Structure of the wake for a three-dimensional hill geometry

Daniel MacGregor[1] & Philippe Lavoie[1]
1 Institute for Aerospace Studies, University of Toronto, Toronto, Ontario, Canada

There are several instances in literature where geometries under nominally symmetric flow conditions display asymmetric flow features; however, investigations into this unexpected phenomena remain limited. An example of this behaviour is seen with the three-dimensional hill geometry, know as the BeVERLI hill, which produces a bi-stable wake under nominally symmetric inflow conditions. This hill is based on a fifth-degree polynomial and a modified super-elliptic curve, as seen in Figure 1. Experiments were conducted using the recirculating wind tunnel at the University of Toronto Institute for Aerospace Studies using a copy of the hill with a height of $h = 0.12$ m set at a yaw angle of 0°. The hill was positioned 2.82 m downstream from the leading edge of a boundary layer plate setup that spans the length and width of the tunnel test section. The origin of the global coordinate system is positioned at the hill centre with the x-axis oriented in the direction of the freestream velocity and the y-axis orthogonal to the boundary plate surface. For these experiments, the hill height based Reynolds numbers ranged from 38,000 to 250,000. Flow field measurements at various orientations and positions within the wake were collected using stereoscopic particle image velocimetry (PIV) synchronized with surface-pressure measurements. The surface-pressure measurements were used to track the bi-stable mode of the wake to facilitate conditional averaging of the collected snapshots. Cross flow planes at $x/h = 2.6, 3.2, 4,$ and 10 downstream of the hill are used with previously collected PIV results in the x-y and x-z planes to advance the description of the bi-stable wake structure. Since the two bi-stable modes are mirror symmetric about the centerline, only the mode where the centroid of the recirculation region is positioned on the $+z$ side of the hill is discussed. The wake consists of a recirculating region and a single $-x$ oriented streamwise vortex that forms downstream of the recirculating region. Within the recirculating region, there is an asymmetric arch vortex with one foci point near the base of the hill on the $+z$ side and another near the hill apex on the $-z$ side of the hill. The crossflow measurements just downstream of the recirculation region at $x/h = 3.2$ and 4 show the formation of the single streamwise vortex at $z/h = 0.5$ via the merging of the flows around the hill. The spanwsie flow produced by the hill and the formation of the streamwise vortex induces a pair of smaller vortices located at $\pm z/h \approx 1.5$. As this vortex grows, it drifts farther in the $+z$ direction away from the centerline due to the stronger spanwise flow from the $-z$ side of the hill. These findings provide an improved characterization of the bi-stable wake for the BeVERLI hill.

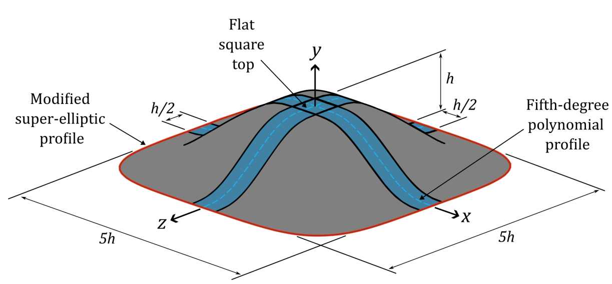

Figure 1: BeVERLI Hill

Email address for correspondence: *daniel.macgregor@mail.utoronto.ca*