Direct Numerical Simulation of Autoignition in a Jet in a Cross-Flow

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Abstract

• Autoignition of a diluted H2 jet in a cross channel flow of preheated air is studied via DNS, using **Nek5000 spectral element code**, at a friction Reynolds number of 180 and two cross flow temperatures (930K and 950K).

• At 950K, Spatially-isolated flame kernels form downstream of the jet that tend to propagate upstream. These kernels are eventually swept out of the domain. Later on in the simulation, a strongly burning stable flame forms near the jet nozzle. At 930K similar dynamics are observed, however at significantly later time and farther downstream.

Introduction

• The enhanced turbulent mixing between the fuel and oxidizer streams of the jet in cross flow (JICF) makes it an essential component in the design of premixing sections of the next generation lean premixed (LP) and lean premixed prevaporized (LPP) combustion devices such as stationary gas turbines, subsonic ramjets and supersonic scramjets.

• Understanding the propensity of reactive mixtures to auto-ignite is of primary importance for the design and flash-back-safe operation of such devices.

Objectives

• Sensitivity of the JICF to cross flow temperature in terms of both the short and long term dynamics.

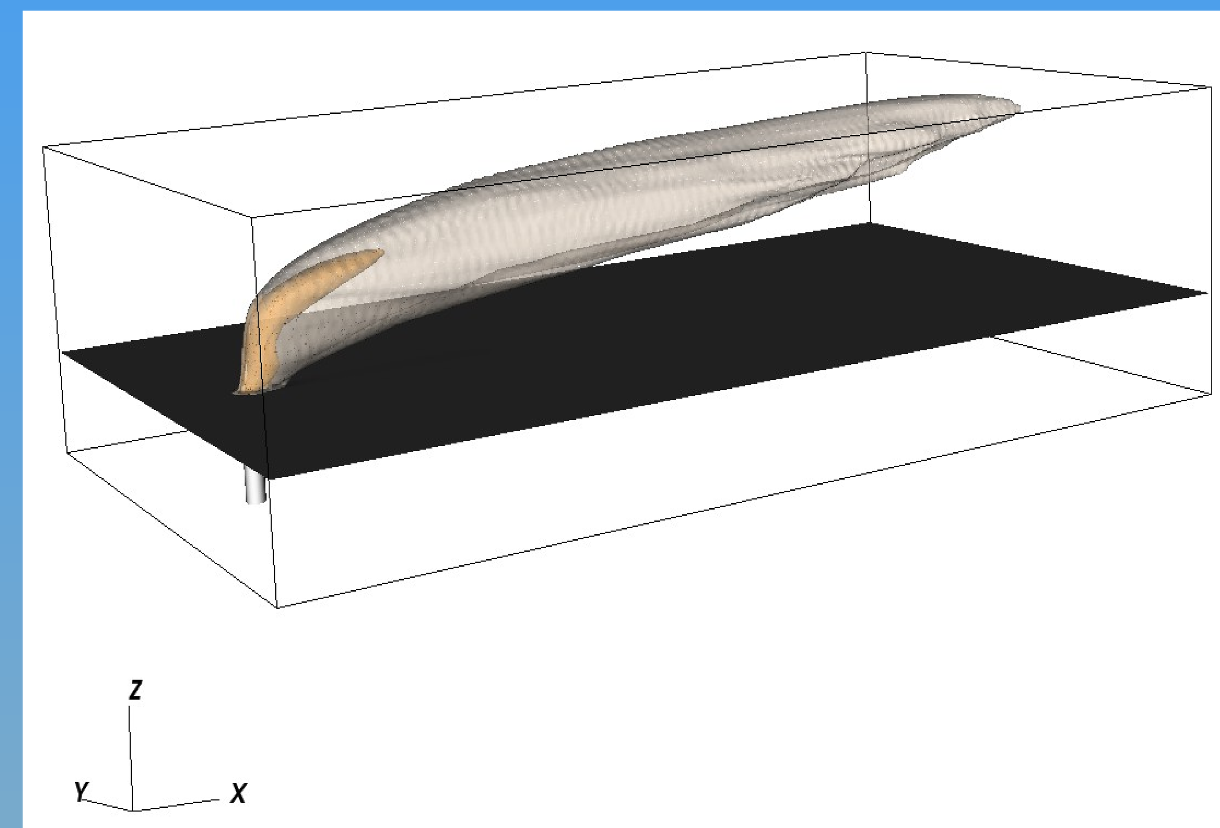
• Probing any connection between flame kernel evolution and the later formation of a stable burning flame.

