一般
社団法人 電子情報通信学会
THE INSTITUTE OF ELECTRONICS,
INFORMATION AND COMMUNICATION ENGINEERS

信学技報
IEICE Technical Report

# 平和と安全のための宇宙航空システムの提案

市吉　修

†二十一世紀を楽しく生きよう会

〒252-0136 神奈川県相模原市緑区上九沢２３０－７
E-mail: osamu-ichiyoshi@muf.biglobe.ne.jp

あらまし
今日の世界はまさに宇宙航空時代であり生活は極めて便利になったが、その分宇宙航空圏における事故の脅威も増している。航空機事故としては2014年のMH370が記憶に新しい。突然地上との連絡が取れなくなり、少なくとも4時間は飛行を続けた事以外は全く詳細不明の事故には今も生々しい恐怖を覚えざるを得ない。MH370の事故原因の一つの可能性は機上の突然の酸欠状態で操縦、運用不能になったのかも知れない。或いは操縦士の精神異常もしくはテロリストによる乗っ取りの可能性もある。実際にそういう事例は過去にあった[1]。
今日米国を先頭に世界は宇宙旅行時代に入ろうとしている。宇宙圏においても航空圏と同様の事故は起るであろう。また巨大隕石やミサイル等の自然及び人為的脅威に対しても対応する必要がある。その対策として筆者は地上と衛星から常時宇宙航空圏を監視し、異常な飛行物体を発見したら直ちに地上から救難機が発進して航空圏または宇宙圏における対象物体に接近して捕獲するシステムを提案した[3],[4]。実現に当たりその最大の問題は救難機の規模が大き過ぎる事であった。今回その点を解決できる新たなシステムを考案したので報告する。

キーワード
航空機事故，宇宙事故、航空通信、宇宙通信、監視衛星、遠距離レーダー、ロケット、方向転換、捕獲

# A Space & Air System for Peace and Security of the World

― ―

Osamu Ichiyoshi

Human Network for Better 21 Century

230-7 Kamikuzawa, Midori-ku, Sagamihara City, Kanagawa prefecture , 252-0136 Japan
E-mail: osamu-ichiyoshi@muf.biglobe.ne.jp

**Abstract**

This is the age of space and air travels. Proportional to the convenience of life, dangers of various types have also increased. As for the air accidents, the case of MH370 is still vivid in our memories. The communication was suddenly lost and nothing in detail is known except for the fact the airplane kept flying for about four hours. In order to prevent such an accident, the author proposed a satellite communication system using **existing** satellites that can provide continuous communications to air planes in flight all over the world [2]. Air accidents can occur of varieties of causes [1]. Similar accidents can also occur in space. The author has proposed space & air systems that constantly monitor the enormous space & air spheres from grounds and satellites. Upon detection of an abnormal object, immediately rescue planes take off, close in to the object to capture it for appropriate actions [3, 4]. The problem was, however, the unrealistically excessive scales required for the rescue planes. The author has now found a method to solve the problem as herein reported.

**Keywords;** Air accidents, Space accidents, Radio communications, Monitoring satellites, Long distance RADAR, Docking, capture, missiles, meteorites

## 1. Dangers in Air and Space Spheres

We are now getting into space age. People are going to travel into space. We must then be prepared to cope with unexpected disasters in space; failures of space ships, collision with space debris, falling of big meteorites, or even missiles.

Aviation has now history longer than a century. Many accidents have occurred of various causes [1]. There are cases the airplanes lost control because of oxygen loss on board the planes. There are even some disasters caused by mental disorder of the pilots or take-over by terrorists..

The disaster of MH370 just 10 years ago (8, March, 2014) still gives us vivid memories and horrors. Nothing is known about the 239 people on the plane except for the fact that the airplane kept flying at least for 4 hours after losing contacts. There is a possibility that the communication links were deliberately cut off or the airplane was taken over by some criminals. The greatest difficulty in rescue operation was caused by lack of information about the location of the aircraft.

## 2. Methods for Security in Space & Air Spheres

In order to prevent disasters in Space & Air spheres, we need to establish the following technologies.

