Anticipatory Simulation of Charged Particle Flows in Electric and Magnetic Fields. Image Method for Anticipatory Modeling Disturbances due to Bodies in Motion Through a Magnetoplasma.

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Abstract
The time-dependent anticipatory simulations of charged particle flows and disturbances due to bodies in motion through magnetoplasma are discussed. The flows and disturbances are described on the basis of the Boltzmann equation. The equation is solved analytically in different specific cases taking into account the ambient electric and magnetic fields. The particle flows are evaluated on the basis of the obtained solutions. The distributions of mean densities and pressures of the flows are calculated in 3D space, the corresponding iso-surfaces are plotted. The time-dependent stratifications are described analytically for the charged particle flows across the ambient magnetic field. Developing flute structures are described analytically for the flows along the ambient magnetic fields.
Anticipatory disturbances of charged particle flows due to the ambient flow interactions with bodies are simulated taking into account the ambient magnetic field effect. Effects of interactions between solid surfaces and charged particle flows have been simulated using the original image method (M.Ponomarjov, Planet. Space Sci., 43, 1419-1427, 1995; Physical Review E, 54, 5591-5598, 1996). The flow disturbances are described by the Boltzmann equation. In the case of the homogeneous ambient magnetic field the Boltzmann equation is solved analytically.
Different specific cases of the particle interactions with solid surfaces are considered in detail. These cases are: (i) absorbing, (ii) direct reflection and (iii) diffuse reflection of the particles impinging the solid surfaces. The disturbances of mean densities and pressures of the flows are calculated in 3D space, the corresponding iso-surfaces are plotted. The time-dependent stratifications of the disturbed flows are obtained analytically for the solid surface in motion across the ambient magnetic field. Developing flute structures of the disturbed flows is predicted analytically for the solid surface in motion along the ambient magnetic fields.

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1. Introduction

This paper is concerned with the method, which allows describing numerically and analytically the most famous structures in the non-equilibrium ionosphere and Space. Some of these structures are as follows: stratified and yacht sail like structures, flute jets, wakes and clouds. These problems are of practical interest in the space sciences, astrophysics and in the turbulence theory, also have some fundamental interest in their own right, as they enable one to concentrate on the effects of the ambient electric and magnetic fields.

The time-dependent anticipatory simulations of charged particle flows and disturbances due to bodies in motion through magnetoplasma are discussed. The flows and disturbances are described on the basis of the Boltzmann equation. The equation is solved analytically in different specific cases taking into account the ambient electric and magnetic fields. The particle flows are evaluated on the basis of the obtained solutions. The distributions of mean densities and pressures of the flows are calculated in 3D space, the corresponding iso-surfaces are plotted. The time-dependent stratifications are predicted analytically for the charged particle flows across the ambient magnetic field. Developing flute structures is obtained analytically for the flows along the ambient magnetic fields.

Anticipatory disturbances of charged particle flows due to the ambient flow interactions with bodies are simulated taking into account the ambient magnetic field effect. The effects of interactions between solid surfaces and charged particle flows have been simulated using the original image method (Ponomarjov, 1995, 1996). The flow disturbances are described by the Boltzmann equation. In the case of the ambient homogeneous magnetic field the Boltzmann equation is solved analytically. Different specific cases of the particle interactions with solid surfaces are considered in detail. These cases are: (i) absorbing, (ii) direct reflection and (iii) diffuse reflection of the particles impinging the solid surfaces. The disturbances of mean densities and pressures of the flows are calculated in 3D space, the corresponding iso-surfaces are plotted. The time-dependent stratifications of the disturbed flows are predicted analytically for the solid surface in motion across the ambient magnetic field. Developing flute structures of the disturbed flows is described analytically for the solid surface in motion along the ambient magnetic fields.

The contours of constant particle concentration (i.e. isodensity contours) are plotted using the computer simulation and modern software (Mathematica 3.0). These contours show the dynamics of developing stratifications and flute structures in charged particle jets and wakes under the ambient magnetic field effect.

The results are of great interest for general public too. This interest is because of the outlined method and its first results, which allow prediction, explanation and evaluation for observed structures in the atmosphere and Space. Some of these structures are as follows: silvery clouds, wakes of different objects and Undefined Flow Objects (UFO), Heliosphere and Heliopause.

The basic goal of this paper is to attract the organizations and specialists in related fields to the method and the possibility of its adaptation and development for the simulation of turbulence, plasma jets, wakes and clouds in the ionosphere and Space under effects of electric and magnetic fields.

2. Anticipatory Simulation of Charged Particle Flows

The basic unknown in an anticipatory (kinetic) description of a plasma is the charged particle velocity distribution $F_\alpha(\vec{r},\vec{v},t)$ (of plasma species α), giving the anticipatory number density of the spice at position $\vec{r}$ and time t, per unit volume in physical and velocity space. This function is governed by Boltzmann equation

$$\frac{\partial F_\alpha}{\partial t} + \vec{v}\,\frac{\partial F_\alpha}{\partial \vec{r}} + \frac{q_\alpha}{m_\alpha}([\vec{v},\vec{B}] + \vec{E})\frac{\partial F_\alpha}{\partial \vec{v}} = Q(\vec{r},\vec{v},t) + \sum_\beta C_{\alpha\beta}(F_\alpha, F_\beta) \qquad (1.1)$$

