Mission Planning and Analysis Division
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS 77058

IN REPLY REFER TO: 70-FM47-243

MEMORANDUM TO: See list below

FROM : FM4/Assistant Chief, Mathematical Physics Branch

SUBJECT : Modifications to the RTCC offline star-horizon observation processor for Apollo 14

1. Reference: MSC Internal Note 69-FM-326, "RTCC Offline Requirements for H-2: Star-Horizon Observation Processor," by Paul Flanagan, MPB, and Robert Kidd, TRW Systems Group, February 24, 1970.

2. The modifications to the RTCC offline star-horizon observation processor for Apollo 14 are of two types. The first is the inclusion of additional quantities which will aid in the analysis of the sightings. In addition to calculating new quantities, a statistical summary of several parameters for each star is required. The second modification is to change the computer format so that the desired information is more readily available.

Emil R. Schiesser

Emil R. Schiesser

The Flight Software Branch concurs with the above recommendation and requests IBM to proceed accordingly.

James C. Stokes

James C. Stokes, Jr., Chief
Flight Software Branch

APPROVED BY:

Carl R. Huss for

John P. Mayer
Chief, Mission Planning and Analysis Division

Enclosure
Addressees: (See attached list)
FM4:RTSavely:rmr

NASA - Manned Spacecraft Center RELEASE APPROVAL	1. Type of Document Change sheet to Internal Note 2. Identification 69-FM-326 dated February 24, 1970 Page 1 of 1 Pages

TO:	3. FROM: Division Mission Planning and Analysis Branch Mathematical Physics Section

4. Title or Subject RTCC OFFLINE REQUIREMENTS FOR E-2: STAR-HORIZON OBSERVATION PROCESSOR	Date of Paper October 8, 1970

5. Author(s) Paul Flanagan, MPB, and Robert Kidd, TRW Systems Group
Change 1 by Ronnie R. Lanier, MSC, and Sam Crigler, TRW

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CHANGE SHEET

FOR

MSC INTERNAL NOTE 69-FM-326 DATED FEBRUARY 24, 1970

RTCC OFFLINE REQUIREMENTS FOR H-2:

STAR-HORIZON OBSERVATION PROCESSOR

By Paul Flanagan, MPB, and

Robert Kidd, TRW Systems Group

Change 1

By Ronnie R. Lanier, MSC, and
Sam Crigler, TRW

October 8, 1970

James C. McPherson, Chief
Mathematical Physics Branch

Carl R Huss for John P. Mayer, Chief
Mission Planning and Analysis Division

Page 1 of 13
(with enclosures)

NOTE: A black bar in the margin indicates the area of change.

After the attached enclosures, which are replacement pages, have been inserted, place this CHANGE SHEET between the cover and title page and write on the cover, "CHANGE 1 inserted".

1. Replace pages 13, 14, 21, and 22.

CHANGE HISTORY FOR 69-FM-326

Number	Date	Description
1		Replace pages 13, 14: Eliminated some original parameters and added some new parameters. Expanded original pages to include additional discussion. Replace pages 21, 22: Flow charts added to define new computation logic for parameters mentioned above.

A priori bT_o (MRD), h_o (KM)

σ_{bTo} (MRD), σ_{ho} (KM), ρ_o (correlation coefficient)

For each iteration:

Solution bT (MRD), h (KM)

σ_{bT} (MRD), σ_h (KM), ρ (correlation coefficient)

Iteration number, N

For each observation processed by method 2, five additional quantities will be computed to isolate sources of sighting errors and to evaluate the sighting.

SFOV (DEG)

NROT (DEG)

PLANE ERROR (DEG)

POINT ERROR (MINUTES OF ARC)

TERM ANG (DEG)

These variables are illustrated in the two figures on the following page.

