IMPLEMENTATION AND VALIDATION OF A NOVEL TABULATED CHEMISTRY TURBULENT COMBUSTION MODLE IN OPENFOAM

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1. Introduction

Objectives:

- To aviod the limitations of the presumed PDF (PPDF) method, e.g. assumption on the statistic independence of the controlling variables and expensive storage requirement due to large lookup tables, that is used in the conventional flamelet-based models, a novel turbulent combustion model was developed by combining of the Flamelet Generated Manifolds (FGM) model and Eulerian Stochastic Field (ESF) mehtod.

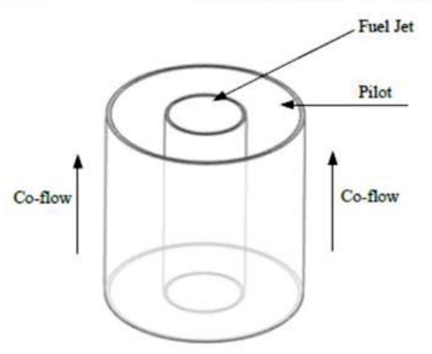
2. Validation Dataset

Burner details:

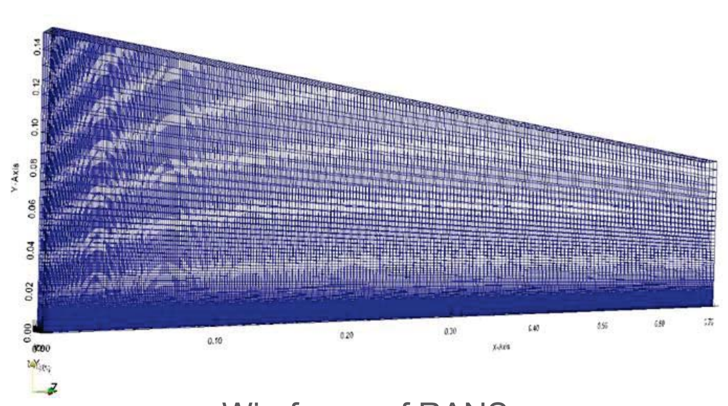
- **Main jet inner diameter:** 7.2mm
- **Pilot annulus inner diameter:** 7.7mm
- **Pilot annulus outer diameter:** 18.2mm
- **Burner outer wall diameter:** 18.9mm
- **Wind tunnel exit:** 30cm by 30cm
- **Coflow velocity:** 0.9m/s(+/- 0.05 m/s)
- **Main jet composition;** 25%CH4, 75% dry air
- **Main jet kinematic viscosity:** 1.58e-05 m^2/s
- **Main jet velocity:** U_D = 49.6 m/s

Model details:

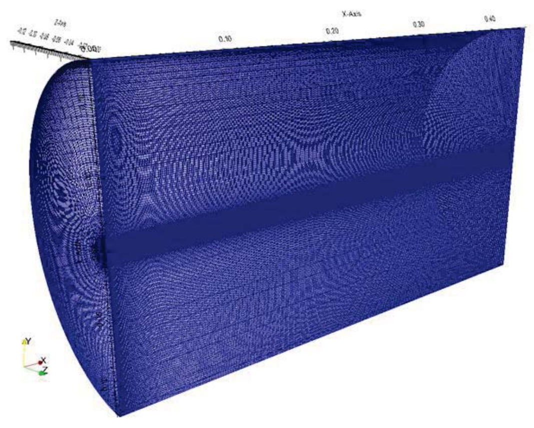
- **RANS Model:** standard *k-ε*
- **RANS Grid:** 51,957
- **LES Model:** *HybridSGS*
- **LES Grid:** 3,477,600



Sandia D flame



Wireframe of RANS



Wireframe of LES

3. Numerical method (1)

FGM Model: select two control variables to characterize Chemical reaction in turbulent combustion. The "mixture fraction", Z, that characterizes the mixed state of fuel and oxidant and the "progress variable", C, that characterizes the progress of chemical reaction are usually selected as independent variables.