which is valid for each of the plasma components indicated by the α index,

q_α is the electric charge of the α-particles, m_α the α-particle mass, $\vec{B}$ the magnetic field induction, $\vec{E}$ the electric field strength. The last term in the Boltzmann equation refers to particle collisions, $Q_\alpha(\vec{r},\vec{v},t)$ is intensity of α-particle sources. In general, $\vec{E}$, $\vec{B}$ and $F_\alpha(\vec{r},\vec{v},t)$ are related by the Maxwell's equations with appropriate boundary conditions. Due to the complexity of all these correlated equations, it is nearly impossible to obtain their solutions in general case. So, different simplifications have been made in the definition of existing theoretical models. Rokhlenko (1991) investigated spatially homogeneous stationary solutions of the Boltzmann equation describing the electron component of a gas plasma in a homogeneous electric field. Ion distribution function in a weakly collisional sheath is obtained analytically for different electric field configurations by Hamaguchi et al. (1991). In both these papers the effects of ambient magnetic field are disregarded. However, there are many interesting cases where the magnetic field effects are dominated (see, for instance, Greaves et al. (1990)). In the present work we are specifically concerned with the time dependent processes in a low-density plasma with emphasis on the ambient magnetic field effects.

This paper extends the previous results of Ponomarjov and Gunko (1995), where the special cases of emission and charged particle cloud expansion have been considered in the ambient electric and magnetic fields.
According to the image method, the problem of flow simulation is concerned with modelling wakes of bodies in motion through ambient media.

3. Anticipatory Dynamics of Wakes

Any relative motion between a solid surface and its ambient plasma results in a complex interaction that modifies both the electrodynamic characteristics of the surface and the flow field of the plasma. A set of processes that need to be considered in a complete description of the plasma-surface interactions includes the effects of differential charging, the ambient magnetic field, ion shock wave disturbances ahead of the surface, charged particle missions from the surface (and photoemission) and neutral particle emission and subsequent ionization.

Due to the complexity of all these correlated effects, their theoretical models must involve considerable simplifications. Three basic simplifications have been made in the definition of the existing theoretical models for bodies moving through a thin plasma (see also Al'pert et al (1964); Gurevich et al.(1969); Senbetu and Henley (1989); Samir et al.(1989)):

(1) In the case of the very small size of the Debye length compared to the body radius, the quasi-neutral condition of equal local density for ions and electrons in the plasma is assumed to be valid;

(2) If the object velocity is much greater than the average thermal velocity of the ions, a common practice is to neglect ion thermal motion and to replace the unknown ion distribution function in front of the object by a beam moving in a straight line with the constant object velocity;

(3) It has been suggested that plasma expansion processes may have a direct relation to the problem of the flow of a rarefied plasma past a rapidly moving object.

When considering magnetoplasma disturbances due to object motion, in general four flow regions should be separated: the far and near regions on the upstream side of the body, the near and far regions downstream of the body. In the near regions, which includes boundary sheath, the effects of self-consistent fields are important rather than the ambient magnetic field effects. In the far regions (i.e. at distances from the surface which are of order or more than $2\pi V/\omega$, where V is a plasma drifting velocity, ω - the gyrofrequency) the ambient magnetic field effects become important. Usually the near regions have been considered in the self-consistent electric field. Magnetic field effects are disregarded. It is impossible, however, to overlook these effects for the far regions. The present work devoted to analytic and numerical description of the ambient magnetic field effects on the dynamics of disturbances due to motion of diffuse reflecting bodies in the far regions. The more simple cases of absorption and the direct reflection of any particle impinging on the body surface have been considered in the previous author's papers (Ponomarjov,1995, 1996).

So in the present work, we are specifically concerned with the low-density charged-particle fluxes, for which a kinetic, rather than fluid description is appropriate. We consider charged-particle fluxes whose currents are so small that the flux-generated magnetic field is very small compared to the ambient field. Further, we also assume that effects of any polarization electric fields present in the far regions are very small compared to the ambient field effects on the charged-particle motion. It should be noted that these conditions are also satisfied if $V/\omega_{pi} >> \rho_i$, where V is a plasma drifting velocity, ω_{pi} the ion plasma frequency, ρ_i the ion gyroradius. The above-outlined condition is known as the condition of a tenuous plasma (Koga et al.,1989; Chrien et al.,1986).

So, according to our model, the collisionless ionospheric and space plasma is described in phase space by the collisionless Boltzmann equation

$$\frac{\partial F_i}{\partial t} + \vec{v}\frac{\partial F_i}{\partial \vec{r}} + \frac{q_i}{m_i}\left(\frac{1}{c}[\vec{v},\vec{H}] + \vec{E}\right)\frac{\partial F_\alpha}{\partial \vec{v}} = 0 \qquad (1.2)$$

which is valid for each of the plasma components indicated by the i index,

$F_i(\vec{r},\vec{v},t)$ is the distribution function of plasma species i,

q_i the electric charge of the i-particles, m_i the i-particle mass, $\vec{H}$ the magnetic field strength, $\vec{E}$ the electric field strength.

