# Spread of sneezing and coughing in a subway car

# Tüsszentés és köhögés terjedése metrókocsiban

HETYEI Csaba[1] – SZLIVKA Ferenc[2]


## Abstract

Throughout human history, epidemics have occurred in many cases, which have also affected society and the economy. At the end of 2019, the COVID-19 or SARS-CoV-19 virus appeared and caused a pandemic in 2020, which resulted in unprecedented changes both globally and individually. In our article, we were analysing the spreading and evolution of a violent expiratory event (sneeze, cough) in a subway car. In our research, we followed a sneezed/coughed air using a computational fluid dynamics (CFD) software, thus it became visible in which directions the coughed volume spreads. Using our results, passengers' sense of security can be increased, therefore if someone sneezes in the studied subway car, the passengers can decide that the sneezing is a real risk of infection for them or not.

## Absztrakt

Az emberiség történelme során számos esetben előfordultak járványok, melyek hatással voltak a társadalomra és a gazdaságra is. 2020-ban a 2019-es év végén megjelenő COVID-19, azaz a SARS-CoV-19 vírus okozott világjárványt. A 2020-as pandémia eddig nem látott világméretű járványügyi intézkedéseket eredményezett, mely az országok és az egyének életét is nagyban befolyásolták. Cikkünkben egy erőteljes légúti kilégzést (tüsszentés, köhögés) terjedését vizsgáljuk Budapest egyik legnagyobb lélekszámban használt közlekedési eszközén, az M3-as metró egyik kocsijában. Kutatásunk során egy numerikus áramlástani szoftver segítségével feltérképeztük a kiköhögött/kitüsszentett levegő útját, így láthatóvá vált, hogy mely irányokba terjed a kitüsszentett levegő. Eredményeinket felhasználva az utazók biztonságérzete növelhető így, ha a metrókocsiban valaki tüsszent, az utazók eldönthetik, hogy az a tüsszentés valós fertőzésveszélyt jelent-e számukra.



## Keywords

CFD simulation, Coughing and sneezing, COVID, Health security, Public transportation, Traffic safety

## Kulcsszavak

CFD szimuláció, COVID, Egészségbiztonság, Köhögés és tüsszentés, Közlekedésbiztonság, Tömegközlekedés


[1] hetyei.csaba@uni-obuda.hu | ORCID: 0000-0003-2915-4540 | PhD student, Óbuda University Doctoral School on Safety and Security Sciences | doktorandusz, Óbudai Egyetem Biztonságtudományi Doktori Iskola

[2] szlivka.ferenc@bgk.uni-obuda.hu | ORCID: 0000-0002-3298-4142 | professor, Óbuda University Bánki Donát Faculty of Mechanical and Safety Engineering | egyetemi tanár, Óbudai Egyetem Bánki Donát Gépész és Biztonságtechnikai Mérnöki Kar

## INTRODUCTION

Thought the human history, there have been pandemics, which was a biological thread for mankind. In the last centuries, the pandemics were endangering the whole world due to the word trade and tourism. Epidemics in addition to human lives can cause economic crises [1], the developing and the slow responding countries are in the greatest danger [2]. In our modern days, the pandemics also can cause panic and anxiety in thwe individual's life both in the real and in the virtual life [3]. In the last decades, the diseases were able to travel around the world in a few days by infected peoples. Just to mention a couple of diseases from the last two decades which hit mankind: SARS in 2003, H5N1 in 1997 and 2005, H1N1 in 2009, MERS in 2012, Ebola in 2014 and right now with COVID-19 (SARS-CoV-2) which started to spread at the end of 2019 [4].

The first mathematical model for the infectious disease was made by Daniel Bernoulli in 1760 for the spread of smallpox [5], with time in 1927 William Ogilvy Kermack and Anderson Gray McKendrick published their epidemic model [6]. The compartment model of Kermack and McKendrick contained the SIR notations, where S is susceptible, I is infective and R is removed or recovered class. By this model, when a member of the S class is infected, it is going to the infected (I) group, when this individual cured, he is going to the R stock, where he has immunity against the pathogen. The SIR flow can see in Figure 1.


*Figure 1. The flow of the SIR model*

The mathematical description for the SIR model was presented 1932 [7] and 1933 [8] by Kermack and McKendrick with the following equations:

$$\frac{dS}{dt} = -\frac{\beta \cdot S \cdot I}{N}$$

$$\frac{dI}{dt} = \frac{\beta \cdot S \cdot I}{N} - \gamma \cdot I$$

$$\frac{dR}{dt} = \gamma \cdot I$$

$$R_0 = \frac{\beta}{\gamma}$$

In the previous equations and Figure 1, *S*, *I* and *R* are the previously introduced susceptible, infective and removed or recovered compartments, *N* is the sum population of these three groups, $R_0$ is the initial number or the R class, $\beta$ is the transmission rate and $\gamma$ is the removal rate.

The SIR model is a simple form of a disease transmission when the member of the population can infect only once. In this case, if the $R_0$ is less than 1, the herd immunity may develop and the disease dies out, if $R_0$ is more than 1, the epidemic is spreading [9]. For different diseases different infection types exist, which can describe with the S, I and R classes, e.g., SIS, is when the patent is cured of the infection and he can become newly infected, or extending the model with the D, E and M classes, where D is the deceased class, E, the exposed class, when there is an incubation period between the infected and the infectious condition and M is the materially-derived immunity class [9].

For decreasing the infections, in the metric word generally the 1.5 meters social distance is the required [10], in the regions where the imperial system is used, usually the safe distance is 6 feet (1.8 meters) [11], while the WHO suggest at least 1-meter distance [12]. The origin of the safety gap was made by Carle Flügge in 1897 who found the most of the large droplets expelled from the nose and mouth fell to the ground within 3 to 6 feet of the person with infection [11]. Since Flügge, researchers have begun to study the diseases transmission mechanism, for easier and more precise understanding its physics and they are arranged the droplets by their sizes. The “large droplet” transmission route is when the target tissue has direct contact with the pathogen-bearing droplets, the “small droplets” and the airborne transmission is an indirect contact via inhalation of pathogen-bearing droplets. Generally, the size association for the “small” droplets are droplet nuclei which can form from via evaporation and they diameter are less than 5 μm, when the diameter of the droplet is between 5 μm and 10 μm they are respiratory droplets, if the droplet size is more than 10 μm they are “large” droplet [13]. Approached from elsewhere the “large” droplets are settling by gravity and the small droplets are not [14].

Fluid dynamic studies shown the cloud of the violent respiratory events (sneeze and cough) are multiphase turbulent flows and they are traceable with schlieren optics. Lydia Bourouiba *et al.* [15] was observed the evolution of a respiratory event with a high fps camera, which is shown in Figure 2.

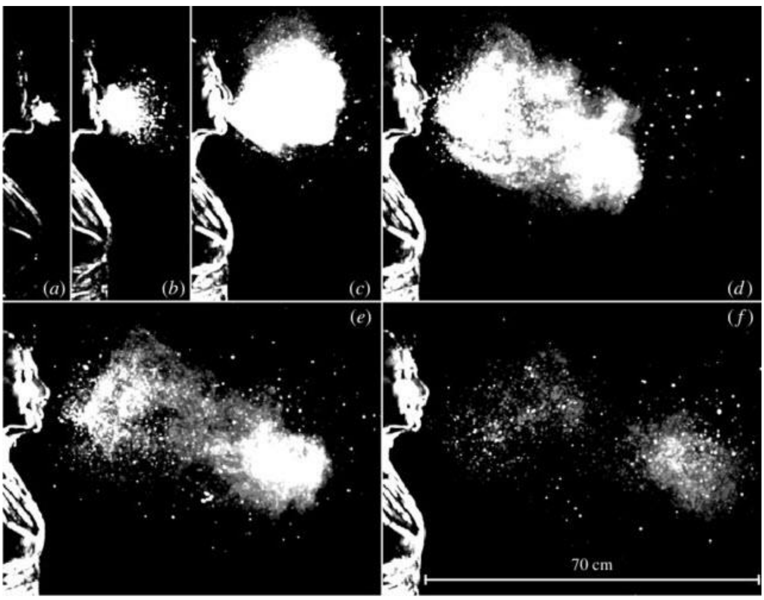


*Figure 2. Sneezing in different time moments, a, 0.006 sec; b, 0.029 sec; c, 0.106 sec; d, 0,161 sec, e, 0.222 sec and f, 0.341 sec [15]*

The schematic evolution of a respiratory event by Bourouiba *et al*. [15] shown in Figure 3.

