

MISSION PLANNING AND ANALYSIS DIVISION

a

MANNED SPACECRAFT CENTER HOUSTON, TEXAS

ACILITY FORM 602 (ACCESSION NUMBER)

(CATEGORY)

(THRU)

none (CODE)

MSC INTERNAL NOTE NO. 68-FM-30

PROJECT APOLLO

RTCC REQUIREMENTS FOR MISSION G: SELECTING AND VERIFYING USBS DOPPLER DATA SOURCES DURING LM ASCENT AND DESCENT

> By Alan D. Wylie Mathematical Physics Branch

> > February 1, 1968

MISSION PLANNING AND ANALYSIS DIVISION NATIONAL AERONAUTICS AND SPACE ADMINISTRATION MANNED SPACECRAFT CENTER HOUSTON, TEXAS

Approved James C. McPherson, Chief Mathematical Physics Branch -Approved: John P. Mayer, Chief Mission Planning and Analysis Division

CONTENTS

Section	age
SUMMARY AND INTRODUCTION	l
GENERAL PROCEDURE FOR SELECTING AND VERIFYING DOPPLER DATA SOURCES	l
Residual Computations	1
Operational Modes and Procedures	3
DETAILED EQUATIONS AND LOGIC	3
Telemetry Vector Preprocessor	3
MSFN Preprocessor	4
Main Program Control Logic	4
Iteration Subroutine	6
Interpolation Subroutine	8
Residual Subroutine	9
APPENDIX A - FLOW CHARTS FOR PREPROCESSOR ROUTINES FOR TELEMETRY AND MSFN DATA	13
APPENDIX B - FLOW CHARTS FOR PROGRAM CONTROL LOGIC	25
REFERENCES	43

RTCC REQUIREMENTS FOR MISSION G: SELECTING AND

VERIFYING USBS DOPPLER DATA SOURCES DURING LM ASCENT AND DESCENT

By Alan D. Wylie

SUMMARY AND INTRODUCTION

This note describes a program for computing MSFN high-speed Doppler tracking residuals used in the Real-Time Computer Complex for verifying and selecting USBS Doppler data sources during LM ascent and descent. These same residuals are used for detecting the more correct LM navigation system if the two significantly disagree. The two systems, which are sources of telemetry vectors, are the primary guidance and navigation control system (PGNCS) and abort guidance system (AGS). The program has the capability of processing nondestruct Doppler data for up to four USBS ground stations simultaneously tracking the LM during ascent and descent, one of which may be the transmitter. It is assumed that the Doppler biases for these stations have been computed.

In order to check the validity of the ground tracking data, Doppler residuals are computed for each tracker using common telemetry vectors from either PGNCS or AGS. The "residuals" should agree to within some expected tolerance. Should one station disagree, it can be replaced.

Doppler residuals are actually computed using both telemetry vector sources so that the computer controller may display either set of residuals and so that both sets are available for the flight control vector source selections. For each vector source an average is taken of the valid station residuals in order to indicate which system is providing the better data.

The information in this note supersedes that in reference 1.

GENERAL PROCEDURE FOR SELECTING AND VERIFYING DOPPLER DATA SOURCES

Residual Computations

The main purpose of this program is to verify the Doppler data of the ground stations tracking the LM during ascent and descent. The most efficient method is to calculate a Doppler residual - that is, to find for each station the difference between observed and computed Doppler values. Each tracking station receives time-tagged raw Doppler count observations at a 10-per-second rate. The observations pass through a preprocessor routine which makes simple edit checks and stores the valid data for the main program. During the powered flight mode, telemetered LM state vectors arrive at the stations at an effective one-per-two-second rate for each onboard navigation system. During free flight or the time the LM is on the moon, the program predictor generates the LM state vectors at the same real-time rate. A separate preprocessor routine for each vector source makes simple edit checks on the vectors and stores the valid values for future processing.

