R. Larson
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Charles S. Draper Laboratory
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Mission Techniques Memo #41B

To: Distribution
From: Malcolm W. Johnston
Date: 1 April 1970
Subject: "H 2" Final Document Review

(1) In some cases corrections noted in previous MTM's have not been incorporated in these new Mission Techniques document editions. These are so noted.

* (2) Item #8 of MTM #41A should be changed to read "some special considerations concerning LM DAP control of the CSM docked configuration are outlined in the enclosed Luminary Memo #117 by G. Kalan." Also, since the UV jets should always be disabled, via V65 during a CSM docked burn, this memo applies only to a coasting flight situation.

(3) A proposed method for estimating the landing site location is outlined in the enclosed memo by R. White, dated January 20, 1970.

(4) The following comments are mostly editorial, though asterisked items should be reviewed prior to mission H2.

SV. Launch Phase Aborts - (dated 3/31/69)

Update for Mission H2 not received as of April 3, 1970.

EPO and TLI - (dated 2/27/70)

On page 2-3, first paragraph, do they really mean a probability of 1% or more and TLI is Go?

TL (MCC) and LOI - (dated 6/10/69)

Update for Mission H2 not received as of April 3, 1970.

Lunar Descent - (dated 2/15/70)

* The changes noted in MTM #39B, item 13, under Lunar Descent page 4-13, Figure 4-3, and page 4-16 still apply.

Aborts from Descent - (dated 1/7/70)

The changes noted in MTM #29B, items 10 and 11 still apply!

Lunar Surface Phase - (dated 1/30/70)

The last paragraph on page 9 (20 degree check) should be amplified to include the warnings contained in the enclosed memo by R. White, dated January 6, 1970.

Referring to page 43, the change noted in MTM #39B, item 13, last paragraph under "Lunar Surface Phase" still applies!

* Techniques for updating PIPA bias and gyro drift compensation have been discussed (MTM #30A, items 8 and 9; MTM #30C, item #1; MTM #35A, item #4). This document does not mention PIPA bias update ... Have the above MTM items been reviewed? Also, azimuth drift determinations presently depend on AOT use which could introduce dangerous errors. R. White has a technique for

augmenting these test results in real time should the RTCC be interested.

Powered Ascent - (dated 2/9/70)

The changes noted in MTM #31, items #3,4, and 6 still apply!

Manual Ascent - (dated 2/23/70)

* The changes noted in MTM #34 and item #2 of MTM #35B are still applicable.

Lunar Orbit Activities - (dated 1/30/70)

On page 3.3, table 3.2, (and in the Descent Abort document) W-matrix re-initializations for CSI,CDH, and the plane change are scheduled directly following the maneuver. After our last confrontation, MSC's peace offering was to change this back to "three marks in" after mission H1!

* On page 4.5, it should be stated that the LM attitude during the second V06N20 should be "approximately" the same as during the first V06N20 ... so that drift estimates are not affected by errors in the docking ring. Ken Goodwin's (MIT/MSC) initial study results indicate that 15° is OK! This conclusion is presently being verified by both K. Goodwin and R. White (Cambridge).

* The drift test limits (for PDI misalignment protection) stated on page 4.5 are OK. However, a subsequent memo by A. David Long, dated March 18, 1970, indicates a cross track limit of 0.5° rather than the old 0.2° limit. Even postulating an immediate and accurate 4000 ft. re-designation at hi gate, and taking advantage of a larger than 4000 ft. projected surface error at hi gate, (which I assume he did), this limit seems very tight!

On page 4.9, no mention is made of the sending of the lunar surface pad (old table 4-5). Is this an oversight?

On page 4.9, bottom, shouldn't it be 0°, 80°, 0°?

On page 4.11, second paragraph, for the low pass land mark tracking the sextant trunnion angle constraint is more important ... should be 20°-30°! On page 4.11, bottom shouldn't we look at ΔR (ΔV=0!)

On page 4.23, top, should read ΔVGZ < 6FPS.

On page 5.2, what does Note (1) refer to?

On page 5.4, was the GNCS drift limit tightened from 0.075°/hr. to 0.045°/hr. due to good past experience? OK with MIT, but only for GNCS ... not PGNCS!

<u>TEI, TE (MCC), and Entry</u> - (dated 2/27/70)

On page 14, the changes noted in MTM #39C are still applicable!

<u>Contingency Procedures</u> - (dated 2/27/70)

On page 25, under CMC TB6 Load, the values loaded into R_1, R_2, R_3 are 26000E, 1513E, and 10067E respectively.

* Also, both comments made in MTM #39C <u>still</u> apply!

<u>Tracking Data Selection Controllers Procedures</u> - (dated 2/20/70)

This document contains little reference to GNCS/PGNCS operation and only received a limited review. No statements were noted that were inconsistent with satisfactory GNCS/PGNCS operation or performance.

