vorticity distribution normal to the flame. (See Fig. 5)

– Effect of heat release on vorticity elongation: As heat release increases, voriticy elongation increa

Under review...

2.2 Watanabe et al. (2007): Spray flamelets in Laminar CouterFlow

Title

Characteristics of Flamelets in Spray Flames Formed in a Laminar Counterflow

Authors

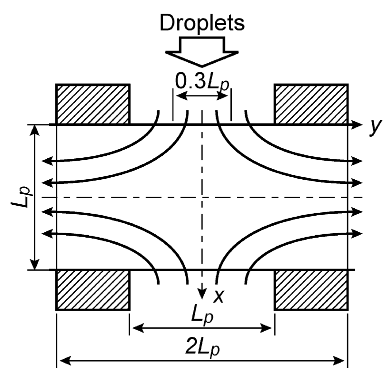
Hiroaki Watanabe, Ryoichi Kurose, Seung-Min Hwang, Fumiteru Akamatsu

Summary

Characteristics of flamelets within two-phase combustion. 2D numerical simulation. Effects of strain rate, equivalence ratio, and droplet size are examined in terms of mixture fraction and scalar dissipation rate.

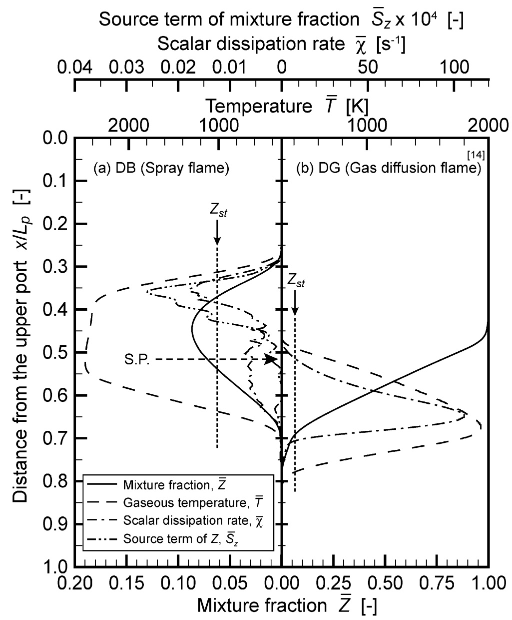
There appear differences in the trends of gaseous temperature and mass fractions of chemical species in the mixture fraction space between the spray flame and the gaseous diffusion flame. The spray flame jhas lower scalar dissipation rate and the coesistence of premixed and diffusion-limited flame.

1. Computational domain

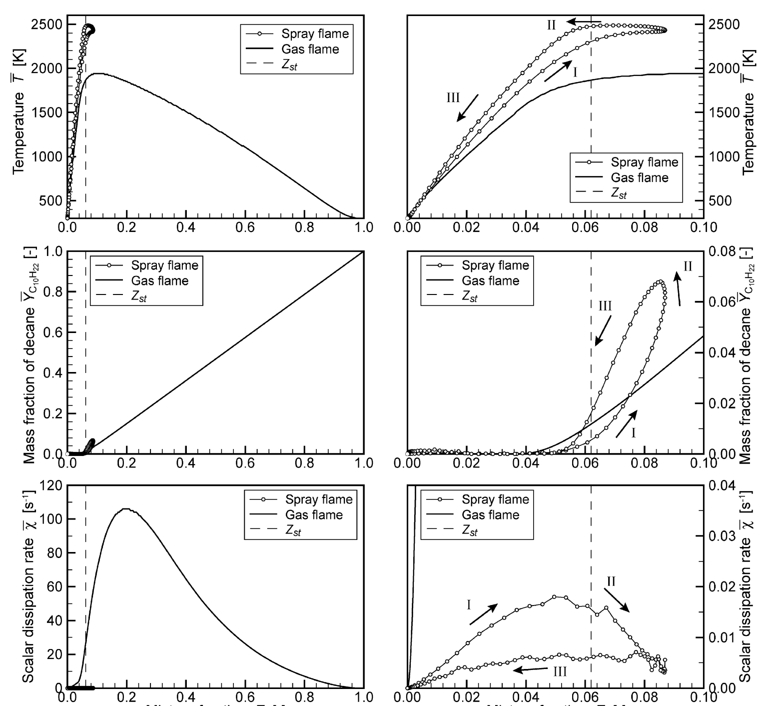


2. Mean mixture fraction $\overline{Z}$, gaseous temperature $\overline{T}$, and scalar dissipation rate $\overline{\chi}$

