

FURTHER OBSERVATIONS OF SPACE SHUTTLE  
 PLASMA-ELECTRODYNAMIC EFFECTS FROM OSS-1/STS-3

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**Abstract.** Recent analyses of ion measurements obtained from the Differential Ion Flux Probe (DIFP) on the deployed Plasma Diagnostics Package (PDP) during the OSS-1/STS-3 mission have provided an additional insight into the plasma-electrodynamics of the Space Shuttle Orbiter: (1) Measured ion flow directions and energies suggest that the disturbance created in the ionospheric plasma by the Shuttle Orbiter may be confined to an interaction region that extends on the order of 10 m in the forward direction and has a boundary thickness of about 2 m. (2) A correlation between the DIFP and pressure gauge measurements indicates a direct, local proportionality between the neutral gas and ion densities. (3) Preliminary results from a theoretical model of the possible interaction between measured secondary, high inclination ion streams and the ambient plasma indicate the generation of broad-band electrostatic noise such as that observed by wave instruments on the PDP.

Introduction

The OSS-1 payload, carried on the third Space Shuttle flight (STS-3), included the Plasma Diagnostics Package (PDP) experiment. The PDP is a self-contained, deployable satellite that carries an ensemble of 14 scientific instruments [Shawhan et al., 1984]. During the 9-day STS-3 mission, the PDP was deployed up to 15 m above the Orbiter payload bay with the Remote Manipulator System (RMS) on mission days three and four. As a result, the PDP performed a partial mapping of the Orbiter's near environment. Some of the initial observations (specifically, the existence of secondary, high inclination ion streams) were reported in Stone et al. [1983]. In this paper, we discuss three additional aspects of the Orbiter's plasma environment based on ion measurements obtained from the deployed PDP: (1) the spatial extent of the interaction region in the forward direction; (2) a correlation between the neutral pressure (i.e., neutral particle density) and the primary and secondary ion stream intensities [Stone et al., 1983]; and (3) a possible connection between the secondary ion streams and broad-

band electrostatic noise observed in the frequency range of 30 Hz to 178 kHz [Shawhan et al., 1984].

The Differential Ion Flux Probe (DIFP), used for the ion measurements, has been described in Stone [1977] and Stone et al. [1985]. Briefly, this instrument has the capability to deconvolve and measure the characteristics of multiple ion streams differing in flow direction and/or energy.

Differential Ion Flow and Energy Measurements  
 from OSS-1/STS-3

The mounting arrangement and field-of-view of the DIFP on the PDP are discussed in Stone et al. [1983]. Figure 1 shows the track and orientation of the PDP during an RMS maneuver on Julian day 85, 1982 for the period 16:48:40 to 16:51:05 UT. During this period, the Orbiter traveled so that the orbital velocity vector was nearly aligned with the Orbiter Y-axis. Since the Shuttle made two rolls per orbit, Orbiter attitude changes represent only a small correction factor. The main source of attitude change was, therefore, the PDP/RMS maneuver. Notice that while being translated, the PDP also performed a positive roll, followed by a negative roll which rotated the DIFP from a

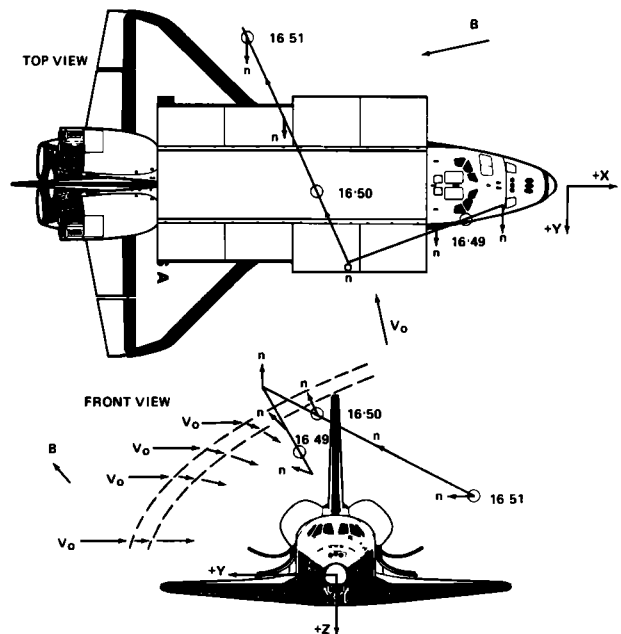


Fig. 1. The PDP track in the Orbiter's reference frame on Julian day 85 for the period 16:48:40 to 16:51:05. DIFP normal is indicated by  $n$ , while the dashed lines indicate the inferred position, shape, and thickness of the boundary of the interaction region. The indicated deflection of the ram ion stream lines is obtained from the data of Figure 3. The geomagnetic field and orbital velocity are indicated by  $B_0$  and  $V_0$ , respectively.

