National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No.NAS-5-12487

ST — PF — GM — 10747

CERTAIN PECULIARITIES IN THE DISTRIBUTION OF PLASMA CONCENTRATION AND OF THE FIELD OF ALFVEN WAVES IN THE EARTH'S MAGNETOSPHERE

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29 AUGUST 1968

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Kosmicheskiye Issledovaniya
Tom 6, vyp.4, 612 - 616,
Izd-vo "NAUKA", 1968.

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SUMMARY

The peculiarities are considered of plasma concentration and velocity field of Alfvén waves distribution in the Earth's magnetosphere, taking into account the distortion of the Earth's magnetic dipole field by the field of the radiation belt's ring current. The presence of the latter in the Earth's magnetosphere results in the variation of propagation conditions of magnetohydrodynamic (MHD) waves. Obtained in particular is an outstripping effect of the Alfvén wave propagating along the field line closest to the Earth, by the Alfven wave propagating along the distant line of force. An identical effect of outstripping is possible during propagation of whistlers.

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The study of plasma density distribution in the magnetosphere after data on whistlers shows the presence of a rather sharp jump in particle density (Carpenter's "knee") in the equatorial plane at a distance of the order of 3.5 to 6 Earth's radii (R_E) [1]. Starting from this jump, Angerami and Carpenter [2] reached the conclusion that there takes place in the "knee" region of the magnetosphere a change in the course of the curve for plasma density distribution. However, when computing the density of the plasma, they did not point out the existence of magnetic field singularities in the "knee" region, and all calculations were conducted in the assumption of undistorted dipole distribution of the geomagnetic field.

Nishida [3] proposed to explain the "knee" with the aid of "vortices" suggested by Axford and Hines [4].

There forms in this case a certain closed oval region around the Earth, with vortices flowing past it and returning back into the magnetosphere tail. The outer boundary of the oval region is called "plasmapause", with different laws of plasma distribution on both sides of it. In their reasonings, the authors [2, 3] are not concerned with those possible variations in plasma concentrations that may be caused by depressions of the Earth's dipole magnetic field at those distances, as a consequence of the existence of a magnetic field of radiation belts' ring current, as well as of possible magnetic fields of currents arising at the plasmapause boundary.

It is well known that the distortion of the dipole field may reach significant values [5], being essentially dependent on the magnetic activity.

Considered in the present work are the possible vatiations in plasma concentration and of the field of Alfvên velocities in the Earth's magnetosphere as a consequence of dipole geomagnetic field distortion by the ring current of trapped radiation belt. We assumed for model radiation belt that of the V_E with center at $6R_E$ [6 - 8]. The location of the lines of force of the total magnetic field (dipole and ring current fields) in the belt is shown in Fig.1. The lines of force of the dipole field are figured by dashed lines.

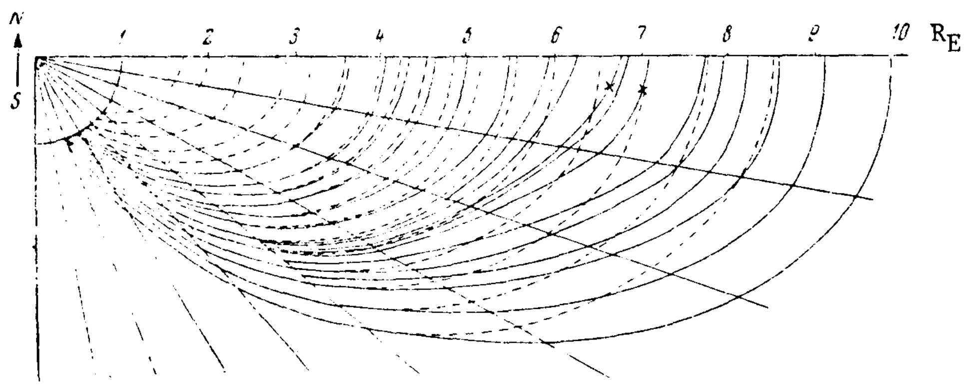

Fig.1

It was further assumed that at distances above $2R_E$ the cold magnetosphere plasma may be considered as collisionless; a unique law of particle distribution, as proposed by Parker [9], was adopted for that region :

$$N(r) = N(R)\left(\frac{B_0}{B}\right)^{\alpha}, \tag{1}$$

where N(r) is the concentration of particles at the distance r; N(R) is the concentration of particles at the initial level R = 1.15 R_E; B_0 is the value of the magnetic field at level R; B is the magnitude of the magnetic field at the distance r.

