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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

APOLLO

GUIDANCE AND NAVIGATION

G. L. Silver

PRELIMINARY
E-1297

INERTIAL SUBSYSTEM (ISS)
CALIBRATION TESTS

by

James H. Flanders

18 June 1963

MIT

**INSTRUMENTATION
LABORATORY**

CAMBRIDGE 39, MASSACHUSETTS

APOLLO

GUIDANCE AND NAVIGATION

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I. GENERAL INFORMATION

A. PURPOSE OF THE ISS CALIBRATION TESTS

These tests are for the purpose of measuring the responses of APOLLO PIP's and IRIG's to known inputs in order to certify that PIP's and IRIG's, in conjunction with their support electronics in the Power and Servo Assembly, meet specifications with regard to both scale factors and error outputs. By periodic calibration of the IMU, it is intended to establish confidence in the sign, magnitude, and stability of these quantities.

PRELIMINARY

Table I-1. Summary of Calibration Test Uncertainties

(Maximum Expected)

PIPA Bias Uncertainty (U_{a_B})	=	.0195 cm/sec ²
PIPA Scale Factor Uncertainty ($\frac{U_{SF}}{SF}$)	=	85 parts/million
IRIG NBD Uncertainty (U_{NBD})	=	3.0 Meru
IRIG ADSRA Uncertainty (U_{ADSRA})	=	3.3 Meru
IRIG ADIA Uncertainty (U_{ADIA})	=	1.7 Meru
IRIG Scale Factor Uncertainty (U_{SFG})	=	9 parts/million

Table I-2. Summary of Times to Collect Single Data Points

PIPA Bias	=	45 min. (estimate)
PIPA Scale Factor	=	5.0 min.
IRIG ADSRA	=	5.5 min. (40° Latitude)
IRIG ADIA	=	6.5 min. (40° Latitude)
IRIG NBD	=	5.5/6.5 min. (40° Latitude)
IRIG Scale Factor	=	5.4 min.

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B. GENERAL DESCRIPTION OF THE IMU CALIBRATION TESTS

At the IMU Subsystem level, the operational* elements in the PIP and IRIG loops are closed for the first time. Checking of these loops as an integrated subsystem is necessary before complete system integration in order to reduce the duration and complexity of system tests to a level which will ensure that schedule and cost goals are met. These tests are conducted with the IMU and its PSA operational support electronics mounted on a two-axis precision table. See figure I-1.

The PIPA calibration tests determine the output at three points on the plot in figure II-1.

1. zero g (approximately)
2. + 1 g
3. - 1 g

From this data, the following can be determined:

1. True Bias
2. Positive Scale Factor
3. Negative Scale Factor
4. Average Bias
5. Average Scale Factor
6. Scale Factor Equalization (Refer to page 12 for definition.)

The zero g PIPA response in acceleration units is defined as true bias and is determined from two successive nulls of the PIPA output nearly 180° apart. See figures II-1 and II-2. The angular orientation for Input Axis (IA) up and down (the + 1 g and - 1 g orientations) is also given.

These two IA up and down positions are then set up by appropriate Tilt Table and IMU Gimbal Angles to get PIPA responses to + 1 g and - 1 g inputs. The responses are determined by counting the time taken to accumulate specific ΔV pulse counts. The accuracy of this process is discussed under Section II, PIPA Calibration Theory.

*"Operational" describes those items that will go into space as part of the APOLLO Guidance Equipment.

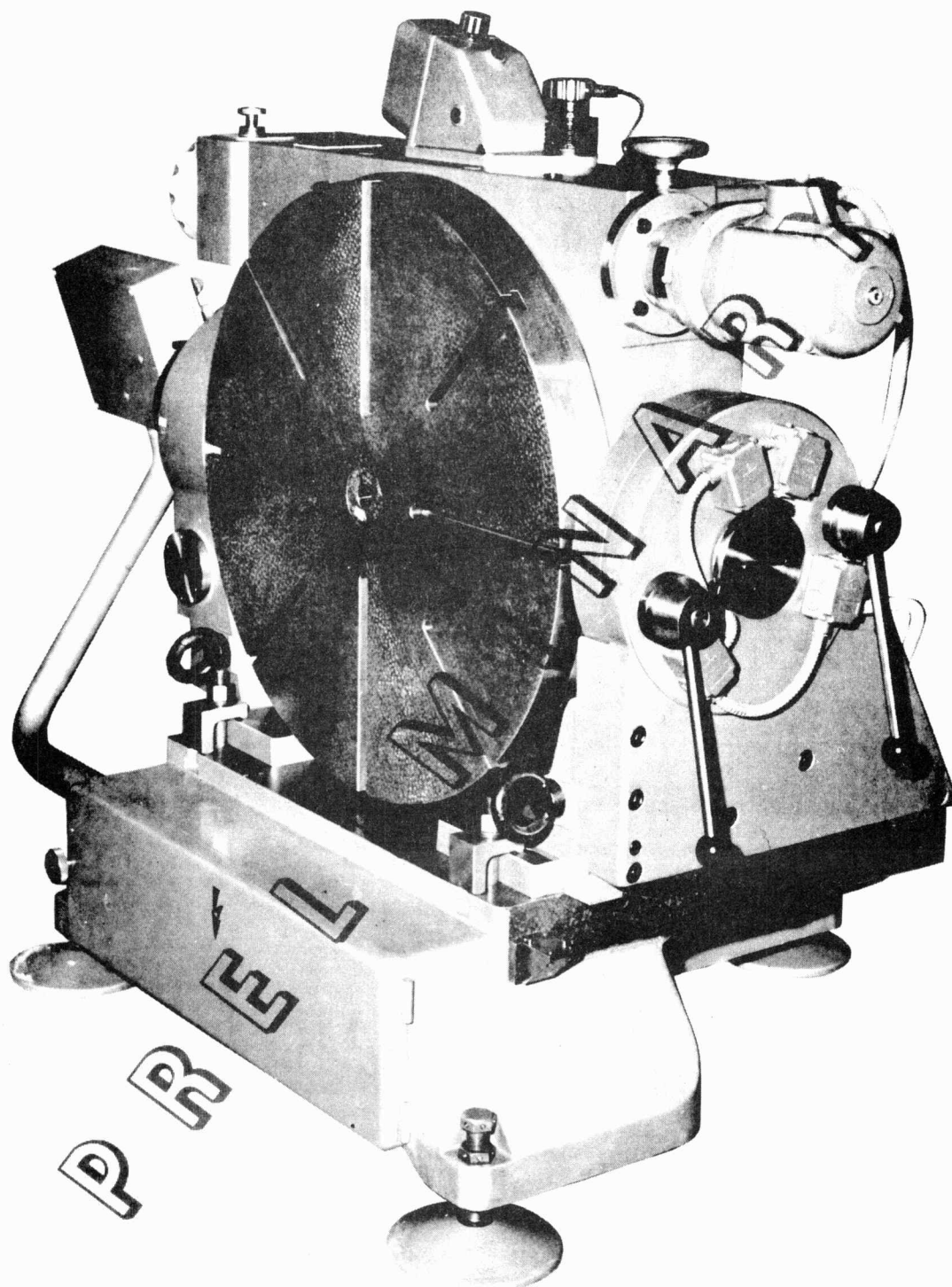


Figure I-1. Two-Axis Precision Table.

The IRIG calibration tests are based on measuring the gimbal angle drift induced by placing the pertinent gyro in a particular orientation with respect to the earth rate vector and the error-inducing local gravity vector. The gimbal angle measurement is achieved by monitoring the output of the Coupling and Display Unit (CDU) shaft as it goes through one complete revolution. This measurement is used to gate time pulses on and off so that an angular rate measurement may be achieved.

Data from the first two orientations (figure III-1) provide measurements of Noncompensated Bias Drift (NBD) and of Acceleration Drift - Spin Reference Axis (ADSRA). Data from the second two orientations (figure III-2) provide a second measurement of Noncompensated Bias Drift (NBD) and of Acceleration Drift - Input Axis (ADIA). The fifth orientation (figure III-3) is used to measure the gyro scale factor, i.e., the gimbal-angle change per unit gyro command-torque pulse. The accuracy of these processes is discussed under IRIG Calibration Theory.

C. DEFINITIONS OF TEST QUANTITIES

1. Axis Systems.

Earth Fixed Axes (See figure I-2.)

North..... Collinear with local horizontal component of earth rate.

Vertical..... Collinear with local gravitational attraction (down).

East..... Collinear with $\bar{g} \times N$.*

Trunnion Fixed Axes (See figure I-2.)

Y_{TR} Collinear with negative of tilt axis.

Z_{TR} Collinear with rotary axis.

X_{TR} Collinear with $Y_{TR} \times Z_{TR}$.

*On this page, the "x" between two axes refers to a vector crossproduct, which is defined in any standard text on vector mathematics.

1. Axis Systems. (continued)

Table Fixed Axes (See figure I-2.)

 Z_T Collinear with Z_{TR} . X_T Collinear with X_{TR} when rotary angle θ as read in optigon screen equals 0. Y_T Collinear with $Z_T \times X_T$.*

Fixture Fixed Axes (See figures I-4, I-5, and I-6.)

 X_{FXT} Parallel to fixture's IMU mounting surface and along X "Pin Line," real or phantom. Y_{FXT} Collinear with $Z_{FXT} \times X_{FXT}$. Z_{FXT} Collinear with the negative normal of the fixture's IMU mounting surface.**

Gimbal-Case Fixed Axes (See figures I-4, I-5, and I-6.)

 X_{GC} Collinear with outer gimbal axis in gimbal case. Y_{GC} Collinear with $Z_{GC} \times X_{GC}$. Z_{GC} Collinear with the normal of the case's mounting flange surface.**

Outer Gimbal Fixed Axes (See figure I-7.)

 X_{OG} Collinear with X_{GC} and OGA. Y_{OG} Collinear with MGA $\times$ OGA. Z_{OG} Collinear with $X_{OG} \times Y_{OG}$.

Middle Gimbal Fixed Axes (See figure I-8.)

 Z_{MG} Collinear with MGA. X_{MG} Collinear with IGA $\times$ MGA. Y_{MG} Collinear with $Z_{MG} \times X_{MG}$.

*On this page, the "x" between two axes refers to a vector crossproduct, which is defined in any standard text on vector mathematics.

**The normal to a surface sticks out of that surface.

1. Axis Systems. (continued)

Stable Member Fixed Axes (See figure I-9.)

Y_{sp} Collinear with IGA.

X_{sp} Collinear with IGA x Z PIP IRA.

Z_{sp} Collinear with X_{sp} x Y_{sp} . *

m PIPA-Case Fixed Axes (See figure I-10.)

$IRA_{m(p)}^{**}$ Input Reference Axis. Collinear with PRA x OA.

PRA_m Pendulous Reference Axis. Fixed to case along null
Pendulosity Axis.

$OA_{m(p)}^{**}$ Output Axis. Fixed to case along Ideal Float Axis.

m IRIG-Case Fixed Axes (See figure I-11.)

$IRA_{m(g)}^{**}$ Input References Axis. Collinear with OA x SRA.

SRA_m Spin Reference Axis. Fixed to case along null wheel
spin axis.

$OA_{m(g)}^{**}$ Output Axis. Fixed to case along Ideal Float Axis.

2. Table Angle Definitions.

Φ_j The j th reading taken from the Tilt Axis Optigon Screen.
Positive Φ involves rotation about TA. (See figure I-2.)

θ_i The i th reading taken from the Rotary Axis Optigon Screen.
Note that positive θ involves positive rotation about Z_{sp} .
(See figure I-2.)

ϵ_{τ_5} Leveling error of the tilt table in the vertical plane con-
taining the Tilt Axis. Positive when TA is rotated about
the south vector. (See figure I-3.)

*On this page, the "x" between two axes refers to a vector crossproduct, which is defined in any standard text on vector mathematics.

**Subscript p (pendulum) or g (gyro) will be dropped in text sections where only one type of component is to be discussed.

2. Table Angle Definitions. (continued)

- ϵ_{T_r} Leveling error of the tilt table in the vertical plane normal to the Tilt Axis. Positive when RA at $\Phi = 0$ rotates positively about TA.
- Φ_{HRA} Corrected reading taken from the Tilt Axis Optigon Screen when, with the table loaded*, the Rotary Axis is in the horizontal plane.
- Φ_{MGA} Corrected reading taken from the Tilt Axis Optigon Screen when, with the table loaded*: (a) the Rotary Axis is set at θ_{HGA} ; (b) the Outer Gimbal is positioned at Precision Zero; and (c) the Middle Gimbal Axis is in the horizontal plane.
- Φ'_{MGA} Corrected reading taken from the Tilt Axis Optigon Screen when, with the table loaded*: (a) the Rotary Axis is set at $\theta_{HGA} + 90^\circ 00' 00''$; (b) the Outer Gimbal is positioned at Precision Zero; and (c) the Middle Gimbal Axis is in the horizontal plane.
- θ_{HGA} Corrected reading taken from the Rotary Axis Optigon Screen when: (a) the Rotary Axis is horizontal (Φ_{HRA}), and (b) the Outer Gimbal Axis is also horizontal and East.
- θ_{IGA} Corrected reading taken from the Rotary Axis Optigon Screen (when: (a) the Tilt Axis is set at Φ_{MGA} ; (b) the Outer and Middle Gimbals are set at Precision Zero; and (c) the Inner Gimbal Axis is pointing down the local vertical) $-90^\circ 00' 00''$.

*Table loading to include IMU, IMU Fixture, and all table-mounted support equipment used during tests.

2. Table Angle Definitions. (continued)

$\theta_{+1g(n)}$ The true Table Rotary Axis Angle, which places the n PIPA Input Axis opposite to the local vertical vector ($\bar{g}$).

$\theta_{-1g(n)}$ The true Table Rotary Axis Angle, which places the n PIPA Input Axis along the local vertical vector ($\bar{g}$).

3. IMU Flange and Test Fixture Errors.

(See figures I-4, I-5, and I-6.)

$\epsilon_{F, X, Y, \text{ OR } Z}$ Cumulative misalignments between Table Fixed Axes and Gimbal-Case Fixed Axes, using small angle approximations.

$\epsilon_{(FXT), X, Y, \text{ OR } Z}$ Misalignment between Table Fixed Axes and Fixture Fixed Axes, using small angle approximations.

$\epsilon_{(FLANGE), X, Y, \text{ OR } Z}$ Misalignment between Fixture Fixed Axes and Gimbal-Case Fixed Axes, using small angle approximations.

$$\begin{aligned}\epsilon_{F_X} &= \epsilon_{(FXT)_X} + \epsilon_{(FLANGE)_X} \\ &= \epsilon_{(FXT)_X} \text{ because } \epsilon_{(FLANGE)_X} = 0 \text{ by definition}\end{aligned}$$

$$\epsilon_{F_Y} = \epsilon_{(FXT)_Y} + \epsilon_{(FLANGE)_Y}$$

$$\epsilon_{F_Z} = \epsilon_{(FXT)_Z} + \epsilon_{(FLANGE)_Z}$$

4. Gimbal Angle Definitions.

A_{OG} Outer Gimbal Angle. Angle from Y_{GC} to Y_{OG} , positive when Outer Gimbal rotates negatively, or by the left hand-rule, about OGA with respect to a fixed Gimbal Case. (See figure I-7.)

A_{MG} Middle Gimbal Angle. Angle from Y_{OG} to Y_{MG} , positive when Middle Gimbal rotates negatively, or by the left-hand rule, about MGA with respect to a fixed Outer Gimbal. (See figure I-8.)

4. Gimbal Angle Definitions. (continued)

- A_{IG} Inner Gimbal Angle. Angle from X_{MG} to Y_{SM} , positive when stable member rotates negatively, or by the left-hand rule, about IGA with respect to a fixed Middle Gimbal. (See figure I-9.)
- ϵ_{UGR} Outer Gimbal Resolver Error. The misalignment of the 16X resolver null on the OGA, positive when the null misplacement produces a positive Outer Gimbal Angle in the precision zero mode. (See figure I-14.)
- ϵ_{IGR} Inner Gimbal Resolver Error. The misalignment of the 16X resolver null on the IGA, positive when the null misplacement produces a positive Inner Gimbal Angle in the precision zero mode. (See figure I-14.)
- ϵ_{MGR} Middle Gimbal Resolver Error. The misalignment of the 16X resolver null on the MGA, positive when the null misplacement produces a positive Middle Gimbal Angle in the precision zero mode. (See figure I-14.)
- ϵ_{MGA} Middle Gimbal Axis Error. The misalignment of the MGA with respect to the OGA; represented as positive rotation of MGA away from Z_{UG} about Y_{UG} . (See figure I-7.)
- ϵ_{IGA} Inner Gimbal Axis Error. The misalignment of the IGA with respect to the MGA; represented as positive rotation of IGA away from Y_{MG} about X_{MG} . (See figure I-8.)

5. Accelerometer (PIPA) Misalignments and Biases. (See figure I-12.)

If $n = X, Y, \text{ or } Z$, and $m = X, Y, \text{ or } Z$, then:

α_{n_m} Misalignment Rotation of the n PIPA case-fixed triad, [consisting of the Input Reference Axis (IRA), the Pendulous Reference Axis (PRA), and the Output Axis (OA)] about the stable member " m " axis.

α_{b_n} A fictitious rotation of the n PIPA case [either about its Output Axis (OA) or its Pendulous Reference Axis (PRA)] which will produce a moment due to gravity equal in sign and magnitude to the actual bias moment.

6. Gyro (IRIG) Misalignments.

If $n = X, Y, \text{ or } Z$, and $m = X, Y, \text{ or } Z$, then:

γ_{n_m} Misalignment rotation of the n IRIG case-fixed triad [consisting of the Input Reference Axis (IRA), the Spin Reference Axis (SRA), and the Output Axis (OA)] about the Stable Member " m " axis. (See figure I-13.)

7. Accelerometer (PIPA) Test Definitions.

If $m = +X, -X, +Y, -Y, +Z, \text{ or } -Z$; or $X, Y, \text{ or } Z$ for average values, then:

$SF (A)_{(m)}$ Scale Factor of the m PIPA defined as the velocity content of each net output pulse from the binary loop. (See figure II-1.) Units: $\frac{\text{cm/sec}}{\text{pulse}}$.

ΔSF Scale Factor equalization, 10^6 times the positive scale factor minus the negative scale factor divided by the average scale factor. Units: parts/million.

N_T Number of Timing Pulses counted during a test run. (See figure II-6.)

7. Accelerometer (PIPA) Test Definitions. (continued)

- ΔT Time content of each N_r pulse. Units: seconds.
- N_A Number of net PIPA ΔV pulses counted during a test run. (See figure II-6.)
- A_r Angle by which the plus or minus PIPA Input Axis (IA) is not collinear with the local vertical vector ($+\bar{g}$) in the IRA-OA plane. (See figure II-7.) Units: radians.
- $\Delta\theta_{B(m)}$ Angular Equivalent of bias in m PIPA. (See figure II-1.) Units: degrees, minutes, seconds.
- $a_{B(m)}$ Bias of the m PIPA defined as the indicated acceleration at a zero $\bar{g}$ input. Units: centimeters/second².
- $U_{(j)}$ Uncertainty in quantity j in the test equation. Units: Same units as quantity j.

8. Gyro (IRIG) Test Definitions.

- $NBD_{(n)}$ Noncompensated Bias Drift of the n* IRIG defined as the drift which is not dependent on $\bar{g}$ or $\bar{g}'^2$. Units: thousandths of earth rate (or Meru).
- $ADIA_{(n)}$ Drift of the n IRIG due to $1\bar{g}$ acceleration along the positive Input Axis (IA). Units: thousandths of earth rate (or Meru) per $\bar{g}$.
- $ADSRA_{(n)}$ Drift of the n IRIG due to $1\bar{g}$ acceleration along the positive Spin Reference Axis (SRA). Units: thousandths of earth rate (or Meru) per $\bar{g}$.
- $SF(G)_{(m)}$ Scale Factor of the m IRIG defined as the gimbal angle change per command torque pulse. Units: milliradians/pulse.

*n = X, Y, or Z.

8. Gyro (IRIG) Test Definitions. (continued)

- A_1 Angle by which the IRIG Input Axis (IA) is not in the local meridian during the measurement of ADSRA. (See figure III-1.)
Units: radians.
- A_2 Angle by which the IRIG Input Axis (IA) is not in the local horizontal during measurement of ADSRA. (See figure III-1.)
Units: radians.
- A_3 Angle by which the IRIG is rotated about its Input Axis, thus moving the IRIG Spin Reference Axis (SRA) out of the vertical plane containing IA. (See figure III-1.) Units: radians.
- A_4 Angle by which the IRIG Input Axis (IA) rotates about North during the measurement of ADIA so that it is not aligned with the local vertical. (See figure III-2.)
- A_5 Angle by which the IRIG is rotated about its Spin Reference Axis (SRA) out of the East - West vertical plane. (See figure III-2.) Units: radians.
- A_6 Angle through which the appropriate IMU Gimbal is allowed to drift or be torqued during a test for NBD, ADIA, ADSRA, or SF(G). Units: radians.
- W_j Actual Gimbal Angular Velocity due to gyro drift or torquing, occurring during test j. Units: radians/second.
- T_j Elapsed time required for Gimbal to drift or be torqued through angle A_6 during test j. Units: seconds.

8. Gyro (IRIG) Test Definitions. (continued)

W_{IE} Earth Inertial Angular Velocity. Units: radians/second.

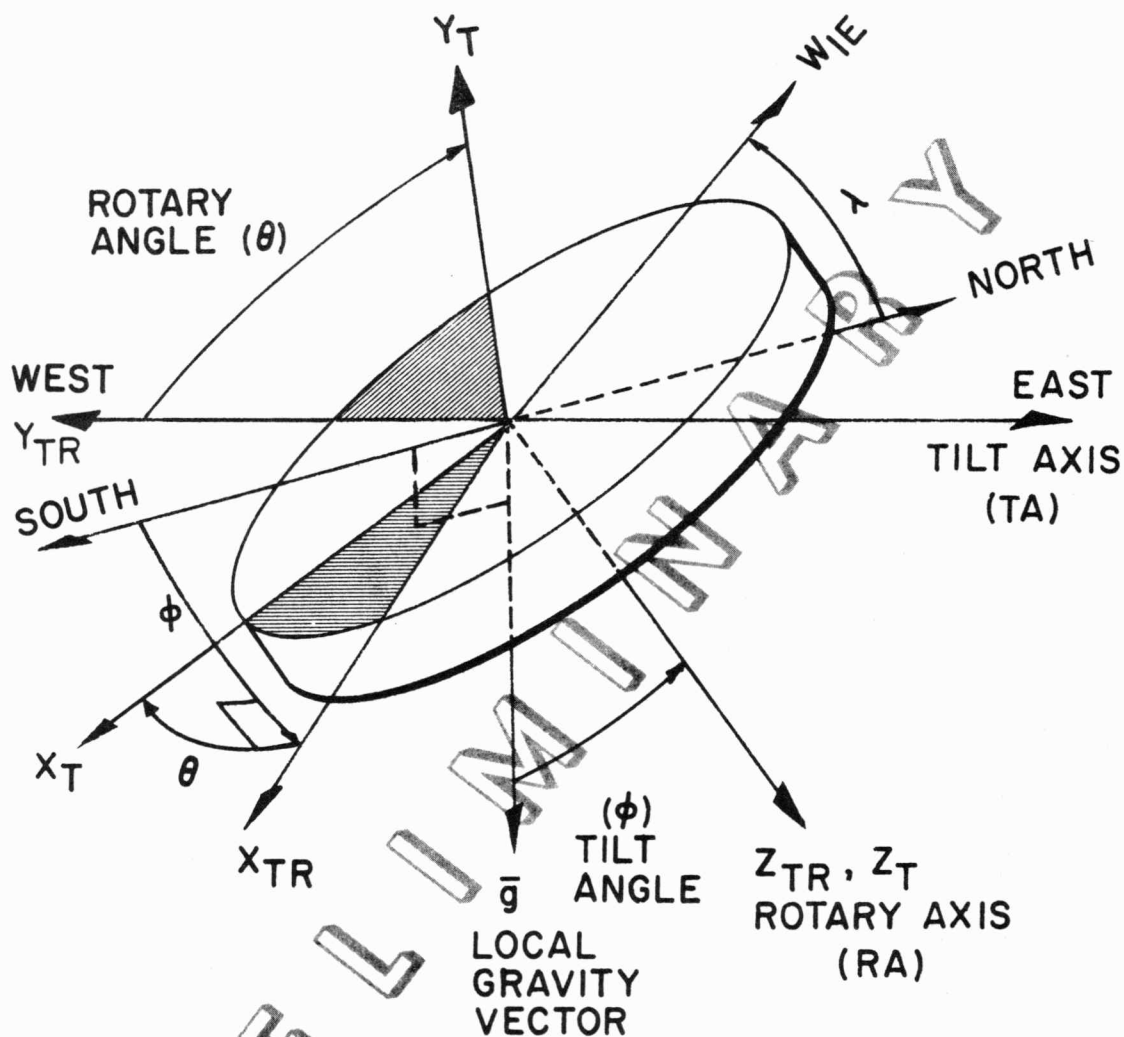
Meru..... Angular Velocity in fractions of earth rate x 1000.

λ Local Latitude of test site.

ΔN Amount any count of a pair of counts differs from the average of the pair.

K Conversion factor from Meru to radians/second and equal to $7.292 \times 10^{-8} \frac{\text{rads/sec}}{\text{Meru}}$.

PRELIMINARY



Earth Fixed Axes: NORTH, EAST, $\bar{g}$

Trunnion Fixed Axes: X_{TR} , Y_{TR} , Z_{TR}

Table Fixed Axes: X_T , Y_T , Z_T

Figure I-2. Ideal Tilt-Table Orientation.

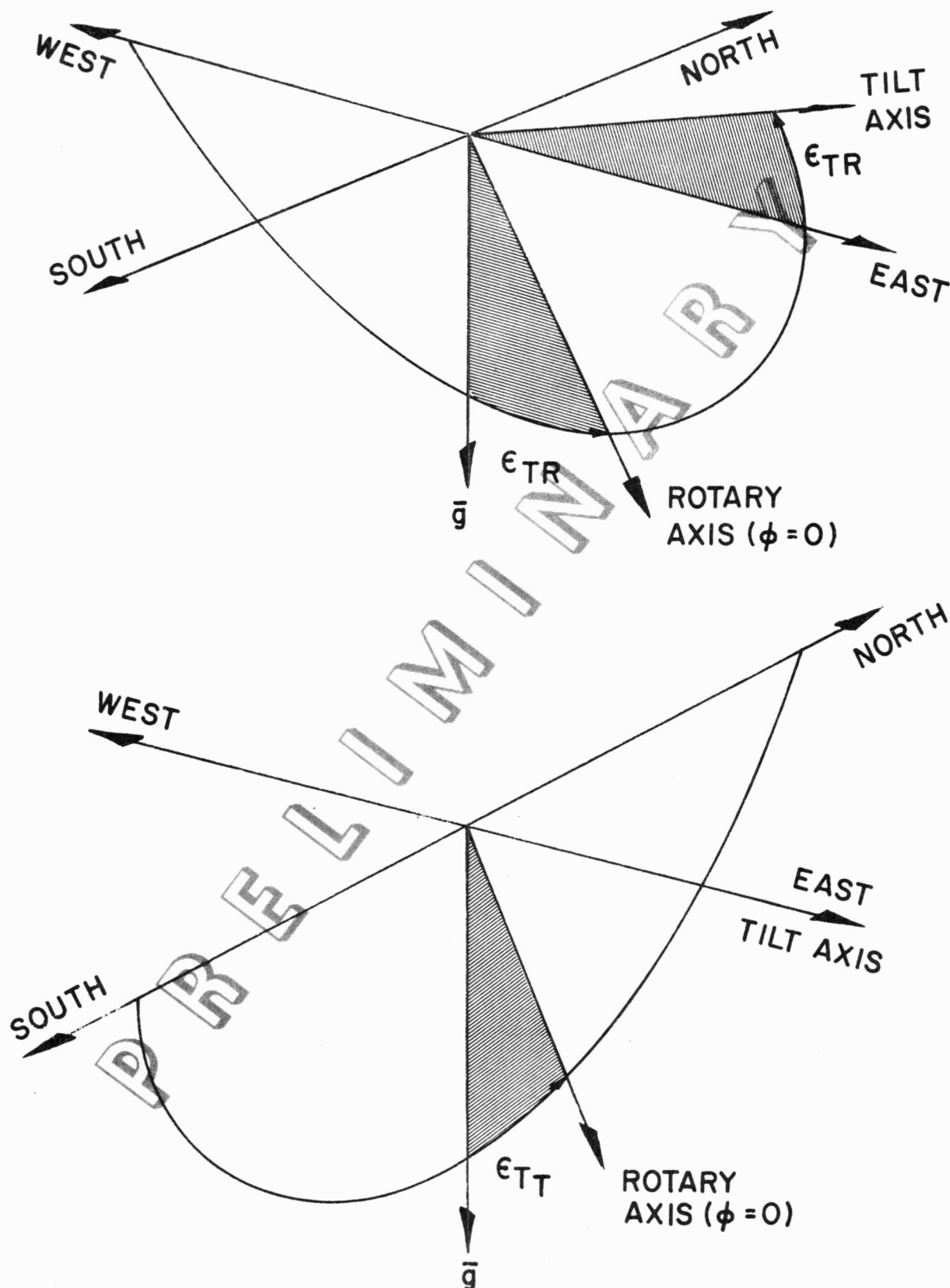


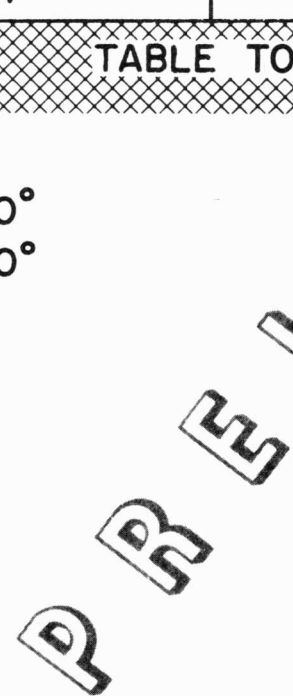
Figure I-3. Tilt-Table Leveling Errors.



