Virtual Research Presentation Conference

SIGNAL ATTENUATION MODELING DURING HYPERSONIC ENTRY OF MARS VEHICLES

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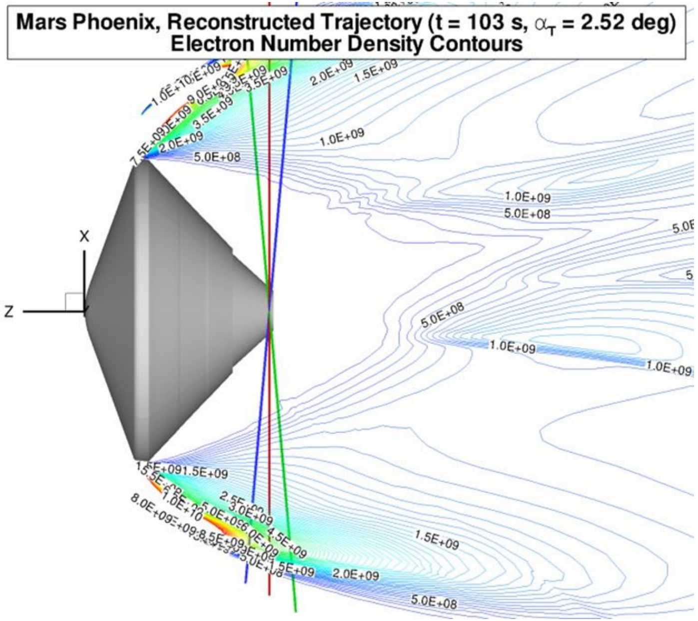
Tutorial Introduction

Abstract

When a spacecraft enters a planetary atmosphere at hypersonic velocities, a shock layer forms in the front of the body. An ionized sheath of plasma develops around the spacecraft, which results from the thermal ionization of the atmospheric constituents as they are compressed and heated by the shock or heated within the boundary layer next to the surface. When the electron density surrounding the spacecraft becomes sufficiently high, communications can be disrupted resulting in attenuation (brownout) or total loss of signal (blackout).

Several atmospheric entry cases of Mars vehicles were examined in the past (Mars Pathfinder, Mars Exploration Rovers, Mars Phoenix, MSL and InSight) [1-3]. The most recent case involved the analysis of communications degradation experienced by the Mars InSight spacecraft during its entry into the Martian atmosphere on Nov. 26, 2018 [3]. The UHF (401 MHz) relay links from InSight to several receive assets suffered ~52 s of degradation. These assets included the Mars Reconnaissance Orbiter and the MarCO A and B Cubesats. The observations were in agreement with existing models of signal degradation within known uncertainties. However, evidence emerged that suggested possible improvement can be realized in the atmospheric chemistry models used in the CFD software.



Morabito, et al., "The Mars Phoenix Communications Brownout during Entry into the Martian Atmosphere," IPN PR 42-179, pp. 1-20, November 15, 2009.

Problem Description

a) Context – Several Mars entries cases have been analyzed where we found consistency of the model attenuation versus observed attenuation within the factor-of-ten uncertainty in electron number densities output from Computational Fluid Dynamic (CFD) tools [2-3]. Estimates of signal attenuation during the degradation period at chosen time stamps were derived from the difference between signal strength measurements from flight data and the signal strengths derived from link analysis [2]. These signal attenuation measurements were compared against model attenuation estimated from electron number density profiles along the line-of-sight (LOS) directions from InSight towards the relay assets. The electron number density profiles were extracted from solutions from NASAs CFD tools. The model and measured attenuations were found to be consistent at the start of each signal degradation period. However, near the end of these periods, the difference between model and measured signal attenuation differed implying up to a factor of three underestimation of electrons by the CFD tools (but still within the factor-of-ten uncertainty). Other experimenters [4-5] noted such discrepancies near the end of their signal degradation period. Our initial suspicion was to check the chemistry reaction rates going into the CFD code. After performing the analysis it was found that the chemistry rates used for the $N + O \leftrightarrow NO^+ + e^-$ reactions were likely contributing to the underestimating of the number of electrons.

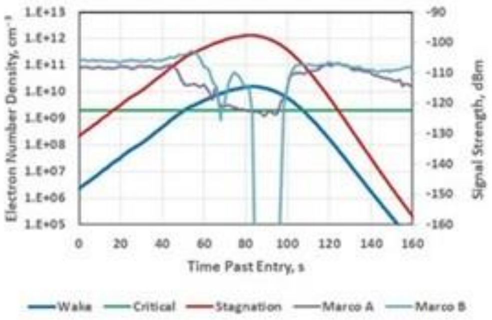
b) SOA - This work will benefit future Mars missions involving hypersonic entry scenarios (e.g. Mars 2020, Mars 2026) in that uncertainties of various CFD parameters can be tightened up. This would include reducing the uncertainty of estimated electron number density below its factor-of-ten value currently assumed for CFD tools.

c) Relevance to NASA and JPL - Such work could be beneficial for better assessing and predicting blackout/brownout outages and well as possibly better assessing heat-shield performance.

