Advanced Computational Fluid Dynamics Modelling of Water Sprays in Fire-Driven Flows

22nd IWMC– 11/10/2023
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Promotors: Tarek **Beji**
Bart **Merci**

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IWMA
International Water Mist Association

fwo

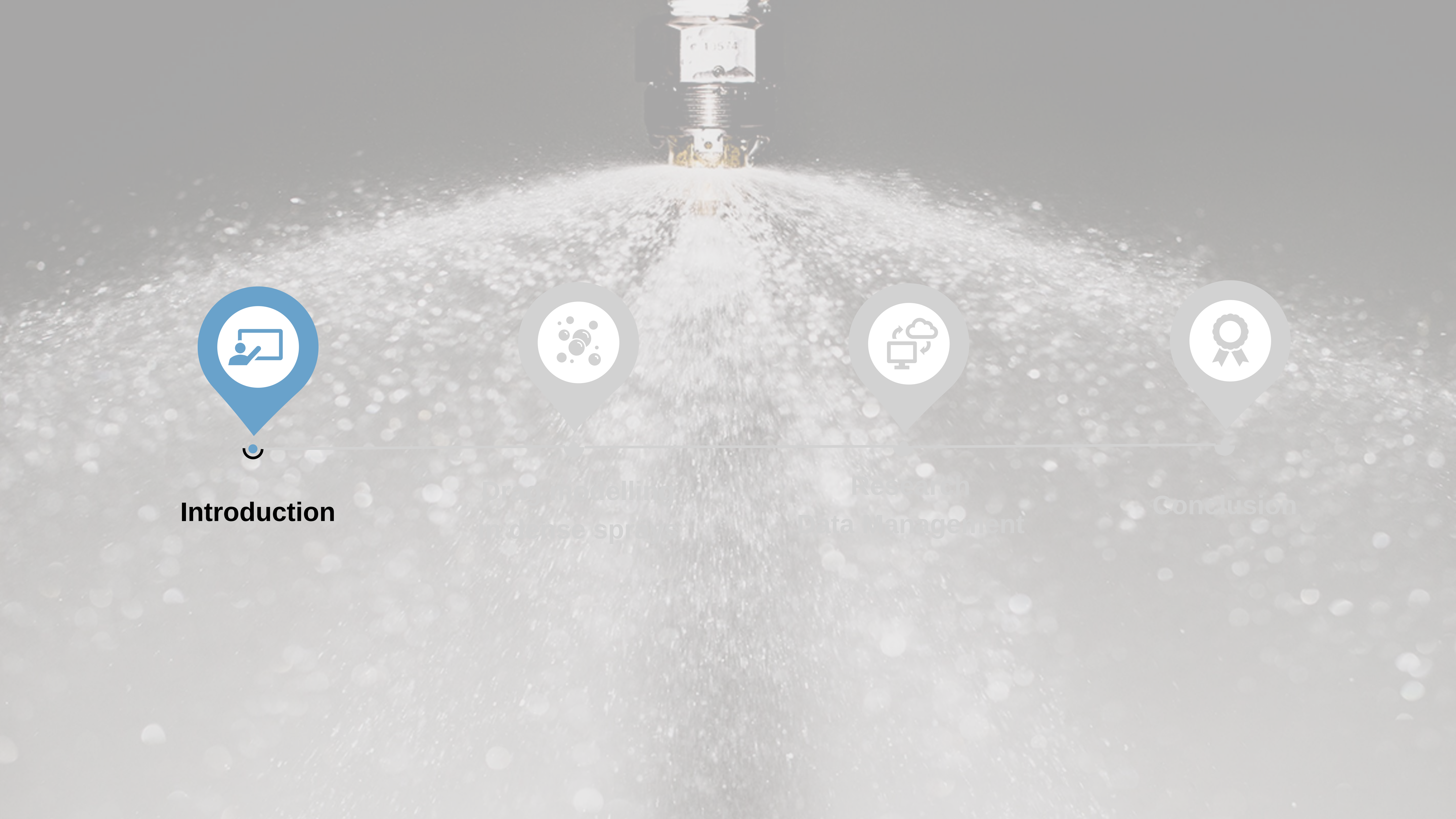
Mandate number : 1182919N

Introduction

Drag modelling in dense sprays

Research Data Management

Conclusion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INTRODUCTION

➢ **Long-term objective:**

'Improve the predictive capabilities of CFD modelling of water sprays interaction with fire-driven flows'

Evaluate existing models:

- Droplet heat-up → ~ large droplets → Sprinklers
- Drag reduction in dense sprays → ~ fine droplets → Water mist

➢ **More fundamental approach → stepwise approach**

- Simple test cases prior to more complex test cases
- In-house code prior to CFD

FIRE DYNAMICS SIMULATOR

- FDS
  - Particularly appropriate for thermally-driven flows
  - Simulation of water sprays : Eulerian-Lagrangian approach

Gas phase

Liquid phase
(water droplets)

  - Computational droplets : representative droplets with same properties and weighting factor

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in dense sprays

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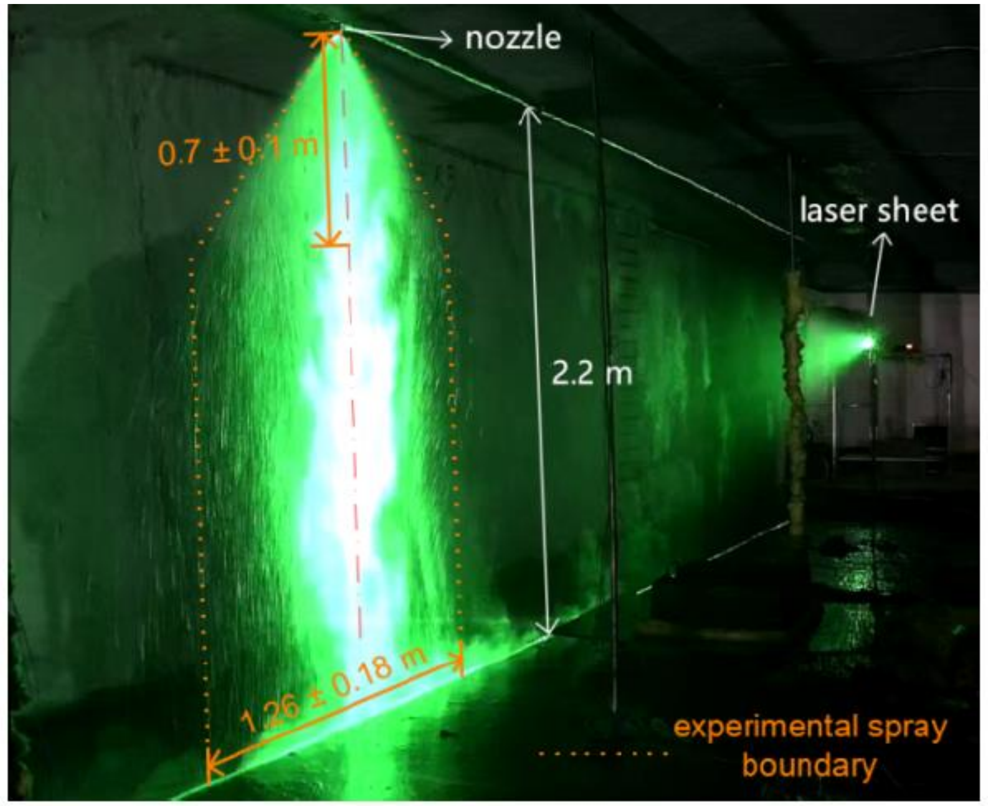
I. WUHAN SPRAY