• Investigating possible correlation of the observed ignition time (stable flame) to that of the corresponding homogenous system.

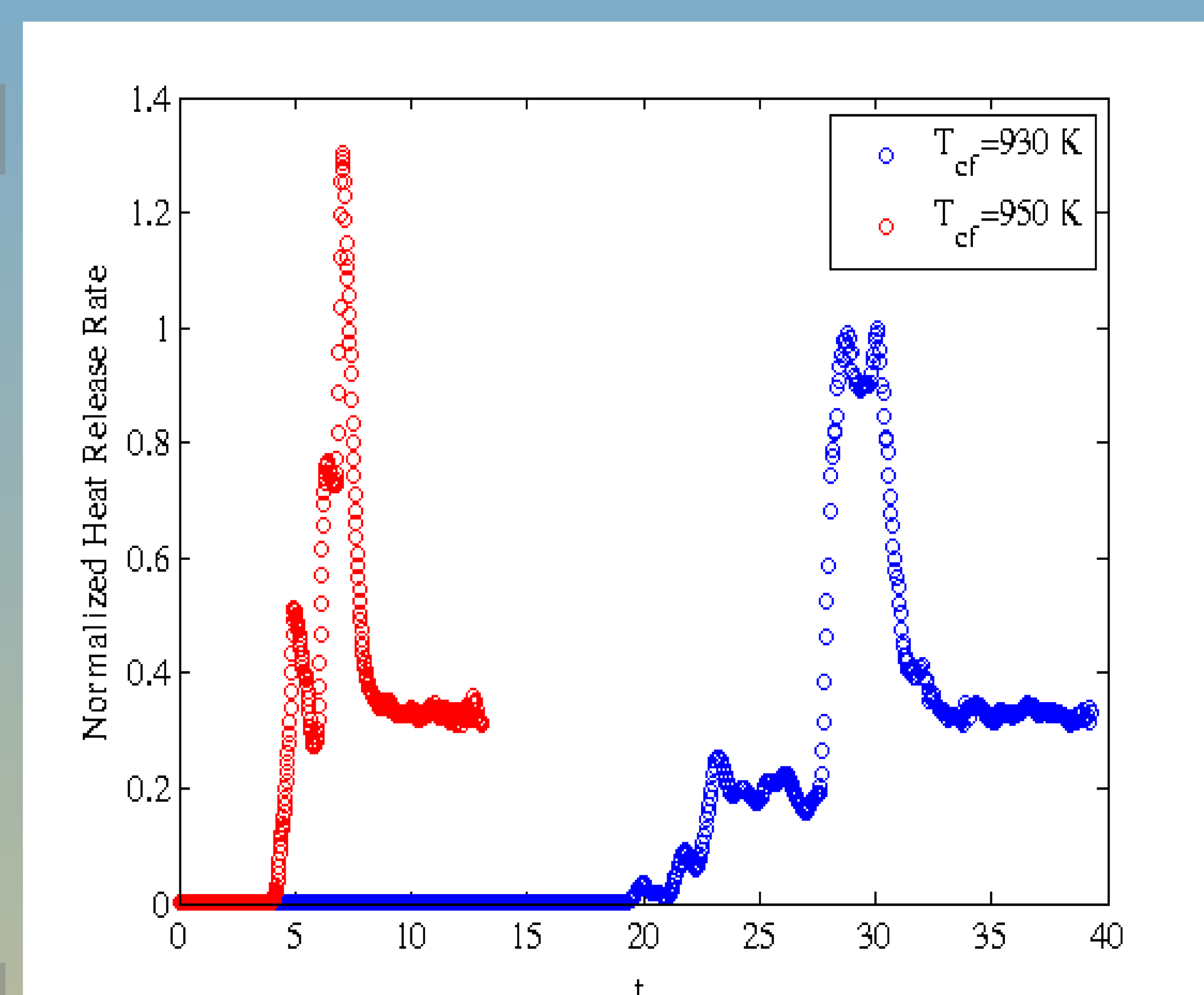
• Exploring flame stabilization mechanism and understanding the local combustion mode.

