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Development of a New, Redundant Flight Safety System Using Inertial Sensors

By

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Summary: Flight Safety System requires high reliability on its operation because of the crucial duties, duties to decide to destruct a flying vehicle or not, etc. in a state of emergency. A new Flight Safety System which is totally independent from our old one, that depends on radar information, is based upon the principle of inertial navigation in calculating a real time trajectory and impact points on earth by online PCM-Telemetry data. We have applied this back up system for practical missions such as Halley mission and Ginga mission, and have had successful results. An efficient, redundant system was born only by connecting ordinary personal computer to the line, for rapid calculation can be expected in constructing transfer matrix in single pole representation of attitude.

Symbols & Notations

$\mathbf{I}_1,\mathbf{I}_2,\mathbf{I}_3$	: unit vectors fixed to one axis platform
$\mathbf{e}_1,\mathbf{e}_2,\mathbf{e}_3$	: unit vectors fixed to reference inertial frame
x_1,x_2,x_3	: coordinates of the point A
$\bar{x}_1,\bar{x}_2,\bar{x}_3$	: coordinates of the point B
g	: gravity acceleration
g_0	: gravity acceleration at KSC
ξ	: a single pole coordinate
η	: a single pole coordinate
Ω	: angular velocity of the earth
ϕ_0	: lattitude at KSC
C_{RP}	: A transfer matrix from the platform coordinate to reference inertial coordinate
C_{PR}	: A reverse matrix of C_{RP}
C_{RK}	: A transfer matrix from KSC coordinate to inertial one
R_0	: Radius of the earth
A	: A point (x_1,x_2,x_3) on the unit sphere, a direction of body axis
B	: A point on a circlet on the unit sphere
S	: Singular point $(-1, 0, 0)$

1. INTRODUCTION

It is essentially important in the case of emergency of a flying vehicle to grasp an exact situation what really happened to the vehicle and to provide a rapid safety operation so as to prevent inducing a disaster on the ground. We have to have, for this sake, at least one real time monitoring system showing us a whole flight situtation to prepare against abnormal events. Our old Range Safety System (Fig. 1, real line shows the old system, dotted line the new one on which this paper refers to) consists of radars, telemetry, TVs and computers, and each component is connected with online, real time network. All information concerning the flight safety gather up to the Range

Safety operation desk in control center.

We sum up these information sources.

1) RADAR

Three redundant radars track a flying rocket. The dominant position source is the precision radar which has 20 bits data length in range measurement.

Information from other radars, 3.6m ϕ radar and 4.0m ϕ radar, can be exchanged autonomatically under computer control of data quality. Unit transfer rate of radar information is 52 byte/100ms for prec. radar and 4.0m ϕ radar, 26 byte/100ms for 3.6m ϕ radar.

2) TELEMETRY

Attitude parameters, angular rate vector, error angles, acceleration vector, chamber pressures and sequence monitoring signals are obtained by processing 300 MHz PCM Telemetry raw data by mini-computer in Telemetry center and are transferred to our systems. Quantity of information unit, 72 byte/100ms.

3) On board TV

Two CCD cameras on upper part of 2nd stage booster take pictures and high speed TV information is transferred on 13 GHz microwave.

4) TV cameras at optical site in KSC track the vehicle and fixed TV cameras also monitor it. Visual information is significantly important in making use of multi-functional ability of human beings.

5) Flight Safety monitoring computer system

Dual online system of minicomputers takes imput data above mentioned and predicts impact position, judges it at the critical situations, and it displays the present position (PPI) in two scales, instantaneous impact position prediction (IIP) and telemetry information. All of these functions must be done, of course, in real time.

When the chief director of flight security judges the case dangerous and irreversible from the point of range safety, he has to send commands and prevent a disaster which may befall if he does not do it.

Commands provided are;

COMMAND ITEMS

i) Timer stop

ii) Destruction of the 1st stage chamber at the 1st segment by shaped charge
Destruction of the 2nd stage chamber at the upper part by ring shaped charge

iii) Control stop

2. Redundancy and Range Safety System

Flight Safety System requires high reliability on its operation. Our old system have been improved for many times in consideration of reliability by introducing redundant radars and dual computers (Fig. 1). The redundant system has proved itself useful in our previous flight tests. We give here some examples.

We had an experience that one radar failed to track a flying rocket temporarily and so had no radar information while position data (PPI) and predicted impact point data (IIP) went to balck-out. It takes several ten seconds to recatch the vehicle for an ordinary tracking radar because once it fails to track, a wide angle, auxiliary radar must take a role to recatch. We have faced a problem of instability of on board radar transponder. If it works instably, we will have noisy data, which sometimes produce fatal results because differentiation is to be operated for the data to acquire velocity vector in IIP calculation. And we had an accident that the central host computer failed down because of overload at one of the terminals.

By considering these negative examples we can easily understand the advantage of pararell, dispersive system, which is completely independent and cooperative.

We had developed a new, redundant Range Safety System in which a different principle from old one, a principle of inertial navigation, is adopted in acquiring position data (PPI) and predicted impact point data (IIP). We have applied this device (RS-INS) as a complete back up of radars in flight tests. The results have been successful.

