HiSST: International Conference on
High-Speed Vehicle Science Technology
26–29 November 2018, Moscow, Russia

The effect of combustion on the dynamic characteristics of the supersonic wake flow

Qing Li[1], *Jianhan Liang*[2]

Abstract

The strut is a frequently used flameholder in the scramjet. A recirculation area is generated in the base of the strut, providing a low-speed region with kinetically favourable conditions to anchor the flame base. The reactions of the combust mixtures continue take place in the wake area of the strut. Although the characteristics of Kármán vortex instability (wake instability) has been extensively studied using experimental and numerical methods, the effect of combustion on the dynamic characteristics of the supersonic wake flow is still unclear.

In order to explorer the mechanism behind, reacting and non-reacting flows of the laboratory scramjet at the Institute for Chemical Propulsion of the German Aerospace Center (DLR) is study with large eddy simulation approach. The configuration of DLR scramjet combustor is shown in Fig 1. The statics temperature of the Ma2 inflow is 340K, with the statics pressure being 100000Pa. One-eddy equation model is used in subgrid scale, and the turbulent/combustion interaction is considered according to LES-PaSR model proposed by Fureby in the reacting case. A skeleton reaction mechanism is employed in the reacting case.

The supersonic wake flow exhibit complex dynamics over a wide range of spatial and temporal scales, to reveal these spatiotemporal characteristics, flow structures are often decomposed into modes and analysed. Dynamic Mode Decomposition (DMD) proposed by Schmidt is employed in this study. DMD build on the theory of Krylov subspace, and employed Koopman method to extract mode from the nonlinear system and attribute a unique frequency to each mode.

1000 snapshots with time interval of 2.5×10^{-5}s are collected for the reacting case and 2000 snapshots with time interval of 5×10^{-6}s are collected for the non-reacting case. Eigenvalues λ_j of the matrix S for velocity field in the non-reacting case is showed in fig.2. Almost all of the eigenvalues are located on the unit circle$|\lambda_j| = 1$, suggesting that the flow field is fully-non-linear and quasi-neutral stable, while those eigenvalues fallen inside the unit circle represent the modes that will damp rapidly.

DMD modes of key radical fields such as OH, HO_2 for the reacting flow, along with pressure and velocity fields for both the reacting and non-reacting case are extracted. The dominant frequencies of different fields are extracted and corresponding DMD modes are compared, in order to illustrate the dynamic characteristics of the supersonic wake flow.

The iso-surfaces of X component of the velocity DMD modes for the non-reacting case and reacting case are shown in Fig 3 and fig 4, exhibiting similar patterns of antisymmetric structures in the wake area. At the same time, the iso-surfaces of Y component of the velocity DMD modes for the non-reacting case and reacting case are shown in Fig 5 and fig 6, exhibiting similar patterns of symmetric structures. Although the patterns of the DMD modes for reacting and non-reacting cases are similar, the shapes of the iso-surfaces are quite different.

According to DMD spectra of velocity field, the distribution of frequencies in the reacting is more complicated, compared with that of the non-reacting case. The dominated frequency shifted in the reacting case as a result of the combustion process in the wake area.

[1] Associate Professor, College of Aerospace Science and Engineering, National university of Defense Technology, 410073, Changsha, China, *combustion@msn.cn*

[2] Professor, College of Aerospace Science and Engineering, National university of Defense Technology, 410073, Changsha, China, *jhleon@vip.sina.com*

