# Development of Three-Dimensional Ray Tracing Solver for Communication Blackout in Atmospheric Entries

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**Abstract:**
This works presents the development of a three-dimensional solver for the numerical analysis of the communication blackout encountered in atmospheric entry flights. The proposed methodology is based on computational fluid dynamic (CFD) simulation in combination with a ray tracing numerical technique. The ray tracing algorithm is based on the implementation of the Eikonal system of equation, a fast, efficient and accurate method to analyse interaction of electromagnetic signals and weakly ionised plasmas. The proposed methodology is applied to the atmospheric entry of the ExoMars capsule in Martian environemnt and shows the capability of a three-dimensional approach to analyse real flight configuration. Results demonstrate the validity of the proposed ray tracing approach for the analysis of communication blackout, where signals emitted from the on-board antenna undergo reflection and refraction from the plasma surrounding the entry vehicle.

*Keywords:* Numerical Algorithms, Computational Fluid Dynamics, Hypersonic, Plasma flows.

## 1 Introduction

Atmospheric entry represents one of the most critical phases of a space mission. The safety of the expensive payload strongly depends on the spacecraft survival to the harsh conditions experienced during the hypersonic descent into the target planetary atmosphere, characterised by high thermal loads on the vehicle surface. In addition, flight at hypersonic speed generates a plasma layer around the vehicle, leading to a disruption of the communication system during the crucial terminal phase of a space mission. The formation of entry plasma prevents radio signals to be received and transmitted from spacecraft, leading to a communication blackout, which can last several minutes, endangering the whole mission and deeply affecting crew or payload safety. The current aerospace technology requires further investigations and investments to overcome

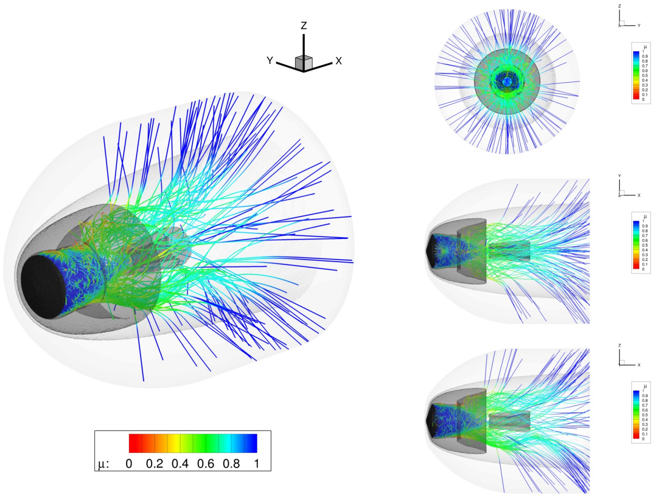


Figure 1: 3D ray tracing solution for flow over ExoMars entry capsule.

the communication blackout, especially considering the recent renewed interest in future human missions to colonise the space system.

## 2 Problem Statement

In general, blackout analysis is composed by two different steps. The first step consist in obtaining plasma density profiles and collision frequencies around the space re-entry vehicle from non-equilibrium hypersonic CFD simulation. The methodology used in this work starts with the numerical simulations of different trajectory points during re-entry missions. Then the CFD solutions are used as input solutions to analyse communication blackout with the application of ray-tracing algorithms.

## 3 Conclusion and Future Work

The methodology proposed in this work is focused on the innovative use of optical ray-tracing analysis to characterize the phenomena of the communications blackout. This will allow to overcome the limits of the current state-of-the-art approaches that are not capable to deliver the information needed to develop blackout mitigation solutions for future space missions. The proposed methodology, based on research efforts carried on at the von Karman Institute for Fluid Mechanics over the past years, has been applied to the Martian re-entry of the ExoMars Schiaparelli module in [1] and [2] with a two-dimensional approach. In this work, the blackout numerical solver will be upgraded to a three-dimensional formulation to deliver a tool capable of reproducing real flight configurations.

## References


[1] Ramjatan, S., Lani, A., Boccelli, S., Van Hove, B., Karatekin, Ö., Magin, T. & Thoemel, J. Blackout analysis of Mars entry missions. *Journal Of Fluid Mechanics*. **904**, 2020.

[2] Giangaspero, V., Lani, A., Poedts, S., Thoemel, J. & Munafò, A. Radio communication blackout analysis of ExoMars re-entry mission using raytracing method. *AIAA Scitech 2021 Forum*. pp. 0154 , 2021.