The role of the bow shock in Solar wind-Magnetosphere coupling

Ramon E. Lopez
Dept. of Physics
UT Arlington
How do we think about the Solar wind-Magnetosphere interaction?
How do we think about the Solar wind-Magnetosphere interaction?
How do we think about the Solar wind-Magnetosphere interaction?

Dungey [1961]
Reconnection
How do we think about the Solar wind-Magnetosphere interaction?

Dungey [1961]
Reconnection
How do we think about the Solar wind-Magnetosphere interaction?

Dungey [1961]
Reconnection

Axford and Hines (1961)
Viscous interaction
How is the energy to power convection extracted from the solar wind?

Where is work done against the solar wind and where are forces exerted in the system?
The Lyon-Fedder-Mobary (LFM) code is a fully 3-D MHD simulation that can be run with real solar wind input if desired. Magnetosphere modeled via ideal MHD equations within 30 to \(-300R_E\) (x) and 100 \(R_E\) (y,z). Upstream and side BCs -> Solar wind data. Downstream BC -> Supersonic outflow. Inner BC -> 2-D Ionospheric simulation. Reconnection occurs due to numerical effects.
V=400 km/s, n= 5/cc, Bz = -5 nT
The Chapman-Ferraro current: Load and Generator

For southward IMF
E = VBz (dusk-direction)

\( \mathbf{J} \cdot \mathbf{E} > 0 \) at low latitude

\( \mathbf{J} \cdot \mathbf{E} < 0 \) at high latitude (the mantle region)

C-F current exerts outward \( \mathbf{J} \times \mathbf{B} \) force on solar wind

Wednesday, June 2, 2010
Simulations show the same thing -

Bz = -5 nT

Ey > 0

so

Jy > 0 load

Jy < 0 generator
The bow shock and dynamics

\[ V_x \quad \rightarrow \quad B_z \quad \downarrow \quad B'_z \quad \downarrow \]
The bow shock and dynamics

\[ V_x \rightarrow \]

\[ B_z \downarrow \rightarrow J \]

\[ B'_z \]
The bow shock and dynamics

\[ J_y = \frac{\Delta B_z}{\mu_0} = \frac{B_z (r - 1)}{\mu_0} \]
The bow shock and dynamics

\[ \vec{J} \times \vec{B} \]

\[ J_y = \frac{\Delta B_z}{\mu_0} = \frac{B_z(r - 1)}{\mu_0} \]
The bow shock and dynamics

\[ J \times B \]

\[ V_x \]

\[ B_z \]

\[ J \]

\[ J_y = \frac{\Delta B_z}{\mu_0} = \frac{B_z(r - 1)}{\mu_0} \]

\[ P_x = J_y B_z = J_y \frac{B_z + rB_z}{2} = \frac{B_z^2(r^2 - 1)}{2 \mu_0} \]
The bow shock and dynamics

\[ \vec{J} \times \vec{B} \]

\[ V_x \]

\[ B_z \]

\[ \vec{J} \]

\[ J_y = \frac{\Delta B_z}{\mu_0} = \frac{B_z(r-1)}{\mu_0} \]

\[ P_x = J_yB_z = J_y \frac{B_z + rB_z}{2} = \frac{B_z^2(r^2-1)}{2\mu_0} \]

\[ \frac{1}{2} \rho V^2 \]

\[ \frac{P_x}{\mu_0 \rho V^2} = \frac{B_z^2(r^2-1)}{M_a^2} \]
Driving via the Bow Shock Generator

The current in the bow shock is a generator
\[ \vec{J} \cdot \vec{E} < 0 \]

This dynamo current acts as a source for potential
\[ J_{\parallel} = \sum_p \nabla^2 \Phi \]

\[ B_z = -20 \text{ nT}, V = 400 \text{ km/s}, n = 5/\text{cc} \]

Wednesday, June 2, 2010
C-F generator and load for nominal solar wind conditions

\[ B_z = -5 \text{ nT} \]
\[ V = 400 \text{ kms} \]
\[ n = 5/\text{cc} \]
\( B_z = -20 \) nT

C-F generator disappears.

This means that the bow shock as the only generator in the system!
Where does the current go?
Look at the direction of the current in the volume at \( Z=0 \)

\[
\begin{align*}
B_z &= -20 \text{ nT} \\
V &= 400 \text{ km/s} \\
n &= 5 \\
C_s &= 40 \text{ km/s}
\end{align*}
\]
The magnetic force can be the largest force in the magnetosheath if beta < 1
Astrophysical connections?

• What about current closure in astrophysical shocks? Where is the electromagnetic energy extracted from the flow at the shock dissipated?

• And what about the Heliopause? Where does the energy extracted at the termination shock go?
Bow shock dynamo and coupling to geospace
Bow shock dynamo and coupling to geospace

- The solar wind flow energy dissipated at the bow shock creates a dynamo ($J\cdot E<0$). This in part powers dayside merging (Siebert and Siscoe, 2002). For large enough IMF (low Mach number shock), this is the *only* generator in the system!
Bow shock dynamo and coupling to geospace

- The solar wind flow energy dissipated at the bow shock creates a dynamo ($J \cdot E < 0$). This in part powers dayside merging (Siebert and Siscoe, 2002). For large enough IMF (low Mach number shock), this is the only generator in the system!
- The bow shock current closes in part through the ionospheric load ($J \cdot E > 0$) where it can impose a potential in the polar cap and dissipate solar wind mechanical energy extracted at the shock.
Bow shock dynamo and coupling to geospace

• The solar wind flow energy dissipated at the bow shock creates a dynamo ($J\cdot E < 0$). This in part powers dayside merging (Siebert and Siscoe, 2002). For large enough IMF (low Mach number shock), this is the only generator in the system!

• The bow shock current closes in part through the ionospheric load ($J\cdot E > 0$) where it can impose a potential in the polar cap and dissipate solar wind mechanical energy extracted at the shock.

• This represents a means of transferring energy from the solar wind to the geospace system without reconnection or viscous interaction at the magnetopause - perhaps a third fundamental mode of energy transfer!
Bow shock dynamo and coupling to geospace

• The solar wind flow energy dissipated at the bow shock creates a dynamo ($J\cdot E < 0$). This in part powers dayside merging (Siebert and Siscoe, 2002). For large enough IMF (low Mach number shock), this is the only generator in the system!

• The bow shock current closes in part through the ionospheric load ($J\cdot E > 0$) where it can impose a potential in the polar cap and dissipate solar wind mechanical energy extracted at the shock.

• This represents a means of transferring energy from the solar wind to the geospace system without reconnection or viscous interaction at the magnetopause - perhaps a third fundamental mode of energy transfer!

• In astrophysical plasmas, similar process will be at work in shocks. Where is the EM energy generated at such shocks dissipated? How do the current close?