Numerical Analysis of Smoke Transport in Reduced Gravity

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Objectives

- To improve spacecraft fire safety by studying smoke emission and transport in the Orion Multi-Purpose Crew Vehicle using Computational Fluid Dynamics (CFD) simulations;
- To evaluate the impact of gravity (i.e., Earth, lunar, Mars, and microgravity) on smoke transport;
- To identify optimal locations for smoke detector placement;
- To compare flow orientation on smoke transport and clearance.

Simulation Method

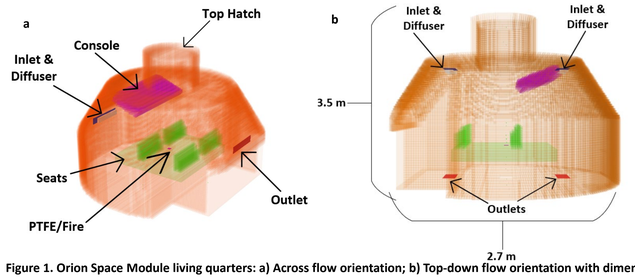

Figure 1. Orion Space Module living quarters: a) Across flow orientation; b) Top-down flow orientation with dimensions

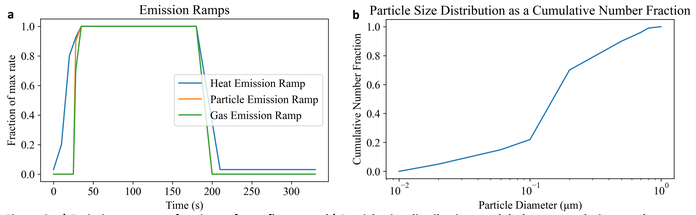

Figure 2. a) Emission ramps as fractions of max flux rates; b) Particle size distribution modeled as a cumulative number fraction.

- Simulation software: Fire Dynamics Simulator (FDS) by the National Institute of Standards and Technology.
- Orion space module dimensions: from other publications and public release notes on the Artemis missions.
- Ventilation rates: 77 air exchanges per hour (same as that in the International Space Station).
- Gravity: Earth (1 g); Mars (0.38 g); Lunar (g/6); and microgravity (0 g).
- Smoke source: a 5 g polytetrafluoroethylene (PTFE) cube overheated to 640° C.
- Smoke emission rate: from experimental study by our group.

Modeled Emissions & Numerical Output

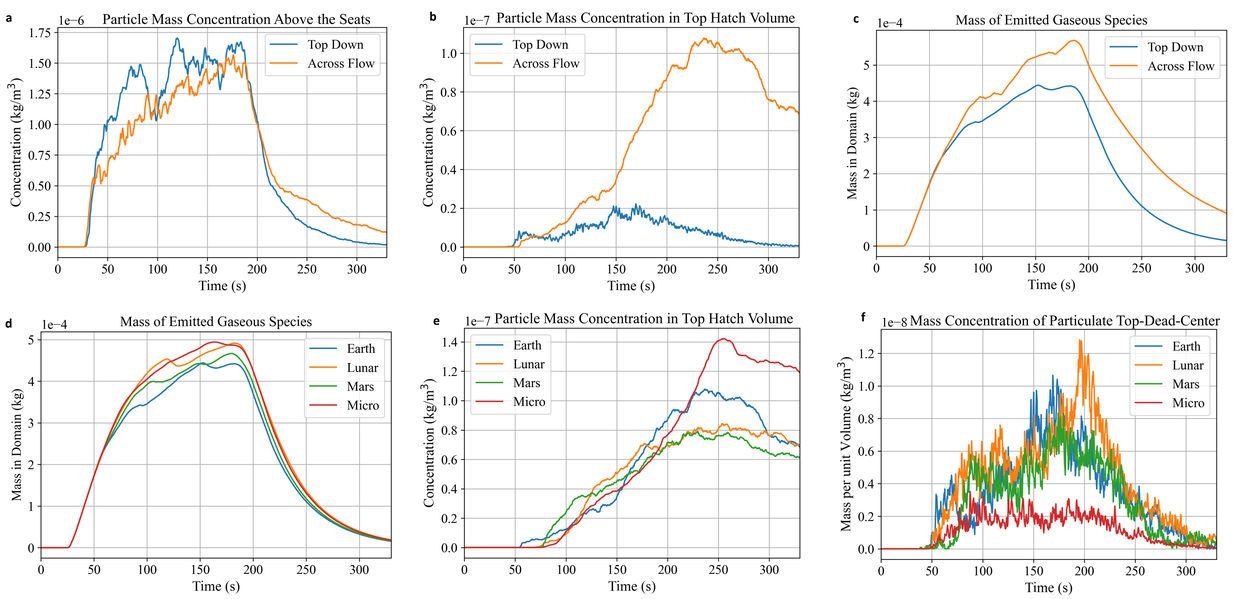

Figure 3. a-c) comparing flow orientations: a) Particle mass concentration above the seats around where astronauts would be; b) Particle mass concentration in the volume below the hatch; c) total mass of gaseous emissions within the domain.; d-f) comparing gravities: d)Total mass of emitted gaseous species in domain; e) Particulate concentration in top hatch volume; f) Mass concentration of particulate in the top of the main volume.