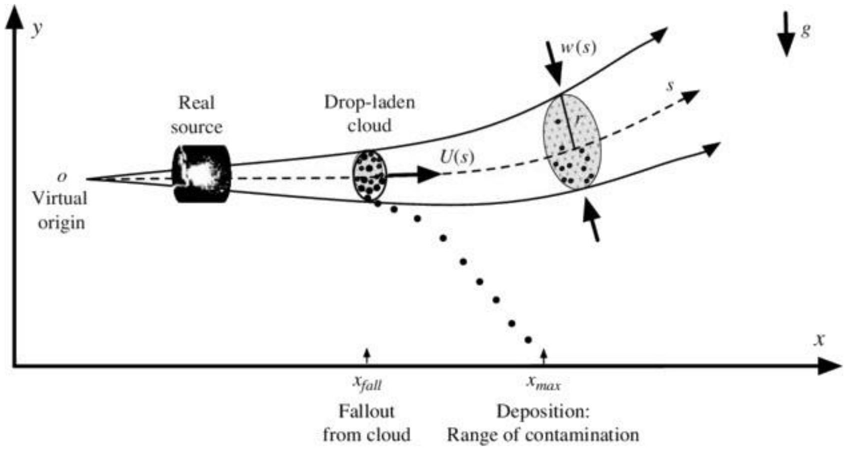


*Figure 3. Evolution of a sneeze or cough [15]*

On the previous figure, we can observe a virtual origin where a sneeze or cough starts, then its exit on a real source (nose and mouth), then with distance, the large droplets starts to fall out from the cloud, the small droplets which remain in the puff of moist by the buoyant force start to rise, until they evaporate. During the lifetime of a cough, the puff cloud has a self-similarity describe by the plume theory [16, 17], and represented in Figure 3. with the expanding envelop curve.

Lydia Bourouiba *et al.* [15] using their images and the existing knowledge, they created both discrete and continuous fallout models for different particle sizes and they were compared against experimental results which showed a good match. The particle size distribution can depend on the sneezing speed and its humidity. A droplet size distribution for a cough is shown in Figure 4.

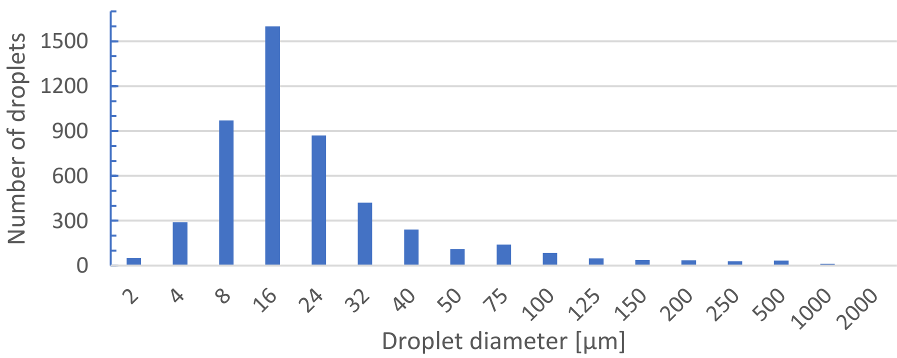


*Figure 4. Droplet size distribution [18]*

During the evolution of a sneeze or a cough the unsteady fluid fragmentation occurs due to the hydrodynamic instabilities, e.g. Kevin – Helmholtz type instability appears when there is differential of speed at interfaces, Plateau – Rayleigh type instability driven by surface tension or Reyleight – Taylor instability which is the result of different fluid densities. Due to the instabilities, the fluid sheet of the wet cough fragments into rim, then ligament and to droplets [19, 20], hench viruses and other pathogens do not settle, due evaporation they can travel farther and they can stay in the air for a longer time.

Using a mask can protecting us and others to reducing exposed droplets. The used mask quality can depend on its manufacturing technology, e.g. for the N95 mask the requirement is filtering at least 95% of solid and liquid aerosols. Researchers from Wake Forest Institute for Regenerative Medicine tested 13 different design from approximately 400 masks made by community volunteers. They find the worst cloth mask filtered 1% of the particles and the best cloth mask performed with 79% filtration, the industrial made surgical mask achieved 62-65% filtration and the best N95 mask had 97% [21]. Examining the best performing masks researchers from Sydney [22, 23] and Duke [24] find similar results than the researchers from the Wake Forest Institute, the higher filtration level comes with the two or more layers, they have a tight weave and they made of heavyweight cotton fabric. The best-performing industrial masks are the N95, and the other respirator masks e.g. FFP2, KN95, P2, KF94, etc. [25] which are critical supplies for the healthcare workers, therefore the general recommendation is for the people to wear cloth mask in public with social distancing [26]. Researchers also find, the aerosol production during speech is more when we use plosive consonants like “p” “b”, and it is less when we use milder consonants like “m”. They also find the droplet quantity can be reduced with lip balm [27]. A comparison between the produced droplets of speaking, sneezing, and coughing with and without covered mount shown in Figure 5.

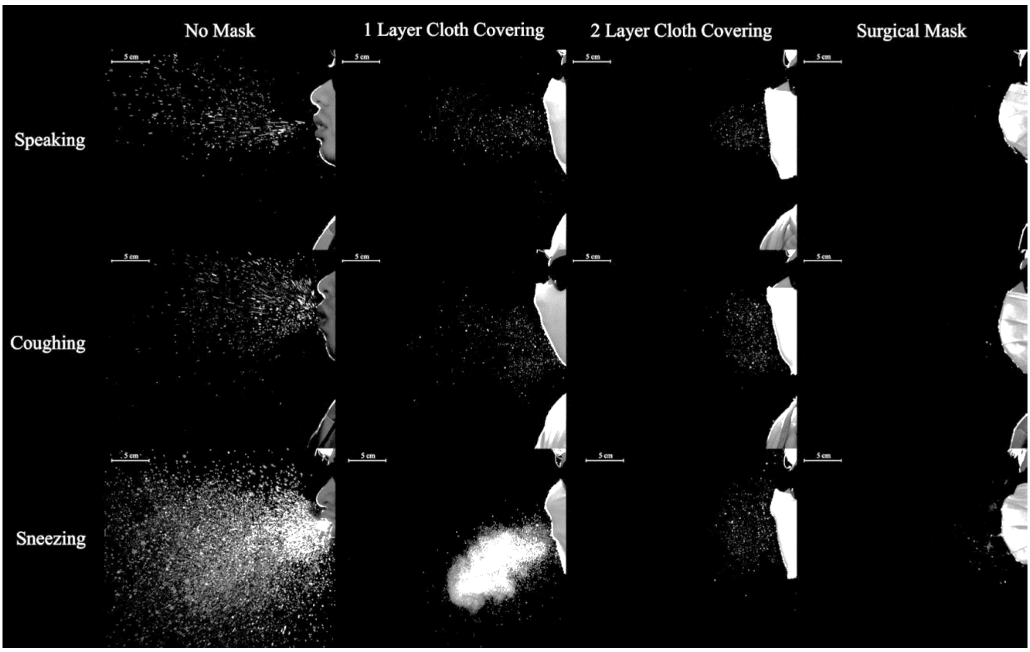


*Figure 5. Droplet comparison for speaking, coughing and sneezing, without a face mask, with covered face by 1 and 2 layer cloth and by surgical mask [22]*

The key factor of the droplet filtering is to use properly the face mask. The mask should cover the mouth and the nose, and it should fit tightly to the face. In any hole between the face and the mask the droplets could exit, and it can infect others. The outlet flow from a mask [28] is shown in Figure 6.

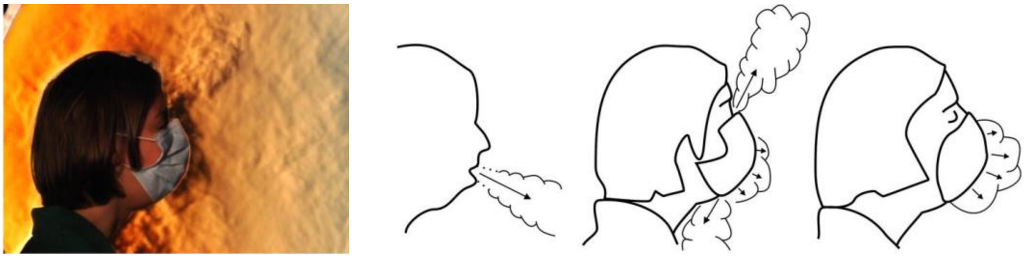

*Figure 6. Outlet flow from a facemask captured by schlieren optic and a schematic image for cough spreading without a face mask and with different face masks [28]*

## MOTIVATION

In Budapest the Metro Line 3 or shortly the M3, before its renovation (November 2017), it has the highest transport capacity in peak hours (26 326) and the highest passenger number in peak hours (17 300), in addition to the greatest traveller number, it has the longest line (17.06 km) and the largest number of stations (20) [29].

While using the subway, the passengers may feel less safe during the viral period, and if someone sneezes, it can cause panic among passengers. Our goal to simulate a sneeze or a cough in a subway car and visualize its path and for reducing anxiety and increase travel security.

For creating the worst-case scenario, we created a CAD model of the M3 train (shown in Figure 7) with passengers, wherefrom the simulation we used only one people, the others and the tubular handrail, was used just for visualization. The violent expiratory event happened in the “corner” of the subway car and it could spread harshly in just one direction. The sneeze or cough occur in a realistic way as passengers usually travel and are likely to sneeze, towards the inside of the metro and not longitudinally.

