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EQUATORIAL IONOSPHERE
WAVE PROPAGATION

AUTORIZADA POR/AUTHORIZED BY
Marco Antonio Raupp
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AUTOR RESPONSÁVEL / RESPONSIBLE AUTHOR
M.A. Abdu

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TÍTULO/TITLE

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AUTORES/AUTHORSHIP

M.A. Abdu
P. Muralikrishna
I.S. Batista
A.H.P. Chaves

*Revised work in February, 1987

RESUMO-NOTAS/ABSTRACT-NOTES

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OBSERVAÇÕES/REMARKS

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TÍTULO

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IDENTIFICAÇÃO

AUTOR(ES)

M.A. Abdu
P. Muralikrishna
I.S. Batista
A.H.P. Chaves

ORIENTADOR

CO-ORIENTADOR

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M. A. Abdu, P. Muralikrishna, and I. S. Batista

Instituto de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil

A. H. P. Chaves

Instituto de Atividades Espaciais-Centro Técnico Aeroespacial
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Introduction

In situ measurements of the equatorial daytime ionosphere over Natal, Brazil, were carried out using an electron density probe mounted on a SONDA III rocket that was launched at 1505 LT (1805 UT) on July 26, 1984, from the launch base at Barreira do Inferno (12°S, 38°W, -11° dip). Successful measurements were obtained during both the upleg and the downleg of the trajectory that reached an apogee of 566 km. The electron density detector used in the experiment was a high-frequency capacitance (HFC) probe [Heikkila et al., 1968; Rao et al., 1970]. Briefly, the HFC probe utilized the nose tip of the rocket as a capacitance element that determined the frequency of a stable oscillator whose operation in a double-frequency mode (~10 MHz and ~5 MHz) was achieved by switching at a convenient rate between two suitably selected inductors. Changes in the capacitance of the nose tip produced by the ionosphere modify the oscillator frequency f, by Δf, which is related to the ambient electron density (neglecting the electron-neutral collision frequency and electron gyrofrequency) by the relation $N \approx (2f^2/f_0)\ 81\ SK\ \Delta f$, where f_0 is the free space frequency, S is the ion sheath factor (approximately 0.5 at E region heights), and $K = C_0/(C_0 + C_s)$ is a sensitivity factor, C_0 being the free space capacitance of the sensor and C_s the stray capacitance of the oscillator assembly. In the dual-frequency mode, when the oscillator operates at one frequency, the frequency information in the other mode is transmitted, and vice versa, for equal durations of ~120 ms each, thus forming an operation cycle of ~240 ms. For calibration purposes (namely, for obtaining conditions approaching those of free space), a negative voltage of ~100 V is applied to the sensor during one out of every four cycles of operation. The height resolution of the measurements, thus, varied from about 800 m in the E region to about 100 m in the F region and near the apogee. The rocket had a spin rate of ~5 rps and precession rate, to be discussed below, of ~0.07 rps (a period of ~15 s).

Results

The electron densities calculated using the Δf measured in the 10-MHz mode and using an S factor of 0.5 are shown in Figure 1 for the upleg and downleg, starting from 95 km (the lowest height sensitive to 10 MHz) up to the apogee of 566 km. The E layer peak occurred at 112 km, where the density deduced from the Fortaleza (some 400 km westward of Natal) ionogram is also marked, which showed that there is good agreement between the two results. The discontinuity of the data between 270 km and 455 km during the upleg and between 420 km and 292 km during the downleg is due to the limitation imposed by the oscillator frequency becoming equal to the plasma frequency at these heights, which resulted in the failure of the oscillator operation. (Although on one hand this situation has resulted in the loss of data on the peak density, it has, on the other hand, provided reliable absolute densities at two adjacent heights on either side of the F_2 peak.) There are some significant differences between the upleg and downleg electron density profiles, more than what can be explained by the geographic (and local time) separation of the two parts of the trajectories. The downleg profile is characterized by the presence of significant wave structure, but the average shape of the curve would suggest densities significantly less than in the upleg part. These low densities are produced as a result of the HFC sensor's being situated in the rocket wake during the descent. We shall not discuss in this paper the absolute densities or their height distributions; rather we shall focus our attention on the wave structure superimposed on the descent profile, the subject of the present report.