Fixture Fixed Axes: X_{FXT} , Y_{FXT} , Z_{FXT}

Gimbal-Case Fixed Axes: X_{GC}, Y_{GC}, Z_{GC}

Figure I-4. IMU Flange and Test Fixture Errors About the X Axis.



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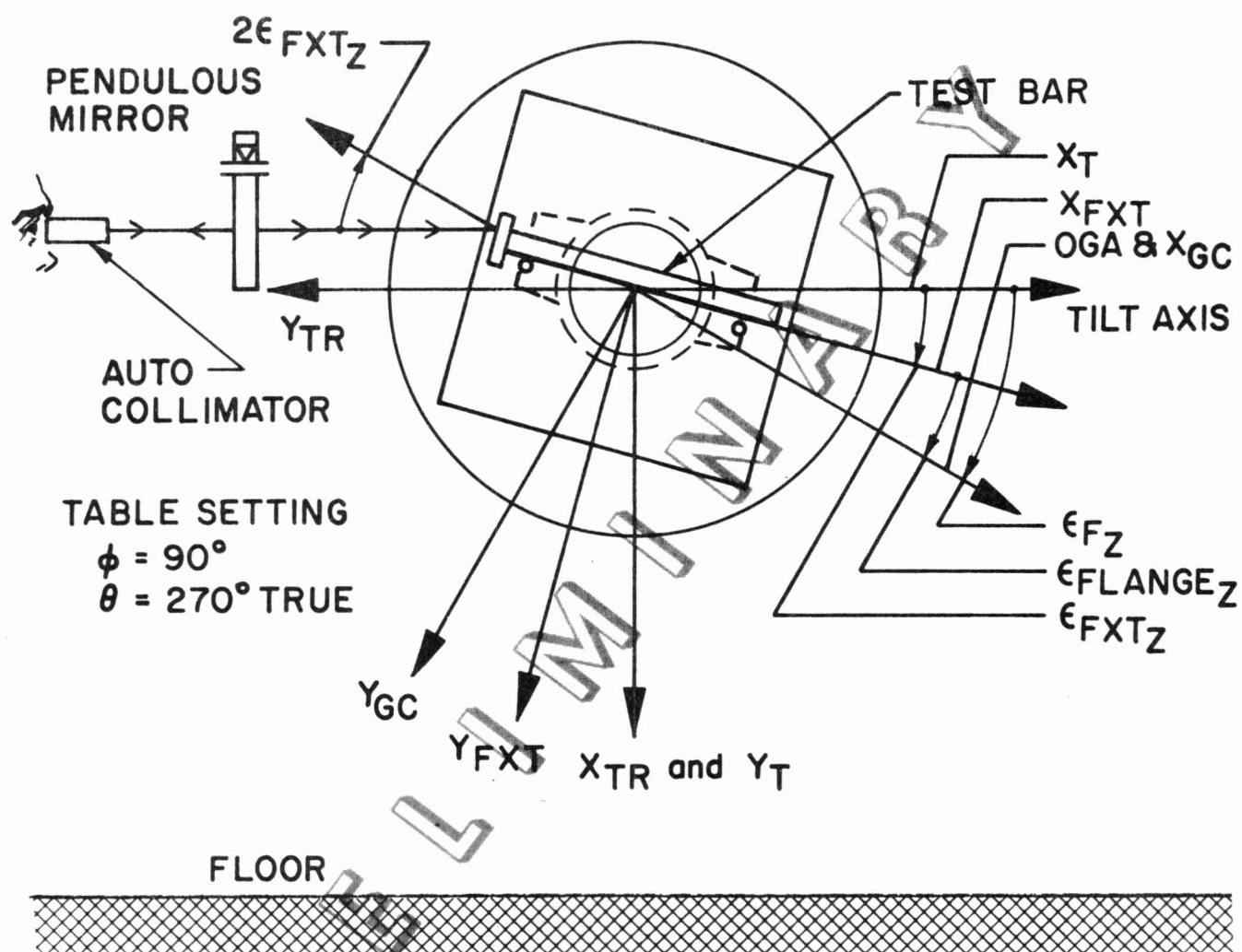
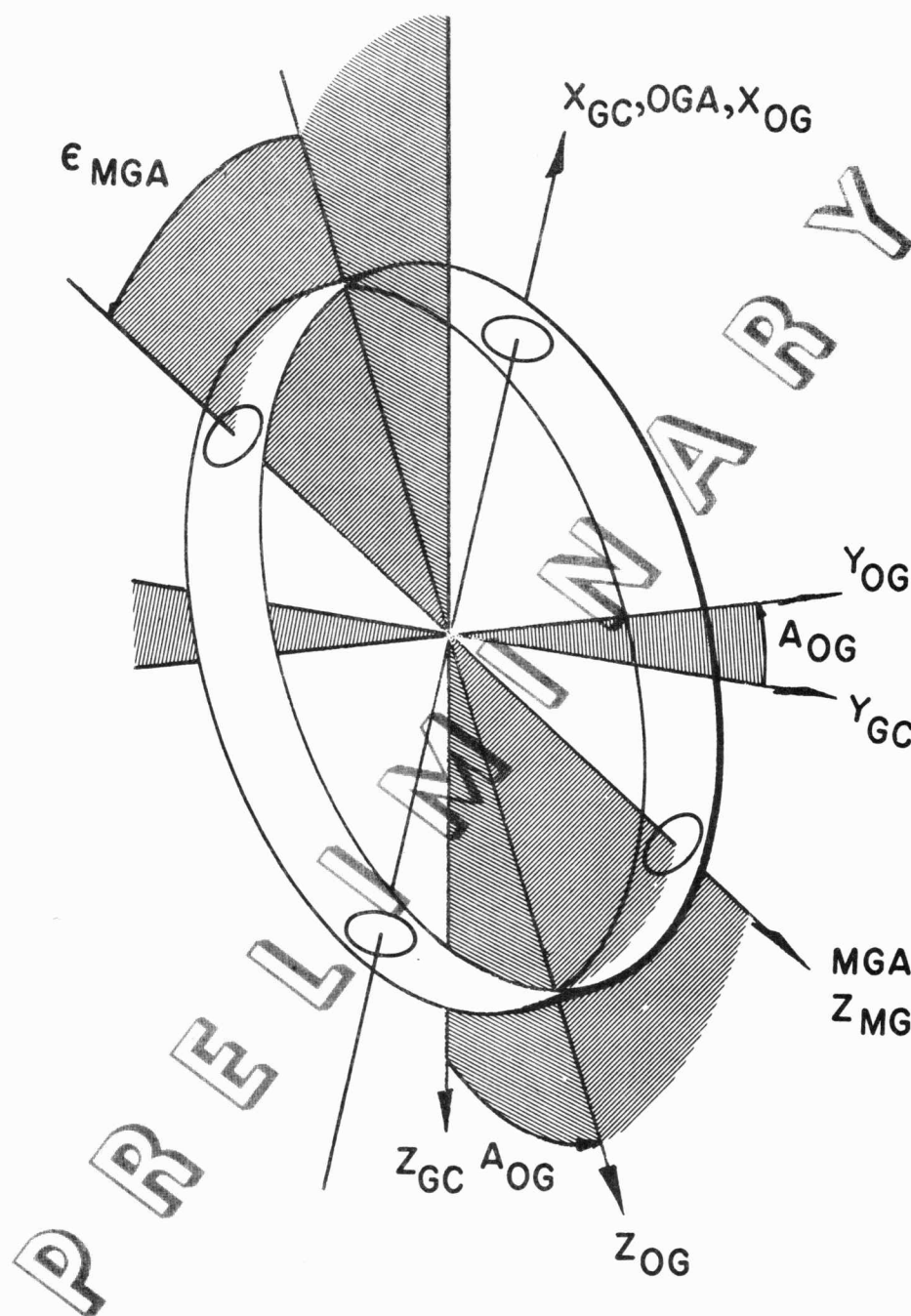


Table Fixed Axes: X_T, Y_T, Z_T

Fixture Fixed Axes: $X_{FXT}, Y_{FXT}, Z_{FXT}$

Gimbal-Case Fixed Axes: X_{GC}, Y_{GC}, Z_{GC}

Figure I-6. IMU Flange and Test Fixture Errors About the Z Axis.



Gimbal-Case Fixed Axes: X_{GC} , Y_{GC} , Z_{GC}

Outer Gimbal Fixed Axes: X_{OG} , Y_{OG} , Z_{OG}

Middle Gimbal Fixed Axes: X_{MG} , Y_{MG} , Z_{MG}

Figure I-7. IMU Outer Gimbal Showing Outer Gimbal Angle and Middle Gimbal Axis Error.

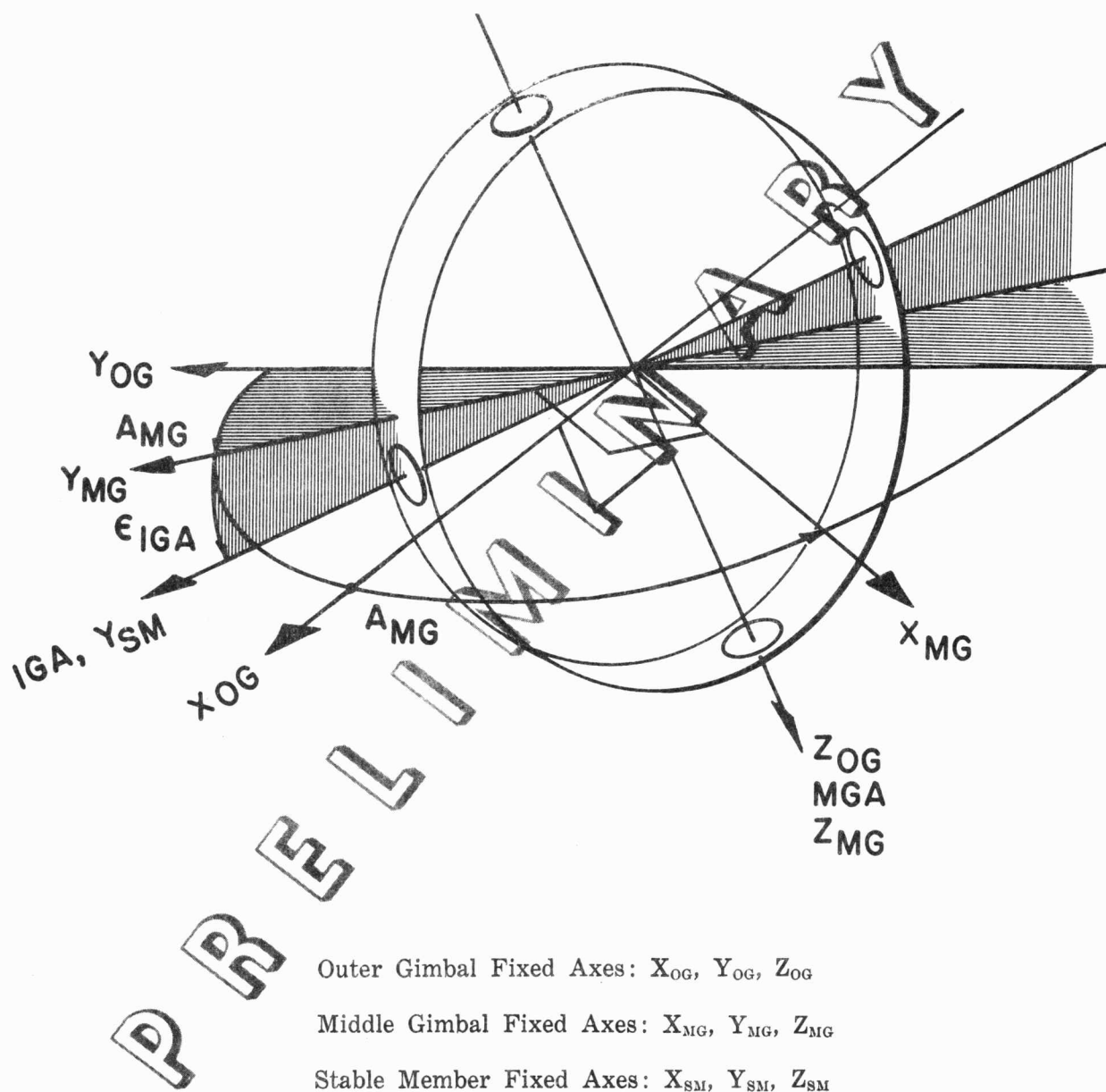


Figure I-8. IMU Middle Gimbal Showing Middle Gimbal Angle and Inner Gimbal Axis Error.

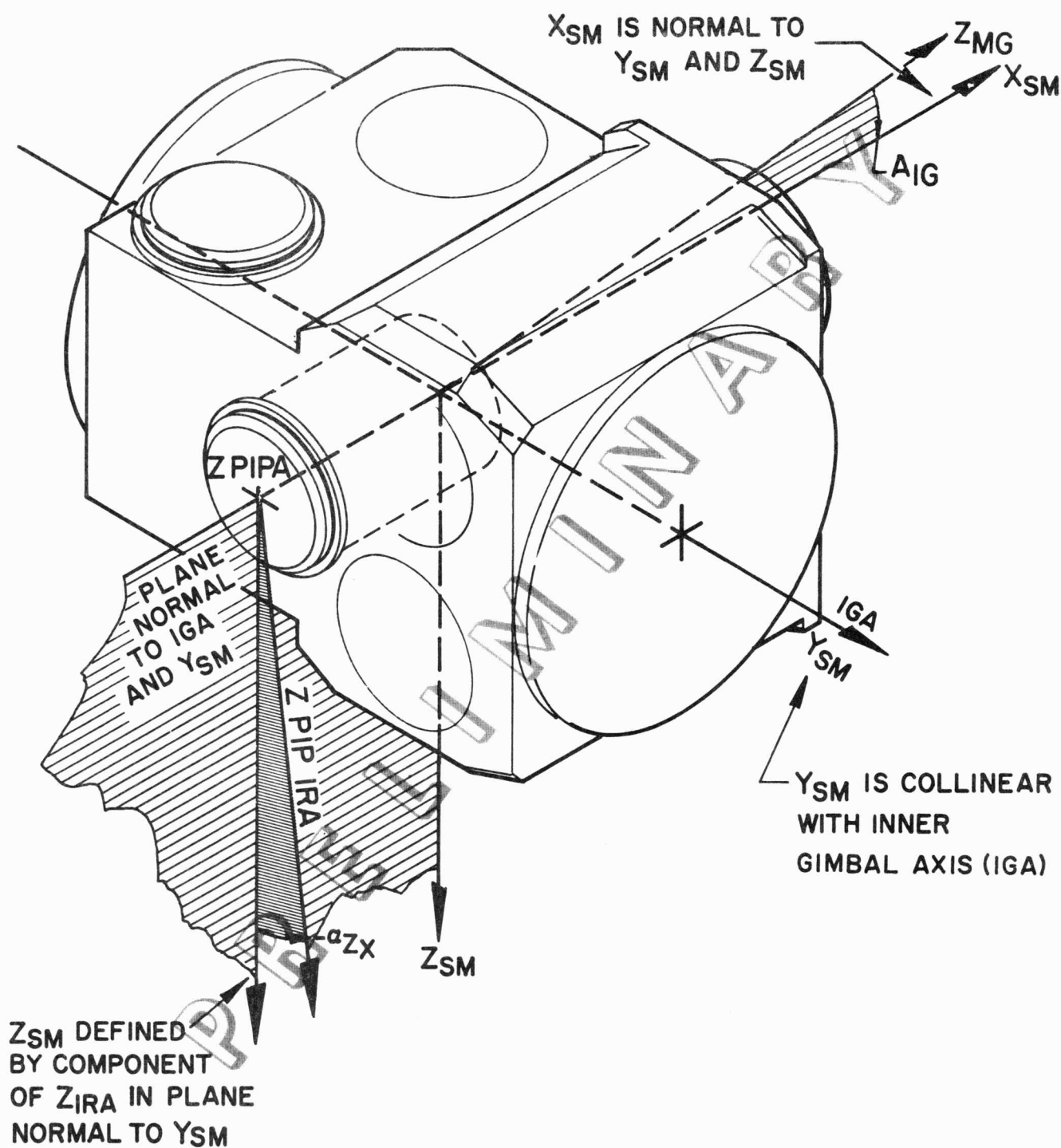


Figure I-9. IMU Stable Member Showing Definition of Stable Member Triad.

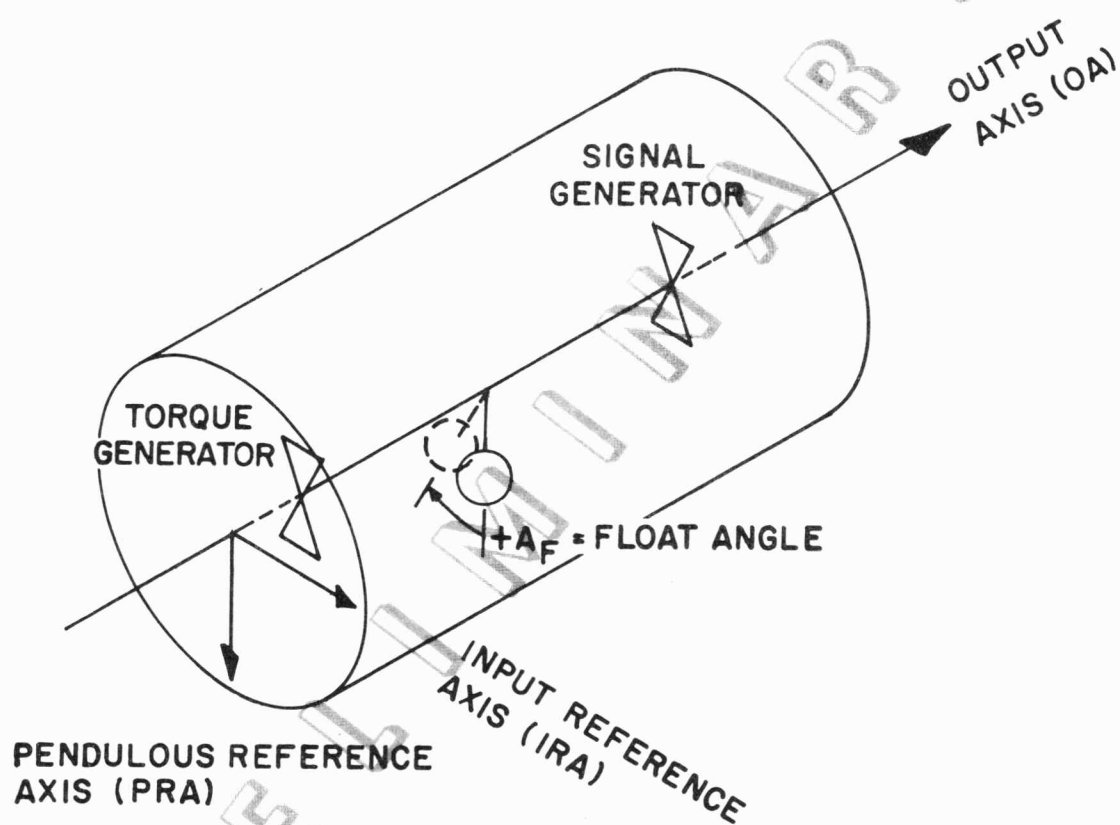


Figure I-10. PIPA-Case Fixed Axes.

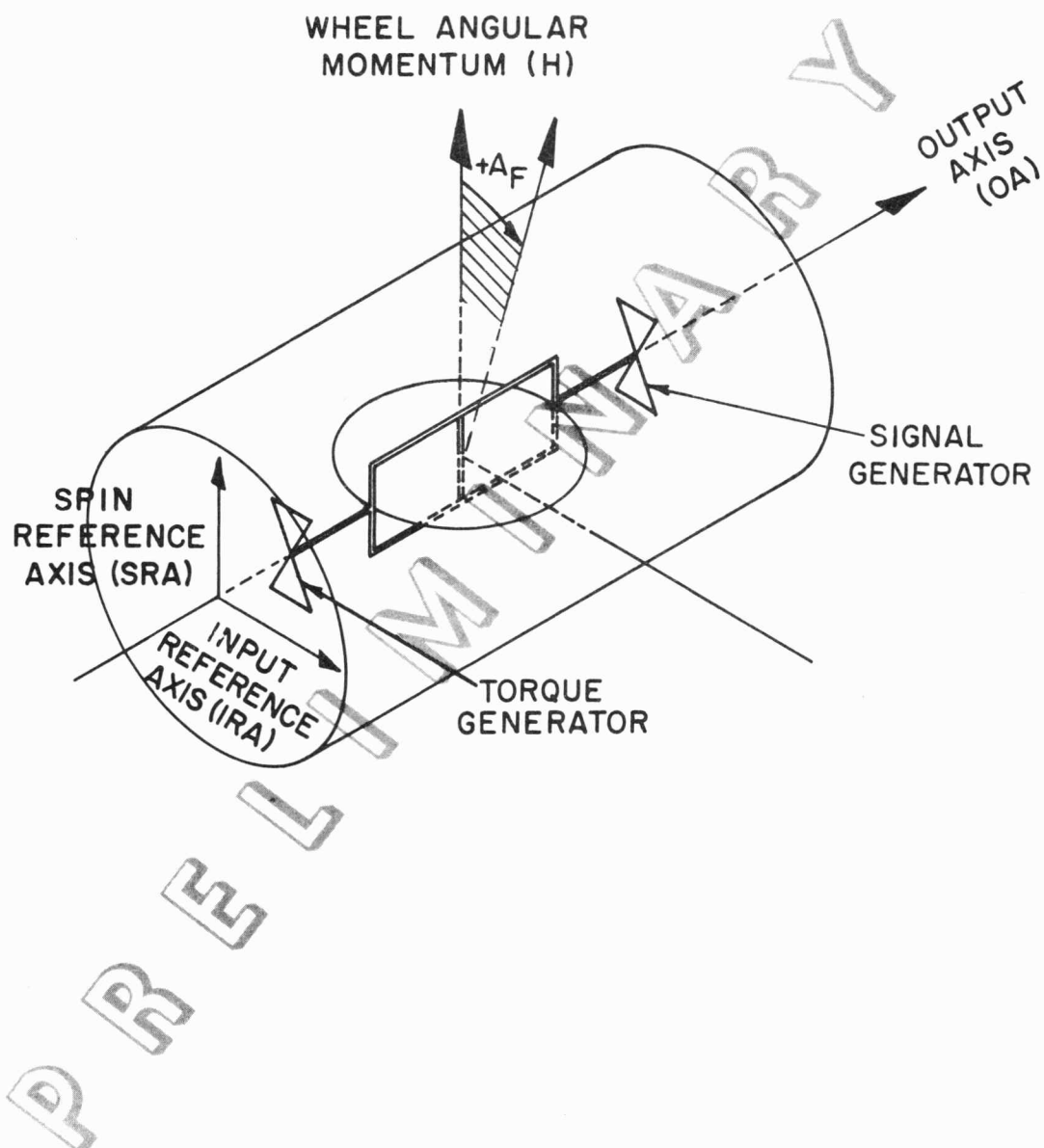


Figure I-11. IRIG-Case Fixed Axes.

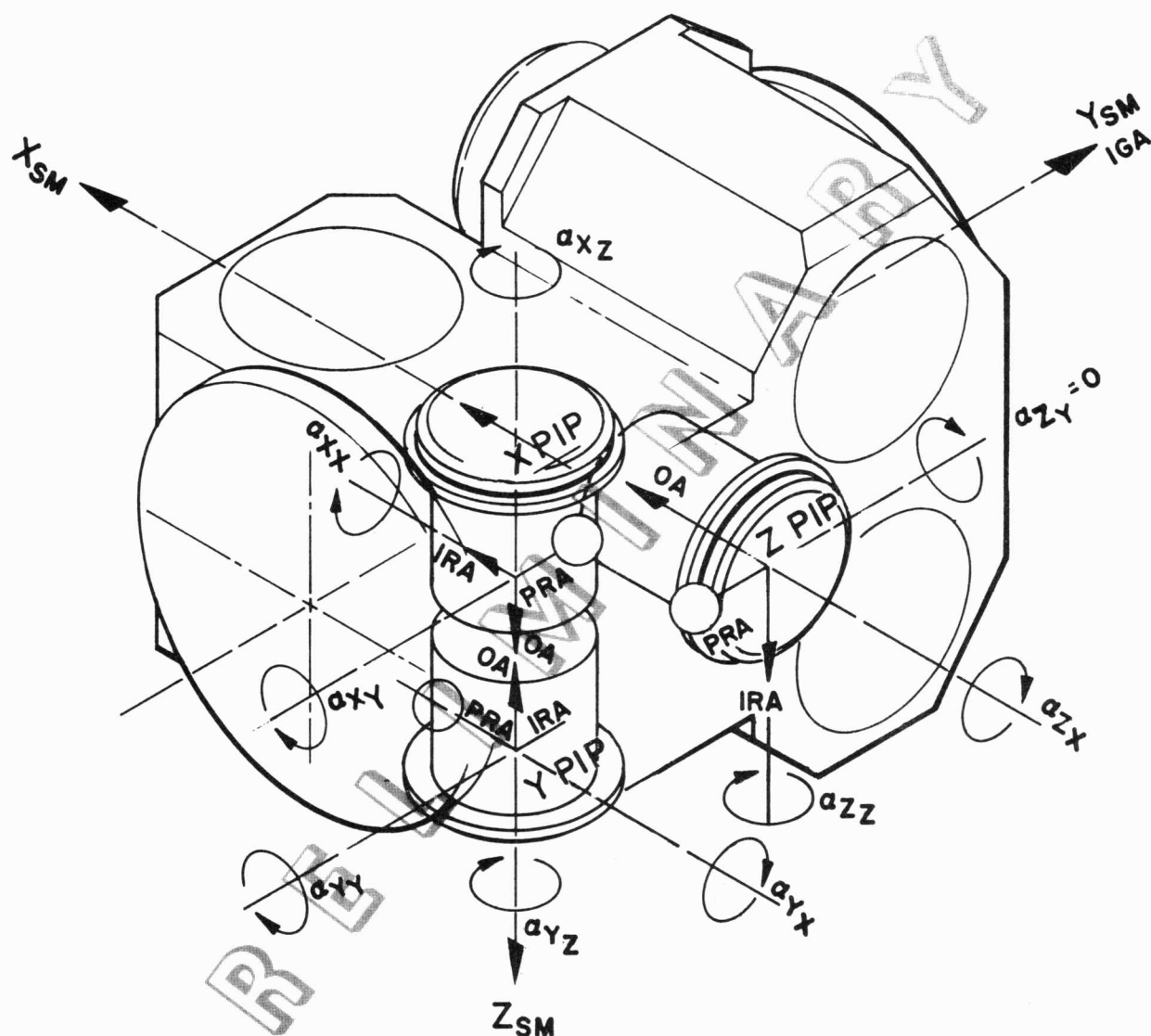


Figure I-12. PIPA Misalignments.