EXPERIMENTAL DATA

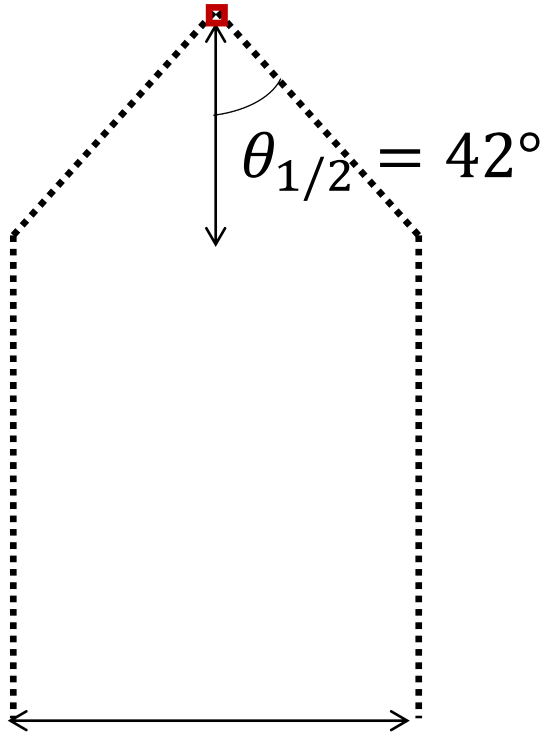
➢ **Cold flow**

$\dot{q} = 1\ L/min,\ \theta_{1/2} = 42°,\ d_0 = 90\mu m$

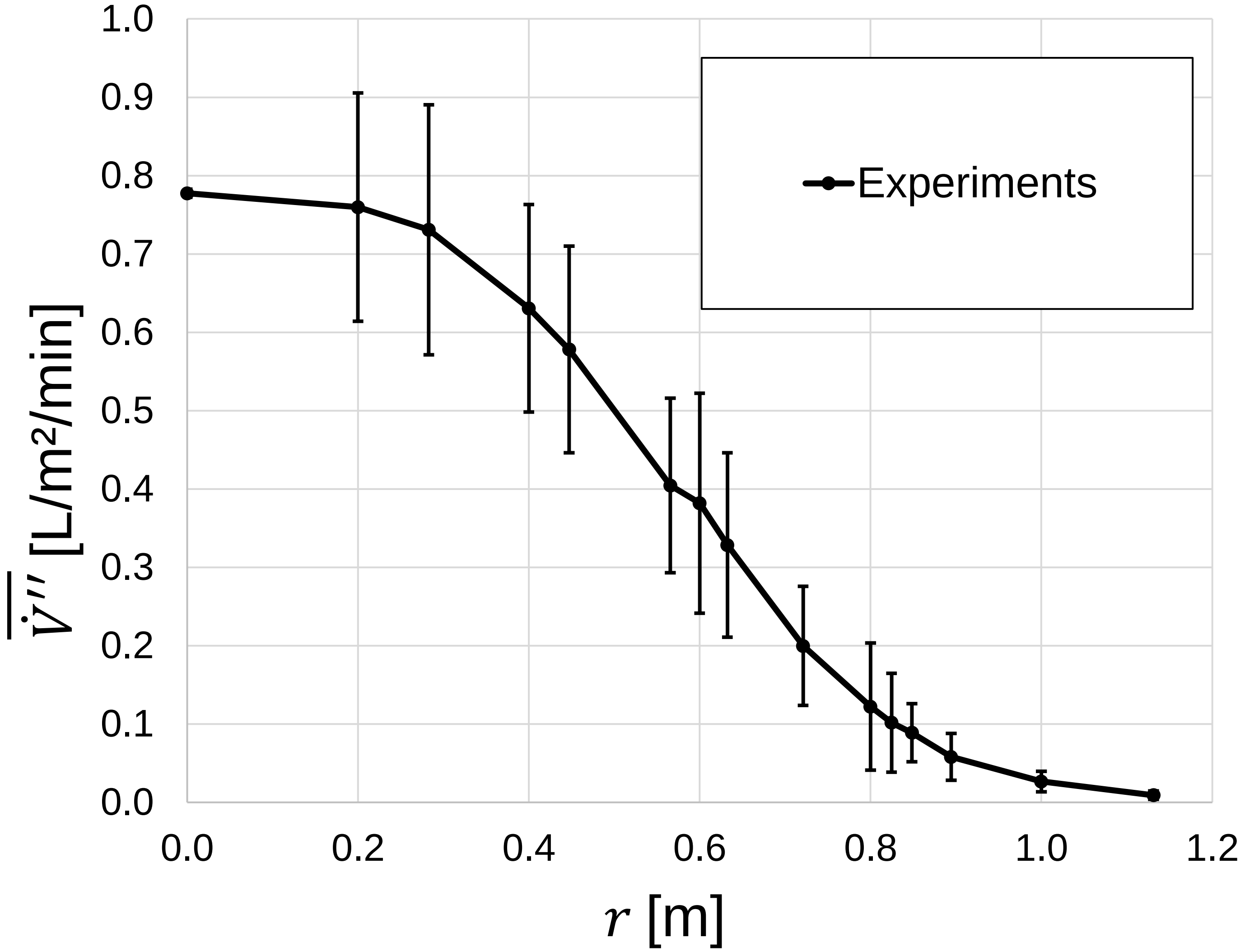
➢ Spray envelope



Configuration and laser sheet visualization of the spray from [1]



➢ Water flux density at the ground floor



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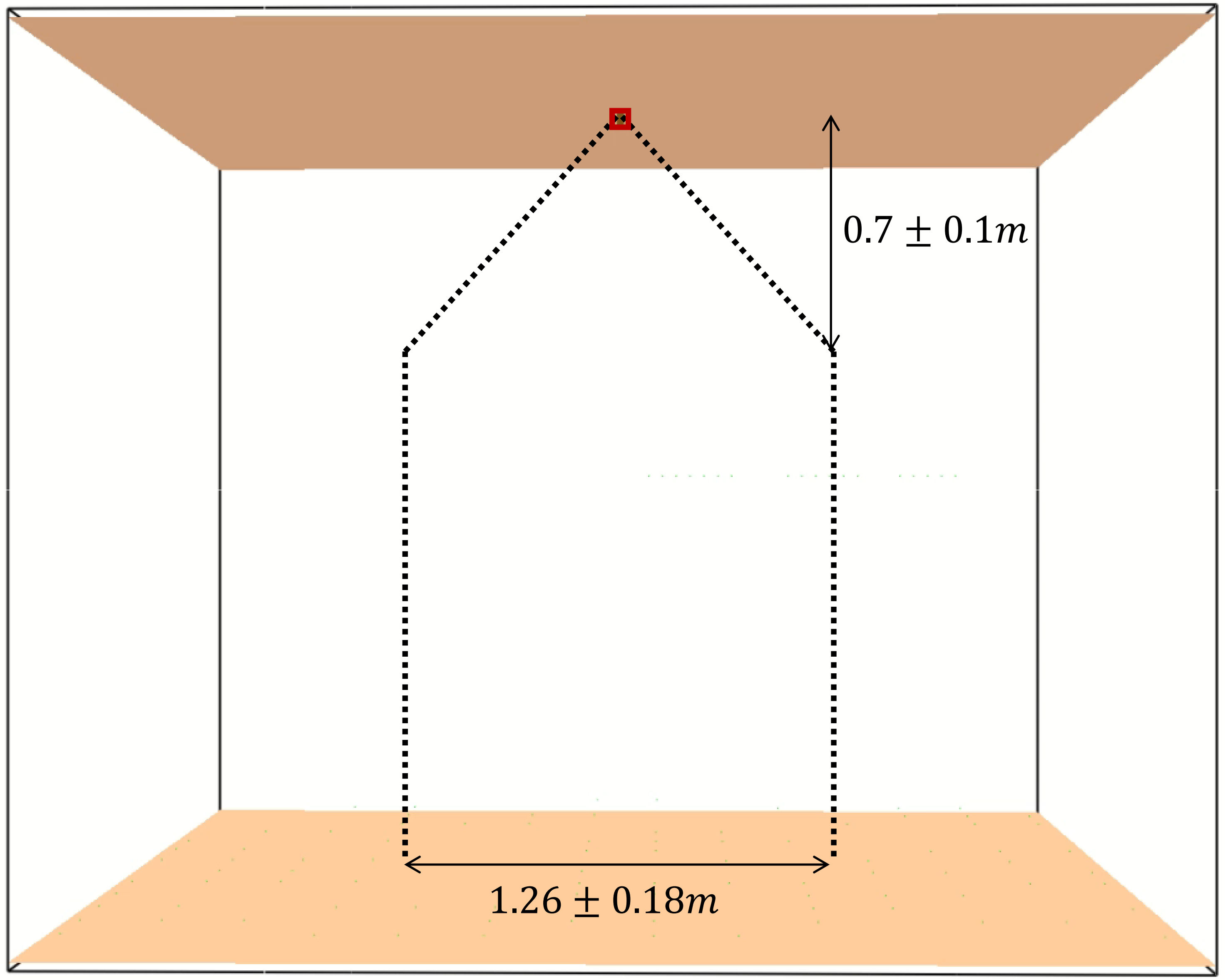
BASE CASE SIMULATION RESULTS

Default FDS 6.7.6

➢ Spray envelope



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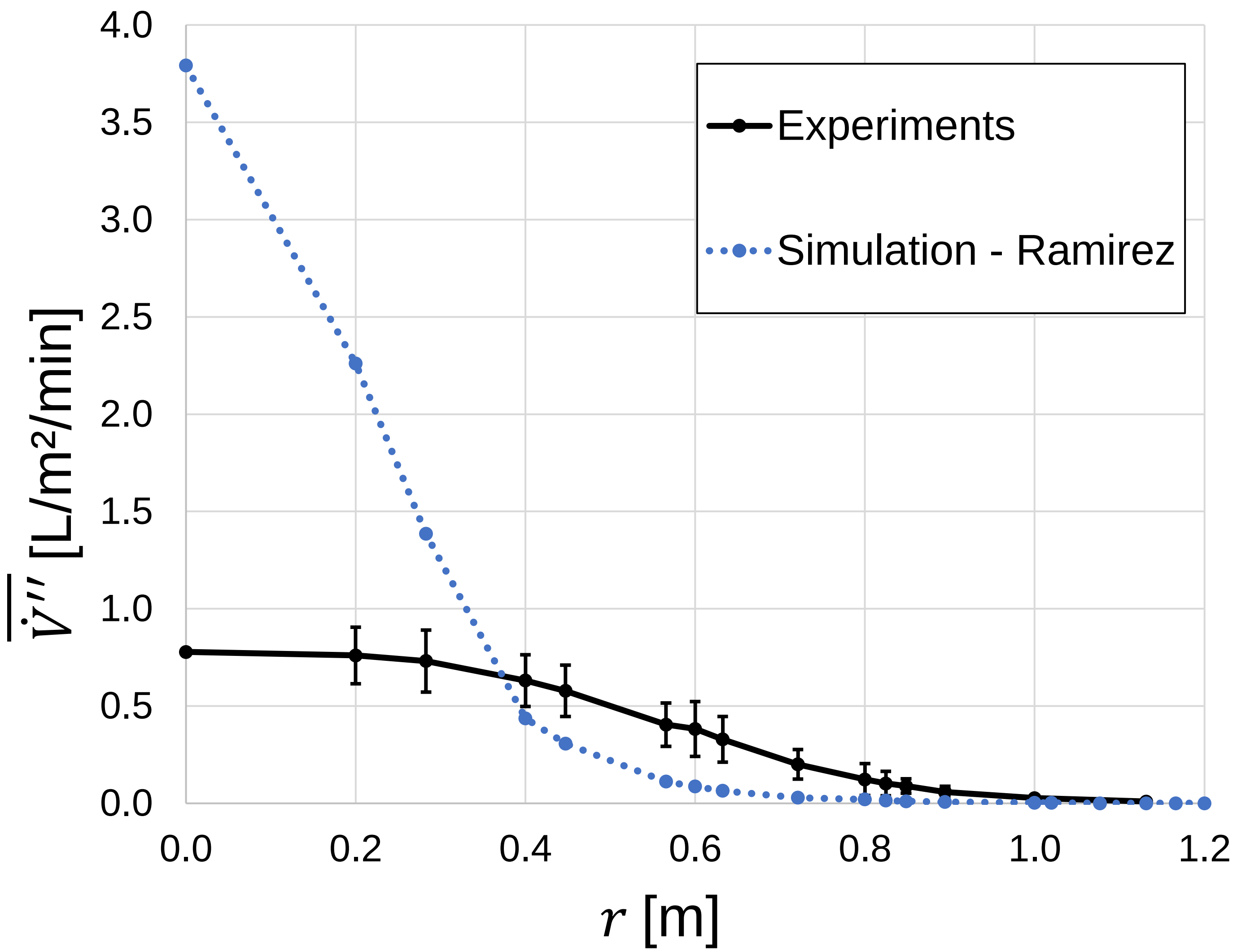

