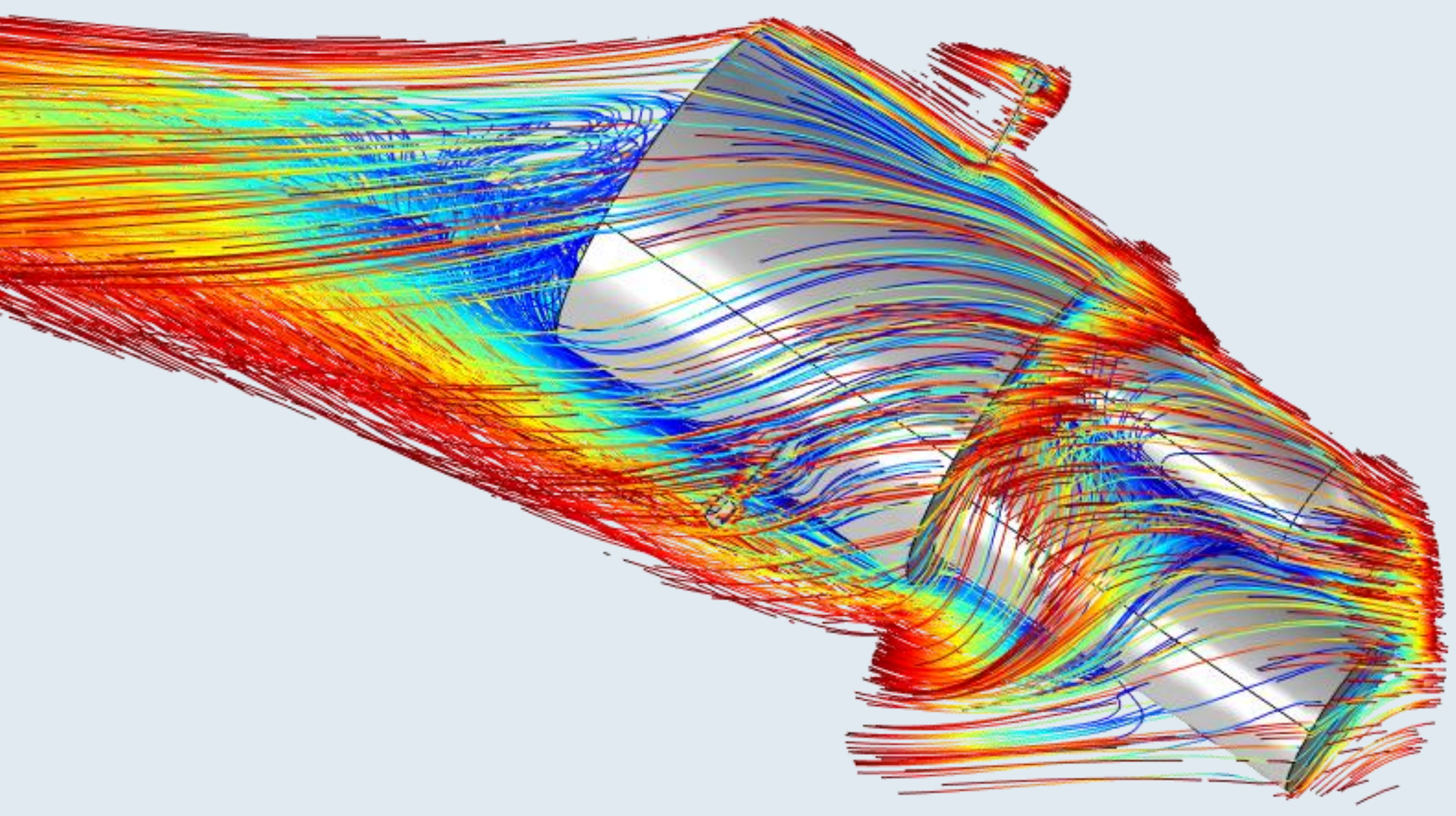

Efficiency of a Supersonic Rocket Aerosol Collector

This study aims to support the design and development of a rocket-borne particle collector through COMSOL Multiphysics® and its performance characterization.

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Abstract

In this study, simulations of supersonic flow fields by COMSOL Multiphysics® are used to design and develop an impaction-based particle collector for sampling nanometer-sized aerosols in the mesosphere, at 85 km altitude, mounted on a sounding rocket.

The goal is to collect the aerosols for physico-chemical analyses to study high-altitude processes such as the meteoric ablation and their potential effects on noctilucent cloud formation.

The simulations focus on the analyses of the supersonic flow fields, the shockwave localizations, and the boundary layer thickness around the rocket payload.

