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USER'S GUIDE FOR RECONSTRUCTED ROLL REFERENCE (γ_{RR})

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March 31, 1975

Prepared for:
George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812

Contract No.: NAS8-20899
IBM No.: 75W-00064

IBM Federal Systems Division Space Systems/Huntsville, Alabama

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PREFACE

This User's Guide is intended to be used with both the Analysis Data printout and the Compressed Data printout of the reconstructed roll reference for Skylab. Discussion of the Data Tape is left to Appendix C.

A general description of the theory and techniques used for reconstruction of the roll reference between star tracker updates is given in Section 1. Information directly applicable to the printouts is given in Section 2, Parameter Units and Definitions; and Section 3, Message Definitions. Since vehicle drift plays such an important role in the reconstruction, and since its factors are somewhat complex, an entire section, Section 4, is devoted to a discussion of it. And, finally, some discussion of the estimated accuracies of the roll reference for each mission is covered in Section 5.

Two complete sets of reconstructed data have been produced and delivered. The first set uses all ATMDC data, some of which reflects 1950 Ephemeris data. The second set was generated by substituting 1973 Ephemeris data for the corresponding ATMDC values and reprocessing all the data. A discussion of the differences in these data sets is covered in Appendix D.

SECTION 1

GENERAL DESCRIPTION OF RECONSTRUCTION

1.1 INTRODUCTION

In an effort to make the information contained in the remaining sections of this manual, which relate directly to the roll reference data printout, more meaningful, this first section is devoted to an explanation of the physical relationships which made the roll reference reconstruction necessary. It is felt that a basic understanding of at least the overall affects of the Workshop control system, the control rate gyros, the momentum dump scheme, and the star tracker on the roll attitude will make the information relative to the printout much more comprehensive. Other factors, rate gyro drift compensation and rate gyro scale factor errors, are covered in Section 4.

1.2 THE ROLL REFERENCE ANGLE

The roll reference angle, γ_{RR}, is the angle between the projection of solar north and the experiment pointing control system X_{EPC} axis as seen in the plane of the solar disc. This angle was calculated once per second in the flight software during the mission as a function of several navigation parameters, the star tracker outer gimbal angle, and the canister roll angle, and its value was telemetered with the normal ATMDC telemetry (see Appendix A). Each of the independent parameters was maintained with enough accuracy throughout the mission to give a roll reference accurate to a few arcminutes as long as the star tracker was actively tracking a star. And this accuracy would continue for several hours following an active star tracker period if the roll attitude of the Workshop remained space-fixed inertially.

There were several physical constraints related to the Skylab vehicle and its orbit which prevented a continuously active star tracker condition and other constraints which prevented inertial attitudes between active star tracker periods. These constraints eventually led to the seriously degraded roll reference maintained by the flight software, no fault of which was the flight software itself. These constraints are discussed in the following paragraphs.

1.3 Z-AXIS CONTROL

The control moment gyros, CMG's, were used in the primary control system and were capable of a pointing accuracy better than one arcminute about the Workshop roll (Z) axis. In roll, the only feedback came from the Z-axis rate gyros. In theory, if the CMG's kept the integral of the rate gyro output at zero, the Z-axis would remain space-fixed inertially. In the real world, however, the rate gyros had a bias, and the CMG's had to continuously drive the Workshop at a rate large enough to null the rate gyro output. This rate is referred to as drift, and a more detailed discussion of its affects on the reconstruction and its complexity are covered in Section 4. For the discussion in this section, it is sufficient to say that it was necessary to determine this Z-axis drift between each pair of star tracker updates in order to reconstruct the roll reference continuously between the updates.

1.4 MOMENTUM DUMP

Due to the gravity gradient on the Skylab vehicle, the available momentum in the CMG's for control would soon be depleted (CMG saturation) just holding the solar inertial attitude if it were not for the momentum dump scheme. The dump scheme was a set of maneuvers about all three axes which took the Workshop away from the solar inertial attitude near orbital sunset and returned the attitude before sunrise, while at the same time desaturating the CMG's. The dump scheme also provided one other function. It changed the inertial attitude about the Z-axis in order to maintain an optimum orbital plane error. The optimum orbital plane error angle did not itself change for a given vehicle configuration, but the orbital plane did. It precessed inertially at a rate of 5^{o} per day.

The effects of the precession on the roll reference can be seen in the plots of γ_{RR} for the unmanned portions of the mission in Appendix B. The sinusoidal curve is skewed due to the continuous rotation inertially about the Y-axis (yaw) needed to maintain solar inertial attitude (360^{o} per year).

1.5 STAR TRACKER

The flight software maintained its navigation data and monitored the canister roll angle throughout the Skylab mission within the accuracy required for the roll reference. Bit it depended upon the star tracker to relate vehicle roll attitude to some known celestial body. (Details of this relationship are left to Appendix A.)

This star tracker reference angle had meaning only if the vehicle were at the solar inertial attitude; hence, the flight software turned off an active star tracker when the solar inertial mode (or experiment pointing mode) was exited. It also turned off an active star tracker during dump maneuvers and when the reference star was occulted by the earth. During these inactive periods, and when the star tracker was turned off manually, the flight software used the last good reference angle for the roll reference calculations. When all of the necessary conditions for an active star tracker returned, the software returned the star tracker to its track/search mode to relocate and track the reference star. This it did without fail unless the star tracker had been moved manually from its last track position or the vehicle was not returned to its original attitude. The tolerance on these conditions was ± 2 degrees about each of the two star tracker gimbal angles. If the star tracker could not locate the star within its 4x4 degree search area in 25 seconds, the flight software turned it off and continued using the last good reference angle. Manual intervention was then required to relocate the star, and the roll reference was in error until the star was relocated.

1.6 ROLL REFERENCE HISTORY

Early in the SL-2 mission the star tracker performed as it was intended and the roll reference provided by the flight software was accurate. On day-of-year (DOY) 149, however, a momentum dump occurred which changed the roll attitude more than 2 degrees (EVZ3=4.0^{o}). After the dump was completed, the star tracker searched for but could not locate its star.

Once the reason for the "failure" was determined, the star tracker was manually driven to predicted gimbal angles, i.e., a position which should place the star within the 4x4 degree search pattern. The star was then pinpointed by the star tracker via the search mode and the reference angle was updated in the flight software. Roll reference was accurate once again.

This problem with the large dump angle occurred again on DOY 149 fifteen hours later, and on DOY 150, DOY 153 (twice), and DOY 154. Between these times the star tracker performed well. The manual intervention required when the tracker lost the star, however, interrupted the work schedule of the crew.

The procedure which was used to solve this roll reference problem still involved crew intervention, but it became a part of the work schedule at scheduled intervals instead of unplanned interruptions. The procedure was much the same as described above for the first failure except that the star tracker was made inactive as soon as the software was updated with a current reference angle. Star tracker "updates" were made several times a day at key times for experiments.

1.7 ROLL REFERENCE RECONSTRUCTION

From the discussions in the previous paragraphs it is obvious that the error in the roll reference angle maintained by the flight software was negligible when the star tracker was active (see Section 5), and was a function of roll drift and orbital plane error adjustment when the star tracker was inactive. Reconstruction, then, is a matter of using the star tracker updates as roll reference points and adjusting for all inertial roll vehicle movement between updates. Although this method for reconstruction appears simple in theory, there were two major problems involved in the application; neither the drifts nor the orbital plane error adjustments were known to the accuracy required.

