MISSION TECHNIQUES MEMO #30A

TO: Distribution
FROM: Malcolm W. Johnston
DATE: April 23, 1969
SUBJECT: "G" Lunar Surface Phase

1. Can the P68 Lat and Lon noun be changed to be consistant (scaling) to P57's and the CM's P22 display?

Ans. Not in time for "G", but the idea will be suggested for later ropes. (Colossus and Luminary)

2. What procedures are necessary to avoid RCS jet firings by the DAP after landing?

Ans. Enclosure 1 to MTM #4, dated August 20, 1968, discusses this subject ---- among other things. To summarize, lunar rotation and gyro torquing could cause jet firings. Therefore, disable the DAP (switch attitude control off, or switch to attitude hold and enter V76.) before 8-10 hrs. or the execution of P57. The latter (P57) will most likely be exercised within one hour of touchdown.

3. Lunar surface operations presently call for the IMU and LGC to be continuously operated. The LGC should be left operating in POO when not executing a lunar surface program. This retains downlink, compensation, LGC warning capabilities, etc.

4. What gross PGNCS "Stay/No Stay" check can be made during the first (3 and 8 minute) decision points to enable an AGS align decision?

Ans. If the landing is successful and apparently accurate, if a PGNCS/AGS alignment comparison via the FDAI looks good, and if no PGNCS warning lights are present -- O.K.!

5. The LM crew may have to change RLS after landing to correct for previous adjustment to it. How is the altitude measured? Above what?

Ans. RLS is updated in P57 by loading the desired Lat, Lon, and altitude. The altitude loaded should correspond to the desired incremental change from the last (present) RLS magnitude.

6. Does P12 get its lift off time from the Talign last loaded into P57?

Ans. Yes! P12 gives the crew the opportunity to change this time if they so desire. (If no P57 operation had preceded P12, a prelaunch erasable loaded value is used.)

7. Are the pitch and yaw angles, expected after pitch-over and displayed prior to liftoff, based on the liftoff REFSMMAT or expected "body" angles? (Nominally, the crew expects to see these angles on the FDAI after pitchover).

Ans. If the nominal liftoff IMU alignment is not used, these angles will not be seen on the FDAI after pitch-over (i.e., they are dependent on the IMU alignment). However, the angular change will be as displayed pre-liftoff.

8. PGNCS drift tests while on the lunar surface are described in the enclosed STG memo #1328 by G. Edmonds, dated April 14, 1969. Alignment mode sequences, thresholds to fail PGNCS or update compensation, effects of gravity/axis etc., are discussed. It should be pointed out that RTCC tracking of PGNCS gimbal (CDU) angles while on the surface provides drift indications only if there is no settling.

9. Procedures to check for X gyro acceleration sensitive drift and X PIPA bias are described in the enclosed STG memos #1337 and #1338 by G. Edmonds. (By the way, compensation for acceleration sensitive terms becomes active when the Surf flag is set).

10. Consecutive platform alignments on the lunar surface utilizing the gravity options (1 or 3) will, among other things, display the angular difference between the gravity vectors calculated each time -- a direct measure of vehicle settling! P68 initializes the gravity vector with the X S/C unit vector. Therefore, the first use of a gravity option in P57 will result in an angular display representing initial S/C tilt from the local vertical.

Malcolm W. Johnston

Malcolm Johnston

M. Johnston
x1523

MIT/IL
Apollo Guidance and Navigation
System Test Group Memo No. 1328

To: A. Laats

From: G.P. Edmonds, Jr.

Date: 14 April 1969

Subject: Calculation of Error in Gyro Drift Using Successive P57 Alignments

References:
1. AG 472-67, Use of AOT in Rear Detents
2. SGA 1-68, An Error Analysis of the Gravity Vector Determination Routine
3. Recommended PGNCS Alignment sequences for the Lunar Landing Surface Phase and P-57 Drift Checks - TRW No. 69: 7252.4-34
4. MEI No. 6016000. Primary Guidance Navigation, and Control System for Lunar Excursion Module
5. STG Memo No. 1256, "Red-line" Limits for In-Flight G&N Perf.
6. STG Memo No. 1081 Checkout of The PGNCS on the Lunar Surface

I. Introduction

Gyro drift measurements are made on the lunar surface by observing the gyro torquing angle resulting from successive IMU alignments. These measured drifts are used to determine if a gyro has failed or if the compensation should be updated.

