# DUSTFLOW Software – Fairing Particulate Contamination Flow Simulator

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# Motivation

## increased deposition at launch position

The **launch** has always been a **critical environment** of which little information is known; compliance to requirements is frequently not verifiable (historical assumptions are “recycled”).

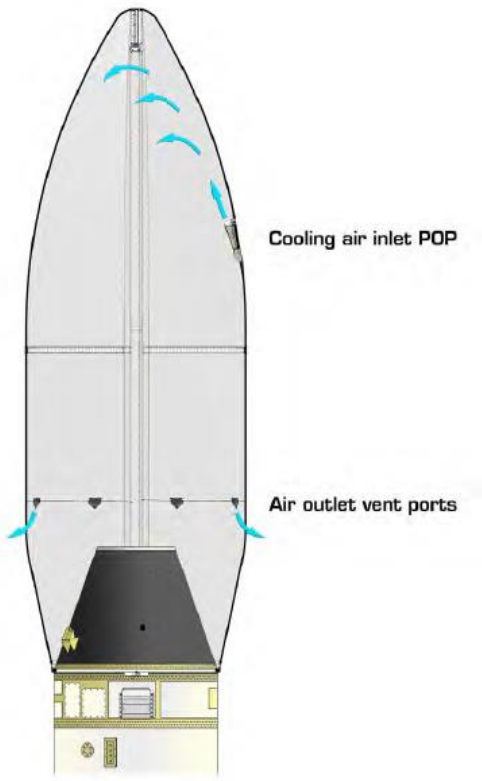
ESA R&D activities in recent years aim to bridge the gap:

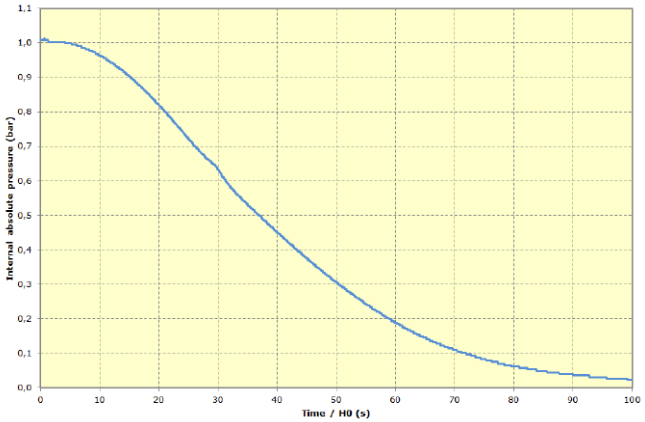
- The **XCAM sensor** (see other presentations during CCMPP) will provide actual flight data about particulate contamination and redistribution
- **DUSTFLOW** is a 3D simulation software that simulates the launch (and pre-launch) environments. It can be used as a **verification** tool, **CCC** tool, and **design** tool (different fairing configurations with respect to critical payloads).

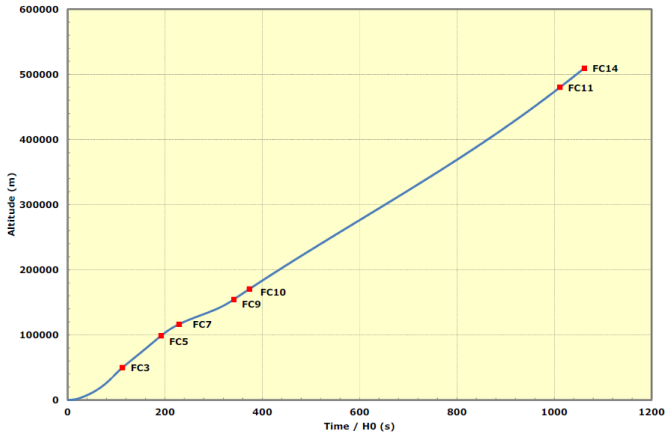
**Develop an SW tool which can predict the final particle distribution and support the reduction of final contamination – project funded by ESA**