Schemes were defined, implemented, and tested to determine both of these unknowns. Methods to check the accuracy of the resulting values were also devised. Discussion of these methods and the accuracies are covered in Section 5. Details of the schemes are covered in Appendix A, but a summary follows.

Orbital Plane Error Adjustment - As was mentioned in Section 1.4, the momentum dump scheme returned the vehicle to its initial attitude about the X- and Y-axes (solar inertial attitude) but left it offset about the Z-axis in order to maintain the proper orbital plane error. The amount of change for each dump was calculated as the angle EVZ3. This value was telemetered with the normal telemetry, but only the high order 11 bits of data (binary) were transmitted, giving an accuracy of -0, +5.3 arc-minutes. In order for the Workshop control system to maintain this offset, the control quaternian, which reflected the desired attitude, had to be adjusted, or initialized, for this change. This initialization occurred at the same instant that the dump maneuvers ended, so a check at that time for the amount of change in the quaternian would reveal the change in inertial roll attitude and, thus, the change in roll reference.

Roll Drift - The total roll attitude change from one update to the next can be determined simply as the change in the star tracker reference angle. This difference minus the amount of change due to the EVZ3 maneuvers shows the change in roll due to rate gyro drift. It was assumed that the drift was constant over the reconstruction interval between updates. Problems with this assumption and the resulting inaccuracies are covered in Sections 4 and 5.

Once the individual values of EVZ3 and the roll drift were known, roll reference reconstruction was accomplished by making the same calculations as the flight software and biasing the last good star tracker reference angle (ψ_{3R}) for changes it would have seen due to drift and EVZ3 maneuvers if the star tracker had been active. A reconstructed value for γ_{RR} was determined for each telemetry cycle for which data was available. For most of the mission, this frequency was once each 15 seconds.

SECTION 2

PARAMETER UNITS AND DEFINITIONS

2.1 INTRODUCTION

Two printouts have been created containing reconstructed roll reference data. The first of these, the Compressed Data, was originally intended to be the only distributed output. It contains the roll reference angle each time it changed by 3 arcminutes or more. It also tabulated for reference only the flight software value for roll reference at the corresponding time. The other printout, the Analysis Data, was originally intended for use by the analyst who examined each reconstruction segment for errors in the data. The Analysis printout contains all the data necessary to explain every change in the roll reference angle.

2.2 COMPRESSED DATA

The Compressed Data printout contains a value for γ_{RR} at each time that it changed from the previously printed value by three arcminutes or more. Hence, it can be used as a table of roll reference angles versus time accurate to three arcminutes of the reconstructed value. (Reconstructed accuracies are discussed in Section 5.) Time frames for which reconstruction cannot be accomplished (see Section 3) are indicated by comments. The units and definitions of all parameters are given in Table 2.1 in alphabetical order.

2.3 ANALYSIS DATA

The Analysis Data printout contains a value for γ_{RR} at each time that a significant event occurred, a significant independent parameter changed values, or γ_{RR} changed by three arcminutes or more from the previously printed value. Tabulation of an intermediate calculation for γ_{RR} needed

Table 2.1

PARAMETER DEFINITIONS FOR COMPRESSED DATA PRINTOUT

PARAMETER	UNITS	DEFINITION
GAMMARR(R)	arcmin.	The reconstructed roll reference angle. It has been adjusted to be in the same range as the telemetered value from the flight software for comparison purposes.
GAMMARR(TM)	arcmin.	The value of roll reference contained in the flight software. It is the telemetered value converted to the same units as requested for the reconstructed roll reference for comparison purposes.
GAMMARR(TM)	pirads	The telemetered value of roll reference from the flight software. Its range is $\pm 1\ \pi$ radian (± 180 degrees).
GMT	days/ hrs/ min/ sec	The day-of-year and Greenwich Mean Time used as the time sync for the current telemetry cycle. It is the ground sync on the telemetry time of ATMDC telemetered value of Mission Timer.
Mission Timer	days/ hrs/ min/ sec	The telemetered value of the onboard mission clock. This clock was updated via ground command to maintain a Greenwich Mean Time reference. Clock overflowed (reset to zero) every 64 days.

for analysis is also included. All the data given in the comments are defined in Table 2.2 with the complete list of parameters. All the data needed for reconstruction at any time in the mission is provided by this printout except for certain constants which are given in Appendix A and the quaternian values used to calculate EVZ3P, ZERR, and PHIZE (see Appendix A for definition of PHIZE).

Table 2.2

PARAMETER DEFINITIONS FOR ANALYSIS DATA PRINTOUT

PARAMETER	UNITS	DEFINITIONS
BETAZ	Deg.	The telemetered value of the canister roll angle. A value is printed in the comments field each time β_z changes by one arcminute or more from the previously printed value.
D	arcmin/hr	The drift used in the reconstruction of the segment which is terminated at the time this value is printed.
DEL T	sec & (hrs)	The time interval of the reconstruction segment which is terminated at the time this value is printed.
D1	arcmin/hr	The drift calculated between the current and the previous star tracker update.
EVZ3	Deg.	The telemetered value of the roll attitude adjustment from the previous dump maneuvers.
EVZ3P	Deg.	The calculated value of the roll attitude adjustment from the previous dump maneuvers.
GAMMARR(C)	arcmin.	An intermediate calculated value for roll reference. See Appendix A for complete definition.

Table 2.2 (Continued)

PARAMETER	UNITS	DEFINITIONS
GAMMARR(R)	arcmin.	The reconstructed roll reference angle. It has been adjusted to be in the same range as the telemetered value from the flight software for comparison purposes.
GAMMA Y	Deg.	The telemetered value of the yearly sun angle computed by the flight software.
GMT	days/ hrs/ min/ sec	The day-of-year and Greenwich Mean Time used as the time sync for the current telemetry cycle. It is the ground sync on the telemetry time of ATMDC telemetered value of Mission Timer.
Mission Timer	days/ hrs/ min/ sec	The telemetered value of the onboard mission clock. This clock was updated via ground command to maintain a Greenwich Mean Time reference. Clock overflowed (reset to zero) every 64 days.
PSI1	Deg.	The telemetered value of the star tracker inner gimbal angle at the time of the current update.
PS13	Deg.	The telemetered value of the star tracker outer gimbal angle at the time of the current update.

Table 2.2 (Continued)

PARAMETER	UNITS	DEFINITIONS
STAR	N/A	A coded message which identifies the star currently used for update: 1 - Achernar 2 - Alpha Crux 3 - Rigil Kent 4 - Canopus
SUM EVZ3P	Deg.	The summation of EVZ3 maneuvers since the last star tracker update. Incremented by EVZ3P if it is reasonable; otherwise incremented by EVZ3.
T( )	N/A	An integer count of the reconstruction segment terminated at the time of print if D, DEL T, etc., are also printed. If only PSI1, PSI3, and ZERR are printed with this parameter, it indicates the end of an active star tracker period and the beginning of the reconstruction segment. Segments are numbered for reference only.
ZERR	arcmin.	The offset error about the Z-axis from the control null position. See Appendix A for complete definition.

SECTION 3

MESSAGE DEFINITIONS

3.1 INTRODUCTION

The messages in the comments field of both printouts are discussed in this section. The Compressed Data printout contains only a subset of the Analysis Data printout messages, those which identify time intervals for which reconstruction cannot be accomplished. Messages in the comments field which give data only have already been defined in Section 2 and will not be discussed here. The messages are discussed in alphabetical order for easier reference.