Results

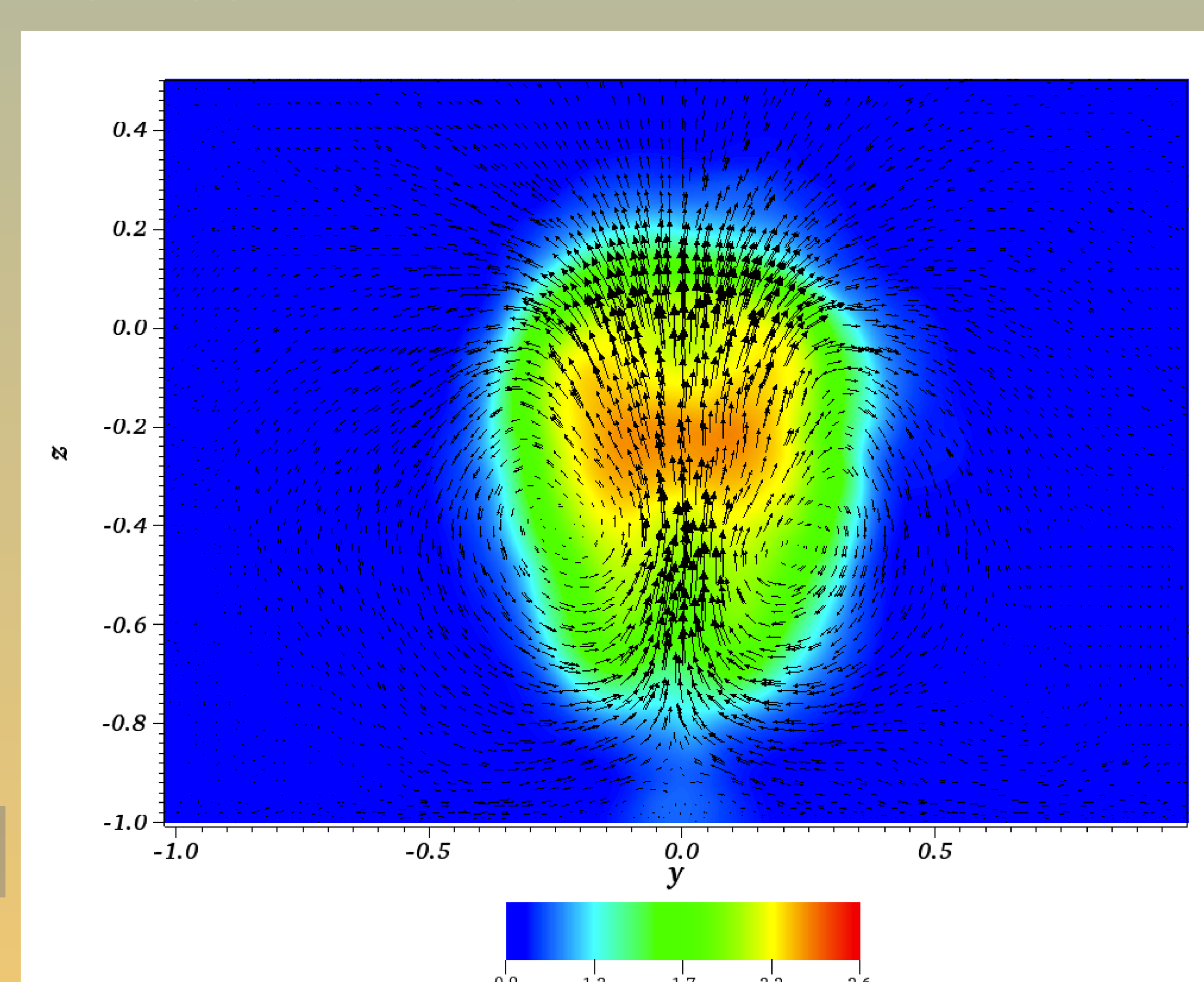
Key results of the DNS are shown using both instantaneous as well as time averaged fields (over one flow through time after stable flame formation).