With the final collector design, simulations of particle trajectories characterize the collector's performance, where impactions onto designated collector surfaces are highly probable.

Methodology

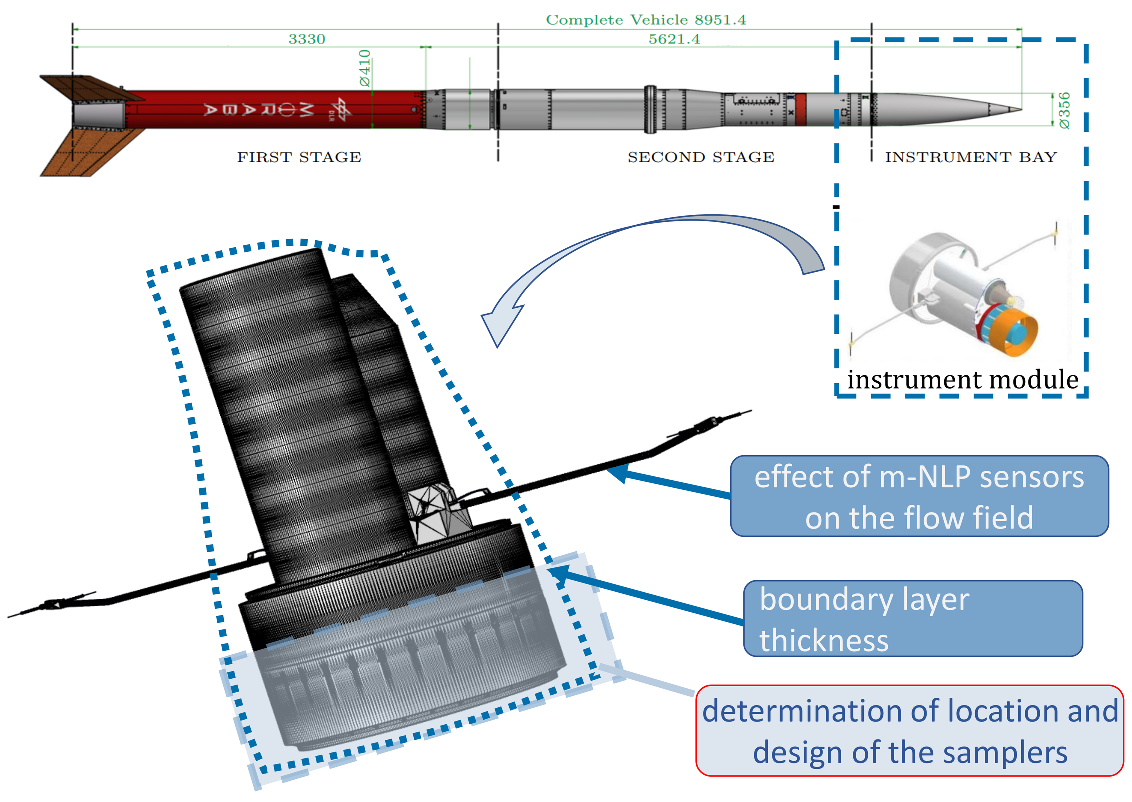

FIGURE 1: Sounding rocket (adapted from [1]) and instrument module, which is implemented into the COMSOL® model.

Mathematical model

compressible Navier-Stokes equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho\, \vec{u}) = 0$$

$$\frac{\partial (\rho \vec{u})}{\partial t} + \nabla \cdot (\rho \vec{u} \vec{u}^T) = \nabla \cdot \mathrm{T_f} + \rho \vec{f}$$

$$\frac{\partial}{\partial t}(\rho E) + \nabla \cdot (\rho \vec{u} E) = -\nabla \cdot k \nabla T + Q + \nabla \cdot (\mathrm{T_f} \vec{u}) + \rho(\vec{f} \cdot \vec{u})$$

$$\text{with } E = e + \frac{u^2}{2}, \text{ and } e = c_v\, T, \rho = \frac{p}{\mathrm{R_s}\, T},$$

$$\mathrm{T_f} = -p\mathbf{I} + \left[\mu \left(\nabla \vec{u} + (\nabla \vec{u})^T - \frac{2}{3}(\nabla \cdot \vec{u})\mathbf{I}\right)\right]$$

equation of particle motion

$$m_p \frac{d^2 \vec{x}}{dt^2} = \underbrace{\vec{\xi} \sqrt{\frac{6\pi\mu k_B T d_p}{\Delta t C_c}}}_{\text{Brownian force}} + \underbrace{\frac{3\pi\mu d_p \vec{u}_r}{C_c}}_{\text{Stokes drag force}}$$