(1) Unstoppable onboard communication

(2) All time monitoring of the space & air spheres from space and grounds

(3) Rescue operations to capture any spaceships or aircrafts in trouble or any abnormal objects in space & air spheres

The above technologies are discussed in detail in the following sections.

## 3. Aircraft Tracking & Communication Satellites

Mobile satellite communications are offered globally by Inmarsat through L bands. The available bandwidth is, however, very limited for the expanding demands. Considering the problem, the author proposed a satellite communication & positioning system that can use the existing satellites in operation [2].

The features of the system are

(1) Accumulation of bandwidth by using multiple satellites in operation

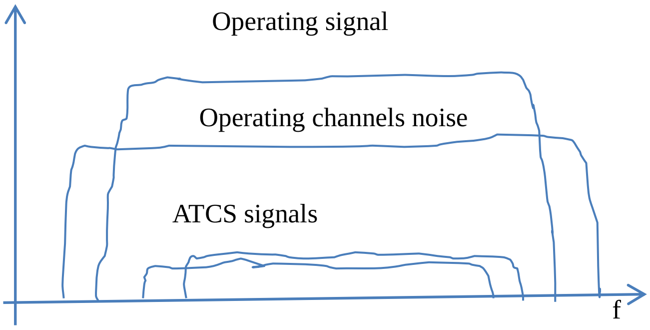
(2) Minimum interference to operating satellite systems by spectrum spreading technology

(3) Simultaneous Positioning with communication

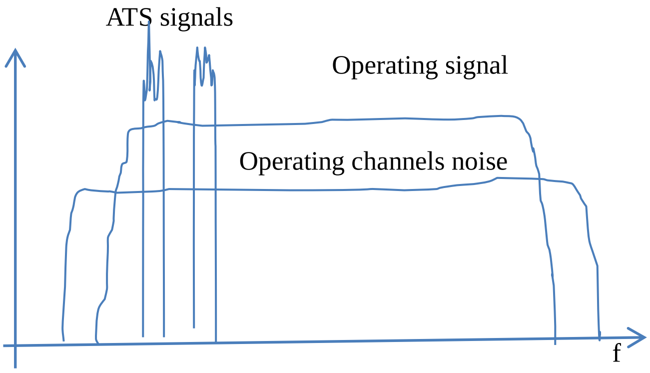
For example,

Under the following specifications:

- Symbol rates of ATCS signals : 5kbaud
- Chip rate for spectrum spreading ; 50 (Mchip/s)
- Process gain; ; 40 (dB)
- ATCS signal Power level vs operating signals ; -30 (dB)
- ATCS signals are multiplexed by FDMA
- Operating systems normal C/N condition ; 10(dB)



TX Spectrum with ATCS in Spread Spectra



RX Spectrum with ATCS after Spectrum de-spreading

Then the available C/N For the ATCS receiver is;

C/N = -30 + 40 = 10 (dB)

The degradation given by ATS signals to the operating satellite system is ;

One ATCS channel ; - 30 (dB) ; negligible
2 ATCS channels ; -27 (dB) ; negligible
20 ATS channels ; -30 + 10log20 = -17 (dB)

The relative noise against the operating satellite channel is

0.1 (-10dB) + 20/1000 = 0.12 = - 9.2 (dB)
Degradation = -9.2 – (-10) = 0.8 (dB)

Channel capacity

The above system can provide 20 channels / 50MHz.

With 50GHz, 20,000channels, that will be sufficient to provide continuous communications to all major airplanes flying at all times.

Location information

GPS data from the airplanes can be reported through the communication links.

## 4. Monitoring from Grounds and Satellites

The author has proposed a system for all time monitoring of the air & space spheres for finding abnormal objects [3.4].