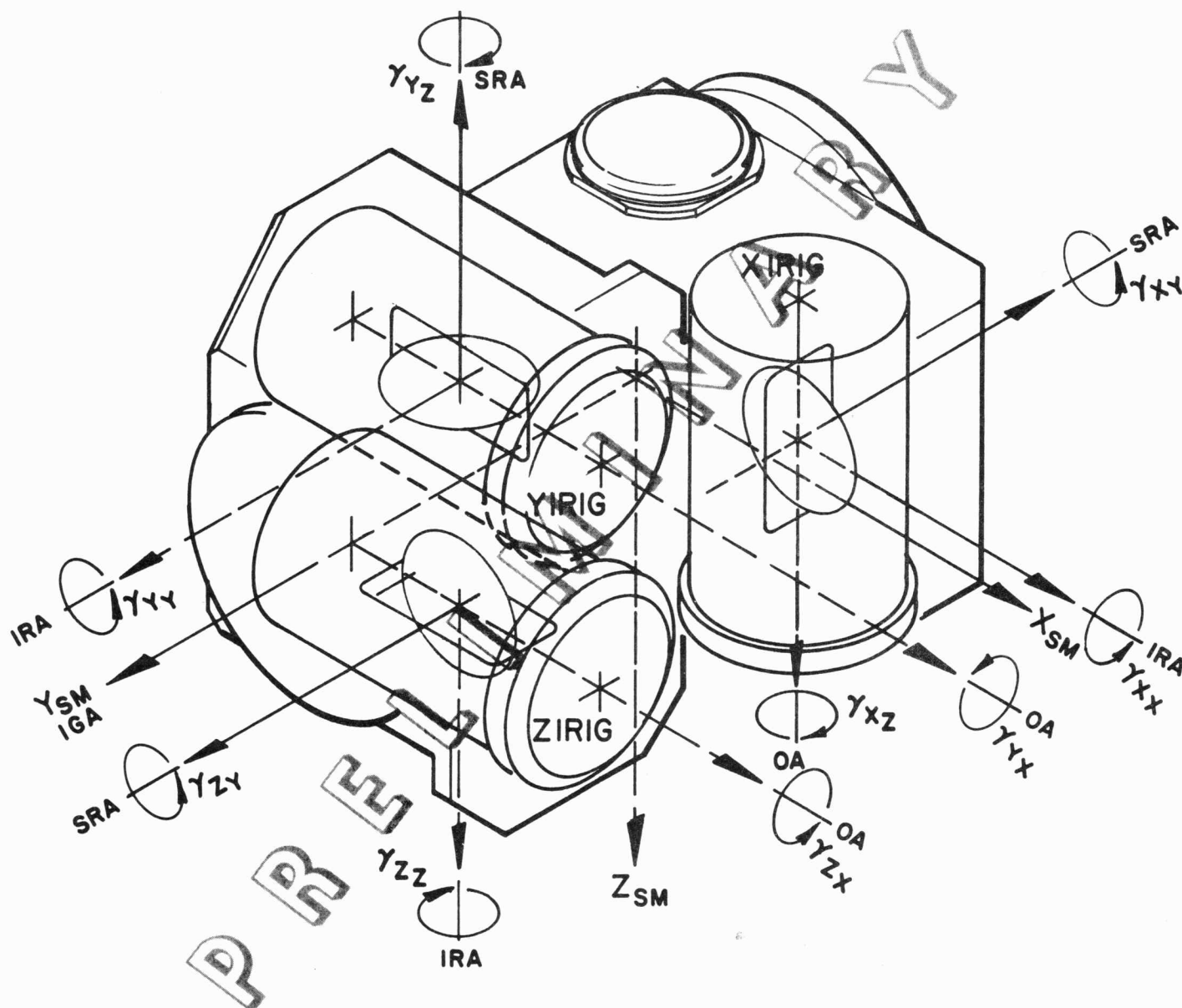


Figure I-13. IRIG Misalignments.

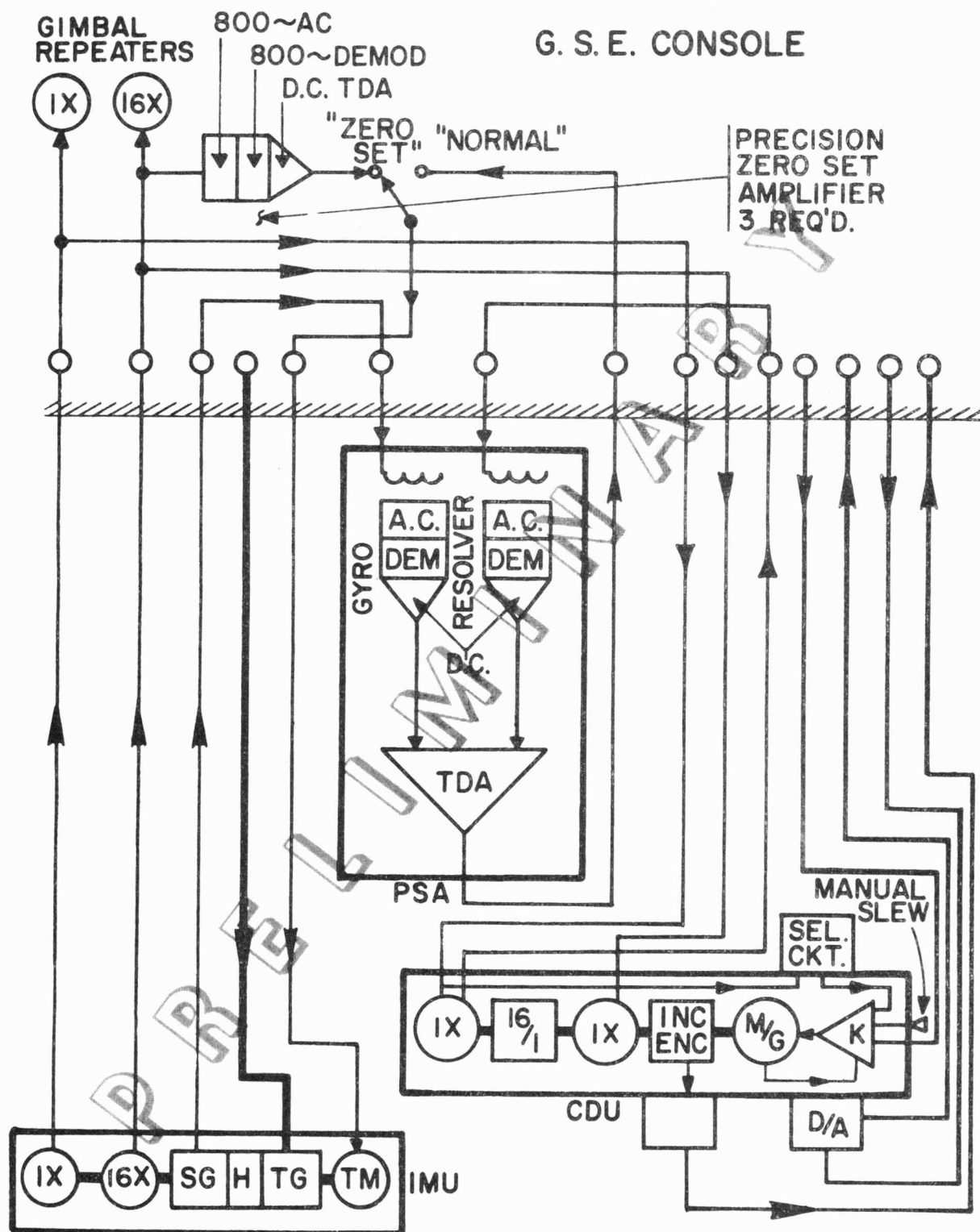


Figure I-14. 16X Resolver Loop, Simplified Signal Diagram.

II. PIPA CALIBRATION THEORY

The principal quantities of interest in PIPA Calibration are displayed graphically in figure II-1, which is a plot of pulse rate output of the digital instrument versus applied load factor or specific force.

The situation that exists during null measurements of accelerometer bias is depicted in figure II-2. The angular equivalent of the PIPA bias is determined by two successive nulls of the instrument, 180° apart. This process is identical to that described in the IMU Alignment Manual, E-1230, and yields an expected maximum inaccuracy of ± 4.1 arc seconds of angle. The same pair of measurements also yields the table setting for input axis up along the local vertical (θ_{+1g}) and down along the local vertical (θ_{-1g}).

For scale factor determination, the θ_{+1g} and θ_{-1g} orientations are assumed; and the pulse rate output is monitored by using a preset counter and gate to determine the time it takes to accumulate a given pulse output. An error analysis of the scale factor measurement is to be developed, but, first, it is in order to discuss the binary mode in which the PIPA loops are operated.

In this mode, the pendulum is interrogated every ΔT seconds; and an output pulse is always found on the $+\Delta V$ or $-\Delta V$ line. The pendulum in binary torquing has a limit cycle of its own, even with no bias and no acceleration input. Typically, this may appear as three positive ΔV 's alternating with three negative ΔV 's. This is known as 3:3 moding. If two positive ΔV 's alternate with two negative ΔV 's, it is known as 2:2 moding. The presence of an input acceleration or a pseudo-input (bias) acceleration is indicated by an excess of ΔV 's of the input sense over those of the opposite sense. It is this excess with which we are concerned in getting usable data out of the instrument.

The measurement of excess ΔV pulses is assisted by the presence of a two-bit, four-state, up-down counter in the PSA. This counter accepts the positive and negative ΔV pulses from the PIPA loop and provides the positive and negative excess ΔV pulses as an output. In the operational system, the excess pulses go to the APOLLO Guidance Computer. During PIPA calibration, these pulses are used for measuring.

The counter design assumes a 3:3 moding condition. An extra bit of uncertainty is added if: (a) 2:2 moding prevails and (b) the input signal has changed sign. Figure II-3 shows this uncertainty. Figure II-4 shows that during the start of a 3:3 mode monitoring sequence, assuming empty counter registers, an initial count error of two bits may occur. It also shows that, after one cycle, the uncertainty disappears and that this uncertainty need not be included during calibration when a preset counter is connected to a PIPA loop and its up-down counter in the steady state.

Finally, referring to the counter diagram of figure II-5 and the pulse trains depicted in figure II-6, the conclusion can be reached that the uncertainty in gating time pulses with the output of the up-down counter (in the steady state) will be zero counts when all equipment is operating properly.

The scale factor is given by:

$$\begin{aligned} SF (A) &= \frac{\text{Velocity Increment}}{\text{Pulse}} \\ &= \frac{\text{Acceleration Input}}{\text{Pulse Rate}} \\ &= \frac{\text{Load Factor and Bias Input}}{\text{Pulse Rate}} \end{aligned}$$

During calibration tests:

$$\begin{aligned} SF (A) &= \frac{(g \cos A_p + a_b)}{N_A} \\ &= \frac{(g \cos A_p + a_b) N_r \Delta T}{N_A} \end{aligned}$$

The following is an error analysis of the PIPA Calibration Test.

$$\left(\frac{U_{SF}}{SF}\right)^2 = \left(\frac{\partial SF}{\partial g} \times \frac{U_g}{SF}\right)^2 + \left(\frac{\partial SF}{\partial A_p} \times \frac{U_{A_p}}{SF}\right)^2 + \left(\frac{\partial SF}{\partial a_b} \times \frac{U_{a_b}}{SF}\right)^2$$

$$+ \left(\frac{\partial SF}{\partial N_T} \times \frac{U_{N_T}}{SF}\right)^2 + \left(\frac{\partial SF}{\partial \Delta T} \times \frac{U_{\Delta T}}{SF}\right)^2 + \left(\frac{\partial SF}{\partial N_A} \times \frac{U_{N_A}}{SF}\right)^2$$

$$\frac{\partial SF}{\partial g} = \frac{\cos A_p N_T \Delta T}{N_A}$$

$$\frac{\partial SF}{\partial A_p} = \frac{\sin A_p g N_T \Delta T}{N_A}$$

$$\frac{\partial SF}{\partial a_b} = \frac{N_T \Delta T}{N_A}$$

$$\frac{\partial SF}{\partial N_T} = \frac{(g \cos A_p + a_b) \Delta T}{N_A}$$

$$= \frac{\Delta T g \cos A_p}{N_A} \left(1 + \frac{a_b}{g \cos A_p}\right)$$

$$\frac{\partial SF}{\partial \Delta T} = \frac{(g \cos A_p + a_B) N_T}{N_A}$$

$$= \frac{N_T g \cos A_p}{N_A} \left(1 + \frac{a_B}{g \cos A_p} \right)$$

$$\frac{\partial SF}{\partial N_A} = - \frac{(g \cos A_p + a_B) N_T \Delta T}{(N_A)^2}$$

$$= - \frac{N_T \Delta T g \cos A_p}{(N_A)^2} \left(1 + \frac{a_B}{g \cos A_p} \right)$$

Where:

$$\left(1 + \frac{a_B}{g \cos A_p} \right) \approx 1$$

within the desired accuracy
of the error coefficients

Also, for purposes of calculating error coefficients:

$$SF(A) = \frac{(g \cos A_p + a_B) N_T \Delta T}{N_A}$$

$$= \frac{g \cos A_p N_T \Delta T}{N_A} \left(1 + \frac{a_B}{g \cos A_p} \right)$$

$$\approx \frac{g \cos A_p N_T \Delta T}{N_A}$$

$$\begin{aligned}
 \left(\frac{U_{sf}}{SF} \right)^2 = & \left(\frac{\cos A_p N_T \Delta T}{N_A} \right)^2 + \left(\frac{-(\sin A_p) g N_T \Delta T}{N_A} \right)^2 \\
 & + \left(\frac{N_T \Delta T}{N_A} \right)^2 + \left(\frac{\Delta T g \cos A_p}{N_A} \right)^2 \\
 & + \left(\frac{N_T g \cos A_p}{N_A} \right)^2 + \left(\frac{-N_T \Delta T g \cos A_p}{(N_A)^2} \right)^2
 \end{aligned}$$

By cancelling and ignoring minus signs which will be squared:

$$\begin{aligned}
 \left(\frac{U_{sf}}{SF} \right)^2 = & \left(\frac{U_g}{g} \right)^2 + (\tan A_p \times U_{Ap})^2 + \left(\frac{U_{aB}}{g \cos A_p} \right)^2 \\
 & + \left(\frac{U_{N_T}}{N_T} \right)^2 + \left(\frac{U_{\Delta T}}{\Delta T} \right)^2 + \left(\frac{U_{N_A}}{N_A} \right)^2
 \end{aligned}$$

For small values of A_p : $\tan A_p = A_p$, $\cos A_p = 1$.

$$\begin{aligned}
 \left(\frac{U_{sf}}{SF} \right)^2 = & \left(\frac{U_g}{g} \right)^2 + (A_p \times U_{Ap})^2 + \left(\frac{U_{aB}}{g} \right)^2 + \left(\frac{U_{N_T}}{N_T} \right)^2 \\
 & + \left(\frac{U_{\Delta T}}{\Delta T} \right)^2 + \left(\frac{U_{N_A}}{N_A} \right)^2
 \end{aligned}$$

Units: Dimensionless.

The following uncertainty numbers will now be substituted into the error equation.

$\frac{U_g}{g} = 1 \times 10^{-6}$. This is a specification on the RMS measurement of $\bar{g}$ which should be met at each test site.

$A_p = U_{A_p}$, assuming that the table is orientated for a horizontal rotary axis but that no correction is attempted for fixture, gimbal, or component errors.

$$\begin{aligned} \text{RMS } U_{A_p} \times A_p &\approx (U_{AP})^2 = (\epsilon_{FAT})^2 + (\epsilon_{GA})^2 + (\alpha_{n_m})^2 \\ &= (0.3 \text{ mr})^2 + (0.3 \text{ mr})^2 + (0.1 \text{ mr})^2 \\ &= 0.19 (\text{mr})^2 = 0.19 \times 10^{-6} (\text{rads})^2 \end{aligned}$$

$$\begin{aligned} \text{Max. } \frac{U_{a_B}}{g} &= \frac{4.1^* \times g}{206 \times 1000 \times g} \\ &= 19.8 \times 10^{-6} \text{ radians} \end{aligned}$$

$$\begin{aligned} \text{RMS } \frac{U_{a_B}}{g} &= \frac{19.8 \times 10^{-6}}{\sqrt{3}} \\ &= 11.4 \times 10^{-6} \text{ radians} \end{aligned}$$

$$\frac{U_{N_T}}{N_T} = \frac{U_{N_A}}{N_A} = \text{Zero.}$$

This is based on the proposition that the counter gate is mechanized so that, if it is working properly, it will not miss a pulse. Furthermore, if it is malfunctioning, the error will be gross and clearly evident.

*Refer to "Maximum Expected Uncertainties" listed in Section II, Paragraph A of E-1230, IMU Alignment Tests.

Max. $\frac{U_{\Delta T}}{\Delta T} = 5 \times 10^{-6}$, based upon the specification for the frequency source in the GSE Computer Simulator.

$$\text{RMS } \frac{U_{\Delta T}}{\Delta T} = \frac{5}{\sqrt{3}} \times 10^{-6} = 2.88 \times 10^{-6}$$

The following is a summary of squared error contributions.

$$\left(\frac{U_g}{g}\right)^2 = 1.0 \times 10^{-12}$$

$$(A_P \times U_{A_P})^2 = (U_{A_P})^4 = 0.04 \times 10^{-12}$$

$$\left(\frac{U_{a_B}}{g}\right)^2 = 130.0 \times 10^{-12}$$

$$\left(\frac{U_{\Delta T}}{\Delta T}\right)^2 = 8.3 \times 10^{-12}$$

$$\left(\frac{U_{SF}}{SF}\right)^2 = 139.3 \times 10^{-12}$$

$$\text{RMS } \frac{U_{SF}}{SF} = 11.8 \times 10^{-6}$$

$$3 \text{ Sigma } \frac{U_{SF}}{SF} = 35.4 \times 10^{-6} \text{ or about 35 parts per million.}$$

The preceding analysis would seem to imply that the percentage error for a test based on one interval between N_A pulses would be as valid as the percentage error for a longer test. Unfortunately, this is true only when the scale factor happens to produce an equal time interval between each pulse. Such special-case scale factors are those given by:

$$SF = \left(\frac{6n + 1}{3200} \frac{\text{sec}}{\text{data pulse}} \right) \left(980 \frac{\text{cm}}{\text{sec}^2} \right) \text{ Where } n = \text{number of binary cycles between each extra pulse}$$

In general, however, the N_A pulse train will exhibit a periodicity of its own which cannot in all cases be predicted ahead of time. Therefore, the calibration tests will be run for 5 minutes, or 300 seconds, to minimize the effect of a particular pattern of N_A counts versus time. This uses the counter to almost its storage capacity ($N_T = 3200 \text{ pps} \times 300 \text{ secs} = 960,000$) and still is not an unreasonably long time for the test. For this test, the preset counter in figure II-5 is set to 50,000.

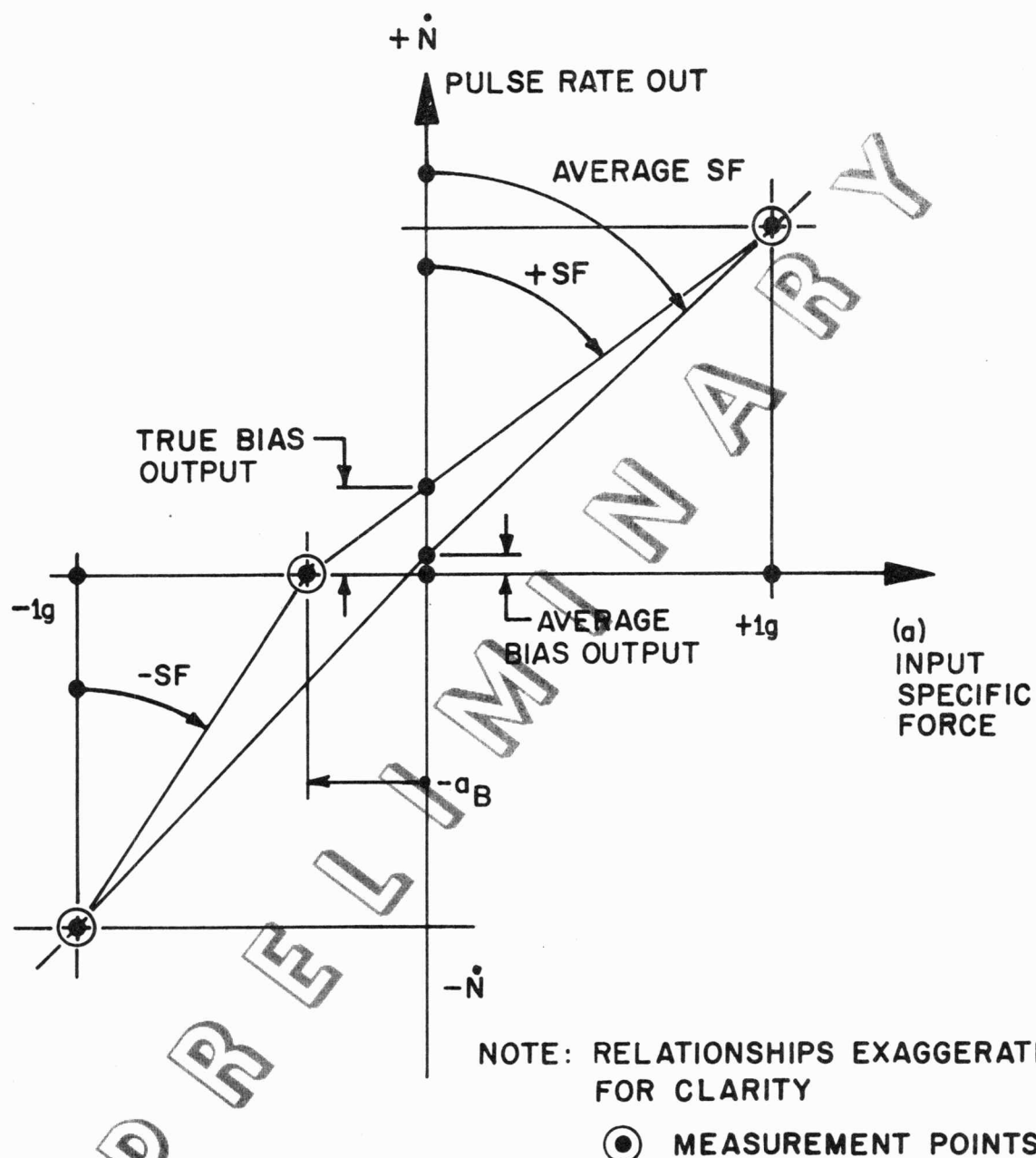
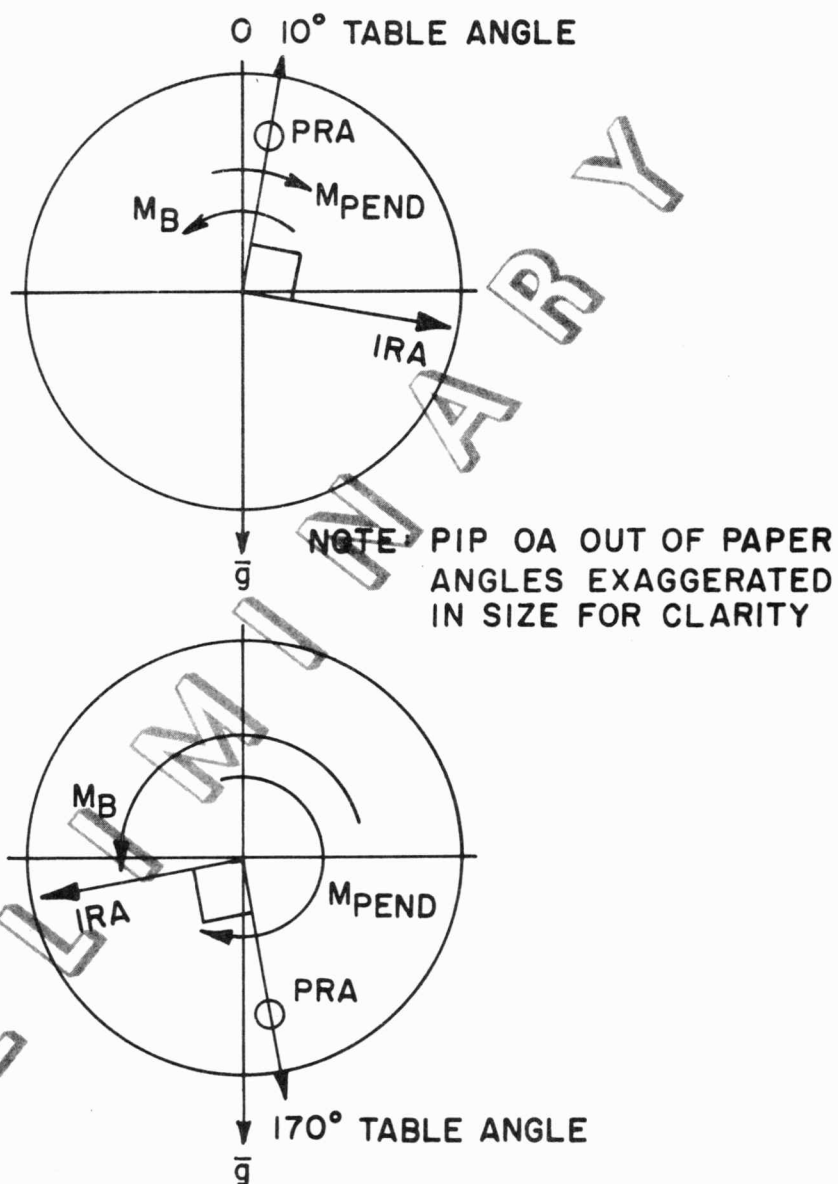


Figure II-1. PIPA Quantities.



$$\begin{aligned}
 a_{BIAS} &= N_B \times SF \\
 &= \sin (\Delta \theta)_{BIAS} \times g \\
 &= g \sin \frac{[(10^\circ) - (170^\circ) + (180^\circ)]}{2}
 \end{aligned}$$

Figure II-2. PIPA Bias Nulls, Example.

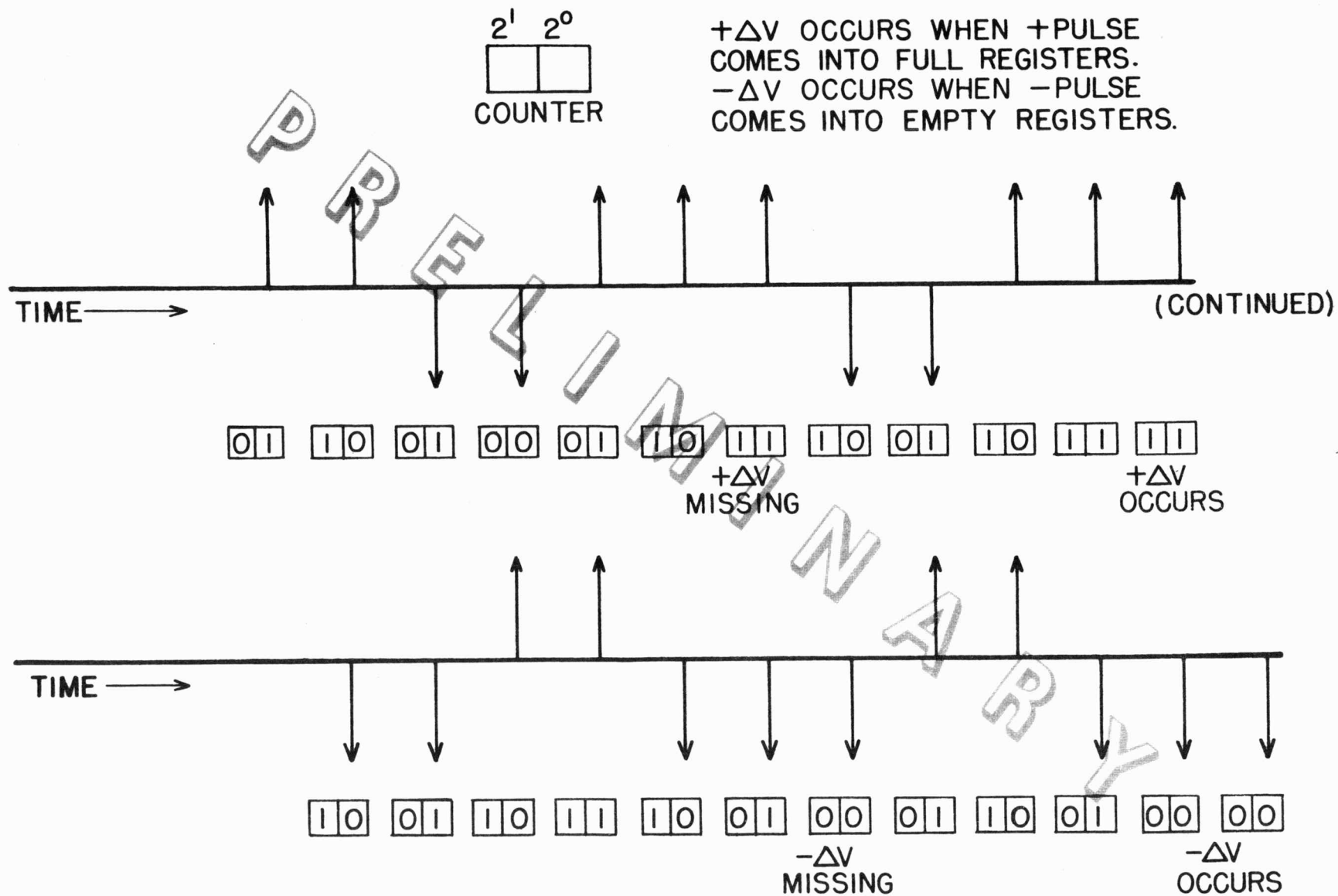


Figure II-3. 2:2 Moding Uncertainty with Two-Bit Counter.