To solve the above equation, it is necessary to specify the appropriate boundary conditions for $F_i(\vec{r},\vec{v},t)$. At distances far from the object the plasma will be considered undisturbed and in a state of thermodynamic equilibrium, so that at great distances from the object surface

$$F_i\Big|_{|\vec{r}|\to+\infty} \to N\left(\frac{\beta_i}{\pi}\right)^{3/2}\exp(-\beta_i(\vec{v})^2) \qquad (1.3)$$

where $\vec{v}$ is a velocity of a particle with reference to the coordinate system at rest. It should be noted that the symbol $|\vec{r}| \to +\infty$ denotes the distances from the object surface those are greater than the object sizes and these distances are small compared to the mean free paths of the corresponding particles in the ambient plasma. The boundary condition at the object surface depends on complex interactions of particles with surface materials. In fact, these interactions include a number of complex effects such as reflection, secondary particle emission, photoemission and absorption. So that, in general the boundary condition at the object surface S ($\vec{r} \in S, \vec{n} \cdot \vec{u} > 0$) is as follows:

$$(\vec{n} \cdot \vec{u}) F_i(\vec{r}, \vec{u}, t) = - \int_{\vec{n} \cdot \vec{u}_1 < 0} \sum_k w_k^i(\vec{u}, \vec{u}_1, \vec{r}, t)(\vec{n} \cdot \vec{u}_1) F_k^f(\vec{r}, \vec{u}_1, t) \, d\vec{u}_1 \qquad (1.4)$$

where $\vec{u}$, $\vec{u}_1$ are the velocities of particles with reference to the coordinate system in which the moving object is at rest, $\vec{n}$ is the outside normal to the object surface S at the point $\vec{r}$, $w_k^i(\vec{u}, \vec{u}_1, \vec{r}, t)$ the probability that the k-particle, impinging on the object surface S at the point $\vec{r}$ with the velocity $\vec{u}_1$, will produce the i-particle emitting from the S at the $\vec{r}$ with the velocity $\vec{u}$ at time t. Usually it is supposed that reflected particles are divided into two parts: $1 - \alpha_\tau$ part of particles is directly reflected and the

α_T part of particles is diffuse reflected by the body surface (see Cercignani, 1969; Kogan, 1967). So, the distribution of particles near reflecting surface is as follows:

$$F_i^r(\vec{r}, \vec{u}, t) = (1 - \alpha_\tau) F_i^f(\vec{r}, \vec{u} - 2(\vec{n} \cdot \vec{u})\vec{n}, t)$$

$$+\alpha_\tau n_r \left(\frac{\beta_r}{\pi}\right)^{3/2} \exp\left(-\beta_r (\vec{u})^2\right) \qquad (1.5)$$

where $\beta_r = \dfrac{m}{2kT_r}$, the r indexes denote parameters of reflected particles near the body surface, and the f indexes denote parameters of particles impinging on the surface. Taking into account the equality of impinged and reflected particles we have for the probability in eq.(3) $w_k^i = 0$ if $i \neq k$ and

$$w_i^i(\vec{u}, \vec{u}_1, \vec{r}, t) = -(1 - \alpha_\tau)\delta\{\vec{u}_1 - \vec{u} + 2(\vec{u} \cdot \vec{n})\vec{n}\}$$

$$\times \frac{(\vec{u} \cdot \vec{n})}{(\vec{u}_1 \cdot \vec{n})} + \alpha_\tau n_r \left(\frac{\beta_r^2}{\pi}\right) \exp\left(-\beta_r (\vec{u})^2\right)(\vec{u} \cdot \vec{n}) \qquad (1.6)$$

where α_T is the accommodation factor of the tangent momentum. It should be noted that α_T =0 for the direct reflection of any particle impinging on the surface. In the case of α_T =1 the eqs. 1.4 - 1.6 describe the diffuse reflection of any particle hitting the object surface. The cases of direct reflection and absorption are considered in detail in the previous author's papers (Ponomarjov 1995, 1996). The present paper is concerned with the simulation of charged particle disturbances due to the motion of diffuse reflecting objects through a magnetoplasma. So below we have $\alpha_T = 1$, i.e. we will consider the following distribution of reflected particles near surface

$$F^r(\vec{r},\vec{u},t) = n_r\left(\frac{\beta_r}{\pi}\right)^{3/2} \exp\left(-\beta_r(\vec{u})^2\right) \tag{1.7}$$

According to the imaginary emission method (Ponomarjov 1995, 1996),we must introduce the following imaginary and additional sources for the simulation of disturbances of one plasma spice by small plate dS:

$$Q_i^{im} + Q_i^{w} = Q_i^{im+} + Q_i^{im-} + Q_i^{w+} + Q_i^{w-} \tag{1.8}$$

where

$$Q_i^{im+} + Q_i^{w+} = \delta\{\vec{r} - \vec{r}_S\} \times$$

$$\left[\begin{array}{ll} \displaystyle\int_{\vec{n}\cdot\vec{u}_1<0} \sum_k w_k^i(\vec{u},\vec{u}_1,\vec{r},t)(\vec{n}\cdot\vec{u}_1)F_k^f(\vec{r},\vec{u}_1,t)d\vec{u}_1 & \text{if} \quad (\vec{n}\cdot\vec{u})>0 \\ -(\vec{n}\cdot\vec{u})F_i^f(\vec{r},\vec{u},t) & \text{if} \quad (\vec{n}\cdot\vec{u})<0 \end{array}\right.$$

$$Q_i^{im-} + Q_i^{w-} = \delta\{\vec{r} - \vec{r}_S\} \times$$

$$\left[\begin{array}{ll} \displaystyle -\int_{\vec{n}\cdot\vec{u}_1<0} \sum_k w_k^i(\vec{u},\vec{u}_1,\vec{r},t)(\vec{n}\cdot\vec{u}_1)F_k^f(\vec{r},\vec{u}_1,t)d\vec{u}_1 & \text{if} \quad (\vec{n}\cdot\vec{u})<0 \\ (\vec{n}\cdot\vec{u})F_i^f(\vec{r},\vec{u},t) & \text{if} \quad (\vec{n}\cdot\vec{u})>0 \end{array}\right.$$