➔ Extensive numerical analysis

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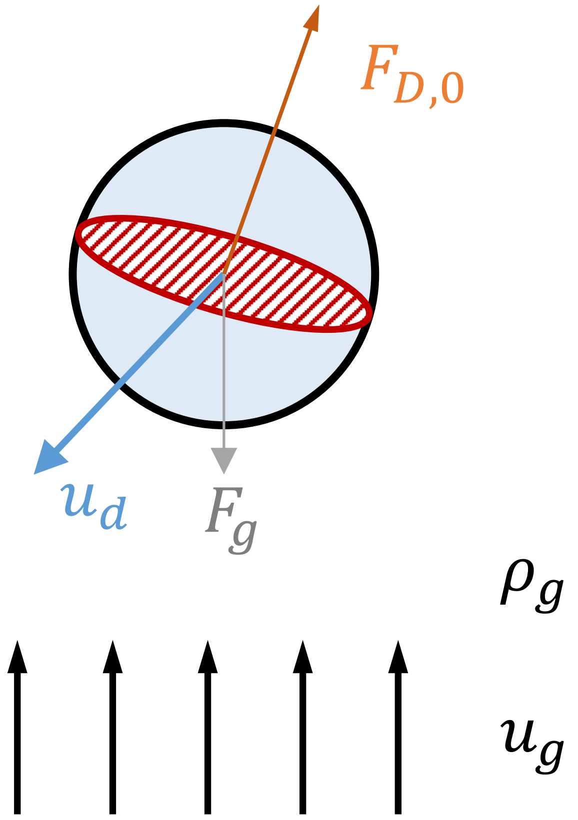
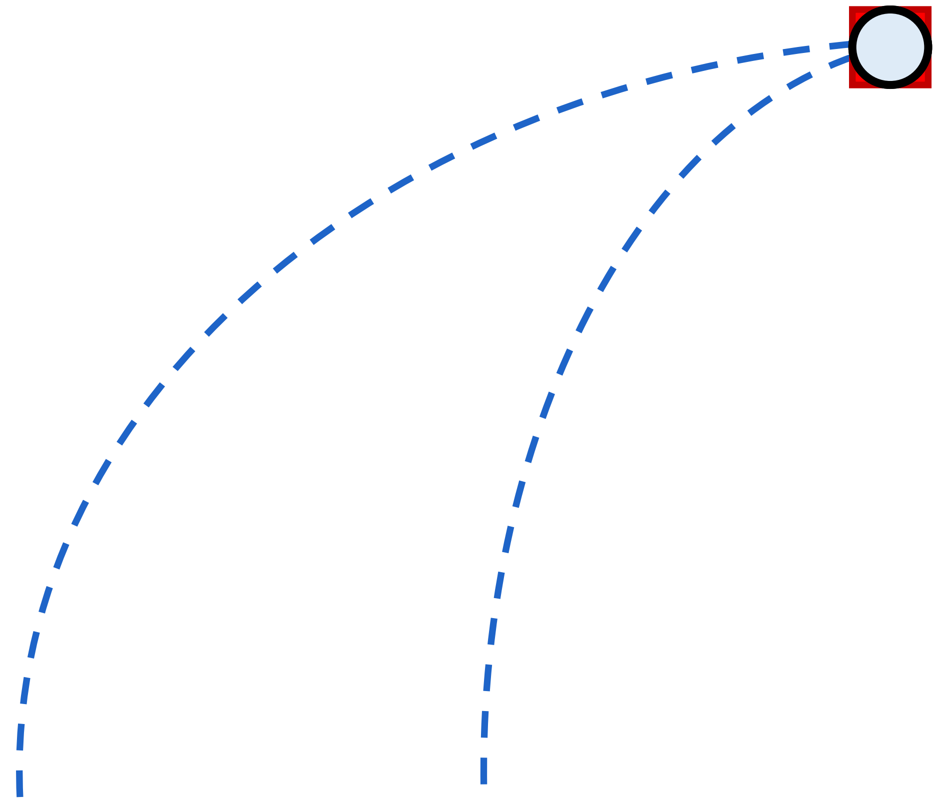
TRAJECTORY OF A PARTICLE

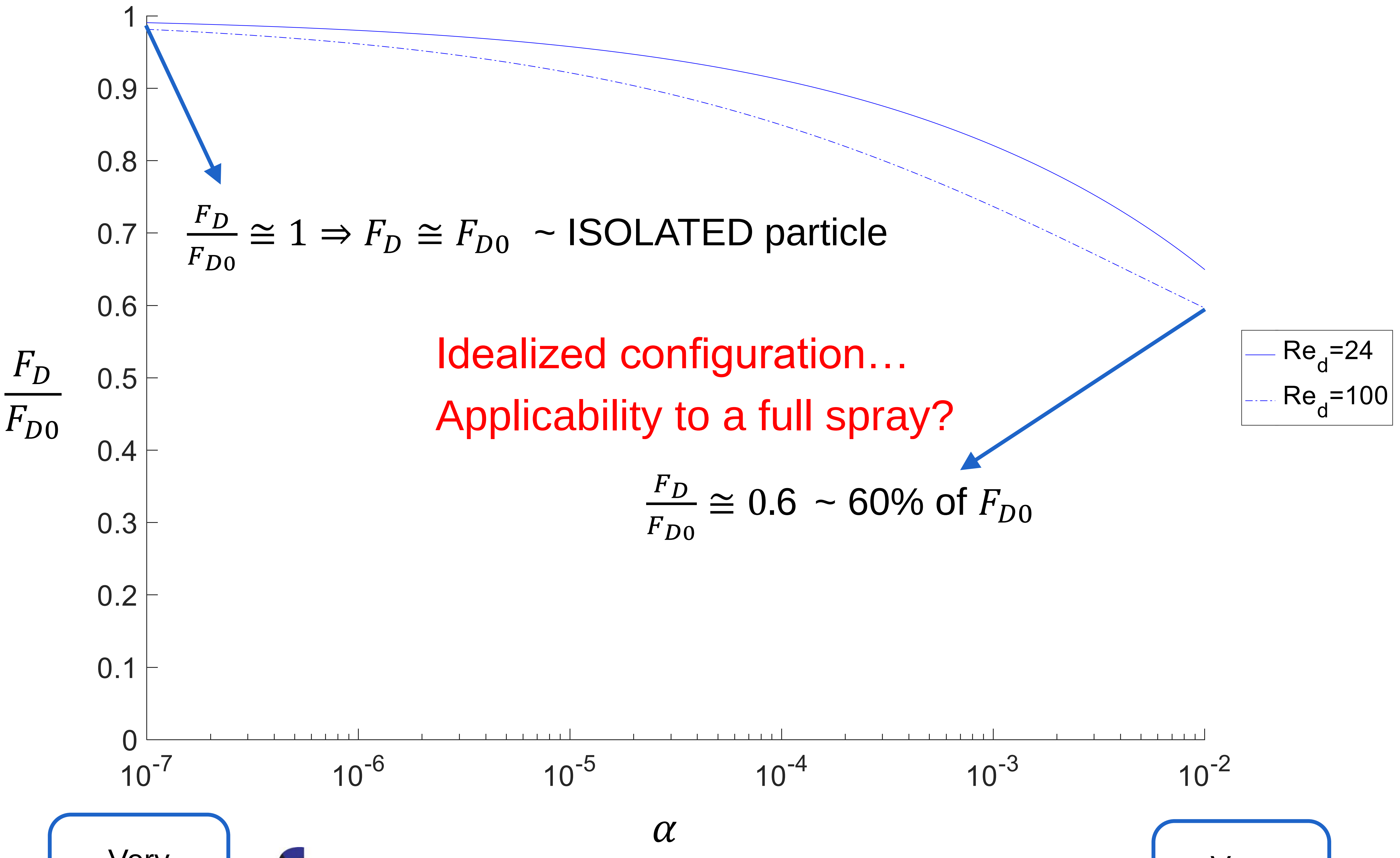
$C_{d,0}$ ↘

$$m_d \frac{\mathrm{d}\,\vec{u}_d}{\mathrm{d}t} = \underbrace{m_d\,\vec{g}}_{F_g} \underbrace{- \frac{1}{2} C_{d,0} A_{d,c}\,\rho_g \left(u_g - u_p\right)^2 \frac{\vec{u}_g - \vec{u}_p}{\left\|\vec{u}_g - \vec{u}_p\right\|}}_{F_{D,0}}$$





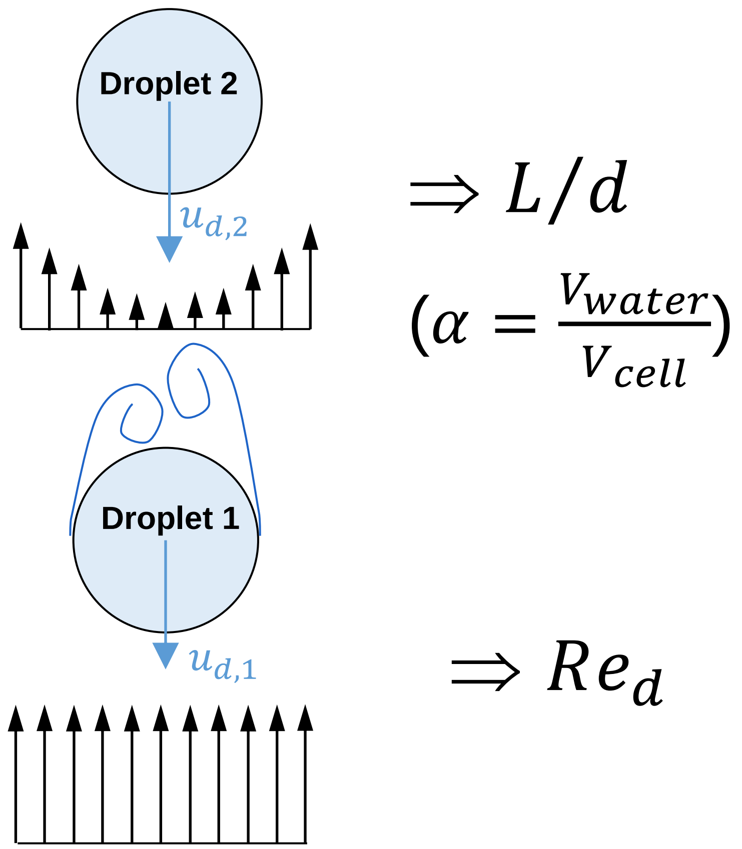
RAMIREZ REDUCTION FUNCTION



Very dilute

Very dense

- Two droplets
- Same size
- Perfectly aligned



$\Rightarrow L/d$

$(\alpha = \frac{V_{water}}{V_{cell}})$

$\Rightarrow Re_d$

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II. NOVEL DRAG REDUCTION (NDR) CORRELATION

M. Thielens, Y. Liu, B. Merci, T. Beji (2022)
Comprehensive analysis of a novel droplet volume fraction-based drag reduction correlation in a numerical study on water sprays with different level of density
https://doi.org/10.1007/s10694-022-01317-z