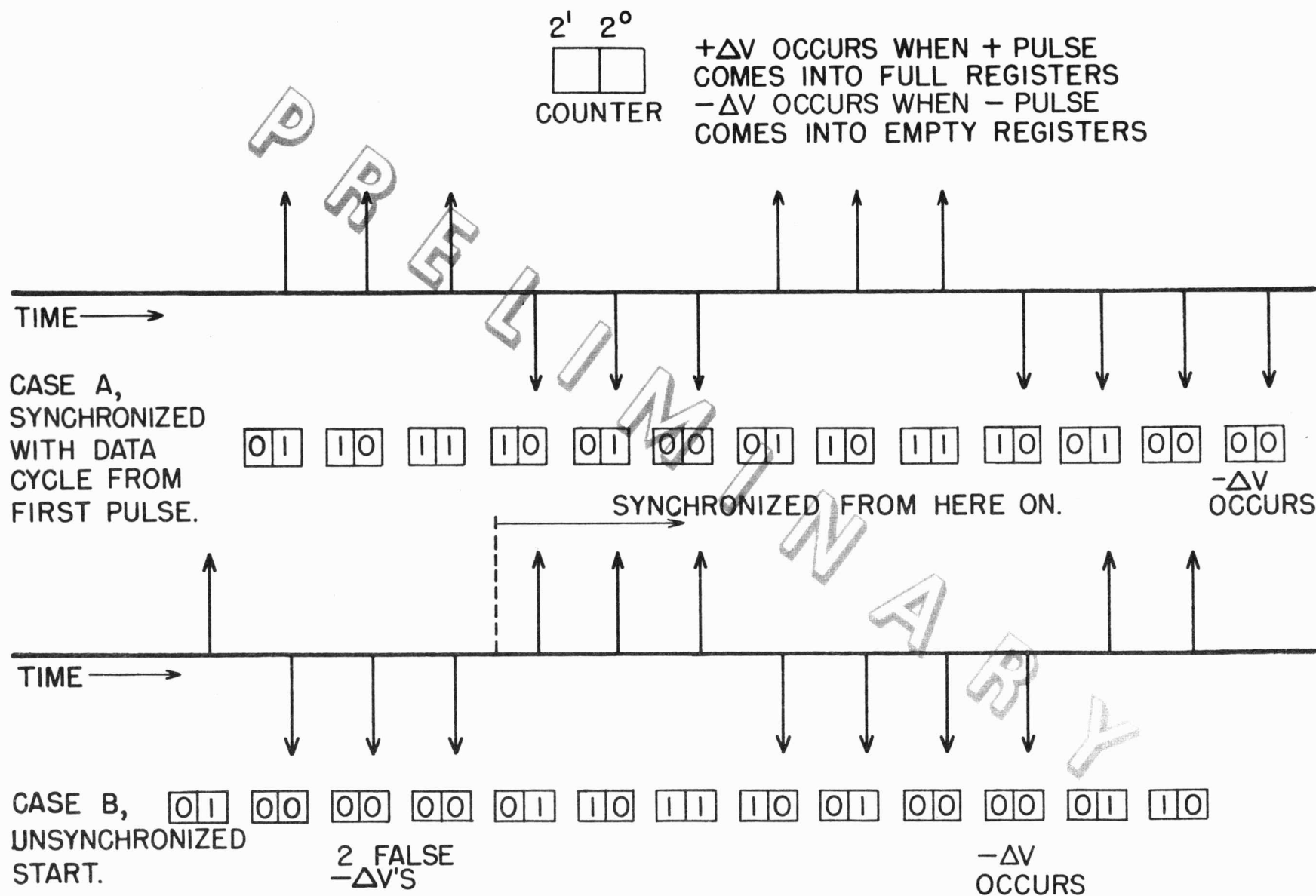


Figure II-4. 3:3 Moding Transient Uncertainty with Two-Bit Counter.

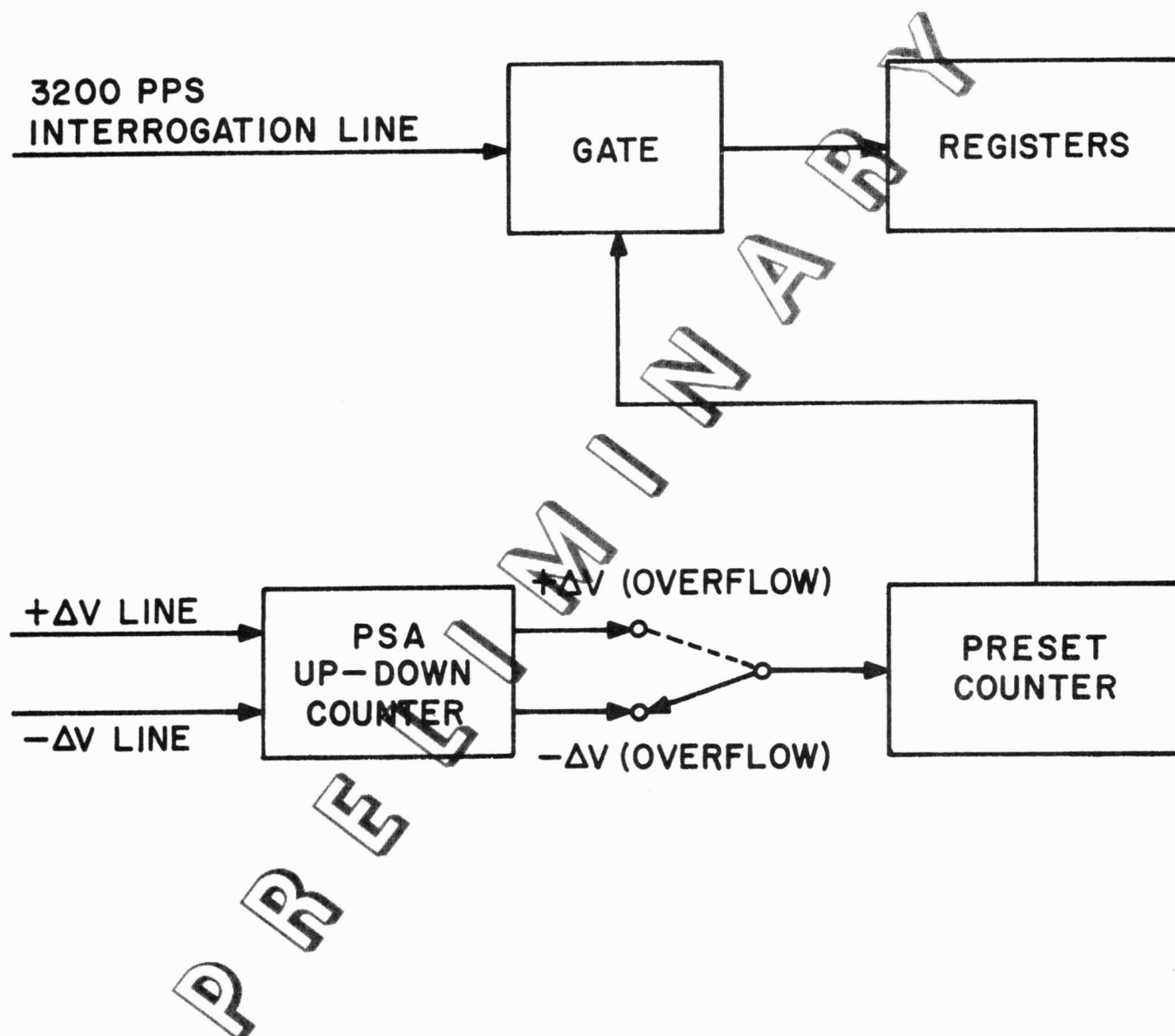


Figure II-5. PIPA Calibration Counter.

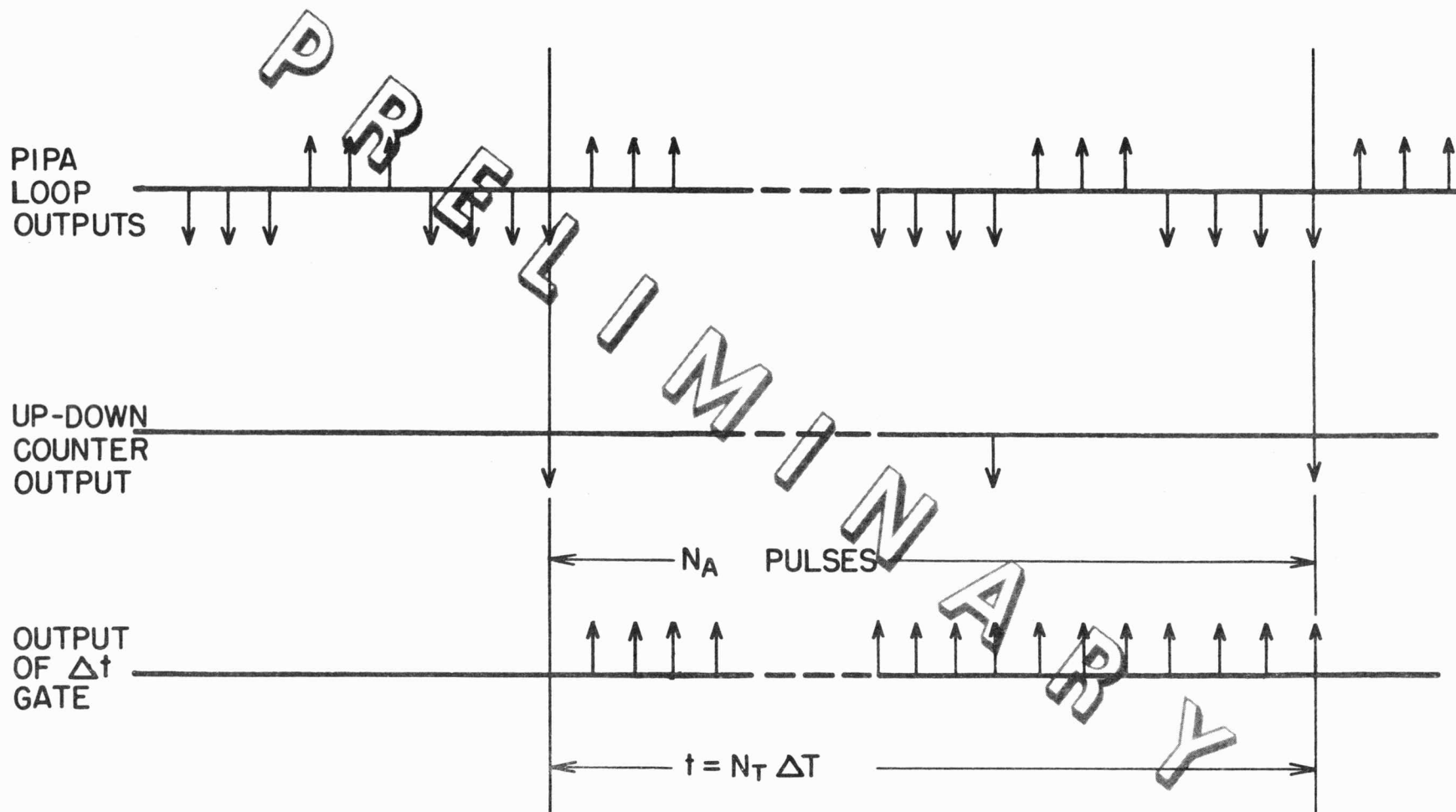


Figure II-6. Synchronization of PIPA Calibration Counting.

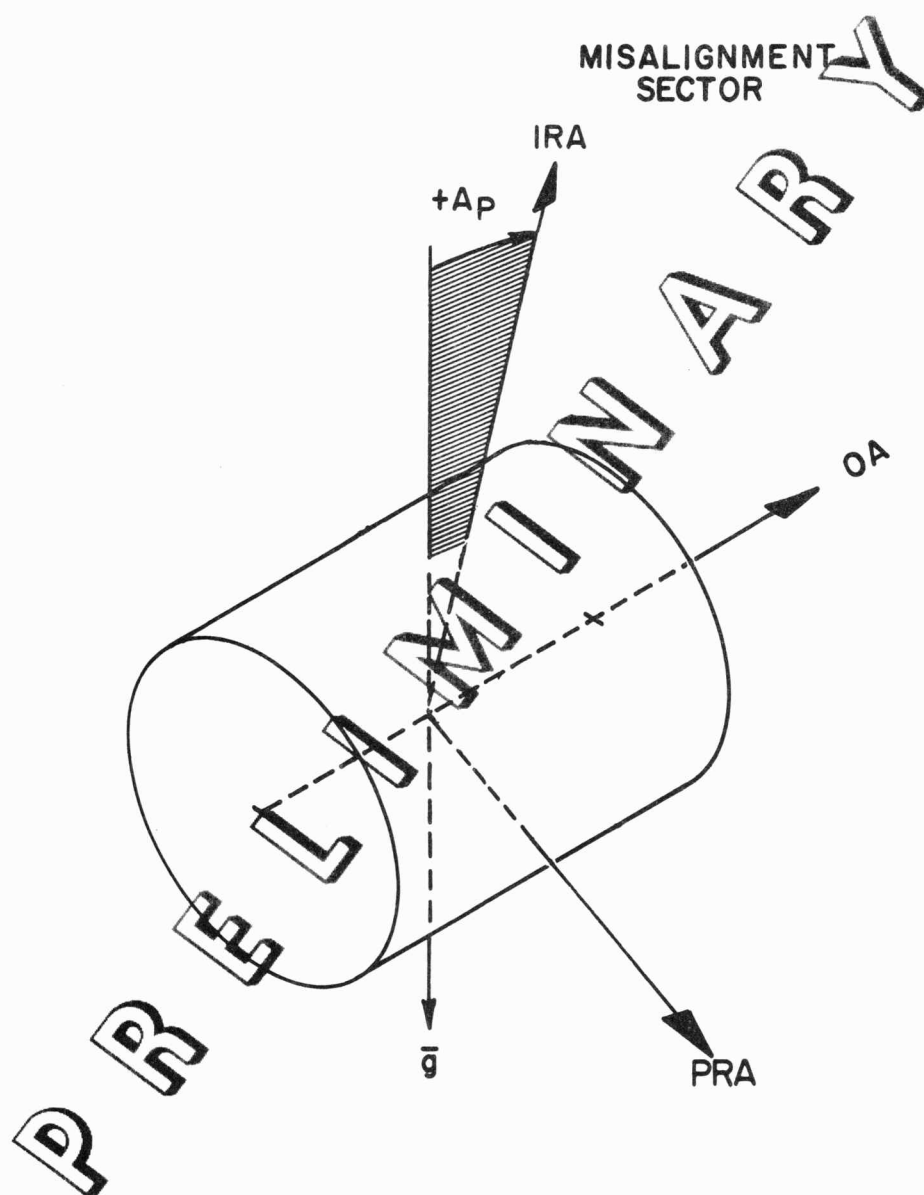


Figure II-7. Geometry of PIPA Calibration Tests.

III. IRIG CALIBRATION THEORY

A. GENERAL

The measurement of IRIG performance is divided into three sections. The first two orientations (figure III-1) produce a value for NBD and ADSRA. The second two orientations (figure III-2) produce a value for ADIA as well as a second value for NBD. The fifth orientation (figure III-3) is used to measure the scale factor of the command gyro torquing mode, SF (G).

In every case, it is desired to measure these quantities under the circumstances that will prevail in the operational equipment. The tests are designed to do just this. In particular, care is taken to ensure that the residual magnetism in the IRIG torquer coil is always at the level associated with the last pulses having been positive. Facilities for applying positive pulses are provided in the GSF.

B. ADSRA ORIENTATION

In this orientation, defined by figure III-1, the Spin Reference Axis (SRA) is placed along the local vertical downwards; the Input Axis (IA) is placed in the horizontal plane and North; and the Output Axis (OA) is consequently in the horizontal plane and East. After the gyro has been caged, uncaged, and the system placed in Fine Align mode, the pertinent gimbal will drift. This is monitored by counting the output pulses of the CDU Encoder for that gimbal.

As shown on figure III-4, the CDU pulses are used to gate time pulses while the CDU goes through one complete shaft revolution. This corresponds to a Gimbal Angle Drift (A_0) of 12.272 milliradians. The drift time is then given by $T_1 = N_1 \Delta T$. The gyro is then reoriented, with the SRA up, by rotation about North; and the test is repeated to give $T_2 = N_2 \Delta T$. The misalignments for these tests, A_1 , A_2 , and A_3 , are considered along with other uncertainties in the following error analysis for the ADSRA orientation.

Deriving the first equation for NBD:

$$W_1 = (NBD - ADSRA \cos A_2 \cos A_3) K$$

$$+ W_{IE} (\cos \lambda \cos A_1 \cos A_2 + \sin \lambda \cos A_1 \sin A_2)$$

$$W_2 = (NBD + ADSRA \cos A_2 \cos A_3) K$$

$$+ W_{IE} (\cos \lambda \cos A_1 \cos A_2 - \sin \lambda \cos A_1 \sin A_2)$$

$$W_1 + W_2 = 2 (NBD) K + 2 W_{IE} \cos \lambda \cos A_1 \cos A_2$$

$$NBD = \frac{W_1 + W_2}{2K} - \frac{W_{IE}}{K} \cos \lambda \cos A_1 \cos A_2$$

$$= \frac{A_0}{2K\Delta T} \left(\frac{1}{N_{T_1}} + \frac{1}{N_{T_2}} \right) - \frac{W_{IE}}{K} \cos \lambda \cos A_1 \cos A_2$$

Deriving the first error equation for NBD:

$$(U_{\text{NBD}})^2 = \left(\frac{\partial \text{NBD}}{\partial A_0} \right)^2 (U_{A_0})^2 + \left(\frac{\partial \text{NBD}}{\partial \Delta T} \right)^2 (U_{\Delta T})^2 + 2 \left(\frac{\partial \text{NBD}}{\partial N_T} \right)^2 (U_{N_T})^2 \\ + \left(\frac{\partial \text{NBD}}{\partial W_{IE}} \right)^2 (U_{W_{IE}})^2 + \left(\frac{\partial \text{NBD}}{\partial \lambda} \right)^2 (U_{\lambda})^2 + 2 \left(\frac{\partial \text{NBD}}{\partial A_{1,2}} \right)^2 (U_{A_{1,2}})^2$$

where $U_{N_T} = U_{N_1} = U_{N_2}$, and $U_{A_1} = U_{A_2} = U_{A_{1,2}}$

$$\frac{\partial \text{NBD}}{\partial A_0} = \frac{1}{2K\Delta T} + \left(\frac{1}{N_T} + \frac{1}{N_T} \right) = \frac{1}{N_T K \Delta T}$$

$$\frac{\partial \text{NBD}}{\partial \Delta T} = - \frac{A_0}{N_T K (\Delta T)^2}$$

$$\frac{\partial \text{NBD}}{\partial N_T} = - \frac{A_0}{2 K \Delta T (N_T)^2}$$

$$\frac{\partial \text{NBD}}{\partial W_{IE}} = - \frac{\cos \lambda}{K} \quad \text{for small } A_1 \text{ and } A_2$$

$$\frac{\partial \text{NBD}}{\partial \lambda} = \frac{W_{IE}}{K} \sin \lambda \quad \text{for small } A_1 \text{ and } A_2$$

$$\frac{\partial \text{NBD}}{\partial A_{1,2}} = \frac{W_{IE}}{K} \cos \lambda \sin A_{1,2} \quad \text{for small } A_1 \text{ and } A_2$$

$$\begin{aligned}
 (U_{NBD})^2 &= \left(\frac{U_{A_D}}{N_T K \Delta T} \right)^2 + \left(\frac{A_D}{N_T K \Delta T} \times \frac{U_{\Delta T}}{\Delta T} \right)^2 \\
 &+ 2 \left(\frac{A_D}{2 K \Delta T N_T} \times \frac{U_{N_T}}{N_T} \right)^2 + \left(\frac{\cos \lambda}{K} U_{W_{IE}} \right)^2 \\
 &+ \left(\frac{W_{IE} \sin \lambda}{K} \times U_{\lambda} \right)^2 + 2 \left(\frac{W_{IE}}{K} \cos \lambda \sin A_{1,2} U_{A_{1,2}} \right)^2
 \end{aligned}$$

Since $N_T \Delta T \approx \frac{A_D}{W_{IE} \cos \lambda}$,

$$\begin{aligned}
 (U_{NBD})^2 &= \left(\frac{W_{IE} \cos \lambda}{K} \times \frac{U_{A_D}}{A_D} \right)^2 + \left(\frac{W_{IE} \cos \lambda}{K} \times \frac{U_{\Delta T}}{\Delta T} \right)^2 \\
 &+ \left(\frac{W_{IE} \cos \lambda}{\sqrt{2} K} \times \frac{U_{N_T}}{N_T} \right)^2 + \left(\frac{W_{IE} \cos \lambda}{K} \times \frac{U_{W_{IE}}}{W_{IE}} \right)^2 \\
 &+ \left(\frac{W_{IE} \sin \lambda}{K} \times U_{\lambda} \right)^2 + \left(\frac{\sqrt{2} W_{IE} \cos \lambda \sin A_{1,2}}{K} \times U_{A_{1,2}} \right)^2
 \end{aligned}$$

Units: (Meru)²

Selection of Values for terms in the previous equation:

$$\text{Assume } \cos \lambda = \cos 30^\circ = 0.866$$

Then :

$$\begin{aligned} \frac{W_{IE} \cos \lambda}{K} &= \frac{(7.292 \times 10^{-5}) (0.866)}{(7.292 \times 10^{-8})} \\ &= 866.0 \end{aligned}$$

$$A_D = 12.272 \times 10^{-3} \text{ radians}$$

U_{A_D} is given as a maximum of 5 arc seconds when A_D is less than 1° or 17.45×10^{-3} radians

$$\begin{aligned} \text{Max } U_{A_D} &= 5'' \\ &= 24.272 \times 10^{-6} \text{ radians} \end{aligned}$$

$$\text{RMS } U_{A_D} = \frac{24.272 \times 10^{-6}}{\sqrt{3}}$$

$$= 14.0 \times 10^{-6} \text{ radians}$$

$$\frac{W_{IE} \cos \lambda}{K} \times \frac{U_{A_D}}{A_D} = 866 \times \frac{14.0 \times 10^{-6}}{12.272 \times 10^{-3}}$$

$$= 0.986 \text{ Meru}$$

$$\text{Max } \frac{U_{\Delta\tau}}{\Delta T} = 5 \times 10^{-6}, \text{ based on the specification for the}$$

GSE Computer Simulator.

$$\begin{aligned} \text{RMS } \frac{U_{\Delta\tau}}{\Delta T} &= \frac{5}{\sqrt{3}} \times 10^{-6} \\ &= 2.88 \times 10^{-6} \end{aligned}$$

$$\begin{aligned} \frac{W_{IE} \cos \lambda}{K} \times \frac{U_{\Delta\tau}}{\Delta T} &= 866 \times 2.88 \times 10^{-6} \\ &= 2.49 \times 10^{-6} \text{ Meru} \end{aligned}$$

$$\frac{U_{N\tau}}{N\tau} = \text{Zero, based on the proposition that the counter gate is mechanized so that it will not miss a pulse (if the counter gate is working properly). If the counter gate is malfunctioning, the error(s) will be gross and clearly evident.}$$

$$\text{RMS } \frac{U_{WIE}}{W_{IE}} = 1 \times 10^{-6} \text{ by rounding off significant figures in the value for earth rate listed on page 68 of AGANI.}$$

$$\frac{W_{IE} \cos \lambda}{K} \times \frac{U_{W_{IE}}}{W_{IE}} = (866 \times 1 \times 10^{-6})$$

$$= 866 \times 10^{-6} \text{ Meru}$$

$$\text{RMS } U_{\lambda} = 1 \text{ arc second (estimated)}$$

$$= 4.85 \times 10^{-6} \text{ radians}$$

$$\frac{W_{IE} \sin \lambda}{K} \times U_{\lambda} = (500) (4.85 \times 10^{-6})$$

$$= 2.43 \times 10^{-3} \text{ Meru}$$

$$U_{A_{1,2}} = \sin A_{1,2}$$

$$= \sqrt{\left(\frac{\text{Max Gimbal Error}}{3}\right)^2 + \left(\frac{\text{Max IRIG/IA Alignment*}}{3}\right)^2}$$

$$= \sqrt{(0.10 \times 10^{-3})^2 + (0.97 \times 10^{-3})^2}$$

$$= 0.97 \times 10^{-3} \text{ radians}$$

$$\frac{\sqrt{2} W_{IE} \cos \lambda}{K} \times \sin A_{1,2} \times U_{A_{1,2}} = \sqrt{2} \ 866 \times (0.97 \times 10^{-3})^2$$

$$= 1.19 \times 10^{-3} \text{ Meru}$$

*As discussed in E-1097, maximum IRIG misalignment is 10 arc minutes or 2.91×10^{-3} radians.

Summarizing Errors for NBD in ADSRA Test:

$$\left(\frac{W_{IE} \cos \lambda}{K} \times \frac{U_{A_D}}{A_D} \right)^2 = (0.986)^2$$

$$\left(\frac{W_{IE} \cos \lambda}{K} \times \frac{U_{\Delta T}}{\Delta T} \right)^2 = (2.49 \times 10^{-3})^2$$

$$\left(\frac{W_{IE} \cos \lambda}{\sqrt{2} K} \times \frac{U_{N_r}}{N_r} \right)^2 = \text{Zero}$$

$$\left(\frac{W_{IE} \cos \lambda}{K} \times \frac{U_{W_{IE}}}{W_{IE}} \right)^2 = (0.866 \times 10^{-3})^2$$

$$\left(\frac{W_{IE} \sin \lambda}{K} \times U_{\lambda} \right)^2 = (2.43 \times 10^{-3})^2$$

$$\left(\frac{\sqrt{2} W_{IE} \cos \lambda}{K} \sin A_{1,2} \times U_{A_{1,2}} \right)^2 = (1.19 \times 10^{-3})^2$$

$$U_{NBD} = 0.99 \text{ Meru RMS}$$

$$\approx 3 \text{ Meru (3 Sigma)}$$

Deriving the equation for ADSRA:

$$W_1 = (NBD - ADSRA \cos A_2 \cos A_3) K$$

$$+ W_{IE} (\cos \lambda \cos A_1 \cos A_2 + \sin \lambda \cos A_1 \sin A_2)$$

$$W_2 = (NBD + ADSRA \cos A_2 \cos A_3) K$$

$$+ W_{IE} (\cos \lambda \cos A_1 \cos A_2 - \sin \lambda \cos A_1 \sin A_2)$$

$$W_2 - W_1 = 2 (ADSRA \cos A_2 \cos A_3) K - 2 W_{IE} \sin \lambda \cos A_1 \sin A_2$$

$$ADSRA = \frac{W_2 - W_1}{2K \cos A_2 \cos A_3} + \frac{W_{IE} \sin \lambda \cos A_1 \sin A_2}{K \cos A_2 \cos A_3}$$

$$= \frac{A_0 \left(\frac{1}{N_{r_2}} - \frac{1}{N_{r_1}} \right)}{2K \Delta T \cos A_2 \cos A_3} + \frac{W_{IE} \sin \lambda \cos A_1 \tan A_2}{K \cos A_3}$$

Deriving the error equation for ADSRA:

$$\begin{aligned}
 (U_{\text{ADSRA}})^2 = & \left(\frac{\partial \text{ADSRA}}{\partial A_0} \right)^2 (U_{A_0})^2 + \left(\frac{\partial \text{ADSRA}}{\partial \Delta T} \right)^2 (U_{\Delta T})^2 \\
 & + 2 \left(\frac{\partial \text{ADSRA}}{\partial N_T} \right)^2 (U_{N_T})^2 + \left(\frac{\partial \text{ADSRA}}{\partial W_{IE}} \right)^2 (U_{W_{IE}})^2 \\
 & + \left(\frac{\partial \text{ADSRA}}{\partial \lambda} \right)^2 (U_{\lambda})^2 + \left(\frac{\partial \text{ADSRA}}{\partial A_1} \right)^2 (U_{A_1})^2 \\
 & + \left(\frac{\partial \text{ADSRA}}{\partial A_2} \right)^2 (U_{A_2})^2 + \left(\frac{\partial \text{ADSRA}}{\partial A_3} \right)^2 (U_{A_3})^2
 \end{aligned}$$

The following approximation will be used.

$$N_{T_1} = N_T + \Delta N$$

$$N_{T_2} = N_T - \Delta N$$

$$\frac{1}{N_{T_2}} - \frac{1}{N_{T_1}} = \frac{1}{N_T - \Delta N} - \frac{1}{N_T + \Delta N}$$

$$\approx \frac{2 \Delta N}{N_T^2}$$

$$\frac{\partial \text{ADSRA}}{\partial A_0} = \frac{\Delta N}{K \Delta T (N_T)^2} \quad \text{for small } A_1, A_2, \text{ and } A_3$$

$$\frac{\partial \text{ADSRA}}{\partial \Delta T} = \frac{-A_0 \Delta N}{K (N_T)^2 (\Delta T)^2}$$

$$\frac{\partial \text{ADSRA}}{\partial N_T} = \frac{A_0}{2K \Delta T (N_T)^2}$$

$$\frac{\partial \text{ADSRA}}{\partial W_{IE}} = \frac{\sin \lambda}{K} \times A_2$$

$$\frac{\partial \text{ADSRA}}{\partial \lambda} = \frac{W_{IE} \cos \lambda}{K} \times A_2$$

$$\frac{\partial \text{ADSRA}}{\partial A_1} = \frac{W_{IE} \cos \lambda}{K} \times A_1 \times A_2$$

$$\frac{\partial \text{ADSRA}}{\partial A_2} = \frac{A_0 \Delta N}{K \Delta T (N_T)^2} \times A_2 + \frac{W_{IE} \sin \lambda}{K}$$

$$\frac{\partial \text{ADSRA}}{\partial A_3} = \left(\frac{A_0 \Delta N}{K \Delta T (N_T)^2} + \frac{W_{IE} \sin \lambda \times A_2}{K} \right) A_3$$

In actual fact, $\frac{\Delta N}{N_T} \ll 1.0$; but, in evaluating uncertainty, $\frac{\Delta N}{N_T} = 1.0$ will be used.

