Numerical simulation of turbulent combustion using turbulent flamelet model

VG500 Poster

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Abstract

Numerical simulation of turbulent combustion is carried out using the turbulent flamelet model. Numerical results, compared with traditional methods, suggest that this new model is well designed for Large Eddy Simulation(LES) and has better agreement with experimental data.

Combustor Model

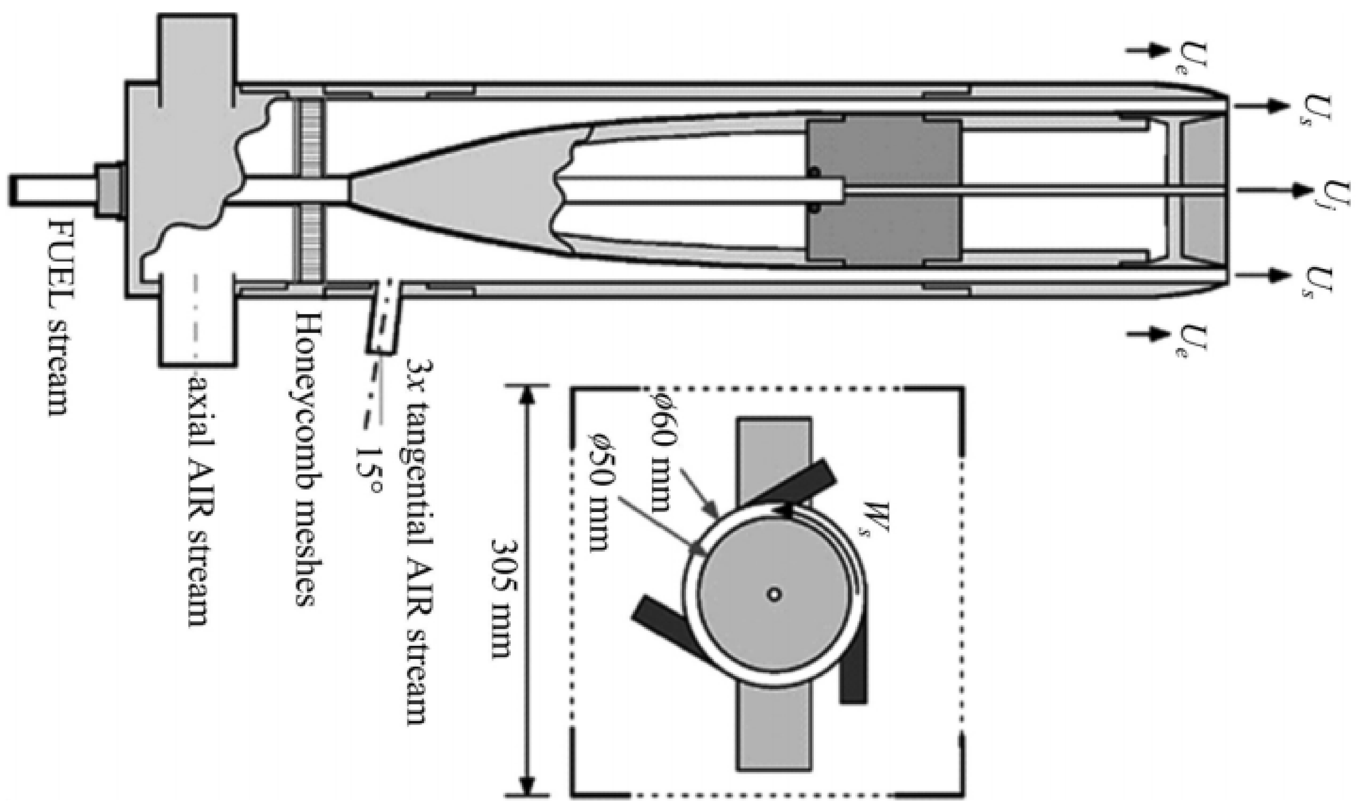

Fig. 1 Channel Model with Sawtoothed Surface

Governing Equations

$$\text{(Continuity)} \quad \frac{\partial \bar{\rho}}{\partial t} + \frac{\partial(\bar{\rho}\tilde{u}_j)}{\partial x_j} = 0 \tag{1}$$

