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NUMERICAL ANALYSIS OF TURBULENT FLAME IN AN ENCLOSED CHAMBER

Naveen Kumar D[1*], Pradeep R[2] and Bhaktavatsala H R[3]

[1]Assistant Professor Department of Mechanical Engineering, M S Engineering College, Bangalore.

[2] Assistant Professor, Department of Mechanical Engineering, M S Engineering College, Bangalore,

[3]Associate Professor Department of Mechanical Engineering, M S Engineering College, Bangalore..

*Email: dnaveenmech@gmail.com

ABSTRACT: A combustion model based on a turbulent flame speed closure (TFC) model is proposed for Reynolds stress model (RSM) of premixed combustion in an enclosed chamber the turbulent quantities that determine the turbulent flame speed are obtained at the level of the grid cut- off. The model has been applied to a simple premixed jet flame in a backward-facing step combustor to investigate the combustor response to forced excitations. The present model reported a comprehensive theoretical study on flame velocity in spark ignition engine for iso-octane air mixture. The present model developed is a two-dimensional RSM model. Computer simulations have been performed for the turbulent flame velocity of premixed flame.

The speed of propagation of a premixed turbulent flame correlates with the intensity of the turbulence encountered by the flame we outline the numerical procedure, and illustrate the behaviour of the control algorithm on methane flames at various equivalence ratios in two dimensions. The simulation data are used to study the local variation in the speed of propagation due to flame surface curvature. The effects of turbulence and operating conditions on the position, shape, fluctuation, corrugation of the flame front, and the turbulent flame speed are investigated in this study. The results of this work allow a better fundamental understanding of the influence of turbulence on flame front structure, which is of prime interest for fundamental research.

Keywords: Turbulent flame speed closure, Reynolds stress model, GAMBIT software, Discretization, Damkohler number, Equivalence ratio and Computational analysis.

1. INTRODUCTION

Combustion or burning is the sequence of exothermic chemical reactions between a fuel and an oxidant accompanied by the production of heat and conversion of chemical species. The release of heat can result in the production of light in the form of either glowing or a flame. Fuels of interest often include organic compounds (especially hydrocarbons) in the gas, liquid or solid phase.

In a complete combustion reaction, a compound reacts with an oxidizing element, such as oxygen or fluorine, and the products are compounds of each element in the fuel with the oxidizing element. For example

$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O + \text{energy}$

A simple example can be seen in the combustion of hydrogen and oxygen, which is a commonly used reaction in rocket engines

$2\ H_2 + O_2 \rightarrow 2H_2O\ (g) + \text{heat}$

The result is water vapour complete combustion is almost impossible to achieve

Flame study

A flame is a mixture of reacting gases and solids emitting visible, infrared, and sometimes ultraviolet light, the frequency spectrum of which depends on the chemical composition of the burning material and intermediate reaction products

Flame types

Before we discuss details of flame temperatures, it is important to distinguish between some of the major flame types. Flames can be divided into 4 categories:

- laminar, premixed
- laminar, diffusion
- turbulent, premixed
- turbulent, diffusion