Mal

M. Johnston

Massachusetts Institute of Technology
Instrumentation Laboratory

23S MEMO 70-5

TO: Distribution
FROM: Robert L. White
DATE: 20 January 1970
SUBJECT: A proposed method of estimating the landing site location using V06N05 in the Lunar Surface Alignment Program

I. INTRODUCTION

Recently a simple change (PCR 972) was made to Luminary 1C to provide an additional method of estimating the landing site location during the use of the Lunar Surface Alignment Program (P57). This change was made in V06N05 so that it would also display the polarity of the sighting angle difference. In the past only the absolute value of the sighting angle difference was displayed.

In the proposed method of site determination use is made of the angular differences displayed in V06N05 during Alignment Technique No. 3 (AT3) of Program P57 to determine the angular differences in latitude and longitude between the gravity vector and the landing site position vector contained in the LGC. It is assumed that the gravity vector represents the direction of the true local vertical and landing site. Most of the post flight analyses made on Apollos 11 and 12 support this assumption.

The proposed method can be used by the crew and/or the Earth, and has the following advantages and disadvantages:

Advantages:

1. The data requirements for the Earth are simple and there is no requirement to transmit vectors from the LM to the Earth. Consequently, there is less chance of making an error in the site determinations and the data can be more easily transmitted by voice in case of downlink failure.

2. The selection of stars to sight on for improvement in the estimate of site location in latitude and/or longitude is simple. For example, stars toward the lunar north or south pole will help improve the estimate in latitude; while stars east or west of the site will help improve the estimate in longitude.

3. Since the method is independent of IMU orientation, the star sightings of all AT3's can be easily combined to improve the estimate.

4. Additional estimates can be more quickly obtained in AT3 than in Alignment Technique No. 2 (AT2) simply by remaining in AT3 and sighting on a number of different stars. In other words, it is not necessary to repeat the entire alignment program in order to obtain additional estimates of site location as would be the case with AT2.

Disadvantages:

1. The estimate of site location in latitude and longitude is not displayed to the crew as in AT2. However, the crew can make an estimate with this method without too much difficulty.

2. The method may not give as good an answer as other methods which process additional data such as all of the gravity vectors and all of the spiral and cursor readings of the Alignment Optical Telescope (AOT). However, this is what is sacrificed in order to simplify the data requirements.

II. GENERAL DESCRIPTION OF PROPOSED METHOD

To align the IMU to a desired orientation with Alignment Technique No. 3 measurements are made to determine the directions of gravity and a single star. After these measurements have been made the quantity $\alpha_1 - \beta_1$ is displayed in V06N05 where α_1 and β_1 are the angles shown in Figure 1.

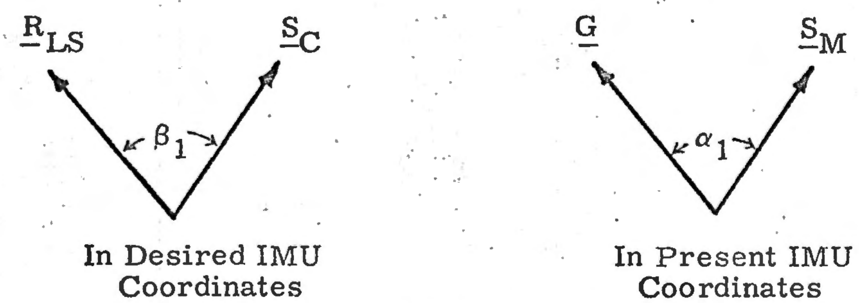


Figure 1

In Figure 1, $\underline{G}$ and $\underline{S}_M$ are the vectors defining the corresponding directions of the measured gravity and star line-of-sight in the present IMU Coordinate System, and $\underline{R}_{LS}$ and $\underline{S}_C$ are the vectors defining the corresponding directions of the LGC's present knowledge of the landing site position and the catalogued line-of-sight to the star in the desired IMU Coordinate System. If a perfect measurement had been made on the star (so that $\underline{S}_M$ and $\underline{S}_C$ coincided in inertial space) and the star had a reasonable angle of separation from the local vertical, it is seen that any angular difference displayed in V06N05 would be the angular difference between $\underline{G}$ and $\underline{R}_{LS}$ in essentially the plane defined by $\underline{G}$ and $\underline{S}_M$ or

$\underline{R}_{LS}$ and $\underline{S}_C$. For reasonable errors in $\underline{R}_{LS}$ and $\underline{G}$ these two planes are essentially the same in inertial space. To determine the direction of the angular difference on the lunar surface either $\underline{R}_{LS}$ and $\underline{S}_C$, or $\underline{G}$ and $\underline{S}_M$ must be transformed to the Moon Fixed Coordinate System (MFCS) which is defined to be a coordinate system centered with respect to the Moon and rotates with it in inertial space.