$$\text{(Momentum)} \quad \frac{\partial(\bar{\rho}\tilde{u}_i)}{\partial t} + \frac{\partial(\bar{\rho}\tilde{u}_i\tilde{u}_j)}{\partial x_j} = -\frac{\partial \bar{p}}{\partial x_i} + 2\frac{\partial \bar{\mu}\tilde{S}_{ij}}{\partial x_j} + \frac{\partial t_{ij}}{\partial x_j} \tag{2}$$

$$\text{(Scalar transport)} \quad \frac{\partial(\bar{\rho}\tilde{\phi}_i)}{\partial t} + \frac{\partial(\bar{\rho}\tilde{\phi}_i\tilde{u}_j)}{\partial x_j} = \frac{\partial \bar{\rho}\tilde{\alpha}_i\tilde{\phi}_{i,k}}{\partial x_k} + \bar{\rho}\tilde{\omega}_i + \frac{\partial q_{ik}}{\partial x_k} \tag{3}$$

where

$$\tilde{S}_{ij} = \frac{1}{2}(\tilde{u}_{i,j} + \tilde{u}_{j,i}) - \frac{1}{3}\delta_{ij}\tilde{u}_{k,k}$$

Flamelet Assumption

Locally, the characteristic timescale of chemical reaction is much smaller that that of flow($t_c \ll t_f$). Thus, local flame structure can be described by the difffusion flame under counterflow configuration.

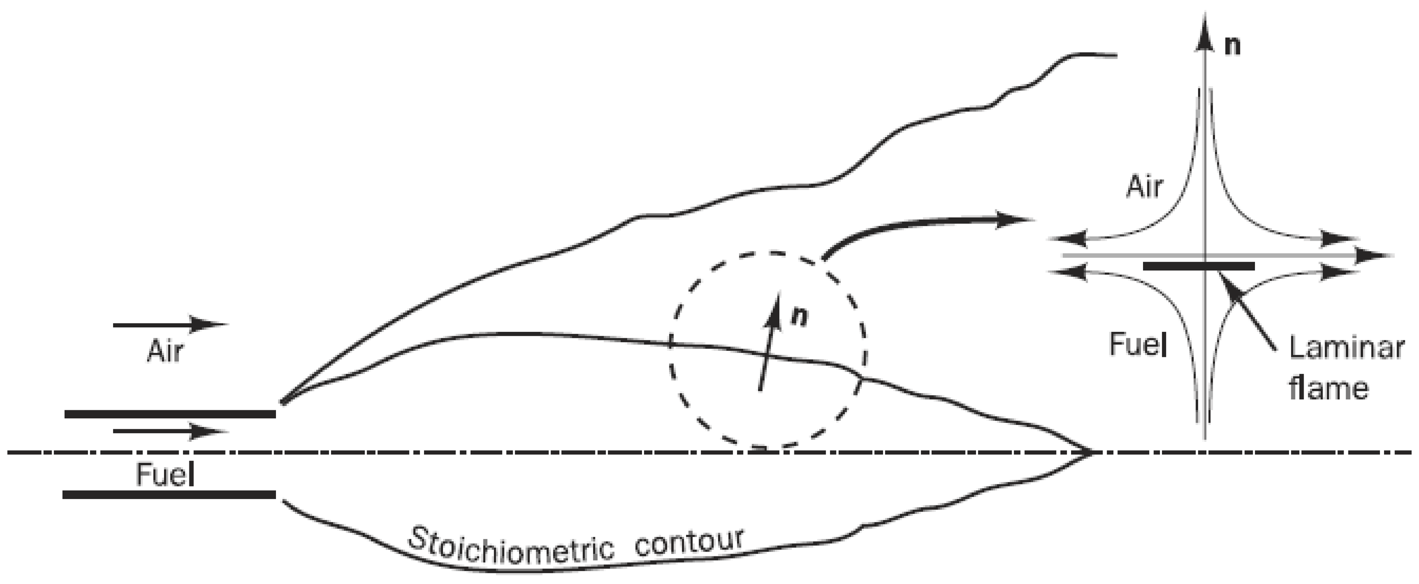

Fig. 2 Local laminar flamelet

Solution Procedure

An iterative process:

(1) Prepare all properties at $t = n$.

(2) Update flow properties at $t = n + 1$ from CFD solver.

(3) Calculate mix-fraction(Z) and strain-rate(χ).

(4) From pre-computed table, lookup temperature(T) and mass fraction(Y_i) at $t = n + 1$.