3.2 ATTITUDE NOT SI OR EP

This message indicates that the Workshop control system is no longer maintaining the solar inertial (SI) nor experiment pointing (EP) attitude. This message is reserved for those occasions when the Attitude and Pointing Control System (APCS) mode is SI or EP, but the deviation from the desired X or Y attitude is equal to or greater than 4.2^0 or the Z attitude deviates from the desired by 20^0 or more. The deviation in each case is caused by loss of control due to saturated CMG's, a condition which was seldom a problem until one of the three CMG's failed on DOY 327. Reconstructed roll reference is maintained up to the time that this message is printed since deviations from the desired roll attitude are included in reconstruction (in all delivered printouts except the SL-4 data dated 18 November 1974). As long as the deviations exceed the above control tolerances, no reconstruction is attempted. See Section 3.13 for the "return" message.

3.3 CALCULATED DRIFT NOT REASONABLE

After the rate gyro SIX-PACK installation on DOY 236, the calculated drift between star tracker updates was predictable within certain limits. Each time a drift was calculated outside these limits, this message was printed at the same time as the second update to notify the analyst of this condition. Note that each time this message is printed, the drift, D, used for the preceding segment is not equal to the calculated drift, D1. See Section 4 for additional information regarding drift.

3.4 CHANGE TO EXPERIMENT POINTING MODE

This message is used only to indicate a switch from the solar inertial mode to the experiment pointing mode. It does not imply any maneuvering nor does it affect the reconstruction in any way.

3.5 CHANGE TO SOLAR INERTIAL MODE

This message is used only to indicate a switch from the experiment pointing mode to the solar inertial mode. It does not imply any maneuvering nor does it affect the reconstruction in any way.

3.6 DUMP COMMENCE

This message indicates that the momentum dump maneuvers have begun. Reconstruction is discontinued until the maneuvers are completed.

3.7 DUMP COMPLETE

This message indicates that the momentum dump maneuvers are all completed. Reconstruction is continued on the first telemetry cycle following this message and includes the orbital plane error adjustment, EVZ3P, for this dump. It should be noted that occasionally the maneuvers are completed without the vehicle being at the exact desired attitude; hence, the vehicle will roll slightly after this message is printed until the control system finds the desired position. This condition does not affect the accuracy of the reconstructed roll reference since deviations from the desired roll attitude are included (in all delivered printout except the SL-4 data dated 18 November 1974).

3.8 EVZ3P DOES NOT COMPARE TO EVZ3

This message flags the analyst that the attempt to calculate a more accurate orbital plane error adjustment angle from the control quaternian has failed. The telemetered value will be used to increment SUM EVZ3P used in the reconstruction. See Appendix A for more information regarding this message.

3.9 MODE NOT SOLAR INERTIAL OR EXPERIMENT POINTING

This message is printed when any APCS mode other than SI or EP is entered while in the SI or EP mode. Reconstruction is discontinued until a return is made (see Sections 3.11 and 3.12). Due to rate gyro scale factor errors and the use of the SI mode for Kohoutek pointing accuracies, reconstruction could not be accomplished for any SI/EP mode interval flanked by other modes unless the interval contained a star tracker update. Hence, if departure from the SI/EP mode was made more than once between any two consecutive updates, roll reference could only be constructed from the first update to the first departure, and from the last SI/EP mode return to the second update.

3.10 NEW STAR - (STAR NAME)

Each time a different star was selected, this message is printed with the particular star name. In the original design of the Analysis Data printout, this message was the only way to determine which star was being used at any particular update. The message, however, was printed so seldom that it was extremely difficult to locate. So another message was added at each update to indicate the star currently being tracked. Lack of space on the update line dictated that this latter message be abbreviated to a code. See Table 2.2 in Section 2, Parameter STAR.

3.11 RETURN TO EXPERIMENT POINTING MODE

This message is printed when a return is made from some mode, other than SI, to the experiment pointing attitude. When the experiment pointing mode is first selected, a maneuver commences which takes the vehicle from its present attitude to the desired EP/SI attitude. This maneuver takes a variable amount of time, and roll reference essentially has no meaning until the maneuver is complete, or, more exact, the desired attitude is achieved. For this reason, the control quaternian is monitored from the time the EP mode was first selected and this message is delayed (along with roll reference reconstruction) until the quaternian indicates that the EP attitude has been achieved within 1.5 arcminutes in all axes.

3.12 RETURN TO SOLAR INERTIAL MODE

This message is printed when a return is made from some mode, other than EP, to the solar inertial attitude. The comments relative to the print time of the message in the preceding paragraph apply also to this message.

3.13 RETURNED TO SI/EP ATTITUDE

This message is printed when SI/EP attitude is approached following a deviation due to loss of control while in the SI or EP mode. The tolerance test for this condition is within 4.2^{o} of desired X and Y attitude and within 20^{o} of Z. Reconstruction is resummed following this message. The roll reference remains accurate as the roll (Z) attitude approaches its desired position since deviations from the desired roll attitude are included in the reconstruction (in all delivered printout except the SL-4 data dated 18 November 1974).

SECTION 4

CONTROL DRIFT

4.1 INTRODUCTION

The apparent roll drift calculated between star tracker updates is a function of more factors than just the rate gyro drift bias. This section discusses those factors and their affects on the accuracy of the reconstructed roll reference.

4.2 RATE GYRO DRIFT

The rate gyro drift; i.e., the biased output from the gyros, is the most prevalent contributor to the roll attitude change between updates for most segments. Prior to the rate gyro SIX-PACK installation on DOY 236 this drift was very erratic in some reconstruction segments and very large in others. These conditions made it very difficult to determine reasonable limits on the calculated drift between updates.

After the SIX-PACK was installed, drifts became very constant. When any calculated drift exceeded certain limits, it was assumed that the scale factor error (see Section 4.6) caused the deviation. An average value from the previous segments was then substituted for the drift used in reconstruction.

4.3 RATE GYRO AVERAGING

Another contributor to the apparent drift calculation is related to rate gyro averaging. Normally, rate is measured from two of the three gyros in each axis and their rates are averaged. Naturally, their drifts are effectively averaged, also. If the two gyros disagree in their rate indications, one of the gyros is selected for single gyro control by the flight software via a rate gyro redundancy management scheme. Note that when this change occurs, the drift also changes. This condition occurred only in the pre-SIX-PACK time frame, but it occurred many times there, especially during the SL-3 Mission.

4.4 RATE GYRO SWITCHING

Any single gyro or any pair of gyros could be selected for control by uplink command. When problems began to occur with the gyros, different combinations were selected for varying times in an effort to find the most stable combination. When this action was taken, as it was many times before the SIX-PACK installation, effective drifts changed drastically.

4.5 RATE GYRO DRIFT COMPENSATION

Some amount of gyro drift was expected for the Skylab Mission since all gyros have inherent drift. These drifts were expected to be relatively constant. Knowing this, provisions were made in the flight software to bias the readings of each gyro so that the gyro drift could be compensated. The software biases were commanded by ground uplink. Needless to say, this command code was exercised frequently before DOY 236 since the real gyro drifts were so erratic. Each time the compensation was changed on a gyro currently being used for control the effective drift changed.

4.6 RATE GYRO SCALE FACTOR ERROR

The rate gyro scale factor error is the error in the proportionality of the indicated rate to the real rate. Maneuvers were accomplished on Skylab by driving the Workshop at a constant rate (determined by gyro feedback) for a fixed length of time. It can be readily seen that the resulting attitude error is related directly to the rate gyro scale factor error and is proportional to the magnitude of the maneuver.

