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# UAP Propulsion Principle and Resulting Flight Performance
# - Theoretical Analysis of UAP Flight Characteristics -

Yoshinari Minami
*Advanced Space Propulsion Investigation Laboratory (ASPIL)*
(*Formerly NEC Space Development Division*)
*Corresponding Author: Yoshinari Minami*

***ABSTRACT :****In response to an Unidentified Aerial Phenomena (UAP) investigation report released by the US Department of Defense in June 2021, NASA has announced that it will form a team of scientists this fall to begin investigating unidentified aerial phenomena (UAPs). The objects appearing in the images have shapes and movements that are completely unrealizable with today's technology. Therefore, the greatest achievement is the elucidation of the propulsion principle of the UAP and the theoretical explanation of the flight performance obtained from it. Unfortunately, current momentum thrust-based propulsion systems are limited in maximum speed and acceleration performance, so this is simply not possible. The new propulsion theory as the space drive propulsion system has already been completed. The flight performance and flight characteristics of space drive propulsion system homologize those of the UAP, so the flight performance of UAP is theoretically explained. Space drive propulsion system (also known as field propulsion) based on pressure thrust using the nature of space-time as a continuum is essential and become a proposal to explain the propulsion principle of UAP theoretically. This paper describes that the UAP's propulsion principle and propulsion mechanism, as well as the UAP's flight pattern and flight performance which are inevitably derived from it, can all be explained theoretically based on mathematical formulas.*

***KEYWORDS*** *UAP, propulsion, space drive, spaceship, curvature, space-time, acceleration, vortex.*

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## I. INTRODUCTION

An Unidentified Aerial Phenomena (UAP) investigation report released by the US Department of Defense in June 2021 has caused various ripples [1].

In response to this report, NASA has announced that it will form a team of scientists this fall to begin investigating unidentified aerial phenomena (UAPs). The objects appearing in the images have shapes and movements that are completely unrealizable with today's technology. Therefore, the greatest achievement is the elucidation of the propulsion principle of the UAP and the theoretical explanation of the flight performance obtained from it. Unfortunately, current momentum thrust-based propulsion systems are limited in maximum speed and acceleration performance, so this is simply not possible.

Today's space rockets have a limited maximum speed, so author started researching new space propulsion principles and presented them at international conferences in 1988, and have been presenting them in Journal and international conferences for 40 years since then. The new propulsion theory as the space drive propulsion system has already been completed.

Space drive propulsion system (representative Field propulsion system) is the concept of propulsion theory of spaceship not based on momentum thrust but based on pressure thrust derived from an interaction of the spaceship with external fields. Space drive propulsion system is propelled without mass expulsion. The space drive propulsion system proposed here is utilizing the action through medium of strained or deformed field of space, and is based on the propulsion principle of pressure thrust.

The propulsive force is a pressure thrust which arises from the interaction of space-time around the spaceship and the spaceship itself; the spaceship is propelled against space-time structure.

Based on the supposition that space is an infinite continuum like elastic body, space drive propulsion theory induced by space curvature can be possible.

The flight performance and flight characteristics of space drive propulsion system homologize those of the UAP, so the flight performance of UAP is theoretically explained. Space drive propulsion system (also known as field propulsion) based on pressure thrust using the nature of space-time as a continuum is essential and become a proposal to explain the propulsion principle of UAP theoretically.

As the one of final output, the UAP's propulsion principle and propulsion mechanism, as well as the UAP's flight pattern and flight characteristics, which are inevitably derived from it, can all be explained theoretically based on mathematical formulas.

In the subsequent chapters, the technical status and problems of the current propulsion system, the propulsion theory of the space drive propulsion system, the propulsion mechanism, flight performance and its characteristics, trial calculation of acceleration, propulsion engine and power source are introduced.

## II. TECHNICAL STATUS AND PROBLEM OF PROPULSION SYSTEM

At the present stage of space propulsion technology, the only practical propulsion system is a chemical propulsion system and an electric propulsion system, which are based on the expulsion of a mass to induce a momentum thrust. The momentum thrust based on momentum conservation low is widely used in the present propulsion systems. Since the maximum speed is limited by the product of the gas effective exhaust velocity and the natural logarithm of mass ratio, its speed is too slow for the spaceship to achieve the interplanetary travel and interstellar travel. Thus, the breakthrough of propulsion method has been required until now.

### 2.1 Momentum Thrust (Reaction Thrust)

As described above, all kinds of current propulsion systems except solar sail and light sail are based on momentum conservation law. In the case of the momentum thrust based on momentum conservation law, the maximum speed (*V*) is limited by the product of the gas effective exhaust speed (w) and the natural logarithm of the mass ratio (*R*).

$$V = w \cdot \ln R = gI_{SP} \cdot \ln R \ . \qquad (2.1)$$

where $I_{SP}$ is the specific impulse, g is gravitational acceleration (9.8m/s$^2$).

The maximum speed *V* which a rocket can reach is theoretically determined by the gas jet speed w (m/s) and the mass ratio *R*.

Because the velocity of the present rocket is too slow as compared with the speed of planet, the interplanetary exploration by mankind, not to speak of interstellar exploration, has various technical difficulties. We need the super-high-speed and high acceleration of spaceship. For example, the origin of the problem that the manned Mars exploration takes long-term time is due to the cruising speed of a spacecraft being too slow. The second astronomical speed (11.2 km/s) that a rocket obtains for Earth escape is slightly slow compared with the orbital speed (24 km/s) of Mars and the orbital speed (30 km/s) of the Earth.

This too slow speed is because the maximum speed of a rocket is limited by the product of gas effective exhaust speed and the natural logarithm of the mass ratio (about its value is 7). The speed beyond this cannot be theoretically taken out from the propulsion principle of a rocket based on the momentum conservation law.

Concerning a chemical rocket which has the multi-stage composition, about 10km/s speed is a practical limit. In the case of a chemical rocket, its specific impulse $I_{SP}$ is 460 seconds, so the maximum speed becomes 4.5km/s for single stage rocket. If the speed is 1000 times quick compared with Mars or the Earth, a straight-line orbit can be attained. Whenever you like always, it can reach to the target planet in a short time without restriction of orbital calculation, a start time, and return time, just like it may operate by car as it were.

Equation (2.1) can be represented as follows in detail:

$$V_f - V_i = \Delta V = \int_0^T \alpha dt = \int_0^T \frac{F}{m} dt = \int_0^T \frac{I_{SP}(-\dot{m}g)}{m} dt = I_{SP}\, g \ln \frac{m_i}{m_f} \ . \qquad (2.2)$$

Eq.(2.2) indicates that the speed increment $\Delta V$ of rocket when the rocket of the initial mass $m_i$ reduces mass to the rocket of the final mass $m_f$ by combustion for T seconds. Since the propellant mass $m_p$ is given by Eq.(2.3), combining Eqs.(2.2) and (2.3) yields the Eq.(2.4).

$$m_p = m_i - m_f \ , \qquad (2.3)$$

$$m_p = m_i \left[ 1 - \exp\left( -\frac{\Delta V}{g I_{SP}} \right) \right] \quad . \tag{2.4}$$

By expelling the mass of a propellant $m_p$ outside, a rocket obtains thrust and increases the speed of $\Delta V$ , that is, the propellant is indispensable for the conventional propulsion system based on momentum thrust. Further, since a large thrust is required for the large weight of the payload, a large amount of propellant is needed for the rocket; therefore, the rocket becomes increasingly heavy due to increased weight of propellant.

**2.2 Pressure Thrust**

Next is pressure thrust. The pressure thrust is to be pushed from the back and move forward. Solar sail and laser sail are so.

Pressure thrust also contributes partly to rocket and jet aircraft. That is, since the engine nozzle pressure at the rear of the rocket is larger than the atmospheric pressure at the front of the rocket, the rocket is pushed out from behind. As another example, the swimmer turns by pushing the wall of the pool with a foot; a car tire pushes the ground of the Earth, etc.

The propulsion mechanism of pressure thrust is explained as follows: the propulsion method obtained by pushing or kicking a huge massive body such as wall and ground. In this case, the wall or ground pushes it back conversely as an external force, i.e., reaction. For example, a man can move forward by pushing his sole to the ground. At the local system between man and ground, the ground is fixed and does not move. However, at the global system between man and the Earth, since the Earth kicked by his sole moves back very slightly, the momentum conservation law is satisfied. All the same, the velocity of the Earth is nearly zero, then we can say that the Earth is fixed.

Considering the above, let us now think of four-wheel drive motorcar as an example of pressure thrust. In the case of the accelerating four-wheel drive motor car, the wheel kicks (pushes) the ground by rotating, and the wheel is subject to friction force from the ground. These frictions become a propulsive force of the motor car, i.e., thrust. Namely, this is the propulsion mechanism on the four wheels that kick the ground. Since these frictions from the ground are external forces for the motor car, the momentum conservation law is not satisfied so long as there exists an external force. In addition, the exhaust gas from the motor car is disregarded as thrust. However, at the global system including the Earth, the momentum conservation law is satisfied but this does not make any sense.

If the ground continues to an infinite cosmic space, the motor car can always move on the ground. There is no significance in applying the momentum conservation law to the infinitely continued ground as a global system. The propulsion mechanism of the motor car is not momentum thrust but pressure thrust.

As the motorcar moves by kicking the ground continuously, the spaceship moves by pushing the cosmic space continuously. The cosmic space as an infinite continuum may be deformed very slightly by being pushed, just like the Earth moves back very slightly by being kicked due to the motorcar. However, this pushing is absorbed by the deformation of infinitely continued space itself. The whole cosmic space is considered as like the ground for kicking. Thus, since the space behaves like the elastic field, the stress between spaceship and space itself is the key of propulsion principle.

Momentum is conserved from a global perspective of the car and the Earth. Because the Earth moves back slightly due to the advance of the car. However, the backward movement of the Earth is negligible, and the backward movement can be ignored locally. It is important to see things in a local system or a global system.

The solar sail or light sail (laser sail) spreads large lightweight sail in outer space and propels by receiving light pressure as wind. It will be pushed and accelerated by light pressure, so there is no limitation of speed, i.e., the maximum final speed is close to the light speed (quasi-light speed). However, since the light pressure is very small, the thrust is small, and the acceleration is the very small value of several micro-G. If it is 1 micro-G acceleration, it will take about 3 years to reach the speed of 1 km per second. To reach 100 km per second, it has to be kept pushed for about 300 years. But if we only have time to spare, we can reach the speed close to the light. Somehow, we want to get a large acceleration of a few G.

Later, we introduce a new propulsion concept. It becomes possible by space drive propulsion, that is, pressure of field derived from space-time.

**2.3 Summary of Basic Knowledge of Propulsion System**

As mentioned above, the current practical propulsion systems are based on the expulsion of a mass to induce a momentum thrust. Since the maximum speed $V_{\max}$ is limited by the product of the gas effective exhaust velocity $V_E$ and the natural logarithm of mass ratio $R$ , its speed is too slow for the spaceship to achieve the interplanetary travel and interstellar travel. Thus, the breakthrough of propulsion method has been required until now.