### 4.1 Monitoring from grounds

A long distance RADAR system was proposed with the following features

[1] Measurement Capability

－Velocity of the target; Mach 6, or 2,000 (m/s)
－Distance Range ; Normally 1500km､

[2] RADAR system

- Positioning by measurements from 3 RADAR stations
- Separation of Transmit & Receive timing;

Tx; 10ms + 0 + 0
Rx; 0 + 10ms + 10ms

- Impulse expansion & compression code ; PN code
- CDMA among multiple RADAR stations
- Simultaneous measurements of transmission time and Doppler frequency shift

[3] RF frequency

- Wavelength $\lambda = 1$(m)
- RF frequency fr = 300(MHz)

[4] Link power design

Pt ; Signal Power at input of TX antenna
Gt; TX antenna gain
d; distance to the object
σ ; RADAR aperture of the target
Ar; Effective aperture of Rx antenna

Then the signal power at the output of the Rx antenna is

$$Pr = Pt \cdot Gt / (4\pi \cdot d^2) \cdot \sigma / (4\pi \cdot d^2) \cdot Ar$$

Numerical design

| | | | |
|---|---|---|---|
| Transmitter | | | |
| | Tx power Pt | (dBW) | 40 |
| | Tx antenna gain Gt | (dBi) | 20 |
| Tx path | distance ; d | (km) | (1500) |
| | Path loss (1/(4π.d^2) | (dB/m^2) | -134.5 |
| Target | RADAR area σ | (m^2) | 10 |
| Return path | | | |
| | Distance (d) | (km) | (1500) |
| | Path loss 1/(4π.d^2) | (dB/m^2) | -134.5 |
| Receiver | | | |
| | Rx antenna effective area Ar | dBm^2) | 20 |
| | Signal power at antenna output Pr | (dBW) | -179 |
| Noise | System Noise temperature | (dBK) | 20 |
| | Boltzman constant | (dB) | -228.6 |
| | Noise power density No | (dBW/Hz) | -208.6 |
| C/N power ratio density C/No | | (dB/Hz) | 29.6 |
| | C/N | (dB) | 9.6 |

(10ms integration time is equivalent to 100Hzbandwidth)

[5] Pulse expansion & compression code

<> Pulse width $\Delta t = 1.2\,\mu s$

<> Spread spectrum code PNcode

- Code length 2^13 (chips)
- Code duration 10ms
- Chip rate 819.2kc/s
- Modulation Direct spread (BPSK)

<> PN code correlation detection

- Baseband correlation integration
- Frequency analysis ; $\Delta f = 10$(Hz) steps

<> Measurement distance accuracy

$\Delta t = 1/\text{Chip} = 1/(819\text{kHz}) = 1.2\,\mu s$

Distance; $\Delta d = c.\Delta t = 366$(m) ($c=3\text{x}10^8$(m/s))

(can be improved to a few m by additional processing )

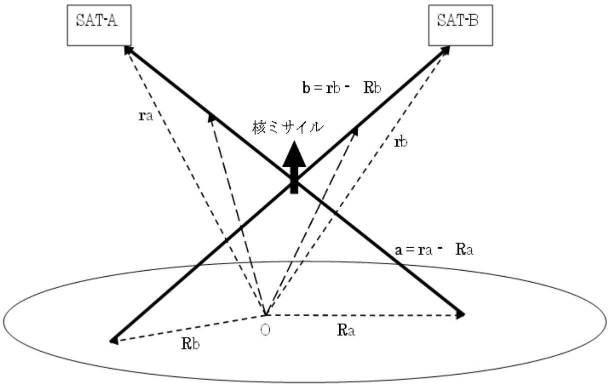
<>Measurement velocity accuracy

$v = c \cdot \Delta f / fr = 3\text{x}10^8 \text{ x } 10 / 300\text{M(Hz)} = 10$(m/s)

4.2 Monitoring from satellites

4.2.1 Detection of a flying object from two satellites

Two pictures (photographic or infra-red) taken each from two satellites as depicted in the following figure can tell the position of the object.



Method of detection;

Define the following vectors;

Vector of the object from a fixed origin O $\mathbf{r} = (x, y, z)$

Location of satellite A $\mathbf{r}a = (xa, ya, za)$,

Point A' is where the image of the object is on the picture.

