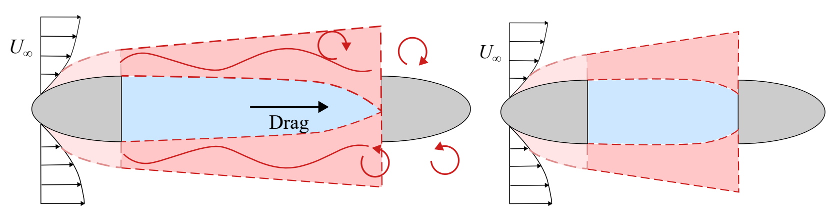
Flow instabilities for an edgewise flow over hollow cylindrical cavities

Yilan Lu[1] & Jovan Nedić[1]
1 Department of Mechanical Engineering, McGill University, Montreal, Quebec, CANADA

Shrouded rotors in rotorcraft and vertical take-off and landing (VTOL) vehicles experience complex unsteady inflow when edgewise freestream flow dominates axial rotor ingestion, as in forward flight and cruise. To isolate the shroud's aerodynamic influence independent of the rotor, it is modeled as a hollow cylindrical cavity open at both ends and subjected to edgewise inflow. Wind tunnel experiments were conducted on cavities with depth-to-diameter ratios $0.1 \leq h/d \leq 0.6$, representative of rotor shrouds in practical applications. Flow dynamics induced by cavity geometry and inflow conditions were characterized using spectral analysis of wall pressure within the cavity and freestream velocity near the cavity opening. For $0.1 \leq h/d \leq 0.3$, the cavity flow develops a spontaneous vortex-shedding instability that is strongly coherent and anti-phase between two cavity openings. These shallow cavities exhibit streamwise pressure asymmetry and elevated cavity drag. For deeper cavities ($0.4 \leq h/d \leq 0.6$), the coherent oscillation peak disappears within the cavity, and pressure drag is significantly reduced. The hollow cylindrical cavity flow response under edgewise inflow is governed primarily by cavity geometry. Typical rotor shrouds, modeled by low h/d cavities, are susceptible to alternating vortex-shedding flow dynamics. Shroud designs with $h/d \approx 0.4$ appear to be favorable for mitigating non-uniform inflow and rotor vortex ingestion in edgewise flight.



(a) $0.1 \geq h/d \geq 0.3$ (b) $0.4 \geq h/d \geq 0.6$

Figure 1: Proposed overview schematic of hollow cylindrical cavity flow mechanisms based on depth-to-diameter ratio.

Email address for correspondence: *yilan.lu@mail.mcgill.ca*