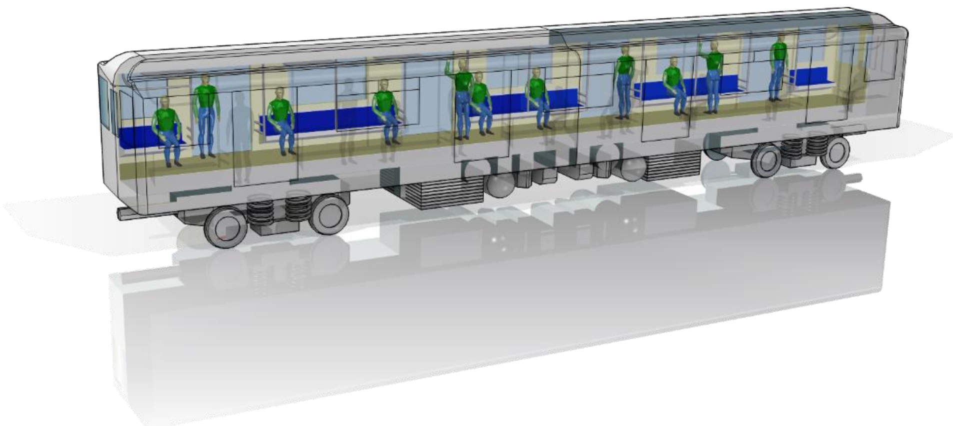

*Figure 7. M3 metro train with travellers*

For comparison, we were simulated cases both with and without a face mask, with and without AC (air conditioning), and with opened and closed windows. The estimated droplet route (yellow lines) and the opened and closed windows (inside the red rectangles) shown in Figure 8. We choose a detailed mannequin (shown in Figure 9) for the simulation, so its geometry provides more realistic results than an exaggerated man-like one, built of cylinders and rectangles.

For the simulation we would like to model and visualize just the fluid dynamic effects, therefore the particle deposition on the surfaces was not examined.

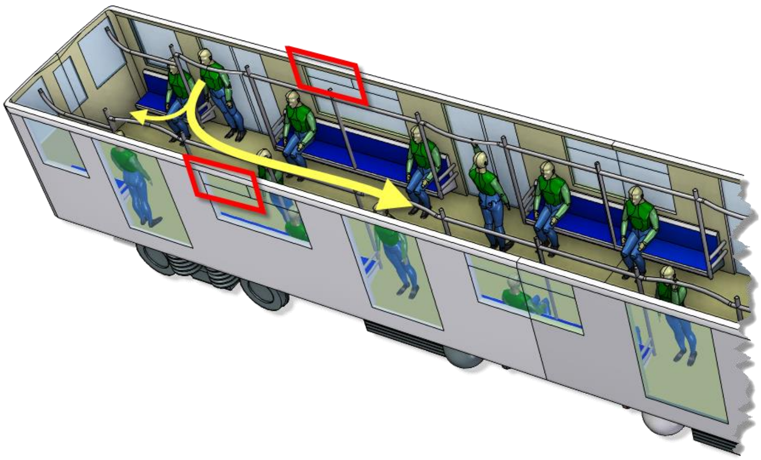

*Figure 8. Estimated sneeze route and the opened/closed windows*

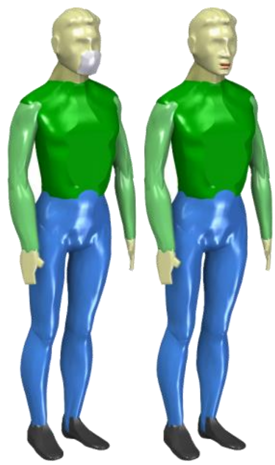

*Figure 9. Mannequin with and without a face mask*

## FOUNDATIONS OF COMPUTATIONAL FLUID DYNAMICS

The computational fluid dynamics (CFD) simulation is a tool to mimic the physical world. For our research, we used a finite volume method (FVM) based CFD software, which method divides the computational domain into finite volumes, within it is using the continuity, momentum, and energy equations to compute the flow field's properties. Based on the tree previous equations the FVM based CFD codes generally use the following transport equation:

$$\frac{\partial}{\partial t}\int_V U\,dV + \oint_A \underline{F}\,d\underline{A} - \int_V S_V\,dV - \oint_A \underline{S_A}\,d\underline{A} = R$$

In this equation, $V$ denotes an arbitrary enclosed control volume, $A$ denotes the surface of this control volume, $U$ is a conserved quantity (e.g.: mass), $F$ is the same quantity's flux over the $A$ surface, $S_V$ is the volumetric source of quantity $U$ over volume $V$, $S_A$ is the surface source of quantity $U$ over surface $A$, and $R$ is the error of the equation (residual).

The previous equation can be written for every cell of the mesh and solved in a system of equations. To do so, CFD codes utilise iterative methods that converge to a solution by reducing the residuals of the equations.

## SIMULATION PROPERTIES

For simulation we used Mentor Graphics' frontloaded CFD software the FLOEFD integrated into Siemens' Solid Edge CAD software.

For the default fluid, we choose "Air" from FLOEFD's material database, the ambient temperature was 20.05°C and the environmental pressure was 1 atm (101 325 Pa). The gravity was defined in a downwards direction perpendicular to the floor. The sneezing mannequin body temperature was 38.3°C.

Due to the needed computational resource for the simulation, we cut the model in half, and the farther half was modelled with an environmental pressure boundary condition (BC), which can be both inlet and outlet depending on its environment.

When the windows were open, the speed of the external air was 8.5 $m \cdot s^{-1}$ (30.6 $km \cdot h^{-1}$), which is the average travel speed of M3.

When the AC (air conditioning) was running, the air enters into the computational domain with environmental temperature (20.05°C), with 0.5 $m \cdot s^{-1}$ speed, and with 50% relative humidity. The 0.5 $m \cdot s^{-1}$ airspeed is a twice than the recommended velocity [30], which we chose for faster air exchange, and the 50% of relative humidity is a recommended humidity value for ACs during the summer [30].

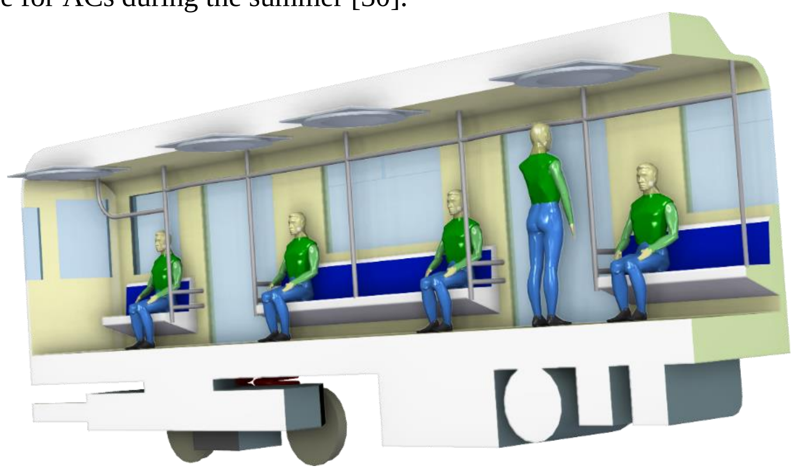

*Figure 10. M3 metro train with ACs*

For sneezing or coughing, we define a time-dependent volume flow BC, with 2, 4, and 5 litres total volume. We defined this value by the average human lung capacity, which is 6 litres for man and 4 litres for women [31]. The sneezing or coughing was simulated in a transient simulation with a trapezoid distribution within 0.25 seconds. For the volume flow of 5 litres coughed air, the sneezing function shown in Figure 11.

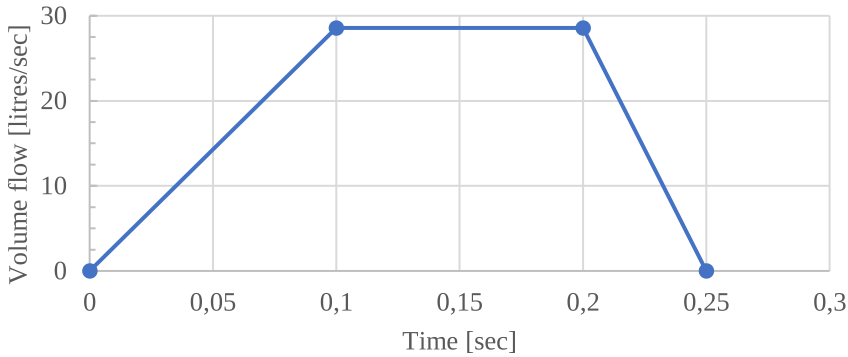


*Figure 11. Sneeze distribution during the sneezing*

The sneezing was starting at 1 second with 100% of relative humidity and with 38.3°C fluid temperature. For clarity, the density of the 100 % humid air is lighter than the dry air and it can be determined by the following formula [32]:

$$\rho_{humid\ air} = \frac{p_d}{R_d + T} + \frac{p_v}{R_v + T}$$

In the previous equation $\rho_{humid\ air}$ is the humid air density, $p_d$ is the partial pressure of dry air, $p_v$ is the pressure of water vapour, $R_d$ is the specific gas constant for dry air, $R_v$ is the specific gas constant for water vapour and $T$ is the temperature. The $\rho_{humid\ air}$ for 20°C is 1.1936 kg $m^{-3}$, and 1.1215 kg $m^{-3}$ for 35°C, until the density of the dry air is 1.2041 kg $m^{-3}$ for 20°C and 1.1455 kg $m^{-3}$ for 35°C.

