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Technical Memorandum

PROGRAM REQUIREMENTS FOR TWO-MINUTE INTEGRATED DOPPLER SATELLITE NAVIGATION SOLUTION

Edited by J. B. MOFFETT

THE JOHNS HOPKINS UNIVERSITY ▪ APPLIED PHYSICS LABORATORY

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The geometrical basis of the equations for obtaining a navigation fix is developed. The formatting and processing of the receiver data for the navigation solution are described preparatory to a presentation of step-by-step procedures for computing a three-variable navigation fix. Procedures for calculating satellite alerts, using data from the navigation solution, are also described. A representative FORTRAN program for obtaining a navigation fix and for calculating alerts is presented.

Information is also provided on scaling for the navigation fix computations, on the calculations for a four-variable (velocity north) navigation solution, on the procedures for applying a correction for tropospheric refraction, on a computer program for geodetic coordinate transformation, and on nonstandard numerical computation routines applicable to the navigation program.

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PREFACE

In support of the Naval Electronic Systems Command, the Applied Physics Laboratory is responsible for the development and evaluation of integrated doppler satellite navigation equipment and programs. In partial fulfillment of this responsibility, this report presents the computer program requirements for the 2-minute integrated doppler satellite navigation computations. The report is intended to provide all the information necessary for writing a digital computer program to obtain a position fix using data from the Navy Navigation Satellite System.

The information presented updates the program requirements given in TG 819-1 (Ref. 1) and, in addition, includes the on-line data processing procedures that are required before the calculation of a real-time navigation fix.

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ILLUSTRATIONS (cont'd)

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1. NAVY NAVIGATION SATELLITE SYSTEM

The Satellite Navigation System developed by the Department of the Navy is a worldwide, all-weather navigation system that can provide a navigational fix at intervals of approximately 2 hours or less. The system is shown schematically in Fig. 1 and consists of near-earth satellites, tracking stations, injection stations, a computing center, and shipboard navigation equipment.

The system employs the doppler effect for both satellite position determination and navigation. In the former, four tracking stations in precisely known locations observe the doppler shift of the ultrastable radio signals generated by the satellite transmitter as the satellite approaches and recedes from the stations. This doppler information is translated into satellite positions as a function of time by the computing center. From this information and with the knowledge that the motion of the satellite is governed by Newton's laws of motion, the position of the satellite as a function of time can be predicted. These predictions become the ephemeris of the satellite for the predicted duration (16 hours) and are stored in the memory of the satellite by the injection station. As the satellite orbits the earth, it continually reads out data from which its position can be computed together with precision time. This transmission is continually updated by the satellite by discarding obsolete data and drawing more timely data from its memory. To determine his position, a navigator equipped with shipboard navigation equipment need only observe the doppler shift in the satellite signals, obtain the data on the satellite position, and perform the necessary computations. The navigator remains completely passive; i. e., no interrogation of the satellite is necessary.

The ground support system consists of tracking stations to receive, record, and digitize doppler signals

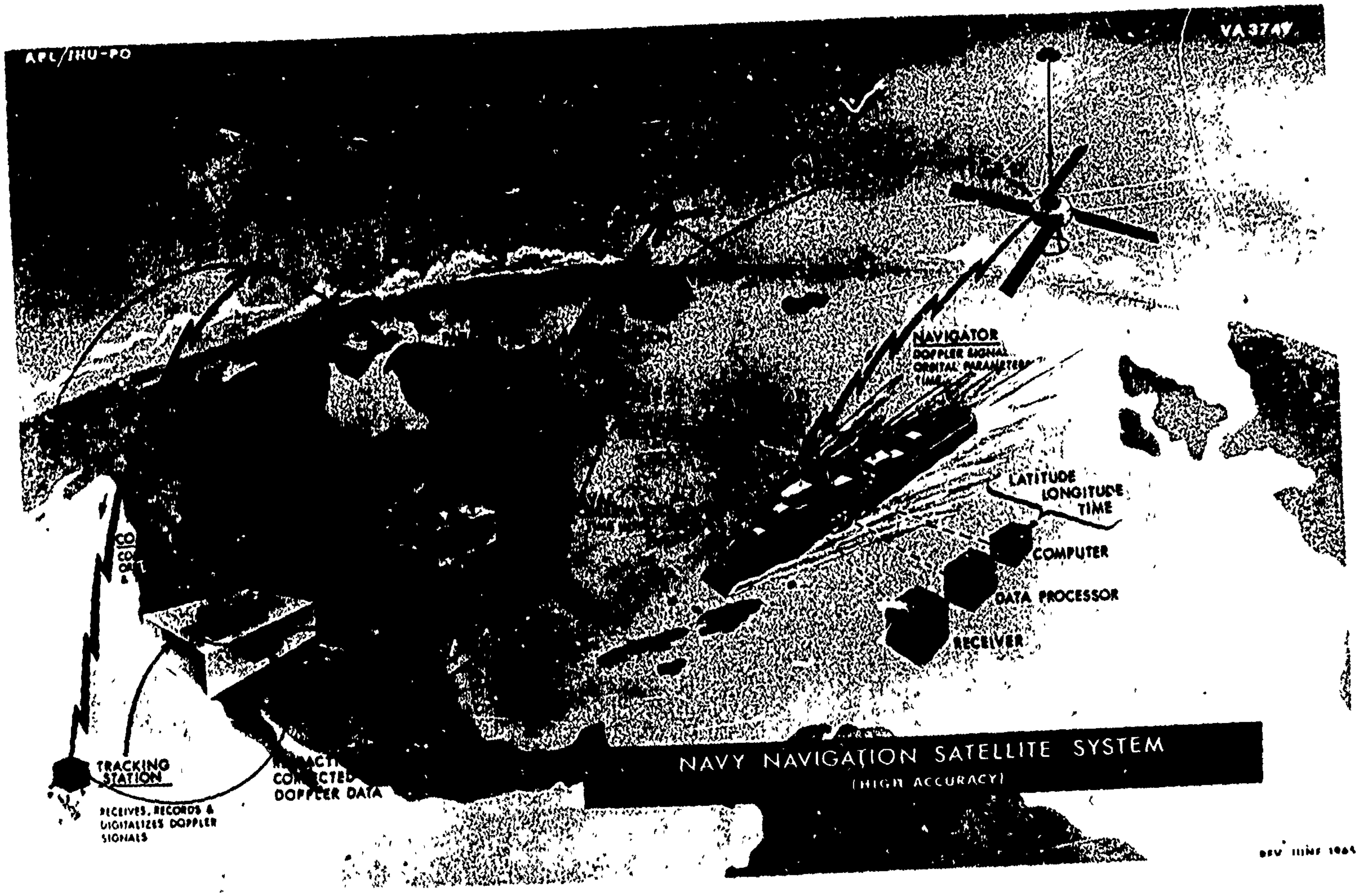


Fig. 1 NAVY NAVIGATION SATELLITE SYSTEM

from the satellites; a computing center where future orbits, orbital parameters, and time corrections are computed; and an injection station to transmit these new orbital parameters and time corrections to the satellite. In addition, the satellite time signals are compared with Universal Time. This information is used in the computing center for the time correction computations. The U. S. Navy Astronautics Group, with headquarters at Point Mugu, California, is responsible for operating the system.

Figure 2 shows a block diagram of the AN/SRN-9 system. The purpose of this report is to provide detailed information for the navigation solution and alert computations shown as part of the computer programming. The descriptions of the remainder of the system provided in this report are intended to provide background information only and are not a specification of any form.

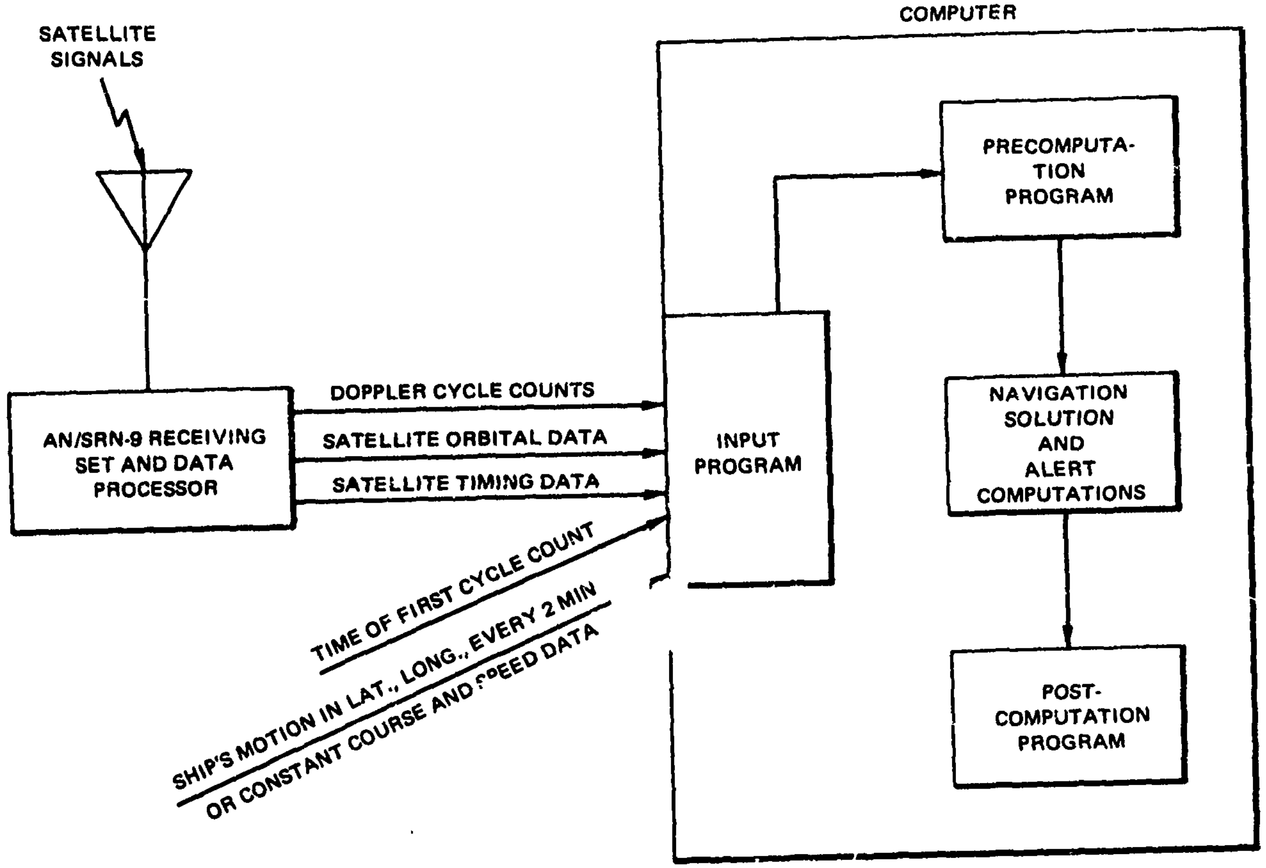


Fig. 2 BLOCK DIAGRAM OF AN/SRN-9 SYSTEM

2. INTEGRATED DOPPLER MEASUREMENT OF SLANT RANGE CHANGE

Integrated doppler navigation is based on the concept that the integral of the doppler shift of the satellite signal, as observed by the navigator, over a fixed time interval is a measure of the change in the slant range from the satellite to the navigator over this same interval (Fig. 3). The theory of the slant range change measurement is as follows:

A satellite signal transmitted at time t_k with slant range S_k will be received by the navigator at time $t_k + S_k/c$. If the satellite is transmitting a stable signal at frequency $(f_o-\bar{f})$ continuously between transmission of two time mark signals (transmitted at times t_k and t_{k-1}) the ground observer will count $(f_o-\bar{f})X\tau$ cycles for the interval between receipt of the time markers ($\tau = t_k - t_{k-1}$). The frequency of this received signal will be denoted $f_R(t)$ and the receiver reference frequency f_o. A difference frequency therefore exists in the ground receiver of frequency $f_o-f_R(t)$. The total number of cycles of this difference frequency between receipt of two satellite time marks is measured by counting positive zero-crossings between times $t_{k-1} + S_{k-1/c}$ and $t_k + S_{k/c}$. The apparent doppler count accumulation at a particular frequency (nominally f_o) between receipt of two such successive time marks is therefore:

$$N_k = \int_{t_{k-1}+\frac{S_{k-1}}{c}}^{t_k+\frac{S_k}{c}} (f_o - f_R(t))\, dt = f_o t \Bigg|_{t_{k-1}+\frac{S_{k-1}}{c}}^{t_k+\frac{S_k}{c}} - (f_o - \bar{f})\,\tau; \qquad (1)$$

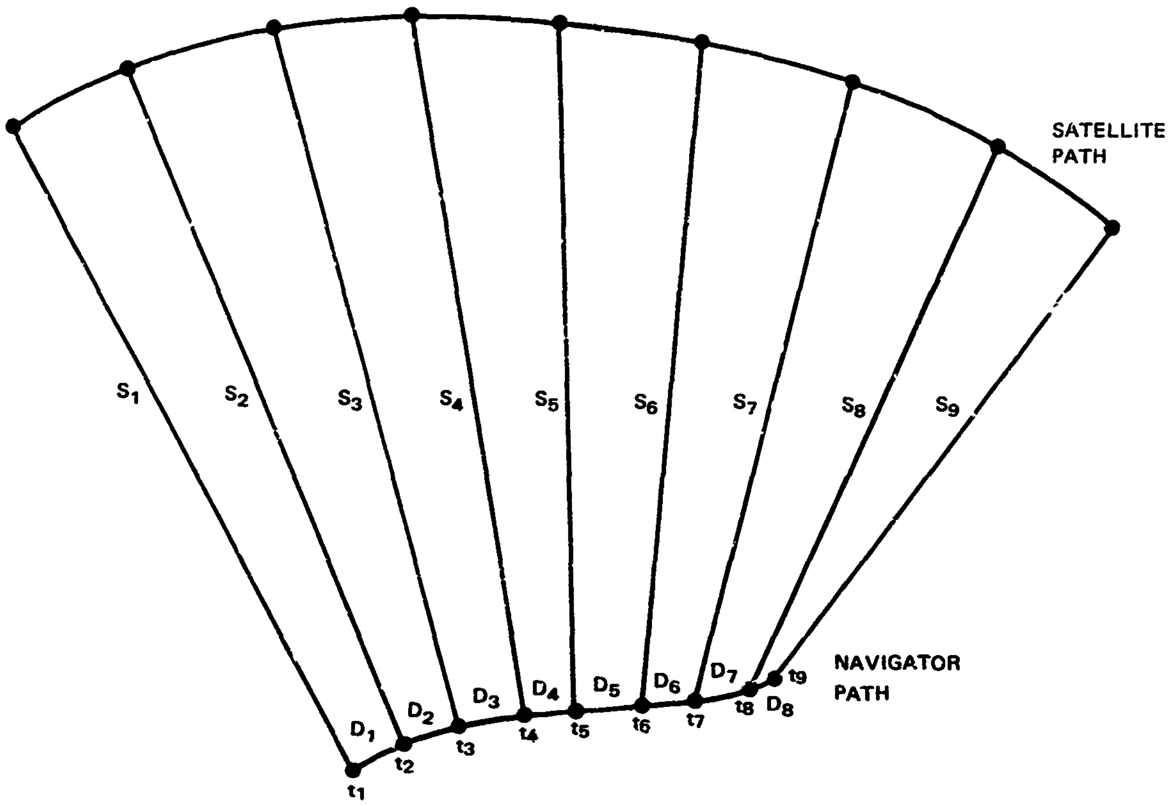


Fig. 3 SLANT RANGE MEASUREMENT

i.e., as noted,

$$\int_{T_{k-1} + \frac{S_{k-1}}{c}}^{t_k + \frac{S_k}{c}} f_R(t)\,dt = (f_o - \bar{f})\tau \tag{2}$$

where

$\tau = t_k - t_{k-1}$,

f_o = reference frequency,

$\bar{f}$ = constant satellite offset frequency, and

c = vacuum speed of light.

Therefore

$$N_k = \frac{f_o}{c}(S_k - S_{k-1}) + \bar{f}\,\tau, \tag{3}$$

from which the apparent slant range change over the kth interval is

$$S_k - S_{k-1} = \hat{S}_k = L_o N_k - \bar{f} L_o \tau, \tag{4}$$

where

$L_o = \frac{c}{f_o}$ = vacuum wavelength at reference frequency f_o.

The quantity $S_k - S_{k-1}$ would be an exact measurement of the slant range change if the process took place in a vacuum. The slant range change of Eq. (4) is the effective RF path length change in the refractive media through which the RF energy must pass to reach earth. Therefore, the doppler cycle count must be corrected for refraction to make it correspond more nearly to a vacuum doppler count.

Details of the correction for ionospheric refraction as implemented in the APL, International Telephone and Telegraph Company (ITT), and Magnavox equipment are given in Section 3.

3. INTEGRATED DOPPLER TRACKING EQUIPMENT

DEVELOPMENTAL AN/SRN-9 EQUIPMENT

In the early stages of the APL development of receiving equipment for use in the integrated doppler count method of navigation, the technical approach was centered around a single-frequency system. It was recognized that the use of a single-frequency system operating at the higher frequencies, i.e., 400 MHz, would result in a navigation error of approximately 1 nmi because of the refraction effect of the ionosphere. The elimination of the requirements for a 150-MHz phase-locked receiver, for a more complex antenna with dual preamplifiers, and for refraction correction equipment appeared desirable in terms of the resultant equipment simplification and lower cost. The single-frequency system was built in breadboard form at the Laboratory, and the feasibility of the system demonstrated in mid-1961. A block diagram of this system is shown in Fig. 4.

The design of a two-frequency system, shown in block diagram form in Fig. 5, was begun by the Laboratory about the same time the single-frequency system reached its breadboard stage. This design effort disclosed that since the two received frequencies are always in constant ratio within a few parts in 10^{-8} (the order of the refraction effect) the second receiver need not be a phase-locked receiver, but could be merely slaved to the 400-MHz phase-locked receiver. The two-frequency system design was developed and tested as an engineering model and subsequently developed into a prototype form designated XN-5. No further development of the single-frequency system was undertaken by the Laboratory.

Basic to the design of both systems is the stable oscillator. Any bias in measuring frequency that is maintained over a pass (as opposed to point-to-point noise within a pass) produces a proportional error in position. The assumption is made, therefore, that the frequency of the local oscillator is an unknown. This assumption requires

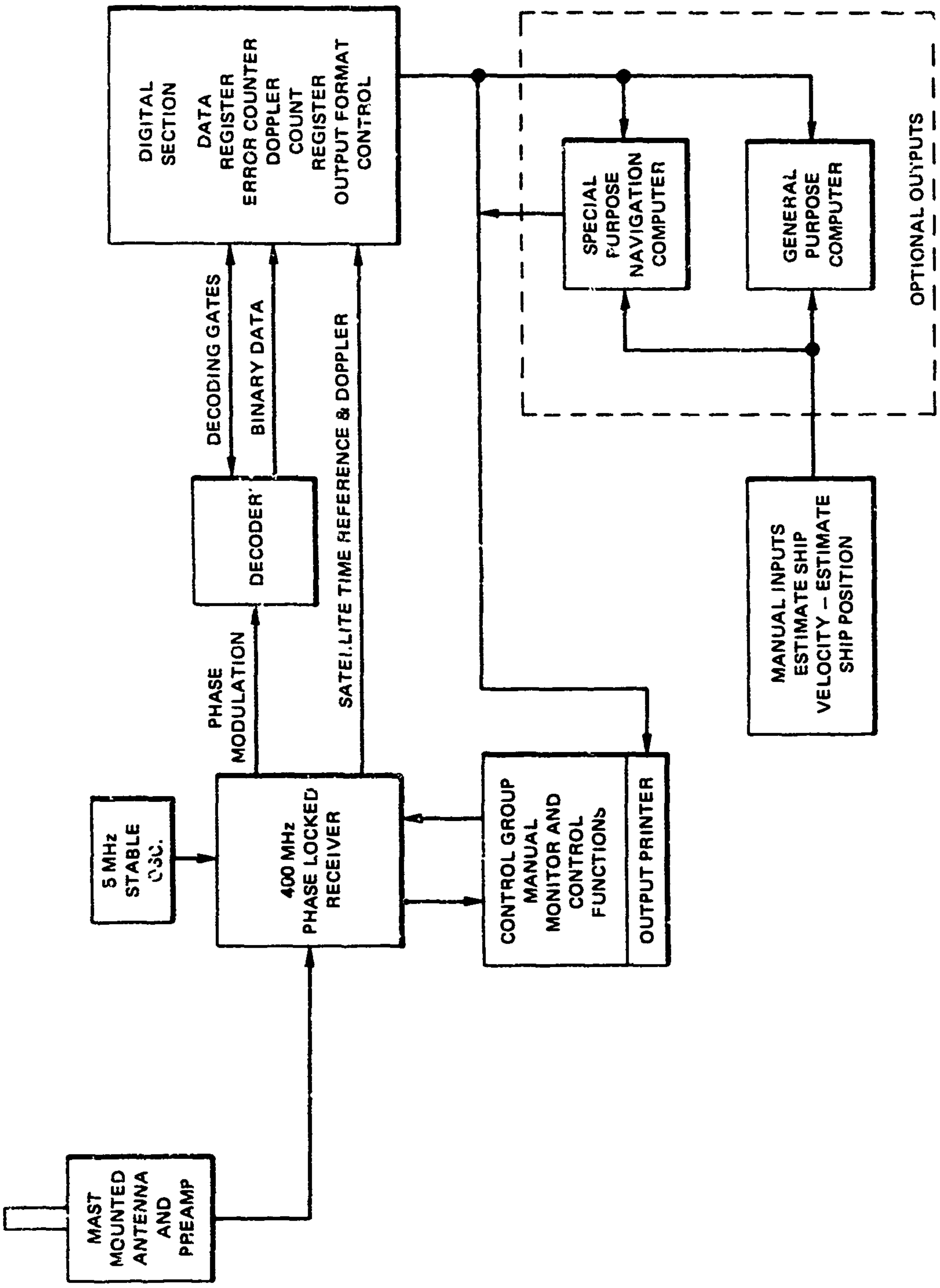


Fig. 4 BLOCK DIAGRAM OF SATELLITE INTEGRATED DOPPLER NAVIGATION EQUIPMENT, SINGLE-FREQUENCY SYSTEM

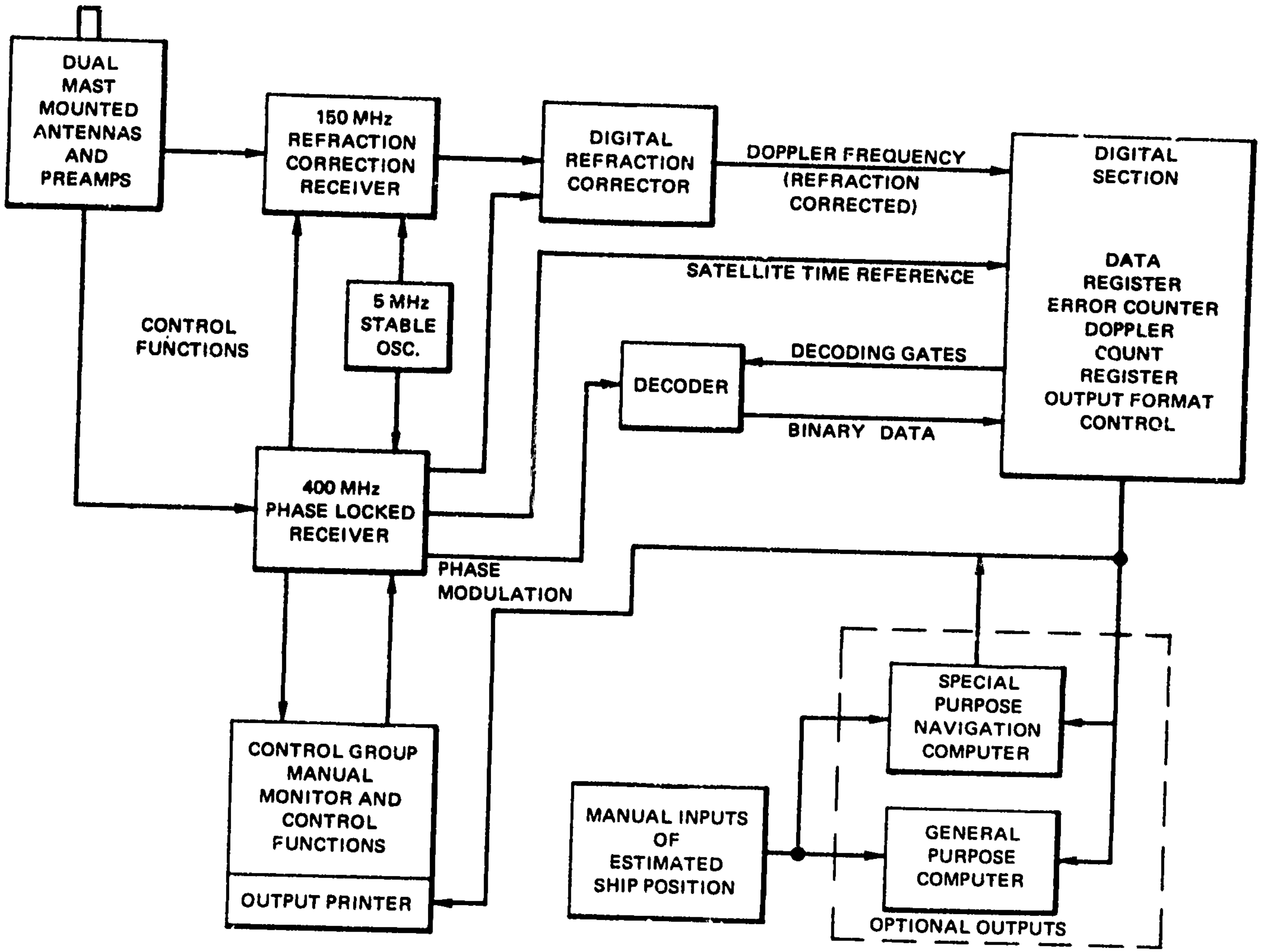


Fig. 5 BLOCK DIAGRAM OF SATELLITE INTEGRATED DOPPLER NAVIGATION EQUIPMENT, DUAL-FREQUENCY SYSTEM

that the measurements and computations needed for a navigation fix be arranged to eliminate the value of the frequency of the oscillator. When this elimination is done properly, the only stability required is five parts in 10^{11} over a 2-minute period. Such stability can be achieved, and a carefully chosen crystal in a thermostatically controlled oven with a large thermal time constant is entirely adequate.

The AN/SRN-9 (XN-5) receiving equipment has five basic elements: (1) the antenna and preamplifiers, (2) the receiver-demodulator, (3) the digital section, (4) the control group (output section), and (5) the 5-MHz oscillator (Fig. 6).

The antenna is a whip over a ground-plane mounted on the superstructure of the ship, along with preamplifiers for the 150- and 400-MHz signals.

The receiver-demodulator contains circuitry to perform the following functions:

1. Selectively track a satellite signal after manual lock-on.
2. Demodulate the binary data from the carriers. Figure 7 shows the binary modulation format.
3. Provide timing signals to the digital section at the doublet (half bit) rate (one every 9.83 ms) as derived from the doublet coding in the satellite messages.
4. Produce a sequence of pulses from which a refraction corrected doppler count is obtained.

These functions are described in detail on the following pages.

The higher frequency signal transmitted from the satellite is 400 MHz - f_H, where $f_H \approx 32$ kHz, since the

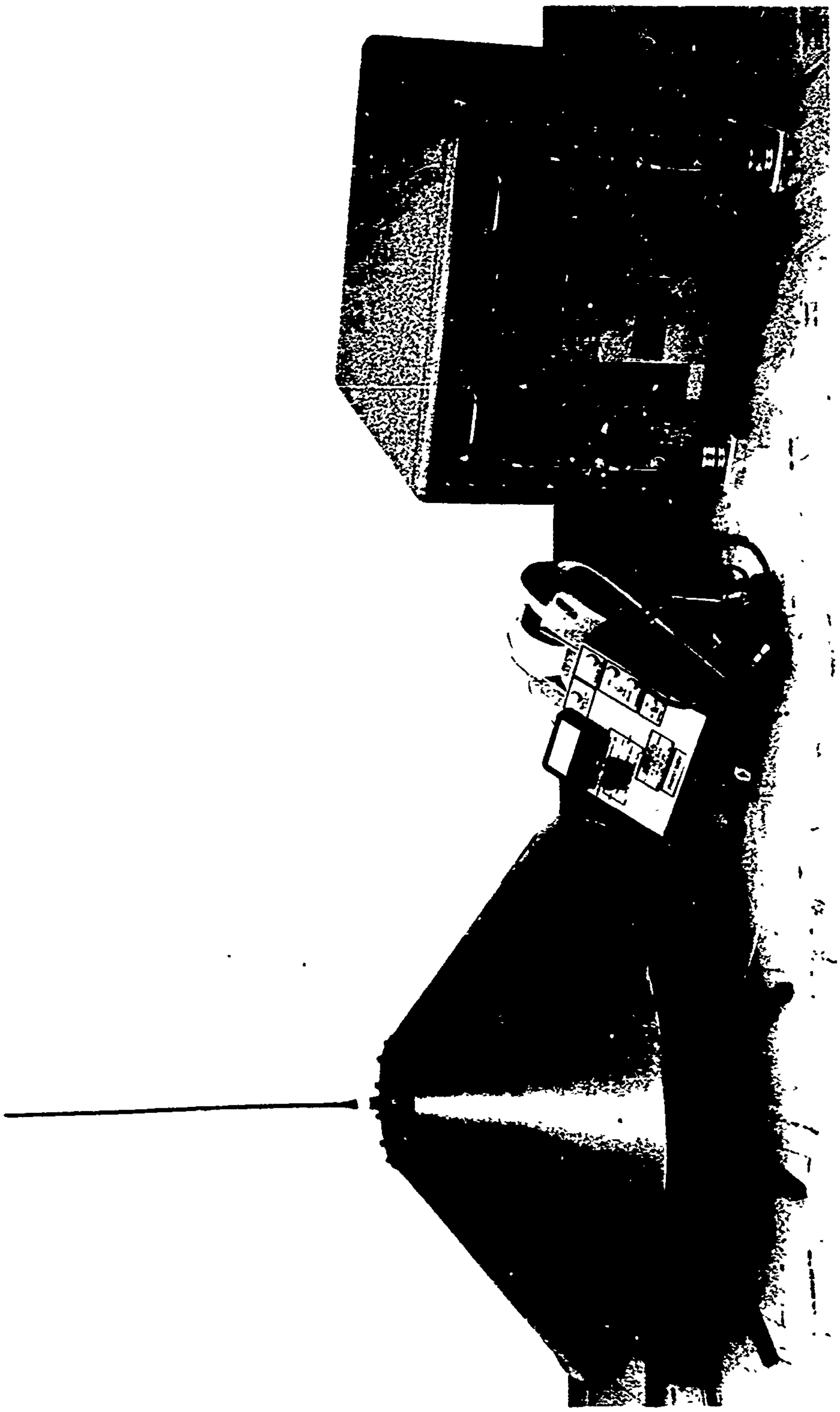
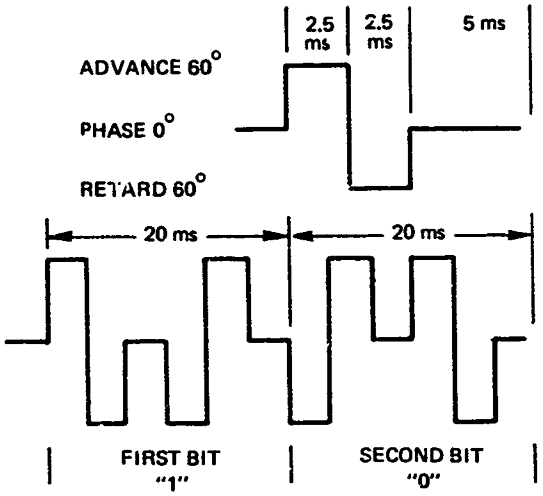


Fig. 6 AN/SRN (XN-5) RECEIVING EQUIPMENT



THE PHASE OF THE DOPPLER SIGNAL IS ADVANCED AND THEN RETARDED TO REPRESENT ONE POLARITY, RETARDED AND THEN ADVANCED FOR THE REVERSE POLARITY. EACH HALF BIT IS TRANSMITTED TWICE, THE SECOND TIME IN REVERSE POLARITY.

"1" = ADVANCE–RETARD–SPACE
RETARD–ADVANCE–SPACE

"0" = RETARD–ADVANCE–SPACE
ADVANCE–RETARD–SPACE

BIT RATE ≅ 50/S

Fig. 7 COMMUNICATION LINK MODULATION WAVEFORMS frequency offset is nominally 80 ppm. This signal is shifted d_H because of the doppler effect and ϵ_H because of ionospheric refraction. For the system parameters used d_H is between ±10 kHz and ϵ_H is between ±3 Hz. The set receives a signal from the satellite on a whip antenna at a frequency of 400 MHz - $f_H + d_H + \epsilon_H$. This signal is amplified in a 400-MHz automatic gain controlled (AGC) preamplifier with a maximum gain of 70 dB, a bandwidth of 1 MHz, and a noise figure of 10 dB.

The signal from the preamplifier then is mixed with a local RF reference signal. The resulting 5-MHz difference frequency is amplified in a high gain, 3-kHz bandwidth 5-MHz IF amplifier.

The IF output is fed in parallel to two phase comparators in which it is compared with the phase of quadrature components of a stable 5-MHz reference signal.

The phase comparator produces a DC voltage that is used to detect phase or frequency errors in the RF frequency and control a second order frequency/phase loop, which maintains the frequency and phase relationship between the RF reference signal and the received signal.

The stable 5-MHz reference oscillator uses design concepts similar to those used in the satellite oscillator, i.e., a thermostatically controlled oven with a very long thermal time constant between the oven and a monel slug, which contains the critical circuits. Since the vacuum of space is not available for the earthbound oscillator, a great amount of thermal insulation is used, resulting in a relatively large physical size.

The 5-MHz stable reference frequency is multiplied by a factor of 81 to 405 MHz. The difference between this frequency and the locally generated RF reference signal is, provided the phase-locked loop is tracking a signal, the amount by which the received signal is below 400 MHz, i.e., $f_H - d_H - \epsilon_H$. A pulse generator converts the doppler cycles from the doppler mixer into pulses.

The 150-MHz receiver is slaved to the 400-MHz receiver to "listen" to a very narrow 20-Hz bandwidth portion of the RF spectrum centered at a "predicted" frequency exactly 3/8 of the frequency tracked by the 400 MHz phase-locked receiver. The slaved receiver produces two signals at the difference frequency between the predicted frequency and the 150-MHz signal received. The relative phase of these signals indicates whether the 150-MHz signal is above or below 3/8 of the high frequency signal.

The satellite transmits as its lower frequency 150 MHz - f_L (where $f_L \approx 12$ kHz), i.e., 3/8 of the high frequency transmitted. This signal is shifted by doppler and ionospheric effects to a received frequency of 150 MHz - $f_L + d_L + \epsilon_L$. The doppler shift is proportional to frequency, but the ionospheric refraction shift has been found to be inversely proportional to frequency. The received frequency may then be expressed as,

$$150 \text{ MHz} + 3/8\,(-f_H + d_H) + 8/3\,\epsilon_H.$$

A local reference signal at 3/8 of the high frequency local reference signal is mixed with the amplified low frequency signal with the following results:

$$\begin{aligned} &3/8\,[405 \text{ MHz} - f_H + d_H + \epsilon_H] - [150 \text{ MHz} + 3/8\,(-f_H + d_H) + \\ &\quad 8/3\,\epsilon_H] = 1.875 \text{ MHz} + [3/8 - 8/3]\,\epsilon_H = \qquad (5) \\ &\quad 1.875 \text{ MHz} - 55/24\,\epsilon_H . \end{aligned}$$

Because $55/24\,\epsilon_H$ is typically less than 5 Hz, this signal can be amplified in a very narrow 20-Hz bandwidth IF amplifier. AGC detection may safely be performed in this narrow bandwidth.

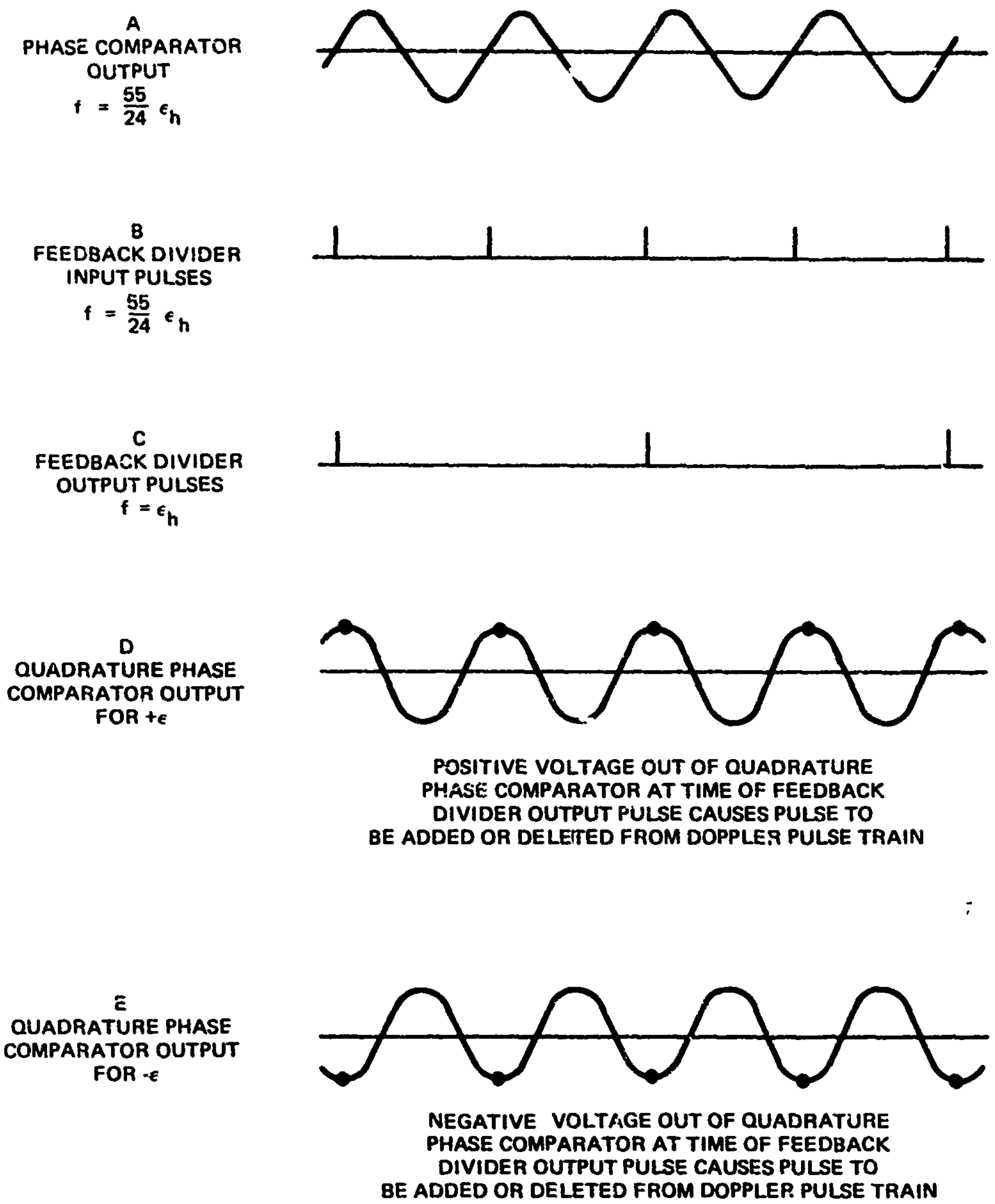
The phase relationship of this RF output and the stable reference oscillator determines whether the refraction correction adds or deletes cycles from the doppler count. The corrected doppler pulse train is then counted in the doppler accumulator to measure satellite slant range change during the count interval.

The 400-MHz phase comparator also produces a signal whose voltage excursions versus time are an accurate representation of the phase excursions of the input signal [illegible] in Fig. 8. The decoder accepts these doublet data fr[illegible] phase comparator, synchronously detects them, [illegible]rts them to a binary format compatible with the a[illegible]ection. The synchronous detection is followed by an integration with end-of-bit sampling to afford maximum immunity from noise errors. The properly timed gating signals required for synchronous decoding are derived from the digital section.

The decoder thus associates the adjacent doublets in the received signals with appropriate binary bits. The process is initiated with an arbitrary association of adjacent doublets. The resulting binary bits are observed in the digital section, and pulses generated by the pairing of doublets are counted. If the count exceeds a specified threshold the doublet association is reversed, and the correct pairing of doublets into binary bits is achieved. Binary data are sent serially from the receiver-demodulator into the digital unit.

A precise timing signal based upon the message modulation rate is derived in an internal clock in the receiving equipment. This synchronized internal clock controls the decoding, printing, and doppler count gating operations with an accuracy of better than 0.2 ms. Because the operational satellites transmit the end of message word two at each Universal 2-minute Time ±500 μs, adequate time information is obtained from the satellite for navigation and doppler gating.

The digital section contains shift registers for accumulating the doppler count and for storing the serial binary data decoded from the satellite messages.



POSITIVE VOLTAGE OUT OF QUADRATURE PHASE COMPARATOR AT TIME OF FEEDBACK DIVIDER OUTPUT PULSE CAUSES PULSE TO BE ADDED OR DELETED FROM DOPPLER PULSE TRAIN

NEGATIVE VOLTAGE OUT OF QUADRATURE PHASE COMPARATOR AT TIME OF FEEDBACK DIVIDER OUTPUT PULSE CAUSES PULSE TO BE ADDED OR DELETED FROM DOPPLER PULSE TRAIN

Fig. 8 AN/SRN-9 (XN-5) REFRACTION CHANNEL WAVEFORMS

The digital section also contains an output register and the necessary counting and control logic to organize the satellite messages into words and digits (output format control). It also programs the data and other timing signals to the output terminals. The message data are extracted in four-bit groups (i.e., excess-three binary coded decimal format). Control signals are available to take all data (every word) or select only every sixth word (all that is necessary) for normal navigation.

The data used by the integrated doppler navigator are contained in words 8, 14, 20, 26, etc., up to 128. These words include the satellite orbit parameters; the output format control selects these words and prints them out on a paper tape along with the integrated doppler count.

The control group of the receiving equipment in its simplest form produces a printed tape listing:

1. Between three and eight accumulated refraction corrected doppler counts, each for a 2-minute period and with end points precisely governed by satellite-transmitted Universal Time 2-minute marks.

2. Between three and eight readouts of the satellite-stored orbit parameters, defining satellite positions every 2 minutes.

All equipment control functions are provided by a control group packaged with the numerical printer. Figure 9 shows one control group-printer configuration. The printer in this configuration prints eight of the nine digits of the satellite word. Other later control group configurations print all nine digits.

From the control group, the navigator can monitor the operation of the equipment. In operation, the navigator remotely tunes the 400-MHz receiver from whence it obtains all necessary control functions.

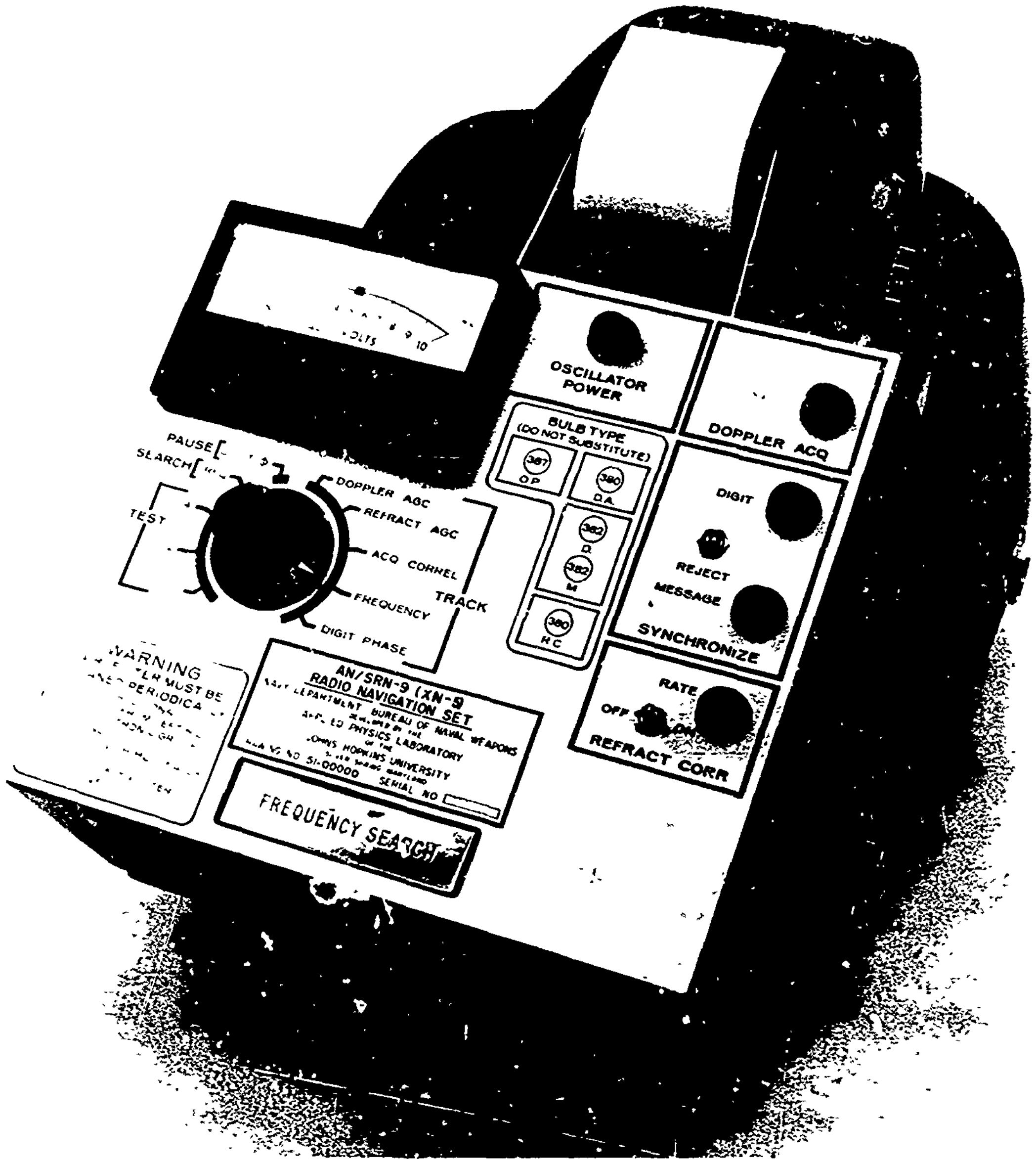


Fig. 9 AN/SRN–9 (XN-5) CONTROL GROUP-PRINTER CONFIGURATION

A sample of the nine digit printer output is shown in Fig. 10. The first line is one value of the total refraction corrected cycle count for the previous 2 minutes. The second line is the orbital information for the epoch 6 minutes before the beginning of the 2-minute interval, followed by the orbital information for the epoch 4 minutes before, and so on through the information for the epoch 8 minutes after the end of the 2-minute interval. After these 8 lines, there occur 17 lines of data from the fixed portion of the satellite memory. Following these lines of data there is another reading of the doppler counter. This reading is readily distinguished from the orbital data by the different number of digits in the line. The shifting of the ephemeral or variable portion of the memory can be observed by noting the next 8 lines of the printout. The single and double signs at the beginning of the fixed and ephemeral readout are a code that is described in Section 5.

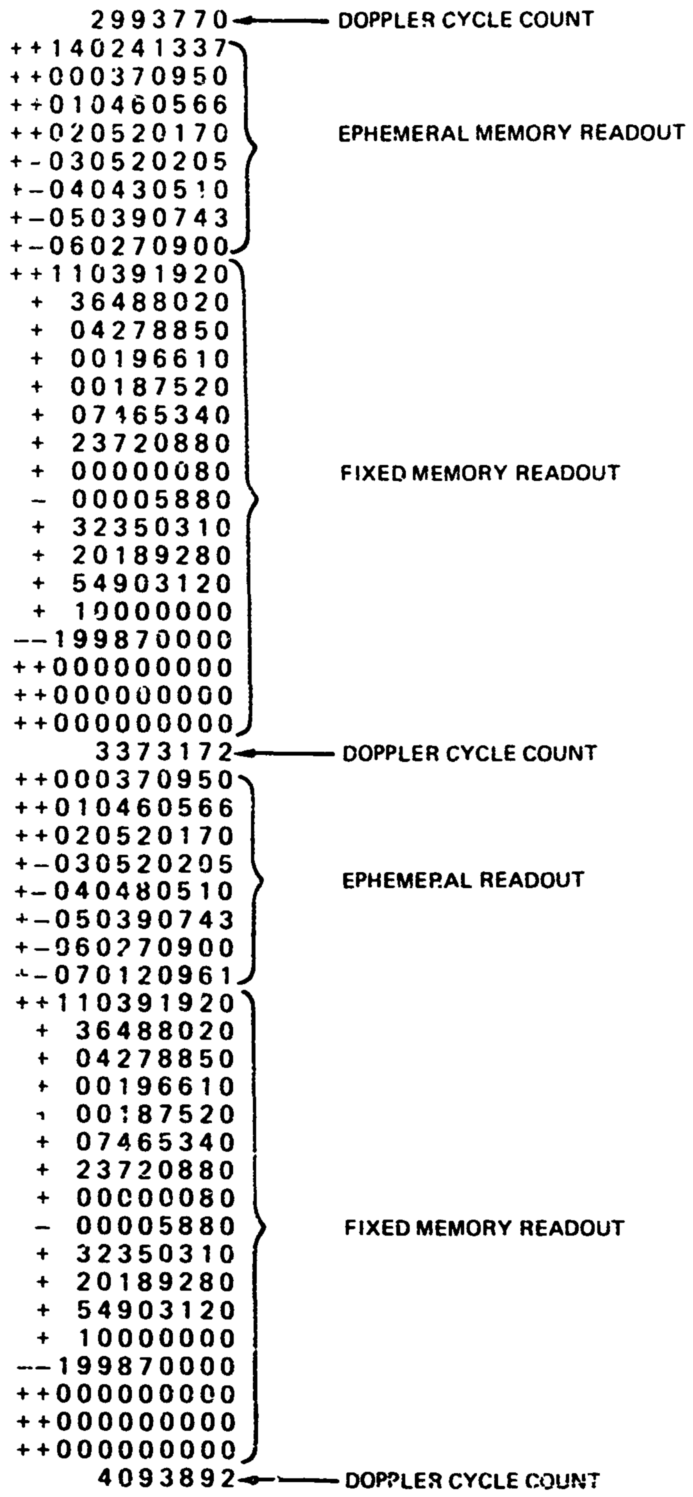
In summary, for any satellite pass the following sequence of events will occur in the receiving equipment:

1. The receiver-demodulator is manually locked onto the satellite signals and phase tracks during the satellite pass.

2. The receiver-demodulator begins decoding the binary data based on an arbitrary association of adjacent doublets.

3. The digital section monitors the decoded data and properly pairs the demodulated doublets to form binary bits. When the proper pairing is achieved, the digital section energizes the bit synchronization line.

4. The counting and control logic is reset by the synchronization word in the satellite data format. The first time the synchronization word is received after bit synchronization, the digital section outputs a synchronization pulse. A 2-minute Universal Time pulse is also generated each time the synchronization sequence



```
    2993770   DOPPLER CYCLE COUNT
++140241337
++000370950
++010460566
++020520170   EPHEMERAL MEMORY READOUT
+-030520205
+-040430510
+-050390743
+-060270900
++110391920
+ 36488020
+ 04278850
+ 00196610
+ 00187520
+ 07465340
+ 23720880
+ 00000080   FIXED MEMORY READOUT
- 00005880
+ 32350310
+ 20189280
+ 54903120
+ 10000000
--199870000
++000000000
++000000000
++000000000
    3373172   DOPPLER CYCLE COUNT
++000370950
++010460566
++020520170
+-030520205
+-040480510   EPHEMERAL READOUT
+-050390743
+-060270900
+-070120961
++110391920
+ 36488020
+ 04278850
+ 00196610
+ 00187520
+ 07465340
+ 23720880
+ 00000080
- 00005880   FIXED MEMORY READOUT
+ 32350310
+ 20189280
+ 54903120
+ 10000000
--199870000
++000000000
++000000000
++000000000
    4093892   DOPPLER CYCLE COUNT
```

Fig. 10 AN/SRN-9 (XN-5) DOPPLER AND ORBITAL PARAMETER NINE-DIGIT PRINTOUT

(0111111111111111111111110)

is received.

5. The counting and format control logic in the digital section governs the handling of the binary data from the satellite and the accumulation and output of the doppler count.

6. The 2-minute doppler count and satellite message data are printed out in decimal form on the control group printer.

7. Whenever an interrupt in the satellite signal occurs, bit synchronization must be reestablished.

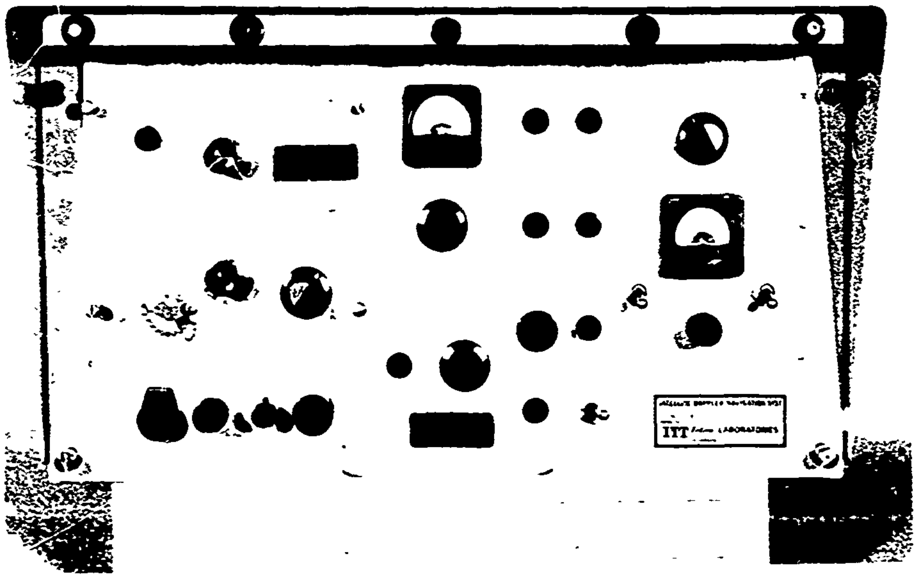
Reference 2 is a detailed description of the AN/SRN-9 (XN-5) Radio Navigation Set.

RADIO NAVIGATION SETS AN/SRN-9 AND AN/SRN-9A

Under contract to the Naval Ship Systems Command, ITT has produced shipboard navigation equipment designated RadioNavigation Sets AN/SRN-9 and AN/SRN-9A to the specifications SHIPS-R-5111 (Ref. 3), SHIPS-R-5111A (Ref. 4), and SHIPS-R-5111B (Ref. 5). These specifications embody APL experience with the developmental AN/SRN-9 equipment. Radio Navigation Set AN/SRN-9 is shown in Fig. 11 and described in Ref. 6. Radio Navigation Set AN/SRN-9A is shown in Fig. 12 and described in Ref. 7. Reference 8 describes operational procedures for both sets when used with the CP-967/UYK computer.

The two sets differ in that the AN/SRN-9A has automatic signal acquisition and coast mode features (explained below); in addition, doppler data may be obtained over either 2-minute intervals or approximately 4.6-second intervals at operator option. The following sections will apply only to 2-minute interval data inasmuch as programming procedures for 4.6-s interval (or short count) data are beyond the scope of this report.

(a) ANTENNA



(b) RECEIVER

Fig. 11 AN/SRN–9 RADIO NAVIGATION SET

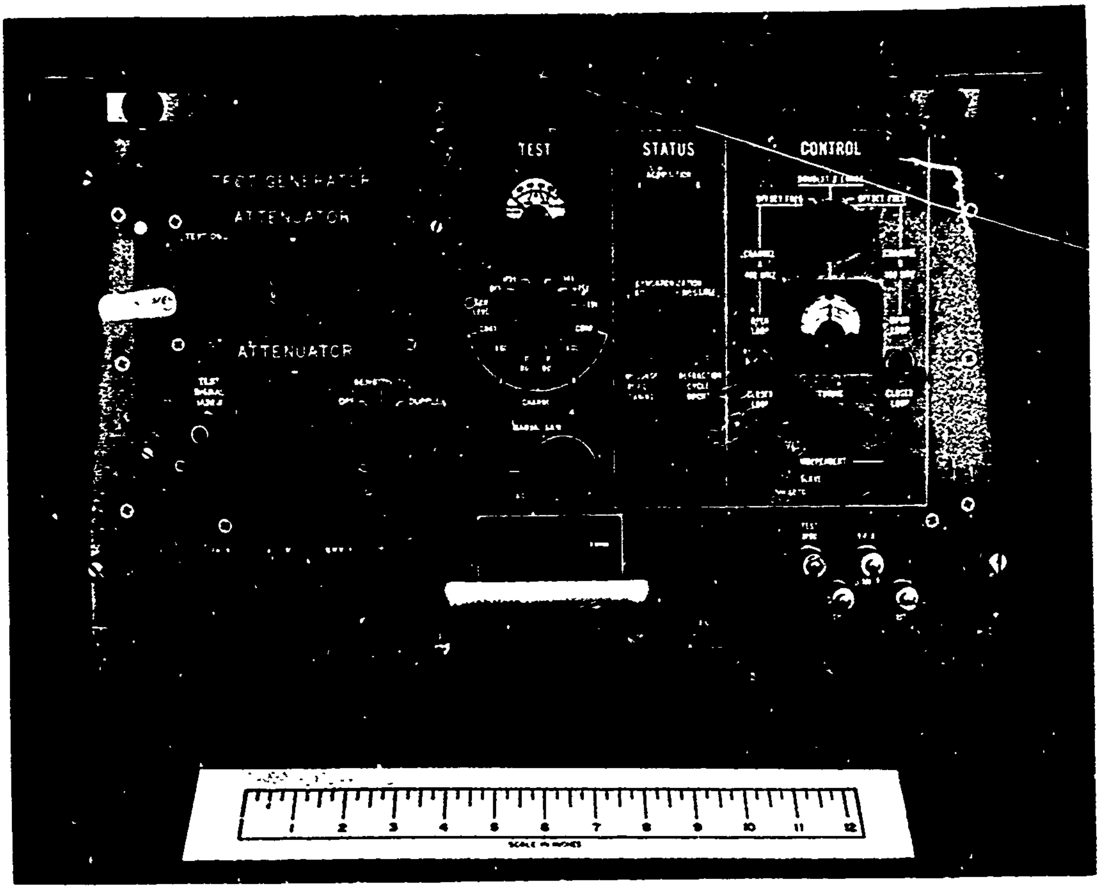


Fig. 12 AN/SRN–9A RADIO NAVIGATION SET

In the AN/SRN-9 set, loss of lock during a 2-minute interval results in loss of all data for that interval. If the AN/SRN-9A set loses lock during a 2-minute interval, however, the coast mode feature allows satellite message data to be obtained upon signal reacquisition, provided the time between loss of lock and reacquisition does not exceed 60 seconds. In addition varying combinations of doppler, refraction, and satellite message data are obtainable in a loss of lock situation, depending upon whether it is the 150 MHz, 400 MHz, or both signals that are lost. The following tabulation shows all the consequences for the various combinations:

Condition	Doppler Data	Refraction Data	Message Data
Unlocked	-	-	-
Both channels locked during first transfers (initial message sync.) (1)	BCDX3"0"	BCDX3"0"	BCDX3
Both channels locked	BCDX3	BCDX3	BCDX3
400 MHz locked 150 MHz unlocked	BCDX3	BCDX3"0"	BCDX3
400 MHz unlocked 150 MHz locked	BCDX3"0"	BCDX3"0"	BCDX3
Coast Mode (2)	Binary "0"	Binary "0"	Binary "0"

Note (1) BCDX3 denotes valid data format.
(2) During coast mode, binary "0" will be outputted to computer.

