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The nature of the Coriolis force and the flyby anomaly

Annotation

The existing understanding of the nature of the Coriolis force and centrifugal force raises many puzzling questions. The article proves that these forces can be justified as consequence of the equations Maxwell for gravitomagnetism. It is further shown that the flyby anomaly is a consequence of the influence of Coriolis forces and a method for calculating this influence is indicated.

Contents

1. Introduction

Modern ideas about the Coriolis force [1] are as follows:

- the Coriolis force is in no way related to any interaction of the body in question with other bodies,
- the Coriolis force is determined by the choice of a particular non-inertial reference frame.
- The Coriolis force is not a physical force and does not do work.

Roughly speaking, the Coriolis force acting on a body appears because another body rotates next to this body at a certain speed. Our body does not interact with this body and therefore "does not know" the magnitude of this speed, but the Coriolis force depends on this speed. The mass of this other body and the distance to it do not matter. The Coriolis force does not do work, but

- a freely falling body is deflected
- the rails of one-way railways wear unevenly,
- long-range artillery shells deviate from the calculated trajectory, etc.

So,

- there is an inertial reference system rotating with the angular velocity vector $\overline{\omega}$,
- there is a non-inertial frame of reference that does not interact in any way with inertial reference system,
- in a non-inertial frame a body of mass m moves with speed $\overline{v}$,
- in this case, the Coriolis force is observed acting on the body perpendicular to the speed $\overline{v}$, which is determined by the formula$\overline{v}$

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

This force is observed as fictitious from a non-inertial frame of reference, as, for example, in the experiment with the Foucault pendulum. But this same force is also observed from an inertial frame of reference, such as, for example, the real force of coastal erosion. Observation can also be carried out from a third system, in which a non-inertial reference system rotates, in which the inertial reference system is located, as in experiment [5]. In this case, we observe how, in a non-inertial system, a fictitious force physically draws a spiral... Therefore, the Coriolis force cannot be considered fictitious and cannot be explained by the peculiarities of the observer's perception.

It is necessary to try to find a physical connection between a real rotating system and a body moving in it or near this system. These issues are discussed in more detail in[8].

It is further shown that the Coriolis force is found as a consequence of Maxwell's equations for gravitomagnetism. These equations exist in the vicinity of a gravitating body (Earth). Consequently, the Coriolis force can only arise in the vicinity of such a body and cannot exist in open space. The Coriolis force is a full-fledged force that does work. The energy expended to perform this work is supplied by the gravitating body. This proof was first given by the author in [6]. It is discussed in more detail here.

2. Interaction of moving electric charges

Let's look at Fig. 1, where at points A and B two charges q_1 and q_1 are shown, moving with speeds v_1 and v_2 respectively. Let us assume that the quantity q_2 is the density of charges distributed uniformly over the entire horizontal plane, and the speed v_2 is the speed of the entire plane.

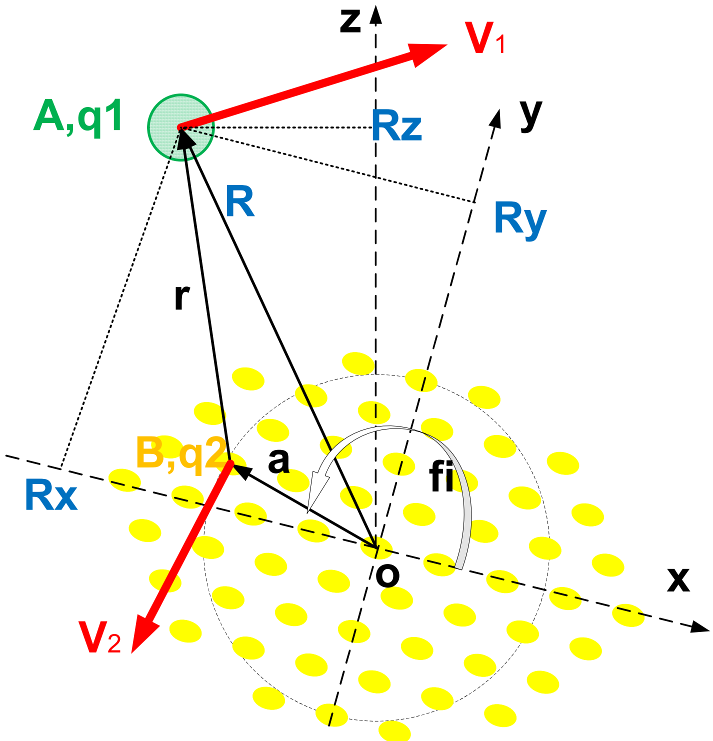

Fig. 1.

