Modeling deposition and resuspension of aerosols in an Euler/Euler approach

Quentin BEY , Florian COHN & Jérémie TACHE

FLUIDIAN - Immeuble “Les Bureaux de Cergy”
2, rue des Chauffours - 95000 Cergy

INTRODUCTION

Determining human exposure to aerosol particles during an indoor dispersion requires a key parameter which is the rate of deposition and resuspension of particles from the surfaces. The modeling of such phenomenon is therefore an important issue to simulate accurately the evolution of airborne particles in confined spaces.

We have implemented dedicated models for deposition and resuspension of aerosols using Code_Saturne in an Euler/Euler approach. Aerosols are supposed to be dry, well-mixed and electrically neutral. Turbulence is modeled with a RANS (k-ε) model. Particles movements are considered to not affect airflow.
In these models, deposition and resuspension on smooth surfaces are evaluated with semi-empirical models as a function of particle size, density and friction velocity. We finally confronted the simulation results with experimental data from literature.

METHODS

Aerosol transport

A “drift–flux” model has been adopted from [1]. A drift velocity consisting of gravitational settling is added to the transport equation of airborne concentration.

$$\frac{\partial C}{\partial t}+\frac{\partial}{\partial x_i}\left[\left(U_i+V_{s,i}\right)C\right]=\left(D_b+D_t\right)\frac{\partial^2 C}{\partial x_i^2}+S_c$$

$$\vec{V_s}=\frac{d_p^2\rho_p Cu}{18\mu}\vec{g}$$

C concentration (part.m^{-3})
D_t turbulent diffusion coefficient (m².s^{-1})
D_b Brownian diffusion coefficient (m².s^{-1})
U air velocity (m.s^{-1})
V_s gravitational settling velocity (m².s^{-1})
S_c source therm (part.m^{-3}.s^{-1})
ρ_p particules density (Kg.m^{-3})
d_p particules diameter (m)
Cu Cunningham number

Walls Boundary Conditions

A flux balance between deposited particles and resuspended ones is computed on walls at each iteration.

$$J=F_d-F_r$$

J total particles flux (part.m^{-2}.s^{-1})
F_d deposition flux (part.m^{-2}.s^{-1})
F_r resuspension flux (part.m^{-2}.s^{-1})

Deposition

The particle deposition rate is assumed to be determined only by local concentration, turbulent flow field in the vicinity of the wall and surface orientation. A semi-empirical model [2] is employed to evaluate the local deposition rate.

$$F_d=V_d C_{bulk}$$

V_d deposition velocity (m.s^{-1})
C_{bulk} bulk concentration (part.m^{-3})

Resuspension

We implement a force balance model [4] that considers that the resuspension rate depends on the resultant force F acting on deposited particles.

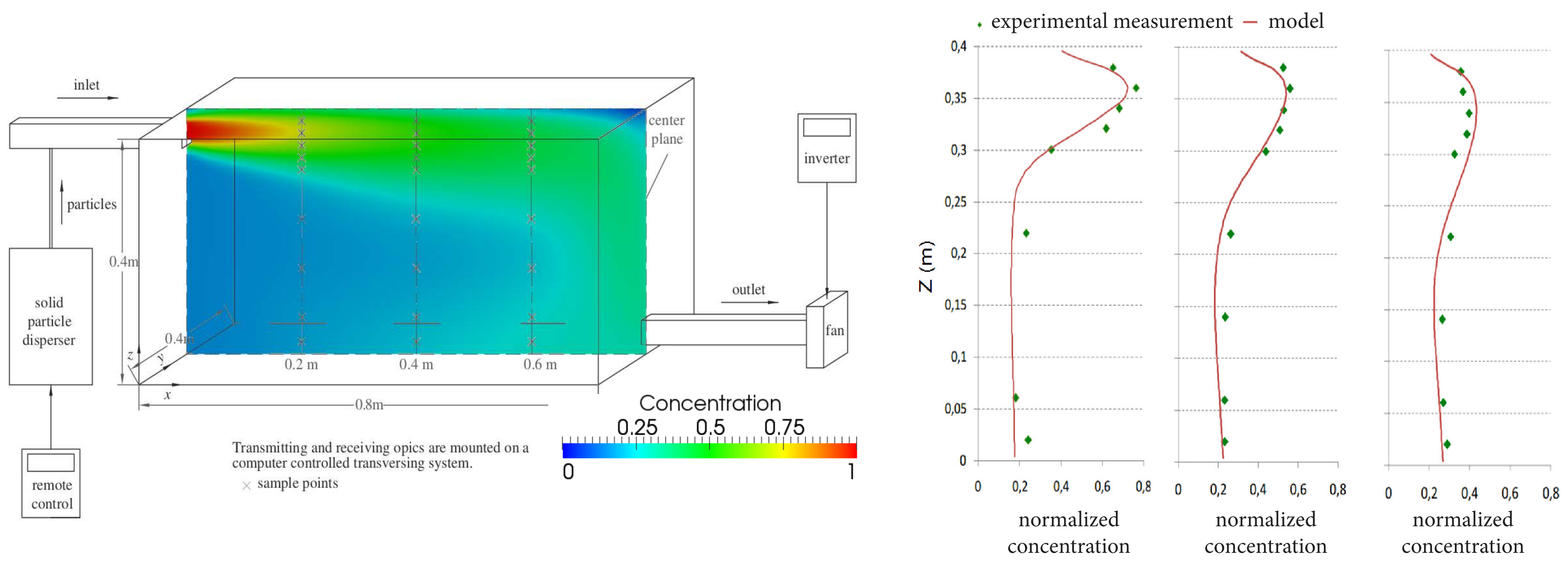
$$F_r=\Lambda C_{surf} \qquad \Lambda=A\left(F\right)^B$$

