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Experimental and Numerical Investigations of Flames Stabilized by Swirl Flow and Bluff-body:Flame Structures and Flame Instabilities

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Popular Science Summary

Combustion and its control play an important role in everyday life. Combustion has been the cornerstone of industrial development for nearly two centuries. The burning of fuel to produce heat and power is an integral part of industrial processes generally. Combustion of fossil fuel produces the largest share of the world's electrical power. In addition, most transportation systems rely on combustion. The drawbacks of combustion in daily life are the formations of environmental pollutions, causing fires threatening people's lives, etc. Although considerable progress has been made over the years in achieving a basic scientific understanding of combustion, these drawbacks still remain. The strong regulatory and competitive forces at work aimed at developing combustion equipment with greater flexibility, improved performance and less environmental impact, all at a reasonable cost are needed. Being able to achieve these goals is a basic objective in efforts to obtain a better understanding of combustion and its control.

In most industrial combustion systems, combustion occurs in process involving highly turbulent flow, a matter that strongly increases the complexity. In addition, the turbulent flow can result in instabilities in combustion in the form of oscillations of large-amplitude and marked changes in flame structures inside the combustor. The occurrence of such instabilities is generally problematic since it can produce oscillations in pressure and velocity of large-amplitude, which in turn can lead to oscillations in thrust, to severe vibrations that can interfere with the operation of the control-system, to enhanced heat transfer and thermal stresses to combustor walls, to oscillatory mechanical loads that result in the low- or high-cycle fatigue of system components, to flame blowoff (the flame extinction) or flashback (the flame propagating into the upstream region), and to oscillations in combustion efficiency along with high emission levels. These phenomena may result in premature component wear that can lead to costly shutdown or to failure with missions that are undertaken. Thus, flame stabilization is of fundamental importance in the design, efficient performance and reliable operation of combustion systems.

In addition, flame instability can create unstable flame structures and marked variations in the heat that released from combustion. The interaction of flame structures and flow fields determines the flame instabilities and its performance in terms of emissions as well. The geometries of the combustor/confinement and the burner as well as the operating conditions that are present (such as the flow swirl strength) affect the flow fields and the flame behaviors considerably. It is thus highly important to investigate the mechanisms involved in flame stabilization.

Flame stabilization is usually accomplished through the recirculation of combustion products with high temperature so as to continually ignite the reactants. The hot recirculating gases transfer heat to the cold reactants to ignite them and thus to maintain the spread of flame. The burnt gases transfer heat to the recirculation zone, this serving to balance the heat lost in igniting the combustible gases. Two common methods of generating recirculating flows to stabilize the flames are the use of swirl flow and of a bluff-body. Swirl flow is the flow with strong tangential component of the velocity, while a bluff-body can be defined as a solid body inside the flow field that creates a recirculation downstream of it.

In the thesis, experimental and numerical investigations of flames stabilized by swirl flow and a disk-shape bluff-body are presented. The experimental work was carried out on a model gas turbine swirl burner under atmospheric conditions and on an adjustable bluff-body burner both with and without swirl flow. Advanced laser-based non-intrusive diagnostics techniques and flame visualization methods were employed in the experimental study. In addition, numerical simulation work was carried out to complement the experimental work in efforts to better understand the flame behaviors involved.