The mask was an isotropic porous media with 0.5 porosity and with a linear pressure difference versus mass flow rate function.

For each case, we started the simulation in steady-state and it was running until the 3000$^{th}$ iterations. When the steady-state simulation terminated its values was transferred to a transient (time-dependent) simulation for initial value, which was running until 6 seconds.

In each simulation started with an initial basic mesh, which contains approx. 1.8 million cells, then it was refined with an adaptive mesh refinement algorithm until 3.3 million cells during the steady-state and time-dependent simulations. The refinements for steady-state occurs in every 500$^{th}$ iterations after the 1000$^{th}$ iteration, for transient it occurred at 0.4, 0.8, 1.35, 2, 3, 4.15, and 5 seconds. The initial mesh in the region of the mannequin shown in Figure 12.

In each simulation, the k-ε turbulence model was used with a two-scale wall function based on the Van Driest model.

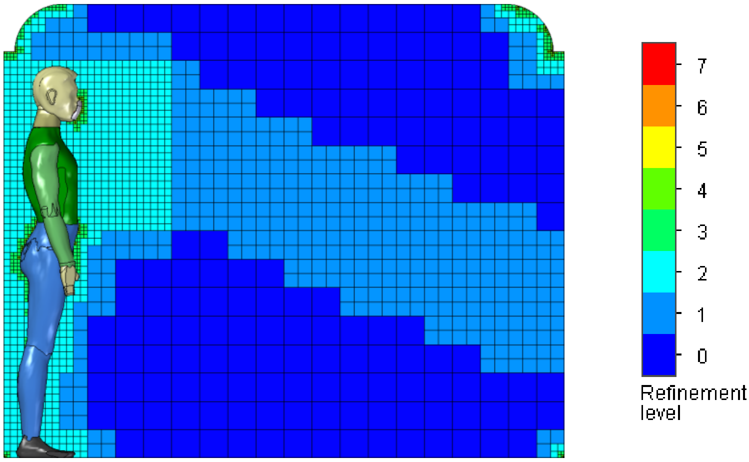


*Figure 12. Initial mesh in the region of the mannequin*

## RESULTS

Before the results for clarity, the simulation was done with a finite volume method (FVM) based computational fluid dynamics (CFD) software, where the cough/sneeze was simulated with a continuum. By the used method we are able the represent the cough puff and its evolution due time, however, the particle-based approach and evaluation not feasible. If we would like to run the simulations with particle tracking a discrete element method based simulation approach is required, e.g. the SPH (smoothed particle hydrodynamics) method or an FVM based VOF (volume of fluid) method with a Lagrangian Multiphase (LMP) resolved transition model.

Each simulation approach has advantages and disadvantages, e.g. simulating the cough as a continuum benefit are lower computing resource requirements and the mathematical model for the porous media, which allows us to use a simplified mask geometry instead of modelling the real geometry of the mask without holes and porous channels. The particle-based approaches benefits are the cough or sneeze simulation with different particle sizes and with this method, the simulation with mask show a realistic result because its true geometry was modelled.

Summarizing the previous thoughts, the FVM based simulations without multiphase transition or any particle-based approach and with porous medium simplification the mask just a volumetric part which dissipates and slows down the flow depending by the pressure and volumetric flow rate of the cough. With this method, we can represent where the flow is able to go, and we are not able to simulate the filtering process of the face mask.

Our first simulation was a base study for comparison where the AC was off. In this case, the total volume of the mannequin's sneeze or cough was 5 litres and it is shown without a mask in Figure 13 and with a mask in Figure 14. In the following figures, the mass fraction of water is represented in the flow field. For the 50% humidity, the mass fraction of the water in the air is 0.0072422341 for 20.05°C, the 100% is 0.0145506907 for 38.3°C. In our figures, for representation, we chose the rendered volume limits to 0.007275 and 0.00735, and the colour chart limits to 0.0072 and 0.00775.

In this case, we were able to observe the sneeze spreading in time, while with a half-splitted isosurface plot we were able to see the internal flow of the sneeze.

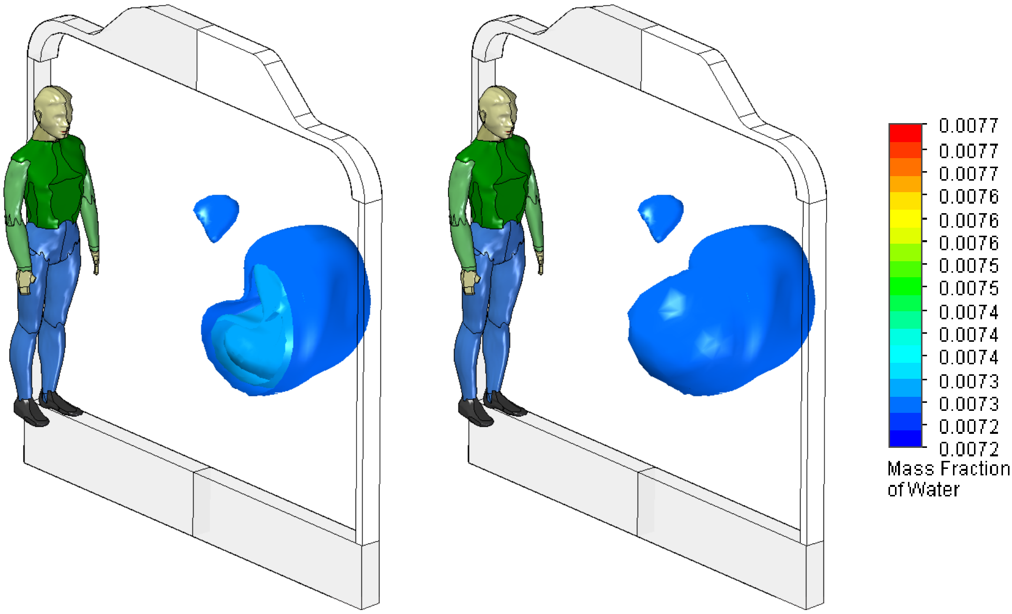


*Figure 13. Sneeze spreading without AC and face mask after the sneezing with 5 seconds (the internal flow of sneeze showed in half-splitted plot and the whole in uncut)*

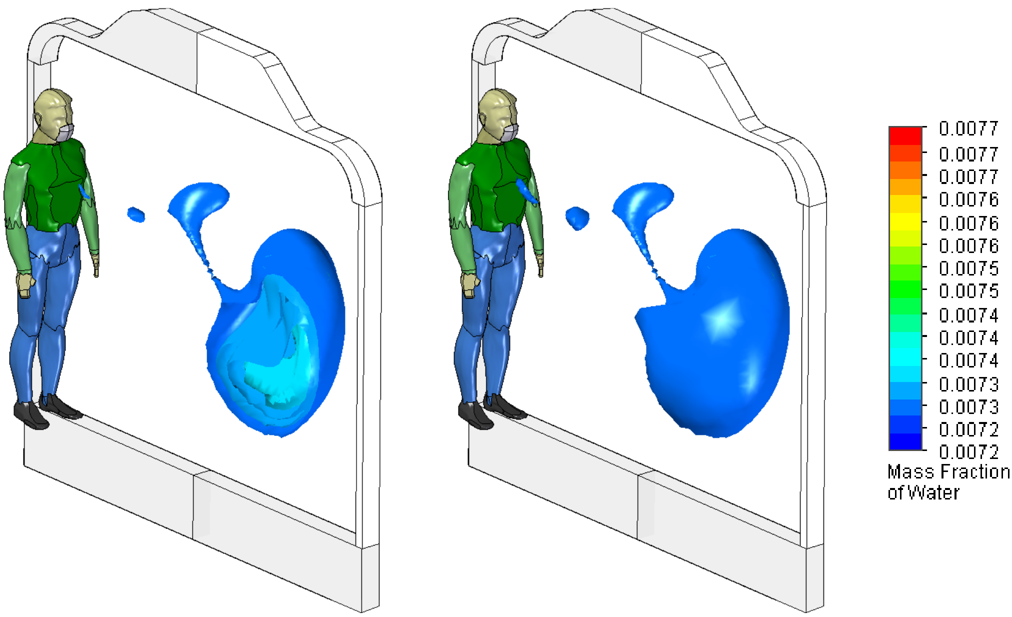


*Figure 14. Sneeze spreading without AC and with face mask after the sneezing with 5 seconds (the internal flow of sneeze showed in half-splitted plot and the whole in uncut)*

Comparing the results with and without a face mask, we observed on the case where the mannequin has no mask, the coughing cloud remain together as a *C* shaped wet cloud with a smaller bubble detachment. In the case where the mannequin has a mask, the *C* shape changed to an "italic" *O* shape with a tail, which is connected with the detached bubble.

The next simulation was running with AC, where the total volume of cough was 2, 4, and 5 litres. The result of the expiratory event is shown in the following figures (Figure 15, Figure 16, and Figure 17) with and without mask after 5 seconds of the cough or sneeze started.

