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The Probability of Infection, through Aerosol Transmission, by SARS-CoV-2 Coronavirus

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Abstract: The spread of the exhaled cloud of aerosols carrying the SARS-CoV-2 Coronavirus is computed using the Lagrangian theory of passive scalars.

Keywords: Lagrangian turbulence, passive scalars, SARS-CoV-2 Coronavirus, aerosols.

1. Introduction

It is now generally accepted that infections by the SARS-CoV-2 Coronavirus beyond the social distance of 2 meters or 6 feet, are primarily caused by aerosol transmission. It has also been shown that the virus can live for several hours and the flow of air plays a larger role in transmitting the virus than social distancing of 2 meters.

The details of how the virus-laden aerosols are carried around by airflow are complicated. This is because the airflow is very turbulent and thus hard to simulate. This makes the application of computational fluid dynamics (CFD) hard, since in order to compute the concentration of the aerosols, one must perform many simulations and take their average, a labour intensive and time-consuming process.

There is another mathematical theory, which can be applied more easily to compute the distribution of the virus-laden aerosols in turbulent airflow. This is the so-called Lagrangian theory of passive scalars [1],[2].

This theory explains how particles that are too small and light to disturb the flow are distributed in the fluid. It was developed by theoretical physicists 50 year ago and has been used successfully to compute the distributions of many different types of particles that are carried around by the air-flow, without disturbing the airflow itself [3].

2. Results and Discussion

We employ the theory of passive scalars in Lagrangian flow to compute the infection rate for infectious diseases. The theory of passive scalars allows one to do two things. First, given how many aerosols a person is emitting during a time period, we can compute the aerosol concentration in the cloud of air that is emanating from them. This is the air mixed with their exhaled air, by the ambient airflow. The concentration will vary depending on whether the person is at rest, doing heavy exercise or singing. Secondly, if the ventilation is deficient in the space where the person is located, we can compute what part of that space gets contaminated, and the concentration of the aerosol in that part of the space. This frequently depends on the airflow, and in many spaces the air in not well-mixed in the whole space.

If the ventilation is better, however, the air in the whole space is well mixed and then it is easier to compute the concentration of aerosols. We provide and explain a program that does this. This program has been used configure safe work-spaces at the University of California, Santa Barbara. We will explain how that is done using two study rooms for the students in the UC Santa Barbara Library as an example. The program computes how many students can safely work in these spaces, given their volume and ventilation, and how long a time they can safely spend in them.

We give an example [4] below, by using the program to plot the number of people that can safely be inside a restaurant versus the ventilation in the restaurant, measured in air exchanges per hour (ACH), in the restaurant. ACH measures how often the air in the restaurant is completely replaced by fresh or filtered air in one hour. We need to know the size (volume) of the restaurant and the how large a percentage of the population has been vaccinated. Let us assume that the restaurant has the volume 125 cubic meters (or roughly 4,400 cubic feet). This is restaurant, with the height of the ceiling 2.5 meters, could contain 50 guests under normal conditions.

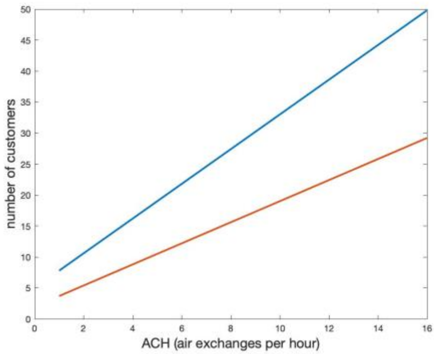

Fig. 1. The figure shows the number of customers that can safely be in a restaurant, that can have 50 customers under normal conditions. The number of customers is on the vertical axis and the ventilation, measured in ACH, on the horizontal axis. The blue line shows the number of customers when 70% of the population has been vaccinated, the red line when 50% of the population has been vaccinated. Safe means that the probability of infecting 2 customers in two hours is 10% or less. The probability of one person being infected is high, if that person is sitting next to or directly across the infected person in the exhaled aerosol cloud. But the probability that two or more people are infected can be effectively controlled by the ventilation.

3. Concluding Remarks

The spread of the aerosols carrying the SARS-CoV-2 Coronavirus can be effectively controlled by ventilation. The probability of infection is minimized, using the Lagrangian theory of passive scalars.

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