Innovation : abandon the P-PDF method (the original FGM model) and choose real-time solutions to components jointing probability density function of two independent variables transported equation and integrate them in the sample space to obtain all the single-point statistics of all the space and time of two independent variables in real time. The Eulerian Stochastic Field (ESF) model in the transported probability density function class model is used to accomplish this task.

ESF Model: use a series of stochastic fields N_F to represent joint-composition PDF required by this model. In this N_F stochastic fields, each field contains each component value at each position in the entire flow field. It can be expressed as

$$f_\varphi(\psi;\vec{x},t) \approx \frac{1}{N_F}\sum_{n=1}^{N_F}\prod_{\alpha=1}^{N_s}\delta(\psi_\alpha - \varphi_{\alpha,n})$$

$\varphi_{\alpha,n}$ is the value of scalar α under $\vec{x}$ position under t time in n field. In this model, $\varphi_\alpha = [Z, C]$, each stochastic field evolves according to the stochastic partial differential equations (SPDE) derived from transport equation of

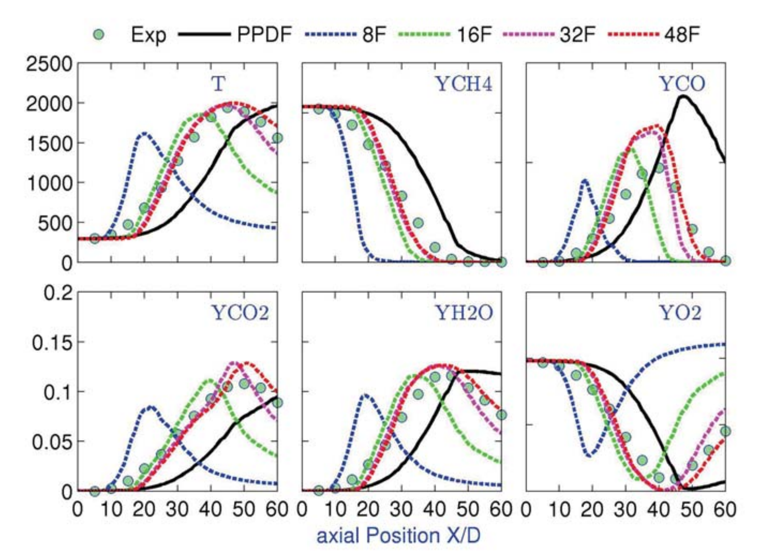
3. Numerical method(2)

the joint-composition PDF. These SPDE can be expressed as

$$d(\bar{\rho}\varphi_{\alpha,n}) = -\frac{\partial}{\partial x_j}(\bar{\rho}\tilde{u}_j\varphi_{\alpha,n})dt + \frac{\partial}{\partial x_j}\left[\left(\frac{\mu}{S_C}+\frac{\mu_t}{S_{Ct}}\right)\frac{\partial\varphi_{\alpha,n}}{\partial x_j}\right]dt + \dot{\omega}_\alpha^n dt - \frac{\bar{\rho}}{2\tau_{sgs}}(\varphi_{\alpha,n}-\tilde{\phi}_\alpha)dt + \left(2\bar{\rho}^2\frac{\mu_t}{S_{Ct}}\right)^{1/2}\frac{\partial\varphi_{\alpha,n}}{\partial x_j}dW_{j,n}, \quad for \quad n=1,\cdots N_F \ and \quad \alpha=1,\cdots N_s$$