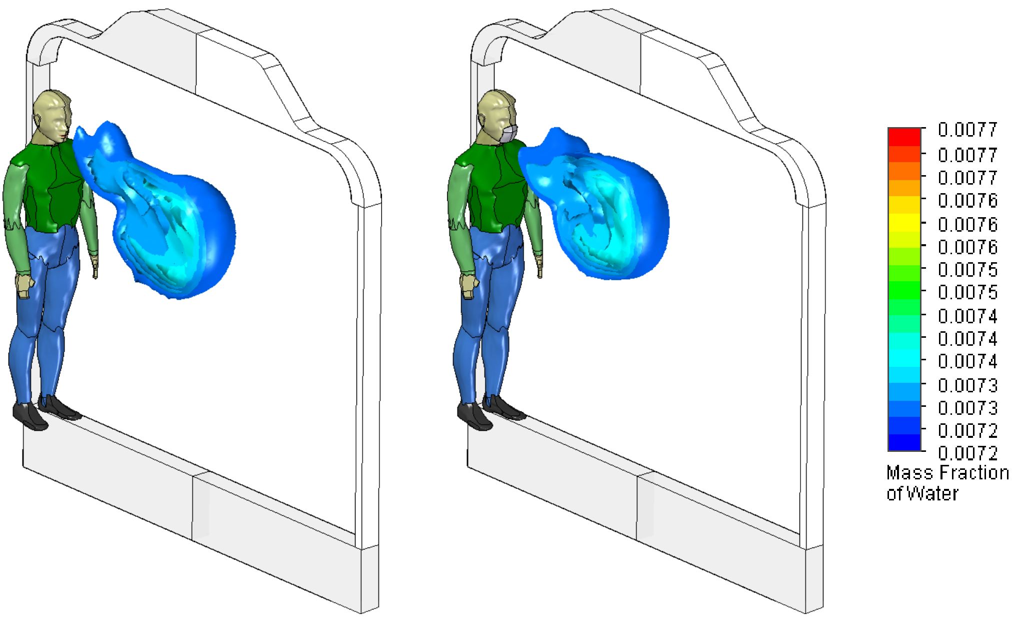


*Figure 15. 2 litres of sneeze spreading with AC and without and with face mask after the sneezing started with 5 seconds (the sneeze was cut in the half for better representation for the internal flows)*

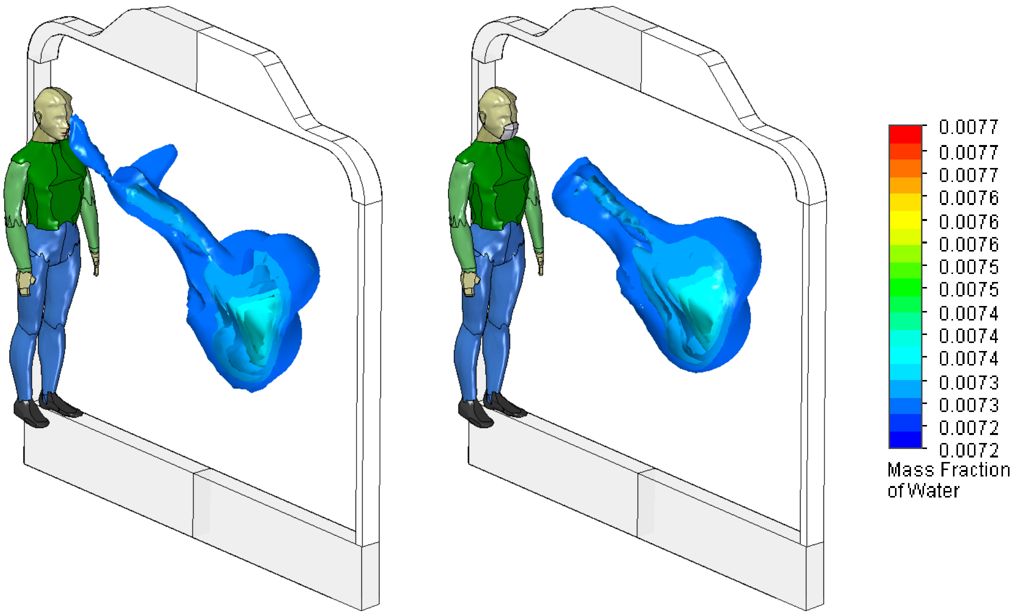


*Figure 16. 4 litres of sneeze spreading with AC and without and with face mask after the sneezing started with 5 seconds (the sneeze was cut in the half for better representation for the internal flows)*

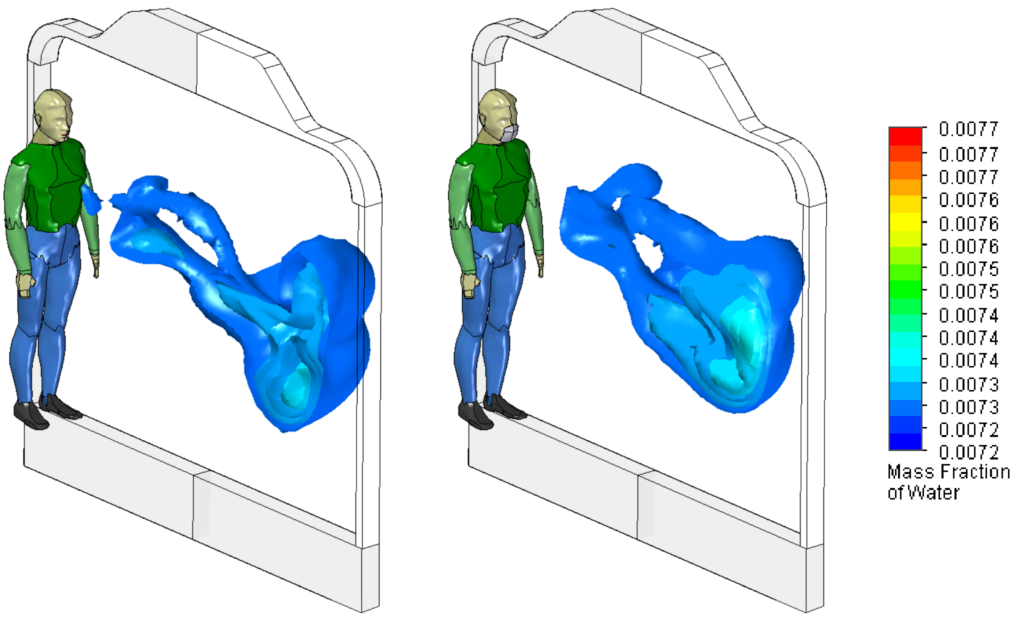


*Figure 17. 5 litres of sneeze spreading with AC and without and with face mask after the sneezing started with 5 seconds (the sneeze cut in the half for better representation for the internal flows)*

In this result, we were able to see a mushroom cloud shape, due to the ACs which has driven the sneezing forward and prevented its spread along the length of the subway. Other hands, we found in a small volume (2 litres) the sneeze shape remains spherical after 5 seconds of the sneeze started and it remains in front of the mannequin. In these cases, we found the puff clouds are longer and narrowed without a mask, because the cough enters into the computational domain without any slowing effect, therefore it has more kinetic energy and it can spread farther. In Figure 18, 0.75 seconds after the cough was ended the remaining cough can see near the mannequin face, without a mask, a small amount of water vapour remaining, while with a mask a larger amount of water vapour gets out of the mask.

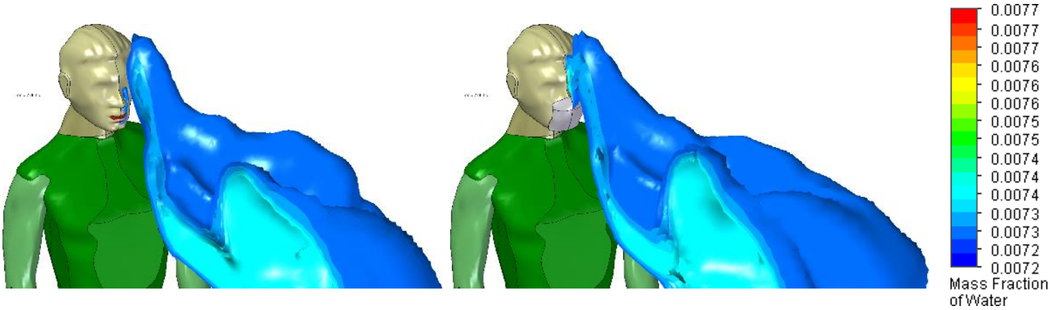


*Figure 18. Sneeze spreading after the sneeze ended with 0.75 seconds without and with a mask*

In the following figures the sneeze spreading shown with opened windows without and with a face mask.