**There exist <Two types of propulsion method>:**

(1) Momentum thrust (e.g., jet aircraft, rocket): $V_{\max} = \ln R \cdot gI_{SP} = \ln R \cdot V_E$ (gas jet speed)

(2) Pressure thrust (e.g., Light sail, Laser sail, Space drive propulsion): $V_{\max} \approx c$ (quasi-light speed)

Pressure thrust and momentum thrust are completely different. Here is one example: Thrust of about 10% of jet aircraft and rockets is generated by the pressure difference between the atmospheric pressure in front and the high pressure in the rear engine nozzle. In other words, jet aircraft and rockets generate pressure thrust that is pushed from the rear, in addition to the momentum thrust that accelerates the air sucked in from the front or accelerates the injected gas to the rear.

As a representative field propulsion system, space drive propulsion system is the concept of propulsion theory of spaceship not based on momentum thrust but based on pressure thrust derived from an interaction of the spaceship with external fields. Space drive propulsion system is propelled without mass expulsion.

The propulsive force is a pressure thrust which arises from the interaction of space-time around the spaceship and the spaceship itself; the spaceship is propelled against space-time structure. Based on the supposition that space is an infinite continuum like elastic body, space drive propulsion theory induced by space curvature can be possible.

## III. SPACEDRIVE PROPULSION SYSTEM

The principle of space drive propulsion system is derived from General Relativity and the theory of continuum mechanics. We assume the so-called "vacuum" of space as an infinite elastic body like rubber. The curvature of space plays a significant role in propulsion theory. From the gravitational field equation, the strong magnetic field, as well as, mass density generates the curvature of space, and this curved space region produces the uni-directional acceleration field. The spaceship in the curved space can be propelled in a single direction. Since the force they produce acts uniformly on every atom inside the spaceship, accelerations of any magnitude can be produced with no strain on the crews, that is, there is no action of inertial force because the thrust is a body force (i.e., it is equivalent to free-fall). Yoshinari Minami proposed new propulsion theory used General Relativity in 1988. The paper entitled "Space Strain Propulsion System" was presented at 16th ISTS 1988 [2]. After then, Minami presented the second paper entitled "Possibility of Space Drive Propulsion" at 45th IAF 1994 [3]. The term of "space strain" was changed to "space drive" receiving the recommendation by Robert L. Forward [4]. Minami derived the equation of curvature of space induced by magnetic field in 1988. It was found that this equation was in accordance with the equation that Levi-Civita considered (i.e., the static magnetic field creates scalar curvature) by Minami in 1995.

Assuming that vacuum space is an infinite continuum, the propulsion principle utilizes the pressure field derived from the geometrical structure of space, by applying both continuum mechanics and General Relativity to space. The propulsive force is a pressure thrust which arises from the interaction of space-time around the spaceship and the spaceship itself; the spaceship is propelled against space-time continuum structure.

This means that space can be considered as a kind of transparent elastic field. That is, space as a vacuum performs the motions of deformation such as expansion, contraction, elongation, torsion and bending. The latest expanding universe theory (Friedmann, de Sitter, inflationary cosmological model) supports this assumption. Space can be regarded as an elastic body like rubber.

Space drive propulsion system is the concept of propulsion theory of spaceship not based on momentum thrust but based on pressure thrust derived from an interaction of the spaceship with external fields. Accordingly, space drive propulsion system is propelled without mass expulsion. The space drive propulsion system proposed here is utilizing the action through medium of strained or deformed field of space, and is based on the propulsion principle of pressure thrust.

In the following sections, the concept of space drive propulsion, propulsion principle, propulsion mechanism, propulsion operation, characteristics of flight performance, trial calculation of acceleration, and essential power sources are explained. Please refer to the references for details of each part [5, 6, 7 - 21].

### 3.1 Basic Concept of Space Drive Propulsion

When the space curves, a pressure "P" (inward stress) is generated inside the curved surface, and an acceleration field $\alpha$ is generated. The accumulation of many curved thin membrane layers creates a unidirectional acceleration field $\alpha$ (Fig.1).

If space curves, then an inward normal stress "$-P$" is generated. This normal stress, i.e., surface force serves as a sort of pressure field.

$$-P = N \cdot (2R^{00})^{1/2} = N \cdot (1/R_1 + 1/R_2) \;, \tag{3.1}$$

where N is the line stress, $R_1$ , $R_2$ are the radius of principal curvature of a curved surface, and $R^{00}$ is spatial curvature. **(See APPENDIX A for derivation process)**

A large number of curved thin layers form the unidirectional surface force, i.e., acceleration field. Accordingly, the spatial curvature $R^{00}$ produces the acceleration field $\alpha$ .

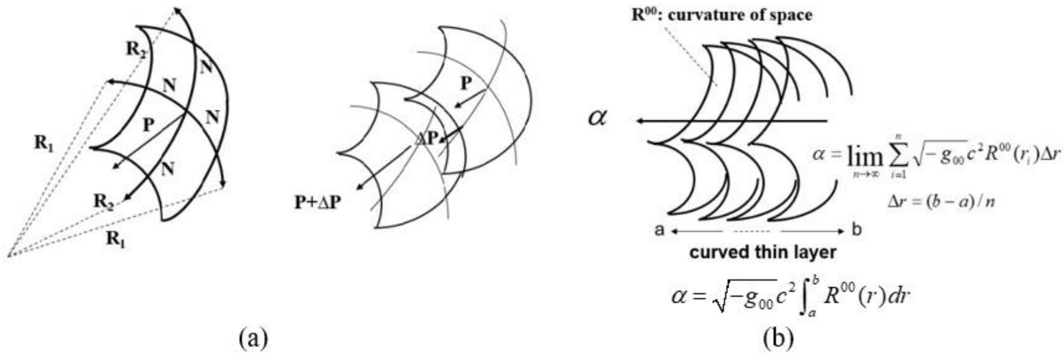



**Fig. 1. Curvature of Space: (a) curvature of space plays a significant role. If space curves, then inward stress (surface force) "P" is generated $\Rightarrow$ A sort of pressure field; (b) a large number of curved thin layers form the unidirectional surface force, i.e., acceleration field $\alpha$ .**

From the following linear approximation scheme for the gravitational field equation:(1) weak gravitational field, i.e., small curvature limit, (2) quasi-static, (3) slow-motion approximation (i.e., $v/c \ll 1$ ), and considering range of curved region, we get the following relation between acceleration of curved space and curvature of space:

$$\alpha = \sqrt{-g_{00}} c^2 \int_a^b R^{00}(r) dr \;, \tag{3.2}$$

where $\alpha$ : acceleration (m/s$^2$), $g_{00}$ : time component of metric tensor (≈ -1), a-b: range of curved space region(m), $r$: direction of the radius of curvature "$r$", $c$: velocity of light, $R^{00}$ : major component of spatial curvature ( $1/m^2$ ). **(See APPENDIX B for derivation process)**

Eq.(3.2) indicates that the acceleration field $\alpha$ is produced in curved space. The intensity of acceleration produced in curved space is proportional to the product of spatial curvature $R^{00}$ and the length of curved region (a to b).

Here, as an example, the mechanism of how an apple falls to the Earth is explained [22,23,24,25]. Gravitational field around the Earth is multiply covered by concentric or spherical curved spaces centered on the Earth. Since the apple exists in the curved spatial region from the curved spatial layer at the apple's position to the curved spatial layer at the distant position, the apple is pushed by the generated curved space (i.e., pressure) and falls. Although the spatial curvature at the surface of the Earth is very small value $R^{00}: 1.71 \times 10^{-23} (1/m^2)$ , it is enough value to produce 1G (9.8 m/s$^2$) acceleration.

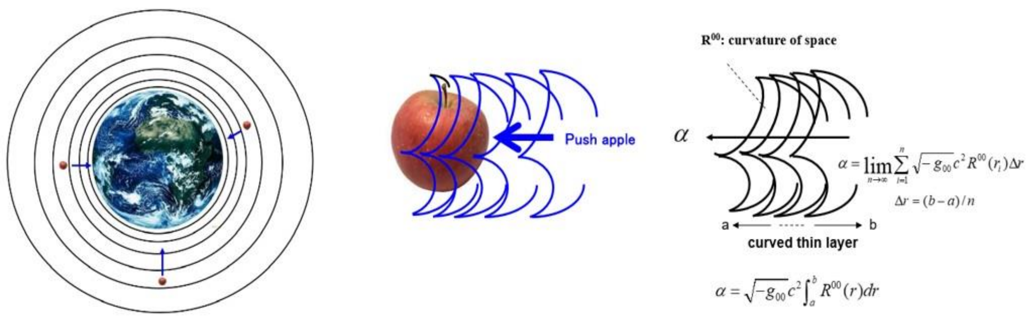



**Fig. 2. Why apples fall: apples on the Earth will not be pulled by the Earth, but will be pushed and fall in the direction of the Earth due to the pressure of the field in the curved space area around the Earth.**

General Relativity expresses the phenomenon of gravity very strictly, but the origin and generation mechanism of the force of gravity are insufficient. The current situation is that there is no convincing explanation of why gravity occurs when the space curves. Curved space, or curvature of space, is purely mathematical geometric quantities, but with the help of continuum mechanics, it is shown that they are related to actual forces. Given a priori assumption that space as a vacuum has a physical fine structure like continuum, it enables us to apply a continuum mechanics to the so-called “vacuum” of space. Applying the continuum mechanics of space to General Relativity, the mechanism of gravity has shown as one possibility [23, 24, 25]. In order to associate the pure geometric quantity of curvature with the actual force, the association between strain and stress in continuum mechanics is important.

Therefore, General Relativity alone cannot explain the force & acceleration generation mechanism of gravity and is not enough to explain the flight performance of UAP.

The propulsion principle of UAP cannot be derived by General Relativity alone. The propulsion principle can be derived from the theory that applies General Relativity and continuum mechanics

**3.2 Space Drive Propulsion Theory**

The theory of space drive propulsion is summarized as follows [9, 10].

1) On the supposition that space is an infinite continuum, continuum mechanics can be applied to the so-called “vacuum” of space. This means that space can be considered as a kind of transparent elastic field. That is, space as a vacuum performs the motion of deformation such as expansion, contraction, elongation, torsion, and bending. The latest expanding universe theory (Friedmann, de Sitter, inflationary cosmological model) supports this assumption. We can regard the space as an infinite elastic body like rubber.

2) From General Relativity, the major component of curvature of space (hereinafter referred to as the major component of spatial curvature) $R^{00}$ can be produced by not only mass density but also magnetic field *B* as follows **(See APPENDIX C for derivation process):**

$$R^{00} = \frac{4\pi G}{\mu_0 c^4} B^2 = 8.2\times10^{-38} B^2 , \tag{3.3}$$

where $\mu_0 = 4\pi\times10^{-7}(H/m)$, $c = 3\times10^8(m/s)$, $G = 6.672\times10^{-11}(N\cdot m^2/kg^2)$, $B$ is a magnetic field with Tesla and $R^{00}$ is a major component of spatial curvature ($1/m^2$ ).

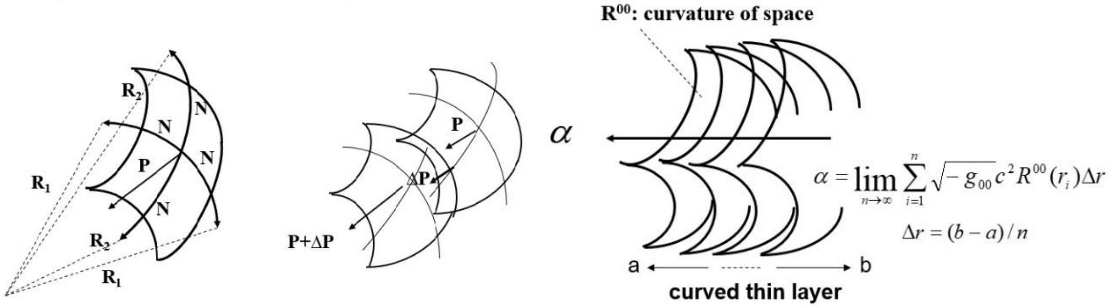
Eq.(3.3) indicates that the major component of spatial curvature can be controlled by magnetic field.

