Unsteady Surface Pressure Measurements on a Confined Gaussian Bump Flow

Adam Steacy[1], Owen Williams[2] & Chris Morton[1]
1 Department of Mechanical Engineering, McMaster University, Hamilton, Ontario, CANADA
2 Department of Aeronautics and Astronautics, University of Washington, Seattle, Washington, USA

The separated flow over a Gaussian speed bump is investigated experimentally in the University of Washington 3×3 Low-Speed Wind Tunnel to examine the influence of confinement on its unsteady dynamics. Four confinement levels are considered, from 13% up to 26% blockage based on the bump height ($h = 76.6$ mm), at a freestream velocity of $U_\infty = 45$ m/s ($Re_h \approx 2.26 \times 10^5$). Time-resolved surface pressure measurements from an array of 32 taps are used to characterize the flow. Across all confinement levels, the flow exhibits a consistent set of dominant low frequencies linked to large-scale spanwise motion of the separated region (1 Hz), shear layer flapping/breathing (13.5 Hz), and surface vorticity downstream of separation (22 Hz). The behaviour of the low-frequency component at $St_h \approx 10^{-3}$ (1 Hz) changes significantly with confinement. As confinement increases, a transition to bimodal behaviour is observed, indicating the emergence of bistable switching between two antisymmetric states. Proper Orthogonal Decomposition (POD) identifies the leading mode as the primary indicator of the bistable dynamics, with the mode capturing strong spanwise asymmetry and containing 50% to 60% of the total energy. Figure 1(a) shows the state-segmented distributions of the first POD mode temporal coefficient for the highest confinement case. Statistical analysis of the switching reveals long dwell times ($St_h \approx 10^{-3}$) and log-normal dwell time distributions shown in Figure 1(b) and (c). These switching characteristics are consistent with stochastic transitions between metastable states and closely match findings from other canonical bistable flows.

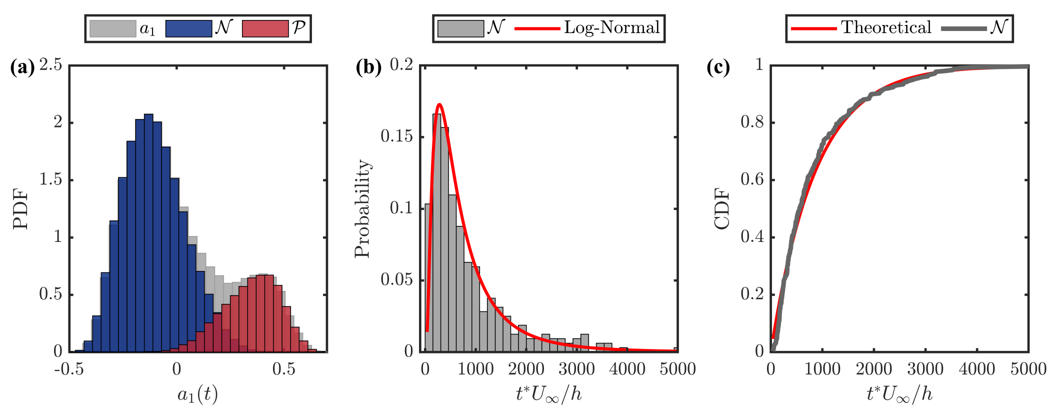

Figure 1: (a) Probability density functions (PDFs) of the first POD mode temporal coefficient, $a_1(t)$, along with the conditionally binned positive ($\mathcal{P}$) and negative ($\mathcal{N}$) states. (b) Probability of dwell times for the segmented ($\mathcal{N}$) state signal, plotted in convective time t^*U_∞/h, with a log-normal fit using the distribution mean and variance. (c) Cumulative distribution function (CDF) of the dwell times compared to a theoretical exponential distribution using the governing parameter of $1/t^*$.

Email address for correspondence: *steacyr@mcmaster.ca*