NEW DEVELOPMENT OF SPACE PROPULSION THEORY-BREAKTHROUGH OF CONVENTIONAL PROPULSION TECHNOLOGY

Yoshinari Minami
Advanced Science-Technology Research Organization (Formerly NEC Space Development Division), 35-13, Higashikubo-Cho, Nishi-Ku, Yokohama, 220-0062 JAPAN;

Abstract
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. 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. Apart from momentum thrust based on momentum conservation law, there is another pressure thrust that is pushed and advanced like a solar sail or light sail.

This paper describes the problems of conventional propulsion theory and introduces space propulsion theory beyond the conventional propulsion. In chapter 2, as a problem of the current space propulsion, we describe the momentum thrust, and then discuss the pressure thrust of a solar sail. In chapter 3, the propulsion theory using pressure thrust based on the mechanical structure of space is introduced: relatively well-considered space drive propulsion as a representative example of field propulsion is explained. In chapter 4, space propulsion physics using astrophysical phenomena such as accretion disk and astrophysical jet around a black hole is discussed.

Keywords: space-time; continuum; space drive; propulsion; spaceship; curvature; accretion disk; astrophysical jet; magnetic field; plasma; solar sail; astrophysics.

1. Introduction

The dream of space travel by rocket propulsion that originated the edge in 1903 has steadily expanded the range of the exploration to not only the moon but also the planet in the solar system by the predecessors' efforts. As is well known, chemical rocket propulsion system, ion propulsion engine of "Hayabusa (MUSES-C)" and solar sail "IKAROS (Interplanetary Kite-craft Accelerated by Radiation of the Sun)" support this technology of space exploration at present.

It is a beginning a landing to the moon by Apollo 11 of July 21, 1969, that manned space exploration by the human was performed. The arrival time to the moon depends on the selected orbit; for example, in the case of Apollo 12, it takes three days (for the way home 72 hours for outward trip 80 hours). Such small amount of navigation time (3 days) is not the problem, but in the case of the distantly with a remote planet from the Earth, it is an already dreamlike story because the speed is late in the current rocket technology. The distance 384,400km (cislunar distance) is too short distances if it sees from a universe scale. It can be said that travelling to the planet and the stars by the method of going to the moon are impossible due to the present rocket technical limitation. It is a fact that mankind has no possession of the space propulsion technology that can accelerate at a high speed in a short time. In the front of space as the ocean, mankind is obtaining only a technology advanced in the vicinity of the shore in sands with the boat. It is only the moon that mankind could reach. Apart from the unmanned spacecraft, mankind has a boat that goes near the beach, and we do not yet have a ship that is going through the vast universe. If the speed of spaceship increases marvelously, that is, if the arrival time to the planet is becoming several hours or about several weeks, it is considerably surmountable. It is understood that it is important for the manned space exploration to develop the space transportation system of the very high speed.

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. 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.

Instead of conventional chemical propulsion systems, field propulsion systems, which are based on General Relativity Theory, Quantum Field Theory and other exotic theories, have been proposed by many researchers to overcome the speed limit of the conventional space rocket. 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. Field 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.

As a representative example of a well-studied field propulsion system, space drive propulsion theory induced by space curvature based on the supposition that space is an infinite continuum like the elastic body is introduced in this paper.

2. Technical Status and Problem of Present Propulsion System

The problems of existing space propulsion system and new concept are introduced in this section.

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} the specific impulse, g is 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 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 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, so that it may operate by car as it were.

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

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

Eq.(2.2) indicates that the speed increment ΔV 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).

$$m_p = m_i - m_f, \tag{2.3}$$

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

By expelling the mass of a propellant m_p outside, a rocket obtains thrust and increases the speed of ΔV, 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 sails 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 to push the wall of the pool with a foot; a car tire pushes the ground of the Earth, etc.

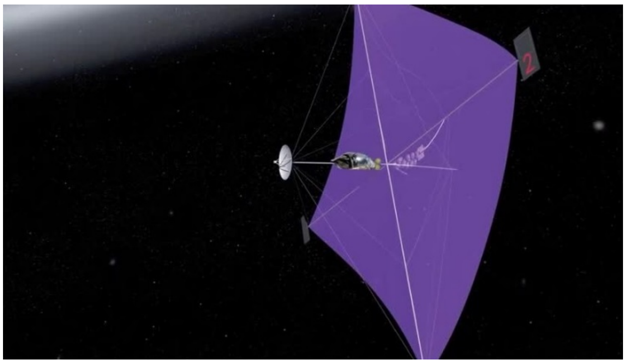


Fig.2.1 Solar Sail, Light Sail.

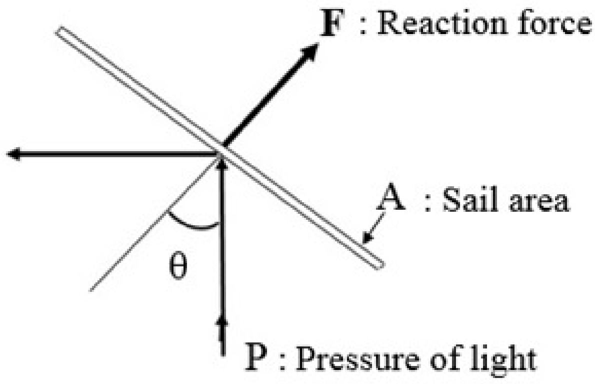


Fig.2.2 Reaction force of light received by sail.

As shown in Fig.2.1, the solar sail or light 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 micros G. If it is 1 micro G acceleration, it will take about 3 years to reach 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. The relationships between energy (*E*) and momentum (*P*) is given by the following equation using light speed "c":

$$E = Pc \quad . \tag{2.5}$$

Then we get the reaction force *F*:

$$F = \frac{d}{dt}P = \frac{d}{dt}\left(\frac{E}{c}\right) = \frac{1}{c}\frac{dE}{dt} = \frac{1}{c}P_W \quad , \tag{2.6}$$

where P_W is the power of light (W).

Referring to Fig.2.2, reaction force of light received by sail is given by

$$F = P_p A(1+\varepsilon)\cos\theta \quad , \tag{2.7}$$

where F: reaction force (N), P_p:the pressure of light (N/m^2), A: sail area (m^2), ε: reflectance of light.

In case that sail is perpendicular to light (θ=0) and perfect reflection (ε=1), we get

$$F = 2P_p A \quad . \tag{2.8}$$

Solar light pressure near Earth is very small at 4.6×10^{-6}N/m^2. Assuming that the area density β of the sail is about $\beta = 100\,g/m^2$, the acceleration α of the sail is, $\alpha = F/\beta A = 2P_p/\beta = 9.2\times10^{-5}\,m/s^2$, which is equivalent to that of the ion thruster and the plasma thruster.

From Eqs.(2.6) and (2.7), we obtain

$$P_p = \frac{F}{A} = \frac{1}{c}\frac{P_W}{A} \quad , \tag{2.9}$$

$$F = P_p A(1+\varepsilon)\cos\theta = \frac{1}{c}P_W(1+\varepsilon)\cos\theta \quad . \tag{2.10}$$

2.3 Field Propulsion: Pressure of Field derived from Space-Time

Here we introduce a new propulsion concept.

The term "Field Propulsion" was firstly notarized by Minami. He firstly introduced its concept in his literature and made a bid for its cognition. The detailed concept is summarized in [Y. Minami, "An Introduction to Concepts of Field Propulsion," *JBIS*, .**56**, pp.350-359 (2003) [1]].The field propulsion is defined as follows:

<Definition>

Field propulsion is the propulsion method using the field, which is propelled by being pushed or pulled by surrounding space-time as a field. Field propulsion is propelled receiving the propulsive force (i.e., thrust) arises from the interaction of space-time around the spaceship and the spaceship itself, that is, the field propulsion is propelled against space-time structure. The field propulsion principle is based on the assumption that space as a vacuum possesses a substantial physical structure. The field propulsion utilizes the mechanical property of space-time possessing structure (continuum mechanics in the view of the macroscopic structure, statistical mechanics in the view of the microscopic structure). However, a propulsion using the momentum thrust generated by an independent matter, such as plasma, ion, and photon with unrelated to the structure of space-time (or pressure thrust induced by mutual interaction with an independent matter, such as plasma, ion, and photon with unrelated to the structure of space-time) is not applicable to field propulsion. The pressure thrust in field propulsion is different from the pressure thrust in solar sails and light sails induced by receiving the pressure of light.

The most remarkable results attainable through Field Propulsion are as follows: 1) high acceleration such as several ten G can be obtained, 2) theoretical final velocity close to the speed of light, 3) no action of inertial force.

As to item 3), this comes from the thrust as 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 crew, i.e., it is equivalent to free-fall. Therefore, the flight patterns such as quick start from the stationary state to all directions in the atmosphere, quick stop, perpendicular turn, and zigzag turn are possible.

For instance, as an example of field propulsion system, Space Strain Propulsion System [2] and alternatively Space Drive Propulsion System [3] derived from General Relativity were firstly introduced by Y. Minami. The expression "space strain" was changed to "space drive" after recommendation by R.L. Forward [4].Further, Space Coupling Propulsion System was introduced by Marc G. Millis [5]. At present, physics admits the Zero-Point Energy (Media of Electromagnetic Fluctuations of the Vacuum: Zero-Point Fluctuations or Zero-Point Field). It is said that the Zero-Point Field is related to both gravitation and inertia. Space as a vacuum is a kind of actual field, which repeats the creation and annihilation of particle and anti-particle continuously. ZPF (Zero-Point Field) propulsion system was introduced by H.D. Froning and T.W. Barrett [6, 7]. The various standpoints for engineering of the Zero-Point Field were introduced by H.E. Put-off [8].

The field propulsion system appears to violate the conservation law of momentum because the reaction mass is not readily apparent. As is well known, all propulsion system based on the momentum thrust receives the reaction thrust by expelling the propellant mass. However, since no propellant is necessary for field propulsion, field propulsion is well called propellant-less propulsion.

NASA (Marc G. Millis; Breakthrough Propulsion Physics project) considers that conservation of momentum can be satisfied in various ways that do not require having an on-board supply of reaction mass about conservation of momentum, as follows [5]:

1) conservation by using the contents of space (Interstellar Matter, Star Light, Magnetic Field, Cosmic Microwave, etc.) as the reaction mass, 2) conservation by expelling non-mass momentum (equivalent momentum $P=E/c$) such as hypothetical "Space Waves", 3) conservation by negative mass, 4) conservation by coupling to distant masses via the intervening space.

However, we propose that the most promising interpretation is to consider that space itself as the vacuum is a kind of reaction mass.

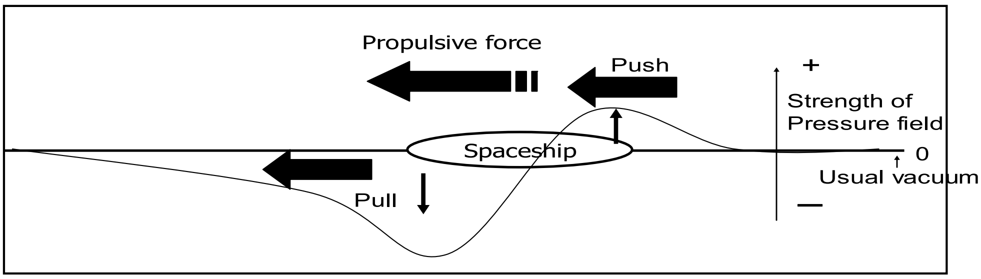
Now, a field propulsion system must satisfy the following criteria [1, 9]:

1) conservation of momentum, 2) conservation of energy, 3) ability to induce a unidirectional acceleration of the spaceship, 4) controllability of direction and thrust, 5) sustainability during spaceship motion, 6) effective capability of propelling the spaceship.