The program starts the residual computations process by selecting a recent telemetry vector and iterating to find the transmitter-vehicle (uplink) range and vehicle-receiver (downlink) ranges. A linear interpolation scheme is used for each station to find the "pseudoactual" Doppler count which corresponds in time to the receiver time of the vector. The program recycles, processes a second vector from the same source, and obtains a new Doppler count for each station. The observed and computed Doppler frequencies are then calculated and differenced to obtain the residual. This residual process is a sliding type such that the oldest of the two vectors is replaced by a new vector from the same source before each computation.

The residuals are converted from cycles per second to feet per second and plotted continuously in time as in figure 1.



Time, sec

Figure 1.- Station Verification Display

Residuals will also be computed using the other vector source. Each set of valid station residuals is then averaged and plotted continuously in time on a flight control display to indicate which telemetry system is in better agreement with the MSFN trackers.

Operational Modes and Procedures

The ascent-descent program is designed primarily to function in the "average G" or powered-flight mode. However, it has been extended to cover short periods of free flight and the LM's stay on the moon.

Program use actually begins approximately 5 minutes before ignition for powered descent and is initialized by MED 1 (table I). A RTCC predictor, possibly the analytic ephemeris generator (AEG), will use the best LM anchor vector to project LM state vectors which are processed in the high-speed mode in the same manner as the powered-flight PGNCS and AGS vectors. Residuals are computed and displayed by the stations for checkout purposes. Approximately 30 seconds before ignition the LM begins to send updated vectors, and a switch is set at the RTCC console to initiate high-speed processing of actual telemetry vectors.

After touchdown on the lunar surface, the LM continues to send vectors used by this program for approximately 3 minutes. At the end of that time, a MED is entered to terminate residual generation. About 5 minutes prior to lunar lift-off, MED 1 is reentered and the program resumes high-speed processing of RTCC-computed LM vectors and MSFN observations in preparation for the ascent phase. A switch will initiate the use of actual telemetry vectors when they are received.

During the ascent stage, high speed processing of PGNCS and AGS vectors continues until averaged vectors become available following engine cutoff. At that time the controller has the option either to continue using actual telemetry vectors or to switch and use the RTCC predicted vectors based on the computed average vectors. If the average vectors are not available, the last powered-flight vectors will be considered in the option. The program continues to process the vectors (either actual or predicted) in the high speed mode until an orbit switch is thrown, signifying the end of the ascent phase.

DETAILED EQUATIONS AND LOGIC

Telemetry Vector Preprocessor

Two telemetry vector preprocessors (appendix A) are used in this program in order that the telemetered powered-flight vectors and the predicted free-flight or lunar-stay vectors may be treated separately. Each preprocessor is a totally independent routine which is started by executive control. Only one of the two may function at any given time.

The telemetry vector preprocessor receives the LM powered-flight state vectors telemetered from the onboard PGNCS and AGS navigation systems and performs simple tests on the vectors and time tags. Basic telemetry tests are included, and all necessary granularities are applied. All vectors not edited out are stored in one table for future processing. The logic is described in flow chart A-1(a).

The predicted vector preprocessor generates LM state vectors at the real-time rate while the LM is either in free flight or on the lunar surface. The logic is described in flow chart A-1(b).

MSFN Preprocessor

The MSFN preprocessor (appendix A) also is an autonomous routine started by executive control. It receives from the tracking stations high-speed data consisting of raw Doppler counts accumulated from count initialization and not a count difference over a fixed time interval. Continuous tests are performed to check if the identity of the transmitter or any of the four tracking stations has been changed. If a new station is added, only its storage area is reinitialized. All four storage areas are reinitialized for a new transmitter. Any necessary granularities are applied. Simple tests and an edit routine insure that the data remains within a set range.

The MSFN data passing the above tests are stored into the arrays $N_{j/i}$, $t_{j/i}$, where i represents the station and j represents the position in the table. Flow chart A-2(a) describes the logic for the preprocessor. Flow chart A-2(b) describes the edit routine logic.

Main Program Control Logic

The main program control logic (appendix B) completes the list of processors which are started by executive control. It is broken down into four parts: the main program logic or driver, the iteration subroutine, the interpolation subroutine, and the residual computation subroutine. Flow charts B-1 through B-4 present the equations and logic for each of the four parts of the program.