# Conditions during prelaunch and launch phase

## Ventilation, pressure drop, acceleration, shocks

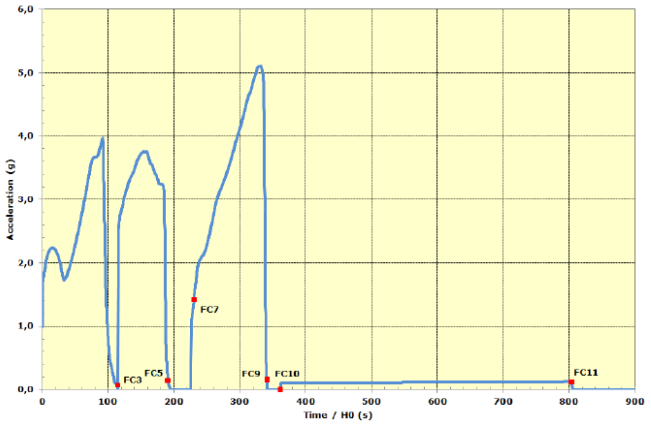


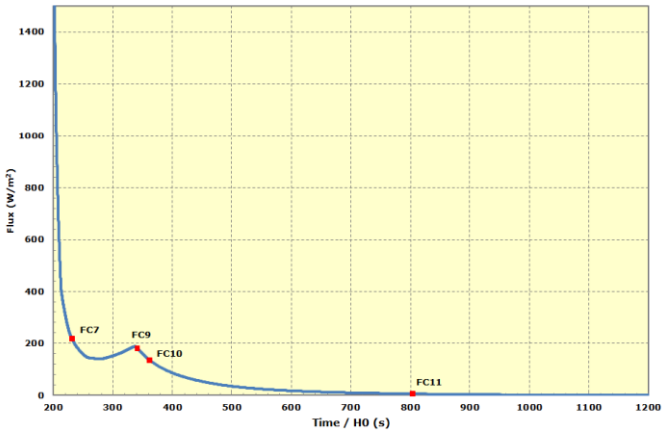




Mass flow at vent outlets as a function of time

Mass flow at inlets as a function of time



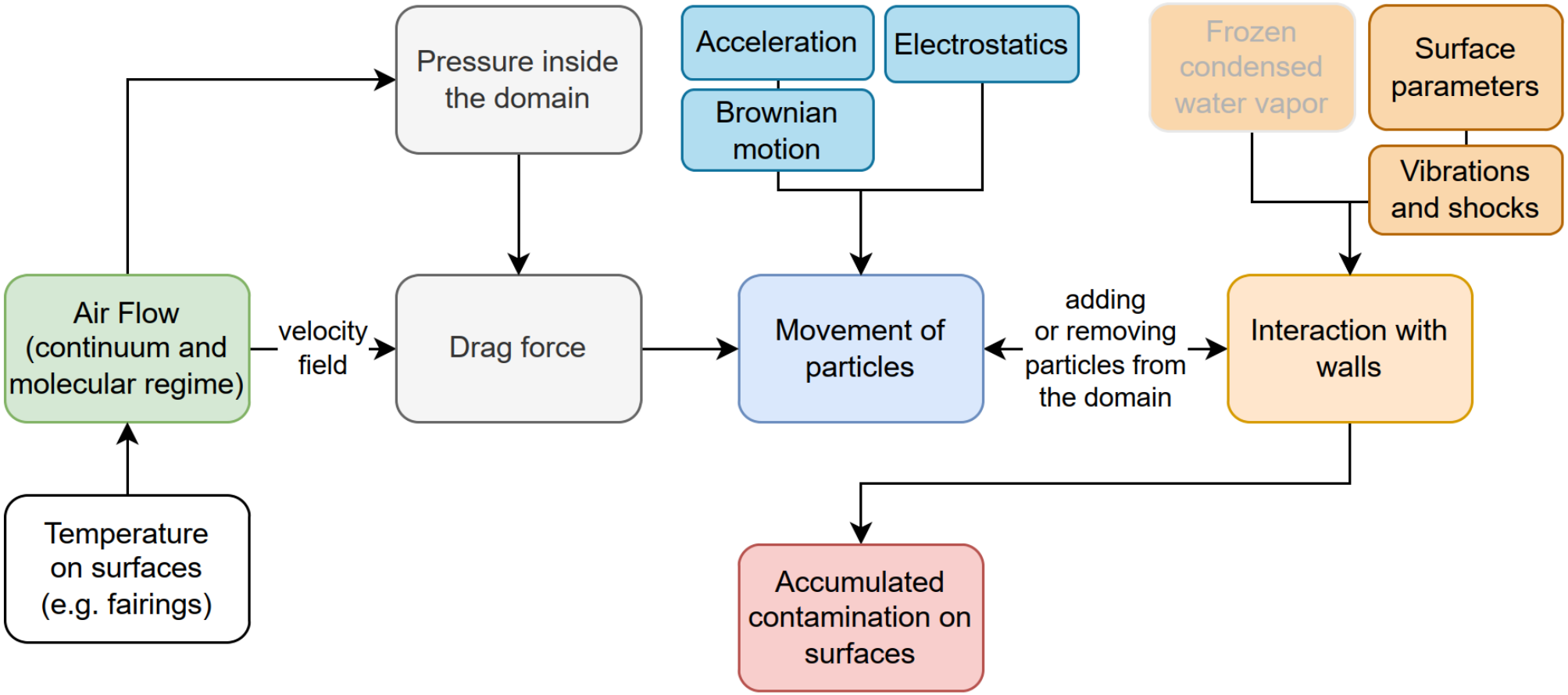




Operating conditions for fluid flow

source: Vega and Ariane 5 user manual

# Physics to simulate

- Ventilation, pressure drop, acceleration, shocks



# Approach

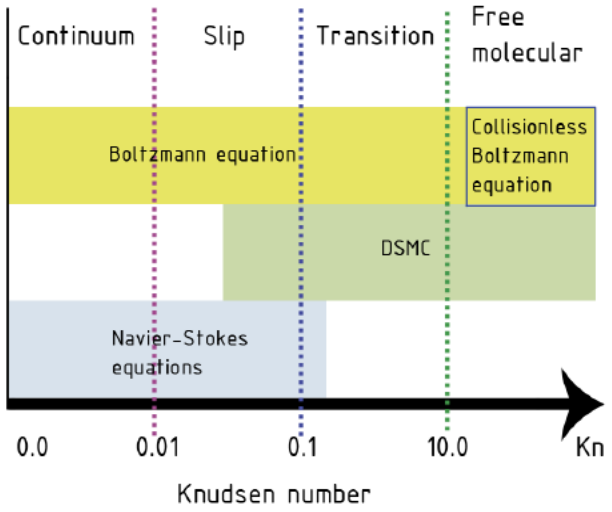
## Flow solvers: FVM and DSMC

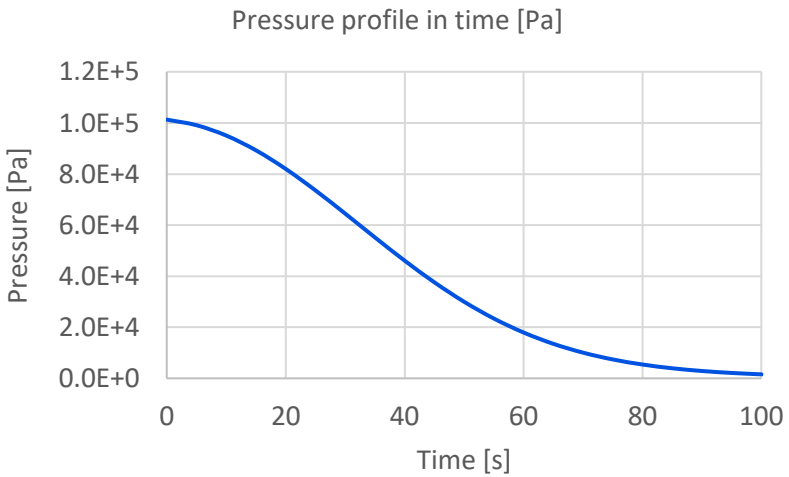
**Implemented flow solvers:**

1. **Incompressible** pimpleFoam
2. **Compressible** rhoPimpleFoam
3. **DSMC: dsmcFoam+**
4. **Import from ANSYS Fluent**

**Available options include:**

1. Constant and variable **timesteps**
2. **Divergence** schemes settings
3. **Slip condition** on walls
4. **Two turbulence models**: k-epsilon and k-omega SST
5. **Wall shear stress** calculation
6. Time-dependent **user-defined data profiles**

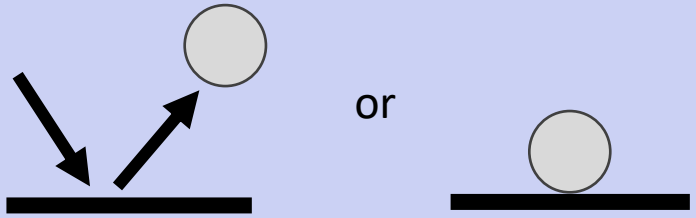
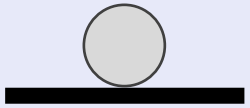
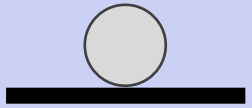



| No. | Physics | pimpleFoam | rhoPimpleFoam | reactingFoam |
|---|---|---|---|---|
| 1 | State | Transient | Transient | Transient (multispecies) |
| 2 | Turbulence | Yes | Yes | Yes |
| 3 | Heat transfer | No | Yes | Yes |
| 4 | Convection | No | Yes | Yes |
| 5 | Compressible | No | Yes | Yes |

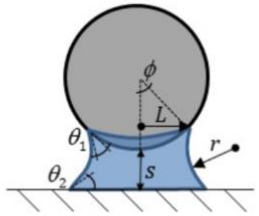
# Approach

## Deposition models

| No | Deposition options | Resulting particle position |
|---|---|---|
| 1 | **DLVO model**<br>Based on energy relation of interacting bodies |  <br>resuspended or at the surface |
| 2 | **Always sticking model**<br>Each impact particle against wall results in particle deposition |  <br>always sticks to the surface but **can be** resuspended |
| 3 | **Escape model**<br>Always sticking and no resuspension in the following time steps |  <br>always sticks to the surface and **cannot be** resuspended |

Forces in DLVO model:

