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RTCC REQUIREMENTS FOR THE  
TLI BURN  
GO - NO-GO PROCEDURE

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Guidance and Performance Branch

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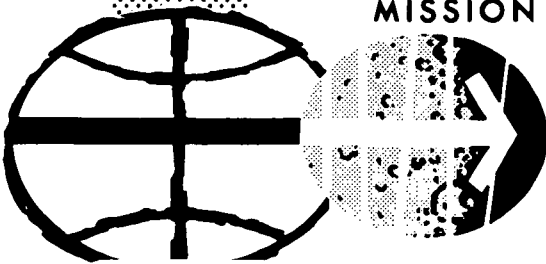
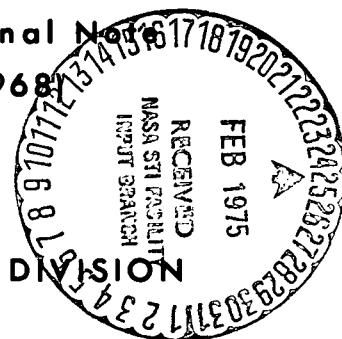
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS

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PROJECT APOLLO

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## RTCC REQUIREMENTS FOR THE TLI BURN GO - NO-GO PROCEDURE

By Herbert S. Estes

### SUMMARY

This internal note presents RTCC logic and display parameters necessary for the translunar injection (TLI) GO - NO-GO decision. The equations presented show the calculation of the "decision" parameters which allow the flight control guidance officer to make an intelligent evaluation of spacecraft and launch vehicle guidance systems prior to performing the TLI burn.

The parameters required are divided into two distinct periods of flight, (1) launch phase (lift-off to insertion), and (2) earth parking orbit (EPO) phase. The parameters needed during EPO are presently available in the "Vector Comparison Display". Briefly the required displays for the launch phase are

1.  $\Delta$  - difference between Saturn ST124-M and CSM G&N platforms (Saturn - CSM in CSM G&N coordinates).
2.  $\Delta V_T$  - total velocity differences
3.  $\Delta \dot{X}$ ,  $\Delta \dot{Y}$ ,  $\Delta \dot{Z}$  - velocity component differences in X, Y, Z CSM G&N coordinates
4.  $\Delta \theta_X$ ,  $\Delta \theta_Y$ ,  $\Delta \theta_Z$  - misalignment angle about X, Y, and Z CSM G&N coordinates

Those required for the EPO phase are all presently defined parameters for "Vector Comparison Display".

### INTRODUCTION

A TLI GO - NO-GO procedure has been developed to assist the flight control guidance officer in making a decision to continue the primary mission through the TLI maneuver. The procedure enables both CSM and Saturn guidance and navigation systems to be evaluated as required by

the basic ground rule established and delineated in the reference. This ground rule is that a TLI maneuver will not be attempted if there is any indication that the S-IVB IU guidance system is not working properly. Considering the above ground rule plus the time element involved with making the decision before the first opportunity, it was decided to

1. Assume single-failure criteria and compare the Saturn and CSM guidance systems during launch to determine if one system has degraded to an unacceptable level.

2. If anomalous performance is indicated during launch phase, then it can be determined which system is in error by comparing Saturn, CSM, and MSFN tracking data during EPO.

In order to implement the required TLI GO - NO-GO procedure, several equations need to be incorporated into the RTCC real-time program and output on appropriate digital displays and strip charts. These displays will provide the guidance officer with the parameters most sensitive to platform degradation as well as show trends on which to base an intelligent engineering decision. This report presents recommended equations for calculating these desired parameters.

## LAUNCH PHASE REQUIREMENTS

### Velocity Vector Comparison

A time history of comparisons between the Saturn and CSM velocity vector components and total velocity is required to discern if one system has degraded to an unacceptable level. The components will be compared in the G&N stable member coordinates system since individual error sources from both the Saturn and CSM guidance system will propagate uniquely and predictably in this coordinate system.

Before the differences are calculated, the downlink vectors must be transformed into the desired coordinate system and time synchronized, and the CSM IMU initial azimuth misalignment must be removed. A diagram depicting logic flow is presented in figure 1. Stable member coordinates systems for the Saturn and CSM vehicles are shown in figure 2. Velocity vectors from both Saturn and CSM guidance systems are initially available in RTCC earth-centered inertial (ECI) coordinates. This coordinate system is defined as follows:

X is in the equatorial plane positive through Greenwich at midnight prior to launch

Y is in equatorial plane so as to form orthogonal coordinate system

Z is positive through the North Pole along earth's rotational axis.