3. Propulsion Theory based on Mechanical Structure of Space: Space Drive Propulsion as a Representative of Field Propulsion

In this chapter, the theory of propulsion based on the mechanical structure of space is introduced. That is, we describe relatively well-considered space drive propulsion as a representative example of field propulsion.
The space drive propulsion system proposed here is one of field propulsion system utilizing the action of the medium of the strained or deformed field of space, which is based on the propulsion principle of the kind of pressure thrust. Figure 3.1 shows the basic propulsion principle of common to all kinds of field propulsion system. As shown in Fig.3.1, the propulsion principle of field propulsion system is not momentum thrust but pressure thrust induced by a pressure gradient (or potential gradient) of the space-time field (or vacuum field) between bow and stern of a spaceship. Since the pressure of the vacuum field is high in the rear vicinity of the spaceship, the spaceship is pushed from the vacuum field. The pressure of vacuum field in the front vicinity of the spaceship is low, so the spaceship is pulled from the vacuum field. In the front vicinity of the spaceship, the pressure of vacuum field is not necessarily low but the ordinary vacuum field that is, just as only a high pressure of vacuum field in the rear vicinity of the spaceship. The spaceship is propelled by this distribution of pressure of the vacuum field. Vice versa, it is the same principle that the pressure of vacuum field in the front vicinity of the spaceship is just only low and the pressure of vacuum field in the rear vicinity of the spaceship is ordinary. In any case, the pressure gradient from the vacuum field (potential gradient) is formed over the entire range of the spaceship, so that the spaceship is propelled by the pressure gradient.

Propulsion Principle



Asymmetrically interaction with the pressure of field creates propulsive force for the spaceship.

The strength of pressure field ahead of the spaceship is diminished and its behind increased, this would result in favorable pressure gradients.

Fig.3.1 Fundamental propulsion principle of Field propulsion.

3.1 Space Drive Propulsion System

In this section, the space drive propulsion system considered comparatively well is introduced in detail.

3.1.1 Background

Assuming that the space vacuum 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 that arises from the interaction of space-time around the spaceship and the spaceship itself; the spaceship is propelled against the 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.

General Relativity implies that space is curved by the existence of energy (mass etc.) and based on Riemannian geometry. If we admit this space curvature, space is assumed as an elastic body. According to continuum mechanics, the elastic body has the property of the motion of deformation such as expansion, contraction, elongation, torsion, and bending. General Relativity uses just only the curvature of space. Expansion and contraction of space are used in cosmology, and a theory using torsion is also studied by Hayasaka [10]. Perhaps, Twist or Theory by Roger Penrose is also applied to the torsion of space [11].

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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 the 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). Minami derived the equation of curvature of space induced by the magnetic field in 1988 [2]. 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 (APPENDIX A: Curvature Control by Magnetic Field).

Since the propulsion mechanism used the magnetic field, in the beginning, is easy to understand, we explain it using the magnetic field. At present, space drive propulsion does not need the strong magnetic field under the favor of *de Sitter solution*.

The principle of the space drive propulsion system is summarized in the following.

First of all, 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 α becomes zero. Such a curved space is generated not only by mass density but also by the 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 $(B^2/2\mu_0)$. As a consequence, the electric field only negligibly contributes to the spatial curvature as compared with the magnetic field. Accordingly, it is effective that space can be curved by a 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 Newton's second law.

In the latest cosmology, the terms vacuum energy and cosmological term "Λg^{ij}" are used synonymously. Λ is known as the cosmological constant. The term with the cosmological constant is identical to the stress-energy tensor associated with the vacuum energy. The properties of vacuum energy, i.e., cosmological term are crucial to the expansion of the Universe, that is, to inflationary cosmology.

In the beginning, the acceleration generated by the curvature of space induced by the strong magnetic field based on external and internal Schwarzschild solution was studied [3]. However, superior acceleration based on de Sitter solution is obtained and presented at 47th IAF in 1996 [12]. The details are published in JBIS, Vol.50 [13] and presented at STAIF-98 in 1998[14].

At the present day, the space drive propulsion system is based on the de Sitter solution as follows:

The acceleration derived from the de Sitter solution does not require a strong magnetic field. At the present day, space drive propulsion system based on the de Sitter solution needs not a strong magnetic field but the technology to excite space.

Additionally, the inflationary universe which shows the rapid expansion of space is based on the phase transition of vacuum exhibited by the Weinberg-Salam model of the electroweak interaction. The vacuum has the property of a phase transition, just like water may become ice and vice versa. This shows that a vacuum possesses a substantial physical structure such as the material. It coincides with the precondition of a space drive propulsion principle. As is well known in cosmology, the expansion rule of the universe is governed by the Friedman's equations and the Robertson-Walker metric.

In the last section, the propulsion principle for this space drive is newly studied from another angle, that is, the pressure of the field induced by rapid local expansion of space is completely considered in the propulsion principle based on the latest cosmology.

3.1.2 Gravitational Acceleration at the Surface of the Earth

Let's think about gravity. When we make a comparison between the space on the Earth and outer space throughout the universe, although there seems to be no difference, obviously a different phenomenon occurs. Simply put, an object moves radially inward, that is, drops straight down on the Earth, but in the universe, the object floats and does not move.

The difference between the two phenomena can be explained as whether space is curved or not, that is, whether 20 independent components of a Riemann curvature tensor is zero or not. In essence, the existence of spatial curvature (and curved extent region) determines whether the object drops straight down or not. Although the spatial curvature at the surface of the Earth is very small value, i.e., $3.42\times10^{-23}(1/m^2)$, it is of enough value to produce 1G($9.8m/s^2$) acceleration considering the size of the curved spatial region above the ground surface. Conversely, the spatial curvature in the universe is zero. Therefore any acceleration is not produced. Accordingly, if the spatial curvature of a localized area including the object is controlled to the curvature of $3.42\times10^{-23}(1/m^2)$ with an extent, the object moves receiving 1G acceleration in the universe. Of course, we are required to control both the magnitude and extent of curvature. Above-mentioned fact implies that space has a mechanical property.

3.2 Fundamental Supposition of Space

Although this section is related to the mechanical structure of space which is the basis of the propulsion principle, there is no hindrance even if you skip reading [2, 15, 16, 17].

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 space as an infinite elastic body like rubber.

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 the spatial curvature.

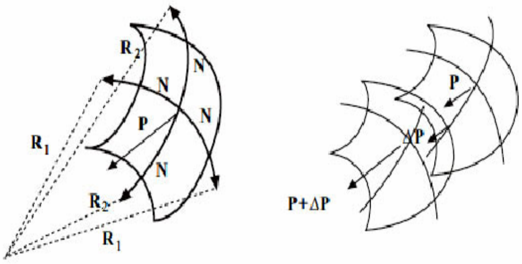
A large number of curved thin layers form the unidirectional surface force, i.e., acceleration field. Accordingly, the spatial curvature R^{00} produces the acceleration field α.

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

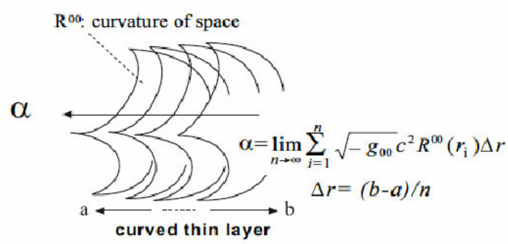
$$K = \frac{R_{1212}}{(g_{11}g_{22} - g_{12}{}^2)} = \frac{1}{2}\cdot R^{00}, \tag{3.2}$$

where R_{1212} is a non-zero component of Riemann curvature tensor?

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.3.2 (a).
A thin-layer of the 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.(3.1) 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.



(a)



(b)

Fig.3.2 Curvature of Space: (a) ccurvature of space plays a significant role for propulsion theory. 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 α.

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.3.2(b)). Accordingly, the spatial curvature R^{00} produces the acceleration field α.Therefore, the curvature of space plays a significant role to generate thrust.

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

$$N^{\alpha\beta} b_{\alpha\beta} + P = 0\,, \tag{3.3}$$

where $N^{\alpha\beta}$ is a membrane force, i.e., line stress of curved space, $b_{\alpha\beta}$ is the second fundamental metric of the curved surface, P is the normal stress on the curved surface [18].

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

$$b_{\alpha\beta} = K_{(i)} g_{\alpha\beta}\,. \tag{3.4}$$

Therefore we get

$$N^{\alpha\beta} b_{\alpha\beta} = N^{\alpha\beta} K_{(i)} g_{\alpha\beta} = g_{\alpha\beta} N^{\alpha\beta} K_{(i)} = N_{\alpha}{}^{\alpha} K_{(i)} = N \cdot K_{(i)}\,. \tag{3.5}$$

From Eq.(3.3) and Eq.(3.5), we get

$$N_{\alpha}{}^{\alpha} K_{(i)} = -P\,. \tag{3.6}$$

As for the quadratic surface, the indices α and i take two different values, i.e., 1 and 2.

Therefore Eq.(3.6) becomes

$$N_1{}^1 K_{(1)} + N_2{}^2 K_{(2)} = -P\,, \tag{3.7}$$

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

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The Gaussian curvature K is represented as

$$K = K_{(1)} \cdot K_{(2)} = (1/R_1) \cdot (1/R_2)\,. \tag{3.8}$$

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

$$N \cdot (1/R_1 + 1/R_2) = -P\,. \tag{3.9}$$

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.3.2. A thin-layer of the 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. (3.2) and (3.8), we get

$$K = \frac{1}{R_1} \cdot \frac{1}{R_2} = \frac{1}{R^2} = \frac{R^{00}}{2}\,. \tag{3.10}$$

Considering $N \cdot (2/R) = -P$ of Eq.(3.9), and substituting Eq.(3.10) into Eq.(3.9), the following equation is obtained:

$$-P = N \cdot \sqrt{2R^{00}}\,. \tag{3.11}$$

Since the membrane force N (serving as the line stress) can be assumed to have a constant value, Eq.(3.11) 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. 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 of unidirectional surface force (i.e. normal stress). Since the field of surface force is the field of a kind of force, matter in the field is accelerated by force, i.e., we can regard the field of surface force as the acceleration field. Accordingly, the cumulated curved region of curvature R^{00} produces the acceleration field α.

Therefore, the curvature of space plays a significant role.

3.3 Strain Induced by Structural Deformation of Space

Although this section is also related to the mechanical structure of space which is the basis of the propulsion principle, there is no hindrance even if you skip reading [2, 15, 16, 17].

Space is an infinite continuum, and its structure is determined by Riemannian geometry. Space satisfies the following conditions:

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a) When the infinitesimal distance regulating the distance between the two points changes by certain physical action, the change is continuous, and space maintains a continuum even after its change. Now, the concept of strain of continuum mechanics is very important to relate a spatial curvature to a practical force. Because the spatial curvature is a purely geometrical quantity. A strain field is required for the conversion of geometrical quantity to a practical force.

b) The spatial strain is defined as a localized geometrical structural change of space. It implies a change from flat space involved in zero curvature components to curved Riemann space involved in non-zero curvature components.

c) Space has the only strain-free natural state, and space always returns to the strain-free natural state, i.e., flat space, when an external physical action causing spatial strain is removed.

d) Spatial strain means some kinds of structural deformation of space, and a body filling up space is affected by the action from its spatial strain. We must distinguish space from an isolated body. An isolated body occupies an area of space by its movement. An isolated body can move in space and also can change its position.

e) To keep the continuity of space, the velocity of the body filling up space cannot exceed the strain rate of space itself.

