Mars-GRAM Support for the Mars Ascent Vehicle

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Background

Mars sample return is a bold concept, which entails gathering a varied, scientifically-relevant collection of Martian rock core samples and bringing them to Earth for analysis. To support this endeavor, the Marshall Space Flight Center (**MSFC**) is developing the Mars Ascent Vehicle (**MAV**), which is responsible for getting the collected samples off the planet. The MAV Preliminary Architecture Assessment (**PAA**) study is designing two vehicle architectures based on different propulsion configurations: a two-stage solid-solid concept, and a hybrid concept. Given different thrust profiles for the two configurations, each concept uses a unique trajectory to reach the same orbit. In support of the PAA, The MSFC Natural Environments Branch (**EV44**) was asked to produce tables of atmospheric parameters along each of the two trajectories. The Mars Global Reference Atmospheric Model (**Mars-GRAM**) is an EV44 tool that is ideally suited for this analysis. Mars-GRAM will continue supporting MAV development in future design cycles.

Methodology

- The trajectory values were taken directly from spreadsheets provided by the MAV PAA team and subsequently saved in Mars-GRAM-formatted trajectory text files. The solid-solid concept trajectory contains 1383 data points. The hybrid concept trajectory contains 833 data points.
- 1000 dispersed Monte Carlo runs were performed for each configuration trajectory, to allow computation of mean (μ) and standard deviations (σ).

Assumptions

1. It was assumed that the MAV liftoff would occur sometime around the year 2031, in a late autumn timeframe to avoid mission loitering through the winter months. Also, a local noontime launch was preferred to provide optimal possibilities for video observation of the liftoff and ascent from the lander/fetch rover. An earth date/time for liftoff initiation was selected as October 31, 2031, at 1540 UTC. For the Jezero Crater mission target, this provides a liftoff from Mars at Ls=241.2 and a local true solar time of 1209 hours.
2. The EV44 Solar Activity Forecast website (https://sail.msfc.nasa.gov/) was consulted to estimate the F10.7 flux for the given launch time frame. The solar cycle is projected to be near solar minimum during the mission timeframe. A flux value of 100.0 (at Earth-sun distance) was selected to provide a reasonable measure of conservatism.
3. A globally uniform dust loading was applied with an optical depth of 1.0. This gives a nominal (approximately average) dust loading.

Outputs

- Dispersed east-west (**U**), north-south (**V**), and vertical (**W**) wind components were saved for each Monte Carlo run, from which μ and σ were computed.
- Temperature (**T**), pressure (**P**), and average molecular weight (**MW**) data are constant across Monte Carlo runs and only μ are computed. While MW is not a requested parameter, it is necessary in the computation of speed of sound (**SoS**), as described below.
- Dispersed total density (**D**) values were saved for each run, from which μ and σ were computed.
- Chemical constituent concentrations (CO_2, N_2, Ar, O_2, CO, O, He, H_2, H, and $H_2$0), in the form of molar mass fractions (**f_m**), are constant across runs and only μ are computed.
- Speed of sound must be computed during post-processing. Since none of the functional dependent variables are dispersed in Mars-GRAM, only μ was computed for SoS.

Computing speed of sound.

The formula used is:

$SoS = \sqrt{\gamma_{net} \times R_{sp} \times T}$, where γ_{net} is the ratio of the specific heat at constant pressure (**C_p**) to the specific heat at constant volume (**C_v**) for the local gas mixture, **R_{sp}** is the specific gas constant given by **R_{sp} = R*/MW**, with the universal gas constant, **R* = 8314.46**.