- For the gas diffusion flame, $\overline{Z}$ decreases monotonously as the axial distance increases.
- For the spray flame, $\overline{Z}$ has the peak value at the center of the high temperature region, where the stagnation plane is located. This is because Z is produced by droplet evaporation.
- $\overline{T}$ and $\overline{\chi}$ have the peak value at two points on both side with respect to the peak of $\overline{Z}$.
- The decrease in $\overline{T}$ between twh two peaks is due to the droplet group combustion behavior: *Cooling effect* and slow combustion due to lack of oxygen.
- Source term of Z ($\overline{S_Z}$): the droplet evaporate mainly in the upstream region.
- The distributions of $\overline{Z}$, $\overline{T}$, $\overline{\chi}$ of the spray flame do not correspond with those of the gaseous diffusion flame.
- The peak temperature is larger than that of gaseous diffusion flame: This is because $\overline{\chi}$ in the spray flame is much lower. Flame temperature generally rises as χ decreases.
- $\overline{Z}$, $\overline{T}$, $\overline{\chi}$ of the spray flame are not unique in Z space and cannot be uniquely related to $\overline{Z}$



Source term of mixture fraction $\bar{S}_z \times 10^4$ [-]
Scalar dissipation rate $\bar{\chi}$ [s^{-1}]
Temperature $\bar{T}$ [K]
(a) DB (Spray flame)
(b) DG (Gas diffusion flame)
[14]
Z_{st}
S.P.
Distance from the upper port x/L_p [-]
Mixture fraction, $\bar{Z}$
Gaseous temperature, $\bar{T}$
Scalar dissipation rate, $\bar{\chi}$
Source term of Z, $\bar{S}_z$
Mixture fraction $\bar{Z}$ [-]

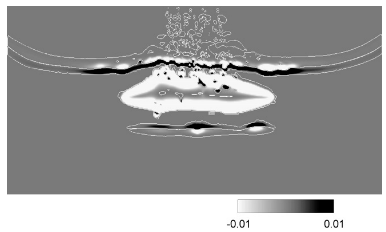


Spray flame
Gas flame
Z_{st}
Temperature $\bar{T}$ [K]
Mass fraction of decane $\bar{Y}_{C_{10}H_{22}}$ [-]
Scalar dissipation rate $\bar{\chi}$ [s^{-1}]
I
II
III
Mixture fraction Z [-]

- The differences between upstream region and downstream region exist for $\overline{Z}$, $\overline{T}$, $\overline{\chi}$ of the spray flame: This is caused by an imbalance between the production rate of Z in the upstream region and its transport-diffusion rate in the downstream.

3. Flame index result

   FI $= \Delta Y_{C_{10}H_{22}} \cdot \Delta Y_{O_2}$



- Diffusion and premixed flame are found to coexist in the spray flame.
- Negative FI region first appears: Diffusion flame occurs. Rapid evaporation region.
- Positive and nefative FI region on the lower side of the rapid evaporation region: This indicates the presence of premixed and diffusion flames. The reason why gas temperature in the spray flame is larger than the gaseous diffusion flame is because of the existence of premixed flame region.

4. Strain rate effect (See Fig. 6, 7, and 8)

- The ignition occurs earlier and the high $\overline{T}$ region spreads wider for the lower strain rate case.
- Larger strain rates suppress the evaporation of the droplets; it reduces the residence time in the high temperatures and increases teh number of droplets penetrating the flame.

