The Influence of Cough Airflows on Aerosol Transmission

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BACKGROUND

- The COVID-19 virus has caused a global pandemic that resulted in significant shutdowns, restrictions, and economic instability across the globe.
- As of February 13th, 2022, there have been 77 million cases and 915,425 deaths in the US; only 64.4% of the population has been fully vaccinated [1].
- The COVID-19 virus has three main transmission modes; the most significant is the inhalation of very fine aerosol particles and respiratory droplets [2].
- A chemical engineering senior project group in 2021 used MATLAB to simulate simple aerosol transmission under the direction of Dr. Mingheng Li.
  - Results showed that the size of the aerosol particle had a significant impact on its velocity and displacement once released into the air [3].
- Research at the Shenzhen Institute of Research and Innovation showed that cough airflows enhanced the spread of larger aerosol particles [4].
- Research at University of Colorado found that the speed of respiratory droplets in a cough reached peak velocity before rapidly decreasing to match the velocity of the environmental air flow field [5].
- This Capstone Project decided to improve upon previous undergraduate research by incorporating equations defining air velocity fields influenced by coughs into MATLAB to get a better understanding of aerosol transmission.
  - This is critical, as stopping the transmission of viral aerosol particles is necessary to stop the spread of COVID-19 and protect our communities.

OBJECTIVE

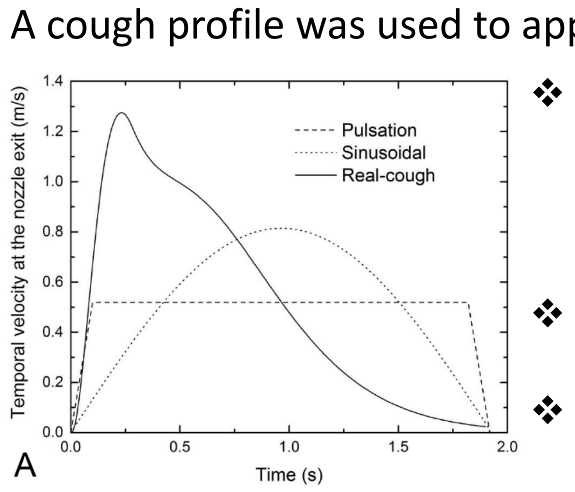
To utilize MATLAB, a technical computing software program, to program a series of differential equations based on Navier-Stokes's equations to simulate air flow fields generated by coughs and how it affects the velocity and displacement of three differently sized aerosol particles as they travel through the medium.

THEORY & CODE SET-UP

- Navier-Stokes equation, total drag force, drag coefficient, Reynolds Number, Knudsen's Number, slip coefficient, and relaxation time were used as a basis for the MATLAB simulation, and resulted in these six equations:

1. $a_x = \frac{v_{air}-v_x}{\tau}$
2. $a_y = \frac{v_{air}-v_y}{\tau} + g\left(1-\frac{\rho_{air}}{\rho_{particle}}\right)$
3. $\frac{dv_x}{dt} = a_x$
4. $\frac{dv_y}{dt} = a_y$
5. $\frac{dx_x}{dt} = v_x$
6. $\frac{dx_y}{dt} = v_y$

- A cough profile was used to approximate equations capable of tracking it [4]:



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- From this profile, it was assumed that the air velocity profile had a triangular profile. Thus,
  - $v_{air} = \frac{v_{max}t}{\frac{t_{dur}}{2}} + 1e^{-8}$
  - $v_{air} = \frac{v_{max}(t-2)}{\left(\frac{t_{dur}}{2}\right)}$
- The cough is assumed to reach a maximum velocity of 10 m/s at 0.25 seconds, and last for 0.5 seconds.
- The distance travelled by the cough and aerosol was tracked using this equation [4]:
  - $x = DC_{x1}\left(\frac{U_c t}{D}\right)^{1/2}$

- The MATLAB code was developed into a series of files. Function files for the slip correction factor, drag coefficient, x-direction displacement, air/cough velocity profile, and aerosol velocity profile were developed and housed separately. A final script file was used to execute all the function files, store results, and graph the velocity and displacement of the particles in the x- and y-directions, respectively.