But first, let's consider the interaction of point charges. It is known 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 equal to

$$\overline{B} = q_2(\overline{v_2} \times \overline{r})/r^3. \tag{2}$$

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 is q_1,

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

or

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

In Fig. 1 also shows the vectors $\overline{a}$ and $\overline{R}$, and the vector$\overline{a}$ is with the axis ox corner φ and

$$\overline{r} = \overline{R} - \overline{a}. \tag{5}$$

First we will consider the case when all these vectors lie in the horizontal plane xoy, and we will denote the projections of all vectors by the coordinate subscript. Then the vector

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

where $\overline{z}$ is the unit vector of the vertical axis. Let's denote

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

Then

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

If the plane rotates with angular velocity ω around point O, then the charge q_2 also rotates around point O with angular velocity ω. Moreover, this charge has a velocity vector

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

is tangent to a circle with radius. In this case$a$.

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

or

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

From (4, 6) we get:

$$\overline{F_{12}} = q_1q_2(\overline{v_1} \times \overline{w})/(r^3) \quad (12)$$

or, taking into account (8, 11),

$$\overline{F_{12}} = q_1q_2\omega\left(\overline{v_1} \times \bar{z}\frac{w_z}{\omega}\right)/(r^3). \quad (13)$$

We'll find force acting from <u>all</u> charged and rotating plane per charge q_1:

$$\bar{F} = \int_{\varphi,a} \overline{F_{12}}\, d\varphi da = \int_{\varphi,a} \left(q_1q_2\omega\left(\overline{v_1} \times \bar{z}\frac{w_z}{\omega}\right)/(r^3)\right) d\varphi da$$

or

$$\bar{F} = q_1q_2(\overline{v_1} \times \bar{\omega}W), \quad (14)$$

Where

$$\bar{\omega} = \bar{z}\omega, \quad (15)$$

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

From (16, 11) 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 (5):

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

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

Integration using these formulas gives a remarkable result: <u>the value W does not depend on R and, as the upper limit tends to ∞</u>, it approaches the value

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

This means that <u>the charge q_1 can be located at any height above the infinite plane of charges q_2</u>

Taking into account (20) formula (14) can be written in the form

$$\bar{F} = q_1q_2W(\overline{v_1} \times \bar{\omega}), \quad (21)$$

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

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

Let us now consider an electric charge q_1 that rotates above the field <u>stationary</u> electric charges and at the same time moves forward at a 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 the analogy between the formulas for force (21) and for the Coriolis force, which arises during the translational motion of a body with a speed $\overline{-v_2}$ that simultaneously rotates with an angular velocity $\bar{\omega}$ above a stationary Earth (the Earth's rotation speed is much less $\bar{\omega}$).

4. Interaction of a rotating electric charge with a stationary field of electric charges

Let us now consider an electric charge q_1 that rotates above the field stationary electric charges. Coulomb forces from the rotating charge must rotate the field of electric charges. In this case, the problem is reduced to the previous one: indeed, the charge q_1 moves above a rotating field of electric charges. For these problems to be identical, 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 we can use formula (21). The linear velocity of a charge and its angular velocity ω are related by the formula

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

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

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

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

5.EquationsMaxwellForgravitomagnetism and Coriolis force

In [2] the author proposes a new solution to the equations Maxwell for gravitomagnetism, which is used to build mathematical models of various natural phenomena (sand vortex, sea currents, whirlpool, funnel, water soliton, water and sand tsunami, turbulent currents, additional *non-Newtonian* interaction forces of celestial bodies). All these models use the idea of mass currents as flows of mass particles. The speed of mass particles can be very small and often their flow can be as invisible as the flow of electrons. But the existence of these phenomena and the possibility of constructing these mathematical models, similar to the mathematical models of direct current in electrodynamics [4], confirm the assumption of the existence of mass currents and the interaction of mass particles, completely analogous to the interaction of electric charges.

Based on this, it can be assumed that the rotation of a body is accompanied by a mass current, similar to how the rotation of a charged body is accompanied by a convection electric current. Eichenwald [3] showed that such a current creates magnetic induction. Based on the complete analogy between Maxwell's equations for electrodynamics and gravitomagnetism [2], it can be argued that when a body rotates, gravitomagnetic induction is created. A mass m moving in a gravimagnetic field with a speed v is acted upon by the Lorentz gravitomagnetic force (an analogue of the Lorentz magnetic force).

Based on the above, we rewrite formula (21), obtained above for the interaction of electric charges, as applied to the interaction of mass charges:

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

where $W \approx -45$,

$m, \bar{v}$ are mass and speed of a moving body,

p is surface density of masses, as elements of mass current,

$\bar{\omega}$ is angular velocity of rotation of the plane on which these elements are evenly distributed.