To clearly illustrate the angular difference on the lunar surface let us assume that all four of the vectors have been transformed to MFCS and are as shown in Figure 2 where it is assumed that $\underline{S}_M$ and $\underline{S}_C$ are coincident. It is seen in Figure 2 that $\alpha_1 - \beta_1$ gives only one component of the difference between $\underline{G}$ and $\underline{R}_{LS}$, and that another component $\alpha_2 - \beta_2$ must be obtained by sighting on a second star at a different azimuth before a complete estimate of $\underline{G}$ location can be obtained.

III. SUGGESTED PROCEDURE FOR EARTH

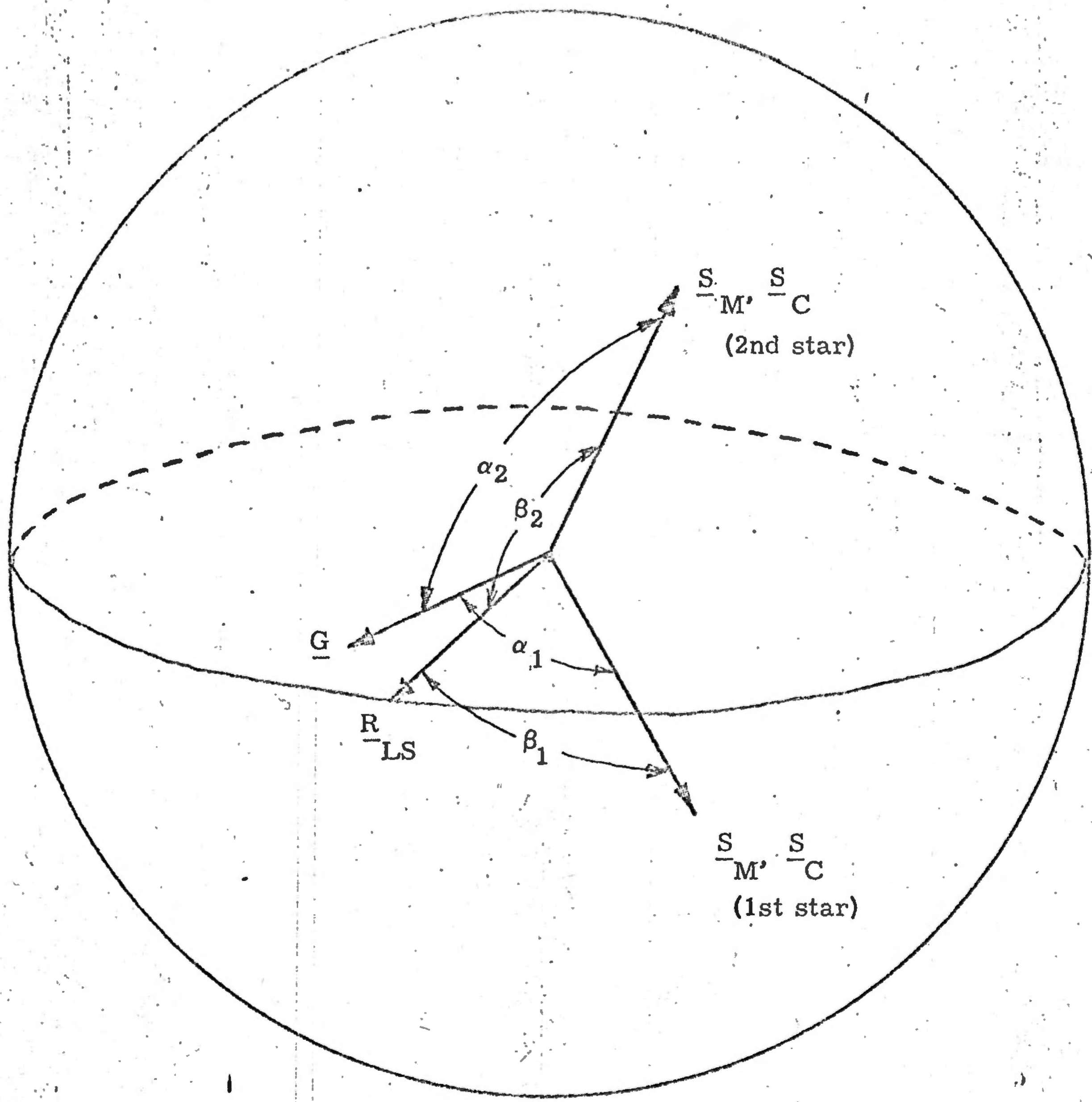
To determine the location of the site with this method the Earth needs the following data from the LM for at least two stars during Alignment Technique No. 3:

1. The sighting angle difference ($\alpha - \beta$) displayed in V06N05.

2. The approximate time T when the LGC transforms $\underline{G}$ from navigation base to IMU stable member coordinates. This occurs just before the sighting on the star. The time when V06N70 appears may be used for this purpose.

3. The identity of the star so that the correct vector $\underline{S}$ defining the direction of the star in basic reference coordinates will be used. These vectors are available prior to the mission.