Let the vector $\mathbf{R}a = (Xa, Ya, Za)$

And vector A→A' be $\mathbf{a} = ra - Ra$

For satellite B, we can define the similar vectors ; $\mathbf{r}b$, $\mathbf{R}b$, $\mathbf{b}$,

Then the position of the object must be on the following two straight lines;

Line AA' ; $\mathbf{r}a + t \cdot \mathbf{a}$ $( 0 < t < 1)$

Line BB' ; $\mathbf{r}b + u \cdot \mathbf{b}$ $( 0 < u < 1)$

Let

$$\mathbf{r}a + t \cdot \mathbf{a} = \mathbf{r}b + u \cdot \mathbf{b}$$

the solution is

$$t = ( \mathbf{r}b - \mathbf{r}a) \cdot \{ ( \mathbf{a} \text{ x } \mathbf{b} ) \text{ x } \mathbf{b} ) \} / \{ (\mathbf{a} \cdot \mathbf{b}) \cdot (\mathbf{a} \cdot \mathbf{b}) - (\mathbf{a} \cdot \mathbf{a}) \cdot (\mathbf{b} \cdot \mathbf{b}) \}$$

$$u = ( \mathbf{r}a - \mathbf{r}b) \cdot \{ (\mathbf{b} \text{ x } \mathbf{a} ) \text{ x } \mathbf{a} ) \} / \{ (\mathbf{a} \cdot \mathbf{b}) \cdot (\mathbf{a} \cdot b) - (\mathbf{a} \cdot \mathbf{a}) \cdot (\mathbf{b} \cdot \mathbf{b}) \}$$

Where $\mathbf{a} \cdot \mathbf{b}$ is scalar product and $\mathbf{b} \text{ x } \mathbf{a}$ is vector product.

The location of the object is;

$$\mathbf{r} = \mathbf{r}a + t \cdot \mathbf{a} = \mathbf{r}b + u \cdot \mathbf{b}$$

4.2.2. Required Satellites Systems

The observable range from a satellite on 100km altitude is a circle on the ground with 1100km radius. From geostationary satellite, the radius is 9,000 km. Another feature of GEO is availability of stable communication link with ground stations. The difficulty is geographical accuracy of detection of the targets. Imaging with proper wavelength can achieve the accuracy down to 1km x 1km [4].

## 5. Space & Air Rescue Methods

### 5.1. Operation of the proposed system

At detection of an abnormal object, the target is to be captured by a rescue plane with rocket docking technology. The process starts with open loop access that takes the rescue plane to the neighborhood of the planed site of the capture. Then the closed loop access follows by minimizing the measured distance and velocity difference between the target and rescue plane [4].

### 5.2. Open loop access

At detection of the target object, based on the monitoring data, the rescue system determines time, position and velocity at the planned capture, then launch the rescue plane.

### 5.2.1. Requirements for rescue plane

The rescue plane must be ready for launch at any time. Automatic operation is essential. We assume a two stages rocket system.

### 5.2.2. Procedure of open loop access

[1] Calculation of the orbit and determination of acquisition

If the orbit of the object is alarming, the rescue system determines time ta, position **R**a and velocity **V**a for acquisition of the target.

[2]Launch of rescue plane, event times and spaces

Define the following symbols;

At launch; time ; t0, Location ; **r0**, Velocity; **v0** = 0
Separation of $1^{st}$ stage rocket ; t1, **r**1, **v**1
At acquisition of the target ; ta, **R**a, **V**a

[3] Rising by first stage rocket to < t < t1

Let Ti be the duration of burning of the first stage rocket

Then,

$$t1 = to + Ti$$

Let **a**o be the acceleration, **f**o the thrusting force of the engine, and Mo the average mass of the plane. Then,

$$\mathbf{a}o = \mathbf{f}o/Mo - \mathbf{g}$$

where **g** is the acceleration of gravity by the earth.

Velocity is time integration of acceleration;

$$\mathbf{v}o(t1) = \mathbf{a}o.(t1 - to) = \mathbf{a}o.Ti$$

Further integration gives the position;

$$\mathbf{r}(t1) = \mathbf{r}(to) + \mathbf{a}o.Ti^2 / 2$$

The energy consumed in ths stage ;

$$Eo = [to, t1] \int \mathbf{f}o.\mathbf{v}(t)dt = Mo.(\mathbf{a}o + \mathbf{g}).\mathbf{a}o.Ti^2 / 2$$

Where M0 is total mass of the rockets.

[4] Stage for acquisition of the target t1< t < ta

Let **a**1 be the acceleration in this stage.