From the standpoint of programming a computer for use with data obtained with either the AN/SRN-9 or AN/SRN-9A Radio Navigation Set, the differences between these equipments and the developmental AN/SRN-9 equipment described in the previous section lie in the treatment of the ionospheric refraction correction and in the formatting of the output data. Whereas the refraction correction circuitry in the developmental equipment adds or deletes cycles from the doppler count such that a refraction corrected doppler count is obtained for use in navigation computations, the AN/SRN-9 and AN/SRN-9A equipment is designed to present the refraction information separately from the doppler count, and the requisite correction must be done during subsequent computations. The refraction count data in the AN/SRN-9 and AN/SRN-9A equipment take on values between 1000 and 3000 and are scaled such that a count of 2000 is an indication that no correction is required or (in the AN/SRN-9 only) that the refraction count is invalid.

The refraction correction equation to be implemented then is

$$N_k = N_{k_{400}} - \frac{24}{55} (R_k - 2000) \tag{6}$$

where

N_k = ionospheric refraction corrected doppler count,

$N_{k_{400}}$ = 400-MHz doppler count from ITT equipment, and

R_k = refraction count from ITT equipment.

The ITT equipment may be configured to output its data into a readout device, such as a printer or a paper tape punch, for later off-line calculation, or directly into a computer for real-time navigation. Figure 13 shows a thermal printer readout that could have been obtained from either an AN/SRN-9 or an AN/SRN-9A, for comparison with Fig. 10. Specific details of the format of the output data from the ITT equipment are described in the Data Types and Formats Section.

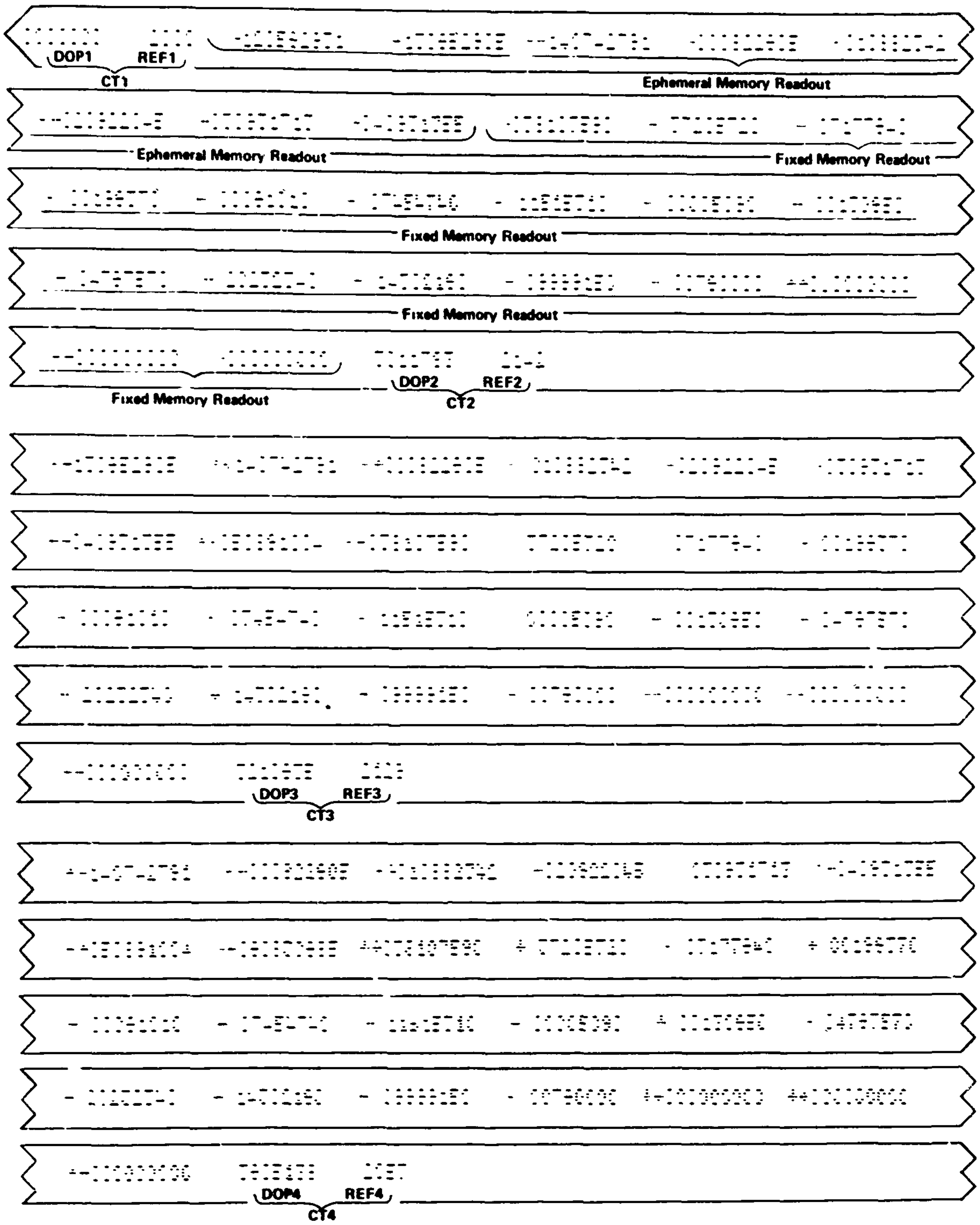


Fig. 13 AN/SRN-9 OR AN/SRN-9A TWO-MINUTE DOPPLER, REFRACTION, AND ORBITAL PARAMETER PRINTOUT

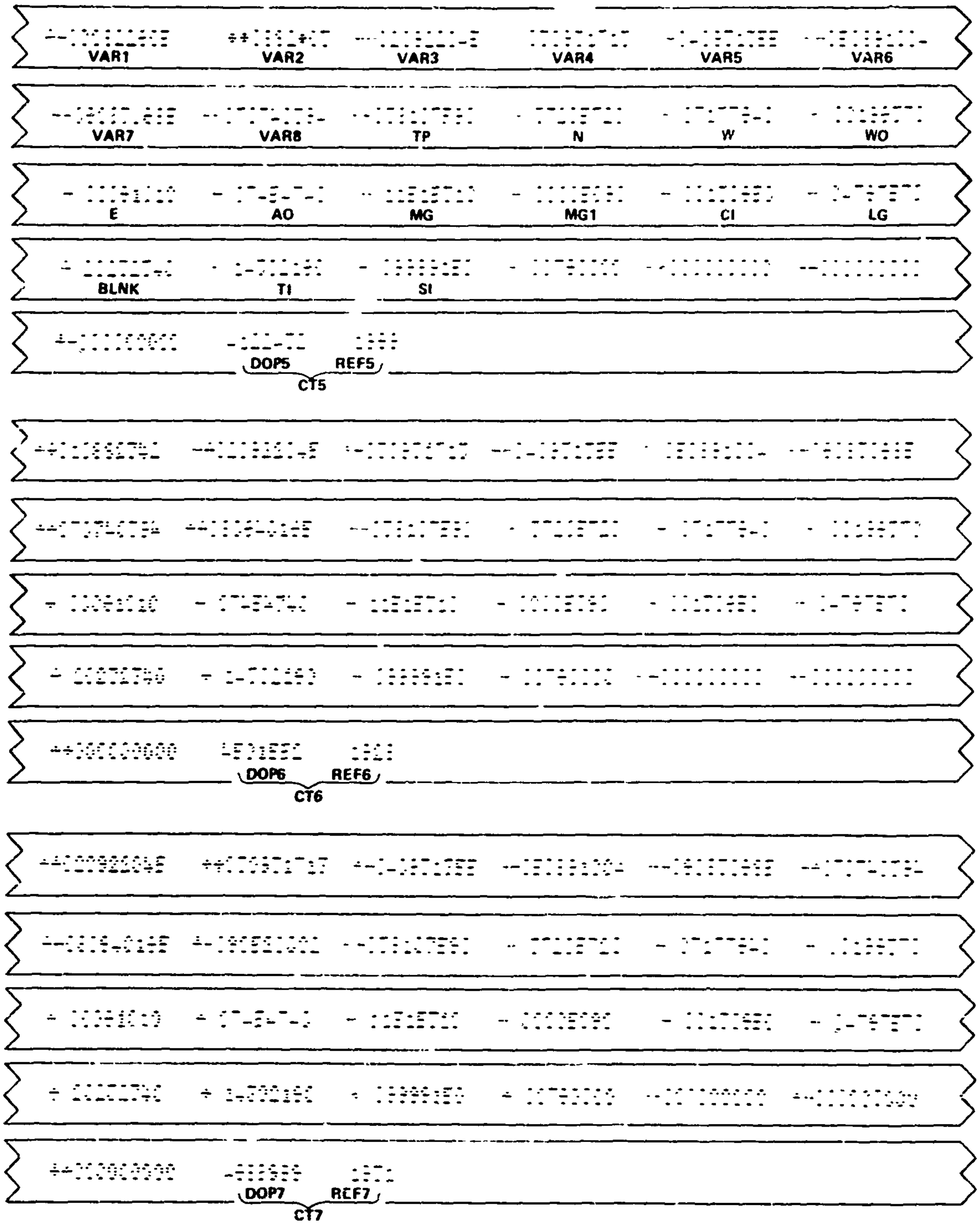


Fig. 13 AN/SRN-9 OR AN/SRN-9A TWO-MINUTE DOPPLER, REFRACTION, AND ORBITAL PARAMETER PRINTOUT (cont'd)

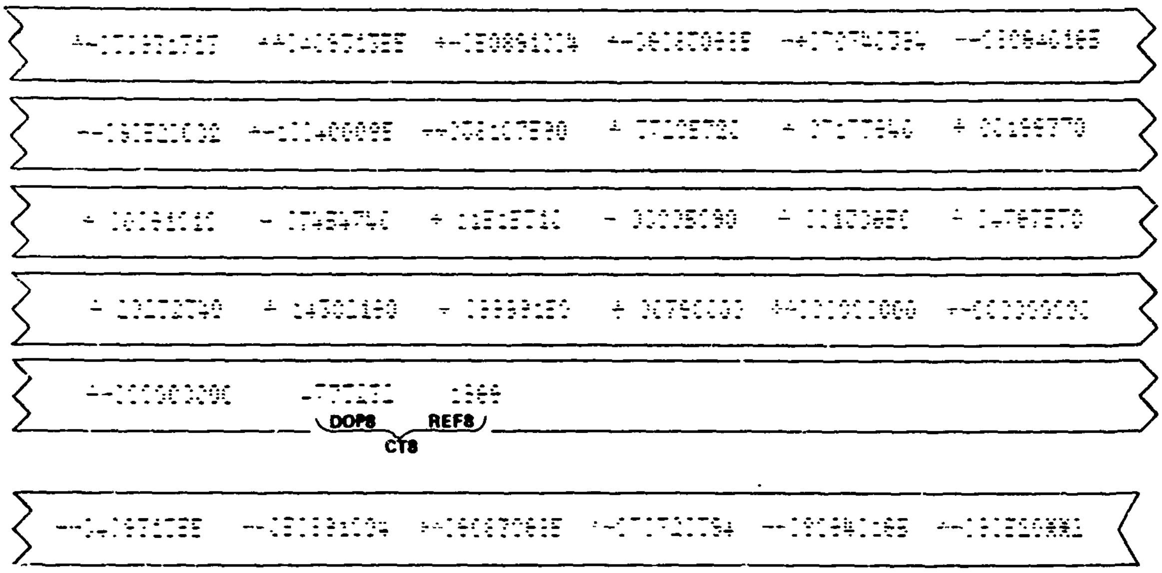


Fig. 13 AN/SRN-9 OR AN/SRN-9A TWO-MINUTE DOPPLER, REFRACTION, AND ORBITAL PARAMETER PRINTOUT (cont'd)

NAVIGATION SATELLITE RECEIVER SET 702CA

Under the sponsorship of the Office of Naval Research, the Scripps Institution of Oceanography of the University of California has contracted with the Magnavox Company for the Navigation Satellite Receiver Set 702CA, produced in accordance with Scripps Specification 0A0088 (Ref. 9). This specification also embodies APL experience with developmental integrated doppler navigation equipment. Figure 14 shows the equipment; Ref. 10 describes its operation and maintenance.

From the standpoint of programming a computer for use with the Navigation Satellite Receiver Set 702CA, the differences between this equipment and the developmental AN/SRN-9 equipment described previously lie in the treatment of the ionospheric refraction correction and in the formatting of the output data. Like the ITT AN/SRN-9 equipment the 702CA equipment also provides separate outputs for use in later calculations to obtain a refraction corrected doppler count. The 702CA outputs, however, are a 400-MHz doppler count and a 150-MHz doppler count scaled by the receiver to 400 MHz.

The refraction correction equation for Magnavox 702CA data is then

$$N_k = N_{k_{400}} + \frac{9}{55} (N_{k_{400}} - N_{k_{150}}) \tag{7}$$

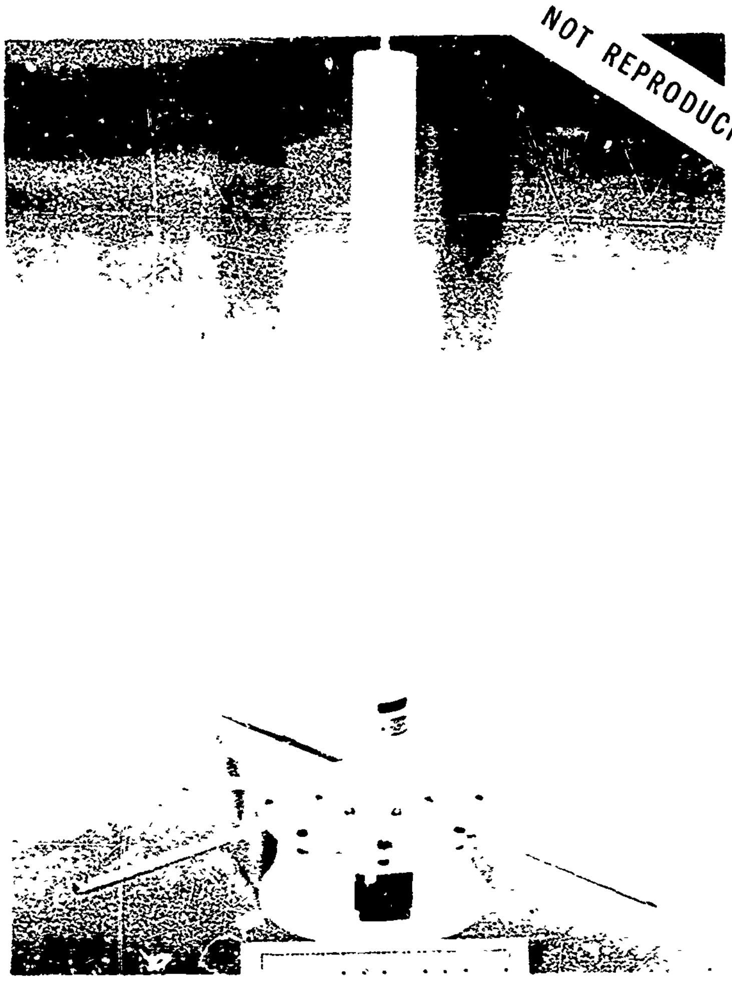
where

N_k = ionospheric refraction corrected doppler count,

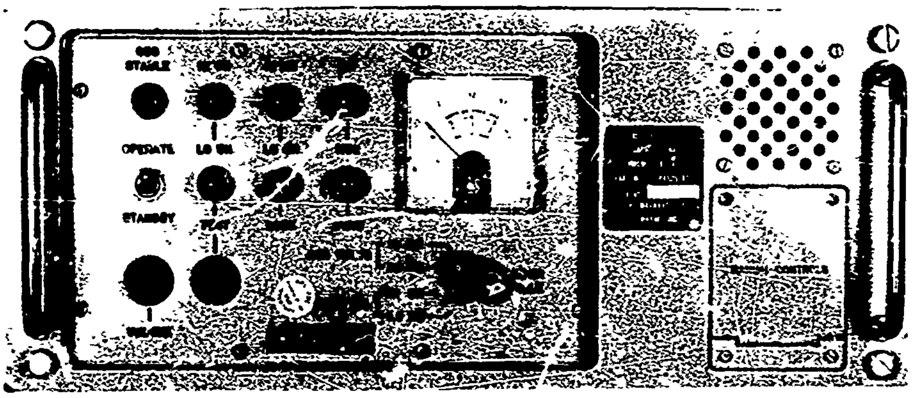
$N_{k_{400}}$ = 400-MHz doppler count, and

$N_{k_{150}}$ = 150-MHz doppler count.

NOT REPRODUCIBLE



(a) ANTENNA



(b) RECEIVER

Fig. 14 NAVIGATION SATELLITE SET 702 CA

Figure 15 shows a printout obtained from the 702CA receiver on the HP 2115A computer for comparison with Fig. 10 (AN/SRN-9 (XN-5) printout) and Fig. 13 (ITT AN/SRN-9 or AN/SRN-9A printout). Note that the coding in the form of single and double signs shown in Figs. 10 and 13 is expressed in Fig. 15 as a digital coding. Specific details of the format of the output data from the Magnavox equipment are described later in the Data Types and Formats Section.

```
000000000 003023322
430732390 440812742 000872531 010912255
020931942 030921605 040891252 050830915
414088460 837170670 810687490 800197580
800061330 807455250 815310080 900004850
800125170 809053730 82023024  851800660
809999220 800510000 000000000  000000000
000000000 400 MHz DOPPLER   150 MHz DOPPLER

003263772 003263945
440812745 000872531 010912255 020931942  EPHEMERAL MEMORY READOUT
030921605 040891252 050830915 060750602
414088460 837170670 810687490 800197580
800061330 807455250 815310080 900004850
800125170 809053730 820230240 851800660   FIXED MEMORY READOUT
809999220 800510000 000000000 000000000
000000000

003737842 003737907
000872531 010912255 020931942 030921605
040891252 050830915 060750602 070640345
414088460 837170670 810687490 800197580
800061330 807455250 815310080 900004850
800125170 809053730 820230240 851800660
809999220 800510000 000000000 000000000
000000000
```

Fig. 15 702CA DOPPLER, REFRACTION, AND ORBITAL PARAMETER PRINTOUT AS OBTAINED ON HP2115A COMPUTER

4. GEOMETRICAL BASIS OF NAVIGATION EQUATIONS

The derivation of the equations used in the navigation solution as presented here is divided into two parts. The first of these parts will show the method of coordinate system transformation, which is used to obtain the navigator and satellite positions in a common coordinate system. The second part will show the derivation of satellite and navigator positions from basic information available to the navigator.

COORDINATE TRANSFORMATIONS

To show the derivation of the coordinate system transformations used in the navigation solution, first define a right-hand, earth-centered, inertial cartesian coordinate system XYZ which is oriented such that (1) its center is at the center of the earth, (2) its X-Y plane is coincident with the equatorial plane of the earth, (3) its Z-axis is coincident with the spin axis of the earth (the positive Z-axis points toward the north pole), and (4) its X-axis is coincident with the vernal equinox (First Line of Aries).

In a similar manner, define a right-hand, earth-centered coordinate system which is fixed with respect to the rotating earth. This system, denoted xyz, is oriented such that (1) its center is at the center of the earth, (2) its x-y plane is coincident with the equatorial plane of the earth, (3) its z-axis coincides with the spin axis of the earth, and (4) its x-axis is coincident with the plane of the Greenwich Meridian.

It can be easily visualized that, since the xyz coordinate system rotates with the earth, any fixed point on the earth will remain fixed with respect to the xyz system. This coordinate system would then be desirable as a reference system for the navigator, since his position at any time may be represented as a point in the xyz system and, if he is not moving, his position within the coordinate system will not change with time.

Now define the angle between a line through the Greenwich Meridian on the x-y plane and the vernal equinox (First Line of Aries) as Λ_G. This angle is called the hour angle or Right Ascension of Greenwich. Pictorially, the XYZ and xyz coordinate systems appear as in Fig. 16. The transformation from XYZ to xyz coordinates is given by

$$\begin{aligned} x &= X \cos \Lambda_G + Y \sin \Lambda_G \\ y &= -X \sin \Lambda_G + Y \cos \Lambda_G \\ z &= Z \ . \end{aligned} \tag{8}$$

Now define a three-dimensional coordinate system x'y'z' whose center is at the center of the earth and whose x'-axis lies in the equatorial plane of the XYZ coordinate system. The x' and y' directions in this coordinate system define a plane which is the orbital plane of the satellite. Further, define the inclination angle, i, of the satellite plane as the angle between the y'-axis and the equatorial plane, XY, and the angle Ω_o, the right ascension of the ascending node, as the angle between the x'-axis of the orbital plane and the X-axis of the XYZ coordinate system. The orientation of the orbital plane is shown in Fig. 17.

From examination of the geometry of the XYZ coordinate system and the x'y' plane, the transformation from the x'y' plane to the XYZ coordinate system is given by

$$\begin{aligned} X &= x' \cos \Omega_o - y' \cos i \ \sin \Omega_o \\ Y &= x' \sin \Omega_o + y \ \cos i \ \cos \Omega_o \\ Z &= y' \ \sin i \ . \end{aligned} \tag{9a}$$

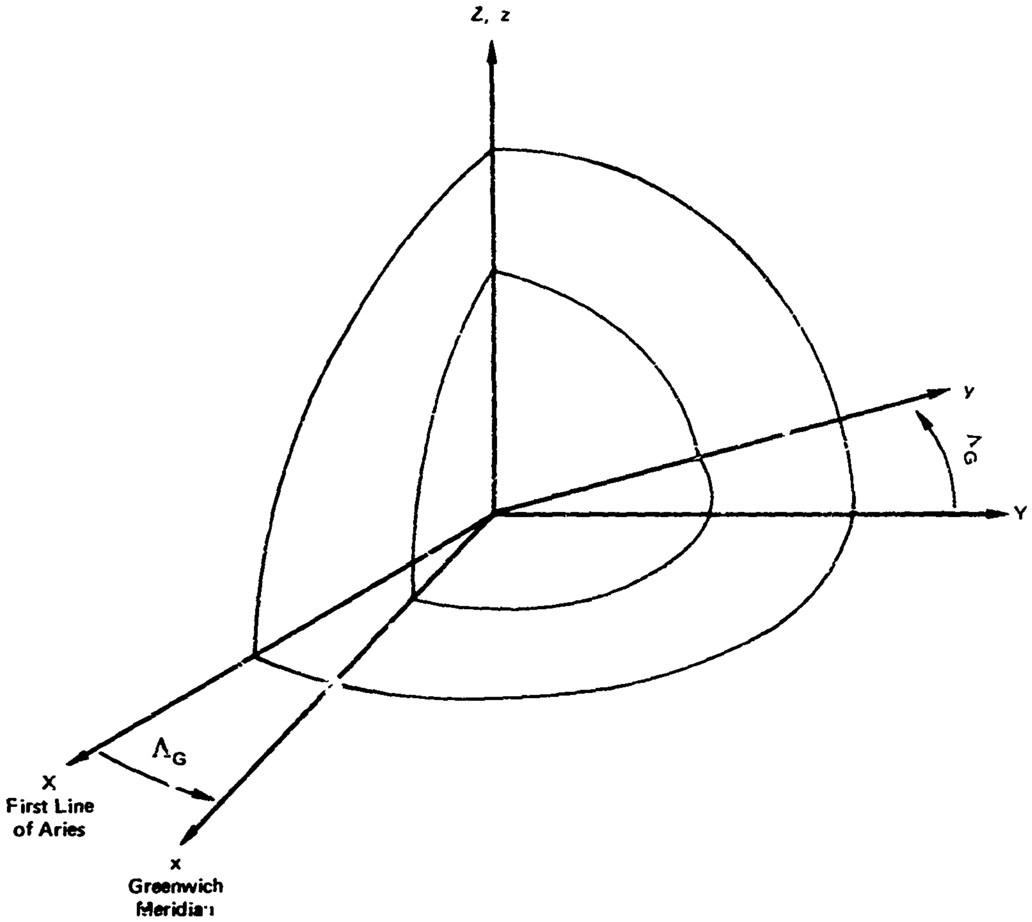


Fig. 16 XYZ AND xyz COORDINATE SYSTEMS

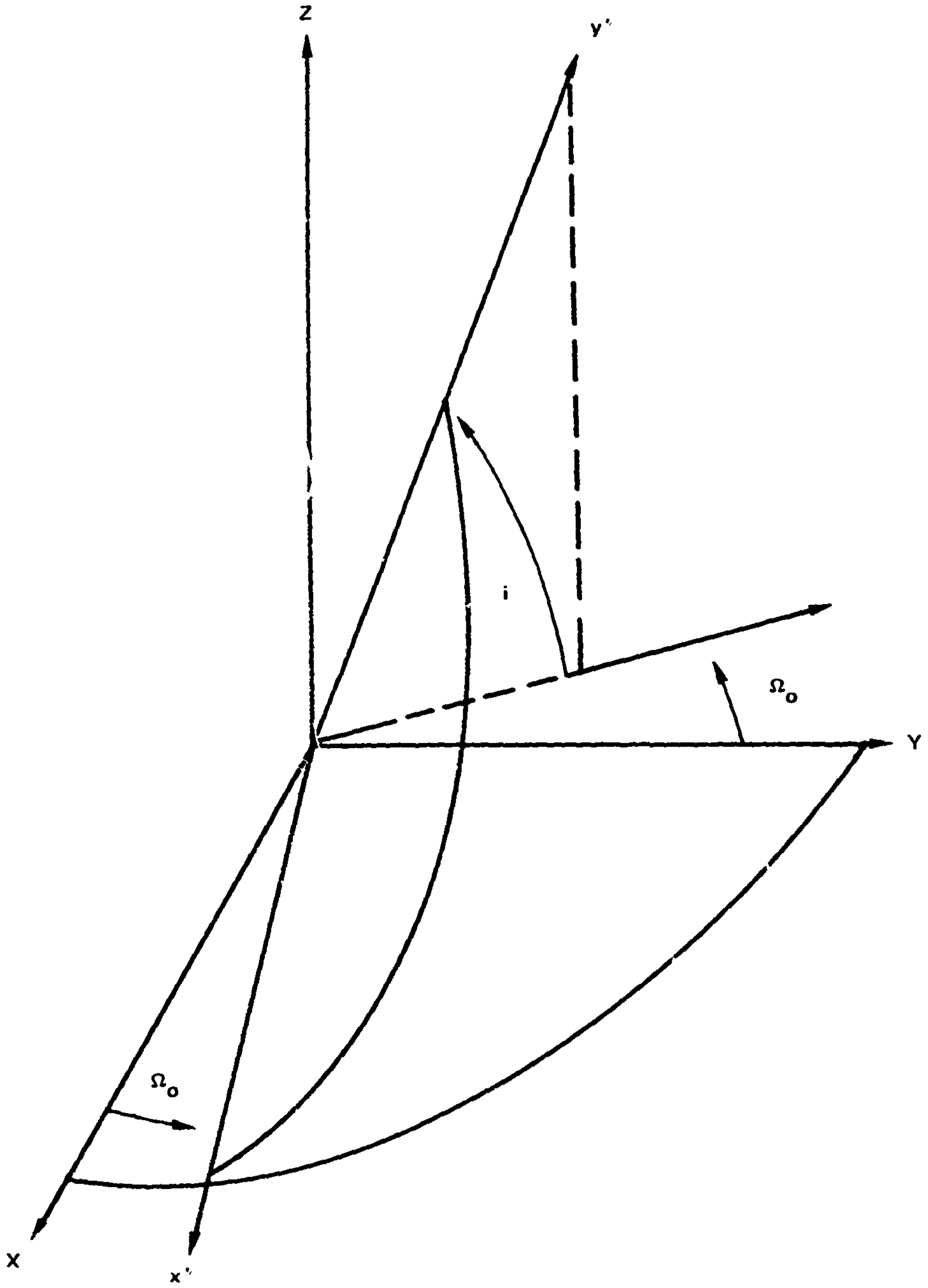


Fig. 17 ORIENTATION OF ORBITAL PLANE

Although the primary motion of the satellite will be in the x'y' plane, allowance will be made at this point for motion that is perpendicular to the plane of the satellite orbit. This direction will be defined as the z' direction and will be pointed such that the positive z'-axis forms a right-hand coordinate system with the x'y' plane. Figure 18 shows this x'y'z' coordinate system. The transformation to XYZ coordinates is given by

$$\begin{aligned} X &= x' \cos \Omega_o - y' \cos i \sin \Omega_o + z' \sin i \sin \Omega_o \\ Y &= x' \sin \Omega_o + y' \cos i \cos \Omega_o - z' \sin i \cos \Omega_o \\ Z &= y' \sin i + z' \cos i . \end{aligned} \tag{9b}$$

Now define the angle β to be the angle between the plane of the satellite orbit and the plane of the Greenwich Meridian. This difference is given by

$$\beta = \Omega_o - \Lambda_G . \tag{10}$$

By using the angle β it is now possible to transform the satellite orbital x'y'z' coordinate system directly into the navigator's xyz coordinate system without performing the initial transformation to XYZ coordinates. This transformation is of prime importance since it is the navigator's xyz coordinate system that will be used as the common coordinate system for the navigation solution computations. The transformation is given as follows:

$$\begin{aligned} x &= x' \cos \beta - y' \cos i \sin \beta + z' \sin i \sin \beta \\ y &= x' \sin \beta + y' \cos i \cos \beta \quad z' \sin i \cos \beta \\ z &= y' \sin i + z' \cos i . \end{aligned} \tag{11}$$

Since satellite orbital data as transmitted are not directly positions in the x'y'z' coordinate system, but as

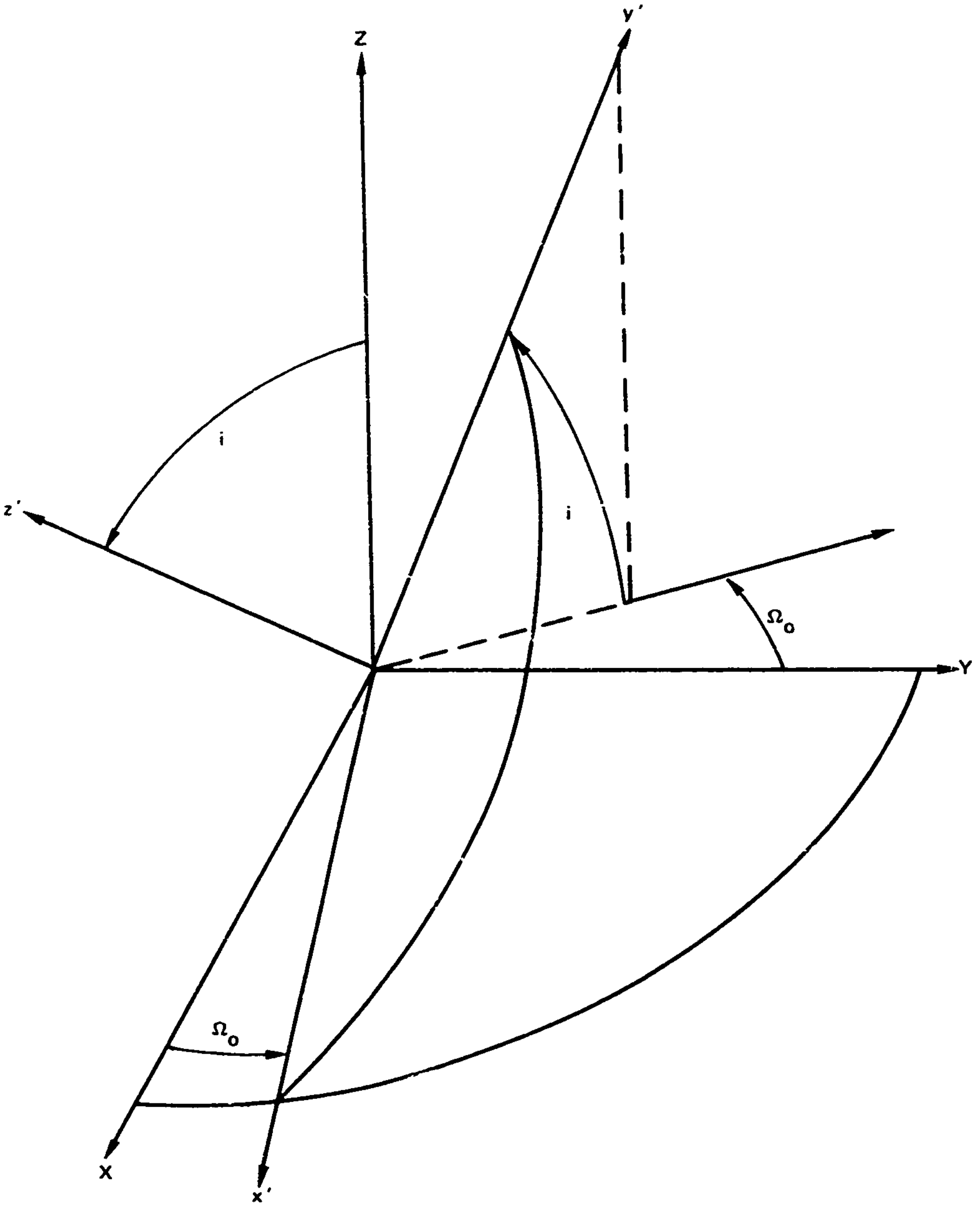


Fig. 18 x'y'z' COORDINATE SYSTEM

In Eq. (14), the mean anomaly is the same as in Eq. (13). The eccentric anomaly is given explicitly in Eq. (14). Also in Eq. (14), the factor $\sqrt{1 - \epsilon^2}$ is implicit in the expression for v_k.

In the simple classical theory, the angles Ω_o and ω_o are invariant in time. In the integrated doppler navigation computation, however, they do vary with time but are assumed to have constant time derivatives, $\dot{\Omega}$ and $\dot{\omega}$, respectively.

To summarize, in the integrated doppler navigation computation the satellite orbit is treated as a corrected ($\Delta E(t_k)$, $\Delta A(t_k)$, $\eta(t_k)$), precessing ($\dot{\omega}$, $\dot{\Omega}$) Keplerian ellipse.

The equations for computing satellite coordinates given in Step F of Section 7 follow those given here.

The term reference ellipsoid is applied here to the surface used to approximate the figure of the earth in the navigation computation. The reference ellipsoid is taken to be an ellipsoid of revolution. The axis of revolution is the z-axis or the spin axis of the earth. The center of the ellipsoid is the center of the earth.

The intersection of any plane containing the z-axis, i.e., a meridian plane, and the ellipsoid is an ellipse. The intersection of a plane parallel to the equatorial xy plane and the ellipsoid is a circle.

The rectangular coordinates (x, y, z) of any point on the surface of the ellipsoid satisfy the function F (x, y, z) = 0 in

$$F(x, y, z) = \frac{x^2 + y^2}{R_o^2} + \frac{z^2}{[R_o (1 - f)]^2} - 1 = 0 . \qquad (15)$$

In Eq. (15), R_o is the (major) equatorial semiaxis of the ellipsoid, and $R_o(1 - f)$ is the (minor) polar semiaxis.

The partial derivatives of F(x, y, z) with respect to x, y, and z are denoted by F_x, F_y, and F_z, respectively, and by Eq. (15), are

$$F_x = \frac{2x}{R_o^2}$$

$$F_y = \frac{2y}{R_o^2} \qquad (16)$$

$$F_z = \frac{2z}{[R_o(1 - f)]^2} .$$

Any (outward directed) normal to the ellipsoid is inclined at an angle to the equatorial xy plane, which is denoted by φ. The angle between the x-axis and the projection of the normal on the xy plane is denoted by λ. Therefore, the direction cosines of the normal with respect to x-, y-, and z-axes are, respectively, ($\cos\varphi$, $\cos\lambda$), ($\cos\varphi$, $\sin\lambda$), and $\sin\varphi$. These direction cosines are given by

$$\cos\varphi \cos\lambda = F_x/(F_x^2 + F_y^2 + F_z^2)^{1/2}$$

$$\cos\varphi \sin\lambda = F_y/(F_x^2 + F_y^2 + F_z^2)^{1/2} \qquad (17)$$

$$\sin\varphi = F_z/(F_x^2 + F_y^2 + F_z^2)^{1/2} .$$

From Eqs. (16) and (17), we find

parameters defining its elliptical orbit, it is necessary to define an additional coordinate system, uvw, in which the w and z' axes are coincident and in which the angle ω_o, between the x' and u axes is called the argument of perigee. Figure 19 shows the relation between the x'y' and uv planes. The transformation from uvw to x'y'z' coordinates is given by

$$
\begin{aligned}
x' &= u \cos \omega_o - v \sin \omega_o \\
y' &= u \sin \omega_o + v \cos \omega_o \qquad (12) \\
z' &= w \, .
\end{aligned}
$$

Now consider the pictorial representation of the satellite orbit as shown in Fig. 20. The point 0' is the center of the ellipse PSA and of the circumscribed circle PCA. The origin of the uvw coordinate system is taken as 0. The uv coordinates are shown. The w coordinate is the axis pointing off the page on Fig. 20.

Now define the time at which the satellite is at its perigee P as t_p and call it time of perigee. The position of the satellite at an arbitrary time t after t_p is represented by the point S on the ellipse PSA. The orbital ellipse has a semimajor axis denoted by A_o and an eccentricity denoted by ϵ. The angle E is called the eccentric anomaly and is the angle through which the satellite has moved on the ellipse since t_p. Further let T denote the orbital period of the satellite; then n, the mean motion, is given by $2\pi/T$.

SATELLITE AND NAVIGATOR POSITIONS

A problem in classical orbits is this: given A_o, ϵ, t_p, and t, find u(t), v(t), and w(t), the coordinates of S at time t. The computation that provides the solution of this problem is defined by Eq. (13):

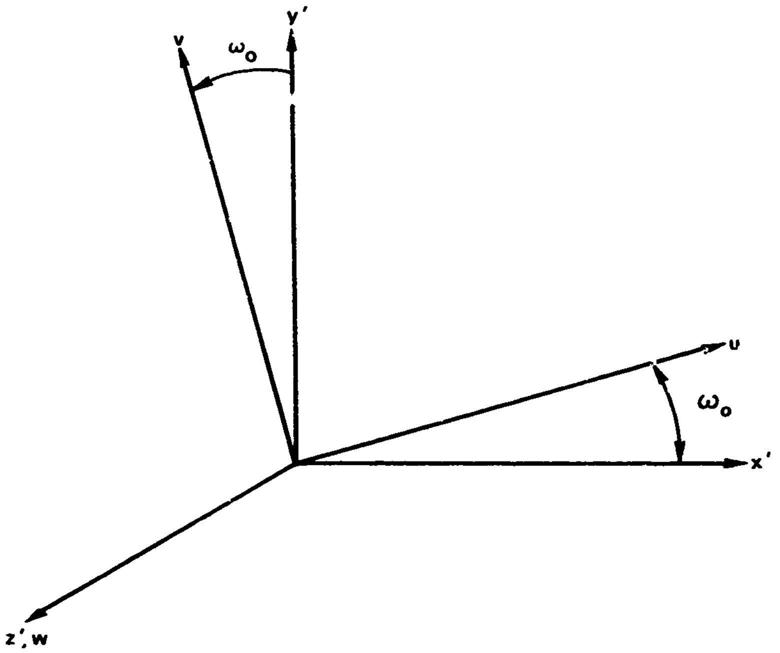


Fig. 19 RELATION BETWEEN x'y' AND uv PLANES

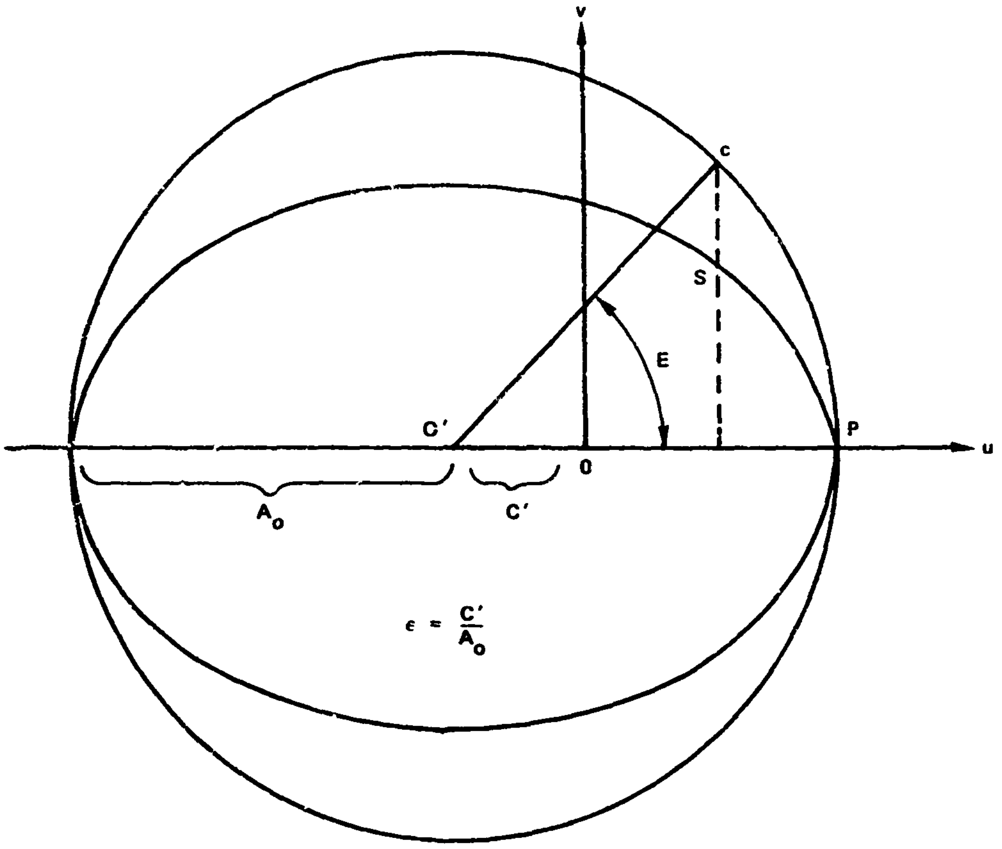


Fig. 20 SATELLITE ORBIT

$$
\begin{aligned}
M(t) &= n(t-t_p) \\
E(t) &= M(t) + \epsilon \sin E(t) \\
A &= A_o \\
u(t) &= A(\cos E(t) - \epsilon \\
v(t) &= A\sqrt{1-\epsilon^2} \sin E(t) \\
&w(t) \text{ is undefined.}
\end{aligned}
\qquad (13)
$$

The quantities $M(t)$ and $E(t)$ in Eq. (13) are called the mean and eccentric anomalies, respectively. The equation defining $E(t)$ (Kepler's Equation) is transcendental, and its solution can be obtained by various means.

For the integrated doppler navigation computation, this part of the computation of the satellite coordinates is carried out in a different manner.

The integrated doppler navigation problem can be stated as follows: given A_o, ϵ, n, t_p, $\Delta E(t_k)$, $\Delta A(t_k)$, and $\eta(t_k)$, find $u(t_k)$, $v(t_k)$, and $w(t_k)$. The equations which define the computation are given by

$$
\begin{aligned}
M_k &= n\,(t_k - t_p) \\
E_k &= M_k + \epsilon \sin M_k + \Delta E(t_k) \\
A_k &= A_o + \Delta A(t_k) \\
u_k &= A_k\,(\cos\,(E_k) - \epsilon) \\
v_k &= A_k \sin\,(E_k) \\
w_k &= \eta(t_k).
\end{aligned}
\qquad (14)
$$

$$\begin{aligned} x/R_o &= F_x R_o/2 = (R_o/2)\left(F_x^2 + F_y^2 + F_z^2\right)^{1/2} \cos\varphi \cos\lambda \\ y/R_o &= F_y R_o/2 = (R_o/2)\left(F_x^2 + F_y^2 + F_z^2\right)^{1/2} \cos\varphi \sin\lambda \qquad (18) \\ z/R_o(1-f) &= F_z R_o(1-f)/2 = \left[R_o(1-f)/2\right]\left[F_x^2 + F_y^2 + F_z^2\right]^{1/2} \sin\varphi . \end{aligned}$$

Now, by Eq. (15)

$$(x/R_o)^2 + (y/R_o)^2 + [z/R_o(1-f)]^2 = 1. \qquad (19)$$

Expanding Eq. (19) in terms of the right-hand side of Eq. (18), we determine

$$\left(F_x^2 + F_y^2 + F_z^2\right) = \frac{4}{R_o^2 \cos^2\varphi + [R_o(1-f)]^2 \sin^2\varphi} \qquad (20)$$

Substituting from Eq. (20) for $\left(F_x^2 + F_y^2 + F_z^2\right)^{1/2}$ in Eq. (18), we obtain for the rectangular coordinates of any point on the surface of the ellipsoid:

$$\begin{aligned} x(\varphi, \lambda) &= \frac{R_o \cos\varphi \cos\lambda}{\left(\cos^2\varphi + (1-f)^2 \sin^2\varphi\right)^{1/2}} \\ y(\varphi, \lambda) &= \frac{R_o \cos\varphi \sin\lambda}{\left(\cos^2\varphi + (1-f)^2 \sin^2\varphi\right)^{1/2}} \qquad (21) \\ z(\varphi) &= \frac{R_o (1-f)^2 \sin\varphi}{\left(\cos^2\varphi + (1-f)^2 \sin^2\varphi\right)^{1/2}} \end{aligned}$$

The angular coordinates φ and λ are called the geodetic latitude and longitude, respectively, of a point on the geodetic surface. Points not on the geodetic surface can be given a geodetic representation by means of a third coordinate, the geodetic altitude, which is denoted by h. The geoidal height above the reference ellipsoid is denoted by H, and $h' = (h + H)$.

A value for H in meters may be determined through use of Fig. 21, a geoidal height contour map. To use this map the navigator locates his approximate position on it and interpolates between contour lines to obtain the value for geoidal height in meters.

Let (x, y, z) represent the coordinates of any point in space. The h′ is defined to be the distance from the point to the geodetic surface. The coordinate h is positive if the point (x, y, z) is above the surface. To be specific, $h' \gtrless 0$ according to

$$\frac{x^2 + y^2}{R_o^2} + \frac{z^2}{R_o^2 (1-f)^2} \gtrless 1 .$$

Now let

$$D(\varphi) = \left(R_o^2 \cos^2 \varphi + [R_o (1-f)]^2 \sin^2 \varphi\right)^{1/2} . \tag{22}$$

Then the earth-fixed rectangular coordinates (x, y, z) of a point having the geodetic coordinates (φ, λ, h') are given by

$$\begin{aligned} x(\varphi, \lambda, h') &= \left[\frac{R_o^2}{D(\varphi)} + h'\right] \cos\varphi \cos\lambda \\ y(\varphi, \lambda, h') &= \left[\frac{R_o^2}{D(\varphi)} + h'\right] \cos\varphi \sin\lambda \\ z(\varphi, h') &= \left[\frac{R_o^2 (1-f)^2}{D(\varphi)} + h'\right] \sin\varphi . \end{aligned} \tag{23}$$

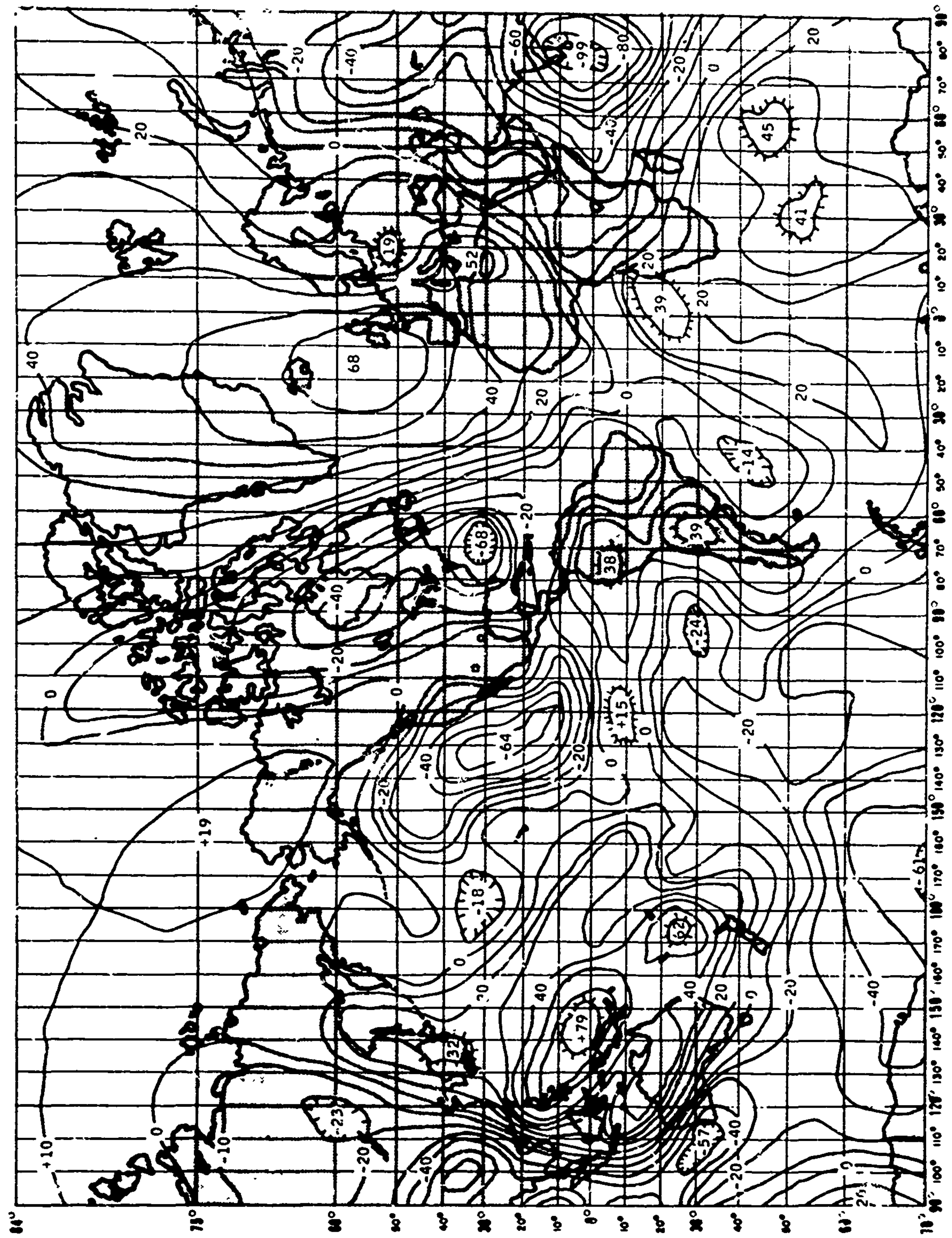


Fig. 21 GEOIDAL HEIGHT (H) CONTOUR MAP (METERS)

In the integrated doppler navigation computation, use is made of the partial derivative of x, y, and z with respect to φ and λ. A partial derivative with respect to φ is denoted by superscript $(^2)$ and with respect to λ by superscript $(^3)$. From Eqs. (22) and (23), it is seen that

$$\begin{aligned}
x(^2)\,(\varphi, \lambda, h') &= -\left(\left(R_o{}^2\,[R_o\,(1-f)]^2/D^3\,(\varphi)\right) + h'\right) \sin\varphi \cos\lambda \\
y(^2)\,(\varphi, \lambda, h') &= -\left(\left(R_o{}^2[R_o\,(1-f)]^2/D^3\,(\varphi)\right) + h'\right) \sin\varphi \sin\lambda \\
z(^2)\,(\varphi, h') &= \left(R_o{}^2\,[R_o\,(1-f)]^2/D^3\,(\varphi)\right) + h'\right) \cos\varphi \\
x(^3)\,(\varphi, \lambda, h') &= -y\,(\varphi, \lambda, h') \\
y(^3)\,(\varphi, \lambda, h') &= x\,(\varphi, \lambda, h') .
\end{aligned} \tag{24}$$

5. DATA TYPES AND FORMATS

TYPES OF DATA

Four types of data are processed for entry into the navigation solution equations. These data types are

1. Doppler and refraction data,
2. Satellite orbital data,
3. Navigator's estimates of time (GMT) of first fiducial mark, position, antenna height, heading, ship's velocity, day number of pass, and alert instructions, and
4. Program constants.

Doppler and Refraction Data

Section 3 describes the doppler and refraction data obtained from the ITT and Magnavox equipment, respectively.

Satellite Orbital Data

During every 2 minutes of a satellite pass, data describing the orbit are transmitted from the satellite in 156 BCDX3 words of 39 bits each plus an additional 19 bits. The data are in two groups: fixed parameters, describing a precessing Kepler ellipse that approximates the satellite orbit; and variable parameters, describing the deviations of the orbit from the precessing ellipse for each 2-minute interval. Tables 1 and 2 describe the variable and fixed parameters, respectively.

Each of the eight variable data words consists of the parameters t_k, ΔE_k, ΔA_k, and η_k combined in a single word. Of the eight variable words the fourth word (satellite word No. 26) describes the orbit deviations from the precessing ellipse for the present 2-minute interval. The

Table 1

Variable Orbit Parameters in Navigation Message

Satellite Word No [1]	Parameter Symbol	Units	No of Digits	Sign	Magnitude	Definition of Parameter
8, 14, 20, 26, 32, 38, 44, and 50	t_k	Minutes modulo 15	2	[2]	XX. 0	Time in integer even UT minutes following an integer one-half hour of kth transmission
	ΔE_k	Degrees	3	[2]	0 0XXX	Correction to eccentric anomaly for kth time point
	ΔA_k	Meters	3	[2]	XXX0. 0	Correction to mean semimajor axis for kth time point
	η_k	Meters	2	[3]	XX0. 0	Out of plane orbit component

[1] Each word of variable orbit data is a 9-digit combination of the parameters t_k, ΔE_k, ΔA_k, and η_k. The method of combination is as follows, where each of the 9 digits is represented by the letter X:

X	X	XXX	XXX	X
Code value for signs of ΔE_k and ΔA_k and first digit of t_k	Second digit of t_k	Value of ΔE_k	Value of ΔA_k	One digit of η_k

[2] The decimal code value for the signs of ΔA_k and ΔE_k and for the first digit of t_k is as follows:

Sign of ΔA_k	Sign of ΔE_k	First Digit of t_k	Decimal Code Value
+	+	0	0
-	+	0	1
+	-	0	2
-	-	0	3
+	+	1	4
-	+	1	5
+	-	1	6
-	-	1	7

[3] Quantity η consists of two digits $\eta^{(m)}$ and $\eta^{(1)}$, the digits being transmitted in successive 2-minute messages. In reconstructed form, $\eta = \pm 0.\eta^{(m)}\eta^{(1)}$, and is partitioned as follows: $\eta^{(m)}$ is transmitted in each variable parameter word whose fiducial time (UT) in minutes is divisible by 4 (zero included); $\eta^{(1)}$ is transmitted in the next 2-minute message. In addition, $\eta^{(m)}$ is transmitted in a code that indicates both value and sign. The code is:

Decimal Equivalent of Transmitted BCDX3 Digit (D_2)	$\eta^{(m)}$	Decimal Equivalent of Transmitted BCDX3 Digit (D_2)	$\eta^{(m)}$
0	-0	5	+0
1	-4	6	+1
2	-3	7	+2
3	-2	8	+3
4	-1	9	+4

The decoding for $\eta^{(m)}$ is as follows: $\eta^{(m)} = (D_2 - 5)$ when $1 \leq D_2 \leq 9$ When $D_2 = 0$, $\eta^{(m)} = -0$. When $D_2 = 5$, $\eta^{(m)} = +0$. The quantity $\eta^{(1)}$ is not coded. It should be noted that t_k is modulo 15 (i. e., 30 minutes) whereas the time associated with η_k is modulo 60 minutes. Values of η_k for fiducial times not divisible by 4 are obtained by interpolation.

Table 2

Fixed Orbit Parameters in Navigation Message

Satellite Word No.	Parameter Symbol	Units	No. of Digits	Sign and Magnitude[1]	Definition of Parameter
56	t_p	Minutes UT modulo 1440	9	TXXX. XXXXX	Time of first perigee in the time span of ephemeral memory on the day when that perigee occurs
62	n	Degrees/ minute minus three [2]	9	S. XXXXXXXX	Mean motion of satellite
68	ω_o	Degrees	9	SXXX. XXXXX[3]	Argument of perigee at t_p
74	$\dot{\omega}$	Degrees/ minute	9	S. XXXXXXXX	Precession rate of perigee
80	ϵ	Dimensionless	9	SX. XXXXXXX	Eccentricity
86	A_o	Meters	9	SXXXXXXXX. 0[3]	Mean semimajor axis
92	Ω_o	Degrees	9	SXXX. XXXXX[3]	Right ascension of ascending node at t_p
98	$\dot{\Omega}$	Degrees/ minute	9	S. XXXXXXXX	Precession rate of node
104	Ci	Dimensionless	9	SX. XXXXXXX	Cosine of inclination
110	Λ_G	Degrees modulo 360	9	SXXX. XXXXX[3]	Inertial longitude of Greenwich relative to Aries at t_p
116	ΔM	----	9	----	Change in mean anomaly for 1-hour time interval (unused).
122	δM	Minutes UT	9	----	Change in mean anomaly for 2-minute time interval (unused).
128	Si	Dimensionless	9	SX. XXXXXXX	Sine of inclination
134	$\Delta\gamma_s$	----	9	----	Satellite frequency offset (unused)
140, 146 and 152	--	----	9	---	Zeros at time of injection[4]

[1] The first digit of each word is coded as follows:

T is transmitted as either 0 or 4; 0 is interpreted as 0, 4 is interpreted as 1.
S is transmitted as either 8 or 9; 8 is interpreted as +, 9 is interpreted as -.

[2] The value of n as received reflects only the fractional portion of n. The value should be 3. XXXXXXXX and can be obtained by adding 3 to the received value.

[3] Always a positive value.

[4] Words 122, 140, 146, and 152 are not necessary to the fix computations but may prove helpful in the detection of satellite memory injections.

third word (satellite word No. 20) is for the previous 2-minute interval. The fifth word (satellite word No. 32) is for the following 2-minute interval. The variable words are updated every 2 minutes such that variable word 2 becomes variable word 1, 3 becomes 2, 4 becomes 3, etc., and a new variable word is introduced from satellite memory to replace variable word 8. Variable word 1 is lost. In this way the observer receives not only the variable words for the present 2-minute interval, but also data for the past three 2-minute intervals and the four future 2-minute intervals.

During data processing (described in Section 6) the satellite orbital data are validated by a majority vote procedure that accepts data as error-free when agreement is found in two out of three instances. The data are also processed into tables for convenient use in the navigation solution.

Navigator's Estimates

Table 3 lists the data that the navigator is required to enter into the computer for the navigation solution.