Since the subject of our study is a four-dimensional Riemann space as curved space, we ascribe a great deal of importance to the curvature of space. We a priori accept that the nature of actual physical space is a 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).

The square of the infinitesimal distance "ds" between two infinitely proximate point's x^i and x^i+dx^i is given by the equation of the form:

$$ds^2 = g_{ij} dx^i dx^j , \qquad (3.12)$$

where g_{ij} is a metric tensor.

The metric tensor g_{ij} determines all the geometrical properties of space, and it is a function of this space coordinate. In Riemann space, the metric tensor g_{ij} determines a Riemannian connection coefficient $\Gamma^i{}_{jk}$, and furthermore determines the Riemann curvature tensor $R^p{}_{ijk}$ or R_{pijk}. Thus the geometry of space is determined by a metric tensor.

Riemannian geometry is a geometry which provides a tool to describe curved Riemann space. Therefore a Riemann curvature tensor is a principal quantity. All the components of Riemann curvature tensor are zero for flat space and non-zero for curved space. If a non-zero component of Riemann curvature tensor exists, space is not flat space, but curved space. In curved space, it is well known that the result of the parallel displacement of vector depends on the choice of the

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path. Further, the components of a vector differ from the initial value, after we displace a vector parallel along a closed curve until it returns to the starting point.

An external physical action such as the existence of mass-energy or electromagnetic energy yields the structural deformation of space. In the deformed space region, the infinitesimal distance is given by:

$$ds'^2 = g'_{ij} dx^i dx^j , \qquad (3.13)$$

where g'_{ij} is the metric tensor of the deformed space region, and we use the convected coordinates ($x'^i = x^i$).

As shown in Fig.3.3, if the line element between the arbitrary two near points (A and B) in space region **S** (before structural deformation) is defined as $ds = g_i dx^i$, the infinitesimal distance between the two near points is given by Eq.(3.12): $ds^2 = g_{ij} dx^i dx^j$.

Let us assume that a space region **S** is structurally deformed by external physical action and transformed to space region **T**. In the deformed space region **T**, the line element between the identical two near point (A' and B') of the identical space region newly changes, differs from the length and direction, and becomes $ds' = g'_i dx^i$.

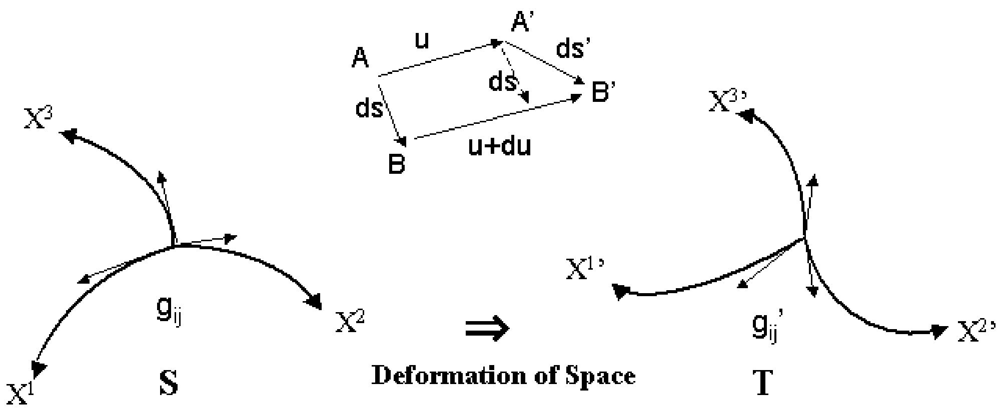

Fig.3.3 Fundamental structure of Space.

Therefore, the infinitesimal distance between the two near points using the convected coordinate ($x'^i = x^i$) is given by:

$$ds'^2 = g'_{ij} dx^i dx^j . \qquad (3.14)$$

The g'_i is the transformed base vector from the original vase vector g_i and the g'_{ij} is the transformed metric tensor from the original metric tensor g_{ij}. Since the degree of deformation can be expressed as the change of distance between the two points, we get:

$$ds'^2 - ds^2 = g'_{ij}dx^i dx^j - g_{ij}dx^i dx^j = (g'_{ij} - g_{ij})dx^i dx^j = r_{ij}dx^i dx^j \quad . \tag{3.15}$$

Hence the degree of geometrical and structural deformation can be expressed by the quantity denoted change of metric tensor, i.e.

$$r_{ij} = g'_{ij} - g_{ij} \quad . \tag{3.16}$$

On the other hand, the state of deformation can also be expressed by the displacement vector "*u*" (see Fig.3.3).

From the continuum mechanics [18, 19, 20, 21], we use the following equations:

$$du = g^i u_{i:j} dx^j , \tag{3.17}$$

$$ds' = ds + du = ds + g^i u_{i:j} dx^j . \tag{3.18}$$

Here we use the usual notation ":" for covariant differentiation. As is well known, the partial derivative $u_{i,j} = \frac{\partial u_i}{\partial x^j}$ is not a tensor equation. The covariant derivative $u_{i:j} = u_{i,j} - u_k \Gamma^k_{ij}$ is a tensor equation and can be carried over into all coordinate systems.

From the usual continuum mechanics, the infinitesimal distance after deformation becomes [15, 18]:

$$ds'^2 - ds^2 = r_{ij}dx^i dx^j = (u_{i:j} + u_{j:i} + u^k{}_{:i} u_{k:j})dx^i dx^j \quad . \tag{3.19}$$

The terms of higher order than the second $u^k{}_{:i} u_{k:j}$ can be neglected if the displacement is of small enough value. As the actual physical space can be dealt with the minute displacement from the trial calculation of strain, we get:

$$r_{ij} = u_{i:j} + u_{j:i} \quad . \tag{3.20}$$

Whereas, according to the continuum mechanics [18], the strain tensor e_{ij} is given by:

$$e_{ij} = \frac{1}{2} \cdot r_{ij} = \frac{1}{2} \cdot (u_{i:j} + u_{j:i}) \quad . \tag{3.21}$$

So, we get:

$$ds'^2 - ds^2 = (g'_{ij} - g_{ij})dx^i dx^j = 2e_{ij}dx^i dx^j , \tag{3.22}$$

where g'_{ij}, g_{ij} is a metric tensor, e_{ij} is a strain tensor, and $ds'^2 - ds^2$ is the square of the infinitesimal distance between two infinitely proximate points x^i and x^i+dx^i.

Eq.(3.22) indicates that a certain geometrical structural deformation of space is shown by the concept of strain. In essence, the change of metric tensor $(g'_{ij} - g_{ij})$ due to the existence of mass-energy or electromagnetic energy tensor produces the strain field e_{ij}.

Since space-time is distorted, the infinitesimal distance between two infinitely proximate points x^i and x^i+dx^i is important in our understanding of the geometry of the space-time; the physical strain is generated by the difference of a geometrical metric of space-time. Namely, a certain structural deformation is described by strain tensor e_{ij}. From Eq.(3.22), the strain of space is described as follows:

$$e_{ij} = 1/2 \cdot (g_{ij}' - g_{ij}) \quad . \tag{3.23}$$

It is also worth noting that this result yields the principle of constancy of light velocity in Special Relativity.

3.4 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 a free particle is a geodesic line in space-time and is given by the following geodesic equation;

$$\frac{d^2x^i}{d\tau^2} + \Gamma^i_{jk} \cdot \frac{dx^j}{d\tau} \cdot \frac{dx^k}{d\tau} = 0, \tag{3.24}$$

where $\Gamma^i{}_{jk}$ is Riemannian connection coefficient, τ is proper time, x^i is four-dimensional Riemann space coordinate, that is, three-dimensional space ($x=x^1$, $y=x^2$, $z=x^3$) and one-dimensional time ($w=ct=x^0$), 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):

$$d\tau = \sqrt{-g_{00}}dx^0 = \sqrt{-g_{00}}cdt \quad . \tag{3.25}$$

From Eq. (3.24), the acceleration of a free particle is obtained by

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$$\alpha^i = \frac{d^2x^i}{d\tau^2} = -\Gamma^i_{jk} \cdot \frac{dx^j}{d\tau} \cdot \frac{dx^k}{d\tau} . \qquad (3.26)$$

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) :

$$F^i = m\Gamma^i_{jk} \cdot \frac{dx^j}{d\tau} \cdot \frac{dx^k}{d\tau} = m\sqrt{-g_{00}}c^2\Gamma^i_{jk}u^ju^k = m\alpha^i , \qquad (3.27)$$

where u^j, u^k are the four-velocity, Γ^i_{jk} is the Riemannian connection coefficient, and τ is the proper time.

From Eqs.(3.26),(3.27), we obtain:

$$\alpha^i = \frac{d^2x^i}{d\tau^2} = -\Gamma^i_{jk} \cdot \frac{dx^j}{d\tau} \cdot \frac{dx^k}{d\tau} = -\sqrt{-g_{00}}c^2\Gamma^i{}_{jk}u^ju^k \quad . \qquad (3.28)$$

Eq.(3.28) yields a more simple equation from the condition of linear approximation, that is, weak-field, quasi-static, and slow motion (speed v << speed of light c: $u^0 \approx 1$):

$$\alpha^i = -\sqrt{-g_{00}} \cdot c^2\Gamma^i_{00} . \qquad (3.29)$$

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

$$R^{00} \approx R_{00} = R^{\mu}_{0\mu 0} = \partial_0\Gamma^{\mu}_{0\mu} - \partial_{\mu}\Gamma^{\mu}_{00} + \Gamma^{\nu}_{0\mu}\Gamma^{\mu}_{\nu 0} - \Gamma^{\nu}_{00}\Gamma^{\mu}_{\nu\mu} \quad . \qquad (3.30)$$

In the nearly Cartesian coordinate system, the value of $\Gamma^{\mu}_{\nu\rho}$ being small, so we can neglect the last two terms in Eq.(3.30), and using the quasi-static condition we get

$$R^{00} \approx -\partial_{\mu}\Gamma^{\mu}_{00} = -\partial_i\Gamma^i_{00} . \qquad (3.31)$$

From Eq.(3.31), we get formally

$$\Gamma^i_{00} = -\int R^{00}(x^i)dx^i . \qquad (3.32)$$

Substituting Eq.(3.32) into Eq.(3.29), we obtain

$$\alpha^i = \sqrt{-g_{00}}c^2\int R^{00}(x^i)dx^i . \qquad (3.33)$$

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., $v/c << 1$), and considering range of curved region, we get the following relation between acceleration of curved space and curvature of space:

$$\alpha^i = \sqrt{-g_{00}}c^2 \int_a^b R^{00}(x^i)dx^i \ , \tag{3.34}$$

where α^i : acceleration (m/s^2), g_{00} : time component of metric tensor, a-b: range of curved space region(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.(3.34) indicates that the acceleration field α^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 the curved region.