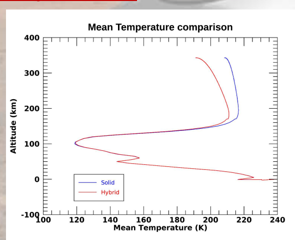
Constituent	Cp	Cv
CO_2	0.844	0.655
N_2	1.040	0.743
Ar	0.520	0.312
O_2	0.919	0.659
CO	1.020	0.720
O	1.301	0.781
He	5.190	3.120
H_2	14.320	10.160
H	20.635	12.401
H_2O	1.930	1.460

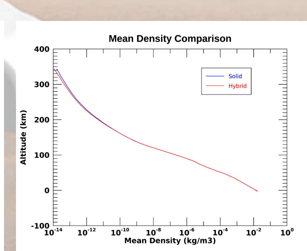
$$\gamma_{net} = \frac{C_{p,net}}{C_{v,net}}$$

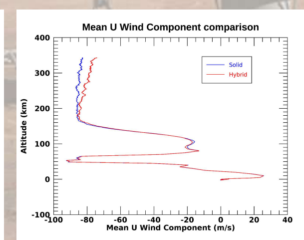
$$C_{p,net} = \sum_i C_{p,i} \times f_{m,i}$$

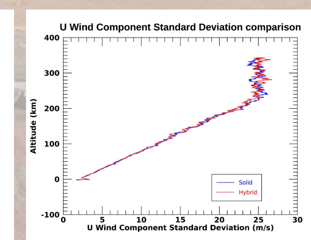
$$C_{v,net} = \sum_i C_{v,i} \times f_{m,i}$$

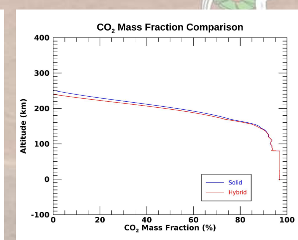
Sample Results











Mars-GRAM Basics

Mars-GRAM is an engineering-level model of the Martian atmosphere used to provide environment definitions in support of payload and entry system hardware design and advanced mission planning. Mars-GRAM provides estimates of mean and extreme values of temperature, pressure, density, wind components, and chemical compositions, with variability over latitude, longitude, altitude, time of day, season, dust loading, and solar output. Mars-GRAM can produce realistic dispersions and can be integrated into high-fidelity trajectory simulations to provide atmospheric state values at each integration step. Mars-GRAM is one of a suite of Global Reference Atmospheric Models (**GRAMs**) including those for Earth, Venus, Neptune, and Titan. New GRAMs are currently being developed for Jupiter, Saturn, and Uranus. All existing GRAMs are being rewritten in C++ to provide a common, integrated framework and to take advantage of object oriented programming techniques. In addition, new climatology data are being developed and will be integrated into future GRAM releases. New Mars General Circulation Model output data are being provided by the NASA Ames Research Center.

MAV Basics

The Mars Ascent Vehicle is a major MSFC contribution to the Mars Sample Return mission. The NASA 2020 Mars Rover will collect over two dozen core samples from multiple rock types and deposit them at appropriate locations for later retrieval. A later launch will take the MAV to Mars, co-manifested on a lander with a "fetch rover." The fetch rover will retrieve the cached samples and load then onto the MAV. The MAV will then lift off from the surface and deliver the samples into Mars orbit. A European Space Agency orbiter will then rendezvous with the orbiting sample container, bring it onboard, and return it to Earth for scientific analysis. Based on results of the PAA, decision makers will down-select to a preferred architecture, and detailed MAV design cycles will begin. Deployment is expected in the late 2020's.

Acknowledgements

The current analysis was in support of the Mars Ascent Vehicle Preliminary Architecture Assessment study. Current and ongoing GRAM development is funded by the NASA Science Mission Directorate (**SMD**).

GRAM Development Team

The GRAM models are MSFC products. The current SMD-funded GRAM development is a joint venture between MSFC and the Langley Research Center (**LaRC**), including the following personnel:

LaRC

Alicia Dwyer Cianciolo	Project Manager	NASA
James Hoffman	Code Architect	Analytical Mechanical Associates
Richard Powell	User Representative	Analytical Mechanical Associates

MSFC

Hilary Justh	Atmosphere Modeling Lead	NASA
Patrick White	EarthGRAM Developer	NASA
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