All variables must be initialized to zero at the start of the program. The orbit determination constants described in appendix B and the RNP matrix of current time are then read in. In addition, station characteristics and a lunar ephemeris must be available. Tables of time and edited Doppler N-count observations are generated for n stations. The program begins by picking up a telemetered vector and testing whether this vector is from the PGNCS or AGS. It then checks if its time tag has been updated since the time of the preceding vector from the same source. If the last test fails, the program recycles to pick up another vector.

If the time tag has been updated, then the ranges from the vehicle to the transmitter and receiver are computed for each tracker. Since there is but one transmitter and four receivers, one uplink range and four downlink ranges are computed. The iteration routine computes these ranges and the receiver times for each station.

For each station the raw observations are set up in the following arrays: $t_{j/i}$ and $N_{j/i}$ where i = 1, ..., n and j = 1, ..., Ml. The variable Ml represents the most current observation at a station and is determined by the time length of the data table. Two time tests are then performed the first to determine if the receiver time for station i obtained from the iteration routine lies within the range of the current observation table plus 6 seconds, and the second to determine if the receiver time lies immediately within the range of the table. Failure of the first test causes the program logic to check the next station. If the second test fails, the program waits for more data from the station. An additional test was inserted to limit the time the program will wait for data from late reporting stations. If all stations fail the tests, the program proceeds to the interpolation routine.

The linear interpolation routine is called to yield the interpolated value of the count for each station at each receiver time. The main program then checks whether the telemetry vector $R(t_{IM})$ is PGNCS or AGS and

then tests if the time interval since the previous telemetry vector from the same source is less than TMAX, where TMAX is the maximum τ interval for which the Doppler frequency is allowed to be computed. If this test fails, the current values of vehicle time tag, observation time, uplink and downlink ranges, and Doppler count are stored; and the program recycles by reading in a new telemetry vector. Once this test is passed, however, the program proceeds to the residual computation subroutine.

Outputs of the residual computation subroutine are ΔY_i , the residuals computed using one vector source and the interpolated counts from each of the n stations. The ΔY_i are then displayed as shown in figure 1. The average residual δY computed by using one vector source is then compared on a display with the average residual of the other vector source for the selected stations. The current values of time tag, observation time, uplink and downlink ranges, and Doppler count are then stored, and the program recycles by reading in a new telemetry vector.

Iteration Subroutine

One input to the iteration subroutine (flow chart B-2) is the telemetry position vector, $R(t_{IM})$, in a selenocentric coordinate system with the X-Y plane parallel to the earth's mean equatorial plane, the X-axis through Aries at the beginning of the nearest Besselian year (NBY), and the Z-axis directed along the mean pole. Also input are a vector time tag, t_{IM} , referenced to Greenwich midnight prior to launch, station characteristics for station i (i = 1, ..., n), and a lunar ephemeris. The first computation transforms the mean NBY selenocentric vector to a mean NBY earth-centered inertial (ECI) vector by

$$R'(t_{LM}) = R(t_{LM}) + R_{M}$$

where R_{M} is the position of the moon in the earth-referenced mean NBY system. The next computation involves finding the range between the transmitting station and lunar orbiting vehicle.

In computing the range, the program must iterate to find the time, t_{TR} , the signal was transmitted from the transmitting station in order to have arrived at the vehicle at t_{LM} (ref. 2). Let c be the velocity of light, R'(t_{LM}) the geocentric inertial position vector of the vehicle at t_{LM} in the mean NBY coordinate system, and $R_s(t')$ the geocentric inertial position vector of the transmitting station at the computed transmission time, t'. Then

$$t' = t_{LM} - \frac{\rho}{c}$$
 (1)

where

$$\rho = |R'(t_{IM}) - R_{s}(t')| .$$
 (2)

For an initial guess of $R_s(t')$, we set $t' = t_{TM}$; thus,

$$\rho = |\mathbf{R}'(\mathbf{t}_{\mathrm{LM}}) - \mathbf{R}_{\mathrm{s}}(\mathbf{t}_{\mathrm{LM}})| \quad . \tag{3}$$