Eq.(3.27) yields a more simple equation from above-stated linear approximation ($u^0 \approx 1$),

$$F^i = m\sqrt{-g_{00}}c^2\Gamma^i_{00}u^0u^0 = m\sqrt{-g_{00}}c^2\Gamma^i_{00} = m\alpha^i = m\sqrt{-g_{00}}c^2 \int_a^b R^{00}(x^i)dx^i \ . \tag{3.35}$$

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

$$F^3 = F = m\alpha = m\sqrt{-g_{00}}c^2 \int_a^b R^{00}(r)dr = m\sqrt{-g_{00}}c^2\Gamma^3_{00} \ . \tag{3.36}$$

The acceleration (α) of curved space and its Riemannian connection coefficient (Γ^3_{00}) are given by:

$$\alpha = \sqrt{-g_{00}}c^2\Gamma^3_{00} \ , \quad \Gamma^3_{00} = \frac{-g_{00,3}}{2g_{33}} , \tag{3.37}$$

where c: velocity of light, g_{00} and g_{33}: the component of the 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 α 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.

The acceleration of space drive propulsion system is based on the solutions of the gravitational field equation, which is derived from Eq.(3.37). That is, the acceleration performance of this system is found by the solution of the gravitational field equation, such as the Schwarzschild solution, Reissner-Nordstrom solution, Kerr solution, and de Sitter solution by using Eq.(3.37) [13, 16, 17, 22, 23].

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3.5 Space Drive Propulsion Theory

The theory of space drive propulsion is summarized as follows.

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 A: Curvature Control by Magnetic Field):

$$R^{00} = \frac{4\pi G}{\mu_0 c^4} B^2 = 8.2 \times 10^{-38} B^2, \tag{3.38}$$

where $\mu_0 = 4\pi \times 10^{-7} (H/m)$, $c = 3 \times 10^8 (m/s)$, $G = 6.672 \times 10^{-11} (N \cdot m^2 / kg^2)$, B is a magnetic field with Tesla and R^{00} is a major component of spatial curvature ($1/m^2$).

Eq.(3.38) indicates that the major component of spatial curvature can be controlled by a magnetic field.

3) If space curves, then inward normal stress "$-P$" is generated (see Fig.3.2).

This normal stress, i.e., surface force serves as a sort of pressure field.

$$-P = N \cdot (2R^{00})^{1/2} = N \cdot (1/R_1 + 1/R_2), \tag{3.39}$$

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. Accordingly, the spatial curvature R^{00} produces the acceleration field α (see Fig.3.2).

4) 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., $v/c \ll 1$), we get the following relation between the acceleration of curved space and curvature of space :

$$\alpha^i = \sqrt{-g_{00}}c^2\int_a^b R^{00}(x^i)dx^i \ , \qquad (3.40)$$

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

Eq. (3.40) indicates that the acceleration field α^i 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.

5) 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) :

$$F^i = m\Gamma^i_{jk}\cdot\frac{dx^j}{d\tau}\cdot\frac{dx^k}{d\tau} = m\sqrt{-g_{00}}c^2\Gamma^i_{jk}u^j u^k = m\alpha^i \ , \qquad (3.41)$$

where u^j, u^k are the four-velocity, Γ^i_{jk} is the Riemannian connection coefficient, and τ is the proper time.

Eq.(3.41) yields a more simple equation from above-stated linear approximation ($u^0 \approx 1$),

$$F^i = m\sqrt{-g_{00}}c^2\Gamma^i_{00} = m\alpha^i = m\sqrt{-g_{00}}c^2\int_a^b R^{00}(x^i)dx^i \ . \qquad (3.42)$$

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

$$F^3 = F = m\alpha = m\sqrt{-g_{00}}c^2\int_a^b R^{00}(r)dr = m\sqrt{-g_{00}}c^2\Gamma^3_{00} \ . \qquad (3.43)$$

3.6 Some Evaluations of Space Drive Propulsion

Here let us evaluate other features of space drive propulsion such as momentum conservation law, energy conservation law, and the feature of flight performance.

3.6.1 Momentum and Energy Conservation Law

The question is that if the spaceship moves forward, then what moves back? As previously mentioned, the mechanism of propulsion can be classified into two kinds, i.e., momentum thrust (reaction thrust) and pressure thrust. The momentum thrust based on momentum conservation low is widely used in the present propulsion systems. On the other hand, 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 conversation law is satisfied. All the same, the velocity of the Earth is nearly zero; then we can say that the Earth is fixed. Since man cannot throw out the Earth, it is not appropriate to apply the momentum thrust.

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. Also, 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.

Now, concerning the space drive propulsion system, the propulsion mechanism is also a kind of pressure thrust. As mentioned previously, its propulsion principle is based on the fact that space is an infinite continuum. We regard the present space as an elastic body described by solid mechanics rather than by fluid dynamics. It may be easy to understand that the spaceship moves by pushing space itself, that is, by being pushed from space. The expression of “moves by pushing space or being pushed from space” indicates that the spaceship produces a curved space region and moves forward by being subjected to the thrust from the acceleration field of curved space. As the motorcar moves by kicking the ground continually, 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 space itself continued infinitely. The whole cosmic space is considered as like the ground for kicking. Thus, since space behaves like the elastic field, the stress between spaceship and space itself is the key of propulsion principle. Accordingly, the analogy of rocket which obeys the momentum conservation law in Newtonian mechanics is not adequate.

If the body (spaceship) in the space region gets the energy and the momentum, it means that the outside of the body (spaceship), i.e. space as a field just loses them. Such a continuity equation means the global physical quantity conservation law. And when the body (spaceship) interacts with the field (space), to conserve the energy and momentum as a whole, it is necessary for the field (space) itself to get the energy, momentum, and stress. That is, it is the fundamental concept of the field theory.

In general, the energy-momentum conservation law is described by the continuity equation of the flow of physical quantities between the internal region V surrounded by an arbitrary closed surface (i.e., spaceship) and its surrounding field (i.e., space), that is,

$$-\frac{\partial}{\partial t}\int_V udV = \int_V \nabla SdV + \int_V fvdV , \qquad (3.44)$$

where u=energy density in the region (volume V), S=the energy flux of the field (the flow of energy per unit time across a unit area perpendicular to the flow), fv=the rate of doing work inside volume V, (f: force, v: speed).

Eq. (3.44) stands for the conservation law in the field.

The total energy, as well as the total momentum, remains unchanged. They merely stream from one part of the field to another and become transformed from field-energy and field momentum into kinetic-energy and kinetic-momentum of matter and vice versa.

According to Relativity, these quantities are related by the continuity equation as follows:

$$\frac{\partial}{\partial t}T^{00} + \frac{\partial}{\partial x^i}T^{0i} = 0, \ \frac{\partial}{\partial t}T^{i0} + \frac{\partial}{\partial x^j}T^{ij} = 0 \ ; namely, \quad T^{ij}_{;j} = 0, \qquad (3.45)$$

where T^{00}=energy density, T^{0i}=energy flux, T^{i0}=momentum density, T^{ij}=momentum flux.

We can apply Eq.(3.44) and Eq.(3.45) to space drive propulsion mechanism. The space drive is the propulsion system utilizing the properties of the continuum of space, and the interaction between spaceship and outside of spaceship (i.e., surrounding field) is the basic concept. The energy flux T^{0i} carries the momentum density T^{i0} (T^{0i}=T^{i0}). There is an important theorem in mechanics, that is, whenever there is a flow of energy in any circumstance at all (field energy or any kind of energy), the energy flowing through a unit area per unit time when multiplied by $1/c^2$, is equal to the momentum per unit volume in the space.

The engine system of spaceship operates, and in the process of generating spatial curvature by compressing magnetic flux, the compressing energy from power source flows out as a strain energy flux T^{0i} and is stored in the surrounding space as a strain energy density T^{00}. The strain energy flux T^{0i} is accompanied by the strain momentum flux T^{ij}, and the momentum flux is stored in the surrounding space as a strain momentum density T^{i0}.

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Next, shutting off the engine system of spaceship and releasing the compression of magnetic flux, the strain energy density T^{00} and strain momentum density T^{i0} stored in the surrounding space flow into the area of spaceship and is transformed into kinetic-energy and kinetic-momentum of spaceship with loss during this process. The above-mentioned mechanism is an interpretation of space drive propulsion from the standpoint of energy-momentum conservation law.

3.6.2 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 with spaceship, the aerodynamic heating can be reduced even if the spaceship moves in the atmosphere at high speed (10-100km/s). However, it is expected that a plasma (ionized air) envelops the spaceship, e) Due to the electromagnetic propulsion engine, there is no roar and no exhaust gas, 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., 36G). h) Deceleration is easy for re-entry into the atmosphere.

3.7 Acceleration induced by de Sitter Cosmological Solution

The most general form of the gravitational field equation which includes cosmological constant is given by:

$$R^{ij} - \frac{1}{2} \cdot g^{ij} R = -\frac{8\pi G}{c^4} T^{ij} + \Lambda g^{ij}, \qquad (3.46)$$

where R^{ij} is the Ricci tensor, R is the scalar curvature, G is the gravitational constant, c is the velocity of light, T^{ij} is the energy momentum tensor, and Λ is the cosmological constant.

It is simple to see that a cosmological term Λg^{ij} is equivalent to an additional form of energy momentum tensor. The cosmological term is identical to the energy momentum tensor associated with the vacuum.

Now, concerning the de Sitter cosmological model with non-zero vacuum energy (i.e., cosmological constant), the de Sitter line element is written as

$$ds^2 = -(1-\frac{1}{3}\Lambda r^2)c^2dt^2 + \frac{1}{1-\frac{1}{3}\Lambda r^2}dr^2 + r^2(d\theta^2 + \sin^2\theta d\varphi^2), \quad (3.47)$$

where the metrics are given by

$$g_{00} = -(1-1/3\cdot\Lambda r^2),\ \ g_{11} = g_{22} = 1,\ \ g_{33} = 1/(1-1/3\cdot\Lambda r^2),\ \ other\ g_{ij} = 0\ . \quad (3.48)$$

The acceleration α of de Sitter solution can be obtained by combining Eq.(3.37) with Eq.(3.48)

$$\alpha = \frac{1}{3}c^2\Lambda r\ \ (1 > 1/3\cdot\Lambda r^2)\,. \quad (3.49)$$

The acceleration induced by the cosmological constant is proportional to the distance "r" from the generative source, i.e., engine system. According to the gauge theories, the physical space as a vacuum is filled with a spin-zero scalar fields, called a Higgs field. The vacuum energy fluctuates in proportion to the fluctuation of the Higgs field [13, 24]. The vacuum potential (vacuum energy density) V (ϕ) is given by the vacuum expectation value ϕ of Higgs field, and we get the minimum of the vacuum potential V_0 (ϕ) as follows:

$$V_0(\phi) = \frac{\lambda}{4}\phi_0{}^4\,. \quad (3.50)$$

Here, λ is arbitrary Higgs self-coupling in the Higgs potential (λ is not known and is not determined by a gauge principle, presumably $\lambda \geq 1/10$) [24].

Since the vacuum potential V_0 (ϕ) shall be invariant under the Lorentz transformation, the energy momentum tensor of vacuum $T^{ij}{}_{vac}$ is written in the form

$$T^{ij}{}_{vac} = V_0(\phi)g^{ij}\,. \quad (3.51)$$

The energy momentum tensor of vacuum exerts the same action like that for the cosmological term. It should be noted that $T^{ij}{}_{vac}$ is not energy momentum tensor for matter but the vacuum itself.

