Active Flow Control of Cantilevered Cylinders of Low Aspect Ratio

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ABSTRACT

The effectiveness of a finite span synthetic jet oriented parallel to the freestream direction, actuated on a finite span cylinder of low aspect ratio and issuing normal to the cylinder surface was investigated experimentally using stereoscopic particle image velocimetry (*SPIV*), surface pressure measurements, and hot-wire anemometry. The flow field associated with a low aspect ratio cylinder is highly three-dimensional, due to the influence of a downwash from the free end, which interacts with the wake along the entire span of the cylinder, decreasing the frequency of vortex shedding within the wake and altering the structure of the shed vortex entirely. Furthermore, the downwash adds momentum to the near wake, decreasing the pressure drag

Surface pressure measurements were used to investigate the alterations to the cylinder pressure distribution in both spanwise and azimuthal directions. The presence of the downwash negatively impacts the ability of the synthetic jets to achieve global changes to the pressure distribution about the cylinder; however it was shown that the synthetic jets are capable of enacting asymmetric changes to the azimuthal surface pressure distribution. Furthermore, the synthetic jets achieve a spanwise effect much greater than the physical dimensions of the jet orifice, and this effect was measureable even when a single synthetic jet actuator was used.

The results of the surface pressure measurements prompted further investigation using *SPIV* to measure the global and local changes to the cylinder flow field induced by a single synthetic jet. The synthetic jet was able to vector and narrow the wake, increasing turbulent kinetic energy and mixing with the downwash closer to the rear of the cylinder. Furthermore, the largest effect of the synthetic jet was at spanwise

locations outboard of the jet orifice. This resulted in a measureable change to the streamwise vorticity field, specifically in a vortex dislocation, and a change in the near wake power spectra. The synthetic jet creates a pair of counter-rotating streamwise vortices about the jet orifice that interact with the near-wall upwash, reattaching the boundary layer outboard of the jet orifice, while redirecting flow inboard. As a result, a three-dimensional separation line was created, translating to the spanwise effect mentioned previously within the near wake.

Further investigation was conducted using hydrodynamic stability theory in order to estimate the stability characteristics within the near wake. By using a simplified linear theory, assuming a quasi-two-dimensional flow at each spanwise location, it was possible to estimate the shedding frequency from the cylinder, with and without synthetic jet actuation, and compare these results to power spectra measurements attained using hot-wire anemometry, which showed good agreement. These results, obtained using a cusp method, were classified as either absolute or convectively unstable. Taking the vortex formation length to be a region of absolute instability downstream of the cylinder, stability analysis showed that synthetic jet forcing decreases this vortex formation *region*, indicating that synthetic jet forcing results in an altered flow field. In addition, the shape of the eigenfunctions corresponding to the most amplified spatial instability was compared to the turbulence normal stresses measured within the wake using *SPIV*. For the unforced case, the turbulence intensity showed good agreement with the eigenfunctions estimated using this method; however the level of agreement decreased for the forced wake, which may be due to the influence of other instability frequencies.