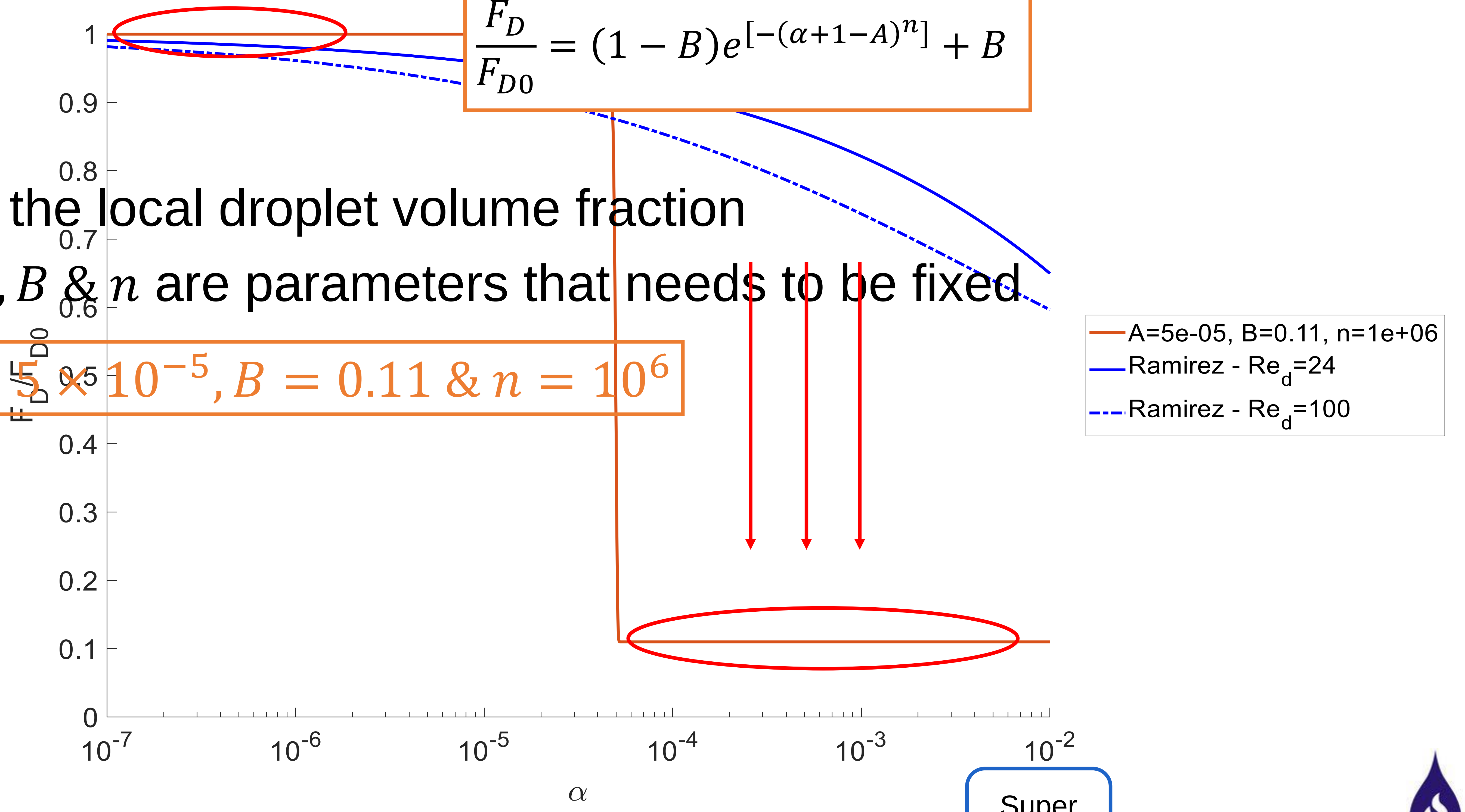
NOVEL EQUATION

$$\frac{F_D}{F_{D0}} = (1 - B)e^{[-(\alpha+1-A)^n]} + B$$

with α the local droplet volume fraction

And A, B & n are parameters that needs to be fixed

$\Rightarrow A = 5 \times 10^{-5}, B = 0.11$ & $n = 10^6$



Super dense

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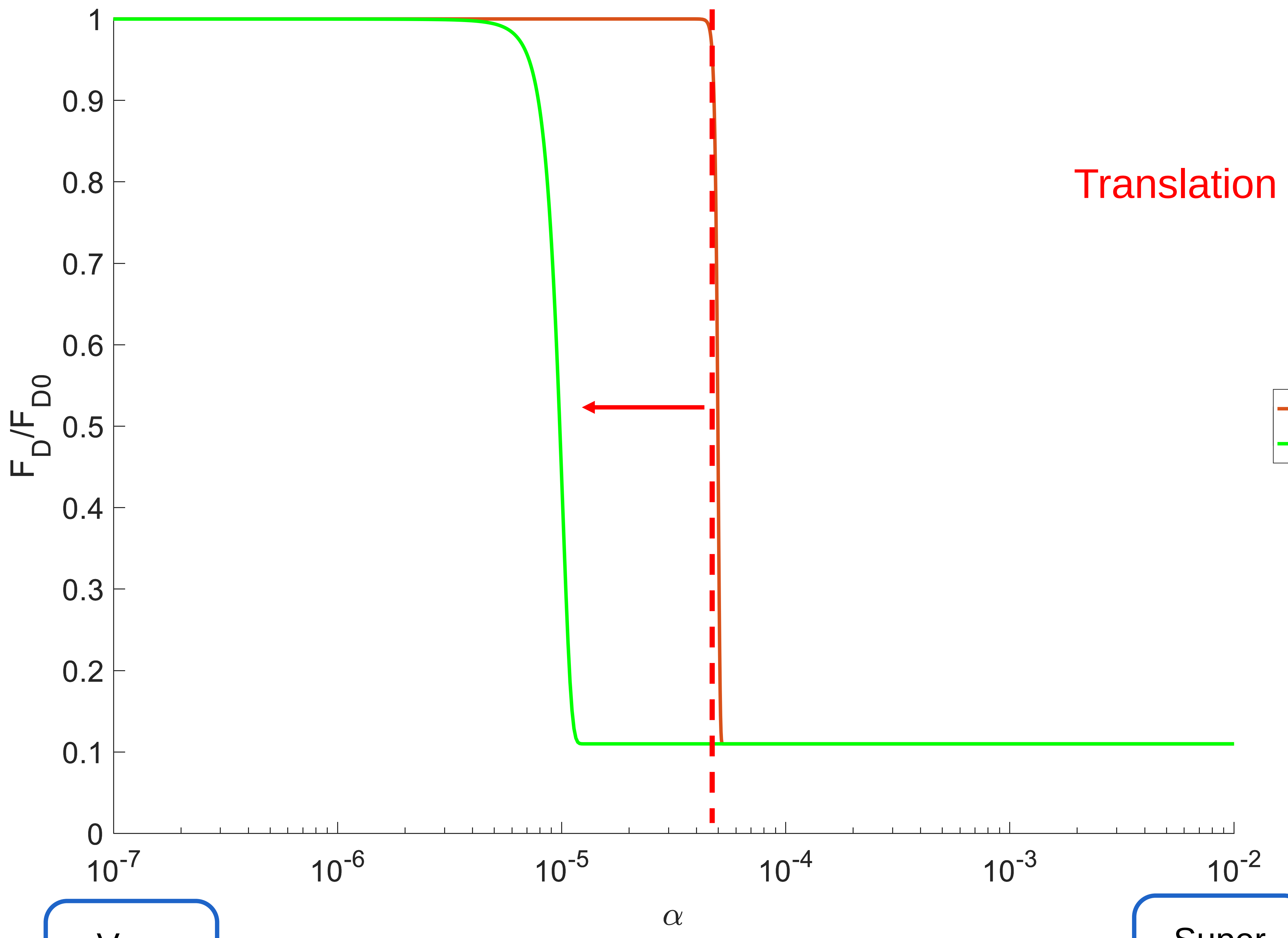
INFLUENCE OF A, B & n

$$\frac{F_D}{F_{D0}} = (1-B)e^{[-(\alpha+1-A)^n]} + B$$



A ↘

Translation of the transition region

Very dilute

Super dense

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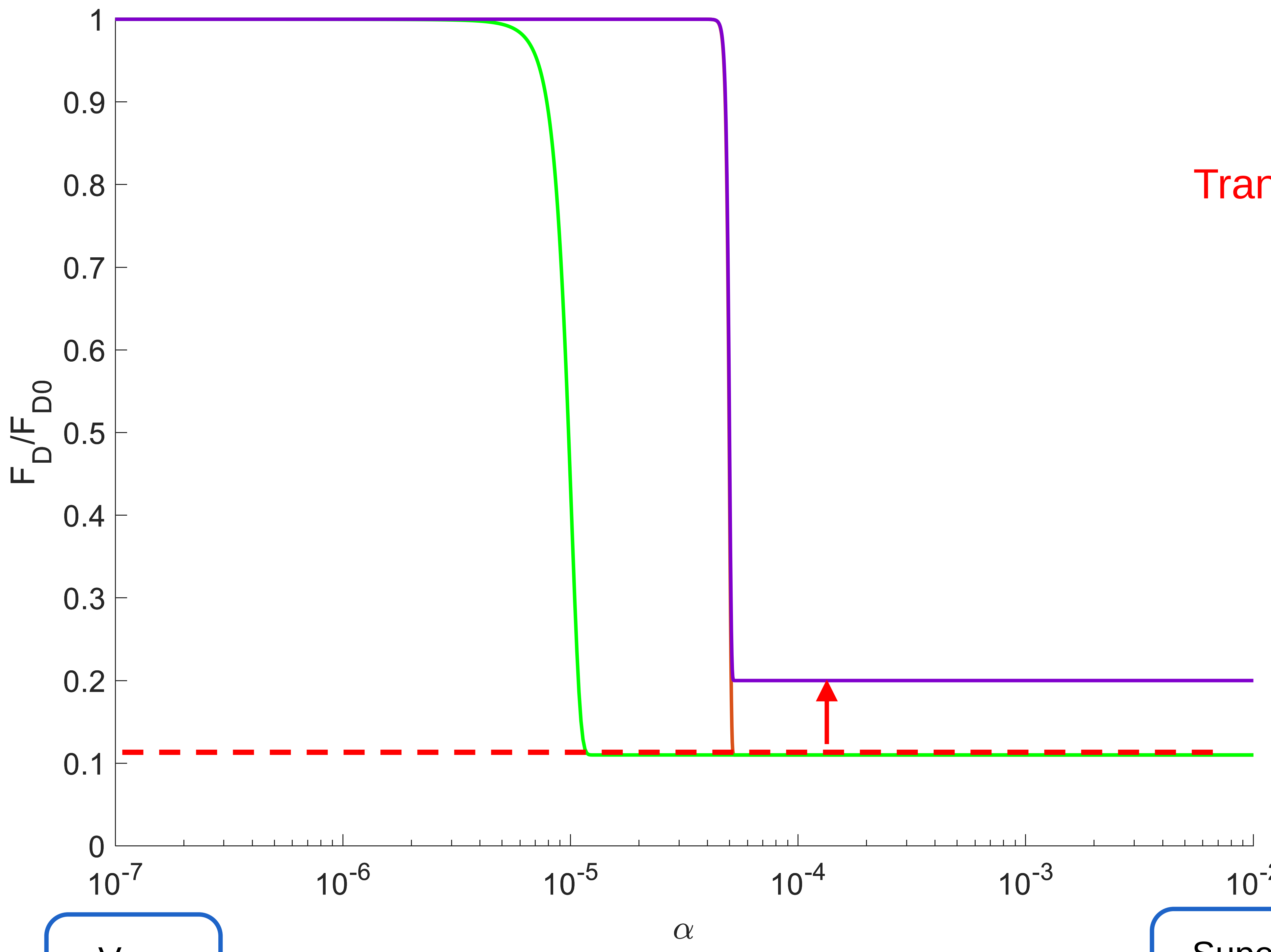
INFLUENCE OF A, B & n

$$\frac{F_D}{F_{D0}} = (1 - \boldsymbol{B})e^{[-(\alpha+1-A)^n]} + \boldsymbol{B}$$