4. The location of the site used by the LGC during the AT3. If this location is given in terms of latitude and longitude it will be necessary to compute a vector $\underline{R}_{LS}$ specifying the direction



Note: The separation shown between $\underline{R}_{LS}$ and $\underline{G}$ is larger than what would be the case.

Figure 2

of the site in moon fixed coordinates.

For the moment let us assume that the above data has been obtained for two stars and that subscripts 1 and 2 identify the data for the first and second star, respectively. In addition, let us assume that the landing site vector $\underline{R}_{LS}$ used by the LGC is the same for both stars.

The first step is to determine the directions of the stars $\underline{S}_1$ and $\underline{S}_2$ in moon fixed coordinates for the corresponding times T_1 and T_2. This may be accomplished with the Planetary Inertial Orientation Subroutine described in Section 5.5.2 of the Colossus or Luminary GSOP.

Since $\alpha_1 - \beta_1$ and $\alpha_2 - \beta_2$ are usually small angles they can be replaced by the small horizontal displacement vectors $\underline{A}$ and $\underline{B}$ shown in Figure 3 where

$$\underline{A} = (\alpha_1 - \beta_1) \text{ UNIT } [\underline{R}_{LS} \times (\underline{R}_{LS} \times \underline{S}_1)]$$

$$\underline{B} = (\alpha_2 - \beta_2) \text{ UNIT } [\underline{R}_{LS} \times (\underline{R}_{LS} \times \underline{S}_2)]$$

where $(\alpha_1 - \beta_1)$ and $(\alpha_2 - \beta_2)$ are in radians. Since $\underline{A}$ and $\underline{B}$ are usually not orthogonal the following computations are necessary in order to obtain the overall displacement vector $\underline{D}$ between $\underline{R}_{LS}$ and $\underline{G}$.

$$\cos\delta = \text{UNIT }(\underline{A}) \cdot \text{UNIT }(\underline{B})$$
$$\sin\delta = \left|\text{UNIT }(\underline{A}) \times \text{UNIT }(\underline{B})\right|$$

$$\tan\theta = \frac{1}{\sin\delta}\left[\frac{|\underline{B}|}{|\underline{A}|} - \cos\delta\right]$$

$$\underline{D} = \underline{A} + |\underline{A}| \tan\theta \left[\text{UNIT}\left((\underline{A} \times \underline{B}) \times \underline{A}\right)\right]$$

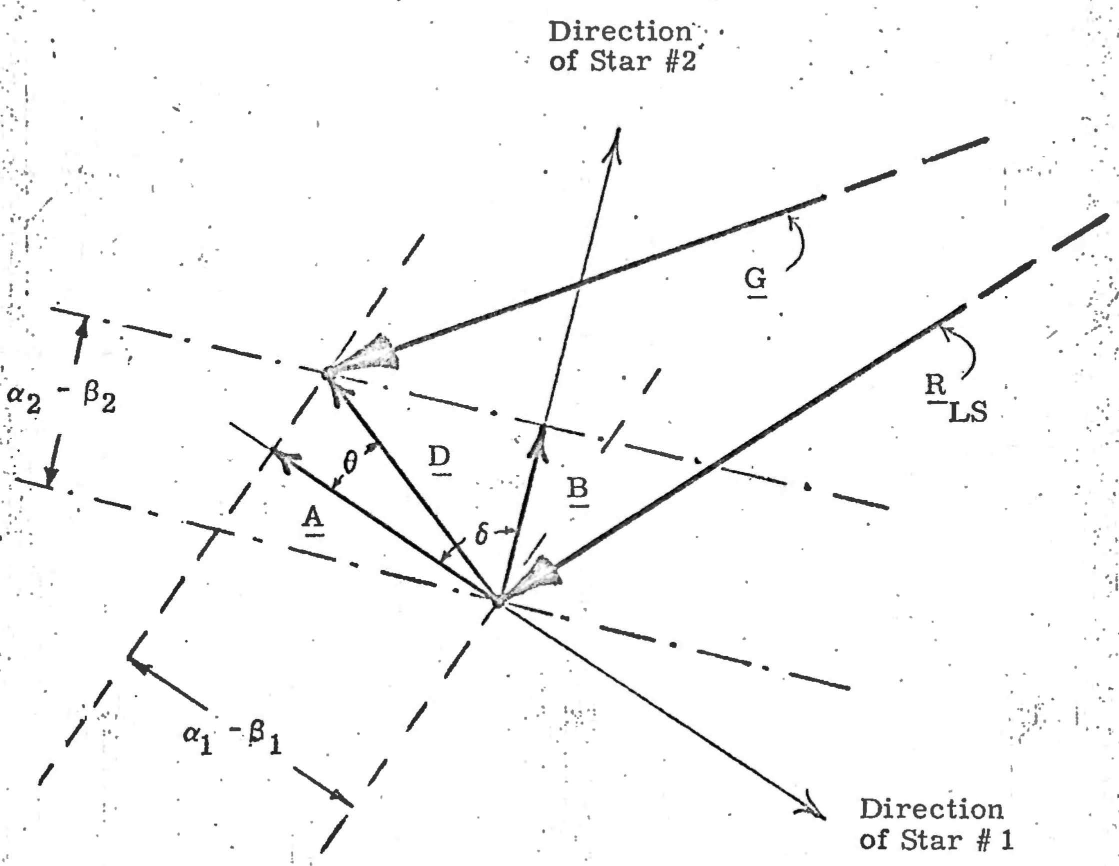


Figure 3

The unit vector $\underline{U}_{LS}$ defining the direction of $\underline{G}$ (i.e., the true landing site) in moon fixed coordinates is therefore