3) If space curves, then inward normal stress “$-P$” is generated (see Fig.1).
This normal stress, i.e., surface force serves as a sort of pressure field (see Eq.3.1).

$$-P = N\cdot(2R^{00})^{1/2} = N\cdot(1/R_1 + 1/R_2), \tag{3.4}$$

where *N* is the line stress, $R_1$,$R_2$ are the radius of principal curvature of the curved surface.

A large number of curved thin layers form the unidirectional surface force, i.e., acceleration field.




4) Accordingly, the spatial curvature $R^{00}$ produces the acceleration $\alpha$ of curved space:

$$\alpha = \sqrt{-g_{00}}\,c^2\int_a^b R^{00}(r)dr , \tag{3.5}$$

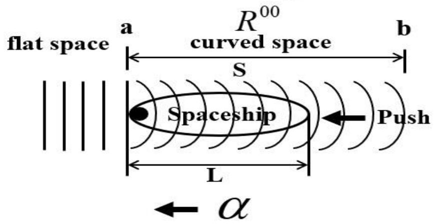
where $\alpha$ : acceleration (m/s$^2$), $g_{00}$ : time component of metric tensor (≈ -1), a-b: range of curved space region(m), $r$: direction of the radius of curvature "$r$", $c$: velocity of light, $R^{00}$ : major component of spatial curvature ($1/m^2$ ).

Eq.(3.5) indicates that the acceleration field $\alpha$ is produced in curved space. The intensity of acceleration produced in curved space is proportional to both spatial curvature and the size of curved space. This equation is an important expression for the acceleration that occurs in regions of curved space. Give not only the acceleration of the propulsion system but also the acceleration of the earth's gravitational force.

As described above, firstly it is necessary for the space to be curved. Because the curvature of flat space $R^{00}$ is zero (strictly speaking, only 20 independent components of Riemann curvature tensor $R_{pijk}$ are zero), then the acceleration $\alpha$ becomes zero. Such a curved space is generated not only by mass density but also by magnetic field or electric field. In case that the intensities of the magnetic field B and the electric field E are equal, the value of $(1/2 \cdot \varepsilon_0 E^2)$ is about seventeen figures smaller than the value of $(B^2/2\mu_0)$ . Consequently, the electric field only negligibly contributes to the spatial curvature as compared with the magnetic field. Accordingly, it is effective that the space can be curved by magnetic field. Since the region of curved space produces the field of acceleration, the massive body existing in this acceleration field (i.e., curved space region) is moved by thrust in accordance with Newton's second law.

Next, the propulsion operation by the engine will be explained using Fig.3, Fig.4 and Fig.5.

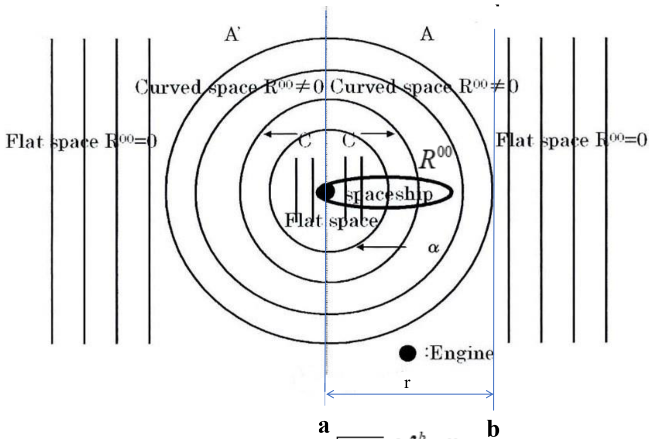
$$\alpha = \sqrt{-g_{00}}c^2 \int_a^b R^{00}(r)dr$$




**A curved space around the spaceship is created by the spaceship engine "●". The spaceship is propelled in one direction by the acceleration of the field generated in the curved space. The magnitude of acceleration $\alpha$ is proportional to the curvature of space $R^{00}$ and the range of the curved space region "s" (a-b).**

**Fig. 3. Propulsion principle by pressure thrust.**

In detail, a curved space around the spaceship is created by the spaceship engine [9, 11, 12].




$$\alpha = \sqrt{-g_{00}}c^2 \int_a^b R^{00}(r)dr$$

**Fig. 4. The spaceship is propelled in one direction by the acceleration of the field generated in the curved space. The magnitude of acceleration is proportional to the curvature of space and the magnitude of the curved space region (a-b).**

In order to propel as described above, the engine "●" of spaceship is first turned on and curves the space to generate a curved space area. Space is curved by a magnetic field. During the transition time when the space-curving engine is turned off and the curved space returns to a flat space, the spaceship and the curved space are independent, so the spaceship is pushed forward from the curved space. Continuous thrust is obtained by repeating this engine on-off operation.

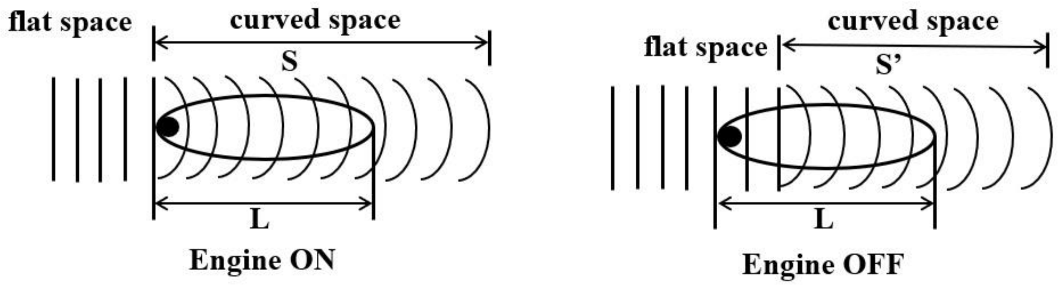



**Fig. 5. Generated a curved space by Engine On-Off.**

In the Fig.5, "●" indicates the engine of the spaceship, which is loaded on the front of the spaceship. When the engine is turned on (Magnetic field of engine: ON), a flat space centered on the engine changes to a curved space, and this change propagates to a space around the engine like ripples. It propagates at the light velocity, which is the distortion rate (deformation rate). Conversely, when the engine is turned off (Magnetic field of engine: OFF), the curved space around the engine changes to a flat space, and this change propagates to a space around the engine like ripples. It propagates at the light velocity, which is the distortion velocity (deformation velocity) of space.

### 3.3 Mechanism and Features of Flight Motion

#### 3.3.1 Omni-directional Propulsion by the Space Curvature Generation Engine

As shown in Fig.6, six engines will be placed on the spaceship in front, back, left, right, up and down so that they can move forth and back, left, right, up and down. Here, for the sake of simplicity, one engine propels in one direction (see the previous Fig.3). In fact, it is possible to move in all directions with three engines by vector synthesis [9, 10, 11, 19].

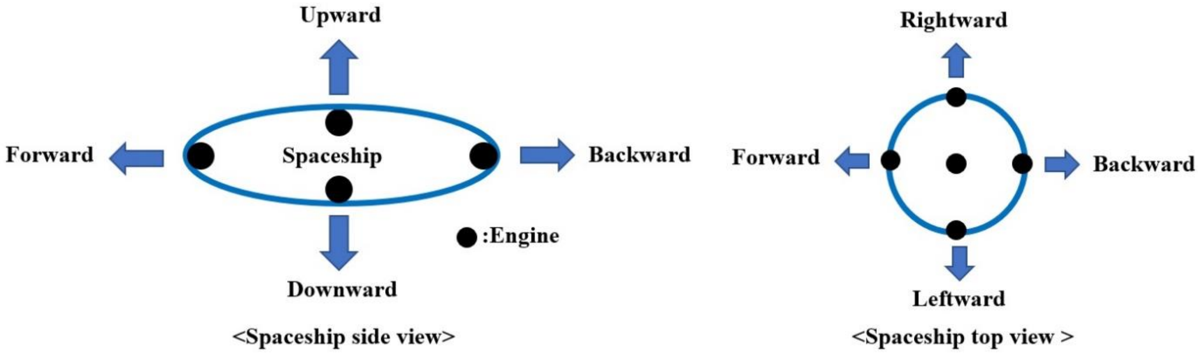



**Fig. 6. Spaceship engine layout.**

Start the engine placed in the front of the spaceship to move the spaceship forward, start the engine placed in the rear of the spaceship to move backward, and start the engine placed in the upper part of the spaceship to raise the spaceship. Start the engine located at the bottom of the spaceship for the spaceship to descend. Also, the engine located on the right side of the spaceship starts to move the spaceship to the right, and the engine placed on the left side of the spaceship starts to move the spaceship to the left.

#### 3.3.2 Spatial Curvature Generation Engine by Convergence of Magnetic Field Lines

As a function of the engine in the previous section, a strong magnetic field is generated by confining and converging magnetic field lines. The magnetic field lines freeze in the plasma and move in conjunction with it. The magnetic field lines converge to one point by narrowing the flow of plasma at any one point in the flow path. By narrowing down the magnetic field lines, the magnetic field is strengthened and the curvature of the space is generated. That is, by narrowing down the plasma in the flow paths at the engine positions at six locations, front, back, left, right, up and down of the spaceship, the magnetic field lines frozen in the plasma are

narrowed down to generate a strong magnetic field. Accordingly, the curvature of the space is generated by strong magnetic field.
It functions as an engine by controlling the flow path of the plasma flow and the route that narrows the diameter of the plasma flow. So, the flow path of the magnetic field lines frozen in the plasma and the control of the magnetic field lines density are important.

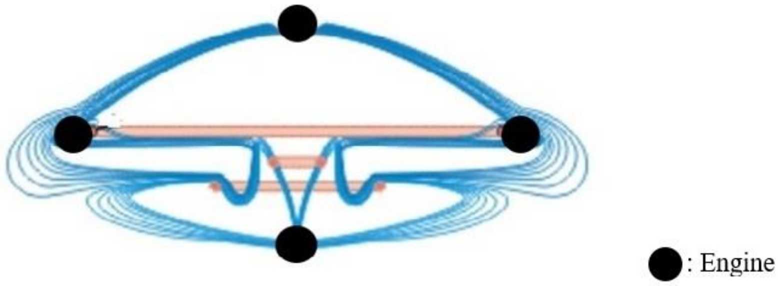



**Fig. 7. Path of magnetic field lines frozen in plasma in spaceship.**

Fig.7 shows the path of magnetic field lines frozen in plasma in spaceship. The blue line is the magnetic field lines frozen in the plasma flow. The plasma flow is narrowed down and the magnetic field lines are converged near the engine black circles on the top, bottom, left, right, front and back of the spaceship.
Fig.8 (a) and Fig.8 (b) show the narrowing down the plasma flow by Pinch effect of compressing plasma. For narrowing down the plasma flow, for example, the plasma confinement technique using the mirror magnetic field shown in the Fig.8 (c) can be used.