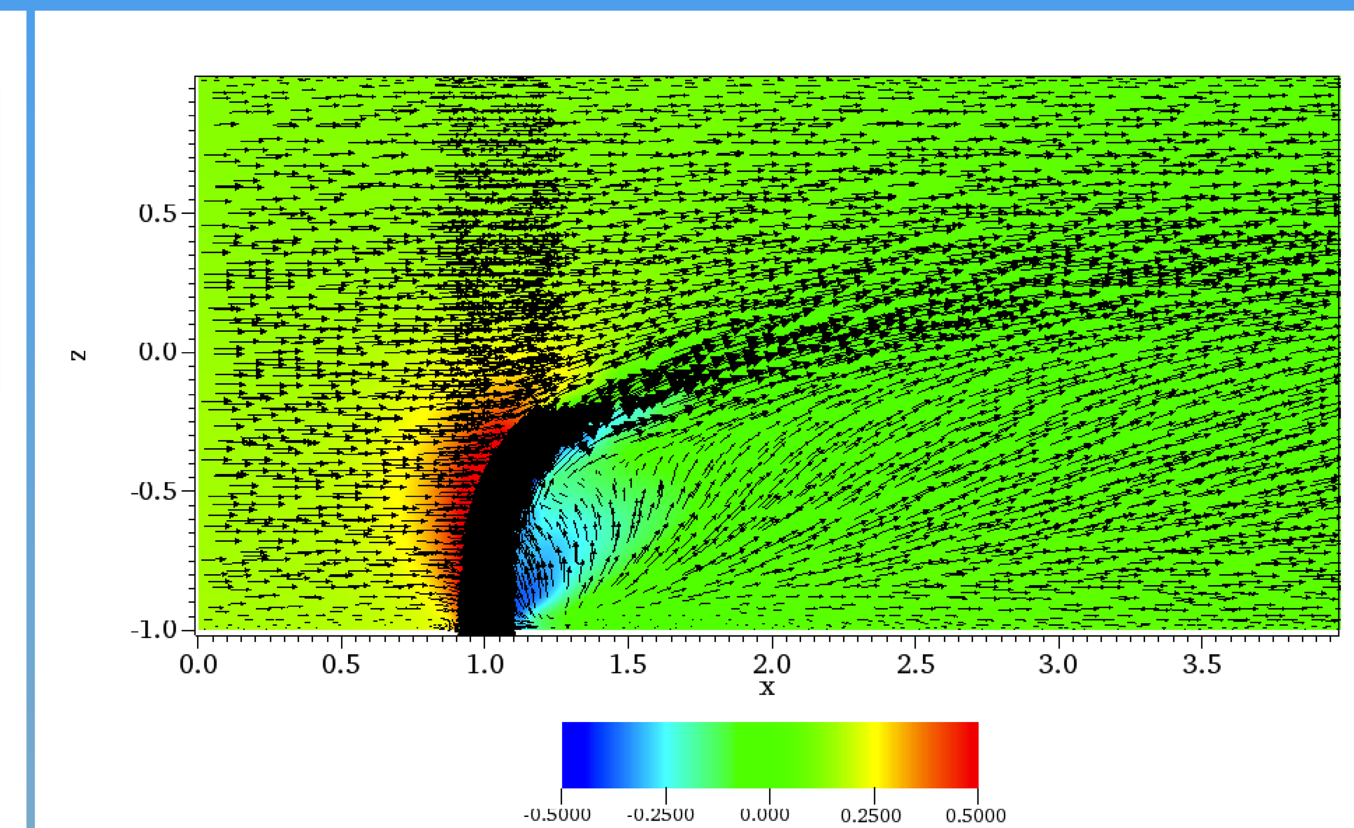
Figure(1)Schematic of a JICF