ECI to G&N coordinate transformation.-

Logic:

$$\begin{pmatrix} \dot{X}_{G\&N} \\ \dot{Y}_{G\&N} \\ \dot{Z}_{G\&N} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix} \begin{pmatrix} \dot{X}_{ECI} \\ \dot{Y}_{ECI} \\ \dot{Z}_{ECI} \end{pmatrix}$$

where

$$a_{11} = -\cos AZ_0 \sin \phi \cos \theta - \sin AZ_0 \sin \theta$$

$$a_{12} = -\cos AZ_0 \sin \phi \sin \theta + \sin AZ_0 \cos \theta$$

$$a_{13} = \cos AZ_0 \cos \phi$$

$$a_{21} = \sin AZ_0 \sin \phi \cos \theta - \cos AZ_0 \sin \theta$$

$$a_{22} = \sin AZ_0 \sin \phi \sin \theta + \cos AZ_0 \cos \theta$$

$$a_{23} = -\sin AZ_0 \cos \phi$$

$$a_{31} = -\cos \phi \cos \theta$$

$$a_{32} = -\cos \phi \sin \theta$$

$$a_{33} = -\sin \phi$$

$$\theta = \lambda + W_E * \Delta t$$

Input:

$\dot{X}_{ECI}, \dot{Y}_{ECI}, \dot{Z}_{ECI}$  - Saturn or G&N velocity vectors expressed in RTCC ECI coordinates

$AZ_0$  - flight azimuth based on the G.m.t. at lift-off

$\phi$  - geodetic latitude of launch site

$\lambda$  - longitude of launch site

$W_E$  - rotational rate of earth

$\Delta t$  - time from midnight prior to launch to G.m.t.. GRR

Output:

$X_{G\&N}$ ,  $Y_{G\&N}$ ,  $Z_{G\&N}$  - Saturn or G&N velocity vector in G&N coordinates

Suggested interpolation routine.-

Logic:

$$P = \frac{t_s - t_{n-1}}{t_n - t_{n-1}}$$

$$\dot{X}_{t_s} = \dot{X}_{t_{n-1}} + P(\dot{X}_{t_n} - \dot{X}_{t_{n-1}})$$

$$\dot{Y}_{t_s} = \dot{Y}_{t_{n-1}} + P(\dot{Y}_{t_n} - \dot{Y}_{t_{n-1}})$$

$$\dot{Z}_{t_s} = \dot{Z}_{t_{n-1}} + P(\dot{Z}_{t_n} - \dot{Z}_{t_{n-1}})$$

Input:

$t_s$  - time tag on latest Saturn or G&N vector which precedes present vector of the system

$t_n$ ,  $t_{n-1}$  - time tag on present and previous Saturn or G&N velocity vector

$\dot{X}$ ,  $\dot{Y}$ ,  $\dot{Z}$  - velocity component corresponding to time  $t_s$ ,  $t_n$ , and  $t_{n-1}$  as subscripted

Output:

$\dot{X}_s$ ,  $\dot{Y}_s$ ,  $\dot{Z}_s$  - Saturn and G&N velocity component at time  $t_s$

Initial misalignment calculation.- The initial misalignment is calculated once each time the flight controller commands.

Logic:

$$\dot{X}_{t=0} = 1341. * \sin AZ_0$$

$$\dot{Y}_{t=0} = 1341. * \cos AZ_0$$

$$\Delta AZ = \frac{\dot{Y}_{G\&N} - \dot{Y}_{Saturn}}{\dot{X}_{G\&N} - \dot{X}_{t=0}}$$

Input:

$AZ_0$  - flight azimuth based on predicted GMTLO

$\dot{X}_{G\&N}$ ,  $\dot{Y}_{G\&N}$  - G&N velocity components

$\dot{Y}_{Saturn}$  - Saturn velocity component in G&N coordinate

Output:

$\Delta AZ$  - present IMU misalignment in azimuth

$\dot{X}_{t=0}$ ,  $\dot{Y}_{t=0}$  - initial velocity at lift-off

Total velocity and velocity component calculations.-

Logic:

$$\begin{aligned} \dot{X}'_{G\&N} = & \dot{X}_{t=0} + \sin \Delta AZ (\dot{Y}_{G\&N} - \dot{Y}_{t=0}) \\ & + \cos \Delta AZ (\dot{X}_{G\&N} - \dot{X}_{t=0}) \end{aligned}$$

$$\begin{aligned} \dot{Y}'_{G\&N} = & \dot{Y}_{t=0} - \sin \Delta AZ (\dot{X}_{G\&N} - \dot{X}_{t=0}) \\ & + \cos \Delta AZ (\dot{Y}_{G\&N} - \dot{Y}_{t=0}) \end{aligned}$$

$$\dot{Z}'_{G\&N} = \dot{Z}_{G\&N}$$

Input:

$\dot{X}_{G\&N}, \dot{Y}_{G\&N}, \dot{Z}_{G\&N}$  - G&N velocity components at time  $t_s$

$\Delta AZ$  - G&N IMU initial misalignment in azimuth

Output:

$\dot{X}'_{G\&N}, \dot{Y}'_{G\&N}, \dot{Z}'_{G\&N}, V'_{G\&N}$  - G&N velocity vector corrected for initial azimuth misalignment

#### Differencing routine.-

Logic:

$$\Delta \dot{X} = \dot{X}_{Saturn} - \dot{X}'_{G\&N}$$

$$\Delta \dot{Y} = \dot{Y}_{Saturn} - \dot{Y}'_{G\&N}$$

$$\Delta \dot{Z} = \dot{Z}_{Saturn} - \dot{Z}'_{G\&N}$$

$$\Delta V_T = \sqrt{\dot{X}_{Saturn}^2 + \dot{Y}_{Saturn}^2 + \dot{Z}_{Saturn}^2} - \sqrt{\dot{X}'_{G\&N}^2 + \dot{Y}'_{G\&N}^2 + \dot{Z}'_{G\&N}^2}$$

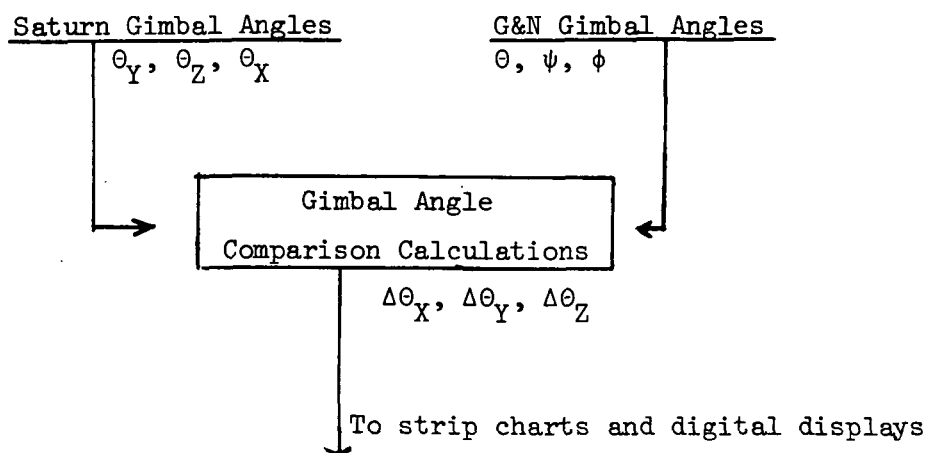
Input: Saturn and G&N velocity components and total velocity evaluated at time  $t_s$ .

Output: Saturn and G&N total velocity and velocity components differences to digital and strip chart.

#### Gimbal Angle Comparisons

Also exhibited on the display and strip charts will be a comparison of gimbal angles from the two platforms. These comparisons need not be time synchronized. This allows the guidance officer to evaluate gyro failures occurring near insertion. These errors would not have an appreciable effect on the velocity comparison but will be very evident on a gimbal angle comparison strip chart. Equations and logic flow depicting operations necessary to implement them follow.