In Figure 2a we have shown the downleg profile below 300 km, and in Figure 2b the same profile after passing through a band-pass filter to remove the 20 to 50 km scale modulation on the profile. The filtered component is plotted in Figure 2c together with the magnetic field z component measured by the on-board magnetometer. The almost perfect correlation, with a certain time shift, between them shows that the electron density profile modulation with scale sizes of ~30-40 km is indeed produced by our sampling the density distribution in the wake region during the rocket precession.

The wave disturbances of shorter wavelength that are present in Figure 2b, shown separately in Figure 2d, are our primary concern here. They are related neither to the rocket spin rate (which was ~5 rps) nor to any operational sequences of the payload instrumentation (less than 1 s as mentioned before), which leads us to the conclusion that they are real modulations in the ambient electron densities seen by the instrument only during the downleg trajectory of the rocket. The wavelengths and periods of these disturbances are plotted in Figure 3, considering only the region where the wave structure and period could be clearly identified. The absence of data between ~290 km and ~420 km, of course, represents the same region of the absence of data in Figure 1. The wavelength of the disturbances is seen to increase from approximately 1.5 km near 500 km height to ~10 km near 135 km, the height up to which these waves were clearly defined, indicating that in the height range around 350 km the wavelength varied by a factor of ~6. (The occurrence of the E layer peak at 112 km together with other fluctuations in the density has made difficult a clear identification of these waves below 135 km.)

In the search for a source of these waves, the possible role of acoustic gravity waves seems to be immediately ruled out since the wave period at the lower height limit, 135 km (see Figure 3), is well below the Brunt-Vaisala period, given by

$$T_b = 2\pi\, g^{-1} \left(\frac{\Gamma-1}{\Gamma}\ \frac{M}{RT}\right)^{-1/2} \simeq 8 \text{ min}$$

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Concluding Remarks

The wave pattern in the count rate of the oscillation frequency measured by the rocket does represent disturbances in the ionization having wavelengths from ~ 1.5 to ~ 10 km and periods ~ 1.5 to 3.8 s and is not associated with any well-known rocket performance feature, such as the spin or precession rate, or with the payload performance characteristics. Since propagating waves in the acoustic spectrum (that have high attenuation at these heights) could not have caused detection of such a disturbance, we have postulated their generation by the rocket body itself during the descent part, the detection having been made possible by the location of the sensor in the wake region. Identical perturbation amplitudes would be present in the neutral and ionized components in the magnetic field line parallel direction in which the rocket velocity has a significant component, which might be responsible for this direct detection of the plasma fluctuations. In the field line perpendicular direction, observable plasma fluctuations could be induced by the neutral pressure fluctuations depending upon the values of the ion-neutral chemistry and dynamic interaction time constants in relation to the fluctuation period.

The rapid attenuation of the perturbations in the medium does pose problems for their investigation by other independent diagnostic techniques. However, if such disturbances could trigger a plasma instability mechanism to generate intermediate- or shorter-scale ionization irregularities under favorable nighttime equatorial ionospheric conditions, then their detection by well-known ground-based diagnostic techniques presents itself as a good possibility. The amplitude of the perturbation is adequate compared to those used (5%) in the simulations based on the nonlinear theory of irregularity development [Zalesak et al., 1982] (see also the review article by Kelley [1985]).

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References

Heikkila, W. J., N. Eaker, J. A. Fejer, K. R. Tipple, J. Huggil, D. E. Schneible, and W. Calvert, Comparison of several probe techniques for ionospheric electron concentration measurements, J. Geophys. Res., 73, 3511-3535, 1968.