From Eq.(3.46) and above Eq.(3.51), as its metric source, $8\pi G/c^4\cdot T^{ij}{}_{vac} = 8\pi G/c^4\cdot V_0(\phi)g^{ij} = \Lambda g^{ij}$, then we get

$$\Lambda = \frac{8\pi G}{c^4}V_0(\phi) = 2.1\times10^{-43}V_0(\phi)\,. \quad (3.52)$$

In general, since the potential from its source is inversely proportional to the distance "r" from the potential source, assuming that the vacuum potential V_0 (ϕ) in Eq.(3.50) is the energy source, the potential at distance "r" apart from its energy source is written in the form

$$V_0(\phi) \Rightarrow V_0(\phi)/r = \frac{\lambda}{4r}\phi_0^{\ 4}. \qquad (3.53)$$

Combining Eq.(3.52) with Eq.(3.53) yields:

$$\Lambda = 2\pi G\lambda\phi_0^{\ 4}/c^4 r. \qquad (3.54)$$

Substituting Eq.(3.54) into Eq.(3.49), finally, we get :

$$\alpha = \frac{2\pi G\lambda}{3c^2}\phi_0^{\ 4} = 1.6\times 10^{-27}\lambda\phi_0^{\ 4}. \qquad (3.55)$$

Eq.(3.55) indicates that the vacuum expectation value ϕ_0 for the Higgs field (i.e. vacuum scalar field) produces the constant acceleration field. As a result, we found out that the acceleration became constant, that is, we can get rid of the tidal force inside of the spaceship. Please refer to Ref.[13, 16, 22, 23] for an example of trial acceleration calculation. The scalar field ϕ can be thought of arising from a source in much the same way as the electromagnetic fields arise from charged particles. We have to search for the fields with the source. The size L of the spaceship (i.e., length or diameter) is limited to the range r_S, where r_S is the range determined by the following: $V_0(r) \propto V_0/r_S \approx 0$ $(L = r_s)$. Within the range of $L = r_s$, the tidal force in the spaceship and in the vicinity of the spaceship can be removed, that is, the acceleration becomes constant within the range of a given region "r_s". The vacuum expectation value ϕ of the Higgs field can be considered as the strength of the field, i.e., energy of the field.

A condensed summary of the propulsion principle of the space drive propulsion system is shown as Fig.3.4.

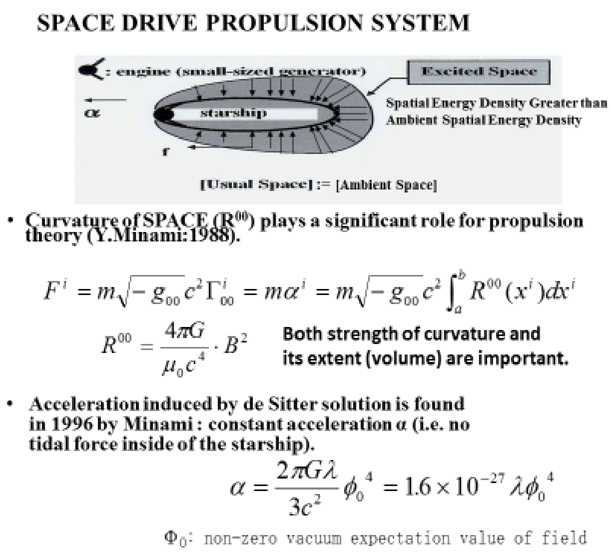

Fig.3.4 Summary of Space drives propulsion.

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3.8 Space Drive Propulsion from the Aspect of Cosmology

In the previous sections 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7, we ran over the theory behind space drive propulsion system. However, in this section, we explore the possibility that the expanding space generates thrust via the cosmology. That is, we study a propulsion principle based on the aspects of the latest expanding universe theories of Friedmann, de Sitter, and the inflationary cosmological model. Concerning the equations used in this section, please refer to the textbook of Cosmology [25, 26, 27, 28, 29, 30].

The inflationary universe shows a rapid expansion of space based on the phase transition of the vacuum exhibited by the Weinberg-Salam model of the electroweak interaction. Weinberg-Salam theory is based on the idea that space as a vacuum gives rise to the phenomenon of phase transition. This theory is based on Ginzburg–Landau theory to explain superconductivity.

The vacuum has the property of a phase transition, just like water may become ice and vice versa. This shows that a vacuum possesses a substantial physical structure such as the material. It coincides with the precondition of a space drive propulsion principle. In general, phase transitions are associated with a spontaneous loss of symmetry as the temperature of a system is lowered. For instance, the phase transition known as “freezing water”, at a temperature T>273K, water is liquid. Individual water molecules are randomly oriented, and the liquid water thus has rotational symmetry about any point; in other words, it is isotropic. However, when the temperature drops below T=273K, the water undergoes a phase transition, from liquid to solid, and the rotational symmetry or molecular geometry of the water is lost. The water molecules are now locked into a ‘solid’ crystalline structure, and the ice no longer has rotational symmetry about an arbitrary point. In other words, the ice crystal is anisotropic, with preferred directions corresponding to the crystal’s axes of symmetry [27].

Supposing that the universe expands, and then what form can the metric of space-time be assumed if the universe is spatially homogeneous and isotropic at all time, and what if the distance is allowed to expand as a function of time? The metric they derived is called the Robertson-Walker metric. It is generally written in the form:

$$ds^2 = -c^2 dt^2 + a(t)^2 \left(\frac{dr^2}{1 - Kr^2} + r^2 (d\theta^2 + \sin^2 \theta d\varphi^2) \right), \quad (3.56)$$

where $a(t)$ is the scale factor that describes how distance grows or decreases with time; it is normalized so that $a(t_0) = 1$ at the present moment. K is the curvature that takes one of three discrete constant values: K=1 if the universe has positive spatial curvature, K=0 if the universe is spatially flat, and K=-1 if the universe has negative spatial curvature. The value of scale factor $a(t)$ is obtained by substituting the Robertson-Walker metric for the following gravitational field equation:

$$R^{ij} - \frac{1}{2} \cdot g^{ij} R = -\frac{8\pi G}{c^4} T^{ij} + \Lambda g^{ij}, \quad (3.57)$$

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where R^{ij} is the Ricci tensor, R is the scalar curvature, G is the gravitational constant, c is the velocity of light, T^{ij} is the energy momentum tensor, and Λ is the cosmological constant.
That is, from the Robertson-Walker metric of Eq. (3.56), the Riemannian connection coefficient, the scalar curvature R, the Ricci tensor R^{ij} are obtained, and then substituting their value for Eq.(3.57), we get Eq.(3.58) as the case of i=0, j=0. Here ε is the energy density of space, $\dot{a}(t) = da(t)/dt$.

$$\frac{\dot{a}(t)^2}{a(t)^2} = \frac{8\pi G}{3c^2}\varepsilon - \frac{c^2 K}{a(t)^2} + \frac{1}{3}\Lambda c^2 \quad . \tag{3.58}$$

Eq.(3.58) is called as the Friedmann equation and dominates the law of an expanding universe.
In a spatially flat universe (K=0) and no cosmological constant (Λ=0), the Friedmann equation takes a particularly simple form:

$$\frac{\dot{a}(t)^2}{a(t)^2} = \frac{8\pi G}{3c^2}\varepsilon . \tag{3.59}$$

From $\frac{\dot{a}(t)}{a(t)} = \sqrt{\frac{8\pi G}{3c^2}\varepsilon}$,

$a(t)$ is obtained as the following:

$$a(t) = a_0 \exp\left[\left(\frac{8\pi G\varepsilon}{3c^2}\right)^{\frac{1}{2}} t\right] = a_0 \exp\sqrt{\frac{\Lambda}{3}}\, ct . \tag{3.60}$$

Here, we used from Eq.(3.52): $$\Lambda = \frac{8\pi G}{c^4}\varepsilon . \tag{3.61}$$

The dimension of vacuum potential $V_0(\phi)$ in Eq.(3.52) is J/m^3.

We used the relation of $\varepsilon = \frac{c^4 \Lambda}{8\pi G}$ from Eq.(3.61).

A spatially flat universe with the energy density ε is exponentially expanding (Eq.(3.60)). Such a universe is called a *de Sitter universe*. Even if there is no cosmological constant Λ from the outset, in the nature of things, expanding universe is indicated by General Relativity. In initial assumptions, the energy density ε is considered for the matter. At the present day, the energy density ε can be considered as the cosmological constant Λ.

Now, regarding the cosmological constant Λ as a kind of energy momentum tensor of fluid, the energy density ε and the pressure P of vacuum space give the following:

$$\varepsilon_\Lambda + P_\Lambda = 0 \quad . \tag{3.62}$$

If the cosmological constant Λ remains constant with time, then so does its associated energy density ε_Λ , namely energy density ε_Λ is constant. The fluid equation indicates that to have ε_Λ constant with time, the Λ term must have an associated pressure P_Λ . Although details are omitted, we can think of the cosmological constant as a component of the universe, which has a constant density ε_Λ and a constant pressure $P_\Lambda = -\varepsilon_\Lambda$.

Further, the energy density ε of the field of vacuum space is given by (see Eq.(3.61); the dimension of vacuum potential V(ϕ) is J/m^3)

$$\varepsilon_\Lambda = \frac{c^4 \Lambda}{8\pi G} . \tag{3.63}$$

Accordingly, the pressure P of the field of vacuum space becomes from Eq.(3.62):

$$P_\Lambda = -\varepsilon_\Lambda = -\frac{c^4 \Lambda}{8\pi G} . \tag{3.64}$$

In the case of $\Lambda > 0$, the pressure P_Λ of the vacuum field in Eq.(3.64) indicates the negative pressure, i.e., repulsive force.

Since the energy momentum tensor T^{ij} in the gravitational field equation aims at the matter, the gravitation arises between different matters. However, the cosmological term "Λg^{ij}" in Eq.(3.57) implies that the force between the vacuum spaces, that is, the repulsive force between one vacuum space and another vacuum space.

Next, we explain the space propulsion principle brought about by locally-expanded space in accordance with described above result. The vacuum space which envelops the spaceship is pushed by other expanding vacuum space. Hence the spaceship is propelled by being pushed from the expanding vacuum space.

Concerning the propulsion principle for the space drive propulsion, in the strict sense, it may be easy to understand that the spaceship moves by pushing space itself, that is, by being pushed from space. The expression of "moves by pushing space or being pushed from 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. As the motorcar moves by kicking the infinitely continued ground, the spaceship moves by pushing the infinitely continued cosmic space. 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 being similar to the ground for kicking. Thus, since the space behaves like an elastic field, the stress between spaceship and space itself is the key of propulsion principle.

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Contrary to this, although it may be a loose expression, we can get an easy image of the propulsion principle: since the pressure of vacuum field in the rear vicinity of the spaceship is high due to an expansion of space, the spaceship is pushed from the vacuum field just like blowing up a balloon that can push an object.

Here, we explain the motion of the spaceship in detail using computer graphics as shown in Fig.3.5. For the sake of simplicity, the shape of the spaceship is an omni directional disk type.

As shown in Fig.3.5 (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.3.5 (a),(b)). Space including the spaceship is pushed from the expanded space and advances forward (Fig.3.5 (b)). The space including the spaceship is propelled to the forward (Fig.3.5 (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.3.5 (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.3.5 (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. 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 (Fig3.5 (h)).