Velocity;

$$\mathbf{v}(ta) = \mathbf{v}(t1) + \mathbf{a}1.(ta - t1) = \mathbf{V}a$$

Similarly for the position

$$\mathbf{r}(ta) = \mathbf{r}(t1) + \mathbf{v}(t1).(ta-t1) + \mathbf{a}1.(tr - t1)^2/2 = \mathbf{R}a$$

Then we get accelerations **a**o and **a**1as follows;

$$\mathbf{a}1 = \{ -2(\mathbf{R}a - \mathbf{r}o) + \mathbf{V}a.(2(ta-to)-Ti) \} / \{ (ta-to-Ti).(ta - to) \}$$

$$\mathbf{a}o = \{ 2(\mathbf{R}a - \mathbf{r}o) - \mathbf{V}a.(ta - to - Ti) \} / \{ Ti.(ta - to) \}$$

The energy E1 consumed in this stage is calculated using the thrusting force **f**1 and he average mass M1;

$$\mathbf{f}1/ M1 - \mathbf{g} = \mathbf{a}1$$

$$E1 = [t1, ta] \int M1(\mathbf{a}1+ \mathbf{g}). (\mathbf{v}(t1) + \mathbf{a}1(t - t1) )dt$$
$$= M1. (\mathbf{a}1 + \mathbf{g} ). (ta - to - Ti).\{ \mathbf{a}o.Ti + \mathbf{a}1.(ta - to - Ti) / 2 \}$$

[5] What to do with the acquired target

It must be decided by human controller depending on the nature of the target; space ship in failure, big meteorite, or missiles.

### 5.2.3. Estimate of the scale of the proposed system

Here we adopt the Cartesian coordinate system shown in the following figure. The position is depicted by (horizon, altitude).

The space location of the acquisition is expressed as

**R**a-**r**0 = (horizon, altitude ) (km)
= (100, 100), (0, 100), (-100, 100)

These three cases will be studied.

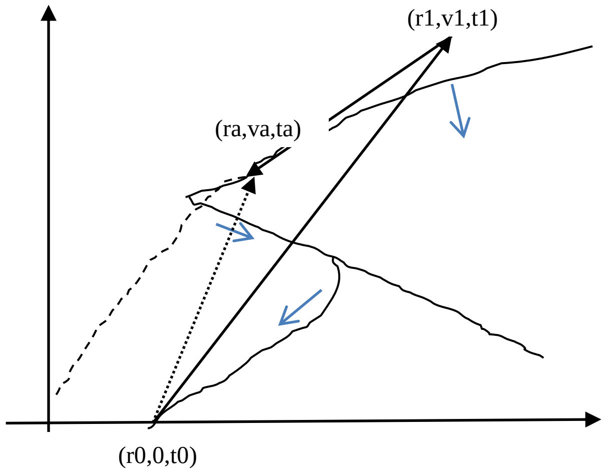
The velocity at the acquisition is assumed as

**V**a = (-2000, -1000) (m/s)

Duration of rocket burning shall be;

Ti = t1 - t0 = 120(sec)
ta – t1 = 120(sec)

。



Operation of the rescue system

Then the required acceleration in the three cases are calculated as shown in the following table.

| Ra-r0 (km) | a0 G = 9.8m/s^2 | a1 G; Gravity |
|---|---|---|
| (100, 100) | (15.3, 11.1)(m/s^2)<br>= (1.56, 1.13)G | (-31.9,-19.4)(m/s^2)<br>= (-3.26, -1.98) G |
| (0, 100) | (8.3, 11.1) (m/s^2)<br>= (0.85, 1.13)G | (-25, -19.4)(m/s^2)<br>= (-2.55, -1.98)G |
| (-100, 100) | (1.39, 11.1) (m/s^2)<br>=(0.14, 1.13)G | (-18.6, -19.4) (m/s^2)<br>= (-2.0, 1.98)G |

We now estimate the scale of the first stage. The rocket engine must generate the above acceleration plus that of the gravity.

With the total mass M0 the first stage rocket engine must generate force fo that meet the following equation;

f0/M0 = a0 + g (g; gravity acceleration)

| Ra-r0 (km) | f0/M0 = a0+g G = 9.8m/s^2 | \|f0/M0\| G; gravity unit |
|---|---|---|
| (100, 100) | (1.56, 2.13)G | 2.64 G |
| (0, 100) | (0.85, 2.13)G | 2.30 G |
| (-100, 100) | (0.14, 2.13)G | 2.13 G |

The mass ratios of the first and the second stages is usually around

M1/M0 = 1/10.

