Convective Exchange During Respiratory-type Flows

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Abstract

Respiratory-type flows occur across a wide range of scales in environmental systems, from bay-ocean tidal exchange processes to jellyfish propulsion. During respiratory-type flows, a fixed volume of fluid is cyclically drawn inward and expelled outward through the same opening. From a biological perspective, these flows typically occur in the process of respiration, ingestion, and olfaction such that it is advantageous to minimize the reingestion of exhaled fluid during the subsequent inhale. Motivated by this biological perspective, we investigate these processes using a fundamental fluid mechanics approach. Flow visualization illustrates that, rather than the superposition of a purely inhalant flow with a purely exhalant flow, complex non-linear fluid interactions occur resulting in dynamic spatiotemporal flow patterns unique to this class of flows. Utilizing a numerical model with experimental validation, we further investigate the effects of varying of key flow parameters including the Reynolds number (Re), Strouhal number (Sr), and the ratio of the inhalation time to the exhalation time (I:E ratio). Increasing Re causes a dramatic increase in the degree of asymmetry in the inhalation flow structures compared to the exhalation flow structures. Time-resolved flow-fields from the numerical model allow us to map the spatial extents of the fluid volume inhaled and exhaled during a single cycle. We call volume of the overlapping region between the inhale and exhale relative to the tidal volume the exchange ratio: r_E. Our results to date show that r_E is sensitive to changes in both Re and Sr. Because organisms have the potential to modify or manipulate these parameters, this study indicates that they could be used to optimize the intake of nutrients or information. Future work will build upon this foundational study with more complicated and realistic morphologies relevant to respiration.