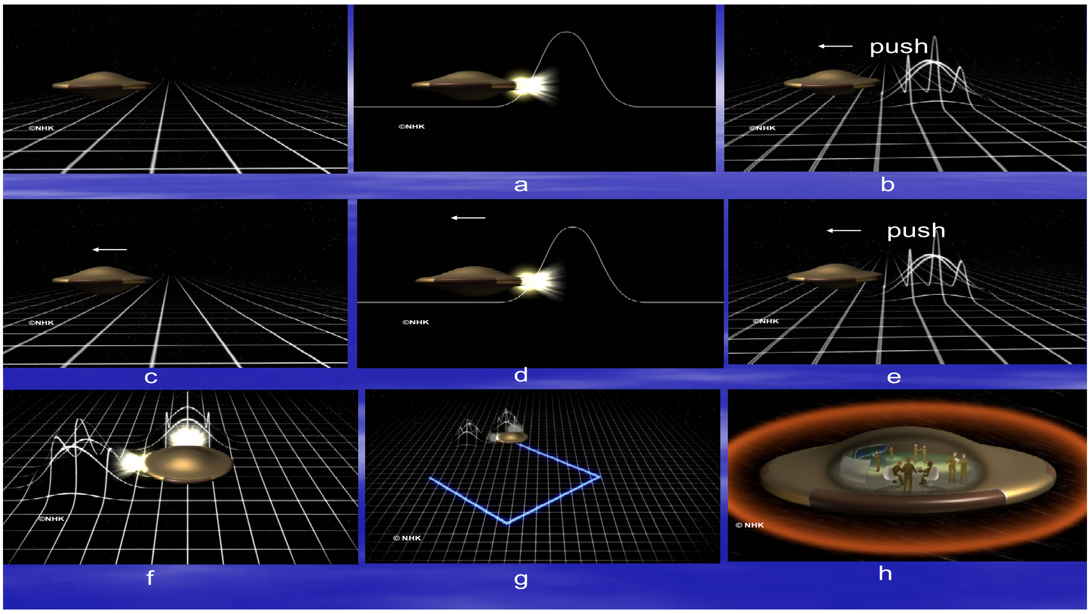

Fig.3.5 Explanation of spaceship operation.

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4. Space Drive Propulsion Using Astrophysical Phenomena

Here, astrophysical phenomena refer mainly accretion disk and astrophysical jet around black holes. The accretion disk is rotating gaseous disk with accretion flow, which forms around gravitating object, such as white dwarfs, neutron stars, and black holes. At the present day, owing to the development of observational technology, it is believed that accretion disk causes the various active phenomena in the universe: star formation, high energy radiation, astrophysical jet, and so on.

It should be noted, these stars such as white dwarfs, neutron stars, and black holes have a strong magnetic field (10^8Tesla－10^{11}Tesla). Matter falling onto an accretion disk around black hole is ejected in narrow jet moving at close to the speed of light like an accelerator. The entity of the astrophysical jet is a jet of the plasma gas from the active galactic nucleus (accretion disk in there). It is said that such astrophysical jet is held together by strong magnetic field tendrils, while the jet's light is created by particles revolving around these wisp-thin magnetic field lines. Furthermore since the system of black hole and accretion disk is like a gravitational power plants, the energy of the heat and the light are produced by the release of gravitational energy [31, 32, 33, 34, 35, 36, 37, 38].

Fig.4.1 shows astrophysical jet and accretion disk around the black hole.

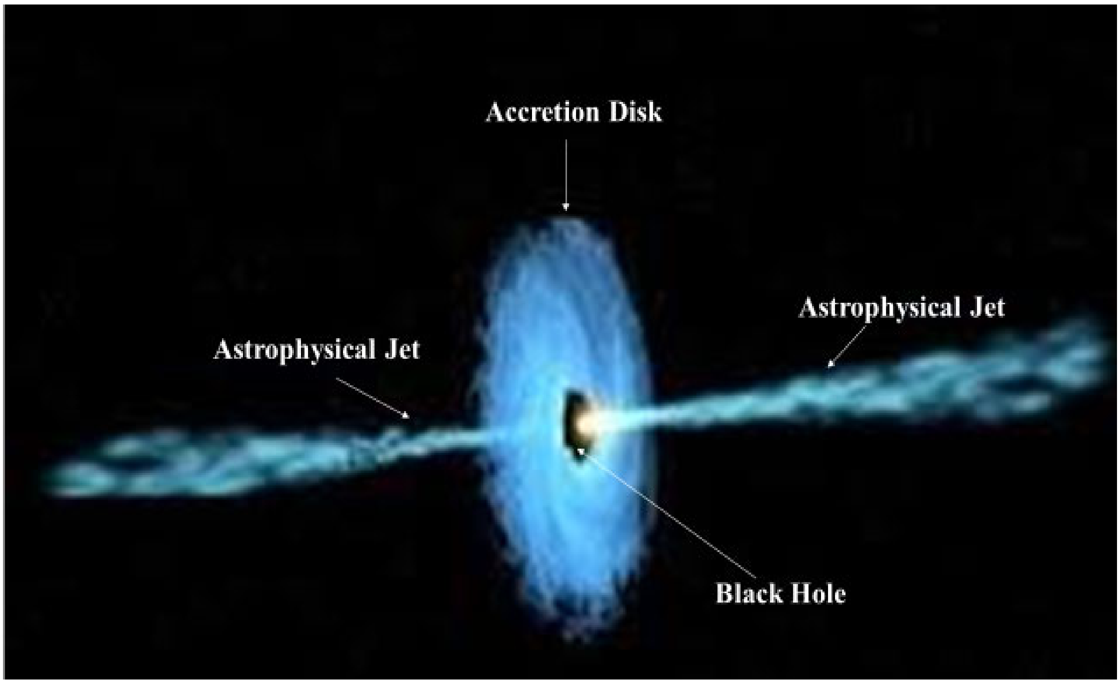

Fig.4.1 Accretion diskand astrophysical jet around black hole.

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Although the system of the accretion disk and astrophysical jet around the black hole are currently left many unresolved issues, the elucidation of these mechanisms and principles that are common to the entire universe may provide a new space propulsion principle. Especially, the breaking of magnetic field lines and magnetic field reconnection are possible to produce many kinds of charged particles such as electron-positron pairs. Generally, in a high-temperature plasma, electron - positron pairs are readily formed by collisions between the high energy protons, electrons, photons. Since the dynamics of the accretion disk has been decided by a magnetic field, it is important that solving the dynamics of the magnetic field. The acceleration mechanism of the astrophysical jet and the collimation mechanism narrowing down to a long distance have been examined so far. They are due to thermal gas pressure, light radiation pressure, and magnetic field pressure. Currently, Radiative Acceleration model accelerated by the radiation field of the accretion disk and Magnetic Acceleration model accelerated by magnetic field penetrating the accretion disk are representative models. When the magnetic field is twisted in the direction of rotation by the actuation rotation of the plasma material, the twisted magnetic field acts like a spring to accelerate the plasma material further upward. In other words, it is acceleration by magnetic pressure. If the jet is magnetically accelerated, the jet is expected to have a twisted helical magnetic field. Furthermore, the twisted magnetic field acts like a rubber string, and the force of the rubber band shrinks (magnetic pinch) so that the flow of the plasma substance is directed in the rotation axis direction. This is the collimation of the jet by a magnetic field. Collimation also occurs voluntarily in addition to acceleration in a model where a jet is driven from an accretion disk by magnetic field and rotation.

In this way, it is assumed that the magnetic field plays an important role at the core of the astrophysical phenomenon. The application of mechanism of accretion disk and astrophysical jet around the black hole will lead to the concrete system design of propulsion engine and power source installed in the space drive propulsion system. The important essence 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 power source of the propulsion system.

4.1 Study of Propulsion Engine by Magnetic Field

As described in Chapter 3, in the beginning, the acceleration generated by the curvature of space induced by the strong magnetic field based on external Schwarzschild solution was studied. In this case, the strong magnetic field is generated by a frozen-in magnetic technology like a neutron star. Theoretically, a frozen-in magnetic field is a phenomenon that when an electrically conducting fluid such as liquid metal moves in the magnetic field as if the magnetic flux or magnetic field adheres to the electrically conducting fluid to move altogether. Since the magnetic flux adheres to the fluid, the magnetic flux is either deformed or intensified by the movement of fluid. Note that it never simply flows giant current through the coil. Fig.4.2 shows interstellar magnetic field lines frozen into that plasma within accretion disk.

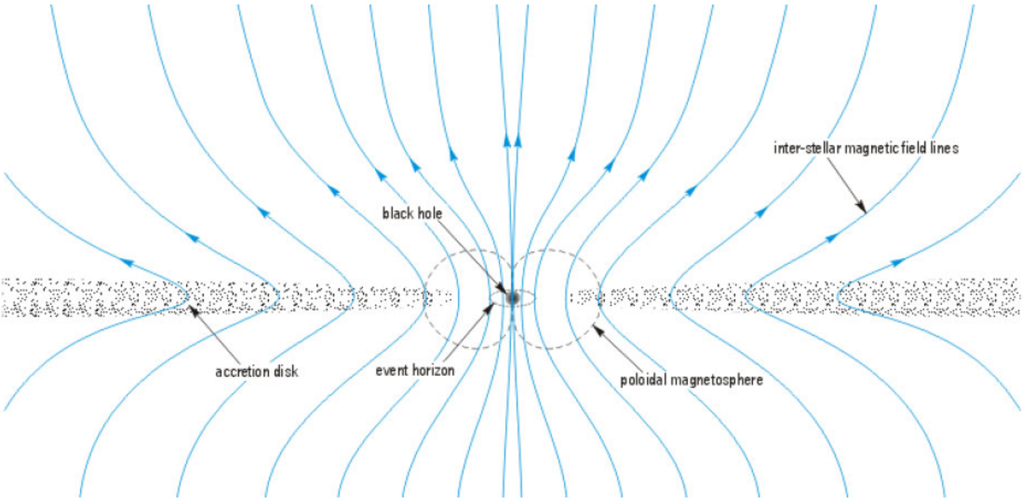

Fig.4.2 Interstellar magnetic field lines will become frozen into that plasma which rotates within accretion disk.

The author filed a patent on a propulsion system using a strong magnetic field engine utilized a frozen-in magnetic technology (electro-magnetic flux compression): Space drive propulsion device, UK Patent GB 2262 844 B Patents published: 16.08.1995.

For reference, the claims are listed below for the outline:

UK Patent GB 2262 844 B (Space drive propulsion device)

Claims 1 and 2 that understand the whole function are described and claims 3 to 6 are omitted here.

CLAIMS

1. A space drive propulsion device enclosing a hollow device region of space and surrounded by a surrounding region of said space, said space being capable of having a field of curvature components, said device comprising:
   the magnetic field generating means for generating a controllable magnetic field which controllably generates said field of curvature components in said hollow device region and in said surrounding region; and field control means for controlling said magnetic field generating means to make said magnetic field locally vary said curvature components substantially an symmetric in said surrounding region.
2. A space drive propulsion device as claimed in Claim 1, said space drive propulsion device defining first through third axes of an orthogonal coordinate system, where in:
   Said magnetic field generating means comprises a plurality of magnetic field generating engines in predetermined relationships to said first through said third axes;
   Each of said magnetic field generating engines

Comprising:

a spherical shell of a superconductive material enclosing a hollow shell space;

at least one controllable superconductor magnet in said hollow shell space to generate a pulsed magnetic field with a controllable pulse repetition frequency as at least a part of said controllable magnetic field;

said field control means individually controlling the superconductor magnets of said magnetic field generating engines to control the repetition frequency of the pulsed magnetic field generated by at least one of said superconductor magnets and to locally vary said curvature components substantially antisymmetric in said surrounding region.

On the other hand, recently, author was informed the book entitled "*Gravitational Manipulation of Domed Craft*; Potter, P. E. (**2008**) [39]" by Paul Murad (Retired Department of Defense).