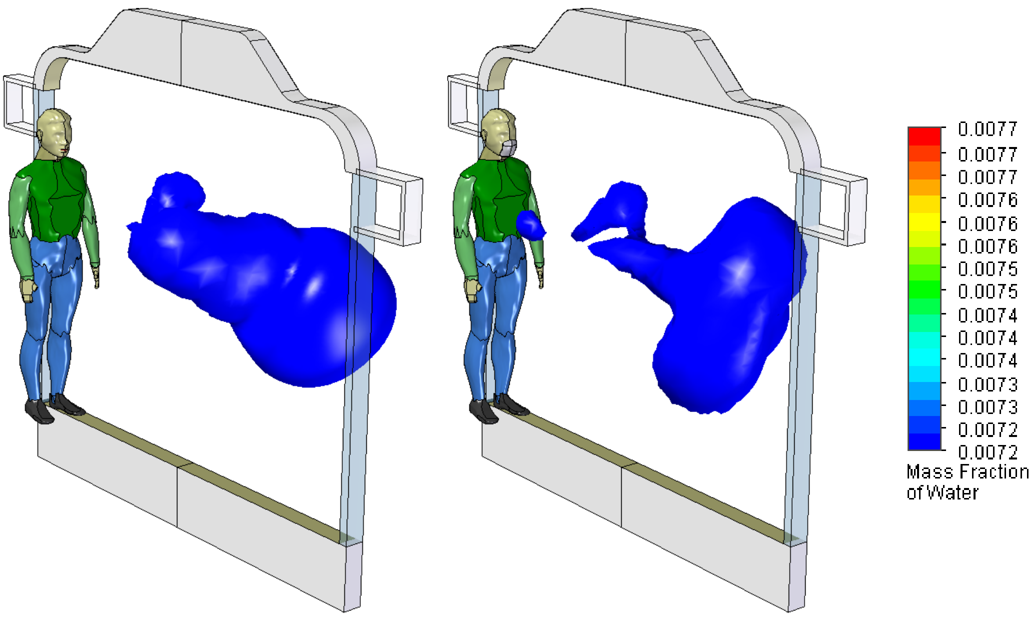


*Figure 19. 5 litres of sneeze spreading with opened windows without and with face mask after the sneezing started with 5 seconds (isometric view)*

In the previous figure the "usual" angle with the half splitted view does not represent well the sneeze, and it could be deceptive because the sneeze is highly unsymmetric. For better visualization, the sneeze is shown from two back views in the next two figures.

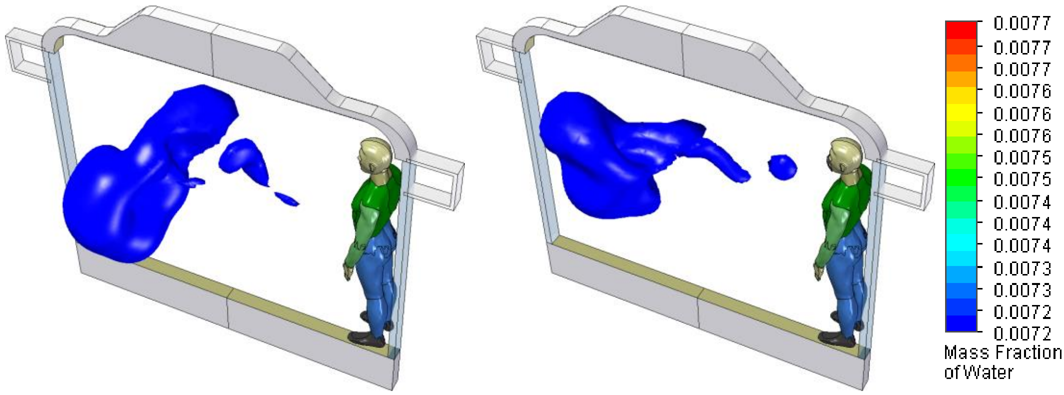


*Figure 20. 5 litres of sneeze spreading with opened windows without and with a face mask after the sneezing started with 5 seconds (back view 1.)*

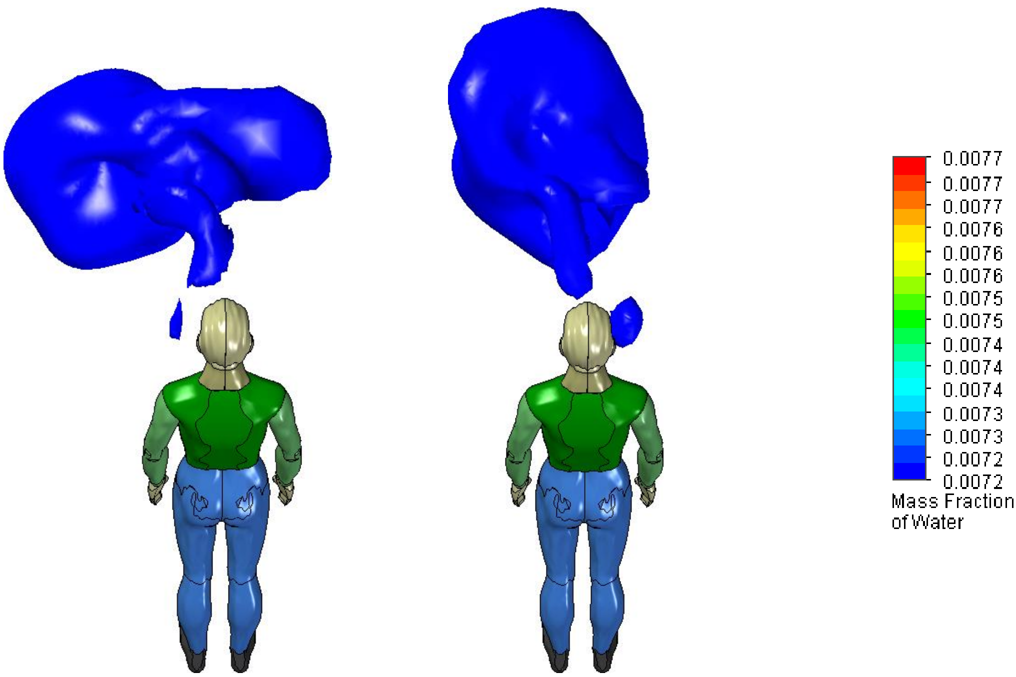


*Figure 21. 5 litres of sneeze spreading with opened windows without and with a face mask after the sneezing started with 5 seconds (back view 2.)*

In the case of open windows, the spatial extent of sneezing was greater to the sides than in the other cases. In these studies, the sneezing spread laterally, but its effect was much smaller than we expected. For better representation of this volume, the cough/sneeze with the travellers and with the subway car interior shown from front view in Figure 22 and Figure 23.

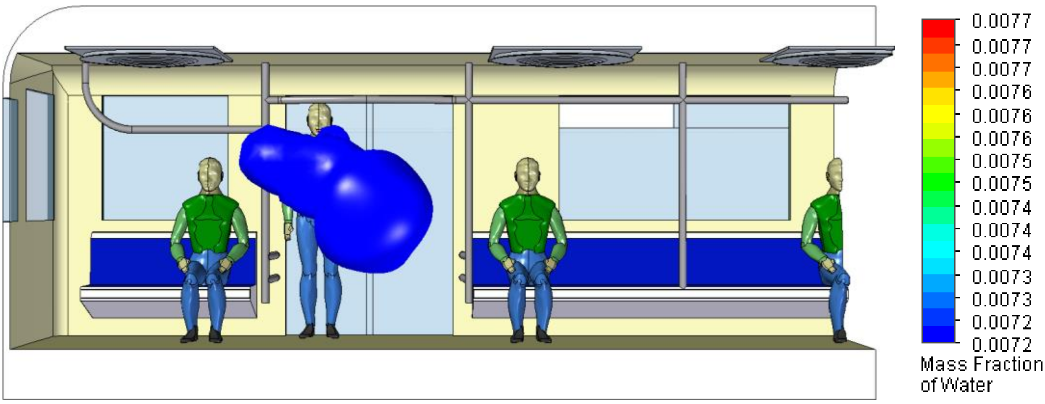


*Figure 22. 5 litres of sneeze spreading with opened windows without a face mask after the sneezing started with 5 seconds (front view)*

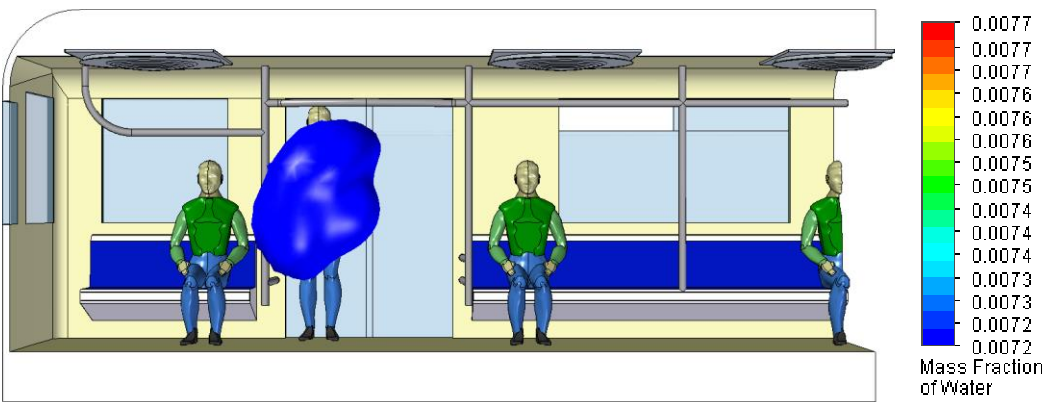


*Figure 23. 5 litres of sneeze spreading with opened windows with a face mask after the sneezing started with 5 seconds (front view)*

The following figures (Figure 24 and Figure 25) shown the cough/sneeze with streamlines.