Let us see the cases

M0 = 200, 100, 50 (ton)

Then the required engine output of the first stage is calculated as shown in the following table.

| | | f0 = \|f0/M0\| ・M0 (tonf) | | |
|---|---|---|---|---|
| Ra-r0 (km) | \|f0/M0\| | M0=200 (ton) | M0=100 (ton) | M0=50 (ton) |
| (100, 100) | 2.64 G | 528 | 264 | 132 |
| (0, 100) | 2.30 G | 460 | 230 | 115 |
| (-100, 100) | 2.13 G | 426 | 213 | 107 |

## 6. Proposed Space & Air Security System

### 6.1. Problems to be solved

The above systems have the following problems.

(1) Required size of the spacecraft is too large.

(2) The gravity loss is too large.

The force required for the first stage engine is

f0/M0 = a0 + g (g; gravity acceleration)

For the case **R**a-**r**0 = (100, 100) (km),

f0/M0 = 2.64G = 1.64G + 1.0G

The gravity loss ; 1.0/2.64 = 0.38

(3) Momentum loss is too large

The rescue plane must initially fly toward the target.

Then in the second stage the rescue plane must reverse its direction to collect the same velocity as the target. Changing the velocity requires a great loss of energy.

(4) Operational difficulty

Separation of the first stage rockets extremely limits the geographical ranges of operation. It is also very difficult to reuse the first stage engines.

### 6.2. Winged Aircraft and Spacecraft system

In order to solve the above problems the author proposes winged aircraft and spacecraft system.

(1) The first stage aircraft carries the second stage spacecraft toward the target.

(2) Before separation, the first stage aircraft turns around to change the direction of its velocity to that of the target.

(3) After separation, the spacecraft flies toward the time space (ta, **R**a, **V**a) planned to capture the target.

(4) The first stage aircraft returns to the base airport.

(5) The spacecraft accelerates to reach the planned acquisition space-time point (ta, **R**a, **V**a).

(6) The spacecraft closes in to the target by controlling the distance and velocity difference.

(7) The spacecraft captures the target to carry it toward the planned location.

(8) The spacecraft is winged. As it comes down, the atmosphere gets gradually thicker to generate floating force that cancels gravity to prevent collecting excessive speed.

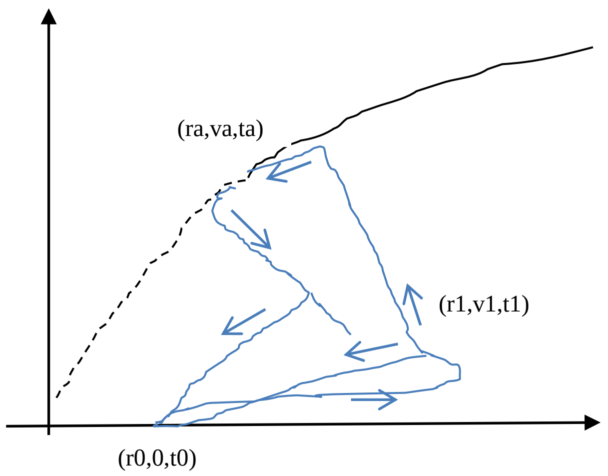
(9) As the spacecraft comes down it functions as an

ordinary aircraft.

(10) The spacecraft drops the target at the designated site.

(11) The spacecraft returns to its base airport.

The above processes are depicted in the following figure.



Operation of the rescue system with winged crafts

## 6.3. Features of the proposed system

### 6.3.1 Functions of winged aircraft

Horizontal components

Let M be the mass, f be the horizontal thrust force of the engine, u be horizontal velocity. Then the equation of motion in the horizontal components is;

$$M \cdot [d/dt]u = f - d \cdot u^2$$

Where d is air resistance coefficient.

The solution under the initial condition u = 0 at t = 0 is

$$u = \sqrt{(f/d)} \cdot \tanh(\sqrt{(f.d)} /M \cdot t) \quad \rightarrow \quad \sqrt{(f/d)} \quad (t >> 0)$$

If $\sqrt{(f.d)} /M >> 1$, then the horizontal velocity reaches the steady state very rapidly.

