



HAL
open science

Phenomena Induced by Charged Particle Beams

Christian Béghin, J.P. Lebreton, B.N. Maehlum, J.L. Michau

► **To cite this version:**

Christian Béghin, J.P. Lebreton, B.N. Maehlum, J.L. Michau. Phenomena Induced by Charged Particle Beams. *Science*, 1984, 225 (4658), pp.188-191. 10.1126/science.225.4658.188 . insu-02886246

HAL Id: insu-02886246

<https://insu.hal.science/insu-02886246>

Submitted on 13 Jun 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Phenomena Induced by Charged Particle Beams

Abstract. The effects of electron beam emissions from Spacelab were recorded with onboard diagnostic instruments. The variation of the Spacelab-shuttle potential with respect to the ambient plasma near the scientific air lock was investigated. Data on the waves and instabilities triggered by the electron beams are discussed. Within the electron gyrofrequency and electron plasma frequency range, strong signals were detected by both electric and magnetic antennas during the beam emissions. The frequencies of the emitted waves were compared to the characteristic plasma frequencies to enable mode identification.

One of the active experiments on Spacelab 1 was designed to investigate phenomena induced by charged particle beams (PICPAB) emitted from the space shuttle. The primary scientific objectives of the PICPAB experiment are related to spacecraft charging, neutralization processes, and beam-plasma interactions. In addition, the experiment was designed to study the transition range between low- and high-power electron beams. Laboratory experiments and experiments in which particle beams were injected into space from rockets had shown that different interaction regimes exist. An initially linear regime extended into intricate nonlinear regimes involving complex mechanisms such as the beam-plasma discharge (1). The PICPAB experiment was also designed to begin studies on high-energy ion beams in the ionosphere.

Instrumentation. The PICPAB instrumentation consisted of three packages (2, 3). The active package, located on the pallet, contained the electron and ion accelerators and diagnostic instruments (particle analyzers and a plasma potential probe). The passive package, deployed outside the scientific air lock by the crew, contained high-frequency (HF) electric (0.1 to 90.9 MHz) and magnetic (0.1 to 11.4 MHz) antennas, a double-

sphere electric probe (d-c to 500 Hz), a plasma frequency probe, and an electron temperature probe (ETP). The rack unit, located in the module, was composed of a sweep frequency analyzer connected to the HF antennas and a control unit devoted to mode control, data collection, and main interfacing with the active and passive units and with the general onboard Command and Data Management System. The telemetry rate of the experiment was 1 Mbit/sec. Two basic modes were used and are referred to as "floating" and "nonfloating." In the floating mode the active package was electrically insulated from the Spacelab structure; the package could "float" with respect to the Spacelab potential (limited to ± 200 V by design). In the nonfloating mode the active package was electrically grounded to the Spacelab structure, and the net current flowing between the package and the structure was measured. Using one of these two modes, a 5-minute sequence was divided into several modules including low (10 mA) or high (100 mA) beam currents with an electron energy of 8 keV, a pure ion beam (2 mA, 6 keV), two beams of electrons (10 mA) and ions (2 mA), and a neutralized ion beam (ions at 2 mA and electrons at 0 to 4 mA, 100 to 200 eV) (4). The PICPAB accelerators were operated

