Low frequency dynamics of the bi-stable wake from a three-dimensional hill

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Several geometries under nominally symmetric flow conditions have been found to produce a quasi-stable wake that alternates between two mirror symmetric states. One geometry with this bi-stable wake behaviour is the three-dimensional hill known in the literature as the BeVERLI hill. This geometry is based on a fifth-degree polynomial that is traced around a modified super-elliptic profile to give an overall shape with four-fold rotational symmetry. The objective of this presentation is to explore the low frequency dynamics of the bi-stable wake of the BeVERLI hill.

Experiments were conducted using the recirculating wind tunnel at the University of Toronto Institute for Aerospace Studies (UTIAS). A scaled version of the BeVERLI hill with height $h = 0.12$ m was positioned 2.82 m from the leading edge of a boundary layer plate setup that spans the length and width of the test section. The hill height based Reynolds numbers that were tested ranged from $\mathrm{Re}_h = 38,000 - 250,000$ with corresponding hill height to boundary layer ratios, h/δ, (measured $5.5h$ upstream of the hill centre) of 2.84 to 3.86, respectively. Measurements collected to characterize the low frequency dynamics of the wake included: low frequency unsteady surface-pressure, particle image velocimetry (PIV) and hot-wire anemometry (HWA).

Low frequency unsteady surface-pressure measurements were collected continuously over periods spanning $\mathcal{O}(10^5)$ times the convective timescale. These measurements were repeated over a range of yaw angles, which revealed the bi-stability to be present over an approximately 4.5° range. Furthermore, the 50-50 split between bi-stable states was found to occur at a yaw angle of about 1°, instead of the expected nominally symmetric orientation of 0°. This deviation highlights the sensitivity of the bi-stability to its boundary conditions. The average time that the flow remained in one of the bi-stable states before switching to the other was found to vary with yaw angle ranging between $\mathcal{O}(10^2 - 10^4)$ times the convective timescale. At a given yaw angle, these times follow a non-monotonic trend with Re_h. The switching between states was found to be random and behave as a stationary Markov chain similar to other bodies that display the bi-stable behaviour. Proper orthogonal decomposition was applied to the unsteady surface-pressure measurements, of which the first and second modes captured the bi-stability and a breathing of the recirculation region, respectively. The hill height based Strouhal number of the breathing mode was found to be $\mathrm{St}_h = 0.065$. PIV measurements along the centerline of the leeward face of the hill were used to track the movement of the separated shear layer. HWA and unsteady surface-pressure measurements were used to relate the shear layer movement with the recirculation region breathing mode. HWA measurements of the separated shear layer also identified the development of a shear layer instability centred around $\mathrm{St}_h = 0.65$.

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