Hines, C. O., Internal atmospheric gravity waves at ionospheric heights, Can. J. Phys., 38, 1441-1481, 1960.
Kelley, M. C., Equatorial spread-F: Recent results and outstanding problems, J. Atmos. Terr. Phys., 10, 745-752, 1985.
Rao, U. R., S. S. Degaonkar, M. A. Abdu, S. Bansidhar, and R. M. Patel, Rocket based ionospheric measurements at Thumba with high frequency capacitance probe, Space Res., 10, 703-706, 1970.
Zalesak, S. T., S. L. Ossakow, and P. K. Chaturvedi, Nonlinear equatorial spread F: The effect of neutral winds and background Pederson conductivity, J. Geophys. Res., 87, 157-166, 1982.

M. A. Abdu, I. S. Batista, and P. Muralikrishna, Instituto de Pesquisas Espaciais, C. P. 515, 12201 São José dos Campos, São Paulo, Brazil.

A. H. P. Chaves, Instituto de Atividades Espaciais - Centro Técnico Aeroespacial, 12200 São José dos Campos, São Paulo, Brazil.

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Fig. 2. (a) Electron density profiles for the INPE 1 flight corresponding to the downleg of the trajectory from 300 km to 95 km. (b) The same profiles after passing through a band-pass filter to remove the 20 to 50 km scale modulation in the density. (c) The filtered component plotted together with the magnetic field z component that indicates the precession rate of the rocket. (d) Shorter-wavelength disturbances filtered out of the profile (Figure 2a).

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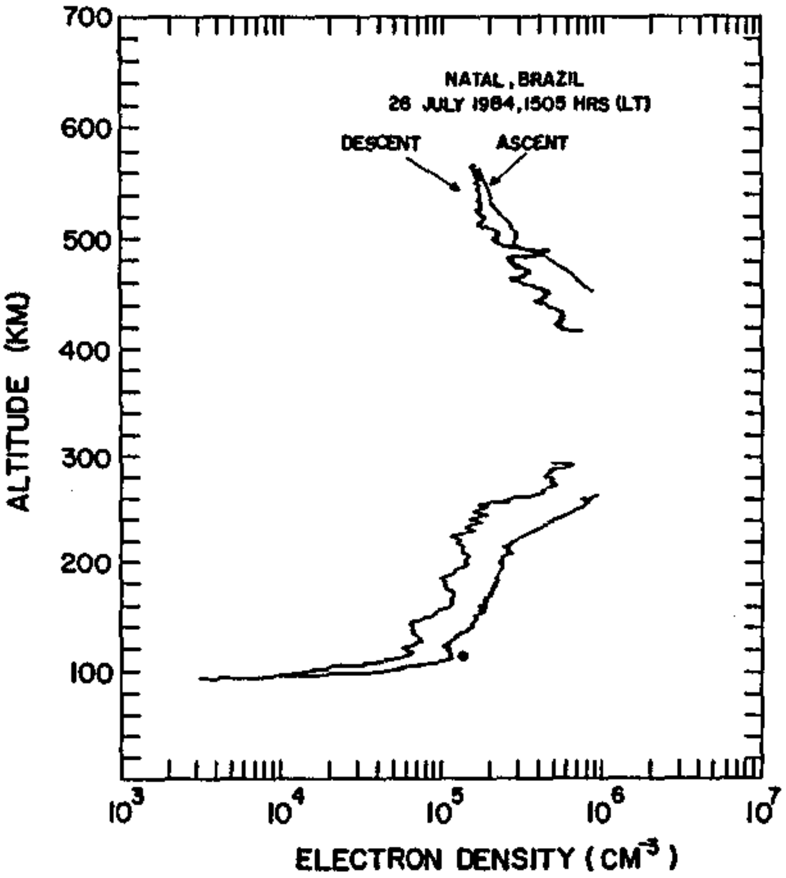
NATAL, BRAZIL
26 JULY 1984, 1505 HRS (LT)
DESCENT
ASCENT
ALTITUDE (KM)
ELECTRON DENSITY (CM⁻³)

