MULTIPLE ION STREAMS IN THE NEAR VICINITY OF THE SPACE SHUTTLE

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Abstract. Differential measurements of ion flow direction and energy during the third Space Shuttle mission (STS-3) have revealed the existence of ion streams in the near vicinity of the Orbiter at angles of attack as great as 50° with respect to the ram direction and typically with 10% of the ram current intensity. Neither the source nor the mechanism by which these secondary ion streams were created are known at present; however, it is reasonably certain that they are not of geophysical origin, but result from the interaction of the Orbiter with its environmental ionospheric plasma. The energy of the secondary streams was observed to be very close to the ion ram energy and they were, therefore, not detected by a standard planar Retarding Potential Analyzer (RPA) instrument. This leaves open the question as to their existence in the vicinity of orbiting spacecraft in general. Possible connections between secondary ion streams and phenomena previously observed in the vicinity of ionospheric spacecraft are mentioned.

Introduction

The STS-3 mission offered the first opportunity to measure the plasma and field environment of the Space Shuttle Orbiter. This was accomplished by the Plasma Diagnostics Package (PDP) experiment which is a self-contained, deployable satellite that carries an ensemble of fourteen instruments. During the 7-day mission, the PDP was deployed up to 15 m above the Orbiter bay with the Remote Manipulator System (RMS) on mission days three and four. The effects reported herein were observed on both of these days with one of the PDP instruments, the Differential Ion Flux Probe (DIFP).

The DIFP was developed at the Marshall Space Flight Center for use in laboratory investigations of the electrodynamic interaction of rarefied plasma flows with test bodies [Stone, 1977]. Its unique feature is the ability to deconvolve and measure the characteristics of multiple ion streams, differing in flow direction and/or energy at a single point in space. The DIFP has been used extensively in laboratory investigations and, in addition to the STS-3 mission, has flown on two sounding rocket missions (Project Centaur Multiple Auroral Probe missions, MAP-1 and MAP-2, launched in December 1981).

The existence of ion streams in the disturbed region of ionospheric satellites was inferred by Henderson and Samir [1967] and has been studied extensively in the laboratory; e.g., Hester and Sonin [1970a,b], Stone et al. [1972], Samir et al. [1974], Fournier and Pigache [1975], and Stone [1981a,b,c]. In all of the above cases, the ion streams were associated with the downstream wake region and, in fact, one of the PDP science objectives was to study the wake of the Orbiter. However, the secondary ion streams observed during the STS-3 mission were totally unexpected in that they were measured when the PDP was not in the wake of the Orbiter and, in some cases, when extended upstream from the Orbiter.

Experimental Data from STS-3

The geometry of the PDP and the field-of-view of the DIFP are shown in Figure 1a. The DIFP scan discerns the ion flux angle of incidence only in the plane containing the PDP axis of symmetry. The azimuthal angle must be determined from spin phase modulation. Since the PDP did not spin during the STS-3 mission, there is no straightforward measurement of the azimuthal dependence. (This should be measured on the Spacelab 2 mission when the PDP will be free-flying.) Figure 1b shows the PDP position and orientation at the point in the example maneuver (described below) when the ram current passed through normal incidence. Note that the location of the secondary ion streams in the plane of the velocity vector—PDP axis may not be as shown due to the azimuthal ambiguity discussed above.

Figure 2 gives a spectrogram presentation of data obtained over a period of several minutes during which the PDP underwent a maneuver that changed the angle between its axis of symmetry and the ram direction, beginning with a negative angle of attack, then rotating through normal incidence to a smaller positive angle of attack, which was approximately maintained for the duration of the maneuver. The spectrogram shows the time variation (horizontal axis) of the current collected as a function of the deflection voltage (vertical axis) which produces a sweep and, therefore, related to the ion flux angle of attack relative to the instrument normal. Normal incidence occurs at 0 volts (center) while positive and negative angles of incidence are indicated by positive and negative voltages (above and below the center line), respectively. The current levels indicated beside the color scale are powers of ten.

The most intense (red) ion stream in Figure 2 is the ram ion flux which is seen to change direction, following the PDP orientation changes...
during the maneuver. In addition, secondary, less intense (green) ion streams occur at high angles of incidence. These secondary streams also follow the PDP orientation changes.

The energy of the ram and the secondary ion streams were determined by retarding potential analysis to be approximately 10 eV, which indicates the PDP to be negatively charged to approximately -5 volts. (The ram energy of atomic oxygen at 240 km altitude is about 5 eV.) This is in agreement with the expected emf generated between the main engine nozzles (the only significant conducting surface on the Orbiter) and the PDP location by the geomagnetic field [Shawhan and Murphy, 1983].