$$\underline{U}_{LS} = \text{UNIT} \left[\text{UNIT} (\underline{R}_{LS}) + \underline{D} \right]$$

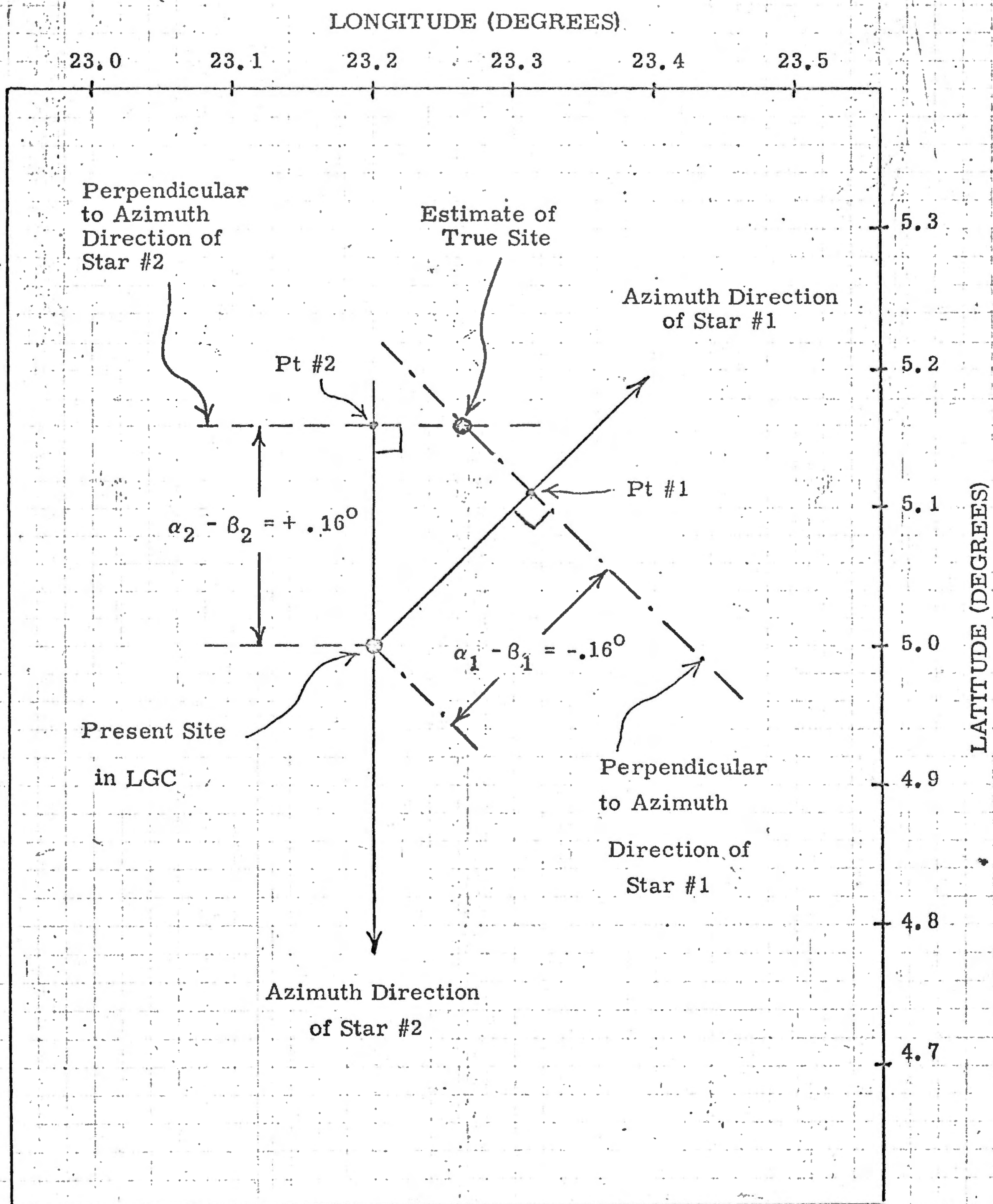
It should be noted that an angle δ of 90^o between the two displacement vectors $\underline{A}$ and $\underline{B}$ is optimum for the above determination of $\underline{U}_{LS}$ and that values of δ near 0^o, 180^o, 360^o, etc. are unsatisfactory since the displacement vectors are essentially in the same or opposite directions with respect to each other and should be more properly paired with vectors in other directions.