The gyro drifts measured are made up of:

1. Errors in measurements of the IMU alignments
2. Uncompensated gyro drift

Part II of this memo will show expected measurements error and give general expressions for the alignment measurement error and part III will compute the uncompensated rss gyro drift on the moon with specific values for the IMU now in LM5. Part IV will combine the above two parts with the expected time line on the moon and show the resulting rss measured gyro drifts. Part V will discuss the very large g sensitive term problem, and part VI will make recommendations for Mission G.

I I. SM Alignment Error

The error in alignment is determined by the sum of the errors in the two successive alignments.For P57 (Lunar Surface) alignments estimation of this error is complicated by the fact that several types of alignment are available. The errors are different about the horizontal and vertical axis in alignments using gravity.

Table I shows the rms errors expected for each type of alignment (except option 0). The following error sources are included:

1. Total AOT inaccuracies from Reference 1
2. Errors in gravity determination from Reference 2

The reader is assumed to be familiar with the various alignment options as defined in the GSOP.

Spacecraft shifts can also cause errors if they occur after the option zero alignment. This is discussed in Reference 3. Shifts are ignored in this analysis. In order to calculated drift measurement error about any axis the following procedure is used:

1. Rss the two errors for the option used from table I
2. Rss with the CDU quantization error for option 0 (usually negligible)
3. Calculate the rss drift by

$$\text{rss drift (meru)} = \frac{\text{rss error (deg.)}}{\text{time (hours)} \times 0.015}$$

As an example the following errors about the X axis can be calculated for two successive option 3 alignments separated by 16 hours.

$$\text{rss measurement error} = \sqrt{0.0378^2 + 0.0378^2 + (.0061)^2} = 0.054^\circ$$

$$\text{rss drift uncertainty} = \frac{0.054}{16 \times 0.015} = 0.22 \text{ meru}$$

III. RSS Gyro Drifts on the Moon

In coasting flight the only gyro drift terms expected are the NBD terms, and the rms uncertainty in NBD terms is 2 meru (reference 4).

G Sensitive Terms

The gyro drift measurements on the moon will include g sensitive terms as well as the NDB terms. Lunar surface alignments place X_{sm} up as shown in Figure 1*.

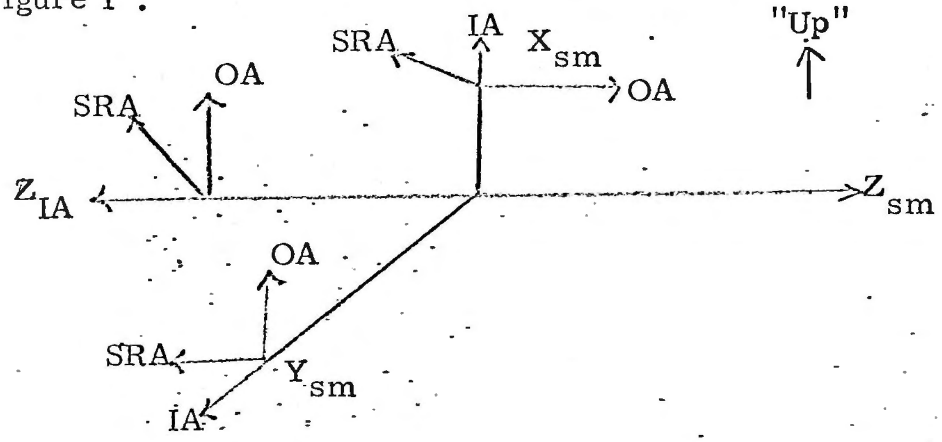

Figure I

The following terms can be expected:

ADIAX - Drift due to acceleration along the X gyro input axis.

The known ADIAX term is compensated for however there is an ADIAX uncertainty. The measured drift will be the sum of the uncompensated drifts.

Measured drift = (uncompensated NBDX)+0.16(uncompensated ADIAX)

The specification for rms uncertainty in ADIA is 8 meru/g. (Reference 4)

ADOAY and ADOAZ - Drift due to acceleration along the Y and Z gyro output axis. These terms are not compensated, but the last measured value for the system in LM5 of ADOAY was 0 meru and of ADOAZ was +1.0 meru/g.

* Due to moon rotation after alignment components of Lunar g will be sensed along Z and Y but the total angle in during the longest period (16 hrs. -see section IV) is 8.5° which is a negligible effect. (except as discussed in part V) Alignment definitions are found in the GSOP.

Therefore these terms can be neglected on the moon, at least for Apollo 11.

