THE ROLES OF YXB AND DENSITY GRADIENTS IN PLASMA ELECTRIC FIELDS MEASURED. (U) S-CUBED LA JOLLA CA J R LILLEY ET AL. JUN 85 555-R-85-7339 AFGL-TR-85-0257 UNCLASSIFIED F19628-82-C-0081
THE ROLES OF $\mathbf{V} \times \mathbf{B}$ AND DENSITY GRADIENTS IN PLASMA ELECTRIC FIELDS MEASURED FROM THE SHUTTLE ORBITER

J. R. Lilley, Jr., I. Katz and D. L. Cooke

S-CUBED
P.O.Box 1620
La Jolla, CA 92038

June 1985

Scientific Report No. 3

Approved for public release; distribution unlimited

Air Force Geophysics Laboratory
Air Force Systems Command
United States Air Force
Hanscom Air Force Base, MA 01731
This technical report has been reviewed and is approved for publication

MICHAEL HEINEMANN
Contract Manager
Spacecraft Interactions Branch
Space Physics Division

CHARLES P. PIKE, Chief
Spacecraft Interactions Branch
Space Physics Division

FOR THE COMMANDER

RITA C. SAGALYN, Director
Space Physics Division

This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

If your address has changed, or if you wish to be removed from the mailing list, or if the addressee is no longer employed by your organization, please notify AFGL/DAA, Hanscom AFB, MA 01731. This will assist us in maintaining a current mailing list.
### The Roles of $\mathbf{v \times B}$ and Density Gradients in Plasma Electric Fields Measured from the Shuttle Orbiter

**Personal Author(s):** Lilley, Jr., J. R., Katz, I. and Cooke, D. L.

**Type of Report and Date Covered:** Scientific Report #3, June 1985

Plasma electric fields due to motion through the geomagnetic field and to density gradients are of the same order of magnitude in the wake of shuttle sized objects. Density gradient fields dominate in the wakes of smaller satellites while $\mathbf{v \times B}$ fields dominate behind larger structures. Supporting experimental data is cited. Computational results (calculated using the spacecraft charging code POLAR) which demonstrate the roles of the two fields in the wake are also presented.
THE ROLES OF $\mathbf{v} \times \mathbf{B}$ AND DENSITY GRADIENTS IN PLASMA ELECTRIC FIELDS MEASURED FROM THE SHUTTLE ORBITER

The electric fields observed on satellites can be due to a number of environmental influences. Density gradients and $\mathbf{v} \times \mathbf{B}$ are two causes of electric fields measured in low earth orbit. The electric fields due to density gradients affect mainly the smaller satellites while voltages generated by moving through magnetic fields are dominant on larger objects. For spacecraft the size of Space Shuttle Orbiter (10-30 m) the two effects are of the same order of magnitude. Measurements made during flights of the orbiter support this observation.

When a good conductor moves across magnetic field lines it develops a tangential electric field to cancel the Lorentz force on its conduction electrons. The tangential electric field can be found in the plasma's frame of reference by solving

$$F_L = e(E + \mathbf{v} \times \mathbf{B}) = 0$$

to find

$$\mathbf{E} = -\mathbf{v} \times \mathbf{B}$$

(1)

An electric field is also generated by the density gradient found in the wake of a fast moving spacecraft moving through a dense
plasma. By fast we mean that the spacecraft is supersonic with respect to the dominant ion species, and by dense we mean that spacecraft dimensions are large compared with the unperturbed ionospheric plasma Debye length. The shuttle orbiter satisfies both these conditions. The potential in the wake can be estimated using quasineutrality and the Boltzmann relation for electrons.

\[ n_i \approx n_e \]

\[ n_e = n_0 e^{(\phi/e_e)} \]

where \( n_e(n_i) \) is the local density of electrons (ions), \( n_0 \) is the undisturbed density, \( e_e \) is the temperature of the electrons in eV, and \( \phi \) is the local potential. Solving for \( \phi \)

\[ \phi = e_e \ln \left( \frac{n_e}{n_0} \right) \]

The electric field resulting from density gradients can be approximated by the change in the local potential over a length roughly the size of the cross-section of spacecraft with respect to the ram direction. Or

\[ |E| \approx \frac{\Delta \phi}{L} \approx \frac{e_e}{e} \left( \ln \left( \frac{n_2}{n_0} \right) - \ln \left( \frac{n_1}{n_0} \right) \right) \]

where \( n_1 \) and \( n_2 \) are two local densities.