When maneuvers were made away from the SI attitude with a later return, the exact attitude would be returned only if the maneuvers about each axis on the return were the negative of the maneuvers away from SI. This condition was rarely the case. Hence, the returned attitude was not the same as before the maneuver, and the magnitude of the error was proportional to the difference of the maneuvers.

The scale factor error only affected the roll reference reconstruction when maneuvers were made about the Z-axis. The resulting roll attitude change due to a set of Z-axis maneuvers was impossible to determine with the available data. The roll attitude change did, however, affect the drift as calculated between updates.

4.7 SUMMARY

The reconstruction technique, as discussed in Section 1, depends upon the accountability of all roll attitude changes between updates. The only method of determining drift has to assume that the drift was constant for a given segment. From the preceding discussions it is obvious that prior to the SIX-PACK installation drifts might not be constant. The consistency in the drift values for several consecutive segments does, however, indicate a relatively accurate determination of drift for those segments and, in turn, an accurate roll reference. The factors which affect the accuracy of a particular segment are discussed in Section 5.

SECTION 5

RECONSTRUCTED ROLL REFERENCE ACCURACIES

5.1 INTRODUCTION

The accuracy of the reconstructed roll reference is a function of many factors. These factors are discussed in this section. Since each reconstruction segment is influenced by combinations of factors, the discussions are directed toward helping the user determine which factors must be considered for a particular segment. From this determination, the confidence level in the roll reference can be determined for any time period.

5.2 HARDWARE

The star tracker and the EPC subsystem (canister roll) are the only significant hardware contributors to the roll reference inaccuracy (significant is herein defined as 1 arcminute or more). The star tracker errors influence roll reference directly only when the tracker is active. But this influence is carried throughout a segment for two reasons. First, the star tracker update at the beginning of a segment is used as the reference angle for reconstruction; and second, both updates are used to calculate the drift which is applied over the segment in reconstruction. The maximum error in the star tracker reference angle is 1.17 arcminutes.

The canister roll angle error influences the roll reference at all times. The maximum error is less than 2.2 arcminutes. The RSS value of the contributors to this error is less than 1.8 arcminutes. The affects of this inaccuracy can be seen in the Analysis Data printout when the canister roll angle, β_z, appears to oscillate (see example at 14 hours on DOY 350).

5.3 ORBITAL PLANE ERROR ADJUSTMENT

A flight software change was made at the beginning of the SL-4 Mission which provided accurate EVZ3 data for portions of each segment. Using this data (351 data points), the following statistical analysis was made:

maximum error:	4.9 arcminutes
average error:	.86 arcminutes
1 sigma:	1.37 arcminutes

The affects of each individual error on the roll reference are a maximum at dump commence and dump complete, and decrease linearly to zero at the updates. The affects are, however, accumulative from several dumps within one segment. Considering the accumulative affects, the following roll reference errors were determined:

maximum error:	4.98 arcminutes
1 sigma:	1.09 arcminutes

The sigma value above was determined by considering only the errors at dump commence and dump complete, where the errors are maximum.

5.4 LINEAR DRIFT ASSUMPTION

The drift calculation for each segment is a function of star tracker accuracy, EVZ3 accuracy, rate gyro drift, and rate gyro scale factor influence. For segments which show a drift close to the average of the preceding segments and had no maneuvers away from SI attitude, the error in roll reference due to the linear drift assumption is negligible. Drifts may vary slightly due to EVZ3 inaccuracies, but if the errors due to this factor have already been considered independently they should not be included again in the linear drift assumption errors. Also, it should be noted that the deviation in drift due to star tracker errors is also a function of the time interval of the segment. If, for example, a star tracker reference angle has a one arcminute error and the time interval is .5 hours, the drift will deviate from the average by 2 arcminutes per hour, quite an extreme. As with the error consideration for EVZ3 rotations, this error must only be considered once relative to its affect on roll reference accuracy.

For segments which show very erratic drifts, roll reference errors of approximately .5 degrees might be expected. It should be noted, though, that even for these segments, the errors are small near the updates (except for the reconstruction following star tracker failure, see Appendix E).

Unmanned data accuracy approx. 5° (App. B)

APPENDIX A

ROLL REFERENCE RECONSTRUCTION

The roll reference, γ_{RR}, has been reconstructed during that part of each orbit in which the solar inertial attitude was maintained except for solar inertial timeframes which did not include a star tracker update. Time intervals during which the star tracker remained active for 60 seconds or more, referred to as star tracker intervals, were not included in the reconstruction segments. The roll reference for the these intervals was calculated directly from the current star tracker data.

All of the variable data needed for reconstruction was taken from the ATMDC telemetry. This data was output at regular intervals in a cyclic fashion. One complete set of ATMDC data was available every 2.458333 seconds when Real Time data was used, and every 15.0 seconds when the Auxiliary Storage and Playback (ASAP) data had to be used. For reconstruction purposes, a telemetry cycle was defined as the set of data which began with the star tracker inner gimbal angle, ψ_1, and ended with discrete output register 5, DO5. Time sync for each set of data was the telemetry time (or record time for ASAP) of the Mission Timer as determined by ground recording systems. This sync time has been labeled GMT for Greenwich Mean Time and it includes the day-of-year.

The star tracker updates (single point references) and intervals were found manually by analysts from tabulated printouts. Once determined, these times were input to a computer program which was also fed all the telemetry data. The calculations made and the logic exercised by this program are discussed below.

At each star tracker update and for each star tracker interval, the roll reference was calculated each telemetry cycle as

$$\gamma_{RR} = \phi_{ZRI} - \psi_{3R} - \rho_N + \beta_Z$$

where ϕ_{ZRI}, the angle in the solar disc between the ecliptic north pole and the star tracker X-axis, is determined from

$$\phi_{ZRI} = \text{Arctan}\ (A/B) - 90^{\circ} \text{ where}$$

$$A = \cos \Gamma_y\ (\sin \alpha \cos \delta \cos \phi_z + \sin \delta \sin \phi_z)$$

$$- \cos \delta \cos \alpha \sin \Gamma_y$$

$$B = \cos \delta \sin \alpha \sin \phi_z - \sin \delta \cos \phi_z$$

(See Table A.1 for values and definitions of constants),

ψ_{3R}, the star tracker reference angle between the vehicle X-axis and the star tracker X-axis, is determined from

$$\psi_{3R} = \psi_3 + \tan \psi_1\ (\phi_{XES} \sin \psi_3 - \phi_{YES} \cos \psi_3)$$

where ϕ_{XES} = the offset angle about the X-axis from SI due to offset pointing as determined from the control quaternian

ϕ_{YES} = the offset angle about the Y-axis from SI due to offset pointing as determined from the control quaternian,

ρ_N, the angle in the solar disc between the solar north pole projection and the ecliptic north pole, was determined from

Table A.1: Baseline Data and Sources

PARAMETER	VALUE	DEFINITION	SOURCE
Γ_Y	VARIABLE	YEARLY SUN ANGLE	CALCULATED AND NAV UPDATE
α_1	95.710833^{o}	RT ASCEN. - CANOPUS	NASA MSC MEMO FM83 (72-143) (1950 EPHEMERIS DATA)
α_2	23.965000^{o}	RT ASCEN. - ACHERNAR	
α_3	-174.049999^{o}	RT ASCEN. - ALPHA CRUX	
δ_1	-52.667473^{o}	DECLINATION - CANOPUS	
δ_2	-57.490445^{o}	DECLINATION - ACHERNAR	
δ_3	-62.822167^{o}	DECLINATION - ALPHA CRUX	
φ_Z	23.442840^{o}	INCLINATION - ECLIPTIC PLANE TO EARTH EQUATORIAL PLANE	THE AMERICAN EPHEMERIS AND NAUTICAL ALMANAC
Γ_Y	75.388140^{o}	VERNAL EQUINOX TO ASCENDING NODE OF SOLAR EQUATORIAL PLANE WITH RESPECT TO ECLIPTIC PLANE	
τ_Z	7.250004^{o}	INCLINATION - SOLAR EQUATORIAL PLANE TO ECLIPTIC PLANE	

$$\rho_N = \text{Arctan}\left[\tan \tau_z \cos (\Gamma_y - \tau_y)\right]$$

(see Table A.1 for values and definitions of constants),

and β_z, the angle between the Workshop X-axis and the Experiment Pointing Control X-axis, is taken from telemetry. The yearly sun angle, Γ_y, was also taken from telemetry. It was calculated by the flight software every 400 seconds.