First we will explain a coordinate system to which our new device owes in Chapter 3, and the results of this redundant system in real flight tests will be discussed in Chapter 4.

3. Single Pole Coordinate and Range Safety

3–1 Merits and demerits of Single Pole representation in Range Safety System

It is natural that 3 axis motion of attitude for a slender axisymmetrical bodies should be treated in such a way as to separate motion of body axis and a roll motion. We have used one axis platform system for attitude control in ISAS vehicles, on which 2 axis gyros detect the direction of body axis while another gyro detects a rotational motion of body in roll and controls the platform motion in roll.

We have adopted single pole coordinate in representation of attitude in stead of Euler angle representation since M-3SII-1 flight in 1985. The single pole representation has been used in inertial navigation system even in commercial airlines. We will have a definition of the coordinate first and then will comment on merits and demerits not from a standpoint of inertial navigation in general but from a standpoint of our usage, range safety operation.

Imagine a sphere with unit radius, at center of which is located the origin of the coordinate. (Fig. 2) Let the point on which the vehicle's body axis intersects the sphere be called A. And we call the point $(-1, 0, 0)$ S because it is a singular point in single pole representation. The sphere is sometimes called Riemann's sphere. The point (ξ, η) is defined as the point on which the line SA intersects the x_2 x_3 plane.

In single pole representation an attitude of vehicle in space is expressed not by 3 rotation angles but by 4 components, $(\xi, \eta, \cos R, \sin R)$, where R means a roll angle.

Now we will first sum up merits and demerits of the coordinate for our system, and in later section we will introduce mathematical explanations on these points.

MERITS

A) We would face an accidental case such as tumbling of a vehicle and even in that case attitude must be expressed normally from range safety standpoint. We can use wider normal region in representation of attitude in single pole coordinate than that in

Euler representation which has two symmetrical poles in the celestial sphere.

B) In computing the transfer matrix between body fixed coordinate and inertial one, single pole representation (ξ, η, cos R, sin R) is more advantageous for INS use because no component in the matrix contains trigonometric function. The matrix component has at highest 2nd order term in ξ and η. We can expect high speed computing in calculation of the transfer matrix.

C) There is no problem concerning order of rotations which is essential in Euler representation. This is not a trivial matter for a practical group researcher who must work together with many engineers.

D) Boundary, inside which instantaneous direction of the body central axis must stay during the flight, depicts a circlet on the celestial sphere. If we want to represent the circlet in Euler coordinate, say in pitch and yaw plane, the circlet maps to a transcendental curve and so real time drawing is time-consuming matter.

But the circlet suprisingly transfers to a circle in (ξ, η) plane in single pole representation. This coincidence helps real time drawing of the boundary.

DEMERITS

A) Single pole representation may not be intuitive. We cannot always say, however, that Euler representation is intuitive, for it requires high skill to know a mode of attitude motion when 3 parameters vary in real time.

B) A special microprocessor must be on board for single pole representation. We were lucky that a microprocessor for single pole representation was installed for attitude control usage.

3.2 Single Pole coordinate and Transfer matrix

By taking into consideration of similarity relations on the triangles in Fig. 2, we have these relations as,

$$\frac{1}{x_1+1} = \frac{\eta}{x_2} = \frac{-\xi}{x_3} = \frac{1}{K} .$$

Point $A(x_1,x_2,x_3)$ lies, of course, on the unit sphere, so we have a relation as

$$x_1^2 + x_2^2 + x_3^2 = 1$$

These relations reduce to

$$\begin{aligned} k &= 2/(\xi^2 + \eta + 1), \\ x_1 &= (1 - \xi^2 - \eta^2)/(\xi^2 + \eta^2 + 1), \\ x_2 &= 2\eta/(\xi^2 + \eta^2 + 1), \\ x_3 &= -2\xi/(\xi^2 + \eta^2 + 1), \end{aligned}$$

A unit vector in OA direction $\mathbf{I}_1$ can be expressed as

$$\mathbf{I}_1 = [(1 - \xi^2 - \eta^2)\mathbf{e}_1 + 2\eta\mathbf{e}_2 + (-2\xi)\mathbf{e}_3]/(\xi^2 + \eta^2 + 1),$$

$$= \mathbf{A}$$

And we have also expressions for $\mathbf{I}_2$ and $\mathbf{I}_3$ as

$$\mathbf{I}_2 = \frac{\partial \mathbf{A}}{\partial \eta} \Big/ \left|\frac{\partial \mathbf{A}}{\partial \eta}\right|$$
$$= [-2\eta \mathbf{e}_1 + (1+\xi^2-\eta^2)\mathbf{e}_2 + 2\xi\eta \mathbf{e}_3]/(\xi^2+\eta^2+1),$$

and

$$\mathbf{I}_3 = \frac{\partial \mathbf{A}}{\partial(-\xi)} \Big/ \left|\frac{\partial \mathbf{A}}{\partial(-\xi)}\right|$$
$$= [2\xi \mathbf{e}_1 + 2\xi\eta \mathbf{e}_2 + (1-\xi^2+\eta^2)\mathbf{e}_3] \,/\, (\xi^2+\eta^2+1).$$