When computing the concentration of particles in the Earth's magnetosphere we used as a reference profile the averaged level of electron concentration and temperature at 1000 km altitude after the data of "Explorer-22" [10]. We disregarded the present singularities of the daily, seasonal, disturbed and quiet periods in the course of electron concentration at 1000 kn after the data of satellite investigations [10, 11].

The concentrations of particles (in cm^{-3}), computed by formula (1), taking into account the distorted magnetic field in case of polar distribution of particles ($\alpha = -1$) is shown in Fig.2.

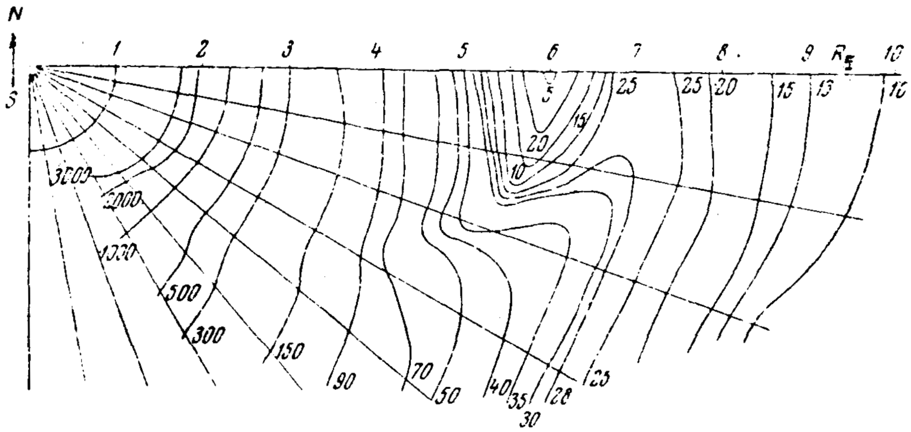

Fig.2

The equatorial profile of particle concentration is shown in Fig.3, curve a. There is also presented an experimental graph (curve c) obtained by Serbu after the data of IMP-2 [12]. It follows from Fig.3 that the theoretical and the experimental curves qualitatively repeat one another, whereupon the the numerical coincidence of these curves would be possible for a less polar distribution of particles ($\alpha \sim -0{,}8$) and somewhat lesser distortion of the dipole field.

Plotted in the same Fig.3 (curve b) is the equatorial profile of particle concentration, converted from the altitude of 1000 km by formula of Eviator et al [13]:

$$\frac{N(r,r_e)}{N(R,r_e)} = \left\{1-\left(1-\frac{B}{B_0}\right)^{1/2}\exp\left[-\frac{mV_\infty^2 B\left(1-\frac{R}{r}\right)}{2kT(B_0-B)}\right]\right\}\times$$
$$\times\exp\left[-\frac{mV_\infty^2\left(1-\frac{R}{r}\right)}{2kT}\right], \qquad (2)$$

where r is the geocentric distance; r_e is the equatorial distance, R is the radius of the baropause ($R = 1.5\ R_E$); $N(r,r_e)$ is the concentration of particles at the distance r; $N(R,r_e)$ is the concentration of particles at baropause boundary; B_0 is the magnitude of the magnetic field at the distance r; m is the mass of the particle $V_\infty^2 = 2\gamma/R$, where γ is the product of the gravitational constant and of the Earth's mass, k is the Boltzmann constant, T is the temperature of particles at baropause boundary.

According to the opinion of Angerami and Carpenter [2], the law of collisionless plasma distribution, proposed by Eviator et al [13], is fulfilled beyond the region of the "knee". As may be seen, the assumption of this law does not affect, in principle, the general configuration of the concentration field, as shown in Fig.2. It only introduces numerical changes into the obtained results.