The rss drift expected on the moon can now be computed as:

rss X gyro drift = $2^2 + (.16 \times 8)^2$ = 2.4 meru

rss Y gyro drift = rss Z gyro drift = 2 meru

In summary normal g sensitive terms do not contribute to the expected drifts except for ADIAX which makes a small addition to the rss X gyro drift uncertainty. Very large g sensitive terms corresponding to failing gyros are considered in Part V.

IV. RSS Gyro Drift Measured for Apollo 11 on the Lunar Surface

The following time line for alignments just before landing and on the surface was obtained from Reference 3 and conversation with R. White. The times are only approximate.

P52 In Flight
↓ 3 hrs.
P57 Option 1 for $\bar{g}$ only. No drift measurement
↓ 10 minutes
P57 Option 2 REFSMMAT. First drift measurement
↓ 30 minutes
P57 Option 3 Landing Site T_{Align} = current time. - Second drift measurement
↓ 16 hours
P57 Option 3 REFSMMAT - Third drift measurement
↓ 2 hours
P57 Option 3 Landing Site T_{Align} = launch time. Fourth drift measurement

Table II shows the result of using parts I and II of this memo with the above time line to obtain expected gyro drift measurements. Columns 1 - 2 are self explanatory. Column 3 shows the alignment option.

The option for the first and second alignment in any drift check is shown. Column 4 gives the orientation that is used in the second alignment. These orientations are defined in the GSOP. Column 5 gives the rss measurement errors from part II of this memo. Column 6 is the final rss expected gyro drift measurements resulting from measurement errors of part II and the gyro uncertainties of part III.

V. Failing Gyros With Very Large g Sensitive Terms

When a gyro is failing it is likely that very large (greater than 100 meru)g sensitive terms will exist while the bias terms remain nominal. If this occurs on the moon, drift measurements will show only nominal values which might be assumed to be NBD terms. The drift measured will depend on the size of the g sensitive term and on what fraction of gravity is along that particular gyro axis. The X gyro input axis will sense lunar g or 1/6 earth g. The other axis will sense smaller amounts depending on the errors in alignment, gyro drift, and lunar rotation between T_{align} and the GET of the drift measurement.

Measurements of G Sensitive Terms

It would be highly desirable to make approximate measurements of g sensitive terms. Two possibilities have been considered:

1. Further analysis of the data during presently planned alignment might reveal g sensitive terms. For the X gyro all data includes ADIAX and NBDX with the ADIAX terms 1/6 of what would occur on the earth. There is no way to separate these except to place the X_{sm} axis near horizontal which is not presently planned.

For the Y and Z gyros and SRAX it may be possible to use data on stable member motion during some presently planned periods when lunar g is not very close to parallel to the sm X axis so that the Y_{sm} and Z_{sm} sensitive axis will see a large fraction of lunar g. The only such time is during the "gravity determination" portion of an option 1 or 3. Unfortunately calculations show that only g sensitive terms greater than 800 meru can be detected and these only if no spacecraft motion is assumed.

The sm x axis is about 8° from lunar g after the 16 hours period shown in part IV. However, again a practical measurement is not possible.

It is concluded that the present lunar time line does not permit measurement of g sensitive terms to a sufficient accuracy to identify failing gyros.

2. A lunar surface checkout program was developed but was rejected for inclusion in the luminary programs (Ref. 6). The program would have detected a failing gyro with large g sensitive terms.

VI. Recommendations

The only measurements of gyro performance that will be available are NBD terms. Therefore, it is recommended that the failure red lines and compensation update limits be as follows:

a) Failed gyro

The gyro failure "red line" is set so that there is no reasonable probability that the combination of gyro performance uncertainty and measurement errors can exceed the red line. To achieve this the red line is set at 13 times the largest value in column 6 of table II.

$$13 \times 7.6 = 100 \text{ meru}$$

This is the same value recommended for other mission times (ref. 5), and is to be used for all lunar surface drift measurements. Failures causing large g sensitive terms will not be detected.

b) Compensation Update

The compensation should be updated when there is a reasonable probability that the result will be an improvement. This will be achieved by updating the NBD terms only whenever the measured drift exceeds 2 times the value in column 6 of Table II.* The drift compensation is updated as follows:

Updated compensation = measured drift + existing compensation

It is further recommended that the inclusion of a lunar surface checkout program for post mission G programs be studied.