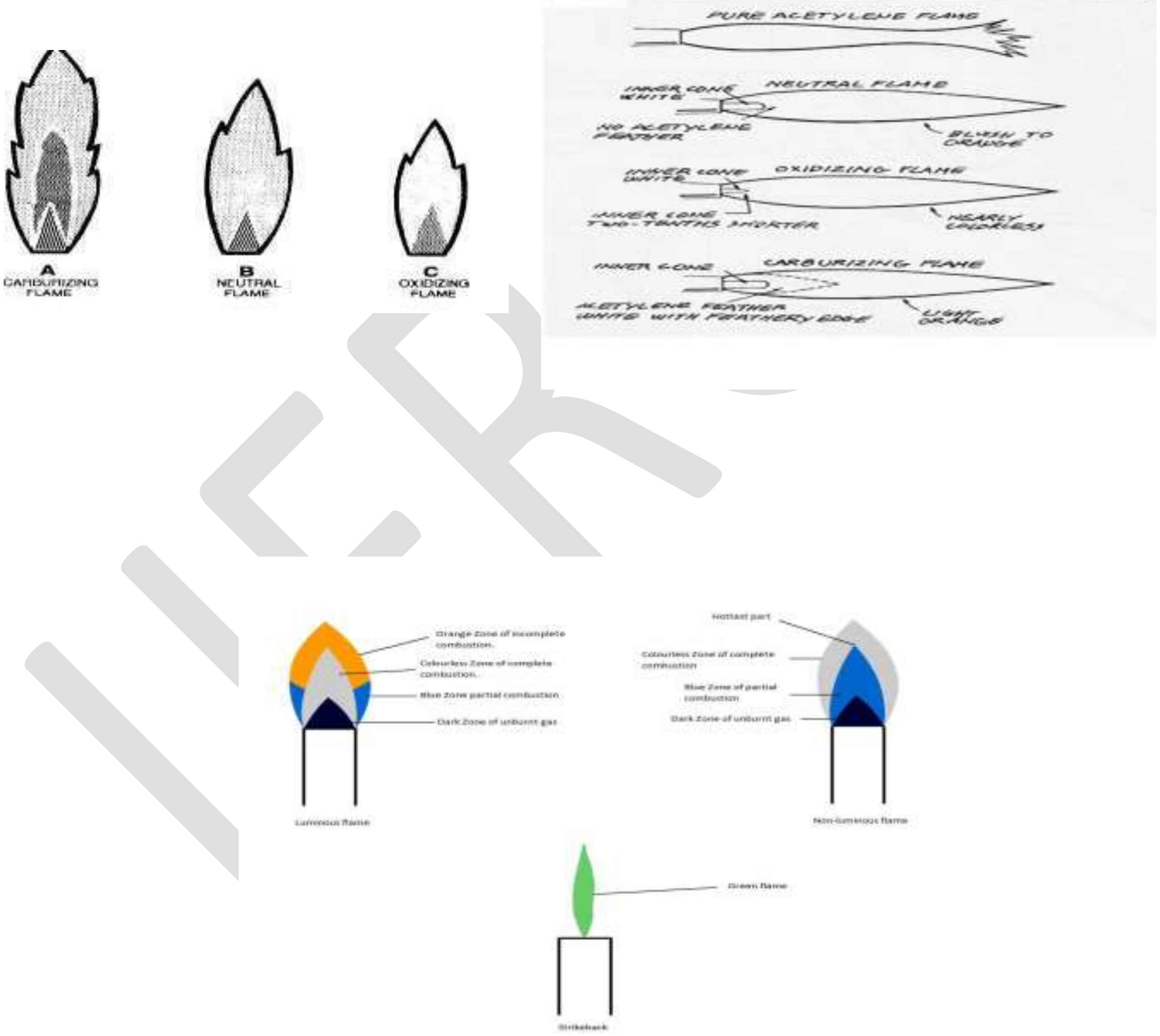


Fig.1.1 Different types of flames.

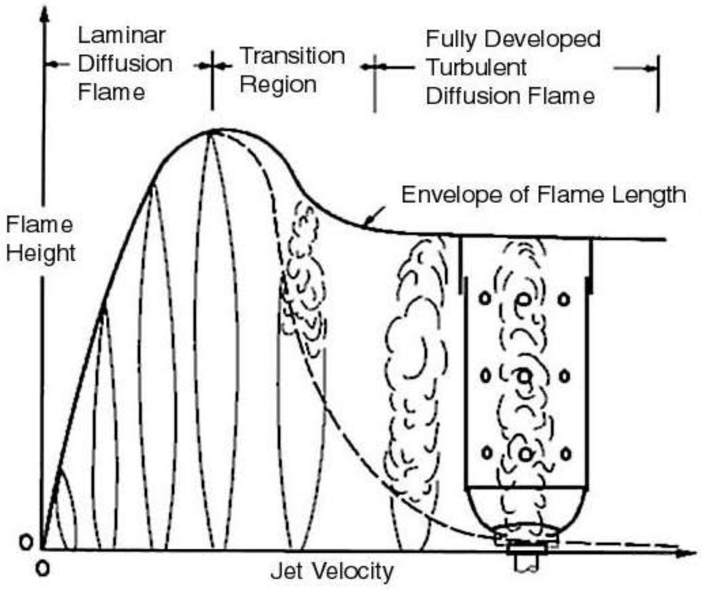


Fig.1.2.Turbulent flame structure and propagation

A flow streamlines are smooth and do not bounce around significantly. Two photos taken a few seconds apart will show nearly identical images. Premixed means that the fuel and the oxidizer are mixed before the combustion zone occurs.