ρ: density
$\vec{u}$: velocity
p: pressure
$\vec{x}$: particle position
μ: dynamic viscosity
$\vec{f}$: body force
e: internal energy
k_B: Boltzmann constant
c_v: specific heat capacity
T: temperature
R_s: specific gas constant
m_p: particle mass
C_c: Cunningham slip corrector
d_p: particle diameter
k: thermal conductivity
$\mathbf{I}$: identity matrix

Mesh generation

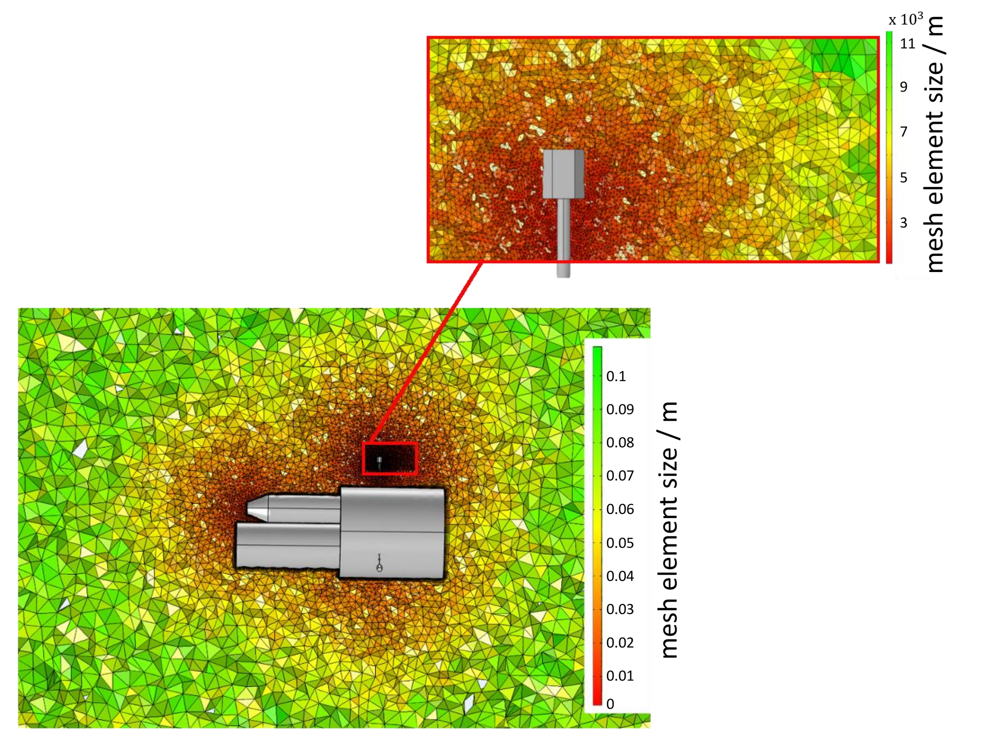

FIGURE 2: Generated mesh with refinement around the collector surface for the fluid flow simulations.