- Van der Waals forces
- Electrostatic forces
- Capillary forces




DLVO theory

**Condition for deposition:**

$$\frac{1}{2} m_p v_p^2 > E_{barrier} \quad \rightarrow rebound$$

$$\frac{1}{2} m_p v_p^2 < E_{barrier} \quad \rightarrow deposition$$

# Approach

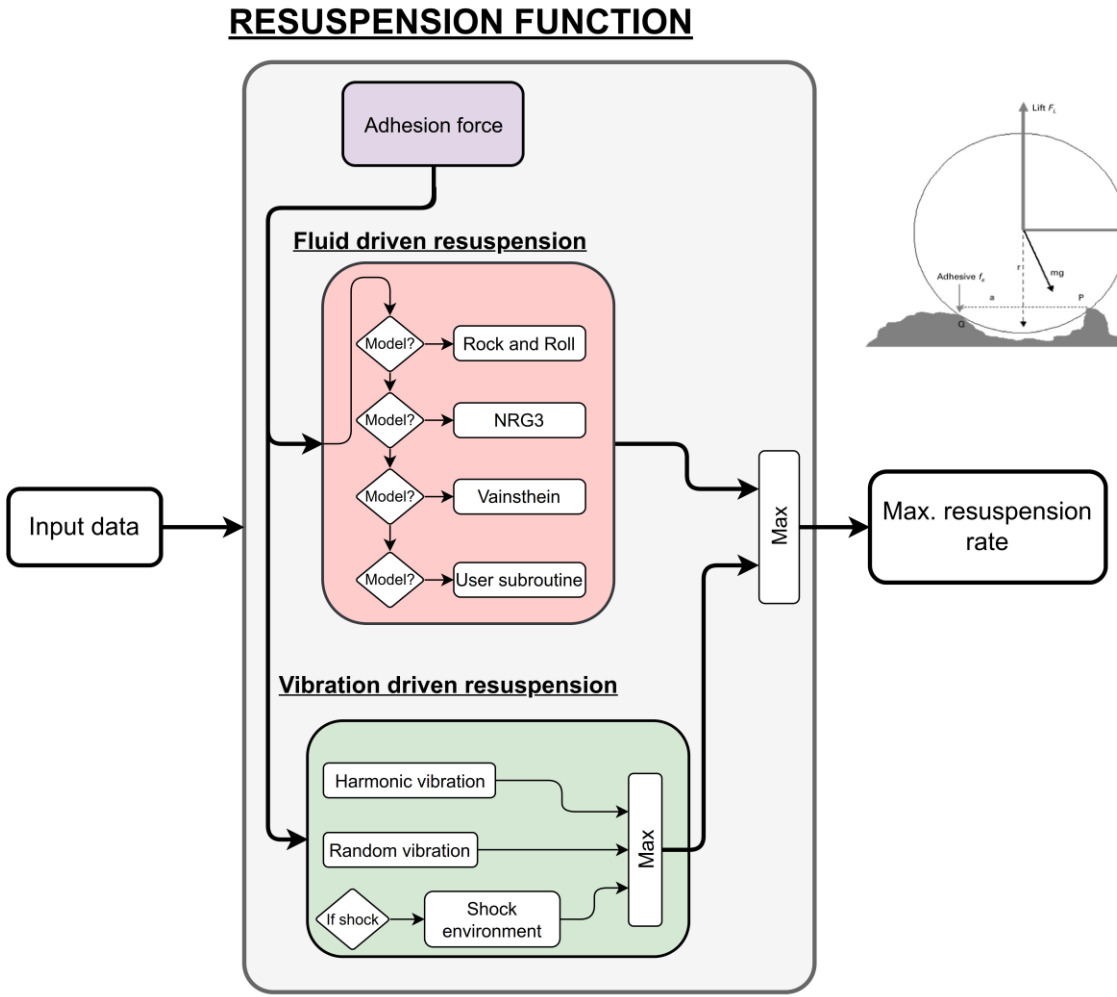
## Resuspension models

- **Flow-driven resuspension** can be simulated using three built-in models and user-subroutine

| No | Model |
|---|---|
| 1 | Vainshtein, Ziskind, Fichman, and Gutfinger (VZFG) |
| 2 | Rock and Roll model |
| 3 | NRG3 model |
| 4 | User subroutine |

- **The particle is detached from a surface** when the **accumulated potential energy** surpasses the potential energy well

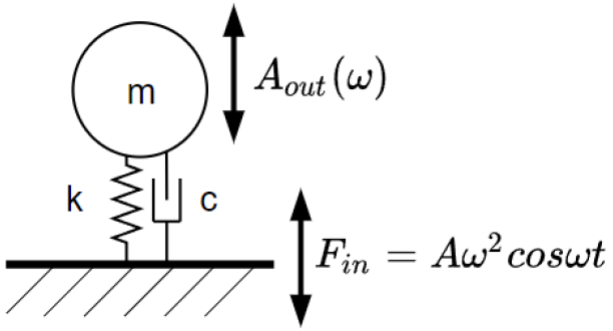
- **The vibrationally driven resuspension** is simulated using a separate model

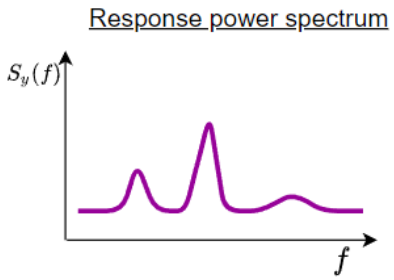


# Approach

## Vibration & shocks

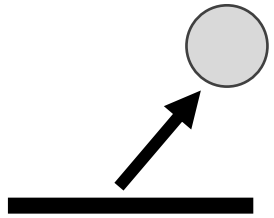
### Random and harmonic vibration



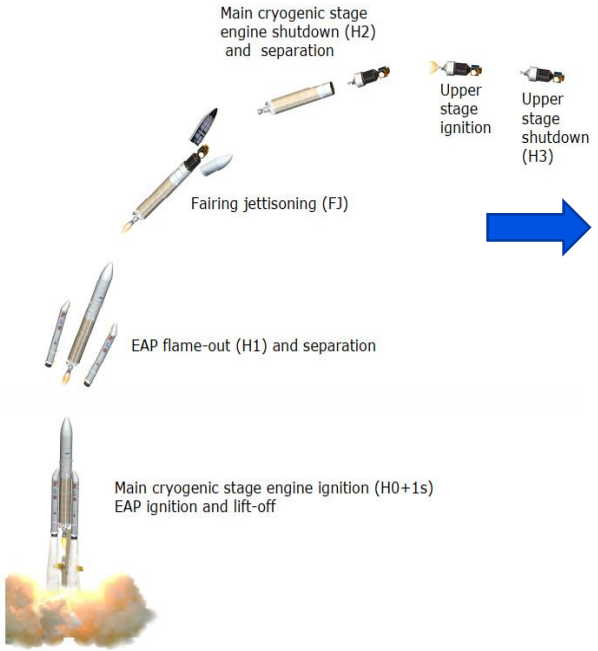

For a given profile and particle-surface system, a maximum dynamic force acting on the particle is calculated.