RESULTS & DISCUSSION

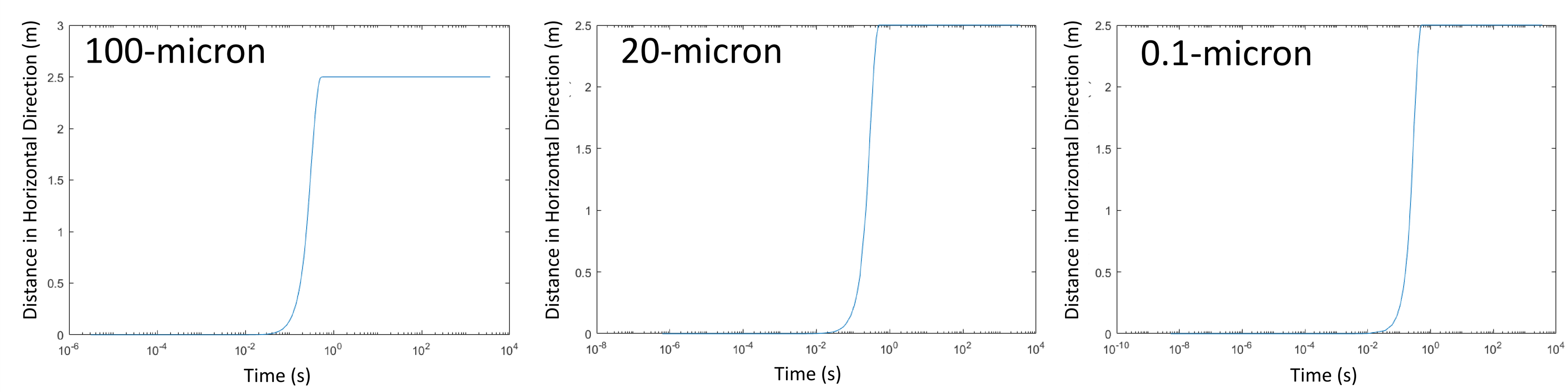

Figure 1: Horizontal Distance Traveled Over Time

- The particle's size influences how far the particle travels and how long it takes to reach the maximum horizontal distance.
- Since all particles were relatively small, they travelled more or less the same horizontal distance.
  - The 100-micron particle, the largest and not as easily influenced by air flow fields, traveled 2.50016 meters in 0.679 seconds. The 0.1-micron particle, which is the smallest and more easily influenced by air flow fields, travelled 2.49997 meters in 0.4997 seconds.
  - 2.5 meters is approximately eight feet, which is ***two feet over the CDC's six-foot social distancing recommendation.***

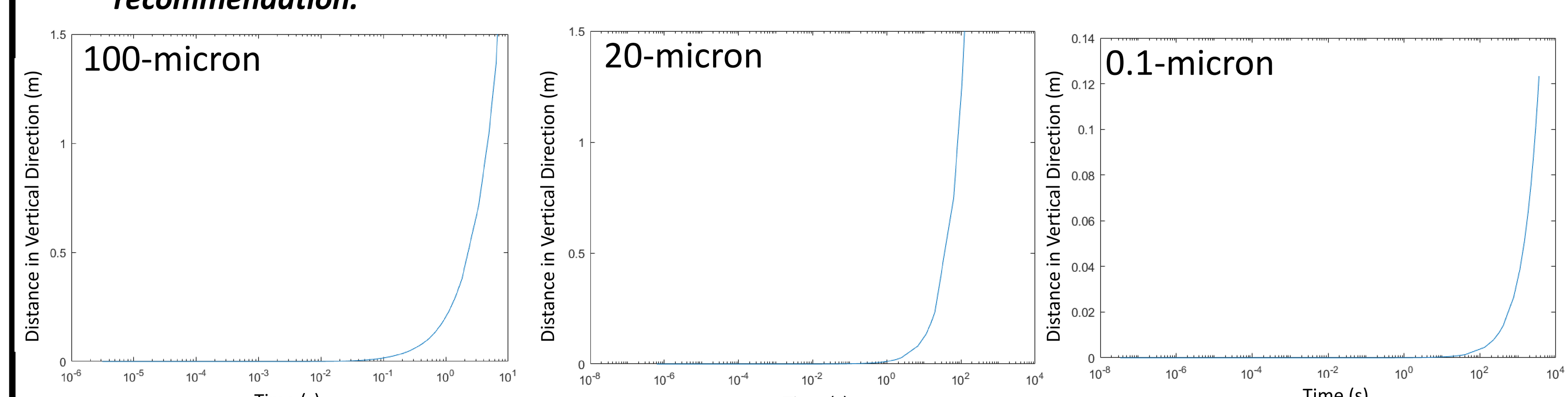

Figure 2: Vertical Distance Traveled Over Time

- It takes longer for the particle to fall 1.5 meters (average height of an adult) as its size decreases.
  - The 100-micron particle took 6.72 seconds, the 20-micron particle took 2 minutes, and the 0.1-micron particle ***remained in the air after 1 hour***.
  - Thus, smaller particles stay in the air longer, and they are more likely to be inhaled by someone else.

