

Use of the National Aeronautics and Space Administration’s (NASA’s) Global Reference Atmospheric Model (Mars-GRAM) Software for Modeling Gas Capture at the Martian Surface

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Open-source Modeling

NASA’s open-source Mars-GRAM software can model the abundances of constituent atmospheric gases under various conditions.

With an expanded emphasis on in-situ resource utilization (ISRU), it is desirable to model the densities of atmospheric gases at a higher fidelity than is possible with simpler calculations based on atmospheric composition percentages. This poster suggests a novel application of NASA’s Mars-GRAM software to model the availability of an atmospheric gas by adjusting the parameters that have historically described a spacecraft’s trajectory to instead describe sampling points across the volume of a notional gas collector. In this way, masses of constituent atmospheric gases can be modeled for ISRU gas-capture systems. The example presented models dinitrogen (N₂) gas, but the method could readily be applied to any atmospheric gas.

Although N₂ is ubiquitous in Earth’s atmosphere (constituting approximately 78%), Mars’ atmosphere is only about one-sixtieth the density of Earth’s and contains only about 2.59% N₂ on average [5], [6], [7]. At the Martian surface, dinitrogen densities have been measured at significantly lower percentages, however, demonstrating the potential inaccuracies of calculations that rely on component averages. For example, Curiosity’s quadruple mass spectrometer (QMS) measured volume mixing ratios of the Martian atmosphere over a period of 105 sols in 2012 [8]. QMS provided data on N₂, assessing the volume mixing ratio as 1.93% (± 0.03%) [1], “30% lower than the Viking values” [8] and just over 25% lower than the adjusted average N₂ value of 2.59% [6]. These differences highlight the need to model constituent gases as accurately possible in order to properly scale ISRU systems (and by extension, mission cost) and to reasonably estimate system outputs (thereby reducing mission risk).

Methods

In effect, the software models a “spacecraft” traversing the atmosphere a very short distance at a very low speed. This “spacecraft” provides point-sample data on gas abundances.

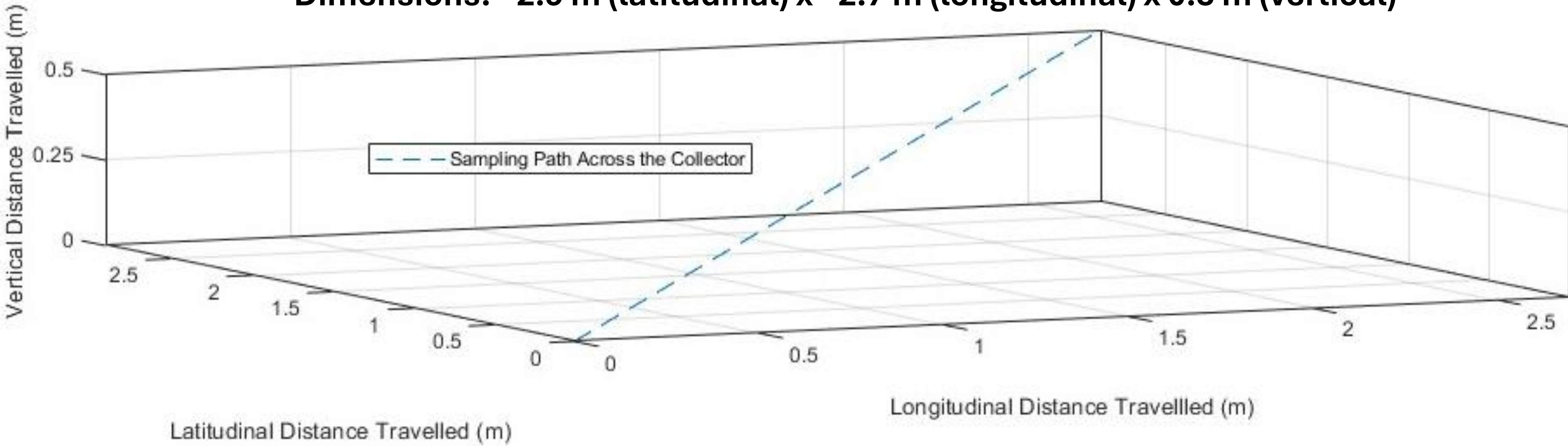
Mars-GRAM employs two different models for atmospheric circulation, the Mars General Circulation Model (MGCM) and the Mars Thermospheric General Circulation Model (MTGCM) [1]. Of particular importance to this study is the MGCM, which models the atmosphere “from the surface to 80km altitude” [1]. Software is available from the NASA software catalog [9]. A supplemental Spacecraft Planet Instrument C-matrix Events (SPICE) library is necessary to properly execute ephemeris calculations; these are available from NASA’s Navigation and Ancillary Information Facility (NAIF) at [10].

A test run was conducted using the model’s standard input parameters, which come with the software in a text file (Appendix B, [1]). The outputs of the test run with default parameters were validated against the sample output parameters provided in Appendix C of [1]. Appropriately scaling the initial conditions for the changes in latitude and longitude required an intermediate step to accurately convert degree changes in latitude and longitude (the input parameters necessary to define the path) to linear distances across the surface of Mars. Planetary parameters from [6] were used to define a reference ellipsoid within the Matrix Laboratory’s (MATLAB’s) mapping toolbox. The definition of this ellipsoid allowed for calculations of the arclength and directional azimuth between the simulation’s start and end points, accounting for the variation in linear distance over the ellipsoid.

