Safe Distance of Viruses

Quantitative Analysis the Trajectory of Pathogen Containing Droplets in Respiratory Airways

Hanwen Alvin Miao†  
Junior Student (High School)  
 Princeton International School of Mathematics and Science  
 Princeton, New Jersey, The United States  
 † alvin.miao@prismsus.org

ABSTRACT

Droplets of mucosalivary ejecta emitted by sneezing or coughing are a major carrier of numerous types of bacterial and viral diseases. This study develops a numerical model to estimate the spread distance for inhalable droplets (1–50 µm) in the air, the inhalability of the particles, and the trajectory as well as velocity of these pathogen-containing droplets in human respiratory airways. Moreover, particularly for droplets with diameters of 1µm, 5µm, 10 µm, and 50 µm, specific comparisons between their inhalability and transmission velocities are made. Data extracted from previous papers such as the paper by Scharfman et al. [1] discussing the visualization of sneeze ejecta and the paper by Shang et al. [2] on deposition features of inhaled drops. These data are then used to obtain parameters to fit the model prediction of this work.

CCS CONCEPTS

• Applied Computing

KEYWORDS

Life and Medical Science, Epidemiology, SARS-CoV-2, Mathematical Modeling, Fluid Dynamic.

1 Introduction

Inhaled pathogen bearing droplets may enter the lung through respiratory airways and cause infection, or they may be exhaled and lead to an escalating re-transmission [2]. Many epidemics are spread by pathogen-containing particles, for example, the COVID-19.

Corona virus disease 2019 (COVID-19) is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [3]. It was first identified in December 2019 in Wuhan, Hubei, China, and has resulted in an ongoing pandemic. Common symptoms of COVID-19 infection include cough, sore throat, congestion or runny nose, nausea or vomiting, and diarrhea [4]. If not properly treated, the disease may lead to death. Unfortunately, ejecta caused by coughing and sneezing feature turbulent, multiphase flows that may contain pathogen-bearing droplets of mucosalivary fluid, and thereby induce a secondary spread of the pathogens in the air by the infected persons [5].

The COVID-19 pandemic, being one of the most serious epidemics in recent years, has affected over 36 million people and caused more than 1 million deaths [6]. It can be seen as a type of influenza (flu) that is a contagious illness [4]. Syndrome coronavirus 2 bearing ejecta droplets transmit between people and are mainly spread by those who show symptoms [7]. People will be easily infected by not only COVID- 19 but also other major types of respiratory diseases when they are in close contact with infected persons and inhale small droplets produced by them while coughing, sneezing, talking, and even breathing [8]. These droplets can land in the mouths or noses of people who are in proximity with one another (within about 6 feet for typical epidemic diseases that spread through pathogen-containing droplets) and possibly be inhaled into the lungs [5]. Therefore, keeping a safe distance is one of the most important methods to prevent getting contagious illnesses such as COVID-19.

Additionally, as most governments would suggest, the citizens (except those who are too young or working in places where wearing masks would be dangerous according to the workplace risk assessment) [9] wear face masks as an essential way to avoid COVID-19 infection [10]. Wearing a face mask effectively protects the wearer and those around him or her, as a result of its capability to significantly reduce the inhalability and expelling potential of droplets, inhibiting direct and secondary infection at the same time [9]. This fact reveals that when studying the spread of an epidemic, investigations of probability for the pathogen droplets being inhaled and re-expelled are necessary considerations.

Based on the idea of exploring the fundamental elements determining the condition of a pandemic being contagious through pathogen-bearing droplets such as COVID-19, this work investigated the velocity of sneeze ejecta leaving the nasal cavity and the spread-distance of these particles, the inhalability and expelling potential, and the velocity of the pathogen-containing droplets inside respiratory airways after being inhaled in the following three sections, respectively.

2 Velocity and Spread Distance of Sneeze Ejecta after Exhalation

Considering the condition of the pathogen-containing particles as soon as they leave the nasal or oral cavities of the infected person, a model was generated that represents their trajectories, which is influenced by the initial horizontal and vertical velocities and , respectively. The velocities are presented in Figure 1.

图示

描述已自动生成

Figure 1: Free body diagram illustrating the initial condition of a droplet after exhalation

The graph is presented in a Cartesian plane . The initial velocities in the x and y direction are and ; together, they produce the net initial velocity . Also presented in the graph is the gravitational acceleration, , which is in the y direction.