George P. Edmonds, Jr.
System Test Group

GPE: ek

Distribution:
D. Dolan
MIT at GAEC
MIT at KSC
MIT at MSC
MIT at NAR
E. Grace
R. Lones
J. Reedy
R. Sheridan
R. White
M. Johnston
N. Sears
F. Grant
K. Kido
V. Megna
P. Felleman
J. Feldman

---

*A preliminary study (using Fred Grant's error study) of updating NBDX when ADIAX was actually the changed component, indicates very small additional trajectory errors.

Option # Description	Rms Error about X_{sm} Axis	Rms Error about Each Y_{sm} and Z_{sm} Axis	Data Source	Remarks
1. -Use stored attitude or REFSMMAT and gravity	Alignment not meas.	0.0141°	Lab test and Reference 2	Lab test gave 0.02° for 2 axis, or 0.0141 per axis. SGA #1-68 gives 25 mr = .0132° for 2 axis or 0.10° for single axis. Used larger value.
2. - Sight on 2 stars	0.0415°	0.0415°	Ref. 1	Used values for 1 sighting per star. For multiple sightings divide by $\sqrt{\text{number of sightings}}$. Assumed forward detents.
3. - Sight on 1 star and gravity	0.0378°	0.0141°	Ref. 1	All star error assumed about x axis. Also star near horizon assumed. Otherwise, error increase by 1/cos(elevation angle)
In Flight	0.025°	0.025°	Ref. 1	Same comments as for Option 2.

TABLE I

1 Drift Meas. Number	2 Time Between Alignment-hrs.	3 Alignment Option First/second	4 Second Alignment Orientation Option	5 Rss Drift measurement uncertainty Section II	6 Total rss drift Uncertainty
1	4.0 hrs.	flight/2*	REFSMMAT	$\left.\begin{matrix}X\\Y\\Z\end{matrix}\right\}$ = 0.80 meru	$\left.\begin{matrix}X\\Y\\Z\end{matrix}\right\}$ 2.2 meru
2	1/2 hour	2/3	Landing site T_{align}=present	X = 7.2 meru $\left.\begin{matrix}Y\\Z\end{matrix}\right\}$ = 5.4 meru	X = 7.6 meru $\left.\begin{matrix}Y\\Z\end{matrix}\right\}$ = 5.8 meru
3	16 hours	3/3	REFSMMAT	X = 0.22 meru $\left.\begin{matrix}Y\\Z\end{matrix}\right\}$ =0.09 meru	X = 2.4 meru $\left.\begin{matrix}Y\\Z\end{matrix}\right\}$ =2.0meru
4	2 hours	3/3	Landing site T_{align}=launch time	X = 1.8 meru $\left.\begin{matrix}Y\\Z\end{matrix}\right\}$ = 0.73 meru	X = 3.0 meru $\left.\begin{matrix}Y\\Z\end{matrix}\right\}$ =2.1 meru

Rss Drift Uncertainty Values for Apollo 11

TABLE II

---

*An option 1 alignment is planned shortly after landing, but on a g vector is obtained and no drift measurement is available.

MIT/IL
Apollo Guidance and Navigation
System Test Group Memo No. 1337

Johnston

To: Ain Laats

From: George P. Edmonds, Jr.

Date: 25 April 1969

Subject: Further Information on Lunar Surface Drift Measurements

Reference: STG Memo No. 1328, "Calculation of Error in Gyro Drift Using Successive P57 Alignments

Introduction

The referenced memo set Lunar Surface criteria for:

1. Gyro Failure red lines
2. Gyro compensation updates.

For the X gyro, a limit can be set above which a large ADIAX term is likely. Above this limit a special non-scheduled test with the X gyro input axis rotated to be down (instead of up) is required.

Value Requiring Special Test

The special test should be run if the measured gyro drift is larger than can be expected from a combination of measurement errors and gyro uncertainties. This will be achieved by setting the limits at 3 times the total rss drift uncertainty shown in column 3 of Table II of Reference 1. The following table gives the limit for each drift measurement and the ADIAX required to give a drift equal to this limit.

Drift Measurement #	X Gyro Drift Retest Criteria meru	ADIAX to give this drift meru/earth g
1	7	40
2	23	137
3	7	43
4	9	54

Test Procedure Outline

1. Obtain usual drift measurement with X input axis up.
2. UPLINK new REFSMMAT placing the X input axis down.
3. Option 0 alignment to preferred orientation uplinked.
4. Remeasure drift.
5. Change in ADIAX = 1/2 (Drift measured in 1 above - Drift measured in 4 above).
6. If a change in ADIAX of greater than 100 meru/earth g is indicated, a gyro failure is indicated. Below this limit update the compensation values.