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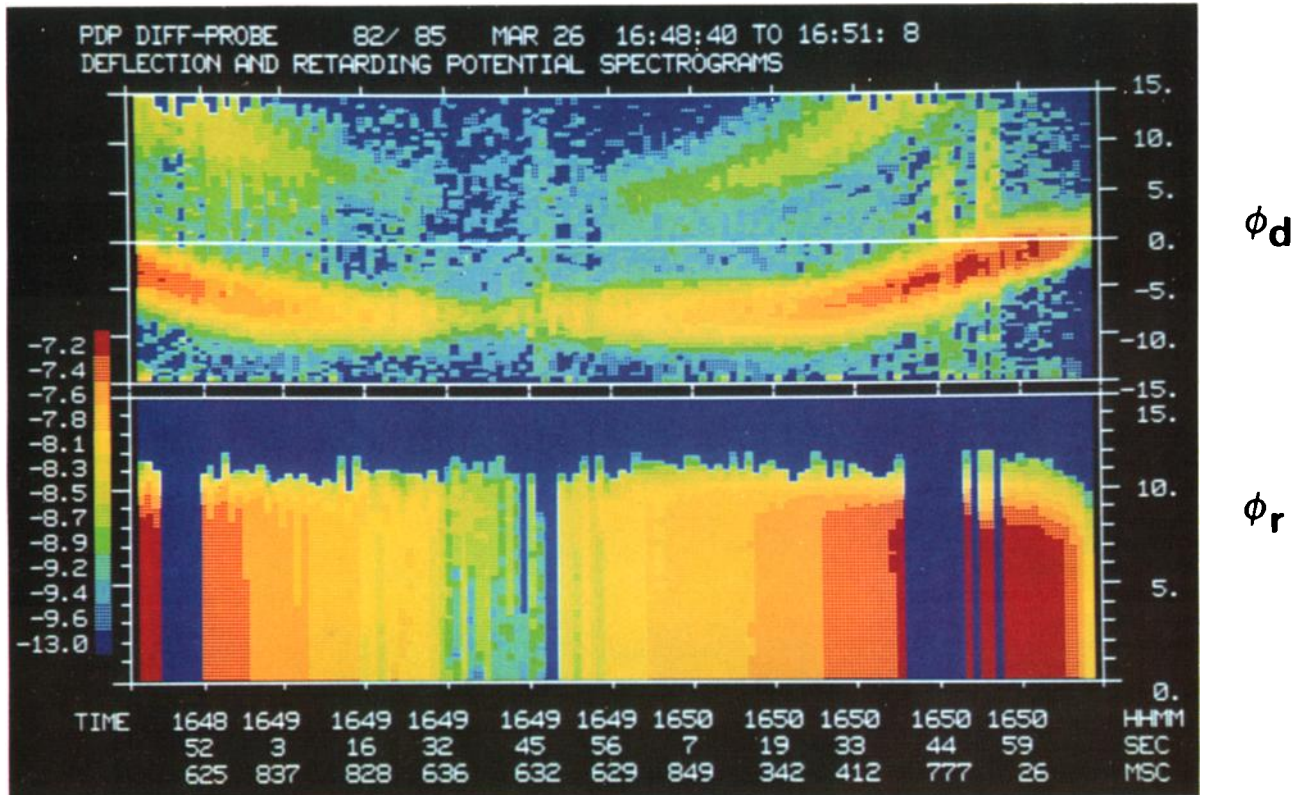