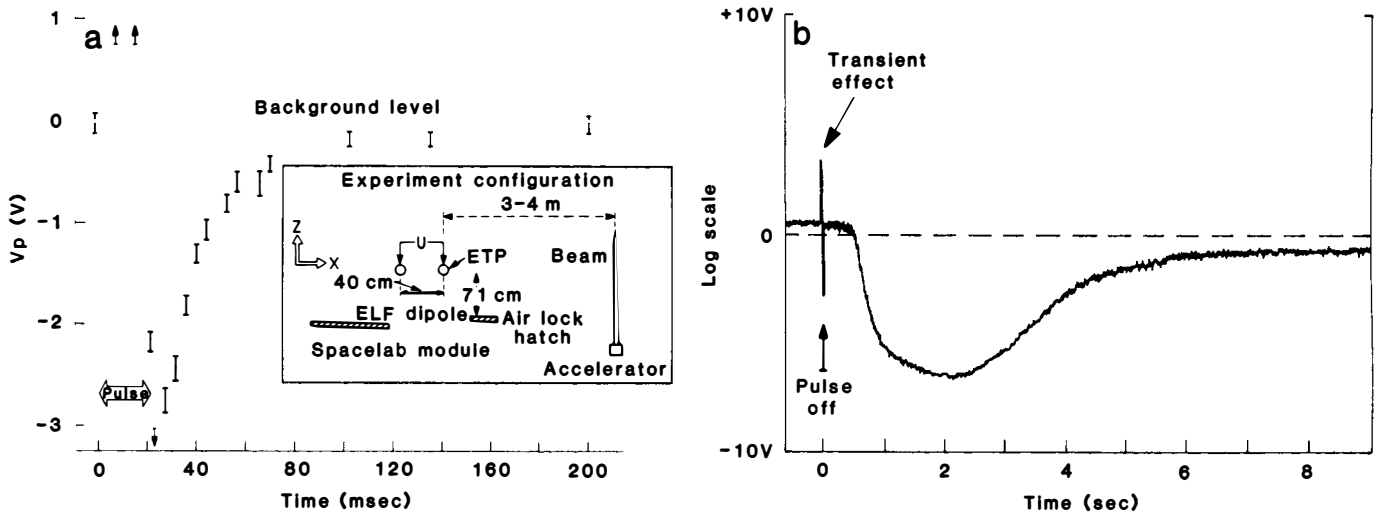


Fig. 1. Time history of neutralization of the shuttle. (a) Shuttle potential variation measured by the electron temperature probe after a pulse (10 mA, 8 kV) emitted by the PICPAB electron accelerator. (b) Potential difference between the two spheres of the axial electric dipole after a SEPAC electron beam accelerator pulse (300 mA, 4 kV).

separately or simultaneously according to a preprogrammed sequence. During a 48-second module the experiment ran in a pulse mode (91 pulses of 20 msec were emitted every 266 msec) and in a modulated mode (91 pulses of 40 msec with 500-Hz modulation were emitted every 266 msec). In addition to the stand-alone operations supported by experiment 1ES019 (5), there were operations involving the other two plasma physics experiments, SEPAC (6) and AEPI (7).

Neutralization processes. The shuttle charges positively (negatively) when the electron beam (ion beam) is emitted. This charging, which occurs during beam firing, is expected to take place in a very short time. Such short-time events have not yet been fully analyzed. In this report we concentrate on the neutralization of the shuttle which takes place on a longer time scale after the accelerator pulse. Examples of the observations of the shuttle discharging are presented in Fig. 1. Figure 1a shows the evolution of the shuttle potential with respect to the local plasma potential after a PICPAB low-current electron beam pulse. After an increase of the shuttle potential during the beam pulse, there is a clear overshoot when the beam is switched off. The return to the initial level takes place, in this example, in 200 msec. The evolution of the local d-c electric field along the x-axis of the shuttle after a SEPAC electron beam accelerator (EBA) pulse is depicted in Fig. 1b. Our interpretation of the data is as follows. In the local environment of the scientific air lock, where these measurements are performed, surfaces made of different conducting and nonconducting materials are charged at different rates during the