$\vec{r}_S$ is the center of small plate dS. So, the problem of solving eq.1.1 with the boundary conditions eqs.1.3 and 1.4 is reduced to the treatment of the following equation:

$$\frac{\partial F_i^{imw}}{\partial t} + \vec{v}\,\frac{\partial F_i^{imw}}{\partial \vec{r}} + \frac{q_i}{m_i}\left(\frac{1}{c}[\vec{v},\vec{H}] + \vec{E}\right)\frac{\partial F_i^{imw}}{\partial \vec{v}} = Q_i^{im} + Q_i^{w} \tag{1.9}$$

It should be noted that for bodies with a boundary surface S we can introduce the following imaginary and additional sources:

$$Q_i^{imS} + Q_i^{wS} = \oint_S \left(Q_i^{im+} + Q_i^{w+}\right)dS \tag{1.10}$$

4. Small Diffuse Reflecting Plate

Below we consider disturbances of one spice of magnetoplasma due to motion of diffuse reflecting small plate. So, according to eqs. 1.7 and 1.8 we obtain for imaginary and additional sources

$$Q_i^{im+} + Q_i^{w+} = \delta\{\vec{r} - \vec{r}_S\} \times$$

$$\left[\begin{array}{ll} -(\vec{n}\cdot\vec{u})N_r^+\left(\frac{\beta}{\pi}\right)^{3/2} \exp\left(-\beta(\vec{u})^2\right) & \text{if } (\vec{n}\cdot\vec{u})>0 \\ -(\vec{n}\cdot\vec{u})F^f(\vec{r},\vec{u},t) & \text{if } (\vec{n}\cdot\vec{u})<0 \end{array}\right. \tag{1.11}$$

$$Q_i^{im-} + Q_i^{w-} = \delta\{\vec{r} - \vec{r}_S\} \times$$

$$\left[\begin{array}{ll} (\vec{n}\cdot\vec{u})N_r^+\left(\frac{\beta}{\pi}\right)^{3/2} \exp\left(-\beta(\vec{u})^2\right) & \text{if } (\vec{n}\cdot\vec{u})<0 \\ (\vec{n}\cdot\vec{u})F^f(\vec{r},\vec{u},t) & \text{if } (\vec{n}\cdot\vec{u})>0 \end{array}\right. \tag{1.12}$$

where $\vec{r}_S$ is the center of small plate dS.
Suppose the plate velocity V is well above the mean thermal velocity of charged particles then

$$F^f(\vec{r},\vec{u},t) = F|_{|\vec{r}|\to+\infty} = N(\tfrac{\beta}{\pi})^{3/2}\exp(-\beta(\vec{u}+\vec{V})^2) \tag{1.13}$$

Below we use the coordinate system OXYZ in which the plate moves with $\vec{V}$. So, according to eqs.1.11, 1.12 and 1.13, the imaginary and additional sources take the form

$$Q_i^{im+} + Q_i^{w+} = \delta\{\vec{r} - \vec{r}_S\} \times$$

$$\left[\begin{array}{ll} -(\vec{n}\cdot(\vec{v}-\vec{V}))N_r^-\left(\frac{\beta}{\pi}\right)^{3/2} \exp\left(-\beta(\vec{v}-\vec{V})^2\right) & \text{if } (\vec{n}\cdot(\vec{v}-\vec{V}))>0 \\ -(\vec{n}\cdot(\vec{v}-\vec{V}))N^-\left(\frac{\beta}{\pi}\right)^{3/2} \exp\left(-\beta(\vec{v})^2\right) & \text{if } (\vec{n}\cdot(\vec{v}-\vec{V}))<0 \end{array}\right.$$

$$Q_i^{im-} + Q_i^{w-} = \delta\{\vec{r} - \vec{r}_S\} \times$$

$$\left[\begin{array}{ll} (\vec{n}\cdot(\vec{v}-\vec{V}))N_r^-\left(\frac{\beta}{\pi}\right)^{3/2} \exp\left(-\beta(\vec{v}-\vec{V})^2\right) & \text{if } (\vec{n}\cdot(\vec{v}-\vec{V}))<0 \\ (\vec{n}\cdot(\vec{v}-\vec{V}))N^-\left(\frac{\beta}{\pi}\right)^{3/2} \exp\left(-\beta(\vec{v})^2\right) & \text{if } (\vec{n}\cdot(\vec{v}-\vec{V}))>0 \end{array}\right. \tag{1.14}$$

where $\vec{v}$ is a velocity with respect to the OXYZ. Taking into account eqs.1.7 and 1.13, the equality of impinged and reflected particles we obtain

