



AC ELECTRONICS

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January 15, 1971
AP71-00038-NO017

National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas - 77058

Attention: Mr. R. Albon - Project Officer

Subject: NAS9-10356 - The Two Degree Yaw at the End of P64

Gentlemen:

Attached are copies of Delco Memorandum SE-71-10 which provides an explanation of the positive yaw at the end of LGC Program P64.

The memorandum explains how a truncation error in the integration of the landing site position is sufficient to cause the positive two degree yaw. While this may not be the only error contributing to the yaw, we feel it clearly indicates the diminutive magnitude of cross-range error needed to generate a two degree yaw as P64 approaches the landing site.

Although we do not consider that this two degree yaw will present any mission problems, consideration should be given to correcting these truncation errors for future programs.

This information is of particular interest to Mr. R. Nobles, NASA/MS.

Very truly yours,

DELCO ELECTRONICS DIVISION
General Motors Corporation

J. L. Stridde - Head
Program Office
APOLLO

JLS:dw
Attachment

CC:w/attach: Messrs. H. Hodges, M. Holley, R. Nobles (2), C. Tilman (GAC),
A. Klumpp (MIT/SDL), R. Larson (MIT/SDL), O. Cerbins (TRW/Houston)

SYSTEMS ENGINEERING MEMORANDUM SE-71-10

12 January 1971

To: D. Ziemer

cc: T. Hanley, S. Macy, P. Seligsohn, C. Clark, H. Neuville,
J. Stridde, J. Landwehr (10), File

From: L. Hull

SUBJECT: THE TWO DEGREE YAW AT THE END OF P64

An intermittent one degree to three degree positive yaw of the LM during the last six to ten seconds of LGC Approach Phase Program of P64 was discovered by Grumman, Bethpage. Although this problem was not noticed in simulations of missions before Apollo 14, it could have gone unnoticed because it is so small in magnitude.

Conclusions

Program P64 computes a desired yaw angle to point the windows toward the landing site. Changes in this commanded yaw angle (THETAD) are caused by the cross-range motion of the LM. Uncertainties in LM autopilot control appear to generate random cross-range motion. Therefore, the observed variations of $+1^{\circ}$ to $+3^{\circ}$ from run to run are logically attributable to the autopilot. However, the autopilot is not generating the positive yaw bias.

This positive yaw bias is a result of truncation errors in the LGC landing guidance equations. The most obvious error is the integration of the landing site position. There is a 1/16 meter per two second servicer cycle error in the Y component of the landing site integration.

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Discussion of the Positive Yaw Bias Effect

The pad loaded landing site (\overline{RLS}) is operated upon in Program P63 to compute the location of the landing site (\overline{LAND}) at throttle-up time in stable member coordinates. From throttle-up time, \overline{LAND} is integrated to present time each two second servicer cycle.

$$\overline{LAND}_{NEW} = /LAND/ \text{ UNIT } (\overline{LAND}_{OLD} - \Delta t \overline{LAND}_{OLD} \times \overline{\omega M})$$

$/LAND/$ is the magnitude of \overline{RLS}

Δt is the difference between PIPTIMES, approximately two seconds

$\overline{\omega M}$ is the moon's rotational rate.

This computation has an intermediate scaling of 2^{25} meters or 1/8 meter quantization. With the platform in the preferred orientation, Y_{SM} is in the cross-range direction. The cross-range velocity of the landing site is approximately 1-3/32 M/sec or 2-3/16 M per servicer cycle. The \overline{LAND} integration truncates this to 2-1/8 meters. Downlink data from the hybrid simulation verified that the LGC indeed updates \overline{LAND}_Y by 2-1/8 meter every two seconds.

Landing guidance is done in a "moon-fixed" coordinate system. The transformation (CG) from stable member coordinates to guidance coordinates is done by the following vector equations.

$$\overline{RGU} = CG^* (\overline{R} - \overline{LAND})$$

$$\overline{VGU} = CG^* (\overline{V} - \overline{\omega M} \times \overline{R})$$

where \overline{R} and \overline{V} are the stable member components of the LM state vector.

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During P64 landing guidance can only do velocity nulling in cross-range because $\overset{*}{\text{CG}}$ is erected every two seconds. When the cross-range velocity (VGU_Y) is nulled, the LM has 1/32 meter/second cross-range velocity with respect to $\overline{\text{LAND}}$. Therefore, the commanded yaw angle will tend to turn at

$$\frac{1/32 \text{ M/sec}}{\text{range}} \quad (\text{approx. } .2 \text{ deg/sec at end of P64})$$

where range is computed in vehicle coordinates.

In an effort to verify that the truncation error in the computation of $\overline{\text{LAND}}$ was responsible for the yaw bias, the LGC was patched to add 1/8 meter to the Y component of $\overline{\text{LAND}}$ each servicer cycle. This is equivalent to "rounding up" in the integration of $\overline{\text{LAND}}$, which changes the sign of the cross-range integration error. This "minimum" change was sufficient to change the yaw direction. Therefore, it is concluded that the truncation error of the $\overline{\text{LAND}}$ integration is responsible for the positive yaw bias during P64.

Similar results were obtained by a scientific simulation of the landing guidance equations when a 1/16 meter integration error was introduced into the computation of $\overline{\text{LAND}}$.

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Other Causes Considered

Before finding that LAND has a truncation error in its integration, a number of other things were considered and ruled out as causes for the positive yaw bias.

1. Window Geometry

Since the thrust vector is not along the X axis of the vehicle, the X axis of the LM will be slightly out of the X-Z guidance plane. This misalignment coupled with the pitch attitude would necessitate a slight yaw angle to point the windows toward the landing sight.

This was ruled out as a cause when the yaw was still positive when the thrust vector alignment was changed.

2. Loss of Visibility

When the look angle of the landing site exceeds approximately 65° , the LGC points the window in the direction of +Z axis of the guidance coordinate system rather than the landing site. This is done in an attempt to prevent a 180° yaw if the landing site were to be beneath the LM X axis at the end of a nominal auto P64; the look angle is in the neighborhood of 65° .

This was ruled out as a cause for the yaw because the yaw command seemed continuous. Also, +Z guidance is in the same plane as LAND and the look vector (and the X axis of the LM, almost).

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3. Moon Rotation

The guidance frame is rotating about $\overline{\omega M}$, in addition to \overline{LAND} due to cross-range velocity. Even if there were no cross-range velocity, this would be a changing yaw command due to moon rate.

This was ruled out when it was shown to be a rotation of -9.5×10^{-6} radians/second.

4. Autopilot Bias Error

The LM DAP has a 0.3° deadband during P64. In addition to the deadband, there are truncation errors in the interface between guidance and the DAP, FINDCDUW, which amounts to 0.22° deadband between guidance's desired attitude and the desired attitude of the DAP (\overline{CDUXD}). Even worse, FINDCDUW does not use the same truncation when computing a desired rate ($\overline{OMEGAPD}$) for the autopilot. Hence, there can be a .11 deg/sec greater rate desired than the rate of change of the desired attitude (\overline{CDUXD}).

Although the inputs to the DAP are inconsistent, no evidence of a significant bias error was found. This was confirmed by the symmetry of the yaw response to quantization of the \overline{LAND} integration.

Recommendations

The \overline{LAND} truncation error does not present any mission problem for Apollo 14. Consideration should be given to correcting the obvious truncation errors in the integration of \overline{LAND} and in FINDCDUW for future programs.