Revisiting the magnetic field and flow models in the planetary magnetosheath

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The steady-state magnetosheath model has various applications in studying the plasma and magnetic field profile around the planetary magnetospheres. Such a model can be used to evaluate the growth rate of plasma instabilities (mirror mode, in particular) by tracking the plasma parcel along the streamline, to navigate the data analysis, and even to estimate the upstream solar wind condition by inverting the model. The steady-state magnetosheath model is analytically modeled by constructing the Laplace equation for a scalar potential that cancels the solar wind field (such as the magnetic field or the flow velocity field) in the planetary magnetosphere [1]. The Laplace equation can be solved in different ways, which lead to different modeling approaches.

One may of course solve the Laplace equation numerically with the current computing resource but the boundary values of the scalar potential surrounding the magnetosheath must be set by hand, which turns out to be a difficult task because the magnetosheath is physically bounded in the radial direction (by the bow shock and the magnetopause) but not along the flow in the magnetosheath.

Our approach is based on the fact that the Laplace equation on the magnetosheath can exactly be solved to obtain an analytic expression of the scalar potential in the magnetosheath under a special condition, that is for the parabolic shape of the magnetosheath bounded by the parabolic bow shock and magnetopause [1]. The solution is found by expanding the potential with the Bessel functions and truncating at the second order due to the boundary condition. The exact solution can then be used to model the magnetic field and flow velocity field for a non-parabolic (i.e., more realistic) magnetosheath.

One possibility is to iterate in the stream-wise sense (along the flow) by tracking along the flow direction step by step [2,3], which is computationally expensive due to the need for many iterations and also for solving the shock condition ad hoc to obtain the initial condition properly.

The other possibility is to implement a mapping of the magnetosheath coordinates by retaining the grids orthogonal or nearly-orthogonal upon the coordinate transformation. Conformal mapping (angle-preserving mapping) on the complex plane is the ideal method to this goal, [4] but finding the proper conformal mapping turns out to be a mathematical challenge due to the non-bounded nature of magnetosheath along the flow. We propose an orthogonal grid system at and around the magnetopause and extend the grids to the bow shock (magnetopause-normal mapping) [5], which is advantageous in the following aspects: (1) the quality of scalar-potential mapping is high with the nearly-orthogonal nature of the mapping (Fig. 1), (2) the computation is numerically by far inexpensive compared to the iteration method, (3) the mapping is applicable to a user-specified shape of bow shock and magnetopause, and (4) the algorithm is easy to implement.

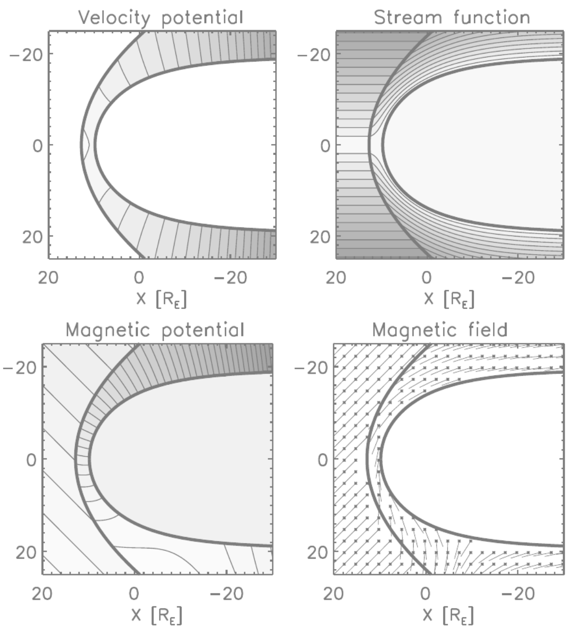

Figure 1. Flow velocity potential, stream function, magnetic scalar potential, and magnetic field directions in the empirical Earth magnetosheath obtained by magetopause-normall mapping [5].

Reference
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