

General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.


DPA



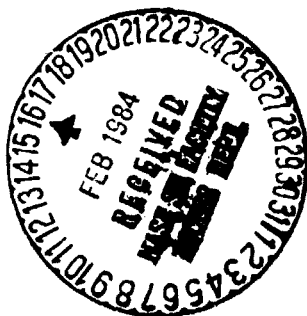
Semiannual Technical Progress Report

1.0 General

- 1.1 Date of Report : 27 January 1984
- 1.2 Period Covered : 10 July 1983 through 25 January 1984
- 1.3 Title of Grant : Interpretation of STS-3/Plasma Diagnostics Package Results in Terms of Large Space Structure Plasma Interactions
- 1.4 Principal Investigator : William S. Kurth
- 1.5 Grant Number : NAG3-449
- 1.6 Grantee's Institution : The University of Iowa
Dept. of Physics & Astronomy
Iowa City, IA 52242
- 1.7 Signature : Submitted by:



 William S. Kurth
 Principal Investigator



(NASA-CR-173266) INTERPRETATION OF
 STS-3/PLASMA DIAGNOSTICS PACKAGE RESULTS IN
 TERMS OF LARGE SPACE STRUCTURE PLASMA
 INTERACTIONS Semiannual Technical Progress
 Report. 10 Jul. 1983 - 25 Jan. 1984 (Iowa

N84-16991

Unclas
00568

G3/75

2.0 Summary of Progress During Reporting Period

During the initial reporting period of this grant, considerable progress has been made in understanding the interaction of a large space structure with the ionospheric plasma by interpreting the data obtained during the third shuttle flight by the Plasma Diagnostics Package (PDP). In view of the early stage of the work, however, it should be understood that our progress has been along the lines of identifying promising directions of research as opposed to arriving at final conclusions.

A major personnel change occurred when William S. Kurth assumed the role of Principal Investigator when the former PI, Stanley D. Shawhan, took a leave of absence from the University to serve as Branch Chief for Space Plasma Physics in the Earth Science and Application Division of NASA Headquarters. While any change of this nature results in some short-term reduction in efficiency, the transition trauma has been minimized through the excellent support of G. B. Murphy and J. S. Pickett.

Several advances have been made during the reporting period which affect the efficiency of our data analysis effort. First, the University of Iowa has come up as a full node on NASA's SCAN data network allowing access to the database management system at Marshall Space Flight Center. This is the first step in putting the STS-3/PDP data into a database in order to facilitate sorting the data set according to complex sets of operational mode and orbit-attitude configurations. For example, under database management, it will be very simple to search the data set for periods when the PDP is in the

wake of the Orbiter so that density and electric field data may be plotted to look for variations which might be related to day/night differences in the ionosphere.

Also, a DEC Professional 350 computer and associated peripherals and software have been procured which will facilitate access to the data in the database and which has already increased the efficiency of doing specialized analysis of small data sets, allowed enhanced communication with other STS-3 investigators, and improved the quality of graphic displays for publications and oral presentations.

One of the most critical issues concerning the interaction of a large space vehicle or structure with the plasma environment is the way in which the potential of that structure is neutralized. William Paterson, a graduate student at Iowa, is studying the "return current" observed primarily by the Low Energy Proton and Electron Differential Energy Analyzer (LEPEDEA) during periods when the Fast Pulse Electron Generator (FPEG) was operating. The emission of electrons, of course, tends to drive the spacecraft potential positive. The LEPEDEA shows that a net flow of electrons back to the Orbiter can be detected outside the primary beam. A complication in this analysis is that it may be that the reverse flow of electrons could be due to a beam-plasma interaction and not simply a response to a charged body in a plasma. A large portion of a three-dimensional velocity distribution was measured several times during the beam operations, and it is hoped these observations will be able to differentiate between a beam-plasma interaction mechanism and a simple acceleration due to a field-aligned potential. This is also a reliable method of measuring the spacecraft potential since the PDP and therefore, LEPEDEA instrument is at Orbiter chassis potential.