After rough reading, the author was surprised to see the shape of the engine and its arrangement method.The engine shape is analogous to the engine bowling pin-like shape in the patent: Space drive propulsion device, UK Patent GB 2262 844 B Patent published: 16.08.1995.

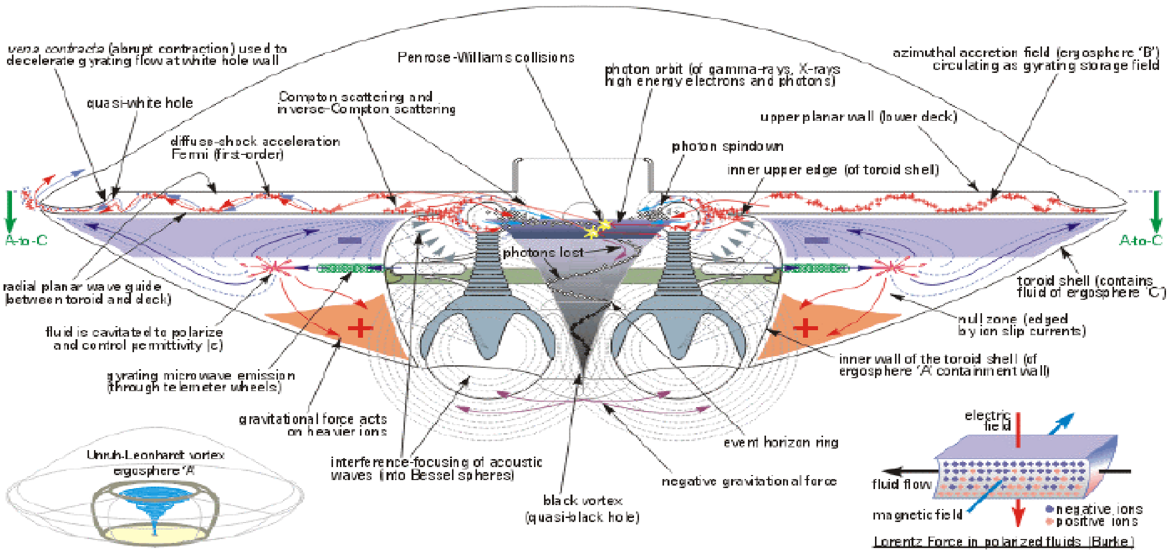

Fig.4.3 Spacecraft internal structure (Quoted from*Gravitational Manipulation of Domed Craft*; Potter, P. E. (2008)).

As well as UK Patent GB 2262 844 B, the strong magnetic field is also a key item in this book's spacecraft.

Fig.4.3 shows that there exist four engines or three engines bowling pin-like shape.

However, in this book, propulsion principle has not been explained clearly at all. Referring to Fig.4.3, the center black vortex (quasi-black hole) surrounded by the engine plays significant role for the strong magnetic field generating mechanism and generating power source, which seems to be utilized the principle of the black hole and its accretion disk in the latest astrophysics. This content is functionally very interesting. Anyway, the function and form of the spacecraft described in patents and books are very similar.

In the following section, considering the latest developments in the astrophysics, we will explain the possibility of astrophysical space drive propulsion theory.

4.2 Astrophysical Propulsion Engine by Magnetic Field

Comparing the physical mechanisms shown in Fig.4.3 with the astrophysics, they seem to be related to the strong magnetic field, the ergo sphere, the rotating vortex, the accretion disk's shearing field, the inertial frame dragging, the avalanche-ionization processes by magnetic flux line breaking and reconnection, the emission of synchrotron radiation, etc.

Especially, magnetic flux line breaking or magnetic field reconnection can be found working in all areas of space at all times. Anyway, 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. It is interesting for energy generating means as a power source and strong magnetic field generation.

The astrophysical propulsion principle is solved by applying the propulsion principle of space drive propulsion described in Chapter 3.

4.3 Strong Magnetic Field Generation by Magnetic Field Line Break-Reconnection

In astrophysics, magnetic field reconnection can be working in all areas of space at all times. It works not only on the surface of the sun and in the sun's solar flares but also rotating fields of accretion disks in space. The energy of the magnetic field is increased by compressing the gas or stretching the magnetic field lines due to the plasma gas. The phenomenon in which energy stored in the form of a magnetic field is released locally and in large quantities in a short time is well known for solar flares. The acceleration mechanism for these jets may be similar to the magnetic reconnection processes observed in the Earth's magnetosphere and the solar wind.

As magnetic rotation instability grows, magnetic field lines are stretched in the azimuth direction, the magnetic field is strengthened, and the magnetic energy exponentially increases. As is well known, magnetic field reconnection will provide copious productions of electron-positron charged particles, and will produce so much energy. The magnetic reconnection is considered to be promising as a solar flare energy release mechanism, but it seems not necessarily clear at present.

The magnetic field lines play a role analogous to that of conducting wires in an electronic circuit. If the magnetic field lines are broken, then the entire voltage potential drop would be developed across that break. Where the magnetic flux lines are snapped, the electric voltage that was being carried along the whole of that unbroken line would continue to traverse the gap between the snapped ends of that flux line and would continue to increase in potential.

The virtual particle of the vacuum will become unstable at that gap and will break down to transform those virtual particles into real electrically charged particles. When the breakdown in the vacuum occurs, avalanches of electron-positron pairs will be produced out of that of space. In space, the potential drop threshold for when this effect takes place around the breaking of magnetic flux lines is said to be about 10^{12} volts. This particle producing mechanism can be found around Sun, where the chromospheres continually produces electrons and positrons by this method and then has to eject out from it around a million tons of those charged particles every second.

This magnetic field line reconnection process is working throughout the whole cosmos, and in active galactic nuclei which are some of all the astrophysical jets. The magnetic field reconnection system is regarded as one of the most efficient production methods of charged particles in the galaxy. 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.

In impulsive reconnection mechanism which also occurs in the accretion disk, these magnetic field line breaks and reconnections would lead to intense heating, and then anomalous dissipation of additional charged particles in localized regions around those flux lines. With the subsequent production of electron-positron pairs and then these particles feed back into the accretion disk to complete the dynamo effect. As the instabilities accumulate in energy and when the electron velocity exceeds that of the ion-acoustic wave, a flurry of fast reconnection occurs resulting in an explosive outburst of charged particles.

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. 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 energy generation and spatial curvature generation as a propulsion system.

Astrophysical Space Drive Propulsion is promising for propulsion engine and its power source. This is because the strong magnetic field and the power source for spatial curvature generation of space drive propulsion system can be simultaneously solved by a just single technology.

4.4 Simulation of the Accretion Disk Function by Plasma Hole

4.4.1 Released Gravitational Energy

As mentioned before, the essential of the accretion disk is that the role of the power generation function to extract the gravitational energy of the black hole. The system of a black hole and accretion disk is a gravitational power station of 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, gravitational energy cannot be released by free fall where 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, 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.

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 [23, 33, 35].

The local potential energy *dE* released by accreting material *dm* falling in the potential well from *r* to *r-dr* is obtained as follows:

$$dE = E(r) - E(r-dr) = \left(-\frac{GM}{r} + \frac{GM}{r-dr} \right) dm = \frac{GMdm}{r^2} dr \,, \qquad (4.1)$$

where M is the mass of black hole.

Half of this goes to rotation energy (kinetic energy) $E_{rotation}$, while the rest $E_{radiate}$ should be radiated away, that is,

$$E_{rotation} = E_{radiate} = \frac{1}{2} \frac{GMdm}{r^2} dr \quad . \qquad (4.2)$$

When the mass of *dm* falls from the radius *r* to the radius *r-dr*, half of the gravitational energy released by the orbit's drop is spent to increase the rotation, but the other half is used to heat the gas of accretion disk through viscous friction, finally it is converted to light and emitted from the surface of the accretion disk.

This is the mechanism of gravitational energy release: the gravity of the central compact object, the rotation of the surrounding plasma gas (angular momentum), the viscosity between the rotating adjacent gases dominate the accretion disk are key functions.

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, 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:

$$E_{rotation} = E_{radiate} = \frac{1}{2}(dE = E(r) - E(r-dr)) = \frac{1}{4\pi\varepsilon_0}\cdot\frac{Qdqdr}{2r^2}, \qquad (4.3)$$

where Q is the charge of quasi-black hole model, $\varepsilon_0 = 8.85\times10^{-12}(F/m) := 1/36\pi\times10^{-9}(F/m)$.

We make simple calculation here. As a trial calculation example applying the same mechanism to the electric field, let Q = 1000C, dq=0.01C, dr=0.1m, r=1m, we get:

$$dE = \frac{1}{4\pi\varepsilon_0}\times\frac{Qdqdr}{2r^2} = \frac{1}{4\pi\times8.85\times10^{-12}}\times\frac{10^3\times0.01\times0.1}{2\times1^2} = \frac{1}{222\times10^{-12}} =\approx 4.5\times10^9 J. \quad (4.4)$$

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.

However, since this calculation is simply applied, it is necessary to consider whether the similar mechanism of accretion disk can be realized by electric field. Next, the current possibility is described.

4.4.2 Accretion Disk Function by Plasma Hole

By simulating the accretion disk of black hole function by plasma hole, it may be possible to generate a large amount of charged particles by dropping it while turning the plasma.

A plasma hole with a deep potential structure like a black hole is in the experiment state [40, 41].

Fig.4.4 shows the outline of the plasma hole. Fig.4.4 (a) shows the plasma hole, Fig.4.4 (b) shows the spiral pattern observed with plasma. The plasmas are produced by electron cyclotron

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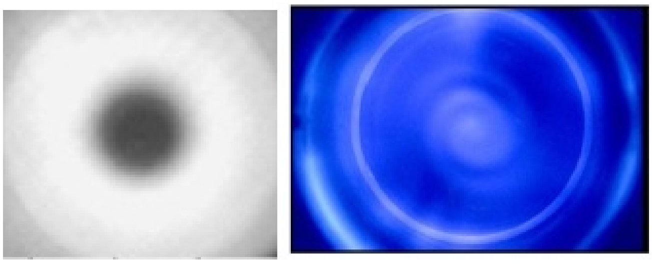
resonance heating, using a microwave frequency of 2.45 GHz. Once the plasma hole structure has arisen, it remains unchanged for an increase of the microwave input power.

The central dark region of Fig.4.4 (a) indicates the density hole, the sizes of which are 6 cm in diameter and more than 100 cm in axial length. This dark part is a cavity of density, and it is named a plasma hole. The density of plasma hole is one-tenth of that in the ambient plasma. This steep density gradient is a remarkable characteristic of the plasma hole.



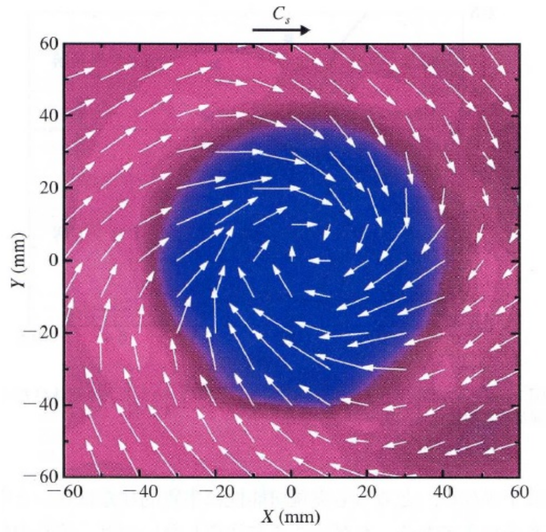
(a) Plasma hole **(b) Spiral pattern observed with plasma**

Fig.4.4 Outline of Plasma Hole (Quoted from [40, 41]).

