VALIDATING AEROSOL DISPERSAL FOR MARS ATMOSPHERIC WARMING AS A FIRST STEP TOWARD TERRAFORMING MARS: A MISSION CONCEPT PROTOTYPE. L. E. Coffin[1], A. Kling[1], C. Jourdain[2], A. Dumitrescu[1], E. S. Kite[1,3]
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Introduction: Mars's surface is currently inhospitable to all known life due in part to low temperatures. It has been proposed that photosynthetic microbes could eventually grow on Mars and slowly oxygenate the atmosphere to support more complex ecosystems, but for this to work Mars would have to be warmed [1,2]. Many methods to warm Mars have been proposed, including using gases [3,4], orbiting reflectors [5,6], and engineered aerosols, which are the focus of this abstract. Climate modeling indicates that dispersal of about 7 million tons of engineered aerosols in the Mars atmosphere could warm the planet by tens of degrees within months, by scattering and absorbing infrared radiation [7,8]. This would require factories to make million-ton quantities of nanoparticles from Mars-derived feedstocks with specialized ISRU plants [9]. To de-risk the factory's aerosol dispersal mechanism, we propose a Mars aerosol release experiment as a hosted payload on a future Mars lander. The payload could validate aerosol plume dispersal, atmospheric transport, and deposition processes in the surface atmosphere, also addressing pressing questions about dust storm forecasting and planetary protection [10].

Mars Aerosol Release Experiment Requirements: (1) The payload shall disperse and track aerosol particles to an altitude of at least 200 m and a range of at least 1000 m. (2) The payload shall successfully image the 3D structure of convective updrafts to an altitude of at least 200 m. (3) The mission shall determine the dry deposition rate of fine-grained and coarse-grained particles (0.2-1.5 μm effective diameter) at the landing site.

Validating Plume Dispersal with LiDAR Tracking: LiDARs are routinely used on Earth for aerosol tracking [11] and flew on NASA's 2008 Mars Phoenix Mission [12]. Further development is required to demonstrate LiDAR for atmospheric aerosol tracking on Mars. The proposed aerosol dispersion process experiment would demonstrate the atmospheric insertion of engineered aerosols from a surface level release, via local wind updrafts.

Our Large Eddy Simulations of local Mars wind conditions simulate updrafts capable of delivering an aerosol plume to the upper atmosphere. An end-to-end plume transport model combines the aerosol dispenser flow velocity, particle flow rate and charge, crosswind velocity, and particle agglomeration physics to calculate the expected plume concentration over time and the signal-to-noise ratio (SNR) seen by the LiDAR. Based on these models, particle dispenser requirements can be bounded. The Mars payload will include 5 kg of 380 nm diameter titanium coated silica nanospheres as an analog for engineered aerosols, due to their similar aerodynamic diameter, 80× improved backscatter efficiency compared to aluminum nanorods, and commercial availability.

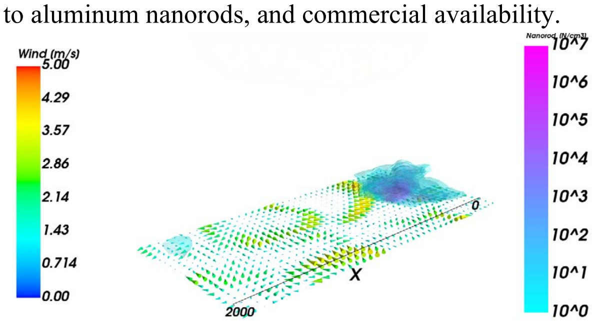


Fig 1: *Preliminary results of Large Eddy Simulation of Mars wind conditions and aerosol plume dispersal. Results show surface winds are dominated by lateral flows with localized updrafts and downdrafts. Periodic domain size 2 km × 1 km.*

Generating a Plume of Aerosol: Aerosolized particulate matter must have number density >20 particles/cm^3 to be measured by the LiDAR with a high SNR relative to scattered sunlight and natural Mars dust. Aerosol mass and flow rate requirements are driven by the downstream particle concentration which must be visible to the LiDAR 1 km downrange. Existing nanoparticle aerosolizers have been demonstrated for applications in aerosol and climate research, with maximum aerosol mass flow rates of hundreds to thousands of g/h and a maximum number density of 10^7 particles/cm^3 [13]. Particles may agglomerate at high concentrations, which reduces effective backscatter. Agglomeration will eventually form particles that may have a decreased residence time in the atmosphere compared to smaller particles, which reduces the warming effect per particle mass. Experimental work seeks to maximize particle flow rate while minimizing clumping.

