SHOCK FRONT NONSTATIONARITY OF SUPERCRITICAL PERPENDICULAR SHOCKS

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The macro-structure of perpendicular shocks in the super-critical regime are modeled by using a method similar to the hybrid model. Unlike the usual hybrid simulation studies, however, time evolution of the system are not solved: instead, we seek for by iteration a self-consistent, time-stationary configuration of the incoming and reflected ion streams, charge-neutralizing electron fluid, and the electromagnetic field, by solving simultaneously the equations of motion of ions and the electron fluid, and the Maxwell's equations. If the plasma and the field variables converge after some iterations, we regard the shock to be time-stationary. Otherwise, the shock is classified as non-stationary. In the latter case, it is typically observed that the incoming ions are strongly decelerated as they couple with the reflected ions, and a strong magnetic field builds up at the point of the interaction. These signatures correspond to the shock front reformation, evidenced in many previous full particle simulations (e.g., Biskamp and Welter, 1972; Lembège and Dawson, 1987a; Lembège and Savoini, 1992). Details of the present model as well as discussion of the results are found in Hada et al (2002).

From a detailed parametric survey, we found that both stationary and unstationary shock states are realized, depending on the parameters specified: the upstream Alfven Mach number, M_A, fraction of reflected to incoming ion densities, α, and the thermal velocities of the incoming and the reflected ion streams, V_{ti} and V_{tr}. The results may be summarized as below:
(1) When M_A, V_{ti}, and V_{tr} are fixed, there is a critical value of $\alpha = \alpha_{cr}$, below (above) which the shock is stationary (unstationary). The critical α_{cr} exists for a wide range of M_A, starting from the critical Mach number (below which the shocks are subcritical) to very high Mach numbers (> 20).
(2) For weak shocks (say, $M_A < 4 - 6$), the stability depends both on M_A and α, while the value α_{cr} saturates for high $M_A > 10$, suggesting that stability of stronger shocks is mainly determined by α. For typical planetary bow shocks, α_{cr} is about 20 %, while for interplanetary shocks, the marginal stability must be determined by using M_A, α, and the thermal velocities of the ion streams, V_{ti} and V_{tr}, and is typically from 5 to 15 %.
(3) A comparison with full particle simulation runs shows a very good agreement with the present computation. Indeed, self-reformation is well evidenced for $M_A = 3.07$, for which one measures a percentage $\alpha = 0.25$ above the theoretical $\alpha_{cr} = 0.14$. In addition, several full particle simulations performed for different of values of M_A (not shown here) confirm such an agreement.
(4) The self-reformation is shown to depend mainly on the interaction between incident and reflected ion streams, while it does not depend much on electron dynamics and the ion-to-electron mass ratio. This supports previous results where self-reformation has been evidenced even for unrealistic mass ratios commonly used in full particle simulations.
(5) Computations including the heavy ion species show that the shocks tend to be more unstable as the heavy ion concentration is increased.

These results may be of great importance for accounting for or predicting conditions in which the terrestrial bow shock may be strongly nonstationary. Herein, this nonstationarity is characterized by the shock front self-reformation. This feature can be analyzed by using multiple satellites such as Cluster-2, located at different distances and large enough to identify different signatures of fields components during the shock front crossing. We further remark that, previous hybrid simulations did not evidence such self-reformation over a foot length scale but rather an unstationarity of the front located at the overshoot (local fields fluctuations only). As a consequence of the work by Lembège and Simonet(2001), some readjustment of grid resolution and of some plasma parameters could allow to recover a similar self-reformation of the shock front in hybrid simulations.

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