Derivation of numerous dynamics of the Special Theory of Relativity for three spatial dimensions

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Abstract:

This paper presents the derivation of numerous dynamics for the Special Theory of Relativity kinematics for three spatial dimensions. It is a continuation of the paper, in which numerous STR dynamics for one-dimension have been derived. It is shown that from each one-dimensional dynamics unambiguously results three-dimensional dynamics.

Discussion on the right angle lever paradox has been presented and the paradox of vector non-parallelism. The explanation of paradoxes under different dynamics can be a method of their theoretical examination and assessment.

Key words: dynamics of bodies, equation of motion, momentum, kinetic energy, right angle lever paradox, Special Theory of Relativity

1. Introduction

The paper [6] presents an original method that enables to derive numerous dynamics for STR kinematics for one spatial dimension. Five examples of specific dynamics have been presented. This paper is a continuation of that research and presents a method of extending any dynamics for one spatial dimension to three spatial dimensions. For each of the five examples of one-dimensional STR dynamics derived in the paper [6], three-dimensional dynamics were derived (transformation of perpendicular force and equations of motion for perpendicular force).

2. Selected properties of STR kinematics

The determinations shown in Figure 1 have been adopted.

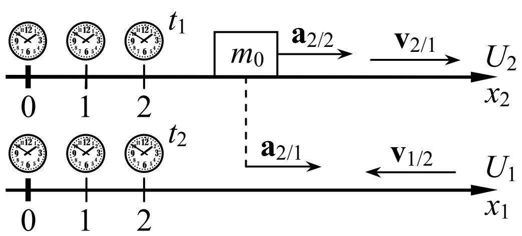

Fig. 1. Relative motion of inertial systems U_1 and U_2 ($|\mathbf{v}_{2/1}| = |\mathbf{v}_{1/2}|$) as well as body acceleration m_0 seen from these systems.

The inertial system U_2 moves in relation to the inertial system U_1 at the velocity of $v_{2/1}$. The inertial system U_1 moves in relation to the inertial system U_2 at the velocity of $v_{1/2}$. In STR, it is $|\mathbf{v}_{2/1}| = |\mathbf{v}_{1/2}|$. The body with rest mass m_0 rests temporarily in U_2 system. This body performs an acceleration. In U_2 system, in which the body was resting temporarily, the acceleration has a value of $\mathbf{a}_{2/2}$. The acceleration in relation to U_1 system, has a value of $\mathbf{a}_{2/1}$. Index i/j will mean that it is a body resting in i system and is observed from j system.

In the STR kinematics the following equations are derived from the Lorentz transformation [3]:

- transformation of dimensions parallel to velocity $\mathbf{v}_{2/1}$ (Lorentz–FitzGerald contraction)

$$\mathbf{L}^{\|}_{2/2} = \gamma \mathbf{L}^{\|}_{2/1} \tag{1}$$

- transformation of dimensions perpendicular to velocity $\mathbf{v}_{2/1}$

$$\mathbf{L}^{\perp}_{2/2} = \mathbf{L}^{\perp}_{2/1} \tag{2}$$

- transformation of acceleration parallel to velocity $\mathbf{v}_{2/1}$

$$\mathbf{a}^{\|}_{2/2} = \gamma^3 \mathbf{a}^{\|}_{2/1} \tag{3}$$

- transformation of acceleration perpendicular to velocity $\mathbf{v}_{2/1}$

$$\mathbf{a}^{\perp}_{2/2} = \gamma^2 \mathbf{a}^{\perp}_{2/1} \tag{4}$$

The symbol || indicates the component parallel to velocity $\mathbf{v}_{2/1}$, while the symbol $\perp$ indicates the component perpendicular to velocity $\mathbf{v}_{2/1}$, where $\mathbf{v}_{2/1}$ is the velocity of body in relation to the observer.