Fig. 1

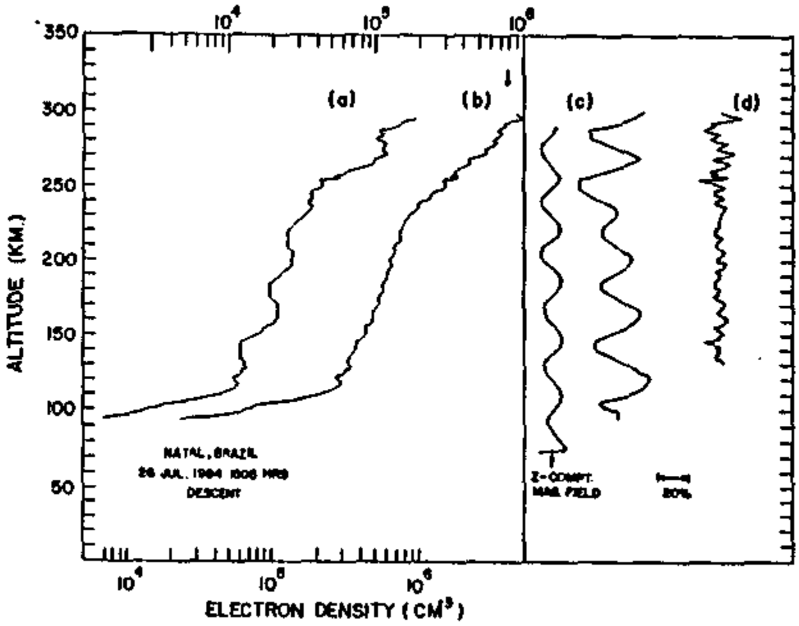
(a)
(b)
(c)
(d)
ALTITUDE (KM.)
ELECTRON DENSITY (CM⁻³)
NATAL, BRAZIL
DESCENT
Z-COMPT.
MAG. FIELD

Fig. 2

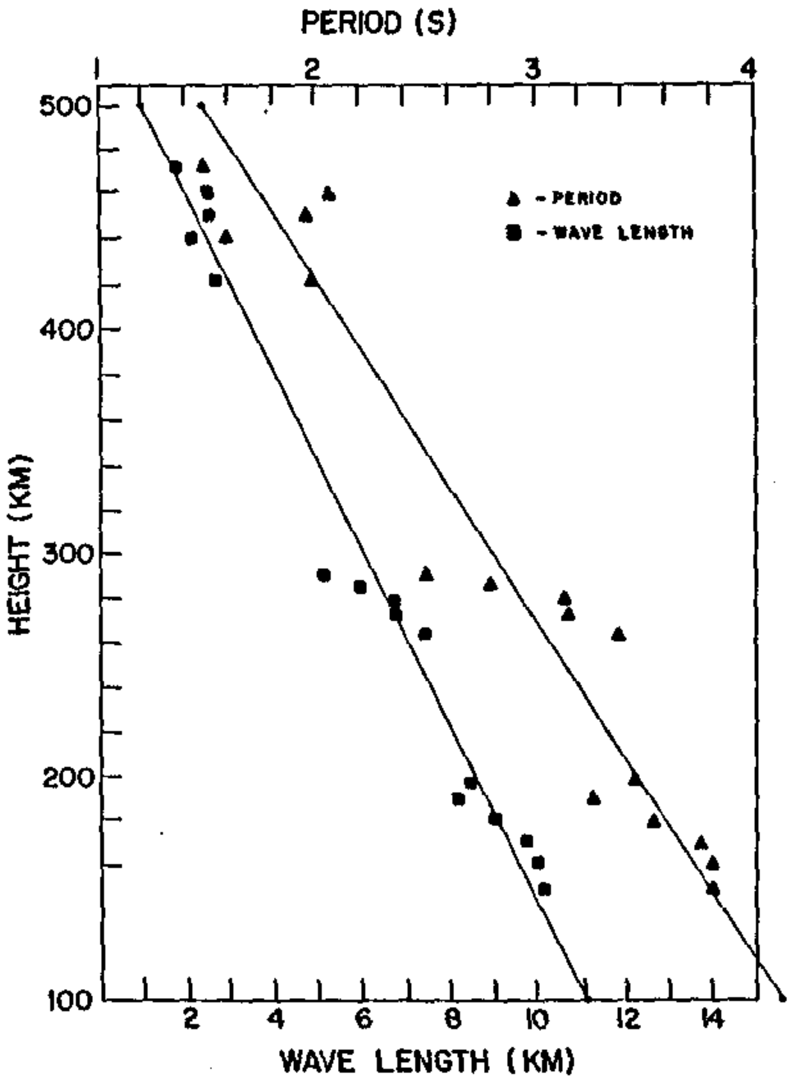
PERIOD (S)
1
2
3
4
500
400
300
200
100
HEIGHT (KM)
▲ - PERIOD
■ - WAVE LENGTH
2
4
6
8
10
12
14
WAVE LENGTH (KM)