$$N_r^+ = N\left(\exp\{-\beta V_1^2\} + V_1\sqrt{\beta\pi}\left(1 + erf\{V_1\sqrt{\beta}\}\right)\right) \tag{1.15}$$

$$N_r^- = N\left(\exp\{-\beta V_1^2\} + V_1\sqrt{\beta\pi}\left(1 - erf\{V_1\sqrt{\beta}\}\right)\right) \quad (1.16)$$

where N is the concentration of particles in the undisturbed plasma.
According to eqs.1.15 and 1.16, there are two limiting cases in which the expressions for N_r take the simplest forms. The first one is the case when $\beta V_1^2 >> 1$ (i.e. the plate velocity directed along the normal is well above the mean thermal velocity of particles). In this case

$$N_r^+ \approx 2NV_1\sqrt{\beta\pi} \qquad N_r^- \approx 2N\exp(-\beta V_1^2)$$

If there is no motion of the plate along its normal (V_1=0), we obtain $N_r^+ = N_r^- = N$. So eqs.1.14 allow to simulate disturbances of collisionless magnetoplasma due to motion of differently shaped bodies with diffuse reflection of particles by the surfaces of this bodies. As examples of this approach, below the disturbances of charged particle concentration are calculated for small plate in motion at different angles to the ambient magnetic field.

Further in all specific cases of this report we consider flows and wakes in the satellite altitude regime (above 150 km) where the faster ionosphere electrons are compensating for the electric field due to the emitted positive ions. The density of the emitted ions is equal or less than the ionosphere ion density. The density of the emitted ions changes slowly enough in a time that is equal to the plasma period of the ambient plasma electrons. The velocities squared of sources and bodies are significantly more than the mean thermal velocity squared of the ambient ions ($\approx 10^3$ m/s) and significantly less than the mean thermal velocity squared of the ambient electrons ($\approx 10^5$ m/s).

5. Disturbances of Charged-Particle Concentration

We use a Cartesian coordinate system OXYZ with the OX--axis directed parallel to the homogeneous magnetic field $\vec{H}$. The velocity of the small plate dS with the normal $\vec{n} = (n_1, n_2, n_3)$, $\vec{V} = (V_1, V_2, V_3)$. Let $\vec{r}_S$ be the radius vector of the center of the small plate dS, and $\vec{r}_S = \vec{V}t$, i.e. at times (0, τ) the small plate dS moves from the point (0,0,0) to the point ($V_1\tau, V_2\tau$, $V_3\tau$). Then for the disturbance of the charged-particle concentration by the unit of area of the diffuse reflecting small plate dS, we have

$$\delta n = n^w - n^{im}$$

where n^w and n^{im} are the concentrations as results of the emissions from the additional and image sources from eqs.1.14. These concentrations are calculated as appropriate moments of the corresponding distribution functions in quadratures. For velocities squared of plates are significantly more than the mean thermal velocity squared of the ambient ions ($\approx 10^3$ m/s) asymptotic expressions are obtained for some of these quadratures. As results of numerical and asymptotic calculations according to the obtained expressions in different special cases the cross-sections of isodensity contours (at the plane Z=0) are plotted for different times t (Figs.1-21). At these Figs. the diffuse reflecting small plate moves along its normal, the OX-axis (horizontal direction from left to right) and the ambient magnetic field from the point $x=5\pi/24 \approx 0.2\pi$ to the point $x=2005\pi/24 \approx 83.54\pi$. The plate trajectory (and the OX-axis) is the unique symmetry axis of the all cross-sections here. The plate is located at the intersection of the most bright region with the most high concentrations (closely ahead the plate) and the most dark region with the most low concentrations (closely behind the plate). The plate velocity V is ten times greater than the mean thermal velocity of particles (i.e. $\beta V=10$). The more bright contours correspond to the higher concentrations. The more dark contours show the lower particle concentrations.

One can see, firstly, the long unstable periodical flute structures of rarefaction regions behind the plate. These structures are very similar to the structures which are described behind perfectly absorbing and directly reflecting plates (Ponomarjov, 1995, 1996). The structures move with the plate as its wake. The space period of these structures (the longitude along the OX-axis) is the way of the plate during the time of the gyro-period of ions in the ambient magnetic field (s=VT).

Secondly, the pulsed higher density region can be observed ahead the plate. The time-period of pulsations of the region is the gyro-period of ions in the ambient magnetic field. It should be noted that the significantly shorter length (along the ambient magnetic field) of this region is obtained when compared with that for the directly reflected plate (Ponomarjov, 1996).

6. Summary and conditions for considered specific cases

It has been discussed the method, which allows to describe numerically and analytically the most famous structures in the non-equilibrium ionosphere and Space (stratified and yacht sail like structures, flute jets, wakes and clouds). The method based on the kinetic Boltzmann equation solution for appropriate boundary and initial conditions. The Boltzmann equation is solved analytically for the following specific cases:

(i) charged particle sources in the ambient magnetic field. The analytical results are obtained, which describe developing magnetic field aligned stratifications of charged particle jets. For magnetic field aligned drifting velocity of jets, formation of flute structures along the edges of the jets is obtained analytically.