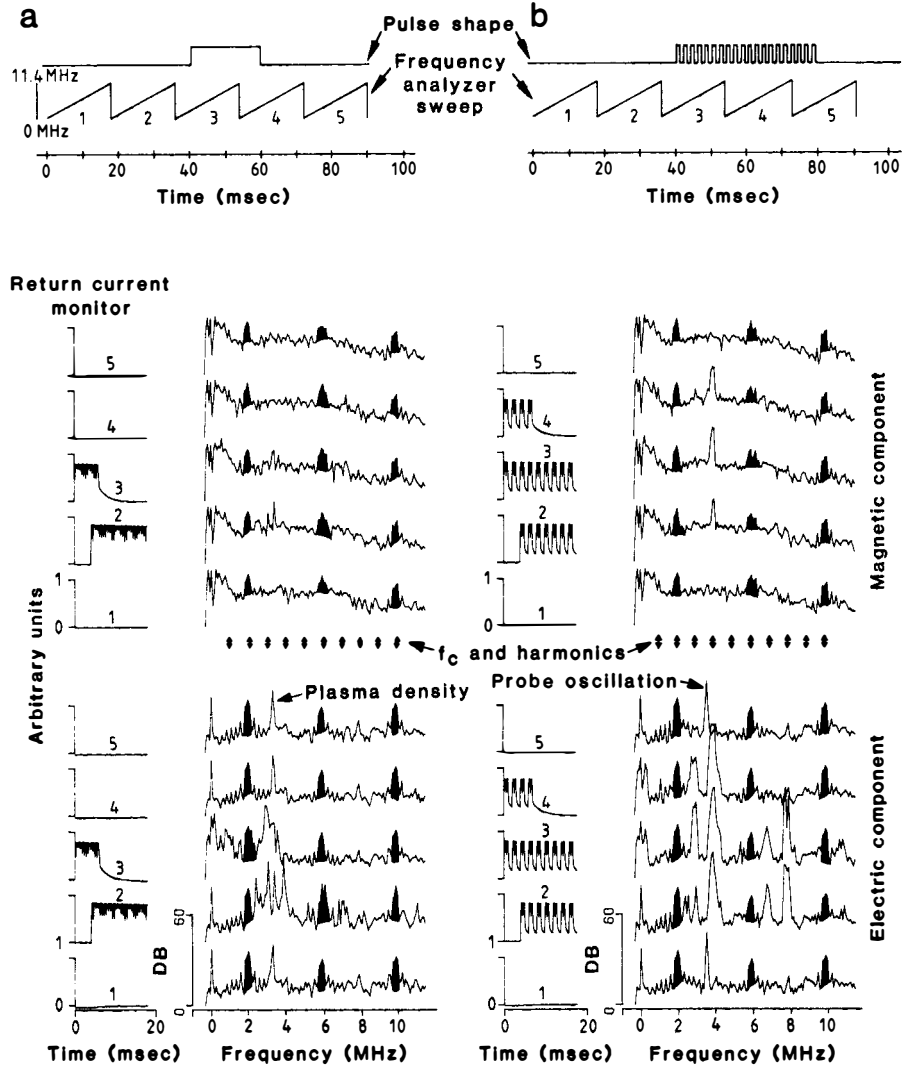


Fig. 2. Frequency spectra recorded before, during, and after a PICPAB electron accelerator pulse (100 mA, 8 kV): (a) in pulse mode (mission elapsed time 0:21:28:50), (b) in modulated mode (2:15:25:48-57). Five consecutive spectra are displayed for the electric and magnetic components. A timing diagram is plotted at the top. Interference lines, filled in black, are instrumental. The frequency of oscillation of the plasma frequency probe at 3.3 MHz is visible on the electric component spectra. In this example the efficiency of the electron beam in creating instabilities is greater in the modulated than in the pulse mode.