The correct star right ascension and declination were chosen by monitoring bits 6 and 7 of Status Word 5 (from telemetry). When the condition of these bits changed, a message was printed which identified the new star selected.

The above calculation for γ_{RR} was also made every telemetry cycle during the reconstruction segment. Its value was printed as the parameter γ_{RRC} and is in error only by the amount of change in the roll attitude since the last update. γ_{RRC} does reflect any change in roll attitude which can be detected by the control quaternian. This is accomplished by calculating the roll offset from the desired attitude using the control quaternian and subtracting this value, PHIZE, from ψ_{3R}. This term was included in the calculations for all delivered reconstructed roll reference data except the SL-4 data dated 18 November 1974.

Other changes in the roll attitude since the last update were determined from the orbital plane error adjustments and drift. The orbital plane error adjustment angle was telemetered each cycle (its value changed once per orbit at dump commence), but it was one of the few truncated telemetry parameters and its value was only accurate to +5.3 arcminutes. The following calculations were made one cycle after the dump was complete (as determined from bit 14 of DO5) in an effort to obtain a more accurate value.

The average rate of change (slope) of the third term of the quaternian was calculated every telemetry cycle:

$$S = 1/3 \left[\frac{QVA3'' - QVA3'''}{\Delta t''} + \frac{QVA3' - QVA3''}{\Delta t'} + \frac{QVA3 - QVA3'}{\Delta t} \right]$$

where the primes indicate first past, second past, and third past values.

Then, one cycle after the indication of dump complete, the following calculations were made:

$$Q3(i-2) = QVA3(i-2) + \Delta t(i-1)\ S\ (i-2)$$

$$Q3(i-1) = QVA3(i-1) + \Delta t(i)\ S\ (i-2)$$

$$Q3(i) = QVA3(i) + \Delta t(i+1)\ S\ (i-2)$$

$$EVZ3P(i-1) = 2\ \text{Arcsin} \left[\frac{Q3(i-2)\ QVA4(i-1) - QVA3(i-1)\ QVA4(i-2)}{Q3(i-2)^2 + QVA4(i-2)^2} \right]$$

$$EVZ3P(i) = 2\ \text{Arcsin} \left[\frac{Q3(i-1)\ QVA4(i) - QVA3(i)\ QVA4(i-1)}{Q3(i-1)^2 + QVA4(i-1)^2} \right]$$

$$EVZ3P(i+1) = 2\ \text{Arcsin} \left[\frac{Q3(i)\ QVA4(i+1) - QVA3(i+1)\ QVA4(i)}{Q3(i)^2 + QVA4(i)^2} \right]$$

where the i th terms are those from the telemetry cycle where dump complete was detected and QVA4 is the fourth term of the quaternian.

The three calculations were needed because of the time inconsistency in the telemetry data, i.e., the data may be spread out over a 15 second period. The correct value for EVZ3P was simply the largest absolute value.

These calculations are particularly sensitive to telemetry data dropouts and noise. Hence, the EVZ3P value had to be validated before it could be included in the reconstruction. Since the telemetered value is known to be no more than +5.3 arcminutes in error, EVZ3P was compared to the telemetered value, EVZ3, and if it was outside the range (0, +5.3) it was judged unreasonable. A message to this effort was printed and EVZ3 had to be used for reconstruction. The accumulation of the adjustments was maintained for each reconstruction segment, ΣEVZ3P.

The vehicle drift between any two updates was determined as the change in the star tracker reference angle, adjusted by the accountable attitude changes, per unit of time:

$$D_1 = \frac{\psi_{3R} - \psi'_{3R} + \Sigma EVZ3P}{\Delta T}$$

where ψ'_{3R} is the past angle and ΔT is the time between updates.

For use in the above equation and when used as the reference angle for reconstruction, ψ_{3R} was adjusted back to the Workshop control null position by adding

$$ZERR = 2\ QVA3\ \left[SIGN\ (QVA4)\right].$$

This way, the offset at the update did not affect the reconstructed roll reference angle during the reconstruction segment.

If the reference star was changed between updates, the past reference angle for the new star was determined from the past reference angle for the old star by

$$\psi'_{3R} = \phi'_{ZRI} - \phi_{ZRI} + \psi_{3R}$$

where the prime values are for the new star.

If the drift, D1, was determined to be unreasonable (see Section 4), a better estimate of drift was substituted for the drift parameter, D, used in reconstruction. This substitution was made by the analyst. Otherwise, D was set equal to D1.

Reconstruction for each telemetry cycle was the accomplished as follows.

If D1 was reasonable, or if D was set equal to another value and the flight mode remained SI and/or EP between updates,