$$F_{dyn} - F_{adh} \geq 0$$



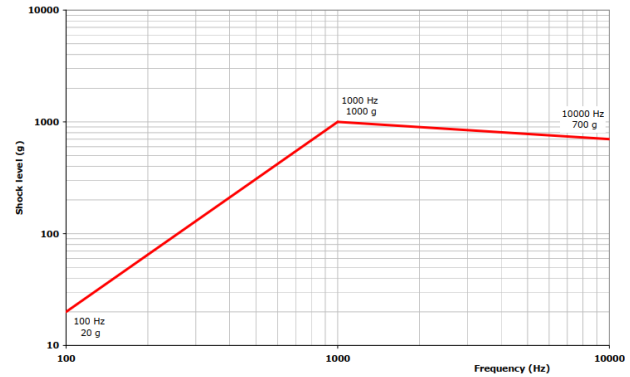
resuspended

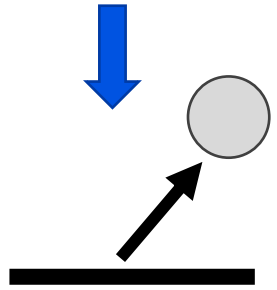
### Shock events




source: Ariane 5 user manual

### Shock input characteristics



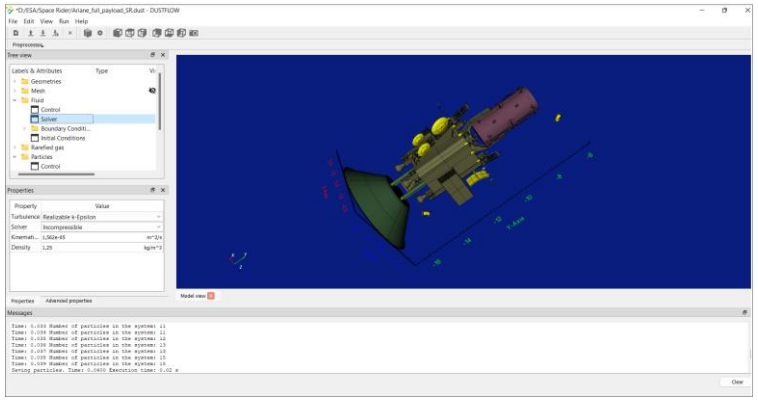
resuspended

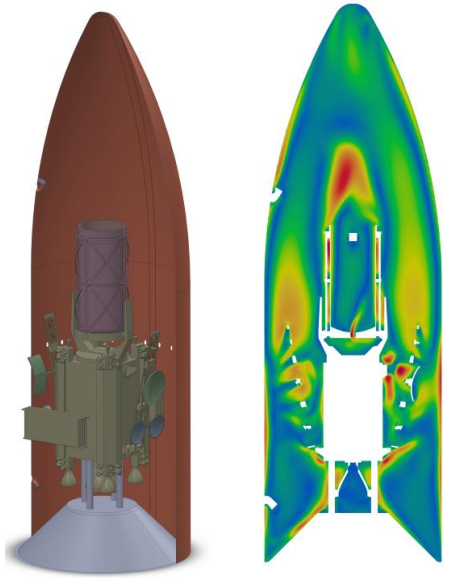
# Simulation workflow

## Graphical interface

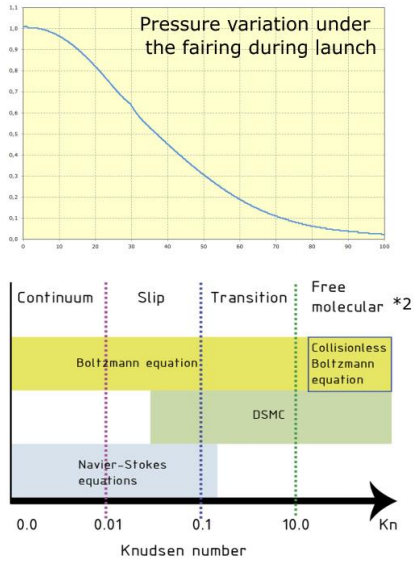
1. Prelaunch and launch simulations
2. Venting and purging
3. Future: lunar dust simulations

### GUI running on Windows & Linux



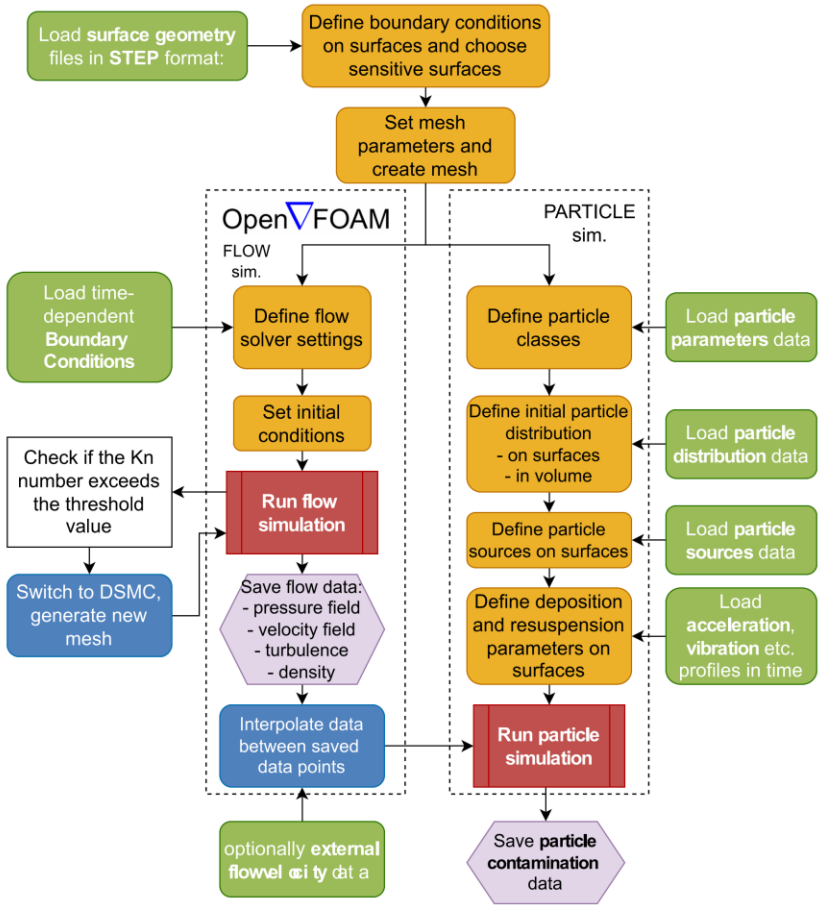







Geometry + BC → Flow simulation → Prelaunch: Ventilation & Purging; Launch: Navier-Stokes FVM; Launch: DSMC → Particle transport simulation

### Simulation workflow

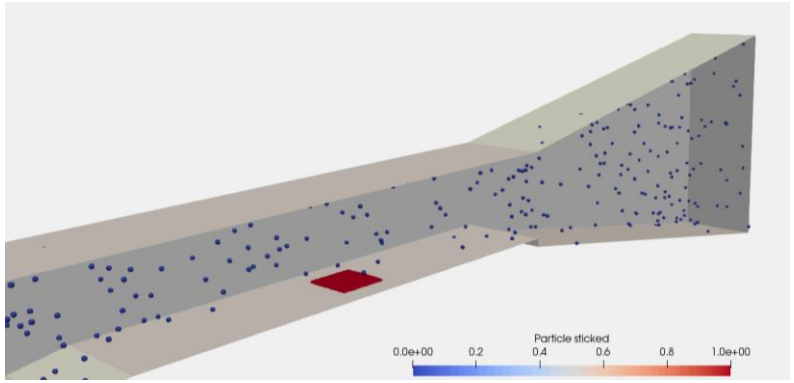


# Validation approach

## Deposition and resuspension

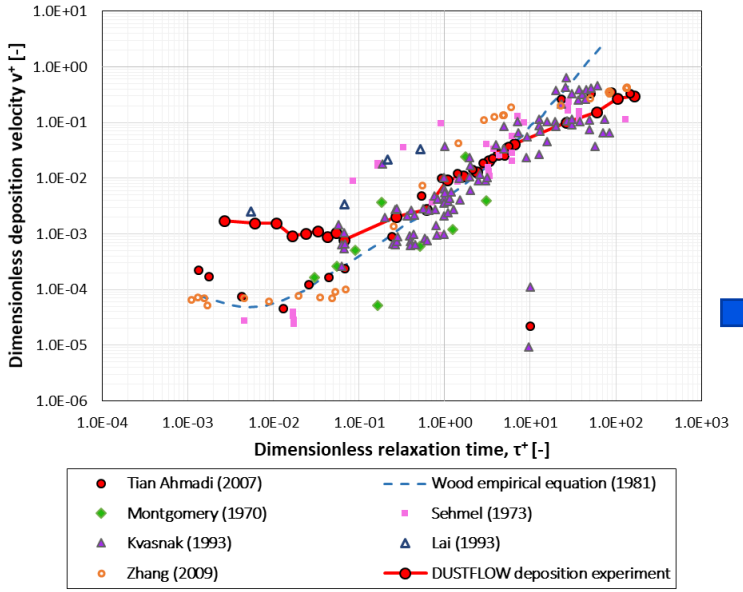
Validation with data using:

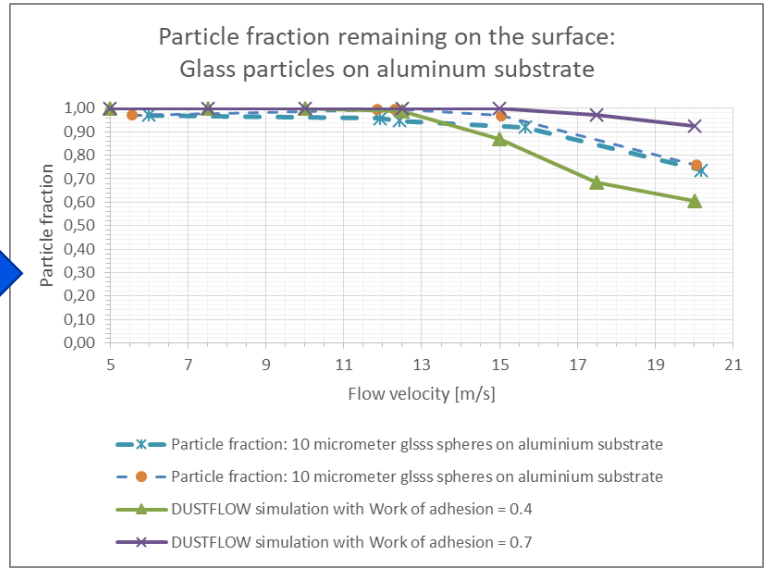
- Literature for resuspension and deposition



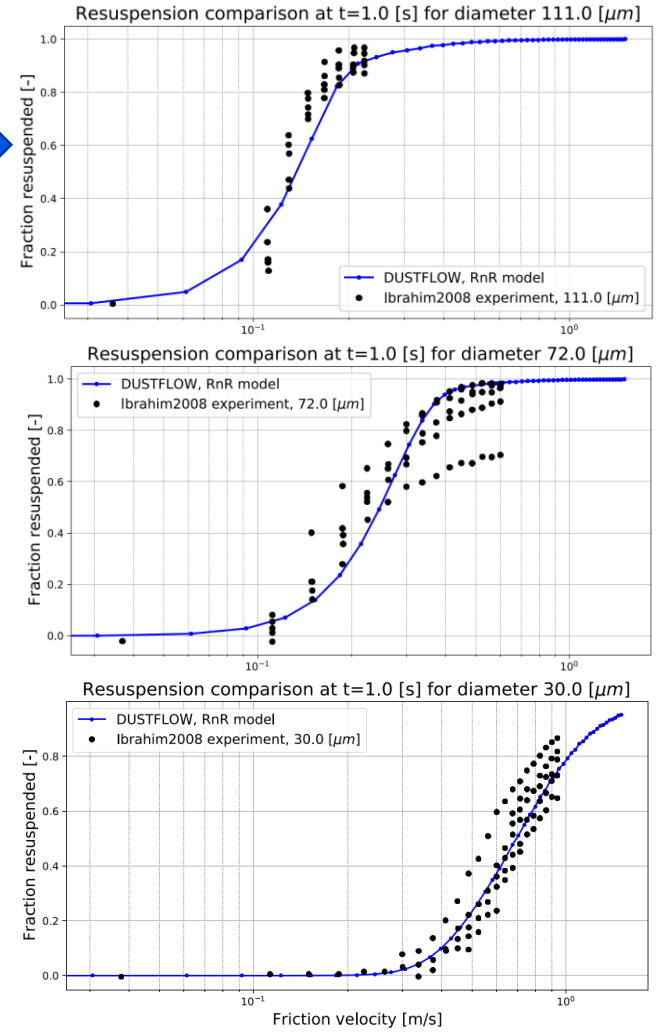

- Own experiment in a wind tunnel

Deposition



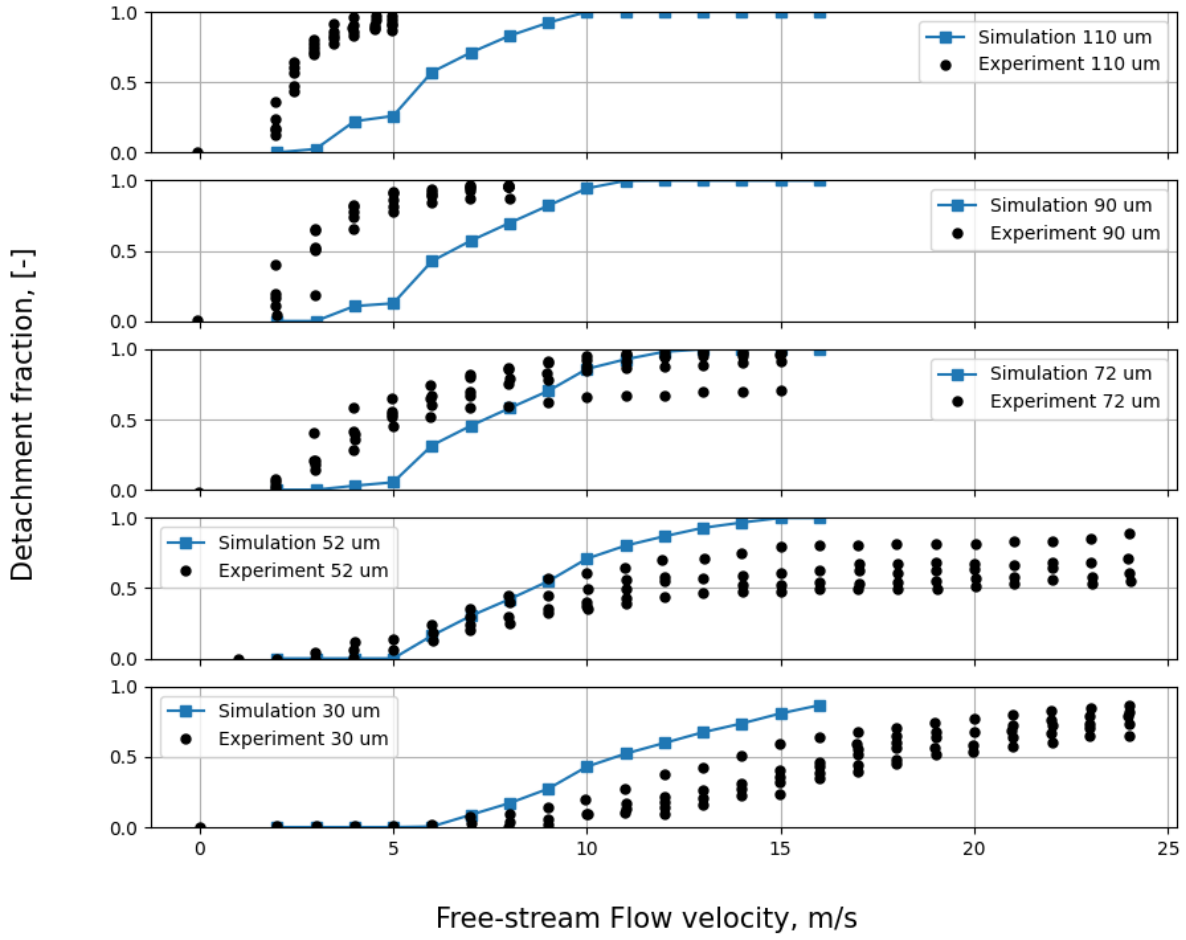

Resuspension



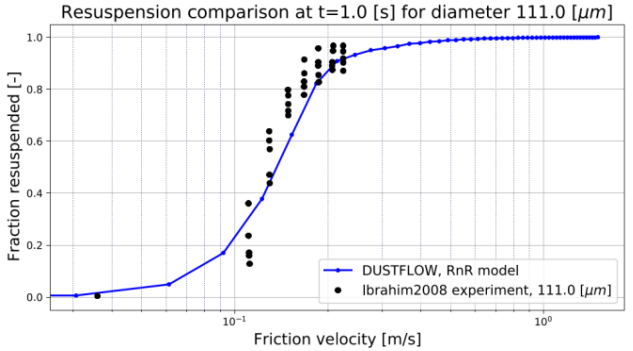
# Validation approach

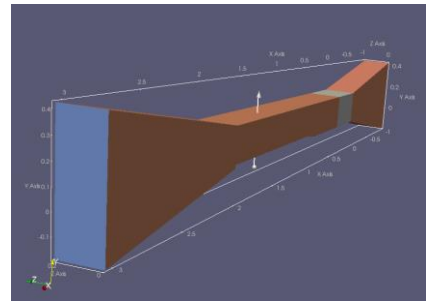
## Acceptable results even without model calibration