Also, as before, $N_T \Delta T = \frac{A_D}{W_{IE} \cos \lambda}$.

$$\begin{aligned}
 (U_{\text{ADSRA}})^2 = & \left(\frac{W_{IE} \cos \lambda}{K} \times \frac{U_{A_D}}{A_D} \right)^2 + \left(\frac{W_{IE} \cos \lambda}{K} \times \frac{U_{\Delta T}}{\Delta T} \right)^2 \\
 & + 2 \left(\frac{W_{IE} \cos \lambda}{2K} \times \frac{U_{N_T}}{N_T} \right)^2 + \left(\frac{W_{IE} \sin \lambda}{K} \times \frac{U_{W_{IE}}}{W_{IE}} \right)^2 (A_2)^2 \\
 & + \left(\frac{W_{IE} \cos \lambda}{K} \times U_1 \right)^2 (A_2)^2 + \left(\frac{W_{IE} \cos \lambda}{K} \times A_1 U_{A_1} \right)^2 (A_2)^2 \\
 & + \left(\frac{W_{IE} \cos \lambda}{K} \times A_2 + \frac{W_{IE} \sin \lambda}{K} \right)^2 (U_{A_2})^2 \\
 & + \left[\left(\frac{W_{IE} \cos \lambda}{K} \times A_3 U_{A_3} \right) + \left(\frac{W_{IE} \sin \lambda}{K} \times A_2 \times A_3 U_{A_3} \right) \right]^2
 \end{aligned}$$

By comparing the terms in $(U_{\text{ADSRA}})^2$ with those in $(U_{\text{NBD}})^2$, the following conclusions can be drawn.

1. U_{A_D} is still most significant.
2. The second term in $\frac{\partial \text{ADSRA}}{\partial A_2}$ is significant.
3. No other error contributions are significant.

$$\begin{aligned} (U_{\text{ADSRA}})^2 &= \left(\frac{W_{IE} \cos \lambda}{K} \times \frac{U_{A_D}}{A_D} \right)^2 + \left(\frac{W_{IE} \sin \lambda}{K} \times U_{A_2} \right)^2 \\ &= (0.986)^2 + (0.485)^2 \end{aligned}$$

$$\begin{aligned} U_{\text{ADSRA}} &= 1.10 \text{ Meru RMS} \\ &\approx 3.3 \text{ Meru (3 Sigma)} \end{aligned}$$

C. ADIA ORIENTATION

In this orientation, defined by figure III-2, the Input Axis (IA) is aligned as closely as possible to the local vertical upwards. The Spin Reference Axis (SRA) and the Output Axis (OA) are in the horizontal plane. Again, time pulses are gated while the appropriate gimbal drifts the equivalent of one CDU shaft rotation. The time is given by $T_3 = N_{T_3} \Delta T$. Finally, the IA is directed downward along the local vertical, and the drift measurement is repeated. The time is given by $T_4 = N_{T_4} \Delta T$. Misalignments A_4 about North and A_5 about the SRA of the gyro from the desired orientation are considered along with other uncertainties in the following error analysis for the ADIA orientation.

Deriving the second equation for NBD:

$$W_3 = (NBD + ADIA \cos A_4 \cos A_5 - ADSRA \sin A_4) K$$

$$+ W_{IE} \sin \lambda \cos A_4 \cos A_5 + W_{IE} \cos \lambda \sin A_5$$

$$W_4 = (NBD - ADIA \cos A_4 \cos A_5 + ADSRA \sin A_4) K$$

$$- W_{IE} \sin \lambda \cos A_4 \cos A_5 + W_{IE} \cos \lambda \sin A_5$$

$$W_3 + W_4 = 2NBD K + 2W_{IE} \cos \lambda \sin A_5$$

$$NBD = \frac{W_3 + W_4}{2K} - \frac{W_{IE} \cos \lambda \sin A_5}{K}$$

$$= \frac{A_D}{2 \Delta T K} \left(\frac{1}{N_{T_3}} + \frac{1}{N_{T_4}} \right) - \frac{W_{IE} \cos \lambda \sin A_5}{K}$$

Deriving the second error equation for NBD:

$$\begin{aligned}
 (U_{\text{NBD}})^2 = & \left(\frac{\partial \text{NBD}}{\partial A_D} \right)^2 (U_{A_D})^2 + \left(\frac{\partial \text{NBD}}{\partial \Delta T} \right)^2 (U_{\Delta T})^2 \\
 & + 2 \left(\frac{\partial \text{NBD}}{\partial N_T} \right)^2 (U_{N_T})^2 + \left(\frac{\partial \text{NBD}}{\partial W_{IE}} \right)^2 (U_{W_{IE}})^2 \\
 & + \left(\frac{\partial \text{NBD}}{\partial \lambda} \right)^2 (U_{\lambda})^2 + \left(\frac{\partial \text{NBD}}{\partial A_5} \right)^2 (U_{A_5})^2
 \end{aligned}$$

$$\text{where } U_{N_{T_1}} = U_{N_{T_2}} = U_{N_T}$$

This equation is similar to the first error equation for NBD except that the last term covering angle uncertainties now becomes more significant.

$$\frac{\partial \text{NBD}}{\partial A_5} = - \frac{W_{IE} \cos \lambda \cos A_5}{K}$$

$$= - \frac{W_{IE} \cos \lambda}{K}$$

$$(U_{NBD})^2 = \left(\frac{\partial NBD}{\partial A_D} \right)^2 (U_{A_D})^2 + \left(\frac{\partial NBD}{\partial A_E} \right)^2 (U_{A_E})^2$$

$$= \left(\frac{U_{A_D}}{N_T K \Delta T} \right)^2 + \left(\frac{W_{IE} \cos \lambda}{K} \times U_{A_E} \right)^2$$

In this test, however, $N_T \Delta T \approx \frac{A_D}{W_{IE} \sin \lambda}$

$$(U_{NBD})^2 = \left(\frac{W_{IE} \sin \lambda}{K} \times \frac{U_{A_D}}{A_D} \right)^2 + \left(\frac{W_{IE} \cos \lambda}{K} \times U_{A_E} \right)^2$$

$$= \left(\frac{500 \times 14.0 \times 10^{-6}}{12.27 \times 10^{-3}} \right)^2 + (866 \times 0.97 \times 10^{-3})^2$$

$$= (0.571)^2 + (0.840)^2$$

$$U_{NBD} = 1.02 \text{ Meru RMS}$$

$$\approx 3.0 \text{ Meru (3 Sigma)}$$

Deriving the equation for ADIA:

$$W_3 = (NBD + ADIA \cos A_4 \cos A_5 - ADSRA \sin A_4) K$$

$$+ W_{IE} \sin \lambda \cos A_4 \cos A_5 + W_{IE} \cos \lambda \sin A_5$$

$$W_4 = (NBD - ADIA \cos A_4 \cos A_5 + ADSRA \sin A_4) K$$

$$- W_{IE} \sin \lambda \cos A_4 \cos A_5 + W_{IE} \cos \lambda \sin A_5$$

$$W_3 - W_4 = 2 (ADIA \cos A_4 \cos A_5 - ADSRA \sin A_4) K$$

$$+ 2 W_{IE} \sin \lambda \cos A_4 \cos A_5$$

$$ADIA = \frac{W_3 - W_4}{2K \cos A_4 \cos A_5} + ADSRA \tan A_4 \sec A_5 - \frac{W_{IE} \sin \lambda}{K}$$

$$= \frac{A_0 \left(\frac{1}{N_{T_3}} - \frac{1}{N_{T_4}} \right)}{2K \Delta T \cos A_4 \cos A_5} + ADSRA \tan A_4 \sec A_5 - \frac{W_{IE} \sin \lambda}{K}$$

Deriving the error equation for ADIA:

$$\begin{aligned}
 (U_{ADIA})^2 = & \left(\frac{\partial ADIA}{\partial A_D} \right)^2 (U_{A_D})^2 + \left(\frac{\partial ADIA}{\partial \Delta T} \right)^2 (U_{\Delta T})^2 \\
 & + 2 \left(\frac{\partial ADIA}{\partial N_T} \right)^2 (U_{N_T})^2 + \left(\frac{\partial ADIA}{\partial W_{IE}} \right)^2 (U_{W_{IE}})^2 \\
 & + \left(\frac{\partial ADIA}{\partial \lambda} \right)^2 (U_{\lambda})^2 + \left(\frac{\partial ADIA}{\partial A_4} \right)^2 (U_{A_4})^2 \\
 & + \left(\frac{\partial ADIA}{\partial A_5} \right)^2 (U_{A_5})^2 + \left(\frac{\partial ADIA}{\partial ADSRA} \right)^2 (U_{ADSRA})^2
 \end{aligned}$$

$$\frac{\partial ADIA}{\partial A_D} = \frac{\Delta N}{K \Delta T (N_T)^2} \quad \text{for small } A_4 \text{ and } A_5$$

$$\frac{\partial ADIA}{\partial \Delta T} = - \frac{A_D \Delta N}{K N_T^2 (\Delta T)^2}$$

$$\frac{\partial ADIA}{\partial N_T} = \frac{A_D}{2K \Delta T (N_T)^2}$$

$$\frac{\partial ADIA}{\partial W_{IE}} = - \frac{\sin \lambda}{K}$$

$$\frac{\partial ADIA}{\partial \lambda} = - \frac{W_{IE} \cos \lambda}{K}$$

$$\frac{\partial ADIA}{\partial A_4} = \frac{A_D \Delta N}{K \Delta T (N_T)^2} \times A_4 + ADSRA$$

$$\frac{\partial \text{ADIA}}{\partial A_5} = \frac{A_D \Delta N}{K \Delta T (N_T)^2} \times A_5 + \text{ADSRA} \left(\frac{A_4}{A_5} \right)$$

(Neglect product of two small angles.)

$$\frac{\partial \text{ADIA}}{\partial \text{ADSRA}} = A_4$$

Again using the expression $N_T \Delta T \approx \frac{A_D}{W_{IE} \sin \lambda}$ to simplify the terms:

$$\begin{aligned} (U_{\text{ADIA}})^2 &= \left(\frac{W_{IE} \sin \lambda}{K} \times \frac{U_{A_D}}{A_D} \right)^2 + \left(\frac{W_{IE} \sin \lambda}{K} \times \frac{U_{\Delta T}}{\Delta T} \right)^2 \\ &+ \left(\frac{W_{IE} \sin \lambda}{\sqrt{2} K} \times \frac{U_{N_T}}{N_T} \right)^2 + \left(\frac{W_{IE} \sin \lambda}{K} \times \frac{U_{W_{IE}}}{W_{IE}} \right)^2 \\ &+ \left(\frac{W_{IE} \cos \lambda}{K} \times U_\lambda \right)^2 + \left(\frac{W_{IE} \sin \lambda}{K} \times A_4 + \text{ADSRA} \right)^2 (U_{A_4})^2 \\ &+ \left(\frac{W_{IE} \sin \lambda}{K} \times A_5 \times U_{A_5} \right)^2 + (A_4 \times U_{\text{ADSRA}})^2 \end{aligned}$$

The first five terms of $(U_{\text{ADIA}})^2$ are similar to the first five terms of $(U_{\text{NBD}})^2$, where only the $(U_{A_D})^2$ term is significant.

$(U_{ADIA})^2$ can now be simplified to:

$$\begin{aligned} (U_{ADIA})^2 = & \left(\frac{W_{IE} \sin \lambda}{K} \times \frac{U_{AD}}{A_D} \right)^2 + (ADSRA \times U_{A_4})^2 \\ & + \left(\frac{W_{IE} \sin \lambda}{K} \times A_4 \times U_{A_4} \right)^2 + \left(\frac{W_{IE} \sin \lambda}{K} \times A_5 \times U_{A_5} \right)^2 \\ & + (A_4 \times U_{ADSRA})^2 \end{aligned}$$

For an evaluation of the classified error contribution of the second term $(ADSRA \times U_{A_4})^2$, refer to the ADSRA specification in R-348 (Rev. A) Specification for Procurement of APOLLO Inertial Reference Integrating Gyro, August 1962.

The third and fourth terms above were shown to be negligible in the NBD calculation.

Finally:

$$\begin{aligned} (A_4 \times U_{ADSRA}) &= (0.97 \times 10^{-3} \times 1.10) \\ &= (.00107) \end{aligned}$$

Therefore:

$$\begin{aligned} U_{ADIA} &= \frac{W_{IE} \sin \lambda}{K} \times \frac{U_{AD}}{A_D} \\ &= 500 \times \frac{14.0 \times 10^{-6}}{12.272 \times 10^{-3}} \\ &= 0.57 \text{ Meru RMS} \\ &= 1.7 \text{ Meru (3 Sigma)} \end{aligned}$$

D. SF(G) ORIENTATION

In this orientation, defined by figure III-3, the Output Axis (OA) is aligned with the positive or negative local vertical. The Input Axis (IA) is in the horizontal plane and pointed East or West. The gyro is torqued at 3200 pulses per second, and the 3200-pps timing pulses are gated by the time required for a complete gimbal revolution (512 revolutions of the CDU shaft and 32,768 pulses from the CDU encoder). See figure III-4. The test is repeated in the negative direction.

The gyro equations which apply to this test are developed below. W_5 is the gimbal angle rate for positive torquing, and W_6 is the gimbal angle rate for negative torquing.

$$W_5 = \frac{SF(G) \times 3200}{1000} + (NBD)(K) + (ADSRA)(K) \int_0^T \sin(W_T t) dt$$

where W_T is the nominal torquing rate.

$$W_6 = -\frac{SF(G) \times 3200}{1000} + (NBD)(K) - (ADSRA)(K) \int_0^T \sin(W_T t) dt$$

$$W_5 - W_6 = 0.4 SF(G) + 2(ADSRA)(K) \int_0^T \sin(W_T t) dt$$

Units: radians/second

$$SF(G) = \frac{W_5 - W_6}{6.4} - \frac{(ADSRA)(K)}{(3.2)} \int_0^T \sin(W_T t) dt$$

Now substitute:

$$W_5 = \frac{2\pi}{N_{T5} \Delta T} \quad \text{and} \quad W_6 = -\frac{2\pi}{N_{T6} \Delta T}$$

Then integrate to obtain:

$$SF(G) = \frac{2\pi}{6.4 \Delta T} \left(\frac{1}{N_{T5}} + \frac{1}{N_{T6}} \right) - \frac{(ADSRA)(K)}{(3.2)} \left[\cos(W_T t) \right]_0^T$$

At $t = 0$, $\cos 0 = 1$, and at $t = T$, $\cos 360^\circ = 1$; therefore:

$$\begin{aligned} SF(G) &= \frac{\pi}{3.2 \Delta T} \left(\frac{1}{N_{T5}} + \frac{1}{N_{T6}} \right) \\ &= \frac{\pi}{3.2 \Delta T} \left(\frac{(N_T - \Delta N) + (N_T + \Delta N)}{(N_T + \Delta N)(N_T - \Delta N)} \right) \\ &= \frac{\pi}{1.6 \Delta T N_T} \end{aligned}$$

$$\begin{aligned}
 \left(\frac{U_{SF}}{SF} \right)^2 &= \left(\frac{\partial SF}{\partial \Delta T} \times \frac{U_{\Delta T}}{SF} \right)^2 + \left(\frac{\partial SF}{\partial N_T} \times \frac{U_{N_T}}{SF} \right)^2 \\
 &= \left(\frac{\pi U_{\Delta T}}{1.6 \Delta T^2 N_T} \times \frac{1.6 \Delta T N_T}{\pi} \right)^2 + \left(\frac{\pi U_{N_T}}{1.6 \Delta T N_T^2} \times \frac{1.6 \Delta T N_T}{\pi} \right)^2 \\
 &= \left(\frac{U_{\Delta T}}{\Delta T} \right)^2 + \left(\frac{U_{N_T}}{N_T} \right)^2 \\
 &= (2.88 \times 10^{-6})^2 + (0)^2 \\
 &= 3 \text{ parts/million RMS} \\
 &= 9 \text{ parts/million (3 Sigma)}
 \end{aligned}$$

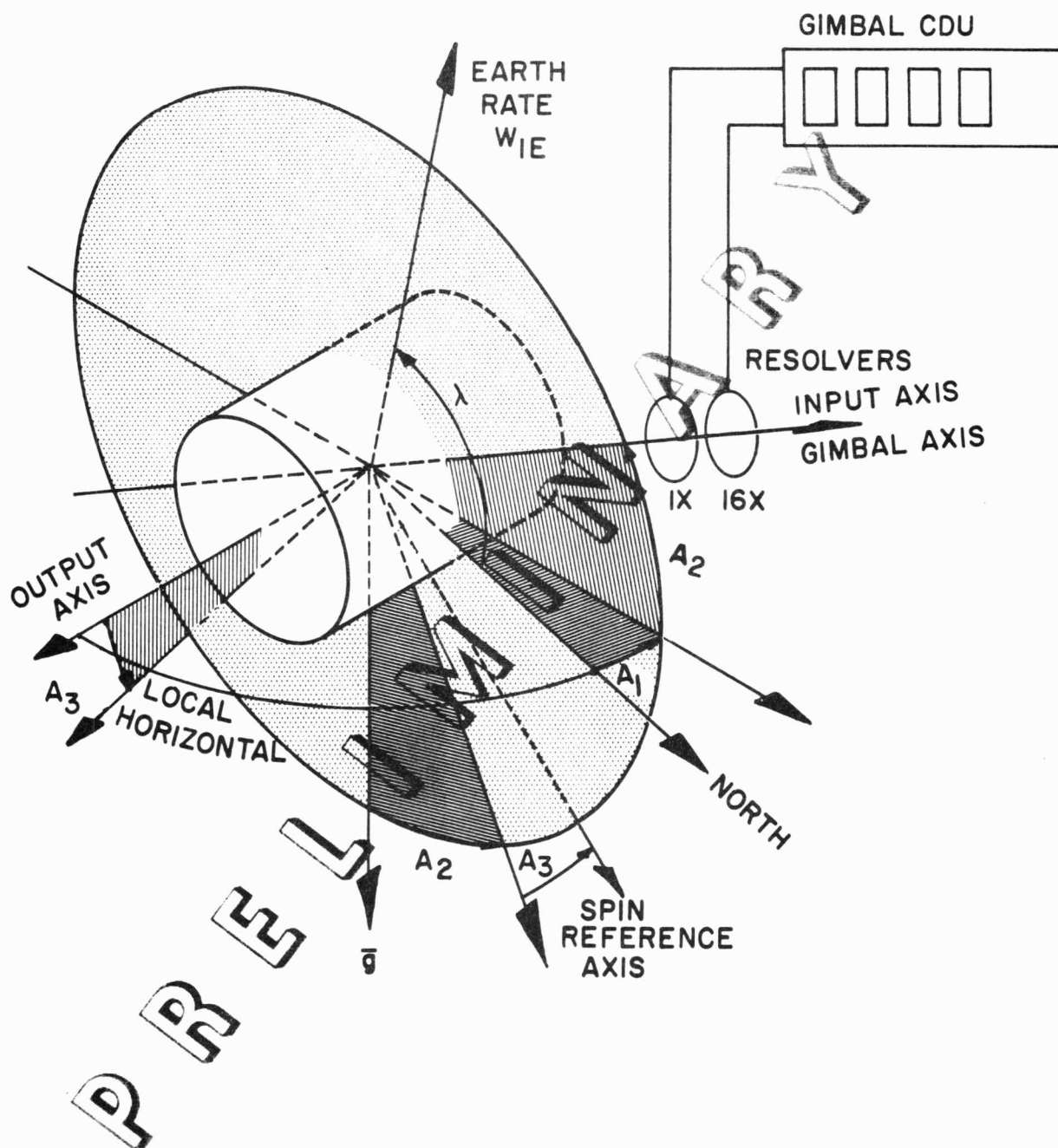


Figure III-1. ADSRA IRIG Calibration Geometry.

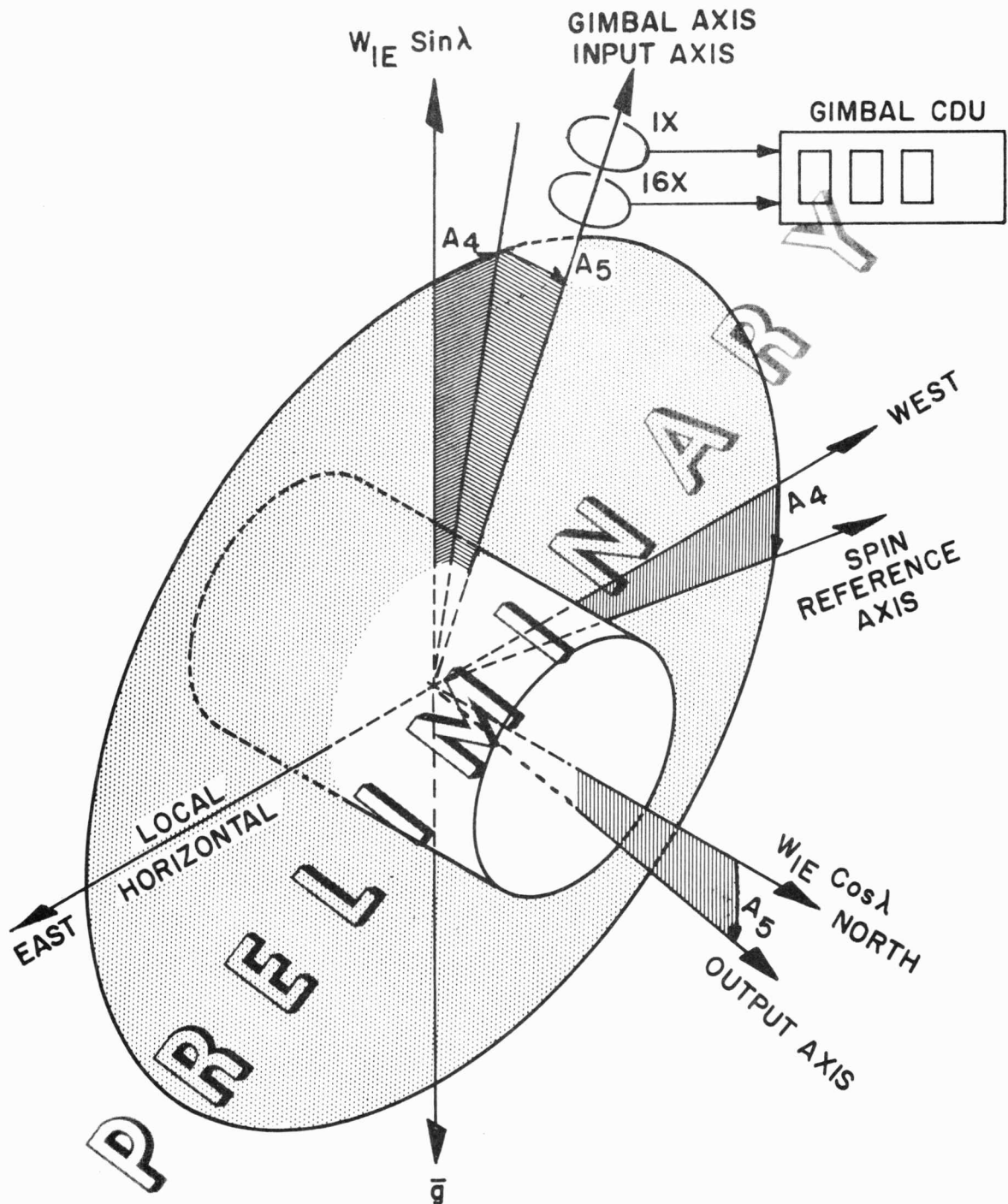


Figure III-2. ADIA IRIG Calibration Geometry.

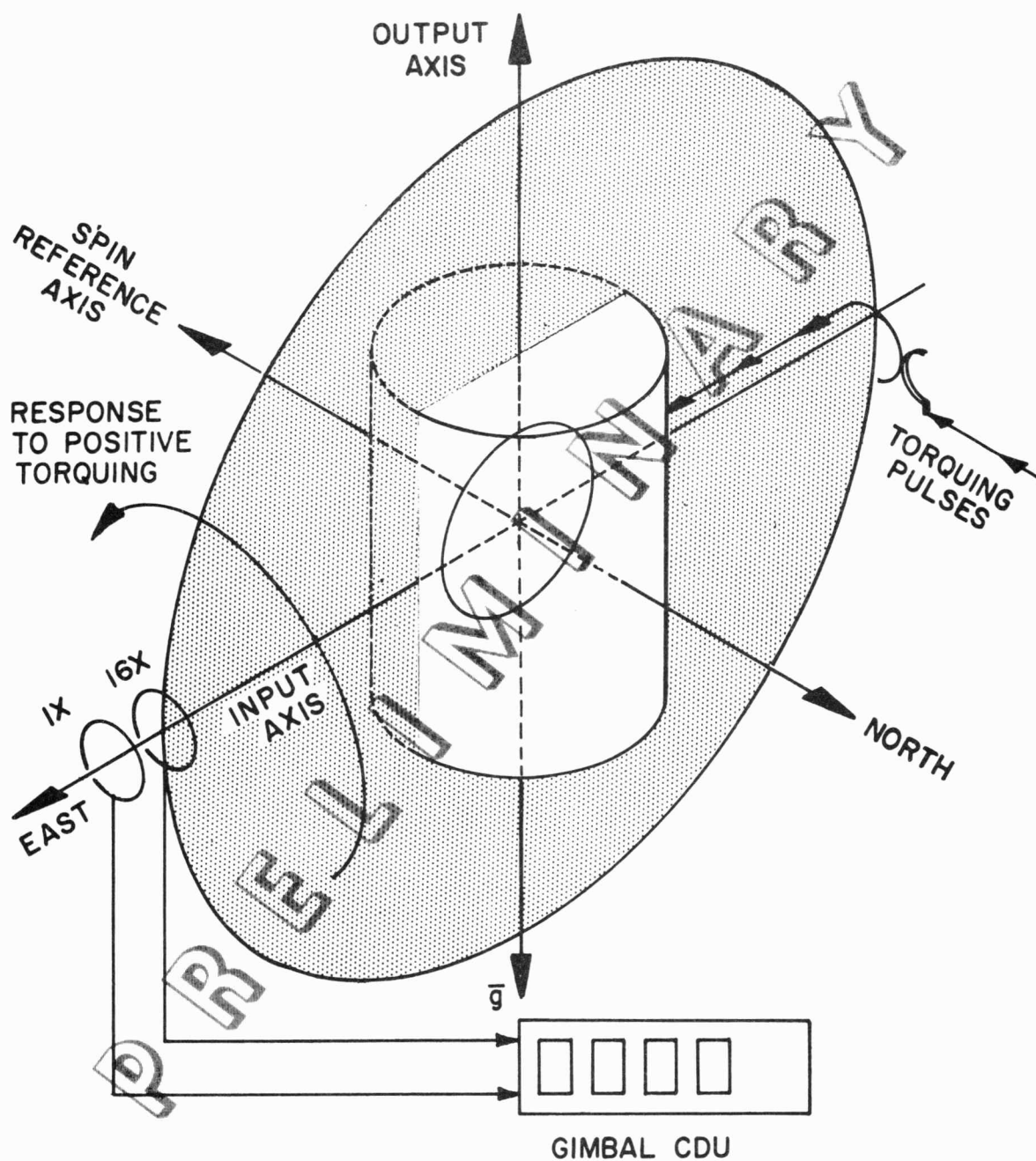


Figure III-3. SF(G) Calibration Geometry.

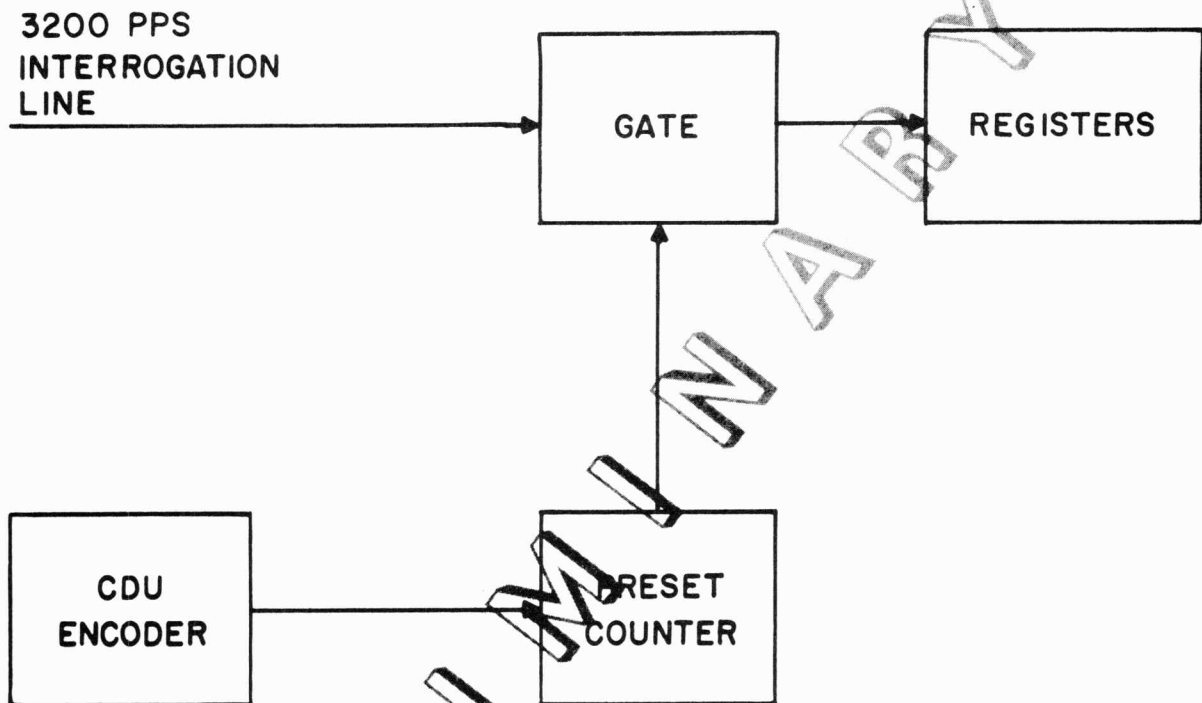


Figure III-4. IRIG Calibration Counter.