Fig. 3

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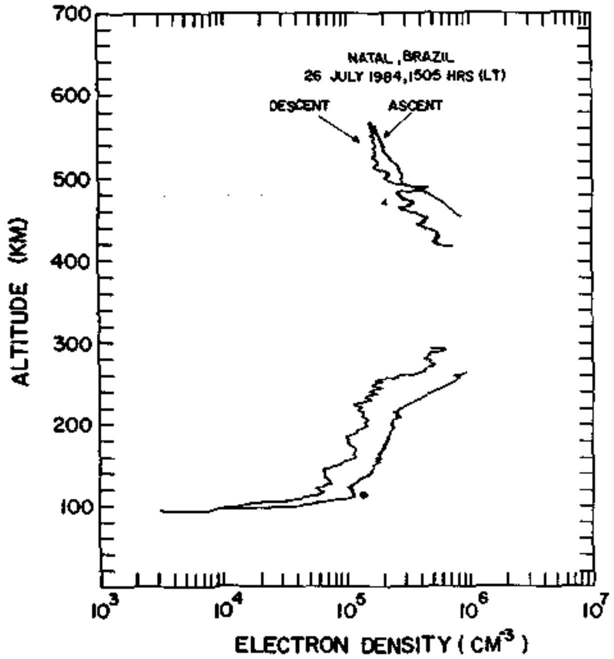

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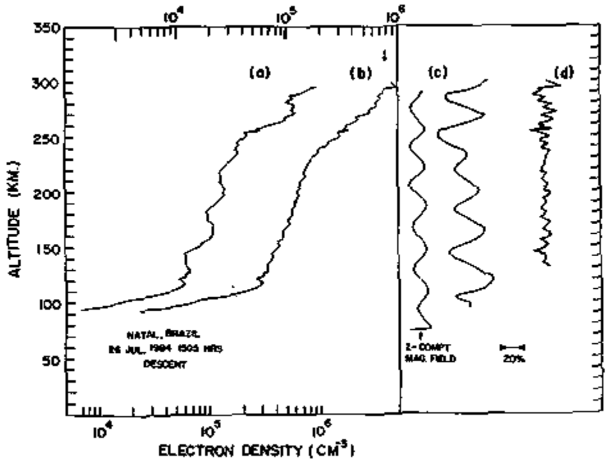

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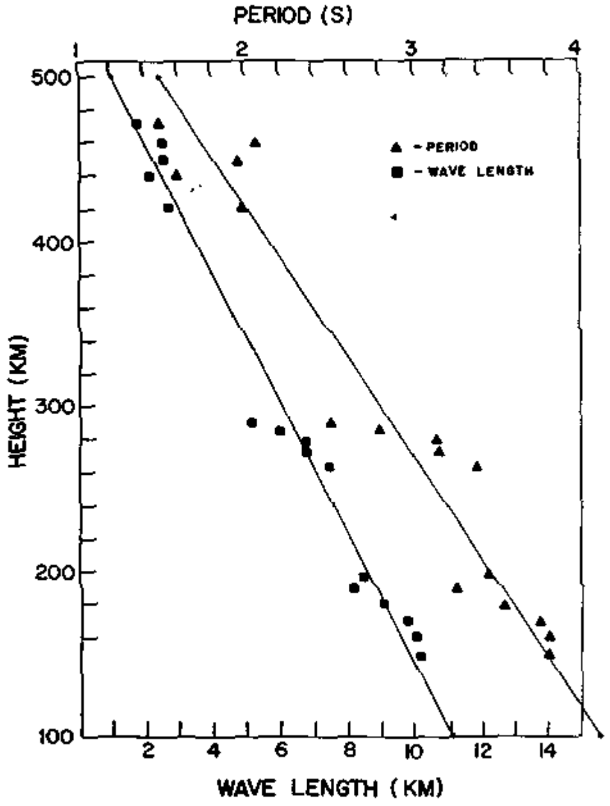