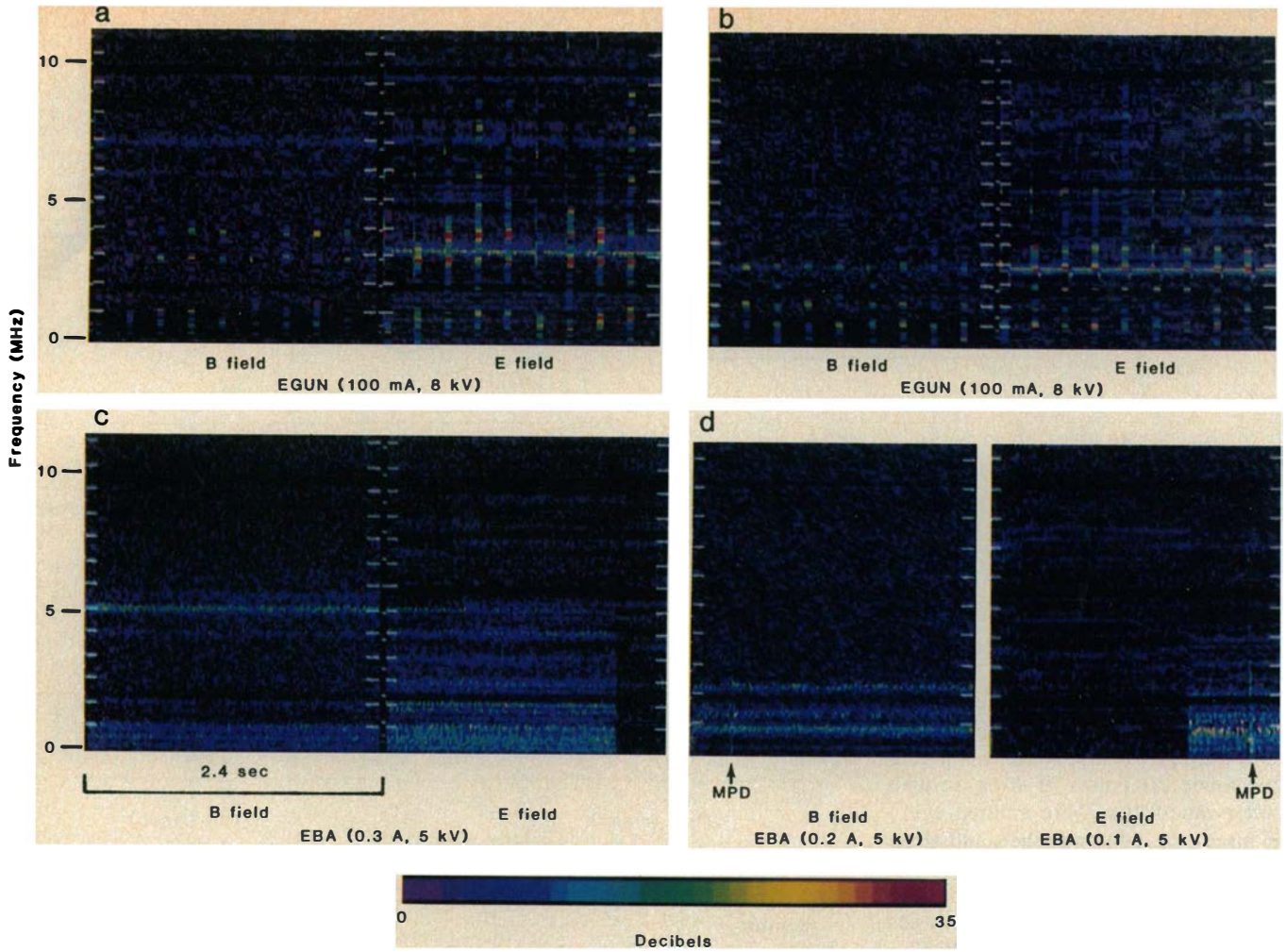


Fig. 3. Color-coded spectrograms for various conditions during the mission (see text). White tick marks indicate the harmonics of the electron gyrofrequency; black tick marks indicate frequency scale, which is the same for all panels. Red corresponds to the highest signal. The spectra are normalized to those obtained during the calibration module at the beginning of each sequence (no beam emission). Data corresponding to the beam emission periods were expanded in time in order to increase readability. Mission elapsed time was: (a) 3:04:31:02–07, (b) 4:04:43:50–55, (c) 2:15:10:33–37, and (d) 2:15:26:10–12 (0.1 A) and 2:15:26:17–19 (0.2 A).

beam pulse. When the beam pulse is switched off, these surfaces discharge at different rates, thus inducing local electric fields. The time constant for the return to the background level may vary from a few milliseconds to several seconds, depending on the level of charging. The parameters that influence the level of charging and the neutralization time constants are now being actively investigated.

An interesting point should be mentioned here. The vehicle is in electrical contact with the plasma through its conductive parts, mainly the engines. Since it moves with a velocity component of up

to $v = 7.5$ km/sec perpendicular to the earth's magnetic field (B), there is, in the reference frame of the shuttle, a $v \times B$ electric field developing in the plasma at points remote from the engines. This introduces an offset in the value of the local Spacelab-plasma potential measured on the pallet or in the air lock. The offset is 0.45 V/m when the velocity vector is perpendicular to the magnetic field vector ($v = 7.5 \times 10^3$ m/sec, $B = 0.6 \times 10^{-4}$ tesla). As we expect the shuttle (engine) potential to be 1 to 2 V negative with respect to the plasma potential, the local plasma potential measured on the pallet or in the air lock may be either slightly positive or 5 to 6 V negative due to the $v \times B$ offset. This effect must be studied before the beam effect can be analyzed further.

Wave instabilities. The plasma wave activity is measured with an electric dipole (0.4 m long) and a magnetic antenna, which are part of the passive package mounted in the air lock. The electric and magnetic signals are analyzed with a swept frequency analyzer (0.1 to 11.4 MHz) in a time-sharing mode. The electric dipole is also part of a mutual impedance probe used in the oscillating mode.