At time , the motion of the particle can be described using the following equations:

(1)

(2)

where and stand for the horizontal and vertical components of the net force acting on the particle. Knowing that the force acting in the x direction is the drag force from air resistance, we use stokes law to find (considering the droplet is an approximate sphere): [11]

(3)

in which stands for the viscosity of the air surrounding the droplets [12]. As an example, we will set [2]. Using Newton’s Second Law, we have that:

(4)

where is the mass of the droplets which we assume remains constant since we are neglecting evaporation.

Similarly, since the particles feel both a gravitational force and a drag force in the direction, the vertical net force can thus be represented by:

(5)

Assuming the droplets are spherical, their mass can be calculated as:

(6)

in which and represent the mass and volume of the droplets, while represents the difference between the density of the fluid and the air, which can be calculated based on the following equation:

(7)

Combining Equations 6 as well as 7 and using the resulting equation for Equation 4, the following result can be found:

(8)

For simplicity, set:

(9)

so that Equation 8 can be re-written into the following form:

(10)

Knowing that represents the initial horizontal velocity, which means , Equation 10 can be solved to yield:

(11)

Similarly, repeating the process in the y direction, Newton’s second law for motion in the direction is:

(12)

which can be further restructured using to give:

(13)

Knowing that (similar to the horizontal portion), Equation 13 can be solved to give:

(14)

Based on Equations 11 and 14, two equations that model the velocity and time relationship on x and y directions, the function relating displacement with time on both directions can be calculated. Starting with the x direction, we have that:

(15)

and we take the origin of the droplet’s trajectory at the patient’s nose, in which case

the initial horizontal position is and the initial vertical position is the height of the person’s nose :

(16)

(17)

Equation 15 can be then solved to obtain the horizontal position as a function of time:

(18)

By repeating the same process for the y direction, we have:

(19)

The relationship between the vertical displacement y and time t can be derived by using Equation 17 as the initial value to solve the differential equation (Equation 19):

(20)

With both equations modeling the horizontal displacement and the vertical displacement as functions of time (Equations 15 and 20), it is possible to eliminate time and derive a direct relationship between the horizontal displacement and the vertical displacement . The process is shown below:

; (21)

; (22)

therefore:

(23)

(24)

If we assume that another person has the same height as the person emitting sneeze ejecta, the distance travelled by the droplet in the direction is then found by setting . The numerical values in Equation 23 are: stands for gravitational acceleration [13], stands for the viscosity of the air surrounding the droplets, stands for the radius of the droplets particles, stands for the density difference between mucosalivary fluid and the air [14], and stands for the average height of people [15].

Two remaining unknown constants in Equation 23 are and . In order to obtain them, data from the paper by Scharfman et al. [1] are used.

图片包含 照片, 黑暗, 夜晚, 站

描述已自动生成

Figure 2: Figure 3 from Scharfman et al.

The figure is the cough recorded with high-speed imaging at 1000 fps and displayed at a. 0.005, b. 0.008, c. 0.015, d. 0.032, and e. 0.015s from onset. From each of the five figures I measured the distance traveled by the sneeze ejecta and record the time take it to reach the certain position, and then use these extracted data to estimate the approximate initial speed of the sneeze ejecta when it leaves the nasal cavity.

Based on the information presented in the graph, the following data recorded in table 1 can be measured or calculated:

Table 1: Data Extracted from Scharfman et al.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | A | B | C | D | E |
| Time (s) | 0.005 | 0.008 | 0.015 | 0.032 | 0.150 |
| Nose-to-hand Distance in Graph (s) | 5.80 | 5.80 | 5.80 | 5.80 | 5.80 |
| Known Horizontal Displacement of Sneeze Ejecta (cm) | NA | NA | NA | NA | 70.00 |
| Known Horizontal Displacement of Sneeze Ejecta in Graph (cm) | NA | NA | NA | NA | 13.00 |
| Ratio of Actual Distance to Distance in Graph | NA | NA | NA | NA | 5.385 |
| Nose-to-hand Distance (cm) | 31.23 | 31.23 | 31.23 | 31.23 | 31.23 |
| The Distance between the Center of Mass of the Cloud of Sneeze Ejecta and the Mouth in Graph (cm) | 0.28 | 0.50 | 0.95 | 1.77 | 6.80 |
| The Ratio of the Distance between the Center of Mass of the Cloud of Sneeze Ejecta and the Mouth in Graph to Nose-to-hand Distance in Graph | 0.048 | 0.086 | 0.164 | 0.305 | 1.172 |
| The Distance between the Center of Mass of the Cloud of Sneeze Ejecta and the Mouth (cm) | 1.50 | 2.69 | 5.12 | 9.53 | 36.60 |
| Thickness of the Cloud of Sneeze Ejecta in Graph Measured by the Vertical Line Passing through the Center of Mass of the Cloud of Sneeze Ejecta (cm) | 0.19 | 0.62 | 1.11 | 2.12 | 5.45 |
| The Ratio of Thickness of the Cloud of Sneeze Ejecta in Graph to Nose-to-hand Distance in Graph | 0.033 | 0.107 | 0.191 | 0.366 | 0.940 |
| Thickness of the Cloud of Sneeze Ejecta (cm) | 1.03 | 3.34 | 5.96 | 11.43 | 29.36 |
| Vertical Displacement of Sneeze Ejecta Calculated by Dividing the Thickness of the Cloud of Sneeze Ejecta by 2 (cm) | 0.52 | 1.67 | 2.98 | 5.72 | 14.68 |
| Range (Angle) of the Cloud of Sneeze Ejecta (°) | 50 | 55 | 64 | 88 | 94 |

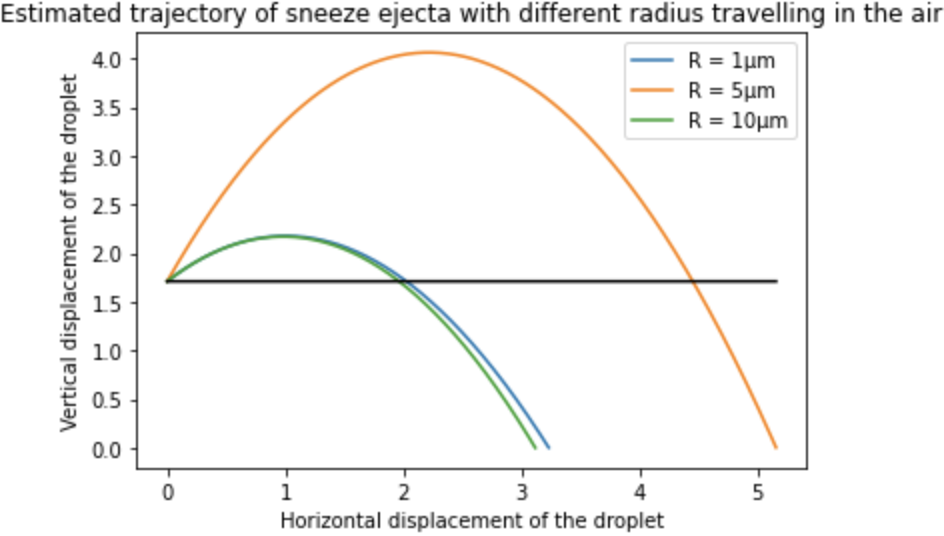
Linear regressions of functions modeling the relationships between horizontal displacement and time as well as vertical displacement and time is necessary to the calculation of velocity on both dimensions — the slope of the best-fitted line would be the velocity. Also, known that , these linear regressions are the special cases that only needs to calculate the slope instead of interception. The following table shows the calculation of getting horizontal and vertical initial velocity soon after the sneeze ejecta leaves the nasal and oral cavity:

Table 2: Calculation Process to Get Initial Horizontal and Vertical Velocity of the Sneeze ejecta after

Leaving the Nasal Cavity

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | | A | B | C | D | E |
| Time (s) | | 0.005 | 0.008 | 0.015 | 0.032 | 0.15 |
| Horizontal Distance (cm) | | 1.50 | 2.69 | 5.12 | 9.53 | 36.6 |
|  | 6.09449 | 0.0075 | 0.2152 | 0.0768 | 0.3050 | 5.49 |
|  | 0.02838 | 0.000025 | 0.000064 | 0.000225 | 0.001025 | 0.0225 |
| Slope – Horizontal Velocity (cm/s) | | 192.54 | | | | |
| Vertical Distance (cm) | | 0.52 | 1.67 | 2.98 | 5.72 | 14.68 |
|  | 2.443 | 0.0026 | 0.01336 | 0.0447 | 0.18034 | 2.202 |
|  | 0.02838 | 0.000025 | 0.000064 | 0.000225 | 0.001025 | 0.0225 |
| Slope – Vertical Velocity (cm/s) | | 69.99 | | | | |

At this point, since the values of and are known, the graph illustrating the relationship between the distance a particle travels and the height it is at can be generated using programming knowledge. The following graph shows the curve drawn based on the data generated by mathematical and computational methods respectively [17].