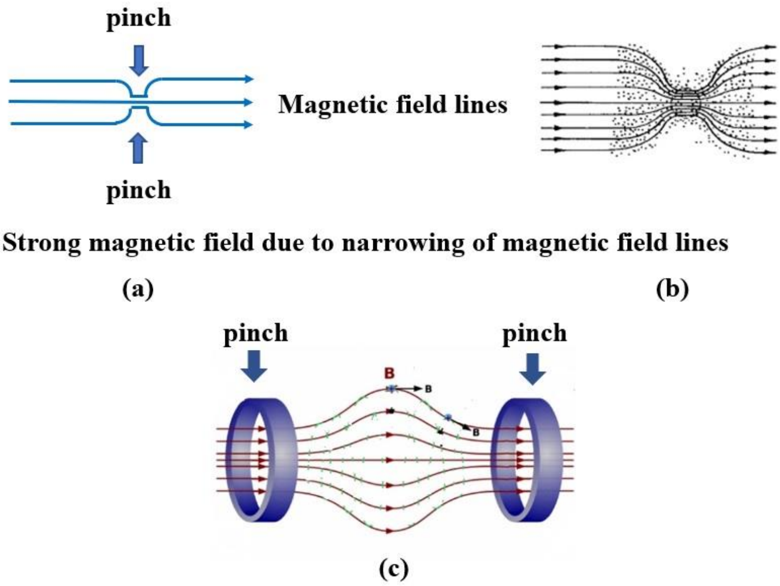



**Fig. 8. Pinch effect of compressing plasma.**

Fig.9 shows the path of magnetic field lines frozen in plasma near engines in spaceship. Engine "●" described in Fig.9 implies the narrowing down the plasma flow by Pinch effect of compressing plasma. The magnetic field lines frozen in the plasma are narrowed down to generate a strong magnetic field, i.e., large spatial curvature.

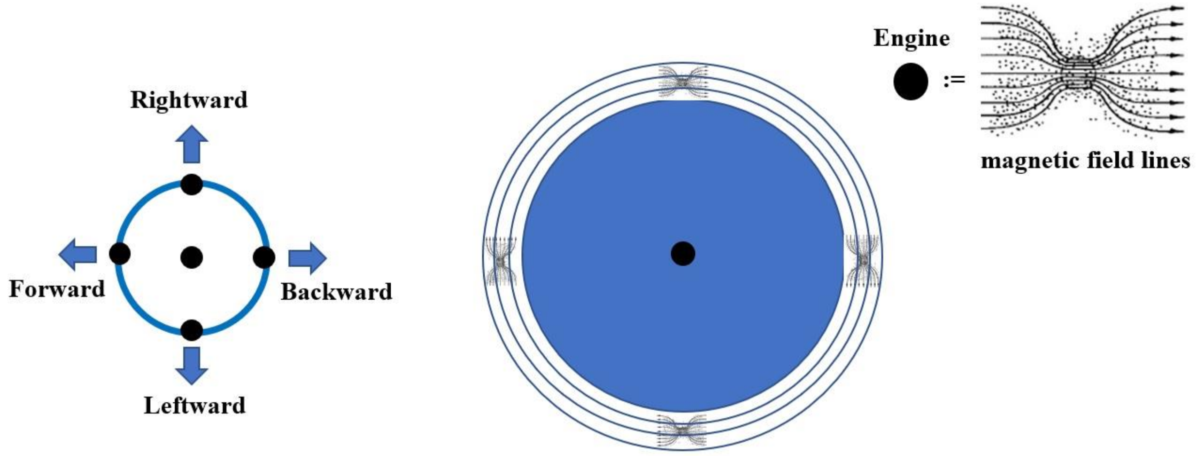



**Fig. 9. Path of magnetic field lines frozen in plasma near engines in spaceship.**

**3.4 Spaceship Flight Performance and Feature**

The spaceship equipped with space drive propulsion system has the following features.

a) There is no action of inertial force because the thrust is a body force. Since the body force they produce acts uniformly on every atom inside the spaceship, accelerations of any magnitude can be produced with no strain on the crews,

b) The flight patterns such as quickly start from stationary state to all directions in the atmosphere, quickly stop, perpendicular turn, and zigzag turn are possible,

c) The final maximum velocity is close to the velocity of light,

d) Since the air around the spaceship is also accelerated together with the spaceship, the aerodynamic heating can be reduced even if the spaceship moves in the atmosphere at high speed (10km/s - 100km/s). However, it is expected that a plasma (ionized air) envelops the spaceship,

e) Since it is an electromagnetic propulsion engine, there is no heat source, noise or exhaust gas associated with combustion,

f) The engine and power source are installed in the spaceship. Therefore, it can fly in the atmosphere of a planet as well as in cosmic space,

g) By pulse control of magnetic field, the acceleration varies from 0G to an arbitrary high acceleration (e.g., 1000G),

h) Deceleration is easy for re-entry into the atmosphere,

i) Similar to item d) above, the seawater around the spaceship is also accelerated together with the spaceship, so the resistance of the seawater is reduced and it is possible to move at high speed in the sea. It is possible to smoothly enter the sea from the atmosphere without splashing water due to a sea surface collision.

Here, we explain the motion of the spaceship in detail using computer graphics as shown in Fig. 10. For the sake of simplicity, the shape of the spaceship is an omni directional disk type.

As shown in Fig.10 (a), the spaceship is able to permeate its local space with a huge amount of energy in a certain direction; this energy should be injected at zero total momentum (in the spaceship-body frame) to excite the local space. Then the excited local space expands instantaneously (Fig.10 (a), (b)). Space including the spaceship is pushed from the expanded space and moves forward (Fig.10 (b)).

***The expression of "moves by being pushed from the expanded space" indicates that the spaceship produces a curved space region and moves forward by being subjected to the thrust from the acceleration field of the curved space.*** The space including the spaceship is propelled to the forward (Fig.10 (c)). Thus, this spaceship is accelerated to the quasi-speed of light by repeating the pulse-like on/off a change of permeating its local space with a huge amount of energy operation (Fig.10 (d), (e)). Changing a place to blow up, the spaceship can move with flight patterns such as quick start from a stationary state to all directions, quickly stop, perpendicular turn, and zigzag turn (Fig.10 (f), (g)). There is no action of inertial force, because the thrust is a body force. Since the body force they produce acts uniformly on every atom inside the spaceship, accelerations of any magnitude can be produced with no strain on the crews inside the spaceship (i.e., same as free fall). Namely, spaceship moves with the whole space around the spaceship, then, even if the spaceship flies about it very intensely, the spaceship holds the stopping state in moving space, and the crews are not shocked at all (Fig.10 (h)).

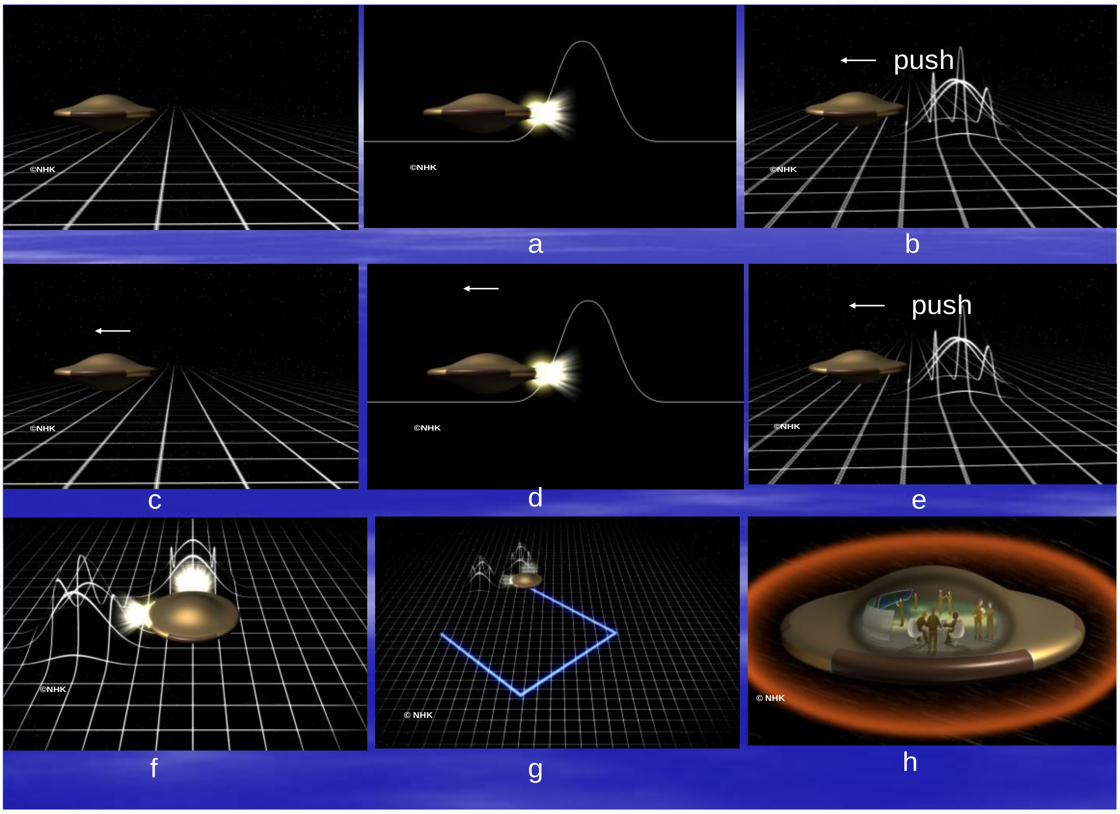
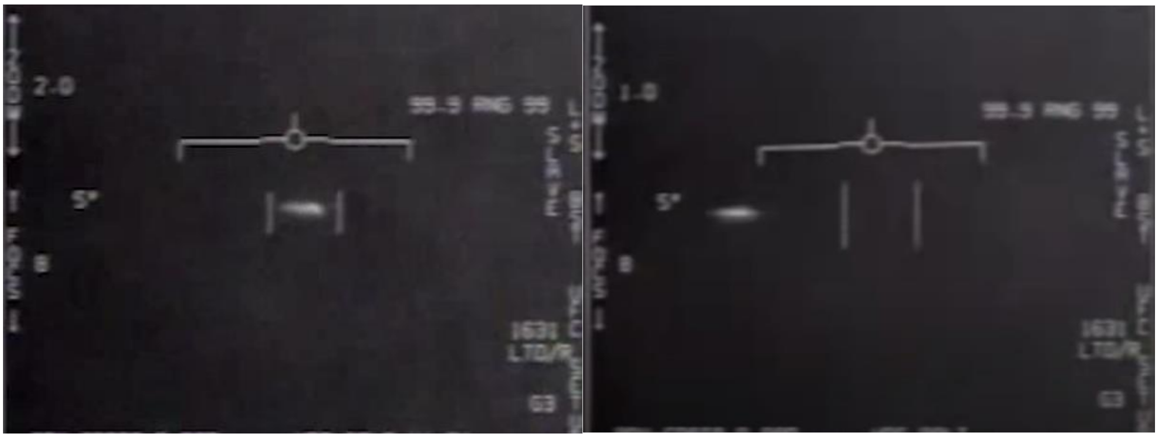



**Fig. 10. A description of the flight operation of a spaceship (© NHK).**

Here, the operation of the spaceship in Fig.11 (a), (b), which is a video of a flying object (UAP) released by the US Department of Defense, is presumed to be the operation in Fig.10 (a), (b), (c).