Program Constants

The values of the program constants used in the navigation solution computation are listed in Table 4.

DATA FORMATS

All the satellite data are in the form of BCDX3 binary bits which can be converted to decimal characters. Doppler data require seven characters, or 28 bits. ITT refraction data require four characters; Magnavox refraction data require seven characters. From Tables 1 and 2 it is seen that an orbital data word requires nine characters.

The satellite transmits orbital data in 39-bit words. Bits 37-39 of each word, however, are reserved for parity,

Table 3

Navigator's Estimates

Parameter	Symbol	Units	Magnitude
Time of first fiducial mark	T_c	Hours and minutes GMT	XX h, XX min
Position:			
Latitude	φ_e	Degrees and minutes	±XX°, XX.XXX′ + = north - = south
Longitude	λ_e	Degrees and minutes	±XXX°, XX.XXX′ + = east - = west
Antenna height	h	Meters	±XX.X[1]
Heading (course)[2]	d	Degrees clockwise from true north	XXX.X°
Rate (speed)[2]	v	knots	XX.X
Day number of pass	IDAY	Days	XXX.
Alerts:			
Day number of last Day for which alerts are to be calculated	MDAY[3]	Days	XXX.

[1] Dependent upon installation; see Fig. 21.

[2] If equipment such as SINS is available, the navigator may use latitude and longitude data at each fiducial mark instead of heading and rate.

[3] If MDAY = IDAY, no alerts will be calculated.

Table 4
Program Constants

Parameter	Symbol	Units	Magnitude
System Constants			
Initial value of offset frequency	$\bar{f}_o$	cycles/second	32,000
Vacuum wavelength at reference frequency	L_o	m/cycle	7.4948125×10^{-1}
Earth Constants			
Rotation rate of earth with respect to x, y, z coordinate system	ω_e	rad/min	4.3752695×10^{-3}
Equatorial radius of reference ellipsoid	R_o	m	6 378 144
Flattening of reference ellipsoid	f	dimensionless	$\frac{1}{298.23}$

telemetry, and clock data of concern in system management. These three bits are discarded by the ITT and Magnavox equipment. For simplicity, therefore, a satellite orbital data word is defined here to have a 36-bit length, and for convenience in computer processing every 36-bit satellite orbital data word is divided in the ITT and Magnavox equipment into three 15-bit computer words. Similarly, doppler and refraction data are formatted in the equipment into three 15-bit computer words, with binary zeros being used to fill in blanks, as will be shown below.

Each 15-bit computer word consists of 12 data bits plus a 3-bit identification (ID) code generated in the receiver. The ID code serves both to identify whether the computer word represents doppler, refraction, or orbital data and also whether the computer word contains the first 12-bit segment or a later 12-bit segment of data.

ITT Interface

Figure 22 shows examples of the 15-bit computer words for orbital data, doppler data, and refraction data provided by the ITT equipment. The 15-bit computer word is transferred from the receiver on 15 data lines denoted 2^0 through 2^{14}. Data lines 2^0 through 2^2 are the ID codes, and lines 2^3 through 2^{14} are the actual data bits. The most significant ID bit is 2^2. The most significant data bits are 2^{14}, 2^{10}, and 2^6. Note that the zeros in front of the doppler and refraction data are binary zeros. The voltage levels of the signals are such that

logic 1 = 0 ±1.5 volts,

logic 0 = -14 ±3.5 volts.

Magnavox Interface

Figure 23 shows examples of the 15-bit computer words provided by the Magnavox 702 equipment. The 15-bit computer word is transferred from the receiver on 15 data lines designated bits 1 through 15. Bits 13 through 15 are the ID codes. Bits 1 through 12 are the actual data

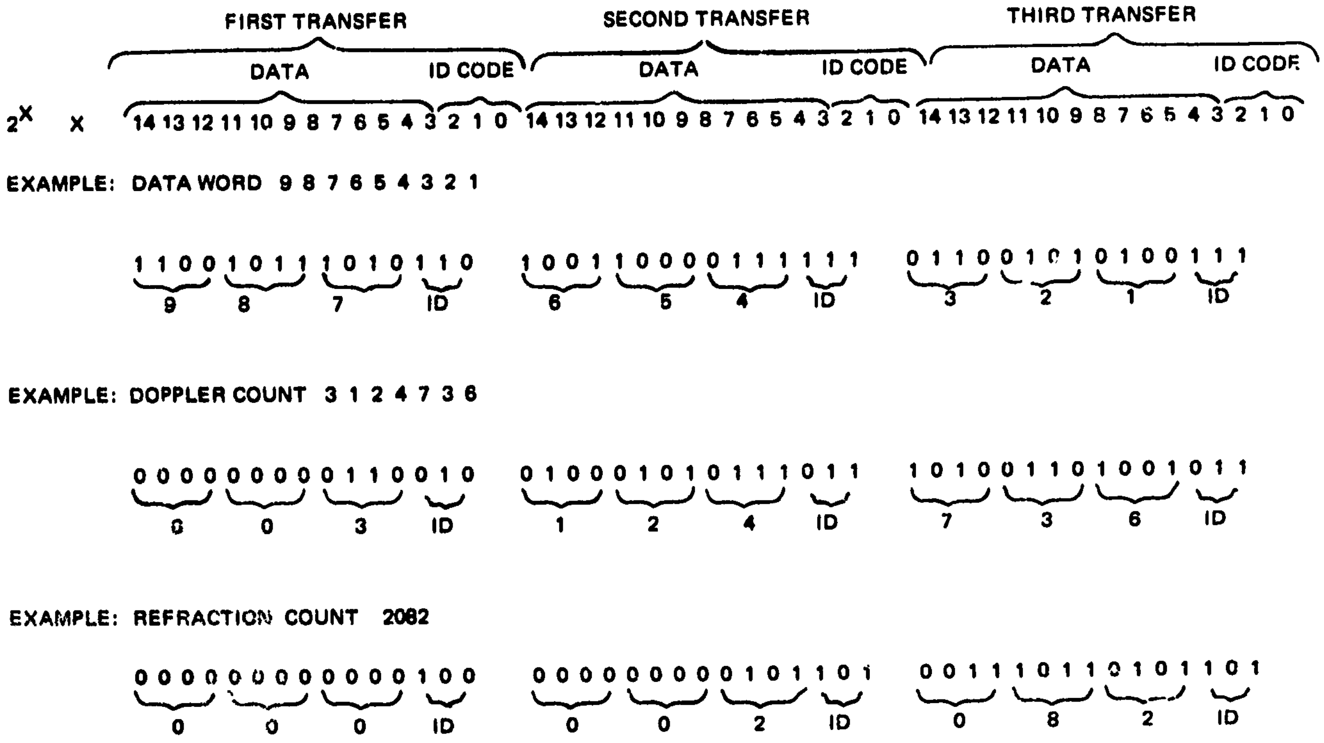
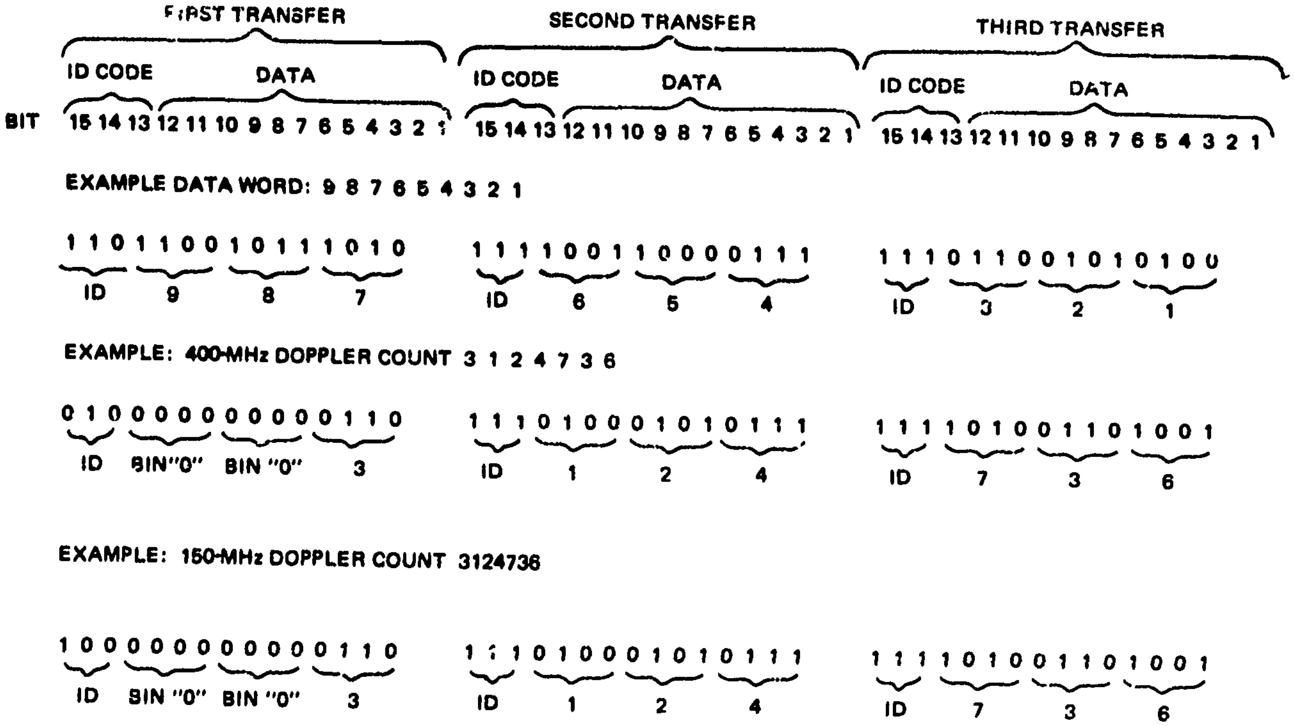


Fig. 22 DATA FORMAT FOR AN/SRN-9 EQUIPMENT



NOTE: DIFFERENCE BETWEEN 400- AND 150-MHz DOPPLER COUNTS IS INITIAL ID CODE

Fig. 23 DATA FORMAT FOR MAGNAVOX EQUIPMENT bits. The most significant ID bit is bit 15. The most significant data bits are bits 12, 8, and 4. Note that the zeros in front of the doppler and refraction data are binary zeros. The voltage levels of the signals are such that

logic 1 = 0 ±0.25 volt,

logic 0 = +6 volts (open circuit).

Sign

A 16-bit, binary word, general purpose computer with input/output devices operating under programmed interrupt control may be used for data processing and for executing the navigation calculations. A computer of this word size accommodates the 15-bit computer word and allows the 16th bit to be used as a sign bit. All the satellite data are transmitted as positive numbers; note from Table 2, however, that positive values in some parameters represent coded values for negative numbers.

Formatting Satellite Words into Computer Words

Figure 24 defines ID codes and shows the format of 36-bit words as output from the ITT and Magnavox equipment in three computer words (each word consisting of 15 bits plus a sign bit). BCDX3 characters are shown as X's. Zeros fill in the blank spaces to make up the required 36 bits per satellite word.

Figure 25 is a timing diagram for the receiver/computer interface. In this diagram the term "word" means the 36-bit satellite orbital data word. The figure shows that in a 2-minute message transmitted from the satellite three computer words of doppler data are transferred from the receiver to the computer during the occurrence of satellite word 3, three computer words of refraction data are transferred during satellite word 5, and 75 computer words of satellite orbital parameter data are transferred during satellite words 8-152, with three computer words being transferred during each sixth satellite

TRANSFER NO.	SIGN				ID		SIGN	ID			
1	0	0000	0000	X	010	DOPPLER	0	010	0000	0000	X
2	0	X	X	X	011	DATA	0	111	X	X	X
3	0	X	X	X	011		0	111	X	X	X
1	0	0000	0000	0000	100	REFRAC-	0	100	0000	0000	X
2	0	0000	0000	X	101	TION	0	111	X	X	X
3	0	X	X	X	101	DATA	0	111	X	X	X
1	0	X	X	X	110	ORBITAL PARAM-	0	110	X	X	X
2	0	X	X	X	111	ETER	0	111	X	X	X
3	0	X	X	X	111	DATA	0	111	X	X	X
	ITT OUTPUT					SATELLITE DATA TYPE	MAGNAVOX OUTPUT				

X = BCDX3 CHARACTER

Fig. 24 FORMAT OF DOPPLER, REFRACTION, AND ORBITAL DATA DIVIDED INTO COMPUTER WORDS IN THE ITT AND MAGNAVOX RECEIVERS

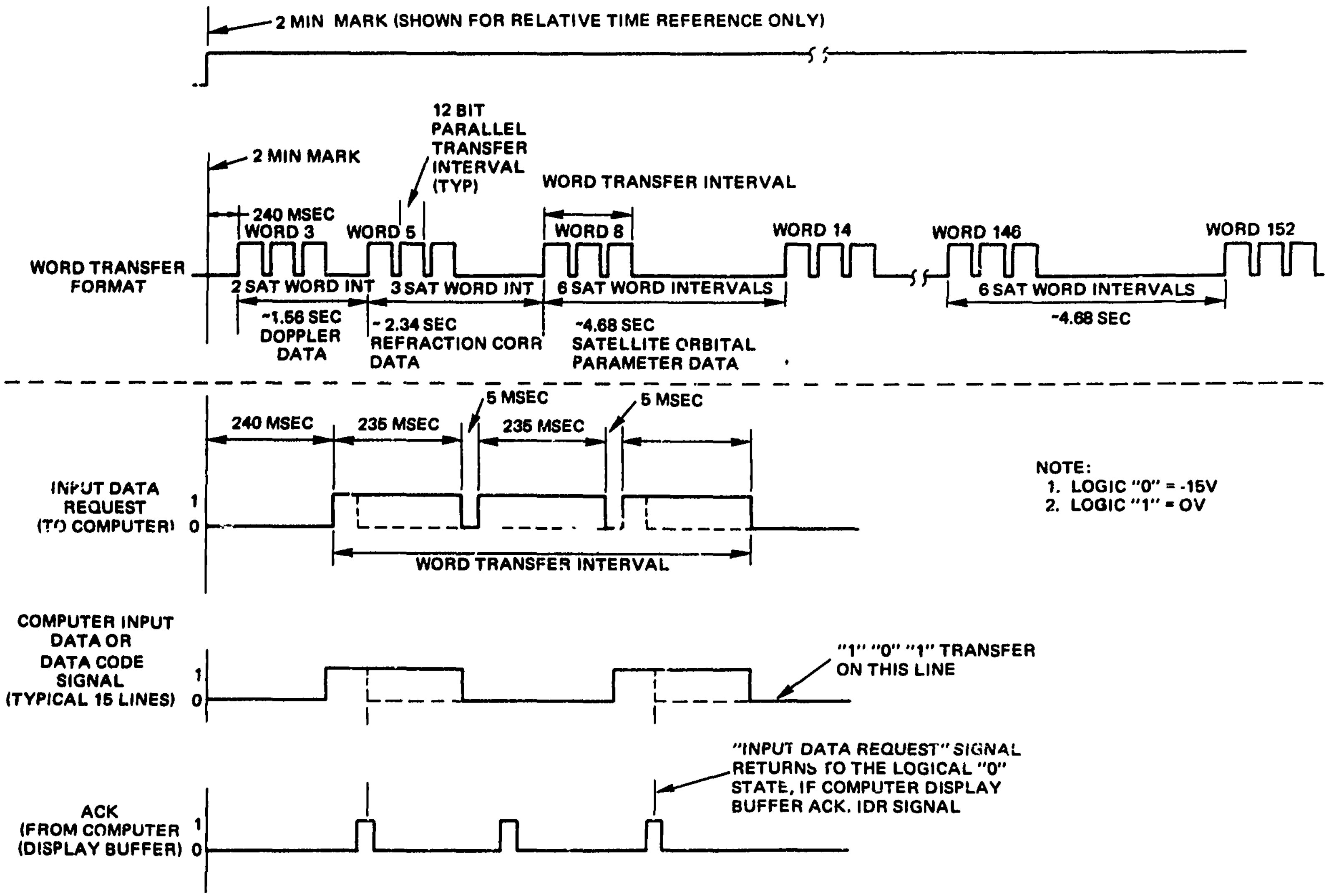


Fig. 25 RECEIVER/COMPUTER INTERFACE TIMING DIAGRAM

word. From Table 2 it may be observed that the data in satellite words 116, 122, 134, 140, 146, and 152 are not required in the navigation routine. Satellite words 122, 140, 146, and 152 contain data that may be used in determining whether the satellite message was updated during a particular 2-minute interval by the ground injection station. This feature will be described in greater detail in Section 6.

6. DATA PROCESSING

The objectives of the real-time processing done on the satellite 2-minute messages are to obtain the fixed orbital parameters, to obtain the variable orbital parameters and the doppler and refraction data and arrange them in time ordered tables with due regard for any missing data, and to check the validity and accuracy of the data in preparation for use in the calculation of the navigation fix. During this process a check is also made to determine if a new message has been injected into the satellite and appropriate action taken if it has. The data supplied by the navigator are also obtained. The processing steps to accomplish these objectives are as follows:

During the first 2-minute message the variable and fixed orbital parameters are obtained.

During the second 2-minute message the doppler data for the first 2-minute interval are obtained and validated, a check is made that the fixed and variable data were obtained during the first 2-minute message, the refraction correction data for the first 2-minute interval are obtained, and the variable and fixed orbital parameters in the second 2-minute message are obtained.

During the third 2-minute message the doppler data for the second 2-minute interval are obtained and validated, a check is made that a new message has not been injected into the satellite memory, the differences between the orbital parameters obtained in the first and second 2-minute messages are calculated, with due regard for the precession of the variable data, the refraction correction data for the second 2-minute interval are obtained and validated, and the variable and fixed orbital parameters in the third 2-minute message are obtained.

During the fourth 2-minute message the doppler and refraction data are collected and validated, the new-message check is done, and for each orbital parameter a determination is made if agreement exists in two of the three messages by a majority vote process. Finally, for any parameter for which a majority vote was not obtained, a new value is obtained from the fourth message.

These procedures are repeated during successive 2-minute messages until the satellite pass is over or until doppler and refraction data have been obtained for nine 2-minute intervals. If loss of lock occurs for a time during the pass, pointer registers keep place in the data tables and appropriate missed data entries are made. If the injection check finds that the satellite is transmitting a new message and majority voted data have not yet been obtained, message collection begins again.

At the end of the pass the data are formatted from BCDX3 to floating point and the navigator enters values for his estimates of sync time, position, antenna height, heading, rate, day number of pass, and the interval for which he desires alerts.

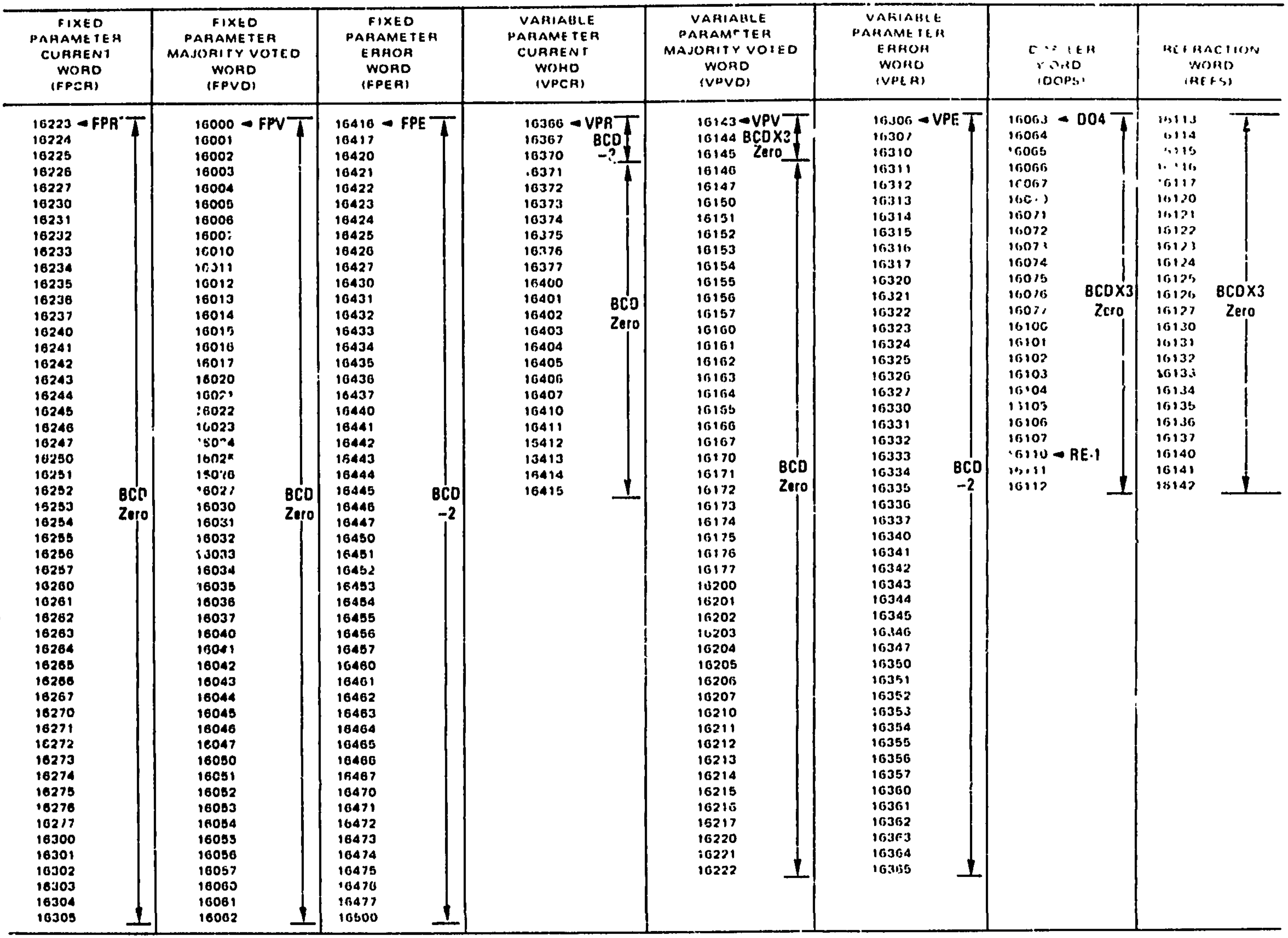
The following sections and accompanying flow charts describe the detailed procedures that occur during real-time data processing of each 2-minute satellite message. For convenience in later reference, the flow charts for both the data processing program described in this Section and the FORTRAN navigation program described in Section 8 are grouped together in Appendix A. The nomenclature used in the flow charts is also used in this description and will be defined at its first mention. The final part of this Section describes modifications to the real-time procedures to allow their use in postpass navigation.

INITIALIZATION

During initialization (Fig. A-1) the program constants are read into memory storage; tables and interrupt interface addresses are set to their assigned locations; and the flags, counters, and pointers used for place keeping and for denoting the status of program execution in the particular computer being used are set to their initial values and locations. Figure 26 shows, for example, the arrangement and initialized values in eight tables that are used in one representative computer program for storing the doppler, refraction, and orbital data. This arrangement requires 321 storage locations for the eight tables. The table locations (shown in octal notation) are specific to this particular computer program and are included here only for reference in discussing the data processing procedures.

The data stored in the tables are as follows: Table FPCR is used to store the fixed parameters in each 2-minute satellite message; Table FPVD is used to store the fixed parameters that either will be subjected to the majority vote test or have passed this test; Table FPER is used to keep track of those parameters that have passed the majority vote test and also the errors in those parameters which have not passed the test. Tables VPCR, VPVD, and VPER perform these same functions for the variable parameters. Tables DOPS and REFS store the doppler and refraction data, respectively.

During initialization, Tables FPCR, FPVD, VPCR, and VPVD are set to values of BCD zero, Tables FPER and VPER are set to values of binary -2, and Tables DOPS and REFS are set to values of BCDX3 zero. The -2 values in error tables FPER and VPER are used in the majority vote process, as explained in later sections. The BCDX3 zero values in the doppler and refraction tables are the values



FIXED PARAMETER CURRENT WORD (FPCR)	FIXED PARAMETER MAJORITY VOTED WORD (FPVD)	FIXED PARAMETER ERROR WORD (FPER)	VARIABLE PARAMETER CURRENT WORD (VPCR)	VARIABLE PARAMETER MAJORITY VOTED WORD (VPVD)	VARIABLE PARAMETER ERROR WORD (VPER)	DOPPLER WORD (DOPS)	REFRACTION WORD (REFS)
16223 ◄ FPR	16000 ◄ FPV	16416 ◄ FPE	16366 ◄ VPR	16143 ◄ VPV	16306 ◄ VPE	16063 ◄ D04	16113
16224	16001	16417	16367 BCD	16144 BCDX3	16307	16064	16114
16225	16002	16420	16370 −2	16145 Zero	16310	16065	16115
16226	16003	16421	16371	16146	16311	16066	16116
16227	16004	16422	16372	16147	16312	16067	16117
16230	16005	16423	16373	16150	16313	16070	16120
16231	16006	16424	16374	16151	16314	16071	16121
16232	16007	16425	16375	16152	16315	16072	16122
16233	16010	16426	16376	16153	16316	16073	16123
16234	16011	16427	16377	16154	16317	16074	16124
16235	16012	16430	16400	16155	16320	16075	16125
16236	16013	16431	16401 BCD	16156	16321	16076 BCDX3	16126 BCDX3
16237	16014	16432	16402 Zero	16157	16322	16077 Zero	16127 Zero
16240	16015	16433	16403	16160	16323	16100	16130
16241	16016	16434	16404	16161	16324	16101	16131
16242	16017	16435	16405	16162	16325	16102	16132
16243	16020	16436	16406	16163	16326	16103	16133
16244	16021	16437	16407	16164	16327	16104	16134
16245	16022	16440	16410	16165	16330	16105	16135
16246	16023	16441	16411	16166	16331	16106	16136
16247	16024	16442	15412	16167	16332	16107	16137
16250	16025	16443	13413	16170	16333	16110 ◄ RE-1	16140
16251	16026	16444	16414	16171 BCD	16334 BCD	16111	16141
16252 BCD	16027 BCD	16445 BCD	16415	16172 Zero	16335 −2	16112	18142
16253 Zero	16030 Zero	16446 −2		16173	16336		
16254	16031	16447		16174	16337		
16255	16032	16450		16175	16340		
16256	16033	16451		16176	16341		
16257	16034	16452		16177	16342		
16260	16035	16453		16200	16343		
16261	16036	16454		16201	16344		
16262	16037	16455		16202	16345		
16263	16040	16456		16203	16346		
16264	16041	16457		16204	16347		
16265	16042	16460		16205	16350		
16266	16043	16461		16206	16351		
16267	16044	16462		16207	16352		
16270	16045	16463		16210	16353		
16271	16046	16464		16211	16354		
16272	16047	16465		16212	16355		
16273	16050	16466		16213	16356		
16274	16051	16467		16214	16357		
16275	16052	16470		16215	16360		
16276	16053	16471		16216	16361		
16277	16054	16472		16217	16362		
16300	16055	16473		16220	16363		
16301	16056	16474		16221	16364		
16302	16057	16475		16222	16365		
16303	16060	16476					
16304	16061	16477					
16305	16062	16500					

Fig. 26 STATUS OF DATA TABLES AT INITIALIZATION

to which entries in these tables should be set if they represent missing entries. The other tables are set to BCD zero values to eliminate the possibility of data accumulated during previous passes from entering into the calculations for the present pass.

Figure 26 also shows the beginning locations of the eight pointer registers used to keep place in the eight data tables. In seven of the tables the pointer registers are set to the beginning addresses of the tables. For Table REFS, however, pointer register RE-1 is set to a location three entries before the beginning of Table REFS. This arrangement provides for updating the pointer registers after receipt of the doppler data, as will be described in a later section.

TEST FOR INTERRUPT

The computer on which this program is designed for execution is one that operates under interrupt control. An interrupt is an action occurring independently of the program that causes a change in the sequence of program execution. The interrupts accommodated in this program are the transfers of data from the receiver or the input-output device (assumed here to be a teletypewriter) and the transfer of data from the computer to the teletype. The occurrence of an interrupt is a computer hardware function that forces a transfer to a dedicated location in the computer memory. In the particular computer for which this program was written the dedicated location is location 63. The interrupt sequence is as follows:

After initialization, the program dwells in subroutine INP3, the test for first interrupt. Subroutine INP3 (Fig. A-1) checks, in turn, whether data have been transferred to the computer from the receiver or whether SW 2 has been set, indicating that the renavigation (ESM) option is to be executed. This latter situation will be covered at the end of the real-time procedures. In a real-time pass subroutine INP3 will be interrupted when data are entered into the computer, and program control will be transferred through dedicated location 63 to the address of subroutine INTR, the interrupt processor.

INTERRUPT PROCESSOR

Subroutine INTR (Fig. A-16) checks, in turn, whether the interrupt represents the receiver or the teletype. In a real-time pass the first interrupt will be from the receiver, signaling the beginning of the processing of the first 2-minute message. Program control will transfer to subroutine RCVD, the receiver interrupt.

ID CODE SEQUENCE

Before describing the processing of the first receiver interrupt it should be noted that if no loss of lock occurs, a total of 81 receiver interrupts in the format shown in Figs. 22 and 23 are generated during each 2-minute interval of a satellite pass. It is convenient to consider the transfer of data from the receiver in terms of the sequence of ID codes that will occur during a 2-minute message. Figure 27 shows this sequence for the ITT receiver data. The mnemonic shown under each ID code will be used in the following description of the processing of the real-time receiver data. It should be noted in Fig. 27 that the first and second occurrences of DP2, RF2, and

010	011	011	100	101	101	110	111	111	110	111	111	110	111	111	----------	110	111	111
DP1	DP2	DP2	RF1	RF2	RF2	MG1	MG2	MG2	MG1	MG2	MG2	MG1	MG2	MG2		MG1	MG2	MG2
	doppler data			refraction data		satellite orbital parameter data (75 computer words)												

Fig. 27 ID CODE SEQUENCE FOR ITT RECEIVER DATA DURING A 2-MINUTE MESSAGE

MG2 are not uniquely coded, thus necessitating the use of an interrupt count switch in the computing program to monitor sequence. In addition the transition from the ephemeral to the fixed portion of the orbital parameters is not uniquely coded and a counter is needed to monitor this transition.

RECEIVER INTERRUPT

Returning to the processing of the first receiver interrupt, subroutine RCVD (Fig. A-17) accepts the 15-bit computer word being transferred from the receiver, storing the 3-bit ID code and the 12-bits of satellite data in buffer storage registers and setting receiver flag RCFG. Three buffer registers are used for storing the satellite data, one each for the three computer word transfers that make up one satellite word. Index register XREC is used to distinguish among buffer registers. After RCFG is set, return is made through subroutine INTR to the point at which subroutine INP3 was interrupted, unless a teletype interrupt has occurred, in which case this interrupt will also be processed. Subroutine INP3 will determine that the first interrupt has occurred (by noting that receiver flag RCFG has been set), and will transfer complete program control to subroutine IDLE.

SUBROUTINE IDLE

Subroutine IDLE (Fig. A-2) is the subroutine to which the program returns after processing each of the 81 interrupts during every 2-minute message. The subroutine checks, in turn, whether a receiver interrupt has occurred, whether 2 minutes have elapsed, and whether 16 minutes of doppler data (eight doppler counts) have been collected. It also controls entry to subroutine INCR which increments time once per minute by updating program clock register CLOC. During its first execution, however, subroutine IDLE will note immediately that the first receiver interrupt has occurred and transfer program control to subroutine IDL2.

SUBROUTINE IDL2

Subroutine IDL2 (Fig. A-2) resets receiver flag RCFG in preparation for receipt of the next receiver interrupt and then tests the ID code that was stored in the buffer register during subroutine RCVD. Transfer will then be made to subroutine DP1, DP2, RF1, RF2, MG1, or MG2, depending on the value of the ID code. In normal real-time data processing the first code to be transferred after sync recognition in the receiver will be the code for subroutine DP1. Transfer to subroutine DP1 therefore marks the beginning of the processing of the first 2-minute message.

FIRST TWO-MINUTE MESSAGE

Doppler and Refraction Count Words

Subroutine DP1 (Fig. A-3) checks whether 16 minutes of doppler data have been obtained, sets the teletypewriter in preparation for data printout, resets internal program clock register CLOC to zero to mark the beginning of the 2-minute interval, and sets sync time register SYNC to a value of 2 minutes to mark the expected time of the next 2-minute interval. Doppler and refraction data are the first receiver outputs in a 2-minute message and apply to the preceding 2-minute interval. Consequently, in the first 2-minute interval after sync recognition these data are meaningless. The computer program takes cognizance of this fact by testing message sync flag FDOP. This flag will not be set until first execution of subroutine MG1. Until then the program discards the doppler and refraction data, returning to subroutine IDLE after each check for message sync in subroutines DP1, DP2, RF1, and RF2 (Figs. A-3 and A-4).

Orbital Parameter Word No. 1

First 15-Bit Transfer. The check on the ID code in subroutine IDLE of the first 15-bit transfer for orbital parameter word No. 1 directs execution of subroutine MG1.

Subroutine MG1 (Fig. A-5) begins by setting message sync flag FDOP, thus allowing data storage to begin. Inasmuch as in a 2-minute satellite message the satellite orbital parameter data are transmitted as eight variable parameters followed by the fixed parameters, the data received during orbital parameter word No. 1 and stored in the first buffer register during receiver interrupt routine RCVD are variable data. These data are placed in Variable Parameter Current Word Table VPCR at the location specified in register VPR, the pointer register for this table. The pointer register is then incremented by a value of 1. The next time data for this table are obtained from the receiver; the pointer register will indicate that the data are to be stored at the next location in the table. Interrupt count switch INTC is then set, in preparation for use during the second and third 15-bit transfers, and program control returns to subroutine IDLE.

Second 15-Bit Transfer. The check on the ID code in subroutine IDLE of the se[illegible] 15-bit transfer for orbital parameter word No. 1 dire[illegible] execution of subroutine MG2.

Subroutine MG2 (Fig. A-5) begins by testing message sync flag FDOP. This flag has been set in subroutine MG1, just completed; therefore, this test directs placement of the data stored in the buffer register during receiver interrupt routine RCVD in Variable Parameter Current Word Table VPCR at the location specified in register VPR, the pointer register for this table. Program control then transfers to subroutine COLL.

Subroutine COLL (Fig. A-6) increments index register XREC, used to distinguish among the buffer registers in receiver interrupt subroutine RCVD, and then resets interrupt count switch INTC. When reset, this switch indicates first execution of subroutine MG2; when set it indicates second execution. The test on the switch after setting indicates that this is not the third interrupt for orbital parameter word No. 1, directing return to subroutine IDLE.

Third 15-Bit Transfer. During this second execution of subroutine MG2 the test in subroutine COLL (Fig. A-6) determines that this interrupt is the third 15-bit transfer and therefore directs return to subroutine MG2 (Fig. A-5). The data for the complete orbital parameter word (all three interrupts) are then converted to ASCII format in subroutine PROC (Fig. A-13) and stored for printout. Transfer is then made to subroutine PRNT.

Subroutine PRNT (Fig. A-11) retrieves the address of the register containing the ASCII-formatted data and stores this address for use in subroutine TTYT. The status of the teletypewriter is checked in subroutine TEST (Fig. A-11). The teletypewriter interrupt is enabled, and when subroutine TEST confirms that the teletypewriter is not busy, subroutine INTR (Fig. A-16) transfers program control via dedicated location 63 to subroutine TTYT (Fig. A-18), which controls the data printout. At this point, therefore, orbital parameter word No. 1 is stored in Table VPCR in BCDX3 format, as transmitted from the satellite, and also printed out on the teletypewriter in ASCII format. Return is made to subroutine MG2 (Fig. A-5) where register WORD is incremented from zero to one, marking the completion of the processing of orbital parameter word No. 1. Receiver index counter register XREC is set to zero in preparation for the processing of the next word, and program control returns to subroutine IDLE.

Orbital Parameter Words Nos. 2-25

The sequence described above for orbital parameter word No. 1 is repeated for orbital parameter words Nos. 2-25 with one difference. At the completion of the eighth word, register WORD will contain the number 8. A test on register WORD will determine that eight words have been processed and that, therefore, the next word to be processed is the first of the fixed parameters. This result directs storage of words 9-25 in Fixed Parameter Current Word Table FPCR. After word 25 the processing of the first 2-minute message is complete, and the program returns to subroutine IDLE until occurrence of the receiver interrupt marking the beginning of the second 2-minute message.

Figure 28 shows the status of the eight data tables and pointer registers at the end of the first 2-minute message. Table FPCR in Fig. 28 has been annotated with the symbols for the fixed parameters to facilitate comparison with Table 2. In Table VFCR, sync time is designated by the symbol T_0, and the table entries are shown at the 2-minute intervals (referred to T_0) that occur in the first 2-minute message. The changes that have occurred in the major counters, registers, flags, and switches during the first 2-minute message are summarized in Table 5.

SECOND TWO-MINUTE MESSAGE

Doppler Count Word

First 15-Bit Transfer. Subroutine DP1 (Fig. A-3) proceeds as described above for the first 2-minute message through the check of message sync flag FDOP. FDOP was set at the beginning of message data word No. 1 in the first 2-minute message and thus directs execution of subroutine BCXS.

Subroutine BCXS (Fig. A-7) checks whether the doppler data stored in the buffer register during subroutine RCVD are valid BCDX3 characters. A character with a BCDX3 value between 0 and 9 (including those values) is accepted as valid. A character outside the range 0-9 is invalid; the subroutine replaces invalid characters with a value of BCDX3 zero. Return is then made to subroutine DP1 (Fig. A-3) where the valid character is stored in doppler word Table DOPS at the location given in pointer register DO4. Register DO4 is incremented, and interrupt count switch INTC is set in preparation for its later use in determining the first and second occurrences of subroutine DP2. Return is then made to subroutine IDLE.

Second 15-Bit Transfer. Subroutine DP2 (Fig. A-3) proceeds as described above for the first 2-minute message

	FIXED PARAMETER CURRENT WORD (FPCR)		FIXED PARAMETER MAJORITY VOTED WORD (FPVD)		FIXED PARAMETER ERROR WORD (FPER)			VARIABLE PARAMETER CURRENT WORD (VPCR)		VARIABLE PARAMETER MAJORITY VOTED WORD (VPVD)		VARIABLE PARAMETER ERROR WORD (VPER)		DOPPLER WORD (DOPS)		REFRACTION WORD (REFS)	
t_p	16223	Contains 17 fixed parameters from first two minute message in BCDX3 format	16000 ← FPV	BCD Zero	16416 VPR	BCD −2	T_0-6	16366	Contains 8 variable parameters from first two minute message in BCDX3 format	16143 ← VPV	BCDX3 Zero	16306 VPE	BCD −2	16063 ← D04	BCDX3 Zero	16113	BCDX3 Zero
	16224		16001		16417 FPE			16367		16144		16307 FPR		16064		16114	
	16225		16002		16420			16370		16145		16310		16065		16115	
η	16226		16003		16421		T_0-4	16371		16146	BCD Zero	16311		16066		16116	
	16227		16004		16422			16372		16147		16312		16067		16117	
	16230		16005		16423			16373		16150		16313		16070		16120	
ω_0	16231		16006		16424		T_0-2	16374		16151		16314		16071		16121	
	16232		16007		16425			16375		16152		16315		16072		16122	
	16233		16010		16426			16376		16153		16316		16073		16123	
$\dot{\omega}$	16234		16011		16427		T_0	16377		16154		16317		16074		16124	
	16235		16012		16430			16400		16155		16320		16075		16125	
	16236		16013		16431			16401		16156		16321		16076		16126	
ϵ	16237		16014		16432		T_0+2	16402		16157		16322		16077		16127	
	16240		16015		16433			16403		16160		16323		16100		16130	
	16241		16016		16434			16404		16161		16324		16101		16131	
A_0	16242		16017		16435		T_0+4	16405		16162		16325		16102		16132	
	16243		16020		16436			16406		16163		16326		16103		16133	
	16244		16021		16437			16407		16164		16327		16104		16134	
Ω_0	16245		16022		16440		T_0+6	16410		16165		16330		16105		16135	
	16246		16023		16441			16411		16166		16331		16106		16136	
	16247		16024		16442			16412		16167		16332		16107		16137	
$\dot{\Omega}$	16250		16025		16443		T_0+8	16413		16170		16333		16110 ← RE-1		16140	
	16251		16026		16444			16414		16171		16334		16111		16141	
	16252		16027		16445			16415		16172		16335		16112		16142	
Ci	16253		16030		16446					16173		16336					
	16254		16031		16447					16174		16337					
	16255		16032		16450					16175		16340					
Λ_G	16256		16033		16451					16176		16341					
	16257		16034		16452					16177		16342					
	16260		16035		16453					16200		16343					
	16261		16036		16454					16201		16344					
	16262		16037		16455					16202		16345					
	16263		16040		16456					16203		16346					
	16264		16041		16457					16204		16347					
	16265		16042		16460					16205		16350					
	16266		16043		16461					16206		16351					
Si	16267		16044		16462					16207		16352					
	16270		16045		16463					16210		16353					
	16271		16046		16464					16211		16354					
	16272		16047		16465					16212		16355					
	16273		16050		16466					16213		16356					
	16274		16051		16467					16214		16357					
	16275		16052		16470					16215		16360					
	16276		16053		16471					16216		16361					
	16277		16054		16472					16217		16362					
	16300		16055		16473					16220		16363					
	16301		16056		16474					16221		16364					
	16302		16057		16475					16222		16365					
	16303		16060		16476												
	16304		16061		16477												
	16305		16062		16500												

Fig. 28 STATUS OF DATA TABLES AND POINTER REGISTERS AT END OF FIRST TWO-MINUTE MESSAGE

Table 5

Summary of Changes in Major Counters, Registers, Flags, and Switches During the First 2-Minute Message

Name	Mnemonic	Action
ESM/Real-Time Switch	SW2	Set to real-time position.
Interrupt Count Switch	INTC	Set in subroutine MG1, reset in first execution of subroutine MG2, set in second execution of subroutine MG2.
Orbital Word Counter	WORD	Initialized to zero; incremented at each odd execution of subroutine MG2.
Receiver Interrupt Flag	RCFC	Set in subroutine RCVD; reset in subroutine IDL2.
Program Clock Register	CLOC	Initialized to zero; incremented once per minute in subroutine INCR.
Sync Time Register	SYNC	Initialized to zero; reset to a value of 2 minutes in subroutine DP1.
Message Sync Flag	FDOP	Initialized to zero; set in subroutine MG1.
Receiver Index Counter	XREC	Initialized to zero; incremented in each execution of subroutines MG1 and MG2; set to zero at end of subroutine MG2.

through the check of message sync flag FDOP. As stated in the previous section, FDOP was set at the beginning of message data word No. 1 in the first 2-minute message and thus directs execution of subroutine BCXS.

Subroutine BCXS (Fig. A-7) and the storage of the doppler word in doppler word Table DOPS proceed as described in the previous section. Subroutine COLL (Fig. A-6) then checks for the second or third interrupt. Since this is the second 15-bit transfer, return is made to subroutine IDLE.

Third 15-Bit Transfer. During this second execution of subroutine DP2, the test in subroutine COLL (Fig. A-6) determines that this interrupt is the third 15-bit transfer and therefore directs return to subroutine DP2 (Fig. A-3). A test is made to confirm that the value stored in Table DOPS during the previous execution of subroutine DP1 is not BCDX3 zero. If it is not, this result is construed as a valid transfer, doppler flag DPFG is incremented, and program controltransfers to subroutine VALD.

Subroutine VALD (Fig. A-8) begins by testing for an injection. At this point it is assumed that the test finds no injection has occurred; the section on Injection during Pass describes the program procedures when injection has occurred. Program control then transfers to subroutine VALI.

Subroutine VALI (Fig. A-9) examines, in turn, the status of error Tables FPER and VPER for the fixed and variable parameters, respectively. At this point in the second 2-minute message these tables contain the value -2. The subroutine increments the error tables to a value of -1, and fills Tables FPVD and VPVD with the values in Tables FPCR and VPCR, respectively. Majority vote count register MJV1 is incremented, and program control transfers to subroutine UPTB.

Subroutine UPTB (Fig. A-7) increments message count register MSCT from zero to one and resets the addresses of the pointer registers for the eight data tables to their initialization values. A test is then made on message count register MSCT, which advances the values in the pointer registers for Tables VPVD, VPER, DOPS, and REFS three locations per message. The MSCT value of 1 directs advancement of the four pointer registers by three locations. Figure 29 shows the status of the eight data tables and pointer registers after execution of subroutine UPTB.

The doppler data are converted to ASCII format in subroutine PROC (Fig. A-13) and printed out on the teletype in subroutine PRNT (Fig. A-11) in the same manner as described for orbital parameter word No. 1 in the previous section on the Third 15-Bit Transfer. Program control returns to subroutine IDLE.

Refraction Count Word

First 15-Bit Transfer. The check on the ID code in subroutine IDLE of the first 15-bit transfer for refraction count word No. 1 directs execution of subroutine RF1.

Subroutine RF1 (Fig. A-4) finds that message sync flag FDOP has been set and therefore stores the data in refraction Table REFS at the location specified by pointer register RE-1. From Fig. 24 note that the value for this first transfer of refraction data is always equal to BCD zero. Program control then returns to subroutine IDLE.

Second and Third 15-Bit Transfers. The check on the ID code in subroutine IDLE of the second and third 15-bit transfers for refraction count word No. 1 directs execution of subroutine RF2.

Subroutine RF2 (Fig. A-4) is executed twice, and the sequence for table storage and printout just described for the doppler data is repeated for the refraction data.

Orbital Parameter Words Nos. 1-25

The sequence described above for orbital parameter words Nos. 1-25 in the first 2-minute message is

FIXED PARAMETER CURRENT WORD (FPCR)		FIXED PARAMETER MAJORITY VOTED WORD (FPVD)		FIXED PARAMETER ERROR WORD (FPER)		VARIABLE PARAMETER CURRENT WORD (VPCR)		VARIABLE PARAMETER MAJORITY VOTED WORD (VPVD)		VARIABLE PARAMETER ERROR WORD (VPER)		DOPPLER WORD (DOPS)		REFRACTION WORD (REFS)	
t_p 16223 ◄ FPR	Contains 17 fixed parameters from first two minute message in BCDX3 format	t_p 16000 ◄ FPV	Contains 17 fixed parameters from first two minute message in BCDX3 format	16416 ◄ FPE	BCD −1	T_0-6 16366 ◄ VPR	Contains 8 variable parameters from first two minute message in BCDX3 format	T_0-6 16143	Contains 8 variable parameters from first two-minute message in BCDX3 format	16306	BCD −1	16063	N_1	16113 ◄ RE-1	BCDX3 Zero
16224		16001		16417		16367		16144		16307		16064		16114	
16225		16002		16420		16370		16145		16310		16065		16115	
η 16226		η 16003		16421		T_0-4 16371		T_0-4 16146 ◄ VPV		16311 ◄ VPE		16066 ◄ D04	BCDX3 Zero	16116	
16227		16004		16422		16372		16147		16312		16067		16117	
16230		16005		16423		16373		16150		16313		16070		16120	
ω_0 16231		ω_0 16006		16424		T_0-2 16374		T_0-2 16151		16314		16071		16121	
16232		16007		16425		16375		16152		16315		16072		16122	
16233		16010		16426		16376		16153		16316		16073		16123	
$\dot{\omega}$ 16234		$\dot{\omega}$ 16011		16427		T_0 16377		T_0 16154		16317		16074		16124	
16235		16012		16430		16400		16155		16320		16075		16125	
16236		16013		16431		16401		16156		16321		16076		16126	
ϵ 16237		ϵ 16014		16432		T_0+2 16402		T_0+2 16157		16322		16077		16127	
16240		16015		16433		16403		16160		16323		16100		16130	
16241		16016		16434		16404		16161		16324		16101		16131	
A_0 16242		A_0 16017		16435		T_0+4 16405		T_0+4 16162		16325		16102		16132	
16243		16020		16436		16406		16163		16326		16103		16133	
16244		16021		16437		16407		16164		16327		16104		16134	
Ω_0 16245		Ω_0 16022		16440		T_0+6 16410		T_0+6 16165		16330		16105		16135	
16246		16023		16441		16411		16166		16331		16106		16136	
16247		16024		16442		16412		16167		16332		16107		16137	
$\dot{\Omega}$ 16250		$\dot{\Omega}$ 16025		16443		T_0+8 16413		T_0+8 16170		16333		16110		16140	
16251		16026		16444		16414		16171		16334		16111		16141	
16252		16027		16445		16415		16172		16335		16112		16142	
C_I 16253		C_I 16030		16446				16173	BCD Zero	16336	BCD −2				
16254		16031		16447				16174		16337					
16255		16032		16450				16175		16340					
Λ_G 16256		Λ_G 16033		16451				16176		16341					
16257		16034		16452				16177		16342					
16260		16035		16453				16200		16343					
16261		16036		16454				16201		16344					
16262		16037		16455				16202		16345					
16263		16040		16456				16203		16346					
16264		16041		16457				16204		16347					
16265		16042		16460				16205		16350					
16266		16043		16461				16206		16351					
S_I 16267		S_I 16044		16462				16207		16352					
16270		16045		16463				16210		16353					
16271		16046		16464				16211		16354					
16272		16047		16465				16212		16355					
16273		16050		16466				16213		16356					
16274		16051		16467				16214		16357					
16275		16052		16470				16215		16360					
16276		16053		16471				16216		16361					
16277		16054		16472				16217		16362					
16300		16055		16473				16220		16363					
16301		16056		16474				16221		16364					
16302		16057		16475				16222		16365					
16303		16060		16476											
16304		16061		16477											
16305		16062		16500											

Fig. 29 STATUS OF DATA TABLES AND POINTER REGISTERS AFTER SUBROUTINE UPTB IN SECOND TWO-MINUTE MESSAGE

repeated for these same words in the second 2-minute message. Figure 30 shows the status of the eight data tables and pointer registers at the end of the second 2-minute message. The changes that have occurred in the major counters, registers, flags, and switches during the second 2-minute message are summarized in Table 6.

THIRD AND FOURTH TWO-MINUTE MESSAGES

During the third execution of the subroutines described above for the first and second 2-minute messages, subroutine VALI (Fig. A-9) will find a BCD value of -1 stored in error Table FPER and the first 24 positions of error Table VPER.

With respect to the fixed parameters, this result directs execution of an exclusive-or comparison, line by line, of the entries in Tables FPCR and FPVD, with the result of the comparison being stored on the corresponding line in Table FPER. Inasmuch as an exclusive-or comparison yields a one bit for each two binary bits that are different, but a zero bit for each two binary bits that are alike, the resultant entries in Table FPER will be the differences between the entries in Tables FPCR and FPVD. In this particular program, which uses two's complement arithmetic, the numbers -2 and -1 are picked for the initial entries in Table FPER because in two's complement arithmetic neither number is likely to occur as an end result of the exclusive-or comparison.

With respect to the variable parameters, an exclusive-or comparison is made of the entries in Tables VPCR and VPVD, with the result stored in Table VPER. For the variable parameters the pointer registers VPV and VPE are set such that data for the same time interval are compared. Pointer register VPE is also set such that the comparison result is entered in Table VPER on the line corresponding to the entry in Table VPVD. Figure 31 shows the status of the eight data tables and pointer registers at the end of the processing of the doppler data in the third 2-minute message.

FIXED PARAMETER CURRENT WORD (FPCR)		FIXED PARAMETER MAJORITY VOTED WORD (FPVO)		FIXED PARAMETER ERROR WORD (FPER)		VARIABLE PARAMETER CURRENT WORD (VPCR)		VARIABLE PARAMETER MAJORITY VOTED WORD (VPVO)		VARIABLE PARAMETER ERROR WORD (VPER)		DOPPLER WORD (DOPS)		REFRACTION WORD (REFS)	
t_p 16223	Contains 17 fixed parameters from second two-minute message in BCDX3 format	t_p 16000	Contains 17 fixed parameters from first two-minute message in BCDX3 format	16416 VPR	BCD −1	T_0-4 16366	Contains 8 Variable parameters from second two-minute message in BCDX3 format	T_0-6 16143	Contains 8 variable parameters from first two-minute message in BCDX3 format	16306 ← FPR	BCD −1	16063 ← FPV		16113	
16224		16001		16417 FPE		16367		16144		16307		16064	N_1	16114	R_1
16225		16002		16420		16370		16145		16310		16065		16115	
η 16226		η 16003		16421		T_0-2 16371		T_0-4 16146 ← VPV		16311 ← VPE		16066 ← DG4	BCDX3 Zero	16116 ← RE-1	BCDX3 Zero
16227		16004		16422		16372		16147		16312		16067		16117	
16230		16005		16423		16373		16150		16313		16070		16120	
ω_0 16231		ω_0 16006		16424		T_0 16374		T_0-2 16151		16314		16071		16121	
16232		16007		16425		16375		16152		16315		16072		16122	
16233		16010		16426		16376		16153		16316		16073		16123	
$\dot{\omega}$ 16234		$\dot{\omega}$ 16011		16427		T_0+2 16377		T_0 16154		16317		16074		16124	
16235		16012		16430		16400		16155		16320		16075		16125	
16236		16013		16431		16401		16156		16321		16076		16126	
ϵ 16237		ϵ 16014		16432		T_0+4 16402		T_0+2 16157		16322		16077		16127	
16240		16015		16433		16403		16160		16323		16100		16130	
16241		16016		16434		16404		16161		16324		16101		16131	
A_0 16242		A_0 16017		16435		T_0+6 16405		T_0+4 16162		16325		16102		16132	
16243		16020		16436		16406		16163		16326		16103		16133	
16244		16021		16437		16407		16164		16327		16104		16134	
Ω_0 16245		Ω_0 16022		16440		T_0+8 16410		T_0+6 16165		16330		16105		16135	
16246		16023		16441		16411		16166		16331		16106		16136	
16247		16024		16442		16412		16167		16332		16107		16137	
$\dot{\Omega}$ 16250		$\dot{\Omega}$ 16025		16443		T_0+10 16413		T_0+8 16170		16333		16110		16140	
16251		16026		16444		16414		16171		16334		16111		16141	
16252		16027		16445		16415		16172		16335		16112		16142	
Ci 16253		Ci 16030		16446				16173	BCD Zero	16336	BCD −2				
16254		16031		16447				16174		16337					
16255		16032		16450				16175		16340					
Λ_G 16256		Λ_G 16033		16451				16176		16341					
16257		16034		16452				16177		16342					
16260		16035		16453				16200		16343					
16261		16036		16454				16201		16344					
16262		16037		16455				16202		16345					
16263		16040		16456				16203		16346					
16264		16041		16457				16204		16347					
16265		16042		16460				16205		16350					
16266		16043		16461				16206		16351					
Si 16267		Si 16044		16462				16207		16352					
16270		16045		16463				16210		16353					
16271		16046		16464				16211		16354					
16272		16047		16465				16212		16355					
16273		16050		16466				16213		16356					
16274		16051		16467				16214		16357					
16275		16052		16470				16215		16360					
16276		16053		16471				16216		16361					
16277		16054		16472				16217		16362					
16300		16055		16473				16220		16363					
16301		16056		16474				16221		16364					
16302		16057		16475				16222		16365					
16303		16060		16476											
16304		16061		16477											
16305		16062		16500											

Fig. 30 STATUS OF DATA TABLES AND POINTER REGISTERS AT END OF SECOND TWO-MINUTE MESSAGE

Table 6

Summary of Changes in Major Counters, Registers, Flags, and Switches During the Second 2-Minute Message

Name	Mnemonic	Action
Orbital Word Counter	WORD	Same as for first 2-minute message.
Receiver Interrupt Flag	RCFG	
Program Clock Register	CLOC	
Sync Time Register	SYNC	
Interrupt Count Switch	INTC	Set in subroutines DP1, RF1, and MG1: reset in first execution of subroutine COLL, set in second execution of subroutine COLL.
Message Sync Flag	FDOP	No change.
Receiver Index Counter	XREC	Incremented in each execution of subroutines DP1 and DP2, then set to zero at end of DP2. Incremented in each execution of subroutines RF1 and RF2, then set to zero at end of RF2. Incremented in each execution of subroutines MG1 and MG2, then set to zero at end of MG2.
Majority Vote Counter	MJV1	Initialized to zero; incremented in subroutine VALI.
Message Counter	MSCT	Initialized to zero; incremented in subroutine UPTB.

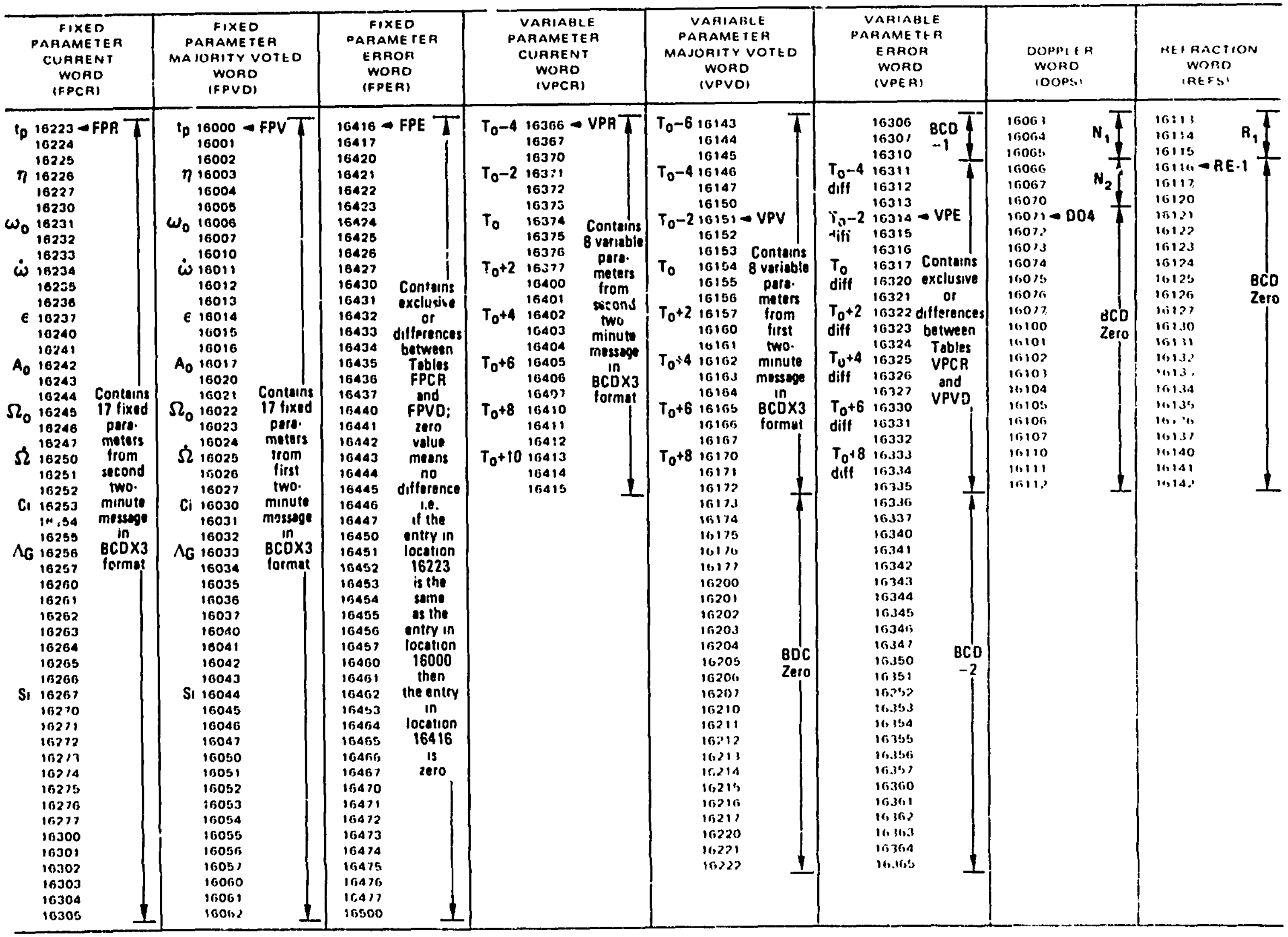


Fig. 31 STATUS OF DATA TABLES AND POINTER REGISTERS AT END OF DOPPLER WORD IN THIRD TWO-MINUTE MESSAGE

During the fourth 2-minute message the content of Tables FPER and VPER will again be examined in subroutine VALI (Fig. A-9). If the entry on any given line of these tables is zero, the corresponding lines of Tables FPCR and FPVD (or VPCR and VPVD) agree and hence the line in Table FPVD (or VPVD) contains valid, majority-voted data.