$$\gamma_{RR} = \gamma_{RRC} + \sum_{1}^{k} EVZ3P(j) - \Delta t\ D$$

where k = number of adjustments made from the last update to the current time

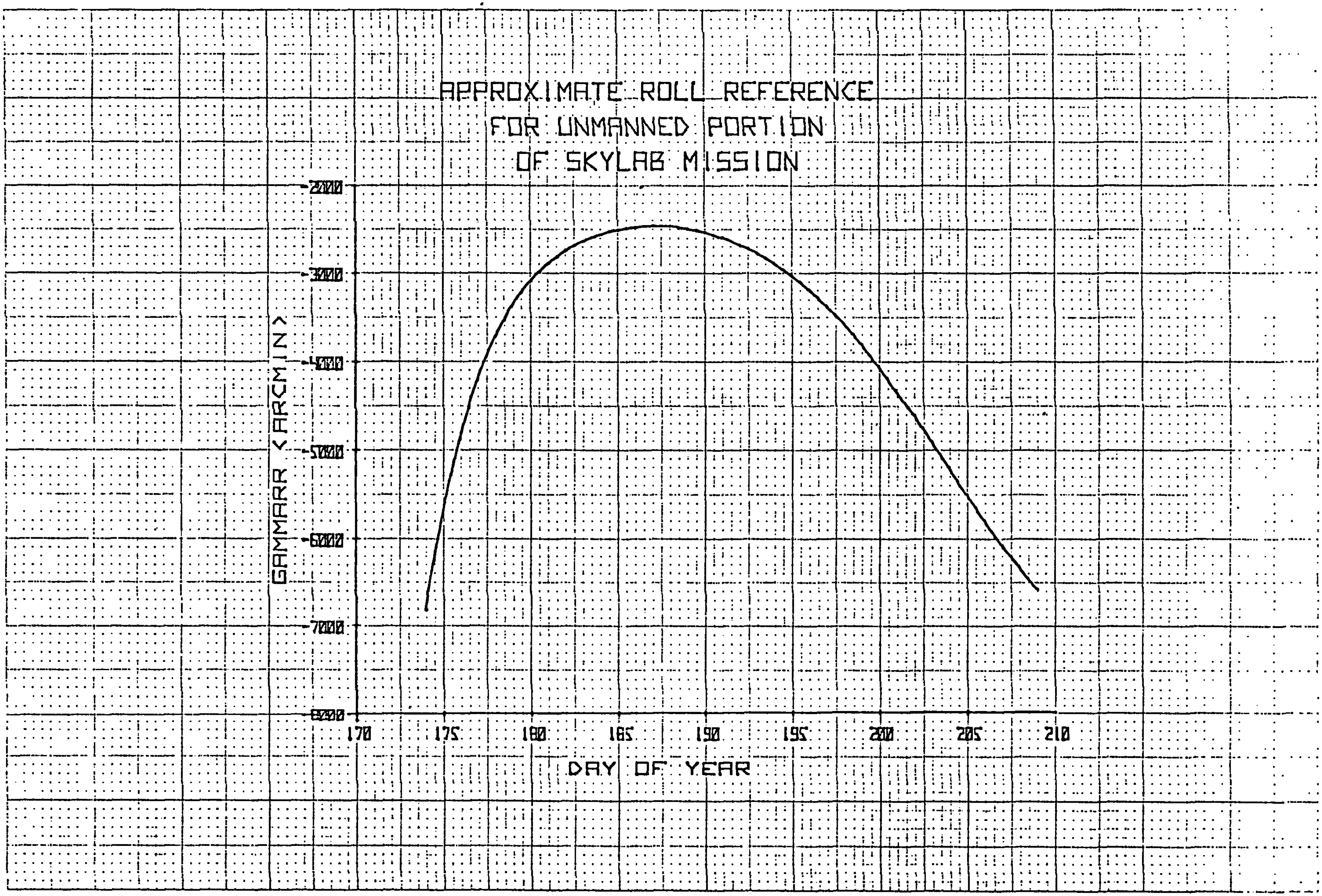
and Δt = time interval from the last update to the current time.

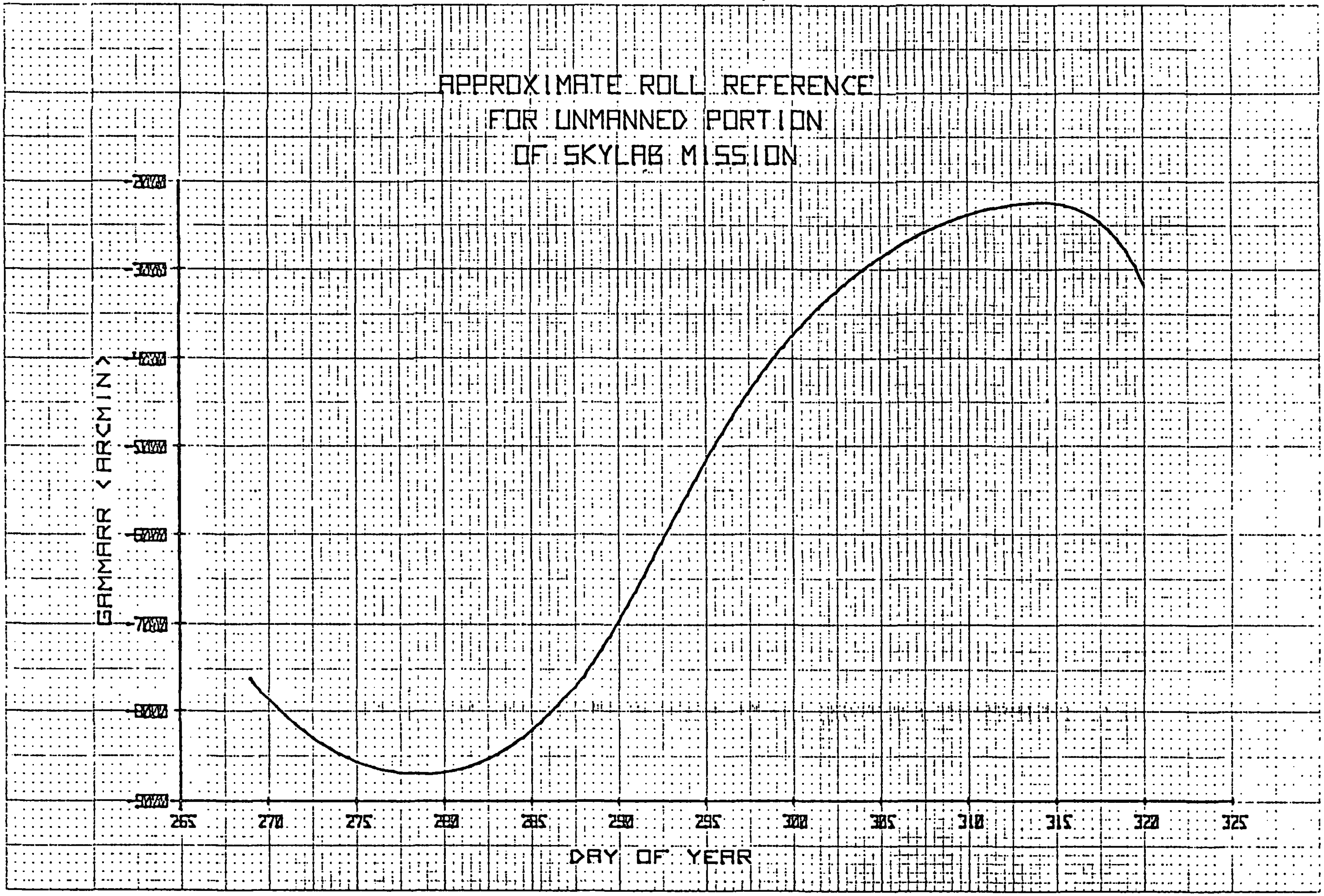
If D was set equal to a value other than D1 and the flight mode did not remain SI and/or EP between updates, the above reconstruction method was used from the beginning of the segment to the first time SI or EP mode was exited. No reconstruction was attempted between the beginning of the first non-SI or EP mode to the end of the last non-SI or EP mode. The last SI and/or EP mode interval of the segment was reconstructed using

$$\gamma_{RR} = \gamma_{RRC} + \sum_{1}^{k} EVZ3P(j) - (D_1 - D)\ \Delta T - \Delta t\ D$$

APPENDIX B

PLOTS OF
APPROXIMATE ROLL REFERENCE
FOR UNMANNED PHASES


APPROXIMATE ROLL REFERENCE
FOR UNMANNED PORTION
OF SKYLAB MISSION
GAMMARR <ARCMIN>
-2000
-3000
-4000
-5000
-6000
-7000
-8000
170
175
180
185
190
195
200
205
210
DAY OF YEAR


APPROXIMATE ROLL REFERENCE
FOR UNMANNED PORTION
OF SKYLAB MISSION
GAMMAR <ARCMIN>
-2000
-3000
-4000
-5000
-6000
-7000
-8000
-9000
265
270
275
280
285
290
295
300
305
310
315
320
325
DAY OF YEAR

APPENDIX C

DATA TAPES

A request was made by S054 for a data tape which would contain the reconstructed roll reference data for each telemetry cycle that data was available. These tapes were created along with the Analysis Data Print Tapes and the Compressed Data Print Tapes, and copies have been included in the delivery package for each experiment. Data for each telemetry cycle is contained on the Data Tape in the following order:

first half-word	integer count of the number of bytes in the data set ($16_{10} = 0010_{16}$)
second half-word	zero
second word	GMT in seconds
third word	reconstructed roll reference in arcminutes
fourth word	telemetered value of roll reference in arcminutes

The value for the reconstructed roll reference in times frames where reconstruction was not possible is $99999.9375_{10} = 1869F.F_{16}$. This value was intended as a code to show non-reconstruction periods.