(a) (b)

**Fig. 11. A video of a flying object released by the US Department of Defense (Quoted from net news).**

### 3.5 Trial Calculation of Acceleration Performance

Fig.12 shows the timing chart of thrust pulse. The net acceleration $\alpha_{NET}$ is given by

$$\alpha_{NET} = 1/2 \cdot \alpha\tau N, \quad t_1 = S/c, \quad t_2 = \tau = L/c, \quad N = 1/(t_1 + t_2 + t_3) \;, \tag{3.6}$$

where $\alpha$ = acceleration obtained by Eq.(3.2) or Eq.(3.5), S= length of curved space region (m), L= length of spaceship (m), c= speed of light (i.e., strain rate of space) (m/s), $\tau$ = effective time of thrust (i.e., thrust pulse width) (s), N= pulse repetition frequency (Hz).

So, the acceleration can be also controlled by N [9, 11].

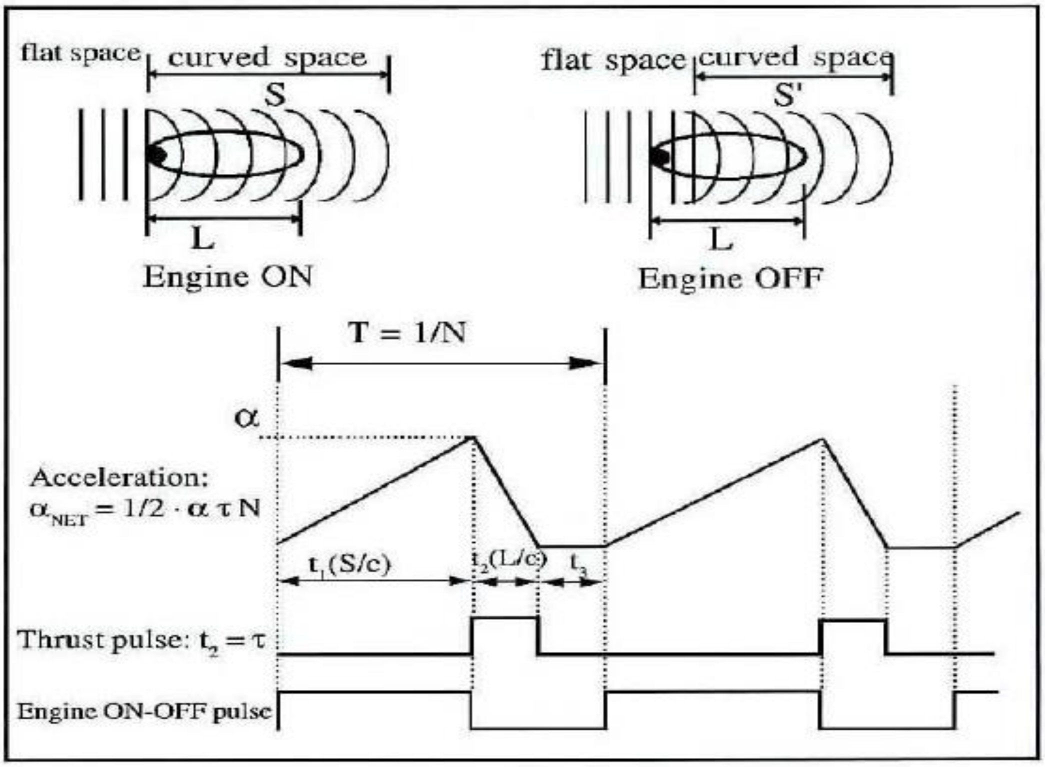



**Fig. 12. Timing chart of thrust pulse.**

Specifically, please refer to the Fig.13 below again.

**A curved space around the spaceship is created by the spaceship engine.**

**The spaceship is propelled in one direction by the acceleration of the field generated in the curved space.**

**The magnitude of acceleration $\alpha$ is proportional to the curvature of space $R^{00}$ and the range of the curved space region "s" (a-b).**

$$\alpha = \sqrt{-g_{00}}\,c^2 \int_a^b R^{00}(r)dr$$

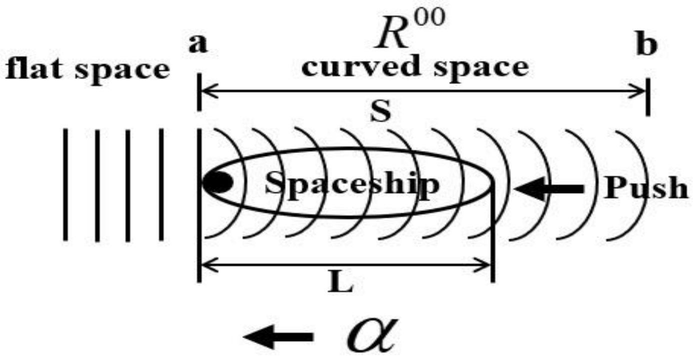



**Fig. 13. Propulsion principle by pressure thrust.**

By substituting Eq.(3.3)&Eq.(3.5) into Eq.(3.6), the following equation is obtained:

$$\alpha_{NET} = \frac{1}{2}\alpha\tau N = \frac{1}{2}\cdot\sqrt{-g_{00}}\,c^2\int_a^b R^{00}(r)dr\cdot\frac{L}{c}N = \frac{1}{2}\cdot\sqrt{-g_{00}}\,c^2\int_a^b \frac{4\pi G}{\mu_0 c^4}\cdot B^2 dr\cdot\frac{L}{c}N \simeq \frac{1}{2}c^2\cdot\frac{4\pi G}{\mu_0 c^4}B^2\cdot S\cdot\frac{L}{c}N$$

, where $S = b - a$, $g_{00} \approx -1$.

**Namely, propulsion acceleration is controlled by magnetic field B and repetition pulse frequency N.**

**UAP acceleration:** $$\alpha_{NET} = \frac{1}{2}c^2 \times 8.2\times 10^{-38} B^2 \times S \times \frac{L}{c} \times N . \quad (3.7)$$

It should be noted, these stars such as white dwarfs, neutron stars, and black holes have a strong magnetic field ($10^8$Tesla－$10^{11}$Tesla). Since the black hole itself does not generate and maintain a magnetic field, the magnetic field is generated by the plasma current of the accretion disk around the black hole.

<Example> L=5m, S=10m $\alpha_{NET} = \frac{1}{2}c^2 \times 8.2\times 10^{-38} B^2 \times S \times \frac{L}{c} \times N = 6\times 10^{-28} B^2 N$ , (1G=9.8m/$s^2$)

B=$10^9$Tesla

$\alpha_{NET} = 6\times 10^{-28} \times 10^{18} N = 6\times 10^{-10} N$

N=1THz=$10^{12}$Hz $\alpha_{NET} = 6\times 10^{-10} N = 6\times 10^{-10} \times 10^{12} = 600 m/s^2 = 61G$

N=20THz $\alpha_{NET} = 6\times 10^{-10} N = 6\times 10^{-10} \times 2\times 10^{13} = 12000 m/s^2 = 1224G$

B=$10^{10}$Tesla

$\alpha_{NET} = 6\times 10^{-28} \times 10^{20} N = 6\times 10^{-8} N$

N=1THz=$10^{12}$Hz $\alpha_{NET} = 6\times 10^{-8} \times 10^{12} = 6\times 10^4 m/s^2 = 6122G$

N=200GHz $\alpha_{NET} = 6\times 10^{-8} \times 2\times 10^{11} = 12\times 10^3 m/s^2 = 1224G$

N=2GHz $\alpha_{NET} = 6\times 10^{-8} \times 2\times 10^9 = 120 m/s^2 = 12G$

### 3.6 Spaceship Power Generation Method

#### 3.6.1 Plasme Vortex Engine

Any propulsion systems, i.e., not only conventional propulsion but also space drive propulsion, require huge energy sources due to their performance for producing high acceleration and high speed. This energy problem is common to all propulsion systems if high speed is required.

In general, a spaceship (mass of M) traveling at a speed V needs the kinetic energy of $E_K = \frac{1}{2}MV^2$. For instance, a spaceship traveling at a speed equal to 0.1 c has a specific kinetic energy equal to 450 TJ per kilogram (of spaceship mass). The required energy of spaceship of 100 ton at a speed of 0.1 c is $4.5\times 10^{19}$ Joules. Its power source in any propulsion system must provide huge energies, that is, $E = Pt$ ( $P$ is power in watts, $t$ (s) is acceleration and deceleration time).

Although this energy problem is common to all propulsion systems, space drive propulsion system is not based on negative rest mass matter as it is commonly said, but allowable the following new technology.

This section introduces a method in which a strong magnetic field for generating spatial curvature and its power source can be solved simultaneously with only one single technology: **Massive charged particle generation by plasma black vortex (quasi-mini black hole) is the key technology; strong magnetic field generation and power source.**

The plasma black vortex has a function of electromagnetically generating a funnel-shaped vortex tornado such as a black hole for attracting charged particles. In other words, it is an electromagnetic spiral quasi-mini black hole that functionally simulates a quasi-black hole and an accretion disk. Fig.14 shows the plasma black vortex [10, 11, 19, 26].

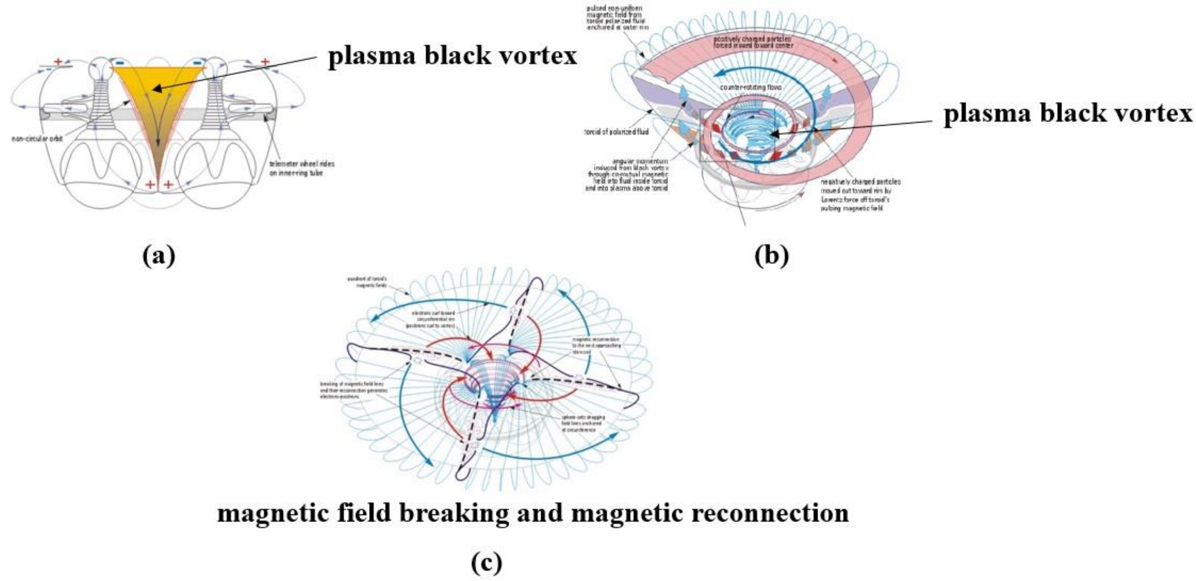



**Fig. 14**. **Outline of Main Engine: Plasma black vortex, breaking and remaking of magnetic field lines (Quoted [26]).**

The main engine (plasma black vortex) behaves based on dynamics of a black hole surrounded by a reflecting sphere wall. The central part of this main engine develops an electromagnetic vortex, so that electrically charged particles are drawn into this vortex. Magnetic fields are empowered to do work on these electrically charged particles (Fig.14 (a), (b)).