In matrix notation we can represent a useful relation as,

$$\begin{pmatrix}\mathbf{I}_1\\ \mathbf{I}_2\\ \mathbf{I}_3\end{pmatrix} = \begin{pmatrix}1-\xi^2-\eta^2, & 2\eta, & -2\xi\\ -2\eta, & 1+\xi^2-\eta^2, & 2\xi\eta\\ 2\xi, & 2\xi\eta, & 1-\xi^2+\eta^2\end{pmatrix}\begin{pmatrix}\mathbf{e}_1\\ \mathbf{e}_2\\ \mathbf{e}_3\end{pmatrix} \Big/ (\xi^2+\eta^2+1)$$

We define the transfer matrices as follows,

$$C_{RP} = \frac{1}{(\xi^2+\eta^2+1)}\begin{pmatrix}1-\xi^2-\eta^2, & 2\eta, & -2\xi\\ -2\eta, & 1+\xi^2-\eta^2, & 2\xi\eta\\ 2\xi, & 2\xi\eta, & 1-\xi^2+\eta^2\end{pmatrix}$$

$$C_{PR} = \frac{1}{(\xi^2+\eta^2+1)}\begin{pmatrix}1-\xi^2-\eta^2, & -2\eta, & 2\xi\\ 2\eta, & 1+\xi^2-\eta^2, & 2\xi\eta\\ -2\xi, & 2\xi\eta, & 1-\xi^2+\eta^2\end{pmatrix}$$

where C_{PR} means a transfer matrix from inertial reference frame to platform frame and C_{RP} means a reverse matrix of C_{PR}.

It is decisively important that any component of the matrix has at highest 2nd order term in ξ and η. This fact makes computation on INS rapider, while functions such as trigonometric one are rather time-consuming.

A transfer matrix from a platform coordinate to a body fixed coordinate is given by an ordinary matrix, rotational, orthogonal one. Important point is that we are given 4 components (ξ, η, cos R, sin R) and so we need not also here compute trigonometric functions.

Coordinate system (x_1,x_2,x_3) is defined in real flight test by taking consideration on launching azimuth and a attitude history. The axis x_1 is defined to be horizontally east, x_2 horizontally south and x_3 vertically downward. The definition decides a direction of the single pole, that is horizontally west. Initial value of ξ is positive by the definition.

3–3 A transfer matrix from inertial frame to KSC frame

As the objects of range safety operation such as lands and islands for example are fixed, of course, on earth, any vector should be expressed in earth fixed coordinate, KSC coordinate.

A transfer matrix from the inertial frame to KSC fixed frame is given as

$$C_{RK}=\begin{pmatrix} B^2+A^2cs, & AB(cs-1), & Asn \\ AB(cs-1), & A^2+B^2cs, & Bsn \\ -Asn, & -Bsn, & cs \end{pmatrix}$$

where the symbols cs, sn A and B are

$$cs = \cos\Omega t;\ sn = \sin\Omega t,$$

and $$A = \cos\phi_0;\ B = \sin\phi_0.$$

The symbol Ω stands for angular velocity of earth, ϕ_0 the lattitude at KSC. Note on the fact that a transfer matrix from inertial frame to KSC one contains trigonometric calculations, and that we need this matrix calculation only for display in GD, once a second in our case.

3–4 Gravity distribution

It is a significant problem for long range missiles and spacecrafts with INS that on-board computer must have a big table of gravity distribution on earth surface. We can assume, however, gravity acceleration is a function of altitude only, because our duty time in flight safety operation is limited, to 250 sec or less.

Gravity acceleration is given in form of

$$\mathbf{g} = -g_0 \frac{(R_0+x_1)\mathbf{e}_1+x_2\mathbf{e}_2+x_3\mathbf{e}_3}{[(R_0+x_1)^2+x_2^2+x_3^2]^{3/2}}\ .$$

3–5 A representation of attitude allowance curve in ξ, η plane
Circle—Circle Coincidence

A point $A(x_1,x_2,x_3)$ lies on the celestial sphere, as shown in Fig. 3, so we have relations as,

$$\mathbf{A} = x_1\mathbf{e}_1 + x_2\mathbf{e}_2 + x_3\mathbf{e}_3,$$
$$x_1^2 + x_2^2 + x_3^2 = 1.$$

Now we draw a circlet on the sphere. Let a center of the circlet be called A. The circlet expresses an attitude allowance curve in this context. We will have a projection of this circlet onto ξ, η plane. What kind of figure this projection brings about? We define a point B (x_1,x_2,x_3) on this circlet. So we have relations just like above as

$$\mathbf{B} = \tilde{x}_1\mathbf{e}_1+\tilde{x}_2\mathbf{e}_2+\tilde{x}_3\mathbf{e}_3 \ ,$$
$$\tilde{x}_1^2+\tilde{x}_2^2+\tilde{x}_3^2=1,$$

and a relation between Aand **B** as

$$\mathbf{A}\cdot\mathbf{B} = x_1\tilde{x}_1 + x_2\tilde{x}_2 + x_3\tilde{x}_3 = \alpha.$$