Fig. 2. Deflection voltage ( $\phi_d$ )-time (top) and retarding potential ( $\phi_r$ )-time (bottom) spectrograms of DIFP data for the period 16:48:40 to 16:51:05 on Julian day 85 ( $\phi_d \sim$  angle of attack and  $\phi_r \sim$  ion energy). Ion current is color coded in powers of ten (amps).

ram-facing attitude to an almost normal attitude and back into the ram again. At all times during the maneuver, the PDP/DIFP had an unobstructed view of the plasma, with the exception of the end of the period near 16:51 when it came near the wake of the starboard payload bay door, which is of no consequence in the present analysis. Ignoring the effect of the translation for the moment, the attitude change can be seen in the angle-time spectrogram given in Figure 2. Note that the peak ram current at the beginning of the maneuver occurs at approximately zero deflection voltage (corresponding to an almost normal incidence of the ion stream to the instrument face). However, as the PDP rolled and the instrument normal rotated upward, the peak ion current occurred at increasingly negative deflection voltages (indicating that the ion stream arrived at an increasingly negative angle). As the PDP was rolled back to its original orientation with the DIFP facing into the ram, the current peak moved back up toward zero voltage. Note that, although the angle determination depends on both the deflection and retarding voltages [Stone, 1977], the energy-time spectrogram in Figure 2 shows the ion energy to be approximately constant over this period so that angle is directly proportional to the deflection voltage. The reduced angles corrected for PDP potential [see Stone et al., 1985] are shown in Figure 3 as a function of time.

In addition to the primary ram ion stream, a secondary stream is clearly visible in the angle-time spectrogram of Figure 2. This stream, with about 65 percent of the current density of the primary stream, arrived at a high positive angle with respect to the Y-axis and (initially) the

DIFP normal. As the DIFP rotated upward, the secondary stream moved toward zero deflection voltage, as expected; i.e., the roll maneuver moved the instrument normal into alignment with the high inclination secondary stream. The reduced angle

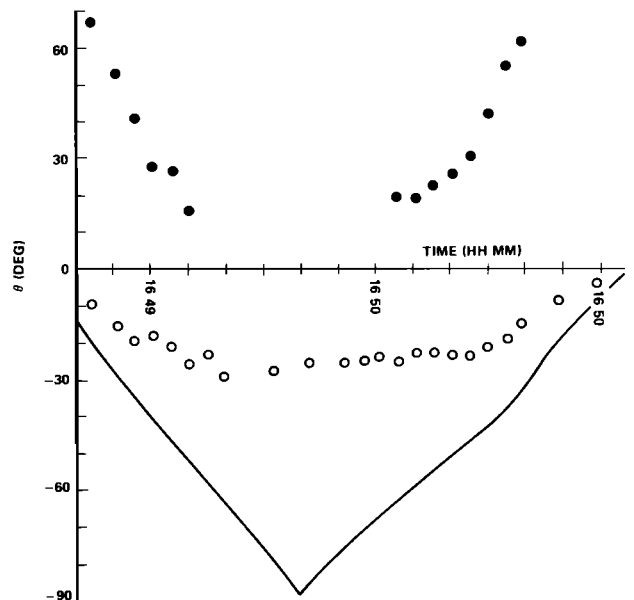


Fig. 3. Angles-of-attack for the primary (open circles) and secondary (closed circles) ion stream for the period 16:48:40 to 16:51:05 on Julian day 85. The solid line is the angle between the DIFP normal and the orbital velocity vector.