The astrophysical jet formation mechanism and the energy generation method by accretion disk centered on black hole hold the possibility of applying to a new propulsion system. These mechanisms are induced by electron-positron generation from magnetic flux reconnection, electron-positron production through the virtual energy field in vacuum space, avalanche productions of more electron-positron pairs, etc. Such a charged particles generating means is effective for generation of power source and strong magnetic field.

In astrophysics, a magnetic field reconnection can be working in all areas of universe at all times. It works not only on the surface of the sun and in the sun's solar flares but also the rotating fields of accretion disks. As is well known, the magnetic field reconnection will provide copious productions of electron-positron charged particles, and it will produce so much energy. The magnetic reconnection is considered to be promising as a solar flare energy release mechanism.

Around accretion disk, the shearing-reconnection of strong magnetic field produces a dynamo effect which gives a rapid amplification of any incoming and smaller electrical field of charged particles (seed field). So, they will develop into the much larger field and go on to accelerate particles which will collide with other particles, to produce more particles, and more collisions, which subsequently will lead to avalanche productions of more electron-positron pairs.

The breaking and remaking of magnetic field lines produce and then amplifies amounts of electrons and positrons from what some have called the 'empty' vacuum of space as shown in Fig.14 (c). After all, the key is energy generation by magnetic field breaking and magnetic reconnection. Because, large production of charged particles by electron avalanche phenomenon and generation of electron-positron pairs accompanying this can be utilized.

**The generation of a large amount of charged particles brings about the generation of a large current, and it is possible to generate a strong magnetic field from this large current. A strong magnetic field is indispensable for the spatial curvature generation as a propulsion system. The strong magnetic field and the power source for the spatial curvature generation of space drive propulsion system can be simultaneously solved by a just single technology.**

### 3.6.2 Released Gravitational Energy

The essential of the accretion disk is that the role of the power generation function to extract the gravitational energy of the black hole and the role of the strong magnetic field generation can be utilized for the propulsion system. The system of a black hole and accretion disk is a gravitational power station of cosmic space. The release of gravitational energy works only when black hole and plasma gas of accretion disk exist. Energy can be extracted from the plasma gas when the plasma gas as fuel falls to the gravitational potential well created by the black hole. However, the gravitational energy cannot be released by free fall where the plasma gas mass is simply sucked into the black hole.

Differential rotation of plasma gas due to viscosity becomes important. When we take out the plug of the bath, water is sucked into the hole while swirling. In the same way, it is important that the plasma gas falls slowly while rotating slowly by the speed difference due to the viscosity in the adjacent gas layers.

When the plasma gas falls to the gravity well of the black hole, enormous energy can be extracted from the falling plasma gas. When the rotating plasma gas of the accretion disk loses its angular momentum due to the viscosity of the gas and gradually moves to the inner trajectory, the gravitational energy becomes excessive by the difference of the gravity gradient of the black hole. Half of the surplus extra gravitational energy is spent to increase the rotation while the other half is used to heat the plasma gas of accretion disk through viscosity (friction). Finally, it is converted into light and released from the accretion disk [10, 11, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36].

The viscosity in the accretion disk plays two important roles: transport of angular momentum and heating of the disk plasma. Here, we indicate the released gravitational energy.

Although it is impossible to manufacture a quasi-black hole or mini black hole as a device in the spaceship, it may be possible to electromagnetically produce the function of an accretion disk.

Applying the same mechanism to the Coulomb force by the electric field instead of gravitational field, the half of local potential energy dE released by accreting plasma charge dq falling in the plasma potential well from r to r-dr is obtained as follows:

$$E_{rotation} = E_{radiate} = \frac{1}{2}(dE = E(r) - E(r-dr)) = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Qdqdr}{2r^2}, \tag{3.8}$$

where Q is the electric charge of quasi-black hole model, $\varepsilon_0 = 8.85 \times 10^{-12}(F/m) = 1/36\pi \times 10^{-9}(F/m)$.

Even in the case of electric field energy, energy release is done as well as the gravitational field of the black hole. Although the released energy is somewhat less than the black hole (it is large enough), the accretion disk by the electric field is considerably compact compared to the astrophysical scale [10, 11].

The current during a lightning strike is said to be several hundred thousand amperes.

If the current is set to 1,000,000 A, which is slightly larger than several hundred thousand amperes at the time of a lightning strike, a current of 1,000,000 A moves a charge of 1,000,000 C per second.

Q = 1000000C, dq=0.01C, dr=0.1m, r=1m, we get

$$dE = \frac{1}{4\pi\varepsilon_0} \times \frac{Qdqdr}{2r^2} = \frac{1}{4\pi \times 8.85 \times 10^{-12}} \times \frac{10^6 \times 0.01 \times 0.1}{2 \times 1^2} = \frac{1}{222 \times 10^{-9}} \simeq 4.5 \times 10^{12} J = 4.5TJ$$

The current value for a lightning strike is quite modest compared to that for an astronomical phenomenon such as a solar flare. It is predicted that there is a possibility that power of several 100 Tera watts can be obtained depending on the design. **Note that this is just a hypothetical calculation.**

**<General Overview>**

The curvature of space plays an important role. The strong magnetic field generation and its power for spatial curvature generation are implemented by a single technology.

The following is key technology:

① A large amount of charged particles produced by avalanche phenomenon, and thereby strong current and strong magnetic field generation.

② Energy generation by magnetic field breaking and magnetic reconnection.

The basic concept is based on the astrophysics of black holes and accretion disks around black holes. The gas of the accretion disk is plasma made of ions and electrons. The release of gravitational energy does not occur if the gas does not gradually in falls (accretes) toward the center object.

The viscosity due to differential rotation between gases starts gas accretion. The viscosity generates frictional heat and heats the gas. First of all, ions in the plasma gas are heated by frictional heat due to viscosity. Friction works in the same manner for both ions and electrons, but since ions are larger in mass than electrons, ions will consequently have greater thermal motion energy.

It is necessary to electromagnetically generate a funnel-shaped vortex like a plasma hole to draw charged particles [35, 36]. As we initially thought, it is important how to generate the curvature of space concentrating the strong magnetic field generated by the gigantic current, which is caused by the flow of charged particles as an engine. **Notice that the current is not the current flowing through the coil or wire, but the charged particles move in the space.**

The detailed studies will be carried out, such as plasma black vortex simulating accretion disk by plasma hole and large quantity charged particle generation, energy generation by the breaking and reconnection of magnetic

field lines. In any case, it is necessary to generate electromagnetically a funnel-like vortex tornado such as a black hole for drawing charged particles. That is, we must create an electromagnetic spiral quasi-mini black hole that functionally simulates quasi black hole and accretion disk.
A large current generates a strong magnetic field. The magnetic field lines are concentrated at four places in the circumferential direction of the spaceship, and at two places on the upper side and the lower side of the spaceship, in order to generate curvature of space and generate acceleration. The magnetic field lines are hollow paths so as not to be affected by magnetic pressure, and large currents are also routed not through the electric wire having the usual electrical resistance or inductance, but through spaces. Charged particles only flow in space.
Concerning Magnetic Flux Break-Reconnection, it is observed in all astronomical phenomena, such as solar flares and accretion disks, and the enormous energy stored in the magnetic field is released immediately by the disconnection of magnetic field lines and subsequent recombination. The magnetic field lines are cut and immediately rejoined (recombination). Magnetic field energy is emitted at the time of this recombination.
During this time, a large amount of charged particles of electron-positron (electrons and positrons) are generated, and photons are generated as γ-rays by annihilation of electrons and positrons.

## IV. CONCLUSION

In response to an Unidentified Aerial Phenomena (UAP) investigation report released by the US Department of Defense in June 2021, NASA forms a team of scientists this fall to begin investigating unidentified aerial phenomena (UAPs).

According to the report released by the US DoD, "A Handful of UAP Appear to Demonstrate Advanced Technology: observers reported unusual UAP movement patterns or flight characteristics. Some UAP appeared to remain stationary in winds aloft, move against the wind, maneuver abruptly, or move at considerable speed, without discernible means of propulsion." is described [1, 37].
At the present stage of space propulsion technology, the only practical propulsion system is a chemical propulsion system and an electric propulsion system, which are based on the expulsion of a mass to induce a momentum thrust. Unfortunately, this method cannot solve the problem due to the theoretical limit of performance.
Thus, the breakthrough of propulsion method has been required until now.

On the other hand, Space Drive Propulsion System is the concept of propulsion theory of spaceship not based on momentum thrust but based on pressure thrust derived from an interaction of the spaceship with external fields. Space drive propulsion system is propelled without mass expulsion. The propulsive force is a pressure thrust which arises from the interaction of space-time around the spaceship and the spaceship itself; the spaceship is propelled against space-time structure.
We must be familiar with the nature of space-time. The principle of space drive propulsion system is derived from General Relativity and the theory of continuum mechanics. We assume the so-called "vacuum" of space as an infinite elastic body like rubber. The curvature of space plays a significant role in propulsion theory. The new propulsion theory as the space drive propulsion system has already been completed. A basic design study of the Plasme Vortex Engine that electromagnetically produces the function of an accretion disk is required in the future.

The flight performance and flight characteristics of space drive propulsion system homologize those of the UAP, so the flight performance of UAP is theoretically explained.
As a result, this paper describes the propulsion principle, the propulsion mechanism, the characteristics of flight performance resulting from them, and the theoretical background for UAP.
We expect that it will be one of the solutions for NASA's UAP study group.

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Finally, the author sincerely thanks for their excellent books continuously guiding this research [38, －, 48, 49].

**APPENDIX A: Generation of Surface Force Induced by Spatial Curvature**

On the supposition that space is an infinite continuum, continuum mechanics can be applied to the so-called "vacuum" of space. This means that space can be considered as a kind of transparent field with elastic properties.

If space curves, then an inward normal stress "$-P$" is generated. This normal stress, i.e., surface force serves as a sort of pressure field.

$$-P = N \cdot (2R^{00})^{1/2} = N \cdot (1/R_1 + 1/R_2), \tag{A1}$$

where N is the line stress, $R_1, R_2$ are the radius of principal curvature of curved surface,and $R^{00}$ is the major component of spatial curvature.

A large number of curved thin layers form the unidirectional surface force, i.e., acceleration field. Accordingly, the spatial curvature $R^{00}$ produces the acceleration field $\alpha$.

The fundamental three-dimensional space structure is determined by quadratic surface structure. Therefore, a Gaussian curvature $K$ in two-dimensional Riemann space is significant. The relationship between $K$ and the major component of spatial curvature $R^{00}$ is given by:

$$K = \frac{R_{1212}}{(g_{11}g_{22} - g_{12}{}^2)} = \frac{1}{2} \cdot R^{00}, \tag{A2}$$

where $R_{1212}$ is non-zero component of Riemann curvature tensor.

**<Reference matters for Eq.(A2)>**

For a spherical surface of radius r, its Gaussian curvature K is 1 / $r^2$.