IV. SUGGESTED PROCEDURE FOR CREW

The manner by which the crew may obtain estimates of the site location with this method is relatively straight forward and requires that they have a map of the local area with the approximate azimuths of the stars they intend to sight on. What is meant by the azimuth of a star with respect to the site is the direction of its projection onto the horizontal plane at the site. Since star azimuths change because of lunar rotation the azimuths used with the map should correspond to a time which is within a few hours of the actual star sightings in order to minimize error.

To illustrate how the map would be used for this purpose let us assume that, during Alignment Technique No. 3, sightings were made on two stars (denoted as Star #1 and Star #2), and that the corresponding angular differences displayed in V06N05 are $\alpha_1 - \beta_1 = -0.16^\circ$ and $\alpha_2 - \beta_2 = 0.16^\circ$. In addition, let us assume that the latitude and longitude of the landing site position vector in the LGC are 5.00° and 23.20°, respectively. In Figure 4 is a map of the local area with the azimuth directions for Stars #1 and #2. The object is to use the values of α-β to determine a point on each azimuth direction line (i.e., Points #1 and #2) where a perpendicular may be constructed. Note that if α-β is negative the point will lie between the LGC's present site and the star. In Figure 4 the point of intersection of the two perpendiculars represents the estimated location of the true site.

Under normal circumstances sightings are made on only one star during Alignment Technique No. 3 (AT3) and it would require two AT3's to obtain an estimate. However, since the largest source of error in an estimate is due to the star sighting, it may be desirable to remain in an AT3 and obtain additional estimates by sighting on a number of different stars. By using this approach a lot of time would not be wasted in torquing the IMU, determining the direction of gravity, etc.



LONGITUDE (DEGREES)
23.0
23.1
23.2
23.3
23.4
23.5
Perpendicular to Azimuth Direction of Star #2
Estimate of True Site
Azimuth Direction of Star #1
Pt #2
Pt #1
$\alpha_2 - \beta_2 = +.16^o$
$\alpha_1 - \beta_1 = -.16^o$
Present Site in LGC
Perpendicular to Azimuth Direction of Star #1
Azimuth Direction of Star #2
5.3
5.2
5.1
5.0
4.9
4.8
4.7
LATITUDE (DEGREES)

Figure 4

The path which should be used in Program P57 for multiple star sightings is indicated by the large arrows in Figure 5. Note that the crew can bypass the final alignment by keying in a RECYCLE (R) for either V06N05 or V06N93. When a PROCEED (PRO) is keyed in for V50N25 the program repeats the transformation of the previously determined gravity vector from navigation base to IMU stable member coordinates before the crew performs the sightings on the next star using the Lunar Surface Sighting Mark Routine (R59).

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C. F. Wasson, EG2
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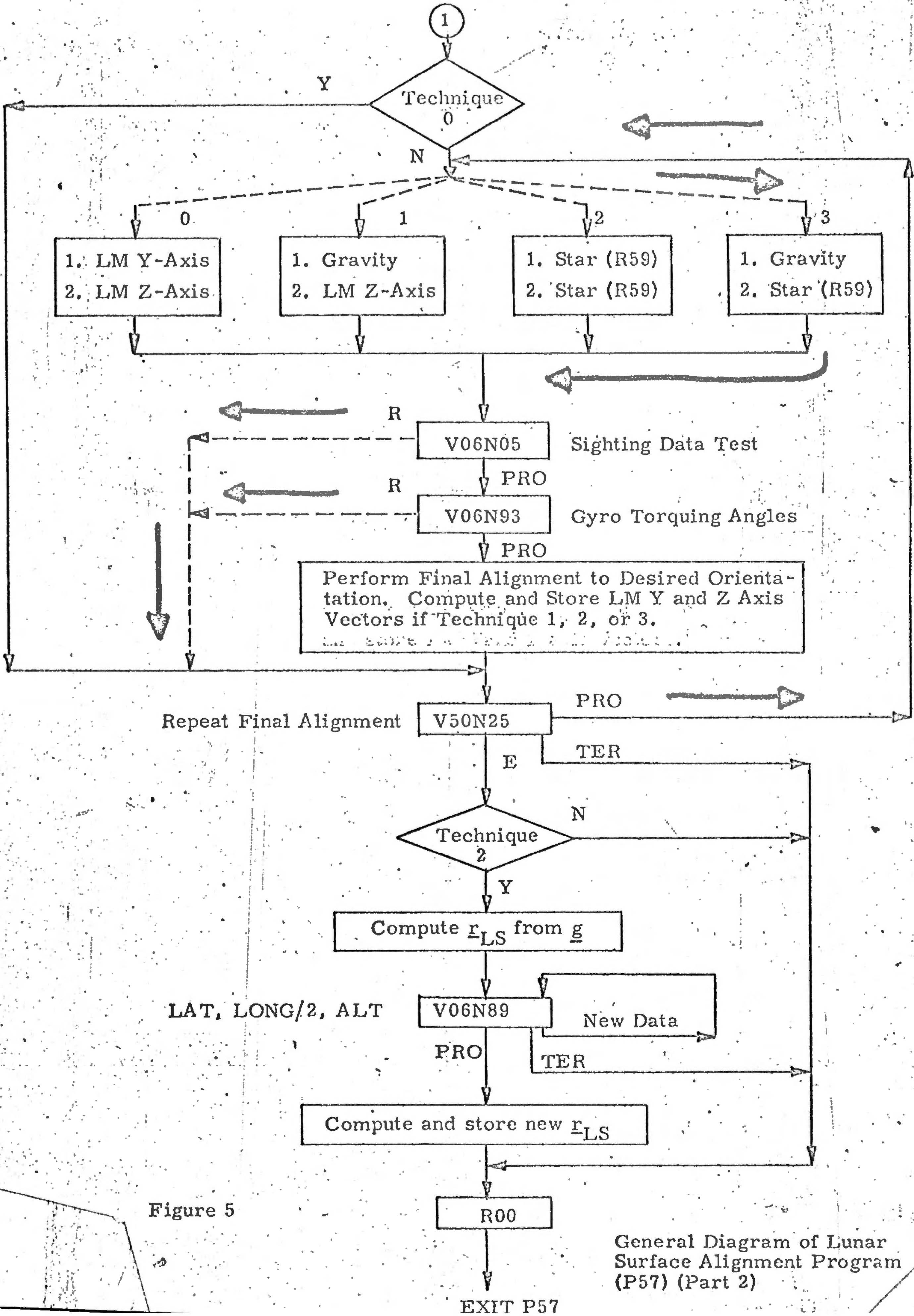