A line which connects the point S $(-1, 0, 0)$ and B $(\tilde{x}_1,\tilde{x}_2,\tilde{x}_3)$ is expressed as,

$$x_2 = \frac{\tilde{x}_2}{\tilde{x}_1+1}(x_1+1),$$
$$x_3 = \frac{\tilde{x}_3}{\tilde{x}_2}x_2$$

We can easily acquire expressions for ξ, η by substituting $x=0$, $\xi=-x_3$ and $\eta=x_2$ in equations just above. And the coordinate of the intersect point are as follows.

$$\eta = \frac{\tilde{x}_2}{\tilde{x}_1+1} \ ,$$
$$-\xi = \frac{\tilde{x}_3}{\tilde{x}_2}\eta = \frac{\tilde{x}_3}{\tilde{x}_1+1} \ .$$

By these formulae and the relations given in earlier part of this section, we can eliminate $\tilde{x}_1$, $\tilde{x}_2$, $\tilde{x}_3$ in this way

$$x_1\tilde{x}_1+x_2\eta(\tilde{x}_1+1)+x_3(-\frac{\xi}{\eta})(\tilde{x}_1+1) = \alpha,$$
$$\tilde{x}_1^2+\eta^2(\tilde{x}_1+1)^2+\xi^2(\tilde{x}_1+1)^2 = 1 \ .$$

A equation above reduces to

$$\tilde{x}_1+1= \frac{x_1+\alpha}{x_1+x_2\eta-x_3\xi} \ .$$

So we have equation as

$$(\alpha-x_2\eta+x_3\xi)^2 + (\xi^2+\eta^2)(\alpha+x_1)^2 = (x_1+x_2\eta-x_3\xi)^2$$

This equation can be reformed to

$$(\xi+\frac{x_3}{p})^2 + (\eta-\frac{x_2}{p})^2 = \frac{1}{p^2}(x_1^2+x_2^2+x_3^2-\alpha^2) = \frac{1}{p^2}(1-\alpha^2)>0$$

where p represents $p=x_1+\alpha$.

This is a equation of a circle in $\xi\,\eta$ plane with the center at $(-x_3/(x_1+\alpha), x_2/(x_1+\alpha))$ and radius $\sqrt{1-\alpha^2}/(x_1+\alpha)$! The simple result brings about a reality of drawing a attitude allowance curve in real time because a quick drawing device of circle is equipped in recent microcomputers.

3–6 Our new Range Safety System, RS-INS

It is well known that inertial sensors were used for position acquisition device since earlier missiles (INS) and they are now developed to a highly complicated missile's brain. Here we utilize gyros for attitude control and ordinary strain gauge type accelerometers, so that we have an economical and effective system.

We can affirm that inertial navigation system is adaptive to our range safety operation in these points as;

1) We must watch a trajectory (PPI) and impact point prediction (IIP) from ignition of 1st stage to the spinning up of 2nd stage. It takes rather short time, say 250 sec.. So we can neglect a gyrodrift and bit round error, and most significant one is due to calibration error of accelerometer in body axis.

2) Most decision in flight safety operation concerns a global judgement whether vehicle's motion intrudes the critical line or not, and so pin point precision on trajectory data is not always necessary. Our gyros for attitude control and economical accelerometers can compose a sufficient device.

3) A short running time of our operation enables our computation to be sufficiently precise, partly because gravity acceleration can be assumed to be a function of altitude only.

4 Application for Real Flights and the Results

4–1 Results in M-3SII-1 Flight

Our new, integral type range safety system was applied for the real flight, launching of M-3SII-1 for the Halley mission in 1985. The results were fruitful.

Fig.4 represents the monitoring GD at the time. The left picture shows the position of the vehicle (PPI) where horizontal axis give down range and vertical one, altitude and side position. The origin is located at the launching site in KSC and unit of distance is Km. Nominal trajectory, allowable range and alarm lines are also drawn. Numbers above in the picture give measured acceleration components and 4 components attitude parameters. Numbers below give time, position vector and velocity. Needless to say, velocity is acquired as intermediate result in calculating position vector.

The picture above right gives a direct representation of attitude. (ξ, η) point and a directional line expressing a roll angle are provided.

The picture below right is a enlarged PPI near KSC, which gives very important information just after ignition of rocket.

16 bit personal computer (PC 9801E, clock 8 MHz) is utilized in this device. All information is transfered from Telemetry minicomputer in bit rate 4800 bit/sec. Attitude parameters have 2 byte data length, on the contrary, acceleration vector has only 1 byte data length, for our accelerometers are rather economical one.

At first we made the software in BASIC INTERPRETER type, we transformed it into compiler type program when we acquired MS-DOS BASIC COMPILER after our success in M-3SII-1 flight test.

Data points in GD are plotted in every second while the coordinate transfer and integration are performed 5 times a second.

These pictures show that the trajectory was close to nominal one as the data points exhibited it. Our device worked well.

After the ignition of the 2nd stage (86 sec.) PCM-TM data became noisy. (Fig. 7) This phenomenon was caused by interference of telemetry transmission wave with the exhaust plume of the 2nd stage motor. Receiving input level went down to the extent of 40 dbm. Integration was continued during this interference. We can recognize the influence on the trajectory, which was pulled down, finally to the extent of 2 degree down equivalent orbit.