The scalar curvature R and the Gaussian curvature K on the quadratic surface are as follows:

$$R = R_i{}^i = g^{ij}R_{ij} = g^{11}R_{11} + g^{22}R_{22} = \frac{1}{r^2}(-1) + \frac{1}{r^2 \sin^2\theta}(-\sin^2\theta) = -\frac{2}{r^2} = -2K$$

The scalar curvature $R$ (1/m$^2$) on a four-dimensional surface is given by

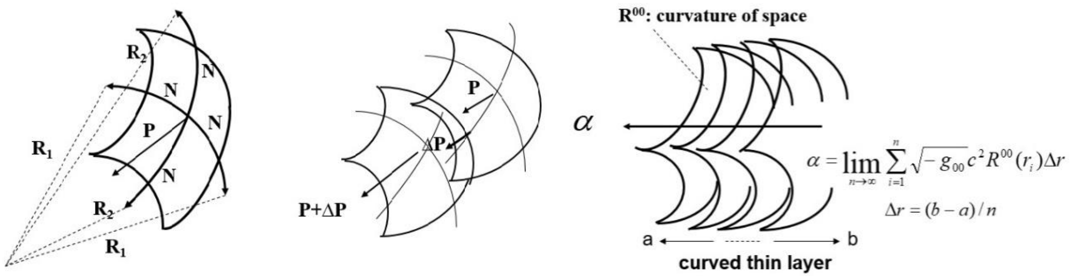
$$R = R_i{}^i = g_{ij}R^{ij} = g_{00}R^{00} + g_{11}R^{11} + g_{22}R^{22} + g_{33}R^{33} \approx g_{00}R^{00} = -R^{00}\ (g_{00} \approx -1: weak\ field)$$

Thus $K = \frac{1}{2} \cdot R^{00}$ is obtained.

It is now understood that the membrane force on the curved surface and each principal curvature generates the normal stress "$-P$" with its direction normal to the curved surface as a surface force. The normal stress "$-P$"acts towards the inside of the surface as shown in Fig. A1 (a).

A thin-layer of curved surface will take into consideration within a spherical space having a radius of $R$ and the principal radii of curvature that are equal to the radius ($R_1$=$R_2$=$R$). Since the membrane force $N$ (serving as the line stress) can be assumed to have a constant value, Eq.(A1) indicates that the curvature $R^{00}$ generates the inward normal stress $P$ of the curved surface. The inwardly directed normal stress serves as a pressure field.

When the curved surfaces are included in a great number, some type of unidirectional pressure field is formed. A region of curved space is made of a large number of curved surfaces and they form the field as a unidirectional surface force (i.e. normal stress). Since the field of the surface force is the field of a kind of force, the force accelerates matter in the field, i.e., we can regard the field of the surface force as the acceleration field. A large number of curved thin layers form the unidirectional acceleration field (Fig. A1 (b)). Accordingly, the spatial curvature $R^{00}$ produces the acceleration field $\alpha$.Therefore, the curvature of space plays a significant role to generate pressure field.




(a) (b)

**Fig. A1.** Curvature of Space: (**a**) curvature of space plays a significant role. If space curves, then inward stress (surface force) "P" is generated ⇒ A sort of pressure field; (**b**) a large number of curved thin layers form the unidirectional surface force, i.e. acceleration field $\alpha$ .

Applying membrane theory, the following equilibrium conditions are obtained in quadratic surface, given by:

$$N^{\alpha\beta} b_{\alpha\beta} + P = 0 , \qquad \text{(A3)}$$

where $N^{\alpha\beta}$ is a membrane force, i.e. line stress of curved space, $b_{\alpha\beta}$ is second fundamental metric of curved surface, and P is the normal stress on curved surface [38].

The second fundamental metric of curved space $b_{\alpha\beta}$ and principal curvature $K_{(i)}$ has the following relationship using the metric tensor $g_{\alpha\beta}$ ,

$$b_{\alpha\beta} = K_{(i)} g_{\alpha\beta} \quad . \qquad \text{(A4)}$$

Therefore, we get:

$$N^{\alpha\beta} b_{\alpha\beta} = N^{\alpha\beta} K_{(i)} g_{\alpha\beta} = g_{\alpha\beta} N^{\alpha\beta} K_{(i)} = N_{\alpha}{}^{\alpha} K_{(i)} = N \cdot K_{(i)} \quad . \qquad \text{(A5)}$$

From Eq.(A3) and Eq.(A5), we get:

$$N_{\alpha}{}^{\alpha} K_{(i)} = -P \quad . \qquad \text{(A6)}$$

As for the quadratic surface, the indices $\alpha$ and i take two different values, i.e. 1 and 2, therefore Eq.(A6) becomes:

$$N_1{}^1 K_{(1)} + N_2{}^2 K_{(2)} = -P , \qquad \text{(A7)}$$

where $K_{(1)}$ and $K_{(2)}$ are principal curvature of curved surface and are inverse number of radius of principal curvature (i.e., $1/R_1$ and $1/R_2$).

The Gaussian curvature K is represented as:

$$K = K_{(1)} \cdot K_{(2)} = (1/R_1) \cdot (1/R_2) \quad . \qquad \text{(A8)}$$

Accordingly, suppose $N_1{}^1 = N_2{}^2 = N$ , we get:

$$N \cdot (1/R_1 + 1/R_2) = -P \quad . \qquad \text{(A9)}$$

It is now understood that the membrane force on the curved surface and each principal curvature generate the normal stress "*–P*" with its direction normal to the curved surface as a surface force. The normal stress "*–P*" is towards the inside of surface as showing in Fig. A1 (a).

A thin-layer of curved surface will be taken into consideration within a spherical space having a radius of R and the principal radii of curvature which are equal to the radius ($R_1=R_2=R$). From Eqs. (A2) and (A8), we then get:

$$K = \frac{1}{R_1} \cdot \frac{1}{R_2} = \frac{1}{R^2} = \frac{R^{00}}{2} \quad . \qquad \text{(A10)}$$

Considering $N \cdot (2/R) = -P$ of Eq.(A9), and substituting Eq.(A10) into Eq.(A9), the following equation is obtained:

$$-P = N \cdot \sqrt{2R^{00}} \quad . \qquad \text{(A11)}$$

Since the membrane force *N* (serving as the line stress) can be assumed to have a constant value, Eq.(A11) indicates that the curvature $R^{00}$ generates the inward normal stress *P* of the curved surface. The inwardly directed normal stress serves as a kind of pressure field. Accordingly, the cumulated curved region of curvature $R^{00}$ produces the acceleration field $\alpha$ .

Here, we give an account of curvature $R^{00}$ in advance. The solution of metric tensor $g^{\mu\nu}$ is found by gravitational field equation as the following:

$$R^{\mu\nu} - \frac{1}{2} \cdot g^{\mu\nu} R = -\frac{8\pi G}{c^4} \cdot T^{\mu\nu} , \qquad \text{(A12)}$$

where $R^{\mu\nu}$ is the Ricci tensor, $R$ is the scalar curvature, $G$ is the gravitational constant, $c$ is the velocity of light, $T^{\mu\nu}$ is the energy momentum tensor.

Furthermore, we have the following relation for scalar curvature $R$ :

$$R = R^{\alpha}{}_{\alpha} = g^{\alpha\beta} R_{\alpha\beta}, \; R^{\mu\nu} = g^{\mu\alpha} g^{\nu\beta} R_{\alpha\beta}, \; R_{\alpha\beta} = R^{j}{}_{\alpha j\beta} = g^{ij} R_{i\alpha j\beta} . \qquad \text{(A13)}$$

Ricci tensor $R_{\mu\nu}$ is also represented by:

$$R_{\mu\nu} = \Gamma^{\alpha}_{\mu\alpha,\nu} - \Gamma^{\alpha}_{\mu\nu,\alpha} - \Gamma^{\alpha}_{\mu\nu}\Gamma^{\beta}_{\alpha\beta} + \Gamma^{\alpha}_{\mu\beta}\Gamma^{\beta}_{\nu\alpha} \quad (= R_{\nu\mu}) , \qquad \text{(A14)}$$

where $\Gamma^{i}{}_{jk}$ is Riemannian connection coefficient.

If the curvature of space is very small, the term of higher order than the second can be neglected, and Ricci tensor becomes:

$$R_{\mu\nu} = \Gamma^{\alpha}_{\mu\alpha,\nu} - \Gamma^{\alpha}_{\mu\nu,\alpha} . \qquad \text{(A15)}$$

The major curvature of Ricci tensor ( $\mu = \nu = 0$ ) is calculated as follows:

$$R^{00} = g^{00} g^{00} R_{00} = -1 \times -1 \times R_{00} = R_{00} . \qquad \text{(A16)}$$

As previously mentioned, Riemannian geometry is a geometry that deals with a curved Riemann space, therefore a Riemann curvature tensor is the principal quantity. All components of Riemann curvature tensor are zero for flat space and non-zero for curved space. If an only non-zero component of Riemann curvature tensor exists, the space is not flat space but curved space. Therefore, the curvature of space plays a significant role.

**APPENDIX B: Acceleration Induced by Spatial Curvature**

A massive body causes the curvature of space-time around it, and a free particle responds by moving along a geodesic line in that space-time. The path of free particle is a geodesic line in space-time and is given by the following geodesic equation;

$$\frac{d^2 x^i}{d\tau^2} + \Gamma^{i}_{jk} \cdot \frac{dx^j}{d\tau} \cdot \frac{dx^k}{d\tau} = 0, \qquad \text{(B1)}$$

where $\Gamma^{i}{}_{jk}$ is Riemannian connection coefficient, $\tau$ is proper time, $x^i$ is four-dimensional Riemann space, that is, three-dimensional space ($x=x^1$, $y=x^2$, $z=x^3$) and one-dimensional time ($w=ct=x^0$), where c is the velocity of light. These four coordinate axes are denoted as $x^i$ (i=0, 1, 2, 3).

Proper time is the time to be measured in a clock resting for a coordinate system. We have the following relation derived from an invariant line element $ds^2$ between Special Relativity (flat space) and General Relativity (curved space):

$$d\tau = \sqrt{-g_{00}}\, dx^0 = \sqrt{-g_{00}}\, cdt . \qquad \text{(B2)}$$

From Eq.(B1), the acceleration of free particle is obtained by

$$\alpha^i = \frac{d^2 x^i}{d\tau^2} = -\Gamma^{i}_{jk} \cdot \frac{dx^j}{d\tau} \cdot \frac{dx^k}{d\tau} . \qquad \text{(B3)}$$

As is well known in General Relativity, in the curved space region, the massive body "$m$ (kg)" existing in the acceleration field is subjected to the following force $F^i$ (N) :

$$F^i = m\Gamma^{i}_{jk} \cdot \frac{dx^j}{d\tau} \cdot \frac{dx^k}{d\tau} = m\sqrt{-g_{00}}\, c^2 \Gamma^{i}_{jk} u^j u^k = m\alpha^i , \qquad \text{(B4)}$$

where $u^j$,$u^k$ are the four velocity, $\Gamma^{i}{}_{jk}$ is the Riemannian connection coefficient, and $\tau$ is the proper time.