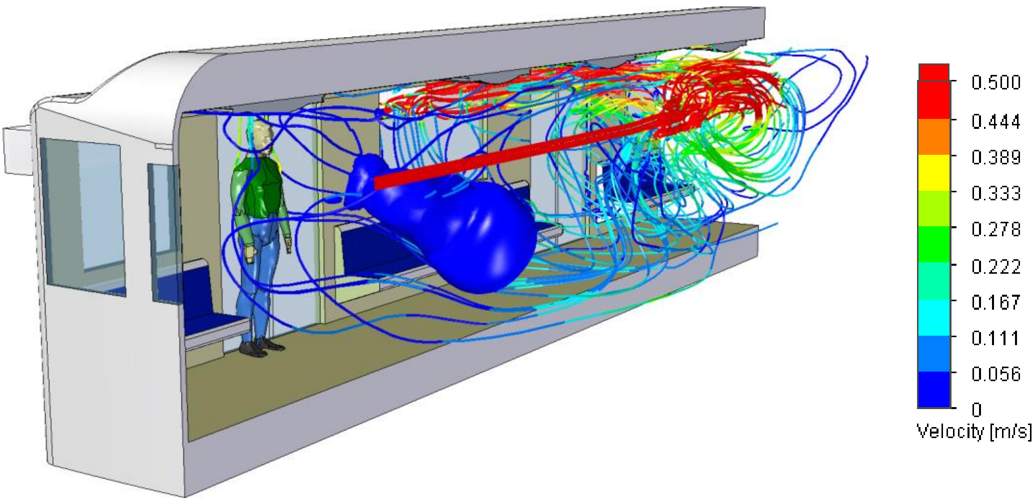


*Figure 24. 5 litres of sneeze spreading with opened windows without a face mask after the sneezing started with 5 seconds (isometric view, with streamlines)*

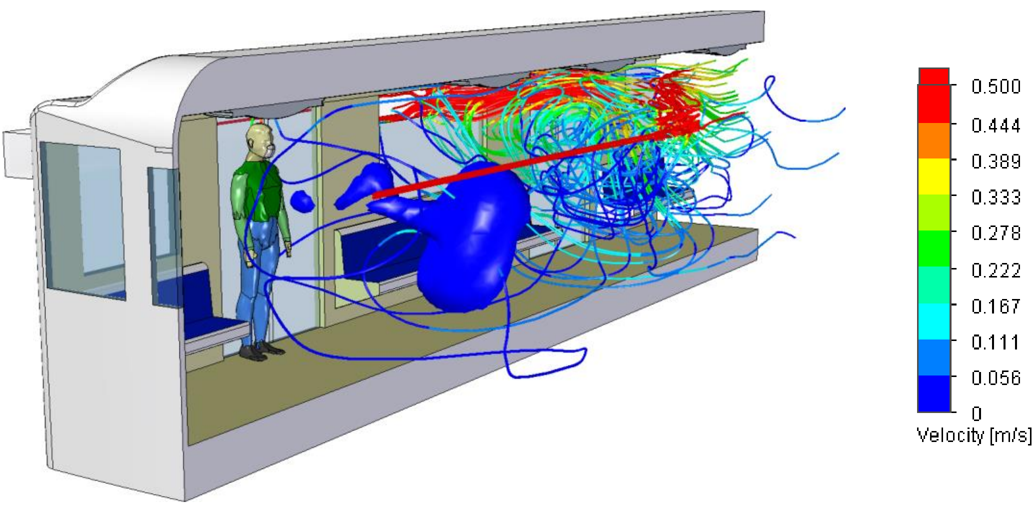


*Figure 25. 5 litres of sneeze spreading with opened windows with a face mask after the sneezing started with 5 seconds (isometric view, with streamlines)*

For the previous cases, the following figures (from Figure 26 to Figure 31) are showing the velocity fields.

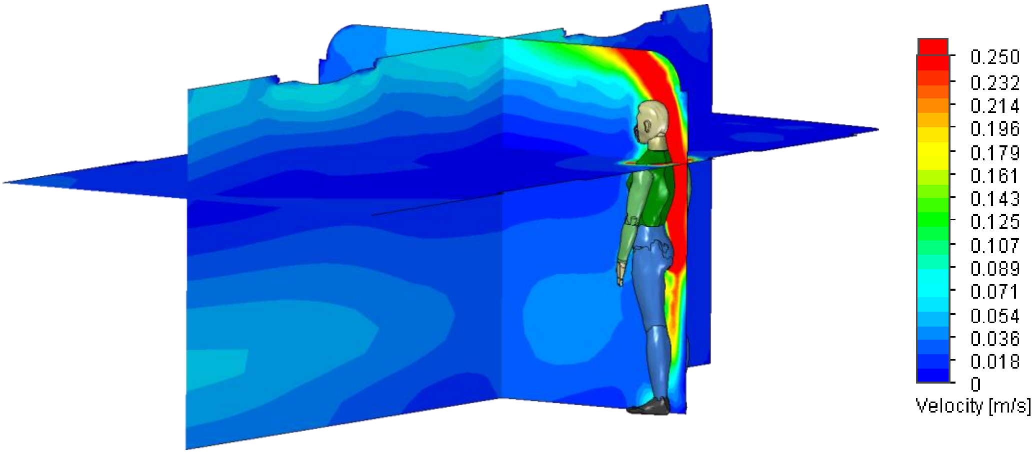


*Figure 26. Velocity filed without AC (section views)*

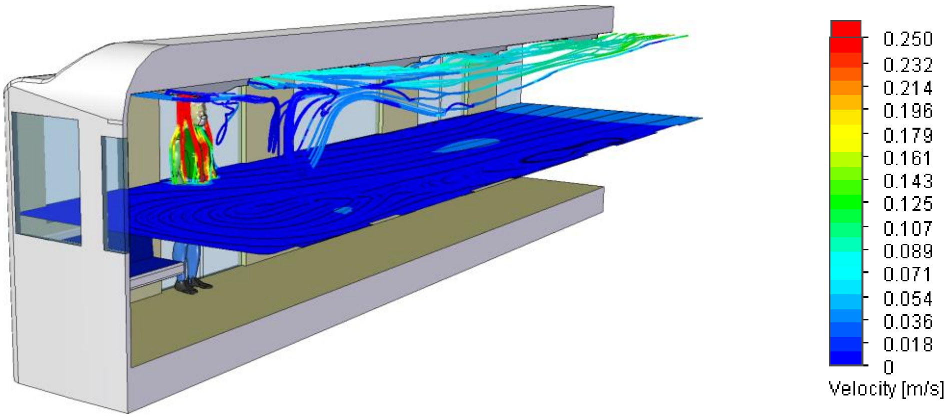


*Figure 27. Velocity filed without AC (isometric view, streamlined from the mannequin)*