The oscillation frequency of this probe is close to the upper hybrid frequency f_{UH} and is a direct measure of the plasma frequency f_P (Eq. 1) and therefore of the plasma density N_E (Eq. 2).

$$f_{UH}^2 = f_P^2 + f_C^2 \quad (1)$$

$$N_E (\text{cm}^{-3}) = 0.0121 f_P^2 (\text{kHz}) \quad (2)$$

Here f_C is the electron gyrofrequency, which is deduced from the magnetic field computed or measured (experiment 1ES019) on board.

A typical wave measurement is shown in Fig. 2. Several consecutive wave spectra, covering a period encompassing a beam pulse, are plotted for both the electric and the magnetic field. These curves display the following features:

1) A broadband emission below f_C in both the electric and the magnetic component. This mode can be identified as the whistler mode.

2) A narrow-band emission near $3f_C$ in the electric component and one near $4f_C$ in both the electric and the magnetic component. Emissions are also seen at higher frequencies, but only in the electric component.

3) A general increase of the noise

background level up to at least 10 MHz in the electric component.

The same wave measurements are also shown in the color spectrograms in Fig. 3a, together with other measurements made under different plasma conditions. Figure 3b shows results of measurements made when the beam was emitted along the magnetic field to within a few degrees. There is a net increase of the wave intensity up to 10 MHz in the electric component. In addition, narrow harmonics of the electron gyrofrequency are excited, as seen in both the electric and magnetic components.

Figure 3c shows the effect of operating the SEPAC electron beam accelerator (5 kV, 0.3 A). The beam was on continuously for 5 seconds. Several narrow-band emissions are observed up to several times f_C . In Fig. 3d, which was recorded during another SEPAC electron beam accelerator operation, the effect of the magneto-plasma dynamic arcjet is clearly visible, about 300 msec after the start of the beam pulse, in both the electric and magnetic components.

Conclusion. The electron beams injected from the Spacelab pallet produced very clear effects. There were large variations of the shuttle-Spacelab potential with respect to the ambient plasma potential. The relaxation time of the vehicle potential with respect to the plasma potential after the beam is switched off varied from a few milliseconds up to several seconds, the latter result being unexpected. The electrical properties of the materials composing the surface of the spacecraft play an important role, which must be understood before the beam effects can be analyzed. The electron beams also created several instabilities linked to the electron gyrofrequency and its harmonics, and to the plasma and the upper hybrid frequency. In most cases there was a net increase of the electric component of the background noise level in a wide frequency range up to 10 MHz.

C. BEGHIN

*Laboratoire de Physique et
Chimie de l'Environnement,
45045 Orleans, France*

J. P. LEBRETON

*Space Science Department,
European Space Agency, European
Space Research and Technology Centre,
2200 AG Noordwijk, Netherlands*

B. N. MAEHLUM

J. TROIM, P. INGSOY

*Norwegian Defense Research
Establishment, Kjeller, Norway*

J. L. MICHAU

*Laboratoire de Physique et
Chimie de l'Environnement*

References and Notes

1. B. Grandal, Ed., *Artificial Particle Beams Utilised in Space Plasma Physics* (Plenum, New York, 1982).
2. C. Beghin, *ESA J.* 3 (No. 2), 123 (1979).
3. ———, in *Active Experiments in Space* (ESA SP-195, European Space Agency, Paris, 1983).
4. The ion accelerator functioned nominally during the first day of the mission until a failure occurred. Ion beam-induced effects will not be discussed in this report.
5. K. Wilhelm *et al.*, *Science* **225**, 186 (1984).
6. T. Obayashi *et al.*, *ibid.*, p. 195.
7. S. Mende *et al.*, *ibid.*, p. 191.
8. The success of this experiment resulted from the work of a number of participants in the PICPAB project. In particular, we thank F. X. Sene, P.

Gille, B. Narheim, and U. Gercke, who worked enthusiastically during integrations, flight simulations, and the flight. We also thank Y. Arnal, J.-J. Berthelier, J.-Y. Delahaye, A. Gonfalone, D. Henry, D. Klinge, J. Lavergnat, F. Malerba, N. Overaas, M. Pirre, L. Pomathiod, M. Sylvain, J. F. Karczewski, P. Decreau, and J. M. Illiano. Fruitful discussions with A. Pedersen in the course of the data analysis are acknowledged. We thank the CNES, ESA, NASA, and ERNO personnel for their support during various phases of the project. In particular, we appreciate the support of the ESA Operations Team and the collaboration of the Plasma Physics Discipline Group in the Payload Operations Control Center before and during the mission.

27 March 1984; accepted 10 May 1984