Other Data Tape information:

Track - 9
Density - 800
File 1 - Header
File 2 - Data
File 3 - Trailer

Also, the first word (4 bytes) of each data record specifies the number of bytes in that record. The maximum number is $448_{10} = 01C0_{16}$.

APPENDIX D

ROLL REFERENCE RECONSTRUCTION USING 1973 EPHEMERIS DATA

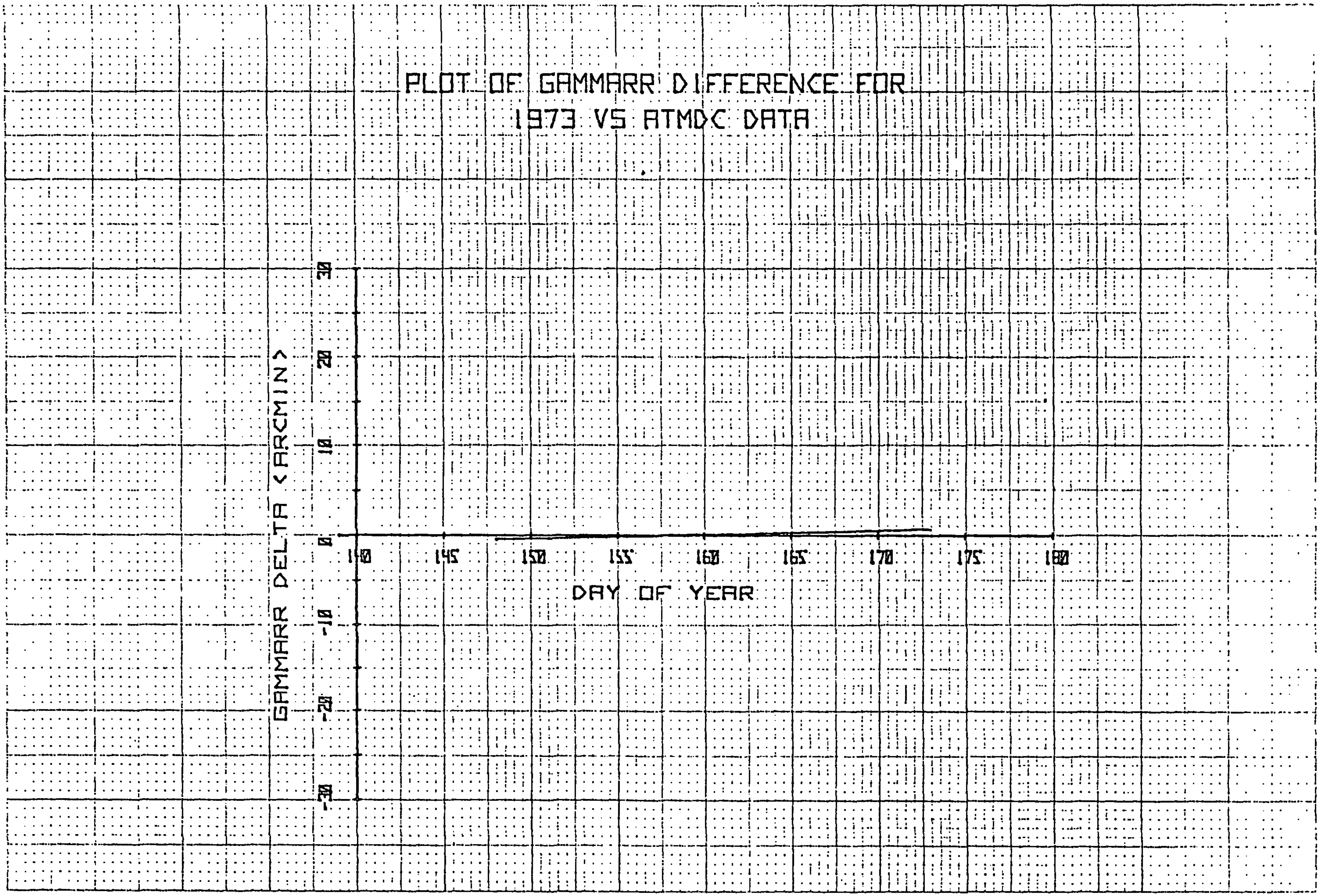
The right ascension and declination of the stars in the flight software were specified as 1950 Epoch data. Also, the yearly sun angle, Γ_y, was calculated as a function of elapsed time for the year 1950. This data caused the reconstructed roll reference to be in error. The attached plots show the errors for each mission. (The errors are considerably smaller than originally anticipated.)

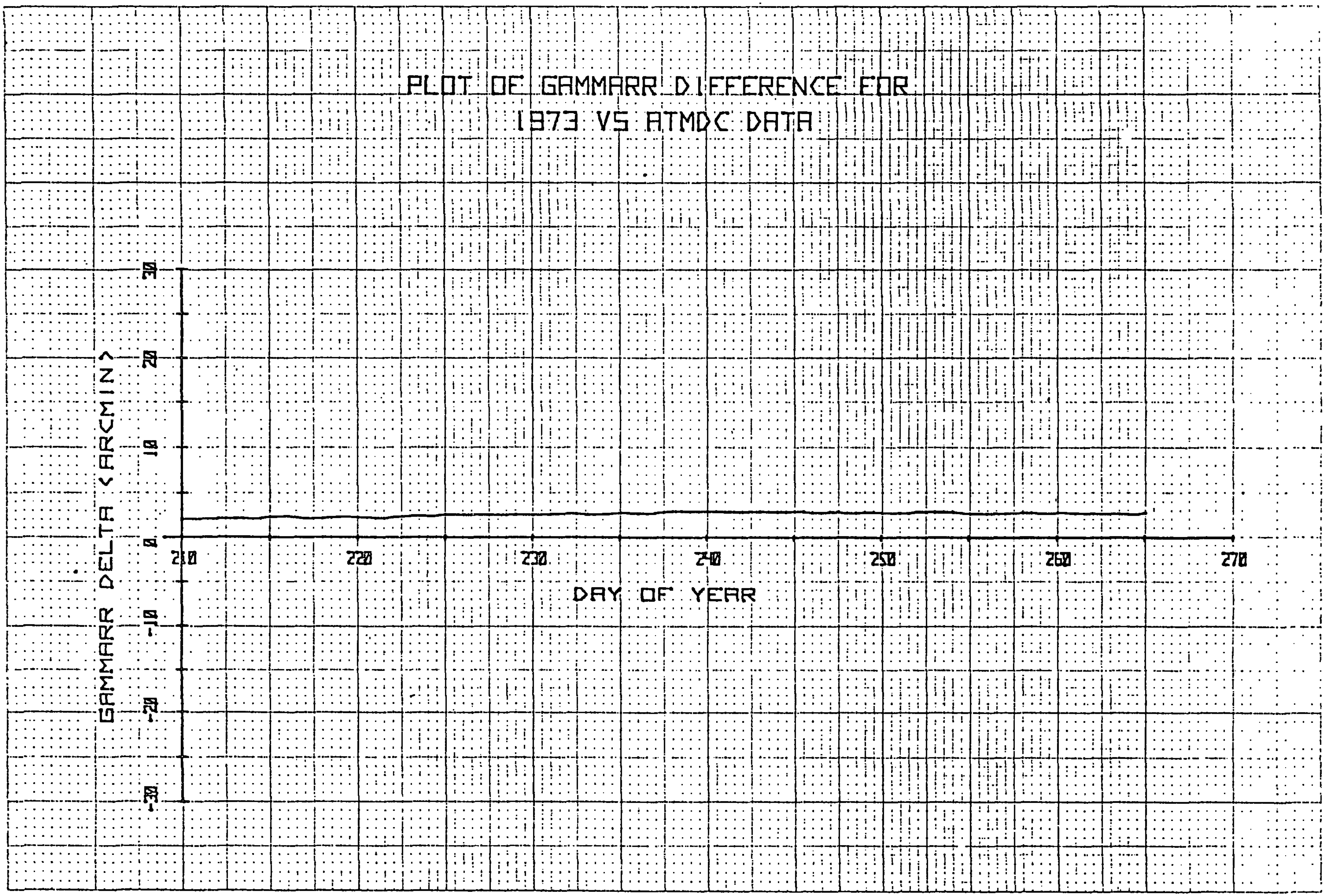
A new set of reconstructed data was delivered 28 March 1975 which used 1973 Ephemeris data instead of ATMDC data. The reprocessing of the data also allowed the correction of several minor discrepancies in the data. Several updates were changed and several EVZ3P determinations were improved. One significant change was made in the SL-4 data. The first SL-4 set (ATMDC) was not corrected for the control offsets (see Appendix A); the 1973 Ephemeris set included PHIZE corrections.