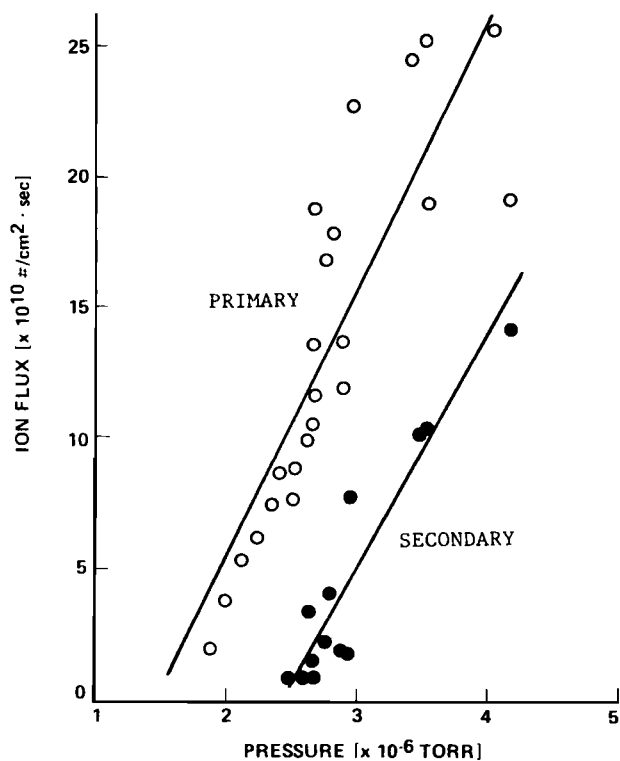


Fig. 4. Ion current density measured by the DIFP vs. pressure (neutral particle density) measured by the University of Iowa PDP pressure gauge. Solid lines are least squares fits of the primary and secondary ion stream data points. The data have been corrected for the variation of DIFP sensitivity with angle.

data for the secondary stream are also shown in Figure 3. This appears to be the same type of secondary ion stream phenomenon reported by Stone et al. [1983] for a different period of time.

#### Discussion

##### Evidence for an Interaction Envelope

The important characteristics of the present data are the behavior of the ram and secondary ion stream current densities and the angle-of-attack of the ram ion stream. The DIFP sensitivity decreases with increasing angle-of-incidence as a result of the collimator; i.e., a given stream at  $0^\circ$  would appear more intense than the same stream at  $40^\circ$  [Stone, 1977]. This is indeed the behavior followed by the ram current. It is maximum at zero deflection voltage and diminishes as its angle of incidence increases and the current peak moves away from the zero voltage line. However, this does not hold for the secondary ion stream.

The secondary ion stream initially arrived at a high angle-of-attack to the ram current; i.e., at 16:48:40 UT the secondary stream entered the DIFP at  $52^\circ$ . At this angle the DIFP sensitivity is reduced by 92 percent and the measured ion current is low, as expected. As the DIFP rotated into alignment with the secondary stream, its sensitivity to this stream increased and there should have been a corresponding increase in the measured current. However, this did not happen. To the contrary, as shown in Figure 2, the secondary ion

stream vanished. Since this cannot be the result of instrument sensitivity, nor can it be the effect of geometric shadowing since the PDP/DIFP had an unobstructed view upstream, it must indicate that the secondary stream was no longer present. At this point on the track, the PDP had translated to a radial distance of about 8.8 m from the Orbiter's X-axis (the axis normal to the velocity vector) and was located  $65^\circ$  above the XY-plane (see Figure 1). If the secondary ion stream was an ionospheric drift, atomic oxygen ions would be required to drift normal to the XY-plane at speeds in excess of the orbital velocity, i.e., about 10 km/s. Since ionic drifts of this magnitude are not known in the undisturbed mid-latitude ionosphere, it is reasonable to conclude that the secondary ion stream is generated within the interaction region surrounding the Orbiter and, that the PDP was extended beyond this region during the period 16:49:20 to 16:50:00. Once the PDP moved beyond the boundary of the source region for the secondary ion population, the secondary streams could no longer be detected by the outward facing DIFP; i.e., there would be no incoming secondary ions beyond the source region and outward traveling ion streams would not be in the field-of-view of the instrument.

Notice that the secondary ion stream current density, shown in Figure 2, diminished gradually as the PDP moved farther out from the Orbiter at 16:49:20 and increased gradually as it moved back in at 16:50:00. These transitions occurred over a 2-m change in radial distance from the Orbiter X-axis. We conclude, therefore, that the boundary of the interaction region (at least for secondary ion production) is approximately 2 m thick.

It is also apparent in Figure 3 that the primary ion stream does not follow the angle-of-attack of the orbital velocity vector as the ram current should. This behavior is consistent with the existence of an electric field within the boundary of the interaction region. If the electric field is everywhere normal to the boundary, then any deflection of the ionospheric ions will be proportional to the angle between the normal of the boundary surface and the velocity vector. Referring to Figure 3, this implies that the boundary was normal to the ram direction at 16:48:40 but became increasingly skewed with distance from the XY-plane, suggesting the general parabolic shape shown by the dashed lines in Figure 1. This shape is generally consistent with a gas source moving through a stationary medium—regardless of the interaction mechanism. (It is recognized that some distortion may be produced by the action of the geomagnetic field.)