Through trial and error, a realistic volume (7.82m³) for a notional gas collector was approximated by allowing the sampling path to traverse 0.5m vertically and 5/100,000th of a degree in both latitude (~2.9m linear distance) and longitude (~2.7m linear distance). It was assumed that the values along the path would be representative of the N₂ values throughout the volume of the collector. The simulation was run under these conditions, changing the simulated date by one month on each iteration to provide a sense of the likely seasonal variability of dinitrogen on the surface (Table 1). Each simulation stopped at the 500-second mark, when an altitude of 0.5m was reached. Thus, the model represents a cyclic intake and capture system more realistically than it does a continuous-flow system.

Sampling Path Across a Notional Dinitrogen Collector

Dimensions: ~2.9 m (latitudinal) x ~2.7 m (longitudinal) x 0.5 m (vertical)



Results

Although not built as an ISRU modeling platform, Mars-GRAM was utilized for that purpose with adjustments to the input parameters, a novel application of the software. While additional input parameters could be adjusted for higher fidelity or for mission-specific scenarios, to demonstrate the feasibility of the method, only the parameters governing height, latitude, longitude, and time were modified. The software, in effect, was programmed to model a “spacecraft” travelling a very short distance at a very slow velocity (about 4m in 500s with a change in altitude of 0.5 m). The “spacecraft” functioned like an internal sampler, measuring multiple data points within a pre-defined volume.

Execution of the simulation provided the results shown in Table 1. Mass percentages reflect estimates nearer to the values measured by QMS than the accepted atmospheric average (2.59%) or the older data of Viking. For this reason, the model is expected to provide more realistic constituent gas estimates. In this case, each cycle of the collector is modeled to take in about 1.5g to 2.6g N₂. Considering that humans need an estimated 14g of nitrogen per day [10], this notional collector provides a small but useful amount of N₂ for conversion into bioavailable forms.

Importantly, because Mars-GRAM was designed to model spacecraft trajectories, each step of the soft-ware’s propagation depends upon the previous step. It is therefore not possible to use the software to model a stationary object; in test runs, keeping the height, latitude, and longitude variables static led to constant outputs, including in the calculated values of the constituent gases, which defeated the purpose of the experiment to assess the potential for modeling atmospheric gas capture.

Simulated Date (yr. 2020)	N ₂ Mass %	Yield for 1 m ³ (kg)	Yield of notional N ₂ collector (kg)
Jan. 25	2.07	2.41E-04	1.88E-03
Feb. 25	2.06	3.01E-04	2.35E-03
Mar. 25	2.00	3.34E-04	2.61E-03
Apr. 25	1.88	3.00E-04	2.35E-03
May 25	1.71	1.98E-04	1.55E-03
Jun. 25	1.64	2.08E-04	1.63E-03
Jul. 25	1.60	2.90E-04	2.27E-03
Aug. 25	1.60	3.07E-04	2.41E-03
Sep. 25	1.64	3.25E-04	2.54E-03
Oct. 25	1.69	2.79E-04	2.18E-03
Nov. 25	1.71	1.99E-04	1.56E-03
Dec. 25	1.76	2.28E-04	1.79E-03

Table 1. Simulated Atmospheric Densities, Dinitrogen Mass Percentages, and Yields at a Sample Location over a Year.

Significance, Way Forward

Simulations like this provide baseline values for ISRU projects that aim to harvest atmospheric resources. GRAM software exists for Earth, Mars, Venus, Jupiter, Titan, Neptune, and Uranus.

The stated goal of NASA to establish a human presence on the Moon and Mars go hand-in-hand with maximizing, to the extent practicable, the use of in-situ resources. Although the most significant research efforts have thus far focused on developing water, oxygen (O₂) and, on Mars, carbon dioxide (CO₂) resources (e.g., [2], [3], [4]), investigations into the availability of other necessary elements, including argon (Ar) and N₂ are less mature.

Concerns about in-situ availability, industrial conversion processes, and power requirements such as those expressed in [12], [13] remain valid for scoping such designs, but the design work now enjoys a firmer footing than would be provided through simpler calculations that use component averages. If employed, such component-based calculations could lead, as they did in this case, to an overestimation of resource availability, encouraging an under-design of system capacity and a potentially dangerous scenario for any settlement dependent upon a minimum system output.

Significantly, this method could be used to estimate harvesting rates for any constituent gas from any planetary atmosphere. Although the focus for this paper was Martian N₂, NASA’s family of GRAM software includes unique modeling routines for Earth, Venus, Jupiter, Titan, Neptune, Uranus. Studies on CO₂ would be useful for O₂ separation, methane synthesis, or air diluent studies. Similarly, capturing Ar would be useful for diluting air or for use-cases that require an inert gas (e.g., in welding, lab experiments). Captured O₂, of course, has numerous potential applications. Until dedicated IRSU modeling software is developed for such efforts, however NASA’s GRAM family of software provides a useful and free alternative.

References

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