This ρ from equation (3) is then used in equation (1) for a new estimate of t'. The position of the station is then computed for the revised t', a new ρ is calculated in equation (2), and a new t' is calculated in equation (1). This iterative process is repeated until the difference between successive values of t' is less than or equal to 10^{-9} seconds or until six iterations have been made. A refraction correction is then applied to the computed uplink range ρ to form ρ ' in the following manner. (See ref. 3.) Let

 $r_s = |R_s(t')|$

and

$$\bar{\rho} = R'(t_{LM}) - R_s(t')$$

Then

$$\rho' = \rho + \frac{c_{nk} r_{s} \rho}{R_{s}(t') \cdot \overline{\rho}}$$
(4)

where c_{nk} is the product of refraction modulus and radio refractivity $\times 10^{-6}$, which are available from the station characteristic table. (See appendix B.) The uplink range, ρ' , will then be stored as ρ_{mp} .

The subroutine then computes downlink ranges and times for the n stations successively. The only change from the uplink computations is in the time-iteration equation which now becomes

$$t' = t_{LM} + \frac{\rho}{c}$$
(5)

where t' is the computed time at which the signal should be received at the station if it left the vehicle at t_{LM} . After the refraction correction has been applied to a downlink range, ρ' is stored as $\rho_{R/i}$ and t' stored as $t_{R/i}$ (i = 1, ..., n) and the subroutine picks up the proper station characteristics for the downlink computation for the next station.

The position of the station, $R_s(t')$, is computed for each successive iteration of time, t', from the station characteristics as follows:

Let θ be the angle between the true position of Greenwich at midnight prior to launch and Greenwich at t'. Then

$$\theta = \omega(t' + DT) \tag{6}$$

where the other constants are defined in appendix B. Then the angle, λ^{i} , of the station is given by

$$\lambda^{\dagger} = \lambda^{\dagger} + \theta \tag{7}$$

where λ is the longitude of the station. Finally, R_a(t') is given by

$$R_{s}(t') = (RNP)^{T} \begin{bmatrix} \cos \lambda' (r \cos \phi' + h \cos \phi) \\ \sin \lambda' (r \cos \phi' + h \cos \phi) \\ r \sin \phi' + h \sin \phi \end{bmatrix} .$$
(8)

All the above variables are defined in appendix B.

Interpolation Subroutine

The interpolation subroutine (flow chart B-3) is called to find a pseudoactual Doppler count, $N_{R/i}$, for each station at the receiver time $t_{R/i}$ which is not likely to be a recorded observation time. Inputs to the subroutine are $t_{R/i}$ (obtained from the iteration routine) and n tables of Ml observation times, $t_{j/i}$, versus Ml observed Doppler counts, $N_{j/i}$, (i = 1, ..., n and j = 1, ..., Ml). All stations for which the flag MSW(i) is zero are processed.

The interpolation scheme tests the $t_{R/i}$ of each station against the corresponding table of recorded observation times to find between which two recorded valid observation times $t_{R/i}$ lies and between which two recorded valid observations $N_{R/i}$ lies. Once these two values of $N_{j/i}$, $t_{j/i}$ are found, the routine tests $t_{j/i}$ and $t_{j+1/i}$ to see if

If so, the time interval is too long to linearly interpolate. Therefore, do not interpolate, but set $N_{R/i}$ equal to a dummy negative value denoted by σ_N , and start the time tests for the next station. If, however,

the time interval is sufficiently short to accurately interpolate for $N_{R/i}$. Therefore, the following equation can be solved for $N_{R/i}$.

$$N_{R/i} = N_{j/i} + \frac{N_{j+1/i} - N_{j/i}}{t_{j+1/i} - t_{j/i}} (t_{R/i} - t_{j/i})$$
(9)

where i is the station number. The outputs $N_{R/i}$ from the interpolation subroutine will then be passed to the main program.