Another major effect of a large vehicle moving through a plasma which has been studied in some detail during this reporting period is the wake. Considerable work has been done in analyzing the plasma depletion in the wake using Langmuir probe measurements. The principal results are a depletion in the plasma density of up to six orders of magnitude in the wake and some evidence of elevated effective temperatures. Both of these effects are predicted by current theories of the expansion of plasma into a vacuum. The need for detailed theoretical modeling of the response of a Langmuir probe has been an obvious conclusion of this research since the high density in ram conditions and low wake density are both beyond the range where the probe response is well understood.

Another phenomenon which may be uniquely associated with the movement of a large (with respect to an ion gyroradius) body in a plasma is a broadband electrostatic noise observed by the plasma wave receivers on the PDP. Some of the characteristics of this noise are explained by a theory of spacecraft glow advanced by K. Papadopoulos. In fact, the electrostatic waves may play an important role in the generation of the glow in terms of the interaction of the waves with the plasma. The study of this electrostatic noise has been broadened to very low frequencies (below a few tens of Hertz) and corresponds to $\Delta n/n$ turbulence as detected by the PDP's Langmuir probe. This relation will provide an important constraint on the identification of the source of the noise.

A very exciting new development with potential application to the restriction of differential charging of large space structures came with an analysis of various types of chemical releases associated with

the normal maintenance and operation of the shuttle. Three of these releases are water dumps, flash evaporator operations, and reaction control system (RCS) thruster operations. Two effects sometimes associated with all of these releases are enhanced levels of electrostatic noise primarily below the lower hybrid resonance frequency and the detection of energetic ions, up to several hundred eV.

A common product of all three of these releases is molecular water. Work by Mendillo and others has shown that neutral water very quickly charge exchanges with the ambient oxygen ions in the ionosphere to form H_2O^+ and O. Through dissociative recombination the ionized water forms OH and H. The result is a rapid depletion of the plasma or plasma "hole". C. K. Goertz, University of Iowa, has begun work on a theory which explains how this process can result in both enhanced low frequency wave amplitudes as well as enhanced fluxes of energetic ions.

Very briefly, the charge exchange only occurs on the boundary of the cloud of neutral water and the motion perpendicular to the magnetic field will result in a charge separation across the cloud. It can be shown that an electric field will be set up which reduces the $V \times B$ electric field within the cloud. The conductivity on the surface of the cloud will be quite high. The next step is the photoionization of ambient O from the ionosphere which enters the cloud with a speed of about 8 km/s. Since the cloud has an internal electric field which is small, the field lines will be swept around the cloud (not through it) which means the newly created O^+ ion inside the

cloud will not be swept out immediately, but will form a ring distribution.

The ring distribution will be unstable to electrostatic waves, probably of the lower hybrid variety, and those will act back on the ring distribution in a quasi-linear fashion to heat the ring. The result of the heating will be to increase the energy of some of those ring particles to energies of several hundred eV.

We repeat that this scenario is still under development, but the exciting application to large space structures is that it could be possible to reduce the $V \times B$ potential by screening the structure with a cloud of water.

3.0 Projected Activities for the Next Reporting Period

We plan to continue our efforts along the lines of the preliminary results reported above and have as products a number of detailed papers submitted for publication. We also hope to make progress on building the database at MSFC to support these studies. It is also hoped that a concrete plan of collaboration with L. Parker and J. Laframboise will be developed.

4.0 Publications and Oral Presentations

Publications:

1. Interaction of the Space Shuttle Orbiter with the Ionospheric Plasma
G. B. Murphy, S. D. Shawhan, L. A. Frank, N. D'Angelo, D. A. Gurnett, J. M. Grebowsky, D. L. Reasoner, and M. Stone
17th Symposium on Spacecraft-Plasma Interactions and their Influence on Field and Particle Measurements, Noordwijk, Netherlands, Proceedings, September, 1983.
[See attached abstract]
2. Suprathermal Plasma Observed on the STS-3 Mission by the Plasma Diagnostics Package
W. Paterson, L. A. Frank, H. Owens, J. S. Pickett, G. B. Murphy, and S. D. Shawhan
USAF/NASA Spacecraft Environmental Interactions Technology Conference, U. S. Air Force Academy, Colorado Springs, CO, Proceedings, 4-6 Oct., 1983.
3. Electron and Ion Density Depletions Measured in the STS-3 Orbiter Wake
G. B. Murphy, J. S. Pickett, W. J. Raitt, and S. D. Shawhan
USAF/NASA Spacecraft Environmental Interactions Technology Conference, U. S. Air Force Academy, Colorado Springs, CO, Proceedings, 4-6 Oct., 1983.
4. Effects of Chemical Releases by the STS-3 Orbiter on the Ionosphere
J. S. Pickett, G. B. Murphy, W. S. Kurth, and S. D. Shawhan
University of Iowa, Dept. of Physics and Astronomy, Report No. 83-11, December, 1983, and J. Geophys. Res., to be submitted, 1984.
[See attached abstract]