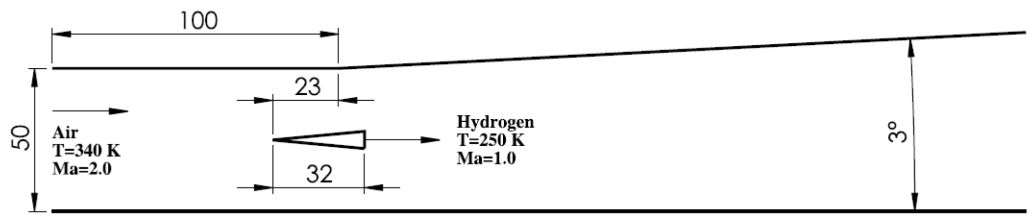

Fig 1. ***Configurations of the DLR scramjet combustor (in millimeters)***

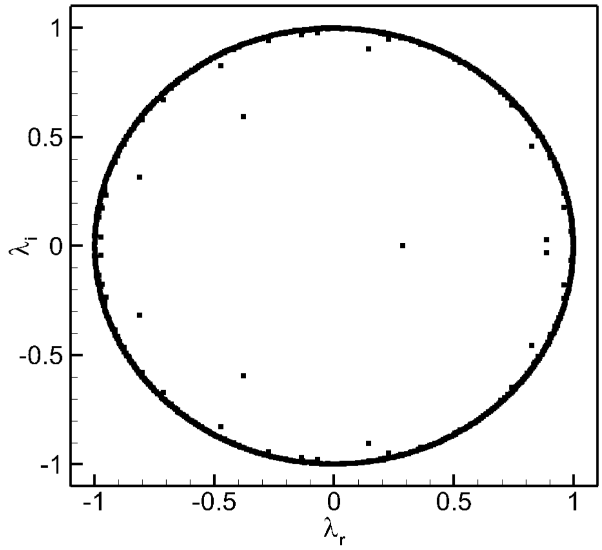

Fig 2. ***Eigenvalues*** λ_j ***of the matrix S***

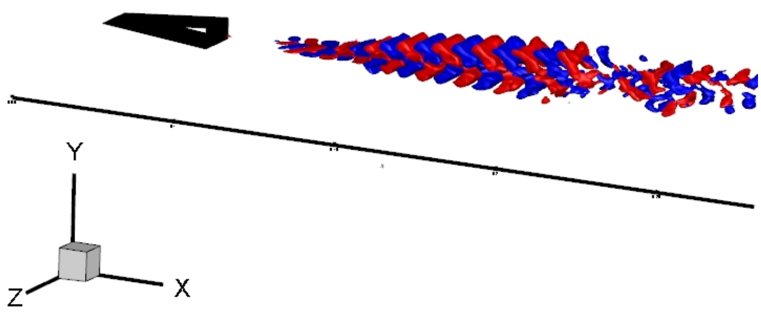

Fig 3. ***X component of the velocity DMD mode for the non-reacting case (red: positive; blue: negative)***

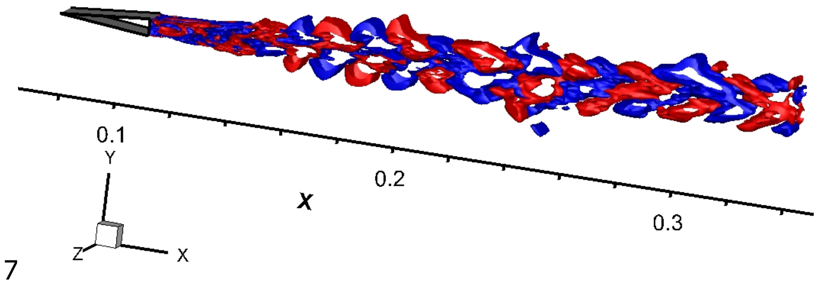

Fig 4. ***X component of the velocity DMD mode for the reacting case (red: positive; blue: negative)***

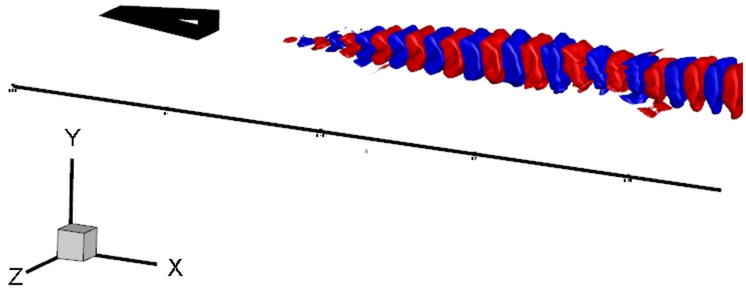

Fig 5. ***Y component of the velocity DMD mode for the non-reacting case (red: positive; blue: negative)***

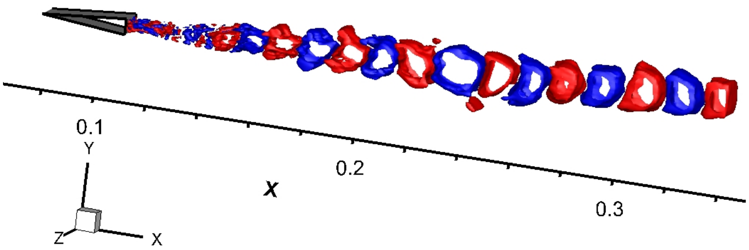

Fig 6. ***Y component of the velocity DMD mode for the non-reacting case (red: positive; blue: negative)***