Alternatively if the entry on any given line of Tables FPER and VPER is not zero, validation is to be performed as follows:

(a) An exclusive-or comparison is made between the entries in Tables FPCR and FPVD (or VPCR and VPVD), with the result placed temporarily in a result register. At this point in the fourth 2-minute message Tables FPCR and VPCR contain the data from the third 2-minute message. Tables FPVD and VPVD contain data from the first 2-minute message. Tables FPER and VPER contain the results of the exclusive-or comparison on data from the first and second messages.

(b) A logical-and operation is now made on the results of the two exclusive-or operations with the result replacing the previous result in the result register. Inasmuch as a logical-and operation results in a one bit for each two bits that are one bit and a zero bit otherwise, the word in the result register reflects differences between the word in the first message and the words in both the second and third messages.

(c) The result of the logical-and operation is then exclusive-or'ed with the validated table word to complement the bits in error, and the error table entry is set to the new error pattern. This process will continue until there is a zero error result.

Figure 32 summarizes the validation process using as example the entry 100 011 010 001, or (in octal notation) $4321_{(8)}$. The example assumes that in the first 2-minute message this entry is received as $5321_{(8)}$, in the

STEP	CURRENT WORD	RESULT WORD	MAJORITY VOTED WORD	ERROR WORD
1. STATUS AFTER INITIALIZATION	000 000 000 000	--- --- --- ---	000 000 000 000	111 111 111 110
2. STATUS AFTER EXECUTION OF SUBROUTINE VALI IN SECOND 2-MINUTE MESSAGE	101 011 010 001	--- --- --- ---	101 011 010 001	111 111 111 111
3. STATUS AFTER EXECUTION OF SUBROUTINE VALI IN THIRD 2-MINUTE MESSAGE	100 011 011 001	--- --- --- ---	101 011 010 001	001 000 001 000
4. STATUS AT BEGINNING OF SUBROUTINE VALI IN FOURTH 2-MINUTE MESSAGE	100 100 010 001	--- --- --- ---	101 011 010 001	001 000 001 000
4a. VALID + CURRENT	100 100 010 001	001 111 000 000	101 011 010 001	001 000 001 000
4b. RESULT · ERROR	100 100 010 001	001 000 000 000	101 011 010 001	001 000 001 000
4c. RESULT + ERROR	100 100 010 001	100 011 010 001	100 011 010 001	000 000 000 000

Fig. 32 SUMMARY OF VALIDATION PROCEDURE

second 2-minute message as $4331_{(8)}$, and in the third 2-minute message as $4421_{(8)}$. After initialization (step 1) processing of the entry is done in the second, third, and fourth messages with the results shown in Fig. 32 in Steps 2, 3, and 4, respectively. The values of -2 and -1 shown in the error word column entries for steps 1 and 2, respectively, are in two's complement format.

After a majority vote is reached for the data on any particular line in Tables FPVD and VPVD, new data read into the corresponding entry in Tables FPCR and VPCR during subsequent 2-minute messages are discarded

TWO-MINUTE MESSAGES NOS. 5-9

The above procedures are repeated for 2-minute messages Nos. 5-9 such that at the end of the ninth message the data tables will appear as shown in Fig. 33, and the check on the number of doppler counts in subroutine IDLE will transfer program control to subroutine NAV. Before discussion of this subroutine, two situations that can affect the real-time program are discussed. These two situations are loss of lock and injection during a pass.

MESSAGE DEVIATIONS

Loss of Lock

A system requirement is that the relative time associated with a 2-minute interval and a particular variable parameter data set be known, i. e., the actual time that a doppler counting interval spans and the associated set of variable parameters for that 2-minute interval.

Time synchronization of doppler data is accomplished by making use of satellite time. The satellite transmits a sync word every 2 minutes at an integral universal 2-minute time. This sync word time determines the doppler counting interval. However, if a receiver loses lock

FIXED PARAMETER CURRENT WORD (FPCR)		FIXED PARAMETER MAJORITY VOTED WORD (FPVD)		FIXED PARAMETER ERROR WORD (FPER)		VARIABLE PARAMETER CURRENT WORD VPCR)		VARIABLE PARAMETER MAJORITY VOTED WORD (VPVD)		VARIABLE PARAMETER ERROR WORD (VPER)		DOPPLER WORD (DOPS)		REFRACTION WORD (REFS)	
t_p 16223	Contain. 17 fixed parameters from the ninth two-minute message in BCDX3 format	t_p 16000	Contains 17 fixed parameters in BCDX3 format; the data in a given location are majority voted if the corresponding location in Table FPER is zero	16416	Contains all zeros except where no majority vote was reached	T_0+10 16366	Contains 8 variable words from the ninth two-minute message in BCDX3 format	T_0-6 16143	Contains the variable parameters in BCDX3 format, the data in a given location are majority voted if the corresponding location in Table VPER is zero	16306	BCD −1	16063		16113	
16224		16001		16417		16367		16144		16307		16064	N_1	16114	R_1
16225		16002		16420		16370		16145		16310		16065		16115	
η 16226		η 16003		16421		T_0+12 16371		T_0-4 16146		16311	Contains all zeros except where no majority vote was reached	16066		16116	
16227		16004		16422		16372		16147		16312		16067	N_2	16117	R_2
16230		16005		16423		16373		16150		16313		16070		16120	
ω_0 16231		ω_0 16006		16424		T_0+14 16374		T_0-2 16151		16314		16071		16121	
16232		16007		16425		16375		16152		16315		16072	N_3	16122	R_3
16233		16010		16426		16376		16153		16316		16073		16123	
$\dot{\omega}$ 16234		$\dot{\omega}$ 16011		16427		T_0+16 16377		T_0 16154		16317		16074		16124	
16235		16012		16430		16400		16155		16320		16075	N_4	16125	R_4
16236		16013		16431		16401		16156		16321		16076		16126	
ϵ 16237		ϵ 16014		16432		T_0+18 16402		T_0+2 16157		16322		16077		16127	
16240		16015		16433		16403		16160		16323		16100	N_5	16130	R_5
16241		16016		16434		16404		16161		16324		16101		16131	
A_0 16242		A_0 16017		16435		T_0+20 16405		T_0+4 16162		16325		16102		16132	
16243		16020		16436		16406		16163		16326		16103	N_6	16133	R_6
16244		16021		16437		16407		16164		16327		16104		16134	
Ω_0 16245		Ω_0 16022		16440		T_0+22 16410		T_0+6 16165		16330		16105		16135	
16246		16023		16441		16411		16166		16331		16106	N_7	16136	R_7
16247		16024		16442		16412		16167		16332		16107		16137	
$\dot{\Omega}$ 16250		$\dot{\Omega}$ 16025		16443		T_0+24 16413		T_0+8 16170		16333		16110		16140	
16251		16026		16444		16414		16171		16334		16111	N_8	16141	R_8
16252		16027		16445		16415		16172		16335		16112		16142	
C_i 16253		C_i 16030		16446				T_0+10 16173		16336					
16254		16031		16447				16174		16337					
16255		16032		16450				16175		16340					
Λ_G 16256		Λ_G 16033		16451				T_0+12 16176		16341					
16257		16034		16452				16177		16342					
16260		16035		16453				16200		16343					
16261		16036		16454				T_0+14 16201		16344					
16262		16037		16455				16202		16345					
16263		16040		16456				16203		16346					
16264		16041		16457				T_0+16 16204		16347					
16265		16042		16460				16205		16350					
16266		16043		16461				16206		16351					
S_i 16267		S_i 16044		16462				T_0+18 16207		16352					
16270		16045		16463				16210		16353					
16271		16046		16464				16211		16354					
16272		16047		16465				T_0+20 16212		16355					
16273		16050		16466				16213		16356					
16274		16051		16467				16214		16357					
16275		16052		16470				T_0+22 16215		16360					
16276		16053		16471				16216		16361					
16277		16054		16472				16217		16362					
16300		16055		16473				T_0+24 16220		16363	BCD −1				
16301		16056		16474				16221		16364					
16302		16057		16475				16222		16365					
16303		16060		16476											
16304		16061		16477											
16305		16062		16500											

Fig. 33 STATUS OF DATA TABLES AT END OF NINTH TWO-MINUTE MESSAGE

from the satellite during a particular interval, doppler counting discontinues until lock is regained and the receiver regains satellite time sync. One or more doppler counts can be lost during this time. Once lock is regained, it is the responsibility of the computer program to locate the right time slot for the doppler data.

This is also true for the variable parameter data, since time dependent variable parameter data precess through the message set one satellite word every 2 minutes; i.e., at the end of transmission of one 2-minute interval of data in the variable parameter portion, parameter 2 becomes parameter 1, 3 becomes 2, 4 becomes 3, etc., and a new parameter replaces parameter 8. For the purpose of real-time validation it is required that a variable parameter set be referenced to the correct relative time interval.

A programmed counter can be used to detect missing doppler counts and thereby use the occurrence or detected nonoccurrence of doppler data to update table storage addresses. A method for accomplishing this function is as follows:

If the receiver loses lock on the satellite signal, interrupt flag RCFG will not be set, and the program will continue to dwell in subroutine IDLE, with time being incremented in subroutine INCR and the 2-minute elapsed test being made in subroutine TES2 (Fig. A-8). When the contents of registers SYNC and CLOC become equal, 2 minutes have elapsed and subroutine TES2 will check doppler flag DPFG to determine if valid doppler data have been received. If loss of lock occurred before valid doppler data have been received, then the doppler flag will not have been set and the table updating done in subroutine DP2 will not have been executed. In subroutine TES2 the finding that the doppler flag has not been set will direct transfer of program control to subroutine UPTB.

Subroutine UPTB (Fig. A-7) is executed as previously described with message count register MSCT being incremented as before. This result will cause the pointer register for Tables VPVD, VPER, DOPS, and REFS to skip over the table positions where the missing data would have been. For this reason the initialization entries in Tables DOPS and REFS are selected to be the correct entries for missing data. Return is made to subroutine TES2, which directs transfer to subroutine RESE.

Subroutine RESE (Fig. A-7) resets internal program clock register CLOC to zero to mark the beginning of the 2-minute interval and sets register SYNC to a value of 2 minutes to mark the time of the next 2-minute interval. Program control then returns through subroutine TES2 to subroutine IDLE where the routine repeats as described above until the operator terminates the collection of real-time data from the receiver, or until the next receiver interrupt occurs.

Injection During Pass

The test to determine if an injection has been made during the pass occurs in subroutine INJT to which transfer is made during subroutine VALD (Fig. A-8).

Subroutine INJT (Fig. A-9) checks whether two or more 2-minute messages have been received. If they have, a comparison is made between the times of perigee in the two messages, which will be in Tables FPCR and FPVD. Inasmuch as the satellite message is updated by the ground injection station twice per day at approximately 12-hour intervals, the change in the value of perigee time in the two messages will yield a bit difference of 6 or greater, if an injection has occurred. If an injection has occurred, a test will then be made on majority vote count register MJV1 to determine how many majority-voted, valid messages have been received. If three or more valid messages have been obtained, sufficient data are already available for use in the fix calculations and return is made to subroutine VALD.

If the number of valid messages is less than three, there will not be a sufficient amount of data available to complete the majority vote process because the satellite is transmitting an updated message and no further data from the old message will be obtained. This result directs that Tables FPER and VPER be reset to -2 again so that the majority vote process may be conducted with the updated message, and return is made to subroutine VALD.

An alternative method for detecting injection uses satellite words 140, 146, or 152. At the time of an injection these words are transmitted with a value of binary zero. This method has the disadvantage that it is not reliable if the receiver loses lock during injection.

SUBROUTINE NAV

Determine Validity of Variable Parameters

Returning to subroutine NAV (Fig. A -1) the first operation is a check to determine if any of the entries in variable parameter majority voted word Table VPVD did not pass the majority vote test. For this operation, program control passes to subroutine VPTS.

Subroutine VPTS (Fig. A-12) begins by summing the three lines in variable parameter majority voted word Table VPER corresponding to the entry for the time interval 2 minutes before sync time (T_0 -2). If the sum is zero the three lines in variable parameter majority voted word Table VPVD for T_0 -2 are valid data. The subroutine repeats until all the variable data received in the interval from 2 minutes before sync time through 18 minutes after sync time are examined.

Assume now, for example, that the entry for a 2-minute entry, say T_0 +4, did not pass the majority vote test, i.e., the sum of the entries in Table VPER for the three transfers is not zero. Subroutine VPTS sets the three lines in variable parameter majority voted word Table VPVD for the entry T_0 +4 to a value of binary zero and also sets the two doppler words N_1 and N_2 (i.e., the two doppler words centered on time T_0 +4) to a value of BCDX3 zero. Deleting these two doppler words minimizes the error in the portion of the navigation mathematic routines in which the differences in the actual and theoretical satellite positions at this time are determined.

The program concludes by discarding the variable data for the intervals for which the data are not received three times (i. e., those prior to T_0-2 and after T_0 +18), and program control then returns to subroutine NAV.

Punch Majority Voted Data, Doppler Data, and Refraction Data on Tape

The next operation in subroutine NAV is to punch a tape for the majority voted data, the doppler data, and the refraction data. For this operation, control passes to subroutine PTAP.

Subroutine PTAP (Fig. A-11), using subroutines PROC and PRNT, causes the 17 fixed parameter majority voted words, the 11 variable parameter majority voted words for the 2-minute intervals from T_0 -2 through T_0 +18, the eight doppler words, and the eight refraction words to be printed out on the teletypewriter in ASCII format and also punched on tape in ASCII format. Program control then returns to subroutine NAV.

Convert Fixed Parameters, Doppler Data, and Refraction Data to Floating Point Format

The next operation in subroutine NAV is to convert the fixed parameters, doppler data, and refraction data to floating point format. For this operation program control passes to subroutine FMTT.

Subroutine FMTT (Fig. A-14) converts the fixed parameters, doppler data, and refraction data from BCDX3 format to BCD format and then to floating point format. With respect to the fixed parameters, Table 2 shows that the coding of the most significant digit in the value for time of perigee differs from the coding of the most significant digit in the values for the remainder of the fixed parameters.

A test is made in subroutine FMTT therefore to locate time of perigee and convert the first character from the coded value in Table 2 to the conventional BCD value. In addition, all the data are treated as integer values; i.e., it is assumed that each value is multiplied by the proper power of 10 to make it an integer.

For example, time of perigee, i.e., the first fixed parameter received from the satellite, is a number consisting of four integer places and five fractional places. The configuration of the number is thus XXXX.XXXXX. For purposes of the conversion from BCD to floating point it is assumed that this number is multiplied by 10^5, thus making it an integer. Later in the navigation math routines the value of time of perigee will be multiplied by 10^{-5} to give it its proper scaling again. The advantage of this process is that a straightforward BCD to binary routine can be used in subroutine FMTT which does not have to account for the scaling of the various parameters. Later in the navigation mathematical routines these scalings can be accounted for very easily.

Program control returns to subroutine NAV.

Convert Variable Parameters to Floating Point Format

The next step in subroutine NAV is to convert the variable parameters from BCDX3 format to BCD format and then to binary floating point format. Next the variable data for each 2-minute entry are separated into their constituent components, i.e., the out-of-plane component (η), the correction (ΔE) to the eccentric anomaly, and the correction (ΔA) to the mean semimajor axis. Program control transfers to subroutine VPMC.

Subroutine VPMC (Fig. A-14) begins by checking the variable parameter entries in Table VPVD to determine if they are binary zero (see section on Subroutine NAV). If they are, the program makes no change in their value. If they are not, the program converts the data from BCDX3 to BCD.

Next the value of the out-of-plane term is extracted from its location in the third transfer of each of the variable parameters. The out-of-plane term is reconverted to BCDX3 format and then checked in subroutine BCXS (Fig. A-7) to determine if it is a legal BCDX3 character. If the term is a legal BCDX3 character it will be reconverted to BCD, formatted to binary floating point, and stored. If it is an illegal BCDX3 character the term is also formatted to binary floating point and stored, but as a negative value. The negative value will be used to delete the illegal data during the navigation mathematical routines.

The program next converts the data for the correction (ΔA) to the mean semimajor axis and the correction (ΔE) to the eccentric anomaly into binary floating point.

Lock-on (T_0) time is next converted to binary floating point and the program returns to subroutine NAV.

Collect Navigator's Estimates

The next step in subroutine NAV is to collect the navigator's estimates of sync time, position, antenna height, heading (course), rate (speed), day number of pass, and the day numbers of the period for which alerts are desired. Program control transfers to subroutine POSI.

Subroutine POSI (Fig. A-15) requests the navigator to enter the estimates in the format shown in Table 3. The program reformats the data as shown on Fig. A-15 and stores them for use in the navigation math routines, described in Sections 7 and 8. These navigation math routines will follow immediately, unless the navigator terminates the program. Before the math routines are discussed, however, the modifications to the real-time data processing procedures to allow their use in nonreal-time, or off-line postpass data processing, will be described.

NONREAL-TIME DATA PROCESSING

Nonreal-time data processing is done if the navigator wishes to renavigate the pass data or if he wishes to execute the navigation math routines using pass data collected at a previous time. The data may be in the form of punched tape prepared as described in the previous section or may be a manual input from the teletypewriter. To select the nonreal-time option the navigator sets the appropriate switch on the computer console (SW2 in the example shown in Fig. A-1). The navigator may also elect to prepare a punched tape by setting another switch (SW4 in the example shown in Fig A-1) on the computer console.

The program (Fig. A-1) is executed as described in Section 6. In the test for interrupt, subroutine INP3 will find SW2 set and transfer control to subroutine ESM.

Subroutine ESM (Fig. A-1) begins by transferring program control to subroutine READ.

Subroutine READ (Fig. A-10) directs the navigator to enter the fixed and variable parameters, the doppler data, and the refraction data either as punched tape or manually through the teletypewriter keyboard in ASCII format.

As each group of nine characters is entered, subroutine INPU (Fig. A-13) converts the entry to BCDX3 format and stores it in the appropriate locations in Tables FPVD, VPVD, DOPS, and REFS.

Depending on the setting of SW4, program control will transfer to either subroutine PTAP or to subroutine FMTT and the sequence described in Section 6 is repeated.

7. THREE-VARIABLE NAVIGATION

METHOD OF SOLUTION

At this point validated satellite orbital data are available and arranged in tables in accordance with the procedures described in Section 6. The doppler and ionospheric refraction data have also been assembled in tables. The variable parameters, the doppler data, and the ionospheric refraction data are time-ordered by 2-minute intervals. The navigator's estimates and the program constants are given in Tables 3 and 4, respectively. A three-variable fix is obtained using these data by a least squares minimization of the residuals formed by differencing the measured and theoretical slant range changes. The solution is an iterative process in which each iteration results in a correction to the navigator's latitude ($\Delta\varphi$), longitude ($\varphi\lambda$), and frequency offset (Δf). Successive iterations produce smaller corrections, and the fix is obtained when these corrections become smaller than predefined breakout constants.

Figure 34 diagrams the steps followed to obtain the navigation fix. These steps are divided into five parts to (1) set up input data, (2) perform initial noniterative computations, (3) solve for the fix by least squares minimization in an iterative process, (4) edit the doppler data preparatory to a repetition of the iterative fix procedures, and (5) calculate alerts.

Input Data

The setting up of input data for the navigation solution computations consists of correcting the 400-MHz doppler data for the effects of ionospheric refraction, setting up the navigator's table of relative position motion, computing the time of the first fiducial point (sync time), setting up the table of out-of-plane orbit corrections at 4-minute intervals, and interpolating for the corrections at 2-minute intervals. In addition a determination is made of

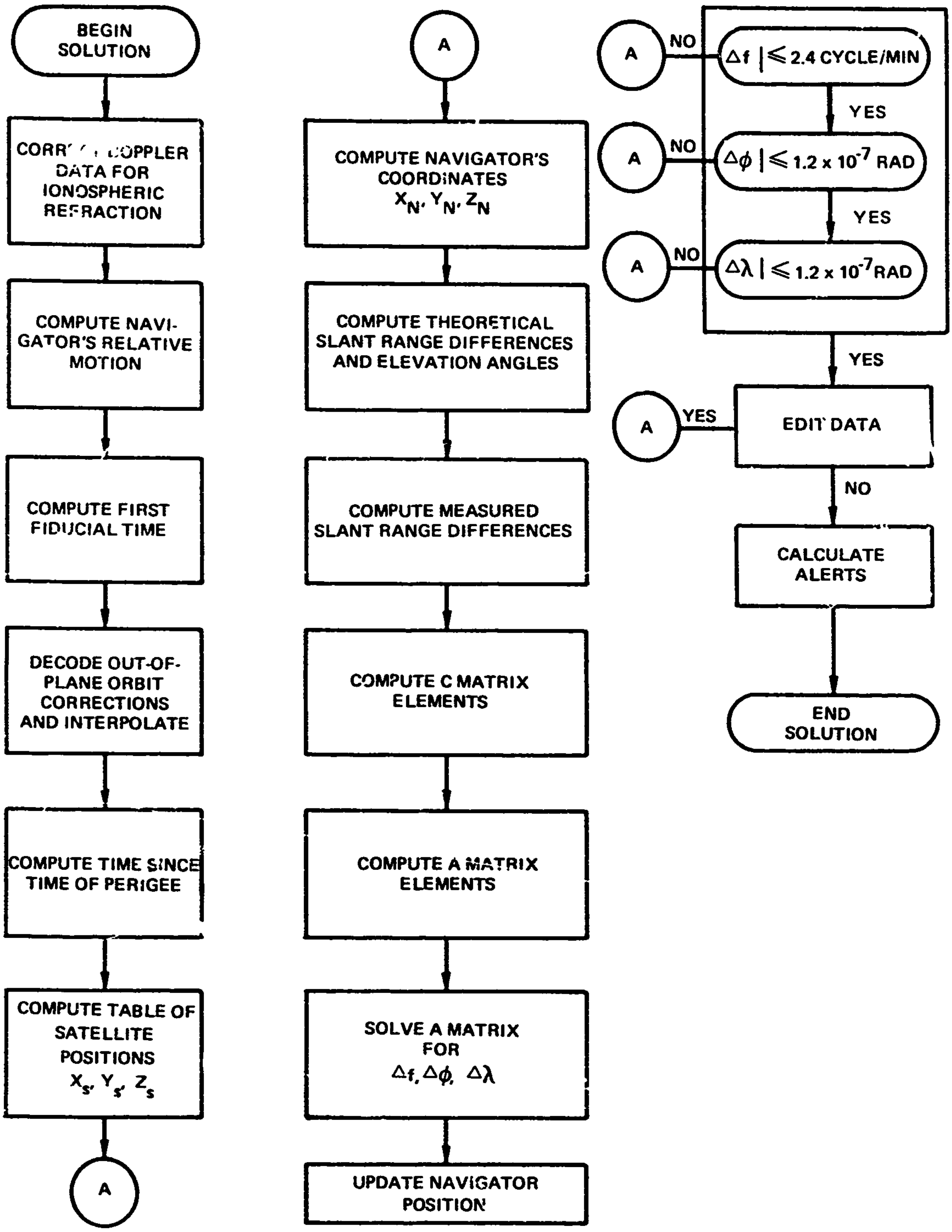


Fig. 34 BLOCK DIAGRAM OF NAVIGATION SOLUTION

which doppler intervals must not be considered in the navigation solution.

Preliminary Computations

Preliminary computations for the navigation solution which are not in the iterative process (i.e., need only be performed once per fix computation) consist of computing the satellite X, Y, Z positions (earth center fixed inertial coordinates) for each interval of the pass.

Iteration

The iterative process consists of eight steps to be executed in order for each iteration. These steps are as follows:

1. Compute navigator's X, Y, Z positions (earth center fixed inertial coordinates) for each interval of the pass.

2. Compute the theoretical slant range differences from the navigator and satellite X, Y, Z coordinates, compute the partial derivatives of slant range differences with respect to φ and λ, and compute the elevation angles of the satellite with respect to the navigator.

3. Compute measured slant range differences from the values of cycle count for each interval of the pass.

4. Set up C matrix where each row of C is an interval and the elements are:

C_{I0} = slant range difference residual,

C_{I1} = constant function of ground frequency vacuum wavelength,

C_{I2} = derivative of slant range difference with respect to φ, and

C_{I3} = derivative of slant range difference with respect to λ.

5. Reduce the C matrix to a 3 × 3 A matrix by taking $C^T \cdot C \cdot \Delta = C^T \cdot c$, where C^T is the transpose of C, thus getting:

$$-a_{10} + a_{11}\,\Delta f + a_{12}\,\Delta\varphi + a_{13}\,\Delta\lambda = 0,$$

$$-a_{20} + a_{21}\,\Delta f + a_{22}\,\Delta\varphi + a_{23}\,\Delta\lambda = 0, \text{ and}$$

$$-a_{30} + a_{31}\,\Delta f + a\,\Delta\varphi + a_{33}\,\Delta\lambda = 0.$$

6. By Cramer's rule of determinant solution, solve for Δf, $\Delta\varphi$, and $\Delta\lambda$.

7. Update each of the navigator's estimated positions by:

$$\varphi_{i+1} = \varphi_i + \Delta\varphi_i \text{ and}$$

$$\lambda_{i+1} = \lambda_i + \Delta\lambda_i,$$

where i is the iteration number.

8. Determine if the values of $\Delta\varphi$, $\Delta\lambda$, Δf are below predefined breakout constants. If so, then the fix is obtained. If not, repeat the iterative process. Breakout constants are chosen as:

$$\Delta\varphi \leq 1.2 \times 10^{-7} \text{ rad},$$

$$\Delta\lambda \leq 1.2 \times 10^{-7} \text{ rad, and}$$

$$\Delta f \leq 2.4 \text{ cycle/minute}.$$

Data Editing

If doppler data have been collected during more than four 2-minute intervals, fix accuracy is improved by editing the doppler data such that intervals with elevation angles less than 7.5° are deleted from the calculations. After deletion of the low elevation doppler data the steps of the iterative process are repeated.

Alert Calculations

The alert computations described here have been designed to minimize computer memory requirements above those required for the position fix computation by repeating several of the steps used in the fix computation.

The procedure to be used is as follows:

1. Compute satellite coordinates at a future time T.
2. Compute navigator's coordinates at time T.
3. Compute elevation angle
   a. If positive a satellite pass is underway,
   b. If negative a satellite pass is not underway.
4. Increment time T and repeat Steps 1-3.
5. Repeat Steps 1-4 until all desired alerts have been generated.

SOLUTION FOR NAVIGATION FIX AND ALERT CALCULATIONS

In the following solution, the equation shown for refraction correction (Step A. 3) is for the ITT equipment, as given in Eq. (6). If the Magnavox equipment is used, Step A should be modified to incorporate Eq. (7).

STEP A — Correct 400-MHz doppler counts for effect of ionospheric refraction.

INPUTS: $N_{k_{400}}$ - Table of measured 400-MHz doppler counts from ITT SRN-9 receiver (cycles).

R_k - Table of measured refraction counts from ITT SRN-9 receiver (cycles).

KM - Number of fiducial times during the time from the first fiducial time and spanning the interval for which the $N_{k_{400}}$ doppler counts were received.

KM-1 - Number of cycle counts.

The following equations shall be executed for each value of k (k = 1, 2, 3, ---, KM-1):

$$\text{If } N_{k_{400}} \leq 2 \times 10^6,\ N_k = 0, \text{ otherwise continue.} \quad \text{(A. 1)}$$

$$\text{If } R_k = 2 \times 10^3,\ N_k = 0, \text{ otherwise continue.} \quad \text{(A. 2)}$$

$$N_k = N_{k_{400}} + \frac{24}{55}(2000 - R_k). \quad \text{(A. 3)}$$

OUTPUTS: N_k - Table of refraction corrected "vacuum" doppler counts (cycles).

NDOP - Number of nonzero doppler counts in N_k table.

STEP B – Compute navigator's relative motion in latitude and longitude.

INPUTS φ_e, λ_e - Navigator's estimate of his position (radians).

d - Navigator's heading at estimated first fiducial time (radians clockwise from true north).

v - Speed at estimated first fiducial time (knots).

KM	-	Number of fiducial times during the time from the first fiducial time and spanning the interval for which the doppler counts were received.
f	-	Flattening of reference ellipsoid.

The following computations shall be performed for each value of k (k = 1, 2, 3, ---, KM):

$$\delta = f(2-f) \tag{B.1}$$

$$\Delta\lambda_k = (k-1)\, v \frac{\sin d}{\cos\varphi_e} \left[\frac{1}{3443.934}\ \frac{2}{1}\ \frac{1}{60}\right]\left[1 - 0.5\delta \sin^2\varphi_e\right] \tag{B.2}$$

$$\Delta\varphi_k = (k-1)\, v \cos d \left[\frac{1}{3443.934}\ \frac{2}{1}\ \frac{1}{60}\right]\left[1 + \delta(1 - 0.5\delta \sin^2\varphi_e\right] \tag{B.3}$$

<u>OUTPUT</u>: $\Delta\varphi_k$, $\Delta\lambda_k$ - Table of navigator's relative motion in latitude ($\Delta\varphi$) and longitude ($\Delta\lambda$) at 2-minute intervals (radians).

<u>STEP C</u> — Compute first fiducial time.

<u>INPUTS</u>:

T_c	-	Navigator's estimate for first fiducial time (minutes GMT).
t_0	-	Two-minute interval number from first variable parameter in satellite message.

$$K' = \left[\frac{T_c}{2}\right] \quad [\ ] \text{ means integer part of} \tag{C.1}$$

$$I = 2K' \tag{C.2}$$

$$T_c' = \left[\frac{I}{30}\right] \tag{C.3}$$

$$J = I - 30\,T_c' \tag{C.4}$$

$$H = 2\,t_0 - J \tag{C.5}$$

$$T_0 = I + H - 30\left[\frac{H}{15}\right] \tag{C.6}$$

OUTPUT: T_0 - First fiducial time (minutes).

STEP D — Decode out-of-plane orbit corrections and interpolate for missing corrections.

INPUTS: T_0 - First fiducial time (minutes).

η_k - Table of up to 11 values (k = 1, 2, 3, ---, 11) from satellite message for reconstructing out-of-plane coordinates where each value is the BCD equivalent of the ninth digit of the corresponding variable parameter and η_1 is the variable corresponding to $T_o - 2$.

KM - Number of fiducial times, etc.

$$N = T_0 - 4\left[\frac{T_0}{4}\right] \quad [\;] \text{ means integer part of} \tag{D.1}$$

For positive values of η_k equations D.3 through D.5 shall be executed for

$$k = 2, 4, 6, \text{---} \text{ if } N = 0 \text{ or for } k = 1, 3, 5, \text{---} \text{ if } N \neq 0. \tag{D.2}$$

For negative values of η_k , $CP(\ell) = 0$ and $CPT(\ell) = k$.

If $\eta_k - 5 \geq 0$ then

$$CP(\ell) = 100\,(\eta_k - 5) + 10\,\eta_{k+1} \tag{D.3}$$

and $CPT(\ell) = k$.

If $\eta_k - 5 < 0$ and

$\eta_k \neq 0$ then

$$CP(\ell) = 100(\eta_k - 5) - 10\,\eta_{k+1} \qquad \text{(D.4)}$$

and $CPT(\ell) = k$.

If $\eta_k - 5 < 0$ and

$\eta_k = 0$ then (D.5)

$$CP(\ell) = -10\,\eta_{k+1}$$

and $CPT(\ell) = k$

where $\ell = 1, 2, 3, ---, OP$.

If $OP \leq 2$ then

$$\eta_k = 0 \text{ for } k = 1, 2, 3, ---, KM. \qquad \text{(D.6)}$$

If OP = 3, execute Eq. (D. 7-a) for k = 1, 2, 3, ---, KM.

If OP = 4 and N = 0 execute Eq. (D. 7-a) for k = 1, 2, 3 and Eq. (D. 7-b) for k = 4, 5, 6, ---, KM.

If OP = 4 and N ≠ 0 execute Eq. (D. 7-a) for k = 1, 2 and Eq. (D. 7-b) for k = 3, 4, 5, ---, KM.

If OP = 5 and N = 0 execute Eq. (D. 7-a) for k = 1, 2, 3, Eq. (D. 7-b) for k = 4, 5, and Eq. (D. 7-c) for k = 6, 7, 8, ---, KM.

If OP = 5 and N ≠ 0 execute Eq. (D. 7-a) for k = 1, 2, 3, Eq. (D. 7-b) for k = 4, and Eq. (D. 7-c) for k = 5, 6, 7, ---, KM.

(D. 7)

$$\begin{aligned}
\eta_k = &\left[\frac{(K+1) - CPT(2)}{CPT(1) - CPT(2)} \cdot \frac{(K+1) - CPT(3)}{CPT(1) - CPT(3)}\right] CP(1) \qquad (D.7\text{-}a)\\
&+\left[\frac{(K+1) - CPT(1)}{CPT(2) - CPT(1)} \cdot \frac{(K+1) - CPT(3)}{CPT(2) - CPT(3)}\right] CP(2)\\
&+\left[\frac{(K+1) - CPT(1)}{CPT(3) - CPT(1)} \cdot \frac{(K+1) - CPT(2)}{CPT(3) - CPT(2)}\right] CP(3),
\end{aligned}$$

$$\begin{aligned}
\eta_k = &\left[\frac{(K+1) - CPT(3)}{CPT(2) - CPT(3)} \cdot \frac{(K+1) - CPT(4)}{CPT(2) - CPT(4)}\right] CP(2) \qquad (D.7\text{-}b)\\
&+\left[\frac{(K+1) - CPT(2)}{CPT(3) - CPT(2)} \cdot \frac{(K+1) - CPT(4)}{CPT(3) - CPT(4)}\right] CP(3)\\
&+\left[\frac{(K+1) - CPT(2)}{CPT(4) - CPT(2)} \cdot \frac{(K+1) - CPT(3)}{CPT(4) - CPT(3)}\right] CP(4),
\end{aligned}$$

$$\begin{aligned}
\eta_k = &\left[\frac{(K+1) - CPT(4)}{CPT(3) - CPT(4)} \cdot \frac{(K+1) - CPT(5)}{CPT(3) - CPT(5)}\right] CP(3) \qquad (D.7\text{-}c)\\
&+\left[\frac{(K+1) - CPT(3)}{CPT(4) - CPT(3)} \cdot \frac{(K+1) - CPT(5)}{CPT(4) - CPT(5)}\right] CP(4)\\
&+\left[\frac{(K+1) - CPT(3)}{CPT(5) - CPT(3)} \cdot \frac{(K+1) - CPT(4)}{CPT(5) - CPT(4)}\right] CP(5).
\end{aligned}$$

OUTPUT: η_k - Table of out-of-plane orbit components (meters) for k = 1, 2, 3, ---, KM.

STEP E — Compute time between time of perigee and first fiducial time.

INPUTS: T_0 - First fiducial time (minutes).

t_p - Time of satellite perigee from message (minutes).

n - Satellite mean motion (radians/minute).

$$t = T_0 - t_p \qquad \text{(E.1)}$$

$$t_R = 1440 - 2\Pi/n \qquad \text{(E.2)}$$

If $t \leq -480$ then $\Delta t_p = t + 1440$. (E.3)

If $-480 < t < t_R$ then $\Delta t_p = t$.

If $t_R \leq t$ then $\Delta t_p = t - 1440$.

OUTPUT: Δt_p - Time between time of perigee and first fiducial time (minutes).

STEP F — Compute satellite coordinates at 2-minute intervals.

INPUTS: Δt_p - Time between time of perigee and first fiducial time (minutes).

KM - Number of positions to be computed.

- All satellite orbit parameters from message.

The following computations shall be performed for each value of k (k = 1, 2, 3, ---, KM):

$$\Delta t_k = \Delta t_p + 2\,(k - 1), \qquad \text{(F.1)}$$

$$M_k = n\,\Delta t_k, \qquad \text{(F.2)}$$

$$E_k = M_k + \epsilon \sin M_k + \Delta E_k, \qquad \text{(F.3)}$$

[assumes that M_k, ΔE_k, and E_k are in radians]

$$A_k = A_0 + \Delta A_k, \qquad \text{(F.4)}$$

$$u_k = A_k (\cos E_k - \epsilon), \qquad \text{(F.5)}$$

$$v_k = A_k (\sin E_k), \qquad \text{(F.6)}$$

$$\omega_k = \omega_0 - \dot{\omega}\,\Delta t_k, \qquad \text{(F.7)}$$

$$x'_k = u_k \cos \omega_k - v_k \sin \omega_k, \tag{F.8}$$

$$y'_k = u_k \sin \omega_k + v_k \cos \omega_k, \tag{F.9}$$

$$z'_k = \eta_k, \tag{F.10}$$

$$\beta_k = (\Omega_0 - \Lambda_G) + (\dot{\Omega} - \omega_e) \Delta t_k, \tag{F.11}$$

$$X_{Sk} = x'_k \cos \beta_k - y'_k \, Ci \sin \beta_k + z'_k \, Si \sin \beta_k, \tag{F.12}$$

$$Y_{Sk} = x'_k \sin \beta_k - y'_k \, Ci \cos \beta_k - z'_k \, Si \cos \beta_k, \text{ and} \tag{F.13}$$

$$Z_{Sk} = y'_k \, Si + z'_k \, Ci. \tag{F.14}$$

OUTPUT: X_{Sk}, Y_{Sk}, Z_{SK} – Satellite coordinates at the fiducial time points (meters).

STEP G – Compute navigator's coordinates and partial derivatives.

INPUTS: $\Delta\varphi_k$ - Table of navigator's relative motion in latitude at fiducial times (radians).

$\Delta\lambda_k$ - Table of navigator's relative motion in longitude at fiducial times radians).

φ_f, λ_f - Fix latitude and longitude (radians) (Note: Initial values of φ_f and λ_f are φ_e and λ_e, the navigator's estimate of his position.)

KM - Number of positions to be computed.

ITER - Number of iterations.

The following computations shall be performed for each value of k (k = 1, 2, 3, ---, KM):

$$\cos \varphi_k = \cos (\varphi_f + \Delta\varphi_k), \tag{G.1}$$

$$\sin \varphi_k = \sin (\varphi_f + \Delta\varphi_k), \tag{G.2}$$

$$\cos \lambda_k = \cos (\lambda_f + \Delta\lambda_k), \qquad \text{(G. 3)}$$

$$\sin \lambda_k = \sin (\lambda_f + \Delta\lambda_k), \qquad \text{(G. 4)}$$

$$D_k^2 = R_0^2 \left[\cos^2 \varphi_k + (1 - f)^2 \sin^2 \varphi_k\right], \qquad \text{(G. 5)}$$

$$X_{Nk} = \left[(R_0^2 / D_k) + h'\right] \cos \varphi_k \cos \lambda_k , \qquad \text{(G. 6)}$$

$$Y_{Nk} = \left[R_0^2 / D_k) + h'\right] \cos \varphi_k \sin \lambda_k, \qquad \text{(G. 7)}$$

$$Z_{Nk} = \left[\frac{R_0^2 (1 - f)^2}{D_k} + h'\right] \sin \varphi_k, \qquad \text{(G. 8)}$$

$$\frac{\partial X_{Nk}}{\partial \varphi} = - \left[\frac{R_0^4 (1 - f)^2}{D_k^3} + h'\right] \sin \varphi_k \cos \lambda_k , \qquad \text{(G. 9)}$$

$$\frac{\partial Y_{Nk}}{\partial \varphi} = - \left[\frac{R_0^4 (1 - f)^2}{D_k^3} + h'\right] \sin \varphi_k \sin \lambda_k , \qquad \text{(G. 10)}$$

$$\frac{\partial Z_{Nk}}{\partial \varphi} = \left[\frac{R_0^4 (1 - f)^2}{D_k^3} + h'\right] \cos \varphi_k , \qquad \text{(G. 11)}$$

$$\frac{\partial X_{Nk}}{\partial \lambda} = - Y_{Nk} , \text{ and} \qquad \text{(G. 12)}$$

$$\frac{\partial Y_{Nk}}{\partial \lambda} = X_{Nk} . \qquad \text{(G. 13)}$$

<u>OUTPUTS</u>: X_{Nk}, Y_{Nk}, Z_{Nk} - Navigator's coordinates at the fiducial time points (meters).

$\frac{\partial X_{Nk}}{\partial \varphi}, \frac{\partial Y_{Nk}}{\partial \varphi}, \frac{\partial Z_{Nk}}{\partial \varphi}$ - Partial derivatives of navigator's coordinates with respect to latitude at the fiducial time points (meters/radian).

$\frac{\partial X_{Nk}}{\partial \lambda}, \frac{\partial Y_{Nk}}{\partial \lambda}$ - Partial derivatives of navigator's coordinates with respect to longitude at the fiducial time points (meters/radian).

ITER - Number of the present iteration.

<u>STEP H</u> – Compute theoretical slant range differences, partial derivatives, and elevation angle.

<u>INPUTS</u>: X_{Nk}, Y_{Nk}, Z_{Nk} - Navigator's coordinates at the fiducial time points (meters).

$\frac{\partial X_{Nk}}{\partial \varphi}, \frac{\partial Y_{Nk}}{\partial \varphi}, \frac{\partial Z_{Nk}}{\partial \varphi}$ - Partial derivatives of navigator's coordinates with respect to latitude at the fiducial time points (meters/radian).

$\frac{\partial X_{Nk}}{\partial \lambda}, \frac{\partial Y_{Nk}}{\partial \lambda}$ - Partial derivatives of navigator's coordinates with respect to longitude at the fiducial time points (meter/radian).

X_{Sk}, Y_{Sk}, Z_{Sk} - Satellite coordinates at the fiducial time points (meters).

KM	- Number of positions to be calculated.

The following computations shall be performed for each value of k (k = 1, 2, 3, ---, KM):

$$X_k = X_{Sk} - X_{Nk}, \qquad (H.1)$$

$$Y_k = Y_{Sk} - Y_{Nk}. \qquad (H.2)$$

$$Z_k = Z_{Sk} - Z_{Nk}, \qquad (H.3)$$

$$S_k^2 = X_k^2 + Y_k^2 + Z_k^2, \qquad (H.4)$$

$$S_k = \left[X_k^2 + Y_k^2 + Z_k^2\right]^{1/2}, \qquad (H.5)$$

$$R_k^2 = X_{Sk}^2 + Y_{Sk}^2 + Z_{Sk}^2, \qquad (H.6)$$

$$r_k^2 = X_{Nk}^2 + Y_{Nk}^2 + Z_{Nk}^2, \qquad (H.7)$$

$$r_k = \left[X_{Nk}^2 + Y_{Nk}^2 + Z_{Nk}^2\right]^{1/2}, \qquad (H.8)$$

$$\frac{\partial S_k}{\partial \varphi} = \frac{-1}{S_k}\left[X_k \frac{\partial X_{NK}}{\partial \varphi} + Y_k \frac{\partial Y_{Nk}}{\partial \varphi} + Z_k \frac{\partial Z_{Nk}}{\partial \varphi}\right] \qquad (H.9)$$

$$\frac{\partial S_k}{\partial \lambda} = \frac{-1}{S_k}\left[X_k \frac{\partial X_{Nk}}{\partial \lambda} + Y_k \frac{\partial Y_{Nk}}{\partial \lambda}\right] \qquad (H.10)$$

$$\sin E_k = \left[\frac{X_k X_{Nk} + Y_k Y_{Nk} + Z_k Z_{Nk}}{S_k r_k}\right], \text{ and} \qquad (H.11)$$

$$\text{If } \sin E_{k+1} < \sin E_k \text{ then } \sin E_{max} = \sin E_k \,. \qquad \text{(H. 12)}$$

OUTPUTS: S_k - Table of theoretical slant ranges at the fiducial time points (meters).

$\frac{\partial S_k}{\partial \varphi}, \frac{\partial S_k}{\partial \varphi}$ - Table of partial derivatives of the theoretical slant ranges with respect to latitude and longitude at the fiducial time points (meters/radian).

$\sin E_{max}$ - Sine of maximum elevation angle for the pass (dimensionless).

STEP I – Compute refraction corrected measured slant range differences.

INPUTS: N_k - Table of refraction corrected "vacuum" doppler counts (cycles).

K - Number of cycle counts.

L_o - Wavelength of navigator's estimate of offset frequency (meters).

$\bar{f}_o$ - Initial value of offset frequency 1 920 000 cycles/min [32 000 cycles/sec]

The following equation shall be performed for each value of k (k = 1, 2, 3, ---, KM-1):

$$S_{ko} = N_k L_o - 2.0 \bar{f}_o L_o \,. \qquad \text{(I. 1)}$$

OUTPUT: $\hat{S}_{ko}$ - Table of measured slant range differences (meters) for KM points.

Note: If any value of $N_k = 0$ the corresponding value of

$$\hat{S}_{ko} = 0.$$

STEP J – Form the C matrix.

INPUTS: $\hat{S}_{ko}$ - Table of (KM-1) measured slant range differences (meters).

S_k - Table of (KM) theoretical slant ranges at the fiducial time points (meters).

$\frac{\partial S_k}{\partial \varphi}, \frac{\partial S_k}{\partial \lambda}$ - Table of (KM) partial derivatives of the theoretical slant ranges with respect to latitude and longitude at the fiducial time points (meters/radian).

The following equations shall be done for each value of k (k = 1, 2, 3, ---, KM-1), for which

$$\hat{S}_{ko} \neq 0:$$

$$C_{J0} = - \hat{S}_{ko} + \left[S_{k+1} - S_k \right], \qquad (J.1)$$

$$C_{J1} = - 2.0 \ L_0 , \qquad (J.2)$$

$$C_{J2} = - \frac{\partial S_{k+1}}{\partial \varphi} + \frac{\partial S_k}{\partial \varphi} , \text{ and} \qquad (J.3)$$

$$C_{J3} = - \frac{\partial S_{k+1}}{\partial \lambda} + \frac{\partial S_k}{\partial \lambda} . \qquad (J.4)$$

OUTPUT: The C matrix

$$\begin{bmatrix} C_{10} & C_{11} & C_{12} & C_{13} \\ C_{20} & C_{21} & C_{22} & C_{23} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ C_{J0} & C_{J1} & C_{J2} & C_{J3} \end{bmatrix}$$

J - Number of rows in the C matrix.

STEP K – Form the A matrix.

INPUTS: - C matrix elements.

J - Number of rows in C matrix.

$$a_{10} = \sum_{m=1}^{J} C_{m1}\, C_{m0} , \qquad (K.1)$$

$$a_{20} = \sum_{m=1}^{J} C_{m2}\, C_{m0} , \qquad (K.2)$$

$$a_{30} = \sum_{m=1}^{J} C_{m3}\, C_{m0} , \qquad (K.3)$$

$$a_{11} = \sum_{m=1}^{J} C_{m1}\, C_{m1} , \qquad (K.4)$$

$$a_{21} = \sum_{m=1}^{J} C_{m2} \; C_{m1}, \qquad \text{Note: } a_{21} = a_{12}, \; a_{31} = a_{13}, \; a_{32} = a_{23} \qquad \text{(K. 5)}$$

$$a_{31} = \sum_{m=1}^{J} C_{m3} \; C_{m1}, \qquad \text{(K. 6)}$$

$$a_{12} = a_{21}, \qquad \text{(K. 7)}$$

$$a_{22} = \sum_{m=1}^{J} C_{m2} \; C_{m2}, \qquad \text{(K. 8)}$$

$$a_{32} = \sum_{m=1}^{J} C_{m3} \; C_{m2}, \qquad \text{(K. 9)}$$

$$a_{13} = a_{31}, \qquad \text{(K. 10)}$$

$$a_{23} = a_{32}, \text{ and} \qquad \text{(K. 11)}$$

$$a_{33} = \sum_{m=1}^{J} C_{m3} \; C_{m3} \, . \qquad \text{(K. 12)}$$

<u>OUTPUT</u>: A matrix

where

$$- a_{10} + a_{11} \Delta f + a_{12} \Delta\varphi + a_{13} \Delta\lambda = 0,$$

$$- a_{20} + a_{21} \Delta f + a_{22} \Delta\varphi + a_{23} \Delta\lambda = 0, \text{ and}$$

$$- a_{30} + a_{31} \Delta f + a_{32} \Delta\varphi + a_{23} \Delta\lambda = 0.$$

STEP L – Solve for Δf, $\Delta\varphi$, $\Delta\lambda$ and update estimates of f, φ, and λ.

INPUT: A matrix elements.

$$B11 = a_{22} - a_{12}\frac{a_{12}}{a_{11}}, \tag{L. 1}$$

$$B12 = a_{23} - a_{13}\frac{a_{12}}{a_{11}}, \tag{L. 2}$$

$$B10 = a_{20} - a_{10}\frac{a_{12}}{a_{11}}, \quad \text{Note: } a_{12} = a_{21} \tag{L. 3}$$

$$a_{13} = a_{31}$$

$$a_{32} = a_{23}$$

$$B22 = a_{33} - a_{13}\frac{a_{13}}{a_{11}}, \tag{L. 4}$$

$$B20 = a_{30} - a_{10}\frac{a_{13}}{a_{11}}, \tag{L. 5}$$

$$\Delta = B11\ B22 - B12\ B12, \tag{L. 6}$$

$$\Delta\varphi = (B22\ B10 - B12\ B20)/\Delta, \tag{L. 7}$$

$$\Delta\lambda = (B11\ B20 - B12\ B10)/\Delta, \tag{L. 8}$$

$$\Delta f = \frac{a_{10} - (a_{12})(\Delta\varphi) - (a_{13})(\Delta\lambda)}{a_{11}}, \tag{L. 9}$$

$$f = f + \Delta f \text{ where } f = \bar{f}_0 \text{ on first iteration,} \tag{L. 10}$$

$$\varphi_f = \varphi_f + \Delta\varphi, \text{ and} \tag{L. 11}$$

$$\lambda_f = \lambda_f + \Delta\lambda. \tag{L. 12}$$

OUTPUTS: Δf - Incremental change in navigator's estimate of offset frequency (cycles/min).

$\Delta \varphi$ - Incremental change in navigator's estimated latitude (radians).

$\Delta \lambda$ - Incremental change in navigator's estimated longitude (radians).

f - Estimated offset frequency (cycles/min). this iteration.

φ_f - Estimated latitude (radians) this iteration.

λ_f - Estimated longitude (radians) this iteration.

STEP M — Write out results.

INPUTS: ITER - Number of this iteration.

φ_e, λ_e - Navigator's initial position estimate (radians).

φ_f, λ_f - Navigator's calculated position this iteration (radians).

$\bar{f}_o$ - Initial value of offset frequency (1 920 000 cycles/min).

f - Navigator's estimate of frequency offset this iteration (cycles/min).

T_0 - First fiducial time (minutes).

IDAY - Day number of pass.

$\sin E_{max}$ - Sine of maximum elevation angle for the pass.

NDOP - Number of doppler counts used in calculation this iteration.

Residual - Residual difference between measured and theoretical slant range differences (meters).

$$DL = \varphi_f - \varphi_e , \qquad (M.1)$$

$$DLO = \lambda_f - \lambda_e , \qquad (M.2)$$

$$FRQ = f - \bar{f}_o , \text{ and} \qquad (M.3)$$

$$TIME = T_0 + 4 . \qquad (M.4)$$

<u>OUTPUTS</u>: ITER - Number of this iteration.

DLA, DLO - Total change in navigator's position (radians).

FRQ - Total change in frequency (cycles/min).

φ_f, λ_f - Navigator's calculated position this iteration (radians).

TIME - Fix time (minutes).

IDAY - Day number of pass.

sin E_{max} - Sine of maximum elevation for pass.

NDOP - Number of doppler counts used in calculations.

Residual - Residual of difference between measured and theoretical slant range differences.

OUTPUTS (Continued)

$$\text{RMS} = \sqrt{\Sigma \frac{\text{Residual}^2}{\text{NDOP-1}}}$$

STEP N – Test for convergence.

INPUTS: Δf - Incremental change in navigator's estimate of offset frequency (cycles/min).

$\Delta\varphi$ - Incremental change in navigator's latitude (radians).

$\Delta\lambda$ - Incremental change in navigator's estimated longitude (radians).

ITER - Number of the present iteration.

$$\text{If } \Delta f > 2.4 \text{ cycle/min,} \tag{N.1}$$

$$\text{or} \quad \text{if } \Delta\varphi > 1.2 \times 10^{-7} \text{ radian,}^{*}$$

$$\text{or} \quad \text{if } \Delta\lambda > \frac{1.2 \times 10^{-7\,*}}{\cos \varphi_f},$$

and if ITER < 10 then return to Step G. Otherwise go to Step O to edit doppler data or Step P to compute alerts.

STEP O – Edit doppler data.

INPUTS: N_k - Table of (KM-1) refraction corrected "vacuum" doppler counts for each 2-minute interval (cycles).

NDOP - Total number of nonzero values in N_k table.

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[*] This convergence criterion is equivalent to 0.0004 nmi. Without loss of significant accuracy this criterion can be broadened to 0.001 nmi or (in radians) approximately 3 x 10^{-7}.

KM - Number of fiducial times, etc.

If NDOP > 4, repeat Steps G and H for each value of k (k = 1, 2, 3, ---, KM).

If $\sin E_{KM - k+1} \leq \sin 7.5°$ and (O.1)

$\sin E_{KM - k+1} \leq \sin E_k$ and

$N_{KM - k} > 0$ then

$N_{KM - k} = 0$ and

NDOP = NDOP - 1.

Or if $\sin E_{KM - k+1} > \sin 7.5°$ and (O.2)

$\sin E_k \leq \sin 7.5°$ and

$N_{k+1} > 0$ then

$N_{k+1} = 0$ and

NDOP = NDOP - 1.

Otherwise make no changes in the N_k table.

OUTPUTS: · Edited N_k table and updated value of NDOP. Repeat Steps G - N.

STEP P — Compute alerts.

INPUTS: T_0 - Time of first fiducial point of last pass (minutes).

IDAY - Day number of last pass.

MDAY - Day number of last day for which alerts are to be calculated.

- Satellite data from last pass and navigator's estimated coordinates during the period IDAY to MDAY.

KM - Number of positions to be calculated.

ISTP = MDAY-IDAY. If ISTP $<$ 0, let ISTP = ISTP + 365. (P. 1)

Let $T_0 = T_0 - 18$, KM = 1, DE(K) = 0, DA(K) = 0, DN(K) = 0, I = 1, 2, 3, ---, ISTP, KDAY = I + IDAY. (P. 2)

Execute Steps F, G, and H. (P. 3)

If $E_k \leq 0$ let $T_0 = T_0 + 10$, and repeat Step P. 3 increasing T_0 by 10 each repetition until $E_k > 0$. (P. 4)

When $E_k > 0$ let $T_0 = T_0 - 10$, repeat Step P. 3, and then execute Step P. 6. (P. 5)

If $E_k \leq 0$, let $T_0 = T_0 + 2$, repeat Step P. 3 increasing T_0 by 2 each time until $E_k \geq 0$, and then execute Step P. 7. (P. 6)

When $E_k \geq 0$ let $T_0 - 2$ = RISE, $E_k = E_A$, $T_0 = T_0 + 0.25$ and repeat Step P. 3 increasing T_0 by 0.25 and letting the new value of $E_k = E_A$ each time until $E_k < E_A$. Then E_A = maximum elevation for that pass. (P. 7)

Write out day number of alert day, RISE time (hours and minutes), and maximum elevation angle for the alert pass. (P. 8)

Let $T_0 = T_0 + 10$ then repeat Steps P. 3 through P. 8 incrementing I and K until $I > ISTP$ indicating that all alerts through the end of MDAY have been obtained. (P. 9)

OUTPUTS:			
	KDAY	-	Day number of alert day.
	RISE	-	Time of rise (hours and minutes) of alert pass.
	E_A	-	Maximum pass elevation (degrees).

8. FORTRAN PROGRAM FOR THREE-VARIABLE NAVIGATION SOLUTION AND ALERT CALCULATIONS

The steps given in Section 7 for the three-variable navigation solutions and for the alert computations have been programmed in FORTRAN. A listing of the program routines is at the end of this Section. Table 7 shows the interface requirements between the real-time data processing program and the navigation fix program and also gives the FORTRAN names of the required parameters, all of which have been discussed in previous sections. The subroutines of the navigation fix program perform the operations described in the next section. Flow charts for the program are in Appendix A.

SUBROUTINES

MAIN

This subroutine is the master routine serving as a driver for the other program routines.

INPUT

Subroutine INPUT allows the program to be used in nonreal-time navigation for study, diagnostic, or debug purposes. It is not used in real-time navigation.

CVTM

Subroutine CVTM (Fig. A-19) scales the constant orbit parameters from their input format to the format used in the program, corrects the doppler data for ionospheric refraction, formats navigator motion for further computation, computes the time of the first fiducial mark, decodes the out-of-plane (cross plane) orbit correction words, and interpolates for the missing out-of-plane corrections (Steps A - D of Section 7).