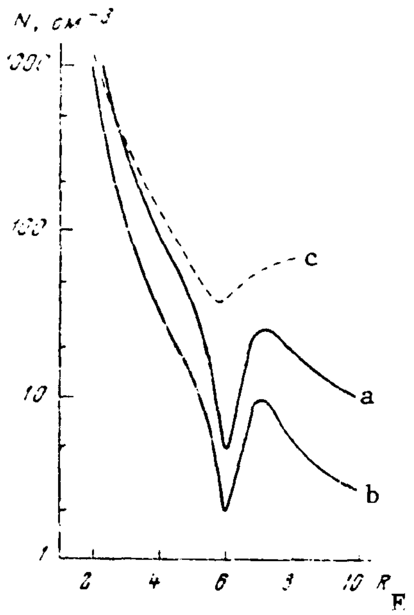

Fig.3

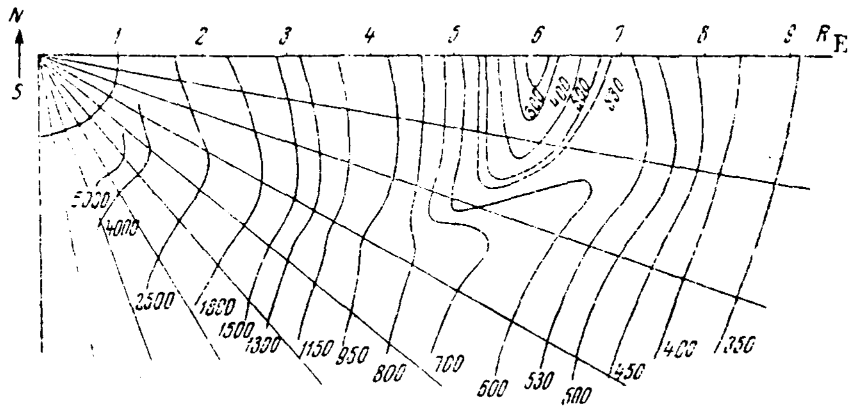

Fig.4

It should be noted that if $B \ll B_0$, one may postulate the first exponent of formula (2) as being equal to unity, i. e.,

$$\frac{N(r\, r_i)}{N(R, r_e)} \sim \left\{1-\left(1-\frac{B}{B_0}\right)^{1/2}\right\} \exp\left[-\frac{mV_\infty^2\left(1-\frac{R}{r}\right)}{2kT}\right] \sim$$

$$\sim \left\{1-\left(1-\frac{B}{B_0}\right)^{1/2}\right\} \Psi(r) \sim \frac{B}{B_0}\frac{1}{2}\Psi(r), \qquad (3)$$

where

$$\Psi(r) = \left[-\frac{mV_\infty^2\left(1-\frac{R}{r}\right)}{2kT}\right]$$

Formula (3) is numerically similar to the Parker formula (1) at $\alpha = -1$, differing only by a factor of $^1/_2$ and a more rapid decrease of concentration with the distance $\underline{r}$.

The field of particle concentration obtained by us (Fig.2) was utilized for the computation of the field of Alfvén velocities $V_A = B/\sqrt{4\pi\rho}$, where B, ρ are respectively the values of the magnetic field and of plasma density.

The values obtained for V_A are plotted in Fig.4 in km/sec. The singularity of the velocity field is the presence of V_A minimum in the region of the center of the ring current, where the velocity V_A drops to 230 km/sec, and then increases to 530 km/sec (Fig.5).

The obtained field of velocities, obtained by us, somewhat reminds of V_A distribution presented in the Van'yan and Al'perovich work [14]. However, contrary to the currently considered case, they assumed a contracted model geomagnetic field after G. MEAD and BEARD [15], and the presence of two laws of plasma density distribution in the magnetosphere.

The noted peculiarity in the distribution of V_A will result in the change of the condition of magnetohydrodynamic wave propagation along, as well as across the geomagnetic field's lines of force. The region of V_A minimum will play a role of a certain lens, capable of focusing on the ground the magneto-acoustic waves propagating from the boundary of the magnetosphere. Moreover, resonances of magneto-acoustic waves are possible in the region bounded by the Dessler velocity maximum of Alfvén waves and the maximum arising as a consequence of the presence of the ring current. Such peculiarities of magneto-acoustic wave propagation were also noted for the above referred-to model, admitted by Van'yan, Zybin and Al'perovich [14, 16].

During the propagation of a magnetohydrodynamic wave along the line of force of the geomagnetic field reflection of MHD-waves may occur in the V_A minimum region , and in case of formation of a standing wave,formation of electric field E's node is possible.

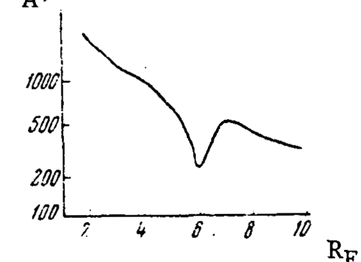

Fig.5

The computations of time dependence of the path length of Alfvén waves on the geomagnetic latitude according to distorted field lines have shown the presence of an advance effect of Alfvén wave propagating along a line of force corresponding to the latitude ϕ = 65°30' and in accord with the admitted radiation belt model, by another Alfvén wave, propagating along a more remote line of force (ϕ = 66°). The lines 65°30' and 66° are noted in Fig.1 by crosses. This outstripping has an order of 3.7 sec for a wave run time along the field line equal to about 120 sec. The length of the segment in the equatorial plane, over which the indicated effect is manifest, constitutes about 0.3 R_E.