Vertical component

The wing generates the lifting force in the vertical direction.

Let ft be horizontal thrust force, fl be lifting force generated by the wing. Then,

$$ft = d \cdot u^2$$

$$fl = c \cdot u^2$$

where d, c are respectively air resistance and lifting forces coefficients.

The vertical force working on the aircraft is $fl - Mg$, where M is the total mass of the aircraft and **g** is gravity acceleration constant.

The vertical force equation is

$$[d/dt]v(t) = (fl/M-g) - k.v(t)$$

where k is coefficient of air resistance.

Solution of the equation with initial condition v(0) =0

$$v(t) = ( c \cdot u^2 / M - g) /k .\{1-e^{(-(k.t))}\}$$

$$\rightarrow \quad ( c \cdot u^2 / M - g) /k \qquad ( t >> 0)$$

Control parameters of the aircraft are;

- Thrust force (engine output) ; ft
- Elevation angle of the fuselage controls the coefficient c , d

Then the following items of the aircraft can be controlled

- Horizontal velocity ; $u = \sqrt{(ft / d)}$
- Vertical velocity ; $v = ( ft.c / d - M.g) / k$

Horizontal cruising is achieved by; $ft= M.g / (c/d)$

### 6.3.2 Improvements

[1] Mechanical reduction of Rescue Planes

The lifting force parameter c is tens of times greater than the air resistance parameter d [5].

$$c/d = 10 \text{ to } 80$$

Thus the required engine force to lift the rescue planes are much reduced as in the following table.

| | f0 = M0 / (c/d) (tonf) | | |
|---|---|---|---|
| Ra-r0 (km) | M0=200 (ton) | M0=100 (ton) | M0=50 (ton) |
| (100, 100) | 20 | 10 | 5 |
| (0, 100) | | | |
| (-100, 100) | | | |

In fact, large commercial airplanes daily carry loads weighing up to 400 tons. The wings are quite effective to avoid the gravity loss.

At separation of the spacecraft from the carrier aircraft the initial velocity of the spacecraft is transmitted from the carrier aircraft without loss of energy, thus the scale of the rescue planes can be reduced.

### [2] Mitigating gravity loss by centrifugal force

The velocity of spacecraft is initially given by the carrier aircraft. Let v be the horizontal speed of the spacecraft. Then the spacecraft get the centrifugal acceleration

$v^2/(Ro + h)$ where $Ro = 6366$(km), radius of the earth and h is the altitude of the spacecraft.

For $v = 2000$ (m/s), and $h = 100$(km), the centrifugal acceleration is

$$\begin{aligned} v^2 / (Ro + h) &= (2 \times 10^3)^2 / 6.466 \times 10^6 \\ &= 0.15\ (m/s^2) \\ &= 0.15g \end{aligned}$$

where g is the gravity constant. Thus the gravity loss is compensated a little. If the horizontal velocity approaches 8km/s, then the gravity is fully compensated by the centrifugal force.

### [3] Flexibility

The proposed system is flexible enough to cope with unpredicted events anytime, anywhere and in any directions.

### [4] Reusability and Safety

Both the carrier aircraft and rescue spacecraft are fully reusable. There is not any falling part in operation of the system. Therefore it is not only safe and economical but also can cope with consecutive events.

## 7. Conclusion

A new system for peace and security of the air and space spheres is proposed based on previous proposals and new ideas.

## References

[1] 加藤寛一朗　「まさかの墜落」
大和書房，2007 年

[2] Osamu Ichiyoshi
“ A Proposal for Aircraft tracking Satellite System
~Never to repeat the disaster of MH370~ “
信学技報 IEICE Technical Reports
Vol. 114, No.265 Sat-2014-49, pp.183-188

[3] Osamu Ichiyoshi
“ A Space and Air System for Peace and Security of the World” IEICE Technical Report SAT-2020-37 (2021-02)

[4] Osamu Ichiyoshi
“An Automatic Method to Capture Target Objects in Space”
IEICE Technical Report　SANE2022-44(2022-08)

[5] 谷　一郎　流れ学　岩波全書