Table 7

Interface Requirements Between Real-Time Data Processing Program and Navigation Fix Program

Program Parameter Name	Description	Input Format	Input Units	Computational Units	Comments	No of Par	Source
ELAT	Estimated Latitude	FP	Min $*10^4$	Radians		1	Navigator
ELON	Estimated Longitude	FP	Min $*10^4$	Radians		1	Navigator
GEOH	Antenna Height	FP	Meters	Meters		1	Navigator
ETIM	Estimated Lock Time	FP	Minutes	Minutes		1	Navigator
HEAD	Ship's Heading	FP	Minutes	Radians		1	Navigator
RATE	Ship's Speed	FP	Knots $*10$	Radians/Min $*2$		1	Navigator
IDAY	Day of Pass	Integers	Days	Days	15 bit dressed Rt	1	Navigator
MDAY	Alert End Day	Integers	Days	Days	15 bit dressed Rt	1	Navigator
DOP(K)	400-MHz Doppler	FP	Cycles	Cycles	=0 Invalid	8	Satellite Signal
REF(K)	Refraction Correction	FP	Cycles	Cycles	=0 Invalid	8	Satellite Signal
DE(K)	Eccentric Anomaly Correction	FP	Degrees $*10^4$	Radians		9	Satellite Message
DA(K)	Semimajor Axis Correction	FP	Meters/10	Meters		9	Satellite Message
DN(K)	Cross Plane Term (transmitted as values at 4-min intervals and interpolated to yield values at 2-min intervals)	FP	$\frac{\text{Meters}}{\text{10 or 100}}$	Meters	XS3 MSD Alternate LSD	11	Satellite Message
DTK	Lock Time Since Half Hour	FP	Minutes/2	Minutes		1	Satellite Message
TP	Time of Perigee	FP	Min/$*10^5$	Minutes		1	Satellite Message
XNDT	Mean Motion	FP	Deg/Min $*10^{8}$-3	Rad/Min		1	Satellite Message
SOME	Argument of Perigee	FP	Degrees $*10^5$	Radians		1	Satellite Message
SOMD	Precession Rate of Perigee	FP	Deg/Min $*10^8$	Rad/Min		1	Satellite Message
E	Eccentricity	FP	Deg/Min $*10^7$	Dimensionless		1	Satellite Message
AO	Mean Semimajor Axis	FP	Meters	Meters		1	Satellite Message
COME	Right Ascension of Ascending Node	FP	Degrees $*10^5$	Radians		1	Satellite Message
COMD	Precession Rate of Node	FP	Deg/Min $*10^8$	Rad/Min		1	Satellite Message
CI	Cosine Inclination	FP	Deg/Min $*10^7$	Dimensionless		1	Satellite Message
XLMG	Greenwich Long. at TP	FP	Degrees $*10^5$	Radians		1	Satellite Message
SI	Sine Inclination	FP	Degrees $*10^7$	Dimensionless		1	Satellite Message
DLAT(K)	Relative Lat. Motion			Radians	Calculated from Head	9	Navigator
DLON(K)	Relative Long. Motion			Radians		9	Navigator
STIM	Correct Msg. Lock Time			Minutes		1	Satellite Message

SATC AND SXYZ

Subroutine SATC (Fig. A-20) computes the time since perigee (Step E of Section 7) and then calls subroutine SXYZ to compute the satellite coordinates for one 2-minute point. Return is made to subroutine SATC to increment time, and subroutine SXYZ is called again to compute the satellite coordinates for the next 2-minute point. The net effect of this sequence is the execution of Step F of Section 7.

SOLVE AND SLANT

The programming approach adopted in subroutines SOLVE and SLANT (Figs. A-21 and A-22) is to set up the elements of the final A matrix and then incrementally modify each element with its C matrix counterpart by means of an iterative process. The net effect of the sequence is the execution of Steps G - L and the determination of the sum of the squares of the residual differences between the measured and theoretical slant ranges, as follows:

Subroutine SOLVE begins by setting up the elements of the A matrix.* Subroutine SLANT is called and the navigator's coordinates and partial derivatives are calculated for the first time point (Step G). Next, the theoretical slant range for the first time point is calculated, plus the partial derivatives and the elevation angle to the satellite (Step H). Return is then made to subroutine SOLVE to compute the constant function of satellite frequency vacuum wavelength. The interval count is incremented and subroutine SLANT is called again to compute the next theoretical slant range, partial derivatives, and elevation

---

*Inasmuch as Fortran arrays may not be indexed with a subzero term, the term for the residual, which is expressed as C_0 in Section 7, is changed to C(4) in the Fortran listing of Section 8.

angle. Return is made to subroutine SOLVE and the differences in successive theoretical slant ranges and partial derivatives of the slant ranges are calculated. Next, if the doppler count is positive, the refraction corrected measured slant range differences are calculated (Step I). The residual difference between the measured and theoretical slant ranges is determined. The C matrix is formed (Step J), the A matrix is formed (Step K), the matrix is solved for the differences in frequency, offset, latitude, and longitude (Step L), and the navigator's estimates of frequency offset and fix position are updated. The convergence test is made (Step N). If no convergence is found, return is made to Step G and the iterative loop repeated until convergence is achieved or until 10 iterations have been made. (If convergence is not achieved after 10 iterations, further attempts at solution are abandoned, and the program terminates). If convergence is achieved, subroutine EDIT is called.

EDIT

Subroutine EDIT (Fig. A-22) examines the doppler data and eliminates data points for elevation angles of 7.5° or below until at least four doppler points remain (Step O). Subroutines SOLVE and SLANT are then repeated using the edited doppler data.

TYPE, UCON, and ARCS

Subroutine TYPE (Fig. A-23) is called to write out the results (Step M). The difference in the fix frequency and the estimated frequency is calculated. The maximum pass elevation is calculated and is converted to degrees in subroutine ARCS (Fig. A-24). Fix time is calculated as the time of the first fiducial point plus 4 minutes and is converted to hours and minutes in subroutine UCON (Fig. A-24). The number of iterations and the number of doppler counts used in the solution are listed. The differences in the estimated and fix latitude and longitude are calculated.

ALERT and AVIS*

If the navigator has elected to calculate alerts, subroutine ALERT (Fig. A-25) is used. Subroutine ALERT, which calls subroutine AVIS (Fig. A-25), calculates the times of future satellite passes by computing the elevation angle at future times. A positive elevation angle is construed as an indication that a pass will be underway at that time (Step P).

PROGRAM LISTING

A listing of the program follows.

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*Subroutines ALERT and AVIS are not used with the Fortran program listed on the following pages and cannot be called in this program; they are included for illustration.

```
LEVEL 18 ( SEPT 69 )                        OS/360  FORTRAN H                              DATE  70.196/18.53.44

        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                           SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
                  C------------ - -------------EXEC DEBUG ----------------------------------EXEC
                  C                                                                         EXEC
                  C                                                                         EXEC
  ISN 0002            1 FORMAT (1H ,(3F15.1//))                                             EXEC
                  C                                                                         EXEC
  ISN 0003              DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ                  EXEC
  ISN 0004              DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5       EXEC
  ISN 0005              DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM           EXEC
  ISN 0006              DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                         EXEC
  ISN 0007              DOUBLE PRECISION DOP,REF,DE,DA,DN,ELAT,ELON,GEOM,ETIM,HEAD,RATE     EXEC
  ISN 0008              DOUBLE PRECISION DTA,TP,XNOT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG       EXEC
  ISN 0009              DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5                   EXEC
  ISN 0010              DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN          EXEC
  ISN 0011              DOUBLE PRECISION T,TEMP,A,DUM                                       EXEC
                  C                                                                         EXEC
                  C-DIMENSION                                                               EXEC
  ISN 0012              DIMENSION DOP(8),REF(8),DE(9),DA(9),DN(11),DLAT(9),DLON(9)          EXEC
  ISN 0013              DIMENSION A([illegible],4),DUM(10)                                  EXEC
                  C                                                                         EXEC
                  C-COMMON                                                                  EXEC
  ISN 0014              COMMON TP,XNOT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG                     EXEC
  ISN 0015              COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                         EXEC
  ISN 0016              COMMON REF                                                          EXEC
  ISN 0017              COMMON DE,DA,DN,DTA,ELAT,ELON,GEOM,HEAD,RATE,IDAY,MDAY,ETIM         EXEC
  ISN 0018              COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN                    EXEC
  ISN 0019              COMMON I,J,K,L,M,N,NDOP,ITER                                        EXEC
  ISN 0020              COMMON T,TEMP,A,DUM                                                 EXEC
                  C                                                                         EXEC
  ISN 0021              COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF              EXEC
  ISN 0022              COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO                 EXEC
  ISN 0023              COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND                EXEC
  ISN 0024              COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM                               EXEC
  ISN 0025              COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC             EXEC
                  C                                                                         EXEC
                  C----------------------------CONSTANTS------------------------------------EXEC
                  C---SYSTEM CONSTANTS                                                      EXEC
                  C     TAW=2.D+0                                                           EXEC
                  C     WAVE=7.49481250-1                                                   EXEC
                  C          METERS VACUUM WAVE LENGTH                                      EXEC
                  C     CVCG=1.2D-7                                                         EXEC
                  C          RADIANS CONVERGENCE CRITERIA = .0004 NM                        EXEC
                  C     FFRQ=1.92D+6                                                        EXEC
                  C     KM=9                                                                EXEC
                  C     IM=8                                                                EXEC
                  C     KF=3                                                                EXEC
                  C---EARTH CONSTANTS                                                       EXEC
                  C     OMGE=4.37526951D-3                                                  EXEC
                  C          RAD/MIN EARTHS ROTATION RATE                                   EXEC
                  C     XO =6.378144D+6                                                     EXEC
                  C          METERS SEMI MAJOR AXIS                                         EXEC
                  C     EFLT= 2.9823D+2                                                     EXEC
                  C          FLATTENING COEFFICIENT                                         EXEC
                  C     XOSQ=XO*XO                                                          EXEC
                  C     ONE=1.D+0                                                           EXEC
                  C     ZO=XO*(ONE-ONE/EFLT)                                                EXEC

                                                                                                          PAGE 002

                  C     ZOSQ=ZO*ZO                                                          EXEC
                  C---UNIT CONVERSIONS AND MISCELLANEOUS                                    EXEC
                  C     NULL=0                                                              EXEC
                  C     IONE=1                                                              EXEC
                  C     ITWO=2                                                              EXEC
                  C     IFOR=4                                                              EXEC
                  C                                                                         EXEC
  ISN 0026              REWIND 8                                                            EXEC
  ISN 0027            2 CALL INPUT                                                          EXEC
  ISN 0028              CALL CVTM                                                           EXEC
  ISN 0029              CALL SATC                                                           EXEC
  ISN 0030              CALL SOLVE                                                          EXEC
  ISN 0031              IFIX=ITER                                                           EXEC
  ISN 0032              CALL EDIT                                                           EXEC
  ISN 0033              CALL SOLVE                                                          EXEC
  ISN 0034              ITER=IFIX                                                           EXEC
  ISN 0035              CALL TYPE                                                           EXEC
  ISN 0036              GO TO 2                                                             EXEC
  ISN 0037              END                                                                 EXEC
```

```
                                                       /     MAIN /      SIZE OF PROGRAM 000140 HEXADECIMAL BYTES PAGE 003

   NAME     TAG  TYPE  ADD.       NAME     TAG  TYPE  ADD.       NAME     TAG  TYPE  ADD.       NAME     TAG  TYPE  ADD.
      A      C   R*8    N.R.         E      C   R*8    N.R.         I      C   I*4    N.R.         J      C   I*4    N.R.
      K      C   I*4    N.R.         L      C   I*4    N.R.         M      C   I*4    N.R.         N      C   I*4    N.R.
      T      C   R*8    N.R.        AD      C   R*8    N.R.        CI      C   R*8    N.R.        DA      C   R*8    N.R.
     DE      C   R*8    N.R.        DN      C   R*8    N.R.        IM      C   I*4    N.R.        KF      C   I*4    N.R.
     KM      C   I*4    N.R.        SI      C   R*8    N.R.        IP      C   R*8    N.R.        VN      C   R*8    N.R.
    ATE      C   R*8    N.R.       C2K      C   R*8    N.R.       C2M      C   R*8    N.R.       DOP      C   R*8    N.R.
    DTK      C   R*8    N.R.       DUM      C   R*8    N.R.       D60      C   R*8    N.R.       I15      C   I*4    N.R.
    I30      C   I*4    N.R.       ONE      C   R*8    N.R.       REF      C   R*8    N.R.       RSQ      C   R*8    N.R.
    TAW      C   R*8    N.R.       TEN      C   R*8    N.R.       TM1      C   R*8    N.R.       TM4      C   R*8    N.R.
    TM5      C   R*8    N.R.       TM7      C   R*8    N.R.       TM8      C   R*8    N.R.       TWO      C   R*8    N.R.
   CKRM      C   R*8    N.R.      CNTR      C   R*8    N.R.      COND      C   R*8    N.R.      COME      C   R*8    N.R.
   CVCG      C   R*8    N.R.      CVTM SF  XF   R*4  000000      C480      C   R*8    N.R.      DLAT      C   R*8    N.R.
   DLON      C   R*8    N.R.      DTOM      C   R*8    N.R.      DTRA      C   R*8    N.R.      DUM1      C   R*8    N.R.
   DUM2      C   R*8    N.R.      DUM3      C   R*8    N.R.      DUM4      C   R*8    N.R.      DUM5      C   R*8    N.R.
   EDIT SF  XF   R*4  000000      EFRQ      C   R*8    N.R.      ELAT      C   R*8    N.R.      ELON      C   R*8    N.R.
   FTIM      C   R*8    N.R.      FFRQ      C   R*8    N.R.      FIVE      C   R*8    N.R.      FLAT      C   R*8    N.R.
   FLON      C   R*8    N.R.      FOUR      C   R*8    N.R.      GEOM      C   R*8    N.R.      HEAD      C   R*8    N.R.
   HUND      C   R*8    N.R.      IDAY      C   I*4    N.R.      IFIX SF       I*4  00008C      IFOR      C   I*4    N.R.
   IONE      C   I*4    N.R.      ITER SF   C   I*4  000314      ITWO      C   I*4    N.R.      I365      C   I*4    N.R.
   MDAY      C   I*4    N.R.      NDOP      C   I*4    N.R.      NULL      C   I*4    N.R.      OFST      C   R*8    N.R.
   ONGE      C   R*8    N.R.      RATE      C   R*8    N.R.      REFC      C   R*8    N.R.      SATC SF  XF   R*4  000000
   SELV      C   R*8    N.R.      SMXE      C   R*8    N.R.      SOND      C   R*8    N.R.      SOME      C   R*8    N.R.
   STPS      C   R*8    N.R.      TEMP      C   R*8    N.R.      THRE      C   R*8    N.R.      TOPI      C   R*8    N.R.
   TYPE SF  XF   R*4  000000      WAVE      C   R*8    N.R.      XLNG      C   R*8    N.R.      XNDT      C   R*8    N.R.
   XOSQ      C   R*8    N.R.      ZERO      C   R*8    N.R.      ZOSQ      C   R*8    N.R.      INPUT SF XF   I*4  000000
   SOLVE SF XF   R*4  000000      IBCOM# F XF   R*4  000000

                                 *****  COMMON INFORMATION  *****

   NAME OF COMMON BLOCK  *        *  SIZE OF BLOCK    00030C HEXADECIMAL BYTES

 VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
       TP    R*8     N.R.           XNDT   R*8     N.R.           SOME   R*8     N.R.           SOND   R*8     N.R.
        E    R*8     N.R.             AD   R*8     N.R.           COME   R*8     N.R.           COND   R*8     N.R.
       CI    R*8     N.R.           XLNG   R*8     N.R.           DUM1   R*8     N.R.           DUM2   R*8     N.R.
       SI    R*8     N.R.           OFST   R*8     N.R.           DUM3   R*8     N.R.           DUM4   R*8     N.R.
     DUM5    R*8     N.R.            DOP   R*8     N.R.            REF   R*8     N.R.             DE   R*8     N.R.
       DA    R*8     N.R.             DN   R*8     N.R.            DTK   R*8     N.R.           ELAT   R*8     N.R.
     ELON    R*8     N.R.           GEOM   R*8     N.R.           HEAD   R*8     N.R.           RATE   R*8     N.R.
     IDAY    I*4     N.R.           MDAY   I*4     N.R.           FTIM   R*8     N.R.           DLAT   R*8     N.R.
     DLON    R*8     N.R.           SMXE   R*8     N.R.           SELV   R*8     N.R.           FLAT   R*8     N.R.
     FLON    R*8     N.R.           FFRQ   R*8     N.R.            RSQ   R*8     N.R.             VN   R*8     N.R.
        I    I*4     N.R.              J   I*4     N.R.              K   I*4     N.R.              L   I*4     N.R.
        M    I*4     N.R.              N   I*4     N.R.           NDOP   I*4     N.R.           ITER   I*4   000314
        T    R*8     N.R.           TEMP   R*8     N.R.              A   R*8     N.R.            DUM   R*8     N.R.

   NAME OF COMMON BLOCK  *  COMC*  SIZE OF BLOCK    000126 HEXADECIMAL BYTES

 VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
     NULL    I*4     N.R.           IONE   I*4     N.R.           ITWO   I*4     N.R.           IFOR   I*4     N.R.
      I15    I*4     N.R.            I30   I*4     N.R.           I365   I*4     N.R.             IM   I*4     N.R.
       KM    I*4     N.R.             KF   I*4     N.R.            TAW   R*8     N.R.           WAVE   R*8     N.R.


                                                                                                PAGE 004
     CVCG    R*8     N.R.           EFRQ   R*8     N.R.           ONGE   R*8     N.R.           XOSQ   R*8     N.R.
     ZOSQ    R*8     N.R.           ZERO   R*8     N.R.            ONE   R*8     N.R.            TWO   R*8     N.R.
     THRE    R*8     N.R.           FOUR   R*8     N.R.           FIVE   R*8     N.R.            ATE   R*8     N.R.
      TEN    R*8     N.R.            D60   R*8     N.R.           HUND   R*8     N.R.           C480   R*8     N.R.
     STPS    R*8     N.R.           TOPI   R*8     N.R.           DTRA   R*8     N.R.           DTOM   R*8     N.R.
      TM1    R*8     N.R.            TM4   R*8     N.R.            TM5   R*8     N.R.            TM7   R*8     N.R.
      TM8    R*8     N.R.           CNTR   R*8     N.R.           CKRM   R*8     N.R.            C2K   R*8     N.R.
      C2M    R*8     N.R.           REFC   R*8     N.R.
```

```
   LABEL   ADDR               LABEL   ADDR               LABEL   ADDR               LABEL   ADDR             PAGE 005
       2  0000C8
*OPTIONS IN EFFECT*      NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
*STATISTICS*     SOURCE STATEMENTS =      36 ,PROGRAM SIZE =      320
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                        61K BYTES OF CORE NOT USED
```

```
LEVEL 18 ( SEPT 69 )                    OS/360  FORTRAN H                              DATE  76.196/18.54.03

          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                             SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002               BLOCK DATA                                                    BKDATA
  ISN 0003               DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ            BKDATA
  ISN 0004               DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND C480,STPS BKDATA
  ISN 0005               DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM     BKDATA
  ISN 0006               DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                   BKDATA
                   C                                                                   BKDATA
                   C---COMMON                                                          BKDATA
  ISN 0007               COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF        BKDATA
  ISN 0008               COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO           BKDATA
  ISN 0009               COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND          BKDATA
  ISN 0010               COMMON /COMC/C480,STPS,TOPI,DTRA,DTOM                         BKDATA
  ISN 0011               COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC       BKDATA
                   C                                                                   BKDATA
  ISN 0012               DATA NULL  ,IONE  ,ITWO  ,IFOR  ,I15   ,I30   ,I365           BKDATA
                        1    /    0,     1,     2,     4,    15,    30,     365 /      BKDATA
  ISN 0013               DATA IM  ,KM  ,KF                                             BKDATA
                        1    / 8,   9,   3 /                                           BKDATA
  ISN 0014               DATA TAW    ,WAVE                ,CVCG                        BKDATA
                        1    /  2D0,     7.4948125D-1,    1.2D-7 /                     BKDATA
  ISN 0015               DATA EFRQ        ,OMGE                                        BKDATA
                        1    /     1.92D+6,      4.37526951D-3  /                      BKDATA
  ISN 0016               DATA XOSQ                        ,ZOSQ                        BKDATA
                        1    /     .40680720884736D+14,       .40408363E630950+14  /   BKDATA
  ISN 0017               DATA ZERO     ,ONE     ,TWO     ,THRE     ,FOUR               BKDATA
                        1    /     0D0,     1D0,     2D0,      3D0,      4D0 /         BKDATA
  ISN 0018               DATA FIVE     ,ATE     ,TEN        ,D60                       BKDATA
                        1    /     5D0,     8D0,     1.0D+1,     6.0D+1  /             BKDATA
  ISN 0019               DATA HUND      ,C480        ,STPS                             BKDATA
                        1    /     1D+2,      4.8D+2,      .130530D0   /               BKDATA
  ISN 0020               DATA TOPI                  ,DTRA                              BKDATA
                        1    /     6.2831853072D0,     1.7453292519943D-2     /        BKDATA
  ISN 0021               DATA DTOM           ,TM1      ,TM4       ,TM5                 BKDATA
                        1    /     1.44D+3,     1D-1,     1D-4,      1D-5  /           BKDATA
  ISN 0022               DATA TM7      ,TM8      ,CMTR                                 BKDATA
                        1    /  1D-7,     1D-8,      2.908882080D-4                    BKDATA
  ISN 0023               DATA CKRM                ,C2K       ,C2M                      BKDATA
                        1    /     9.678853GD-7,     2.D+3,     2.D+5  /               BKDATA
  ISN 0024               DATA REFC/.43636300 /                                         BKDATA
                   C--NOTE CONSTANTS                                                   BKDATA
                   C     I15=15                                                        BKDATA
                   C     I30=30                                                        BKDATA
                   C     I365=365                                                      BKDATA
                   C     ZERO=0.D+0                                                    BKDATA
                   C     TWO=2.D+0                                                     BKDATA
                   C     THRE=3.D+0                                                    BKDATA
                   C     FOUR=4.D+0                                                    BKDATA
                   C     FIVE=5.D+0                                                    BKDATA
                   C     TEN=1.D+1                                                     BKDATA
                   C     ATE=8.D+0                                                     BKDATA
                   C     D60=6.D+1                                                     BKDATA
                   C     HUND=1.D+2                                                    BKDATA
                   C     C480=4.6D+2                                                   BKDATA
                   C     STPS=.13053D+0                                                BKDATA


                                                                                                  PAGE 002

                   C                                                                   BKDATA
                   C     TOPI=6.2831853072D+0                                          BKDATA
                   C     DTRA=1.7453292519943D-2                                       BKDATA
                   C     DTOM=1.44D+3                                                  BKDATA
                   C     TM1=1.D-1                                                     BKDATA
                   C     TM4=1.D-4                                                     BKDATA
                   C     TM5=1.D-5                                                     BKDATA
                   C     TM7=1.D-7                                                     BKDATA
                   C     TM8=1.D-8                                                     BKDATA
                   C     CMTR=2.908882080-4                                            BKDATA
                   C          =PI/180*60 MINUTES TO RADIANS                            BKDATA
                   C     CKRM=9.678853GD-7                                             BKDATA
                   C          =2/60*10*3443.934 KNOTS TO RAD/2MIN                      BKDATA
  ISN 0025               END                                                           BKDATA
```

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                                              /     MAIN /     SIZE OF PROGRAM 000008 HEXADECIMAL BYTES PAGE 003

    NAME    TAG  TYPE  ADD.         NAME    TAG  TYPE  ADD.         NAME    TAG  TYPE  ADD.         NAME    TAG  TYPE  ADD.
      IM     C   I*4    N.R.          KF     C   I*4    N.R.          KM     C   I*4    N.R.          ATE     C   R*8    N.R.
     C2K     C   R*8    N.R.         C2M     C   R*8    N.R.         D60     C   R*8    N.R.          I15     C   I*4    N.R.
     I30     C   I*4    N.R.         ONE     C   R*8    N.R.         TAW     C   R*8    N.R.          TEN     C   R*8    N.R.
     TM1     C   R*8    N.R.         TM4     C   R*8    N.R.         TM5     C   R*8    N.R.          TM7     C   R*8    N.R.
     TM8     C   R*8    N.R.         TWO     C   R*8    N.R.        CKRM     C   R*8    N.R.         CMTR     C   R*8    N.R.
    CVCG     C   R*8    N.R.        C480     C   R*8    N.R.        DTOM     C   R*8    N.R.         DTRA     C   R*8    N.R.
    EFRQ     C   R*8    N.R.        FIVE     C   R*8    N.R.        FOUR     C   R*8    N.R.         HUND     C   R*8    N.R.
    IFOR     C   I*4    N.R.        IONE     C   I*4    N.R.        ITWO     C   I*4    N.R.         I365     C   I*4    N.R.
    NULL     C   I*4    N.R.        OMGE     C   R*8    N.R.        REFC     C   R*8    N.R.         S7P5     C   R*8    N.R.
    THRE     C   R*8    N.R.        TOPI     C   R*8    N.R.        WAVE     C   R*8    N.R.         XOSQ     C   R*8    N.R.
    ZERO     C   R*8    N.R.        ZOSQ     C   R*8    N.R.

                                   *****  COMMON INFORMATION  *****

      NAME OF COMMON BLOCK  *  COMC*   SIZE OF BLOCK    000128 HEXADECIMAL BYTES

    VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
         NULL   I*4     N.R.           IONE   I*4     N.R.           ITWO   I*4     N.R.           IFOR   I*4     N.R.
          I15   I*4     N.R.            I30   I*4     N.R.           I365   I*4     N.R.             IM   I*4     N.R.
           KM   I*4     N.R.             KF   I*4     N.R.            TAW   R*8     N.R.           WAVE   R*8     N.R.
         CVCG   R*8     N.R.           EFRQ   R*8     N.R.           OMGE   R*8     N.R.           XOSQ   R*8     N.R.
         ZOSQ   R*8     N.R.           ZERO   R*8     N.R.            ONE   R*8     N.R.            TWO   R*8     N.R.
         THRE   R*8     N.R.           FOUR   R*8     N.R.           FIVE   R*8     N.R.            ATE   R*8     N.R.
          TEN   R*8     N.R.            D60   R*8     N.R.           HUND   R*8     N.R.           C480   R*8     N.R.
         S7P5   R*8     N.R.           TOPI   R*8     N.R.           DTRA   R*8     N.R.           DTOM   R*8     N.R.
          TM1   R*8     N.R.            TM4   R*8     N.R.            TM5   R*8     N.R.            TM7   R*8     N.R.
          TM8   R*8     N.R.           CMTR   R*8     N.R.           CKRM   R*8     N.R.            C2K   R*8     N.R.
          C2M   R*8     N.R.           REFC   R*8     N.R.

*OPTIONS IN EFFECT*      NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*     SOURCE STATEMENTS =       24 ,PROGRAM SIZE =        8

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                       61K BYTES OF CORE NOT USED
```

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LEVEL 18 ( SEPT 69 )                          OS/360  FORTRAN H                                        DATE  70.196/18.53.55

          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=56,SIZE=0000K,
                             SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002              SUBROUTINE INPUT                                                INPUT
                  C                                                                     INPUT
                  C                                                                     INPUT
  ISN 0003              DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ              INPUT
  ISN 0004              DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5   INPUT
  ISN 0005              DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM       INPUT
  ISN 0006              DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                     INPUT
  ISN 0007              DOUBLE PRECISION DOP,REF,DE,DA,DN,ELAT,ELON,GEOH,ETIM,HEAD,RATE INPUT
  ISN 0008              DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AD,COME,COMD,CI,XLMG   INPUT
  ISN 0009              DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5               INPUT
  ISN 0010              DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN      INPUT
  ISN 0011              DOUBLE PRECISION T,TEMP,A                                       INPUT
  ISN 0012              DOUBLE PRECISION DUM9                                           INPUT
                  C                                                                     INPUT
                  C---DIMENSIONS                                                        INPUT
  ISN 0013              DIMENSION DOP(8),REF(8),DE(9),DA(9),DN(11),DLAT(9),DLON(9)      INPUT
  ISN 0014              DIMENSION A(3,4)                                                INPUT
  ISN 0015              DIMENSION DUM9(17)                                              INPUT
                  C                                                                     INPUT
                  C---COMMON                                                            INPUT
  ISN 0016              COMMON TP,XNDT,SOME,SOMD,E,AD,COME,COMD,CI,XLMG                 INPUT
  ISN 0017              COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                     INPUT
  ISN 0018              COMMON REF                                                      INPUT
  ISN 0019              COMMON DE,DA,DN,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,ETIM     INPUT
  ISN 0020              COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN                INPUT
  ISN 0021              COMMON I,J,K,L,M,N,NLOP,ITER                                    INPUT
  ISN 0022              COMMON T,TEMP,A                                                 INPUT
  ISN 0023              COMMON /COMC/NULL,IONE,IMAD,IFOR,I15,I30,I365,IM,KM,KF          INPUT
  ISN 0024              COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO             INPUT
  ISN 0025              COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND            INPUT
  ISN 0026              COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM                           INPUT
  ISN 0027              COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC         INPUT
                  C                                                                     INPUT
                  C                                                                     INPUT
  ISN 0028              EQUIVALENCE (TP,DUM9(1))                                        INPUT
                  C                                                                     INPUT
  ISN 0029           12 FORMAT(A4,2(I3),I4)                                             INPUT
  ISN 0030           11 FORMAT(5A8)                                                     INPUT
  ISN 0031              READ(5,12) ISTA,ISAT,IDAY,ITIM                                  INPUT
  ISN 0032              IF(ISAT) 30,31,31                                               INPUT
  ISN 0033           30 WRITE(8,12) ISTA,ISAT,IDAY,ITIM                                 INPUT
  ISN 0034              REWIND 8                                                        INPUT
  ISN 0035              CALL EXIT                                                       INPUT
  ISN 0036           31 READ(5,11) DUM1,DUM2,DUM3,DUM4,DUM5                             INPUT
  ISN 0037              WRITE(8,12) ISTA,ISAT,IDAY,ITIM                                 INPUT
  ISN 0038              WRITE(8,11) DUM1,DUM2,DUM3,DUM4,DUM5                            INPUT
  ISN 0039              READ(5,10) TP,XNDT,SOME,SOMD,E,AD,COME,COMD                     INPUT
                       1   ,CI,XLMG,DUM1,DUM2,SI,OFST,DUM3,DUM4                         INPUT
                       2        ,DUM5 ,(DE(K),K=1,9),(DA(K),K=1,9),                     INPUT
                       3   (DN(K),K=1,11),DTK,GEOH,ELAT,ELON,                           INPUT
                       4  HEAD,RATE,(DOP(K),K=1,8),(REF(K),K=1,8),                      INPUT
                       5  ETIM                                                          INPUT
  ISN 0040           10 FORMAT (1X,D9.0)                                                INPUT

                                                                                                                PAGE 002

  ISN 0041              DUM1=ELAT*TM4                                                   INPUT
  ISN 0042              I=DUM1/D60                                                      INPUT
  ISN 0043              DUM1=DABS(DUM1-(DBLE(FLOAT(I))*D60))                            INPUT
  ISN 0044              WRITE(8,13) I,DUM1                                              INPUT
  ISN 0045           13 FORMAT(I4,F8.4)                                                 INPUT
  ISN 0046              DUM1=ELON*TM4                                                   INPUT
  ISN 0047              I=DUM1/D60                                                      INPUT
  ISN 0048              DUM1=DABS(DUM1-(DBLE(FLOAT(I))*D60))                            INPUT
  ISN 0049              WRITE(8,13) I,DUM1                                              INPUT
  ISN 0050              WRITE(8,14) GEOH                                                INPUT
  ISN 0051           14 FORMAT(F9.0)                                                    INPUT
  ISN 0052          114 FORMAT(F10.0,F5.0,F5.0,F3.0,F9.0,F6.0)                          INPUT
  ISN 0053           15 FORMAT(F10.0,F5.0,F5.0,F3.0)                                    INPUT
  ISN 0054           16 FORMAT(F10.0,F3.0)                                              INPUT
  ISN 0055           17 FORMAT(F3.0)                                                    INPUT
  ISN 0056          222 FORMAT(F10.0,F9.0,F6.0)                                         INPUT
  ISN 0057              DO 26 K=1,12                                                    INPUT
  ISN 0058              IF(K-1) 21,21,18                                                INPUT
  ISN 0059           18 IF(K-8) 22,22,19                                                INPUT
  ISN 0060           19 IF(K-10) 23,23,20                                               INPUT
  ISN 0061           20 IF(K-11) 24,24,25                                               INPUT
  ISN 0062           21 WRITE(8,222) DUM9(K),DOP(K),REF(K)                              INPUT
  ISN 0063              GO TO 26                                                        INPUT
  ISN 0064           22 I=K-1                                                           INPUT
  ISN 0065              WRITE(8,114) DUM9(K),DE(I),DA(I),DN(I),DOP(K),REF(K)            INPUT
  ISN 0066              GO TO 26                                                        INPUT
  ISN 0067           23 I=K-1                                                           INPUT
  ISN 0068              WRITE(8,15) DUM9(K),DE(I),DA(I),DN(I)                           INPUT
  ISN 0069              GO TO 26                                                        INPUT
  ISN 0070           24 I=K-1                                                           INPUT
  ISN 0071              WRITE(8,16) SI,DN(I)                                            INPUT
  ISN 0072              GO TO 26                                                        INPUT
  ISN 0073           25 I=K-1                                                           INPUT
  ISN 0074              WRITE(8,17) DN(I)                                               INPUT
  ISN 0075           26 CONTINUE                                                        INPUT
  ISN 0076              I=HEAD/D60                                                      INPUT
  ISN 0077              WRITE(8,27) I,RATE                                              INPUT
  ISN 0078           27 FORMAT(I4,F5.1)                                                 INPUT
  ISN 0079              RETURN                                                          INPUT
  ISN 0080              END                                                             INPUT
```

```
                                       /    INPUT / .   SIZE OF PROGRAM 000738 HEXADECIMAL BYTES PAGE 003

NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.        NAME    TAG   TYPE  ADD.
   A        C  R*6    N.R.          E S     C  R*8  000020          I SFA  C  I*4  0002F8            J       C  I*4    N.R.
```

```
    K SF    C  I*4   000300          L        C  I*4     N.R.          M        C  I*4     N.R.          N        C  I*4     N.R.
    T       C  R*8     N.R.          AO S     C  R*8   000028          CI S     C  R*8   000040          DA SF    C  R*8   000150
   DE SF    C  R*8   000108          DN SF    C  R*8   000198          IM       C  I*4     N.R.          KF       C  I*4     N.R.
   KM       C  I*4     N.R.          SI SF    C  R*8   000060          TP S    CE  R*8   000000          VN       C  R*8     N.R.
  ATE       C  R*8     N.R.          C2K      C  R*8     N.R.          C2M      C  R*8     N.R.          DOP SF   C  R*8   000088
  DTK S     C  R*8   0001F0          D60  FA  C  R*8   0000A0          I15      C  I*4     N.R.          I30      C  I*4     N.R.
  ONE       C  R*8     N.R.          REF SF   C  R*8   0000C8          KSQ      C  R*8     N.R.          TAW      C  R*8     N.R.
  TEN       C  R*8     N.R.          TM1      C  R*8     N.R.          TM4  F   C  R*8   0000E0          TM5      C  R*8     N.R.
  TM7       C  R*8     N.R.          TM8      C  R*8     N.R.          TWO      C  R*8     N.R.          CKRM     C  R*8     N.R.
 CMTR       C  R*8     N.R.          COMD S   C  R*8   000038          CONE S   C  R*8   000030          CVCG     C  R*8     N.R.
 C480       C  R*8     N.R.          DLAT     C  R*8     N.R.          DLON     C  R*8     N.R.          DTOM     C  R*8     N.R.
 DTRA       C  R*8     N.R.          DUM1 SFA C  R*8   000050          DUM2 SF  C  R*8   000058          DUM3 SF  C  R*8   000070
 DUM4 SF    C  R*8   000078          DUM5 SF  C  R*8   000080          DUM9  F CE  R*8   000000          EFRQ     C  R*8     N.R.
 ELAT SF    C  R*8   0001F8          ELON SF  C  R*8   000200          ETIM S   C  R*8   000228          EXIT SF XF  R*4  [illegible]
 FFRQ       C  R*8     N.R.          FIVE     C  R*8     N.R.          FLAT     C  R*8     N.R.          FLON     C  R*8     N.R.
 FOUR       C  R*8     N.R.          GEOH SF  C  R*8   000208          HEAD SF  C  R*8   000210          HUND     C  R*8     N.R.
 IDAY SF    C  I*4   000220          IFOR     C  I*4     N.R.          IONE     C  I*4     N.R.          ISAT SF     I*4  [illegible]
 ISTA SF       I*4   000110          ITER     C  I*4     N.R.          ITIM SF     I*4   000114          ITWO     C  I*4     N.R.
 I365       C  I*4     N.R.          MDAY     C  I*4     N.R.          NDOP     C  I*4     N.R.          NULL     C  I*4     N.R.
 OFST S     C  R*8   000068          OMGE     C  R*8     N.R.          RATE SF  C  R*8   000218          REFC     C  R*8     N.R.
 SELV       C  R*8     N.R.          SMXE     C  R*8     N.R.          SUMD S   C  R*8   000018          [illegible] S C R*8 [illegible]
 STP5       C  R*8     N.R.          TEMP     C  R*8     N.R.          THRE     C  R*8     N.R.          TOPI     C  R*8     N.R.
 WAVE       C  R*8     N.R.          XLMG S   C  R*8   000048          XNDT S   C  R*8   000008          XOSQ     C  R*8     N.R.
 ZERO       C  R*8     N.R.          ZOSQ     C  R*8     N.R.          INPUT       I*4   000118          [illegible]  F XF  I*4  [illegible]

                                         *****  COMMON INFORMATION  *****

   NAME OF COMMON BLOCK  *        *   SIZE OF BLOCK    000388 HEXADECIMAL BYTES

 VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
        P    R*8   000000            XNDT   R*8   000008            SOME   R*8   000010            SUMD   R*8   000018
        E    R*8   000020              AO   R*8   000028            CONE   R*8   000030            COMD   R*8   000038
       CI    R*8   000040            XLMG   R*8   000048            DUM1   R*8   000050            DUM2   R*8   000058
       SI    R*8   000060            OFST   R*8   000068            DUM3   R*8   000070            DUM4   R*8   000078
     DUM5    R*8   000080             DOP   R*8   000088             REF   R*8   0000C8              DE   R*8   000108
       DA    R*8   000150              DN   R*8   000198             DTK   R*8   0001F0            ELAT   R*8   0001F8
     ELON    R*8   000200            GEOH   R*8   000208            HEAD   R*8   000210            RATE   R*8   000218
     IDAY    I*4   000220            MDAY   I*4     N.R.            ETIM   R*8   000228            DLAT   R*8     N.R.
     DLON    R*8     N.R.            SMXE   R*8     N.R.            SELV   R*8     N.R.            FLAT   R*8     N.R.
     FLON    R*8     N.R.            FFRQ   R*8     N.R.             RSQ   R*8     N.R.              VN   R*8     N.R.
        I    I*4   0002F8               J   I*4     N.R.               K   I*4   000300               L   I*4     N.R.
        M    I*4     N.R.               N   I*4     N.R.            NDOP   I*4     N.R.            ITER   I*4     N.R.
        T    R*8     N.R.            TEMP   R*8     N.R.               A   R*8     N.R.

 EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK
   VARIABLE  OFFSET                VARIABLE  OFFSET                VARIABLE  OFFSET                VARIABLE  OFFSET
     DUM9    000000

   NAME OF COMMON BLOCK  *  COMC*   SIZE OF BLOCK    000128 HEXADECIMAL BYTES
```

```
 VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
     NULL    I*4     N.R.            IONE   I*4     N.R.            ITWO   I*4     N.R.            IFOR   I*4     N.R.
      I15    I*4     N.R.             I30   I*4     N.R.            I365   I*4     N.R.              IM   I*4     N.R.
       KM    I*4     N.R.              KF   I*4     N.R.             TAW   R*8     N.R.            WAVE   R*8     N.R.
     CVCG    R*8     N.R.            EFRQ   R*8     N.R.            OMGE   R*8     N.R.            XOSQ   R*8     N.R.
     ZOSQ    R*8     N.R.            ZERO   R*8     N.R.             ONE   R*8     N.R.             TWO   R*8     N.R.
     THRE    R*8     N.R.            FOUR   R*8     N.R.            FIVE   R*8     N.R.             ATE   R*8     N.R.
      TEN    R*8     N.R.             D60   R*8   0000A0            HUND   R*8     N.R.            C480   R*8     N.R.
     STP5    R*8     N.R.            TOPI   R*8     N.R.            DTRA   R*8     N.R.            DTOM   R*8     N.R.
      TM1    R*8     N.R.             TM4   R*8   0000E0             TM5   R*8     N.R.             TM7   R*8     N.R.
      TM9    R*8     N.R.            CMTR   R*8     N.R.            CKRM   R*8     N.R.             C2K   R*8     N.R.
      C2M    R*8     N.R.            REFC   R*8     N.R.
```

```
    LABEL   ADDR              LABEL   ADDR              LABEL   ADDR              LABEL   ADDR            PAGE 005

       10  00019E                11  0001EA                16  00055A                19  000562
       20  00056A                21  000578                22  000548                23  000606
       24  00064A                25  00067A                26  00069E

*OPTIONS IN EFFECT*      NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*     SOURCE STATEMENTS =      79 ,PROGRAM SIZE =     1846

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                           49K BYTES OF CORE NOT USED
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LEVEL 19 ( SEPT 69 )                    OS/360  FORTRAN H                                  DATE  76.106/18.54.04

        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                          SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002             SUBROUTINE CVTM                                            CVTM
                 C                                                                CVTM
                 C                                                                CVTM
                 C CONVERT ORBIT PARAMETERS TO COMPUTATIONAL UNITS                CVTM
                 C COMPUTE INCREMENTAL LAT AND LON GIVEN HEADING AND SPEED        CVTM
                 C CONVERT CROSS PLANE AND INTERPOLATE                            CVTM
                 C RESOLVE TRUE LOCK TIME                                         CVTM
                 C CONVERT INITIAL ESTIMATES AND SET INTO COMPUTATION             CVTM
                 C                                                                CVTM
  ISN 0003             DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ         CVTM
  ISN 0004             DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5 CVTM
  ISN 0005             DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM  CVTM
  ISN 0006             DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                CVTM
  ISN 0007             DOUBLE PRECISION DOP,REF,DE,DA,DN,ELAT,ELON,GECH,STIM,HEAD,RATE CVTM
  ISN 0008             DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG CVTM
  ISN 0009             DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5          CVTM
  ISN 0010             DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN CVTM
  ISN 0011             DOUBLE PRECISION CMSD,CLSD,CPT,TI,P,CP,TEMP,TEMA           CVTM
                 C                                                                CVTM
                 C---DIMENSIONS                                                   CVTM
  ISN 0012             DIMENSION CPT(5),CP(5)                                     CVTM
  ISN 0013             DIMENSION DOP(8),REF(8),DE(9),DA(9),DN(11),DLAT(9),DLON(9) CVTM
  ISN 0014             DIMENSION TEMA(20)                                         CVTM
                 C                                                                CVTM
                 C---COMMON                                                       CVTM
  ISN 0015             COMMON TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG            CVTM
  ISN 0016             COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                CVTM
  ISN 0017             COMMON REF                                                 CVTM
  ISN 0018             COMMON DE,DA,DN,DTK,ELAT,ELON,GECH,HEAD,RATE,ICAL,MDAY,STIM CVTM
  ISN 0019             COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN           CVTM
  ISN 0020             COMMON I,J,K,L,M,N,NDOP,IP                                 CVTM
  ISN 0021             COMMON TI,P,CP,CPT,CMSD,CLSD,TEMP,TEMA                     CVTM
                 C                                                                CVTM
  ISN 0022             COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF     CVTM
  ISN 0023             COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO        CVTM
  ISN 0024             COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND       CVTM
  ISN 0025             COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM                      CVTM
  ISN 0026             COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTK,CKRM,C2K,C2M,REFC    CVTM
                 C                                                                CVTM
                 C CONVERT CONSTANT ORBIT PARAMET.                                CVTM
                 C                                                                CVTM
  ISN 0027             TP=TP*TM5                                                  CVTM
  ISN 0028             XNDT=(XNDT+.3D+9)*DTRA*TM8                                 CVTM
  ISN 0029             SOME=SOME*DTRA*TM5                                         CVTM
  ISN 0030             SOMD=SOMD*DTRA*TM8                                         CVTM
  ISN 0031             E=E*TM7                                                    CVTM
                 C     AO IS IN METERS                                            CVTM
  ISN 0032             COME=COME*DTRA*TM5                                         CVTM
  ISN 0033             COMD=COMD*DTRA*TM8                                         CVTM
  ISN 0034             CI=CI*TM7                                                  CVTM
  ISN 0035             XLMG=XLMG*DTRA*TM5                                         CVTM
  ISN 0036             SI=SI*TM7                                                  CVTM
                 C                                                                CVTM
```

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              C---CHECK AND REFRACTION CORRECT THE DOPPLERS                              CVTM
              C----- 0 DOPPLERS NOT USED IN SOLUTION                                     CVTM
              C                                                                          CVTM
ISN 0037            NDOP=NULL                                                            CVTM
ISN 0038            DO 30 I=1,IM                                                         CVTM
ISN 0039            IF (DOP(I)-C2M) 29,29,21                                             CVTM
ISN 0040         21 IF (REF(I)-C2K) 22,29,22                                             CVTM
ISN 0041         22 DOP(I)=DOP(I)+(C2K-REF(I))*REFC                                      CVTM
ISN 0042            NDOP=NDOP+IONE                                                       CVTM
ISN 0043            GO TO 30                                                             CVTM
ISN 0044         29 DOP(I)=ZERO                                                          CVTM
ISN 0045         30 CONTINUE                                                             CVTM
              C                                                                          CVTM
              C---CONVERT HEADING AND SPEED                                              CVTM
              C                                                                          CVTM
ISN 0046            HEAD=HEAD*CMTR                                                       CVTM
ISN 0047            RATE=RATE*CKRM                                                       CVTM
              C                                                                          CVTM
              C CONVERT DE(K),DA(K) AND COMPUTE INCREMENTAL LAT AND LON                  CVTM
              C                                                                          CVTM
ISN 0048            DO 1 K=1,KM                                                          CVTM
ISN 0049            DE(K)=DE(K)*DTRA*TM4                                                 CVTM
ISN 0050            DA(K)=DA(K)*TEN                                                      CVTM
ISN 0051            TEMP=K-KF                                                            CVTM
ISN 0052            TEMP=TEMP*RATE                                                       CVTM
ISN 0053            DLON(K)=TEMP*DSIN(HEAD)                                              CVTM
ISN 0054          1 DLAT(K)=TEMP*DCOS(HEAD)                                              CVTM
              C---CONVERT AND SET INITIAL ESTIMATES                                      CVTM
ISN 0055            EFRQ=(OFST* 97)*2.4D+4                                               CVTM
ISN 0056            FFRQ=EFRQ                                                            CVTM
ISN 0057            ELAT=ELAT*CMTR*TM4                                                   CVTM
ISN 0058            FLAT=ELAT                                                            CVTM
ISN 0059            ELON=ELON*CMTR*TM4                                                   CVTM
ISN 0060            FLON=ELON                                                            CVTM
              C---RESOLVE TRUE LOCK TIME                                                 CVTM
ISN 0061            IP=STIM/TWO                                                          CVTM
ISN 0062            IP=ITWO*IP                                                           CVTM
ISN 0063            I=IP/I30                                                             CVTM
ISN 0064            I=IP-I30*I                                                           CVTM
ISN 0065            K=TWO*DTK                                                            CVTM
ISN 0066            K=K-I                                                                CVTM
ISN 0067            I=K/I15                                                              CVTM
ISN 0068            K=IP+K-I30*I                                                         CVTM
ISN 0069            STIM=K                                                               CVTM
              C---CONVERT CROSS PLANE ELEMENTS                                           CVTM
ISN 0070            I=K/IFOR                                                             CVTM
ISN 0071            K=K-IFOR*I                                                           CVTM
ISN 0072            IP=NULL                                                              CVTM
ISN 0073            L=ITWO                                                               CVTM
ISN 0074            IF (K) 2,3,2                                                         CVTM
ISN 0075          2 L=IONE                                                               CVTM
ISN 0076          3 DO 10 I=1,5                                                          CVTM
ISN 0077            CP(I)=ZERO                                                           CVTM
ISN 0078            CLSD=DN(IONE+L)                                                      CVTM
ISN 0079            CMSD=DN(L)                                                           CVTM
ISN 0080            IF (CMSD) 9,11,11                                                    CVTM
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ISN 0081         11 IF (CLSD) 9,4,4                                                      CVTM
ISN 0082          4 CMSD=CMSD-FIVE                                                       CVTM
ISN 0083            IF (CMSD) 5,8,8                                                      CVTM
ISN 0084          5 CLSD=-CLSD                                                           CVTM
ISN 0085            IF (CMSD+FIVE) 8,6,8                                                 CVTM
ISN 0086          6 CMSD=ZERO                                                            CVTM
ISN 0087          8 IP=IP+IONE                                                           CVTM
ISN 0088            CP(IP)=HUND*CMSD+TEN*CLSD                                            CVTM
ISN 0089            CPT(IP)=L                                                            CVTM
ISN 0090          9 L=L+ITWO                                                             CVTM
ISN 0091         10 CONTINUE                                                             CVTM
              C---INTERPOLATE FOR MISSING CROSS PLANE ELEMENTS                           CVTM
ISN 0092            TI=TWO                                                               CVTM
ISN 0093            DO 20 K=1,KM                                                         CVTM
ISN 0094            DN(K)=ZERO                                                           CVTM
ISN 0095            IF (IP-ITWO) 20,20,31                                                CVTM
ISN 0096         31 ITA=IONE                                                             CVTM
ISN 0097            I=CPT(1)                                                             CVTM
ISN 0098            J=CPT(IP)                                                            CVTM
ISN 0099            J=J-IFOR                                                             CVTM
ISN 0100            IF (K-I) 16,16,12                                                    CVTM
ISN 0101         12 ITA=IP-ITWO                                                          CVTM
ISN 0102            IF (K-J) 13,16,16                                                    CVTM
ISN 0103         13 ITA=K/ITWO                                                           CVTM
ISN 0104         16 DO 19 L=1,3                                                          CVTM
ISN 0105            J=L+ITA-IONE                                                         CVTM
ISN 0106            P=ONE                                                                CVTM
ISN 0107            DO 18 M=1,3                                                          CVTM
ISN 0108            I=M+ITA-IONE                                                         CVTM
ISN 0109            IF (I-J) 17,18,17                                                    CVTM
ISN 0110         17 P=P*(TI-CPT(I))/(CPT(J)-CPT(I))                                      CVTM
ISN 0111         18 CONTINUE                                                             CVTM
ISN 0112         19 DN(K)=DN(K)+P*CP(J)                                                  CVTM
ISN 0113         20 TI=TI+ONE                                                            CVTM
ISN 0114            RETURN                                                               CVTM
ISN 0115            END                                                                  CVTM
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                                   /     CVTM /     SIZE OF PROGRAM 0006F2 HEXADECIMAL BYTES PAGE 004

NAME     TAG   TYPE  ADD.       NAME     TAG   TYPE  ADD.       NAME     TAG   TYPE  ADD.       NAME     TAG   TYPE  ADD.
   E SF    C   R*8   000020        I SF    C   I*4   0002F8        J SF    C   I*4   0002FC        K SF    C   I*4   000300
   L SF    C   I*4   000304        M SF    C   I*4   000308        N       C   I*4     N.R.        P SF    C   R*8   000320
  AO       C   R*8     N.R.       CI SF    C   R*8   000040       CP SF    C   R*8   000328       DA SF    C   R*8   000150
  DE SF    C   R*8   000108       DN SF    C   R*8   000198       IM  F    C   I*4   00001C       IP SF    C   I*4   000314
  KF  F    C   I*4   000024       KM  F    C   I*4   000020       SI SF    C   R*8   000060       TI SF    C   R*8   000318
  TP SF    C   R*8   000000       VN       C   R*8     N.R.      ATE       C   R*8     N.R.      CPT SF    C   R*8   000350
 C2K  F    C   R*8   000110      C2M       C   R*8   000118      DOP SF    C   R*8   000088      DTK  F    C   R*8   0001F0
 D60       C   R*8     N.R.      ITA SF        I*4   0000AC      I15  F    C   I*4   000010      I30  F    C   I*4   000014
 ONE  F    C   R*8   000068      REF  F    C   R*8   0000C8      RSQ       C   R*8     N.R.      TAW       C   R*8     N.R.
 TEN  F    C   R*8   000098      TM1       C   R*8     N.R.      TM4  F    C   R*8   0000E0      TM5  F    C   R*8   0000E8
 TM7  F    C   R*8   0000F0      TM8  F    C   R*8   0000F8      TWO  F    C   R*8   000070     CKRM  F    C   R*8   000108
CLSD SF    C   R*8   000380     CMSD SF    C   R*8   000378     CMTR  F    C   R*8   000100     COMD SF    C   R*8   000038
CONE SF    C   R*8   000030     CVCG       C   R*8     N.R.     CVTM           R*4   000080     C480       C   R*8     N.R.
DLAT S     C   R*8   000230     DLON S     C   R*8   000278     DTUM       C   R*8     N.R.     DTRA  F    C   R*8   0000C8
DUM1       C   R*8     N.R.     DUM2       C   R*8     N.R.     DUM3       C   R*8     N.R.     DUM4       C   R*8     N.R.
DUM5       C   R*8     N.R.     EFRQ SF    C   R*8   000040     ELAT SF    C   R*8   0001F8     ELON SF    C   R*8   000200
FFRQ S     C   R*8   0002E0     FIVE  F    C   R*8   000088     FLAT S     C   R*8   000200     FLON S     C   R*8   000208
FOUR       C   R*8     N.R.     GEOH       C   R*8     N.R.     HEAD SFA   C   R*8   000210     HUND  F    C   R*8   0000A8
IDAY       C   I*4     N.R.     IFOR  F    C   I*4   00000C     IONE  F    C   I*4   000004     ITWO  F    C   I*4   000008
I365       C   I*4     N.R.     MDAY       C   I*4     N.R.     NOOP SF    C   I*4   000310     NULL  F    C   I*4   000000
OFST  F    C   R*8   000068     ONGE       C   R*8     N.R.     RATE SF    C   R*8   000218     REFC  F    C   R*8   000120
SELV       C   R*8     N.R.     SMXE       C   R*8     N.R.     SOMD SF    C   R*8   000018     SOME SF    C   R*8   000010
STIM SF    C   R*8   000228     STPS       C   R*8     N.R.     TEMA       C   R*8     N.R.     TEMP SF    C   R*8   000388
THRE       C   R*8     N.R.     TOPI       C   R*8     N.R.     WAVE       C   R*8     N.R.     XLMG SF    C   R*8   000048
XNDT SF    C   R*8   000008     XOSG       C   R*8     N.R.     ZERO  F    C   R*8   000060     ZOSG       C   R*8     N.R.
DCOS      XF   R*8   000000     DSIN      XF   R*8   000000

                                ***** COMMON INFORMATION  *****

 NAME OF COMMON BLOCK *       *   SIZE OF BLOCK   000430 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
      TP   R*8   000000           XNDT   R*8   000008           SOME   R*8   000010           SOMD   R*8   000018
       E   R*8   000020             AO   R*8     N.R.           COME   R*8   000030           COMD   R*8   000038
      CI   R*8   000040           XLMG   R*8   000048           DUM1   R*8     N.R.           DUM2   R*8     N.R.
      SI   R*8   000060           OFST   R*8   000068           DUM3   R*8     N.R.           DUM4   R*8     N.R.
    DUM5   R*8     N.R.            DOP   R*8   000088            REF   R*8   0000C8             DE   R*8   000108
      DA   R*8   000150             DN   R*8   000198            DTK   R*8   0001F0           ELAT   R*8   0001F8
    ELON   R*8   000200           GEOH   R*8     N.R.           HEAD   R*8   000210           RATE   R*8   000218
    IDAY   I*4     N.R.           MDAY   I*4     N.R.           STIM   R*8   000228           DLAT   R*8   000230
    DLON   R*8   000278           SMXE   R*8     N.R.           SELV   R*8     N.R.           FLAT   R*8   000200
    FLON   R*8   000208           FFRQ   R*8   0002E0            RSQ   R*8     N.R.             VN   R*8     N.R.
       I   I*4   0002F8              J   I*4   0002FC              K   I*4   000300              L   I*4   000304
       M   I*4   000308              N   I*4     N.R.           NOOP   I*4   000310             IP   I*4   000314
      TI   R*8   000318              P   R*8   000320             CP   R*8   000328            CPT   R*8   000350
    CMSD   R*8   000378           CLSD   R*8   000380           TEMP   R*8   000388           TEMA   R*8     N.R.