4.0 Publications and Oral Presentations (cont.)

Page 2

Oral Presentations:

Presented at the 17th Symposium on Spacecraft-Plasma Interactions and their Influence on Field and Particle Measurements, Noordwijk, Netherlands, September, 1983:

1. Interaction of the Space Shuttle Orbiter with the Ionospheric Plasma
G. B. Murphy, S. D. Shawhan, L. A. Frank, N. D'Angelo, D. A. Gurnett, J. M. Grebowsky, D. L. Reasoner, and N. Stone

Presented at the USAF/NASA Spacecraft Environmental Interactions Technology Conference, U. S. Air Force Academy, Colorado Springs, CO, 4-6 October, 1983:

2. Suprathermal Plasma Observed on the STS-3 Mission by the Plasma Diagnostics Package
S. D. Shawhan, L. A. Frank, H. Owens, W. Paterson, J. Pickett, and G. B. Murphy
[See attached abstract]
3. Electron and Ion Density Depletions in the STS-3 Orbiter Wake
S. D. Shawhan, G. B. Murphy, A. Dresselhaus, J. Pickett, J. Grebowsky, D. L. Reasoner, and W. J. Raitt
[See attached abstract]

Presented at the American Geophysical Union Meeting, San Francisco, CA, 5-10 December, 1983:

4. Observations of a Return Current Induced by an Electron Beam Emitted from the Space Shuttle
W. R. Paterson, W. S. Kurth, L. A. Frank, T. E. Eastman, G. B. Murphy, J. S. Pickett, H. Owens, and S. D. Shawhan
[See attached abstract]
5. Broadband Orbiter-Generated Electrostatic Noise
G. B. Murphy, W. S. Kurth, J. S. Pickett, S. D. Shawhan, and K. Papadopoulos
[See attached abstract]

Presented at the National Radio Science (URSI) Meeting, Boulder, CO, 11-13 January, 1984:

6. Effects of Chemical Releases by the STS-3 Orbiter on the Ionosphere
J. S. Pickett, G. B. Murphy, W. S. Kurth, and S. D. Shawhan
[See attached abstract]
7. Characteristics of Strong Plasma Turbulence Created by the STS Orbiter
G. B. Murphy, N. D'Angelo, W. S. Kurth, J. S. Pickett, and S. D. Shawhan
[See attached abstract]

INTERACTION OF THE SPACE SHUTTLE ORBITER WITH THE IONOSPHERIC PLASMA

G. B. Murphy, S. D. Shawhan, L. A. Frank,
N. D'Angelo, D. A. Gurnett

J. M. Grebowsky

D. L. Reasoner
N. Stone

Department of Physics and Astronomy
University of Iowa
Iowa City, Iowa 52242

NASA/Code 961
Goddard Space Flight Center
Greenbelt, Maryland 20771

NASA/Code ES53
Marshall Space Flight Center
Huntsville, Alabama 35812

ABSTRACT

The Plasma Diagnostics Package (PDP), which flew as part of the NASA Office of Space Science (OSS-1) payload on STS-3 consisted of an instrument complement capable of characterizing the plasma environment in and around the Space Shuttle Orbiter. These measurements coupled with those made by the Vehicle Charging and Potential (VCA_P) experiment also on OSS-1, as well as diagnostics from subsequent flights, provide insight into the effects a large vehicle such as the Orbiter has on the ionospheric plasma. Modification of the environment by contamination such as Orbiter outgassing, thruster operation and water dumps results in altered neutral pressure, modified plasma density and an altered chemical composition. The physical size and velocity of the Orbiter vehicle produces a plasma wake, generates electric fields, results in surface effects and generates broadband electrostatic noise.