Results

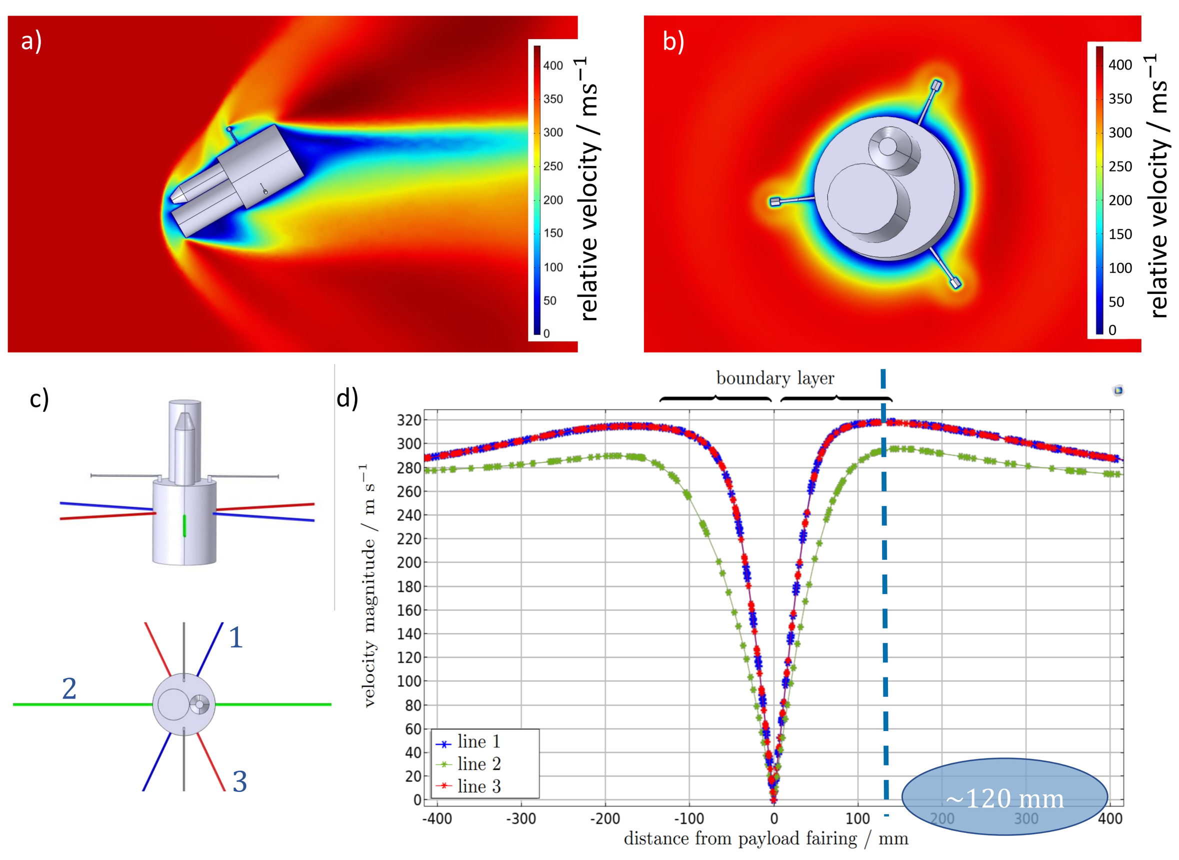

FIGURE 3: a)+b) Flow field around the instrument module. c) Cut lines. d) Velocity values depict the boundary layer thickness.