Residual Subroutine

Inputs to the residual computation subroutine (flow chart B-4) are two receiver times, two uplink ranges, two downlink ranges, two interpolated N-count observations, and a table of bias values. The subroutine will be called in two different places in the main program depending on whether the vector source is PGNCS or AGS; this selection is controlled by the LSW flag (see appendix B). The inputs to this subroutine can be controlled by the arguments of the calling statements (or equivalent); for example, for a PGNCS vector we might have:

CALL RESIDUAL (Pt_{R/i}, t_{R/i},
$$P\rho_{TR}$$
, $P\rho_{R/i}$, ρ_{TR} , $\rho_{R/i}$, $PN_{R/i}$, $N_{R/i}$, ΔY_i , δY)

Then for an AGS vector we would have:

CALL RESIDUAL (At_{R/i}, t_{R/i},
$$^{A\rho}$$
_{TR}, $^{A\rho}$ _{R/i}, $^{\rho}$ _{TR}, $^{\rho}$ _{R/i}, AN _{R/i}, N _{R/i}, AY _i, $^{\delta Y}$)

Once the input arguments have been established, the program processes the residual subroutine, which is of the following form:

SUBROUTINE RESIDUAL (
$$t_{1/i}$$
, $t_{2/i}$, ρ_1 , $\rho_{2/i}$, ρ_3 , $\rho_{4/i}$, $N_{1/i}$, $N_{2/i}$, ΔY_i , δY)

Before computing a residual for an observation station, the validity of the two Doppler counts $N_{1/i}$ and $N_{2/i}$ must be verified. A negative value for either $N_{1/i}$ or $N_{2/i}$ causes the residual computation of that station to be omitted, and the routine checks the Doppler counts for the next station.

Let $\rho_{2/i}$ and $\rho_{4/i}$ be the downlink ranges computed for the receiver times $t_{1/i}$ and $t_{2/i}$ and let ρ_1 and ρ_3 be the corresponding uplink ranges. The computed Doppler observation is obtained from the following equation (ref. 2).

$$D_{i} = (\omega_{3} + b_{i}) + \frac{\omega_{4} f_{TR}}{c(t_{2/i} - t_{1/i})} \left[(\rho_{3} + \rho_{4/i}) - (\rho_{1} + \rho_{2/i}) \right]$$
(10)

where the constants ω_3 , ω_4 , f_{TR} , c, b_i are explained in appendix B. A pseudoactual Doppler observation, S_i, is obtained by

$$S_{i} = \frac{N_{2/i} - N_{1/i}}{t_{2/i} - t_{1/i}} , \qquad (11)$$

and the residual is computed from

$$\Delta Y_{i} = (S_{i} - D_{i}) K, \qquad (12)$$

where K, the conversion factor from Hz to fps, is given by

$$K = \frac{c}{2f_{TR}}$$

9

where $f_{\rm TR}$ is the frequency transmitted to the LM. These $\Delta Y_{\rm i}$ are plotted as in figure 1. The average of the residuals from n' stations is then obtained by

$$\delta Y = \frac{\sum_{\ell=1}^{n'} \Delta Y_{\ell}}{n'}$$
(13)

where n' is the number of stations selected. This δY will then be plotted against δY computed with the other vector source and displayed. Control is then transferred to the main program, and the current values of t_{LM} , $t_{R/i}$, ρ_{TR} , $\rho_{R/i}$, $N_{R/i}$ are saved for the next cycl; for a particular vector source.

TABLE I.- CONTROLS AND DISPLAYS

CONTROLS

Manual Entry Devices

1. <u>Source selection</u>. - This MED allows the program to enter high-speed processing and specifies which MSFN stations will be processed.

Push Button Indicators

1. <u>STA1, STA2, STA3, STA4</u>. - These four PBI's specify whether or not the respective MSFN stations are to be used in the average residual computation.

2. <u>PGNCS</u>. - This PBI designates that PGNCS - MSFN residuals be displayed.

3. AGS.- This PBI designates that AGS - MSFN residuals be displayed.

4. <u>TIM-PRED</u>. - This PBI designates whether telemetered or predicted IM state vectors are to be currently processed.

DISPLAYS

1. <u>Range rate residual no. 1.</u> This display provides an analog trend curve of range rate versus time for two MSFN sources using PGNCS or AGS telemetered vectors.