2. OBJECTIVE OF THE PRESENT STUDY

- To study the flame structure
- To simulate the turbulence flame structure inside the enclosed chamber
- To predict the temperature distribution over the enclosed chamber considering the factors such as air fuel ratio, speed and Pressure of the mixture.
- To validate the numerically obtained results against the experimental and existing.

Methodology

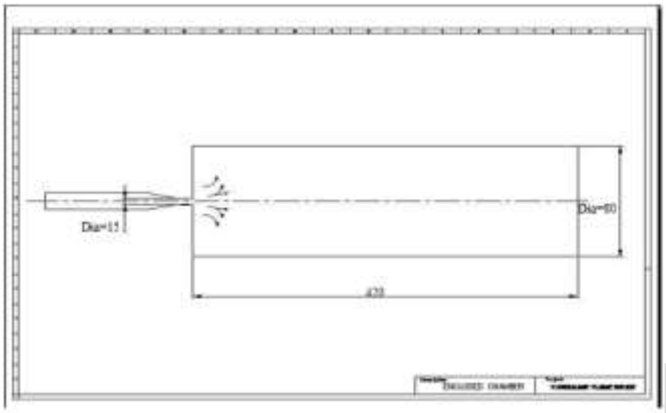
- The geometry (physical bounds) of the problem is defined. The volume occupied by the fluid is divided into discrete cells (the mesh). The mesh may be uniform or non uniform.
- The physical modeling i s defined – for example, the equations of motions + enthalpy + radiation + species conservation
- Boundary conditions are defined. This involves specifying the fluid behavior and properties at the boundaries of the problem. For transient problems, the initial conditions are also defined.
- The simulation is started and the equations are solved iteratively as a steady-state or transient.
- Finally a postprocessor is used for the analysis and visualization of the resulting solution.

3. EXPERIMENTAL WORK

- Develop an enclosed chamber in CAD with an opening at the entrance.
- Mesh the enclosed chamber in GAMBIT software.
- Using fluent solver the computation of the flame region shall be done and flame structure is analyzed.

Modeling and Meshing

CAD Model



Dimensions of the model are:

Length =420mm

Diameter =80mm

Burner dia=15mm

Number of meshes are 24000

Fuel used is methane

The flowchart represents the steps involved in Gambit for modeling and meshing of flat plate.

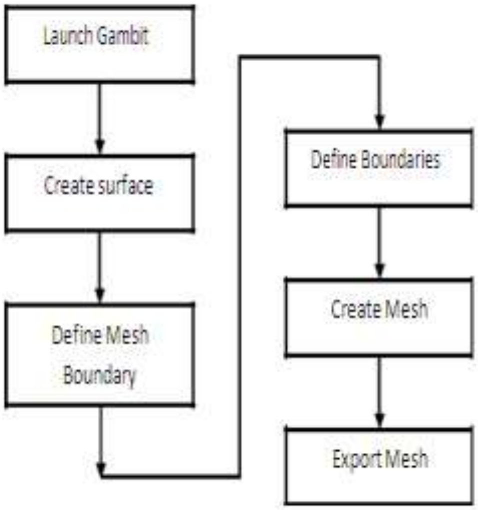
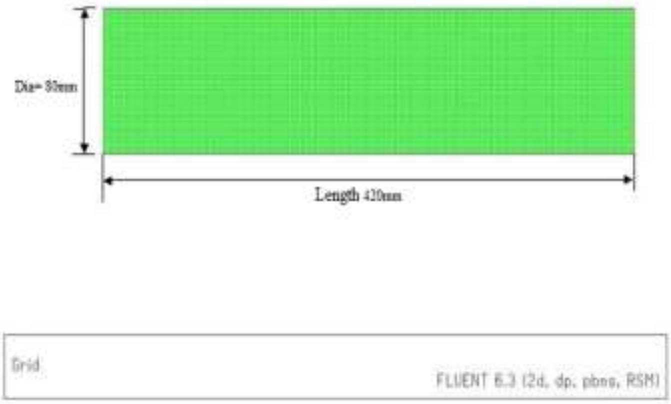