From Eqs.(B3),(B4), we obtain:

$$\alpha^i = \frac{d^2 x^i}{d\tau^2} = -\Gamma^{i}_{jk} \cdot \frac{dx^j}{d\tau} \cdot \frac{dx^k}{d\tau} = -\sqrt{-g_{00}}\, c^2 \Gamma^{i}{}_{jk} u^j u^k . \qquad \text{(B5)}$$

Eq.(B5) yields a simpler equation from the condition of linear approximation, that is, weak-field, quasi-static, and slow motion (speed v << speed of light $c$: $u^0 \approx 1$):

$$\alpha^i = -\sqrt{-g_{00}} \cdot c^2 \Gamma^i_{00} \quad . \tag{B6}$$

On the other hand, the major component of spatial curvature $R^{00}$ in the weak field is given by

$$R^{00} \approx R_{00} = R^{\mu}_{0\mu 0} = \partial_0 \Gamma^{\mu}_{0\mu} - \partial_{\mu} \Gamma^{\mu}_{00} + \Gamma^{\nu}_{0\mu} \Gamma^{\mu}_{\nu 0} - \Gamma^{\nu}_{00} \Gamma^{\mu}_{\nu\mu} \quad . \tag{B7}$$

In the nearly Cartesian coordinate system, the value of $\Gamma^{\mu}_{\nu\rho}$ are small, so we can neglect the last two terms in Eq.(B7), and using the quasi-static condition we get

$$R^{00} = -\partial_{\mu} \Gamma^{\mu}_{00} = -\partial_i \Gamma^i_{00} \quad . \tag{B8}$$

From Eq.(B8), we get formally

$$\Gamma^i_{00} = -\int R^{00}(x^i) dx^i \quad . \tag{B9}$$

Substituting Eq.(B9) into Eq.(B6), we obtain

$$\alpha^i = \sqrt{-g_{00}}\, c^2 \int R^{00}(x^i) dx^i \quad . \tag{B10}$$

Accordingly, from the following linear approximation scheme for the gravitational field equation:(1) weak gravitational field, i.e. small curvature limit, (2) quasi-static, (3) slow-motion approximation (i.e., $v/c \ll 1$), and considering range of curved region, we get the following relation between acceleration of curved space and curvature of space:

$$\alpha^i = \sqrt{-g_{00}}\, c^2 \int_a^b R^{00}(x^i) dx^i \, , \tag{B11}$$

where $\alpha^i$ : acceleration (m/s$^2$), $g_{00}$ : time component of metric tensor, a-b: range of curved space (m), $x^i$: components of coordinate ($i$=0,1,2,3), $c$: velocity of light, $R^{00}$ : major component of spatial curvature(1/m$^2$).

Eq.(B11) indicates that the acceleration field $\alpha^i$ is produced in curved space. The intensity of acceleration produced in curved space is proportional to the product of spatial curvature $R^{00}$ and the length of curved region.

Eq.(B4) yields more simple equation from above-stated linear approximation ($u^0 \approx 1$),

$$F^i = m\sqrt{-g_{00}}\, c^2 \Gamma^i_{00} u^0 u^0 = m\sqrt{-g_{00}}\, c^2 \Gamma^i_{00} = m\alpha^i = m\sqrt{-g_{00}}\, c^2 \int_a^b R^{00}(x^i) dx^i \, . \tag{B12}$$

Setting $i$=3 (i.e., direction of radius of curvature: $r$), we get Newton's second law:

$$F^3 = F = m\alpha = m\sqrt{-g_{00}}\, c^2 \int_a^b R^{00}(r) dr = m\sqrt{-g_{00}}\, c^2 \Gamma^3_{00} \quad . \tag{B13}$$

The acceleration ($\alpha$) of curved space and its Riemannian connection coefficient ($\Gamma^3_{00}$) are given by:

$$\alpha = \sqrt{-g_{00}}\, c^2 \Gamma^3_{00} \, , \qquad \Gamma^3_{00} = \frac{-g_{00,3}}{2g_{33}} \, , \tag{B14}$$

where $c$: velocity of light, $g_{00}$ and $g_{33}$: component of metric tensor, $g_{00,3}$: $\partial g_{00}/\partial x^3 = \partial g_{00}/\partial r$. We choose the spherical coordinates "$ct=x^0$, $r=x^3$, $\theta=x^1$, $\varphi=x^2$ " in space-time. The acceleration $\alpha$ is represented by the equation both in the differential form and in the integral form. Practically, since the metric is usually given by the solution of gravitational field equation, the differential form has been found to be advantageous.

**APPENDIX C: Curvature Control by Magnetic Field**

Let us consider the electromagnetic energy tensor $M^{ij}$ . In this case, the solution of metric tensor $g_{ij}$ is found by

$$R^{ij} - \frac{1}{2} \cdot g^{ij} R = -\frac{8\pi G}{c^4} \cdot M^{ij} \quad . \tag{C.1}$$

Eq.(C.1) determines the structure of space due to the electromagnetic energy.

Here, if we multiply both sides of Eq.(C.1) by $g_{ij}$ , we obtain

$$g_{ij}\left(R^{ij}-\frac{1}{2}\cdot g^{ij}R\right)=g_{ij}R^{ij}-\frac{1}{2}\cdot g_{ij}g^{ij}R=R-\frac{1}{2}\cdot 4R=-R\,, \tag{C.2}$$

$$g_{ij}\left(\frac{-8\pi G}{c^4}\cdot M^{ij}\right)=-\frac{8\pi G}{c^4}\cdot g_{ij}M^{ij}=\frac{-8\pi G}{c^4}\cdot M_i^i=\frac{-8\pi G}{c^4}M \quad . \tag{C.3}$$

The following equation is derived from Eqs.(C.2) and (C.3)

$$R=\frac{8\pi G}{c^4}\cdot M \ . \tag{C.4}$$

Substituting Eq.(C.4) into Eq.(C.1), we obtain

$$R^{ij}=-\frac{8\pi G}{c^4}\cdot M^{ij}+\frac{1}{2}\cdot g^{ij}R=-\frac{8\pi G}{c^4}\cdot\left(M^{ij}-\frac{1}{2}\cdot g^{ij}M\right) \quad . \tag{C.5}$$

Using antisymmetric tensor $f_{ij}$ which denotes the magnitude of electromagnetic field, the electromagnetic energy tensor $M^{ij}$ is represented as follows;

$$M^{ij}=-\frac{1}{\mu_0}\cdot\left(f^{i\rho}f_\rho^{\ j}-\frac{1}{4}\cdot g^{ij}f^{\alpha\beta}f_{\alpha\beta}\right),\quad f^{i\rho}=g^{i\alpha}g^{\rho\beta}f_{\alpha\beta} \quad . \tag{C.6}$$

Therefore, for M, we have

$$\begin{aligned} M &= M_i^i=g_{ij}M^{ij}=-\frac{1}{\mu_0}\cdot\left(g_{ij}f^{i\rho}f_\rho^{\ j}-\frac{1}{4}\cdot g_{ij}g^{ij}f^{\alpha\beta}f_{\alpha\beta}\right) \\ &=-\frac{1}{\mu_0}\cdot\left(f^{i\rho}f_{i\rho}-\frac{1}{4}\cdot 4f^{\alpha\beta}f_{\alpha\beta}\right)=-\frac{1}{\mu_0}\cdot\left(f^{i\rho}f_{i\rho}-f^{i\rho}f_{i\rho}\right)=0 \end{aligned} \quad . \tag{C.7}$$

Accordingly, substituting $M=0$ into Eq.(C.5), we get

$$R^{ij}=-\frac{8\pi G}{c^4}\cdot M^{ij} \quad . \tag{C.8}$$

Although Ricci tensor $R^{ij}$ has 10 independent components, the major component is the case of $i=j=0$, i.e., $R^{00}$ . Therefore, Eq.(C.8) becomes

$$R^{00}=-\frac{8\pi G}{c^4}\cdot M^{00} \quad . \tag{C.9}$$

On the other hand, 6 components of antisymmetric tensor $f_{ij}=-f_{ji}$ are given by electric field E and magnetic field B from the relation to Maxwell's field equations

$$\begin{aligned} &f_{10}=-f_{01}=\frac{1}{c}\cdot E_x,\ f_{20}=-f_{02}=\frac{1}{c}\cdot E_y,\ f_{30}=-f_{03}=\frac{1}{c}E_z \\ &f_{12}=-f_{21}=B_z,\ f_{23}=-f_{32}=B_x,\ f_{31}=-f_{13}=B_y \\ &f_{00}=f_{11}=f_{22}=f_{33}=0 \end{aligned} \quad . \tag{C.10}$$

Substituting Eq.(C.10) into Eq.(C.6), we have

$$M^{00}=-\left(\frac{1}{2}\cdot\varepsilon_0E^2+\frac{1}{2\mu_0}\cdot B^2\right)\approx-\frac{1}{2\mu_0}\cdot B^2 \quad . \tag{C.11}$$

Finally, from Eqs.(C.9) and (C.11), we have

$$R^{00}=\frac{4\pi G}{\mu_0c^4}\cdot B^2=8.2\times10^{-38}\cdot B^2 \quad (B\ in\ Tesla)\ , \tag{C.12}$$

where we let $\mu_0=4\pi\times10^{-7}(H/m)$, $\varepsilon_0=1/(36\pi)\times10^{-9}(F/m)$, $c=3\times10^8(m/s)$,

$G = 6.672\times10^{-11}(N\cdot m^2/kg^2)$, $B$ is a magnetic field in Tesla and $R^{00}$ is a major component of spatial curvature $(1/m^2)$.

The relationship between curvature and magnetic field was derived by Minami and introduced it in 16th International Symposium on Space Technology and Science (1988) [2].
Eq.(C12) is derived from general method.
On the other hand, Levi-Civita also investigated the gravitational field produced by a homogeneous electric or magnetic field, which was expressed by Pauli [47]. If $x^3$ is taken in the direction of a magnetic field of intensity F (Gauss unit), the square of the line element is of the form;

$$ds^2 = (dx^1)^2 + (dx^2)^2 + (dx^3)^2 + \frac{(x^1dx^1 + x^2dx^2)^2}{a^2 - r^2}, \qquad \text{(C.13)}$$
$$-\left[c_1 \exp(x^3/a) + c_2 \exp(-x^3/a)\right]^2 (dx^4)^2$$

where $r=\sqrt{(x^1)^2 + (x^2)^2}$, $c_1$ and $c_2$ are constants, $a = \dfrac{c^2}{\sqrt{kF}}$, $k$ is Newtonian gravitational constant(G), and $x^1 \ldots x^4$ are Cartesian coordinates ($x^1 \ldots x^3$=space, $x^4=ct$) with orthographic projection.
The space is cylindrically symmetric about the direction of the field, and on each plane perpendicular to the field direction the same geometry holds as in Euclidean space on a sphere of radius *a*, that is, the radius of curvature *a* is given by

$$a = \frac{c^2}{\sqrt{kF}} . \qquad \text{(C.14)}$$

Since the relation of between magnetic field B in SI units and magnetic field F in CGS Gauss units are described as follows: $B\sqrt{\dfrac{4\pi}{\mu_0}} \Leftrightarrow F$, then the radius of curvature "*a*" in Eq.(C14) is expressed in SI units as the following (changing symbol, $k \to G, F \to B$):

$$a = \frac{c^2}{\sqrt{GF}} = \frac{c^2}{\sqrt{G}\cdot B\sqrt{\dfrac{4\pi}{\mu_0}}} \approx (3.484\times10^{18}\frac{1}{B}\quad meters) . \qquad \text{(C15)}$$

While, scalar curvature is represented by

$$R^{00} \approx R = \frac{1}{a^2} = \frac{GB^2\dfrac{4\pi}{\mu_0}}{c^4} = \frac{4\pi G}{\mu_0 c^4}B^2, \qquad \text{(C16)}$$

which coincides with (C.12).

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