George P. Edmonds Jr.
George P. Edmonds, Jr.
System Test Group

GPE/mjc
Distribution:
D. Dolan
J. Lawrence
MIT at GAEC
MIT at KSC
MIT at MSC
MIT at NAR
STG File
E. Grace
J. Reedy
R. Sheridan
M. Johnston
N. Sears
P. Felleman
G. Cherry
R. White
J. Feldman
J. St. Amand

MIT/IL
Apollo Guidance and Navigation
System Test Group Memo No. 1338

To: A. Laats

From: G. P. Edmonds, Jr.

Date: 29 April 1969

Subject: Requirement for X Accelerometer Bias Measurement on the Lunar Surface

References:
(1) Unpublished Error Analysis by Fred Grant, MIT
(2) 69-PA-T-52A PGNCS Operations on the Lunar Surface
(3) MEI No. 6016006 Primary Guidance Navigation, and Control System for Lunar Excursion Module
(4) STG No. 1337 Further Information on Lunar Surface Drift Measurements

I. Introduction

The most critical IMU instrument error for boost from the lunar surface is X accelerometer bias (Reference 1), and so a measurement of this term before lift-off is of interest.

Present plans (Reference 2) have the X accelerometer input axis continuously nearly vertical (up), and so lunar g is measured along this axis. Bias can then be calculated by adjusting the lunar g measurement for scale factor error and subtracting lunar g. Therefore, bias measurements will have errors due to lack of knowledge of Lunar g and accelerometer scale factor uncertainty.

This memo will show that adequate X accelerometer[*] bias measurement cannot be obtained and so an additional procedure is required.

II. Errors

Bias can be obtained from the following formula:

$$\text{Accelerometer Bias } (\text{cm/sec}^2) = (\text{X Accelerometer lunar g measurement}) \times (\text{Scale factor correction}) - \text{Lunar g}$$

$$= \left(\frac{\text{Total number of pulses X accelerometer}}{\text{time of measurement}}\right) \times (\text{scale factor correction}) - \text{lunar g}$$

The most important error sources are uncertainty in lunar g and accelerometer scale factor uncertainty.

---

[*] Y and Z accelerometers are near level and adequate bias measurements can be obtained.

Accelerometer Scale Factor

Since the X accelerometer input axis is up, full lunar g will be sensed, and bias errors cannot be separated from scale factor errors. The 1 σ scale factor uncertainty is 116 ppm (Reference 3). The resulting uncertainty in bias is:

$$1/6 \times 979 \times \frac{116}{10^6} = .0189 \text{ cm/sec}^2$$

This is a negligible uncertainty.

Uncertainty in Lunar g

MIT is trying to obtain a firm estimate for the uncertainty in lunar g. The best estimate now available is that g will be between 163 and 167 cm/sec^2 on a 1 σ basis. Reference 1 indicates that a negative bias error of about 4.00 cm/sec^2 will give a 35,000 ft perilune which is about the safe limit. Therefore, if the accelerometer bias is based on knowledge of lunar g, this one error source can result in the minimum perilune on a 1 σ basis. In other words, such a lunar g bias measurement can not increase confidence in the X accelerometer.

Recommendations

Either of the following two policies is recommended:

1. Compare AGS accelerometer measurement of lunar g to the PGNCS measurement. The AGS accelerometer accuracy is not known; however, assuming it to be roughly equivalent of the PGNCS, a limit on the difference (after applying known compensation) of 1 cm/sec^2 would give good confidence that a safe perilune would result. For greater differences the PGNCS bias should be measured as in 2 below to determine which system has the error.

2. Repeat the measurement of lunar g with the X accelerometer input axis down. Uplinking a preferred REFSMMAT for this orientation would be required (this would also allow X gyro input axis g sensitive drift to be measured, (Reference 4). Bias is then obtained as:

   X accelerometer bias (cm/sec^2) = 1/2 x (lunar g measured X up-lunar g measured X down)

In any case continuous monitoring of the X accelerometer output for stability while on the moon will increase confidence in the PIPA. This monitoring will be particularly important if operational considerations preclude either of the above two recommendations.

George P. Edmonds Jr
G.P. Edmonds, Jr.
System Test Group

GPE/ek
Distribution:

D. Dolan
MIT at KSC
MIT at MSC
MIT at NAR
MIT at GAEC
STG File
G. Cox
G. Edmonds
E. Grace
A. Laats
R. Lones
P. Sarda
R. Sheridan
M. Johnston
R. White
P. Felleman
J. Kernan
G. Bukow