5. Effect of equivalence ratio (See Fig. 11, 12)

- As ϕ increases, the fuel ignites earlier, and the high $\overline{T}$ region becomes wider.
- The decrease in the peak temperature value for the higher ϕ is caused by the cooling effect associated with droplet group combustion.

CHAPTER 3

Proceedings of the Combustion Institute

3.1 Vie et al. (2015): 3D Counterflow configuration with spray flame

Title

Analysis of segregation and bifurcation in turbulent spray flames: A 3D counterflow configuration

Authors

Aymeric Vie, Benedetta Franzelli, Yang Gao, Tianfeng Lu, Hai Wang, Matthias Ihme

Summary

3.2 Burguburu et al. (2011): Flame stability for KERO spray with H2 addition

Title

Effects of H2 Enrichment on Flame Stability and Pollutant Emissions for a Kerosene/Air Swirled Flame with an Aeronautical Fuel Injector

Authors

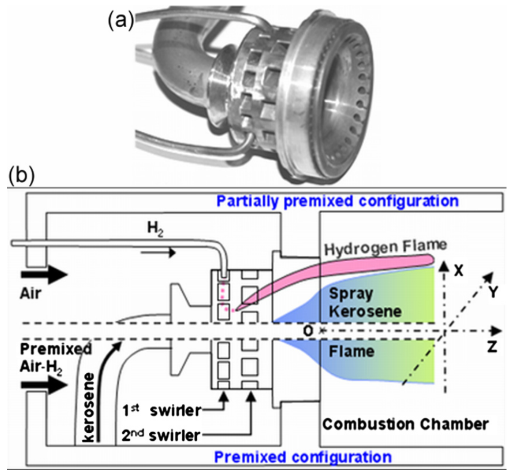
Joseph Burguburu, Gilles Cabot, Bruno Renou, Abdelkrim M. Boukhalfa, Michel Cazalens

Summary

Flame stability is strongly affected by hydrogen injection and the lean blow off (LBO) limit can be reduced. A small amount of H2 is sufficient to reduce CO emissions by a factor of 4 due to the enhancement of reactions involving hydroxyl radicals. NOx emission rises with the increase in H2 concentration, even though the adiabatic temperature remains constant.

- Experimental conditions:

1. Pressure: 0.3 MPa
2. Preheated air temperature: 500 K
3. Primary and secondary air flow rates: 54, 27 g/s
4. The airblast injector generates a spray SMD close to 50 μm.
5. Swirl number: 0.73 (leads to an IRZ)
6. Two different hydrogen introductions:



- Non-reacting burner characterization

  The velocity measurements were performed at atmospheric pressure and for a fixed temperature of 300 K, without fuel injection and dilution air. (See Fig. 2)

1. The intense swirl motion generated by the injection system creates an internal recirculation zone (IRZ). For a swirl number greater than the critical value of 0.6, strong radial and axial pressure gradients are set up near the nozzle exit, resulting in axial recirculation in the form of a central toroidal recirculation zone.
2. A corner recirculation zone (CRZ) appears due to the flow's sudden widening at the outlet of the injection system.
3. A local counter-current flow is formed and located between the CRZ and IRZ. Most of the time, the reactio takes place close to this intense shear layer.

- Flame stability and lean blow off

  Hydrogen enrichment has a positive effect in the widening of the flame stability domain. The difference between two configuration, i.e. PP and FP, can be explained by the analysis of the flame structure.

