CONDUCTIVITY OF AN EXPANDING PLASMA CLOUD ABOVE A HYPERVELOCITY IMPACT.
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An impact-generated, partially ionized vapor cloud (a dusty plasma) may a) compress an ambient magnetic field [1], b) generate a magnetic field [2] and c) interact with incorporated dust grains [3]. The first two processes may have produced certain lunar magnetic anomalies [4,5] and the third may be an important mechanism in the early solar system [6]. Previously, we reported observations of transient magnetic signals produced by impact-generated plasma [7]. It is difficult to distinguish, in practice, magnetic signals produced inherently by the plasma from those produced by interaction between the plasma and an ambient magnetic field. The effects of the latter signals can be removed in two ways: a) understanding how an impact-generated dusty plasma interacts with a magnetic field and b) negating the ambient magnetic field with an opposing field of equal strength [8]. The following discussion focuses on the former through analysis of newly acquired data.

Because a plasma contains a neutral collection of ions, electrons and neutral particles, it readily conducts an electric current. The conductivity of a plasma is a complex function of temperature, pressure, density and the ionized fraction. The interaction between its conductivity and an external magnetic field enables a plasma to compress magnetic field lines, thereby increasing the local magnetic intensity. By measuring the fluctuations in magnetic field strength as a plasma passes an applied magnetic field, we can measure its conductivity and thereby theoretically determine its temperature, density, and ionization fraction [9].

Experiments to determine the conductivity of a plasma cloud expanding above a laboratory hypervelocity impact were conducted at the NASA Ames Vertical Gun Range. A vertically oriented magnetic field was applied by a field coil buried in the target just below the impact point. A search coil was located concentric to the field coil. Signals induced in the search coil by the expanding plasma were amplified and then recorded with an oscilloscope. Systematic variation of the magnetic field intensity permits characterization of the plasma conductivity above the impact point. Previous experiments indicated that a sizable plasma cloud was produced by impacting easily vaporized targets at modest velocites (5.5 km/s) and low angle (15° from horizontal) [10]; the experiments discussed here used powdered dolomite impacted at 15° as described in [11].

We model the plasma as expanding spherically above the impact point. In terms of the conductivity, σ_0, and the expansion velocity, u_1, we can write the integrated signal (B) from the search coil:

$$B = V_0 R \sigma_0 u_1 \exp(-\alpha) \Psi_1$$

where

$$\Psi_1 = \int_0^1 r' \exp\left(\mu r' - \frac{r'^2 R^2}{b^2}\right) dr'$$

and V_0 and b are calibration constants. R is the radius of the expanding plasma cloud, $r' = r / R$ is the dimensionless spatial variable and $\mu = \alpha - \beta$ where, as shown in Fig. 1, $\alpha > 0$ describes the spatial distribution of fluid velocity within the cloud as predicted by thermodynamic models [12] that are consistent with other observations [11] and β approximates the conductivity distribution within the cloud as predicted by Hood and Vickery [5] for the highly ionized case ($\beta = 0$) and the partly ionized case ($\beta > 0$).

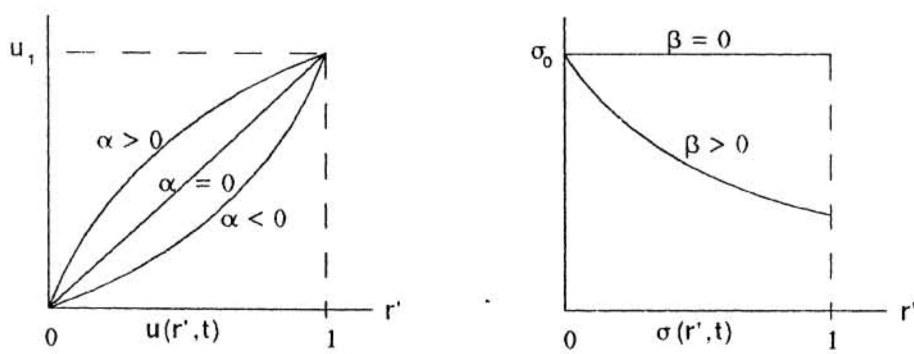

Fig. 1 Fluid velocity = $u(r',t)$ and conductivity = $\sigma(r',t)$ within a hypothetical plasma cloud. α and β describe the spatial distribution of $u(r',t)$ and $\sigma(r',t)$ as shown. σ_0, u_1, α and β are time dependent.

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Fig. 2 shows the integrated data obtained from the search coil with a 0.78 Oe vertically oriented magnetic field (up). A decrease in magnetic field strength is observed as the conducting plasma cloud expands above the impact. Best fit of the model occurrs at $\alpha \sim 1$ and $\beta \sim 0$. We estimate that improving the model will change the maximum conductivity by no more than a factor of three.

