# COMPERATIVE STUDY OF TURBULENCE MODELING IN METHANE SIMPLE JET FLAME

**Witold Zakrzewski / Paweł Ziółkowski**
**Energy Conversion Department, Institute of Fluid Flow Machinery PAS-ci, Gdańsk, Poland**

The topic of this work is the numerical simulation of a turbulent diffusion jet flame fueled with a mixture of $CH_4$, $H_2$, and $N_2$. Simulations have been investigated with different two-equation turbulence models to improve prediction of jet flow-fields. The calculations are validated against existing experimental data provided by DLR. In particular, a comparison of three two-equation turbulence models and their influence on combustion process is presented: the Pope correction, the standard *k-ε* model and realizable *k-ε*. For combustion modeling EDC model with a 25-step reaction is considered. The numerical results for mean velocity components, temperature, and major chemical species are presented and compared with the experimental data.

The additional goal of the work is to investigate the capabilities of the used turbulence models in proper predicting of the round jet spreading in a non-premixed jet flame. Calculations were performed using commercial solver. The Pope correction has been applied via UDF. The advantages and disadvantages of the models are discussed in detail in relationship to the results.

Standard *k-ε* model predicts the velocity field of a two dimensional plane jet quite accurately, but results in large errors for axis-symmetric round jets, overestimating the spreading rate even up to 40% [1]. This "round-jet plane-jet anomaly" takes origin from the numerous simplifying assumptions in all RANS models. Therefore, in order to obtain accurate calculations of round jets, modification to the classical models is required. Modifications to the turbulence constants have been suggested by [2][3]. All modifications involve the turbulence constants becoming functions of the velocity decay rate and a jet width defined as $\delta_{0.5}$ (eq.1) parameter where $y_{1/2}$ is the distance from the centerline to location where the velocity is half the centerline velocity.

$$\delta_{0.5}(x) = \frac{y_{1/2}}{x} \quad , \tag{1}$$

Pope argued that in axis-symmetrical flow the velocity rings will be starched, which results in a higher dissipation rate as compared to planar shear layers. In connection with this Pope proposed to add another source term (eq.2) in energy dissipation equation based on vortex-stretching invariant defined by (eq.3). The new constant $C_{\varepsilon 3}$ = 0.79 with the modified version of epsilon reproduces the spreading rate and the velocity profile to the measured value of $\delta_{0.5}$ = 0.86.
In this paper the Pope correction has been implemented as UDF into Fluent solver in a form of a source term included to energy dissipation equation.

$$P_{correction} = C_{\varepsilon 3}\rho \frac{\varepsilon^2}{k}\chi \quad , \tag{2}$$

Vortex-stretching invariant:

$$\chi = \left(\frac{k}{\varepsilon}\right)^3 \omega_{ij}\omega_{jk}d_{ki} \quad , \tag{3}$$

The correction replaces constant $C_{\varepsilon 2}$ = 1.92 with $C_{\varepsilon 2Pope}$ defined as:

$$C_{\varepsilon 2Pope} = C_{\varepsilon 2} - C_{\varepsilon 3}\chi \quad , \tag{4}$$

After some transformations the transport equation for $\varepsilon$ can be finally written as:

$$\frac{\partial}{\partial t}(\varepsilon) + \frac{\partial}{\partial x_j}(v_j\varepsilon) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{\varepsilon}{k}(C_{\varepsilon 1}P_k - \varepsilon(C_{\varepsilon 2} - C_{\varepsilon 3}\chi)) \tag{5}$$

In the Figure 1 non-reacting flow calculations of jet spreading rates are presented. Figure 2 shows local changes of the $C_{\varepsilon 2Pope}$ coefficient calculated in the flow filed area of the jet.

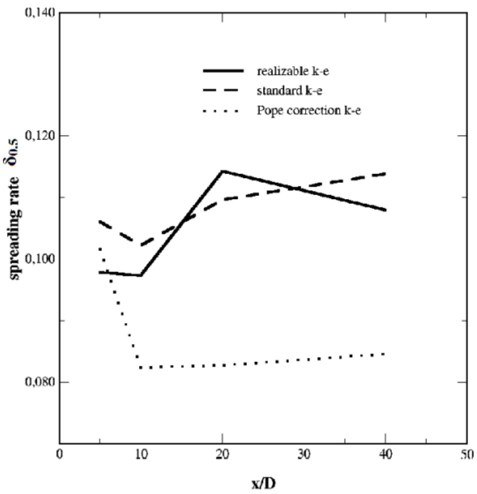
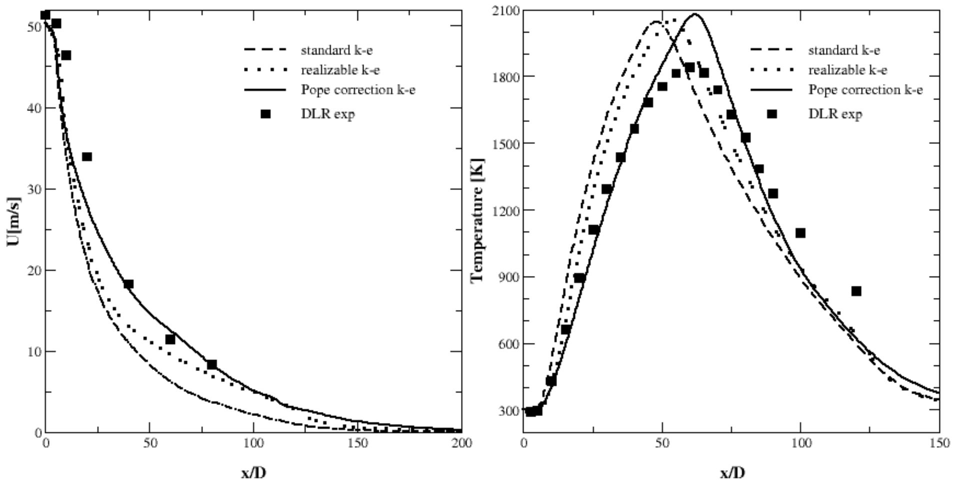




Figure 1. Distribution of the rate of jet $\delta_{0.5}$.

Figure 2. local changes of the $C_{\varepsilon 2Pope}$ coefficient in the flow field.




Fugure 3. Axial velocity and temperature in the centerline.

The calculated results of the mean axial velocity and static temperature are compared to the experimental data along the centerline in Figure 3. The axial velocity calculated with the Pope correction is in sufficient agreement with experimental data. The radial profiles indicate that the spreading rate is calculated quite accurately.


1. Pope, S.B., *An Explanation of the Turbulent Round-Jet/Plane-Jet Anomaly*, AIAA Journal, Vol. 16, No. 3, 1978, pp. 279-281.
2. McGuirk, J.J. and Rodi, W., *The Calculation of Three-Dimensional Turbulent Free Jets*, 1st Symp. On Turbulent Shear flows, editors F. Durst, B.E. Launder, F.W. Schmidt and J.H. Whitelaw, 1979, 71-83.
3. Morse, A.P., *Axisymmetric Turbulent Shear Flows with and without Swirl*, Ph.D. Thesis, London University, 1977.