Canadian Journal of Pure and Applied Sciences
Vol. 17, No. 3, pp. 5783-5787, October 2023
Online ISSN: 1920-3853; Print ISSN: 1715-9997
Available online at www.cjpas.net

THE NATURE OF THE CORIOLIS FORCE AND FLYBY ANOMALY

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ABSTRACT

The existing idea about the nature of the Coriolis force and centrifugal force raises many perplexing questions. The article proves that these forces can be justified as a consequence of Maxwell's equations for gravitomagnetism. Further, it is shown that the flyby anomaly is a consequence of the influence of the Coriolis forces, and the method for calculating this influence is indicated.

Keywords: Equations of Maxwell, centrifugal forces, Coriolis forces, gravitomagnetism, numerical model.

INTRODUCTION

Modern ideas about the Coriolis force (Wikipedia, https://ru.wikipedia.org/wiki/Сила_Кориолиса, in Russian) are as follows:

• The Coriolis force is in no way associated with any interaction of the body in question with other bodies;

• The Coriolis force is not physical strength and does not do work.

Roughly speaking, the Coriolis force acting on a body appears because another body rotates at a certain speed **next** to this body. Such a representation is striking in its "nonphysicality". The author has already discussed this topic in (Khmelnik, 2022). For the first time, the proof of the reality of these forces was given by Khmelnik (2020). Here it is considered in more detail.

It is known that the Coriolis force acting on a body rotating with the angular speed $\overline{\omega}$ and moving with a velocity $\overline{v}$ is determined by the following formula:

$$\overline{F}_K = -2m(\overline{\omega} \times \overline{v}) \quad (1)$$

INTERACTION OF MOVING ELECTRIC CHARGES

Consider moving electric charges shown in Figure 1, where two charges q_1 and q_2 are shown at points A and B, moving at speeds v_1 and v_2, respectively. Let's assume that the quantity q_2 is the density of charges distributed uniformly on the entire horizontal plane, and the velocity v_2 is the velocity of the entire plane.

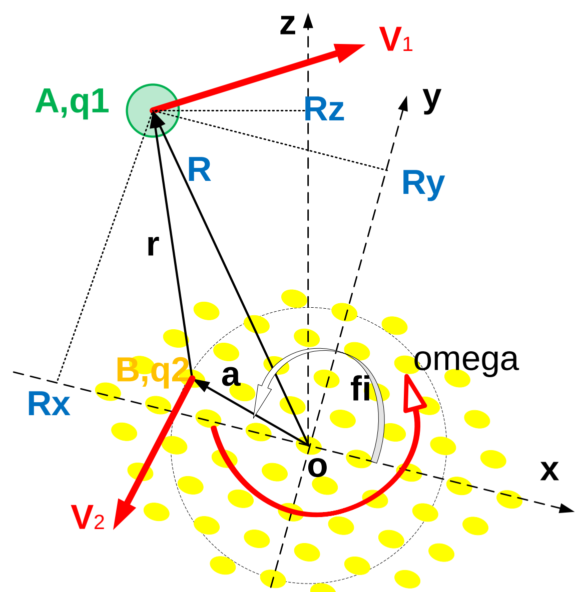

Fig. 1. The moving electric charges' configuration.

But first, consider the interaction of point charges. It is known (Zilberman, 1970) that the magnetic induction of the field created by the charge q_2 at the point where the charge q_1 is currently located is (hereinafter we use the SI system)

$$\overline{B} = \mu\, q_2(\overline{v_2} \times \overline{r})/r^3 \quad (2)$$

In this case, the vector $\overline{r}$ is directed from the point where the moving charge q_1 is located. The Lorentz force acting on the charge q_1 from the side of the charge q_2 is

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$$\overline{F_{12}} = q_1(\overline{v_1} \times \overline{B}) \quad (3)$$

or

$$\overline{F_{12}} = \mu\, q_1 q_2 (\overline{v_1} \times (\overline{v_2} \times \overline{r}))/(r^3) \quad (4)$$

Figure 1 also shows the vectors $\overline{a}$ and $\overline{R}$, with the vector $\overline{a}$ making the angle φ with the x-axis and

$$\overline{r} = \overline{R} - \overline{a} \quad (5)$$

First, we consider the case when all these vectors lie in the horizontal plane xoy, and we denote the projections of all the vectors by the subscript coordinate. Then the vector directed along the z-axis is:

$$\overline{w} = (\overline{v_2} \times \overline{r}) = \overline{z}(v_{2x} r_y - v_{2y} r_x) \quad (6)$$

where $\overline{z}$ is the unit vector of the vertical axis. Denote

$$w_z = (v_{2x} r_y - v_{2y} r_x) \quad (7)$$

Then

$$\overline{w} = \overline{z} w_z \quad (8)$$

Next, we consider several options for the interaction between the charge and the plane of charges (Table 1).

