THEORETICAL AND EXPERIMENTAL STUDIES OF VORTEX BREAKDOWN IN A LEAN, PREMIXED SWIRL-STABILIZED COMBUSTOR

by

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ABSTRACT

Increasingly stringent emissions regulations on fossil fuel-burning combustors in land-based and aviation gas turbine engines has led engine manufacturers to turn to lean burning premixed combustors. In modern lean premixed gas turbine combustors, flame stabilization is achieved by the use of a high level of inlet swirl and an expansion into a larger chamber. This predisposes the inlet vortex flow to transition to a vortex breakdown state, which is characterized by a stagnation and recirculation zone near the exit plane of the inlet region. A compact, turbulent and highly mixed flame results. Although this breakdown phenomenon helps reduce emissions drastically compared to rich-burn engines, it also contributes to the formation of thermo-acoustic instabilities (or combustion dynamics), flashback and lean blow out, which hinder performance and in extreme cases, causes very expensive damage to the combustion system.

Theoretical, computational and experimental studies of vortex breakdown in a finite length, axisymmetric chamber with a swirling inlet flow demonstrate that critical conditions for the first appearance of breakdown in the combustion chamber as well as in the combustor’s inlet region govern the flow’s behavior. These critical conditions are satisfied for both the average and the instantaneous behavior of the flow for ambient temperature, preheated and lean premixed reacting flows. Good agreement is found between the theoretical and numerical simulations, as well as the experimental results. Results show that these critical conditions, as well as the appearance, location, size and stability of the breakdown are affected by inlet airflow rate, inlet air temperature, flame temperature (in reacting flow), inlet tube length, dump plane configuration and chamber air leakage. In the presence of combustion, experimental results show that the existence of a breakdown zone, its shape, location and stability influence flame stabilization, combustion dynamics, flashback and lean blow out. Results confirm that the vorticity transport equation is suitable for describing the balance between the convection of vorticity and the sources of rate of change of vorticity (i.e. tilting and stretching of vorticity, compressibility effects and baroclinic effects).