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Statistics of vorticity alignment with local strain rates in turbulent premixed flames



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HIGHLIGHTS

- The statistics of alignment of vorticity with local principal strain rates have been analysed.
- Effects of regime of combustion and the global Lewis number have been investigated.
- Relative alignments with local principal strain rates are affected by Damköhler and Lewis numbers.
- Detailed physical explanations have been provided for the aforementioned observed behaviours.

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ABSTRACT

The instantaneous alignment of the vorticity vector with local principal strain rates is analysed for statistically planar turbulent premixed flames with different values of heat release parameter and global Lewis number spanning different regimes of combustion. It has been shown that the vorticity vector predominantly aligns with the intermediate principal strain rate in turbulent premixed flames, irrespective of the regime of combustion, heat release parameter and Lewis number. However, the relative alignment of vorticity with the most extensive and compressive principal strain rates changes based on the underlying combustion conditions. Detailed physical explanations are provided for the observed behaviours of vorticity alignment with local principal strain rates. It has been shown that heat release due to combustion significantly affects the alignment of vorticity with local principal strain rates. However, the relative for all cases considered here, irrespective of the nature of the vorticity alignment.

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1. Introduction

The alignment of the vorticity vector with local principal strain rates is of fundamental importance for the understanding and modelling of turbulent fluid motion, as the alignment statistics directly affect the nature of the vortex-stretching mechanism [1]. It has been demonstrated in several previous studies that the vorticity vector instantaneously aligns with the intermediate eigenvector of strain rate tensor for non-reacting turbulence [2–12]. However, relatively limited attention was given to the analysis of alignment of vorticity with local strain rates in the case of turbulent reacting flows [13–15]. In many applications (e.g. Spark Ignition (SI) engines and industrial gas turbines), the fuel and oxidiser are homogeneously mixed prior to the combustion process (i.e. premixed combustion). Thus, the understanding of vorticity alignment with local principal strain rates is of fundamental interest for the development of high-fidelity models which can, in turn, contribute

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to the design of new generation energy-efficient and environmentfriendly combustion devices. The analysis of Nomura and Elghobashi [13], Boratov et al. [14] and Jaberi et al. [15] concentrated on vorticity alignment with local principal strain rates for non-premixed flames where fuel and oxidiser are completely separated from each other prior to the combustion process. Recently, Hamlington et al. [16] analysed vorticity statistics in premixed combustion based on numerical solutions of reactive systems. The analysis by Nomura and Elghobashi [13] demonstrated that the vorticity vector aligns with the intermediate principal strain rate in non-premixed flames similar to non-reacting turbulent flows but vorticity in non-premixed flames shows appreciable probabilities of local alignment with the most extensive principal strain rate. The analysis by Boratov et al. [14] on non-premixed flame DNS data reveals that the extent of vorticity alignment with the most extensive principal strain rate increases in the regions where the magnitude of strain rate dominates over the vorticity magnitude. By contrast, vorticity shows preferential alignment with the intermediate principal strain rate in the regions where the vorticity magnitude dominates over the strain rate magnitude. The analysis by Jaberi et al. [15] further demonstrated that the alignment of







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Jaberi et al. [15] showed that vorticity remains mostly perpendic-

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	e_{β}	Intermediate principal strain rate	γ_p	Angle between pressure gradient and the mos
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$ \begin{array}{llllllllllllllllllllllllllllllllllll$	q _{Ci}	Concerned quantity	ω_i	ith component of vorticity
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boundarypdfProbability density functionRANSReynolds Averaged Navier-Stokesuiith component of fluid velocityuiTarget value of ith component of fluid velocity at the boundaryviRoot mean square turbulent velocity fluctuation magnitudeviVelocity vectorviKolmogorov velocity scaleviVolume	T ^{req}	Target value of non-dimensional temperature at the	LES	Large Eddy Simulation
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	v ["]	Volume	the results	by Nomura and Elghobashi [13] for non-premixed co
<i>v</i> Chemical reaction rate bustion in the presence of inhomogeneous turbulence.	<i>i</i> v	Chemical reaction rate	bustion in	the presence of inhomogeneous turbulence. Moreo

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