3. One-dimensional dynamics for STR

The STR dynamics for one spatial dimension were derived in the paper [6]. In accordance with the designations adopted there, the following equations apply to STR dynamics:

- equation of motion in the own body system U_2 (Newton's second law of motion)

$$\mathbf{F}^{\|}_{2/2} := m_0\, \mathbf{a}^{\|}_{2/2} \quad \wedge \quad \mathbf{F}^{\perp}_{2/2} := m_0\, \mathbf{a}^{\perp}_{2/2} \tag{5}$$

- equation of motion of the body resting temporarily in U_2 system for the observer from U_1 system (these equations represent the generalized Newton's second law of motion)

$$\mathbf{F}^{\|}_{2/1} := m_0\, f^{\|}(v_{2/1})\mathbf{a}^{\|}_{2/1} \quad \wedge \quad \mathbf{F}^{\perp}_{2/1} := m_0\, f^{\perp}(v_{2/1})\mathbf{a}^{\perp}_{2/1} \tag{6}$$

- definition of momentum

$$d\mathbf{p}_{2/1} := \mathbf{F}_{2/1}\, dt_1 = m_0 f^{\|}(v_{2/1})\,\mathbf{a}_{2/1}\, dt_1 = m_0 f^{\|}(v_{2/1})\frac{d\mathbf{v}_{2/1}}{dt_1}dt_1 = m_0 f^{\|}(v_{2/1})d\mathbf{v}_{2/1} \tag{7}$$

In Newton's dynamics $f^{\|}(v_{2/1}) = f^{\perp}(v_{2/1}) = 1$, while in Einstein's STR dynamics $f^{\|}(v_{2/1}) = \gamma^3$, $f^{\perp}(v_{2/1}) = \gamma$.

The dynamics derived in the paper [6] were parameterized by the parameter $x \in R$. In the five dynamics derived in that paper the following equations for momentum and kinetic energy apply:

- Dynamics $\{x\} = \{0\}$, in which for each observer $F^{\|}/a_{2/1} = m_0 f^{\|}(v_{2/1}) = m_0 = constans$:

$$\mathbf{p}^{\{0\}}_{2/1} = \mathbf{p}^{m}_{2/1} = m_0\, \mathbf{v}_{2/1} \tag{8}$$

- Dynamics $\{x\} = \{1/2\}$, in which for each observer $F^{\|}/dv_{2/1} = m_0 f^{\|}(v_{2/1})/\Delta t = constans$:

$$\mathbf{p}_{2/1}^{\{1/2\}} = \mathbf{p}_{2/1}^{m/\Delta t} = m_0\,\mathbf{c}\arcsin\frac{v_{2/1}}{c} = m_0\,\mathbf{v}_{2/1}\frac{\arcsin(v_{2/1}/c)}{v_{2/1}/c} \tag{9}$$

- Dynamics $\{x\} = \{1\}$, in which for each observer $\Delta p = constans$:

$$\mathbf{p}_{2/1}^{\{1\}} = \mathbf{p}_{2/1}^{\Delta p} = \frac{m_0\,\mathbf{c}}{2}\ln\left(\frac{c+v_{2/1}}{c-v_{2/1}}\right) = m_0\,\mathbf{v}_{2/1}\ln\left(\frac{c+v_{2/1}}{c-v_{2/1}}\right)^{\frac{c}{2v_{2/1}}} \tag{10}$$

- Dynamics $\{x\} = \{3/2\}$, Einstein's dynamics, in which for each observer $F^{||} = constans$:

$$\mathbf{p}_{2/1}^{\{3/2\}} = \mathbf{p}_{2/1}^{F} = m_0\,\mathbf{v}_{2/1}\frac{1}{\sqrt{1-(v_{2/1}/c)^2}} \tag{11}$$

- Dynamics $\{x\} = \{2\}$, in which for each observer $F^{||}/\Delta t = constans$:

$$\mathbf{p}_{2/1}^{\{2\}} = \mathbf{p}_{2/1}^{F/\Delta t} = m_0\,\mathbf{v}_{2/1}\frac{1}{2}\left[\frac{1}{1-(v_{2/1}/c)^2} + \ln\left(\frac{c+v_{2/1}}{c-v_{2/1}}\right)^{\frac{c}{2v_{2/1}}}\right] \tag{12}$$

The force transformation for the component parallel to velocity $\boldsymbol{v}_{2/1}$ in dynamics $\{x\}$ has a form of [6]:

$$\mathbf{F}_{2/1}^{||\{x\}} = \gamma^{2x-3}\mathbf{F}_{2/2}^{||} \tag{13}$$

The equation of motion (6) for the component parallel to velocity $\boldsymbol{v}_{2/1}$ in dynamics $\{x\}$ has a form of [6]:

$$\mathbf{F}_{2/1}^{||\{x\}} = m_0\,\gamma^{2x}\mathbf{a}_{2/1}^{||} \tag{14}$$

4. Derivation of three-dimensional dynamics for STR

For each dynamic, the momentum equation in dynamics $\{x\}$, e.g. (8), (9), (10), (11) or (12), has a form of

$$\mathbf{p}_{2/1}^{\{x\}}(\mathbf{v}_{2/1}) = m_0\,\mathbf{v}_{2/1}\,g^{\{x\}}(v_{2/1}) \tag{15}$$

where $g^{\{x\}}(v_{2/1})$ is a dimensionless function.