Effective particle starting positions and particle impacts

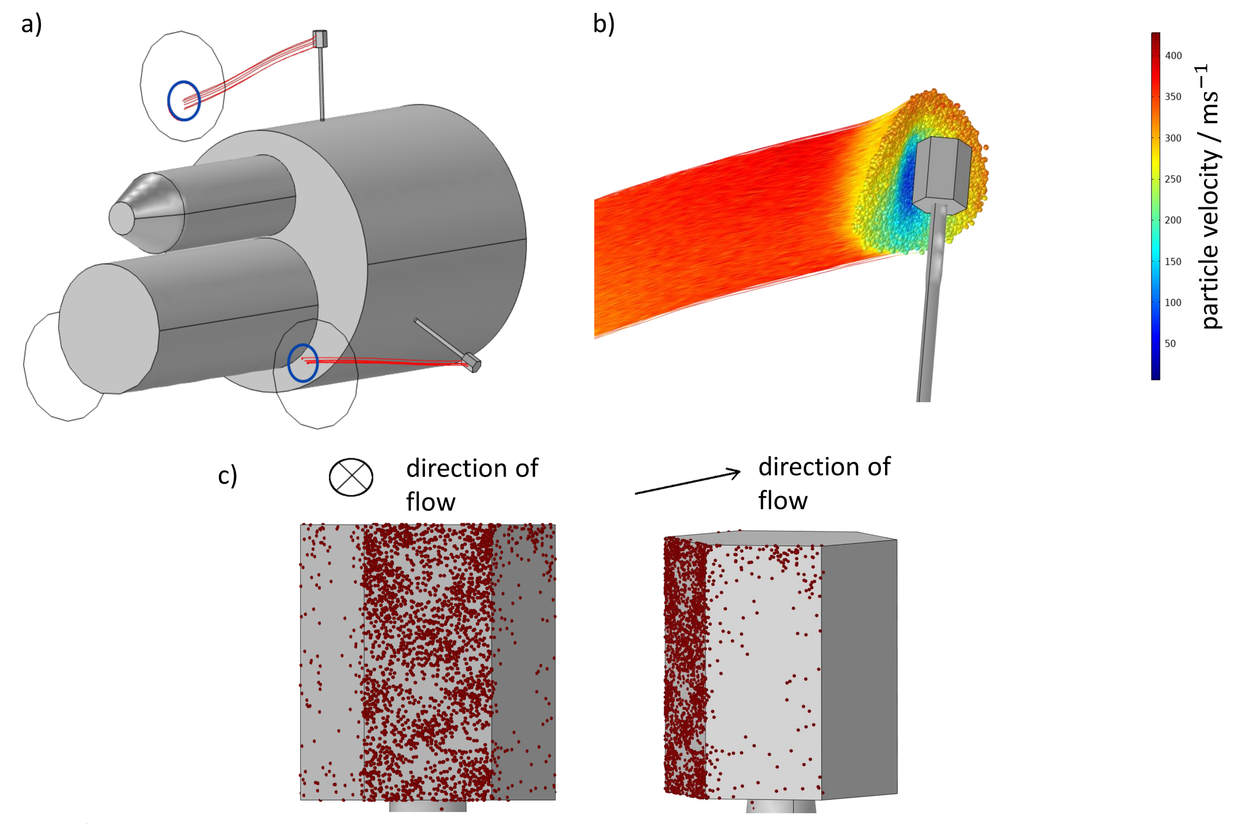

FIGURE 4: a) Determining effective particle inlet starting positions by back-trajectories. b) Ensemble of particle trajectories. c) Impacted particles on a collector surface.

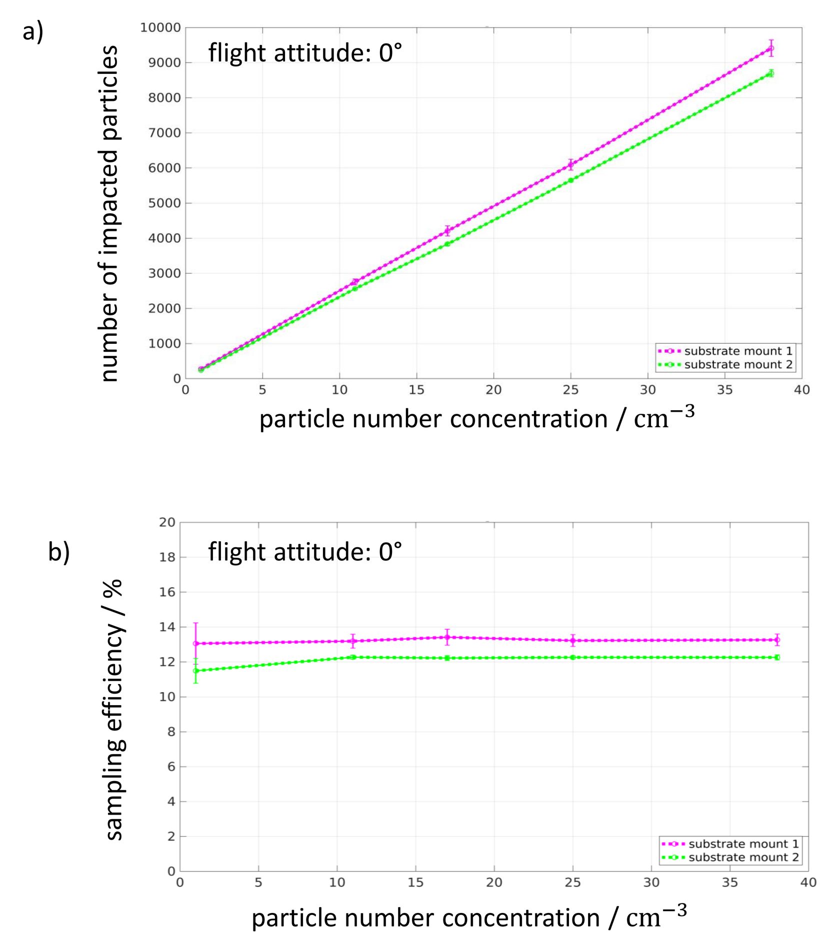

FIGURE 5: a) Number of impacted particles. b) Sampling efficiency with regard to the particle number concentration.

REFERENCES

[1] Naumann, K., et al. "Design of a hovering sounding rocket stage for measurements in the high atmosphere." (2020)

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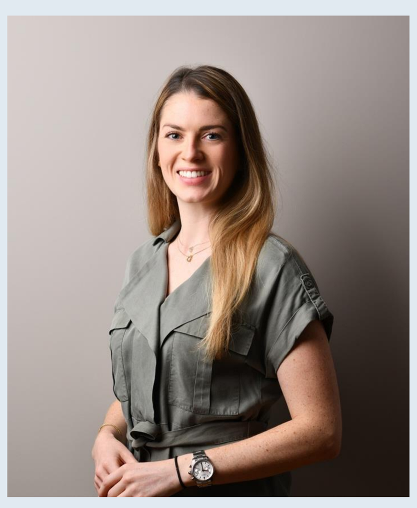

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