# CURVATURE AND VELOCITY STRAIN DEPENDENCIES OF BURNING SPEED IN A TURBULENT PREMIXED JET FLAME

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Abstract In this work the dependency of the turbulent burning speed on flame stretch in a premixed jet flame is analyzed. Considering a reference system attached to the front, the flame stretch is split into three contributions based on flame front curvature, normal fluid velocity and divergence of tangential velocity. The turbulent burning velocity is derived from the measure of the divergence of the mean unconditioned velocity field, that is taken as an estimate of the mean reaction rate in the context of flamelet hypothesis. The results are in a reasonable agreement with the literature data on turbulent combustion rates. Though the present methodology is more complex than the usual one based on reactant consumption rate, it provides the local burning speed and not the overall one. Combining these measurements with the local flame stretch, we show that, for a given flame, it exists a wide region along the flame height where the increase of the local flame speed in respect to the laminar unstretched one (stretching factor) is constant. Since the Reynolds number controls the small-scale behavior of turbulence, these findings denote a direct connection between the local, turbulence-induced, flame front deformation and the increase of the local flame propagation speed. The aim of this work is to establish correlations between the three different terms of flame stretch and the turbulent combustion speed that can lead to the definition of suitable closure models for turbulent combustion numerical simulations.

## METHODOLOGY

Flame stretch acting on reactive surfaces in turbulent premixed combustion deeply influences the turbulent burning speed. Following the classical hypothesis of flamelet structure, the correlation between surface evolution and turbulent burning speed $S_{LB}$ is expressed as $S_{LB}/S_{Lo} = I_o A_T/A_o$, with $S_{Lo}$ the unstretched laminar combustion velocity, where the turbulent and average flame surface are $A_T$ and $A_o$, respectively. The term $I_o$, namely the stretching factor, takes into account the influence of flame surface stretch $K = 1/A(dA/dT)$ on the unstretched laminar combustion velocity. Depending on the chemistry of the reacting mixture, $S_{Lo}$ can raise or lower its value with the flame surface stretch, i.e., $S_L = S_{Lo} - \mathcal{L}\mathcal{K}$. The Markstein length $\mathcal{L}$, available from literature data, is of the order of the flamelet thickness. In this work it is adopted a definition of the stretching factor based on the evolution of a reacting surface conveyed by a velocity field [1]:

$$S_{LB} = S_{Lo}\left[1 - \mathcal{L}\left(kS_{Lo} - v_n k + \nabla_t \cdot \mathbf{v_t}\right)\right](A_T/A_o) = I_o S_{Lo}\left(A_T/A_o\right) \ . \tag{1}$$

being $v_t$, $v_n$ and $k$ the tangential, normal to surface flow velocities and the front curvature.
By means of PIV velocity acquisitions and front position detection in an air methane turbulent premixed jet flame at a relatively high Reynolds numbers ($Re = 5000 \div 15000$), the turbulent burning speed is measured and the evolution of the ratio $A_T/A_o$ and of $I_o$ along the whole flame height is studied. The flame stretch $I_o$ is evaluated following two different

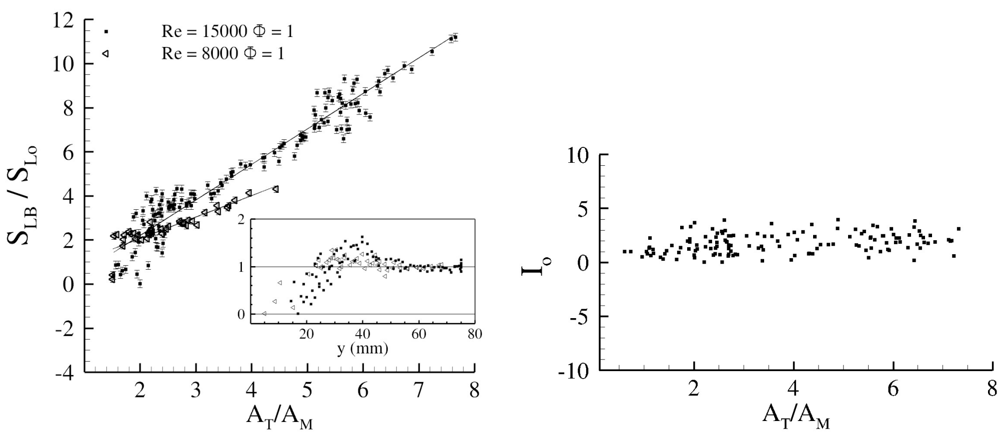


**Figure 1.** Left panel, scatter plot of $S_{LB}/S_{Lo}$ $vs$ $A_T/A_M$. Two best-fits represent values of $I_o = 0.97$ and $I_o = 1.61$. In the inset, compensated plot of $(S_{LB}/S_{Lo})/I_o$ $vs$ axial coordinate $y$. Right panel, scatter plot of $I_o$ $vs$ $A_T/A_o$ for a stoichiometric flame at $Re = 15000$.

methodologies, one is to find the proportionality constant between $S_{LB}/S_{Lo}$ and $A_t/A_M$ (see left panel of figure (1) and the other stems directly from its kinematic definition in equation (1) (right panel of the same figure).
The results will show that $I_o$ has values larger than unity that are substantially constant along the flame, while maintaining a dependence on the Reynolds number of the flame. A linear regression gives values of $I_o$ ranging between 1 and 2.5, which are of the same order of $I_o$ measured by other experiments on highly symmetric configurations, like spherical expanding flames [2]. Since the Reynolds number controls the small-scale behavior of turbulence, these findings denote a direct connection between the local, turbulence-induced, flame front deformation and the increase of the local flame propagation speed. More details on this aspect will be presented at the congress.

## References


[1] S. H. Chung and C. K. Law. An invariant derivation of flame stretch. *Combustion and flame*, **55**:123–125, 1984.

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