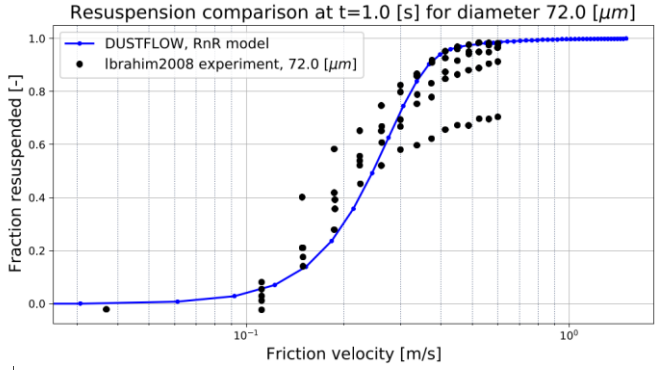
Without calibration

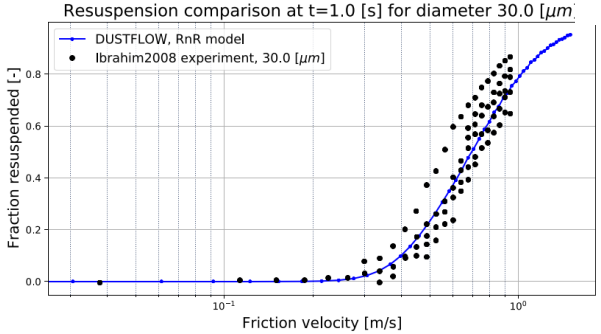



After calibration



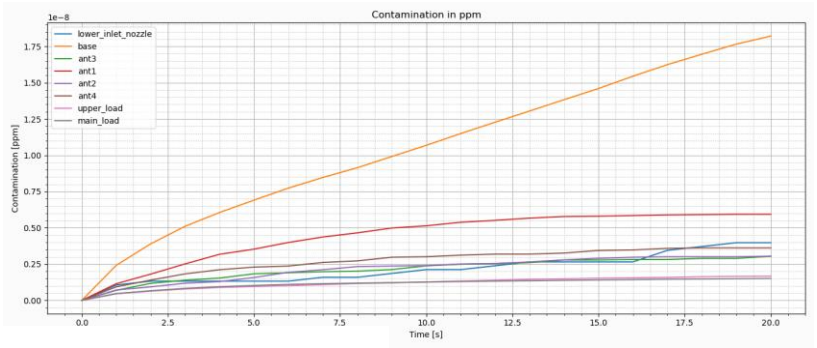



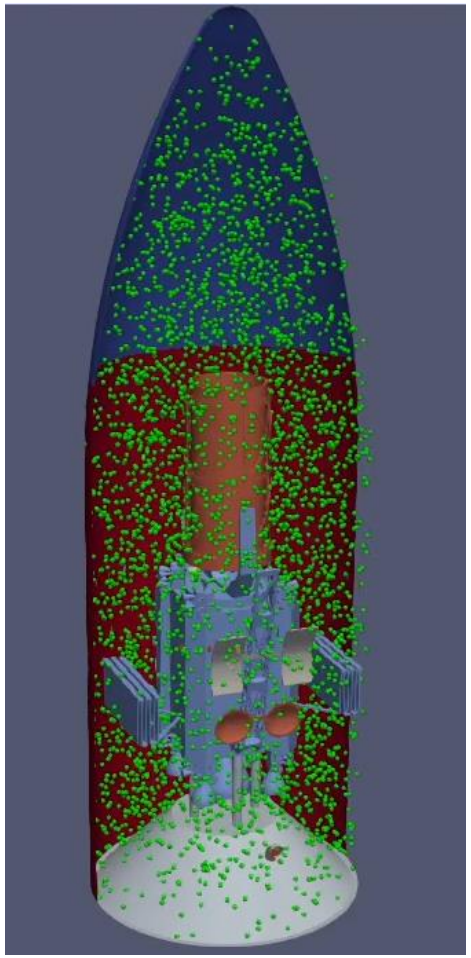


# Simulation results

## Simulation example for Ariane 5

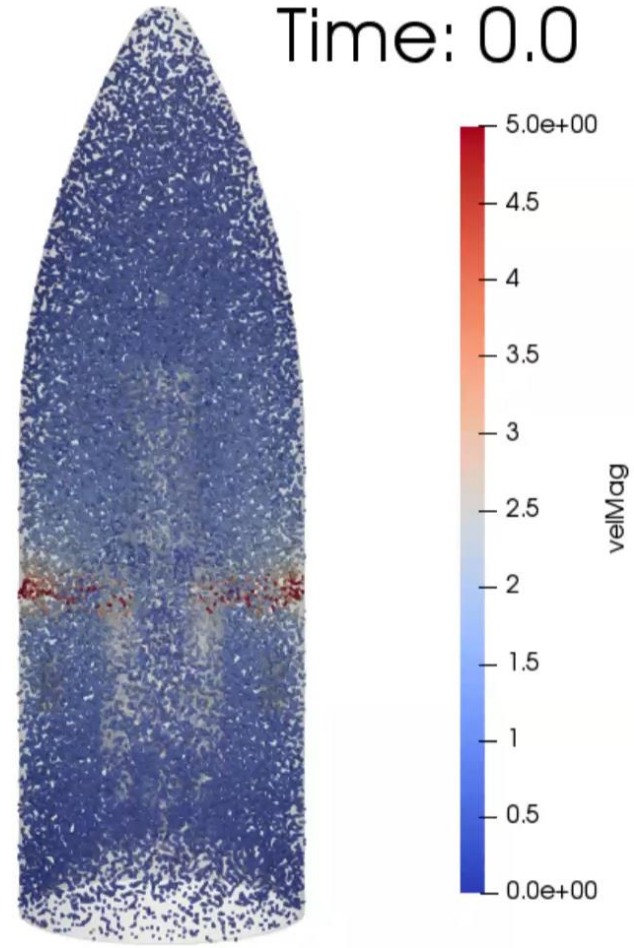


10 µm,
4x10$^4$ particles


10 µm,
10$^5$ particles

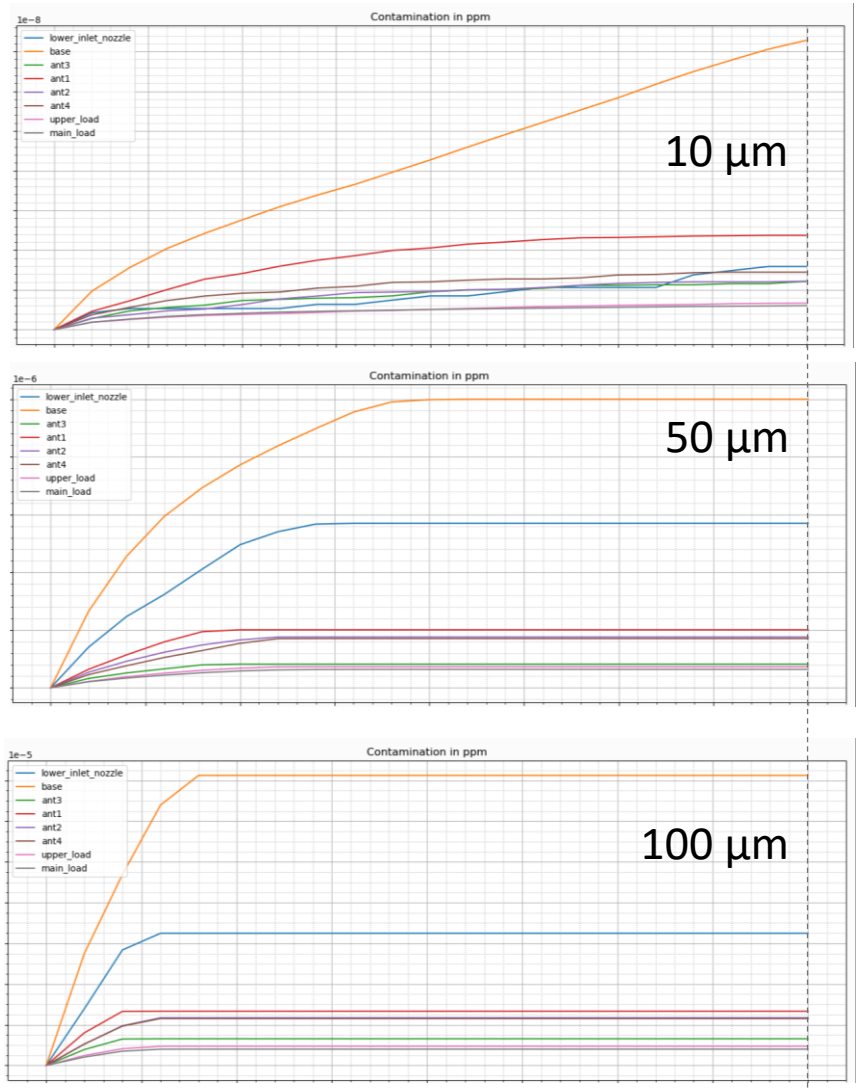

50 µm,