Fig.3.1.Flow Chart for Modeling and Meshing of an Enclosed Chamber

Mesh Model

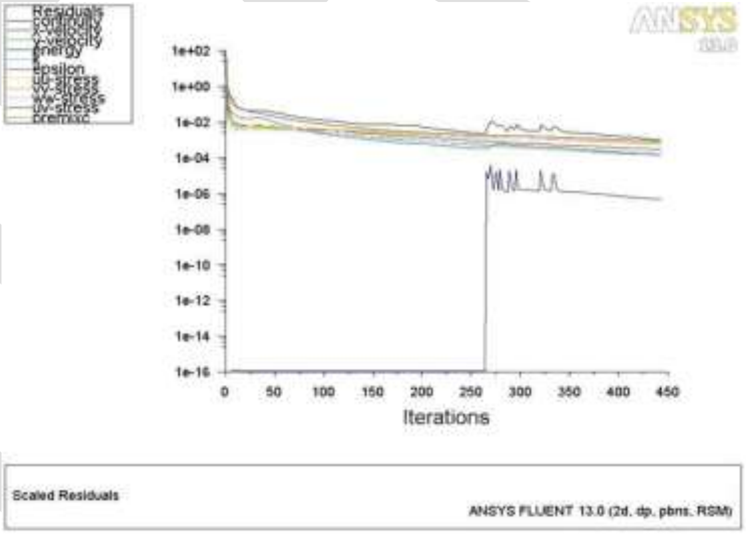


2D grid for length= 420mm and dia=80mm.

Type of mesh used is square structure mesh.

Size of the grid is $1mm^2$

Convergence Screen Shot



Case Study

All computational cases were solved using the standard RSM model within FLUENT^{TM} 6.3. The dimensions are, the diameter of the enclosed chamber is 80mm, length of the chamber is 420mm and diameter of the burner nozzle is 15mm, the simulations were carried out for an enclosed chamber for three fuel jet velocities (40m/s, 50m/s, 60m/s) and three equivalence ratio values (0.4, 0.5 and 0.6). By fixing velocity and varying equivalence ratio and vice versa simulations are carried out. The simulations were carried past the convergence point to ensure a stable solution had been achieved with the default relaxation values.

Following table shows 12 cases for computational analysis.

Case	Velocity of the mixture(V) in m/s	Equivalence ratio (Psi)
1	40	0.4
2		0.5
3		0.6
4		1.2
5	50	0.4
6		0.5
7		0.6
8		1.2
9	60	0.4
10		0.5
11		0.6
12		1.2

EXPERIMENTAL PROCEDURE

Numerical investigations of the complicated turbulent flame, turbulent flame velocity, total temperature and turbulent intensity are carried out with SIMPLE algorithm for pressure – velocity coupling and standard scheme for pressure discretization and upwind scheme for mass, momentum and energy.

The SIMPLE algorithm is an iterative procedure for the calculation of pressure and velocity fields. Starting from an initial pressure field p*, its principle steps are

- Solve the discretized momentum equation to yield the intermediate velocity (u*,v*)
- Solve the continuity equation in the form of an equation for pressure correction p_1.
- Correct pressure and velocity.
- Solve all other discretized transport equations for scalars Φ.
- Repeat until the field p, u, v and Φ have all converged.

Second order upwind scheme for turbulent kinetic energy, turbulent dissipation rate. According to the upwind scheme, the value of the convective property at the interface is equal to the value at the grid point on the upwind side of the face. It has got 3 sub-schemes i.e. 1st order upwind which is a 1st order accurate, 2nd order upwind which is 2nd order accurate scheme and QUICK (quadratic upwind interpolation for convective kinematics) which is a 3rd order accurate scheme.

The flowchart represents the steps involved in Fluent for the solution procedure

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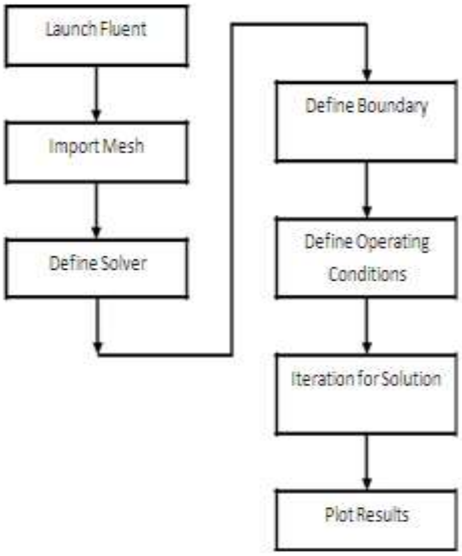


Fig.3.2 Flow Chart for solution procedure of Enclosed Chamber.