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of such waves by the sensor before they are attenuated in the ambient medium. It is interesting to note further that the change in the period of these disturbances by a factor of ~2 (as obtained from Figure 3), between 450 and 150 km, is closely comparable to the factor of variation in the rocket velocity within the same height range, suggesting thereby an approximately linear dependence of the disturbance period on the rocket velocity.

Concluding Remarks

The wave pattern in the count rate of the oscillation frequency measured by the rocket does represent disturbances in the ionization having wavelengths from ~ 1.5 to ~ 10 km and periods ~ 1.5 to 3.8 s and is not associated with any well-known rocket performance feature, such as the spin or precession rate, or with the payload performance characteristics. Since propagating waves in the acoustic spectrum (that have high attenuation at these heights) could not have caused detection of such a disturbance, we have postulated their generation by the rocket body itself during the descent part, the detection having been made possible by the location of the sensor in the wake region. Identical perturbation amplitudes would be present in the neutral and ionized components in the magnetic field line parallel direction in which the rocket velocity has a significant component, which might be responsible for this direct detection of the plasma fluctuations. In the field line perpendicular direction, observable plasma fluctuations could be induced by the neutral pressure fluctuations depending upon the values of the ion-neutral chemistry and dynamic interaction time constants in relation to the fluctuation period.

The rapid attenuation of the perturbations in the medium does pose problems for their investigation by other independent diagnostic techniques. However, if such disturbances could trigger a plasma instability mechanism to generate intermediate- or shorter-scale ionization irregularities under favorable nighttime equatorial ionospheric conditions, then their detection by well-known ground-based diagnostic techniques presents itself as a good possibility. The amplitude of the perturbation is adequate compared to those used (5%) in the simulations based on the nonlinear theory of irregularity development [Zalesak et al., 1982] (see also the review article by Kelley [1985]).

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References

Heikkila, W. J., N. Eaker, J. A. Fejer, K. R. Tipple, J. Huggil, D. E. Schneible, and W. Calvert, Comparison of several probe techniques for ionospheric electron concentration measurements, J. Geophys. Res., 73, 3511-3535, 1968.

Hines, C. O., Internal atmospheric gravity waves at ionospheric heights, Can. J. Phys., 38, 1441-1481, 1960.

Kelley, M. C., Equatorial spread-F: Recent results and outstanding problems, J. Atmos. Terr. Phys., 10, 745-752, 1985.

Rao, U. R., S. S. Degaonkar, M. A. Abdu, S. Bansidhar, and R. M. Patel, Rocket based ionospheric measurements at Thumba with high frequency capacitance probe, Space Res., 10, 703-706, 1970.

Zalesak, S. T., S. L. Ossakow, and P. K. Chaturvedi, Nonlinear equatorial spread F: The effect of neutral winds and background Pederson conductivity, J. Geophys. Res., 87, 157-166, 1982.

M. A. Abdu, I. S. Batista, and P. Muralikrishna, Instituto de Pesquisas Espaciais, C. P. 515, 12201 São José dos Campos, São Paulo, Brazil.

A. H. P. Chaves, Instituto de Atividades Espaciais - Centro Técnico Aeroespacial, 12200 São José dos Campos, São Paulo, Brazil.

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