(5) Update density(ρ) at $t = n + 1$.

(6) Check convergence.

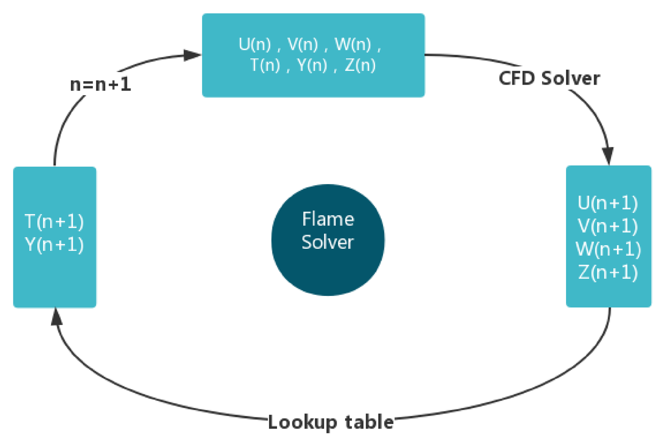

Fig. 3 Solution Flowchart

Grid Layout

Unstructured grid containing tetrahedral, hexahedron and pyramids. Refined locally.

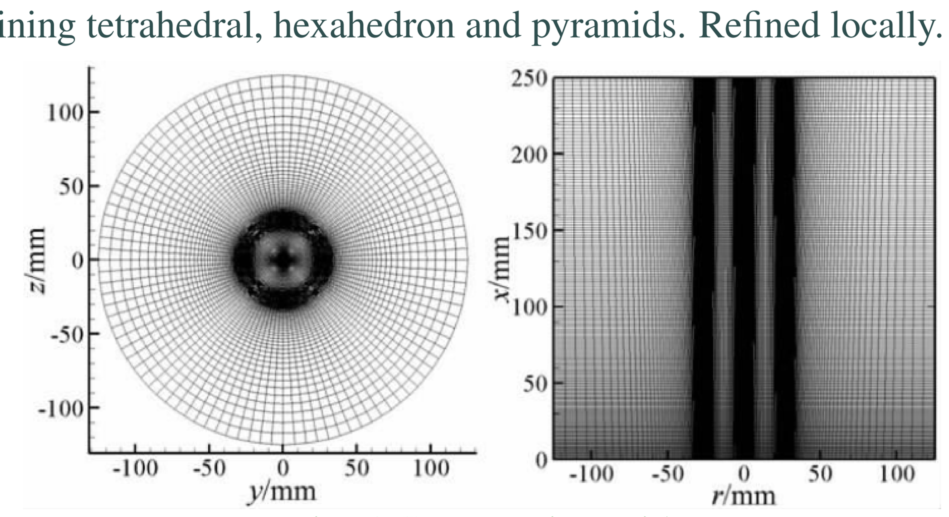

Fig. 4 Computation grid

Numerical Schemes

Based on the Finite Volume Method(FVM), the intercell flux are computed from 2nd-order upwind schemes. Dynamic subgrid model is adopted in the context of Large Eddy Simulation(LES).

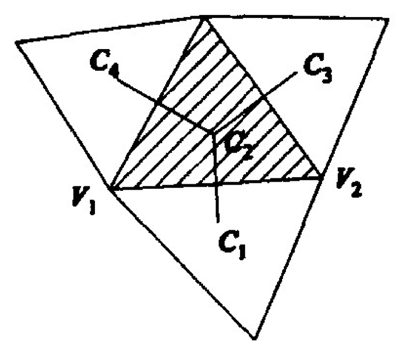

Fig. 5 Cell-centered variable

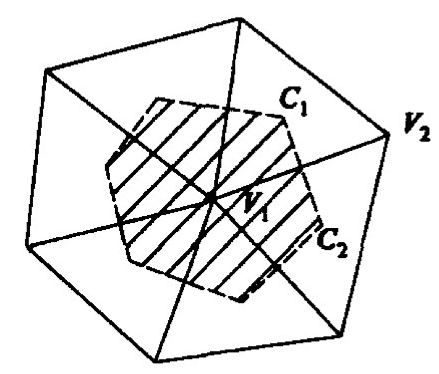

Fig. 6 Vertex-centered variable

Results

(1) **The T_{max} plot**.