Keywords: Large Vehicle Interaction, Wake, Ionospheric Plasma, Shuttle Environment

**EFFECTS OF CHEMICAL RELEASES BY THE
STS-3 ORBITER ON THE IONOSPHERE**

**Jolene S. Pickett
Gerald B. Murphy
William S. Kurth
Department of Physics and Astronomy
University of Iowa
Iowa City, Iowa 52242**

and

**Stanley D. Shawhan
Code EE-8
NASA Headquarters
Washington, D.C. 20546**

December 1983

ABSTRACT

The Plasma Diagnostics Package, which was flown aboard STS-3 as part of the Office of Space Science first payload (OSS-1), recorded various chemical releases from the Orbiter. Changes in the plasma environment were observed to occur during Flash Evaporator System (FES) releases, water dumps and maneuvering thruster operations. During flash evaporator operations, broadband Orbiter-generated electrostatic noise is enhanced and plasma density irregularity ($\Delta N/N$) is observed to increase by as much as 4 times and is strongly peaked below 6 Hz. In the case of water dumps, background electrostatic noise is enhanced or suppressed depending on frequency and $\Delta N/N$ is also seen to increase by as much as 4 times. Various changes in the plasma environment are effected by primary and vernier thruster operations, including increases in electron density by as much as 3 orders of magnitude, neutral pressure increases to as high as 10^{-4} torr from the nominal 10^{-7} torr, and perturbations in the spacecraft potential, particularly when measured relative to the plasma potential in the wake. In addition, thruster activity stimulates electrostatic noise with a spectrum which is most intense at frequencies below 10 kHz.

Spacecraft Environmental Interaction Technology Conference
U.S. Air Force Academy, Colorado Springs, Colorado
4-6 October 1983

**SUPRATHERMAL PLASMA OBSERVED ON THE STS-3 MISSION
BY THE FLASMA DIAGNOSTICS PACKAGE**

by

S. D. Shawhan, L. A. Frank, H. Owens, W. Paterson, J. Pickett and G. B. Murphy
Department of Physics and Astronomy
The University of Iowa
Iowa City, IA 52242

As the Orbiter Columbia orbited at 240 km altitude on the STS-3 Mission in March 1982, characteristics of suprathermal electron and ion plasmas were measured by the Low Energy Proton and Electron Differential Energy Analyzer (LEPEDEA) and the Electron Fluxmeter. These instruments were included as part of the Office of Space Science-1/Plasma Diagnostics Package (PDP) which was operated both in the payload bay and at the end of the Remote Manipulator System (RMS). The LEPEDEA measured electrons and ions in the energy range of 2 eV to 50 keV in 1.6 seconds for seven simultaneous look directions covering 180°. The Electron Fluxmeter provided a measure of the integrated electron flux greater than 12 eV over a range of 10^9 to 10^{14} electrons $\text{cm}^{-2} \text{sec}^{-1}$.

On-orbit suprathermal electrons with energies up to ~ 80 eV were typically observed on the dayside of the orbit, but, these electrons did not have the typical photoelectron energy spectrum. On occasion, suprathermal ions with energies up to ~ 30 eV were observed both with and without the presence of the suprathermal electrons. Observations of this suprathermal plasma is to be related to the Orbiter RAM/WAKE attitude and day/night, to measurements of the local plasma potential with respect to the Orbiter common

and local electric fields and to thrusters, flash evaporator operations and water dumps.

When the 1 keV 50 - 100 ma OSS-1/Fast Pulse Electron Generator, a part of the Vehicle Charge - and Potential Experiment, is operated suprathermal electron plasma with an energy range of 0 to 1 keV is observed to be flowing into the payload bay. This return flux may constitute a return current for the emitted primary beam. Electron Fluxmeter measurements with the PDP on the RMS indicate that the primary electron beam is confined to a region of one gyrodiameter ~ 6 meters. At locations remote from the beam both outgoing and return electron fluxes are observed with energy up to 1 keV; a return current is being collected over a significant portion of the Orbiter's insulating surface. At some points fluxes of suprathermal ions are also observed.