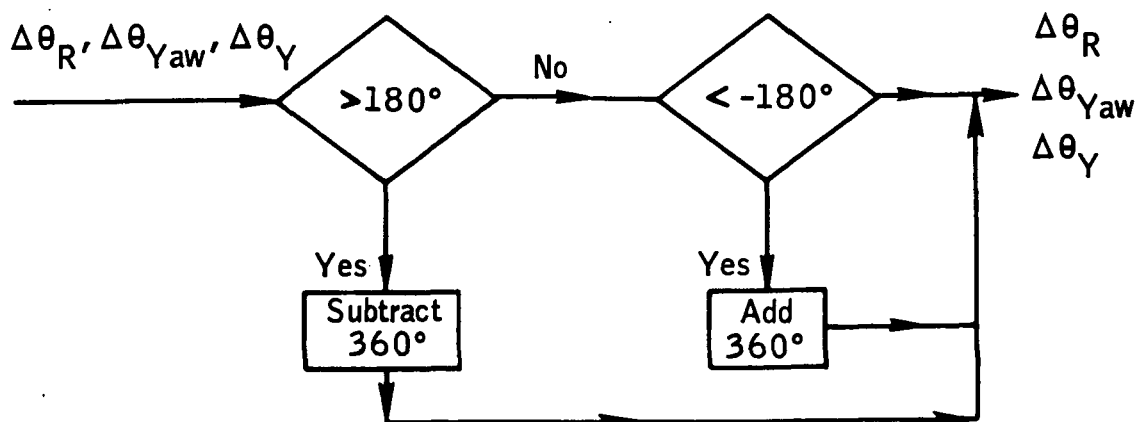
Gimbal angle comparison calculations.-

Logic:

$$\Delta\theta_R = A_{og}^{\text{Saturn}} - A_{og}^{\text{G\&N}} + K_2$$

$$\Delta\theta_{\text{Yaw}} = A_{mg}^{\text{Saturn}} - A_{mg}^{\text{G\&N}}$$

$$\Delta\theta_Y = A_{ig}^{\text{Saturn}} - (A_{ig}^{\text{G\&N}} + K_1)$$



$$\Delta\theta_X = \Delta\theta_R \sin(A_{ig}^{\text{G\&N}} + K_1) - \Delta\theta_{\text{Yaw}} \cos(A_{ig}^{\text{G\&N}} + K_1)$$

$$\Delta\theta_Z = -\Delta\theta_R \cos(A_{ig}^{\text{G\&N}} + K_1) - \Delta\theta_{\text{Yaw}} \sin(A_{ig}^{\text{G\&N}} + K_1) + \Delta\text{AZ}$$

Input:

$K_1$  - rotation angle about the Y stable member axis between the Saturn X-axis and G&N X-axis

$K_2$  - rotation about new X stable member (roll) axis required to place Z (yaw) axis inland.

The constants  $K_1$  and  $K_2$  are presently  $-90^\circ$  and  $-180^\circ$ , respectively.

$A_{og}$ ,  $A_{mg}$ ,  $A_{ig}$  - outer, middle, and inner gimbal angles for the G&N or Saturn system. These angles are equivalenced to downlink telemetry as follows:

$$A_{ig}^{G\&N} = \theta \text{ (actual G\&N Y)}$$

$$A_{mg}^{G\&N} = \psi \text{ (actual G\&N X)}$$

$$A_{og}^{G\&N} = \phi \text{ (actual G\&N Z)}$$

$$A_{ig}^{Saturn} = \theta_Y - \text{Saturn pitch gimbal angle (TSFGA)}$$

$$A_{mg}^{Saturn} = \theta_Z - \text{Saturn yaw gimbal angle (TSFGA)}$$

$$A_{og}^{Saturn} = \theta_X - \text{Saturn roll gimbal angle (TSFGA)}$$

Output:

$\Delta\theta_X$ ,  $\Delta\theta_Y$ ,  $\Delta\theta_Z$  - is misalignment angles about G&N stable member axis.

#### REQUIREMENTS FOR EARTH PARKING ORBIT ORBITAL PARAMETER DISPLAYS

If either the Saturn or G&N system degrades to a unacceptable level during launch then the "Vector Comparison Display" and Gimbal Angle Comparison strip chart will be used to identify which system is in error. This is accomplished by computing Saturn, G&N and MSFN differences in selected parameters and comparing them with characteristic deviations established preflight.

The gimbal angle strip charts should be an extension of the ones used during the launch phase. The magnitude of a constant gyro drift and the errored system, can be determined by comparing gimbal angle differences before and after an IMU re-alignment. As during launch, the comparisons need not be time synchronized.