Figure 5

General Diagram of Lunar Surface Alignment Program (P57) (Part 2)

M Johnston

Massachusetts Institute of Technology
Instrumentation Laboratory

MEMORANDUM

TO: Distribution

FROM: Robert L. White

DATE: 6 January 1970

SUBJECT: Minimum separation angle between star and gravity vector in lunar surface alignment.

In Routine R-59 of Section 4 of the latest Luminary GSOP (Rev. 5) and in the final issue of the Apollo Mission Techniques Document on the H Lunar Surface Phase, it is stated that a celestial body should be separated by at least 20 degrees from the gravity vector in order to insure an acceptable IMU alignment accuracy in azimuth. This statement is based on the assumption that there is very little error in determining the direction of gravity and that most of the error is associated with sighting on the celestial body. Unfortunately, the azimuth alignment can also be affected by a lack of coincidence in the directions of the gravity vector and the landing site position vector used in the alignment. This effect is illustrated by the example in Figure 1 where:

$\underline{G}$ = the gravity vector and is assumed to be the true direction of the landing site position vector.

$\underline{R}_{LS}$ = the landing site position vector used in the alignment.

$\underline{S}$ = the line of sight vector to a star which has been obtained by a perfect measurement with the AOT.

EL = elevation angle of the star with respect to the local horizontal.