(ii) disturbances in the ambient plasma due to motion of bodies at different angles to the ambient magnetic field. Different kinds of interactions of the ambient particles with object surfaces are considered as absorption, direct and diffuse reflection. The analytical results describe the flute structures of wakes of objects in motion along the magnetic field and stratifications of wakes in different cases.

For considered specific cases we are specifically concerned with the low-density charged-particle fluxes, for which a kinetic, rather than fluid description is appropriate.

We consider charged-particle fluxes whose currents are so small that the flux-generated magnetic field is very small compared to the ambient field. Further, we also assume that effects of any polarization electric fields present in the far regions are very small compared to the ambient field effects on the charged-particle motion. It should be noted that these conditions are also satisfied if $V/\omega_{pi} >> \rho_i$, where V is a plasma drifting velocity, ω_{pi} the ion plasma frequency, ρ_i the ion gyroradius. The above-outlined condition is known as the condition of a tenuous plasma (Koga et al.,1989; Chrien et al.,1986).
Further in all specific cases of this report we consider flows and wakes in the satellite altitude regime (f.i. it is actual above 200km from Earth) where the faster ionosphere electrons are compensating for the electric field due to the emitted positive ions. The density of the emitted ions is equal or less than the ionosphere ion density. The density of the emitted ions changes slowly enough in a time that is equal to the plasma period of the ambient plasma electrons. The velocities squared of sources and bodies are significantly more than the mean thermal velocity squared of the ambient ions ($\approx 10^3$ m/s) and significantly less than the mean thermal velocity squared of the ambient electrons ($\approx 10^5$ m/s). Namely, the basic conditions which are correspond to the specific cases are as follows: the concentrations of ambient neutral particles and electrons are $<10^{10}$ and $<10^6$ per cm^3 (respectively), T>500K, the ambient magnetic field strength H ~ 0.5 Oe = 40 A/m, the mean molecular weight of ions M~20-1 atomic mass unit, the mean free paths of electrons, ions and neutral particles are 10^2 m or more, the frequencies of collisions between: electrons, ions and neutral particles ~ 10^3 sec^{-1} or less; between ions ~10^2 sec^{-1} or less; between neutral particles ~10 sec^{-1} or less; the mean thermal speeds of: ions and neutral particles ~ 10^3 m/s, electrons ~ 10^5 m/s. The plasma frequency is 10^7 - 10^8 sec^{-1}, the Debay radius ~ 10^{-3} - 10^{-2} m, the Larmor frequency and radius of electrons are ~ 10^7 sec^{-1} and ~ 10^{-2} m (respectively). The Larmor frequency and radius of ions are ~ 10^2 sec^{-1} and ~ 1-10 m (respectively).

7. Proposed Future Research

1. As developing the methods, the disturbances in ionosphere and Space could be simulated for Comets, Asteroids and their impacts upon the Earth. (Yeomans, 1998)
2. It can be possible to apply the method and first results to the simulation of spacecraft dynamics and disturbances due to its motion through ionosphere and Space taking into account the ambient magnetic fields.
3. For future it can be proposed to simulate the wakes in transitional regimes (from collisionless to MHD) and to generalize the image method for these regimes. Besides there are a number of applications for presented method and first results: simulations of dynamics, pressures and wakes for different 2D-3D bodies as well in unsteady flows, magnetic control of wakes.
4. As the next step, the Solar Wind flows can be simulated using the considered method. The Sun can be introduced to the Boltzmann equation as point-like source because of great distances from the Sun (150 astronomical units) which are

considered. The Wind supersonic flow interactions with the supersonic fluxes of the Interstellar Medium will be included as collisions of the Wind electrons with particles of the Interstellar Medium (Baranov et al., 1971).

The basic goal of this paper is to attract the organizations and specialists in related fields to the method and the possibility of its adaptation and development for widely related topics. So, proposals for collaborations are welcoming.

