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Simulation of Physical Intervention of Face Shields Against Short-Term Sporadic Emissions at Different Angles of Attack

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ABSTRACT

The Covid-19 pandemic has brought questions about the transmission routes for this pandemic disease. Being known as a respiratory disease, the transmission is mainly introduced by sporadic emissions such as coughs and sneezes. However, the uncertainties on the transmission pathways throughout the timeline of the study of this disease led to uncertainties in the physical interventions that should be put into place. Among the interventions mandated in the Philippines, for example, was wearing face shields even in public places—the past evaluation of the physical intervention of the front, which typically happened in hospital settings. However, the Philippine mandate on face shields has widened the range of scenarios, especially now with the different angles of attack from which the emissions can be coming. Another questionable criterion is the nature of which droplets and aerosols behave in the perspective of fluid dynamics. The sporadic emissions coming from different angles of attack are simulated in an unsteady CFD analysis. The turbulent nature of these sporadic emissions is modeled using Large Eddy Simulation. Results showed that even for frontal emissions, the smaller and suspended droplets could recirculate around the face shield posing a risk of being inhaled by the wearer. At other angles of attack, the face shields redirect the jet to the face, exposing the wearer even to the huge droplets.

Keywords: Covid-19; Face Shields; Computational Fluid Dynamics

Introduction

Amidst the Covid-19 pandemic, the Philippines has distinguished itself from other countries by being the only country that mandated the use of face shields even outside of hospital settings. The surge of cases, which saw the Philippines having more than 20,000 new cases daily over the closing days of August 2021 and the first half of September 2021, made people question whether face shields were attributed to the said surge. Despite the questions on face shields and the clamor for the removal of the mandate, the Department of Health (DOH), seconded by the World Health Organization Philippines, announced that it was early to provide definitive justification for lifting the mandate on face shields yet. The DOH insisted that face shields offer a level of protection, citing a recent experimental study on which the percentage of the sprayed droplets coming from a source that reached the droplet counter on the receiver indicates a massive reduction of transmission of said droplets [1]. However, a recent study on the visualization of respiratory droplets determined that although the huge droplets were stopped by the face shield worn by the source, the small droplets lingered longer in the air.

The redirection of the emissions towards the side subjected a more extensive area against these smaller droplets, rendering face shields ineffective as source control [2,3]. And a cough simulation in the study by the National Institute for Occupational Safety and Hazards (NIOSH) in 2014 found that even if the face shield stops the initial impact, after some time, the diffused and still-airborne smaller droplets will make it around the face shields and into the wearer's face, increasing the chance of inhalation [4]. A numerical simulation also concluded that airborne droplets would still make it to the face of the wearer due to turbulent effects, which generated eddies [5]. A recent study also described the nature of exposure against short-range emissions using numerical simulations, revealing two flaws in understanding: first is with the evaporation time of the droplets and the criterion to distinguish droplets from aerosols. Rather than being a simple projectile, the droplets are more influenced by the flow conditions, as the analysis of droplets is more of a fluid dynamics problem than a ballistics one [6]. Apart from the recommendations to change the perception of droplets and aerosols and the guidelines addressed by the previous studies, the scenarios studied are only limited to a single angle of attack: the emission coming from the front. With the critical step forward being the study of fluid dynamics in determining the pathways of the pathogens, this study investigates the other scenarios that the wearer of face shields would be subjected to.

Methods

In this study, the physical intervention of the face shield over different scenarios is simulated using Computational Fluid Dynamics (CFD) [7]. Representing the test subject was a model of a human head, shown in Figure 1. The face shield is defined by a curved surface 20 centimeters high and 15 centimeters wide, which is the cheap face shield used in public settings. The curved surface of the face shield is spaced 4 centimeters from the face, also shown in Figure 1. To simulate the sporadic emission, a source box, 4 centimeters long, 4 centimeters wide, and 2 centimeters high, was introduced into the test setup, placing it 1 meter away from the dummy head. The speed of emissions (cough) is set to be 22 m/s [8]. The emissions are simulated to be coming from different angles of attack: 0 degrees (the emission is coming from the front), 45 degrees (the emission is coming from an oblique angle at the front), 90 degrees (the emission is coming from the side), 135 degrees (the emission is coming from an oblique angle at the back), and 180 degrees (the emission is coming from behind).

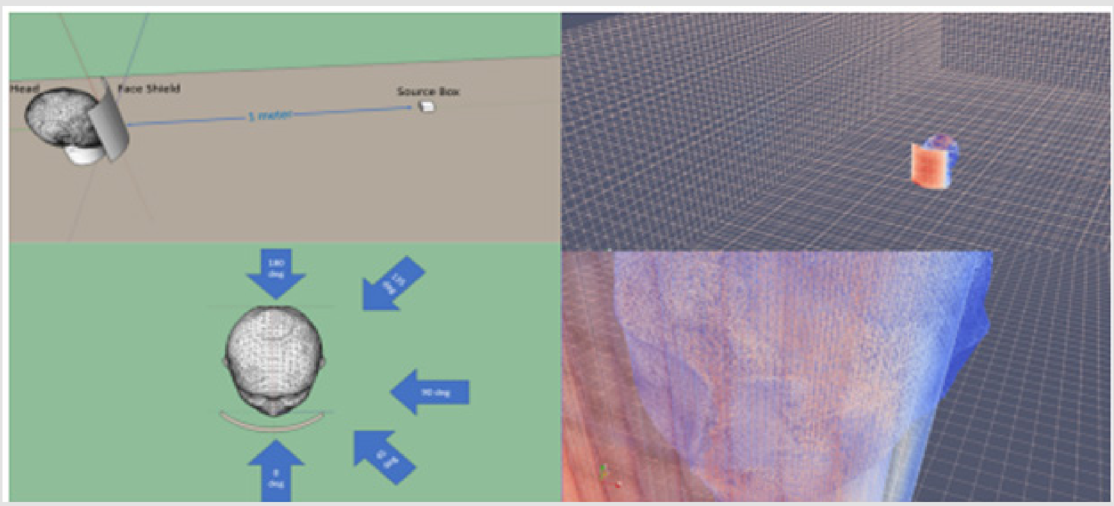

Figure 1: Simulation Setup, Discretization (Meshing), and Angles of Attack.