- One of the most convincing testing cases.
- Nice agreement in ignition range compared with reference data.
- Difference and transition position are also revealed clearly.

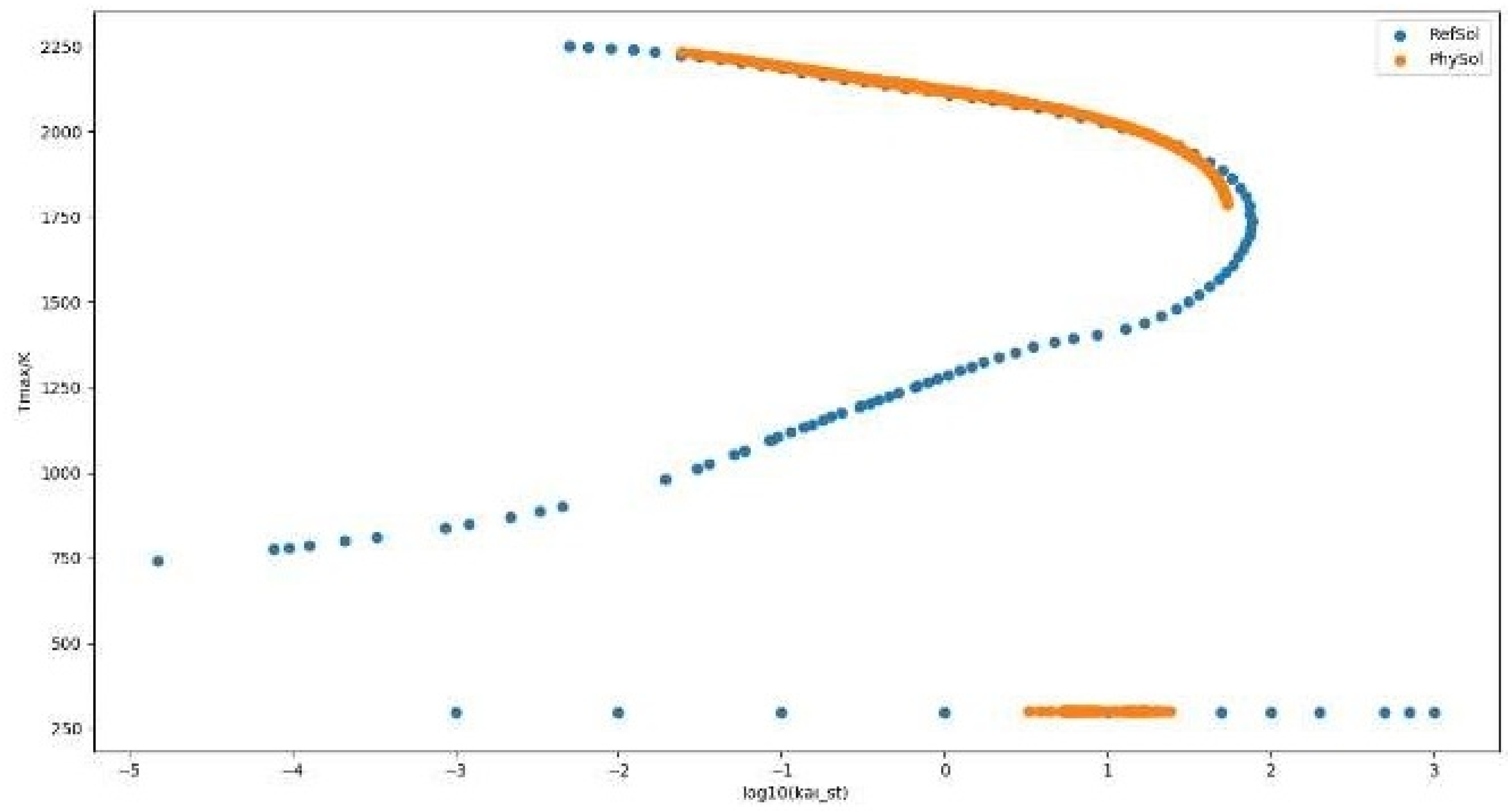

Fig. 6 "S" Curve

(2) **Flame structure**.

- Fine vortex structure is resolved.
- Better prediction of minor species like NOx and COx.