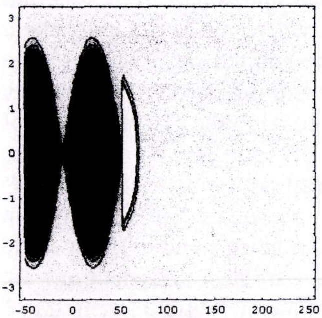

Fig.1. $t = \pi/48 + 5\pi/3$

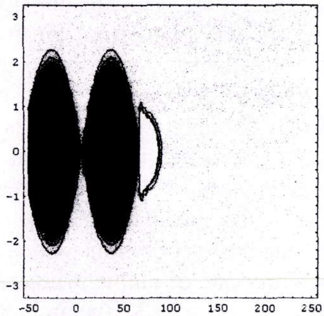

Fig.2. $t = \pi/48 + 13\pi/6$

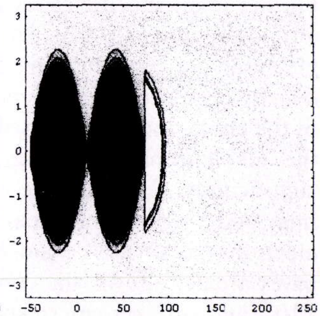

Fig.3. $t = \pi/48 + 7\pi/3$

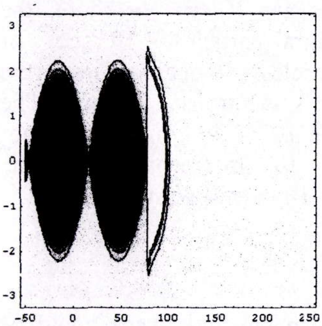

Fig.4. $t = \pi/48 + 15\pi/6$

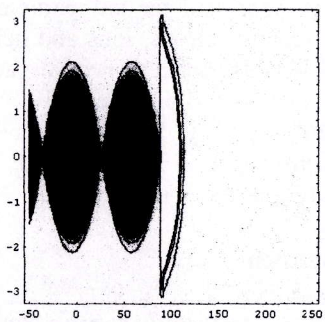

Fig.5. $t = \pi/48 + 17\pi/6$

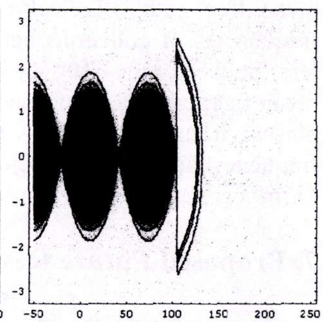

Fig.6. $t = \pi/48 + 10\pi/3$

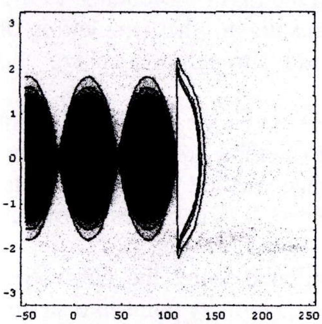

Fig.7. $t = \pi/48 + 7\pi/2$

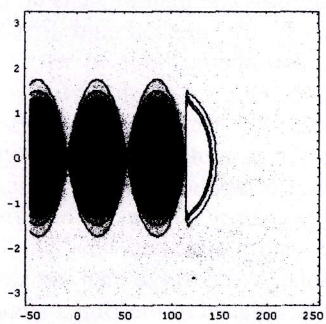

Fig.8. $t = \pi/48 + 11\pi/3$

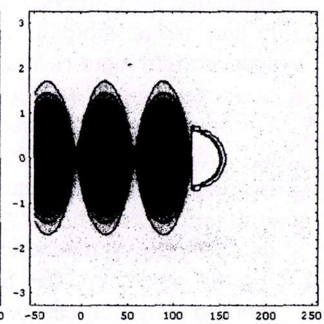

Fig.9. $t = \pi/48 + 23\pi/6$

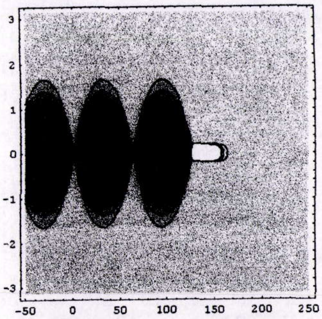

Fig.10. $t = \pi/48 + 4\pi$

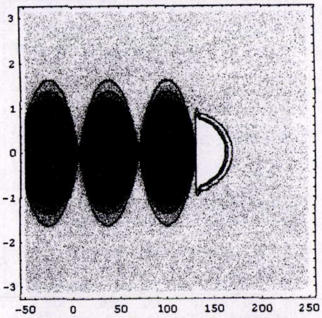

Fig.11. $t = \pi/48 + 25\pi/6$

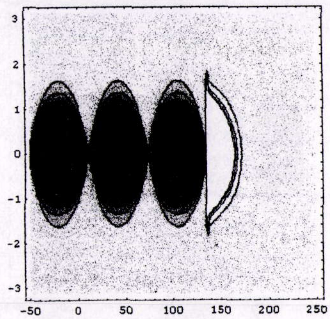

Fig.12 $t = \pi/48 + 13\pi/3$

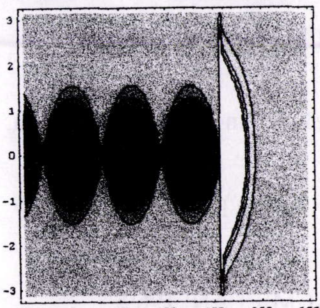

Fig.13 $t = \pi/48 + 5\pi$

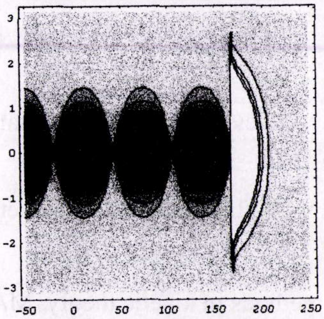

Fig.14 $t = \pi/48 + 16\pi/3$

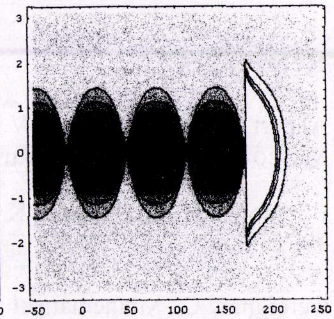

Fig.15. $t = \pi/48 + 11\pi/2$

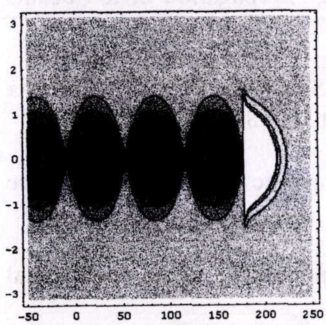

Fig.16. $t = \pi/48 + 17\pi/3$

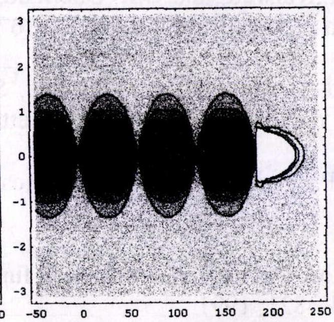

Fig.17 $t = \pi/48 + 35\pi/6$

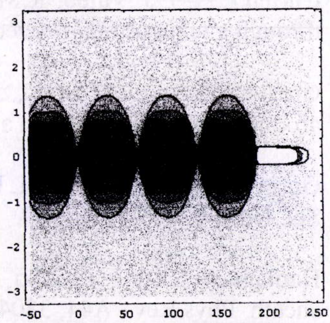

Fig.18 $t = \pi/48 + 6\pi$

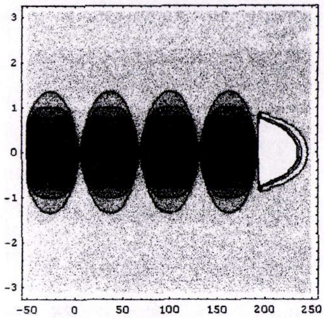

Fig.19. $t = \pi/48 + 37\pi/6$

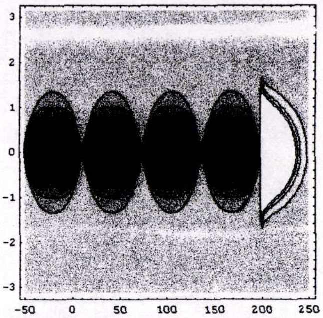

Fig.20. $t = \pi/48 + 19\pi/3$

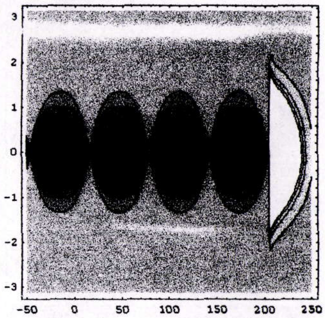

Fig.21. $t = \pi/48 + 39\pi/6$

References

Al'pert,Ya.L., Gurevich,A.V., Pitaevsky,L.P.,Artifical satellites in a rarefied plasma, Moscow, Nauka, 1964 (in Russian).

Baranov V.B., Krasnobaev K.V., Kulikovskiy A.G., Soviet Physics Doklady, v.15, No9, 1971

Cercignani,C., Mathematical methods in kinetic theory, MACMILLAN, 1969.

Chrien,E.F., E.J.,Valeo, R.M.,Kulsrud, and C.R.,Oberman, Propagation of ion beams through a tenuous magnetized plasma, Phys. Fluids, 29, 1675-1681, 1986.