10$^5$ particles

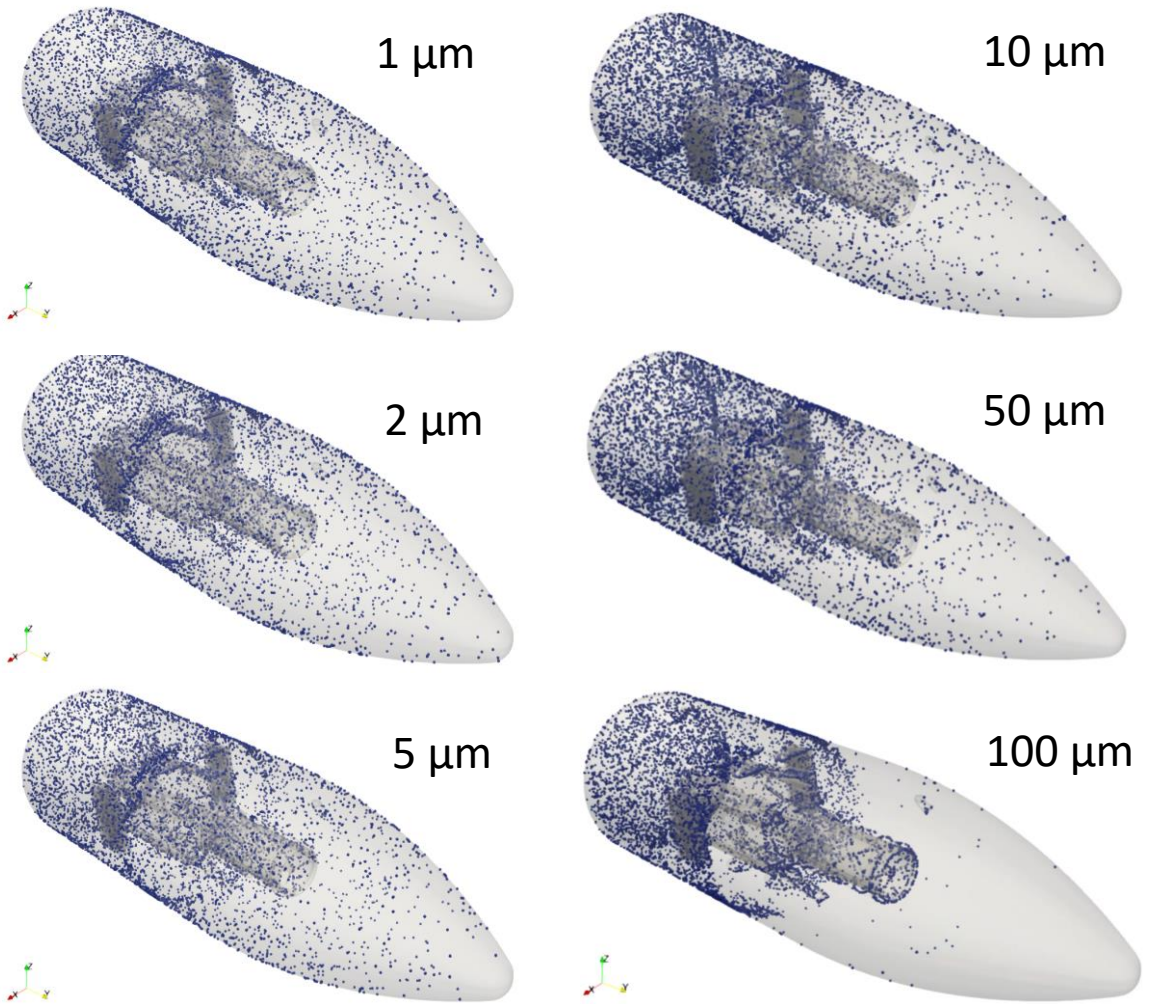



200 µm,
10$^5$ particles

# Simulation results

## Particle size impact



# Ongoing

development

# MoonDUST

## Modeling dust impact in lunar conditions

- **Prediction of particulate contamination** after landing and ascent at the Moon and after docking to the orbital station
- **Simulation of the engine plume** and dust acceleration due to the landing