Spacecraft Environmental Interaction Technology Conference
U.S. Air Force Academy, Colorado Springs, Colorado
4-6 October 1983

ELECTRON AND ION DENSITY DEPLETIONS IN THE STS-3 ORBITER WAKE

by

S. D. Shawhan, G. B. Murphy, A. Dresselhaus and J. Pickett
Department of Physics and Astronomy
The University of Iowa
Iowa City, IA 52242

and

J. Greboweky
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

and

D. L. Reasoner
NASA/Marshall Space Flight Center
Huntsville, AL 35812

and

W. J. Raitt
Department of Physics
Utah State University
Logan, UT 84322

Measurements of the electron and ion densities were made with instruments which were included in the Plasma Diagnostics Package (PDP) and the Vehicle Charging and Potential (VCAP) experiments of the Office of Space Science first payload (OSS-1) on the STS-3 Mission in March 1982. With the PDP, density measurements were provided by a Langmuir Probe, an Ion Mass Spectrometer and an Ion Retarding Potential Analyzer. Other related measurements include the local plasma potential with respect to the Orbiter circuit common, local electric fields, wave emissions, directed ion beams and suprathermal plasma. Measurements are taken both with the PDP located in the payload bay and with

the PDP positioned at various points above the bay and around the Orbiter. VCAP electron density measurements are made with a Langmuir Probe and ion density measurements are made with a Spherical Retarding Potential Analyzer both located in the payload bay just above the sill level.

All instruments indicate a density depletion of at least three orders of magnitude as the Orbiter rolls so that the bay is in the near wake of the Orbiter. The maximum observed density also shows a day-to-night variation by as much as two orders of magnitude at the Orbiter altitude of 240 km. In addition to the periodic variations, shorter time variations are apparent due to wake effects of other payload elements, to water dumps and to the operation of the maneuvering thrusters, the flash evaporators and the VCAP/Fast Pulse Electron Generator.

Observations of a Return Current Induced by an
Electron Beam Emitted from the Space Shuttle

W. R. PATERSON
W. S. KURTH
W. A. FRANK
W. E. EASTMAN
W. B. MURPHY
W. S. PICKETT
W. OWENS (All at the Department of Physics and
Astronomy, The University of Iowa, Iowa City, Iowa
52242)
W. D. SHAWHAN (Code EE-8, NASA Headquarters,
Washington, D.C. 20546)

In March 1982, a Plasma Diagnostics Package (PDP)
was flown aboard the Space Shuttle Columbia as part
of the Office of Space Science-1/STS-3 Mission.
Included in the PDP was a low-energy plasma analyzer
capable of detecting ions and electrons with energies
between 2 eV and 36 keV in seven simultaneous look
directions covering nearly 180 degrees.

During parts of the mission, the PDP was deployed
on the orbiter arm, and a 50 mA, 1 keV electron beam
was emitted from the orbiter bay. During these
times, electron fluxmeter measurements indicate that
the primary electron beam is confined to a region of
one ion gyrodiameter, or about 6 m. At locations
remote from the beam both outgoing and return
electron fluxes are observed with energy up to 1 keV.
At some locations, fluxes of suprathermal ions are
also observed. A preliminary evaluation of the
three-dimensional electron distribution has been
made. This evaluation suggests that for a uniform
isotropic distribution, there is a net return of
electrons to the spacecraft.

1. Fall Meeting
2. KURTO37071
3. (a). Mr. William Paterson
Dept. of Physics & Astronomy
University of Iowa
Iowa City, IA 52242

(b). 319/353-3080
4. SM
5. None
6. 0
7. 10% at AF/NASA Spacecraft
Environmental Interaction
Technology Conference
Colorado Springs, CO
8. (a). E. D. Robison
Dept. of Physics & Astronomy
The University of Iowa
Iowa City, IA 52242