4. RESULTS AND DISCUSSION

CONTOURS OF PROGRESS VARIABLE

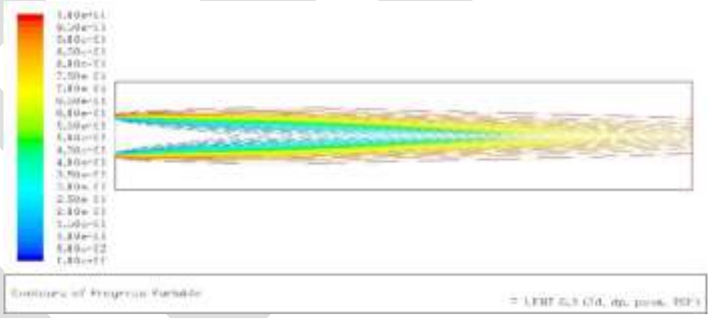


Fig.4.1 Contours of Progress Variable for psi = 0.4 and v = 40m/s.

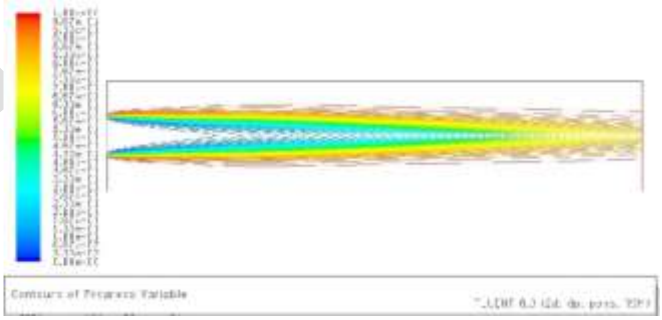


Fig.4.2 Contours of Progress Variable for psi = 0.5 and v = 50m/s.

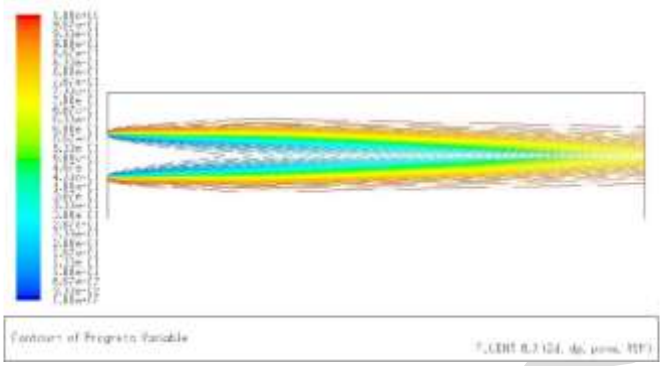


Fig.4.3 Contours of Progress Variable for psi = 0.6 and v = 60m/s.

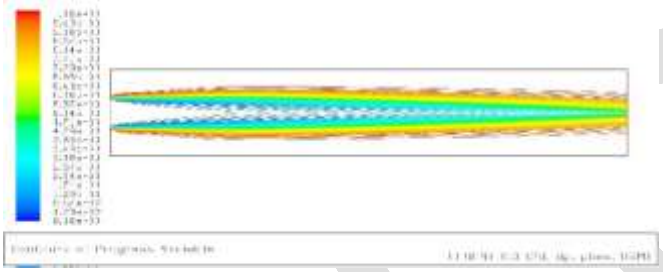
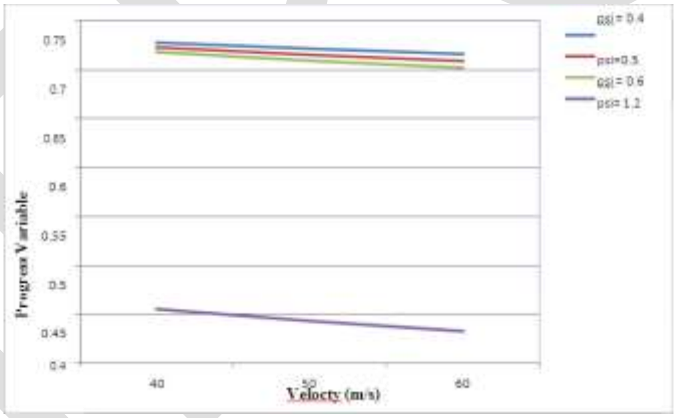


Fig.4.4 Contours of Progress Variable for psi = 1.2 and v = 60m/s.