B ↗
Translation of the plateau

Very dilute

Super dense

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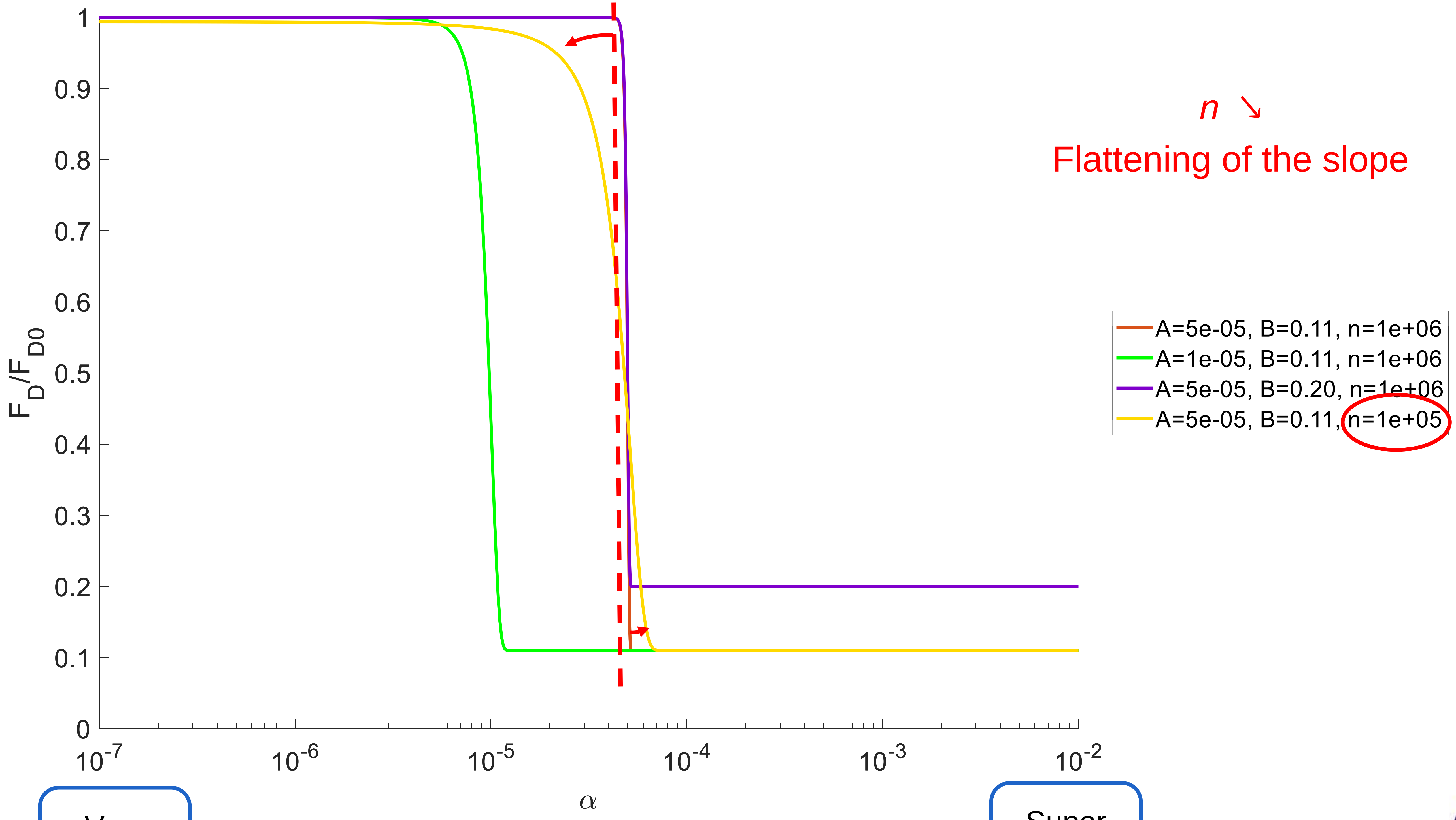
INFLUENCE OF A, B & n

$$\frac{F_D}{F_{D0}} = (1-B)e^{[-(\alpha+1-A)^n]} + B$$



n ↘

Flattening of the slope

Very dilute

Super dense

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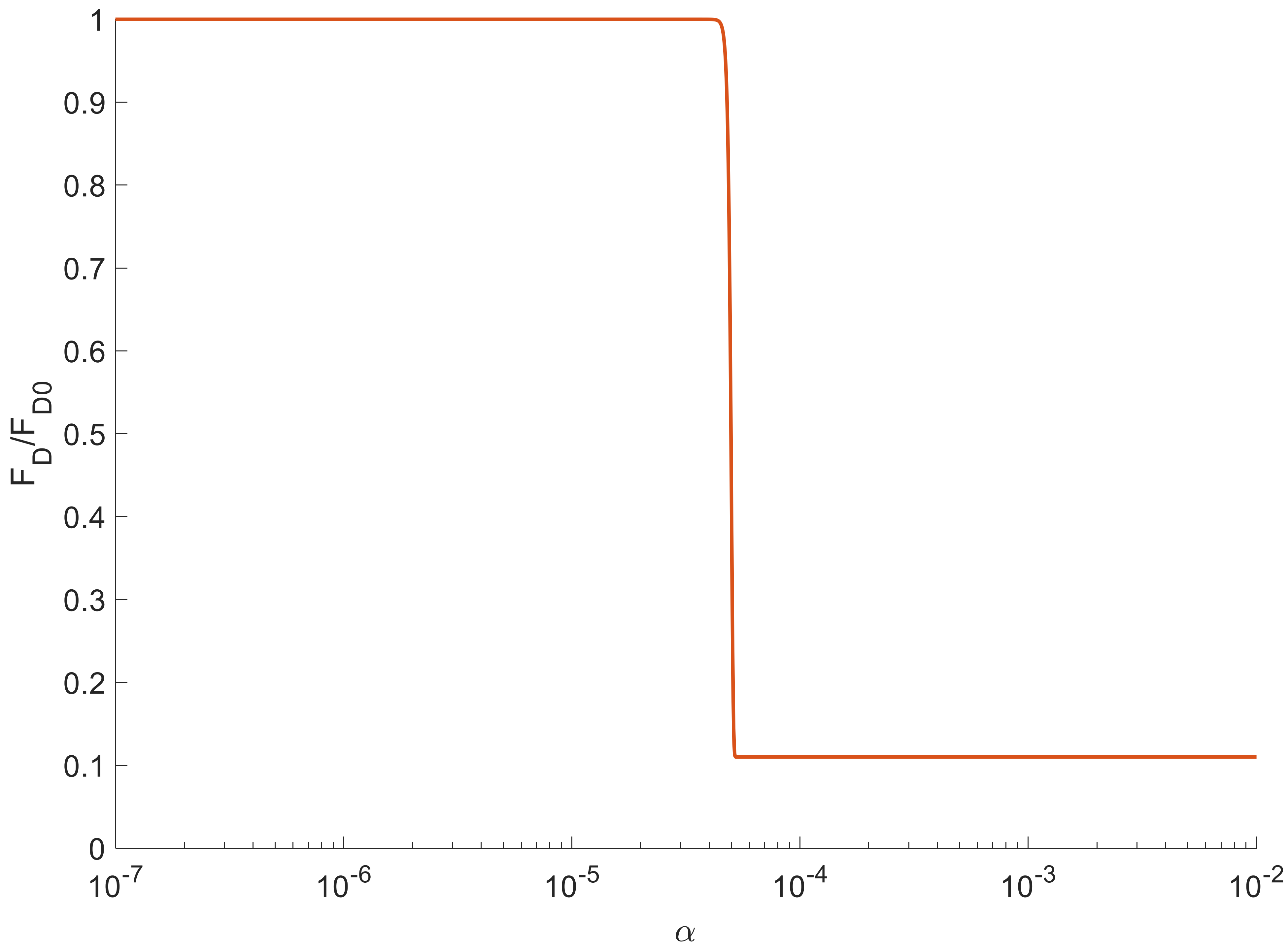
ENGINEERING CALIBRATION

$$\frac{F_D}{F_{D0}} = (1 - B)e^{[-(\alpha+1-A)^n]} + B$$



$A = 5 \times 10^{-5}, B = 0.11, n = 10^6$

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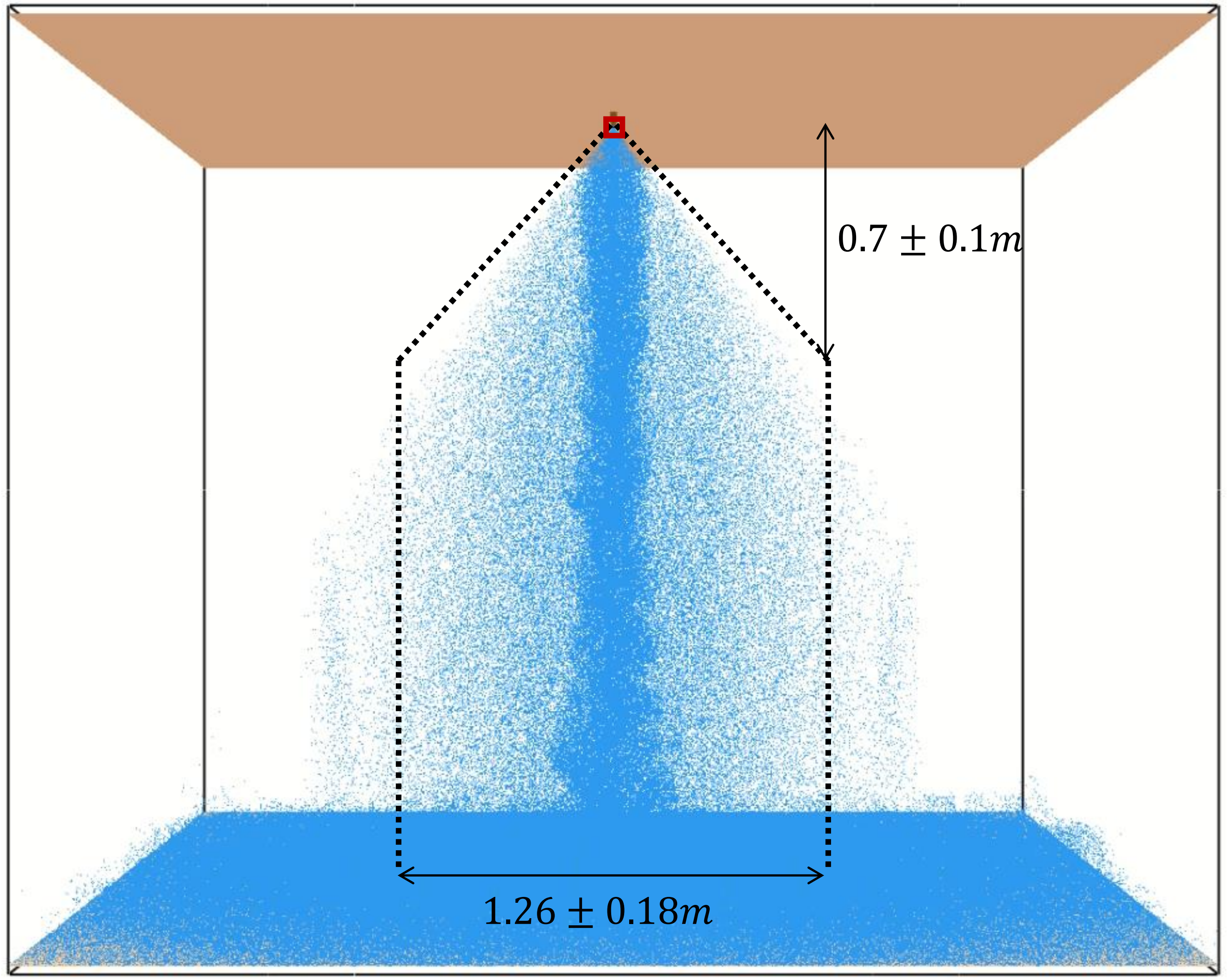
III. EXPERIMENTS VS NOVEL MODEL SIMULATIONS