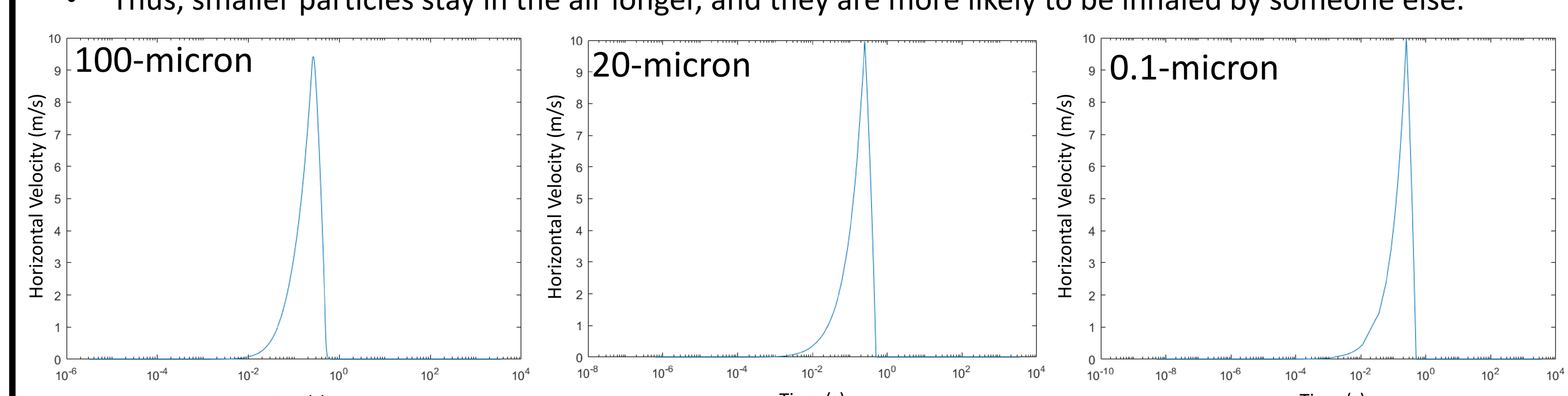

Figure 3: Horizontal Velocity over Time

- **Relaxation Time:** The smaller the aerosol particle is, the more easily it is influenced by the flow fields it is in.
  - **100-micron:** v_{max}= 9.42 m/s at 0.265 seconds
  - **20-micron:** v_{max}= 9.97 m/s at 0.251 seconds
  - **0.1-micron:** v_{max}= 9.99 m/s at 0.250 seconds
  - ***Recall the cough reached a maximum velocity of 10 m/s at 0.25 seconds.***
- The heaviest particle is not as easily influenced as the lightest particle. Nevertheless, airflows generated from coughs have significant potential to carry aerosol particles.
- Magnitude of the vertical velocity decreases as the aerosol particle decreases, which influences how fast the particle falls to the ground, as seen in **Figure 2**.
- Collectively, these results how aerosol transmission is influenced by the air flow fields generated by a cough. Small particles will travel more or less the same distance before falling to the ground after the cough profile reaches 0 m/s and the surrounding air is not disturbed.

CONCLUSIONS

- With the COVID-19 pandemic entering its third year across the globe, it is still critical to understand air velocity field's influence on aerosol transmission.
- MATLAB was utilized to simulate aerosol transmission in the presence of air flow fields generated by an unobstructed cough.
- As the results have shown, the smaller the particle is, the more easily influenced they are by the air's velocity.
  - While all particles travelled approximately 2.5 meters in the horizontal direction, the largest particle had more momentum and travelled slightly farther than the other two particles.
  - The 0.1- and 20-micron particles, on the other hand, started and stopped their movement with the air flow fields; their displacement and velocity almost matched the air's.
- Furthermore, the smaller particles remained in the air far longer than the larger particles, which could allow them to travel a longer distance if intermittent air movement is present.
  - If COVID-19 is being carried by these particles, they have the significant potential to infect other people.
- Thus, these results should have a significant impact on public policy and requirements for indoor spaces.
  - As discussed earlier, 2.5 meters is approximately 8 feet, which is above the 6-foot social distancing recommendation from the CDC.
  - For indoor spaces, especially ones with poor ventilation systems, aerosol particles could easily transmit across the room.
- Thus, it is critically important to study air flow fields, as they significantly impact aerosol transmission.

AKNOWLEDGEMENTS

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