But it is not a fatal error in the sense of range safety. The device proved to be very useful back-up system.

4–2 Results in M-3SII-2 Flight

After successful trial of new system we had in M-3SII-1 flight, we improved the device on several points as follows.

1) CPU time can be shortened to 1/4 comparing to that using in BASIC INTERPRETER by introducing BASIC COMPILER on newly obtained OS, MS-DOS. This improvement enables computing an instantaneous impact point in real time, and the system can compete with the radar system in range safety monitoring.

2) Improvement on receiving antenna was done by exchanging high gain 16 element antenna with 18m ø antenna.

3) Display of attitude representation became more intuitive.

Fig. 5 represents GD results of RS-INS in M-3SII-2 flight, launched on August 19, 1985.

Now we explain IIP illustration left below in Fig. 5. Predicted impact area, critical destruction lines and critical impact lines are drawn in the Pacific, east of Kyusyu island. Inner critical line means that a director of range safety operation must send a destruction command if IIP point intersects this line. The line guards Ogasawara islands and Izu islands. Outer critical line means that a exploded rocket may reach this line if the destruction command is sent on the critical destruction line.

Flight was very normal, as PPI shows, and calculated value of position nearly coincided with the nominal value. Enlarged PPI near KSC also affirms this coincidence.

We can affirm also that IIP was normal and impact point of 1st stage and 2nd one both located in the predicted impact area shown as rectangular zone on the sea.

And we can easily grasp a global motion of attitude, such as spin up motion, by the new attitude illustration right above.

It can be said that this device was completed in this experiment.

Fig. 8 gives telemetry receiving level in this experiment. We had no noise trouble this time, for there remained some margin to the threshold level even in 40 dbm level down after ignition of 2nd stage.

4–3 Results in M-3SII-3 flight

In Fig. 6 the results of RS-INS in the flight test of M-3SII-3 are given. As shown in the picture below right (enlarged PPI) the trajectory deflected about 10 degree north to the nominal one just after the 1st stage ignition, because of unexpected wind disturbance. RS-INS pictures show this alarming trajectory well. The vehicle recovered its motion after burn-out of the subbooster, so we had a safe flight later. The device worked normally during the 1st stage and played a role of a redundant system.

On the contrary, we had hard telemetry noise during burning phase of 2nd stage this time, and so calculation in INS lost its meaning. IIP picture left below shows that a trajectory shrinked and it became useless after ignition of the 2nd stage.

Fig. 9 provides us telemetry receiving input level in the flight test. A long time level down (30–40 dbm) can be recognized in the figure. This accidental phenomenon might be related to the ill-conditioned look angle, an angle between body axis of the vehicle and a radial line from the antenna to the vehicle. The angle is considered to be 7 to 9 degree at 2nd stage, while 12 to 13 degree for M-3SII-1 and 15 degree for M-3SII-2.

4–4 Error check on our RS-INS

We had a chance to check our total system just before launching. Our RS-INS was driven for the vehicle on launcher. Position errors by integrating inertial sensor inputs for 226 sec. in stationary state are measured as follows.

$$\Delta X = 3.38 \text{ Km}$$
$$\Delta Y = 2.92 \text{ Km}$$
$$\Delta Z = 5.96 \text{ Km}$$
$$E = \sqrt{(\Delta X)^2+(\Delta Y)^2+(\Delta Z)^2}$$
$$= 7.44 \text{ Km}$$

By substituting these measured value to the formula,

$$\Delta Z = \frac{1}{2} a t^2$$

we have a average acceleration error as,

$$a = 0.23 \text{ m/sec}^2 = 0.024 \text{ (g)}$$

Least significant degit of our axial accelerometer corresponds to 0.058 (g), by taking into consideration of 8 bit sensor range, that is 15g.

We can say that the error should be tolerable because it is less than half (41%) of

LSD.

Conclusions

1) An economical, redundant Range Safety System (integral type) can be constructed without consuming expensive money on special inertial navigation device. New system is totally independent from our old one (differential type) and has been applied to the practical space mission programs. Successful results show that our device works with increased reliability on total range safety systems.
2) Single pole representation of attitude is of great advantage to Range Safety System. It enables saving time in calculating transfer matrix, it provides wide, non-pole region which enables normal representation of attitude in the case of tubmling. It also gives a beneficial relation, circle-circle correspondence in drawing the critical attitude allowance curve.
3) It can be said that the principle of inertial navigation itself fits to Range Safety System because our duty time in flight operation is rather short, say 250 seconds, and a pin-point precision is not always required in making a decision on safety operation.
4) Telemetry noise is harmful, sometimes fatal, for practical usage of the system, although PCM Telemetry and integral type device both are endurable in principle against noise.

Acknowledgement

The computer working was carried out together with my coworkers, Dr. J. KAWAGUCHI and Dr. Y. INATANI. Their work was outstanding. I also owed much to the people in telemetry center at KSC. I am most grateful to these people for their contributions.