Graph of variation of Progress Variable for psi and velocity



From figures we can conclude that, progress variable is high at the outer core of the flame and decreases to zero towards the inner core of the flame. Complete combustion occurs at the outer edges of the flame since turbulence is high at the outer lamina of the flame and at the centre of the flame complete combustion does not happens since turbulence is less at the centre of the flame .With increase in equivalence ratio, flame thickness increases and with increase in velocity, flame length increases. For the rich mixture from the above graph we can observe that progress variable is very much less than the lean mixture because for rich mixture complete combustion does not happens .

5. CONCLUSION

With reference to the objectives of the project the following conclusions are drawn. The numerical analysis of turbulent flame in an enclose chamber is carried out by varying the inlet fuel jet velocity and equivalence ratio by using Reynolds stress model.

From the results of the analysis obtained are

- Damkohler number is maximum when psi =0.5 and fuel jet velocity (v) =50 m/s.
- Turbulent flame speed is maximum at psi=0.4 and v=60m/s.
- Turbulent intensity is high when psi=0.4 and v=60m/s.

Achieved: Comparison of flame speed, Intensity, pressure for different fuel jet velocity while Equivalence ratio is fixed and vice versa using Reynolds stress model is carried out.

Validation of results has been done with the published work.

- Turbulent flame structure study and interaction between different flame zones is expected.
- With change of equivalence ratio, it is explained that turbulence flame velocity and turbulence intensity might show significant change.
- With change of fuel jet velocity and equivalence ratio temperature distribution, progress variable and pressure distribution are studied.

REFERENCES:

[1]. Premixed turbulent flames stabilized by swirl, Twenty-Fourth Symposium (International) on Combustion/The combustion Institute, 2012/pp.511-518.

[2]. P. Griebel , P. Siewert, P. Jansohn Flame characteristics of turbulent lean premixed methane/air flames at high pressure: Turbulent flame speed and flame brush thickness, Proceedings of the Combustion Institute 31 (2007) 3083–3090

[3]. Sadat Sakak and M. Schreiber, computation of premixed turbulent combustion using the probability density function approach, Twenty-Sixth Symposium (International) on Combustion/The Combustion Institute, 2006/pp. 267–274

[4]. P. Flohry AND H. Pitsch, A turbulent flame speed closure model for LES of industrial burner flows, Centre for Turbulence Research Proceedings of the Summer Program 2010

[5]. JE Kent, AR masri and SH Starner, A new chamber to study premixed flame propagation past repeated obstacles, 5th Asia specific conference on combustion, the university of Adelaide, Adelaide, Australia 17-20 July 2005

[6]. Luc Vervisch AND Arnaud Trouve, LES modelling for lifted turbulent jet flames**,** Centre for Turbulence Research Proceedings of the Summer Program 2008

[7]. Y. Sommerer , D. Galley , T. Poinsot , S. Ducruix ,F. Lacas , and D. Veynante , Large Eddy Simulation and Experimental Study of Flashback and Blow-Off in a Lean Partially Premixed Swirled Burner Preprint submitted to Elsevier Science 23 September 2004

[8]. Dipl.-Ing. P. Siewert, Dr.-Ing. P. Griebel, R. Schären, Dr. R. Bombach, Dr. A. Inauen, Dr. W. Kreutner, Dr. S. Schenker, Villigen/CH, (2003),Turbulence and Flame Characteristics of Premixed Methane/Air Flames at Gas Turbine Relevant Conditions

[9]. Vivek Saxena and Stephen b. Pope , pdf calculations of major and minor species in a turbulent piloted jet flame Twenty-Seventh Symposium (International) on Combustion/The Combustion Institute, 2008/pp. 1081–1086

[10]. Shreekrishna, Santosh Hemchandra and Tim Lieuwen, Premixed flame response equivalence ratio Perturbations, Combustion Theory and Modelling Vol. 14, No. 5, 2010,681–714