 NAME OF COMMON BLOCK *  COMC*   SIZE OF BLOCK   000128 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
    NULL   I*4   000000           IONE   I*4   000004           ITWO   I*4   000008           IFOR   I*4   00000C
     I15   I*4   000010            I30   I*4   000014           I365   I*4     N.R.             IM   I*4   00001C

                                                                                                   PAGE 005

      KM   I*4   000020             KF   I*4   000024            TAW   R*8     N.R.           WAVE   R*8     N.R.
    CVCG   R*8     N.R.           EFRQ   R*8   000040           ONGE   R*8     N.R.           XOSG   R*8     N.R.
    ZOSG   R*8     N.R.           ZERO   R*8   000060            ONE   R*8   000068            TWO   R*8   000070
    THRE   R*8     N.R.           FOUR   R*8     N.R.           FIVE   R*8   000088            ATE   R*8     N.R.
     TEN   R*8   000098            D60   R*8     N.R.           HUND   R*8   0000A8           C480   R*8     N.R.
    STPS   R*8     N.R.           TOPI   R*8     N.R.           DTRA   R*8   0000C8           DTCM   R*8     N.R.
     TM1   R*8     N.R.            TM4   R*8   0000E0            TM5   R*8   0000E8            TM7   R*8   0000F0
     TM8   R*8   0000F8           CMTR   R*8   000100           CKRM   R*8   000108            C2K   R*8   000110
     C2M   R*8   000118           REFC   R*8   000120
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 LABEL   ADDR              LABEL   ADDR              LABEL   ADDR              LABEL   ADDR           PAGE 007

    21  0001EC                22  0001FE                29  000214                30  00021C
     1  00020E                 2  00040E                 3  000412                11  000486
     4  000490                 5  000498                 6  0004AC                 8  0004B0
     9  0004F2                10  0004FA                31  0005A6                12  00055F
    13  000502                16  0005F2                17  00063E                18  00065A
    19  00066A                20  000696

*OPTIONS IN EFFECT*      NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*     SOURCE STATEMENTS =     114 ,PROGRAM SIZE =     1778

*STATISTICS*  0   DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                   496 BYTES OF CORE NOT USED
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LEVEL 18 ( SEPT 69 )                    OS/360  FORTRAN H                                   DATE  70.196/18.53.47

         COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                            SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002            SUBROUTINE SATC                                                    SATC
                C                                                                        SATC
                C-USES SXYZ TO COMPUTE SATELLITE COORDINATES                             SATC
                C DRIVER TO SET TIME AND VARIABLE PARAMETERS AND STORING PARAMETER K     SATC
                C                                                                        SATC
  ISN 0003            DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ                 SATC
  ISN 0004            DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5      SATC
  ISN 0005            DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM          SATC
  ISN 0006            DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                        SATC
  ISN 0007            DOUBLE PRECISION DOP,DJM,DE,DA,DN,ELAT,ELON,GEOH,STIM,HEAD,RATE    SATC
  ISN 0008            DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLNG      SATC
  ISN 0009            DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5                  SATC
  ISN 0010            DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN         SATC
  ISN 0011            DOUBLE PRECISION DEK,DAK,DNK                                       SATC
  ISN 0012            DOUBLE PRECISION T,TEMP                                            SATC
                C                                                                        SATC
                C---DIMENSION                                                            SATC
  ISN 0013            DIMENSION DOP(8),DJM(5),DE(9),DA(9),DN(11),DLAT(9),DLON(9.         SATC
                C                                                                        SATC
                C---COMMON                                                               SATC
  ISN 0014            COMMON TP,XNDT,SOMS,SOMD,E,AO,COME,CUMD,CI,XLNG                    SATC
  ISN 0015            COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                        SATC
  ISN 0016            COMMON DEK,DAK,DNK                                                 SATC
  ISN 0017            COMMON DUM                                                         SATC
  ISN 0018            COMMON DE,DA,DN,DTK,FLAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM        SATC
  ISN 0019            COMMON DLAT DLON,SMXE,SEL ,FLAT,FLON,FFRQ,RSQ,VN                   SATC
  ISN 0020            COMMON I,J,K,L,M,N,MDOP,ITEP                                       SATC
  ISN 0021            COMMON T,TEMP                                                      SATC
                C                                                                        SATC
  ISN 0022            COMMON /COMC/NULL,ICNE,ITWO,IFOR,I15,I30,I365,IM,KM,KF             SATC
  ISN 0023            COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO                SATC
  ISN 0024            COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND               SATC
  ISN 0025            COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM                              SATC
  ISN 0026            COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2K,REFC            SATC
                C                                                                        SATC
                C---COMPUTE TIME SINCE PERIGEE                                           SATC
  ISN 0027            T=STIM-TP                                                          SATC
  ISN 0028            IF (T+C480) 1,1,2                                                  SATC
  ISN 0029          1 T=T+DTOM                                                           SATC
  ISN 0030            GO TO 4                                                            SATC
  ISN 0031          2 IF (T-DTOM+TOPI/XNDT) 4,3,3                                        SATC
  ISN 0032          3 T=T-DTOM                                                           SATC
  ISN 0033          4 DO 5 K=1,KM                                                        SATC
  ISN 0034            DEK=DE(K)                                                          SATC
  ISN 0035            DAK=DA(K)                                                          SATC
  ISN 0036            DNK=DN(K)                                                          SATC
  ISN 0037            CALL SXYZ                                                          SATC
  ISN 0038          5 T=T+TWO                                                            SATC
  ISN 0039            RETURN                                                             SATC
  ISN 0040            END                                                                SATC


                                                   /    SATC /     SIZE OF PROGRAM 000164 HEXADECIMAL BYTES PAGE 002

  NAME   TAG   TYPE  ADD.      NAME   TAG   TYPE  ADD.      NAME   TAG   TYPE  ADD.      NAME   TAG   TYPE  ADD.
     E      C  R*8    N.R.        I      C  I*4    N.R.        J      C  I*4    N.R.        K SF   C  I*4  [illegible]
     L      C  I*4    N.R.        M      C  I*4    N.R.        K      C  I*4    N.R.        T SF   C  R*8  000310
    AO      C  R*8    N.R.       CI      C  R*8    N.R.       DA  F   C  R*8  000150       DE  F   C  R*8  000108
    DN  F   C  R*8  000198       IM      C  I*4    N.R.       KF      C  I*4    N.R.       KM  F   C  I*4  000020
    SI      C  R*8    N.R.       TP  F   C  R*8  000100       VN      C  R*8    N.R.      ATE      C  R*8    N.R.
   C2K      C  R*8    N.R.      C2M      C  R*8    N.R.      DAK S    C  R*8  000000      DEK S    C  R*8  [illegible]
   DNK S    C  R*8  0000C6      DOP      C  R*8    N.R.      DTK      C  R*8    N.R.      DUM      C  R*8    N.R.
   D60      C  R*8    N.R.      I15      C  I*4    N.R.      I30      C  I*4    N.R.      ONE      C  R*8    N.R.
   RSQ      C  R*8    N.R.      TAW      C  R*8    N.R.      TEN      C  R*8    N.R.      TM1      C  R*8    N.R.
   TM4      C  R*8    N.R.      TM5      C  R*8    N.R.      TM7      C  R*8    N.R.      TM8      C  R*8    N.R.
   TWO  F   C  R*8  000070     CKRM      C  R*8    N.R.     CMTR      C  R*8    N.R.     [illegible]  C  R*8  N.R.
  COME      C  R*8    N.R.     CVCG      C  R*8    N.R.     C480      C  R*8  [illegible]  ELAT    C  R*8    N.R.
  DLON      C  R*8    N.R.     DTOM  F   C  R*8  000000     DTRA      C  R*8    N.R.     DUM1      C  R*8    N.R.
  DUM2      C  R*8    N.R.     DUM3      C  R*8    N.R.     DUM4      C  R*8    N.R.     DUM5      C  R*8    N.R.
  EFRQ      C  R*8    N.R.     ELAT      C  R*8    N.R.     ELON      C  R*8    N.R.     FFRQ      C  R*8    N.R.
  FIVE      C  R*8    N.R.     FLAT      C  R*8    N.R.     FLON      C  R*8    N.R.     FOUR      C  R*8    N.R.
  GEOH      C  R*8    N.R.     HEAD      C  R*8    N.R.     HUND      C  R*8    N.R.     IDAY      C  I*4    N.R.
  IFOR      C  I*4    N.R.     ICNE      C  I*4    N.R.     ITEP      C  I*4    N.R.     ITWO      C  I*4    N.R.
  I365      C  I*4    N.R.     MDAY      C  I*4    N.R.     MDOP      C  I*4    N.R.     NULL      C  I*4    N.R.
  OFST      C  R*8    N.R.     OMGE      C  R*8    N.R.     RATE      C  R*8    N.R.     REFC      C  R*8    N.R.
  SATC         R*4  00007C     SELV      C  R*8    N.R.     SMXE      C  R*8    N.R.     SOMD      C  R*8    N.R.
  SOME      C  R*8    N.R.     STIM  F   C  R*8  000228     SXYZ SF  XF  R*4  [illegible]  S7P5    C  R*8    N.R.
  TEMP      C  R*8    N.R.     THRE      C  R*8    N.R.     TOPI      C  R*8  [illegible]  WAVE     C  R*8    N.R.
  XLNG      C  R*8    N.R.     XNDT      C  R*8  000030     XOSQ      C  R*8    N.R.     ZERO      C  R*8    N.R.
  ZOSQ      C  R*8    N.R.

                                       *****  COMMON INFORMATION  *****

     NAME OF COMMON BLOCK  *        *  SIZE OF BLOCK    00032A HEXADECIMAL BYTES

  VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
        TP    R*8   000000           XNDT   R*8   000008           SOMS   R*8    N.R.            SOMD   R*8    N.R.
         E    R*8    N.R.              AO   R*8    N.R.            COME   R*8    N.R.            CUMD   R*8    N.R.
        CI    R*8    N.R.            XLNG   R*8    N.R.            DUM1   R*8    N.R.            DUM2   R*8    N.R.
        SI    R*8    N.R.            OFST   R*8    N.R.            DUM3   R*8    N.R.            DUM4   R*8    N.R.
      DUM5    R*8    N.R.             DOP   R*8    N.R.             DEK   R*8  [illegible]        DAK   R*8    N.R.
       DNK    R*8   0000C8            DUM   R*8    N.R.              DE   R*8  [illegible]         DA   R*8  [illegible]
        DN    R*8   000198            DTK   R*8    N.R.            ELAT   R*8    N.R.            ELON   R*8    N.R.
      GEOH    R*8    N.R.            HEAD   R*8    N.R.            RATE   R*8    N.R.            IDAY   I*4    N.R.
      MDAY    I*4    N.R.            STIM   R*8   000228           DLAT   R*8    N.R.            DLON   R*8    N.R.
      SMXE    R*8    N.R.            SELV   R*8    N.R.            FLAT   R*8    N.R.            FLON   R*8    N.R.
      FFRQ    R*8    N.R.             RSQ   R*8    N.R.              VN   R*8    N.R.               I   I*4    N.R.
         J    I*4    N.R.               K   I*4   000300              L   I*4    N.R.               M   I*4    N.R.
         N    I*4    N.R.            MDOP   I*4    N.R.            ITEP   I*4    N.R.               T   R*8  [illegible]
      TEMP    R*8    N.R.
```

```
 NAME OF COMMON BLOCK  *  CONC*   SIZE OF BLOCK    000128 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
    NULL   I*4     N.R.           IONE   I*4     N.R.           ITWO   I*4     N.R.           IFOR   I*4     N.R.
     I15   I*4     N.R.            I30   I*4     N.R.           I365   I*4     N.R.             IM   I*4     N.R.
      KM   I*4   000020             KF   I*4     N.R.            TAM   R*8     N.R.           WAVE   R*8     N.R.

                                                                                                   PAGE 003

    CVCG   R*8     N.R.           EFRQ   R*8     N.R.           OMGE   R*8     N.R.           XOSQ   R*8     N.R.
    ZOSQ   R*8     N.R.           ZERO   R*8     N.R.            ONE   R*8     N.R.            TWO   R*8   000070
    THRE   R*8     N.R.           FOUR   R*8     N.R.           FIVE   R*8     N.R.            ATE   R*8     N.R.
     TEN   R*8     N.R.            D60   R*8     N.R.           HUND   R*8     N.R.           C480   R*8   0000B0
    S7P5   R*8     N.R.           TOPI   R*8   0000C0           DTRA   R*8     N.R.           DTCM   R*8   0000D0
     TM1   R*8     N.R.            TM4   R*8     N.R.            TM5   R*8     N.R.            TM7   R*8     N.R.
     TM8   R*8     N.R.           CMTR   R*8     N.R.           CKRM   R*8     N.R.            C2K   R*8     N.R.
     C2M   R*8     N.R.           REFC   R*8     N.R.
```

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  LABEL   ADDR              LABEL   ADDR              LABEL   ADDR              LABEL   ADDR          PAGE 004

     1  0000C2                  2  0000D2                  3  0000EC                  4  0000F0
     5  00011E

*OPTIONS IN EFFECT*     NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*     SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*    SOURCE STATEMENTS =      39 ,PROGRAM SIZE =      356

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                  61K BYTES OF CORE NOT USED
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LEVEL 18 ( SEPT 69 )                     OS/360  FORTRAN H                              DATE  70.196/18.54.09

          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                             SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002              SUBROUTINE SXYZ                                                  SXYZ
                  C                                                                      SXYZ
                  C COMPUTE SATELLITE COORDINATES FOR TIME T CORRESPONDING TO POINT K    SXYZ
                  C                                                                      SXYZ
  ISN 0003              DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ               SXYZ
  ISN 0004              DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,STPS    SXYZ
  ISN 0005              DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM        SXYZ
  ISN 0006              DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                      SXYZ
  ISN 0007              DOUBLE PRECISION DOP,XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE      SXYZ
  ISN 0008              DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG    SXYZ
  ISN 0009              DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5                SXYZ
  ISN 0010              DOUBLE PRECISION DUM,T,TEMP                                      SXYZ
  ISN 0011              DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN       SXYZ
  ISN 0012              DOUBLE PRECISION DEK,DAK,DNK                                     SXYZ
  ISN 0013              DOUBLE PRECISION XMK,EK,AK,UK,VK,WK,CWK,SWK,XKP,YKP,BK,CBK,SBK   SXYZ
                  C                                                                      SXYZ
                  C---DIMENSION                                                          SXYZ
  ISN 0014              DIMENSION DOP(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)              SXYZ
  ISN 0015              DIMENSION DUM(4)                                                 SXYZ
                  C                                                                      SXYZ
                  C---COMMON                                                             SXYZ
  ISN 0016              COMMON TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG                  SXYZ
  ISN 0017              COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                      SXYZ
  ISN 0018              COMMON DEK,DAK,DNK,XMK,DUM                                       SXYZ
  ISN 0019              COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM      SXYZ
  ISN 0020              COMMON DLAT,DLON,SMXF,SELV,FLAT,FLON,FFRQ,RSQ,VN                 SXYZ
  ISN 0021              COMMON I,J,K,L,M,N,NDOP,ITER                                     SXYZ
  ISN 0022              COMMON T,TEMP,EK,AK,UK,VK,WK,CWK,SWK,XKP,YKP,BK,CBK,SBK          SXYZ
                  C                                                                      SXYZ
  ISN 0023              COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF           SXYZ
  ISN 0024              COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO              SXYZ
  ISN 0025              COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND             SXYZ
  ISN 0026              COMMON /COMC/C480,STPS,TOPI,DTRA,DTOM                            SXYZ
  ISN 0027              COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC          SXYZ
                  C                                                                      SXYZ
  ISN 0028              XMK=T*XNDT                                                       SXYZ
  ISN 0029              EK=E*DSIN(XMK)+XMK+DEK                                           SXYZ
  ISN 0030              AK=AO+DAK                                                        SXYZ
  ISN 0031              VK=AK*DSIN(EK)                                                   SXYZ
  ISN 0032              UK=(DCOS(EK)-E)*AK                                               SXYZ
  ISN 0033              WK=SOME-T*SOMD                                                   SXYZ
  ISN 0034              CWK=DCOS(WK)                                                     SXYZ
  ISN 0035              SWK=DSIN(WK)                                                     SXYZ
  ISN 0036              XKP=UK*CWK-VK*SWK                                                SXYZ
  ISN 0037              YKP=VK*CWK+UK*SWK                                                SXYZ
  ISN 0038              BK=(COMD-OMGE)*T+COME-                                           SXYZ
  ISN 0039              CBK=DCOS(BK)                                                     SXYZ
  ISN 0040              SBK=DSIN(BK)                                                     SXYZ
  ISN 0041              TEMP=YKP*CI-DNK*SI                                               SXYZ
  ISN 0042              XS(K)=XKP*CBK-TEMP*SBK                                           SXYZ
  ISN 0043              YS(K)=XKP*SBK+TEMP*CBK                                           SXYZ
  ISN 0044              ZS(K)=YKP*SI+DNK*CI                                              SXYZ
  ISN 0045              RETURN                                                           SXYZ

                                                                                                      PAGE 002

  ISN 0046              END                                                              SXYZ
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                                   /    SXYZ /      SIZE OF PROGRAM 000264 HEXADECIMAL BYTES PAGE 003

NAME   TAG  TYPE  ADD.      NAME   TAG  TYPE  ADD.      NAME   TAG  TYPE  ADD.      NAME   TAG  TYPE  ADD.
   E  F   C  R*8  000020       I        C  I*4    N.R.       J        C  I*4    N.R.       K  F   C  I*4  000300
   L      C  I*4    N.R.       M        C  I*4    N.R.       N        C  I*4    N.R.       T  F   C  R*8  000318
  AK SF   C  R*8  000330      AO  F     C  R*8  000028      BK SFA    C  R*8  000370      CI  F   C  R*8  000040
  EK SFA  C  R*8  000328      IM        C  I*4    N.R.      KF        C  I*4    N.R.      KM      C  I*4    N.R.
  SI  F   C  R*8  000060      TP        C  R*8    N.R.      UK SF     C  R*8  000338      VK SF   C  R*8  000340
  VN      C  R*8    N.R.      WK SFA    C  R*8  000348      XS S      C  R*8  000108      YS S    C  R*8  000150
  ZS S    C  R*8  000198     ATE        C  R*8    N.R.     CBK SF     C  R*8  000378     CWK SF   C  R*8  000350
 C2K      C  R*8    N.R.     C2M        C  R*8    N.R.     DAK  F     C  R*8  0000D0     DEK  F   C  R*8  0000C8
 DNK  F   C  R*8  000008     DOP        C  R*8    N.R.     DTK        C  R*8    N.R.     DUM      C  R*8    N.R.
 D60      C  R*8    N.R.     I15        C  I*4    N.R.     I30        C  I*4    N.R.     ONE      C  R*8    N.R.
 RSQ      C  R*8    N.R.     SBK SF     C  R*8  000380     SWK SF     C  R*8  000358     TAW      C  R*8    N.R.
 TEN      C  R*8    N.R.     TM1        C  R*8    N.R.     TM4        C  R*8    N.R.     TM5      C  R*8    N.R.
 TM7      C  R*8    N.R.     TM8        C  R*8    N.R.     TWO        C  R*8    N.R.     XKP SF   C  R*8  000360
 XMK SFA  C  R*8  0000E0     YKP SF     C  R*8  000368    CKKM        C  R*8    N.R.    CMTR      C  R*8    N.R.
COND  F   C  R*8  000038    COME  F     C  R*8  000030    CVCS        C  R*8    N.R.    C460      C  R*8    N.R.
DLAT      C  R*8    N.R.    DLON        C  R*8    N.R.    DTOM        C  R*8    N.R.    DTRA      C  R*8    N.R.
DUM1      C  R*8    N.R.    DUM2        C  R*8    N.R.    DUM3        C  R*8    N.R.    DUM4      C  R*8    N.R.
DUM5      C  R*8    N.R.    EFRQ        C  R*8    N.R.    ELAT        C  R*8    N.R.    ELON      C  R*8    N.R.
FFRQ      C  R*8    N.R.    FIVE        C  R*8    N.R.    FLAT        C  R*8    N.R.    FLON      C  R*8    N.R.
FOUR      C  R*8    N.R.    GEOM        C  R*8    N.R.    HEAD        C  R*8    N.R.    HUND      C  R*8    N.R.
IDAY      C  I*4    N.R.    IFOR        C  I*4    N.R.    IONE        C  I*4    N.R.    ITER      C  I*4    N.R.
ITWO      C  I*4    N.R.    I365        C  I*4    N.R.    MDAY        C  I*4    N.R.    NOOP      C  I*4    N.R.
NULL      C  I*4    N.R.    OFST        C  R*8    N.R.    OMGE  F     C  R*8  000048    RATE      C  R*8    N.R.
REFC      C  R*8    N.R.    SELV        C  R*8    N.R.    SMXE        C  R*8    N.R.    SOMD  F   C  R*8  000018
SOME  F   C  R*8  000010    STIM        C  R*8    N.R.    SXYZ           R*4  000090    STP5      C  R*8    N.R.
TEMP SF   C  R*8  000320    THRE        C  R*8    N.R.    TOPI        C  R*8    N.R.    WAVE      C  R*8    N.R.
XLMG  F   C  R*8  000048    XNDT  F     C  R*8  000008    XOSQ        C  R*8    N.R.    ZERO      C  R*8    N.R.
ZOSQ      C  R*8    N.R.    OCOS       XF  R*8  000000    DSIN       XF  R*8  000000

                                   *****  COMMON INFORMATION  *****

  NAME OF COMMON BLOCK  *       *  SIZE OF BLOCK     000388 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
       TP   R*8      N.R.          XNDT   R*8    000008          SOME   R*8    000010          SOMD   R*8    000018
        E   R*8    000020            AO   R*8    000028          COME   R*8    000030          COND   R*8    000038
       CI   R*8    000040          XLMG   R*8    000048          DUM1   R*8      N.R.          DUM2   R*8      N.R.
       SI   R*8    000060          OFST   R*8      N.R.          DUM3   R*8      N.R.          DUM4   R*8      N.R.
     DUM5   R*8      N.R.           DOP   R*8      N.R.           DEK   R*8    0000C8           DAK   R*8    0000D0
      DNK   R*8    000008           XMK   R*8    0000E0           DUM   R*8      N.R.            XS   R*8    000108
       YS   R*8    000150            ZS   R*8    000198           DTK   R*8      N.R.          ELAT   R*8      N.R.
     ELON   R*8      N.R.          GEOM   R*8      N.R.          HEAD   R*8      N.R.          RATE   R*8      N.R.
     IDAY   I*4      N.R.          MDAY   I*4      N.R.          STIM   R*8      N.R.          DLAT   R*8      N.R.
     DLON   R*8      N.R.          SMXE   R*8      N.R.          SELV   R*8      N.R.          FLAT   R*8      N.R.
     FLON   R*8      N.R.          FFRQ   R*8      N.R.           RSQ   R*8      N.R.            VN   R*8      N.R.
        I   I*4      N.R.             J   I*4      N.R.             K   I*4    000300             L   I*4      N.R.
        M   I*4      N.R.             N   I*4      N.R.          NOOP   I*4      N.R.          ITER   I*4      N.R.
        T   R*8    000318          TEMP   R*8    000320            EK   R*8    000328            AK   R*8    000330
       UK   R*8    000338            VK   R*8    000340            WK   R*8    000348           CWK   R*8    000350
      SWK   R*8    000358           XKP   R*8    000360           YKP   R*8    000368            BK   R*8    000370
      CBK   R*8    000378           SBK   R*8    000380
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                                                                                                 PAGE 004

      NAME OF COMMON BLOCK  *  COMC*   SIZE OF BLOCK    000126 HEXADECIMAL BYTES

    VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
        NULL    I*4     N.R.           IONE   I*4     N.R.           ITWO   I*4     N.R.           IFOR   I*4     N.R.
         I15    I*4     N.R.            I30   I*4     N.R.           I365   I*4     N.R.             IM   I*4     N.R.
          KM    I*4     N.R.             KF   I*4     N.R.            TAW   R*8     N.R.           WAVE   R*8     N.R.
        CVCG    R*8     N.R.           EFRQ   R*8     N.R.           OMGE   R*8   000048           XOSQ   R*8     N.R.
        ZOSQ    R*8     N.R.           ZERO   R*8     N.R.            ONE   R*8     N.R.            TWO   R*8     N.R.
        THRE    R*8     N.R.           FOUR   R*8     N.R.           FIVE   R*8     N.R.            ATE   R*8     N.R.
         TEN    R*8     N.R.            D60   R*8     N.R.           HUND   R*8     N.R.           C480   R*8     N.R.
        STP5    R*8     N.R.           TOPI   R*8     N.R.           DTRA   R*8     N.R.           DTUM   R*8     N.R.
         TM1    R*8     N.R.            TM4   R*8     N.R.            TM5   R*8     N.R.            TM7   R*8     N.R.
         TM8    R*8     N.R.           CMTR   R*8     N.R.           CKRM   R*8     N.R.            C2K   R*8     N.R.
         C2M    R*8     N.R.           REFC   R*8     N.R.

*OPTIONS IN EFFECT*      NAME=  MAIN,OPT=02,LINECNT=56,SIZE=1000K,

*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*     SOURCE STATEMENTS =      45 ,PROGRAM SIZE =      612

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                     61K BYTES OF CORE NOT USED
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LEVEL 18 ( SEPT 69 )                              OS/360  FORTRAN H                                    DATE  70.196/18.53.5

              COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                                 SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
     ISN 0002                 SUBROUTINE SOLVE                                                    SOLVE
                        C                                                                         SOLVE
                        C-USES SLNT WHICH CALCULATES NAVIGATOR COORDINATES AND SLANT RANGE        SOLVE
                        C                                                                         SOLVE
     ISN 0003                 DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ                  SOLVE
     ISN 0004                 DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5       SOLVE
     ISN 0005                 DOUBLE PRECISION TOPI,DTRA,DFUM,TM1,TM4,TM5,TM8,CMTR,CKRM           SOLVE
     ISN 0006                 DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                         SOLVE
     ISN 0007                 DOUBLE PRECISION DOP,XS,YS,ZS,ELAT,ELON,GEOM,STIM,HEAD,RATE         SOLVE
     ISN 0008                 DOUBLE PRECISION DTK,TP,XNOT,SUME,SUMD,E,AU,COME,COMD,CI,XLMG       SOLVE
     ISN 0009                 DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5                   SOLVE
     ISN 0010                 DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN          SOLVE
     ISN 0011                 DOUBLE PRECISION T  ,TEMP,A                                         SOLVE
     ISN 0012                 DOUBLE PRECISION C,    B11,B12,B10,B22,B20                          SOLVE
     ISN 0013                 DOUBLE PRECISION S,S2,S3                                            SOLVE
     ISN 0014                 DOUBLE PRECISION XLAT,XLON,XFRQ                                     SOLVE
     ISN 0015                 DOUBLE PRECISION DET                                                SOLVE
                        C                                                                         SOLVE
                        C---DIMENSION                                                             SOLVE
     ISN 0016                 DIMENSION A(3,4)                                                    SOLVE
     ISN 0017                 DIMENSION DOP(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)                 SOLVE
     ISN 0018                 DIMENSION C(4)                                                      SOLVE
                        C                                                                         SOLVE
                        C---COMMON                                                                SOLVE
     ISN 0019                 COMMON TP,XNOT,SUME,SUMD,E,AU,COME,COMD,CI,XLMG                     SOLVE
     ISN 0020                 COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                         SOLVE
     ISN 0021                 COMMON B11,B12,B22,B10,B20,XLAT,XLON,XFRQ                           SOLVE
     ISN 0022                 COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOM,HEAD,RATE,IDAY,MDAY,STIM         SOLVE
     ISN 0023                 COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN                    SOLVE
     ISN 0024                 COMMON I,J,K,L,M,N,NDOP,ITER                                        SOLVE
     ISN 0025                 COMMON T  ,TEMP,A                                                   SOLVE
     ISN 0026                 COMMON C                                                            SOLVE
                        C                                                                         SOLVE
     ISN 0027                 COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,XM,KF              SOLVE
     ISN 0028                 COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO                 SOLVE
     ISN 0029                 COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND                SOLVE
     ISN 0030                 COMMON /COMC/C480,S7P5,TOPI,DTRA,DFUM                               SOLVE
     ISN 0031                 COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC             SOLVE
                        C                                                                         SOLVE
     ISN 0032                 EQUIVALENCE   (B11,S),(B12,S2),(B22,S3),(TEMP,DET)                  SOLVE
                        C                                                                         SOLVE
     ISN 0033                 DO 9 ITER=1,10                                                      SOLVE
                        C---INITIALIZE                                                            SOLVE
     ISN 0034                 DO 1 I=1,3                                                          SOLVE
     ISN 0035                 DO 1 J=1,4                                                          SOLVE
     ISN 0036               1 A(I,J)=ZERO                                                         SOLVE
     ISN 0037                 SMXE=ZERO                                                           SOLVE
     ISN 0038                 RSQ=ZERO                                                            SOLVE
     ISN 0039                 NDOP=NULL                                                           SOLVE
     ISN 0040                 K=IONE                                                              SOLVE
                        C---FORM THE A MATRIX                                                     SOLVE
     ISN 0041                 CALL SLNT                                                           SOLVE
     ISN 0042                 C(1)=WAVE*TAW                                                       SOLVE

                                                                                                                  PAGE 002

     ISN 0043                 DO 4 N=1,IM                                                         SOLVE
     ISN 0044                 C(2)=S2                                                             SOLVE
     ISN 0045                 C(3)=S3                                                             SOLVE
     ISN 0046                 C(4)=S                                                              SOLVE
     ISN 0047                 K=N+IONE                                                            SOLVE
     ISN 0048                 CALL SLNT                                                           SOLVE
     ISN 0049                 C(2)=S2-C(2)                                                        SOLVE
     ISN 0050                 C(3)=S3-C(3)                                                        SOLVE
     ISN 0051                 C(4)=S-C(4)                                                         SOLVE
     ISN 0052                 IF (DOP(N)) 4,4,2                                                   SOLVE
     ISN 0053               2 NDOP=NDOP+IONE                                                      SOLVE
     ISN 0054                 C(4)=WAVE*DOP(N)-C(1)*FFRQ-C(4)                                     SOLVE
     ISN 0055                 RSQ=RSQ+C(4)*C(4)                                                   SOLVE
     ISN 0056                 DO 3 I=1,3                                                          SOLVE
     ISN 0057                 DO 3 J=1,4                                                          SOLVE
     ISN 0058               3 A(I,J)=A(I,J)+C(I)*C(J)                                             SOLVE
     ISN 0059               4 CONTINUE                                                            SOLVE
                        C---SOLVE A MATRIX FOR DELTA LAT,LON,FREQ  BY ELIMINATING FREQUENCY       SOLVE
     ISN 0060                 DET=A(1,2)/A(1,1)                                                   SOLVE
     ISN 0061                 B11=A(2,2)-A(1,2)*DET                                               SOLVE
     ISN 0062                 B12=A(2,3)-A(1,3)*DET                                               SOLVE
     ISN 0063                 B10=A(2,4)-A(1,4)*DET                                               SOLVE
     ISN 0064                 DET=A(1,3)/A(1,1)                                                   SOLVE
     ISN 0065                 B22=A(3,3)-A(1,3)*DET                                               SOLVE
     ISN 0066                 B20=A(3,4)-A(1,4)*DET                                               SOLVE
     ISN 0067                 DET=B11*B22-B12*B12                                                 SOLVE
     ISN 0068                 XLAT=(B22*B10-B12*B20)/DET                                          SOLVE
     ISN 0069                 XLON=(B11*B20-B12*B10)/DET                                          SOLVE
     ISN 0070                 XFRQ=( A(1,4)-A(1,2)*XLAT-A(1,3)*XLON)/A(1,1)                       SOLVE
                        C---UPDATE NEW ESTIMATE                                                   SOLVE
     ISN 0071                 FLAT=FLAT+XLAT                                                      SOLVE
     ISN 0072                 FLON=FLON+XLON                                                      SOLVE
     ISN 0073                 FFRQ=FFRQ+XFRQ                                                      SOLVE
                        C---CONVERGENCE CRITERIA  = .0004 NM AND  2.4 CPM                         SOLVE
     ISN 0074                 D2P4=2.4D+0                                                         SOLVE
     ISN 0075                 DET=CVCG/DCOS(FLAT)                                                 SOLVE
     ISN 0076                 IF (DABS(XLAT)-CVCG) 7,7,9                                          SOLVE
     ISN 0077               7 IF (DABS(XLON)-DET)  8,8,9                                          SOLVE
     ISN 0078               8 IF (DABS(XFRQ)-D2P4) 10,10,9                                        SOLVE
     ISN 0079               9 CONTINUE                                                            SOLVE
     ISN 0080              10 RETURN                                                              SOLVE
     ISN 0081                 END                                                                 SOLVE
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                                        /    SOLVE /      SIZE OF PROGRAM 000476 HEXADECIMAL BYTES PAGE  03

NAME      TAG    TYPE  ADD.        NAME      TAG    TYPE  ADD.        NAME      TAG    TYPE  ADD.        NAME      TAG    TYPE  ADD.
   A SF     C    R*8   000328         C SF     C    R*8   000388         E         C    R*8    N.R.         I SF     C    I*4   0002F8
   J SF     C    I*4   0002FC         K S      C    I*4   000300         L         C    I*4    N.R.         M        C    I*4    N.R.
   N SF     C    I*4   00030C         S  F    CE    R*8   0000C8         T         C    R*8    N.R.        AO        C    R*8    N.R.
  CI        C    R*8    N.R.         TM  F     C    I*4   00001C        KF         C    I*4    N.R.        KM        C    I*4    N.R.
  SI        C    R*8    N.R.         S2  F    CE    R*8   000000        S3  F     CE    R*8   000008        TP        C    R*8    N.R.
  VN        C    R*8    N.R.         XS        C    R*8    N.R.         YS         C    R*8    N.R.        ZS        C    R*8    N.R.
 ATE        C    R*8    N.R.        B10 SF     C    R*8   0000E0       B11 SF     CE    R*8   0000C8       B12 SF    CE    R*8   0000D0
 B20 SF     C    R*8   0000E8       B22 SF    CE    R*8   0000D8       C2K         C    R*8    N.R.       C2M        C    R*8    N.R.
 DET SF    CE    R*8   000320       DOP  F     C    R*8   000088       DTK         C    R*8    N.R.       D60        C    R*8    N.R.
 I15        C    I*4    N.R.        I30        C    I*4    N.R.        ONE         C    R*8    N.R.       RSQ SF     C    R*8   0002E8
 TAW  F     C    R*8   000028       TEN        C    R*8    N.R.        TM1         C    R*8    N.R.       TM4        C    R*8    N.R.
 TM5        C    R*8    N.R.        TM7        C    R*8    N.R.        TM8         C    R*8    N.R.       TM9        C    R*8    N.R.
CKRM        C    R*8    N.R.       CMTR        C    R*8    N.R.       COMD         C    R*8    N.R.      COME            R*8    N.R.
CVCG  F     C    R*8   000038      C480        C    R*8    N.R.       DLAT         C    R*8    N.R.      DLON        C    R*8    N.R.
DTOM        C    R*8    N.R.       DTRA        C    R*8    N.R.       DUM1         C    R*8    N.R.      DUM2        C    R*8    N.R.
DUM3        C    R*8    N.R.       DUM4        C    R*8    N.R.       DUM5         C    R*8    N.R.      D2P4 S          R*4   000098
EFRQ        C    R*8    N.R.       ELAT        C    R*8    N.R.       ELON         C    R*8    N.R.      FFRQ SF     C    R*8   0002E0
FIVE        C    R*8    N.R.       FLAT SFA    C    R*8   000200      FLON SF      C    R*8   000208      FOUR        C    R*8    N.R.
GEOM        C    R*8    N.R.       HEAD        C    R*8    N.R.       HUND         C    R*8    N.R.      IDAY        C    I*4    N.R.
IFOR        C    I*4    N.R.       IONE  F     C    I*4   000004      ITER SF      C    I*4   000314      ITWO        C    I*4    N.R.
I365        C    I*4    N.R.       MDAY        C    I*4    N.R.       NOOP SF      C    I*4   000310      NULL  F     C    I*4   000000
OFST        C    R*8    N.R.       OMGE        C    R*8    N.R.       RATE         C    R*8    N.R.      REFC        C    R*8    N.R.
SELV        C    R*8    N.R.       SLNT SF    XF    R*4   000000      SMXE S       C    R*8   0002C0      SOMD        C    R*8    N.R.
SOME        C    R*8    N.R.       STIM        C    R*8    N.R.       STPS         C    R*8    N.R.      TEMP       CE    R*8   000320
THRE        C    R*8    N.R.       TOPI        C    R*8    N.R.       WAVE  F      C    R*8   000030      XFRQ SFA    C    R*8   000100
XLAT SFA    C    R*8   0000F0      XLMG        C    R*8    N.R.       XLON SFA     C    R*8   0000F8      XNDT        C    R*8    N.R.
XOSQ        C    R*8    N.R.       ZERO  F     C    R*8   000060      ZOSQ         C    R*8    N.R.      SOLVE            R*4   00009C
DCOS       XF    R*8   000000

                                  *****  COMMON INFORMATION   *****


   NAME OF COMMON BLOCK  *       *   SIZE OF BLOCK     0003A8 HEXADECIMAL BYTES

  VAR. NAME  TYPE  REL  ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
        TP    R*8      N.R.          XNDT    R*8      N.R.          SOME    R*8      N.R.          SOMD    R*8      N.R.
         E    R*8      N.R.            AO    R*8      N.R.          COME    R*8      N.R.          COMD    R*8      N.R.
        CI    R*8      N.R.          XLMG    R*8      N.R.          DUM1    R*8      N.R.          DUM2    R*8      N.R.
        SI    R*8      N.R.          OFST    R*8      N.R.          DUM3    R*8      N.R.          DUM4    R*8      N.R.
      DUM5    R*8      N.R.           DOP    R*8    000088           B11    R*8    0000C8           B12    R*8    0000D0
       B22    R*8    0000D8           B10    R*8    0000E0           B20    R*8    0000E8          XLAT    R*8    0000F0
      XLON    R*8    0000F8          XFRQ    R*8    000100            XS    R*8      N.R.            YS    R*8      N.R.
        ZS    R*8      N.R.           DTK    R*8      N.R.          ELAT    R*8      N.R.          ELON    R*8      N.R.
      GEOM    R*8      N.R.          HEAD    R*8      N.R.          RATE    R*8      N.R.          IDAY    I*4      N.R.
      MDAY    I*4      N.R.          STIM    R*8      N.R.          DLAT    R*8      N.R.          DLON    R*8      N.R.
      SMXE    R*8    0002C0          SELV    R*8      N.R.          FLAT    R*8    000200          FLON    R*8    000208
      FFRQ    R*8    0002E0           RSQ    R*8    0002E8            VN    R*8      N.R.             I    I*4    0002F8
         J    I*4    0002FC             K    I*4    000300             L    I*4      N.R.             M    I*4      N.R.
         N    I*4    00030C          NOOP    I*4    000310          ITER    I*4    000314             T    R*8      N.R.
      TEMP    R*8    000320             A    R*8    000328             C    R*8    000388

  EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK
    VARIABLE  OFFSET                VARIABLE  OFFSET                VARIABLE  OFFSET                VARIABLE  OFFSET
         S    0000C8                     S2    000000                    S3    000008                    DET    000320

                                                                                                              PAGE 004


   NAME OF COMMON BLOCK  *  CONC*   SIZE OF BLOCK     000128 HEXADECIMAL BYTES

  VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
      NULL    I*4    000000          IONE    I*4    000004          ITWO    I*4      N.R.          IFOR    I*4      N.R.
       I15    I*4      N.R.           I30    I*4      N.R.          I365    I*4      N.R.            TM    I*4    00001C
        KM    I*4      N.R.            KF    I*4      N.R.           TAW    R*8    000028          WAVE    R*8    000030
      CVCG    R*8    000038          EFRQ    R*8      N.R.          OMGE    R*8      N.R.          XOSQ    R*8      N.R.
      ZOSQ    R*8      N.R.          ZERO    R*8    000060           ONE    R*8      N.R.           TWO    R*8      N.R.
      THRE    R*8      N.R.          FOUR    R*8      N.R.          FIVE    R*8      N.R.           ATE    R*8      N.R.
       TEN    R*8      N.R.           D60    R*8      N.R.          HUND    R*8      N.R.          C480    R*8      N.R.
      STPS    R*8      N.R.          TOPI    R*8      N.R.          DTRA    R*8      N.R.          DTOM    R*8      N.R.
       TM1    R*8      N.R.           TM4    R*8      N.R.           TM5    R*8      N.R.           TH7    R*8      N.R.
       TM8    R*8      N.R.          CMTR    R*8      N.R.          CKRM    R*8      N.R.           C2K    R*8      N.R.
       C2M    R*8      N.R.          REFC    R*8      N.R.
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    LABEL   ADDR                LABEL   ADDR                LABEL   ADDR                LABEL   ADDR              PAGE 005

        1  00016E                   2  000242                   3  0002A2                   4  0002CC
        7  000426                   8  000434                   9  000442                  10  000454

*OPTIONS IN EFFECT*      NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*     SOURCE STATEMENTS =      90 ,PROGRAM SIZE =     1144

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                  53K BYTES OF CORE NOT USED
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LEVEL 18 ( SEPT 69 )                    OS/360  FORTRAN H                                    DATE  70.196/18.54.25

         COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                            SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002              SUBROUTINE SLNT                                                    SLNT
               C                                                                           SLNT
               C---COMPUTE SLANT RANGE AND DERIVATIVES FOR POINT K AND ELEVATION           SLNT
               C                                                                           SLNT
  ISN 0003              DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,UNGE,XOSQ,ZOSQ                 SLNT
  ISN 0004              DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5      SLNT
  ISN 0005              DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKKM          SLNT
  ISN 0006              DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                        SLNT
  ISN 0007              DOUBLE PRECISION DUP,XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE        SLNT
  ISN 0008              DOUBLE PRECISION DTK,TP,XNDT,SUME,SUMD,E,AO,CUME,CUMD,CI,XLNG      SLNT
  ISN 0009              DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5                  SLNT
  ISN 0010              DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN         SLNT
  ISN 0011              DOUBLE PRECISION T,TEMP                                            SLNT
  ISN 0012              DOUBLE PRECISION A                                                 SLNT
  ISN 0013              DOUBLE PRECISION XN,YN,ZN,XN2,YN2,ZN2,X,Y,Z                        SLNT
  ISN 0014              DOUBLE PRECISION CLAT,SLAT,SLON,CLON,D,C                           SLNT
  ISN 0015              DOUBLE PRECISION S,S2,S3                                           SLNT
               C                                                                           SLNT
               C---DIMENSIONS                                                              SLNT
  ISN 0016              DIMENSION DUP(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)                SLNT
  ISN 0017              DIMENSION A(3,4),C(4)                                              SLNT
               C                                                                           SLNT
               C---COMMON                                                                  SLNT
  ISN 0018              COMMON TP,XNDT,SUME,SUMD,E,AO,CUME,CUMD,CI,XLNG                    SLNT
  ISN 0019              COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DUP                        SLNT
  ISN 0020              COMMON CLAT,SLAT,SLON,CLON,D,XN,YN,ZN                              SLNT
  ISN 0021              COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM        SLNT
  ISN 0022              COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN                   SLNT
  ISN 0023              COMMON I,J,K,L,M,N,NDOP,ITER                                       SLNT
  ISN 0024              COMMON T,TEMP,A                                                    SLNT
  ISN 0025              COMMON C,X,Y,Z,XN2,YN2,ZN2                                         SLNT
               C                                                                           SLNT
  ISN 0026              COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF             SLNT
  ISN 0027              COMMON /COMC/TAW,WAVE,CVCG,EFRQ,UNGE,XOSQ,ZOSQ,ZERO                SLNT
  ISN 0028              COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND               SLNT
  ISN 0029              COMMON /COMC/C480,S7P5,TOP1,DTRA,DTOM                              SLNT
  ISN 0030              COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC            SLNT
               C                                                                           SLNT
  ISN 0031              EQUIVALENCE (CLAT,S),(SLAT,S2),(SLON,S3)                           SLNT
               C                                                                           SLNT
               C                                                                           SLNT
               C---NAVIGATORS COORDINATES AND DERIVATIVES                                  SLNT
  ISN 0032              TEMP=FLAT+DLAT(K)                                                  SLNT
  ISN 0033              CLAT=DCOS(TEMP)                                                    SLNT
  ISN 0034              SLAT=DSIN(TEMP)                                                    SLNT
  ISN 0035              TEMP=FLON+DLON(K)/CLAT                                             SLNT
  ISN 0036              CLON=DCOS(TEMP)                                                    SLNT
  ISN 0037              SLON=DSIN(TEMP)                                                    SLNT
  ISN 0038              D=XOSQ*CLAT*CLAT+ZOSQ*SLAT*SLAT                                    SLNT
  ISN 0039              D=DSQRT(D)                                                         SLNT
  ISN 0040              TEMP=XOSQ/D+GEOH                                                   SLNT
  ISN 0041              XN=TEMP*CLAT                                                       SLNT
  ISN 0042              YN=XN*SLON                                                         SLNT


                                                                                                       PAGE 002
  ISN 0043              XN=XN*CLON                                                         SLNT
  ISN 0044              ZN=(ZOSQ/D+GEOH)*SLAT                                              SLNT
  ISN 0045              XN2=-TEMP*SLAT                                                     SLNT
  ISN 0046              YN2=XN2*SLON                                                       SLNT
  ISN 0047              XN2=XN2*CLON                                                       SLNT
  ISN 0048              ZN2=TEMP*CLAT                                                      SLNT
               C---SLANT RANGE AND DERIVATIVES                                             SLNT
  ISN 0049              X=XS(K)-XN                                                         SLNT
  ISN 0050              Y=YS(K)-YN                                                         SLNT
  ISN 0051              Z=ZS(K)-ZN                                                         SLNT
  ISN 0052              S2=X*X+Y*Y+Z*Z                                                     SLNT
  ISN 0053              S=DSQRT(S2)                                                        SLNT
  ISN 0054              S2=-(X*XN2+Y*YN2+Z*ZN2)/S                                          SLNT
  ISN 0055              S3=(X*YN-Y*XN)/S                                                   SLNT
               C---COMPUTE SIN(ELEV) AND SAVE MAXIMUM                                      SLNT
  ISN 0056              SELV= (X*XN+Y*YN+Z*ZN)/(S*D)                                       SLNT
  ISN 0057              IF (SELV-SMXE) 2,2,1                                               SLNT
  ISN 0058            1 SMXE=SELV                                                          SLNT
  ISN 0059            2 RETURN                                                             SLNT
  ISN 0060              END                                                                SLNT
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                                          /    SLNT /     SIZE OF PROGRAM 0002EE HEXADECIMAL BYTES PAGE 003

NAME   TAG   TYPE  ADD.      NAME   TAG   TYPE  ADD.      NAME   TAG   TYPE  ADD.      NAME   TAG   TYPE  ADD.
   A       C  R*8    N.R.        C       C  R*8    N.R.      D SFA  C  R*8  0000E8        E       C  R*8    N.R.
   I       C  I*4    N.R.        J       C  I*4    N.R.      K  F   C  I*4  000300        L       C  I*4    N.R.
   M       C  I*4    N.R.        N       C  I*4    N.R.      S SF  CE  R*8  0000C8        T       C  R*8    N.R.
   X SF    C  R*8  0003A8        Y SF    C  R*8  000380      Z SF   C  R*8  000388       AD       C  R*8    N.R.
  CI       C  R*4    N.R.       IM       C  I*4    N.R.     KF      C  I*4    N.R.       KM       C  I*4    N.R.
  SI       C  R*8    N.R.       S2 SFA  CE  R*8  000000     S3 S   CE  R*8  0000D8       TP       C  R*8    N.R.
  VN       C  R*8    N.R.       XN SF    C  R*8  0000F0     XS  F   C  R*8  000108       YN SF    C  R*8  0000F8
  YS  F    C  R*8  000150       ZN SF    C  R*8  000100     ZS  F   C  R*8  000198      ATE       C  R*8    N.R.
 C2K       C  R*8    N.R.      C2M       C  R*8    N.R.    DOP      C  R*8    N.R.      OTK       C  R*8    N.R.
 D60       C  R*8    N.R.      I15       C  I*4    N.R.    I30      C  I*4    N.R.      ONE       C  R*8    N.R.
 RSQ       C  R*8    N.R.      TAW       C  R*8    N.R.    TEN      C  R*8    N.R.      TM1       C  R*8    N.R.
 TM4       C  R*8    N.R.      TM5       C  R*8    N.R.    TM7      C  R*8    N.R.      TM8       C  R*8    N.R.
 TWO       C  R*8    N.R.      XN2 SF    C  R*8  0003C0    YN2 SF   C  R*8  0003C8      ZN2 SF    C  R*8  0003D0
CKRN       C  R*8    N.R.     CLAT SF   CE  R*8  0000C8   CLON SF   C  R*8  0000E0     CMTR       C  R*8    N.R.
COMD       C  R*8    N.R.     COME       C  R*8    N.R.   CVCG      C  R*8    N.R.     C480       C  R*8    N.R.
DLAT  F    C  R*8  000230     DLON  F    C  R*8  000278   DTOM      C  R*8    N.R.     DTRA       C  R*8    N.R.
DUM1       C  R*8    N.R.     DUM2       C  R*8    N.R.   DUM3      C  R*8    N.R.     DUM4       C  R*8    N.R.
DUM5       C  R*8    N.R.     EFRQ       C  R*8    N.R.   ELAT      C  R*8    N.R.     ELON       C  R*8    N.R.
FFRQ       C  R*8    N.R.     FIVE       C  R*8    N.R.   FLAT  F   C  R*8  000200     FLON  F    C  R*8  000208
FOUR       C  R*8    N.R.     GEOH  F    C  R*8  000208   HEAD      C  R*8    N.R.     HUND       C  R*8    N.R.
IDAY       C  I*4    N.R.     IFOR       C  I*4    N.R.   IONE      C  I*4    N.R.     ITER       C  I*4    N.R.
ITWO       C  I*4    N.R.     I365       C  I*4    N.R.   MDAY      C  I*4    N.R.     NDOP       C  I*4    N.R.
NULL       C  I*4    N.R.     OFST       C  R*8    N.R.   OMGE      C  R*8    N.R.     RATE       C  R*8    N.R.
REFC       C  R*8    N.R.     SELV SF    C  R*8  0002C8   SLAT SF  CE  R*8  000000     SLNT          R*4  000094
SLON SF   CE  R*8  0000D8     SMXE S     C  R*8  0002C0   SOMD      C  R*8    N.R.     SOME       C  R*8    N.R.
STIM       C  R*8    N.R.     S7P5       C  R*8    N.R.   TEMP SFA  C  R*8  000320     THRE       C  R*8    N.R.
TOPI       C  R*8    N.R.     WAVE       C  R*8    N.R.   XLMG      C  R*8    N.R.     XNDT       C  R*8    N.R.
XOSQ  F    C  R*8  000050     ZERO       C  R*8    N.R.   ZOSQ  F   C  R*8  000058     DSQRT     XF  R*8  000000
OSIN      XF  R*8  000000     DCOS      XF  R*8  000000

                                   *****  COMMON INFORMATION  *****

  NAME OF COMMON BLOCK  *       *   SIZE OF BLOCK    0003D8 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
      TP    R*8     N.R.          XNDT    R*8     N.R.          SOME    R*8     N.R.          SOMD    R*8     N.R.
       E    R*8     N.R.            AD    R*8     N.R.          COME    R*8     N.R.          COMD    R*8     N.R.
      CI    R*8     N.R.          XLMG    R*8     N.R.          DUM1    R*8     N.R.          DUM2    R*8     N.R.
      SI    R*8     N.R.          OFST    R*8     N.R.          DUM3    R*8     N.R.          DUM4    R*8     N.R.
    DUM5    R*8     N.R.           DOP    R*8     N.R.          CLAT    R*8   0000C8          SLAT    R*8   000000
    SLON    R*8   0000D8          CLON    R*8   0000E0             D    R*8   0000E8            XN    R*8   0000F0
      YN    R*8   0000F8            ZN    R*8   000100            XS    R*8   000108            YS    R*8   000150
      ZS    R*8   000198           OTK    R*8     N.R.          ELAT    R*8     N.R.          ELON    R*8     N.R.
    GEOH    R*8   000208          HEAD    R*8     N.R.          RATE    R*8     N.R.          IDAY    I*4     N.R.
    MDAY    I*4     N.R.          STIM    R*8     N.R.          DLAT    R*8   000230          DLON    R*8   000278
    SMXE    R*8   0002C0          SELV    R*8   0002C8          FLAT    R*8   0002D0          FLON    R*8   000208
    FFRQ    R*8     N.R.           RSQ    R*8     N.R.            VN    R*8     N.R.             I    I*4     N.R.
       J    I*4     N.R.             K    I*4   000300             L    I*4     N.R.             M    I*4     N.R.
       N    I*4     N.R.          NDOP    I*4     N.R.          ITER    I*4     N.R.             T    R*8     N.R.
    TEMP    R*8   000320             A    R*8     N.R.             C    R*8     N.R.             X    R*8   0003A8
       Y    R*8   000380             Z    R*8   000388           XN2    R*8   0003C0           YN2    R*8   0003C8
     ZN2    R*8   0003D0
```

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                                                                                                        PAGE 004
EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK
  VARIABLE  OFFSET                VARIABLE  OFFSET                VARIABLE  OFFSET                VARIABLE  OFFSET
      S     0000C8                      S2  0000D0                      S3  0000D8

  NAME OF COMMON BLOCK  *  COMC*   SIZE OF BLOCK    000128 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
     NULL   I*4     N.R.           IONE   I*4     N.R.           ITWO   I*4     N.R.           IFOR   I*4     N.R.
      115   I*4     N.R.            130   I*4     N.R.           1365   I*4     N.R.             IM   I*4     N.R.
       KM   I*4     N.R.             KF   I*4     N.R.            TAW   R*8     N.R.           WAVE   R*8     N.R.
     CVCG   R*8     N.R.           EFRQ   R*8     N.R.           OMGE   R*8     N.R.           XOSQ   R*8   000050
     ZOSQ   R*8   000058           ZERO   R*8     N.R.            ONE   R*8     N.R.            TWO   R*8     N.R.
     THRE   R*8     N.R.           FOUR   R*8     N.R.           FIVE   R*8     N.R.            ATE   R*8     N.R.
      TEN   R*8     N.R.            C60   R*8     N.R.           HUND   R*8     N.R.           C480   R*8     N.R.
     STPS   R*8     N.R.           TOPI   R*8     N.R.           DTRA   R*8     N.R.           DTOM   R*8     N.R.
      TM1   R*8     N.R.            TM4   R*8     N.R.            TM5   R*8     N.R.            TM7   R*8     N.R.
      TM8   R*8     N.R.           CMTR   R*8     N.R.           CKRM   R*8     N.R.            C2K   R*8     N.R.
      C2M   R*8     N.R.           REFC   R*8     N.R.
```

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    LABEL   ADDR               LABEL   ADDR               LABEL   ADDR               LABEL   ADDR            PAGE 005
         1  0002C2                  2  0002CA
*OPTIONS IN EFFECT*      NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
*STATISTICS*     SOURCE STATEMENTS =       59 ,PROGRAM SIZE =       750
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                          61K BYTES OF CORE NOT USED
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LEVEL 18 ( SEPT 69 )                    OS/360  FORTRAN H                                  DATE  70.196/18.54.33

          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                             SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002              SUBROUTINE EDIT                                                EDIT
                  C                                                                    EDIT
                  C-USES SLNT                                                          EDIT
                  C---THROW OUT DOPPLERS BELOW 7.5 DEG AS LONG AS 4 DOPPLER REMAIN     EDIT
                  C                                                                    EDIT
  ISN 0003              DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ             EDIT
  ISN 0004              DOUBLE PRECISION ONE,TWO,THRE,FIVF,ATE,TEN,D60,HUND,C480,S7P5  EDIT
  ISN 0005              DOUBLE PRECISION TOP1,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM      EDIT
  ISN 0006              DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                    EDIT
  ISN 0007              DOUBLE PRECISION DOP,REF,XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE EDIT
  ISN 0008              DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG  EDIT
  ISN 0009              DOUBLE PRECISION DUM1,DUM2,S1,OFST,DUM3,DUM4,DUM5              EDIT
  ISN 0010              DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN     EDIT
  ISN 0011              DOUBLE PRECISION T,TEMP                                        EDIT
  ISN 0012              DOUBLE PRECISION EE,EB                                         EDIT
                  C                                                                    EDIT
                  C---DIMENSIONS                                                       EDIT
  ISN 0013              DIMENSION DOP(8),REF(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)     EDIT
                  C                                                                    EDIT
                  C---COMMON                                                           EDIT
  ISN 0014              COMMON TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG                EDIT
  ISN 0015              COMMON DUM1,DUM2,S1,OFST,DUM3,DUM4,DUM5,DOP                    EDIT
  ISN 0016              COMMON REF                                                     EDIT
  ISN 0017              COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM    EDIT
  ISN 0018              COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN               EDIT
  ISN 0019              COMMON I,J,K,L,M,N,NDOP,ITER                                   EDIT
  ISN 0020              COMMON T,TEMP,EE,EB                                            EDIT
                  C                                                                    EDIT
  ISN 0021              COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF         EDIT
  ISN 0022              COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO            EDIT
  ISN 0023              COMMON /COMC/ONE,TWO,THRE,FOUR,FIVF,ATE,TEN,D60,HUND           EDIT
  ISN 0024              COMMON /COMC/C480,S7P5,TOP1,DTRA,DTOM                          EDIT
  ISN 0025              COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC        EDIT
                  C                                                                    EDIT
  ISN 0026              I=IONE                                                         EDIT
  ISN 0027              J=KM                                                           EDIT
  ISN 0028            1 IF (NDOP-IFOR)11,11,2                                          EDIT
  ISN 0029            2 K=I                                                            EDIT
  ISN 0030              CALL SLNT                                                      EDIT
  ISN 0031              EB=SELV                                                        EDIT
  ISN 0032              K=J                                                            EDIT
  ISN 0033              CALL SLNT                                                      EDIT
  ISN 0034              EE=SELV                                                        EDIT
  ISN 0035              IF (EE-S7P5) 4,4,5                                             EDIT
  ISN 0036            4 IF (EE-EB) 7,7,5                                               EDIT
  ISN 0037            5 IF (EB-S7P5) 6,6,11                                            EDIT
  ISN 0038            6 L=I                                                            EDIT
  ISN 0039              I=I+IONE                                                       EDIT
  ISN 0040              GO TO 8                                                        EDIT
  ISN 0041            7 L=J-IONE                                                       EDIT
  ISN 0042              J=L                                                            EDIT
  ISN 0043            8 IF (DOP(L)) 9,10,9                                             EDIT
  ISN 0044            9 DOP(L)=ZERO                                                    EDIT


                                                                                                      PAGE 002

  ISN 0045              NDOP=NDOP-IONE                                                 EDIT
  ISN 0046           10 GO TO 1                                                        EDIT
  ISN 0047           11 RETURN                                                         EDIT
  ISN 0048              END                                                            EDIT
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                                    /     EDIT /      SIZE OF PROGRAM 000192 HEXADECIMAL BYTES PAGE 003

NAME     TAG  TYPE  ADD.      NAME     TAG  TYPE  ADD.      NAME     TAG  TYPE  ADD.      NAME     TAG  TYPE  ADD.
    E      C  R*8     N.R.       I SF   C  I*4  0002F8        J SF   C  I*4  0002FC        K S    C  I*4  000300
    L SF   C  I*4   000304       M      C  I*4    N.R.        N      C  I*4    N.R.        T      C  R*8    N.R.
   AO      C  R*8     N.R.      CI      C  R*8    N.R.       EB S    C  R*8  000330       EE S    C  R*8  000328
   IM      C  I*4     N.R.      XF      C  I*4    N.R.       KM  F   C  I*4  000020       SI      C  R*8    N.R.
   TP      C  R*8     N.R.      VN      C  R*8    N.R.       XS      C  R*8    N.R.       YS      C  R*8    N.R.
   ZS      C  R*8     N.R.     ATE      C  R*8    N.R.      C2K      C  R*8    N.R.      C2M      C  R*8    N.R.
  DOP S    C  R*8   000088     DTK      C  R*8    N.R.      D60      C  R*8    N.R.      I15      C  I*4    N.R.
  I30      C  I*4     N.R.     ONE      C  R*8    N.R.      REF      C  R*8    N.R.      RSQ      C  R*8    N.R.
  TAW      C  R*8     N.R.     TEN      C  R*8    N.R.      TM1      C  R*8    N.R.      TM4      C  R*8    N.R.
  TM5      C  R*8     N.R.     TM7      C  R*8    N.R.      TM8      C  R*8    N.R.      TWO      C  R*8    N.R.
 CKRM      C  R*8     N.R.    CMTR      C  R*8    N.R.     COMD      C  R*8    N.R.     COME      C  R*8    N.R.
 CVCG      C  R*8     N.R.    C480      C  R*8    N.R.     DLAT      C  R*8    N.R.     DLON      C  R*8    N.R.
 DTOM      C  R*8     N.R.    DTPA      C  R*8    N.R.     DUM1      C  R*8    N.R.     DUM2      C  R*8    N.R.
 DUM3      C  R*8     N.R.    DUM4      C  R*8    N.R.     DUM5      C  R*8    N.R.     EDIT         R*4  000078
 EFRQ      C  R*8     N.R.    ELAT      C  R*8    N.R.     ELON      C  R*8    N.R.     FFRQ      C  R*8    N.R.
 FIVE      C  R*8     N.R.    FLAT      C  R*8    N.R.     FLON      C  R*8    N.R.     FOUR      C  R*8    N.R.
 GEOM      C  R*8     N.R.    HEAD      C  R*8    N.R.     HUND      C  R*8    N.R.     IDAY      C  I*4    N.R.
 IFOR      C  I*4   00000C    IONE  F   C  I*4  000004     ITER      C  I*4    N.R.     ITWO      C  I*4    N.R.
 I365      C  I*4     N.R.    MDAY      C  I*4    N.R.     NOOP SF   C  I*4  000310     NULL      C  I*4    N.R.
 OFST      C  R*8     N.R.    OMGE      C  R*8    N.R.     RATE      C  R*8    N.R.     REFC      C  R*8    N.R.
 SELV  F   C  R*8   0002C8    SLNT SF  XF  R*4  000000     SMXE      C  R*8    N.R.     SOMD      C  R*8    N.R.
 SOME      C  R*8     N.R.    STIM      C  R*8    N.R.     STPS      C  R*8  000088     TEMP      C  R*8    N.R.
 THRE      C  R*8     N.R.    TOPI      C  R*8    N.R.     WAVE      C  R*8    N.R.     XLMG      C  R*8    N.R.
 XNDT      C  R*8     N.R.    XOSQ      C  R*8    N.R.     ZERO  F   C  R*8  000060     ZOSQ      C  R*8    N.R.

                                   *****  COMMON INFORMATION   *****

   NAME OF COMMON.BLOCK  *       *   SIZE OF BLOCK    000338 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
      TP   R*8     N.R.           XNDT   R*8     N.R.           SOME   R*8     N.R.           SOMD   R*8     N.R.
       E   R*8     N.R.             AO   R*8     N.R.           COME   R*8     N.R.           COMD   R*8     N.R.
      CI   R*8     N.R.           XLMG   R*8     N.R.           DUM1   R*8     N.R.           DUM2   R*8     N.R.
      SI   R*8     N.R.           OFST   R*8     N.R.           DUM3   R*8     N.R.           DUM4   R*8     N.R.
    DUM5   R*8     N.R.            DOP   R*8   000088            REF   R*8     N.R.             XS   R*8     N.R.
      YS   R*8     N.R.             ZS   R*8     N.R.            DTK   R*8     N.R.           ELAT   R*8     N.R.
    ELON   R*8     N.R.           GEOM   R*8     N.R.           HEAD   R*8     N.R.           RATE   R*8     N.R.
    IDAY   I*4     N.R.           MDAY   I*4     N.R.           STIM   R*8     N.R.           DLAT   R*8     N.R.
    DLON   R*8     N.R.           SMXE   R*8     N.R.           SELV   R*8   0002C8           FLAT   R*8     N.R.
    FLON   R*8     N.R.           FFRQ   R*8     N.R.            RSQ   R*8     N.R.             VN   R*8     N.R.
       I   I*4   0002F8              J   I*4   0002FC              K   I*4   000300              L   I*4   000304
       M   I*4     N.R.              N   I*4     N.R.           NOOP   I*4   000310           ITER   I*4     N.R.
       T   R*8     N.R.           TEMP   R*8     N.R.             EE   R*8   000328             EB   R*8   000330

   NAME OF COMMON BLOCK  *  CONC*   SIZE OF BLOCK    000128 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
    NULL   I*4     N.R.           IONE   I*4   000004           ITWO   I*4     N.R.           IFOR   I*4   00000C
     I15   I*4     N.R.            I30   I*4     N.R.           I365   I*4     N.R.             IM   I*4     N.R.
      KM   I*4   000020             XF   I*4     N.R.            TAW   R*8     N.R.           WAVE   R*8     N.R.
    CVCG   R*8     N.R.           EFRQ   R*8     N.R.           OMGE   R*8     N.R.           XOSQ   R*8     N.R.

                                                                                        PAGE 004

    ZOSQ   R*8     N.R.           ZERO   R*8   000060            ONE   R*8     N.R.            TWO   R*8     N.R.
    THRE   R*8     N.R.           FOUR   R*8     N.R.           FIVE   R*8     N.R.            ATE   R*8     N.R.
     TEN   R*8     N.R.            D60   R*8     N.R.           HUND   R*8     N.R.           C480   R*8     N.R.
    STPS   R*8   000088           TOPI   R*8     N.R.           DTRA   R*8     N.R.           DTOM   R*8     N.R.
     TM1   R*8     N.R.            TM4   R*8     N.R.            TM5   R*8     N.R.            TM7   R*8     N.R.
     TM8   R*8     N.R.           CMTR   R*8     N.R.           CKRM   R*8     N.R.            C2K   R*8     N.R.
     C2M   R*8     N.R.           REFC   R*8     N.R.
```