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[*2*] A report on the flight test, M-3SII-2 (PLANET-A) SES-TD-85-015 ISAS, 1985
[*3*] A report on the flight test, M-3SII-3 (ASTRO-C) SES-TD-87-008 ISAS, 1987
[*4*] On coordinate system of attitude control device for M-3SII type rocket. WK-1291D, MTSUBISHI PREC.

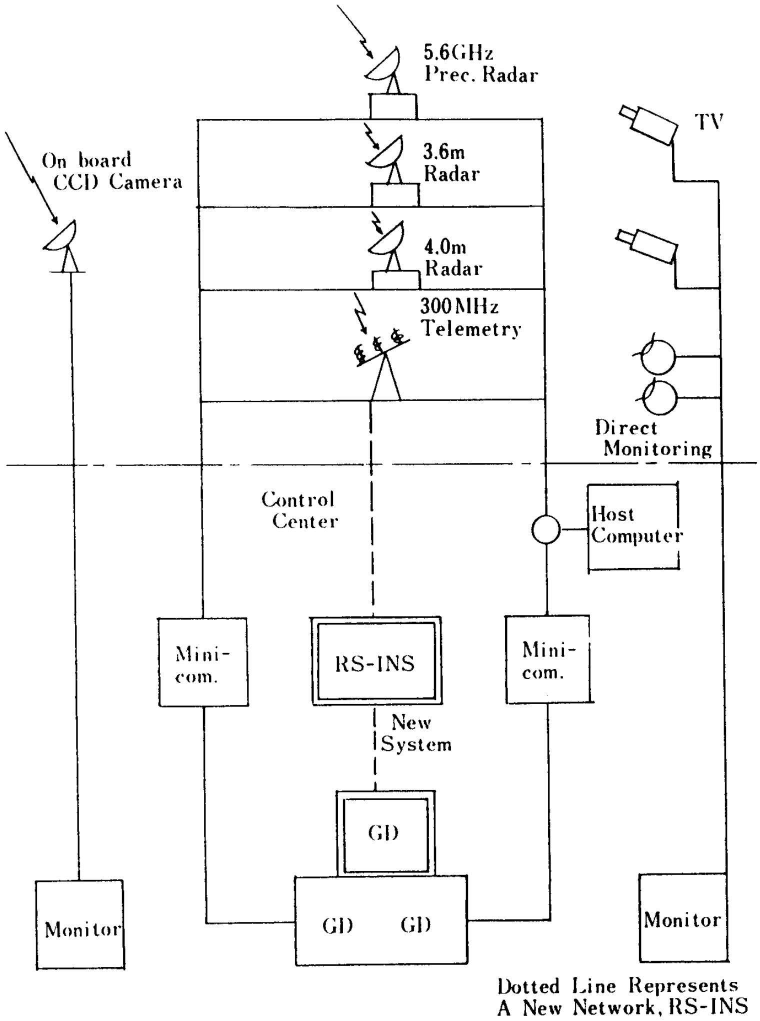


Fig. 1.

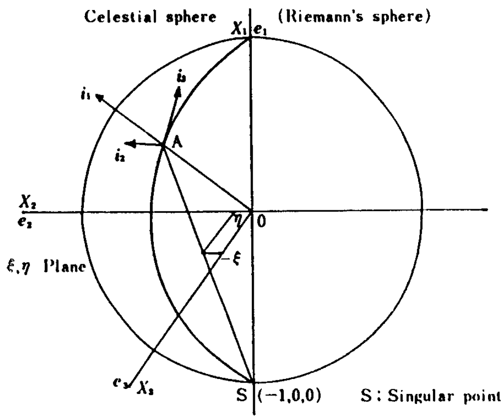


Fig. 2.

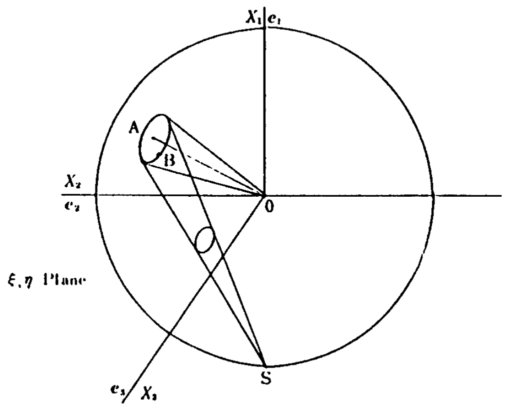


Fig. 3.