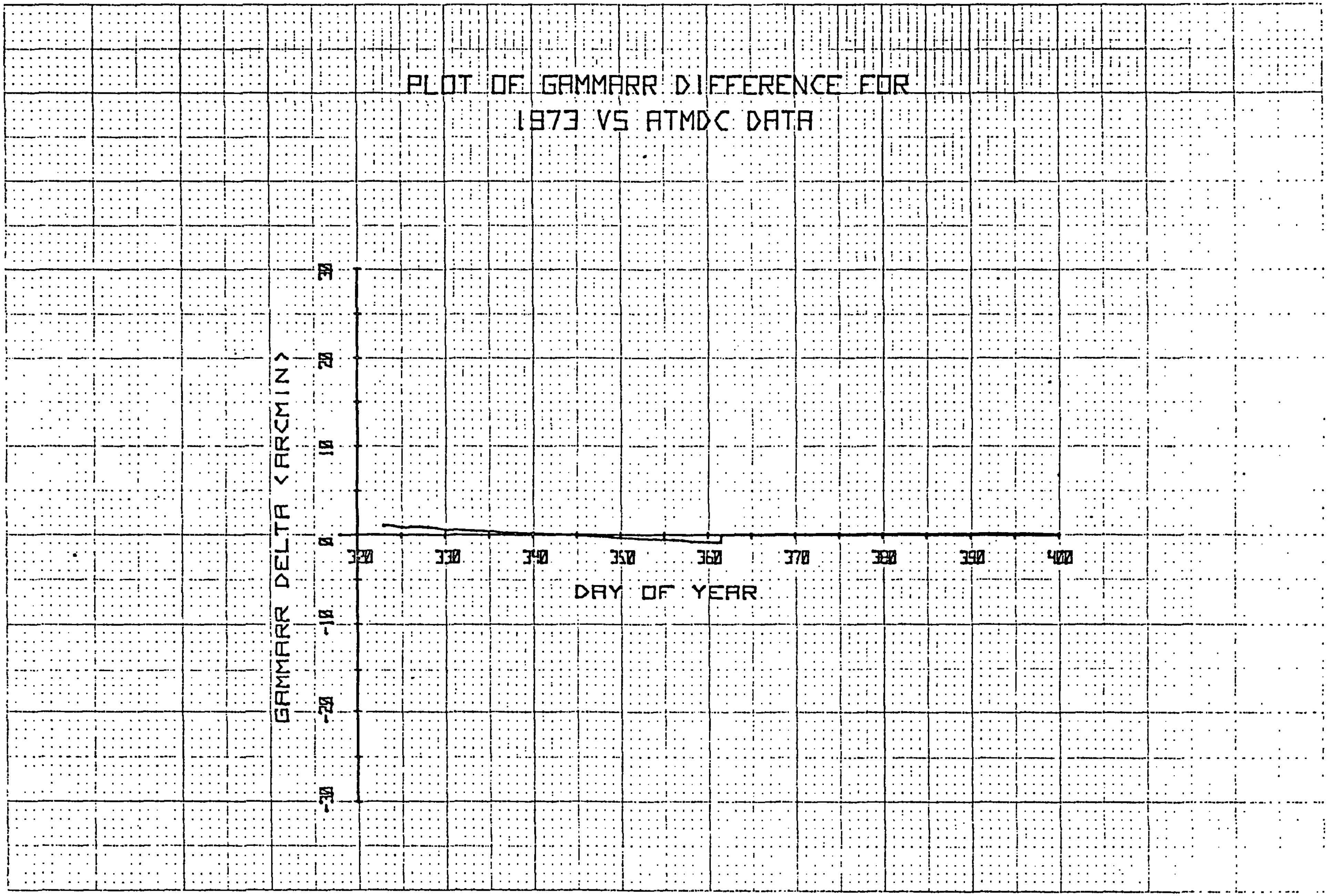
Two errors, however, were overlooked when the reprocessing was done. Both are in the SL-3 data, and both are related to problems in determining EVZ3P. Correct values are as follows:

GMT	EVZ3P	D
213/19/1/41	-1.40350 deg.	4.49365 arcmin/hr.
223/21/24/17	-1.11896 deg.	15.23460 arcmin/hr.

The above information will allow manual reconstruction by the user if more accurate roll reference is required in these segments. Appendix A gives the equation for determining roll reference from GAMMARR(C), the EVZ3P's, D, and time.


PLOT OF GAMMARR DIFFERENCE FOR
1973 VS ATMDC DATA
GAMMARR DELTA <ARCMIN>
30
20
10
0
-10
-20
-30
140
145
150
155
160
165
170
175
180
DAY OF YEAR


PLOT OF GAMMARR DIFFERENCE FOR
1973 VS ATMDC DATA
GAMMARR DELTA <ARCMIN>
30
20
10
0
-10
-20
-30
210
220
230
240
250
260
270
DAY OF YEAR


PLOT OF GAMMARR DIFFERENCE FOR
1973 VS ATMDC DATA
GAMMARR DELTA <ARCMIN>
30
20
10
0
-10
-20
-30
320
330
340
350
360
370
380
390
400
DAY OF YEAR

APPENDIX E

RECONSTRUCTION AFTER STAR TRACKER FAILURE

The reconstruction technique described in Appendix A depends upon star tracker angles for reference points. For the time period after DOY 361, when the star tracker failed, the reference points were supplied by Ball Brothers Research Corporation in the form of the roll reference angles. In order for the existing reconstruction programs to be used, these reference angles were used to determine the star tracker reference angles by simply solving the basic roll reference equation (Appendix A) for ψ_{3R}. Reconstruction was then accomplished as though this angle had been calculated from star tracker gimbal angles.

The accuracy of the supplied data is unknown. The change in the consistency of the drift determinations from the earlier SL-4 data, however, indicates that in some instances the accuracy is not as good as with the star tracker.