Comparing formulas (1, 24) we find that

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

whence it follows that the mass density

$$p = -\frac{2}{W} \approx 0.044\frac{kg}{m^2} = 4.4 \cdot 10^{-5}\frac{mg}{sm^2}. \tag{26}$$

"Excuse me," the attentive reader will be surprised. "You reject the Coriolis theory and at the same time use his formula?" I can only join 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 confident **experimental** verification of the value of the coefficient "2" in formula (1) of the Coriolis force.

The method used to derive the Coriolis force proves the reality and not the fictitiousness of this force and reveals the source of power for this force - the Earth's gravitational field.

6. Centrifugal force

As shown in Section 3, the rotation of a charged plane under a moving charge can be replaced by the rotation of a charge above the charged plane. Then in formula (21) $\bar{\omega}$ is the vector of the angular velocity of the rotating charge, the linear speed of this charge

$$v_1 = R\omega. \quad (27)$$

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

$$\bar{F} = Wpm\omega^2 R. \quad (28)$$

This formula is different from the formula for centrifugal force

$$\bar{F}_C = m\omega^2 R, \quad (29)$$

only by coefficient. By analogy with the previous one, here we find the mass density

$$p = -\frac{1}{W} \approx 0.022\frac{kg}{m^2} = 2.2 \cdot 10^{-5}\frac{mg}{sm^2}. \quad (30)$$

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.

7. Flyby anomaly

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

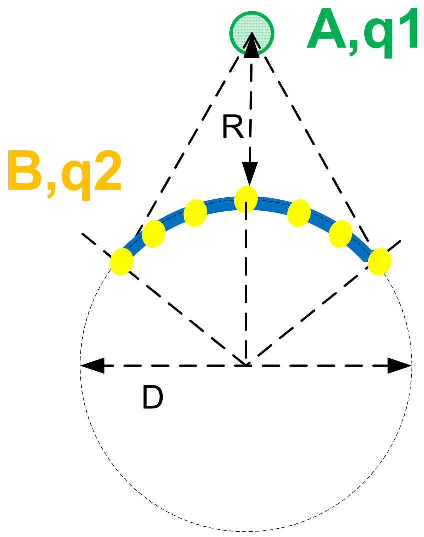

Fig. 2

In Fig. 3 shows the relationship W between the distance of the body to the sphere R and the diameter D of the sphere: in Fig. 3a shows the dependence $W(R/D)$, and in Fig. 3b – dependence $W(D/R)$. It can be seen that when $R > D$ the influence of the Coriolis force disappears. It was shown above that $W \to 45$ at $R \to 0$.

So, the formulas for calculating the Coriolis force become more complex. However, such a task already arises in practice in space research. Known so-called flyby anomaly - an unexpected increase in the energy of a spacecraft during gravity maneuvers near the planets. A spacecraft flying in the vicinity of the planet changes its speed (increasing or decreasing) by units of mm/sec and deviates from the calculated trajectory by tens of degrees. Measurements have established that for this it acquires additional energy of tens J/kg, the source of which is unknown. A generally accepted explanation for the flyby anomaly has not yet been found [7].

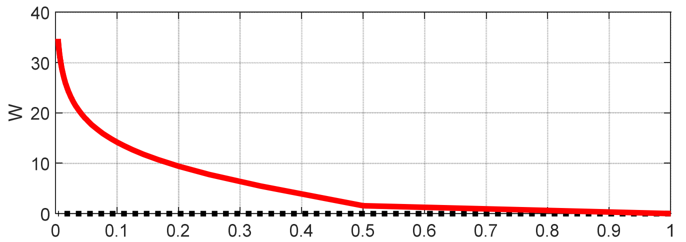

Fig. 3a. (Coriolis23.m)

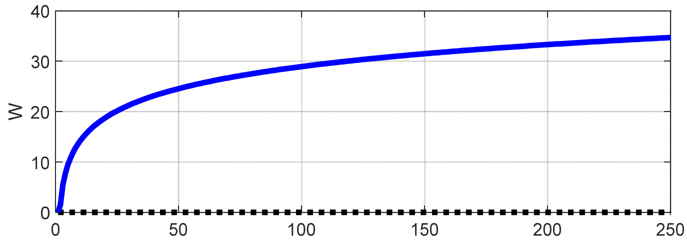

Fig. 3b. (Coriolis23.m)

From the above it follows that the cause of the flyby anomaly is the occurrence of Coriolis forces, which deliver additional energy to the spacecraft, change its speed and significantly distort the calculated trajectory. The appearance of Coriolis forces is due to the rotation of the satellite. In the absence of such rotation, the Coriolis force is created due to the rotation of the planet, but in this case it has a significantly smaller value than during the rotation of the apparatus itself. Apparently, this explains the fact that the flyby anomaly is not always observed.

The very fact that this anomaly appears only near planets confirms the thesis that Coriolis forces arise when a body interacts with a rotating planet.

The above is the method for calculating the flyby anomaly.

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