2. <u>Range rate residual no. 2</u>. - This display provides the same information as no. 1 for two other MSFN sources.

3. <u>PGNCS versus AGS</u>.- This display provides an analog trend curve of range rate versus time for both telemetry sources. Each curve represents the average of the stations' residuals for one of the telemetry sources.

^aReference 4 should be consulted for details on the above general description.

APPENDIX A

FLOW CHARTS FOR PREPROCESSOR ROUTINES

TELEMETRY AND MSFN DATA

CONTENTS

Page

Variables	Used	in	Telemetered	Vec	etc	r	Su	bro	out	ine	•	•	•	•	•	•	•	•	•	16
Variables	Used	MSF	N Subroutine	.		•		•	•		•	•	•	•	•	•	•	•	•	20

FLOW CHARTS

Chart																					Page
A-l	Prep	rocess	or fo	or Ll	l vec	tors															
	(a) (b)	Logic Logic	for for	the the	tele pred:	metered icted LM	LM v	ve ect	ect tor	or 's	s.	•	•	•	•	•	•	•	•	•	17 19
A-2	MSFN	prepro	oces	sor																	
	(a) (b)	Logic Logic	for for	the the	prep edit	rocessor routine	•	•	•	•	•	•	•	•	•	•	•	•	•	•	21 23

Variables Used in Telemetered Vector Subroutine

ta	time tag (g.e.t.) of a PGNCS or AGS telemetry vector unprocessed by the preprocessor routine, sec (UTC)
R _a V _a	selenocentric position and velocity of a telemetered vector at t in mean NBY coordinates, ft and fps a
R*	maximum acceptable value for $ R_a $, ft
V *	maximum acceptable value for $ V_a $, fps
t*, t _{MIN}	maximum and minimum times acceptable for t_a , sec (UTC)
tLM	time tag of a current PGNCS or AGS telemetry vector ref- erenced to Greenwich midnight prior to launch, sec (UTC)
R(t _{LM}) V(t _{LM})	selenocentric state vector (PGNCS or AGS) of the vehicle at time t_{LM} in mean NBY coordinates, ft and fps
LSW	switch set by the identification code of the telemetry vector: LSW = 0 for a PGNCS vector, LSW \neq 0 for an AGS vector







Page 2 of 2

Flow chart A-1.- Preprocessor for LM vectors. (a) Logic for the telemetered vectors - Concluded.



Flow chart A-1.- Preprocessor for LM vectors. (b) Logic for the predicted LM vectors.

19

Variables Used MSFN Subroutine

- Cl(i) station counter of Doppler data which do not pass the extrapolation test; when Cl(i) equals four, all counters for station i are reinitialized and the extrapolation edit routine starts over
- C2(i) station counter of Doppler data which pass the extreme count interval test; C2(i) = 3 initializes the use of extrapolating for Doppler.
- C3(i) station counter of Doppler data which pass the extrapolation test; $C3(i) \ge 4$ causes the data to be tagged valid when stored by the preprocessor routine
- $N_{k/i}$ an array of raw, non-destruct Doppler counts recorded at station i; the element $N_{k/i}$ represents the current value, counts
- $t_{k/i}$ time array for the $N_{k/i}$, sec (UTC)
- $N_{j/i}$ an array of raw, non-destruct Doppler counts accepted and stored by the MSFN preprocessor routine; the element $N_{j/i}$ represents the last accepted value of $N_{k/i}$, counts
- t time array for the $N_{j/i}$, sec (UTC)
- ^{τ}MAX maximum τ interval allowed for linear extrapolation of Doppler, sec (UTC)
- NMAX maximum acceptable count difference between the actual and extrapolated values of $N_{k/i}$, counts
- HIGH maximum acceptable value of $N_{k/i}$ tested when all previous time requirements have been met, counts













24

)