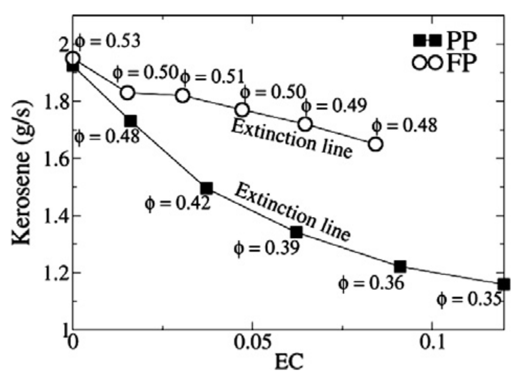


Figure 3.1: <Stability diagran and LBO limit for various EC>

1. PP: Hydrogen/air pilot flames are located in the injection system center core and are stabilized at the first swirler exit. This is due to the high burning velocity of H2/air flames. These flames powerfully preheat the air from the second swirler. This improves the fuel droplets' evaporation rate and helps preheat and homogenize the mixture.
2. FP: The pilot flames are absent from the FP configuration. As the H2 and primary air mixing occurs far upstream, the local H2 equivalnce ratio is too lean to generate a pilot flame into the swirler.

- Pollutant emissions

1. The hydrogen injection dramatically increases the NOx meissions. (See Fig. 6a)
2. The impact of H_2 enrichment in the FP configuration is much smaller than the PP configuration.
3. Increasing EC (H_2 enrichment) leads to a strong decrease in CO emissions: Two factors
    - The replacement of a carbon-containing fuel by a carbon-free fuel: This contribution is known to be very low.
    - The changes in the chemical kinetics brought on by the hydrogen addition: The oxidation mechanism for CO depends on the presence of hydrogen containing compounds.
        (a) H_2 molecules are oxidized into H_2O.
        (b) Small quantities of H_2 or H_2O increase tremendously the oxidation rate of CO.

CHAPTER 4

AIAA

4.1 Gokulakrishnan et al. (2009): Turbulence-Chemistry interaction in Blow-out

Title

Influence of Turbulence-Chemistry Interaction in Blow-out Predictions of Bluff-Body Stabilized Flames

Authors

Ronnuthurai Gokulakrishnan, Ravi Bikkani, Michael S. Klassen, Richard, J. Roby, and Barry V. Kiel

Summary

LES were performed to investigate the effect of turbulence-chemistry interaction on flame instability and flame-vortex interaction in bluff-body stabilized premixed flames (propane-air flames).

The tested models were followings:

1. Semi-global reduced mechanism vs. Skeletal mechanisms
2. Laminar chemistry (LC) vs. Eddy Dissipation Concept (EDC)

The simulations were performed at 0.6 and 0.45 equivalence ratios. LES predictions with the EDC model show that the blow-out occurs at 0.6 of equivalence ratio as observed experimentally.

- LES with Skeletal Propane mechanism (EDC vs. LC)
    1. When the chemical source term was resolved with the EDC model the flame starts to break-up at 0.6 of ϕ.
    2. Further reduction of ϕ to 0.45 shows a complete blow-out of the flame.
    3. But when the simulation with LC model where the sub-grid scale fluctuations in the chemical source were ignored, complte blow-out was not observed.
    4. With the LC model, no significant difference in the flame structure between the two equivalence ratios: This can be attributed to the absence of the sub-grid scale turbulence-chemistry interactions.
    5. When the EDC is used, the effect of turbulence has dissipated the flame in the wake region.
    6. With the LC model, the asymmetric Von-Karman vortex shedding is suppresed in the vicinity of the V-gutter: This is due to the expansion of fluid caused by the heat-release which reduce the vorticity magnitude.
    7. The instantaneous vorticity profiles demonstrate that the EDC results exhibit an asymmertical Von-Karman vortex shedding consistently for two ϕ cases.
- LES with 44-step Reduced Propane mechanism (EDC vs. LC)

1. Same result as (7) above was observed with this test.
2. The flame instability leading to the blow-out conditions observed in LES-EDC modeling results can be attributed to asymmetrical Von-Karman vortex shedding due to the weakening of the dilatation effects.

In conclusion, the flame structure predicted by the LES is same for both kinetics models when the LC combustion model is used. However, when the sub-grid scale turbulence chemistry interactions were resolved using the EDC, more detailed Skeletal mechanism exhibit different flame structure at 0.6 equivalence ratio from the other.

CHAPTER 5

Indices and tables

- *genindex*
- *modindex*
- *search*