For the model radiation belt assumed by us the path lengths of whistlers were computed (Fig.6) by the field lines crossing the ground at latitudes 63° (A), 65°30' (B), 65°45' (C), 66° (D) and 67° (E). The calculation was conducted by the formulas utilized in [17, 18]:

$$V_{gr} = \frac{2cf_n^{1/2}(f_H - f_n)^{3/2}}{f_H f_0}, \tag{4}$$

where c is the speed of sound, f_n is the frequency of the whistler, f_H is the gyrofrequency, f_0 is the plasma frequency and V_{gr} is the group velocity.

$$T = \int_0^{\varphi} \frac{dS}{V_{gr}}, \tag{5}$$

where T is path length of the whistler, dS is the element of the field line and ϕ is the geomagnetic latitude

The choice of f_n for the above-mentioned latitudes was made from [17], where the field influence was investgated of the ring current located at about 40,000 km on the propagation of whistlers.

It may be seen from Fig.6 that the outstripping of the whistler propagating along the 65°30' field line by the whistler propagating along th 66° field line, takes place in the same region, i. e., where the above indicated variation in the path length of Alfvén waves takes place. And although the transit times of Fig.6 are somewhat different from those observed experimentally, the order of whistler propagation resembles considerably to that of experimental data [2] during observations of the "knee". The solution of the inverse problem of finding plasma concentration by the path lengths of whistlers, obtained in the present work in the assumption of dipole character of the magnetic field at the distance of $6R_E$, yields a particle concentration jump by a factor of 6, the width of the region being $0.2R_E$. This is about 5 times less than the jump obtained in the work [2].

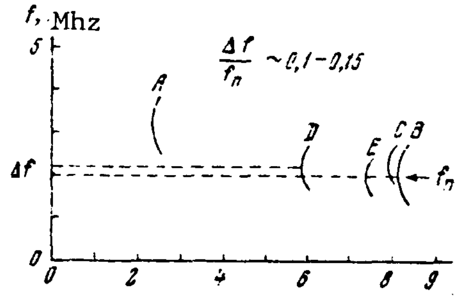

Fig.6

Attention should be called to the fact that the variation of whistler path lengths (transit times) takes place on the geomagnetic field lines, over which increase and not decrease of plasma density takes place in the equatorial plane as the distance from the Earth increases, i. e. (Fig.2) this phenomenon may be adapted to lines of force passing at the outer boundary of the radiation belt, where there is in the equatorial plane an increase of the geomagnetic field distorted by the field of radiation belt's ring current.

Drawing a balance sheet with reference to the above, it is possible to reach the following conclusions.

1. The presence of dipole geomagnetic field distortion by the ring current's field of trapped radiation belt may result in the appearance of a minimum in the distribution of charged particles of the magnetospheric plasma and of a minimum in the field of Alfvén velocities V_A. The indicated minimum is located in the central region of the radiation belt.

2. The peculiarity of V_A distribution in the magnetosphere results in the change in the conditions of magnetohydrodynamic wave propagation, which may assume an essential significance when considering the question of generation of geomagnetic pulsations.

3. There is observed in the distribution of V_A field an advance of Alfvén wave, propagating along the field line closest to Earth, relative to the Alfvén wave propagating along the remote field line; a similar outstripping effect is observed at whistler propagation, which is similar to Carpenter's results in his observations of whistlers in the "knee" region.

4. The obtained peculiarities in the distribution of the field of Alfvén wave velocities and in the propagation of whistlers have a similar character with analogous singularities of the field and whistlers, stemming from the assumption of the presence of a "knee" in the density of the magnetospheric plasma. This allows us to assume that the existence of geomagnetic field depression is possible in the region of the "knee".

Obviously, when computing plasma concentration in the magnetosphere, one must necessarily take into account the influence of electric currents flowing inside the Earth's magnetosphere.

***** THE END *****

Manuscript received on
20 September 1967

Contract No.NAS-5-12487
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Translated by ANDRE L. BRICHANT

on 28 August 1968

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