If the velocity vector of body changes, then the momentum vector of this body changes. This is shown in Figure 2.

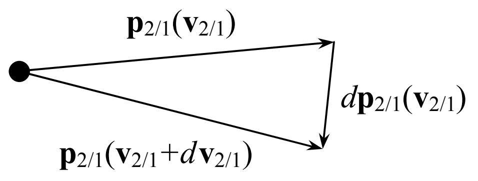

Fig. 2. Change of body momentum resting temporarily in U_2 system seen by an observer from U_1 system.

Based on the definition of momentum (7) and (15) the following is obtained

$$\mathbf{F}_{2/1}^{\{x\}} = \frac{d\mathbf{p}_{2/1}^{\{x\}}(\mathbf{v}_{2/1})}{dt_1} = \frac{d(m_0\,\mathbf{v}_{2/1}\,g^{\{x\}}(v_{2/1}))}{dt_1} = m_0\left[\frac{d\mathbf{v}_{2/1}}{dt_1}g^{\{x\}}(v_{2/1}) + \mathbf{v}_{2/1}\frac{d(g^{\{x\}}(v_{2/1}))}{dt_1}\right] \tag{16}$$

$$\mathbf{F}_{2/1}^{\{x\}} = m_0\left[(\mathbf{a}_{2/1}^{\|} + \mathbf{a}_{2/1}^{\perp})g^{\{x\}}(v_{2/1}) + \mathbf{v}_{2/1}\frac{d(g^{\{x\}}(v_{2/1}))}{dv_{2/1}}\frac{dv_{2/1}}{dt_1}\right] \tag{17}$$

$$\mathbf{F}_{2/1}^{\{x\}} = m_0\, g^{\{x\}}(v_{2/1})\,\mathbf{a}_{2/1}^{\perp} + m_0\left[g^{\{x\}}(v_{2/1})\,\mathbf{a}_{2/1}^{\|} + \frac{d(g^{\{x\}}(v_{2/1}))}{dv_{2/1}}\frac{dv_{2/1}}{dt_1}\mathbf{v}_{2/1}\right] \tag{18}$$

Because

$$\mathbf{v}_{2/1} \parallel \mathbf{a}_{2/1}^{\|} \tag{19}$$

thus, it follows from (18) that

$$\mathbf{F}_{2/1}^{\perp\{x\}} = m_0\, g^{\{x\}}(v_{2/1})\,\mathbf{a}_{2/1}^{\perp} \tag{20}$$

$$\mathbf{F}_{2/1}^{\|\{x\}} = m_0\left[g^{\{x\}}(v_{2/1})\,\mathbf{a}_{2/1}^{\|} + \frac{d(g^{\{x\}}(v_{2/1}))}{dv_{2/1}}\frac{dv_{2/1}}{dt_1}\mathbf{v}_{2/1}\right] \tag{21}$$

The equation (20) can be derived directly from (16), if it is observed that a force acting on the body perpendicular to its velocity $\mathbf{v}_{2/1}$ does not change velocity value $\mathbf{v}_{2/1}$, but only its direction. In this case $g^{\{x\}}(v_{2/1}) = constans$. On this basis, the following is immediately obtained (20).

The equation (20) is an equation of motion for the force perpendicular to the velocity of body $\mathbf{v}_{2/1}$. For the five dynamics derived in the paper [6], the explicit forms of equations of motion are based on (8), (9), (10), (11) and (12) as follows:

- Dynamics $\{x\} = \{0\}$

$$\mathbf{F}_{2/1}^{\perp\{0\}} = \mathbf{F}_{2/1}^{\perp m} = m_0\,\mathbf{a}_{2/1}^{\perp} \tag{22}$$

- Dynamics $\{x\} = \{1/2\}$

$$\mathbf{F}_{2/1}^{\perp\{1/2\}} = \mathbf{F}_{2/1}^{\perp m/\Delta t} = m_0\frac{\arcsin(v_{2/1}/c)}{v_{2/1}/c}\mathbf{a}_{2/1}^{\perp} \tag{23}$$