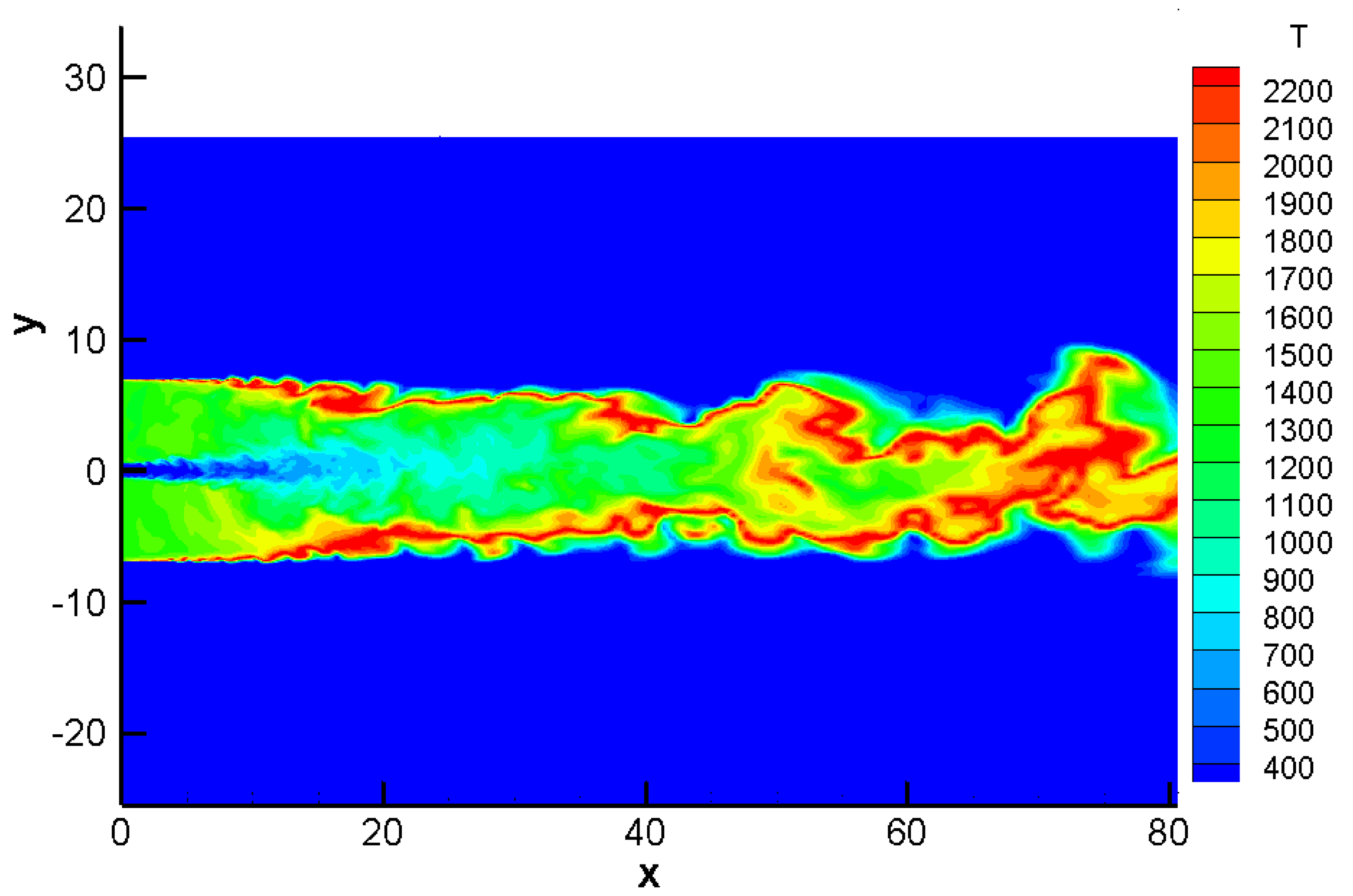

Fig. 7 Jet flame

Conclusions

- Turbulent flamelet model shows better performance that traditional flame models.
- T_{max} curve solved in physical space has lower temperature, which is desired in practice.
- Finer vortex structures can be well resolved.

References

[1] Wang Lipo. "Analysis of the filtered non-premixed turbulent flame". In: *Combustion and Flame* 175 (2017), pp. 259–269.

[2] Charles David Pierce and Parviz Moin. "Progress-variable approach for large-eddy simulation of turbulent combustion". Thesis. 2001.

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