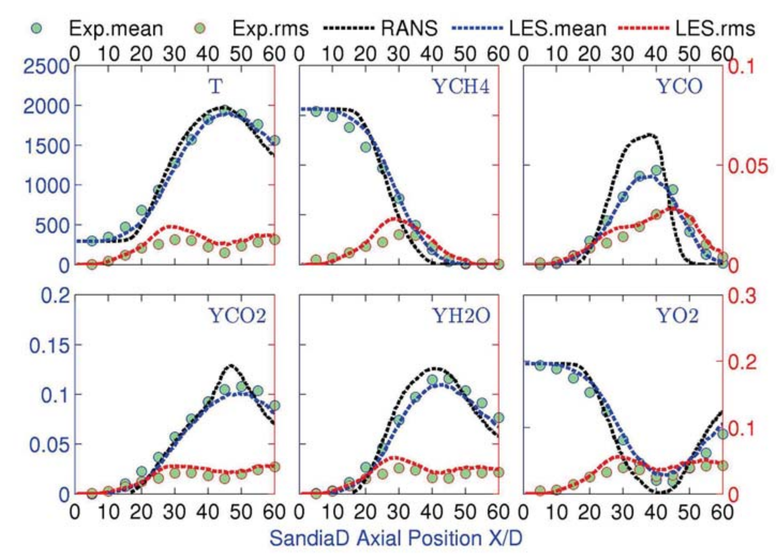
By solving the stochastic differential equations of each stochastic field, the evolution law of the mixture fraction and the progress variables over time in each stochastic field considering the influence of turbulence is obtained. A statistical average is then used to find the control variables for the flamelet look-up table.

4. Results



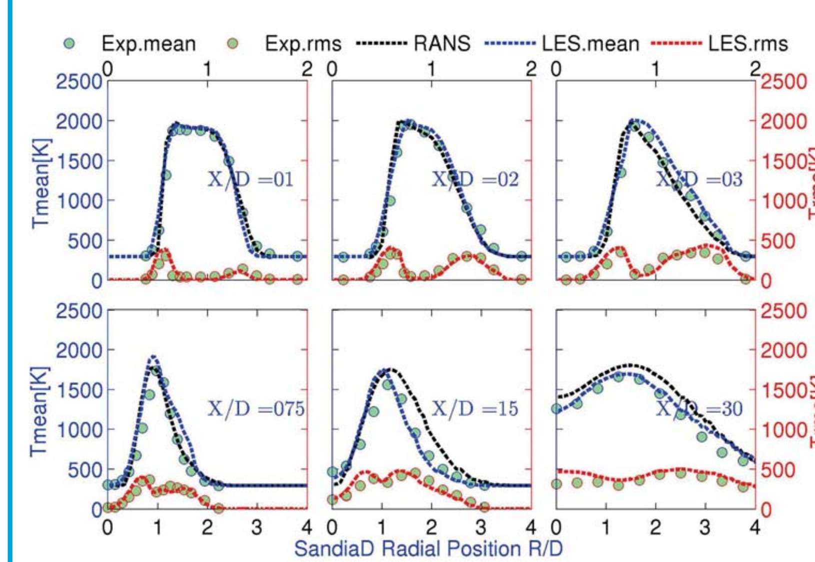
Mean plot of temperature and main components along the centreline of SandiaD flame

[RANS]



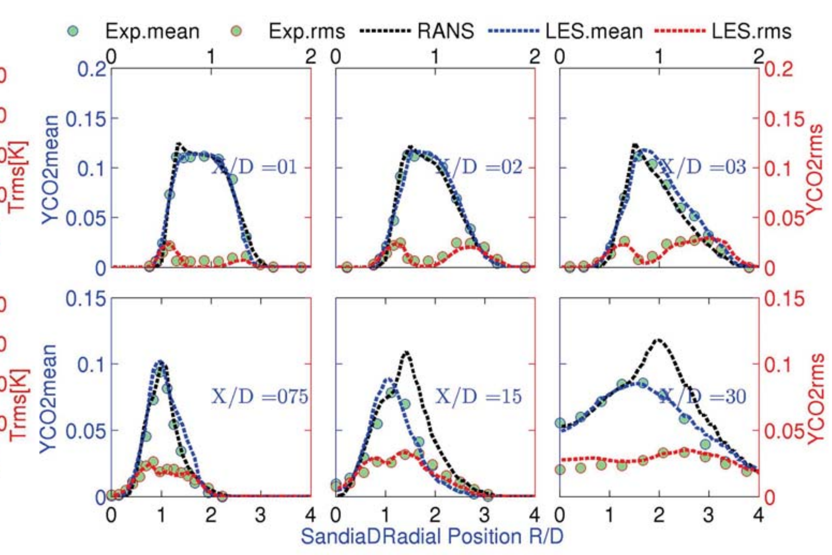
Mean and rms plot of temperature and main components along the centreline of SandiaD flame