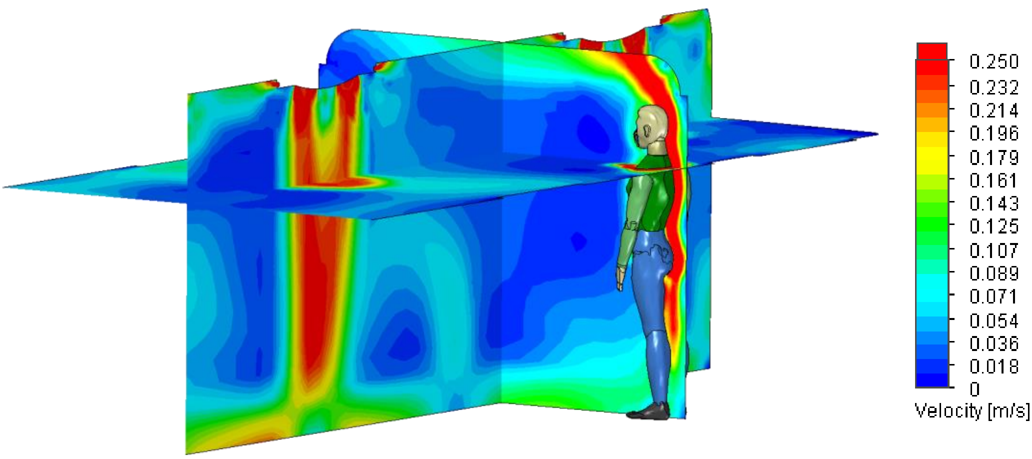


*Figure 28. Velocity filed with AC (section views)*

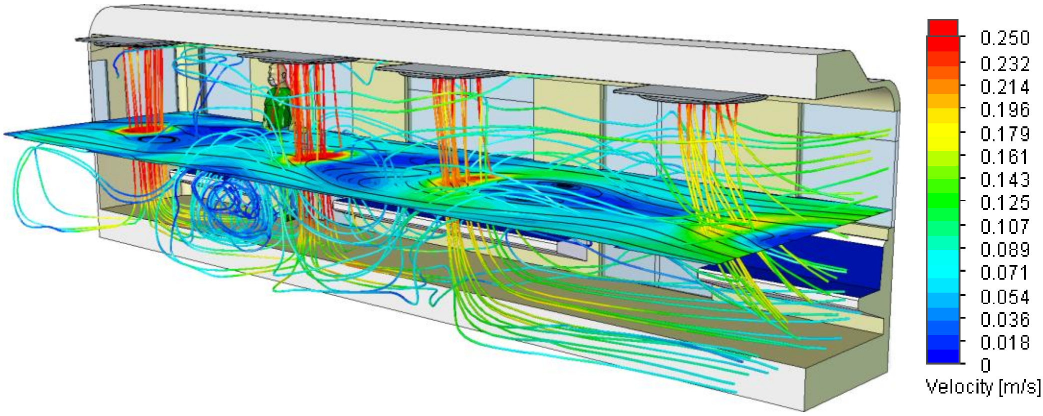


*Figure 29. Velocity filed with AC (isometric view, streamlined from the ACs)*

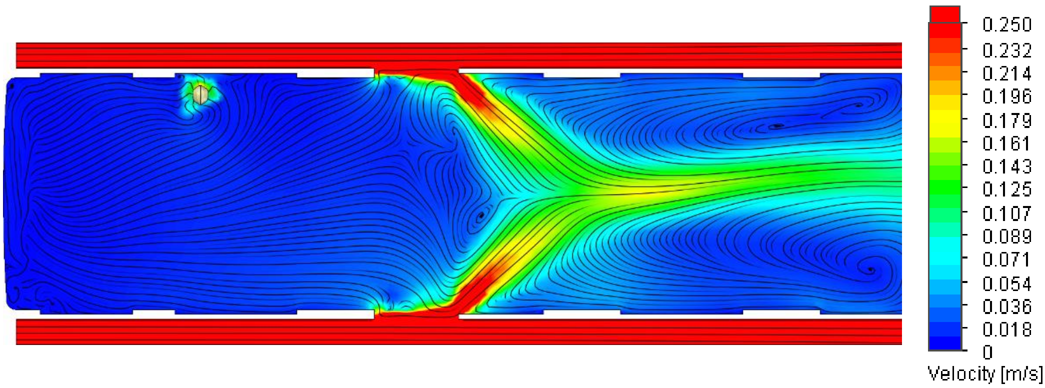


*Figure 30. Velocity filed with opened windows (section view)*

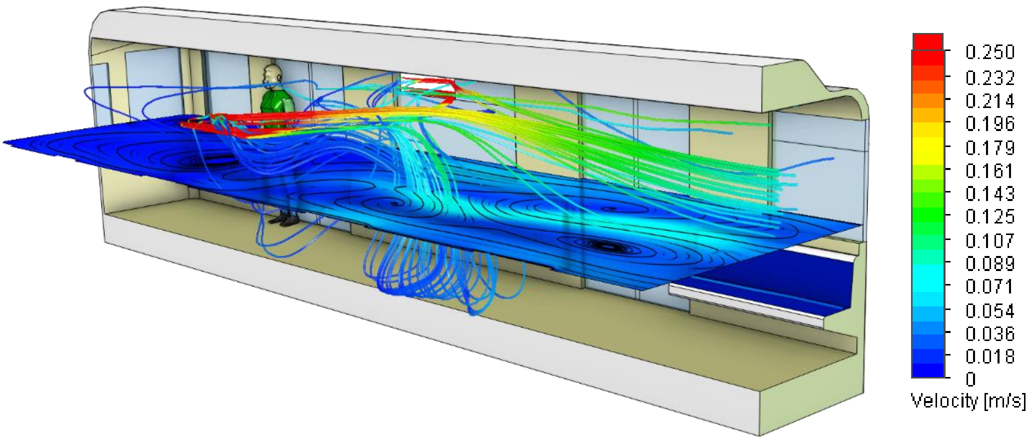


*Figure 31. Velocity filed with opened windows (isometric view, streamlined from the "left" window)*

In Figure 26 and Figure 27, where the AC was off and the windows were closed, we can see an almost non-moving, stationary air. In this case, the flow velocities were non zero, near the mannequin due to his body temperature and it was driven approx. a 0.075 m

$s^{-1}$ airspeed near the ceiling and a 0.035 - 0.05 m $s^{-1}$ airspeed at knee height in the middle of the seat next to the mannequin. In Figure 28 and Figure 29, we can see the same body temperature-driven flow near the mannequin, like in Figure 26 and Figure 27, and we can see the AC driven flow regions under the air conditioner devices. In Figure 30 and Figure 31, we can see the velocity filed at the window and the hip heights and the streamlines in the whole domain (for better and easier visualization just from one window), in this case, the air mixes and the air from the metro train’s front is sucked forward.
Based on the results, the followings can be stated:

1. Using an FVM based CFD software can determine the sneezed or coughed air distribution in the computational domain.
2. With closed windows and without AC, the sneezed or coughed air shape is deformed spherical bubble.
3. With closed windows and with AC the sneezed or coughed air shape is a bubble with a cylindrical tail.
4. With opened windows and without AC the coughed air shape was different in the analysed two cases.
5. With closed windows the sneezed/coughed air typically spreading forward.
6. With opened windows the sneeze/cough spread mostly forward and a little bit laterally by the venturi force, but its effect was much smaller than we expected.
7. The AC’s current baffle plates open outwards (see Figure 32/a and Figure 32/b), which mixes the air. If the AC’s flow was blowing down straight or narrowed (see Figure 32/c), it could create different regions separated by “air walls”, due to the sneeze cannot spread or it would be less likely to spread longitudinally on the metro. The negative effect of this modification is the draft effect, which would decrease the comfort of travellers.
8. The study without AC shows that the air can be stuck around the ceiling. This case with time, the airborne particle due to the buoyancy force can lift and it can remain until an airflow move it to the travelling space [33], therefore the fast and efficient air change is recommended.
9. With closed windows, we were not able to observe the estimated sneeze route (see Figure 8).

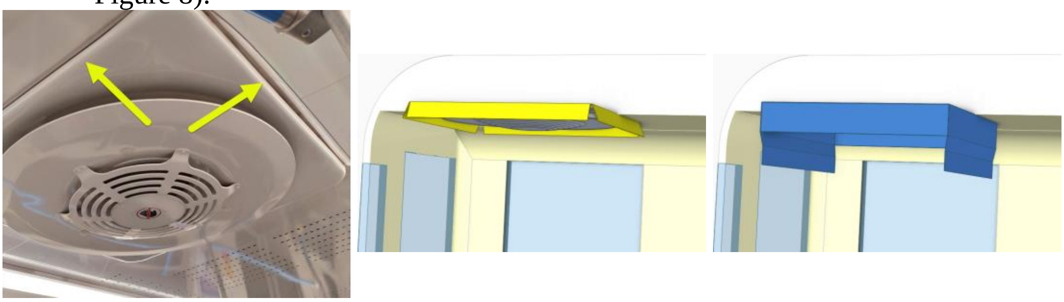

*Figure 32. AC’s baffle plates. a, Current transparent plastic baffle; b, Current transparent plastic baffle (coloured to yellow for better representation in Solid Edge CAD system); c, Recommended AC reducer (coloured to blue for better representation in Solid Edge CAD system)*

For decreasing the probability of infection, according to the WHO [34], the hygiene is important, therefore the following are recommended for the use of public transportation:

- Maintain at least 1-meter social distance.
- Properly wear a mask (it should cover your chin, mouth, and nose).
- Due to the available quantity, use a fabric mask (preferably with multiple layers), if you are in a particular risk group use a medical/surgical mask, or if you are a health worker use a respiratory mask.
- Avoid the closed, crowded places and close contact.
- Regularly and thoroughly clean your hand.
- Avoid touching surfaces which were not cleaned and disinfected, e.g. handrails or ticket machines in the subway.
- Avoid touching your eyes, nose, and mouth.

## SUMMARY

On a pandemic situation, a sneeze or cough can be frightening, and it can cause panic. In this paper, we examined multiple respiratory events with computational fluid dynamic software based on the finite volume method. For determining the sneeze/cough spreading direction we were running the simulations for 5 seconds after the event. With our results, we determined the spreading directions and established some conclusions.

Based on our results we recommend using public transportation with social distancing and with a face mask with the recommendations of the WHO and the other health organization. In one of our case, where the AC was on shown the sneeze spreading almost straight forward, and the sneeze/cough was spreading through the opposite door (approx. 2.5 metres) in 5 seconds (see Figure 17). In this condition, if we are facing with the sneeze or cough a face mask can filter the sneezed air as well and with the social distance, the contact with large particles can be avoided.

Using our results, the spread of sneezing/coughing is visualized in the examined subway car and with these illustrations, the anxiety can be reduced, and the passengers' sense of security can be increased.

## ACKNOWLEDGEMENT

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## APPRENDIX

Our CAD model available here: https://grabcad.com/library/m3-metro-train-renovated-1