One revision to the "Vector Comparison Display" is required to accomodate the parameter differences which are possible. This is to increase the scale on the position difference display for the altitude, down-range, and cross-range (u, v, w) position vector one digit so that differences up to 999 999 ft may be displayed.

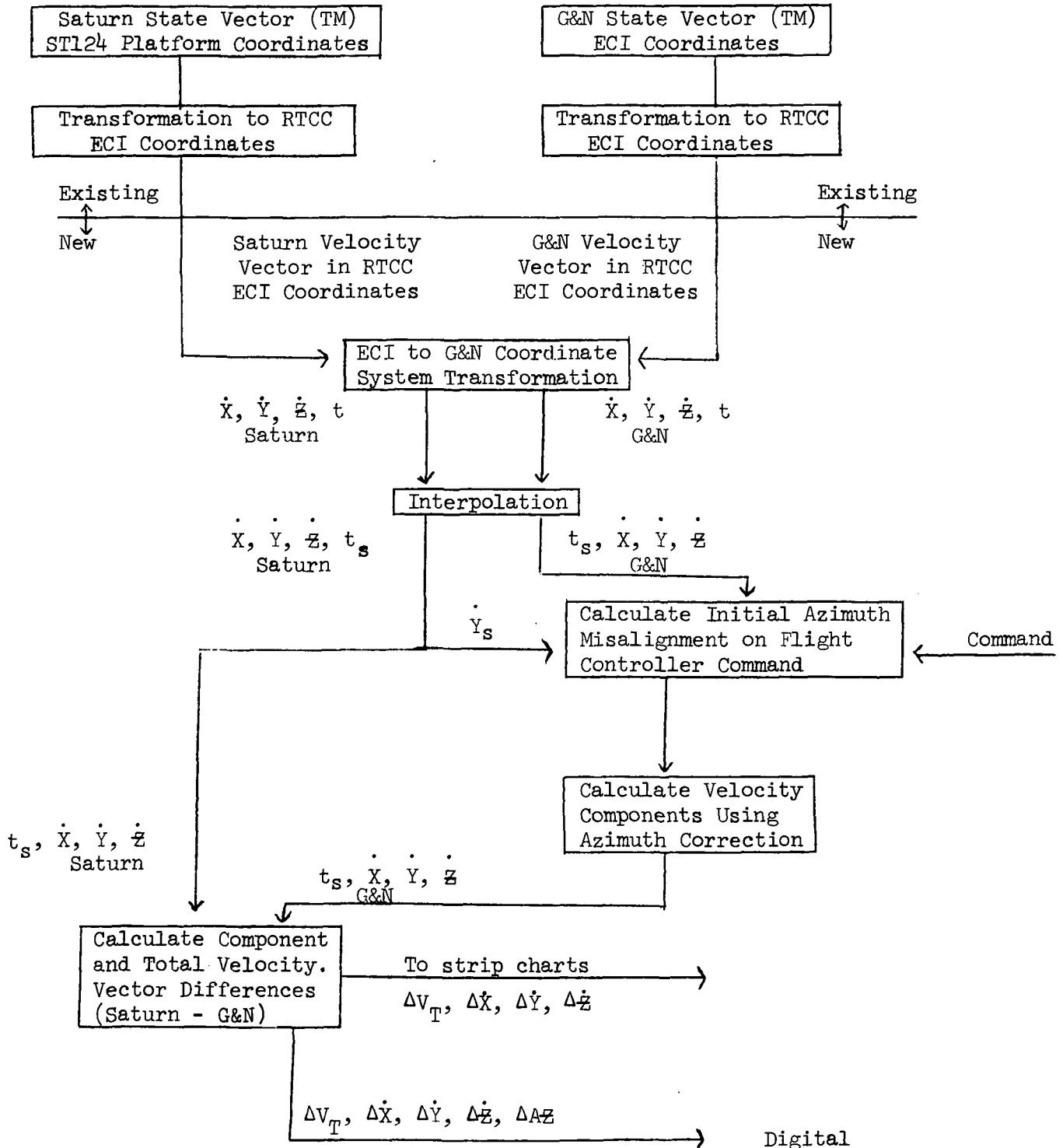


