PULSED JET IN CROSSFLOW - ACTIVELY CONTROLLED FILM COOLING

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ABSTRACT

This study deals with a pulsed jet in cross-flow and aims to provide a better understanding of the physics that are involved to ultimately lead toward more efficient and more versatile film cooling systems. Pulsed jets in cross-flow characteristic parameters are: jet to cross-flow mean mass flux ratio over a cycle (Mean Blowing Ratio - BR<sub>m</sub>), blowing ratio difference between high part and low part of the cycle (BR<sub>pp</sub>), forcing frequency (f<sub>f</sub>) and duty cycle (high part to cycle period time ratio - DC). The first part of this cold-flow study is conducted on a vertical jet in cross-flow over a flat plate with a unitary density ratio and at relatively low to moderate blowing ratios. A second part is conducted on an inclined jet but will not be addressed here. The principal metrics of the experiment are (i) lateral spread of the jet, (ii) sustainability and homogeneity of the coverage downstream of the injection point and (iii) mixing limitation with the mainstream. Observations of the system are conducted using Mie scattering method coupled with a Laser sheet and a digital camera for ‘sliced’ views of the flow (figure 2 and 3(a)), single component Constant Temperature Anemometry (CTA) and mass flow-meters.

The experiments are carried in an aerodynamic wind tunnel with a test section allowing visualizations from the top and the side. The vertical jet is fed by a constant pressure supply and regulated by two metering valves and a solenoid valve to allow pulsed experiments with different sets of conditions. In addition, a jet seeding system allows injection of Titanium Oxide (TiO<sub>2</sub>) particles acting as a tracer for visualization purposes. A system of acquisition/pulsation coupled with the visualization system (Laser + camera) or the hotwire system (CTA probe + traverse system) allows phase locked visualizations and precise measurements in space. The cross-flow has a constant velocity of 1.6 m.s<sup>-1</sup>. The investigated mean blowing ratios are from 0.25 to 0.45 with pulsing frequencies of 0.5, 1.0, 5.0 and 10 Hz at duty cycles of 25, 50, 70 and 100% (Steady State), but only one set will be treated here. Moreover, other settings were investigated for steady state cases with blowing ratios from 0.150 to 0.600.

Figure 1: Experimental setup

Figure 2: Side visualizations at Brm=0.600, Steady State Case

Initially intended for pure understanding of the flow, the visualizations have also been used for extraction of quantitative information like jet penetration and lift-off (side views). Likewise, a coverage estimate is obtained from the top views by normalization of the grayscale intensity of the images and evaluation of the covered area (figure 3(b)). This technique uses the TiO<sub>2</sub> particle density at a given point in space as a passive scalar and the normalized values obtained can be related to adiabatic efficiency measurements (zero heat flux at the wall corresponding to zero particle mass-flux at the wall). Even
though one component CTA probes cannot be trusted on velocity measurements of tri-dimensional flow fields, the captured dynamics of the flow are still relevant and characteristic frequencies can be obtained from such records. In order to extract these frequencies, Fourier spectrum analysis has been carried but due to the strong intermittency of the flow introduced by pulsing and/or uncertainty on the flow field itself, this method happened to be inefficient for a lot of records. The use of Wavelet Analysis allows a time dependent spectrum analysis which helps to isolate relevant frequencies and frequency shifts.

The initial part of the survey consists in the examination of steady state cases in order to provide a good understanding of the system, and to obtain a comparison basis for the pulsed cases. From the side views two principal regimes and a transitional area have been identified, the former being characterized by an attached jet subject to Kelvin-Helmholtz instability type in the upstream shear-layer region (0.150<Br<0.250), while the later is characterized by ring vortices shedding and semi to fully detached jet (0.365<BR<0.600). These results are confirmed by the coverage estimates provided by the top view (figure 3 (c)) which show a dramatic drop in coverage during the transitional region. Moreover, the analysis of the characteristic frequencies of the jet shows a change in behavior during the transitional region.

The presented pulsed case is Br<sub>m</sub>=0.250, Br<sub>pp</sub>=0.250, DC=50%, for all forcing frequencies. Flow-meter records and CTA measurements at the exit of the jet reveal the presence of acoustic frequencies proper to the system during the early moments of the high part of the cycle. Wavelet analysis is used to determine the values of the acoustic frequencies and their decaying time which is of the order of 0.3s (figure 4). It is obvious that these frequencies play a more preponderant role as the duration of the high part of the cycle is reduced (duty cycle decreases and/or forcing frequency increases). The side views reveal an amplification of the ring vortices formation and shedding at a forcing frequency of 5.0Hz, which is corroborated by the coverage coefficient trends. Finally, the overall performance in term of coverage is lower than the fixed mass flow-rate steady state case (Br=Br<sub>m</sub>=0.250), but higher than the fixed pressure steady state case (Br=Br<sub>h</sub>(DC=100%)=0.375).

Other pulsed cases have shown opposite behavior regarding to the structures of the flow and tended to inhibit them instead of exciting them<sup>[2]</sup>. Characterization of these pulsed cases needs to be completed but a lot of difficulties emerge from the predominance of the forcing frequency in both Fourier and wavelet analysis for f<sub>f</sub>=5.0 and 10 Hz. An efficient way to extract the characteristic frequencies has to be found without altering the signature. Similar experiments are currently being conducted on the inclined jet and need to be analyzed with the same tools in order to compare them to the vertical jet results.

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REFERENCES