$$F=F_{drag}+F_{lift}-\left(F_{gravity}+F_{cohesive}+F_{friction}\right)$$

F force balance (µN)
Λ is resuspension rate (s^{-1})
$F_{gravity}$ gravity force (µN)
$F_{friction}$ friction force(µN)
A and B are empirical coefficients
F_{lift} lift force including a shape factor (µN)
F_{drag} drag force including a shape factor (µN)
C_{surf} amount of particles lying on the surface (part.m^{-2})
$F_{cohesive}$ cohesive cause by intermolecular attraction (µN)

RESULTS AND VALIDATION

We simulate an experiment described in [3] with Code_Saturne. Particles of 10 µm diameter with a density of 1400 Kg/m³ are injected in a chamber as shown on figure below. Normalized concentration at x=0.2m, 0.4m and 0.6m are provided by the author on the symmetry plane. The results show that sedimentation effect in the test room has a large effect on steady concentration field of particles. Numerical results agreed well with provided measurement data.

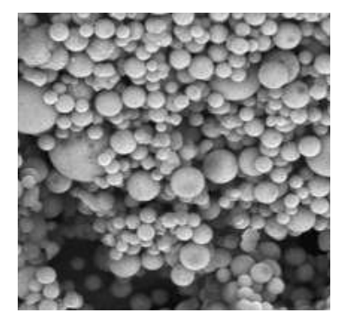


Chen (2005) “Modeling particle distribution and deposition in indoor environments with a new drift–flux model”

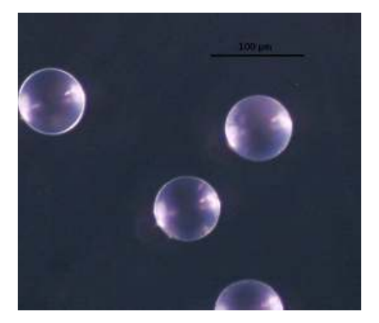
We validated the resuspension model by simulating two wind tunnel experiments from literature [5] [6]. Particles are initially deposed on a test surface as a uniform single layer in both experiments. Several kinds of particles with different characteristics have been used by authors.