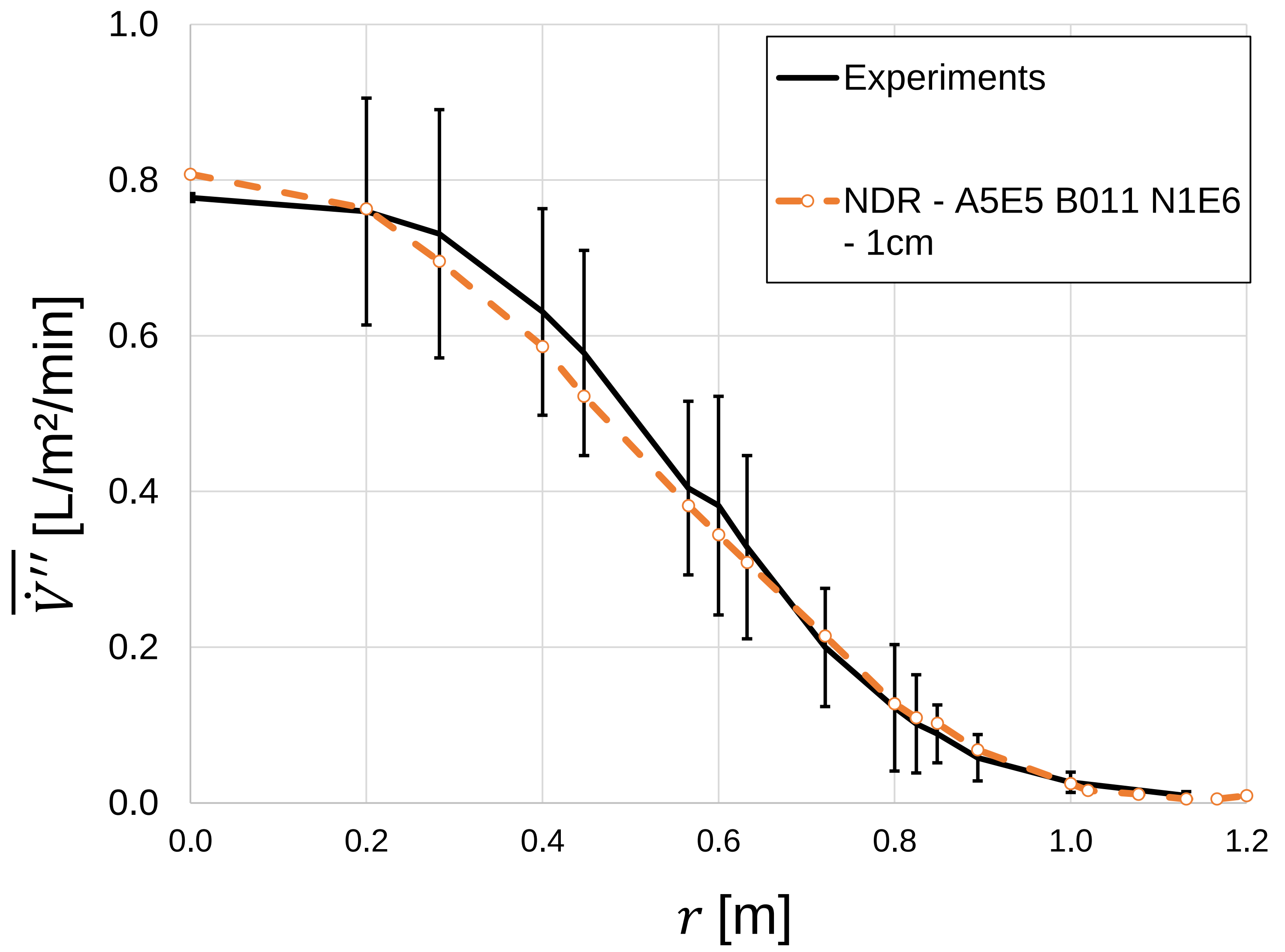
WUHAN SPRAY

Modified FDS 6.7.6, $A = 5 \times 10^{-5}, B = 0.11 \; \& \; n = 10^6$

- Spray envelope



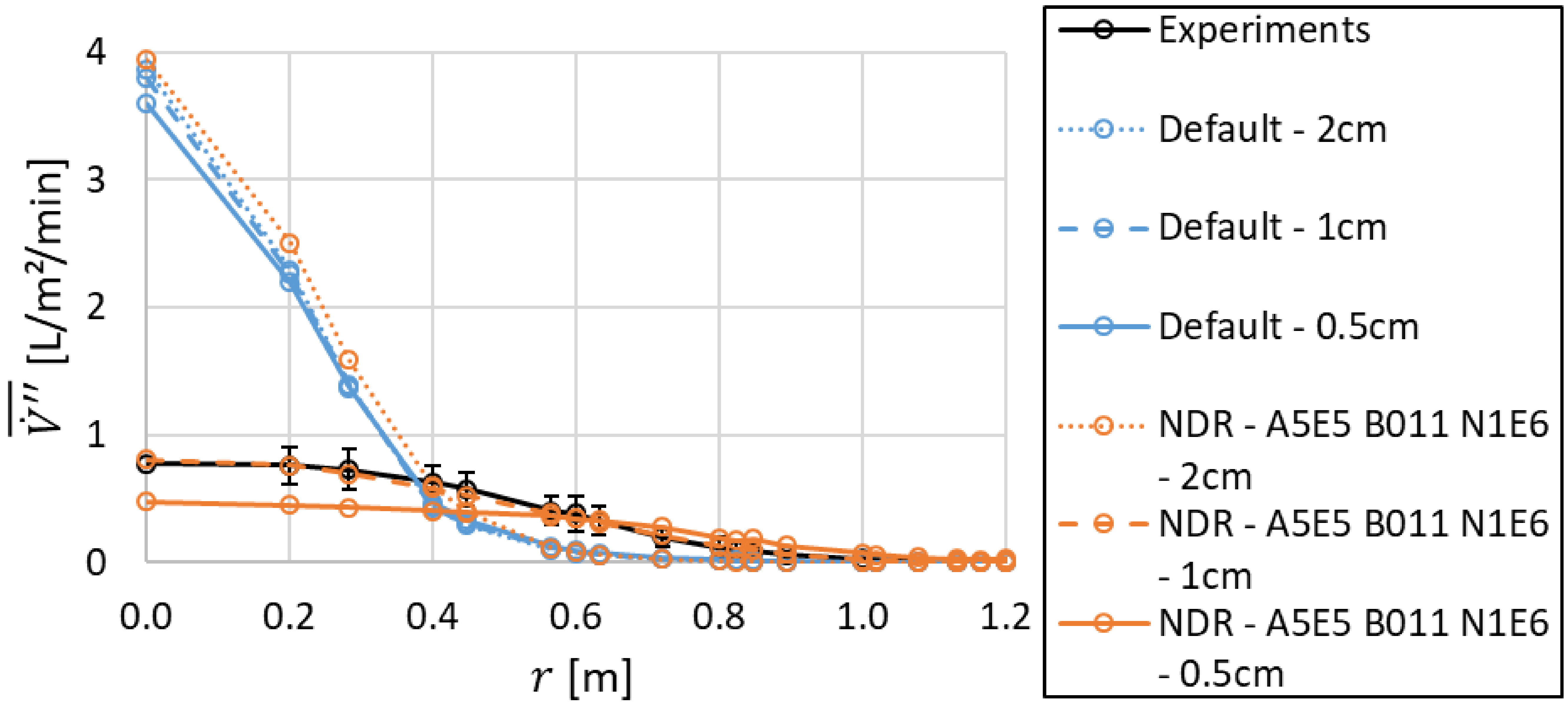
- Water flux density at the ground floor



SENSITIVITY ANALYSIS

- Mesh refinement
  - Better simulation results for the gas phase
  - Eulerian – Lagrangian not so trivial

WUHAN SPRAY : SENSITIVITY ANALYSIS



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IV. OTHER SPRAYS

EXTENDED COLD FLOW ANALYSIS

- 3 sprays with different levels of density

	Wuhan	VTT	Fukui
$\dot{q}$	$1.00\ L/min$	$0.35\ L/min$	$0.44\ L/min$
d_0	$90\ \mu m$	$79\ \mu m$	$258\ \mu m$
$\theta_{1/2}$	$42°$	$30°$	$28°$

'Dense'

Less 'dense'