##### Coupling Between Ion and Neutral Densities

Since the ionosphere is collisionless on the scale size of the Orbiter, the existence of an interaction region that extends upstream suggests that the Orbiter emits particles and/or fields that can interact with the oncoming ionosphere several meters ahead of its leading surface. It is well known that the Orbiter is the source of a significant gas cloud that moves along with it [Shawhan et al., 1984; Pickett et al., 1985; Samir et al., 1986]. In the present maneuver, the PDP traveled 10 m radially out from the Orbiter and back. The pressure gauge data (which correspond to neutral density) follow a  $1/r$  dependence with

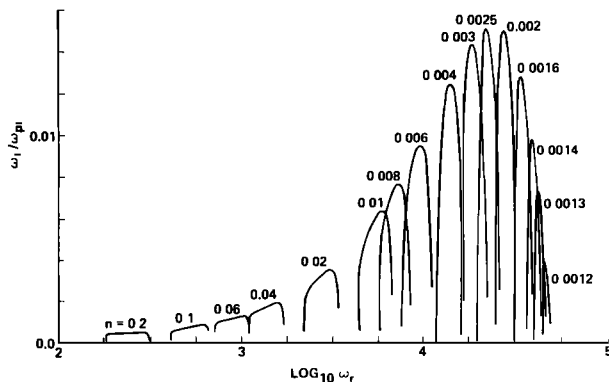


Fig. 5. Theoretical calculation of the normalized growth rate for ion stream-plasma interaction produced ion acoustic waves over a broad frequency range for various propagation angles.

the exception of a pressure burst that occurred as the PDP passed over the port payload bay door. (The pressure gauge was baffled and oriented perpendicular to the ram flow throughout the maneuver.) The ion current density measured by the DIFP also followed a  $1/r$  dependence and increased simultaneously with the pressure burst. The direct proportionality of the ion and neutral particle densities is shown in Figure 4. Although it is possible for neutral gas injections to either reduce or increase ionization locally, this suggests that the neutral gas emitted from the Orbiter is rapidly ionized and contributes significantly to the Orbiter's total plasma environment. This conclusion is in accord with the high plasma density measurements reported by Raitt et al. [1984] and Siskind et al. [1984]. The linear dependence shown in Figure 4 is in agreement with theoretical ionization rate predictions (e.g., Papadopoulos, 1984).

#### A Possible Connection Between Secondary Ion Streams and Other Shuttle-Induced Phenomena

To date, the OSS-1 experiments have revealed the existence of several phenomena peculiar to the near-Orbiter environment, including high inclination secondary ion streams [Stone et al., 1983], broad-band noise measured from 30 Hz to 178 kHz [Shawhan et al., 1984], elevated electron temperatures, and higher than normal plasma densities [Raitt et al., 1984; Siskind et al., 1984].

Intuitively, one would suspect that these phenomena might be linked. In principle, ion streams moving through the ambient plasma should generate instabilities, which may take the form of broad-band noise, and could heat the electron population which could, in turn, ionize the neutral gas cloud. The first step of this process, i.e., secondary ion streams providing the free energy required to generate broad-band noise, has similarities to the mechanism discussed by Kintner et al. [1980]. This is being investigated in the present context (see Figure 1) by inserting the appropriate charged particle distribution functions into the linearized collisionless Vlasov equation to obtain a general dispersion relation for electrostatic

ion acoustic waves. Preliminary computations were made for the conditions encountered by the PDP, using  $T_e/T_i = 7.5$ , in accord with Siskind et al. [1984]. The results, shown in Figure 5, predict the generation of electrostatic ion waves over a wide range of frequencies, in agreement with the OSS-1 broad-band noise observations reported by Shawhan et al. [1984]. However, it is not claimed, at present, that these preliminary computations account for all of the observed properties of the broad-band noise. This work is continuing and the results, along with mathematical details, will be published elsewhere. Evaluation of the possible connections between the broad-band noise, electron heating, and neutral particle ionization will require careful consideration of wave growth rates and the efficiency of coupling with the electrons.

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