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   LABEL   ADDR                LABEL   ADDR                LABEL   ADDR                LABEL   ADDR            PAGE 005

       1  0000A8                   2  0000B8                   4  0000F8                   5  000104
       6  000114                   7  00012C                   8  000140                   9  000152
      10  00016A                  11  00016E

*OPTIONS IN EFFECT*      NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*     SOURCE STATEMENTS    =      47 ,PROGRAM SIZE =      402

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                      61K BYTES OF CORE NOT USED
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LEVEL 18 ( SEPT 69 )                    OS/360  FORTRAN H                                        DATE  70.196/18.54.41

          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                             SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002             SUBROUTINE ALRT                                               ALRT
                C                                                                    ALRT
                C-USES AVIS WHICH USES SLNT AND SXYZ                                 ALRT
                C                                                                    ALRT
  ISN 0003             DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMCE,XOSQ,ZOSQ            ALRT
  ISN 0004             DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5 ALRT
  ISN 0005             DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM     ALRT
  ISN 0006             DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                   ALRT
  ISN 0007             DOUBLE PRECISION DOP,XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE   ALRT
  ISN 0008             DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG ALRT
  ISN 0009             DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5             ALRT
  ISN 0010             DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN    ALRT
  ISN 0011             DOUBLE PRECISION T,TEMP,A                                     ALRT
  ISN 0012             DOUBLE PRECISION DEK,DAK,DNK                                  ALRT
  ISN 0013             DOUBLE PRECISION DUM                                          ALRT
  ISN 0014             DOUBLE PRECISION AELV                                         ALRT
  ISN 0015             DOUBLE PRECISION TO  ,RISE,XMIN                               ALRT
                C                                                                    ALRT
                C---DIMENSIONS                                                       ALRT
  ISN 0016             DIMENSION DOP(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)           ALRT
  ISN 0017             DIMENSION DUM(5),A(3,4)                                       ALRT
                C                                                                    ALRT
                C---COMMON                                                           ALRT
  ISN 0018             COMMON TP,XNDT,SOME,SOMD,F,AO,COME,COMD,CI,XLMG               ALRT
  ISN 0019             COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DUP                   ALRT
  ISN 0020             COMMON DEK,DAK,DNK,DUM                                        ALRT
  ISN 0021             COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM   ALRT
  ISN 0022             COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN              ALRT
  ISN 0023             COMMON I,J,K,L,M,N,NDOP,ITER                                  ALRT
  ISN 0024             COMMON T,TEMP,A                                               ALRT
  ISN 0025             COMMON TO  ,RISE,AELV,XMIN                                    ALRT
                C                                                                    ALRT
  ISN 0026             COMMON /CONC/NULL,IONE,ITWO,IFOR,I15,I30,[illegible],IM,KM,KF ALRT
  ISN 0027             COMMON /CONC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO           ALRT
  ISN 0028             COMMON /CONC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND          ALRT
  ISN 0029             COMMON /CONC/C480,S7P5,TOPI,DTRA,DTOM                         ALRT
  ISN 0030             COMMON /CONC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC       ALRT
                C                                                                    ALRT
  ISN 0031             EQUIVALENCE (ISTP,NDOP),(IELV,ITER)                           ALRT
  ISN 0032           1 FORMAT (1H1,3HDAY,3X,4HRISE,3X,4HELEV)                        ALRT
  ISN 0033             ISTP=MDAY-IDAY                                                ALRT
  ISN 0034             IF (ISTP) 2,13,3                                              ALRT
  ISN 0035           2 ISTP=ISTP+I365                                                ALRT
  ISN 0036           3 TO=T-18.0D0                                                   ALRT
  ISN 0037             T=TO-TEN                                                      ALRT
  ISN 0038             WRITE (6,1)                                                   ALRT
  ISN 0039           4 T=T+TEN                                                       ALRT
  ISN 0040             CALL AVIS                                                     ALRT
  ISN 0041             IF (SELV) 4,4,5                                               ALRT
  ISN 0042           5 T=T-TEN                                                       ALRT
  ISN 0043           6 T=T+TWO                                                       ALRT
  ISN 0044             CALL AVIS                                                     ALRT
  ISN 0045             IF (SELV) 6,7,7                                               ALRT

                                                                                                                  PAGE 002

  ISN 0046           7 RISE=STIM+T-TO                                                ALRT
  ISN 0047           8 AELV=SELV                                                     ALRT
  ISN 0048             T=T+2.5D-1                                                    ALRT
  ISN 0049             CALL AVIS                                                     ALRT
  ISN 0050             IF (SELV-AELV) 9,8,8                                          ALRT
  ISN 0051           9 CALL ARCS (AELV)                                              ALRT
  ISN 0052             IELV=AELV                                                     ALRT
  ISN 0053             I=RISE/DTOM                                                   ALRT
  ISN 0054             K=I+IDAY                                                      ALRT
  ISN 0055             IF (K-I365) 11,11,10                                          ALRT
  ISN 0056          10 K=K-I365                                                      ALRT
  ISN 0057          11 TEMP=I                                                        ALRT
  ISN 0058             RISE=RISE-DTOM*TEMP                                           ALRT
  ISN 0059             TEMP=RISE*CMTR                                                ALRT
  ISN 0060             CALL UCON                                                     ALRT
  ISN 0061             WRITE (6,12) K,L,M,IELV                                       ALRT
  ISN 0062          12 FORMAT (1H,I3,3X,2I2,4X,I2)                                   ALRT
  ISN 0063             IF (I-ISTP) 4,4,13                                            ALRT
  ISN 0064          13 RETURN                                                        ALRT
  ISN 0065             END                                                           ALRT
```

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                                   /     ALRT /      SIZE OF PROGRAM 000310 HEXADECIMAL BYTES PAGE 003

NAME     TAG   TYPE  ADD.        NAME     TAG   TYPE  ADD.        NAME     TAG   TYPE  ADD.        NAME     TAG   TYPE  ADD.
   A        C  R*8     N.R.         E        C  R*8     N.R.         I SF     C  I*    0002F8         J        C  I*4     N.R.
   K SF     C  I*4   000300         L  F     C  I*4   000304         M  F     C  I*4   000308         N        C  I*4     N.R.
   T SF     C  R*8   000318        AO        C  R*8     N.R.        CI        C  R*8     N.R.        IM        C  I*4     N.R.
  KF        C  I*4     N.R.        KM        C  I*4     N.R.        SI        C  R*8     N.R.        TO SF     C  R*8   000388
  TP        C  R*8     N.R.        VN        C  R*8     N.R.        XS        C  R*8     N.R.        YS        C  R*8     N.R.
  ZS        C  R*8     N.R.       ATE        C  R*8     N.R.       C2K        C  R*8     N.R.       C2M        C  R*8     N.R.
 DAK        C  R*8     N.R.       DEK        C  R*8     N.R.       DNK        C  R*8     N.R.       DOP        C  R*8     N.R.
 DTK        C  R*8     N.R.       DUM        C  R*8     N.R.       D60        C  R*8     N.R.       I15        C  I*4     N.R.
 I30        C  I*4     N.R.       ONE        C  R*8     N.R.       RSQ        C  R*8     N.R.       TAW        C  R*8     N.R.
 TEN  F     C  R*8   000098       TM1        C  R*8     N.R.       TM4        C  R*8     N.R.       TM5        C  R*8     N.R.
 TM7        C  R*8     N.R.       TM8        C  R*8     N.R.       TWO  F     C  R*8   000070      AELV SFA    C  R*8   000398
ALRT           R*4   0000CC      ARCS SF   XF  R*4   000000      AVIS SF   XF  R*4   000000      CKRM        C  R*8     N.R.
CMTR  F     C  R*8   000100      COMD        C  R*8     N.R.      COME        C  R*8     N.R.      CVCG        C  R*8     N.R.
C480        C  R*8     N.R.      DLAT        C  R*8     N.R.      DLON        C  R*8     N.R.      DTOM  F     C  R*8   000000
CTRA        C  R*8     N.R.      DUM1        C  R*8     N.R.      DUM2        C  R*8     N.R.      DUM3        C  R*8     N.R.
DUM4        C  R*8     N.R.      DUM5        C  R*8     N.R.      EFRQ        C  R*8     N.R.      ELAT        C  R*8     N.R.
ELON        C  R*8     N.R.      FFRQ        C  R*8     N.R.      FIVE        C  R*8     N.R.      FLAT        C  R*8     N.R.
FLON        C  R*8     N.R.      FOUR        C  R*8     N.R.      GEOH        C  R*8     N.R.      HEAD        C  R*8     N.R.
HUND        C  R*8     N.R.      IDAY  F     C  I*4   000220      IELV SF   CE  I*4   000314      IFOR        C  I*4     N.R.
IONE        C  I*4     N.R.      ISTP SF   CE  I*4   000310      ITER      CE  I*4   000314      ITWO        C  I*4     N.R.
I365  F     C  I*4   000018      MDAY  F     C  I*4   000224      NDOF      CE  I*4   000310      NULL        C  I*4     N.R.
OFST        C  R*8     N.R.      OMGE        C  R*8     N.R.      RATE        C  R*8     N.R.      REFC        C  R*8     N.R.
RISE SF     C  R*8   000390      SELV  F     C  R*8   0002C8      SMXE        C  R*8     N.R.      SOMD        C  R*8     N.R.
SUME        C  R*8     N.R.      STIM  F     C  R*8   000228      S7P5        C  R*8     N.R.      TEMP SF     C  R*8   000320
THRE        C  R*8     N.R.      TOPI        C  R*8     N.R.      UCON SF   XF  R*4   000000      WAVE        C  R*8     N.R.
XLMG        C  R*8     N.R.      XMIN        C  R*8     N.R.      XNOT        C  R*8     N.R.      XOSQ        C  R*8     N.R.
ZERO        C  R*8     N.R.      ZOSD        C  R*8     N.R.     IBCOM  F   XF  R*4   000000

                                    *****  COMMON INFORMATION   *****

  NAME OF COMMON BLOCK  *       *   SIZE OF BLOCK   0003A8 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.    VAR. NAME  TYPE  REL. ADDR.
      TP    R*8     N.R.           XNOT    R*8     N.R.           SOME    R*8     N.R.           SOMD    R*8     N.R.
       E    R*8     N.R.             AO    R*8     N.R.           COME    R*8     N.R.           COMD    R*8     N.R.
      CI    R*8     N.R.           XLMG    R*8     N.R.           DUM1    R*8     N.R.           DUM2    R*8     N.R.
      SI    R*8     N.R.           OFST    R*8     N.R.           DUM3    R*8     N.R.           DUM4    R*8     N.R.
    DUM5    R*8     N.R.            DOP    R*8     N.R.            DEK    R*8     N.R.            DAK    R*8     N.R.
     DNK    R*8     N.R.            DUM    R*8     N.R.             XS    R*8     N.R.             YS    R*8     N.R.
      ZS    R*8     N.R.            DTK    R*8     N.R.           ELAT    R*8     N.R.           ELON    R*8     N.R.
    GEOH    R*8     N.R.           HEAD    R*8     N.R.           RATE    R*8     N.R.           IDAY    I*4   000220
    MDAY    I*4   000224           STIM    R*8   000228           DLAT    R*8     N.R.           DLON    R*8     N.R.
    SMXE    R*8     N.R.           SELV    R*8   0002C8           FLAT    R*8     N.R.           FLON    R*8     N.R.
    FFRQ    R*8     N.R.            RSQ    R*8     N.R.             VN    R*8     N.R.              I    I*4   0002F8
       J    I*4     N.R.              K    I*4   000300              L    I*4   000304              M    I*4   000308
       N    I*4     N.R.           NDOP    I*4   000310           ITER    I*4   000314              T    R*8   000318
    TEMP    R*8   000320              A    R*8     N.R.             TO    R*8   000388           RISE    R*8   000390
    AELV    R*8   000398           XMIN    R*8     N.R.

EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK
  VARIABLE  OFFSET               VARIABLE  OFFSET               VARIABLE  OFFSET               VARIABLE  OFFSET
    ISTP    000310                 IELV    000314
```

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                                                                                                              PAGE 004

   NAME OF COMMON BLOCK  *  COMC*   SIZE OF BLOCK    0001C8 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
    NULL   I*4      N.R.           IONE  I*4      N.R.           ITWO  I*4      N.R.           IFOR  I*4      N.R.
     I15   I*4      N.R.            I30  I*4      N.R.           I365  I*4    000018             IM  I*4      N.R.
      KM   I*4      N.R.             KF  I*4      N.R.            TAW  R*8      N.R.           WAVE  R*8      N.R.
    CVCG   R*8      N.R.           EFRQ  R*8      N.R.           OMGE  R*8      N.R.           XOSQ  R*8      N.R.
    ZOSQ   R*8      N.R.           ZERO  R*8      N.R.            ONE  R*8      N.R.            TWO  R*8    000070
    THRE   R*8      N.R.           FOUR  R*8      N.R.           FIVE  R*8      N.R.            ATE  R*8      N.R.
     TEN   R*8    000098            DEG  R*8      N.R.           HUND  R*8      N.R.           C480  R*8      N.R.
    STP5   R*8      N.R.           TOPI  R*8      N.R.           DTRA  R*8      N.R.           DTOM  R*8    0000D0
     TM1   R*8      N.R.            TM4  R*8      N.R.            TM5  R*8      N.R.            TM7  R*8      N.R.
     TM8   R*8      N.R.           CMTR  R*8    0001C0           CNRM  R*8      N.R.            C2K  R*8      N.R.
     C2M   R*8      N.R.           PEFC  R*8      N.R.
```

```
  LABEL   ADDR             LABEL   ADDR             LABEL   ADDR             LABEL   ADDR          PAGE 0

      2  000110                3  000120                4  00014C                5  000170
      6  000180                7  0001AC                8  00018C                9  0001EE
     10  000254               11  000258               13  0002EC

*OPTIONS IN EFFECT*     NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*     SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*     SOURCE STATEMENTS =      64 ,PROGRAM SIZE =      784

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                          61K BYTES OF CORE NOT USED
```

```
FORTRAN IV G LEVEL  21              AVIS            DATE = 76197          11/06/16              PAGE 0001
0001                 SUBROUTINE AVIS                                                               AVIS
               C                                                                                   AVIS
               C                                                                                   AVIS
0002                 DOUBLE PRECISION TAU,WAVE,CVEL,FREQ,OMGE,XOSQ,ZOSQ                            AVIS
0003                 DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5                 AVIS
0004                 DOUBLE PRECISION TOPI,DTRA,DION,TM1,TM4,TM5,TM8,CMTR,CKRM                     AVIS
0005                 DOUBLE PRECISION ZERO,FOUR,TM7,C2R,C2M,PERC                                   AVIS
0006                 DOUBLE PRECISION DOP,DTR,XS,YS,ZS,ELAT,ELON,GEON,STIM,HEAD,DATE               AVIS
0007                 DOUBLE PRECISION DAT,TP,XNDT,SOPE,SOMD,E,XO,COME,COMD,CI,ALMO                 AVIS
0008                 DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5                             AVIS
0009                 DOUBLE PRECISION DLAT,DLON,SMAL,SELV,FLAT,FLON,FFRQ,RSQ,VA                    AVIS
0010                 DOUBLE PRECISION T,TEMP,A                                                     AVIS
0011                 DOUBLE PRECISION TO                                                           AVIS
0012                 DOUBLE PRECISION DZK,DAK,DNK                                                  AVIS
               C                                                                                   AVIS
               C---DIMENSIONS                                                                      AVIS
0013                 DIMENSION DOP(8),DUT(9),XS(9),YS(9),ZS(11),ELAT(9),ELON(9)                    AVIS
0014                 DIMENSION A(3,4)                                                              AVIS
               C                                                                                   AVIS
               C---COMMON                                                                          AVIS
0015                 COMMON TP,XNDT,SOPE,SOMD,E,XO,COME,COMD,CI,ALMO                               AVIS
0016                 COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                                   AVIS
0017                 COMMON DZK,DAK,DNK,DUM                                                        AVIS
0018                 COMMON XS,YS,ZS,DTR,ELAT,ELON,GEON,HEAD,DATE,IDAY,FDAY,STIM                   AVIS
0019                 COMMON DLAT,DLON,SMAL,SELV,FLAT,FLON,FFRQ,RSQ,VA                              AVIS
0020                 COMMON I,J,K,L,M,N,NDOP,ITER                                                  AVIS
0021                 COMMON T,TEMP,A                                                               AVIS
0022                 COMMON TO                                                                     AVIS
               C                                                                                   AVIS
0023                 COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,KR,KN,KF                        AVIS
0024                 COMMON /COMC/TAU,WAVE,CVEL,FREQ,OMGE,XOSQ,ZOSQ,ZERO                           AVIS
0025                 COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND                          AVIS
0026                 COMMON /COMC/C480,S7P5,TOPI,DTRA,DION                                         AVIS
0027                 COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2R,C2M,PERC                       AVIS
               C                                                                                   AVIS
               C-USES SLNT AND SAYZ TO GET SINE OF ELEVATION ANGLE                                 AVIS
0028                 N=IONE                                                                        AVIS
0029                 DZK=ZERO                                                                      AVIS
0030                 DAK=ZERO                                                                      AVIS
0031                 DNK=ZERO                                                                      AVIS
0032                 CALL SAYZ                                                                     AVIS
0033                 CALL SLNT                                                                     AVIS
0034                 RETURN                                                                        AVIS
0035                 END                                                                           AVIS
```

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FORTRAN IV G LEVEL  18                AVIS               DATE = 70197          11/06/18           PAGE 0002

                              COMMON BLOCK /          / MAP SIZE      390
SYMBOL     LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION
TP                0      XNDT             8      SOME            10      SOMD            18      E               20
AO               28      COME            30      COMD            38      CI              40      XLNG            48
DUM1             50      DUM2            58      SI              60      OFST            68      DUM3            70
DUM4             78      DUM5            80      DOP             88      DEK             C8      DAK             D0
DMK              D8      DUM             E0      XS             108      YS             150      ZS             158
DTK             1F0      ELAT           1F8      ELON           200      GEOM           208      HEAD           210
RATE            218      IDAY           220      MDAY           224      STIM           228      SLAT           230
DLON            278      SMXE           2C0      SELV           2C8      FLAT           2D0      FLOW           2D8
FFRQ            2E0      NSQ            2E8      VN             2F0      I              2F8      J              2FC
K               300      L              304      M              308      N              30C      NDOP           310
ITER            314      T              318      TEMP           320      A              328      TO             388

                              COMMON BLOCK /COMC    / MAP SIZE      128
SYMBOL     LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION
NULL              0      IONE             4      ITWO             8      IFOR             C      I15             10
I30              14      [illegible]     18      IN              1C      KE              20      K2              24
[illegible]      28      WAVE            30      CVEL            38      EFRQ            40      OMGE            48
[illegible]      50      ZOSQ            58      ZERO            60      ONE             68      TWO             70
THRE             78      FOUR            80      FIVE            88      ATE             90      [illegible]     98
[illegible]      AC      HUND            A8      C480            B0      S7P5            B8      TOPI            C0
[illegible]      C8      LTOM            D0      TM1             D8      TP4             E0      TM5             E8
[illegible]      F0      TM8             F8      CNTR           100      CKEE           108      C2N            110
C2M             118      REFC           120

                              SUBPROGRAMS CALLED
SYMBOL     LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION      SYMBOL    LOCATION
SATZ             98      SLAT            9C

    *OPTIONS IN EFFECT*  ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,MAP
    *OPTIONS IN EFFECT*  NAME = AVIS    , LINECNT =       58
    *STATISTICS*    SOURCE STATEMENTS =        [illegible]5,PROGRAM SIZE =       322
    *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
LEVEL 18 ( SEPT 69 )                    OS/360  FORTRAN H                                   DATE  70.196/18.54.52

          COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                             SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002              SUBROUTINE ARCS (ARG)                                          ARCS
  ISN 0003              DOUBLE PRECISION ARG,X                                         ARCS
  ISN 0004              X=.5D+0                                                        ARCS
                C--THE ACCURACY IS DEPENDENT UPON THE NUMBER OF ITERATIONS             ARCS
  ISN 0005              DO 1 I=1,6                                                     ARCS
  ISN 0006            1 X=X+(ARG-DSIN(X))/DCOS(X)                                      ARCS
  ISN 0007              ARG=X*.572957795131D+2                                         ARCS
  ISN 0008              RETURN                                                         ARCS
  ISN 0009              END                                                            ARCS
```

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                                                  /     ARCS /     SIZE OF PROGRAM 000166 HEXADECIMAL BYTES PAGE 002

NAME     TAG   TYPE  ADD.        NAME     TAG   TYPE  ADD.        NAME     TAG   TYPE  ADD.        NAME     TAG   TYPE  ADD.
    I SF       I*4  000098           X SFA      R*8  0000A0         ARG SF       R*8  0000A8        ARCS            R*4  00009C
 DCOS      XF  R*8  000000        DSIN      XF  R*8  000000
```

```
    LABEL    ADDR                 LABEL    ADDR                 LABEL    ADDR                 LABEL    ADDR           PAGE 003
       1  0000DC
*OPTIONS IN EFFECT*      NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
*STATISTICS*     SOURCE STATEMENTS =       8 ,PROGRAM SIZE =      358
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                      65K BYTES OF CORE NOT USED
```

```
LEVEL 18 ( SEPT 69 )                      OS/360  FORTRAN H                                    DATE  70.196/18.53.59

        COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                           SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002              SUBROUTINE TYPE                                                TYPE
                  C                                                                    TYPE
  ISN 0003              DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ             TYPE
  ISN 0004              DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5  TYPE
  ISN 0005              DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM      TYPE
  ISN 0006              DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                    TYPE
  ISN 0007              DOUBLE PRECISION DOP,REF,XS,YS,ZS,ELAT,ELON,GEOH,STIM,HEAD,RATE TYPE
  ISN 0008              DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG  TYPE
  ISN 0009              DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5              TYPE
  ISN 0010              DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN     TYPE
  ISN 0011              DOUBLE PRECISION T,TEMP,A                                      TYPE
                  C                                                                    TYPE
  ISN 0012              DOUBLE PRECISION EDOT,A1,A2,A3,A4,A5                           TYPE
  ISN 0013              DOUBLE PRECISION TEMP1,TEMP2,TEMP3,S2LAT                       TYPE
  ISN 0014              DOUBLE PRECISION V,W,DLATS,DLONS,C4P8                          TYPE
  ISN 0015              DOUBLE PRECISION TEMP4,TEMP5                                   TYPE
                  C                                                                    TYPE
                  C                                                                    TYPE
                  C---DIMENSION                                                        TYPE
  ISN 0016              DIMENSION A(3,4)                                               TYPE
  ISN 0017              DIMENSION DOP(8),REF(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)     TYPE
                  C                                                                    TYPE
                  C---COMMON                                                           TYPE
  ISN 0018              COMMON TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG                TYPE
  ISN 0019              COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                    TYPE
  ISN 0020              COMMON REF                                                     TYPE
  ISN 0021              COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOH,HEAD,RATE,IDAY,MDAY,STIM    TYPE
  ISN 0022              COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN               TYPE
  ISN 0023              COMMON I,J,K,L,M,N,NDOP,ITER                                   TYPE
  ISN 0024              COMMON T,TEMP,A                                                TYPE
                  C                                                                    TYPE
  ISN 0025              COMMON /COMC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF         TYPE
  ISN 0026              COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO            TYPE
  ISN 0027              COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND           TYPE
  ISN 0028              COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM                          TYPE
  ISN 0029              COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC        TYPE
                  C                                                                    TYPE
  ISN 0030              EQUIVALENCE (A(1,1),EDOT )                                     TYPE
  ISN 0031              EQUIVALENCE (A(1,3),TEMP1),(A(1,4),TEMP2)                      TYPE
  ISN 0032              EQUIVALENCE (A(2,1),TEMP3),(A(2,2),S2LAT)                      TYPE
  ISN 0033              EQUIVALENCE (A(2,3),V    ),(A(2,4),W    )                      TYPE
  ISN 0034              EQUIVALENCE (A(3,1),DLATS),(A(3,2),DLONS)                      TYPE
  ISN 0035              EQUIVALENCE (A(3,3),TEMP4),(A(3,4),TEMP5)                      TYPE
                  C                                                                    TYPE
  ISN 0036              I=0                                                            TYPE
  ISN 0037           19 TEMP4=((FFRQ-EFRQ)/D60)*HUND                                   TYPE
  ISN 0038              TEMP5=EFRQ/2.4D+4                                              TYPE
  ISN 0039              WRITE(8,110) TEMP4,TEMP5                                       TYPE
  ISN 0040          110 FORMAT(F7.1,F9.5)                                              TYPE
  ISN 0041              TEMP=SMXE                                                      TYPE
  ISN 0042              CALL ARCS(TEMP)                                                TYPE
  ISN 00                WRITE(8,111) TEMP                                              TYPE
  ISN 0044          111 FORMAT(F5.1)                                                   TYPE

                                                                                                       PAGE 002

  ISN 0045              TEMP=(STIM+FOUR)*CMTR                                          TYPE
  ISN 0046              CALL UCON                                                      TYPE
  ISN 0047              WRITE(8,112) L,M                                               TYPE
  ISN 0048          112 FORMAT(I2,I2)                                                  TYPE
  ISN 0049              WRITE(8,113) NDOP                                              TYPE
  ISN 0050          113 FORMAT(I2)                                                     TYPE
  ISN 0051              WRITE(8,113) ITER                                              TYPE
  ISN 0052          190 TEMP=((FLAT-ELAT)/DTRA)*D60                                    TYPE
  ISN 0053              TEMP1=(((FLON-ELON)*DCOS(FLAT))/DTRA)*D60                      TYPE
  ISN 0054              TEMP3=FLAT/DTRA                                                TYPE
  ISN 0055              J=TEMP3                                                        TYPE
  ISN 0056              TEMP3=DABS((TEMP3-DBLE(FLOAT(J)))*D60)                         TYPE
  ISN 0057              TEMP4=FLON/DTRA                                                TYPE
  ISN 0058              K=TEMP4                                                        TYPE
  ISN 0059              TEMP4=DABS((TEMP4-DBLE(FLOAT(K)))*D60)                         TYPE
  ISN 0060              WRITE(8,114) J,TEMP3,TEMP,K,TEMP4,TEMP1                        TYPE
  ISN 0061          114 FORMAT (I4,F7.4,F8.4,I4,F7.4,F8.4)                             TYPE
  ISN 0062              IF (I) 103,102,102                                             TYPE
  ISN 0063          102 EDOT=0.67393780D-02                                            TYPE
  ISN 0064              A1=-0.93137062D+0                                              TYPE
  ISN 0065              A2=0.21343908D+01                                              TYPE
  ISN 0066              A3=0.13582489D+01                                              TYPE
  ISN 0067              A4=0.11599867D-02                                              TYPE
  ISN 0068              A5=-0.34166622D+0                                              TYPE
  ISN 0069              TEMP =DSIN(FLAT)                                               TYPE
  ISN 0070              TEMP1=DCOS(FLAT)                                               TYPE
  ISN 0071              TEMP2=DSIN(FLON)                                               TYPE
  ISN 0072              TEMP3=DCOS(FLON)                                               TYPE
  ISN 0073              S2LAT=TEMP*TEMP                                                TYPE
  ISN 0074              V=ONE+EDOT*(ONE-THRE*S2LAT/TWO)                                TYPE
  ISN 0075              W=ONE-(EDOT*S2LAT/TWO)                                         TYPE
  ISN 0076              DLATS=((A1*TEMP3+A2*TEMP2)*TEMP+A3*TEMP1)*V                    TYPE
                       1      +(A4*S2LAT+A5)*TEMP*TEMP1                                TYPE
  ISN 0077              DLONS=(A1*TEMP2-A2*TEMP3)*W/TEMP1                              TYPE
  ISN 0078              C4P8=4.848136811D-06                                           TYPE
  ISN 0079              FLAT=FLAT+C4P8*DLATS                                           TYPE
  ISN 0080              FLON=FLON+C4P8*DLONS                                           TYPE
  ISN 0081              I=-1                                                           TYPE
  ISN 0082              GO TO 190                                                      TYPE
  ISN 0083          103 RETURN                                                         TYPE
  ISN 0084              END                                                            TYPE
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                                        /     TYPE /      SIZE OF PROGRAM 000550 HEXADECIMAL BYTES PAGE 003

NAME    TAG   TYPE  ADD.         NAME    TAG   TYPE  ADD.         NAME    TAG   TYPE  ADD.         NAME    TAG   TYPE  ADD.
    A      CE  R*8  000328          E       C  R*8    N.R.          I S      C  I*4  0002F8          J SFA   C  I*4  0002FC
    K SFA   C  I*4  000300          L  F    C  I*4  000304          M  F     C  I*4  000308          N       C  I*4    N.R.
    T       C  R*8    N.R.          V SF   CE  R*8  000360          W SF    CE  R*8  000378         AO       C  R*8    N.R.
   A1 SF       R*8  000120         A2 SF       R*8  000128         A3 SF        R*8  000130         A4 SF      R*8  000138
   A5 SF       R*8  000140         CI       C  R*8    N.R.         IM        C  I*4    N.R.         KF       C  I*4    N.R.
   KM       C  I*4    N.R.         SI       C  R*8    N.R.         TP        C  R*8    N.R.         VN       C  R*8    N.R.
   XS       C  R*8    N.R.         YS       C  R*8    N.R.         ZS        C  R*8    N.R.        ATE       C  R*8    N.R.
  C2K       C  R*8    N.R.        C2M       C  R*8    N.R.        DOP        C  R*8    N.R.        DTK       C  R*8    N.R.
  D60   FA  C  R*8  0000A0        I15       C  I*4    N.R.        I30        C  I*4    N.R.        ONE  F    C  R*8  000068
  REF       C  R*8    N.R.        RSQ       C  R*8    N.R.        TAW        C  R*8    N.R.        TEN       C  R*8    N.R.
  TM1       C  R*8    N.R.        TM4       C  R*8    N.R.        TM5        C  R*8    N.R.        TM7       C  R*8    N.R.
  TM8       C  R*8    N.R.        TWO  F    C  R*8  000070       ARCS SF    XF  R*4  000000       CKRM       C  R*8    N.R.
 CMTR  F    C  R*8  000100       COMD       C  R*8    N.R.       COME        C  R*8    N.R.       CVCG       C  R*8    N.R.
 C4P8 SF       R*8  000148       C480       C  R*8    N.R.       DLAT        C  R*8    N.R.       DLON       C  R*8    N.R.
 DTCM       C  R*8    N.R.       DTRA  F    C  R*8  0000C8       DUM1        C  R*8    N.R.       DUM2       C  R*8    N.R.
 DUM3       C  R*8    N.R.       DUM4       C  R*8    N.R.       DUM5        C  R*8    N.R.       EDOT SF   CE  R*8  000328
 EFRQ  F    C  R*8  000040       ELAT  F    C  R*8  0001F8       ELON  F     C  R*8  000200       FFRQ  F    C  R*8  0002E0
 FIVE       C  R*8    N.R.       FLAT SFA   C  R*8  000200       FLON SFA    C  R*8  000208       FOUR  F    C  R*8  000080
 GEOM       C  R*8    N.R.       HEAD       C  R*8    N.R.       HUND  F     C  R*8  0000A8       IDAY       C  I*4    N.R.
 IFOR       C  I*4    N.R.       IONE       C  I*4    N.R.       ITER  F     C  I*4  000314       ITWO       C  I*4    N.R.
 I365       C  I*4    N.R.       MDAY       C  I*4    N.R.       NDOP  F     C  I*4  000310       NULL       C  I*4    N.R.
 OFST       C  R*8    N.R.       OMGE       C  R*8    N.R.       RATE        C  R*8    N.R.       REFC       C  R*8    N.R.
 SELV       C  R*8    N.R.       SMXE  F    C  R*8  0002C0       SOMD        C  R*8    N.R.       SOME       C  R*8    N.R.
 STIM  F    C  R*8  000228       S7P5       C  R*8    N.R.       TEMP SFA    C  R*8  000320       THRE  F    C  R*8  000078
 TOPI       C  R*8    N.R.       TYPE          R*4  00011C       UCON SF    XF  R*4  000000       WAVE       C  R*8    N.R.
 XLMG       C  R*8    N.R.       XNOT       C  R*8    N.R.       XOSQ        C  R*8    N.R.       ZERO       C  R*8    N.R.
 ZOSQ       C  R*8    N.R.      DLATS SF   CE  R*8  000338      DLONS SF    CE  R*8  000350      S2LAT SF   CE  R*8  000348
TEMP1 SF   CE  R*8  000358      TEMP2 SF   CE  R*8  000370      TEMP3 SFA   CE  R*8  000330      TEMP4 SFA  CE  R*8  000368
TEMP5 SF   CE  R*8  000380       DSIN      XF  R*8  000000       DCOS       XF  R*8  000000      IBCOM#  F  XF  R*8  000000

                                   *****  COMMON INFORMATION   *****

   NAME OF COMMON BLOCK  *       *   SIZE OF BLOCK    000388 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
      TP    R*8     N.R.           XNOT   R*8     N.R.           SOME   R*8     N.R.           SOMD   R*8     N.R.
       E    R*8     N.R.             AO   R*8     N.R.           COME   R*8     N.R.           COMD   R*8     N.R.
      CI    R*8     N.R.           XLMG   R*8     N.R.           DUM1   R*8     N.R.           DUM2   R*8     N.R.
      SI    R*8     N.R.           OFST   R*8     N.R.           DUM3   R*8     N.R.           DUM4   R*8     N.R.
    DUM5    R*8     N.R.            DOP   R*8     N.R.            REF   R*8     N.R.             XS   R*8     N.R.
      YS    R*8     N.R.             ZS   R*8     N.R.            DTK   R*8     N.R.           ELAT   R*8   0001F8
    ELON    R*8   000200           GEOM   R*8     N.R.           HEAD   R*8     N.R.           RATE   R*8     N.R.
    IDAY    I*4     N.R.           MDAY   I*4     N.R.           STIM   R*8   000228           DLAT   R*8     N.R.
    DLON    R*8     N.R.           SMXE   R*8   0002C0           SELV   R*8     N.R.           FLAT   R*8   000200
    FLON    R*8   000208           FFRQ   R*8   0002E0            RSQ   R*8     N.R.             VN   R*8     N.R.
       I    I*4   0002F8              J   I*4   0002FC              K   I*4   000300              L   I*4   000304
       M    I*4   000308              N   I*4     N.R.           NDOP   I*4   000310           ITER   I*4   000314
       T    R*8     N.R.           TEMP   R*8   000320              A   R*8   000328

EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK
  VARIABLE  OFFSET                VARIABLE  OFFSET                VARIABLE  OFFSET                VARIABLE  OFFSET
    EDOT    000328                  TEMP1   000358                  TEMP2   000370                  TEMP3   000330

                                                                                                   PAGE 004

   S2LAT    000348                      V   000360                      W   000378                  DLATS   000338
   DLONS    000350                  TEMP4   000368                  TEMP5   000380

   NAME OF COMMON BLOCK  *  COMC*   SIZE OF BLOCK    000128 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
    NULL    I*4     N.R.           IONE   I*4     N.R.           ITWO   I*4     N.R.           IFOR   I*4     N.R.
     I15    I*4     N.R.            I30   I*4     N.R.           I365   I*4     N.R.             IM   I*4     N.R.
      KM    I*4     N.R.             KF   I*4     N.R.            TAW   R*8     N.R.           WAVE   R*8     N.R.
    CVCG    R*8     N.R.           EFRQ   R*8   000040           OMGE   R*8     N.R.           XOSQ   R*8     N.R.
    ZOSQ    R*8     N.R.           ZERO   R*8     N.R.            ONE   R*8   000068            TWO   R*8   000070
    THRE    R*8   000078           FOUR   R*8   000080           FIVE   R*8     N.R.            ATE   R*8     N.R.
     TEN    R*8     N.R.            D60   R*8   0000A0           HUND   R*8   0000A8           C480   R*8     N.R.
    S7P5    R*8     N.R.           TOPI   R*8     N.R.           DTRA   R*8   0000C8           DTCM   R*8     N.R.
     TM1    R*8     N.R.            TM4   R*8     N.R.            TM5   R*8     N.R.            TM7   R*8     N.R.
     TM8    R*8     N.R.           CMTR   R*8   000100           CKRM   R*8     N.R.            C2K   R*8     N.R.
     C2M    R*8     N.R.           REFC   R*8     N.R.
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   LABEL   ADDR              LABEL   ADDR              LABEL   ADDR              LABEL   ADDR          PAGE 005
      19  000180 NR            190  00028A               102  00041E               103  00052C
*OPTIONS IN EFFECT*     NAME= MAIN,OPT=02,LINECNT=58,SIZE=0000K,
```

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*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
*STATISTICS*     SOURCE STATEMENTS =      83 ,PROGRAM SIZE =     1360
*STATISTICS*  NO  DIAGNOSTICS GENERATED
****** END OF COMPILATION ******                                    57K BYTES OF CORE NOT USED
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LEVEL 18 ( SEPT 69 )                     OS/360  FORTRAN H                                        DATE  70.196/18.54.59

         COMPILER OPTIONS - NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,
                            SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF
  ISN 0002            SUBROUTINE UCON
                C                                                                     UCON
                C                                                                     UCON
  ISN 0003            DOUBLE PRECISION TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ              UCON
  ISN 0004            DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5   UCON
  ISN 0005            DOUBLE PRECISION TUPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CMTR,CKRM       UCON
  ISN 0006            DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC                     UCON
  ISN 0007            DOUBLE PRECISION DOP,REF,DE,DA,DN,ELAT,ELON,GEOM,ETIM,HEAD,RATE UCON
  ISN 0008            DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG   UCON
  ISN 0009            DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5               UCON
  ISN 0010            DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN      UCON
  ISN 0011            DOUBLE PRECISION T,TEMP,A,DUM                                   UCON
  ISN 0012            DOUBLE PRECISION Y,Z                                            UCON
                C                                                                     UCON
                C---DIMENSIONS                                                        UCON
  ISN 0013            DIMENSION DOP(8),REF(9),DE(9),DA(9),DN(11),DLAT(9),DLON(9)      UCON
  ISN 0014            DIMENSION A(3,4),DUM(10)                                        UCON
                C                                                                     UCON
                C---COMMON                                                            UCON
  ISN 0015            COMMON TP,XNDT,SOME,SOMD,E,AO,COME,COMD,CI,XLMG                 UCON
  ISN 0016            COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP                     UCON
  ISN 0017            COMMON REF                                                      UCON
  ISN 0018            COMMON DE,DA,DN,DTK,ELAT,ELON,GEOM,HEAD,RATE,IDAY,MDAY,ETIM     UCON
  ISN 0019            COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN                UCON
  ISN 0020            COMMON I,J,K,L,M,N,NDOP,ITER                                    UCON
  ISN 0021            COMMON T,TEMP,A,DUM                                             UCON
                C                                                                     UCON
  ISN 0022            COMMON /COMC/NULL,IONE,ITWO,IFUR,I15,I30,I365,IM,KM,KF          UCON
  ISN 0023            COMMON /COMC/TAW,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSQ,ZERO             UCON
  ISN 0024            COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND            UCON
  ISN 0025            COMMON /COMC/C480,S7P5,TUPI,DTRA,DTOM                           UCON
  ISN 0026            COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,C2K,C2M,REFC         UCON
                C                                                                     UCON
  ISN 0027            EQUIVALENCE (REF(1),Y),(REF(2),Z)                               UCON
                C                                                                     UCON
  ISN 0028            Y=(TEMP/DTRA)+TM7                                               UCON
  ISN 0029            L=Y                                                             UCON
  ISN 0030            Z=L                                                             UCON
  ISN 0031            Y=DABS((Y-Z)*D60)                                               UCON
  ISN 0032            M=Y                                                             UCON
  ISN 0033             -M                                                             UCON
  ISN 0034            N=(Y-Z)/TM4                                                     UCON
  ISN 0035            RETURN                                                          UCON
  ISN 0036            END                                                             UCON
                                                                                      UCON
```

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                                  /      UCON /      SIZE OF PROGRAM 0001A8 HEXADECIMAL BYTES PAGE 002

NAME     TAG    TYPE   ADD.        NAME     TAG    TYPE   ADD.        NAME     TAG    TYPE   ADD.        NAME     TAG    TYPE   ADD.
   A         C  R*8     N.R.          E          C  R*8     N.R.         I          C  I*4     N.R.         J          C  I*4     N.R.
   K         C  I*4     N.R.          L  SF      C  I*4   000304         M  SF      C  I*4   000308         N  S       C  I*4   00030C
   T         C  R*8     N.R.          Y  SFA CE     R*8   0000C8         Z  SFA CE     R*8   0000D0        AO          C  R*8     N.R.
  CI         C  R*8     N.R.         DA          C  R*8     N.R.        DE          C  R*8     N.R.        DN          C  R*8     N.R.
  IM         C  I*4     N.R.         KF          C  I*4     N.R.        KM          C  I*4     N.R.        SI          C  R*8     N.R.
  TP         C  R*8     N.R.         VN          C  R*8     N.R.       ATE          C  R*8     N.R.       C2K          C  R*8     N.R.
 C2M         C  R*8     N.R.        DOP          C  R*8     N.R.       DTK          C  R*8     N.R.       DUM          C  R*8     N.R.
 D60  FA     C  R*8   0000A0        I15          C  I*4     N.R.       I30          C  I*4     N.R.       ONE          C  R*8     N.R.
 REF       CE   R*8   0000C8        RSQ          C  R*8     N.R.       TAW          C  R*8     N.R.       TEN          C  R*8     N.R.
 TM1         C  R*8     N.R.        TM4   F      C  R*8   0000E0       TM5          C  R*8     N.R.       TM7   F      C  R*8   0000F0
 TM8         C  R*8     N.R.        TWO          C  R*8     N.R.      CKRM          C  R*8     N.R.      CMTR          C  R*8     N.R.
COMD         C  R*8     N.R.       COME          C  R*8     N.R.      CVCG          C  R*8     N.R.      C480          C  R*8     N.R.
DLAT         C  R*8     N.R.       DLON          C  R*8     N.R.      DTOM          C  R*8     N.R.      DTRA  F      C  R*8   0000C8
DUM1         C  R*8     N.R.       DUM2          C  R*8     N.R.      DUM3          C  R*8     N.R.      DUM4          C  R*8     N.R.
DUM5         C  R*8     N.R.       EFRQ          C  R*8     N.R.      ELAT          C  R*8     N.R.      ELON          C  R*8     N.R.
ETIM         C  R*8     N.R.       FFRQ          C  R*8     N.R.      FIVE          C  R*8     N.R.      FLAT          C  R*8     N.R.
FLON         C  R*8     N.R.       FOUR          C  R*8     N.R.      GEOH          C  R*8     N.R.      HEAD          C  R*8     N.R.
HUND         C  R*8     N.R.       IDAY          C          N.R.      IFOR          C  I*4     N.R.      IONE          C  I*4     N.R.
ITER         C  I*4     N.R.       ITWO          C                    I365          C  I*4     N.R.      MDAY          C  I*4     N.R.
NDOP         C  I*4     N.R.       NULL          C                    OFST          C  R*8     N.R.      UMGE          C  R*8     N.R.
RATE         C  R*8     N.R.       REFC          C                    SELV          C  R*8     N.R.      SMXE          C  R*8     N.R.
SOMD         C  R*8     N.R.       SOME          C                    S7P5          C  R*8     N.R.      TEMP  F      C  R*8   000320
THRE         C  R*8     N.R.       TOPI          C                    UCON             R*4   00008C      WAVE          C  R*8     N.R.
XLMG         C  R*8     N.R.       XNDT          C  R*8               XOSQ          C  R*8     N.R.      ZERO          C  R*8     N.R.
ZOSQ         C  R*8     N.R.

                                         *****  COMMON INFORMATION   *****

   NAME OF COMMON BLOCK  *        *   SIZE OF BLOCK    0003D8 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.
      TP    R*8     N.R.           XNDT   R*8     N.R.           SOME   R*8     N.R.           SCMD   R*8     N.R.
       E    R*8     N.R.             AO   R*8     N.R.           COME   R*8     N.R.           COMD   R*8     N.R.
      CI    R*8     N.R.           XLMG   R*8     N.R.           DUM1   R*8     N.R.           DUM2   R*8     N.R.
      SI    R*8     N.R.           OFST   R*8     N.R.           DUM3   R*8     N.R.           DUM4   R*8     N.R.
    DUM5    R*8     N.R.            DOP   R*8     N.R.            REF   R*8   0000C8             DE   R*8     N.R.
      DA    R*8     N.R.             DN   R*8     N.R.            DTK   R*8     N.R.           ELAT   R*8     N.R.
    ELON    R*8     N.R.           GEOH   R*8     N.R.           HEAD   R*8     N.R.           RATE   R*8     N.R.
    IDAY    I*4     N.R.           MDAY   I*4     N.R.           ETIM   R*8     N.R.           DLAT   R*8     N.R.
    DLON    R*8     N.R.           SMXE   R*8     N.R.           SELV   R*8     N.R.           FLAT   R*8     N.R.
    FLON    R*8     N.R.           FFRQ   R*8     N.R.            RSQ   R*8     N.R.             VN   R*8     N.R.
       I    I*4     N.R.              J   I*4     N.R.              K   I*4     N.R.              L   I*4   000304
       M    I*4   000308              N   I*4   00030C           NDOP   I*4     N.R.           ITER   I*4     N.R.
       T    R*8     N.R.           TEMP   R*8   000320              A   R*8     N.R.            DUM   R*8     N.R.

 EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK
   VARIABLE  OFFSET              VARIABLE  OFFSET                VARIABLE  OFFSET               VARIABLE  OFFSET
         Y   0000C8                     Z  0000D0

   NAME OF COMMON BLOCK  *  COMC*   SIZE OF BLOCK    000128 HEXADECIMAL BYTES

VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.   VAR. NAME  TYPE  REL. ADDR.

                                                                                                 PAGE 003

    NULL    I*4     N.R.           IONE   I*4     N.R.           ITWO   I*4     N.R.           IFOR   I*4     N.R.
     I15    I*4     N.R.            I30   I*4     N.R.           I365   I*4     N.R.             IM   I*4     N.R.
      KM    I*4     N.R.             KF   I*4     N.R.            TAW   R*8     N.R.           WAVE   R*8     N.R.
    CVCG    R*8     N.R.           EFRQ   R*8     N.R.           UMGE   R*8     N.R.           XOSQ   R*8     N.R.
    ZOSQ    R*8     N.R            ZERO   R*8     N.R.            ONE   R*8     N.R.            TWO   R*8     N.R.
    THRE    R*8     N.R.           FOUR   R*8     N.R.           FIVE   R*8     N.R.            ATE   R*8     N.R.
     TEN    R*8     N.R.            D60   R*8   0000A0           HUND   R*8     N.R.           C480   R*8     N.R.
    S7P5    R*8     N.R.           TOPI   R*8     N.R.           DTRA   R*8   0000C8           DTOM   R*8     N.R.
     TM1    R*8     N.R.            TM4   R*8   0000E0            TM5   R*8     N.R.            TM7   R*8   0000F0
     TM8    R*8     N.R.           CMTR   R*8     N.R.           CKRM   R*8     N.R.            C2K   R*8     N.R.
     C2M    R*8     N.R.           REFC   R*8     N.R.
*OPTIONS IN EFFECT*      NAME=  MAIN,OPT=02,LINECNT=58,SIZE=0000K,

*OPTIONS IN EFFECT*      SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,ID,NOXREF