A plot of current intensity as a function of the angle of attack, measured at 21:14:30 UT, is shown in Figure 3. Notice that there are two distinct ion streams, the ram ions at +10 degrees and the secondary ion stream at -54 degrees. The ratio of the secondary to ram current intensities is 0.08. The DIFP obtained data while deployed on the RMS during a total of 17 periods. Of these, secondary ion streams similar to those shown in Figure 3 were clearly observed during 12 periods (or 71% of the periods). The ratio of
were made when the Orbiter was in sunlight. Moreover, there was no indication in the RPA data that the secondary ion streams observed by the DIFP during the same period.

The DIFP has been used extensively in the laboratory, and the flight instrument underwent rigorous functional testing and calibration, before and after flight, in a synthesized, collisionless plasma stream with properties similar to those of the ionospheric plasma at the Orbiter. While its ability to deconvolve multiple streams has been well proven by deliberately creating such test conditions, in no case has the instrument ever spuriously indicated the existence of secondary ion streams when none existed. The complete PDP underwent testing in a plasma environment at the Johnson Space Center where no secondary ion streams were found in an unexpected region, and for several different plasma conditions. The RPA was placed at relatively few positions and distances from the Orbiter during the STS-3 mission. Even though the secondary ion streams may occur for all orbiting spacecraft, but have simply gone undetected in the absence of differential vector ion flux measurements.

The observation of secondary ion streams numerous times, at several positions with respect to the Orbiter, and for several different plasma conditions suggests that this may result in a general phenomenon. The fact that all measurements were obtained in sunlight does not preclude the existence of secondary ion streams when the Orbiter is in the Earth’s shadow since, for this condition, no data was obtained with the DIFP—possibly the result of the Orbiter/PDP attitude [Shawhan and Murphy, 1983] or lower ionospheric densities coupled with limited instrument sensitivity. The relative intensity of 3% to 20% of the ambient ram current may be indicative only of values within the limited range of the measurements. The PDP was placed at relatively few positions and distances from the Orbiter during the STS-3 mission. Even though the secondary ion streams were found in an unexpected region, the complete PDP data clearly indicates their presence just as it has in previous laboratory studies where multiple streams were expected and are well understood [Stone, 1981a,c].

The RPA provides scalar measurements of the ion flux intensity and energy. Since the secondary ion streams and ram ion current differ significantly only in flow direction and intensity while having essentially the same energies, it is not surprising that the RPA was unable to observe the secondary streams. However, because of this lack of sensitivity to vector-related effects, one naturally wonders if secondary ion streams may occur for all orbiting spacecraft, but have simply gone undetected in the absence of differential vector ion flux measurements.

This speculation is supported by previous observations of anomalous effects in the near vicinity of orbiting spacecraft which appear to be associated with the interaction of the spacecraft with the terrestrial magnetoplasma. For example, Henderson and Samir [1967] observed significant variations of the electron flux within ±30° of the ram direction of the Ariel 1 satellite, and an enhancement of the electron temperature in the wake region of the Explorer 31 satellite was reported by Samir and Wrenn [1972] and by Troy et al. [1975]. Indications of plasma oscillations generated in the wake region of spacecraft have been reported by Samir and Willmore [1965], based on data from Ariel 1, and by Raftt et al. [1983], based on data from the STS-3 mission. Additionally, Shawhan and Murphy [1983] and Shawhan et al. [1983] report direct observations of electrostatic noise on the STS-3 mission, which is assumed to result from an interaction between the Orbiter and the ionosphere on the basis of an attitude dependence.

It is highly probable that all of the above anomalous effects are products of the electrodynamic interaction between spacecraft and the ionospheric plasma. If so, it may be possible that they are interrelated; i.e., secondary ion streams may generate oscillations which heat the electrons and/or produce electrostatic noise via a two-stream type instability; or, the secondary streams may be involved in setting up plasma instabilities of the type suggested by Papadopoulos and Ko [1983]. However, without further delineation of the specific effects of plasma parameters, spacecraft potential and attitude, measurement location with respect to the Orbiter, and
sunlight, it is difficult to determine the source or the governing mechanisms of the secondary ion streams, or their relationship to other plasma-electrodynamic interaction effects. It is possible that much of the required information may be forthcoming from the Spacelab 2 mission.

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