APPENDIX B

FLOW CHARTS FOR PROGRAM CONTROL LOGIC

CONTENTS

Page

Variables Used in the Main Program	•	•	•	•	•	•	•	•	•	•	28
Variables Used in the Iteration Subroutine	•	•	•	•	•	•	•	•	•	•	33
Variables Used in the Interpolation Subroutine	•	•	•	•	•	•	•	•	•	•	38
Variables Used in the Residual Subroutine	•	•	•	•	•	•	•	٠	•	•	40

CHARTS

Chart																						Page
B-1	Logic	for	the	main	prog	ram.	•	•	•	• •	• •	•	•	•	•	•	•	•	•	•	•	29
B-2	Logic	for	the	itera	ation	subi	rov	ti	ne	• •		•	•	•	•	•	•	•	•	•	•	35
B - 3	Logic	for	the	inter	pola	tion	su	ıbro	out	tir	ıe.	•	•	•	•	•	•	•	•	•	•	39
в-4	Logic	for	the	resid	lual	subro	out	in	e	• •		•	•	•	•	•	•	•	•	•	•	4 <u>1</u>

Variables Used in the Main Program

$\mathtt{Pt}_{\mathtt{LM}}$	time tag of a previous PGNCS vector, sec (UTC)
$\operatorname{At}_{\operatorname{LM}}$	time tag of a previous AGS vector, sec (UTC)
SEC	counter used to limit the length of time that the program will wait for data from late reporting stations
C4	counter which counts the number of stations that cannot meet the time tests for a particular telemetry vector
MSW(i)	switch which denotes MSFN data: $MSW(i) \neq 0$ implies time invalid data for station i; $MSW(i) = 0$ implies valid data
j	position number in an observation table
FSW	switch which when not equal zero prohibits program from waiting for data from late reporting stations
MI.	number of MSFN observations copied into a data table
KSWP	switch which denotes the PGNCS vector: KSWP = 0 for the first PGNCS vector, KSWP \neq 0 thereafter
TMAX	the maximum time interval between two successive telemetry vectors from the same source for which a Doppler residual may be computed, sec
KSWA	switch which denotes the AGS vector: KSWA = 0 for the first AGS vector, KSWA \neq 0 thereafter
Pt _{R/i}	
Pp _{R/i}	temporary storage of previous values of $t_{R/i}$, $\rho_{R/i}$, ρ_{TR} ,
P _p TR	and $N_{R/i}$, respectively, resulting from a PGNCS telemetry
PN _{R/i}	Vector
At _{R/i}	temporary storage of previous values of $t_{R/i}^{\rho}$, $\rho_{R/i}^{\rho}$, r_{TR}^{ρ} ,
Ap _{R/i}	and $N_{R/i}$, respectively, resulting from an AGS telemetry
Ap _{TR}	vec for.
AN _{R/i}	



Flow chart B-1.- Logic for the main program.



Page 2 of 4

Flow chart B-1.- Logic for the main program - Continued.





Page 4 of 4

Flow chart B-1.- Logic for the main program - Concluded.

Variables Used in the Iteration Subroutine

- $R'(t_{LM})$ ECI position vector of the vehicle at t_{LM} in the Aries mean NBY coordinate system, ft
- R_{M} position vector of moon, ECI coordinates, ft

i station number, where i = 1, n

ISW switch which denotes uplink or downlink range computation: ISW = 0 for uplink range computation, ISW \neq 0 for downlink computations

LOOP counter which limits the number of iterations

$$\rho,\rho',t',$$
 temporary storage locations used in the iteration cycle t"

 θ angle between true-of-date position of Greenwich and the position of Greenwich at midnight prior to launch, rad

 ω rotational rate of the earth, rad/sec

- DT difference between UT1 and UTC, DT = UT1 UTC, sec
- λ' $\lambda + \theta$, rad
- λ longitude of station, rad
- R (t') ECI position vector of a station at the computed time t' in the Aries mean NBY coordinate system, ft

 $R_{s}^{(t_{T,M})}$ initial guess of $R_{s}^{(t')}$, ft

(RNP)^T matrix which converts from the Greenwich position at midnight prior to launch true-of-date coordinate system to the Aries mean NBY system