Interaction of a translationally moving charge with a rotating charged plane

If the plane rotates with the angular speed ω around the point O, then the charge q_2 also rotates around the point O with the angular speed ω. At the same time, this charge has the following velocity vector:

$$\overline{v_2} = \omega\overline{a}\exp\left(i\frac{\pi}{2}\right) = \omega\overline{a}\left(\cos\left(\varphi + \frac{\pi}{2}\right) + i\sin\left(\varphi + \frac{\pi}{2}\right)\right) \quad (9)$$

It is tangent to a circle with the radius a. With formulae (6) and (8), we find:

$$w_z = \omega a\left(\cos\left(\varphi + \frac{\pi}{2}\right) r_y - \sin\left(\varphi + \frac{\pi}{2}\right) r_x\right) \quad (10)$$

or

$$w_z = -\omega a(\sin(\varphi) r_y + \cos(\varphi) r_x) \quad (11)$$

Using expressions (3) and (5), we get:

$$\overline{F_{12}} = \mu q_1 q_2 (\overline{v_1} \times \overline{w})/(r^3) \quad (12)$$

or, taking into account formulas (7) and (10),

$$\overline{F_{12}} = \mu\, q_1 q_2 \omega \left(\overline{v_1} \times \overline{z}\frac{w_z}{\omega}\right)/(r^3) \quad (13)$$

Let's find the following force acting from the <u>entirely</u> charged and rotating plane on the charge q_1:

$$\overline{F} = \int_{\varphi,a} \overline{F_{12}}\, d\varphi da = \mu \int_{\varphi,a} \left(q_1 q_2 \omega \left(\overline{v_1} \times \overline{z}\frac{w_z}{\omega}\right)/(r^3)\right) d\varphi da$$

or

$$\overline{F} = \mu q_1 q_2 (\overline{v_1} \times \overline{\omega} W) \quad (14)$$

where

$$\overline{\omega} = \overline{z}\omega \quad (15)$$

$$W = \int_{\varphi,a} \frac{w_z/\omega}{r^3} d\varphi da \quad (16)$$

Exploiting formulas (15) and (10), we find:

$$W = -\int_0^\infty a \left(\int_0^{2\pi} (\sin(\varphi) r_y + \cos(\varphi) r_x) r^{-3}\, d\varphi\right) da \quad (17)$$

where r is determined by formula (4):

$$r_x = R_x - a\cos(\varphi), \qquad r_y = R_y - a\sin(\varphi) \quad (18)$$

$$a_x = a\cos(\varphi), \qquad a_y = a\sin(\varphi) \quad (19)$$

Integration according to these formulas gives a remarkable result: <u>the parameter W does not depend on R and, as the upper limit tends to $+\infty$, approaches the following value:</u>

$$W \approx -45 \quad (20)$$

<u>This means that the charge q_1 can be located at any height above the infinite plane of charges, q_2</u>. Taking into account the parameters in formula (19), formula (13) can be rewritten as follows:

$$\overline{F} = \mu q_1 q_2 W(\overline{v_1} \times \overline{\omega}) \quad (21)$$

One can notice an analogy between the formulas for force (21) and for the Coriolis force, which arises when a body moves with the velocity $\overline{v_1}$ in the field of the Earth, rotating with the angular speed $\overline{\omega}$.

Interaction of a moving and rotating electric charge with a stationary field of electric charges

Consider now the electric charge q_1, which rotates over the field of stationary electric charges and simultaneously moves forward with the speed $-\overline{v}_2$. This case is mathematically equivalent to the previous one and is also described by formula (21). In this case, one can notice an analogy between the formulas for force (21) and for the Coriolis force, which occurs when a body moves forward with the speed $-\overline{v}_2$, which simultaneously rotates with the angular velocity $\overline{\omega}$ over the stationary Earth (rotation speed of the Earth is much smaller than $\overline{\omega}$).

The interaction of a rotating electric charge with a motionless field of electric charges

We now consider the electric charge q_1 that rotates above the field of motionless electric charges. Coulomb forces from the side of a rotating charge should rotate the field of electric charges. In this case, the problem reduces to the previous one: Indeed, the charge q_1 moves above the rotating field of electric charges. For the identity of these problems, we must also assume that the field of charges does not have its own rotation or the speed of this rotation is significantly less than the speed of rotation of the charge q_1. Thus, in this case too, we can use formula (21). The linear velocity v_1 of the charge q_1 and its angular speed ω are related by the following formula:

$$v_1 = R\omega \tag{22}$$

where R is the radius of rotation of the charge q_1. Combining formulas (21) and (22), we find:

$$F = \mu q_1 q_2 W R \omega^2 \tag{23}$$

One can notice an analogy between the formulas for force (23) and for the centrifugal force.