Lycopodium Spores
1180 Kg/m³
28 µm

Timothy pollen
1000 Kg/m³
34 µm

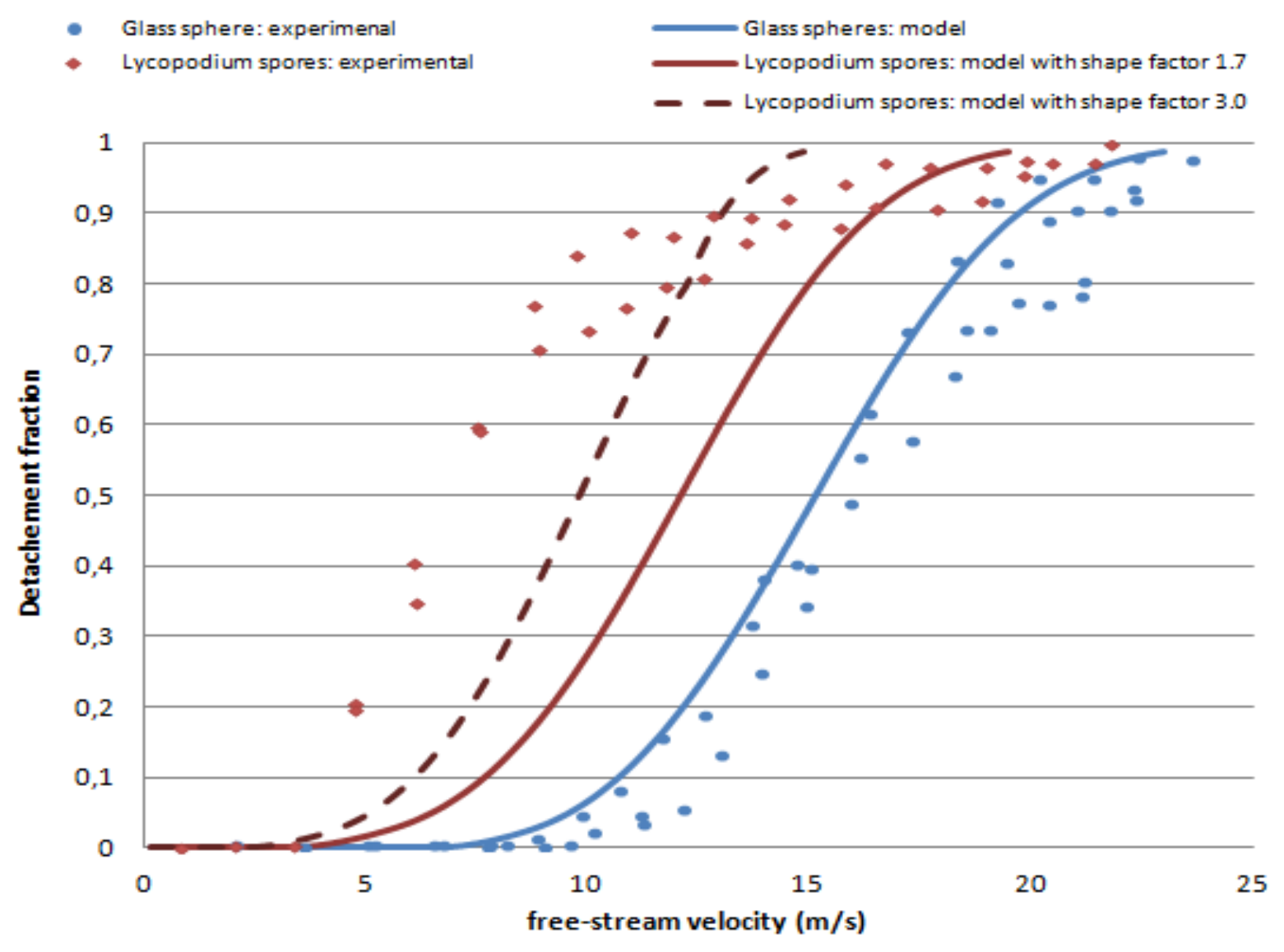


Microballoons
1140 Kg/m³
30 µm

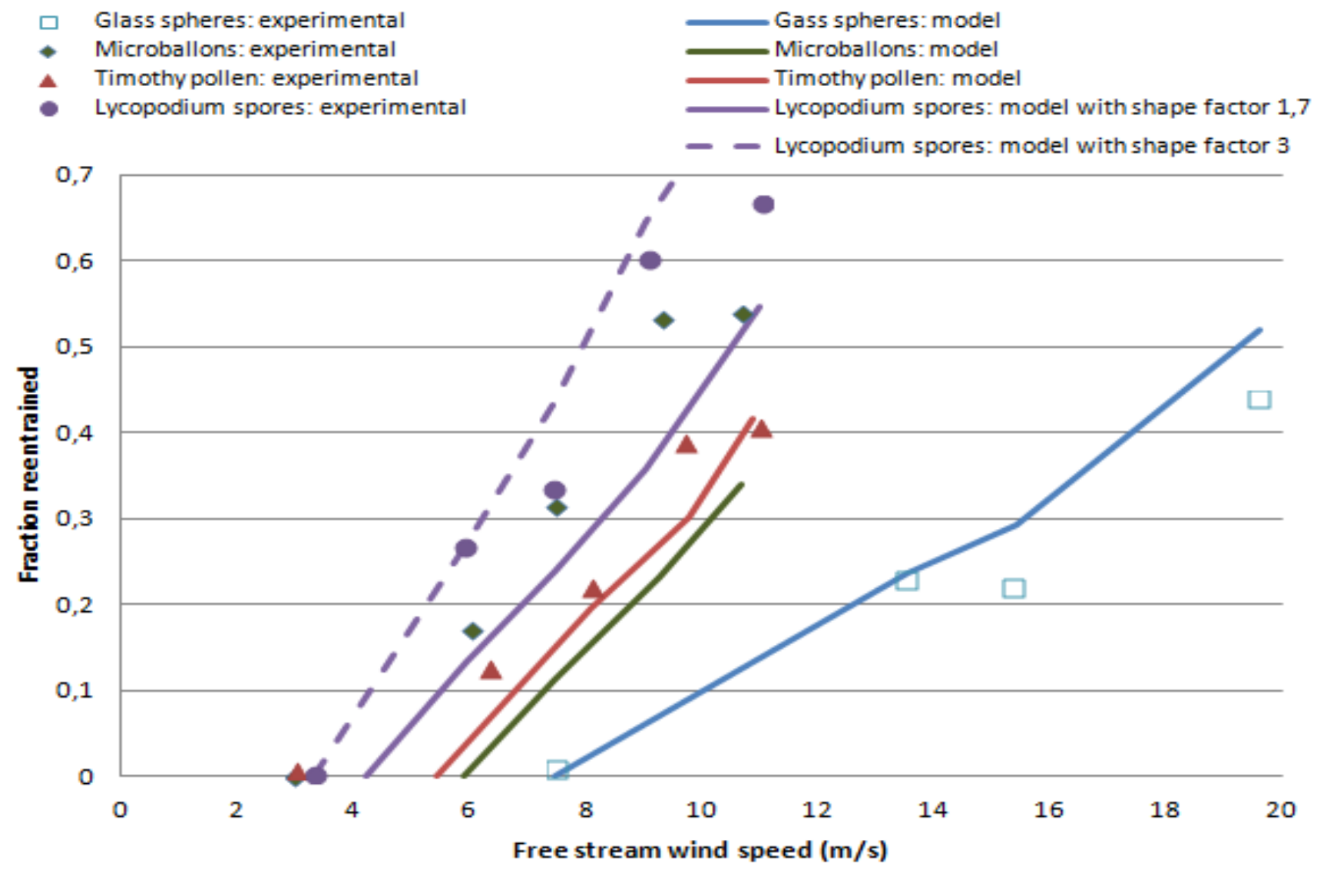


Glass spheres
2420 Kg/m³
20 and 32 µm

Simulation results we obtained agreed reasonably with experimental measurements for non-porous spherical particles. The resuspension rate increases with flow velocity. A key parameter for estimating resuspension rate seems to be the diameter of considered particles.
Concerning some kind of particles (spores of Lycopodium) we had to introduce a special geometric shape factor to improve agreement with measurements. This additional factor is inlcuded in drag and lift forces and is meant to take into account porosity and non-spherical shape of particles.



I. Essawey (2004) “Microparticle detachment from surfaces by fluid flow”



David A. Braaten (1994) “Wind tunnel experiments of Large Particle Reentrainment Deposition and Development of Large Particle Scaling Parameters”

CONCLUSION

Interactions between particles and walls alter the probability of human exposure in confined spaces since a deposited particle cannot be inhaled unless resuspended. In indoor environment, activities surrounding the settled particles are substantial. This increases the risk of overbalancing the gravity and adhesion forces, leading to a resuspension of particles.

An Euler/Euler deposition and resuspension model has successfully been implemented in Code_Saturne through Fortran user routines. Test cases found in literature have been reproduce and compared to simulation results.

Our results are in good agreement with experimental data. The use of an adjusted physical «shape factor» in the resuspension model allows better agreement for specific particles.

REFERENCES

[1] **Murakami (1992)** “Diffusion characteristics of airborne particles with gravitational settling in a convection-dominant indoor flow field.”