The following constants are found on the station characteristics tape:

r cos ¢' + h cos ¢	projection of position vector of the station
	into the x-y plane in the ECI coordinate system
$r \sin \phi' + n \sin \phi$	z coordinate of station in ECL system

where	r	radius	to	ellipsoid	below	station,	ft
				<u> </u>			

- ϕ' geocentric latitude of station, rad
- ϕ geodetic latitude of station, rad
- h height of station above ellipsoid, ft
- $\bar{\rho}$ vector difference between $R'(t_{IM})$ and $R_s(t')$, ft
- r_s magnitude of the vector R_s(t'), ft
- c product of the radio refractivity × 10⁻⁶ and the decay constant calculated from radio refractivity with an exponential reference atmosphere; both variables are found in station characteristics, nd
- t_{TR} time the signal must be transmitted from the transmitting station to arrive at the vehicle at t_{IM} , sec
- $\rho_{\rm TR}$ uplink range from the transmitting station at t' to the vehicle at $t_{\rm TM}$, ft
- $t_{R/i}$ time at which the signal would arrive at station i if it had left the vehicle at t_{TM} , sec
- $\rho_{R/i}$ downlink range from the vehicle at t_{LM} to station i at $t_{R/i}$ (i = 1, n), ft
- n number of stations



Page 1 of 3

Flow chart B-2. - Logic for the iteration subroutine.

35



Page 2 of 3

Flow chart B-2. - Logic for the iteration subroutine - Continued.



Flow chart B-2.- Logic for the iteration subroutine - Concluded.

Variables Used in the Interpolation Subroutine

- $\sigma_{\rm N}$ dummy negative value for $N_{\rm R/i}$ which signifies that a residual will not be computed for station i for the current telemetry vector being processed, counts
- $\sigma_{\rm T}$ the maximum time interval over which the Doppler data may be linearly interpolated, sec
- $N_{R/i}$ an interpolated N-count situated between $N_{j/i}$ and $N_{j+1/i}$, counts



Flow chart B-3.- Logic for the interpolation subroutine.

39

Variables Used in the Residual Subroutine

N _{l/i}	interpolated values of N-count at $t_{1/i}$ and $t_{2/i}$, counts
D _i	computed Doppler frequency at station i, Hz
^ω 3	a bias introduced by the tracking equipment that guarantees that the Doppler shift will never become negative, Hz
^ω 4	a multiplying factor which adjusts the frequency of the signal at the spacecraft, nd
b i	bias for station i on the actual Doppler observables (previously solved for in a preascent routine), Hz
f	frequency transmitted to the LM, Hz
с	velocity of light, fps
^t l/i t _{2/i}	successive computed observation times for station i, sec
^ρ 1 ^ρ 3	uplink ranges computed for $t_{1/i}$ and $t_{2/i}$ respectively, ft
^p 2/i ^p 4/i	downlink ranges computed for $t_{1/i}$ and $t_{2/i}$ respectively, ft
s _i	observed Doppler frequency shift over t _{2/i} - t _{1/i} , Hz
ΔY	residual computed for station i (actual minus computed), Hz
K	constant which converts Hz to fps
δY	average value of the ΔY_i , Hz
n'	number of stations used in computing δY ; the value of n' is subject to external control via the station PBI (table I)



Flow chart B-4.- Logic for the residual subroutine.



Page 2 of 2

Flow chart B-4.- Logic for the residual subroutine - Concluded.

REFERENCES

- Wilson, G. Edward and Wylie, Alan D.: Selection and Verification of USBS Doppler Data Sources During LM Ascent and Descent. MSC IN 67-FM-137, September 26, 1967.
- Schiesser, E. R.; Savely, R. T.; deVezin, H. G.; and Oles, M. J.: Basic Equations and Logic for the Real-Time Ground Navigation Program for the Apollo Lunar Landing Mission. MSC IN 67-FM-51, May 31, 1967.
- 3. deVezin, H. G.: Refraction Formulation. MSC Memorandum 67-FM42-85, April 27, 1967.
- 4. Real-Time Computer Program Requirements for Apollo C-V. NASA PHO-TR170A, March 17, 1967.