Equations required to define this output are as follows. The star field-of-view error is given by

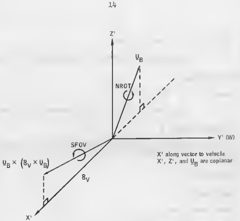
$$\text{SFOV} = \sin^{-1}(\underline{w} \cdot \underline{U}_B)$$

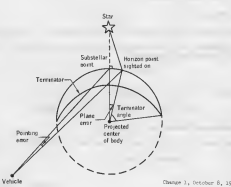
The normal rotation error is given by

$$\text{NROT} = \sin^{-1}\left\{\underline{w} \cdot [\underline{U}_B \times \text{unit } (\underline{R}_V \times \underline{U}_B)]\right\}$$

The measurement plane error is given by

$$\text{PLANE ERROR} = \sin^{-1}\left\{R_V[\cos(\text{SFOV}) \sin(\text{SFOV}) \cos^2(\text{NROT})(1 - \cos T_r) - \sin(\text{NROT}) \sin T_r]\right\}$$


Z'
U_B
NROT
SFOV
Y' (W)
U_B × (B_V × U_B)
B_V
X'
X' along vector to vehicle
X', Z', and U_B are coplanar


Star
Substellar point
Horizon point sighted on
Terminator
Terminator angle
Plane error
Projected center of body
Pointing error
Vehicle

The pointing error is given by

$$\text{POINT ERROR} = 2 \sin^{-1}[1/R_v \sin (\text{PLANE ERROR}/2)]$$

The determination of the terminator angle requires a series of calculations as follows.

$$\underline{L} = \underline{N}(\underline{U}_{sp})$$

where $\underline{U}_{sp}$ is the vector from the planet to the sun.

$$\underline{E} = \underline{N}(\underline{R}_v)$$

$$\underline{Q} = \left(\frac{L_z}{L_z E_x - L_x E_z}, \frac{L_z}{L_y E_z - L_z E_y}, \frac{L_y}{L_z E_y - L_y E_z} - \frac{L_x}{L_z E_x - L_x E_z} \right)^T$$

$$\underline{P} = \left(\frac{L_z}{L_z E_x - L_x E_z}, 0, \frac{L_x}{L_x E_z - L_z E_x} \right)^T$$

$$D_1 = \left(\frac{Q_x}{aQ_z}\right)^2 + \left(\frac{Q_y}{bQ_z}\right)^2 + \left(\frac{1}{c}\right)^2$$

$$D_2 = 2\left[\left(\frac{Q_x}{aQ_z}\right)^2 (Q_z - P_z) - \left(\frac{Q_y}{bQ_z}\right)^2 P_z\right]$$

$$D_3 = \left(\frac{Q_x P_z - Q_z P_x}{aQ_z}\right)^2 + \left(\frac{Q_y P_z}{bQ_z}\right)^2$$

If $D_2{}^2 - D_1 D_3 < 0$, then the terminator is not visible from the spacecraft, and the terminator angle calculations for the batch are not performed. In this case, TERM ANG should be set greater than 1000 to cause an overflow for printout and asterisks should be printed. Otherwise,

$$Z_1 = \frac{-D_2 + \sqrt{D_2^2 - 4D_1D_3}}{2D_1}, \quad Z_2 = \frac{-D_2 - \sqrt{D_2^2 - 4D_1D_3}}{2D_1}$$

$$X_i = \frac{Q_x}{Q_z}(Z_i - P_z) + P_x \qquad i = 1,2$$

$$Y_i = \frac{Q_y}{Q_z}(Z_i - P_z) + P_y \qquad i = 1,2$$

$$\underline{S}_i = (X_i, Y_i, Z_i)^T \qquad i = 1,2$$

$$\underline{G} = \underline{R}_v \left(1 - \frac{|\underline{R}_v - \underline{R}_s|^2}{|\underline{R}_v|^2}\right)$$

$$\alpha_i = \cos^{-1}\left[\text{UNIT }(\underline{R}_s - \underline{G}) \cdot \text{UNIT }(\underline{S}_i - \underline{G})\right] \qquad i = 1,2$$

TERM ANG = smaller of α_1, α_2

The effective height for each observation is given by

$$H_j = h + \Delta m_j / \frac{\partial m_j}{\partial h}$$

Statistics on several parameters listed below are required, and the equations for computing these statistics are the same for each parameter. The weighted statistical mean is given by

$$\mu = \frac{1}{N} \Sigma\ K_j \varepsilon_j$$

The weighted statistical standard deviation is given by

$$\sigma = \left[\frac{\Sigma_j (K_j \varepsilon_j)^2 - N\mu^2}{N - 1}\right]^{1/2}$$

where N is the number of sightings in the set and ε is the required parameter. The mean and standard deviation are to be computed for each star and each batch for the following parameters.