IV. JOB DESCRIPTION CARDS (JDC's)
FOR PIPA AND IRIG CALIBRATION TESTS
AND DATA SHEET FORMS

PRELIMINARY

A. PIPA CALIBRATION TESTS.

JDC 00200	Test to determine a_{B_x} and θ_{+1g_x}
JDC 00201	Test to determine positive $SF(A)_x$, negative $SF(A)_x$, and average $SF(A)_x$
JDC 00202	Test to determine a_{B_y} and θ_{+1g_y}
JDC 00203	Test to determine positive $SF(A)_y$, negative $SF(A)_y$, and average $SF(A)_y$
JDC 00204	Test to determine a_{B_z} and θ_{+1g_z}
JDC 00205	Test to determine positive $SF(A)_z$, negative $SF(A)_z$, and average $SF(A)_z$

PRELIMINARY

B. IRIG CALIBRATION TESTS.

JDC 00236	Test to determine BDX and ADSRAX
JDC 00237	Test to determine BDX and ADIAX
JDC 00238	Test to determine SFTGX
JDC 00239	Test to determine BDY and ADSRAY
JDC 00240	Test to determine BDY and ADIAY
JDC 00241	Test to determine SFTGY
JDC 00242	Test to determine BDZ and ADSRAZ
JDC 00243	Test to determine BDZ and ADIAZ
JDC 00244	Test to determine SFTGZ

PRELIMINARY

C. JDC DATA SHEET FORMS.

PIPA BIAS AND INPUT AXIS CALIBRATION TEST
DATA SHEET FORM E-1297 DS-1used with JDC 00200, JDC 00202, and
JDC 00204PIPA SCALE FACTOR CALIBRATION TEST
DATA SHEET FORM E-1297 DS-2used with JDC 00201, JDC 00203, and
JDC 00205IRIG CALIBRATION TEST
DATA SHEET FORM E-1297 DS-3

used with JDC 00236 through JDC 00244

JOB: X PIPA BIAS AND INPUT AXIS CALIBRATION

JDC 00200

Sheet 1 of 2

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine a_{θ_x} and θ_{1gx}

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

A. PREPARATION

Orientations required for first null measurement:

1. Gimbal Assembly

- a. Outer Gimbal Angle (A_{θ}) = Precision 0°
- b. Middle Gimbal Angle (A_{μ}) = Precision 0°
- c. Inner Gimbal Angle ($A_{1\theta}$) = Precision 0°

2. Test Table

- a. Tilt Angle (Φ)

Desired Angle Designation = Φ_{HRA}

Value of Φ_{HRA} obtained from JDC 00165 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-1.

- b. Initial Rotary Angle (θ)

Desired Angle Designation = $\theta_{HRA} - 180^\circ$

Value of θ_{HRA} obtained from JDC 00162 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-1.

B. PROCEDURE

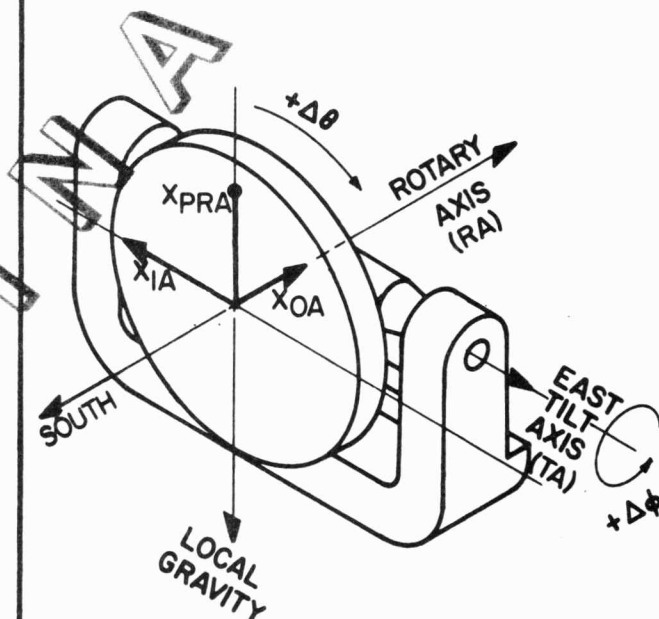
First Null Measurement

Rotate the table about the ROTARY AXIS until a null is obtained from the X PIP.

C. RECORD

Use Data Sheet Form E-1297 DS-1 to record:

Final Rotary Angle θ_{30}



JOB: X PIPA BIAS AND INPUT AXIS CALIBRATION

JDC 00200

Sheet 2 of 2

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine a_{B_x} and θ_{+1g_x}

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

D. PREPARATION

Orientations required for second null measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- Tilt Angle (Φ)

Remains unchanged from Step A. 2. a.

- Initial Rotary Angle (θ)

Desired Angle Designation = θ_{HGA}

Value of θ_{HGA} obtained from JDC 00162 Data Sheet Form E-1230 DS-1

NOTE: Record Value, Indicator Error and Readout Angle on Data Sheet Form E-1297 DS-1.

E. PROCEDURE

Second Null Measurement

Rotate the table about the ROTARY AXIS until a null is obtained from the X PIP.

F. RECORD

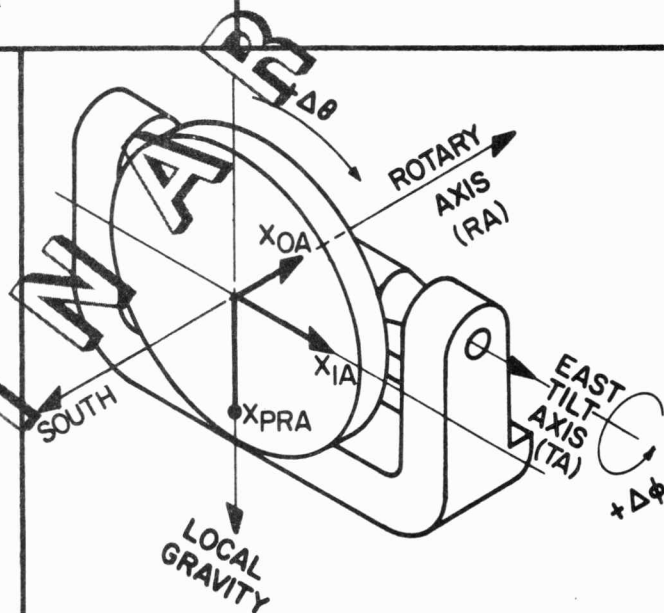
Use Data Sheet Form E-1297 DS-1 to record:

Final Rotary Angle θ_{31}

G. CALCULATIONS

Perform the following calculations using Data Sheet Form E-1297 DS-1.

$$\Delta\theta_{B_x} = \frac{\theta_{31} - \theta_{30} - 180^\circ}{2}$$



G. CALCULATIONS (continued)

$$a_{B_x} = g \Delta\theta_{B_x}$$

where g is obtained from E-Test Site Geodetic Data for APOLLO G & N, and where $\Delta\theta_{B_x}$ is converted from degrees, minutes and seconds to radian measure using U.S. Department of Commerce Spec. Pub. No. 231, Natural Sines and Cosines to Eight Decimal Places.

$$\theta_{+1g_x} = \frac{\theta_{31} + \theta_{30}}{2}$$

H. RECORDING

Record a_{B_x} on PIPA Data Sheet Form E-1297 DS-1, and hold for scale factor results.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine positive SF(A), negative SF(A), and average SF(A).

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00165 and JDC 00200 required to perform this job.

A. PREPARATION

Orientations required for first scale factor measurement:

1. Gimbal Assembly

- a. Outer Gimbal Angle (A_{OG}) = Precision 0°
- b. Middle Gimbal Angle (A_{MG}) = Precision 0°
- c. Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- a. Tilt Angle (Φ)

Desired Angle Designation = Φ_{PRA} Value of Φ_{PRA} obtained from JDC 00165 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-2.

- b. Rotary Angle (θ)

Desired Angle Designation = θ_{RA} Value of θ_{RA} obtained from JDC 00200 Data Sheet Form E-1297 DS-1.

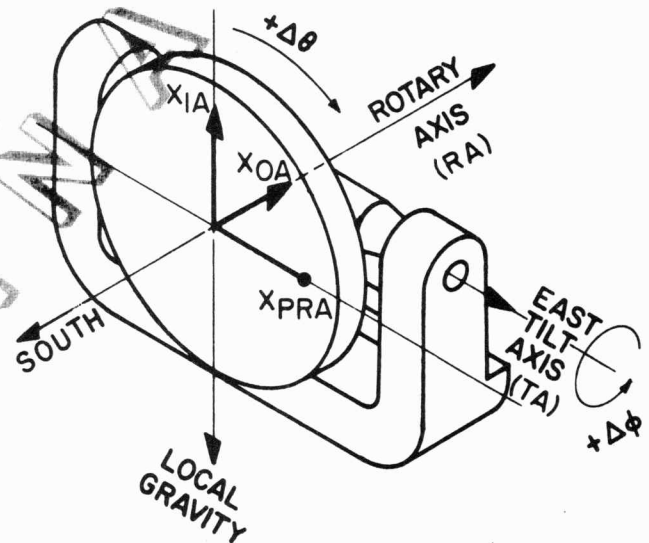
NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-2.

3. Counter

- a. Connect the 3200-pps output of the Computer Simulator to the input of the Forward - Backward Counter.
- b. Connect the positive ΔV output of the X PIPA Up-Down Counter of the PSA to the PRESET Counter. Enter the PRESET Count (N_A) of 50,000.

B. PROCEDURE

1. Start the count. When it is complete, read the accumulation in the Forward - Backward Counter; and record the accumulation as $N_{T_{X1}}$ on Data Sheet Form E-1297 DS-2.
2. Reset the counter, and repeat step 1 for $N_{T_{X2}}$.
3. Reset the counter, and repeat step 1 for $N_{T_{X3}}$.
4. Record IMU Temperature Deviation on Data Sheet Form E-1297 DS-2.



C. CALCULATIONS

Using Data Sheet Form E-1297 DS-2, average $N_{T_{X1}}$, $N_{T_{X2}}$, and $N_{T_{X3}}$. Record average as $N_{T_{X}}$ on Data Sheet Form E-1297 DS-2.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine positive $SF(A)_x$, negative $SF(A)_x$, and average $SF(A)_x$

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00165 and JDC 00200 required to perform this job.

D. PREPARATION

Orientations required for second scale factor measurement:

1. Gimbal Assembly

- a. Outer Gimbal Angle (A_{og}) = Precision 0°
- b. Middle Gimbal Angle (A_{mg}) = Precision 0°
- c. Inner Gimbal Angle (A_{ig}) = Precision 0°

2. Test Table

- a. Tilt Angle (Φ)

Remains unchanged from Step A. 2. a.

- b. Rotary Angle (θ)

Desired Angle Designation = $\theta_{igx} = \theta_{xigx} + 180^\circ$ Value of θ_{xigx} obtained from JDC 00200 Data Sheet Form E-1297 DS-1.

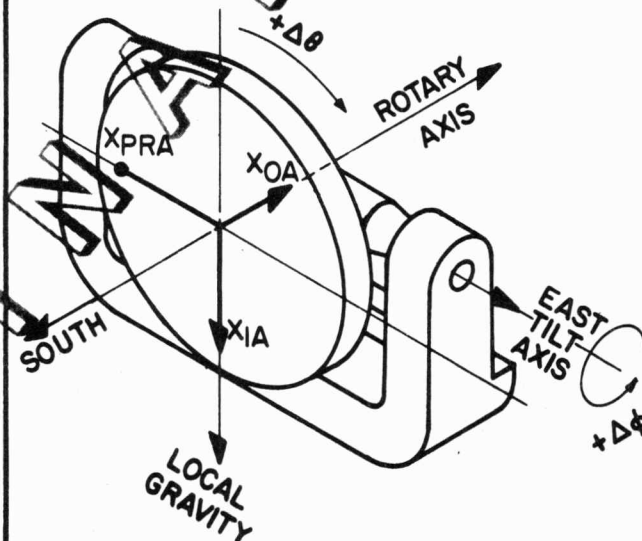
NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-2.

3. Counter

- a. Verify that the 3200-pps output of the Computer Simulator is connected to the input of the Forward - Backward Counter.
- b. Connect the negative ΔV output of the X PIPA Up-Down Counter of the PSA to the PRESET Counter. Enter the PRESET Count (N_A) of 50,000.

E. PROCEDURE

- 1. Start the count. When it is complete, read the accumulation in the Forward - Backward Counter; and record the accumulation as N_{x4} on Data Sheet Form E-1297 DS-2.
- 2. Reset the counter, and repeat step 1 for N_{x5} .
- 3. Reset the counter, and repeat step 1 for N_{x6} .
- 4. Record IMU Temperature Deviation on Data Sheet Form E-1297 DS-2.



F. CALCULATIONS

Using Data Sheet Form E-1297 DS-2, average N_{x4} , N_{x5} , and N_{x6} . Record average as N_{x-} on Data Sheet Form E-1297 DS-2.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine positive $SF(A)_x$, negative $SF(A)_x$, and average $SF(A)_x$ TYPE: Calibration
INTERVAL:TOOLS AND
MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00165 and JDC 00200 required to perform this job.

F. CALCULATIONS (continued)

Using Data Sheet Form E-1297 DS-2, compute:

$$\text{positive } SF(A)_x = \frac{g + a_{g_x}}{1.6 \times 10^8} \times N_{T_{+x}}$$

$$\text{negative } SF(A)_x = \frac{g - a_{g_x}}{1.6 \times 10^8} \times N_{T_{-x}}$$

$$\text{average } SF(A)_x = \frac{g}{1.6 \times 10^8} \times \frac{N_{T_{+x}} + N_{T_{-x}}}{2}$$

$$\Delta SF(A)_x = \frac{\text{positive } SF(A)_x - \text{negative } SF(A)_x}{\text{average } SF(A)_x} \times 10^4$$

Where a_{g_x} is obtained from JDC 00200 Data Sheet Form E-1297 DS-1, and where g is obtained from E-Test Site Geodetic Data for APOLLO G & N.

G. RECORDING

Record the test results on Data Sheet Form E-1297 DS-2 and on PIPA Data Sheet

Forward the

Data Sheet immediately to IMU Systems Group, 75 Cambridge Parkway, Cambridge 42, Mass., Attention: _____.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine a_{B_Y} and θ_{+1g_Y}

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

A. PREPARATION

Orientations required for first null measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Tablea. Tilt Angle (Φ)Desired Angle Designation = $\Phi_{H_{RA}}$

Value of $\Phi_{H_{RA}}$ obtained from JDC 00165 Data
Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator
Error, and Readout Angle on Data
Sheet Form E-1297 DS-1.

b. Initial Rotary Angle (θ)Desired Angle Designation = $\theta_{H_{OGA}} + 90^\circ$

Value of $\theta_{H_{OGA}}$ obtained from JDC 00162 Data
Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator
Error, and Readout Angle on Data
Sheet Form E-1297 DS-1.

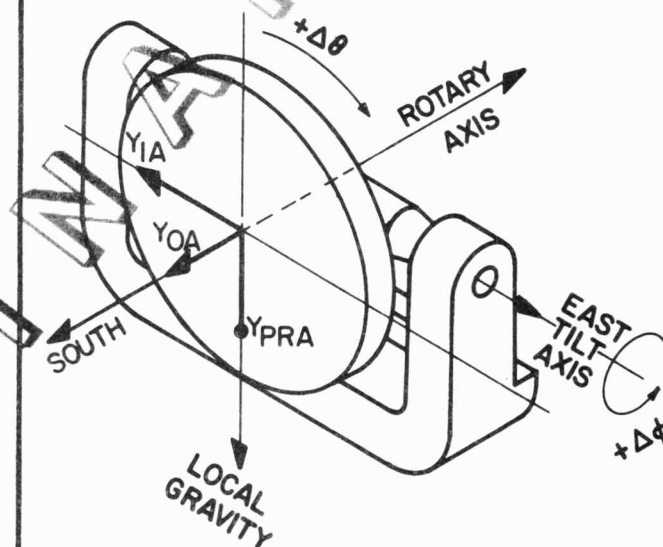
B. PROCEDURE

First Null Measurement

Rotate the table about the ROTARY AXIS until a null
is obtained from the Y PIP.

C. RECORD

Use Data Sheet Form E-1297 DS-1 to record:

Final Rotary Angle θ_{32} 

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine a_{B_Y} and θ_{+1g_Y}

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

D. PREPARATION

Orientations required for second null measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- Tilt Angle (Φ)

Remains unchanged from Step A. 2. a.

- Initial Rotary Angle (θ)

Desired Angle Designation = $\theta_{OGA} - 90^\circ$ Value of θ_{OGA} obtained from JDC 00162 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-1.

E. PROCEDURE

Second Null Measurement

Rotate the table about the ROTARY AXIS until a null is obtained from the Y PIP.

F. RECORD

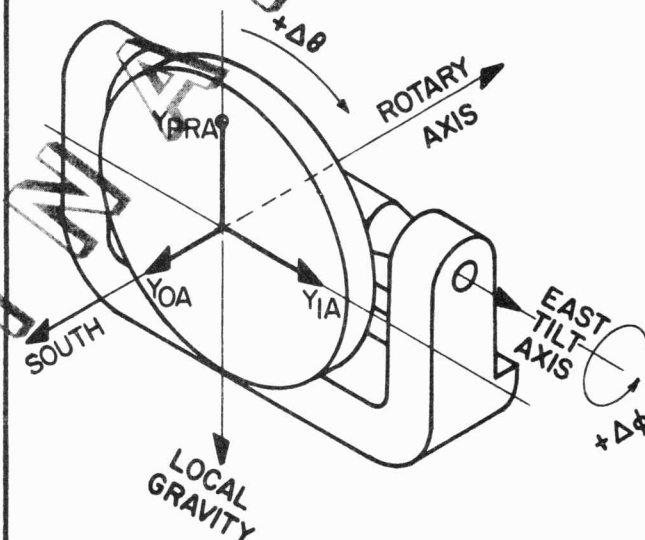
Use Data Sheet Form E-1297 DS-1 to record:

Final Rotary Angle θ_{33}

G. CALCULATIONS

Perform the following calculations using Data Sheet Form E-1297 DS-1.

$$\Delta\theta_{B_Y} = \frac{\theta_{33} - \theta_{32}}{2} + 180^\circ$$



G. CALCULATIONS (continued)

$$a_{B_Y} = g \Delta\theta_{B_Y}$$

where g is obtained from E-Test Site Geodetic Data for APOLLO G & N, and where $\Delta\theta_{B_Y}$ is converted from degrees, minutes, and seconds to radian measure using U.S. Department of Commerce Spec. Pub. No. 231, Natural Sines and Cosines to Eight Decimal Places.

$$\theta_{+1g_Y} = \frac{\theta_{33} + \theta_{32}}{2} - 180^\circ$$

H. RECORDING

Record a_{B_Y} on PIPA Data Sheet Form E-1297 DS-1, and hold for Scale Factor results.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine positive $SF(A)_Y$, negative $SF(A)_Y$, and average $SF(A)_Y$

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00165 and JDC 00202 required to perform this job.

A. PREPARATION

Orientations required for first scale factor measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

a. Tilt Angle (Φ)Desired Angle Designation = $\Phi_{H_{RA}}$ Value of $\Phi_{H_{RA}}$ obtained from JDC 00165 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-2.

b. Rotary Angle (θ)Desired Angle Designation = θ_{+1g_Y} Value of θ_{+1g_Y} obtained from JDC 00202

Data Sheet Form E-1297 DS-1.

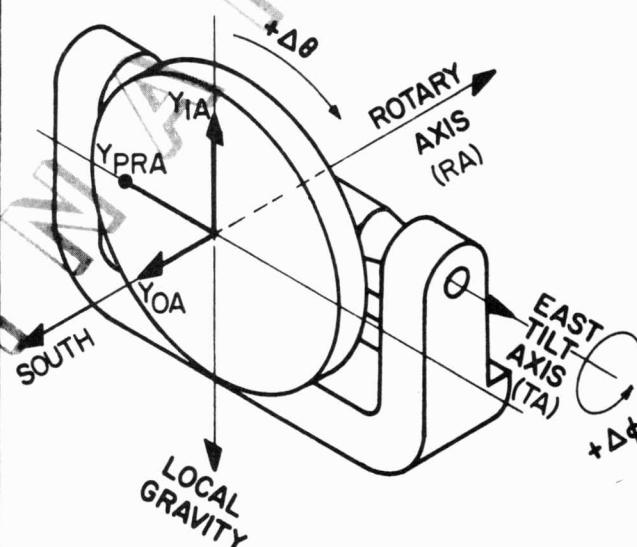
NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-2.

3. Counter

- Connect the 3200-pps output of the Computer Simulator to the input of the Forward - Backward Counter.
- Connect the positive ΔV output of the Y PIPA Up-Down Counter of the PSA to the PRESET Counter. Enter the PRESET Count (N_A) of 50,000.

B. PROCEDURE

- Start the count. When it is complete, read the accumulation in the Forward - Backward Counter, and record the accumulation as N_{Y_1} on Data Sheet Form E-1297 DS-2.
- Reset the counter, and repeat step 1 for N_{Y_2} .
- Reset the counter, and repeat step 1 for N_{Y_3} .
- Record IMU Temperature Deviation on Data Sheet Form E-1297 DS-2.



C. CALCULATIONS

Using Data Sheet Form E-1297 DS-2, average N_{Y_1} , N_{Y_2} , and N_{Y_3} . Record average as $N_{Y_{AV}}$ on Data Sheet Form E-1297 DS-2.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine positive SF(A)_v, negative SF(A)_v, and average SF(A)_v

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00165 and 00202 required to perform this job.

D. PREPARATION

Orientations required for second scale factor measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

a. Tilt Angle (Φ)

Remains unchanged from Step A. 2. a.

b. Rotary Angle (θ)Desired Angle Designation = $\theta_{-1gV} = \theta_{+1gV} + 180^\circ$ Value of θ_{+1gV} obtained from JDC 00202

Data Sheet Form E-1297 DS-1.

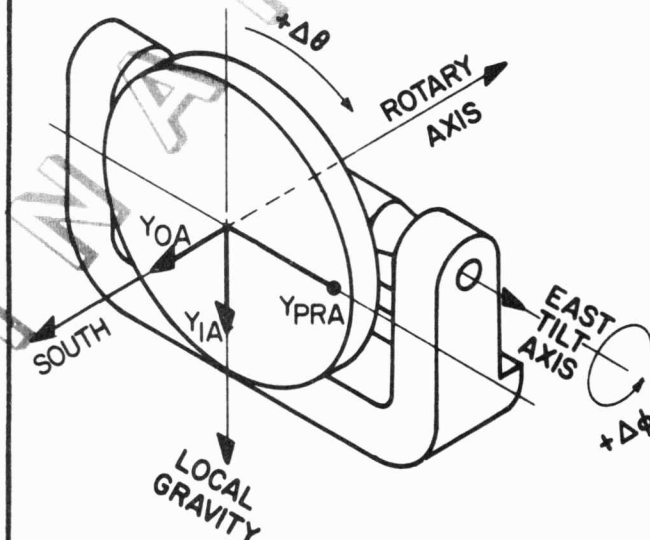
NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-2.

3. Counter

- Verify that the 3200-pps output of the Computer Simulator is connected to the input of the Forward - Backward Counter.
- Connect the negative ΔV output of the Y PIPA Up-Down Counter of the PSA to the PRESET Counter. Enter the PRESET Count (N_A) of 50,000.

E. PROCEDURE

- Start the count. When it is complete, read the accumulation in the Forward - Backward Counter; and record the accumulation as $N_{T_{V4}}$ on Data Sheet Form E-1297 DS-2.
- Reset the counter, and repeat step 1 for $N_{T_{V5}}$



E. PROCEDURE (continued)

- Reset the counter, and repeat step 1 for $N_{T_{V6}}$.
- Record IMU Temperature Deviation on Data Sheet Form E-1297 DS-2.

F. CALCULATIONS

Using Data Sheet Form E-1297 DS-2, average $N_{T_{V4}}$, $N_{T_{V5}}$, and $N_{T_{V6}}$. Record average as $N_{T_{V}}$ on Data Sheet Form E-1297 DS-2.

JOB: Y PIPA SCALE FACTOR CALIBRATION

JDC 00203

Sheet 3 of 3

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine positive SF(A)_y, negative SF(A)_y, and average SF(A)_y

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00165 and JDC 00202 required to perform this job.

F. CALCULATIONS (continued)

Using Data Sheet Form E-1297 DS-2, compute:

$$\text{positive SF(A)}_y = \frac{g + a_{b_y}}{1.6 \times 10^8} \times N_{T_{+y}}$$

$$\text{negative SF(A)}_y = \frac{g - a_{b_y}}{1.6 \times 10^8} \times N_{T_{-y}}$$

$$\text{average SF(A)}_y = \frac{g}{1.6 \times 10^8} \times \frac{N_{T_{+y}} + N_{T_{-y}}}{2}$$

$$\Delta \text{SF(A)}_y = \frac{\text{positive SF(A)}_y - \text{negative SF(A)}_y}{\text{average SF(A)}_y} \times 10^6$$

Where a_{b_y} is obtained from JDC 00202 Data Sheet Form E-1297 DS-1, and where g is obtained from E-

Test Site Geodetic Data for APOLLO G & N.

G. RECORDING

Record the test results on Data Sheet Form E-1297 DS-2 and on PIPA Data Sheet

Forward the

PIPA Data Sheet immediately to IMU Systems Group, 75 Cambridge Parkway, Cambridge 42, Mass., Attention: _____

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine a_{B_z} and θ_{+gz}

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

D. PREPARATION

Orientations required for second null measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 270°

2. Test Table

- Tilt Angle (Φ)

Remains unchanged from Step A. 2. a.

- Initial Rotary Angle (θ)

Desired Angle Designation = θ_{+OGA} Value of θ_{+OGA} obtained from JDC 00162

Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-1.

E. PROCEDURE

Second Null Measurement

Rotate the table about the ROTARY AXIS until a null is obtained from the Z PIP.

F. RECORD

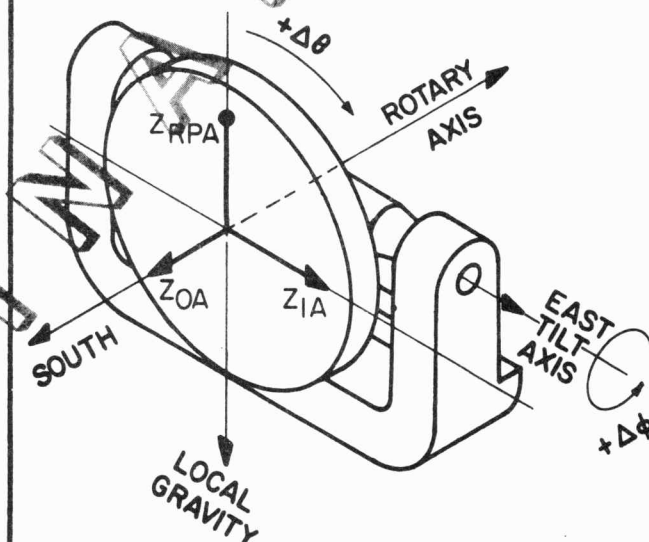
Use Data Sheet Form E-1297 DS-1 to record:

Final Rotary Angle θ_{35}

G. CALCULATIONS

Perform the following calculations using Data Sheet Form E-1297 DS-1:

$$\Delta\theta_{B_z} = \frac{\theta_{35} - \theta_{34} - 180^\circ}{2}$$



G. CALCULATIONS (continued)

$$a_{B_z} = g \Delta\theta_{B_z},$$

where g is obtained from E-
Test Site Geodetic Data for APOLLO G & N,
 and where $\Delta\theta_{B_z}$ is converted from degrees, minutes,
 and seconds to radian measure using U.S.
 Department of Commerce Spec. Pub. No. 231,
Natural Sines and Cosines to Eight Decimal
 Places.

$$\theta_{+gz} = \frac{\theta_{35} + \theta_{34}}{2}$$

H. RECORDING

Record a_{B_z} on PIPA Data Sheet Form E-1297 DS-1,
 and hold for Scale Factor results.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine positive $SF(A)_Z$, negative $SF(A)_Z$, and average $SF(A)_Z$

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00165 and JDC 00204 required to perform this job.

A. PREPARATION

Orientations required for first scale factor measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 270°

2. Test Tablea. Tilt Angle (Φ)Desired Angle Designation = Φ_{HRA} Value of Φ_{HRA} obtained from JDC 00165 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-2.

b. Rotary Angle (θ)Desired Angle Designation = θ_{+1gZ} Value of θ_{+1gZ} obtained from JDC 00204 Data Sheet Form E-1297 DS-1.