**Figure 3: Curve showing the relationship between horizontal and vertical displacement.**

The x-axis in the graph represents the distance travelled in the positive x-direction (away from the person) and they y-axis in the graph illustrates the distance travelled in the negative y-direction (toward the ground); both axes are in the unit of meter(m). The plot is generated based on the result of Equation 24.

By bringing in the result of computational method, which is:

, (25)

(26)

Solving the value of when , one of the solutions would be (the time that the infected patient’s sneezes), and the other solution would be the safe distance (the time that the virus-bearing particles enter another person’s respiratory airway). The process of solving is shown in Equation 27:

(27)

Therefore, the safe distance of contiguous diseases spreading through pathogen containing droplets is 4.03m based on the calculation of the computational method.

By bringing in the result of mathematical method, which is:

, (28)

into Equation 24, the value of and the function relating horizontal and vertical displacement ( and ) can be derived:

(29)

In addition, by bringing in the velocities into Equation 23, the function relating horizontal and vertical displacement ( and ) can be derived:

(30)

Then solve the value of when , which yields the result that is shown in Equation 31:

(31)

Therefore, the safe distance of contiguous diseases spreading through pathogen containing droplets is 0.24m based on the calculation of the mathematical method.

**3 Inhalability and Expelling Potential of Pathogen Containing Particles with Different Radius**

The inhalation of pathogen-containing droplets involves two parts: inhaling and expelling. Only a part of the particles would be inhaled in, while another portion would be expelled out when breathing. From the previous paper by Yidan Shang [2], it is known that the expelling potential (EP) is modeled based on the following equation:

(32)

in which stands for the diameter of the particle, stands for number fraction, stands for inhalability [16], and stands for deposition efficient [16]. According to the same paper:

(33)

And the following list shows several data points about the relationships between inability and diameter as well as deposition efficient and diameter:

**Table 3: Original Data for Calculation of and**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 1 | 2 | 3 | 5 | 7 | 10 | 15 | 20 | 30 | 50 |
|  | 99.2 | 99.2 | 99.2 | 98.9 | 98.5 | 98.1 | 97.3 | 96.4 | 52.5 | 13.9 |
| ) | 6.2 | 6.9 | 8.5 | 19.4 | 41.2 | 58.2 | 51.6 | 57.4 | 54.4 | 45.5 |

Similar to the calculation of releasing velocity of the pathogen-containing droplets documented in the previous section, there are also two ways (mathematical and computational) to fit and [16].

The process of mathematically fit the data points from Table 4 into a three-degree polynomial are listed in the “Appendix Section” [16]. The results of and are:

(34)

(35)

By plugging these fitted functions into the equation modeling, the expelling potential can be calculated:

(36)

With the expelling potential known, the actual inhalability (percentage of pathogen-containing droplets being inhaled in and not expelled out) for particles of different radius can be than calculated. The result is shown in the equations below (the unit of is ):

(37)

(38)

(39)

(40)

Based on the calculation, it can be seen that no matter which way we use to calculate the inhalability, the pathogen-containing droplets with radii of 1, 5, or 10 micro-meters have roughly the same inhalability, which is much greater than that of droplet with a radius of 50 micro-meters.

**4 Velocity of Pathogen-Containing Mucosalivary Droplets after Entering the Respiratory Airway**

Apply Newton’s Second Law:

(41)

to the case of movement of sneeze ejecta for whose

(42)

in which represents the diameter and stands for the density of the droplet. Therefore:

(43)

A special statistical correction factor named “Cumingham correction factor” helps improve the accuracy of this numerical estimation of the status of the pathogen-containing droplet, which can be represented by Equation 44 [18]:

(44)

in which , representing the arg molecular distance of air [2]. Therefore, by adding Cunningham correction factor into Equation 43, a more calibrated estimation (differential equation) of the movement status of the particles can be made:

(45)

which can be re-written into the form of:

(46)

Notice that an unknown constant in Equation 53 is the time . Fortunately, it can be calculated using the average deposition efficiency of sneeze ejecta [2]. and the average volume of human lungs [19]:

(47)