Method 1: Effective height
Residual

Method 2: Effective height
Residual
SFOV
NROT
PLANE ERROR
POINT ERROR

The statistics will not be calculated for a star when fewer than two observations on that star have a non-zero weight for K_j.

In figure 1, the format of the desired program output is illustrated. New pages of data should be initiated by subtitles "Launch Time", "Option 1 Processing Summary", and "Option 2 Processing Summary". In table I, the output is described in detail, and the units for the output variables are specified.

TABLE I.- VARIABLES NEEDED FOR OUTPUT

Variable name	Units	Format	Remarks
Launch time			G.m.t.
Years	Years	I4	Year of launch
Month	Months	I2	Month of launch
Day	Days	I3	Day of launch
H:M:S	Hr:min:sec	I3,1H:,I2,1H:, F5.2	Time of launch
Position	Earth radii	F14.10,4X,F14.10, 4X,F14.10	Vehicle anchor vector for batch
Velocity	Earth radii per hour	F14.11,4XF14.11, 4X,F14.11	Vehicle anchor vector for batch
Time	Hr:min:sec	I3,1H:,I2,1H:, F5.2	Time associated with anchor vector (g.e.t.)
REFSMMAT	None	3(3(F11.8,3X)/)	
Mark time	Hr:min:sec	I3,1H:,I2,1H:, F5.2	Time of observation (g.e.t.)
Range	Earth radii	F5.2	Distance from vehicle to observation planet (always positive)
H	None	A1	N for near horizon; F for far horizon
STAR	None	O3	Star identification number (always positive)
OG	Degrees	F6.2	Outer gimbal angle (always positive)
IG	Degrees	F6.2	Inner gimbal angle (always positive)
MG	Degrees	F6.2	Middle gimbal angle (always positive)
SHAFT	Degrees	F6.2	Shaft angle (always positive)

TABLE I.- VARIABLES NEEDED FOR OUTPUT - Continued

Variable name	Units	Format	Remarks
TRUN	Degrees	F6.3	Trunnion angle
WT	None	F4.2	Relative measurement weighting (usually 1 or 0); never negative
Eff Alt	Kilometers	F5.1	Option 1 solution for attitude; statistics required
Eff Resid	Milliradians	F6.4	Option 1 residual; statistics required
Act Alt	Kilometers	F5.1	Option 2 solution for altitude; statistics required
Act Resid	Milliradians	F6.4	Option 2 residual; statistics required
SFOV	Degrees	F5.3	Statistics required
NROT	Degrees	F5.3	Statistics required
Plane Error	Degrees	F5.2	Statistics required
Point Error	Minutes of arc	F5.1	Statistics required
Term Ang	Degrees	F4.1	Always positive
Row 1 of final solution			
Eff Ht.	Kilometers	F5.1	From iterative solution, option 1
Eff Trun Bias	Milliradians	F7.5	From iterative solution, option 1

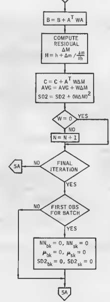
TABLE I.- VARIABLES NEEDED FOR OUTPUT- Concluded