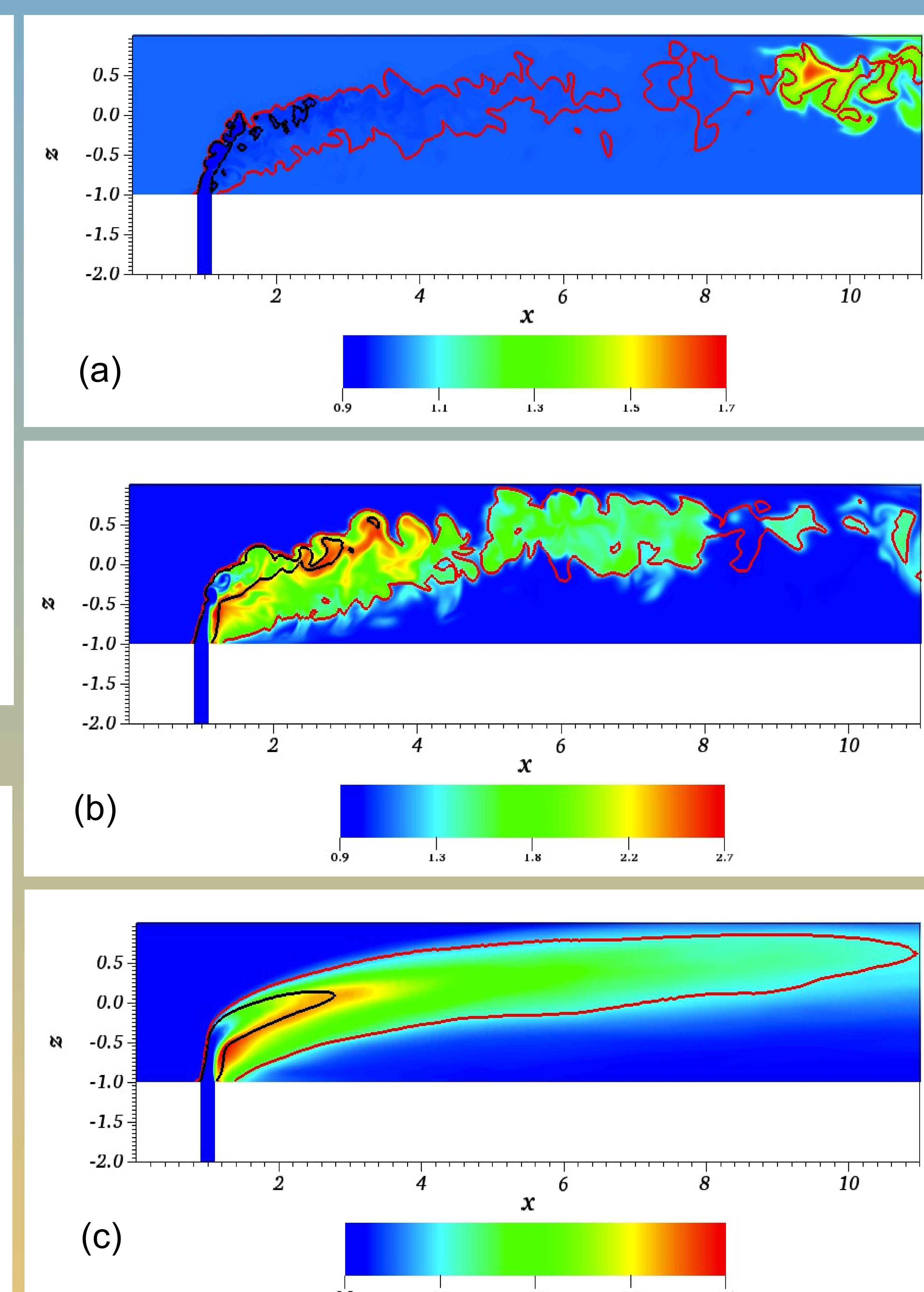
Figure(2) Time history of the heat release rate



