

Modelling buccopharyngeal droplet dispersion in an intensive care unit for Covid patients



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Plan

1 Introduction

- 2 Numerical model description
- 3 Input data for simulations

4 Results

5 Conclusion and discussion





Context, objectives



Previous project "Flowing system" 2018 - 2020

To design novative system to remove

doors (Partership with the CEREA lab, joint lab

between Ecole des Ponts ParisTech - EDF; C. Flageul,

M. Ferrand, Y. Lefranc, J.-F. Wald, C. Beauchêne)

Objectives:

- Study dispersion and deposition of dropplets
- With and without ceiling air conditionning
- Sensivity study of input parameters
- Identify areas at risk of deposit





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Stochastic Lagrangian Modelling Two-phase dispersped flow

equations of the model for the dispersed phase^{1,2,3,4,5}

$$\begin{split} & \mathrm{d}\underline{X}_{p} = \underline{U}_{p} \mathrm{d}t \\ & \mathrm{d}\underline{U}_{p} = \frac{\underline{U}_{s} - \underline{U}_{p}}{\tau_{p}} \mathrm{d}t + \underline{F}_{ext} \mathrm{d}t \\ & \mathrm{d}\underline{U}_{s} = -\frac{1}{\rho_{f}} \, \underline{\nabla}\overline{P_{f}} \mathrm{d}t + \underline{\nabla}\underline{U}_{l} \left(\underline{U}_{p} - \underline{U}_{l} \right) + \underline{\underline{G}}^{\star} \left(\underline{U}_{s} - \underline{U}_{l} \right) \mathrm{d}t + \underline{\underline{B}}_{s} \mathrm{d}\underline{W} \end{split}$$

- X_{p} : instantaneous particle positions
- \underline{U}_{p} : instantaneous particle velocity
- \underline{U}_{s} : instantaneous fluid velocity seen from the particle
- $\overline{U_f}$: averaged fluid velocity seen by the particle



1. J.-P. Minier and E. Peirano, Physics Reports, 2001, The PDF approach to turbulent polydispersed two-phase flows



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^{2.} E. Peirano, S. Chibbaro b, J. Pozorski and J.-P. Minier, Progress in Energy and Combustion Science, 2006, Mean-field/PDF numerical approach for polydispersed turbulent two-phase flows.

^{3.} J.-P. Minier, Physics Reports, 2016, Statistical descriptions of polydisperse turbulent two-phase flows

^{4.} M. Guingo, J.-P. Minier, Physics of Fluids, 2008, A stochastic model of coherent structures for particle deposition in turbulent flows

^{5.} J.-P. Minier, Progress in Energy and Combustion Science, 2015, On Lagrangian stochastic methods for turbulent polydisperse two-phase reactive flows

Multiphase Turbulent Gas Cloud From a Human Sneeze*

^{*} L. Bourouiba: American Medical Association, Clinical Review & Education, 2020 B.E. Scharfman, A.H. Teechet, J.W.M. Bush, L. Bourouiba: Exp Fluids, 2016, Turbulent Gas Clouds and Respiratory Pathogen Emissions Potential Implications for Reducing Transmission of COVID-19

Stochastic Lagrangian Modelling Two-phase dispersped flow

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- code_saturne model well suited to poly-dispersed phases (sedimentation)
- Time integration inumerical scheme robust even when particles become fluid particles $(d_{\rho} = 0)$
- Dispersion models consistant with second order moment methods (well suited for dispersion next to the source)
- Model consitant with the turbulence model of the carrying fluid



Multiphase Turbulent Gas Cloud From a Human Sneeze*



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Input data for the simulations Injection zone



Injection cylinder

- ^{1,2} Air/dropplets mixiture injected volume V: 0,75L;
 1,5L;
- ^{1,2} Injection time *T*: 250*ms* ; 500*ms* ;
- Angle of injection (relative to the horizontal line) ϕ : 45°; 60°;
- 5+2 classes of particle diametres d_p : 1mm; 0, 5mm; 0, 1mm; 10 μ m; 1 μ m; 0, 3 μ m; 0, 1 μ m;
- Numbre of particles per class n_p: 10⁶ (convergence of statistics ~ 1%c)

1. B.E. Scharfman, A.H. Techet, J.W.M. Bush, L. Bourouiba: Exp Fluids, 2016, Visualization of sneeze ejecta: steps of fluid fragmentation leading to respiratory droplets 2. J.W. Tang, et. al.Plos One, 2013, Airflow Dynamics of Human Jets: Sneezing and Breathing - Potential Sources of Infectious Aerosol



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Input data for simulations Ejection velocity



Caugh dispersion¹, 1000 images/s, (a) 0, 005s, (b) 0, 008s, (c) 0, 015s, (d) 0, 032s, and (e) 0, 15s.

1. B.E. Scharfman, A.H. Techet, J.W.M. Bush, L. Bourouiba: Exp Fluids, 2016, Visualization of sneeze ejecta: steps of fluid fragmentation leading to respiratory droplets



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Input data for simulations Ejection velocity



Sneeze dispersion¹, 1000 images/s, (a) 0, 007s, (b) 0, 03s, (c) 0, 107s, (d) 0, 162s, (e) 0, 251s, and (f) 0, 34s.

1. B.E. Scharfman, A.H. Techet, J.W.M. Bush, L. Bourouiba: Exp Fluids, 2016, Visualization of sneeze ejecta: steps of fluid fragmentation leading to respiratory droplets



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Droplet dispersion [4/10]



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Animation of the particle dispersion and desosition, V = 1, 5L, T = 250 ms, $\phi = 45^{\circ}$.



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Deposit $d_p = 1 \mu m$, $V = 1, 5L, \phi = 45^{\circ}$.



M. Ferrand Droplet dispersion [6/10]







Deposit $d_p = 1 \mu m$ after 15 s, $V = 1, 5L, \phi = 45^{\circ}$.



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Deposit $d_p = 10 \mu m$ after 15 s, $V = 1, 5L, \phi = 45^{\circ}$.



M. Ferrand Droplet





Deposit $d_p = 0$, 1*mm after 15 s*, V = 1, 5*L*, $\phi = 45^{\circ}$.



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Deposit $d_p = 0$, 5*mm after 15 s*, V = 1, 5*L*, $\phi = 45^{\circ}$.



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Deposit $d_p = 1$ mm after 15 s, $V = 1, 5L, \phi = 45^{\circ}$.



M. Ferrand Drop



Residence time of dropplets – Deposited particules (all classes) With air conditionning



Residence time of dropplets – Deposited particules (all classes) Without air conditionning





 $V = 1, 5L, T = 250 \text{ms}, \phi = 45^{\circ}.$ **M. Ferrand** Droplet dispersion [8/10]



Performances



Animation of the deposition $d_p = 1 \mu m$, $V = 1, 5L, \phi = 45^{\circ}$.

- Time step $\Delta t = 1 ms$;
- Physical time simulated $T \simeq 20s$;
- CPU time for a run $\simeq 23h$ (4 \times 35 = 140 procs).

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Droplet dispersion [9/10]



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Conclusion



Deposit on the ground, $d_p = 1 \mu m$

Results

- Dispersion: the finer the dropplets, the farther they go
- Sensisitvity performed on input parameters
- Areas with a high risk of deposit: the lamp and nearby equipment; the floor is more impacted when the ceiling is in operation
- Residence time ≤ 30s, major influence of the ceiling air system