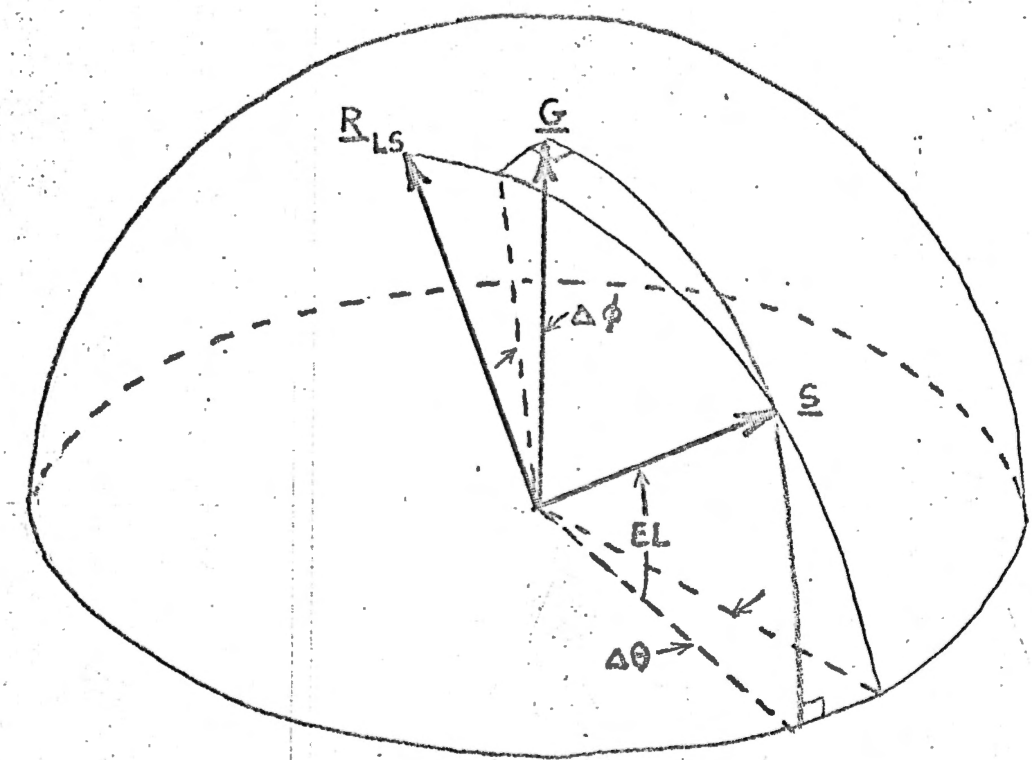

FIGURE 1

$\Delta\phi$ = That component of the angular difference between $\underline{R}_{LS}$ and $\underline{G}$ as defined in Figure 1.

$\Delta\theta$ = Azimuth alignment error.

In Figure 1 the relationship between $\Delta\phi$ and $\Delta\theta$ is:

$$\tan(\Delta\theta) = \tan(EL)\tan(\Delta\phi)$$

For small $\Delta\phi$ and $\Delta\theta$

$$\Delta\theta = [\tan(EL)]\,\Delta\phi$$

For a separation angle of 20^{o} between $\underline{G}$ and $\underline{S}$, the star elevation (EL) is 70^{o} and the azimuth error ($\Delta\theta$) is about 2.7 times $\Delta\phi$. This factor of degradation in azimuth alignment accuracy is about the same as the value (2.5) given in the Apollo Mission Techniques Document for an error in sighting on a star at the same elevation. It should be noted, however, that the azimuth accuracy is affected only by one component of the star sighting error just as it is affected by only one component of the difference between $\underline{R}_{LS}$ and $\underline{G}$. As the star elevation approaches zero, the factor of degradation for angular differences between $\underline{R}_{LS}$ and $\underline{G}$ also approaches zero, while that for star sighting errors approaches unity.

Since angular differences between $\underline{R}_{LS}$ and $\underline{G}$ can cause azimuth alignment errors it is important that the $\underline{R}_{LS}$ used during the lunar surface phase be in close agreement with $\underline{G}$. In addition, it would seem desirable to not use stars as close as 20^{o} from the vertical in Alignment Technique No. 3 of P-57 because of the large factor of degration. A more suitable value for the minimum angle of separation would be about 40^{o} which has a factor of degradation 1.19. In Apollo's 11 and 12 this angle was about 40^{o} for every star used. Naturally there is no hard fast rule on what the minimum angle should be since it depends on what azimuth alignment accuracy is desired and what angular difference is expected between $\underline{R}_{LS}$ and $\underline{G}$.

During the lunar surface phase of Apollo 11 the $\underline{R}_{LS}$ used for IMU alignments was one computed by the ground and transmitted to the LM. The method used to compute this $\underline{R}_{LS}$ is not known to me but I assume it was based on ground tracking of the LM during the powered descent. The latitude and longitude of this $\underline{R}_{LS}$ was 0.799° and 23.461°, respectively. After the mission an $\underline{R}_{LS}$ was obtained by comparing lunar maps with the terrain photography taken by the LM during the powered descent and ascent. This $\underline{R}_{LS}$ had a latitude and longitude of 0.647° and 23.505°, respectively, and is undoubtedly the most accurate estimate available. By using data obtained from Apollo 11 in conjunction with this latter $\underline{R}_{LS}$ it is possible to determine what the azimuth (i.e., X gyro) torquing would have been in the first two alignments with Alignment Technique No. 3* if the latter $\underline{R}_{LS}$ had been used in place of the one used in the mission. The differences in X-gyro torquing for the two values of $\underline{R}_{LS}$ was found to be:

0.076° for the first AT3
0.151° for the second AT3

Although the above differences are larger than what I would consider desirable, they were not serious. Fortunately, there was very little disagreement between the $\underline{G}$'s and $\underline{R}_{LS}$'s used in Apollo 12. One significant point which should be made is that errors in $\underline{G}$ due to gravitational anomalies will have no effect on the azimuth alignment accuracy as long as $\underline{R}_{LS}$ agrees with $\underline{G}$, although they will have an effect on the vertical alignment accuracy. All of the most reliable analyses performed on data from Apollo's 11 and 12 indicate that the $\underline{G}$'s determined on board were very accurate indications of local vertical (i.e., no significant or detectable gravitational anomalies). If we assume this will always be the case then every effort should be made to use an $\underline{R}_{LS}$ in close agreement with $\underline{G}$ in order to minimize the azimuth alignment error.

* This computation could not be made for the last AT3 due to loss of downlink data.

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