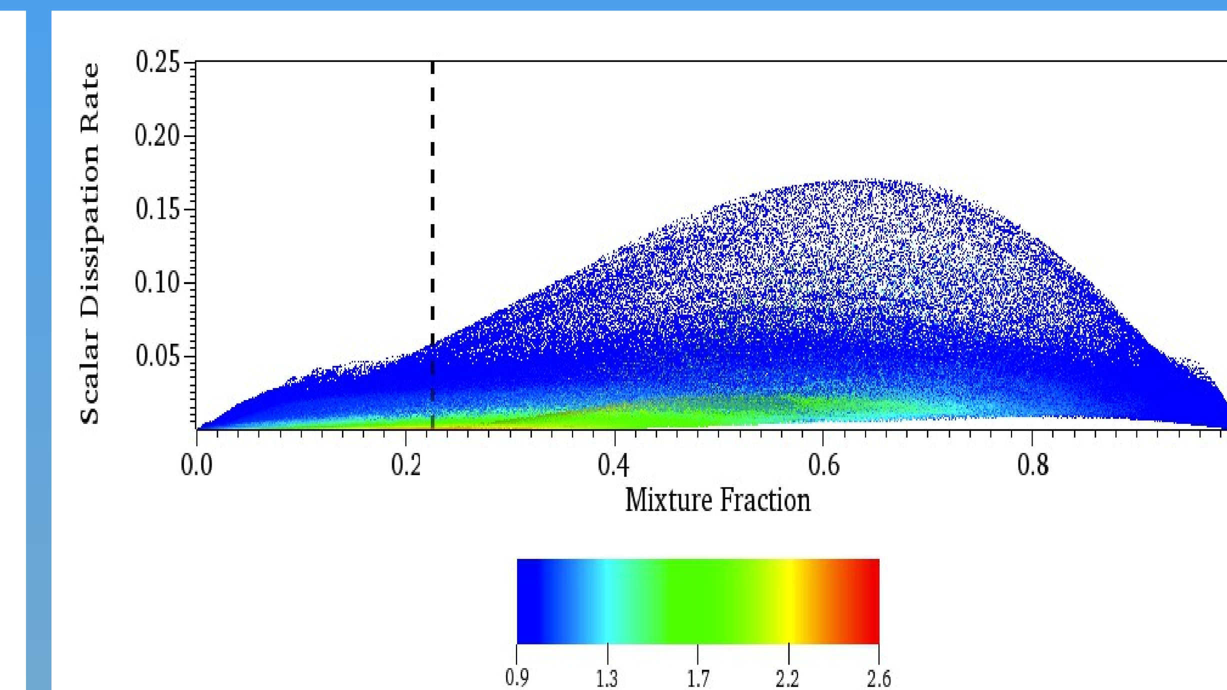
Figure(3) Temperature contours on a lateral plane and velocity vector plots showing CVP formation.



Figure(4)Static pressure field in a JICF on a lateral plane



Figure(5) Temperature contours on a stream wise vertical plane at (a) t=23.5 (b) t=30. (c) time average over 1 flow-through time. Red isoline is the most reactive mixture fraction and black isoline is the stoichiometric mixture fraction.



Figure(6) Time averaged scatter plot of the scalar dissipation rate and mixture fraction, colored by the temperature. The dashed line corresponds to Stoichiometric mixture fraction.

Conclusion

• Flow is characterized by complex pressure field and myriad vortical structures (see Fig. 3, 4) that lead to strong turbulent entrainment of cross flow oxidizer fluid into the H2 jet. Strong turbulent mixing on the leeward side of the jet, as compared to the windward side, leads to noticeable asymmetry in the jet (Fig 5.c).

• Spatially isolated flame kernels form downstream from the jet and propagate back upstream but eventually get convect out of the domain (Fig. 5.a). Later on a stable strongly burning coherent flame forms in the near jet (Fig.5.b).

• The isolated flame kernels can be explained by autoignition since their spatial locations coincide with locations where the mixture fraction is most reactive (according to homogenous calculations). Their propagation is associated with local spatial gradients of autoignition delay time.

• Scatter plots show that the stable burning flame favors locations where the scalar dissipation rate (Fig. 6) and the velocity magnitude (not shown) are relatively low. Furthermore Takeno Index distribution (not shown) indicates predominantly premixed combustion mode on the leeward side of the jet.

Acknowledgements

This research used resources of the Argonne Leadership Computing Facility at Argonne National Laboratory. This work was supported by the Office of Science of the U.S. Department of Energy under contract DE-AC02-06CH11357.