Investigation of Film Cooling Flows using Thermographic Particle Image Velocimetry at a 6 kHz Repetition Rate

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HIGHLIGHTS

• Temperature-velocity fields were simultaneously measured in film cooling flows.
• Phosphor thermometry and particle image velocimetry techniques were used at a sampling rate of 6 kHz.
• Average, RMS and time-resolved temperature-velocity fields are presented.
• The turbulent heat flux between the hot main flow and cooling air was calculated.
• The frequencies of the shear layer fluctuations were analysed.

ABSTRACT

Thermographic Particle Image Velocimetry (thermographic PIV) was used to gather simultaneous planar temperature and velocity data of film cooling flows at representative density and momentum ratios for modern gas turbine combustion chambers. The turbulent heat flux was determined, and due to the sampling rate of 6 kHz, fluctuation spectra could be calculated and analysed. The technique was applied in a closed-loop wind tunnel facility operated with angled and trenched film cooling configurations. BAM:Eu3+ thermographic phosphor particles were seeded into the flow as a tracer. A pulsed high-speed UV laser was used to excite the particles and the luminescence was detected using two high-speed cameras to determine the temperature field by a two-colour radiometric approach. The velocity field was measured using conventional high-speed PIV. The fields were sampled in a vertical plane through the centerline of the symmetrical single-row cooling holes. The flowrate and temperature of the cooling air and heated main flow were chosen to achieve density and momentum flux ratios of 1.6 and 8 respectively. For these conditions the average and RMS temperature fields show that as expected for angled holes the jet is detached from the surface. In contrast, the trenched geometry leads to a cooling film attached to the surface. However, time-resolved image sequences show instances where hot air breaks through the cooling film and almost reaches the surface. Similar image sequences for the angled holes show that the detached coolant jet becomes unstable downstream and pockets of cold air are ejected into the main flow. Average fluctuation spectra calculated from temperature and velocity fast Fourier transform (FFT) results are used to determine the frequency of the shear layer fluctuations. It was also observed that the direction of turbulent heat flux deviates from the direction of the mean temperature gradient.

Example of a single shot image of the temperature and velocity field for cylindrical film cooling holes. A full video at the 6 kHz sampling rate will be available online [P. Schreivogel et al., submitted to Int. J. Heat Mass Transf. (2016)]