Simulation results with NDR model for less dense sprays are not deteriorated ✓

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VI. INTERACTION HOT AIR JET

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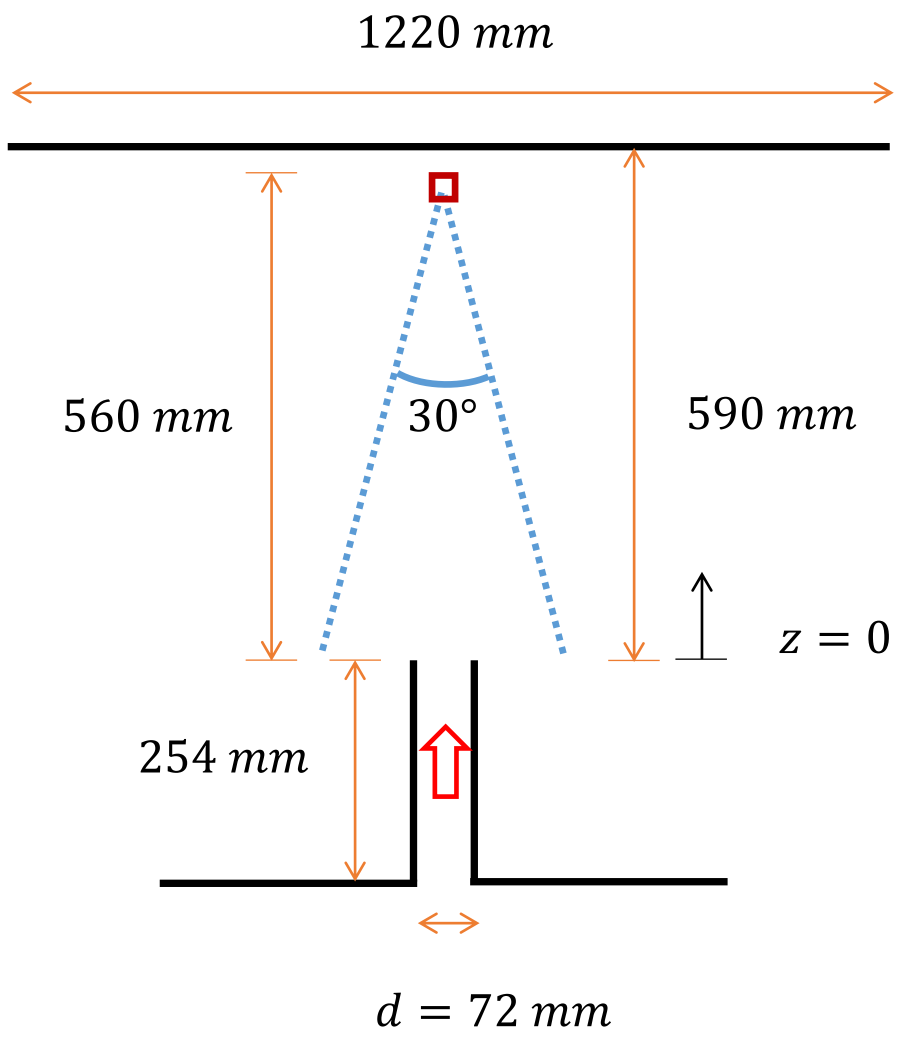
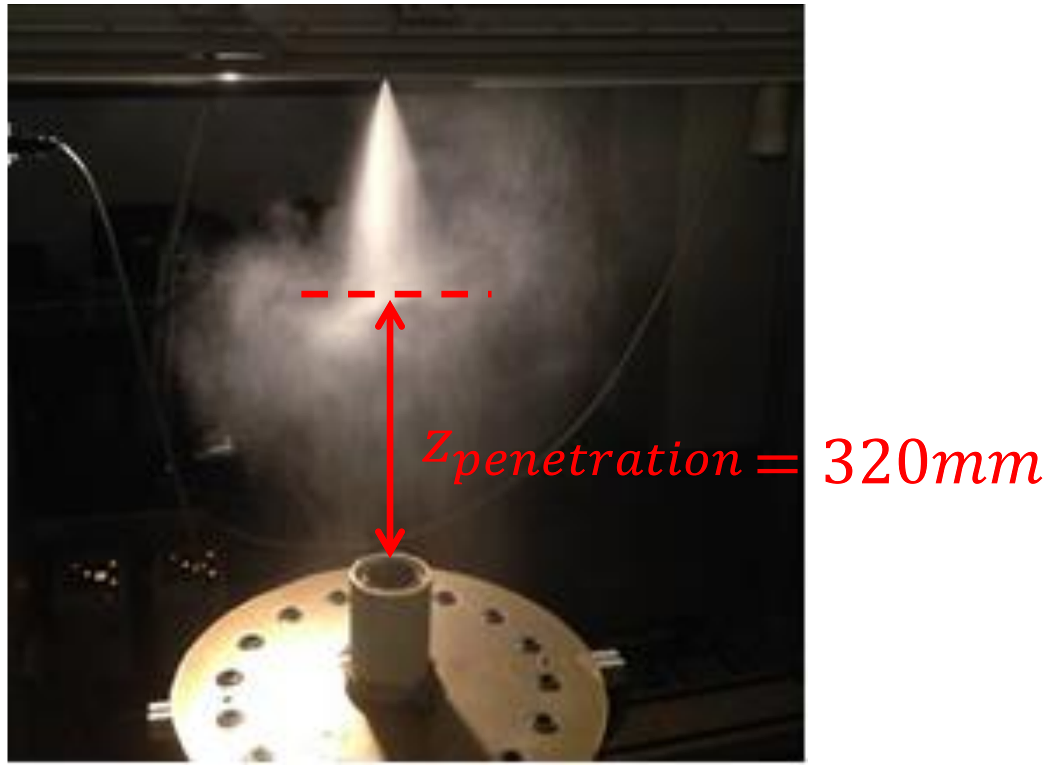
FM GLOBAL SPRAY

- Water spray
  - $\dot{q} \cong 0.084\ L/\text{min}$
  - $d_0 = 60\ \mu m$
  - $v_0 = 26\ m/s$
  - $\theta_{1/2} = 15°$
  - $N_p = 50\ 000$
  - uniform distribution

- Hot air jet
  - $u_{jet} = 4.2\ m/s$
  - $T_{jet} = 205\ °C$



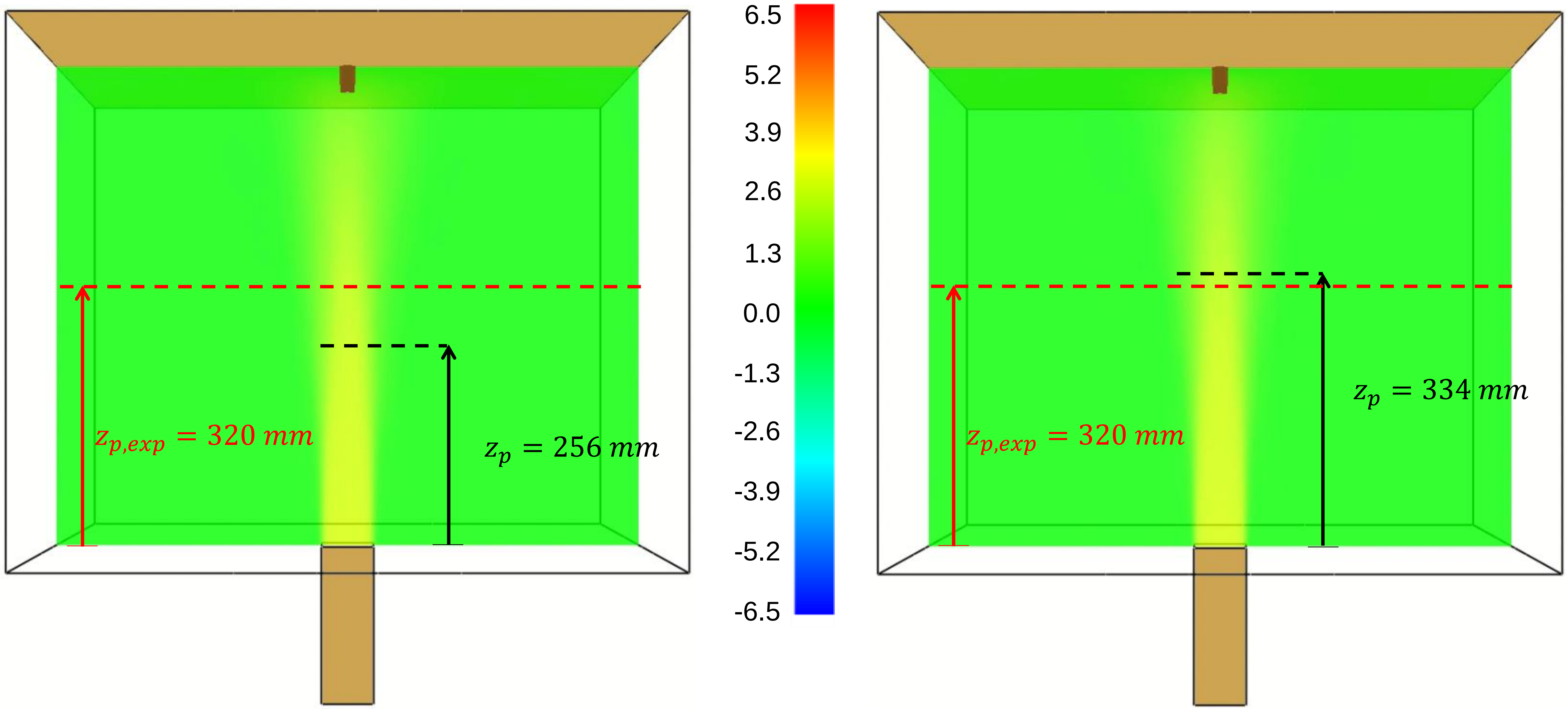


VELOCITY FIELD

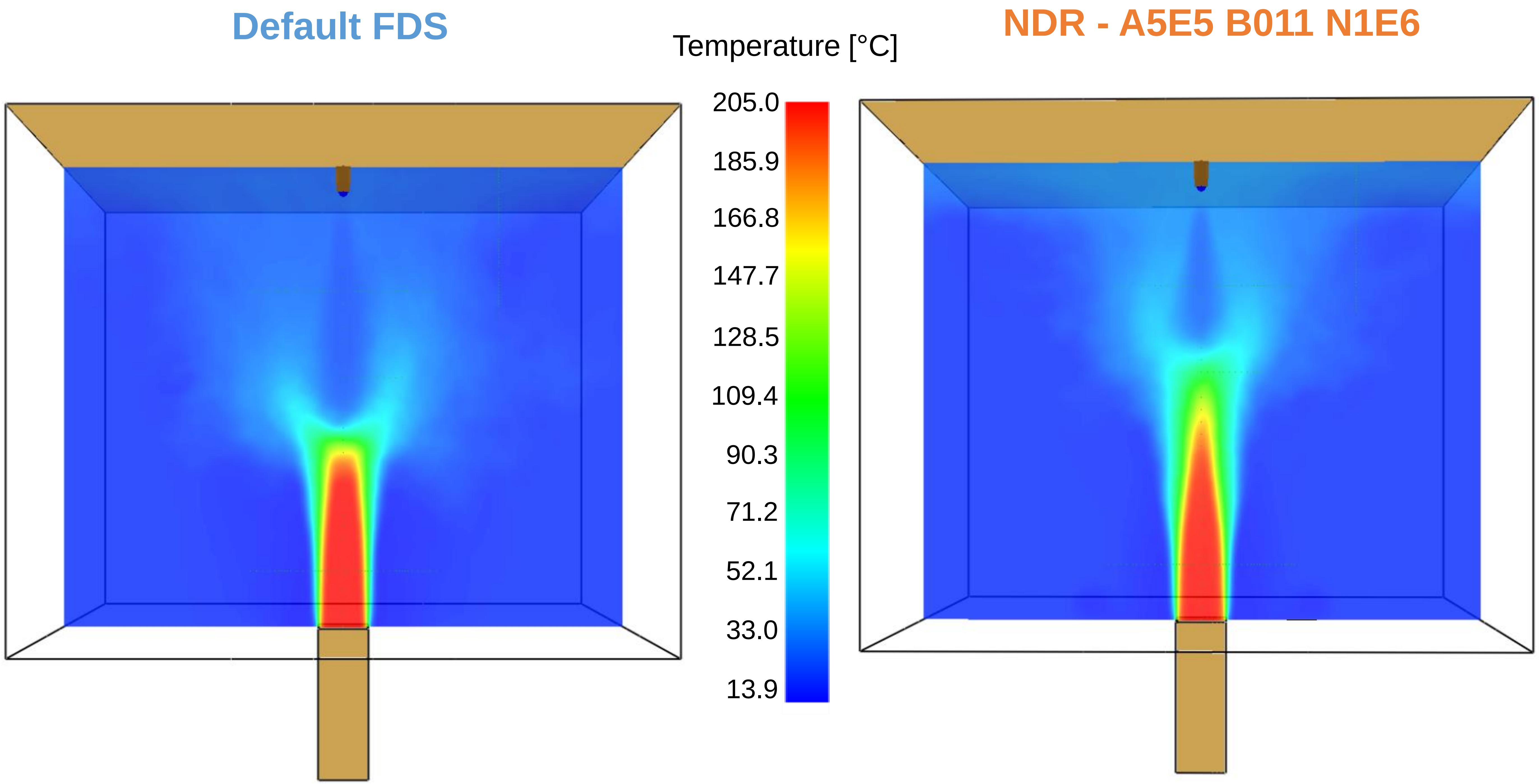
Default FDS

Vertical velocity [m/s]