The magnitude of electric fields due to the two effects can be approximated using Eqs. (1) and (2). Assuming a \( 10^{11} \text{ m}^{-3} \) plasma with a magnetic field of 0.4 gauss and a density gradient of four orders of magnitude in the wake (as observed on the shuttle orbiter by Murphy et al.) we can estimate the magnitude of the electric fields
caused by both processes. Using an orbital velocity of 7.7 km/sec, the \( \vec{v} \times \vec{B} \) field would be 0.31 V/m and independent of vehicle dimensions. Table 1 is for density gradient fields and, as can be seen from Eq. (2), depends inversely on the size of the orbiting spacecraft.

Table 1. Electric Fields Due to Density Gradients of Four Orders of Magnitude (as observed by Murphy et al.)

<table>
<thead>
<tr>
<th>( e = 0.1 ) eV</th>
<th>( e = 0.2 ) eV</th>
</tr>
</thead>
<tbody>
<tr>
<td>L (m)</td>
<td>E (V/m)</td>
</tr>
<tr>
<td>0.5</td>
<td>1.8</td>
</tr>
<tr>
<td>5.0</td>
<td>0.18</td>
</tr>
<tr>
<td>50.0</td>
<td>0.018</td>
</tr>
</tbody>
</table>

The electric field magnitudes lead one to expect small satellites (~1-2 meters in diameter) to have local fields dominated by density gradient fields and large spacecraft (~50-200 meters, i.e., space stations) to have fields mainly dependent on magnetic field effects. Objects the size of the space shuttle (~10-30 m) will experience electric field contributions of the same order of magnitude from both the Lorentz force and the density gradient fields.

Small satellites have observed electric fields of the order of 1 V/m. Samir et al. measured these plasma potentials as their probe rotated through the wake of the Atmospheric Explorer - C (AE-C). Measurements made on Orbiter flights have indeed seen electric fields from both influences. Raitt et al. recorded \( \vec{v} \times \vec{B} \cdot \vec{r} \) on the order of the predicted magnitude, where \( \vec{r} \) was the distance from the detector to spacecraft ground (the engine nozzle). The potentials they observed correspond to a maximum electric field of roughly 0.4 V/m. Smiddy et al. measured a density gradient electric field of 0.16 V/m while moving with the detector aligned with the velocity vector.
Computer calculations performed at S-CUBED in cooperation with the Air Force Geophysics Laboratory (AFGL) using the POLAR code (Cooke et al.) also show the interaction of the two electric fields. Solutions of the space potentials were calculated self-consistently along with current balance of the ambient plasma to the test objects. An object Mach vector of $-82$ through a 0.1 eV plasma at densities of $1 \text{ m}^{-3}$ and $10^{12} \text{ m}^{-3}$ containing a magnetic field of 0.4 gauss in the $-x$ direction was used. Figure 1 is a picture of the $8 \times 8 \times 2$ meter plate used to generate Figures 2 and 3 and Figure 4 is the $6 \times 16 \times 2$ meter box used in Figures 5 and 6.

The magnetic field generated an electric field of $-0.25 \text{ V/m}$ along the y-axis. The density gradient generated electric field was found by the code (Katz et al.). Figure 2(a) shows the potential around the plate due only to $\mathbf{v} \times \mathbf{B}$ field in plasma's reference frame. Figure 2(b) is the same set of potentials as seen in the spacecraft frame. Figures 3(a) and 3(b) are of the same object in the two reference frames with the density gradient electric fields included. In Figure 3(b), the electric fields interact in the wake in an anticipated manner. Note that the $\mathbf{v} \times \mathbf{B}$ field is not perturbed by density gradient fields in the ram direction since the ion density there is almost undisturbed and thus there is no quasineutral electric field. Figures 5 and 6 are of a metal box the size of the shuttle cargo bay under the same circumstances.

In conclusion, for shuttle sized objects care must be taken when interpreting measurements of plasma electric fields or space potentials. Plasma parameters, geometrical effects, and velocity effects may obscure the source of observed electric fields.
Figure 1. Perspective view of 8 m x 8 m x 2 m gold plate used to generate data for Figures 2 and 3.
Figure 2. Plate in low density (1 m⁻³) plasma. No density gradient electric fields.
Figure 3. Plate in high density \(10^{12} \text{ m}^{-3}\) plasma. Both \(\mathbf{v} \times \mathbf{B}\) and density gradient fields are present in the wake.
Figure 4. Perspective view of 16 m x 6 m x 2 m gold box used to generate data for Figures 5 and 6.
Figure 5. Metal box in a low density (1 m⁻³) plasma. There are density gradient electric fields present.
GOLD BOX IN HIGH DENSITY PLASMA

$\mathbf{v} \times \mathbf{B}$

+ Potential relative to box (volts)
+1.7
+2.5
+3.3
+4.1
+4.9

Z (Meters)

Figure 6. Metal box in a high density ($10^{12}$ m$^{-3}$) plasma with both $\mathbf{v} \times \mathbf{B}$ and density gradient electric fields.
REFERENCES