[LES&RANS]



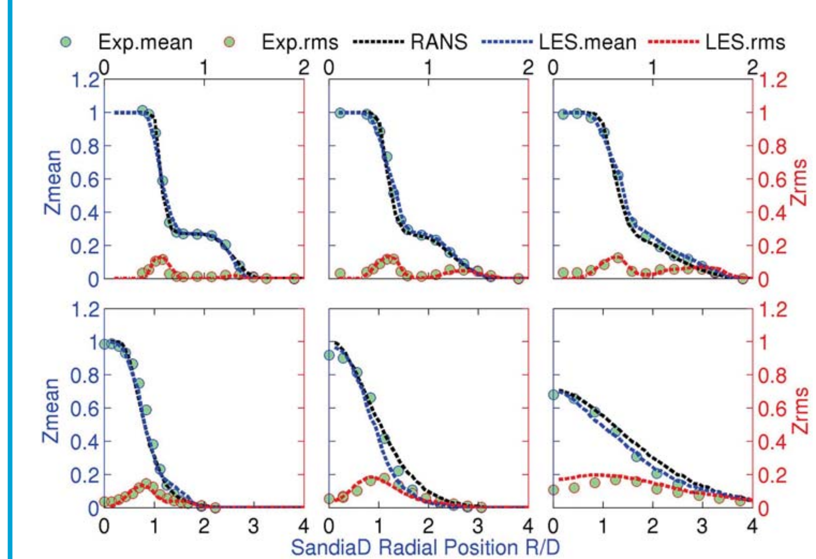
Radial profiles of mean and rms plot of temperature at six axial location of SandiaD flame

[LES&RANS]



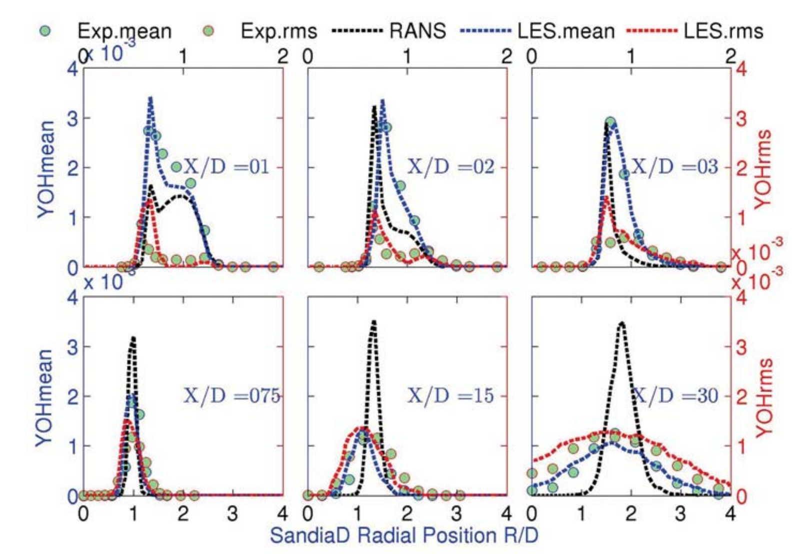
Radial profiles of mean and rms plot of CO2 mass fraction at six axial location of SandiaD flame

[LES&RANS]



Radial profiles of mean and rms plot of Z at six axial location of SandiaD flame

[LES&RANS]



Radial profiles of mean and rms plot of OH mass fraction at six axial location of SandiaD flame

[LES&RANS]

5. Conclusions

- For the simulated case, the accuracy of the proposed model in terms of the predicted temperature and species distribution is higher than the FGM model with PPDF.
- With the increase of the number of stochastic fields, the simulation accuracy of the **ESF/FGM** turbulent combustion model has been continuously improved.
- **LES** model improved the simulation accuracy of the fuel and oxidant mixing process, the results is better than the **RANS** model's.

References:

1. F. Nmira, D. Burot, and J. L. Consalvi, "Stochastic Eulerian field method for radiative heat transfer in a propane oxygen-enhanced turbulent diffusion flame," Combustion Theory & Modelling, vol. 21, pp. 62-78, 2016.

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