Effect of pressure on the flame transfer function of a swirled methane-air premixed flame

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Combustion instabilities are a major issue for the development of modern low-emission gas turbines and aero-engines. The coupling between fluctuations in the heat release rate of the flame and the acoustic field of the combustor can result in self-sustained instabilities, called thermoacoustic instabilities, which have negative consequences on the combustion process and may even lead to structural failure of the entire system. The flame transfer function (FTF), which links heat release rate fluctuations to velocity perturbations upstream of the flame, is commonly used to characterize the flame response to acoustic disturbances. The FTF is the key ingredient for thermoacoustic models that allow to predict system stability. While the FTF has been extensively studied at atmospheric pressure, experimental data at elevated pressure, which is strongly relevant for gas turbine applications, which operate at 20 bar and above, is extremely scarce. As an intermediate step, the present study investigates the effect of pressure up to 5 bar on the response of a swirl-stabilized premixed methane-air flame to acoustic modulation of the incoming flow.

The experimental apparatus is composed of a radial swirl burner, with a swirl number of 0.4, a quartz tube to confine the flame, a hot wire anemometer to measure the velocity and a loudspeaker system for the acoustic forcing of the incoming flow. The burner is placed into a high-pressure duct, allowing the investigation of the response of the flame to acoustic forcing for operating pressures in the range of 1 to 5 bar. The optical diagnostics, placed outside the high pressure duct, in front of a quartz window, comprise a photomultiplier detector to collect the CH* chemiluminescence as a measure of the heat release rate and an intensified high-speed camera (15 kHz) in order to capture the flame dynamics during acoustic forcing. The equivalence ratio for all the investigated pressures is in the range 0.64 to 0.7. It has been adjusted in order to maintain a similar flame shape for all pressures. The velocity at the burner outlet is kept constant, leading to an increase of the thermal power of the flame from 4 kW at 1 bar to 20 kW at 5 bar.

The flame transfer functions obtained for a forcing amplitude of 5% at 1, 2, 3, 4 and 5 bar are compared. The effect of pressure on the gain of the FTF is significant and monotonic. Based on the dynamics of the flame front, investigated with the help of the high-speed visualization system, an explanation for this effect is proposed.