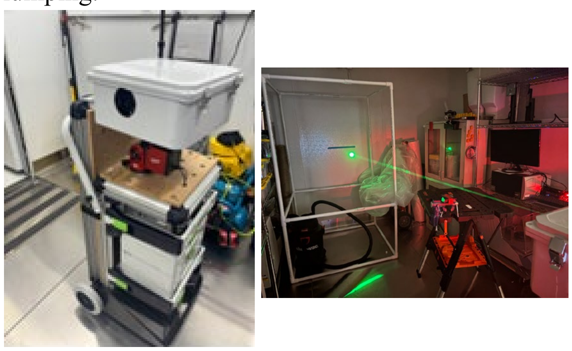
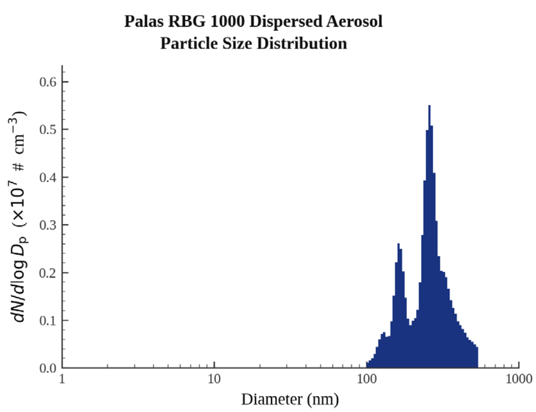


Fig 2: *Mobile field test platform integrates LiDAR, weather station, aerosol dispenser, and particle sizer.*

Planned testing will generate a plume of $CaCO_3$ (chalk) with a prototype adapted from a commercial powder coating gun as a calibration target for the two-wavelength LiDAR in development. The field test unit will validate gas consumption, powder flow rate, and particle clumping requirements with integrated compressed gas flow meter, mass balance, and particle sizer. The prototype dispenser and instrument suite closely resemble the science measurement concept and subsystem architecture of the proposed Mars payload.



V (mm/h)	N_{ave} (#/cm^3)	$d_{geo.mean}$ (nm)	d_{mode} (nm)
100	3.1 x 10^6	290.8	254.0
300	8.8 x 10^6	297.5	259.5
700	1.1 x 10^7	301.7	259.5

Fig 3: *Particle size distribution of 150nm diameter silica nanospheres after being dispensed. The distribution is bimodal with a high concentration of particles within the tail of the primary peak at 160 nm, indicating clear clumping behavior.*

Releasing Monodisperse Powders: Over time powders naturally agglomerate, so it is expected that the particles shipped from Earth will arrive on Mars with an unknown particle size distribution. The Palas RBG 1000 Aerosol Generator was used to dispense a controlled flow of aerosolized silica nanospheres to measure the concentration and size distribution of particles in the generated plume. Early results suggest that particle clumping will occur at the particle concentrations required for effective plume tracking, which motivates further work in outlet particle charging and mechanisms for clump deagglomeration. While there is extensive heritage for particle size sorting and mechanical powder breakup, current methods are largely not applicable to the submicron scale where Brownian diffusion and strong inter-particle adhesion dominate [14]. Further investigations of anti-clumping storage methods and in-situ de-agglomeration are required.

Further Work: Current near-term priorities include demonstrating the integrated aerosol disperser and instrument suite with long-range LiDAR tracking, using these results to validate our end-to-end plume dispersion model, and develop additional subsystems for long term particle storage and deagglomeration. For more information, see marsterraforming.org

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