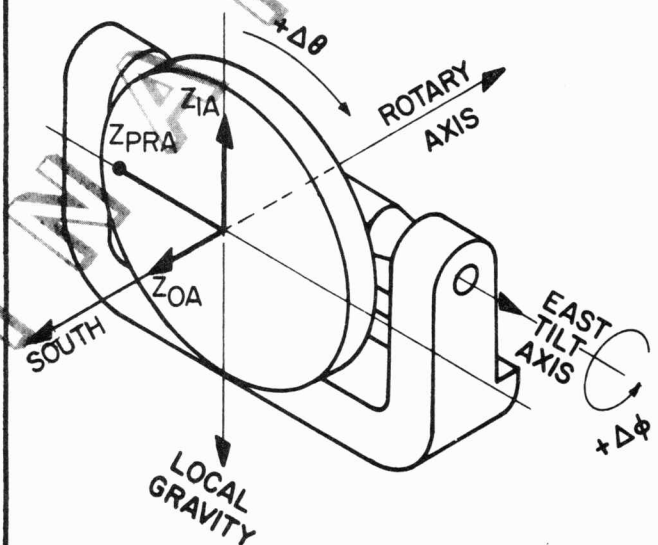
NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-2.

3. Counter

- Connect the 3200-pps output of the Computer Simulator to the input of the Forward - Backward Counter.
- Connect the positive ΔV output of the Z PIPA Up-Down Counter of the PSA to the PRESET Counter. Enter the PRESET Count (N_A) of 50,000.

B. PROCEDURE

- Start the count. When it is complete, read the accumulation in the Forward - Backward Counter; and record the accumulation as N_{T1} on Data Sheet Form E-1297 DS-2.
- Reset the counter, and repeat step 1 for N_{T2} .



B. PROCEDURE (continued)

- Reset the counter, and repeat step 1 for N_{T3} .
- Record IMU Temperature Deviation on Data Sheet Form E-1297 DS-2.

C. CALCULATIONS

Using Data Sheet Form E-1297 DS-2, average N_{T1} , N_{T2} , and N_{T3} . Record average as N_{Tz} on Data Sheet Form E-1297 DS-2.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine positive $SF(A)_Z$, negative $SF(A)_Z$, and average $SF(A)_Z$

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00165 and JDC 00204 required to perform this job.

D. PREPARATION

Orientations required for second scale factor measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 270°

2. Test Table

- Tilt Angle (Φ)

Remains unchanged from Step A. 2. a.

- Rotary Angle (θ)

Desired Angle Designation = $\theta_{-1gZ} = \theta_{-1gZ} + 180^\circ$ Value of θ_{-1gZ} obtained from JDC 00204

Data Sheet Form E-1297 DS-1.

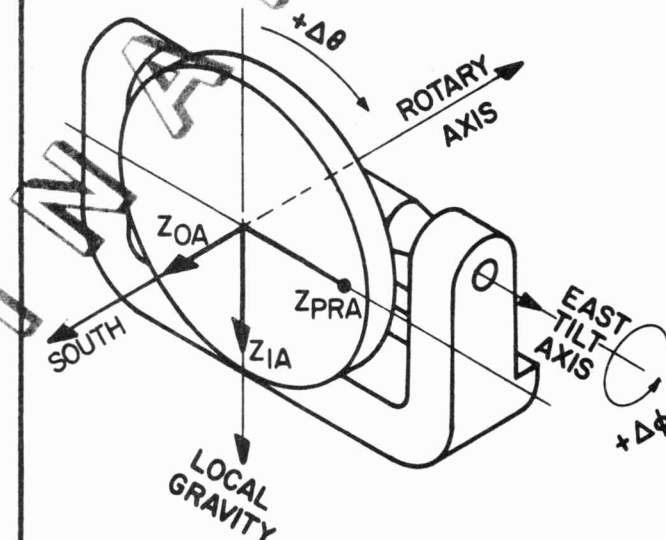
NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-2.

3. Counter

- Verify that the 3200-pps output of the Computer Simulator is connected to the input of the Forward - Backward Counter.
- Connect the negative ΔV output of the Z PIPA Up-Down Counter of the PSA to the PRESET Counter. Enter the PRESET Count (N_A) of 50,000.

E. PROCEDURE

- Start the count. When it is complete, read the accumulation in the Forward - Backward Counter; and record the accumulation as $N_{T_{24}}$ on Data Sheet Form E-1297 DS-2.
- Reset the counter, and repeat step 1 for $N_{T_{25}}$



E. PROCEDURE (continued)

- Reset the counter, and repeat step 1 for $N_{T_{26}}$
- Record IMU Temperature Deviation on Data Sheet Form E-1297 DS-2.

F. CALCULATIONS

Using Data Sheet Form E-1297 DS-2.

average $N_{T_{24}}$, $N_{T_{25}}$, and $N_{T_{26}}$. Record average as $N_{T_{27}}$ on Data Sheet Form E-1297 DS-2.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine positive $SF(A)_z$, negative $SF(A)_z$, and average $SF(A)_z$

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00165 and JDC 00204 required to perform this job.

F. CALCULATIONS (continued)

Using Data Sheet Form E-1297 DS-2, compute:

$$\text{positive } SF(A)_z = \frac{g + a_{e_z}}{1.6 \times 10^8} \times N_{T_{+z}}$$

$$\text{negative } SF(A)_z = \frac{g - a_{e_z}}{1.6 \times 10^8} \times N_{T_{-z}}$$

$$\text{average } SF(A)_z = \frac{g}{1.6 \times 10^8} \times \frac{N_{T_{+z}} + N_{T_{-z}}}{2}$$

$$\Delta SF(A)_z = \frac{\text{positive } SF(A)_z - \text{negative } SF(A)_z}{\text{average } SF(A)_z} \times 10^6$$

Where a_{e_z} is obtained from JDC 00204 Data Sheet Form E-1297 DS-2, and where g is obtained from E-Test Site Geodetic Data for APOLLO G & N.

G. RECORDING

Record the test results on Data Sheet Form E-1297 DS-2 and on PIPA Data Sheet

Forward the

PIPA Data Sheet immediately to IMU Systems Group, 75 Cambridge Parkway, Cambridge 42, Mass., Attention: _____

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine BDX and ADSRAX

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

A. PREPARATION

Orientations required for first drift measurement:

1. Gimbal Assembly

- a. Outer Gimbal Angle (A_{OG}) = Precision 0°
- b. Middle Gimbal Angle (A_{MG}) = Precision 0°
- c. Inner Gimbal Angle (A_{IG}) = Precision 90°

2. Test Table

- a. Initial Tilt Angle (Φ)

Desired Angle Designation = Φ_{RA} Value of Φ_{RA} obtained from JDC 00165 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

- b. Initial Rotary Angle (θ)

Desired Angle Designation = $\theta_{OGA} + 180^\circ$ Value of θ_{OGA} obtained from JDC 00162 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

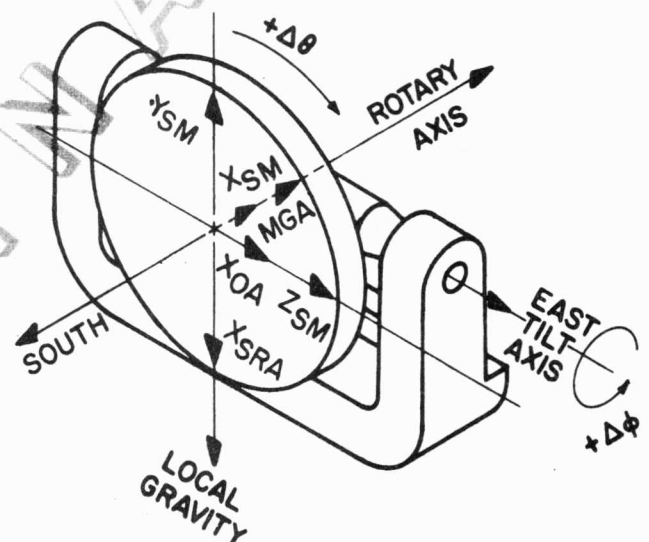
- a. Route the output of the Middle Gimbal CDU Encoder to the preset input of the counter. Set the preset value to 64 pulses. Route the 3200-pps output of the computer simulator to the gated input of the preset counter, and zero the register.
- b. Route the output of the X Gyro around the Inner Gimbal Resolver to the Middle Gimbal Stabilization Amplifier by pushing the "X unresolved to MG" Button.

B. PROCEDURE

First Drift Measurement

- 1. Null the X Gyro by torquing the Gyro from the negative float angle side with positive torque pulses.
- 2. Close the loop from the X Gyro to the Middle Gimbal; the other two loops will be held by their precision set loops.
- 3. Allow the Middle Gimbal to drift through one (1) CDU revolution (64 CDU Encoder pulses).

RECORD

Measure time count (N_t) of gimbal drift, and record results on Data Sheet Form E-1297 DS-3.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine BDX and ADSRAX

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

D. PREPARATION

Orientations required for second drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 90°

2. Test Table

- Initial Tilt Angle (Φ)

Remains unchanged from Step A. 2. a.

- Initial Rotary Angle (θ)

Desired Angle Designation = $\theta_{H_{OGA}}$ Value of $\theta_{H_{OGA}}$ obtained from JDC 00162 Data Sheet

Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

Confirm that the counter register is zeroed and that the X Gyro output is still routed to the Middle Gimbal Stabilization Amplifier.

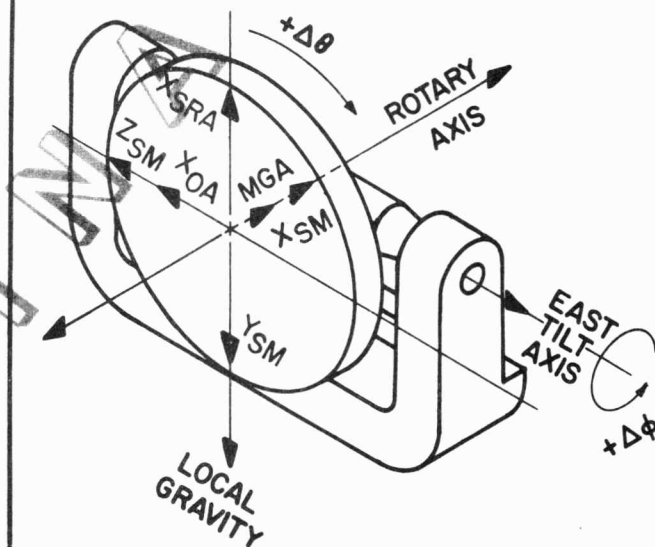
E. PROCEDURE

Second Drift Measurement

- Null the X Gyro by torquing the Gyro from the negative float angle side with positive torque pulses.
- Close the loop from the X Gyro to the Middle Gimbal; the other two loops will be held by their precision set loops.
- Allow the Middle Gimbal to drift through one (1) CDU revolution (64 CDU Encoder pulses).

F. RECORD

Measure time count (N_{T_2}) of gimbal drift, and record results on Data Sheet Form E-1297 DS-3.



G. CALCULATIONS

Perform the following calculations on Data Sheet Form E-1297 DS-3:

$$BDX = \left(\frac{2.6927 \times 10^8}{N_{T_1}} + \frac{2.6927 \times 10^8}{N_{T_2}} - 1000 \cos \lambda \right) \text{ Meru}$$

Where λ is obtained from E_____, Test Site Geodetic Data for Apollo G & N.

$$ADSRAX = \left(\frac{2.6927 \times 10^8}{N_{T_2}} - \frac{2.6927 \times 10^8}{N_{T_1}} \right) \text{ Meru}$$

H. RECORDING

Record the test results on IRIG Data Sheet Form_____.

Forward a copy of the Data Sheet to IMU Systems Group, 75 Cambridge Parkway, Cambridge 42, Mass., Attention_____.

JOB: X IRIG CALIBRATION TEST

JDC 00237

Sheet 1 of 2

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine BD_X and ADI_{AX}

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

A. PREPARATION

Orientations required for third drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- Initial Tilt Angle (Φ)

Desired Angle Designation = $\Phi_{H_{RA}}$

Value of $\Phi_{H_{RA}}$ obtained from JDC 00165 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

- Initial Rotary Angle (θ)

Desired Angle Designation = $\theta_{H_{OGA}} - 90^\circ$

Value of $\theta_{H_{OGA}}$ obtained from JDC 00162 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

- Route the output of the Outer Gimbal CDU Encoder to the preset input of the counter. Set the preset value to 64 pulses. Route the 3200-pps output of the computer simulator to the gated input of the preset counter, and zero the register.
- Route the output of the X Gyro around the Inner Gimbal Resolver to the Outer Gimbal Stabilization Amplifier by pushing the "X unresolved to OG" Button.

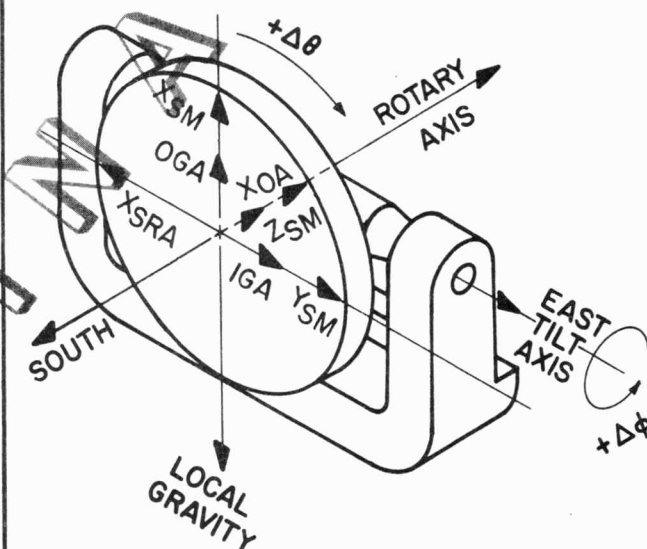
PROCEDURE

Third Drift Measurement

- Null the X Gyro by torquing the Gyro from the negative float angle side with positive torque pulses.
- Close the loop from the X Gyro to the Outer Gimbal; the other two loops will be held by their precision set loops.
- Allow the Middle Gimbal to drift through one (1) CDU revolution (64 CDU Encoder pulses).

RECORD

Measure time count (N_{T_3}) of gimbal drift, and record results on Data Sheet Form E-1297 DS-3.



SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine BDX and ADIAX

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

D. PREPARATION

Orientations required for fourth drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- Initial Tilt Angle (Φ)

Remains unchanged from Step A. 2. a.

- Initial Rotary Angle (θ)

Desired Angle Designation = $\theta_{OGA} + 90^\circ$ Value of θ_{OGA} obtained from JDC 00162 Data Sheet

Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

Confirm that the counter register is zeroed and that the X Gyro output is still routed to the Outer Gimbal Stabilization Amplifier.

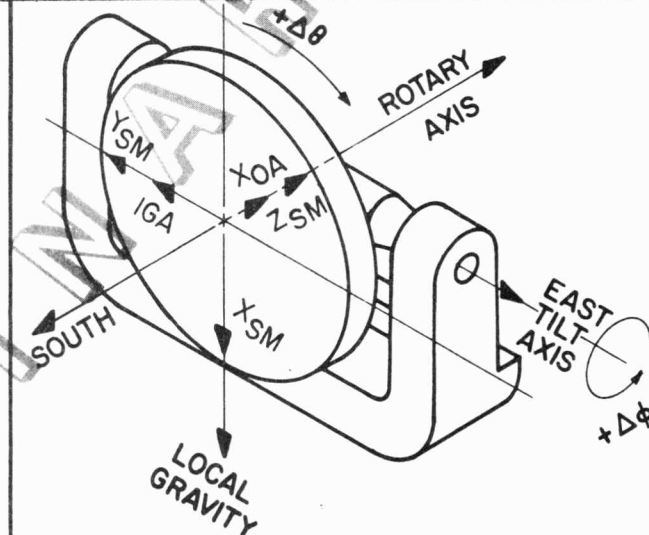
E. PROCEDURE

Fourth Drift Measurement

- Null the X Gyro by torquing the Gyro from the negative float angle side with positive torque pulses.
- Close the loop from the X Gyro to the Outer Gimbal; the other two loops will be held by their precision set loops.
- Allow the Middle Gimbal to drift through one (1) CDU revolution (64 CDU Encoder pulses).

F. RECORD

Measure time count (N_4) of gimbal drift, and record results on Data Sheet Form E-1297 DS-3.



G. CALCULATIONS

Perform the following calculations on Data Sheet Form E-1297 DS-3:

$$BDX = \left(\frac{2.6927 \times 10^5}{N_3} + \frac{2.6927 \times 10^5}{N_4} \right) \text{ Meru}$$

$$ADIAX = \left(\frac{2.6927 \times 10^5}{N_3} - \frac{2.6927 \times 10^5}{N_4} - 1000 \sin \lambda \right) \text{ Meru}$$

Where λ is obtained from E____, Test Site Geodetic Data for Apollo G & N.

H. RECORDING

Record the test results on IRIG Data Sheet Form_____.

Forward a copy of the Data Sheet to IMU Systems Group, 75 Cambridge Parkway, Cambridge 42, Mass., Attention_____.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine SFTGX

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC.00165 required to perform this job.

A. PREPARATION

Orientations required for fifth drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 270°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- Initial Tilt Angle (Φ)

Desired Angle Designation = Φ_{RA}

Value of Φ_{RA} obtained from JDC 00165 Data Sheet
Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout
Angle on Data Sheet Form E-1297 DS-3.

- Initial Rotary Angle (θ)

Desired Angle Designation = θ_{OG}

Value of θ_{OG} obtained from JDC 00162 Data Sheet
Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and
Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

- Route the output of the Outer Gimbal CDU Encoder to the preset input of the counter. Set the preset value to 32,768 pulses. Add the 3200-pps Gyro command output of the computer simulator to the gated input of the preset counter, and zero the register.
- Route the output of the X Gyro around the Inner Gimbal Resolver to the Outer Gimbal Stabilization Amplifier by pushing the "X unresolved to OG" Button.

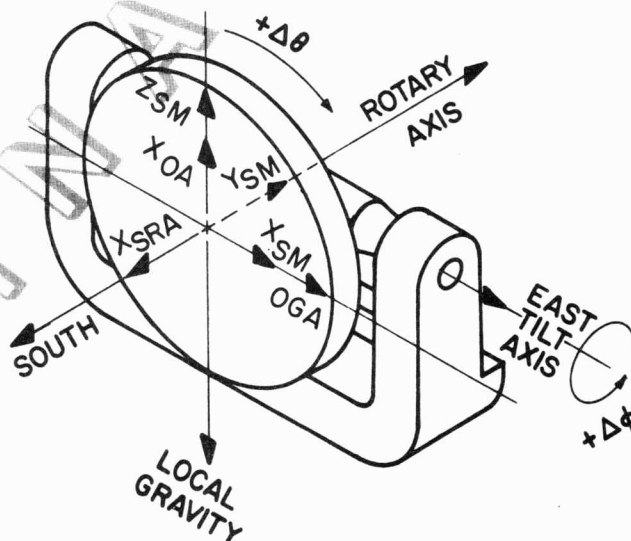
B. PROCEDURE

Fifth Drift Measurement

- Torque the X Gyro to null and normalize the Gyro bias.
- Close the loop from the X Gyro to the Outer Gimbal; the other two loops will be held by their respective CDU's.
- Torque the X Gyro with positive pulses at 3200 pulses/second.

C. RECORD

Measure command count (N_T) for one (1) gimbal revolution (512 revolutions of the CDU; 32,768 pulses from the CDU Encoder), and record results on Data Sheet Form E-1297 DS-3.



SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine SFTGX

TYPE: Calibration
INTERVAL:TOOLS AND
MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165
required to perform this job.

D. PREPARATION

Orientations required for sixth drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OZ}) = Precision 270°
- Middle Gimbal Angle (A_{MZ}) = Precision 0°
- Inner Gimbal Angle (A_{IZ}) = Precision 0°

2. Test Table

- Initial Tilt Angle (Φ)
Remains unchanged from Step A.2.a.
- Initial Rotary Angle (θ)
Remains unchanged from Step A.2.b.

3. Ground Support Equipment

- Confirm that the Outer Gimbal CDU Encoder is routed to the preset input of the counter; that the preset count is 32,768 pulses; that the 3200-pps Gyro command of the computer simulator is added to the gated input of the preset counter; and that the register is zero.
- Confirm that the X Gyro output has been routed around the Inner Gimbal Resolver to the Outer Gimbal Stabilization Amplifier.

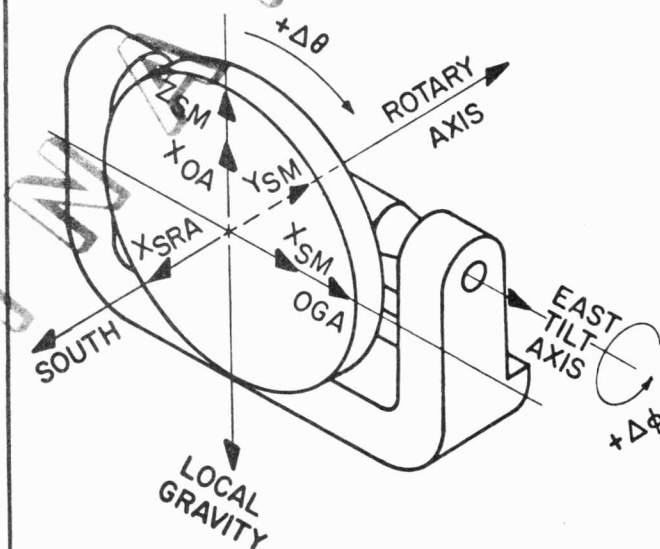
E. PROCEDURE

Sixth Drift Measurement

- Torque the X Gyro to null and normalize the Gyro bias.
- Close the loop from X Gyro to the Outer Gimbal; the other two loops will be held by their respective CDU's.
- Torque the X Gyro with negative pulses at 3200 pulses/second.

F. RECORD

Measure command count (N_{T_0}) for one (1) gimbal revolution (512 revolutions of the CDU; 32,768 pulses from the CDU Encoder), and record results on Data Sheet Form E-1297 DS-3.



G. CALCULATIONS

Perform the following calculations on Data Sheet Form E-1297 DS-3:

$$SF(G) = \frac{3141.59}{N_{T_0}} \cdot \frac{3141.59}{N_{T_1}}$$

H. RECORDING

Record the test results on IRIG Data Sheet Form _____.

Forward a copy of the Data Sheet to IMU Systems Group, 75 Cambridge Parkway, Cambridge 42, Mass., Attention _____.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine BDY and ADSRAY

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

A. PREPARATION

Orientations required for first drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 180°

2. Test Tablea. Initial Tilt Angle (Φ)Desired Angle Designation = $\Phi_{H_{RA}} - 90^\circ$ Value of $\Phi_{H_{RA}}$ obtained from JDC 00165 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

b. Initial Rotary Angle (θ)Desired Angle Designation = $\theta_{OGA} + 180^\circ$ Value of θ_{OGA} obtained from JDC 00162 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

Route the output of the Inner Gimbal CDU Encoder to the preset input of the counter. Set the preset value to 64 pulses. Route the 3200-pps output of the computer simulator to the gated input of the preset counter, and zero the register.

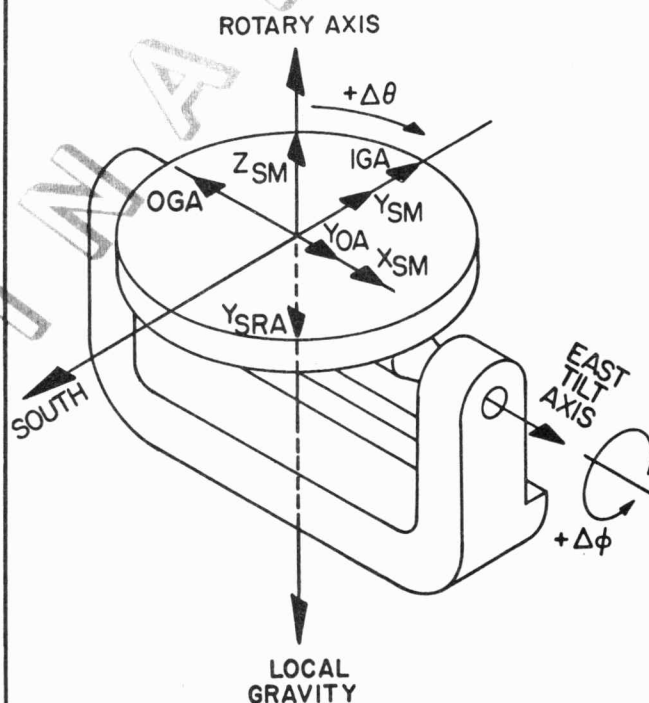
B. PROCEDURE

First Drift Measurement

- Torque the Y Gyro to null and normalize the Gyro bias.
- Close the loop from the Y Gyro to the Inner Gimbal; the other two loops will be held by their respective CDU's.
- Allow the Inner Gimbal to drift through one (1) CDU revolution (64 CDU Encoder pulses).

RECORD

Measure time count (N_1) of gimbal drift, and record results on Data Sheet Form E-1297 DS-3.



SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine BDY and ADSRAY

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

D. PREPARATION

Orientations required for second drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- Initial Tilt Angle (Φ)
Remains unchanged from Step A. 2. a.
- Initial Rotary Angle (θ)
Remains unchanged from Step A. 2. b.

3. Ground Support Equipment

Confirm that the counter register is zeroed.

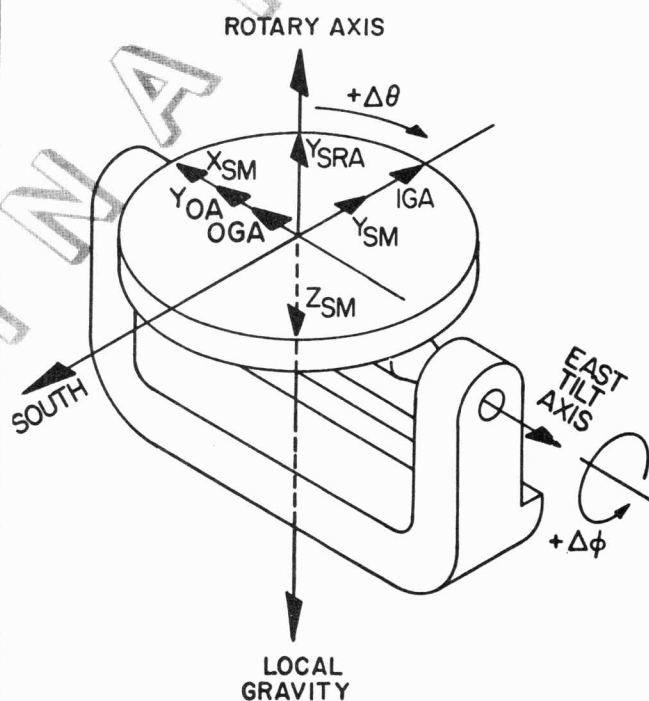
E. PROCEDURE

Second Drift Measurement

- Torque the Y Gyro to null and normalize the Gyro bias.
- Close the loop from the Y Gyro to the Inner Gimbal; the other two loops will be held by their respective CDU's.
- Allow the Inner Gimbal to drift through one (1) CDU revolution (64 CDU Encoder pulses).

F. RECORD

Measure time count (N_{T_2}) of gimbal drift, and record results on Data Sheet Form E-1297 DS-3.



G. CALCULATIONS

Perform the following calculations on Data Sheet Form E-1297 DS-3:

$$BDY = \left(\frac{2.6927 \times 10^8}{N_{T_1}} + \frac{2.6927 \times 10^8}{N_{T_2}} - 1000 \cos \lambda \right) \text{ Meru}$$

Where λ is obtained from E_____, Test Site Geodetic Data for Apollo G & N.

$$ADSRAY = \left(\frac{2.6927 \times 10^8}{N_{T_2}} - \frac{2.6927 \times 10^8}{N_{T_1}} \right) \text{ Meru}$$

H. RECORDING

Record the test results on IRIG Data Sheet Form_____.

Forward a copy of the Data Sheet to IMU Systems Group, 75 Cambridge Parkway, Cambridge 42, Mass., Attention_____.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine BDY and ADIAY

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

A. PREPARATION

Orientations required for third drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- Initial Tilt Angle (Φ)

Desired Angle Designation = Φ_{RA} Value of Φ_{RA} obtained from JDC 00165 Data

Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

- Initial Rotary Angle (θ)

Desired Angle Designation = $\theta_{OGA} + 180^\circ$ Value of θ_{OGA} obtained from JDC 00162 Data

Sheet Form E-1230 DS-1

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

Route the output of the Inner Gimbal CDU Encoder to the preset input of the counter. Set the preset value to 64 pulses. Route the 3200-pps output of the computer simulator to the gated input of the preset counter, and zero the register.