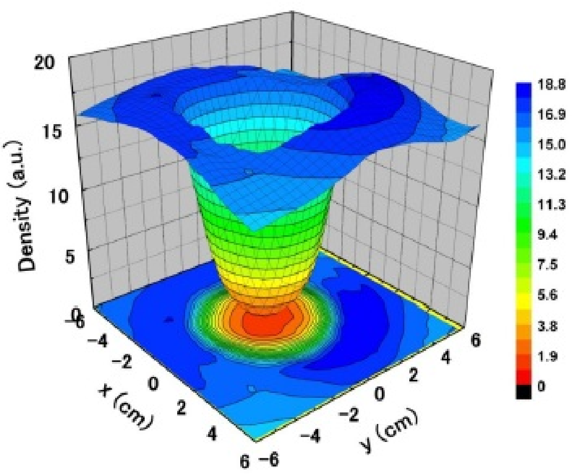
The plasma hole is a unipolar vortex. An important mechanism for driving a flow perpendicular to the magnetic field ***B*** in the plasma is ***E***×***B*** drift driven by the electric field ***E***. This ***E***×***B*** drift has the feature that charge separation does not occur against the occurrence of a macroscopic flow of plasma since ions and electrons move at the same speed in the same direction. ***E***×***B*** drift is the most important mechanism that makes a vortex. The external magnetic field is applied in the cylindrical axis direction of the plasma hole, and the electric field of the plasma faces outward in the radial direction from the central axis. In this case, ***E***×***B*** drift occurs clockwise in a plane perpendicular to the magnetic field.

Fig.4.5 shows the flow field and density distribution of the plasma hole. According to Fig.4.5(a), the plasma hole has a suction vortex structure, and the circumferential rotation coincides with the ***E***×***B*** drift direction. Radial flow is due to viscosity. Plasma collected at the center also flows in the axial direction along the magnetic field.

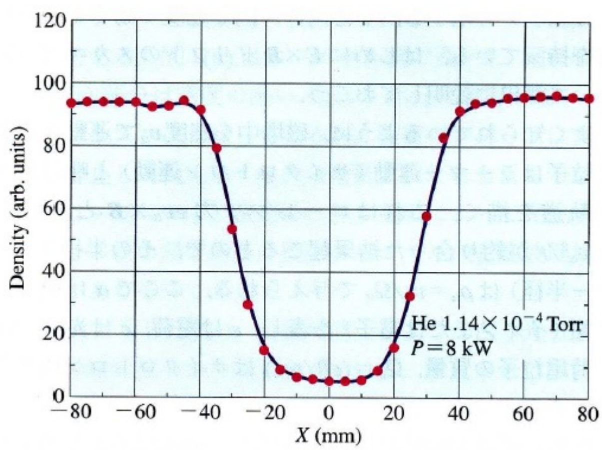
Fig.4.5 (b) shows density distribution of plasma. A cylindrical density cavity (referred to as plasma hole) was spontaneously formed in the plasma.



(a) Flow field in the plasma hole



(b) Density distribution of plasma hole



(c) Radial density profile of the plasma hole (*z*-110 cm)

Fig.4.5 Flow field and density distribution of plasma hole (Quoted from [40, 41]).

Fig.4.5 (c) shows the radial density profile of the plasma hole. The center portion of the plasma hole has a density of 1/10 or less compared with the peripheral portion. It corresponds to where the density cavity looks dark in Fig.4.5 (a). This steep density gradient is a remarkable characteristic of the plasma hole.

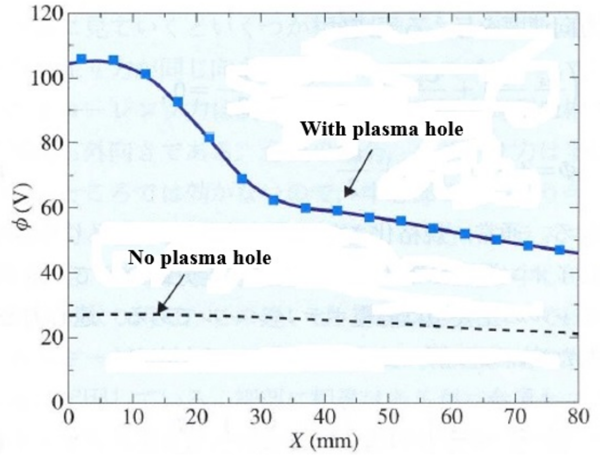


Fig.4.6 Electrostatic potential distribution of plasma hole (Quoted from [41]).

Next, we consider the electrostatic potential distribution of plasma hole referring to Fig.4.6.

The space potentials measured with an emissive probe are +130 V at the hole center and +25 V – +45 V in the ambient plasma. There also exists a steep potential gradient in the density transition layer, and the electric field in this region is 40 V/cm, which results in the azimuthal rotation of the plasma.

The flow pattern exhibits a monopole vortical structure with a sink at the center, and the velocity at r ~3 cm exceeds the ion sound speed.

When a plasma hole is formed, the potential distribution abruptly increases at the center, and a strong radial electric field is formed. A steep potential gradient near the center produces a strong electric field outward from the central axis, and the ***E***×***B*** drift by this electric field drives clockwise circumferential rotation. When there is no plasma hole, it becomes a gentle distribution over the whole plasma.

Finite viscosity causes irreversible thermalization of vortical motion due to the friction of the fluid.

The energy of vortical motion transported by viscous diffusion is finally consumed as heat in this layer. It is pointed out that the energy dissipation undertakes the stationary nature of the plasma hole, which is organized in a plasma with a continuous input of energy. The plasma hole is a dissipative structure in a rotating magnetized plasma.

Formation of spiral structures is a rather general characteristic of magnetized rotating plasmas since the energy stored in the plasma inhomogeneity such as density and velocity shear is released to give instabilities driving a spiral structure. A spiral vortex is generated by a columnar plasma to which an external magnetic field is applied in the axial direction.

This is the same as the accretion disk situation where the plasma gas is sucked into the black hole.

4.5 Propulsion Principle of Astrophysical Space Drive Propulsion

The propulsion principle is the space drive propulsion principle mentioned in Chapter 3, the curvature of space plays an important role. Or the propulsion principle described in the UK Patent GB 2262 844 B (Space drive propulsion device).

The strong magnetic field generation and its power for spatial curvature generation are implemented by a single technology. The following are key technology:

① a large amount of charged particles produced by avalanche phenomenon of electron-positron and thereby strong current and strong magnetic field generation.

②energy generation by magnetic field breaking and magnetic reconnection.

Here, we consider the flow of energy within the accretion disk. Gravitational energy once becomes the thermal energy of ions and electrons, and finally released as light energy. The thermal energy of the ion moves to the thermal energy of the electron due to the Coulomb collision between the ion and the electron. The electrons that obtained the thermal energy collide with the ions again by Coulomb collision to emit energy photons (thermal bremsstrahlung), collide with magnetic lines to emit energy photons (synchrotron radiation), or collide with photons lose energy (inverse Compton scattering). Ions and electrons frequently collide with each other, thermal energy flows from heated ions to electrons, and the ions and electrons are in a state of thermal equilibrium at the same temperature. Furthermore, electrons are cooled by emitting photons.

Generally, positrons are generated in very high energy celestial phenomena. When an electron and a positron collide, it disappears and turns into energy. When electrons and positrons annihilate, a spectral line (electron-positron pair annihilation line) having a peak at 511 keV is generated. Such pair annihilation lines have been detected in many areas of the universe, from solar flares to interstellar spaces, neutron stars, black holes, active galactic nuclei.

In a high-temperature plasma where the temperature reaches the threshold of 6 billion K, electron-positron pairs ($e^- e^+$ pair) are easily formed by high energy protons and collisions between electrons and photons. It is thought that there is a high-temperature plasma around the black hole where electron-positron pairs are generated.

The gas of the accretion disk is plasma, made of ions and electrons. 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. 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, but the charged particles move in the space.

The detailed studies will be carried out in the future, such as 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.

Conclusion

The limitations and problems of the speed and acceleration performance of chemical propulsion, electric propulsion based on momentum thrust and solar sail, light sail based on pressure thrust are described. Meanwhile, we introduced a promising field propulsion theory to solve these problems. Especially, the space drive propulsion theory, which is a typical example of field propulsion, is introduced as a pressure thrust based on the mechanical structure of space from the fundamentals. We also introduced the acceleration performance by the Schwarzschild solution of the gravitational field equation; the superior acceleration performance by the de-Sitter solution. Furthermore the propulsion concept due to the expansion of the local space from the cosmological point of view is explained.

In the end, we introduced the propulsion concept using the most important accretion disk in astrophysics. This is a concept simulating an accretion disk by a spiral structure in a plasma hole, and it generates a strong magnetic field and its power source with a single technology. Since it is a concept under consideration, so we introduced its touch. The author would like to conduct concrete development study in the future.

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APPENDIX A: 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

$$R^{ij} - \frac{1}{2} \cdot g^{ij} R = -\frac{8\pi G}{c^4} \cdot M^{ij} \quad . \qquad \text{(A.1)}$$

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

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

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

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

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

$$R=\frac{8\pi G}{c^4}\cdot M \ . \qquad (A.4)$$

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

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

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

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

Therefore, for M, we have

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

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

$$R^{ij}=-\frac{8\pi G}{c^4}\cdot M^{ij} \ . \qquad (A.8)$$

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.(A.8) becomes

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

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

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

Substituting Eq.(A.10) into Eq.(A.6), we get

$$M^{00} = -\left(\frac{1}{2} \cdot \varepsilon_0 E^2 + \frac{1}{2\mu_0} \cdot B^2 \right) \approx -\frac{1}{2\mu_0} \cdot B^2 . \tag{A.11}$$

Finally, from Eqs.(A.9) and (A.11), we obtain

$$R^{00} = \frac{4\pi G}{\mu_0 c^4} \cdot B^2 = 8.2 \times 10^{-38} \cdot B^2 \quad (B \; in \; Tesla) , \tag{A.12}$$

where we let $\mu_0 = 4\pi \times 10^{-7} (H/m)$, $\varepsilon_0 = 1/(36\pi) \times 10^{-9} (F/m)$, $c = 3 \times 10^8 (m/s)$,

$G = 6.672 \times 10^{-11} (N \cdot m^2 / kg^2)$, 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.(A12) 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 [42]. 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;

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

Where r= $\sqrt{(x^1)^2 + (x^2)^2}$, c_1 and c_2 are constants, $a = \frac{c^2}{\sqrt{kF}}$, 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

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

Since the relation of between magnetic field B in SI units and magnetic field F in CGS Gauss units are described as follows: $B\sqrt{\frac{4\pi}{\mu_0}} \Leftrightarrow F$, then the radius of curvature "*a*" in Eq.(A14) is expressed in SI units as the following (changing symbol, $k \to G, F \to B$):

$$a = \frac{c^2}{\sqrt{GF}} = \frac{c^2}{\sqrt{G} \cdot B\sqrt{\frac{4\pi}{\mu_0}}} \approx (3.484 \times 10^{18} \frac{1}{B} \quad meters) \cdot \quad \text{(A15)}$$

While, scalar curvature is represented by

$$R^{00} \approx R = \frac{1}{a^2} = \frac{GB^2 \frac{4\pi}{\mu_0}}{c^4} = \frac{4\pi G}{\mu_0 c^4} B^2 , \quad \text{(A16)}$$

which coincides with (A.12).

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