Variable name	Units	Format	Remarks
SIGH	Kilometers	F7.4	From iterative solution covariance, option 1
SIGBT	Milliradians	F7.5	From iterative solution covariance, option 1
RHO	None	F7.5	From iterative solution covariance, option 1
	Row 2 of final solution		
ACT HT	Kilometers	F5.1	From iterative solution, option 2
ACT Trun Bias	Milliradians	F7.5	From iterative solution, option 2
SIGH	Kilometers	F7.4	From iterative solution covariance, option 2
SIGBT	Milliradians	F7.5	From iterative solution covariance, option 2
RHO	None	F7.5	From iterative solution covariance, option 2

```
LAUNCH TIME - XXXX YEARS  XX MONTH  XXX DAYS  XX XX XX.XX H M S

VECTOR TIME (GET) - XXX XX XX.XX H M S      REFERENCE - X

POSITION -  ±XX.XXXXXXXXXXX  ±XX.XXXXXXXXXXX  ±XX.XXXXXXXXXXX  EARTH RADII
VELOCITY -  ±XX.XXXXXXXXXXX  ±XX.XXXXXXXXXXX  ±XX.XXXXXXXXXXX  EARTH RADII PER HOUR

REFSMMAT -  ±X.XXXXXXXXX  ±X.XXXXXXXXX  ±X.XXXXXXXXX
            ±X.XXXXXXXXX  ±X.XXXXXXXXX  ±X.XXXXXXXXX
            ±X.XXXXXXXXX  ±X.XXXXXXXXX  ±X.XXXXXXXXX

OBS.  MARK TIME     RANGE  D  STAR  WT    OG       IG       MG       SHAFT    TRUN
      H  M  S       KM        OCT         DEG      DEG      DEG      DEG      DEG

XX    XXX XX XX.XX  XX.XX  X  XXX  X.XX   XXX.XX   XXX.XX   XXX.XX   XXX.XX   XX.XXX
 |     |   |  |      |     |   |    |      |        |        |        |        |
XX    XXX XX XX.XX  XX.XX  X  XXX  X.XX   XXX.XX   XXX.XX   XXX.XX   XXX.XX   XX.XXX


OPTION 1 PROCESSING SUMMARY

OBS.  MARK TIME     STAR  ALT  RESID
      H  M  S       OCT   KM   MRAD

XX    XXX XX XX.XX  XXX  ±XX.X  ±.XXXX
 |     |   |  |      |     |      |
XX    XXX XX XX.XX  XXX  ±XX.X  ±.XXXX

           MEAN     XXX  ±XX.X  ±.XXXX
           STDEV         ±XX.X  ±.XXXX
                     |     |      |
           MEAN     ALL  ±XX.X  ±.XXXX
           STDEV         ±XX.X  ±.XXXX

HEIGHT - XXX.X KM      TRUN BIAS - ±.XXXX MRAD

SIGH   - ±XX.X KM      SIGBT - ±.XXXXX MRAD  RHO - ±.XXXX

OPTION 2 PROCESSING SUMMARY

OBS.  MARK TIME     STAR  ALT   RESID    STDV    RNDT    PLANE    POINT    TERM
      H  M  S       OCT   KM    MRAD     DEG     DEG     ERROR    ERROR    ANG
                                                         DEG      MSD      DE

XX    XXX XX XX.XX  XXX  ±XX.X  ±.XXXX  ±.XXX   ±.XXX   ±X.XX    ±XX.X    XX.X
 |     |   |  |      |     |      |       |       |       |        |        |
XX    XXX XX XX.XX  XXX  ±XX.X  ±.XXXX  ±.XXX   ±.XXX   ±X.XX    ±XX.X    XX.X

           MEAN     XXX  ±XX.X  ±.XXXX  ±.XXX   ±.XXX   ±X.XX    ±XX.X
           STDEV         ±XX.X  ±.XXXX  ±.XXX   ±.XXX   ±X.XX    ±XX.X
                     |     |      |       |       |       |        |
           MEAN     ALL  ±XX.X  ±.XXXX  ±.XXX   ±.XXX   ±X.XX    ±XX.X
           STDEV         ±XX.X  ±.XXXX  ±.XXX   ±.XXX   ±X.XX    ±XX.X

HEIGHT - ±XX.X KM      TRUN BIAS - ±.XXXXX MRAD

SIGH - ±XX.XXXX KM     SIGBT - ±.XXXXX MRAD    RHO - ±.XXXX
```

1 SHEET FOR EACH STAR

Figure 5. Sample output format for a batch [illegible]



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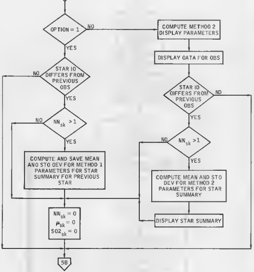
Flow chart 1.- Continued.



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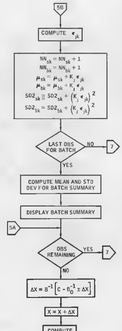
Flow chart 1.- Continued.



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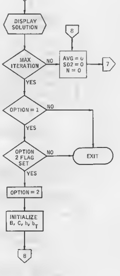
Flow chart 1.- Continued.



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Flow chart 1.- Concluded.