NDR - A5E5 B011 N1E6



TEMPERATURE FIELD

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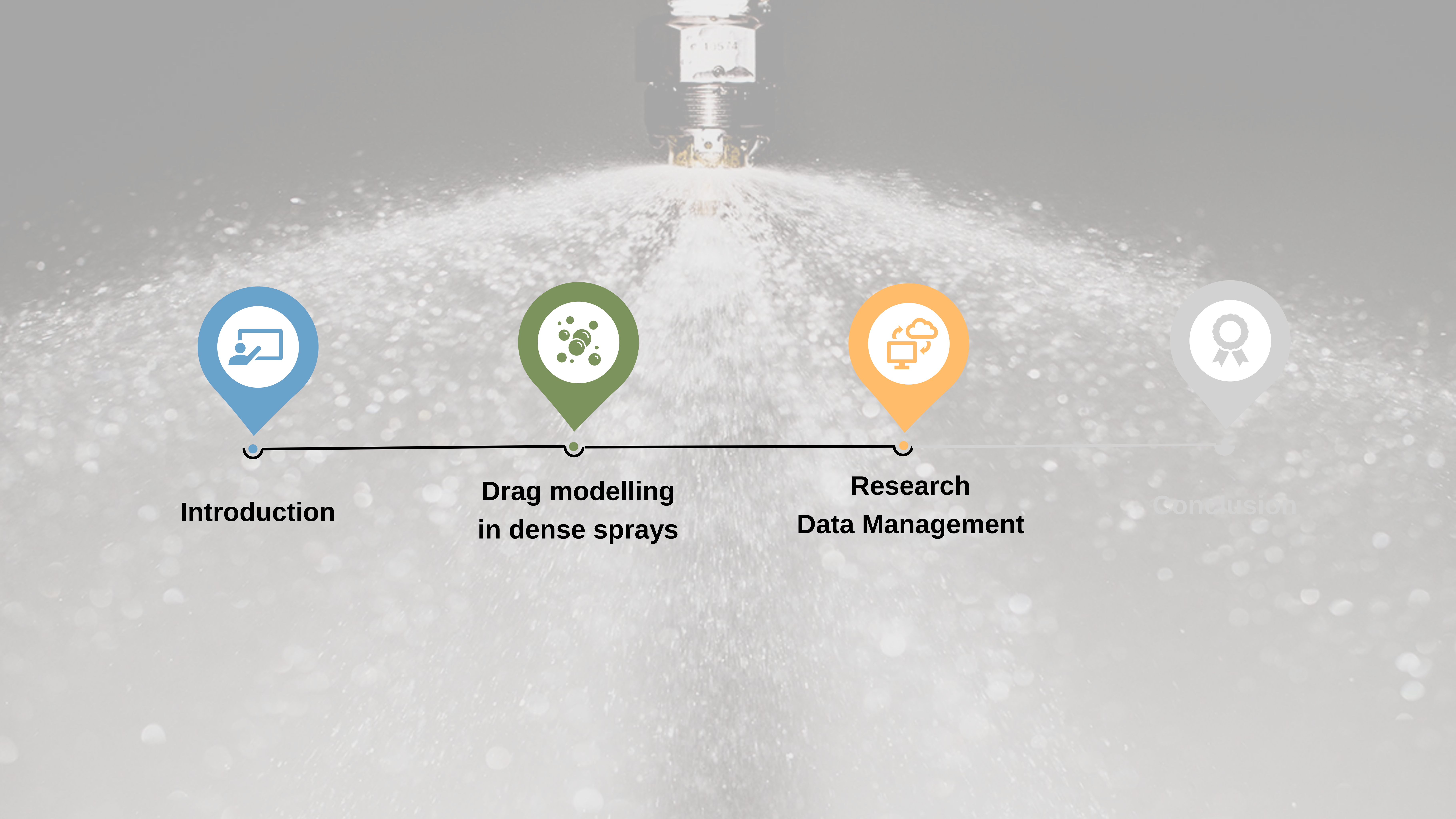
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RDM

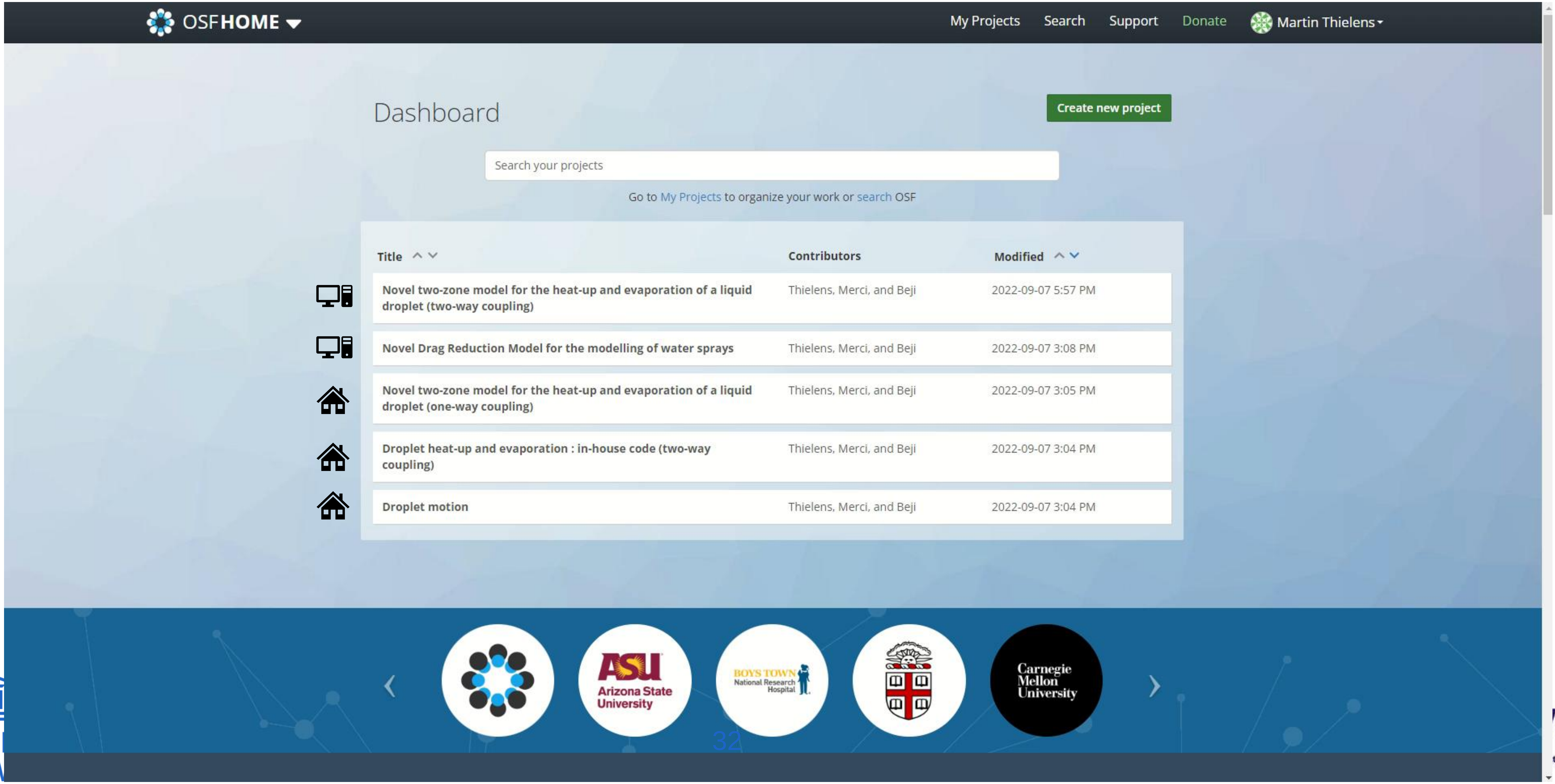
Requires a structured effort and a continuity beyond this PhD

➢ Two platforms

- GitHub (code hosting platform with a version control system)
- OSF (code hosting and corresponding documentation)

OSF

There are 5 repositories : 3 in-house codes & the 2 modified fds codes



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CONCLUSION

- ➢ Novel approach
  - Complexity of the entire spray
  - Droplet volume fraction-based drag reduction
  - Substantially reducing drag in dense regions of the sprays (➔ water mists)
  - No drag reduction in dilute regions

- ➢ Tested against 3 sprays with different levels of density
  - Optimum values (A, B & n) depend on the case and the mesh
  - Not final values but very promising

- ➢ Tested against a 4th spray with the interaction of a hot air jet
  - Very promising

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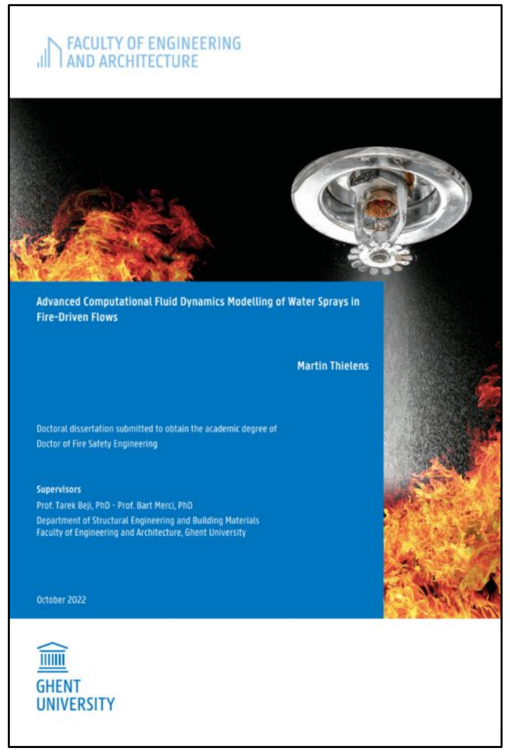
THESIS



https://biblio.ugent.be/publication/8773335

FACULTY OF ENGINEERING
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