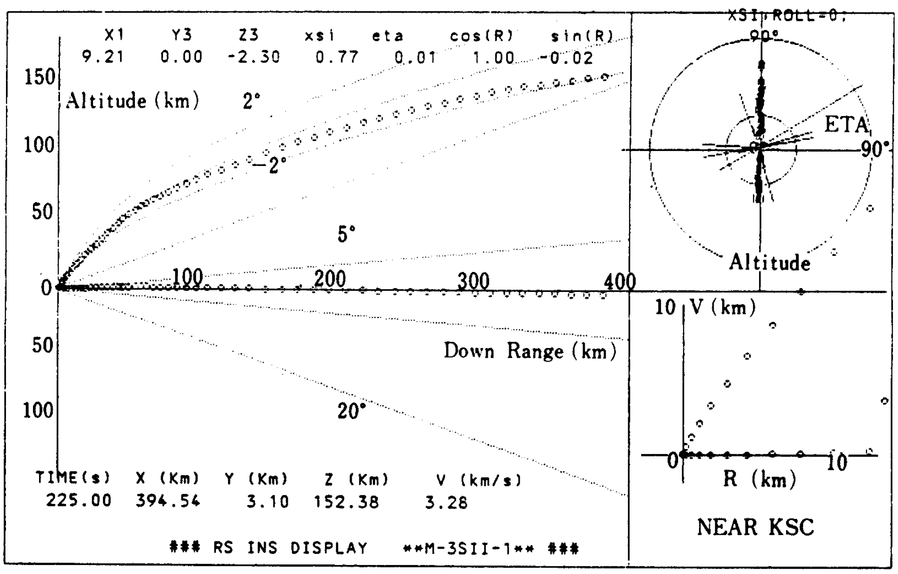


Fig. 4. RS-INS DISPLAY.

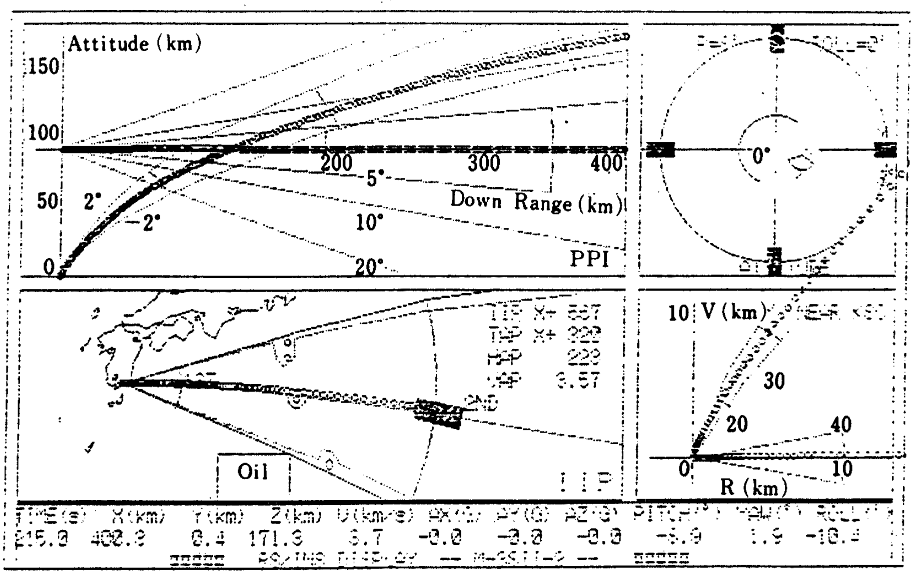


Fig. 5. RS-INS DISPLAY.

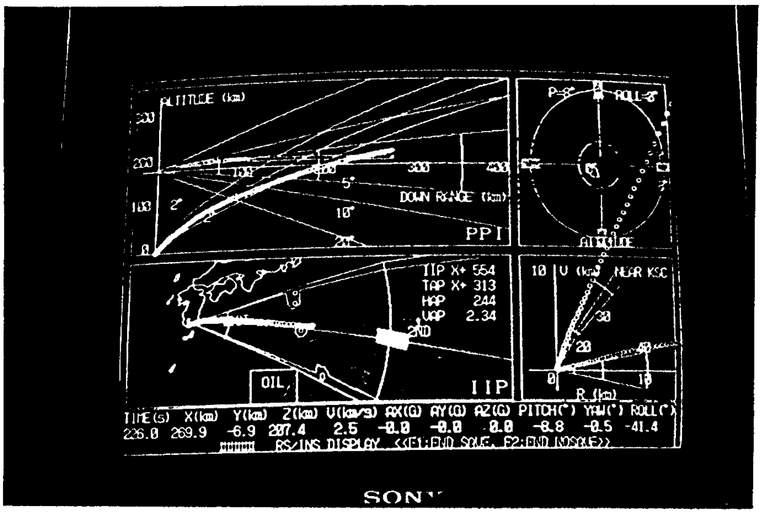


Fig. 6. RS-INS DISPLAY.