Since the velocity is the net velocity of the air transporting the pathogen containing droplets, it is approximately equal to the initial speed of the particles when they first leave the nasal cavity. Due to the difference in the calculations of this initial velocity (mathematical and computational methods, detailed information in section 3), there are two values of :

(48) (computational)

and

(49) (mathematical)

Knowing that , by bringing in the other constants , and , the differential equation (Equation 46) can be transformed with different values of given (the unit of is ):

(50)

(51)

(52)

(53)

Solving the differential equations (Equations 65 to 68) gives the final value of of droplets with different diameters (the unit of is ). The results are listed in the four equations below (Equations 54 to 57):

(54)

(55)

(56)

(57)

Finally, the trajectory of the pathogen-containing droplets can be determined based on the calculation of the “Stoke’s number”. If the Stoke’s number is greater than 1, particles would follow a straight pathway no matter how the fluid carrying them is moving; on the other hand, if the Stoke’s number is smaller than 1, particles would follow the trajectory of the fluid carrying them [20].

As a result, droplets with Stoke’s number greater than 1 would not go deep into the respiratory airway, for the intertwined bronchus easily block these particles only moving straight; while droplets with Stoke’s number smaller than 1 have higher chances to reach the lung, as the mobile mucosalivary fluid contained inside the respiratory airway carry them through the complex system of bronchus and bypass most of the obvious obstacles along their paths [21].

The equation that calculates Stoke's number is [2]:

(58)

in which ( stands for the density of mucosalivary fluid and stands for the diameter of the droplet) ) stands for the viscosity of mucosalivary fluid, represents the average radius of human

respiratory airways [22], and represents the velocity of the particle e relative to the air (approximately similar to the used when calculating the velocity of the pathogen-containing particles after entering the respiratory airway in the former portion of this section).

The value of the initial velocity is . The calculation of Stoke’s number for sneeze ejecta droplets of different radius is shown in the equations below (Equations 59 to 62):

(59)

(60)

(61)

(62)

Based on the result, it can be seen that all droplets with diameter less than have Stoke's number less than 1, meaning they follow the path of the mucosalivary liquid carrying them and are able to reach deep in the respiratory airway. However, droplets with diameter of have a Stoke’s number that is close to 1, meaning that they might still have Stoke's number greater than 1 (since the estimation always has some errors), and therefore move in straight trajectory exclusively and cannot reach to the lung consequently.

After having a brief analysis of both sets of data, it is easy to notice that both the pathogen-containing droplets with radii of 1, 5, or 10 micro-meters are able to reach deep inside the lung, while droplets with a radius of 50 micro-meters cannot. On the other hand, the droplets with a radius of 10 micro-meters have the largest deposition velocity, meaning that it could contact and infect the lung the fastest, making it the most dangerous type among droplets with radii of 1,5, and 10 micro-meters.

**5 Conclusion**

In this study, the initial velocity of the pathogen-containing sneeze ejecta leaving the nasal cavity, the percentage of particles with different diameter being inhaled, as well as the velocity of droplets after entering respiratory systems are calculated, and the trajectory of the mucosalivary fluid carrying particles inside the respiratory airway is determined. A general conclusion can be made based on these parameters investigated: the larger the particle is, the less harmful it is, for a large particle has slower velocity, lower inhalability, and it tends to be blocked by bronchus and thus cannot reach deep into the lung.

An important point to be noticed is that even though the official guide given by CDC illustrates that the safe distance for covid virus especially (also roughly the same for every other type of pathogen-containing droplets) is 6 feet [23], which is significantly different from the value calculated in this experiment (around meters). This is probably due to the neglection of evaporation during the mathematical modeling of the transmission. If the change in the size of the pathogen-containing particle is considered, the accuracy of the model and estimation will be significantly improved.

On the other hand, the most dangerous type of pathogen-bearing droplet is the one with a diameter of — its large probability of being inhaled making it accessible to the respiratory airway, its deposition efficiency is much higher than those particles smaller than it, and its Stoke’s is smaller than one, enabling it to reach the lung following the current of mucosalivary liquid.

Wearing face mask and keeping social distance are indeed the two most effective ways of avoiding viral or bacterial infection transmitted by pathogen-containing droplets. Known that the save distance is approximately at least 2 meters based on the calculation of this paper, so people keeping such a distance with each other can effectively avoid particles entering their respiratory airways. Moreover, wearing face mask can not only significantly reduce the probability of droplets being inhaled but also drastically prevents the expelling of them, both avoiding first-hand transmission and secondary infections, and thus making it an essential way to protect people during epidemics.