Model Output

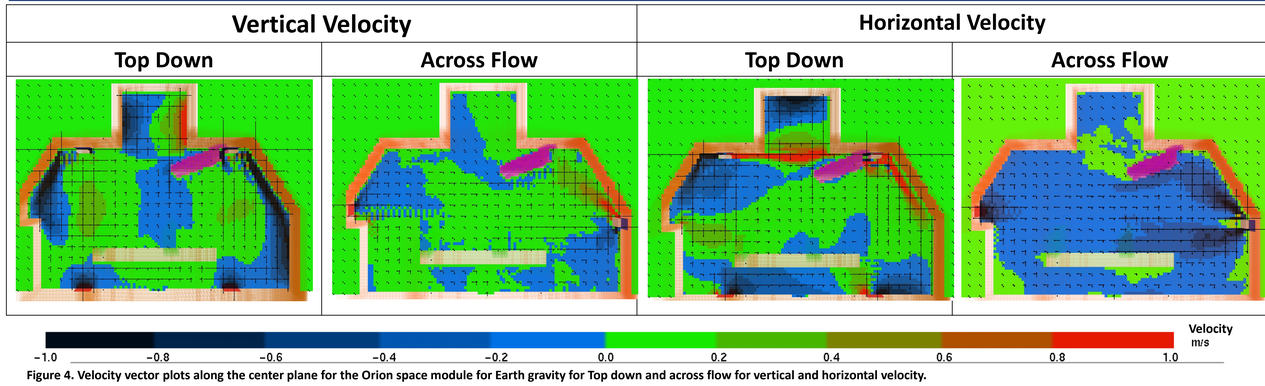

Figure 4. Velocity vector plots along the center plane for the Orion space module for Earth gravity for Top down and across flow for vertical and horizontal velocity.

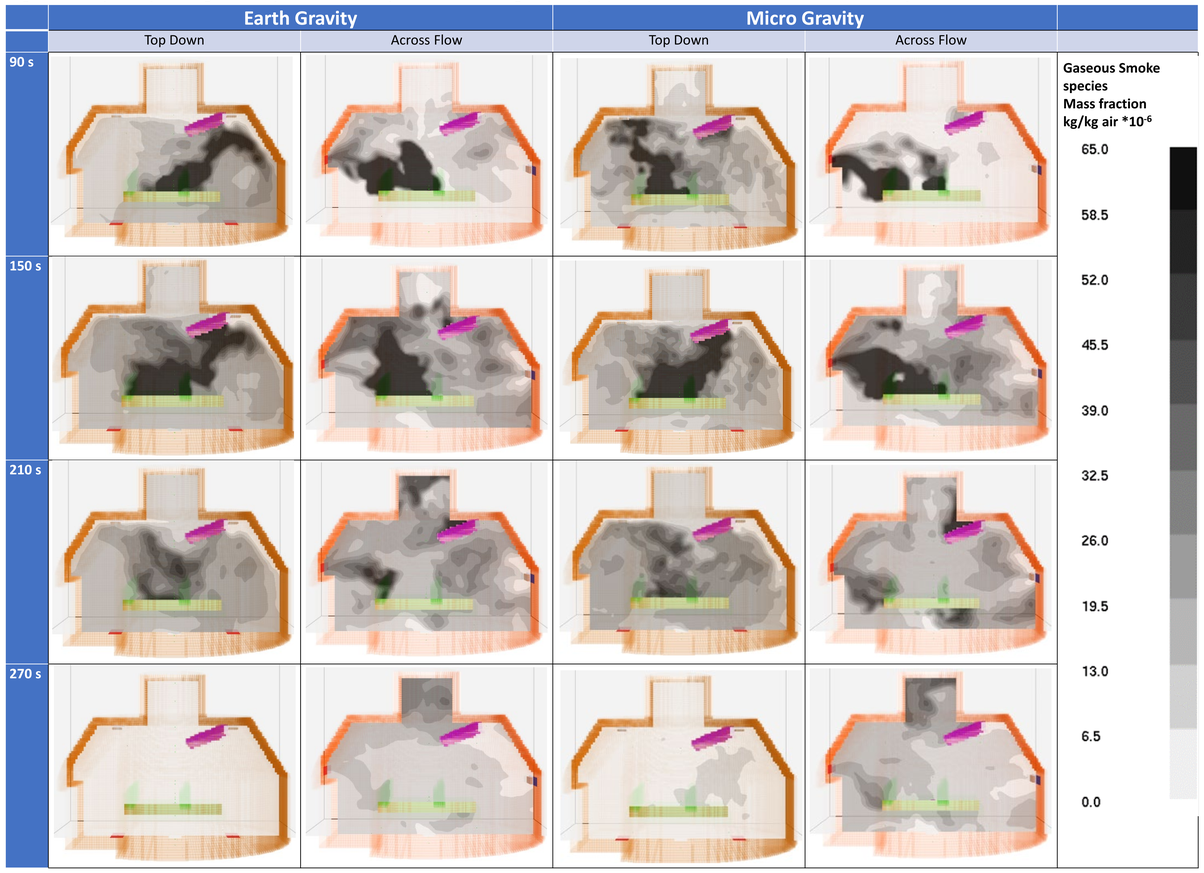

Figure 5: Time evolution of smoke transport for both top down and across flow orientations in Earth gravity and micro gravity,

Conclusions

- Mixing from ventilation reduced the expected stratification of emissions due to gravity. Ventilation design and arrangement, as well as flow obstructions heavily influenced results.
- Top-down ventilation was more effective for long term purge; the across flow cleaned the air around astronauts more effectively, but also had more stagnant areas that trapped emissions.
- Further investigation with laminar flow ventilation is necessary, but smoke detector placement in ventilation outlets seems ideal.