Figure 1. - Velocity Vector Comparison Logic Flow Chart

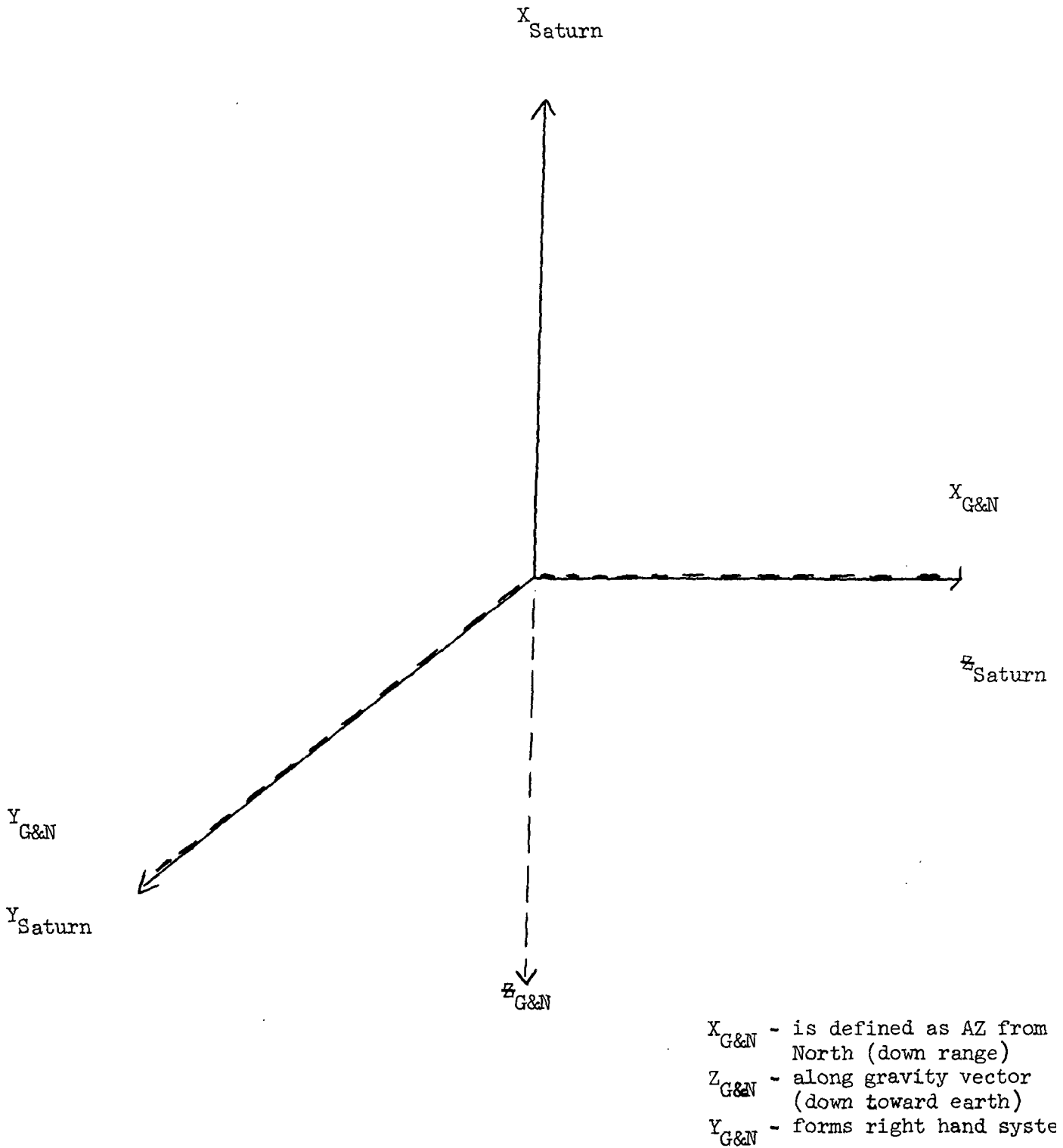


Figure 2. Geometrical Relationship Between G&N and ST124-M Accelerometer Input Axes

REFERENCES

1. Tindall, Howard W.: Guidance System Oriented Ground Rules for  
TLI GO - NO-GO. MSC Memorandum No. 68-PA-T-56A, March 7, 1968.