MAXWELL'S EQUATIONS FOR GRAVITOMAGNETISM AND THE CORIOLIS FORCE

Khmelnik (2017) proposes a new solution of Maxwell's equations for gravitomagnetism, which is used to construct mathematical models of various natural phenomena (sand vortex, sea currents, whirlpool, funnel, water soliton, water and sand tsunami, turbulent flows, additional (non-Newtonian) interaction forces for celestial bodies). All of these models use the concept of mass currents as flows of particles of mass. The velocity of mass particles can be very small and often their flux can be invisible as well as the flux of electrons. However, the existence of these phenomena and the possibility of constructing the indicated mathematical models similar to mathematical models of direct current in electrodynamics (Khmelnik, 2021) confirm the assumption of the existence of mass currents and the interaction of mass particles, which is completely analogous to the interaction of electric charges.

Based on this, it can be assumed that the rotation of the body is accompanied by a mass current, similar to how the rotation of a charged body is accompanied by convection electric current. Eichenwald (1928) showed that such a current creates some magnetic induction. Based on the complete analogy between the Maxwell equations for electrodynamics and gravitomagnetism (Khmelnik, 2017), it can be argued that when the body rotates, gravitomagnetic induction is created. Some mass *m* moving in a gravimagnetic field at speed *v* is affected by the gravitomagnetic Lorentz force (an analog of the Lorentz magnetic force).

The Coriolis force for a body that moves above the rotating Earth

Consider row 3 in Table 1. Based on the foregoing, we rewrite formula (21) obtained above for the interaction of electric charges, as applied to the interaction of mass charges, as follows:

$$\overline{F} = Wpm(\overline{v} \times \overline{\omega}) \tag{24}$$

where

m and $\overline{v}$ are the mass and speed of a moving body,
$W \approx -45$,
p is the surface density of masses as elements of mass current,
$\overline{\omega}$ is the angular speed of rotation of the plane on which these elements are evenly distributed.

Comparing formulas (1) and (24), we find that

$$-2 = Wp \tag{25}$$

Whence it follows that the mass density is

$$p = -\frac{2}{W} \approx 0.044 \left[\frac{\text{kg}}{\text{m}^2}\right] = 4.4 \times 10^{-6} \left[\frac{\text{kg}}{\text{cm}^2}\right] \tag{26}$$

“Let me,” - the attentive reader will be surprised. “Does the reader reject the Coriolis theory and at the same time use its formula?” The author only joins in his surprise and be even more surprised that such different methods of reasoning led to the same formulaic result! Nevertheless, the conclusion of mass density (26) can be accepted only if there is a reliable **experimental** verification of the coefficient “2” in formula (1) of the Coriolis force.

The method used to derive the Coriolis force proves the reality, not the fictitiousness of this force and reveals the source of power for this force, namely the gravitational field of the Earth. Ermolin (2017) considered the influence of the Coriolis forces on the planets of the solar system. The effect of the Coriolis forces on the formation of ocean tides is also explained. The influence of the Coriolis forces on the position of the axes of rotation and planes of the orbits of any space objects, including the planets of the solar system, is established, with the simultaneous rotation of these objects around their own axis and around the center of rotation, which is typical for all planetary systems of the Universe. This serves as proof of the reality of the Coriolis forces (although the author does not note this).

The Coriolis force for a body that moves and rotates over the stationary Earth

Consider row 1 in Table 1. This case assumes that the Earth is stationary. In practice, this means that the speed of the Earth's rotation is negligible compared to the speed of the body. But for its description, the same formula (21) is used, which was used above in the previous subsection, i.e. the same formula (24) and the same constant *W*. This means that the body is affected by the Coriolis force, which depends only on the parameters of the movement of the body itself, however, the Coriolis force appears only due to the existence of the Earth next to the body! Further we will show that in deep Space this Coriolis force is absent! The source of power for this force is the gravitational field of the Earth.

Centrifugal force

Consider row 2 in Table 1. It is shown that the rotation of the charged plane under the moving charge can be replaced by the rotation of the charge above the charged plane. Then in formula (21), $\overline{\varpi}$ is the vector of the angular speed of the rotating charge, and the linear velocity of this charge is

$$v_1 = R\omega \tag{27}$$

When applying formula (23) to the interaction of mass charges, we obtain:

$$\bar{F} = Wpm\omega^2 R \tag{28}$$

This formula is different from the following formula for the centrifugal force only by a coefficient:

$$\bar{F}_C = m\omega^2 R \tag{29}$$

By analogy with the previous one, we find the following mass density:

$$p = -\frac{1}{W} \approx 0.022\ [\text{kg/m}^2] = 2.2 \times 10^{-6}\ [\text{kg/cm}^2] \tag{30}$$

Thus, the nature of the centrifugal force is the same as the nature of the Coriolis force, and the source of power for this force is the Earth's gravitational field. The difference between formulas (30) and (26) raises doubts about the correctness of the coefficient "2" in formula (1).

