Flame Generated Turbulence and Counter-Gradient Turbulent Diffusion in Reactive Flows

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OBJECTIVES

• Propose new closures for **pressure terms** in a full **second order model** to avoid the turbulent viscosity assumption and to be able to take into account flame generated turbulence (FGT) and counter-gradient turbulent diffusion (CGD)
• Validate the new model using **DNS databases** of premixed turbulent flames

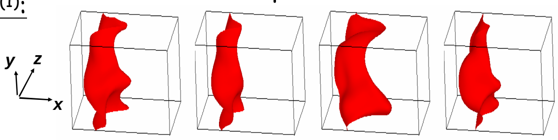
DIRECT NUMERICAL SIMULATIONS DATABASES OF PREMIXED TURBULENT FLAMES

	Case H	Case M	Case L
ρ_u / ρ_b	7.53	5.00	2.50
S_L^0	0.60	0.52	0.42
δ_L^0	0.22	0.19	0.16
u'/S_L^0	0.88	1.01	1.26
l_T/δ_L^0	15.9	18	21.8
Re_T	95.5	95.5	95.5
Da	18.1	17.8	17.3
Ka	0.54	0.55	0.56

Characteristics of the DNS databases[1]:

- Single Step irreversible reaction
- Resolution 512*128*128
- Flame propagate along x-direction
- Mean inflow velocity adjustment ➔ flame statistically steady
- Averaging in homogeneous plane (y,z) directions and in time

Case H: temperature iso-surface



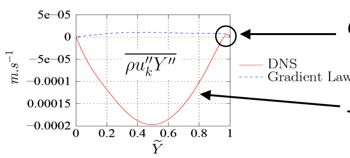
RANS SIMULATIONS : Rij LRR + gradient law

- Mean fuel mass fraction transport equation

$$\frac{\partial}{\partial t}\left(\bar{\rho}\tilde{Y}\right)+\frac{\partial}{\partial x_k}\left(\bar{\rho}\tilde{u}_k\tilde{Y}\right)=\frac{\partial}{\partial x_k}\left(\overline{\rho D\frac{\partial Y}{\partial x_k}}-\overline{\rho u_k''Y''}\right)+\overline{\omega}$$

Gradient law : $\overline{\rho u_k''Y''}=-\bar{\rho}D_T\frac{\partial\tilde{Y}}{\partial x_k}$

LW-P model[2,3] for turbulent combustion



- Momentum transport equations

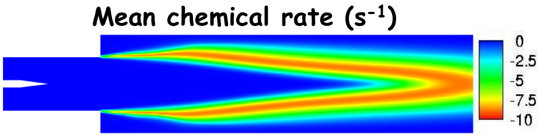
$$\frac{\partial}{\partial t}\left(\bar{\rho}\tilde{u}_i\right)+\frac{\partial}{\partial x_k}\left(\bar{\rho}\tilde{u}_k\tilde{u}_i\right)=\frac{\partial}{\partial x_k}\left(\bar{\tau}_{ik}-\overline{\rho u_i''u_k''}\right)-\frac{\partial\bar{p}}{\partial x_i}$$

- Reynolds Stresses transport equations

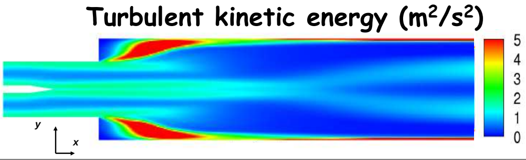
$$\frac{\partial}{\partial t}\left(\overline{\rho u_i''u_j''}\right)+\frac{\partial}{\partial x_k}\left(\tilde{u}_k\overline{\rho u_i''u_j''}\right)=D_{ij}+P_{ij}-\overline{\rho\epsilon}_{ij}+H_{ij}$$

Model LRR : Return to isotropy effects

Mean chemical rate (s⁻¹)



Turbulent kinetic energy (m²/s²)



RANS SIMULATIONS : full 2nd order model[4,5]

- Scalar turbulent fluxes transport equations

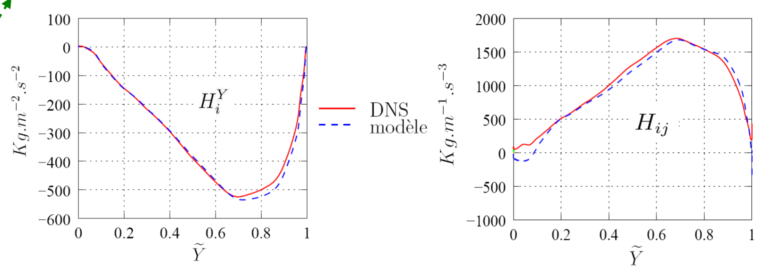
$$\frac{\partial}{\partial t}\left(\overline{\rho u_i''Y''}\right)+\frac{\partial}{\partial x_k}\left(\tilde{u}_k\overline{\rho u_i''Y''}\right)=D_i^Y+P_i^Y-\overline{\rho\epsilon}_i^Y+H_i^Y+\psi_i^Y$$

Pressure terms responsible for FGT and CGD

$$H_i^Y=-\overline{Y''\frac{\partial p}{\partial x_i}}$$

$$H_{ij}=-\overline{u_i''\frac{\partial p}{\partial x_j}}-\overline{u_j''\frac{\partial p}{\partial x_i}}$$

New model :
- Return to isotropy effects
- Effects of the chemical reaction
- Effects of the density variations

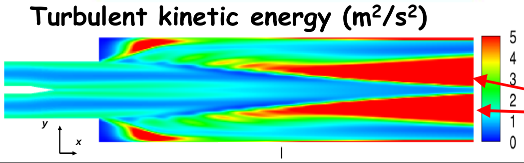


Turbulent fluxes (m.s⁻¹)

Counter-gradient turbulent diffusion in the flame brush

Gradient turbulent diffusion zone at the fresh gas side : *stabilization of the flame*

Turbulent kinetic energy (m²/s²)



Flame Generated Turbulence

CONCLUSIONS

• First order models are not suitable to represent some important features of turbulent combustion : FGT and CGD
• The proposed new model for the pressure terms that appear in the turbulent fluxes and Reynolds Stresses transport equations has been successfully validated through comparisons with 3-D DNS data of planar premixed flames
• RANS simulations using this new model available in perfectly and partially premixed reactive flows has demonstrated its ability to represent FGT and CGD

References

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