**6 Appendix**

**6.1 Mathematical Data Fitting Method**

*1) Three Degree Polynomial Regression*

Suppose the dataset is a list of points and the best fitted curve (a three-degree polynomial) is . Known that the error of a point of the dataset is the absolute value of the vertical distance between the point and the best fitted curve, the error of each point from the original dataset can be represented by the following equation:

(63)

The variance means the square of error, so that the variance can be represented by the following equations:

(64)

(65)

By cleaning up the terms, the value of can be further written into the following equation (Equation 66):

(66)

The main idea of data fitting is minimizing the error (variance). Therefore, the

following four differential equations must be fitted, in order to reach the minimum:

(67)

Solving each differential equation leads to the following results (Equations 68 to 71):

(68)

(69)

(70)

(71)

which can be then re-written into the form of:

(72)

(73)

(74)

(75)

Finally, the value of , , , and can be calculated by solving this system of equations (Equations 72 to 75).

*2) Multi-Degree Polynomial Regression*

Suppose the dataset is and the best fitted curve is . Following the exact same step as the three degree polynomial regression does, the value of all constants inside the best fitted function can be calculated by solving the following system of equations (Equations 76 to 79):

(76)

(77)

(78)

(79)

*3) Linear Regression*

Suppose the dataset is and the best fitted curve is . As for the normal case, applying the multi-degree polynomial regression function and bringing in , it can be known that both and can be calculated based on the following system of equations (Equations 80 and 81), and the result is shown in the third equation below (Equation 82):

(80)

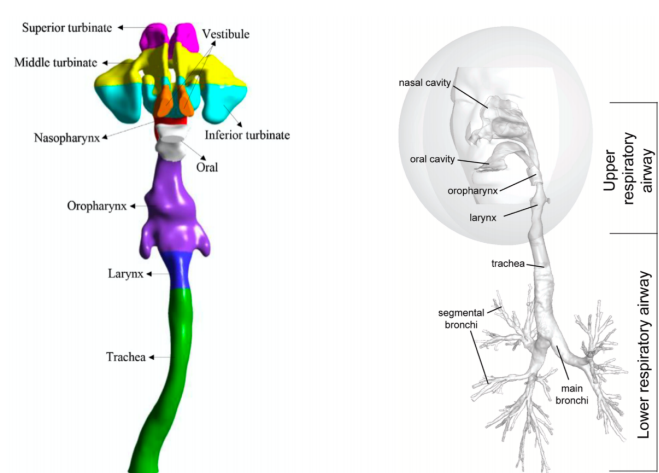
(81)

(82)

However, there is a typical special case for linear regression. Sometimes it is known that the best fit curve must pass through the origin (point ), for example, in the case of calculating the initial velocity of pathogen-containing droplets just after they leave the nasal cavity in section 3 of this paper. As for these special cases, is known to be 0, so that the value of can be calculated in an easier way:

(83)

**6.2 Structure of Respiratory Airway**



**Figure 4: Graphs of Structure of Human Beings’ Respiratory Airways Adopted from “SARS-CoV-2 droplet deposition path and its effects on the human upper airway in the oral inhalation” by Hamed Mortazavi, Hamidreza Mortazavy Beni, Fatemeh Aghaei, and Seyed Hossein Sajadiana (left) [24] and “Deposition features of inhaled viral droplets may lead to rapid secondary transmission of COVID-19” by Yidan Shang, Yao Tao, Jingliang Dong, Fajiang He, and Jiyuan Tu (right) [2]**

**6.3 Regression for Section 3 “Inhalability and Expelling Potential of Pathogen Containing Particles with Different Radius”**