- Dynamics $\{x\} = \{1\}$

$$\mathbf{F}_{2/1}^{\perp\{1\}} = \mathbf{F}_{2/1}^{\perp\Delta p} = m_0 \ln\left(\frac{c+v_{2/1}}{c-v_{2/1}}\right)^{\frac{c}{2v_{2/1}}}\mathbf{a}_{2/1}^{\perp} \tag{24}$$

- Dynamics $\{x\} = \{3/2\}$, Einstein's dynamics

$$\mathbf{F}_{2/1}^{\perp\{3/2\}} = \mathbf{F}_{2/1}^{\perp F} = m_0\frac{1}{\sqrt{1-(v_{2/1}/c)^2}}\mathbf{a}_{2/1}^{\perp} \tag{25}$$

- Dynamics $\{x\} = \{2\}$

$$\mathbf{F}_{2/1}^{\perp\{2\}} = \mathbf{F}_{2/1}^{\perp F/\Delta t} = m_0\frac{1}{2}\left[\frac{1}{1-(v_{2/1}/c)^2} + \ln\left(\frac{c+v_{2/1}}{c-v_{2/1}}\right)^{\frac{c}{2v_{2/1}}}\right]\mathbf{a}_{2/1}^{\perp} \tag{26}$$

Now the transformation of force perpendicular to velocity $\mathbf{v}_{2/1}$ will be determined. The equations of motion (5) are replaced by (3) and (4). Then the following is obtained

$$\mathbf{F}_{2/2}^{\|} = m_0\gamma^3\mathbf{a}_{2/1}^{\|} \quad \wedge \quad \mathbf{F}_{2/2}^{\perp} = m_0\gamma^2\mathbf{a}_{2/1}^{\perp} \tag{27}$$

If to divide the motion equation (14) by the first equation (27), then for dynamics $\{x\}$ the already known transformation of force for the parallel component (13) is obtained. If the equation of motion (20) is divided by the second equation (27), then for dynamics $\{x\}$ the force transformation for the perpendicular component is obtained in a form of

$$\mathbf{F}_{2/1}^{\perp\{x\}} = \frac{g^{\{x\}}(v_{2/1})}{\gamma^2}\mathbf{F}_{2/2}^{\perp} \tag{28}$$

The calculations presented in this chapter show that the dynamics for three spatial dimensions result unambiguously from the dynamics for one spatial dimension.

5. STR dynamics paradoxes

The explanation of various paradoxes occurring in the dynamics of STW can be a method of theoretical study and assessment of these dynamics. Two paradoxes will be presented below, but will not be explained. Their explanation may be the subject of another article.

5.1. Right angle lever paradox

Papers [1], [2], [4] and [5] present the right angle lever paradox, Figure 3. The lever is fixed to the ground at R point by means of a rotary support.

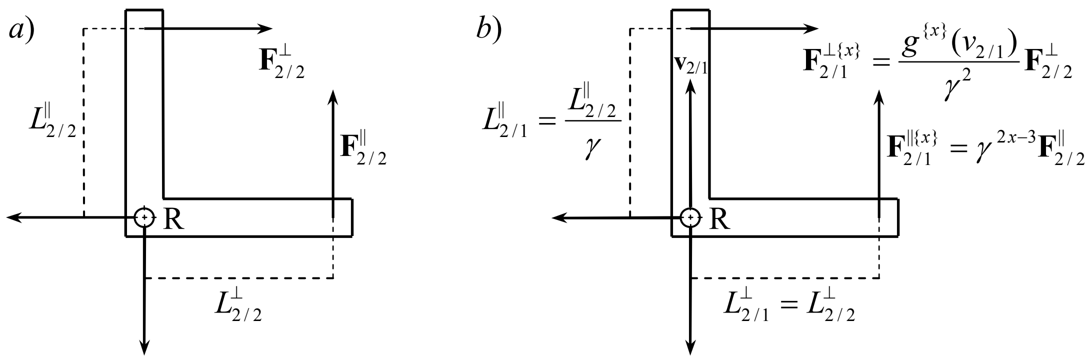

Fig. 3. Right angle lever paradox.
a) lever seen from the own system U_2, *b*) lever seen from the moving inertial system U_1.