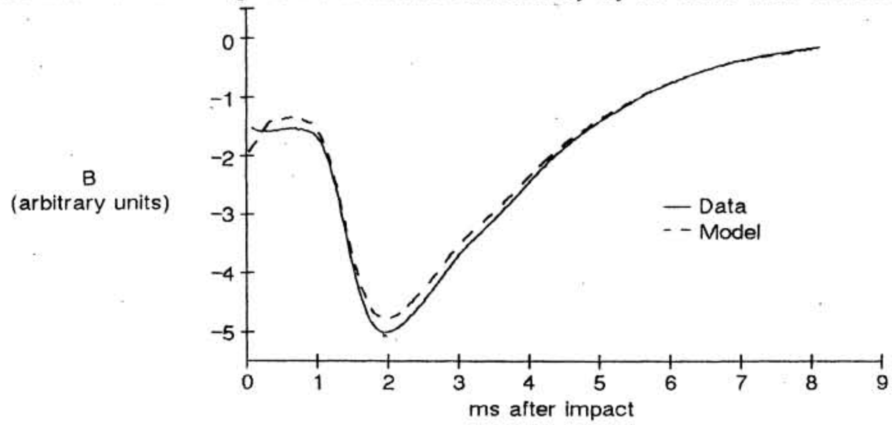

Fig. 2 Fit of the model to the data. The solid line is the integrated data obtained from the search coil. The dashed line is the prediction of the model with $\alpha = 1$ and $\beta = 0$.

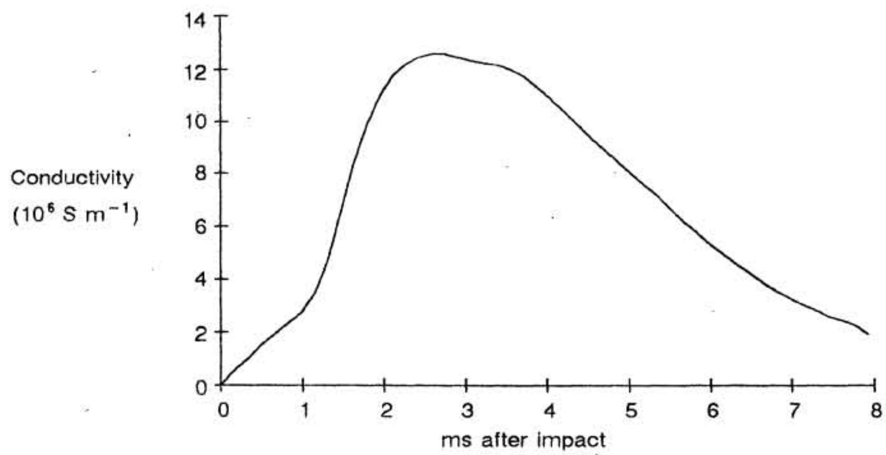

Fig. 3 Conductivity of the plasma cloud. The conductivity reaches a maximum several milliseconds after impact when the decreased density reduces the collision frequency of electrons and ions/neutrals.

As shown in Fig. 3, an impact generated plasma attains a high conductivity with a maximum value that compares favorably with theoretical predictions [5]. The relatively low magnetic Reynolds number ($R_m < 100$) and the short magnetic diffusion time ($10 < \tau < 100$ ms) at laboratory scale, require a fundamental understanding of the processes occurring within an impact generated dusty plasma before the results can be extrapolated to planetary scale (where $R_m > 10^6$; $\tau > 10^4$ s). Future experiments conducted both with and without an ambient magnetic field will help determine the importance of field generation mechanisms [2]. The high conductivity attained at these relatively low impact velocities indicates that the plasma has a substantial ionization fraction which could be significant for grain-plasma interactions in the early, low temperature, solar nebula [13] where collision velocities and *thermal* ionization are low.

[1] Hood, L. L., *Geophys. Res. Letters*, **14**, 844-847 (1987). [2] Srnka, L. J., *Proc. Lunar Science Conf.* **8th**, 893-895 (1977). [3] Alfven, H., *Cosmic Plasma*, D. Reidel Pub. Co. (Boston), 92-93 (1981). [4] Schultz, P.H. and Srnka, L.J., *Nature* **284**, 22-26 (1980). [5] Hood, L. L. and Vickery, A., *J. of Geophys. Res.* **89**, suppl., C211-C223 (1984). [6] Alfven, H. and Arrhenius, G., *Evolution of the Solar System*, **NASA SP 345**, (1976). [7] Crawford, D. and Schultz, P. H., *Lunar Planet. Science* **18th**, 205-206 (1987). [8] Srnka, L. J., personal communication. [9] Shao-Chi Lin et al., *J. of Appl. Phys.* **26**, 95-111 (1955). [10] Schultz, P. H. and Crawford, D., *Lunar Planet. Science* **18th**, 888-889 (1987). [11] Schultz, P. H., *Lunar Planet. Science* **19th**, Impact Vaporization of Volatile-rich Targets: Experimental Results and Implications, this volume (1988). [12] Zel'dovich, Ya. B. and Raizer, Yu. P., *Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena*, Academic Press (N.Y.), 101-106 (1966). [13] Wood, J. A., *The Solar System*, Prentice-Hall, Inc. (N.J.), 157-167 (1979).