[2] **Lai, A.C.K. et Nazaroff (2002)** “Effects of room furnishing and air speed on particle deposition rates indoors.”
[3] **Chen (2005)** “Modeling particle distribution and deposition in indoor environments with a new drift–flux model”
[4] **Parozzi, F. and Tagliaferri, L. (2000)** “Improvement of the dry aerosol resuspension model of ECART code in the light of STORM results”
[5] **I. Essawey (2004)** “Microparticle detachment from surfaces by fluid flow”
[6] **David A. Braaten (1994)** “Wind tunnel experiments of Large Particle Reentrainment Deposition and Development of Large Particle Scaling Parameters”
[7] **F Archambeau, N Méchitoua, M Sakiz (2004)** “Code_Saturne : a Finite Volume Code for the Computation of Turbulent Incompressible Flows - Industrial Applications, International Journal on Finite Volumes, Vol. 1, 2004.”
[8] **Nerisson, Philippe (2009)** “Modélisation du transfert des aérosols dans un local ventilé”

FURTHER INFORMATION

Fluidian is a consulting and development firm specialized in computational fluid dynamics and open-source solutions. We offer CFD services covering the whole R&D spectrum, from modeling of physical phenomena to the development of software and computational solutions. We provide expertise from various sectors such as industry, construction, defense and security. More information are available on our web site at www.fluidian.fr.

These developments were funded by Thales Communications & Security (Vélizy, France) and have been conducted within a project concerning biological and chemical dispersion in critical infrastructures (subway stations, airports ...).

Several others models were implemented to meet the needs for such CFD simulations, such as train traffic effect on flows, chemical dispersion from a volumetric source term or evaporated puddle, virtual sensors of different types, structural alerts and countermeasures on HVAC conditions or train traffic.