**Table 4: Calculation Process of and**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Radius | | 1 | 2 | 3 | 5 | 7 |
|  | | 99.2 | 99.2 | 99.2 | 98.9 | 98.5 |
|  | 4402407.2 | 99.2 | 793.6 | 2678.4 | 12362.5 | 33785.5 |
|  | 160950.3 | 99.2 | 793.6 | 2678.4 | 12362.5 | 33785.5 |
|  | 8417.7 | 99.2 | 198.4 | 297.6 | 494.5 | 689.5 |
|  | 853.2 | 99.2 | 99.2 | 99.2 | 98.9 | 98.5 |
|  | 16430524693 | 1 | 64 | 729 | 15625 | 117649 |
|  | 337999581 | 1 | 32 | 243 | 3125 | 16087 |
|  | 7283749 | 1 | 16 | 81 | 625 | 2401 |
|  | 164879 | 1 | 8 | 27 | 125 | 343 |
|  | 4213 | 1 | 4 | 9 | 25 | 49 |
|  | 143 | 1 | 2 | 3 | 5 | 7 |
|  | | 6.2 | 6.9 | 8.5 | 19.4 | 41.2 |
|  | 7864706.5 | 6.2 | 55.2 | 229.5 | 2425 | 14131.6 |
|  | 207541.1 | 6.2 | 27.6 | 76.5 | 485 | 2018.8 |
|  | 6841.9 | 6.2 | 13.8 | 25.5 | 97 | 288.5 |
|  | 349.3 | 6.2 | 6.9 | 8.5 | 19.4 | 41.2 |
|  | 16430524693 | 1 | 64 | 729 | 15625 | 117649 |
|  | 337999581 | 1 | 32 | 243 | 3125 | 16087 |
|  | 7283749 | 1 | 16 | 81 | 625 | 2401 |
|  | 164879 | 1 | 8 | 27 | 125 | 343 |
|  | 4213 | 1 | 4 | 9 | 25 | 49 |
|  | 143 | 1 | 2 | 3 | 5 | 7 |
| Radius | | 10 | 15 | 20 | 30 | 50 |
|  | | 98.1 | 97.3 | 96.4 | 52.5 | 13.9 |
|  | 4402407.2 | 98100 | 328388 | 771200 | 1417500 | 1737500 |
|  | 160950.3 | 99.2 | 396.8 | 892.8 | 2742.5 | 34750 |
|  | 8417.7 | 981 | 1459.5 | 1928 | 1575 | 695 |
|  | 853.2 | 98.1 | 97.3 | 96.4 | 52.5 | 13.9 |
|  | 16430524693 | 1000000 | 11390625 | 64000000 | 729000000 | 1562000000 |
|  | 337999581 | 1 | 32 | 243 | 3125 | 16087 |
|  | 7283749 | 10000 | 50625 | 160000 | 810000 | 6250000 |
|  | 164879 | 1000 | 3375 | 8000 | 27000 | 125000 |
|  | 4213 | 100 | 225 | 400 | 900 | 2500 |
|  | 143 | 10 | 15 | 20 | 30 | 50 |
|  | | 58.2 | 51.6 | 57.4 | 54.4 | 45.5 |
|  | 7864706.5 | 58200 | 174159 | 459200 | 146800 | 568700 |
|  | 207541.1 | 58200 | 11610 | 22960 | 48960 | 113750 |
|  | 6841.9 | 582 | 774 | 1148 | 1632 | 2275 |
|  | 349.3 | 58.2 | 51.6 | 57.4 | 54.4 | 45.5 |
|  | 16430524693 | 1000000 | 11390625 | 64000000 | 729000000 | 1562000000 |
|  | 337999581 | 1 | 32 | 243 | 3125 | 16087 |
|  | 7283749 | 10000 | 50625 | 160000 | 810000 | 6250000 |
|  | 164879 | 1000 | 3375 | 8000 | 27000 | 125000 |
|  | 4213 | 100 | 225 | 400 | 900 | 2500 |
|  | 143 | 10 | 15 | 20 | 30 | 50 |

According to the data presented in the table above, can be calculated by solving the following system of equations (Equations 84 to 87):

(84)

(85)

(86)

(87)

which means:

(88)

(89)

Following the similar process, can be calculated by solving the following system of equations (Equations 90 to 93):

(90)

(91)

(91)

(93)

which means:

(94)

(95)

**ACKNOWLEDGMENTS**

Thanks to professor Gerald Fuller from the Chemical Engineering of Stanford University for teaching me the basic background knowledge and theoretical foundation of calculation for this research project.

**REFERENCES**

[1] B.E.Scharfman, A.H.Techet, J.W.M.Bush, and L.Bourouiba. “Visualization of sneeze ejecta: steps of fluid fragmentation leading to respiratory droplets.” Exp Fluids (2016) 57:24. dois:10.1007/s00348-015-2078-4.

[2] Yidan Shang, Yao Tao, Jingliang Dong, Fajiang He, and Jiyuan Tu (9 January 2021). “Deposition features of inhaled viral droplets may lead to rapid secondary transmission of COVID-19”. Journal of Aerosol Science, 154(2021) 105745. <https://doi.org/10.1016/j.jaerosci.2021.105745>.

