13th Australasian Natural Convection Workshop (13ANCW)
Canberra, Australia, 1st and 2nd December 2025

Buoyancy in the dispersion of aerosols exhaled during violent expiratory events

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1. INTRODUCTION

Inhalation of aerosols released by infected individuals while talking, laughing, singing, breathing heavily, coughing, or sneezing is recognized as one of the main transmission pathways of COVID-19, as well as other infectious diseases caused by viruses and bacteria, such as human influenza (H1N1), avian influenza (H5N1), SARS, and tuberculosis. Therefore, studying how aerosols are generated, emitted, and dispersed is essential both for understanding the spread of these and future pathogens, and for developing effective, evidence-based strategies for protection, containment, and social distancing. Special attention is paid to dispersion in indoor environments, where the exposure to the inhalation of aerosols and, thus, the risk of infection, is higher than in outdoor situations.

Buoyancy effects occur in the short-term, short-range dispersion, within 1–2 seconds after the relatively warm and humid unsteady turbulent jet of exhaled air is released into a typically cooler and drier environment. Beyond this brief period, ambient air currents, often driven by the combined influence of buoyancy and mechanical ventilation, take over, controlling the long-term, long-range transport of micron-sized aerosols that remain afloat.

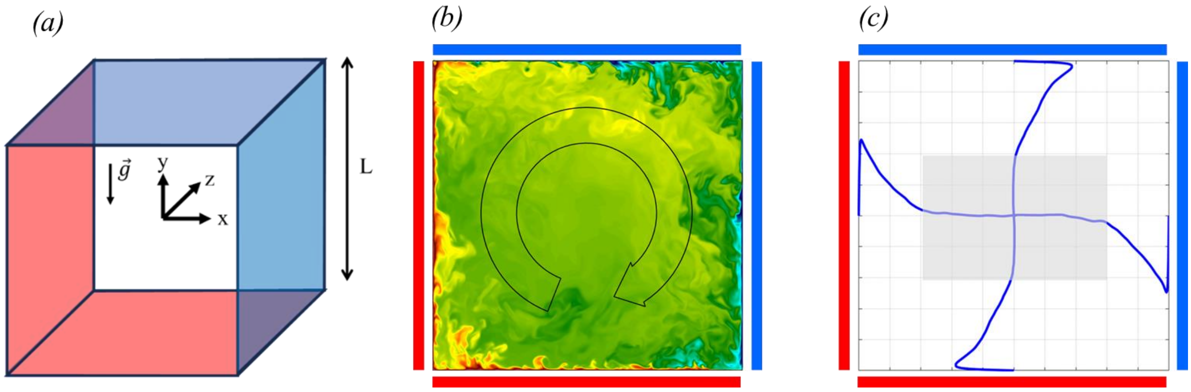

Figure 1. (a) Physical model. (b). Instantaneous temperature contours in the vertical symmetry plane (*z=0*). (c) Time averaged velocity along the vertical and horizontal wall bisectors of the symmetry midplane.

2. APPROACHES

In this paper we summarize our efforts to investigate and clarify the relevant aspects of the aerosol dispersion processes generated in violent expiratory events. On one hand, we focused the attention on the determination of the performance of the currently affordable available numerical models to simulate both the short-term [1] and the long-term dispersion [2]. We organized and conducted two international workshops, in which CFD groups from around the world simulated flow and particle dispersion under identical physical and boundary conditions, using their preferred combinations of numerical and turbulence models, for which DNS databases had been generated. For the simulations of the long-term dispersion, we considered the turbulent natural convection flow ($Ra=3.9\times10^9$, $Pr=0.7$) in a room-sized cubical cavity ($L=3.14\ m$) with two pairs of differentially heated opposed walls kept at constant and uniform temperature ($\Delta T=1.3\ ºC$) (see Fig. 1) [3]. Clouds of particles were released in different locations of the flow, and the dispersion process was monitored by tracking individual particles under the one-way coupling hypothesis.

Studies with human volunteers show wide variability in the intensity and duration of violent expiratory events, and experimental research on how specific parameters influence the short-term turbulent dispersion of aerosols remains highly challenging. To alleviate this, we designed and constructed an experimental setup to generate reproducible flow ejections through a 3D printed model of the upper airways [4]. Measurements and visualizations of the aerosol cloud dynamics show that the density differences between the exhaled flow and the ambient air play a role in the flow entrainment and the turbulent dispersion process. As an example of the results, Figure 2 shows snapshots of the particle clouds generated and released in hot exhalations (*T=37 ºC*) for different colder ambient temperatures. The jet is deflected downwards because of the bend generated by the connection between the pharynx and the oral cavity. The comparison of the upper panels of Figure 1, corresponding to a cold ambient air of (T_a*=27 ºC*), with the lower panels (T_a*=7 ºC*) reveals that buoyancy displaces the centroid of the cloud upwards and inhibits the entrainment of the quiescent external air into the jet.

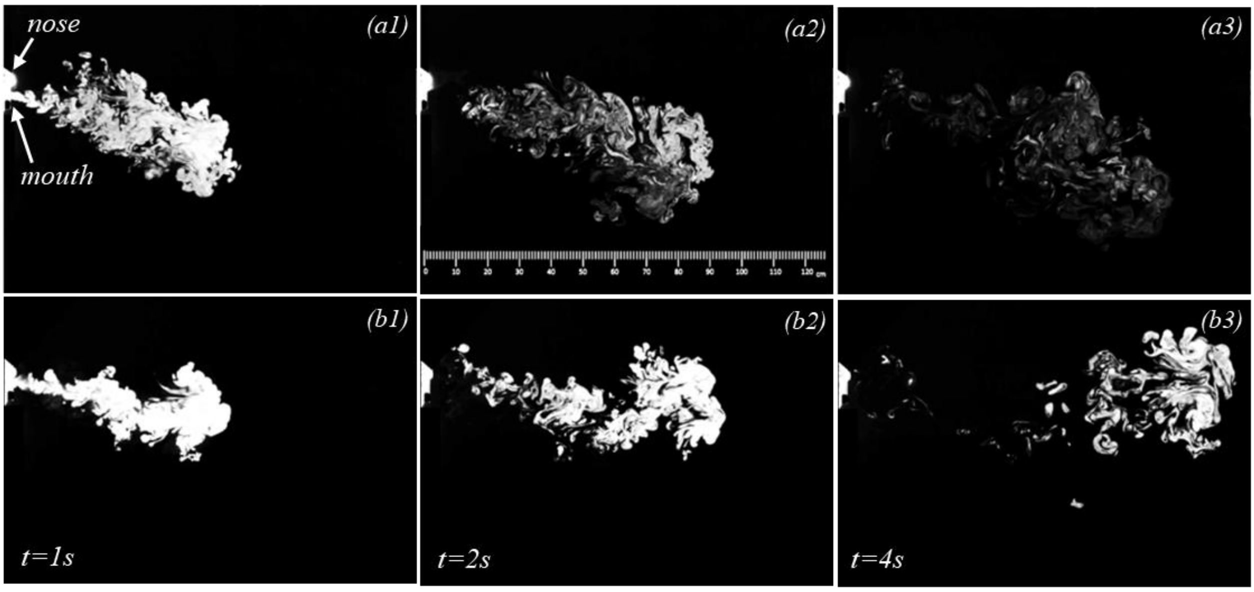

Figure 2. Lateral visualizations of the aerosol cloud at different times. Panels (a1) to (a3) correspond to an ambient temperature of 27ºC and panels (b1) to (b3), to 7ºC.

REFERENCES

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