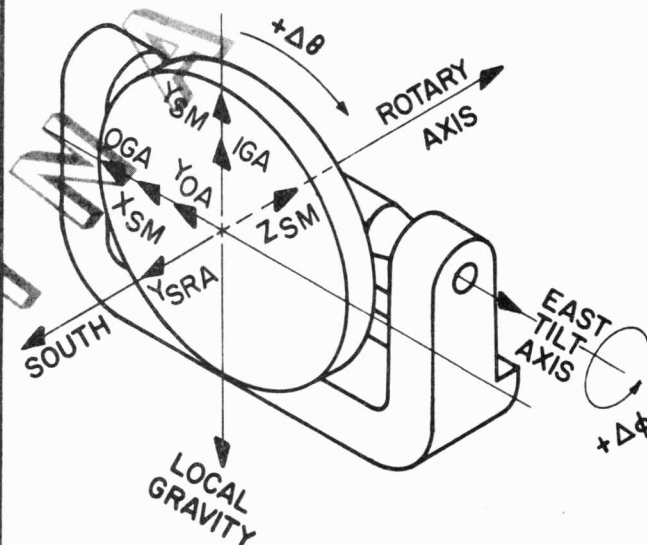
B. PROCEDURE

First Drift Measurement

- Torque the Y Gyro to null and normalize the Gyro bias.
- Close the loop from the Y Gyro to the Inner Gimbal; the other two loops will be held by their respective CDU's.
- Allow the Inner Gimbal to drift through one (1) CDU revolution (64 Encoder pulses).

C. RECORD

Measure time count (N_{τ}) of gimbal drift, and record results on Data Sheet Form E-1297 DS-3.



JOB: Y IRIG CALIBRATION TEST

JDC 00240

Sheet 2 of 2

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine BDY and ADIAY

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

D. PREPARATION

Orientations required for fourth drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- Initial Tilt Angle (Φ)

Remains unchanged from Step A. 2. a.

- Initial Rotary Angle (θ)

Desired Angle Designation = θ_{IGA}

Value of θ_{IGA} obtained from JDC 00162 Data Sheet

Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

Confirm that the counter register is zeroed.

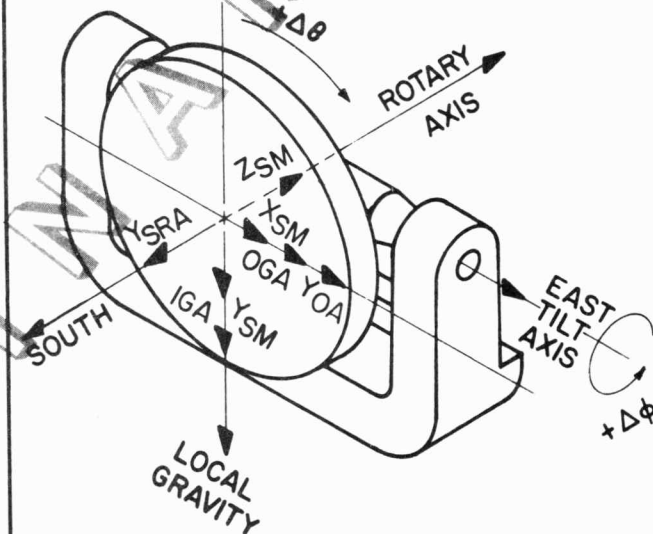
E. PROCEDURE

Fourth Drift Measurement

- Torque the Y Gyro to null and normalize the Gyro bias.
- Close the loop from the Y Gyro to the Inner Gimbal; the other two loops will be held by their respective CDU's.
- Allow the Inner Gimbal to drift through one (1) CDU revolution (64 CDU Encoder pulses).

F. RECORD

Measure time count (N_4) of gimbal drift, and record results on Data Sheet Form E-1297 DS-3.



G. CALCULATIONS

Perform the following calculations on Data Sheet Form E-1297 DS-3:

$$BDY = \left(\frac{2.6927 \times 10^5}{N_{13}} + \frac{2.6927 \times 10^5}{N_{14}} \right) \text{ Meru}$$

Where λ is obtained from E____, Test Site Geodetic Data for Apollo G & N.

$$ADIAY = \left(\frac{2.6927 \times 10^5}{N_{13}} - \frac{2.6927 \times 10^5}{N_{14}} - 1000 \sin \lambda \right) \text{ Meru}$$

H. RECORDING

Record the test results on IRIG Data Sheet Form_____.

Forward a copy of the Data Sheet to IMU Systems Group, 75 Cambridge Parkway, Cambridge 42, Mass., Attention_____.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine SFTGY

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

PREPARATION

Orientations required for fifth drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Tablea. Initial Tilt Angle (Φ)Desired Angle Designation = $\Phi_{i,RA}$ Value of $\Phi_{i,RA}$ obtained from JDC 00165 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

b. Initial Rotary Angle (θ)Desired Angle Designation = $\theta_{i,OGA} + 90^\circ$ Value of $\theta_{i,OGA}$ obtained from JDC 00162 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

Route the output of the inner Gimbal CDU Encoder to the preset input of the counter. Set the preset value to 32,768 pulses. Add the 3200-pps gyro command output of the computer simulator to the gated input of the preset counter, and zero the register.

B. PROCEDURE

Fifth Drift Measurement

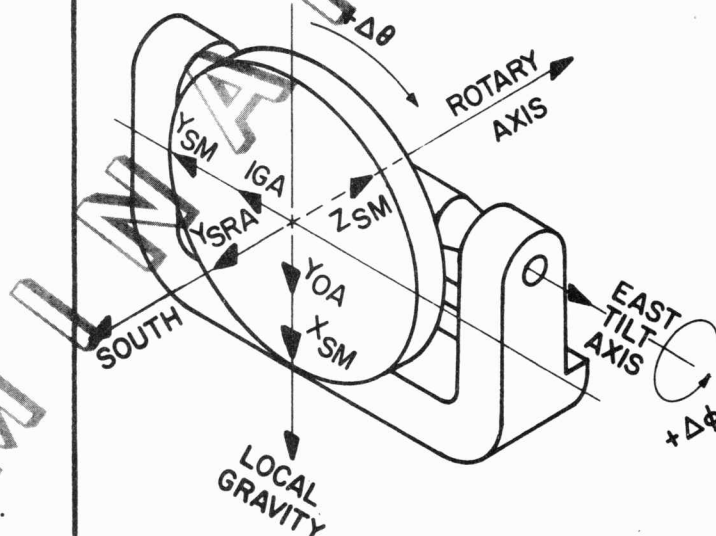
- Torque the Y Gyro to null and normalize the Gyro bias.
- Close the loop from the Y Gyro to the Inner Gimbal; the other two loops will be held by their respective CDU's.
- Torque the Y Gyro with positive pulses at 3200 pulses/second.

C. RECORD

Measure command count (N_r) for one (1) gimbal revolution

(512 revolutions of the CDU; 32,768 pulses from the CDU

Encoder), and record results on Data Sheet Form E-1297 DS-3.



JOB: Z IRIG CALIBRATION TEST**JDC** 00242

Sheet 2 of 2

SUBSYSTEM: INERTIAL MEASUREMENT UNIT**SYSTEM:** AGE/**DESCRIPTION:** Test to determine BDZ and ADSRAZ**TYPE:** Calibration**INTERVAL:****TOOLS AND MATERIAL:****REFERENCES:****IMPORTANT:** Results from JDC 00162 and JDC 00165 required to perform this job.**D. PREPARATION**

Orientations required for second drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- Initial Tilt Angle (Φ)

Remains unchanged from Step A. 2. a.

- Initial Rotary Angle (θ)

Desired Angle Designation = $\theta_{OGA} + 180^\circ$ Value of θ_{OGA} obtained from JDC 00162 Data Sheet

Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

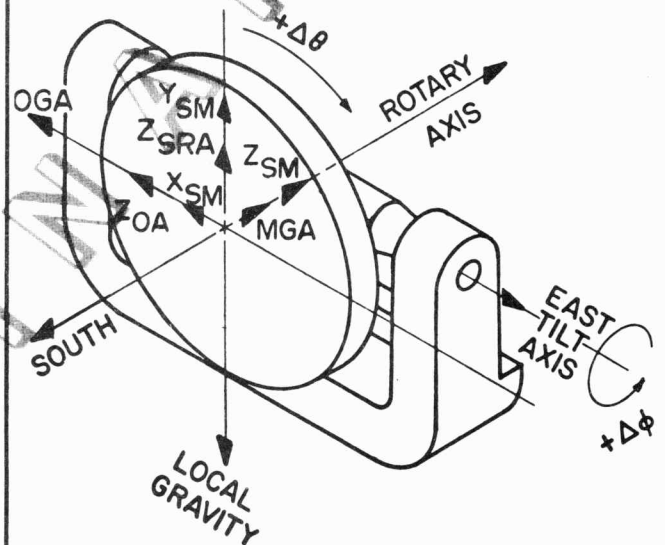
Confirm that the counter register is zeroed and that the Z Gyro output is still routed to the Middle Gimbal Stabilization Amplifier.

E. PROCEDURESecond Drift Measurement

- Torque the Z Gyro to null and normalize the Gyro bias.
- Close the loop from the Z Gyro to the Middle Gimbal; the other two loops will be held by their respective CDU's.
- Allow the Middle Gimbal to drift through one (1) CDU revolution (64 CDU Encoder pulses).

F. RECORD

Measure time count (N_{T_2}) of gimbal drift, and record results on Data Sheet Form E-1297 DS-3.

**G. CALCULATIONS**

Perform the following calculations on Data Sheet Form E-1297 DS-3:

$$BDZ = \left(\frac{2.6927 \times 10^5}{N_{T_1}} + \frac{2.6927 \times 10^5}{N_{T_2}} - 1000 \cos \lambda \right) \text{ Meru}$$

Where λ is obtained from E_____, Test Site Geodetic Data for Apollo G & N.

$$ADSRAZ = \left(\frac{2.6927 \times 10^5}{N_{T_2}} - \frac{2.6927 \times 10^5}{N_{T_1}} \right) \text{ Meru}$$

H. RECORDING

Record the test results on IRIG Data Sheet Form_____.

Forward a copy of the Data Sheet to IMU Systems Group, 75 Cambridge Parkway, Cambridge 42, Mass., Attention_____.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine BDZ and ADIAZ

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

A. PREPARATION

Orientations required for third drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 180°

2. Test Tablea. Initial Tilt Angle (Φ)Desired Angle Designation = $\Phi_{RA} - 90^\circ$ Value of Φ_{RA} obtained from JDC 00165 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

b. Initial Rotary Angle (θ)Desired Angle Designation = θ_{OGA} Value of θ_{OGA} obtained from JDC 00162 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

- Route the output of the Middle Gimbal CDU Encoder to the preset input of the counter. Set the preset value to 64 pulses. Route the 3200-pps output of the computer simulator to the gated input of the preset counter, and zero the register.
- Route the output of the Z Gyro around the Inner Gimbal Resolver to the Middle Gimbal Stabilization Amplifier with reversed phasing by pushing the "Reverse Z Unresolved to MG" Button.

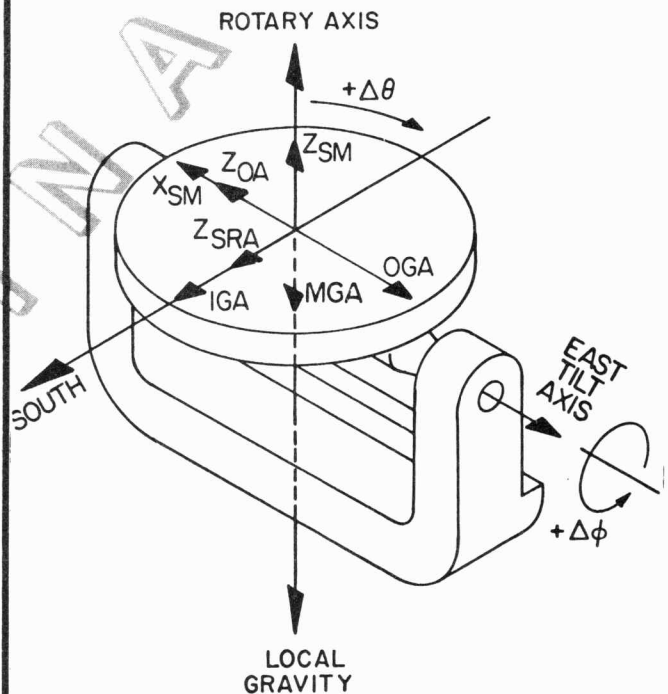
B. PROCEDURE

Third Drift Measurement

- Torque the Z Gyro to null and normalize the Gyro bias.
- Close the loop from the Z Gyro to the Middle Gimbal; the other two loops will be held by their respective CDU's.
- Allow the Middle Gimbal to drift through one (1) CDU revolution (64 CDU Encoder pulses).

C. RECORD

Measure time count (N_T) of gimbal drift, and record results on Data Sheet Form D-1297 DS-3.



SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine BDZ and ADIAZ

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

D. PREPARATION

Orientations required for fourth drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 0°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- Initial Tilt Angle (Φ)
Remains unchanged from Step A.2.a.
- Initial Rotary Angle (θ)
Remains unchanged from Step A.2.b.

3. Ground Support Equipment

- Confirm that the counter register is zeroed.
- Route the output of the Z Gyro around the Inner Gimbal Resolver to the Middle Gimbal Amplifier with normal phasing by pushing the "Z unresolved to MG" Button.

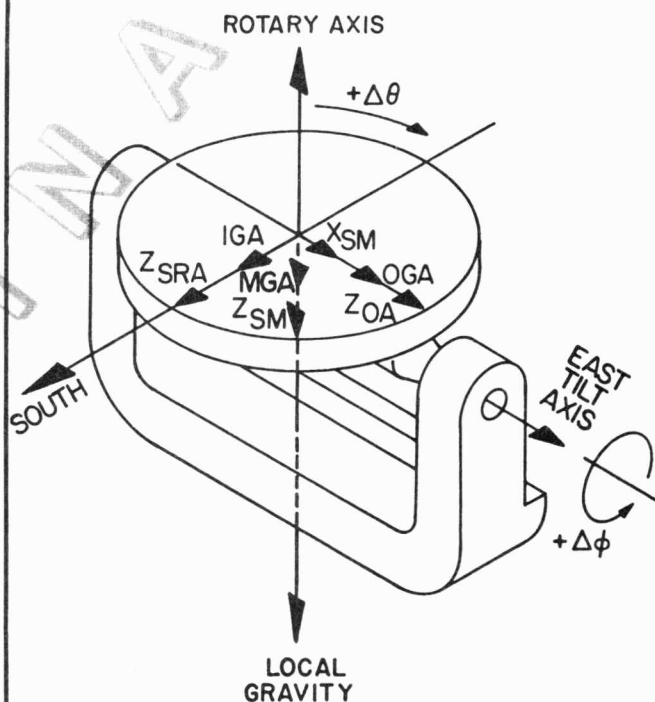
E. PROCEDURE

Fourth Drift Measurement

- Torque the Z Gyro to null and normalize the Gyro bias.
- Close the loop from the Z Gyro to the Middle Gimbal; the other two loops will be held by their respective CDU's.
- Allow the Middle Gimbal to drift through one (1) CDU revolution (64 CDU Encoder pulses).

F. RECORD

Measure time count (N_4) of gimbal drift, and record results on Data Sheet Form E-1297 DS-3.



G. CALCULATIONS

Perform the following calculations on Data Sheet Form E-1297 DS-3:

$$BDZ = \left(\frac{2.6927 \times 10^8}{N_3} + \frac{2.6927 \times 10^8}{N_4} \right) \text{ Meru}$$

$$ADIAZ = \left(\frac{2.6927 \times 10^8}{N_3} - \frac{2.6927 \times 10^8}{N_4} - 1000 \sin \lambda \right) \text{ Meru}$$

Where λ is obtained from E_____, Test Site Geodetic Data for Apollo G & N.

H. RECORDING

Record the test results on IRIG Data Sheet Form _____.

Forward a copy of the Data Sheet to IMU Systems Group, 75 Cambridge Parkway, Cambridge 42, Mass., Attention _____.

SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine SFTGZ

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

A. PREPARATION

Orientations required for fifth drift measurement:

1. Gimbal Assembly

- Outer Gimbal Angle (A_{OG}) = Precision 90°
- Middle Gimbal Angle (A_{MG}) = Precision 0°
- Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

- Initial Tilt Angle (Φ)

Desired Angle Designation = Φ_{RA} Value of Φ_{RA} obtained from JDC 00165 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

- Initial Rotary Angle (θ)

Desired Angle Designation = $\theta_{GA} + 90^\circ$ Value of θ_{GA} obtained from JDC 00162 Data Sheet Form E-1230 DS-1.

NOTE: Record Value, Indicator Error, and Readout Angle on Data Sheet Form E-1297 DS-3.

3. Ground Support Equipment

- Route the output of the Middle Gimbal CDU Encoder to the preset input of the counter. Set the preset value to 32,768 pulses. Add the 3200-pps Gyro command output of the computer simulator to the gated input of the preset counter, and zero the register.
- Route the output of the Z Gyro around the Inner Gimbal Resolver to the Middle Gimbal Stabilization Amplifier by pushing the "Z unresolved to MG" Button.

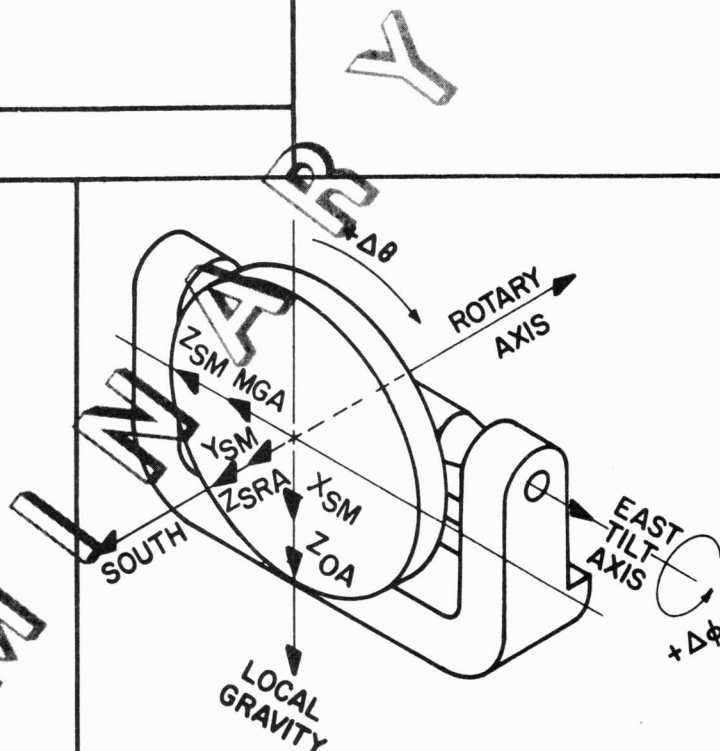
B. PROCEDURE

Fifth Drift Measurement

- Torque the Z Gyro to null and normalize the Gyro bias.
- Close the loop from the Z Gyro to the Middle Gimbal; the other two loops will be held by their respective CDU's.
- Torque the Z Gyro with positive pulses at 3200 pulses/second.

C. RECORD

Measure command count (N_g) for one (1) gimbal revolution (512 revolutions of the CDU; 32,768 pulses from the CDU)



SUBSYSTEM: INERTIAL MEASUREMENT UNIT

SYSTEM: AGE

DESCRIPTION: Test to determine SFTGZ

TYPE: Calibration

INTERVAL:

TOOLS AND MATERIAL:

REFERENCES:

IMPORTANT: Results from JDC 00162 and JDC 00165 required to perform this job.

D. PREPARATION

Orientations required for sixth drift measurement:

1. Gimbal Assembly

- a. Outer Gimbal Angle (A_{OG}) = Precision 90°
- b. Middle Gimbal Angle (A_{MG}) = Precision 0°
- c. Inner Gimbal Angle (A_{IG}) = Precision 0°

2. Test Table

a. Initial Tilt Angle (Φ)

Remains unchanged from Step A.2. a.

b. Initial Rotary Angle (θ)

Remains unchanged from Step A.2. b.

3. Ground Support Equipment

- a. Confirm that the Outer Gimbal CDU Encoder is routed to the preset input of the counter and that the preset count is 32,768 pulses.
- b. Confirm that the Z Gyro output has been routed around the Inner Gimbal Resolver to the Middle Gimbal Stabilization Amplifier.

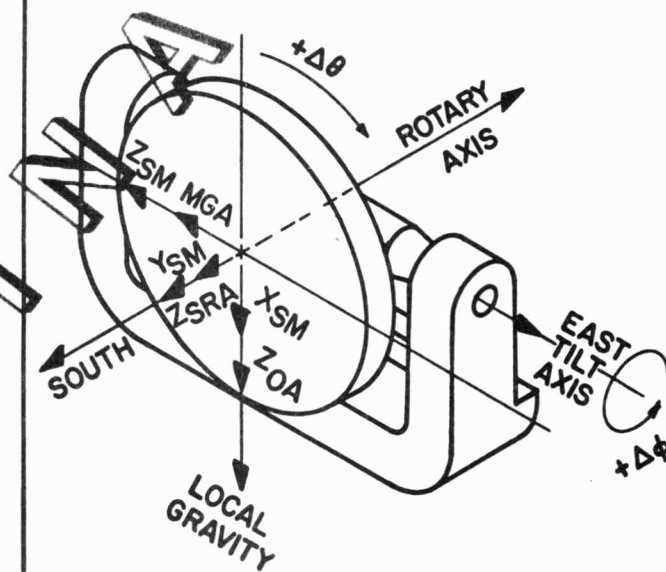
E. PROCEDURE

Sixth Drift Measurement

- 1. Torque the Z Gyro to null and normalize the Gyro bias.
- 2. Close the loop from the Z Gyro to the Middle Gimbal; the other two loops will be held by their respective CDU's.
- 3. Torque the Z Gyro with negative pulses at 3200 pulses/second.

F. RECORD

Measure command count (N_g) for one (1) gimbal revolution (512 revolutions of the CDU; 32,768 pulses from the CDU Encoder), and record results on Data Sheet Form E-1297 DS-3.



G. CALCULATIONS

Perform the following calculations on Data Sheet Form E-1297 DS-3:

$$SF(G) = \frac{3141.59}{N_g} + \frac{3141.59}{N_g}$$

H. RECORDING

Record the test results on IRIG Data Sheet Form _____.

Forward a copy of the Data Sheet to IMU Systems Group, 75 Cambridge Parkway, Cambridge 42, Mass., Attention _____.

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PIPA BIAS AND INPUT AXIS CALIBRATION TEST
DATA SHEET
FORM E-1297 DS-1

NOTE: This Data Sheet to be used with JDC 00200, JDC 00202, and JDC 00204.

TEST STEP NO.	RECORD OR CALCULATE	TEST STEP NO.	RECORD OR CALCULATE
A. 2. a.	<u>Initial Tilt Angle</u> Desired Angle Designation = Value ° ' " Indicator Error (-) " Readout Angle ° ' "	D. 2. a.	<u>Initial Tilt Angle</u> Desired Angle Designation = Value ° ' " Indicator Error (-) " Readout Angle ° ' "
A. 2. b	<u>Initial Rotary Angle</u> Desired Angle Designation = Value ° ' " Indicator Error (-) " Readout Angle ° ' "	D. 2. b	<u>Initial Rotary Angle</u> Desired Angle Designation = Value ° ' " Indicator Error (-) " Readout Angle ° ' "
C	<u>Final Rotary Angle θ</u> Readout Angle ° ' " Indicator Error (+) " Desired Angle ° ' "	F	<u>Final Rotary Angle θ</u> Readout Angle ° ' " Indicator Error (+) " Desired Angle ° ' "

PERFORM CALCULATIONS SHOWN IN TEST STEP G OF SHEET 2 OF JDC.

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PIPA SCALE FACTOR CALIBRATION TEST
DATA SHEET
FORM E-1297 DS-2
SHEET 1 of 2

NOTE: This Data Sheet to be used with JDC 00201, JDC 00203, and JDC 00205.

ROW NUMBER	TEST STEP NO.	RECORD OR CALCULATE	JDC 35.0031 X PIPA	JDC 35.0033 Y PIPA	JDC 35.0035 Z PIPA
1	A. 2. a	Tilt Angle			
—		Desired Angle Designation	Φ_{RA}	Φ_{RA}	Φ_{RA}
—		Value	° ' "	° ' "	° ' "
—		Indicator Error	(-) "	(-) "	(-) "
—		Readout Angle	° ' "	° ' "	° ' "
2	A. 2. b	Rotary Angle			
—		Desired Angle Designation	θ_{IGX}	θ_{IGY}	θ_{IGZ}
—		Value	° ' "	° ' "	° ' "
—		Indicator Error	(-) "	(-) "	(-) "
—		Readout Angle	° ' "	° ' "	° ' "
3	B. 1	N_{T_1}	cts	cts	cts
4	B. 2	N_{T_2}	cts	cts	cts
5	B. 3	N_{T_3}	cts	cts	cts
6	B. 4	IMU Temperature Deviation	°F	°F	°F
7	C	$N_{T_1} + N_{T_2} + N_{T_3} = \text{Row 3} + \text{Row 4} + \text{Row 5}$	cts	cts	cts
8	C	$N_{T_+} = N_{T_2} + N_{T_3} / 3 = \text{Row 7} / 3$	cts	cts	cts
9	D. 2. b	Rotary Angle			
—		Desired Angle Designation	$\theta_{IGX} + 180^\circ$	$\theta_{IGY} + 180^\circ$	$\theta_{IGZ} + 180^\circ$
—		Value	° ' "	° ' "	° ' "
—		Indicator Error	(-) "	(-) "	(-) "
—		Readout Angle	° ' "	° ' "	° ' "
10	E. 1	N_{T_4}	cts	cts	cts
11	E. 2	N_{T_5}	cts	cts	cts
12	E. 3	N_{T_6}	cts	cts	cts
13	E. 4	IMU Temperature Deviation	°F	°F	°F
14	F	$N_{T_4} + N_{T_5} + N_{T_6} = \text{Row 10} + \text{Row 11} + \text{Row 12}$	cts	cts	cts

DATE OF TEST (X PIPA) _____ DATE OF TEST (Y PIPA) _____ DATE OF TEST (Z PIPA) _____
BY _____ CHECKED BY _____ BY _____ CHECKED BY _____ BY _____ CHECKED BY _____

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PIPA SCALE FACTOR CALIBRATION TEST

DATA SHEET
FORM E-1297 DS-2
SHEET 2 of 2

NOTE: This Data Sheet to be used with JDC 00201, JDC 00203, and JDC 00205.

ROW NUMBER	TEST STEP NO.	RECORD OR CALCULATE	JDC 35.0031 X PIPA	JDC 35.0033 Y PIPA	JDC 35.0035 Z PIPA
15	F	$N_{T-} = N_{T_4} + N_{T_5} + N_{T_6} / 3 = \text{Row 14}/3$	cts	cts	cts
16	—	$\frac{N_{T-} + N_{T+}}{2} = \frac{\text{Row 8} + \text{Row 15}}{2}$	cts	cts	cts
17	—	$\frac{g + a_8}{1.6 \times 10^8}$			
18	F	positive SF(A) = $\frac{g + a_8}{1.6 \times 10^8} \times N_{T+}$ = Row 17 x Row 8			
19	—	$\frac{g - a_8}{1.6 \times 10^8}$			
20	F	negative SF(A) = $\frac{g - a_8}{1.6 \times 10^8} \times N_{T-}$ = Row 19 x Row 15			
21	—	$\frac{g}{1.6 \times 10^8}$			
22	F	average SF(A) = $\frac{N_{T+} + N_{T-}}{2} \times \frac{g}{1.6 \times 10^8}$ = Row 21 x Row 16			
23	F	$\Delta SF(A) = \frac{\text{pos. SF(A)} - \text{neg. SF(A)}}{\text{avg. SF(A)}} \times 10^6$ = $\frac{\text{Row 18} - \text{Row 20}}{\text{Row 22}}$			

DATE OF TEST (X PIPA) _____ DATE OF TEST (Y PIPA) _____ DATE OF TEST (Z PIPA) _____
BY _____ CHECKED BY _____ BY _____ CHECKED BY _____ BY _____ CHECKED BY _____

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JDC _____

IRIG CALIBRATION TEST
DATA SHEET
FORM E-1297 DS-3

NOTE: This Data Sheet to be used with JDC 00236 through JDC 00244.

TEST STEP NO.	RECORD OR CALCULATE	TEST STEP NO.	RECORD OR CALCULATE
A. 2. a	<u>Initial Tilt Angle</u> Desired Angle Designation = Value _____ ° _____ ' _____ " Gyro Alignment Correction (±) _____ " Readout Angle _____ ° _____ ' _____ "	D. 2. a	<u>Initial Tilt Angle</u> Desired Angle Designation = Value _____ ° _____ ' _____ " Gyro Alignment Correction (±) _____ " Readout Angle _____ ° _____ ' _____ "
A. 2. b	<u>Initial Rotary Angle</u> Desired Angle Designation = Value _____ ° _____ ' _____ " Gyro Alignment Correction (±) _____ " Readout Angle _____ ° _____ ' _____ "	D. 2. b	<u>Initial Rotary Angle</u> Desired Angle Designation = Value _____ ° _____ ' _____ " Gyro Alignment Correction (±) _____ " Readout Angle _____ ° _____ ' _____ "
C	<u>Time of Gimbal drift or revolution</u>	F	<u>Time of Gimbal drift or revolution T</u>

PERFORM CALCULATIONS SHOWN IN TEST STEP G ON SHEET 2 OF JDC.

DATE OF TEST _____
BY _____ CHECKED BY _____

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