Supplemental Material

Hunziker P, Minimizing exposure to respiratory droplets, 'jet riders' and aerosols in air-conditioned hospital rooms by a 'Shield-and-Sink' strategy. BMJ Open 2021

page 1

Supplemental material

Architectural Modeling

Architecture modeling was done within a computational/modeling/multiphysics environment (“A2” Framework, “Matrix” library developed in a joint project of the University of Basel and ETH Zurich, available at [44]) by creating a 3D vector geometry model using the software module “VolumeRaytracer”). Regular multiresolution finite difference grids from size 512x256x256 down to 32x16x16 were then overlaid on the volume data for modeling.

Fluid dynamics modeling

The fluid dynamics model was based on the same multiphysics framework, module “VolumeNavierStokes” and was typically run on the 256x128x128 grid, with a 16-fold oversampling for particle displays. Fluid dynamics used a Backward Time Centered Space approach and modeled fluid advection, diffusion and divergence using a standard operator splitting approach under the assumption of noncompressibility, also incorporating solute injection at the mouth orifice, solute diffusion as well as heat transfer (orifice exit temperature 37°C) and buoyancy. Aerosol production (modeled in this part as solute injection) was proportional to orifice exit velocity. Diffusion coefficients for spheres of 10um, 1um and 0.1um were 3.0E-8, 3.0E-7 and 3.0E-6 cm^2/s, respectively. Each diffusion coefficient required a separate run. Adaptive time stepping was used to limit fluid advection within a step to at most one grid element, resulting in time steps down to 2ms. Measurement probe volumes could be placed within the model to monitor the changes of a local parameter over time. An overall Reynolds number as predictor of turbulent flow conditions was estimated using the room extents and the overall flow, although precise, local Reynolds number in such complicated geometries cannot easily be determined. While water evaporation may lead to size reduction of droplets and changes of transport behavior, as predicted by Wells[45] and by Xie et al.[46] in models not considering room air flow, the moisture carrying capacity of air is reduced ~2 fold upon a temperature drop from 37° to 25°C[47], in principle promoting water *condensation* in the fully saturated warm exhaled air upon cooling, such that the overall droplet size change will depend heavily on many factors, including small scale mixing, may be highly inhomogenous, is difficult to predict by models, is difficult to measure in the real world and was therefore not included in our model.

Particle modeling

Particle modeling using the Eulerian-Lagrangian approach was done using the same framework, with an object-oriented modeling of each particle in a manner allowing overlay of the particles on the fluid dynamics framework. Specifically, individual droplets and aerosols were considered as spheres with density of water in the Lagrangian frame of reference, moving in the air flow that was modeled by fluid dynamics in the Eulerian frame of reference. Physical effects in sphere modeling included ejection velocity at mouth air speed, aerodynamic drag exerted by the surrounding air, gravitational force, and Brownian motion, each including some random variation. Droplets originated at random positions within the orifice, were generated in numbers proportional to the orifice velocity, in size clusters with mean diameters of 1mm, 100µm, 10µm, 1µm and 0.1µm +/- 20%, corresponding to observed droplet sizes in cough and sneezes down the size of a single virus particle. Initial velocity corresponded to the fluid dynamics velocity field with added Gaussian noise (sigma=25%) to velocity vector components. Drag and terminal velocity for each droplet was determined based on the drag equation, switching to the terminal velocity creeping flow solution[48] when Reynolds number was <1. Dynamics for each droplet were modeled, with separate analysis for each size cluster and in combined analysis to understand differential distribution and fate of droplets. Droplet impact

Supplemental Material

Hunziker P, Minimizing exposure to respiratory droplets, 'jet riders' and aerosols in air-conditioned hospital rooms by a 'Shield-and-Sink' strategy. BMJ Open 2021

page 2

on surfaces led to sticking of the particle to said surface. Droplets sticking to a surface or exiting the room through exhaust pipes or door were counted as inhalable in the exposure statistics.

Cough physiology modeling

The airflow model was similar to the one described in PLOS[49]. In short, on coughing an air jet exited from an orifice (area 5cm^2), with a temporal cough flow profile modeled as two-phase event with a first, stronger but short (peak at 0.25 sec) air emission, overlapping with a somewhat longer (peak at 0.5 sec) but less strong air emission, whereby each component was modeled as a cropped (zero to pi) sinus wave, parameterized such that for “strong cough”, “moderate cough” and “normal exhalation” mouth orifice peak velocities approximated 20m/s, 10m/s, and 2.5m/s, respectively.

Submicron particle exhalation imaging

Submicron particle exhalation imaging was achieved by first filming a particle exhaust plume originating from exhaled E-cigarette smoke with a stationary iPhone 6s camera under strong back-lighting illumination conditions in a darkened room, followed by digital subtraction image processing whereby the initial frame is subtracted digitally from subsequent frames (custom software setup, including ImageJ software[50]).

Visualization in movies

Video clips were produced that show the time course of material dispersion after a cough: in modelled video clips (supplemental online movie 1: without source control; supplemental online movie 2: without source control, at high A/C settings; supplemental online movie 3: with “shield and sink” source control) the first three seconds in first 3 seconds in real time, followed by or a 5-minute time window by in time-lapse. In real-life video clips, the first few seconds after a cough are shown (supplemental online movie 4 “NoShieldNoSink_5254.mp4”: without source control; supplemental online movie 5 “Shield&Sink_5252.mp4”: with “shield and sink” source control).

References to supplemental material

[44] https://svn-dept.inf.ethz.ch/svn/lecturers/a2/trunk/ and https://svn-dept.inf.ethz.ch/svn/lecturers/a2/trunk/ocp/Matrix
[45] *Wells, WF. On Air-Borne Infection". American Journal of Epidemiology. 1934; 20: 611–618.*
[46] Xie X, Li Y, Chwang ATY, Ho PL, Seto WH. How far droplets can move in indoor environments – revisiting the Wells evaporation–falling curve. *Indoor Air* 2007; 17, 211
[47] http://engineeringtoolbox.com/maximum-moisture-content-air-d_1403.html
[48] https://en.wikipedia.org/wiki/Terminal_velocity , accessed July 24,2020
[49] Wei J, Li Y., Human cough as a two-stage jet and its role in particle transport. *PloS one 2017; 12:* e0169235.
[50] Schneider CA, Rasband, WS, Eliceiri KW. "NIH Image to ImageJ: 25 years of image analysis", *Nature methods* 2012; 9: 671-675