For the observer from U_2 system (resting system), both lever arms have the same length, i.e.

$$L_{2/2}^{||} = L_{2/2}^{\perp} \tag{29}$$

The lever is subject to two forces applied to the ends of arms in directions perpendicular to these arms and two reaction forces applied at the support point R. In U_2 system, the lever is in equilibrium, i.e. the sum of torques is 0. That is

$$\mathbf{L}_{2/2}^{||}\,\mathbf{F}_{2/2}^{\perp} = \mathbf{L}_{2/2}^{\perp}\,\mathbf{F}_{2/2}^{||} \quad \overset{L_{2/2}^{||}=L_{2/2}^{\perp}}{\Rightarrow} \quad F_{2/2}^{||} = F_{2/2}^{\perp} \tag{30}$$

For an observer from the inertial system U_1, the lever moves in a straight line at a constant velocity $\boldsymbol{v}_{2/1}$ parallel to one arm. According to the transformation of dimensions (1), (2) and force transformations (13), (28), for the observer from U_2 system, two moments of force act on the lever:

$$\mathbf{L}_{2/1}^{||}\,\mathbf{F}_{2/1}^{\perp\{x\}} = \frac{g^{\{x\}}(v_{2/1})}{\gamma^3}\mathbf{L}_{2/2}^{||}\,\mathbf{F}_{2/2}^{\perp} \tag{31}$$

$$\mathbf{L}_{2/1}^{\perp}\,\mathbf{F}_{2/1}^{||\{x\}} = \gamma^{2x-3}\,\mathbf{L}_{2/2}^{\perp}\,\mathbf{F}_{2/2}^{||} \tag{32}$$

The moments of force (31) and (32) are equal only in such dynamics $\{x\}$, in which due to (29) and (30) there is an equality of

$$\frac{g^{\{x\}}(v_{2/1})}{\gamma^3} = \gamma^{2x-3} \quad \Leftrightarrow \quad g^{\{x\}}(v_{2/1}) = \gamma^{2x} \tag{33}$$

From the paper [6] (equation (126)) and from (15) it follows that

$$g^{\{x\}}(v_{2/1}) = \frac{1}{v_{2/1}} \int_0^{v_{2/1}} \gamma^{2x} dv_{2/1} \tag{34}$$

On this basis, condition (33) takes the form of

$$\frac{1}{v_{2/1}} \int_0^{v_{2/1}} \gamma^{2x} dv_{2/1} = \gamma^{2x} \tag{35}$$

$$\int_0^{v_{2/1}} \gamma^{2x} dv_{2/1} = v_{2/1} \gamma^{2x} \tag{36}$$

After differentiating the sides by the velocity $v_{2/1}$ the following is obtained

$$\gamma^{2x} = \frac{dv_{2/1}}{dv_{2/1}} \gamma^{2x} + v_{2/1} \frac{d\gamma^{2x}}{dv_{2/1}} \tag{37}$$

$$0 = v_{2/1} \frac{d\gamma^{2x}}{dv_{2/1}} \tag{38}$$

Equality must be true for every velocity $v_{2/1}$. This is only possible if

$$\gamma^{2x} = constans(v_{2/1}) \quad \Rightarrow \quad x = 0 \tag{39}$$

It follows that only for one dynamics $\{x\} = \{0\}$ for the observer from the moving inertial system U_1, the moments of force applied to the lever are balanced. So only in this one dynamics right angle lever paradox does not occur. For all other dynamics, including Einstein's, moments of force in the system of moving observer are not balanced. Therefore, it might seem that, according to the moving observer, the lever should rotate. The right angle lever paradox is that if the lever does not rotate in the resting system, it does not rotate for an observer from any other inertial reference system. The right angle lever paradox in Einstein's dynamics, as well as other dynamics $\{x\} \neq \{0\}$, can be explained if you notice that in these dynamics for the moving observer the torques (31) and (32) do not have to be equal for the body to be in static equilibrium.

5.2. Paradox of vector non-parallelism

In dynamics $\{x\} \neq \{0\}$ the vector of acceleration may not be parallel to the force vector causing the acceleration. Then the body accelerates in a slightly different direction than the direction of force. This is shown in Figure 4. In the inertial system U_2, in which the body temporarily rests, the force $\mathbf{F}_{2/2}$ and acceleration $\mathbf{a}_{2/2}$ are parallel to each other. This must be the case in own body system, because the STR should meet the correspondence principle in relation to Newton's mechanics. But for the observer from inertial system U_1 the force $\mathbf{F}_{2/1}$ and acceleration $\mathbf{a}_{2/1}$ are not parallel to each other.