Methodology

a) Formulation, theory or experiment description -The first phase of the study involved retrieving DPLR output data files containing chemical (species concentrations), and physical quantities at various time stamps for both stagnation line and receive asset line of sights. Species concentrations included electron number densities as well as those for the neutral and positive ions (17 in total). We examined the concentrations of chemical species along the stagnation line on the heat shield side of the spacecraft, primarily ions and electrons. Next the concentrations of the various species along the LOS in the aft region spacecraft were examined, to identify those whose parameters may have contributed to any discrepancy between model and measurement attenuations. The case of the InSight to MarCO A link was focused on since it involved more data points with signal lock. We examined the electron number density as well as that of all of the positive ion species as a function of distance from vehicle surface to the direction of the various receive assets for particular time stamps in the signal degradation period. We compared prevalence of various species early in the period when there was good agreement between model and measurement versus that near the end of the period where a large deficiency of electrons was suggested such as from earlier analyses. This allowed us to identify positive ion species whose reaction rates required further scrutiny.

b) Innovation, advancement – Such comparisons of model and measured attenuations have not been previously performed in this level of detail for the case of Mars entries. The results of this work lead to improvement in the CFD models and thus provide improved pre-flight predictions and post-flight reconstruction analyses.



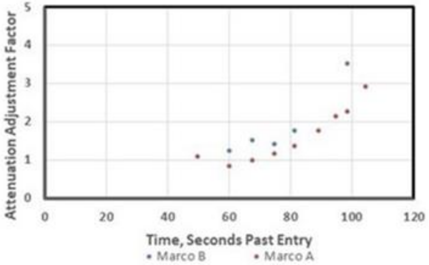
MarCO A (purple), MarCO B (light blue) measured signal strengths along with wake region (dark blue), stagnation (red) and critical (green) electron number density versus time past entry [2].

Results

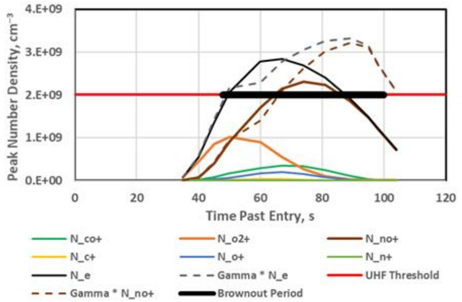
a) Accomplishments versus goals – Our goal was to find some explanation with regards to the high attenuation correction factors derived near the end of the signal degradation periods. Our initial suspicion was to check the chemistry forward and reverse rates going into the CFD code. After performing the analysis it was found that the chemistry rates used for the $N + O \leftrightarrow NO^+ + e^-$ reaction was underestimating the number of electrons. Other factors examined (ablation, radiation and collisions) were found to either be negligible or possibly secondary contributors to electron generation. The electron number density profile along the signal path input to the model was multiplied by an attenuation adjustment factor, Gamma, in order to match the model with the measurement at each time stamp. The resulting adjustment factors for the two MarCO spacecraft are shown in the upper right figure. At the beginning of the degradation period, the Gamma factors were near unity. However, one can see systematic trends as Gamma increases, reaching values of ~3 near the end of the signal degradation, suggesting that DPLR was under-estimating electrons [2]. We thus examined CFD models and their inputs to identify any potential refinements due to chemistry, as well as possible deficiencies due to other factors. It was found that the uncertainty in the chemical reaction rates in [6-8] involving NO^+ were likely suspect and that they could be improved upon. The lower plot to the right shows that the Gamma adjusted electron number density curve lie above the threshold for signal degradation. It was found that independent verification for this is to be reported on elsewhere [9].

b) Significance – By improving the chemistry in the CFD tools, one can improve upon the prediction of signal degradation periods.

c) Next steps – Plan to rerun the CFD software with new rates to see whether the attenuation adjustment factor curves (such as shown in top plot) flatten out and stay around unity. In addition, we plan to rerun software with ablation and radiation modeling turned on to quantify possible smaller secondary effects.



Attenuation adjustment factors (Gamma); MarCO A (orange) and MarCO B (blue) [2].



In-Sight to Marco A LOS peak number densities for key ionic species; electrons (solid black), Gamma-adjusted electrons (dashed black), NO+ (brown), Gamma-adjusted NO+ (dashed brown), and for other species (other colors). Also shown are the UHF threshold curve (red) and the blackout period (heavy black bar).

Publications and References

I. PUBLICATIONS

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J. REFERENCES

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