FLYING ANOMALY

It was proved above that formulas (20) and (21) are valid for an infinite plane of charges q_2 for any height of the body above the plane. Let us now consider the case when charges q_2 are uniformly distributed over the sphere (Fig. 2). In this case, to calculate the parameter *W* (calculated by formula (17)) it is necessary to calculate the integral over the surface of the selected part of the sphere, determined by the constants *D* and *R*. Obviously, such an integral will essentially depend on these constants, and as $R \to D$ increases, it will tend to be equal to zero.

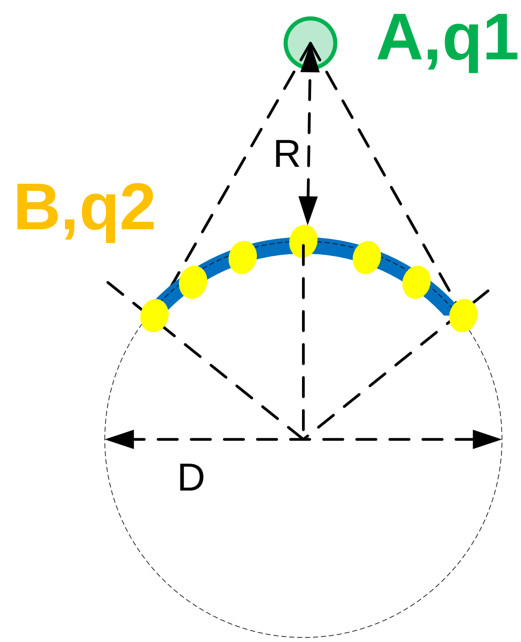

Fig. 2. The other configuration of the electric charges q_1 and q_2.

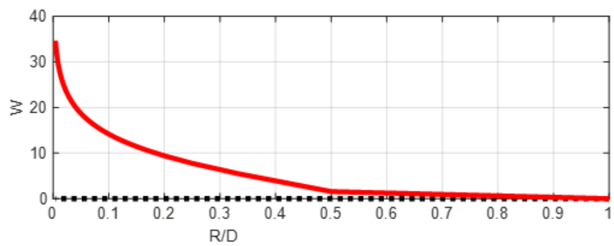

Fig. 3. The parameter *W* versus the ration *R*/*D*.

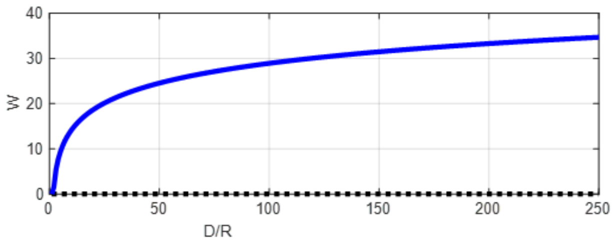

Fig. 4. The parameter *W* versus the ration *D*/*R*.

Figures 3 and 4 show the dependences of *W* on the ratio between the distance of the body to the sphere *R* and the diameter of the sphere *D*: Figure 3 shows the dependence *W*(*R*/*D*) and Figure 4 shows the dependence *W*(*D*/*R*). It can be seen that at $R > D$ the influence of the Coriolis force disappears. It was shown above that at $R \to 0$ the parameter $W \to 45$.

So, the formulas for calculating the Coriolis force become more complicated. Nevertheless, such a problem already arises in practice in space researches. It is known for the flyby anomaly representing an unexpected increase in the energy of a spacecraft during gravitational maneuvers near planets. A spacecraft flying in the vicinity of the planet changes its speed (up or down) by units of [mm/s], deviates from the calculated trajectory by tens of degrees. Measurements establish that for this it acquires additional energy of tens of [J/kg], the source of which is not determined. A generally accepted explanation of the flyby anomaly has not yet been found (https://en.wikipedia.org/wiki/Flyby_anomaly).

The very fact that this anomaly appears only near planets confirms the thesis that the Coriolis forces arise when a body interacts with a rotating planet. So, above there is a method for calculating the flyby anomaly.

CONCLUSION

The Coriolis forces and centrifugal forces are real physical forces. Their existence is explained by the interaction of mass currents existing in moving bodies and the rotating Earth. The interaction of mass currents is similar to the interaction of electric currents. These forces exist in the neighborhood of any rotating celestial bodies, and this neighborhood is a sphere, the radius of which is equal to the diameter of the body. From this it follows that these forces must be taken into account in any calculations of mechanics, hydrodynamics, aerodynamics, and astronautics. These forces must be especially taken into account when designing any rotating structures in spacecraft intended for flights in the vicinity of massive celestial bodies.

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Received: June 28, 2023; Accepted: Sept 15, 2023

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