This can be shown in the following way. As in our own body system the force $\mathbf{F}_{2/2}$ and the acceleration $\mathbf{a}_{2/2}$ are parallel to each other, thus the following occurs

$$\frac{F_{2/2}^{\perp}}{F_{2/2}^{\parallel}} = \frac{a_{2/2}^{\perp}}{a_{2/2}^{\parallel}} \tag{40}$$

From the transformation of forces (13), (28) and the transformation of accelerations (3)-(4) the following is obtained (assuming that the vector $\mathbf{F}_{2/2}$ is not perpendicular to velocity $\mathbf{v}_{2/1}$)

$$tg\alpha_F = \frac{F_{2/1}^{\perp}}{F_{2/1}^{\parallel}} = \frac{g^{\{x\}}(v_{2/1})}{\gamma^{2x-1}} \frac{F_{2/2}^{\perp}}{F_{2/2}^{\parallel}} \quad \wedge \quad tg\alpha_a = \frac{a_{2/1}^{\perp}}{a_{2/1}^{\parallel}} = \frac{a_{2/2}^{\perp}/\gamma^2}{a_{2/2}^{\parallel}/\gamma^3} = \gamma \frac{a_{2/2}^{\perp}}{a_{2/2}^{\parallel}} \tag{41}$$

The angles of force slope and acceleration will be the same in the moving inertial system U_1, only in dynamics $\{x\}$, which meet the condition

$$\frac{g^{\{x\}}(v_{2/1})}{\gamma^{2x-1}} = \gamma \quad \Rightarrow \quad g^{\{x\}}(v_{2/1}) = \gamma^{2x} \tag{42}$$

Calculations (33)-(39) show that such a dynamic is only $\{x\} = \{0\}$.

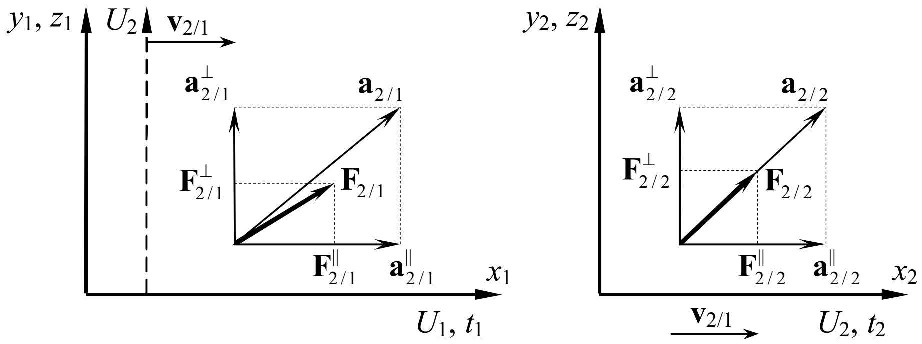

Fig. 4. In dynamics $\{x\} \neq \{0\}$ the acceleration vector may have a different direction than force.
This illustration refers to the dynamics $\{x\} > \{0\}$.

It is important to note that the force vectors $\mathbf{F}_{2/1}$ and $\mathbf{F}_{2/2}$ represent the same force, but measured from different reference systems. The acceleration vectors $\mathbf{a}_{2/1}$ and $\mathbf{a}_{2/2}$ represent the same acceleration, but measured from different reference systems. For the observer from U_2 system, the acceleration vectors and forces are parallel. Nevertheless, in dynamics $\{x\} \neq \{0\}$ for a moving observer, these vectors are not parallel. For the moving observer, one line (direction in space) is divided into two different lines (two directions in space). This seems to be impossible and in dynamics $\{x\} \neq \{0\}$ requires special explanation.

6. Conclusions

The paper shows that from each STR dynamic for one spatial dimension, there is a clear dynamic for three spatial dimensions. The equations for the perpendicular force transformation and the equation of motion for the perpendicular force to body speed have been derived.

It was shown that only in one STR dynamics $\{x\} = \{0\}$ there is no right angle lever paradox nor the paradox of vector non-parallelism. These paradoxes occur in all other STR dynamics, and needs clarification.

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From the General Theory of Relativity (GTR) do not result any gravitational waves, but just ordinary modulation of the gravitational field intensities caused by rotating of bodies.

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