The numerical analysis in Computational Fluid Dynamics involves subdividing the computational domain into finite volumes. Smaller finite volumes are assigned to capture the erratic changes in the pressure and the velocity of the emission across the face shield and the face, shown in Figure 1, with smaller cells having a characteristic length of 1 mm, each surface is enveloped by four 1-mm thick layers, three 1-cm thick layers, and two 10-cm thick layer to resolve the shear stresses present at the surfaces fully.

To model the turbulence, the chaotic pattern changes were treated as the superposition of unsteady vortices or eddies of different sizes and periods [9,10]. The turbulence modeling, known as Large Eddy Simulation, starts with a low-pass filter to separate the large eddies from the larger eddies and then resolves the large eddies using direct numerical simulation while modeling the smaller eddies using a sub-grid scale model [11-13]. To determine the onset of the viscous effects of the surface, the sub-grid scale component was modeled to be transported across the domain [14]. To simulate the smaller periods of the smaller eddies, the time-step of the simulation was set to be equal to 0.00001 seconds. The time frame set for the simulation is 1 second. To ensure the stability of the solution, the simulation would terminate or adjust the time step accordingly to meet the criteria of keeping the Courant number to be less than one throughout the simulation [15]. This also ensures that the eddies were resolved and modeled accurately.

Discussion

The velocity field across different simulation setups is compared to determine the behavior of the sporadic emissions and the intervention/non-intervention brought by face shields displayed in Figure 2. As the previous studies suggest in the performance of face shields against frontal emissions, the risk of the initial impact was mitigated by the interference brought by the face shield. Although, some emissions lingered longer and eventually recirculated back to the inside of the face shield, with a reverse flow at one m/s being observed visualized as a light blue patch inside the face shield in Figure 2. In cases of the oblique orientation of the wearer with respect to the frontal emission would result in a portion of the emission jet being redirected to the face. The constriction brought by the face shield does not allow the flow energy of the emission to diffuse and instead induces recirculation. Since the face shield is worn at the front, the uncovered flanks render the intervention of the face shield trivial against emissions coming from the side. The simulation of the emissions from the rear reveals the scenario where the wearer of the face shield becomes the most vulnerable. The physical intervention of the face shields not only redirected most of the emission jet toward the wearer's face but also allowed the jet itself to recirculate over the wearer's face. Whether the emission was entirely from the rear or an oblique angle, both can happen in public places when people are falling in line or packed together, and the exposure to the emissions increases rather than decrease.

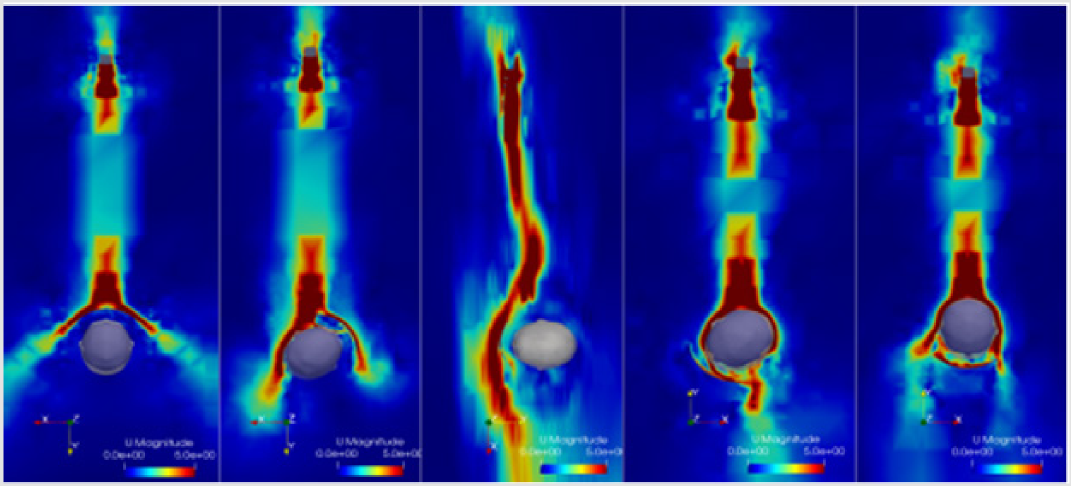

Figure 2:

Conclusion and Recommendations

Being previously used in hospital settings against frontal emissions, an impression that face shields offer a layer of protection across all scenarios resulted in the mandate of the Philippine policymakers to wear face shields even outside of hospital settings. The implementation of the mandate has opened a variety of scenarios to which the wearer of face shields is subjected. The study simulated the flow of emission jet using fluid dynamics and found that face shields don't offer protection for the other scenarios and can even increase the risk of infection of the wearer against the flow of the emission, which can carry heavy droplets. However, studies suggest that airborne transmission now attributes to most respiratory disease transmission since aerosols and airborne particles are easier to breathe in than droplets [16]. To mitigate airborne transmission [17], further understanding of the intervention of physical measures, including face shields, must be evaluated from the perspective of fluid dynamics rather than in an observational manner.

Materials and Methods

The software used to implement the numerical analysis was OpenFOAM. The post-processing was done in ParaView. The maximum value displayed was 5 m/s in order to visualize the dispersion of the emission in the velocity field.

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