[3] Page J, Hinshaw D, McKay B (26 February 2021). “In Hunt for Covid-19 Origin, Patient Zero Points to Second Wuhan Market – The man with the first confirmed infection of the new coronavirus told the WHO team that his parents had shopped there”. The Wall Street Journal.

[4] Centers for Disease Control and Prevention (CDC). “Symptoms of COVID-19”, 22 February 2021. <https://www.cdc.gov/coronavirus/2019-ncov/symptoms-testing/symptoms.html>.

[5] Centers for Disease Control and Prevention (CDC). “Frequent Asked Questions”, 21 October 2021. [Coronavirus (COVID-19) frequently asked questions | CDC](https://www.cdc.gov/coronavirus/2019-ncov/faq.html#Spread).

[6] Betsch, C., Korn, L., et al. (2020). “Social and behavioral consequences of mask policies during the COVID-19 pandemic”. Proceedings of the National Academy of Sciences, 117(36), pp. 21851–21853.

[7] World Health Organization. “Coronavirus disease (COVID-19): How is it transmitted?". <https://www.who.int/emergencies/diseases/novel-coronavirus-2019/coronavirus-disease-answers?query=How+it+spreads&referrerPageUrl=https%3A%2F%2Fwww.who.int%2Femergencies%2Fdiseases%2Fnovel-coronavirus-2019%2Fcoronavirus-disease-answers>. Retrieved 6 December 2020.

[8] Centers for Disease Control and Prevention (CDC). “Coronavirus Disease 2019 (COVID-19)”. Retrieved 6 December 2020. <https://www.cdc.gov/coronavirus/2019-ncov/index.html>.

[9] Centers for Disease Control and Prevention (CDC). “Coronavirus Disease 2019 (COVID-19)”. 25 October 2020. [https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/about-face-coverins.html](https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/about-face-coverings.html).

[10] New Youth Anesthesia Daily. “People’s Daily: Can Wearing Facemask prevents COVID-19”, 22 January 2020. <https://www.sohu.com/a/368399258_377325>.

[11] National Aeronautics and Space Administration (NASA). “What is Drag”, Retrieved 6 December 2020. <https://www.grc.nasa.gov/www/k-12/airplane/drag1.html>.

[12] Symon, Keith R. Mechanics (3rd Edition), December 1971. Boston, MA: Addison-Wesley. ISBN 978-0-201-07392-8.

[13] Hirt, C., Claessens, S., Fecher, T., Kuhn, M.; Pail, R., Rexer, M (2013). “New ultrahighresolution picture of Earth's gravity field”. Geophysical Research Letters, 40 (16), pp. 4279–4283. doi:10.1002/grl.50838.

[14] Ball, Philip (2008). "Water: Water—an enduring mystery". Nature, 452 (7185), pp. 291–2. doi:10.1038/452291a.

[15] Our World Data. “Human Height”, May 2019. <https://ourworldindata.org/human-height>.

[16] Detailed description of both methods is written in the “Appending” section.

[17] The codes responsible for generating these plots are recorded in the “Appending” section.

[18] Cunningham, E., “On the velocity of steady fall of spherical particles through fluid medium,” Proc. Roy. Soc. A 83(1910)357. doi:10.1098/rspa.1910.0024

[19] NCBI. Benjamin J. Delgado, Tushar Bajaj. “Physiology, Lung Capacity”, July 26, 2021. <https://www.ncbi.nlm.nih.gov/books/NBK541029/>.

[20] Cameron Tropea, Alexander Yarin, John Foss, eds. Springer Handbook of Experimental Fluid Mechanics, 9 October 2007. New York: Springer.

[21] Specific model and classification of different parts of the respiratory system can be found in the “Attachment” section.

[22] NCBI. Joshua J. Hurley, Jeremy L. Hensley, “Physiology, Airway Resistance”, 22 September 2021. <https://www.ncbi.nlm.nih.gov/books/NBK542183/>.

[23] CDC. “How to Protect Yourself & Others”, 13 August 2021. <https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/prevention.html>.

[24] Hamed Mortazavi, Hamidreza Mortazavy Beni, Fatemeh Aghaei, Seyed Hossein Sajadiana (11 November 2020). “SARS-CoV-2 droplet deposition path and its effects on the human upper airway in the oral inhalation”. Computer Methods and Programs in Biomedicine 200(2021) 105843. <https://doi.org/10.1016/j.cmpb.2020.105843>.