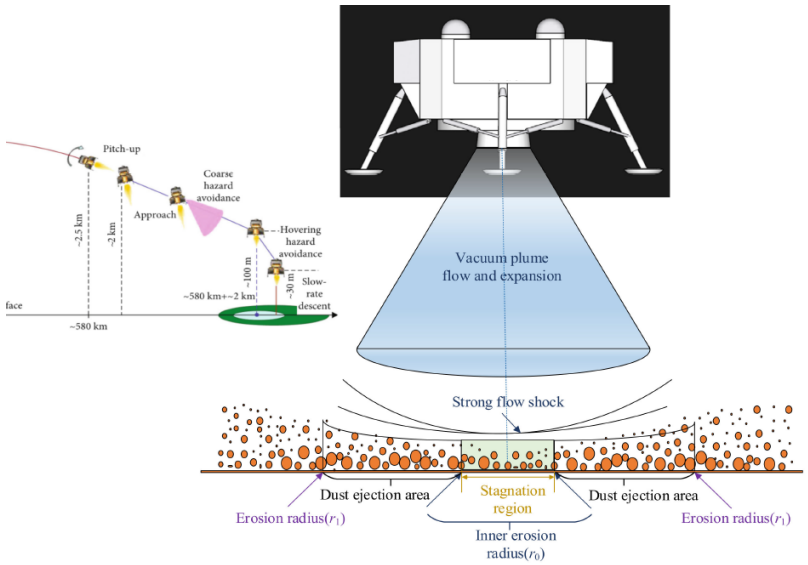
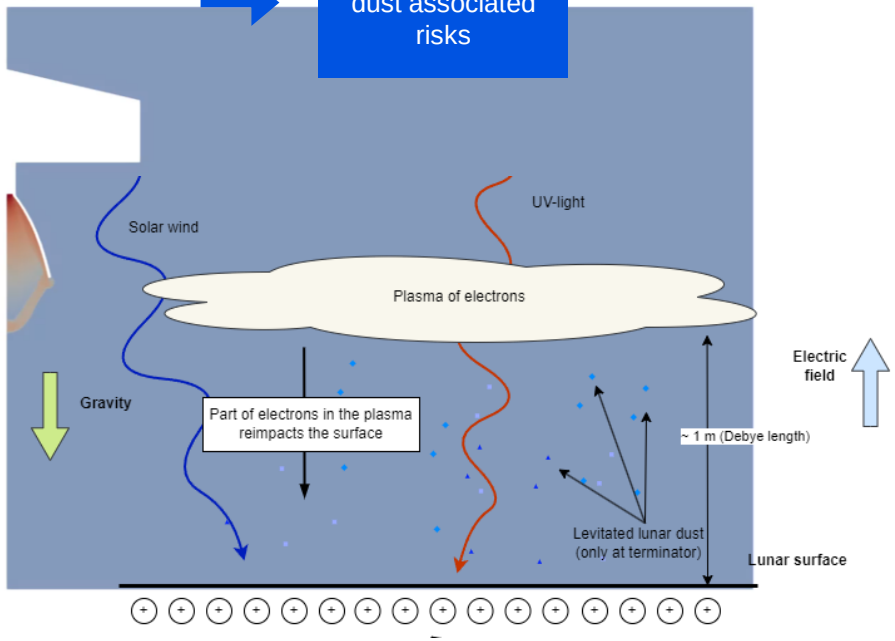



Image source: https://doi.org/10.3390/aerospace9070358

Lunar vehicles dust associated risks




Gateway dust associated risks

**Geometry + BC** → **Simulation of the descent phase** → **Simulation of the ascent phase** → **Simulation of the docking phase** → **Particulate contamination distribution**

# MoonDUST

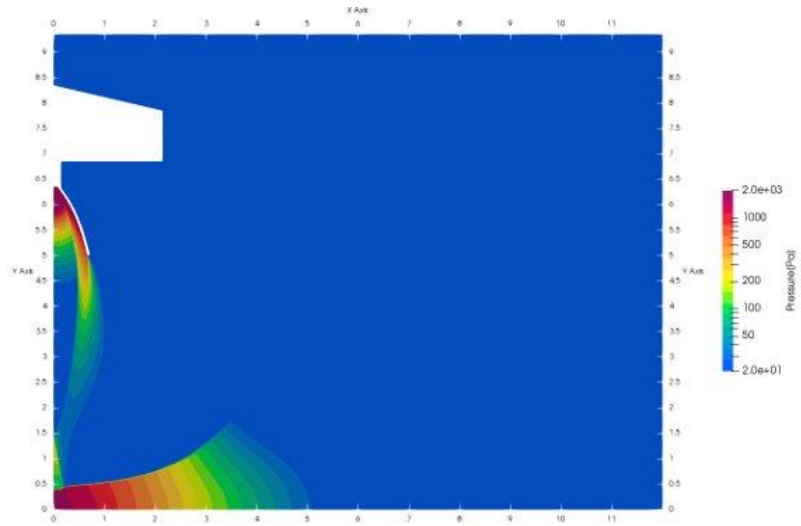
## FVM/DSMC coupling in plume simulations

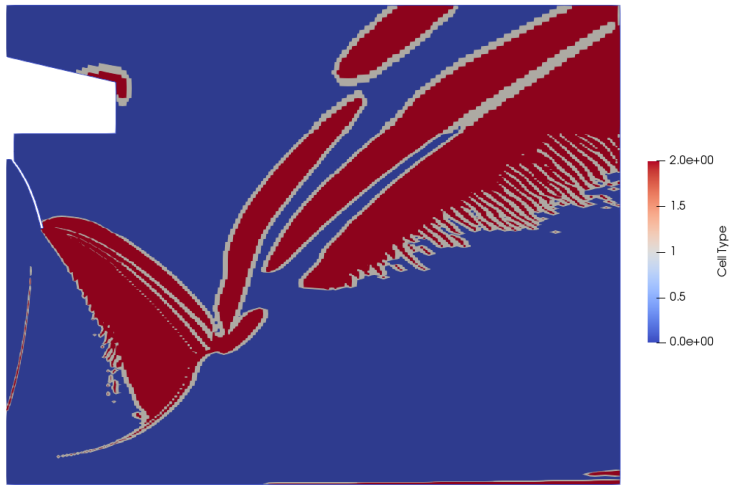
DUSTFLOW

esa European Space Agency

**FVM simulation parameters**

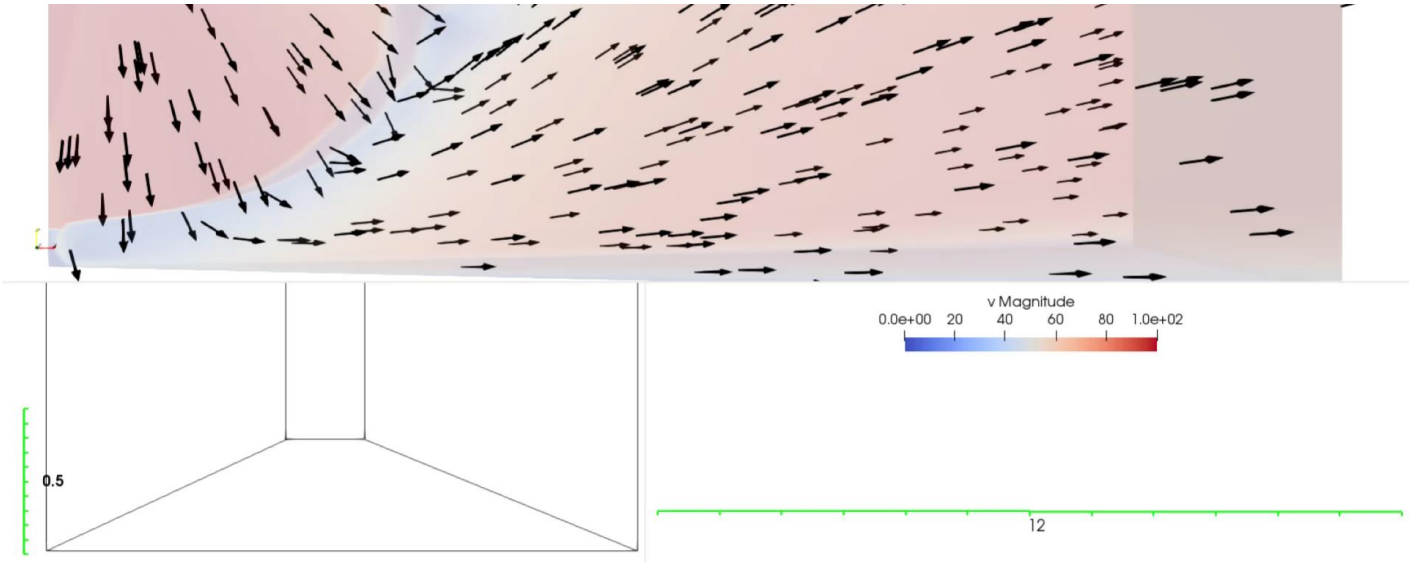
- Altitude: 5 m
- Simulation Time: 0.3 s
- Blue – FVM region
- Grey – interface
- Red – DSMC region




**CFDEM simulation with particles:**

- 2 million particles spherical 500 µm
- Random insertion at layers 5 cm and 10 cm above the surface



# Thank you!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Disclaimer: the view expressed in this presentation can in no way be taken to reflect the official opinion of the European Space Agency.


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