Greaves R.G., D.A. Boyd, J.A. Antoniades, R.F. Ellis, Steady-state toroidal plasma around a spherical anode in a magnetic field, Phys.Rev.Lett., 64, 886-889, 1990.

Gurevich,A.V., Pitaevsky,L.P., and Smirnova,V.V., Ionospheric aerodynamics, Space Sci. Rev., 9, 805-871, 1969.

Hamaguchi S., R.T. Farauki, M. Dalvie, Ion distribution function in a weakly collisional sheath, Phys.Rev., A44, 3804-3821, 1991.

Koga,J., J.L.,Geary, T.,Fujinami, B.S.,Newberger, T.,Tajima, and N.,Rostoker, Numerical investigation of a plasma beam entering transverse magnetic fields, J. Plasma Phys., 42, 91-110, 1989.

Kogan,M.N., Rarefied gas dynamics, Moscow, Nauka, 1967 (in Russian).

Ponomarjov,M.G., Disturbances of the ambient magnetoplasma due to interactions with object surfaces. Imaginary emission method. Far-wake of objects moving through a rarefied plasma at different angles to the ambient magnetic field, Planet. Space Sci., 43, No 10/11, 1419-1427, 1995.

Ponomarjov,M.G., Imaginary-emission method for modeling disturbances of all magnetoplasma species: Reflecting and absorbing objects in motion through a rarefied plasma at different angles to the ambient magnetic field, Physical Review E, 54, No 1, 5591-5598, 1996.

Ponomarjov M.G. and Gunko Yu.F., Kinetic modelling of charged particle cloud expansion and emission in magnetic and electric fields, Planet.Space Sci., 43, No 10/11, 1409-1418, 1995.

Rokhlenko A.V., Electron component of a plasma in a homogeneous electric field, Phys.Rev., A43, 4438-4451, 1991.

Samir,U., R.H.,Comfort, N.,Singh, K.S.,Hwang, and N.H.,Stone, Insight into theory-experiment comparisons of wake measurements in the plasmasphere, Planet. Space Sci., 37, 873-880, 1989.

Senbetu,L., and J.R.,Henley, Distribution of plasma density and potential around a mesothermal ionospheric object, J. geophys. Res.(A), 94, 5441-5448, 1989.

Yeomans D.K., The Impact of Comets and Asteroids Upon the Earth, Bulletin of the American Astronomical Society, 30, No3, 1038, 1998