(b). None required

(c). Student rate applicable
9. C

Broadband Orbiter-Generated Electrostatic Noise

G. B. MURPHY

J. S. KURTH

J. S. PICKETT (All at the Department of Physics and Astronomy, The University of Iowa, Iowa City, Iowa 52242)

S. D. SHAWHAN (Code EE-8, NASA Headquarters, Washington, D. C. 20546)

K. PAPADOPOULOS (University of Maryland, College Park, MD 20742)

The predominant types of wave emissions detected by the Plasma Diagnostics Package (PDP) which was flown as part of the science payload on the third Shuttle Flight (STS-3) was broadband electrostatic noise lying between ~ 30 Hz and 200 kHz with a spectral peak in the range of 100-300 Hz. The spectrum changes character above the lower hybrid resonance frequency f_{LHR} with the primary change being a shift from unpolarized wave below f_{LHR} to highly polarized waves above. The noise is present during most of the mission except for periods when the PDP was inside the wake formed by the Shuttle. The intensity of the noise correlates well with $\Delta N/N$ plasma turbulence as measured by a Langmuir Probe. Possible sources of the electrostatic noise include instabilities associated with a region of enhanced plasma density near the surface of the Shuttle. The spectrum below $2 f_{LHR}$ is consistent with a cross-field ion beam plasma instability of the lower hybrid type.

1. Fall Meeting
2. MURP210084
3. (a). Mr. Gerald B. Murphy
Dept. of Physics & Astronomy
The University of Iowa
Iowa City, IA 52242

(b). 319/353-6036
4. SM
5. None
6. 0
7. 20% at the January 1983
URSI Meeting
8. (a). E. D. Robison
Dept. of Physics & Astronomy
The University of Iowa
Iowa City, IA 52242

(b). None required
9. C

EFFECTS OF CHEMICAL RELEASES BY THE STS-3 ORBITER ON
THE IONOSPHERE, J. S. Pickett, G. B. Murphy,
W. S. Kurth (Department of Physics and Astronomy,
University of Iowa, Iowa City, Iowa 52242) and
S. D. Shawhan (Code EE-8, NASA Headquarters,
Washington, D.C. 20546)

The Plasma Diagnostics Package (PDP) which was flown aboard STS-3 as part of the Office of Space Science first payload (OSS-1) recorded various chemical releases from the orbiter. Changes in the plasma environment were observed to occur during water dumps, flash evaporator system (FES) releases and maneuvering thruster operations.

While not intended to be scientific ventures, the orbiter water dumps and flash evaporator operations are, in effect, chemical releases and provide opportunities to study the effects of relatively large releases of water on the ionospheric environment. Examples of some of the effects noted by the PDP during STS-3 include plasma density irregularity ($\Delta N/N$) increases as great as two orders of magnitude as measured by a spherical Langmuir Probe and enhancement of the broadband orbiter-generated electrostatic noise ($0.1 < f < 100$ kHz) as measured by the plasma wave instruments. In the case of the flash evaporator operations, the $\Delta N/N$ turbulence spectrum is strongly peaked at frequencies below about 6 Hz while for water dumps the turbulence spectrum is much broader and extends to higher frequencies.

The orbiter's primary and vernier thruster operations provide additional opportunity to study a large number of (smaller) chemical releases in the form of monomethyl hydrazine and primary reaction products in the ionosphere. The thruster firings are accompanied by increases in the electron density of up to three orders of magnitude as well as neutral pressure increases to as high as 10^{-4} Torr from the nominal 10^{-7} Torr. During thruster operations, perturbations in the spacecraft potential are observed, particularly when measured relative to the plasma potential in the wake. Thruster activity also stimulates electrostatic noise with a spectrum which is most intense at frequencies below 10 kHz. Further measurements to study the effects of water dumps, FES releases and thruster operations will be made by the PDP on Spacelab-2.

CHARACTERISTICS OF STRONG PLASMA TURBULENCE CREATED
BY THE STS ORBITER, G. B. Murphy, N. D'Angelo,
W. S. Kurth, J. S. Pickett (Department of Physics
and Astronomy, University of Iowa, Iowa City, IA
52242) and S. D. Shawhan (Code EE-8, NASA
Headquarters, Washington, D.C. 20546)

Using a fixed biased spherical probe, the Plasma Diagnostics Package (PDP) on STS-3 observed a high degree of $\Delta N/N$ turbulence in the plasma surrounding the shuttle. The spectra of this turbulence show some variability with ram angle of the vehicle, but are primary flat to high frequency. The intensity of the turbulence is enhanced by thruster operation and water dumps and is most intense where the plasma density gradient is highest. The turbulence shows a correlation with the Broadband Orbiter-Generated Electrostatic (BOGES) noise observed by the PDP wave receivers. Discussion of the characteristics of the turbulence will be followed by a brief summary of current theories about the generation of strong turbulence and plasma waves by large vehicles moving at supersonic velocity through a plasma.