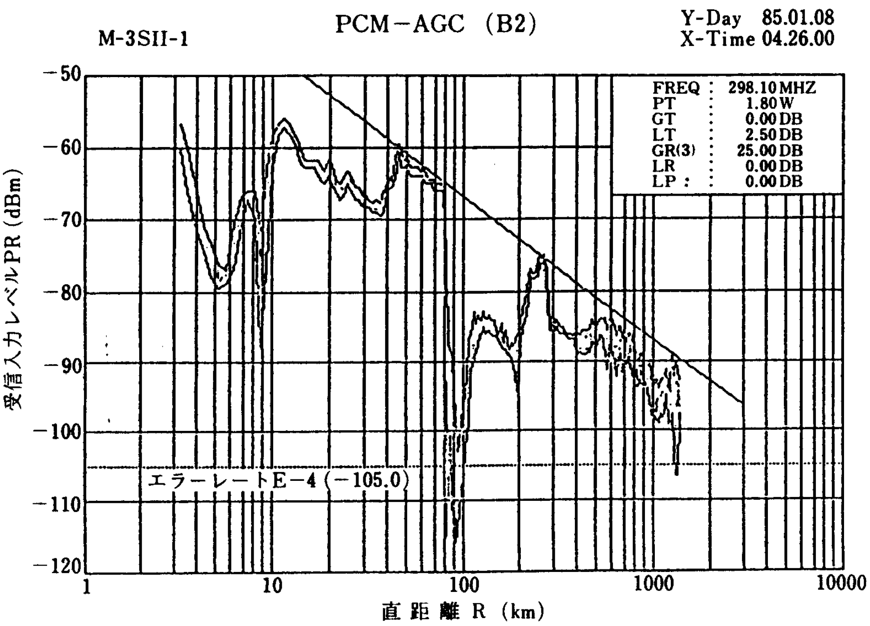
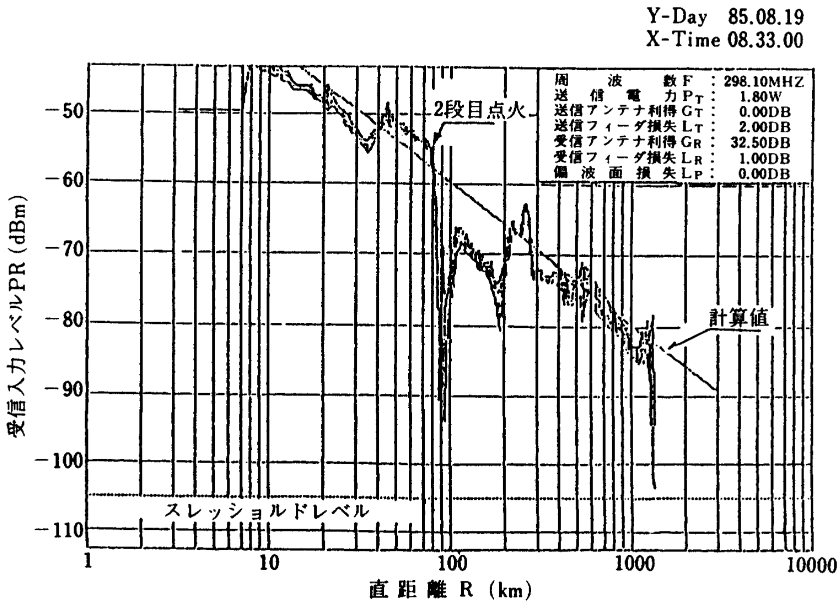


Fig. 7.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X-Time 08.33.00
周波数F : 298.10MHZ
送信電力PT : 1.80W
送信アンテナ利得GT : 0.00DB
送信フィーダ損失LT : 2.00DB
受信アンテナ利得GR : 32.50DB
受信フィーダ損失LR : 1.00DB
偏波面損失LP : 0.00DB
2段目点火
計算値
スレッショルドレベル
受信入力レベルPR (dBm)
直距離 R (km)

Fig. 8.

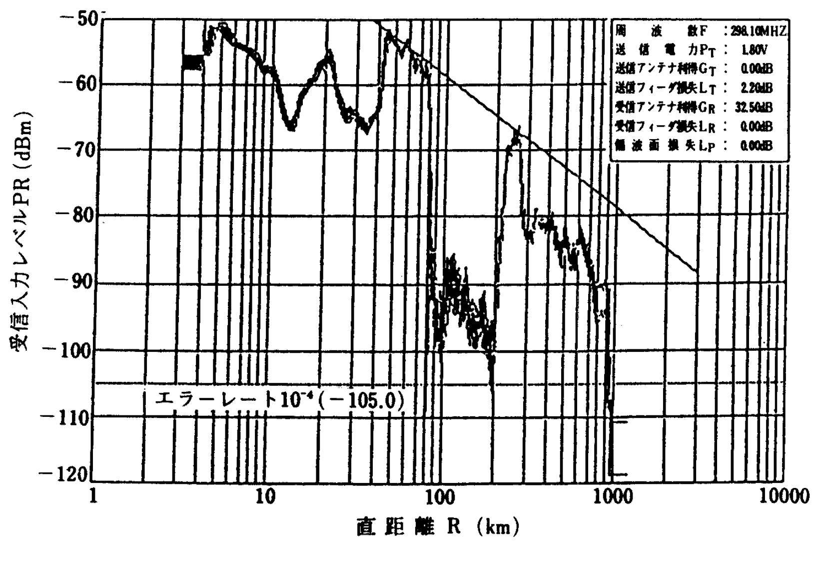
周波数F : 298.10MHZ
送信電力PT : 1.80V
送信アンテナ利得GT : 0.00dB
送信フィーダ損失LT : 2.20dB
受信アンテナ利得GR : 32.50dB
受信フィーダ損失LR : 0.00dB
偏波面損失LP : 0.00dB
エラーレート10⁻⁴ (−105.0)
受信入力レベルPR (dBm)
直距離 R (km)

Fig. 9.