*STATISTICS*      SOURCE STATEMENTS =      35 ,PROGRAM SIZE =      424

*STATISTICS*  NO  DIAGNOSTICS GENERATED

****** END OF COMPILATION ******                                             61K BYTES OF CORE NOT USED

*STATISTICS*  NO  DIAGNOSTICS THIS STEP
```

9. REFERENCES

1. G. C. Gutheim, Program Requirements for Two-Minute Integrated Doppler Satellite Navigation Solution, APL/JHU 819-1, April 1967.

2. Space Development Department, Radio Navigation Set AN/SRN-9 (XN-5) Operation and Maintenance, APL/JHU TG 685-1, August 1965.

3. Naval Ship Systems Command, Ship Systems Command Contract Specification Radio Navigation Set, AN/SRN-9, SHIPS-R-5111, 28 January 1966.

4. Naval Ship Systems Command, Ship Systems Command Contract Specification Radio Navigation Set, AN/SRN-9 ( ), SHIPS-R-5111A, 29 January 1968 (supersedes SHIPS-R-5111).

5. Naval Ship Systems Command, Ship Systems Command Contract Specification Radio Navigation Set, AN/SRN-9, AN/SRN-9A, and AN/SRN-9 ( ), SHIPS-R-5111B, 26 March 1969 (supersedes SHIPS-R-5111A).

6. Naval Ship Systems Command, Technical Manual for Radio Navigation Set AN/SRN-9, NAVSHIPS 0967-306-2010, September 1970.

7. Naval Ship Systems Command, Technical Manual for Radio Navigation Set AN/SRN-9A, NAVSHIPS 0967-315-9010, August 1970.

8. E. Liverette, "Preliminary System Operational Procedures for the AN/SRN-9, 9A Radio Navigation Receivers and CP-967/UYK Digital Data Computer," APL/JHU S3E-70-391, December 1970.

9. University of California Scripps Institute of Oceanography, *Contract Specification for Navigation Satellite Receiver Set*, Specification 0A0088, 26 September 1966.

10. Magnavox Company, *Operation and Maintenance Manual for University of California Navigation Satellite Receiver Set 702CA*, TP68-2040, 30 June 1968.

11. H. S. Hopfield, "A Two-Quartic Refractivity Profile for the Troposphere for Correcting Satellite Data," *Journal of Geophysical Research*, Vol. 74, 1969, 4487-4499.

12. U.S. Navy, *Marine Climatic Atlas of the World*, NAVAER 50-10-529, 1956.

13. U.S. Department of Commerce and U.S. Department of the Navy (Office of Climatology and Oceanographic Analysis), *Climatological and Oceanographic Atlas for Mariners*, 1961.

14. S. M. Yionoulis, "Algorithm to Compute Tropospheric Refraction Effects on Range Measurements," *Journal of Geophysical Research*, Vol. 75, 20 December 1970, 7636-7637.

15. H. S. Hopfield, "Tropospheric Effect on Electromagnetically Measured Range: Prediction from Surface Weather Data," *Radio Science*, Vol. 6, 1971, 357-367.

16. C. Hastings, *Approximations for Digital Computers*, Princeton, 1955.

Appendix A

FLOW CHARTS FOR DATA PROCESSING PROGRAM AND FORTRAN NAVIGATION PROGRAM

Flow charts for the data processing program described in Section 6 are shown in Figs. A-1 through A-18. Flow charts for the navigation program described in Section 8 are shown in Figs. A-19 through A-25.

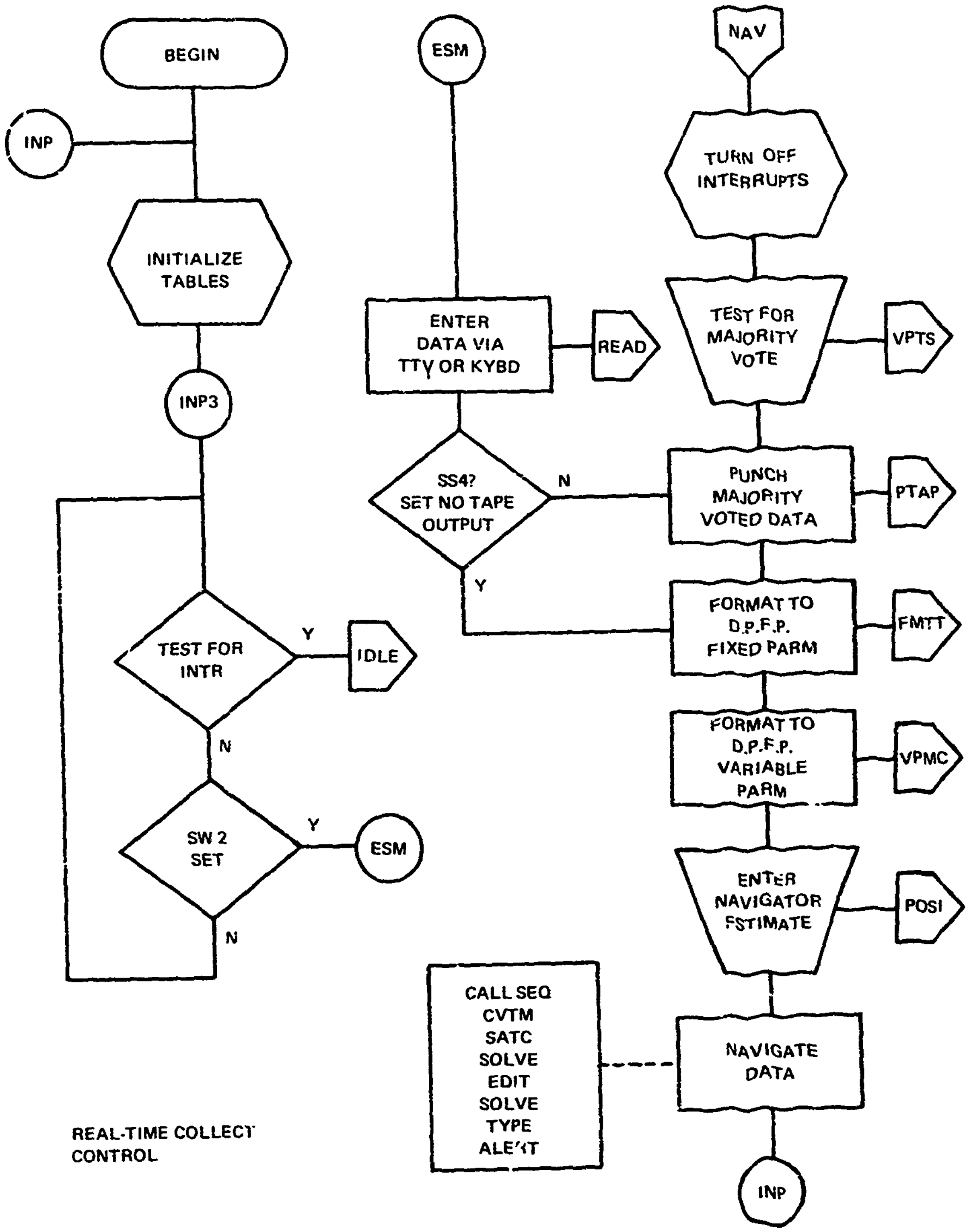


Fig. A-1 SUBROUTINES INP3, ESM, AND NAV

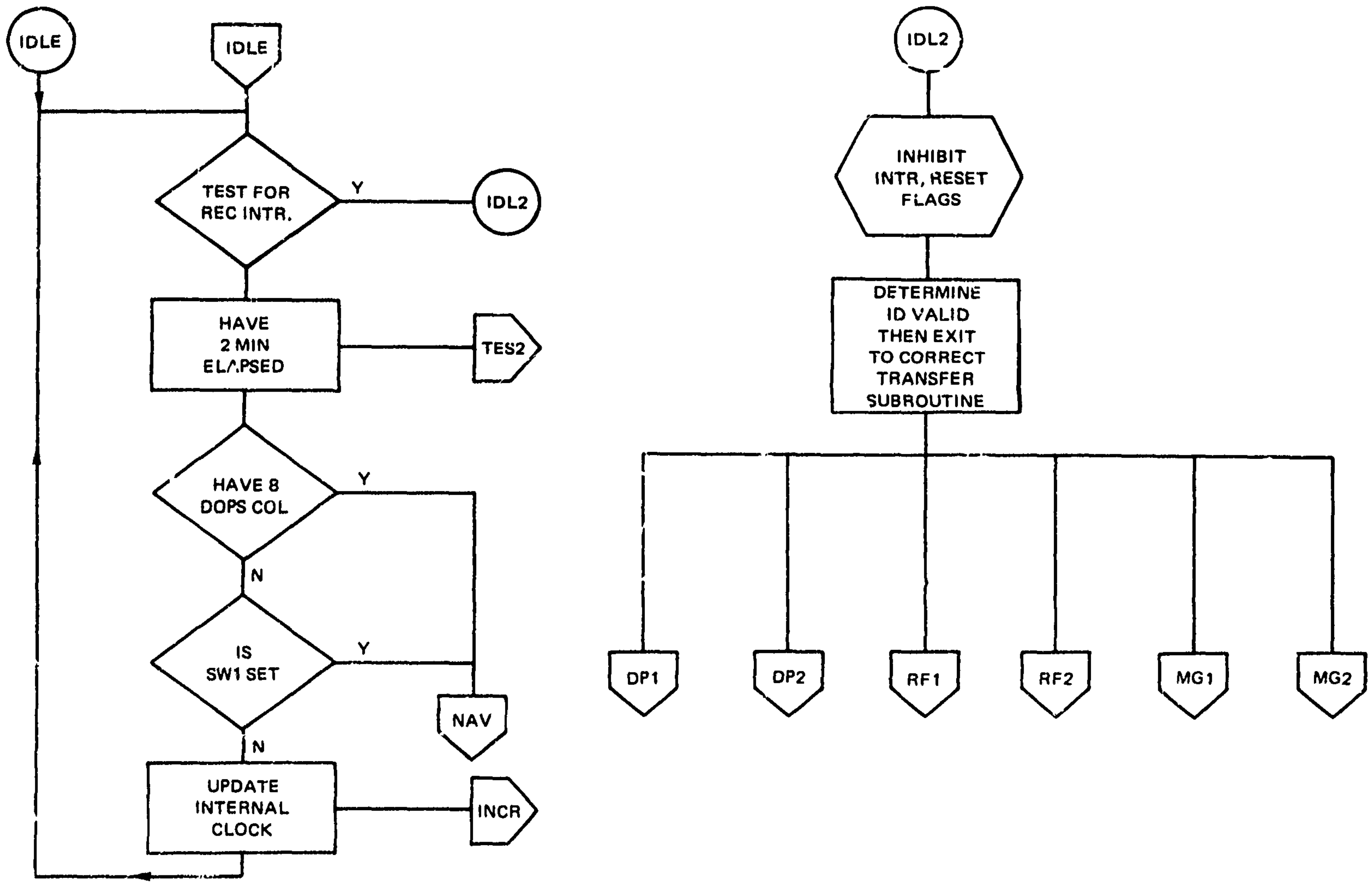


Fig. A-2 SUBROUTINES IDLE AND IDL2

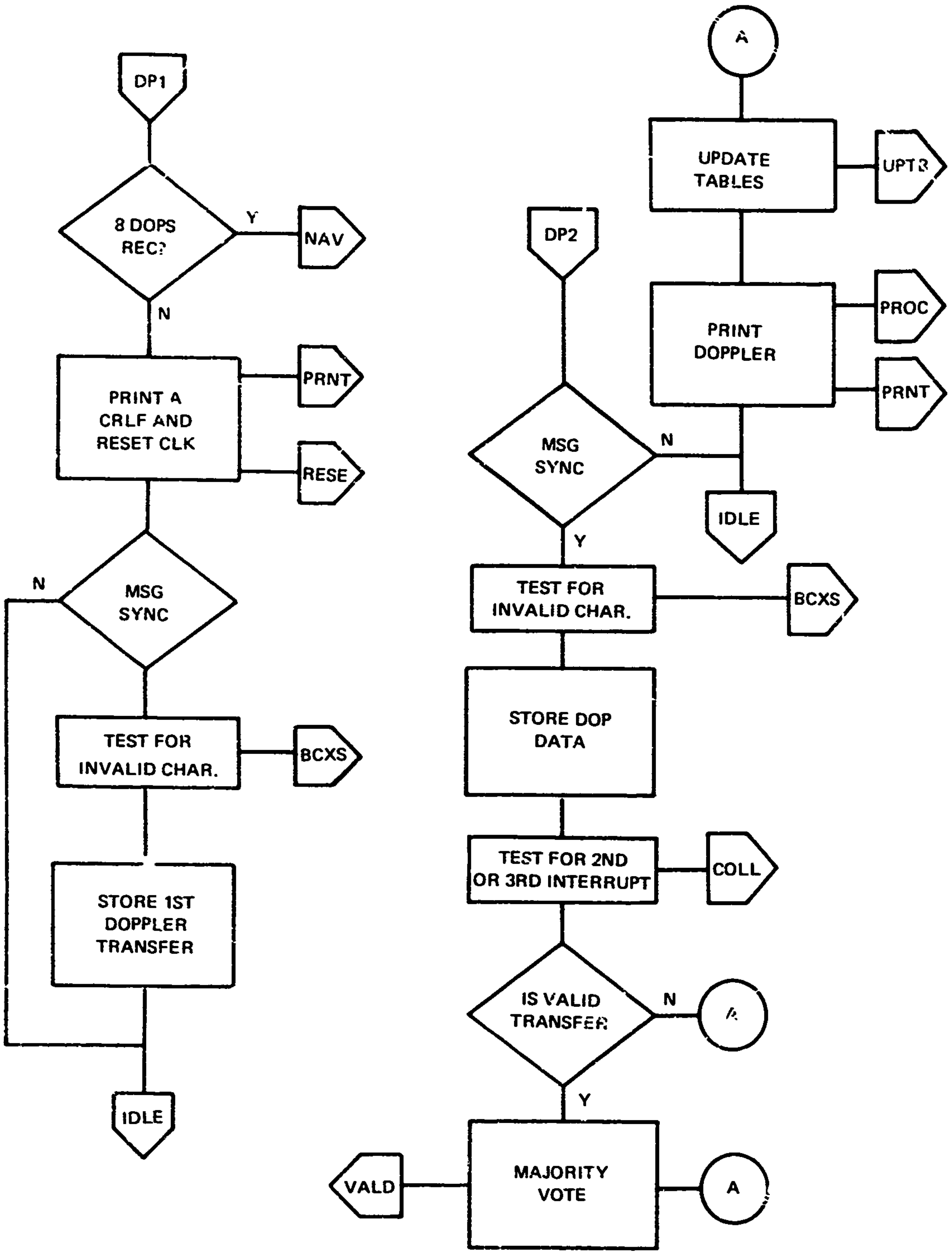


Fig. A-3 SUBROUTINES DP1 AND DP2

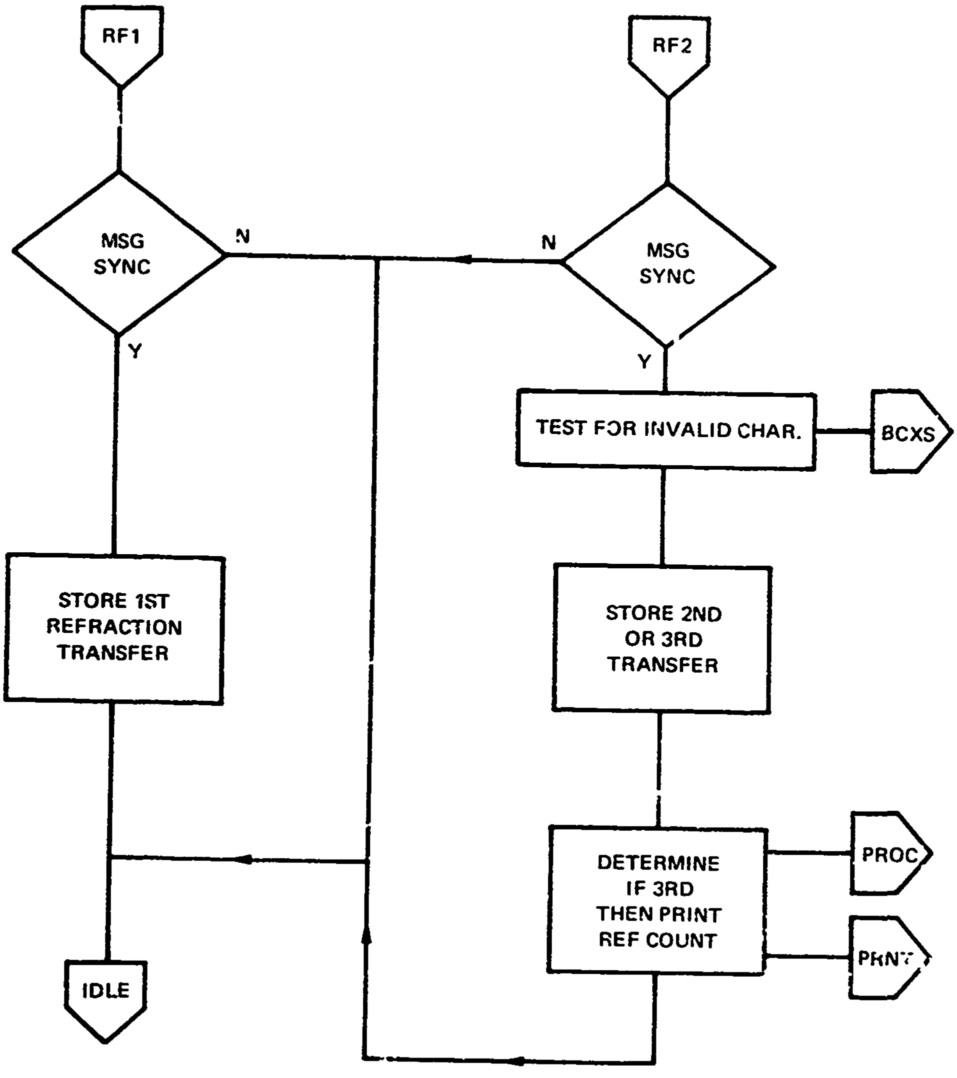


Fig. A-4 SUBROUTINES RF1 AND RF2

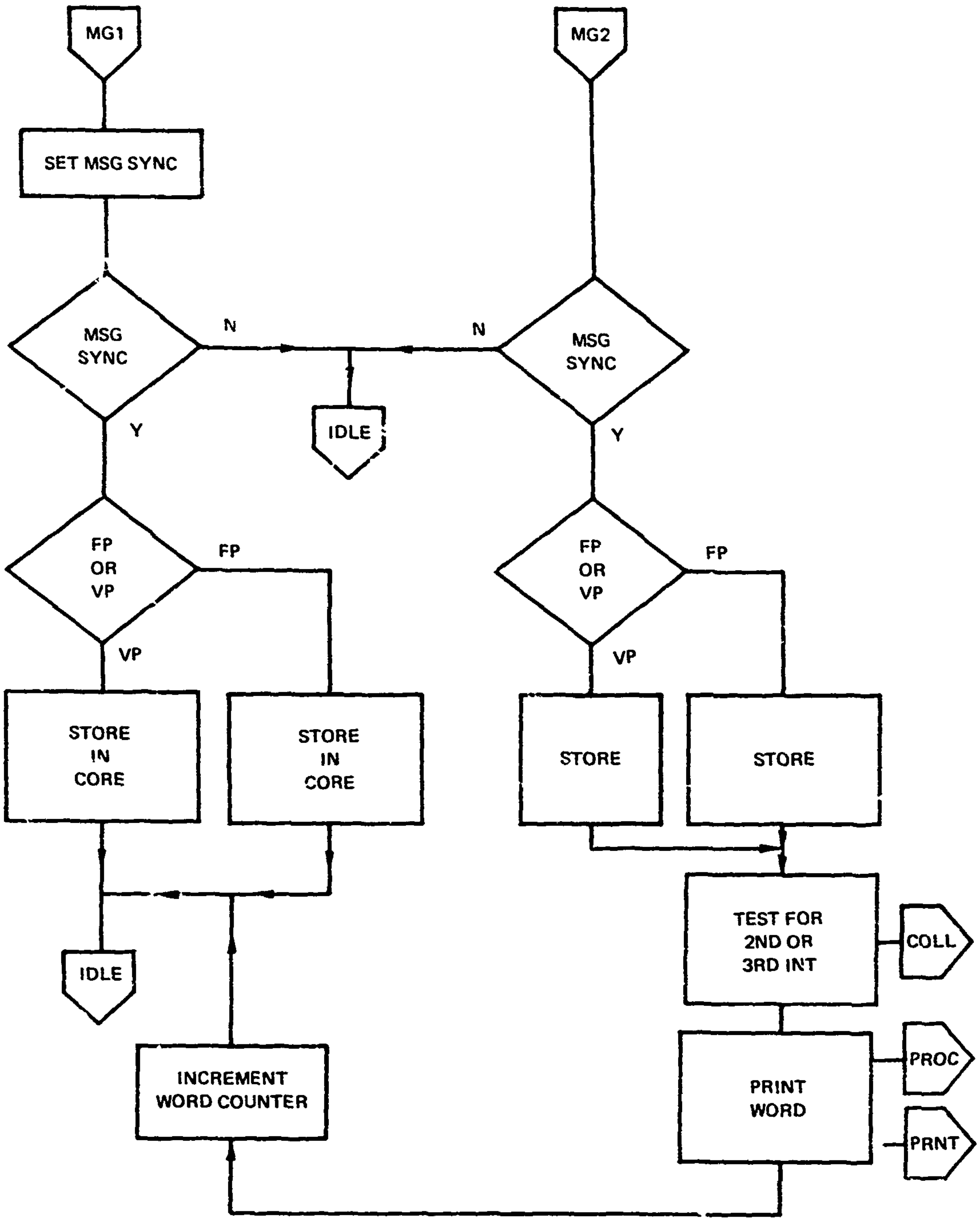


Fig. A-5 SUBROUTINES MG1 AND MG2

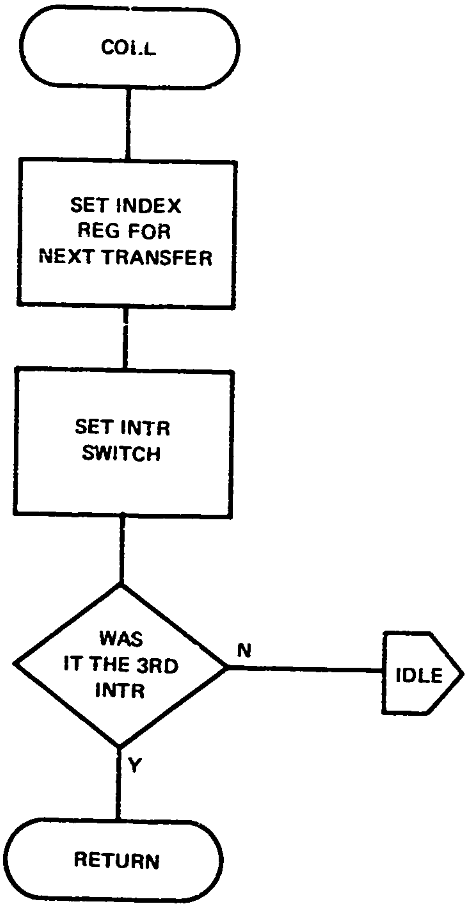


Fig. A-6 SUBROUTINE COLL

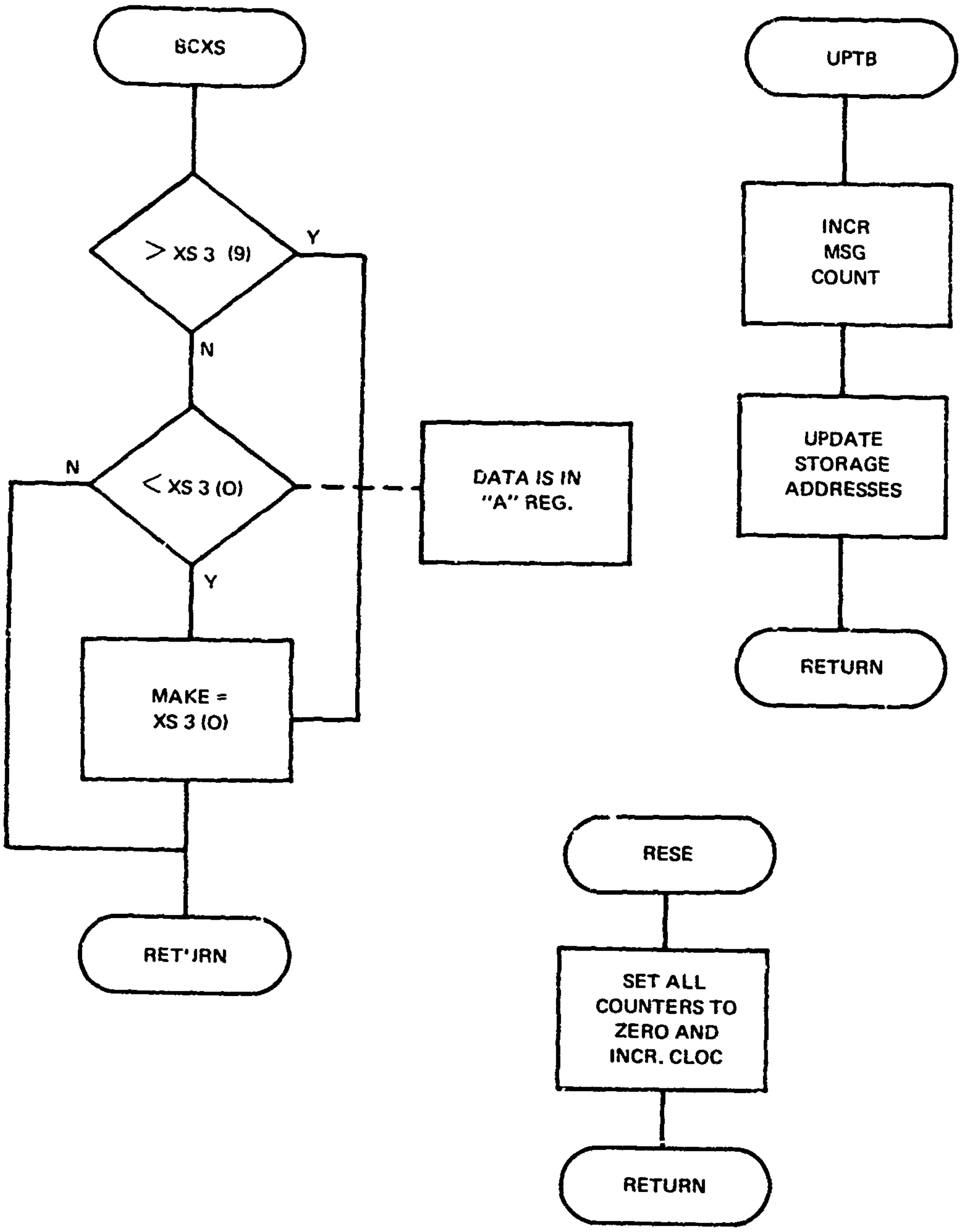


Fig. A-7 SUBROUTINES BCXS, UPTB, AND RESE

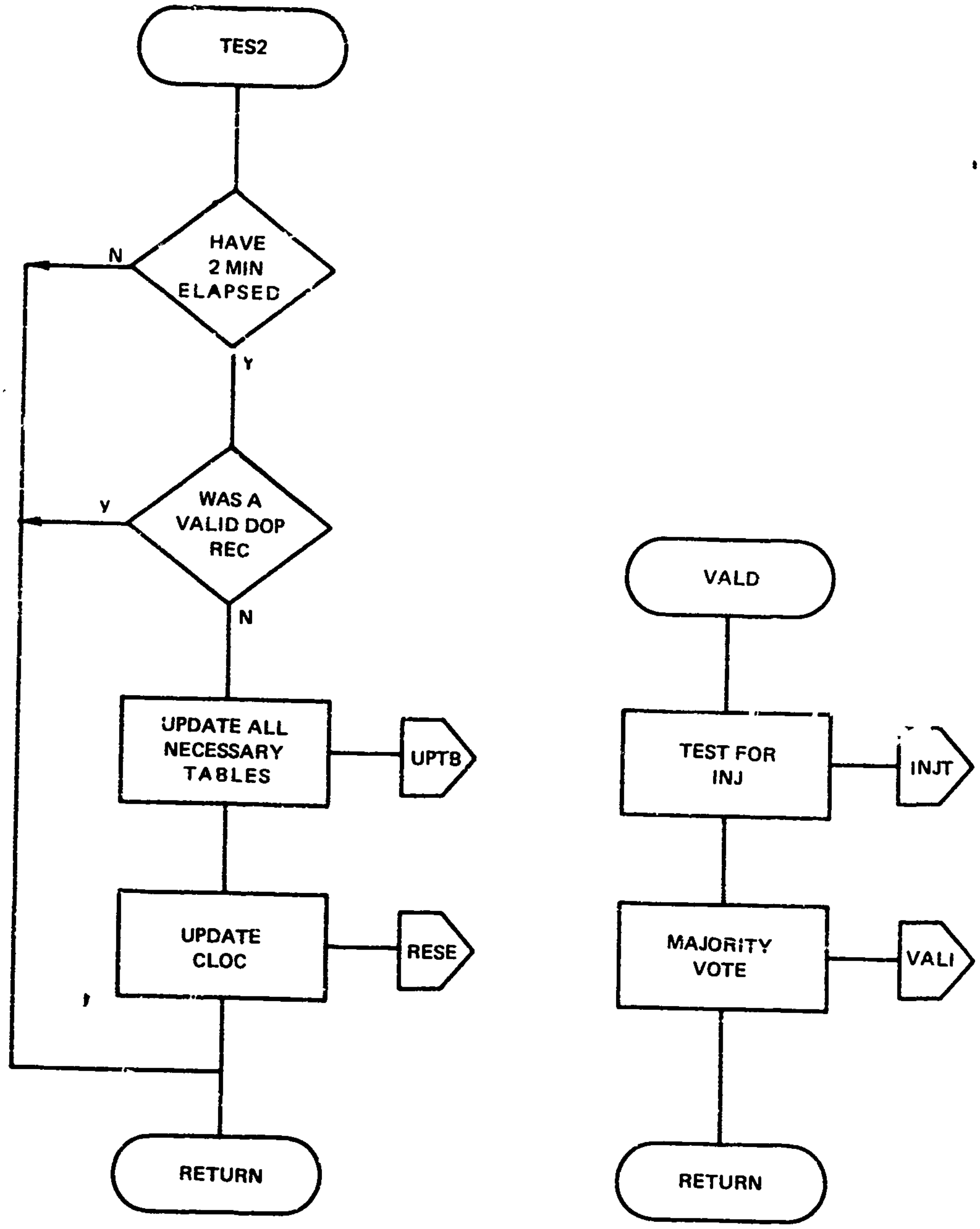


Fig. A-8 SUBROUTINES TES2 AND VALD

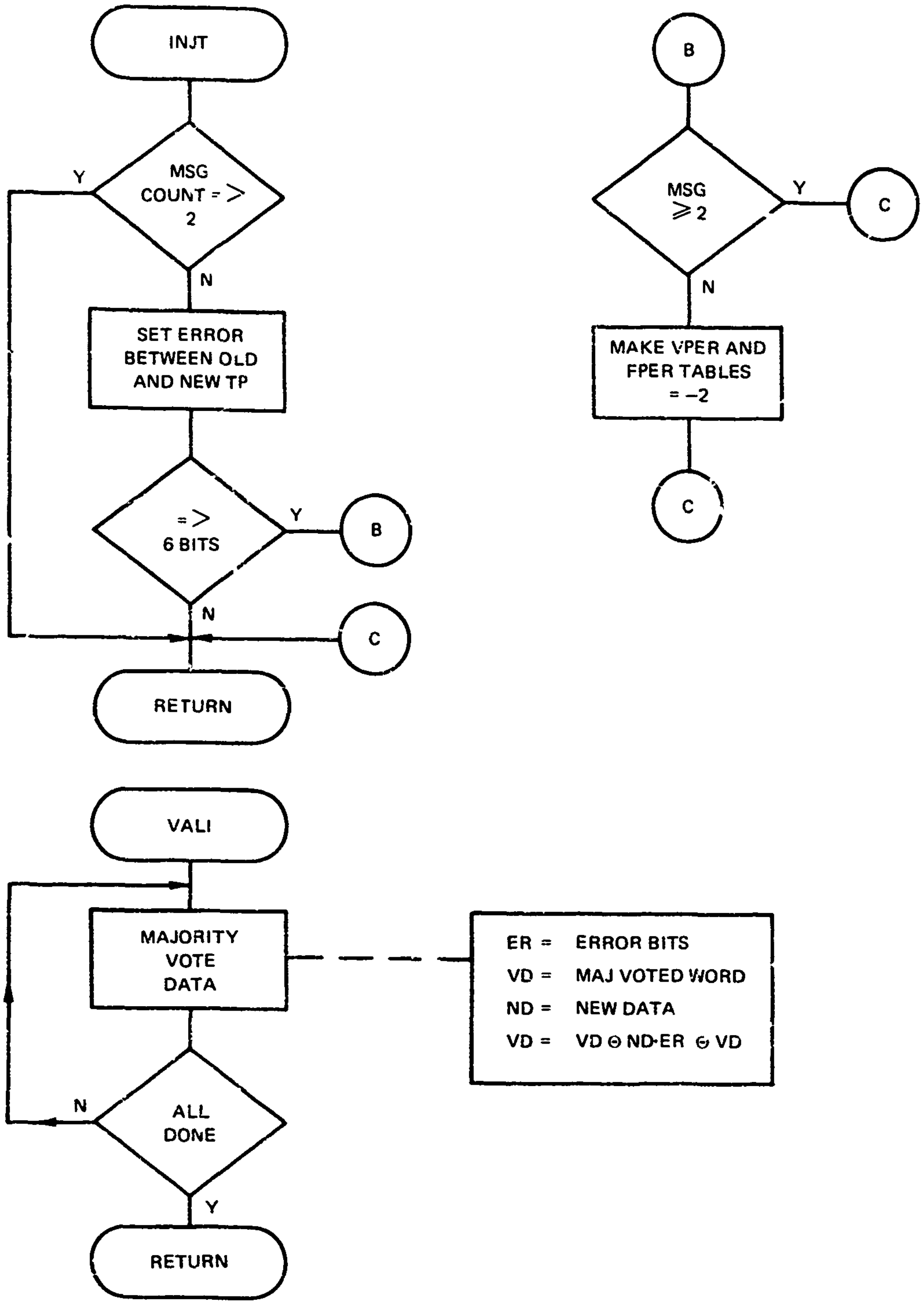


Fig. A-9 SUBROUTINES INJT AND VALI

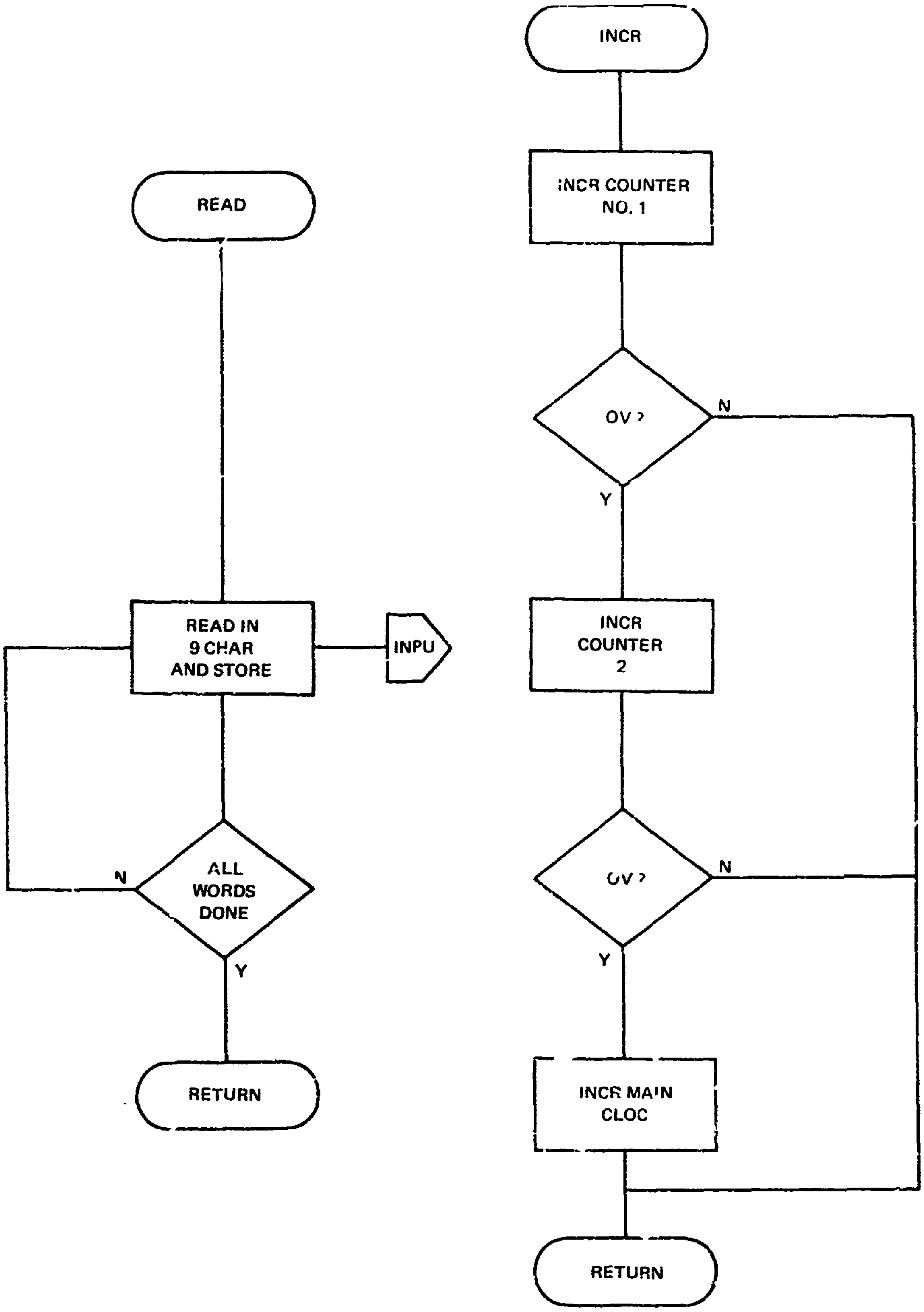


Fig. A-10 SUBROUTINES READ AND INCR

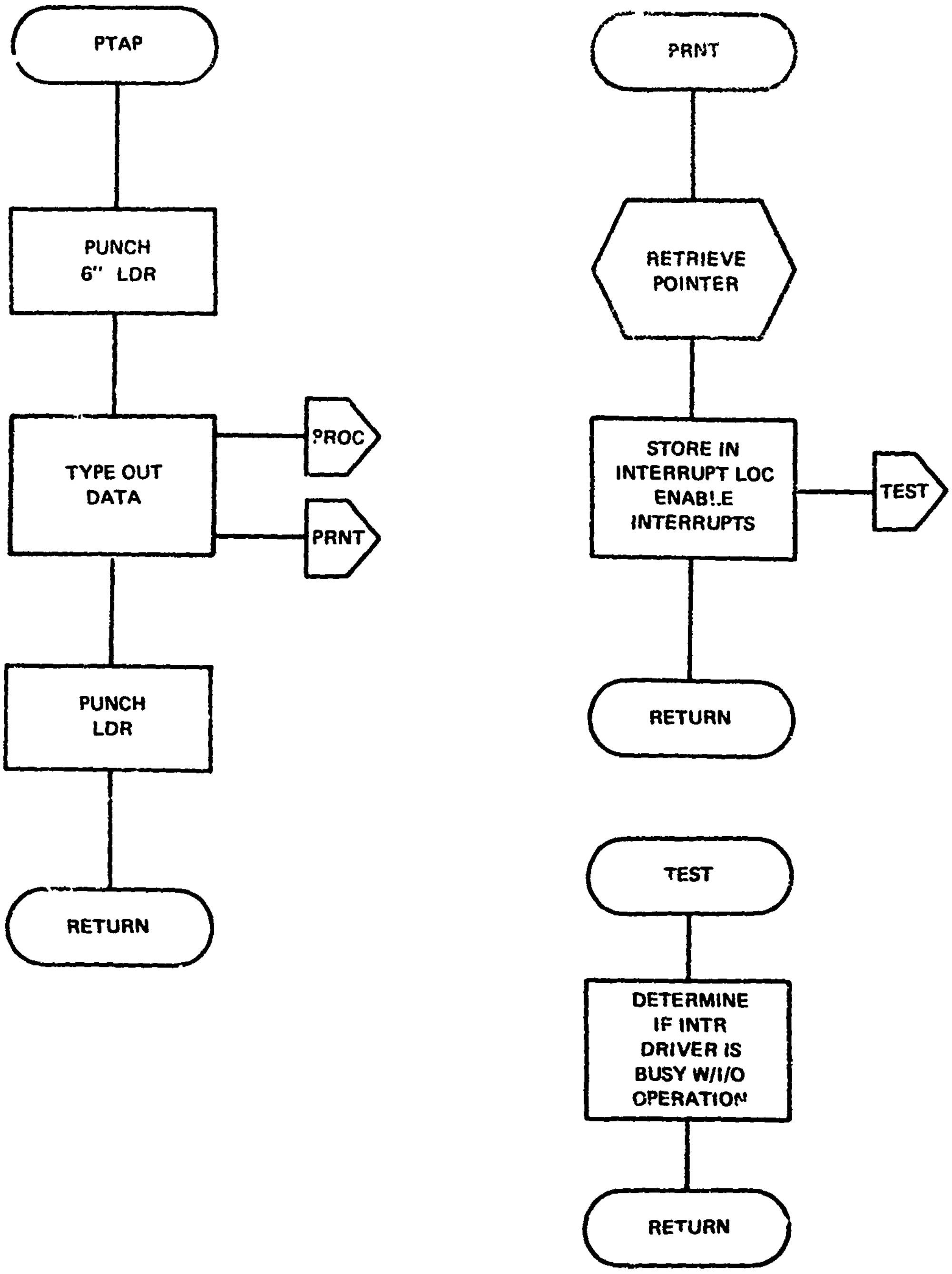


Fig. A-11 SUBROUTINES PTAP, PRNT, AND TEST

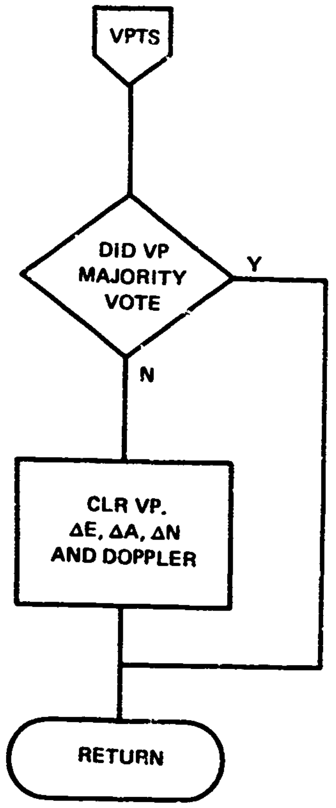


Fig. A-12 SUBROUTINE VPTS

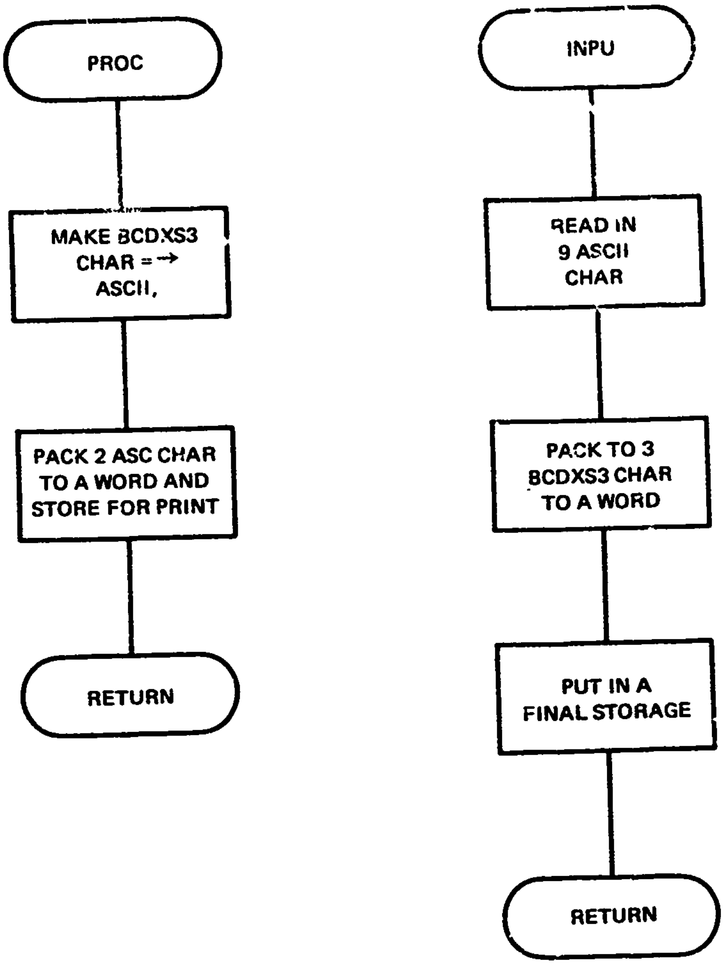


Fig. A-13 SUBROUTINES PROC AND INPU

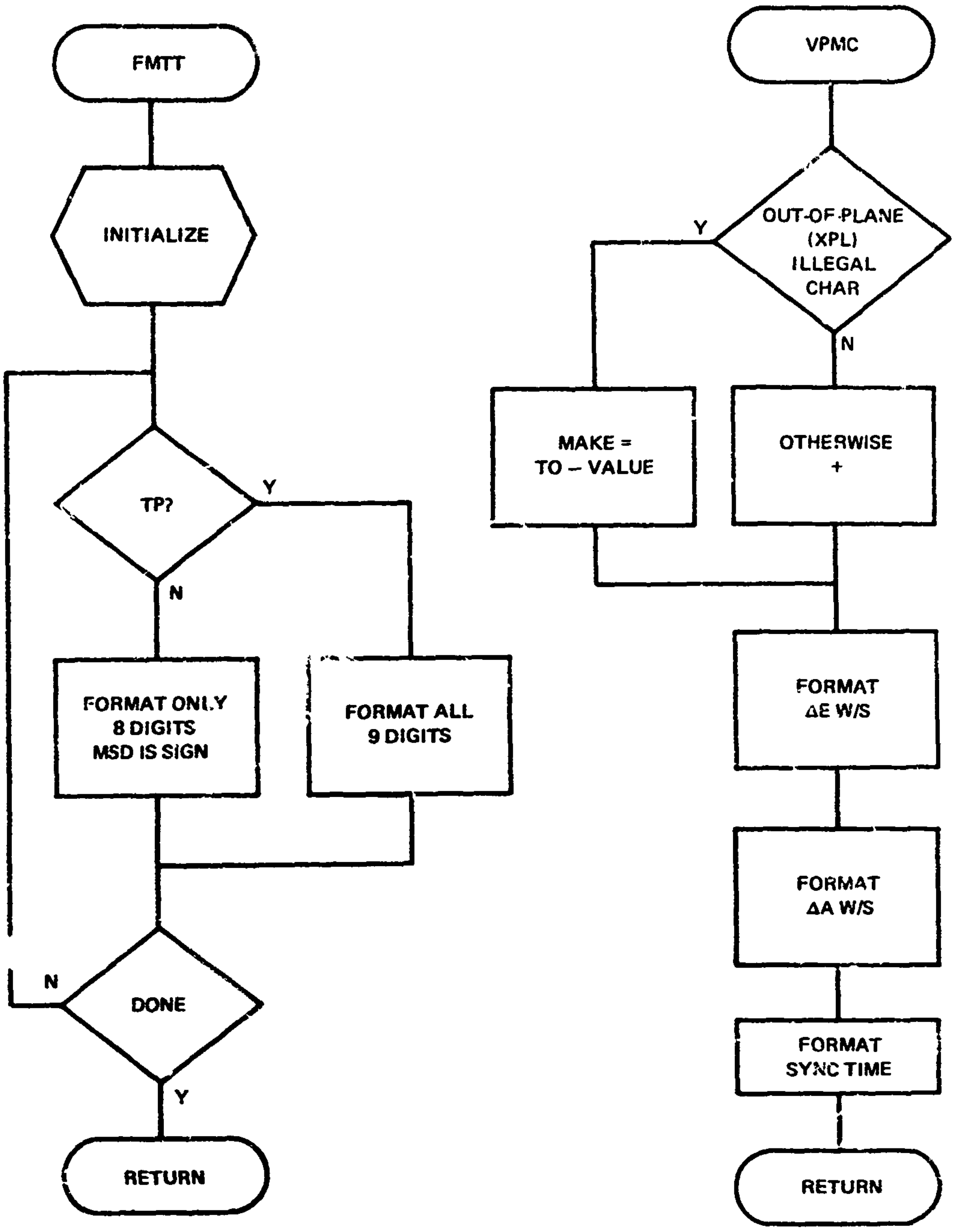


Fig. A-14 SUBROUTINES FMTT AND VPMC

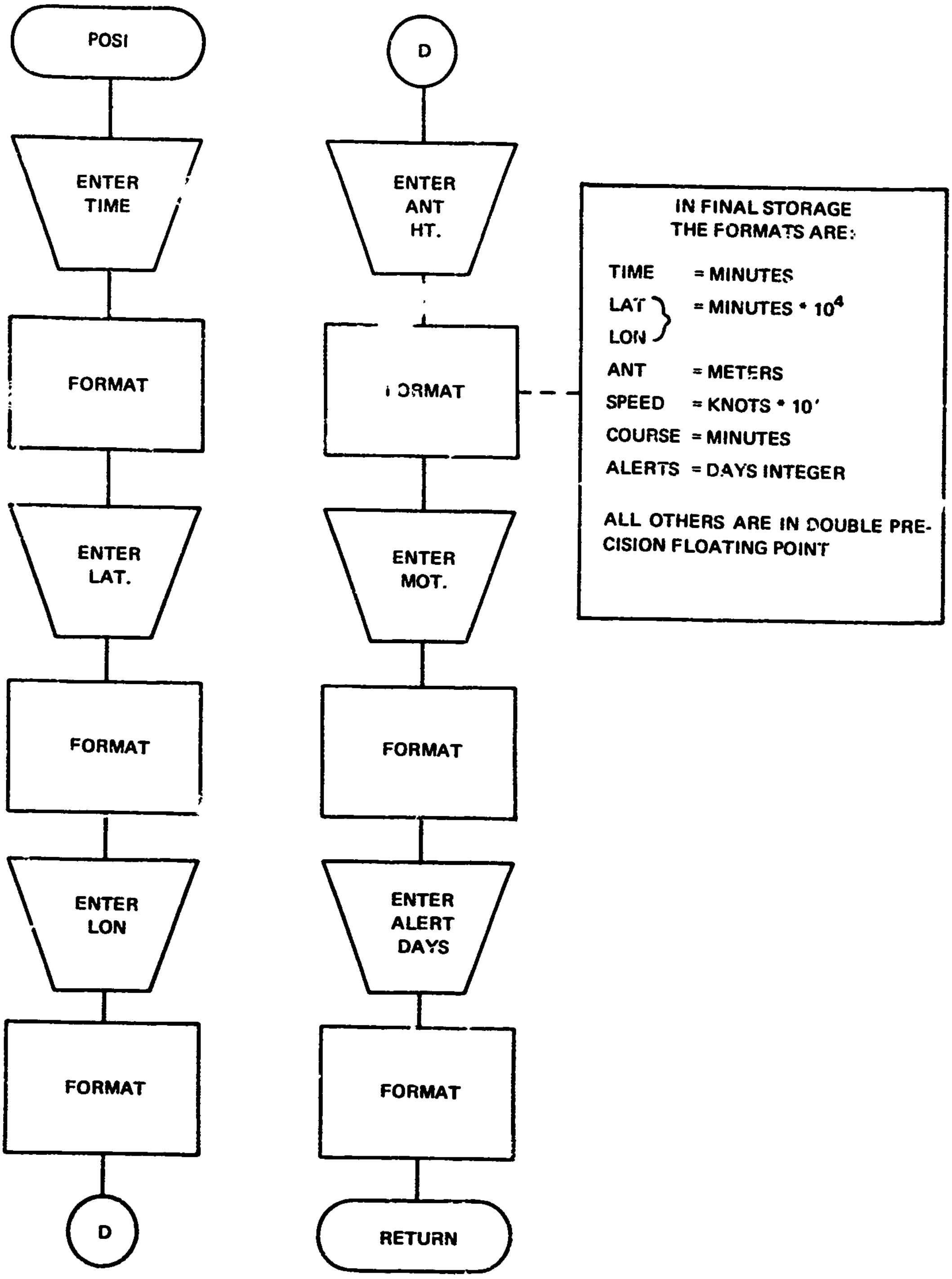


Fig. A-15 SUBROUTINE POSI

INTR PROVIDES LINKAGE BETWEEN PROGRAM AND INTERRUPTS. ENTRANCE IS MADE THROUGH LOCATION 63

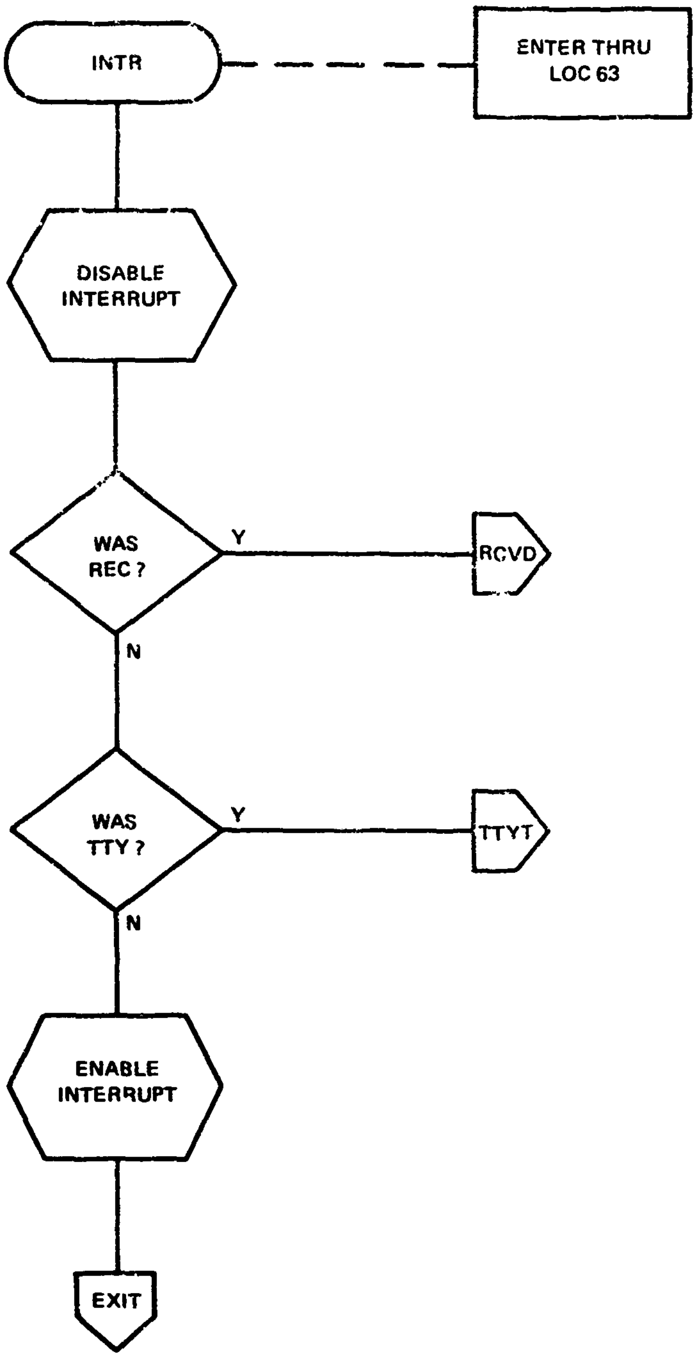


Fig. A-16 SUBROUTINE INTR

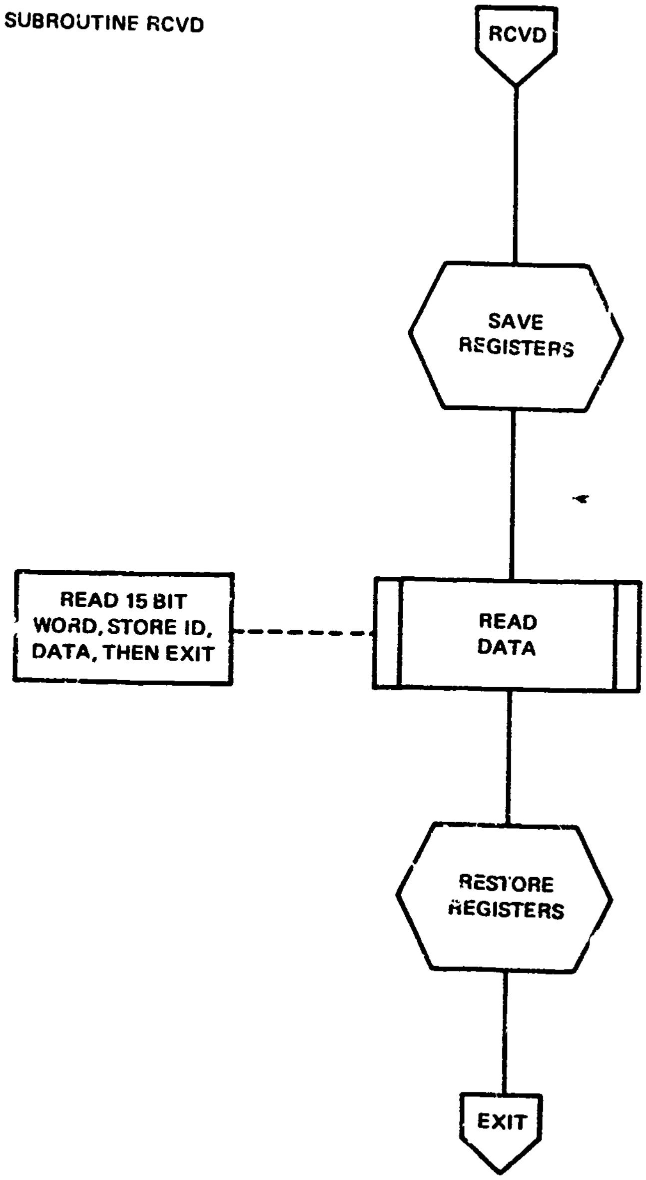


Fig. A-17 SUBROUTINE RCVD

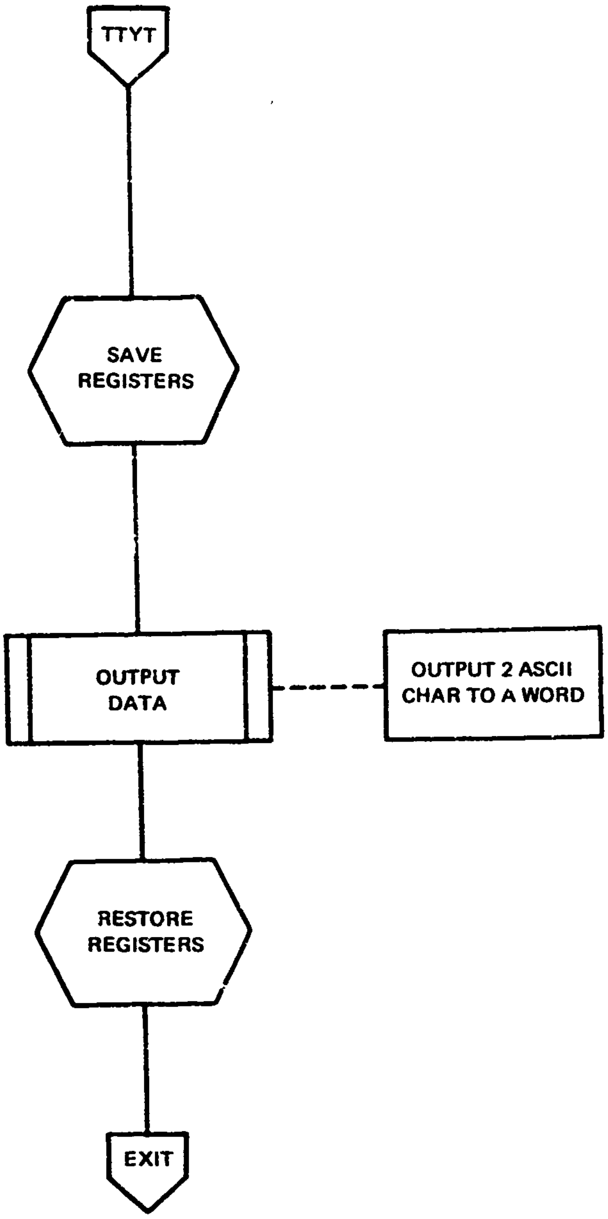


Fig. A-18 SUBROUTINE TTYT

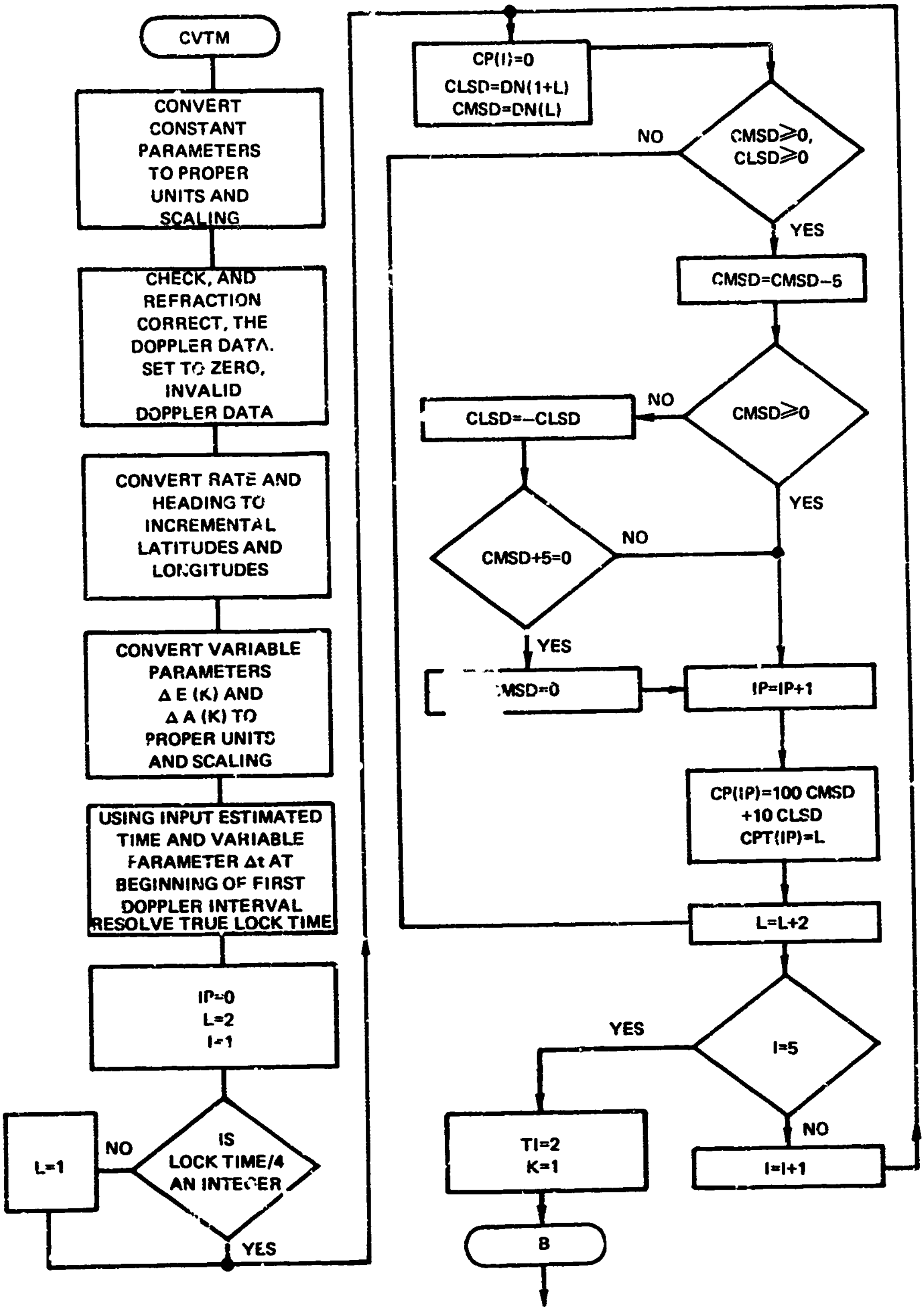


Fig. A-19 SUBROUTINE CVTM

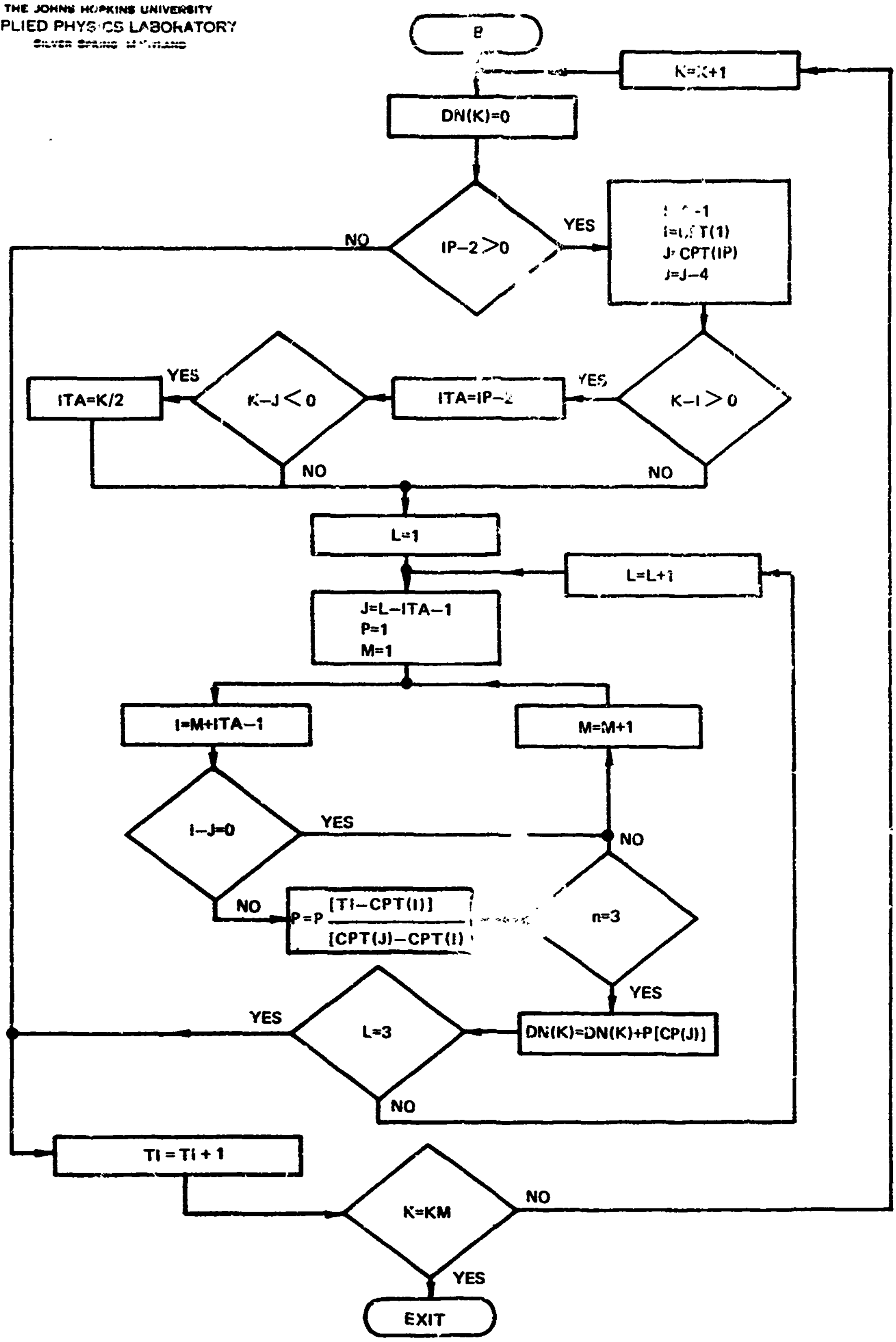


Fig. A-19 SUBROUTINE CVTM (cont'd)

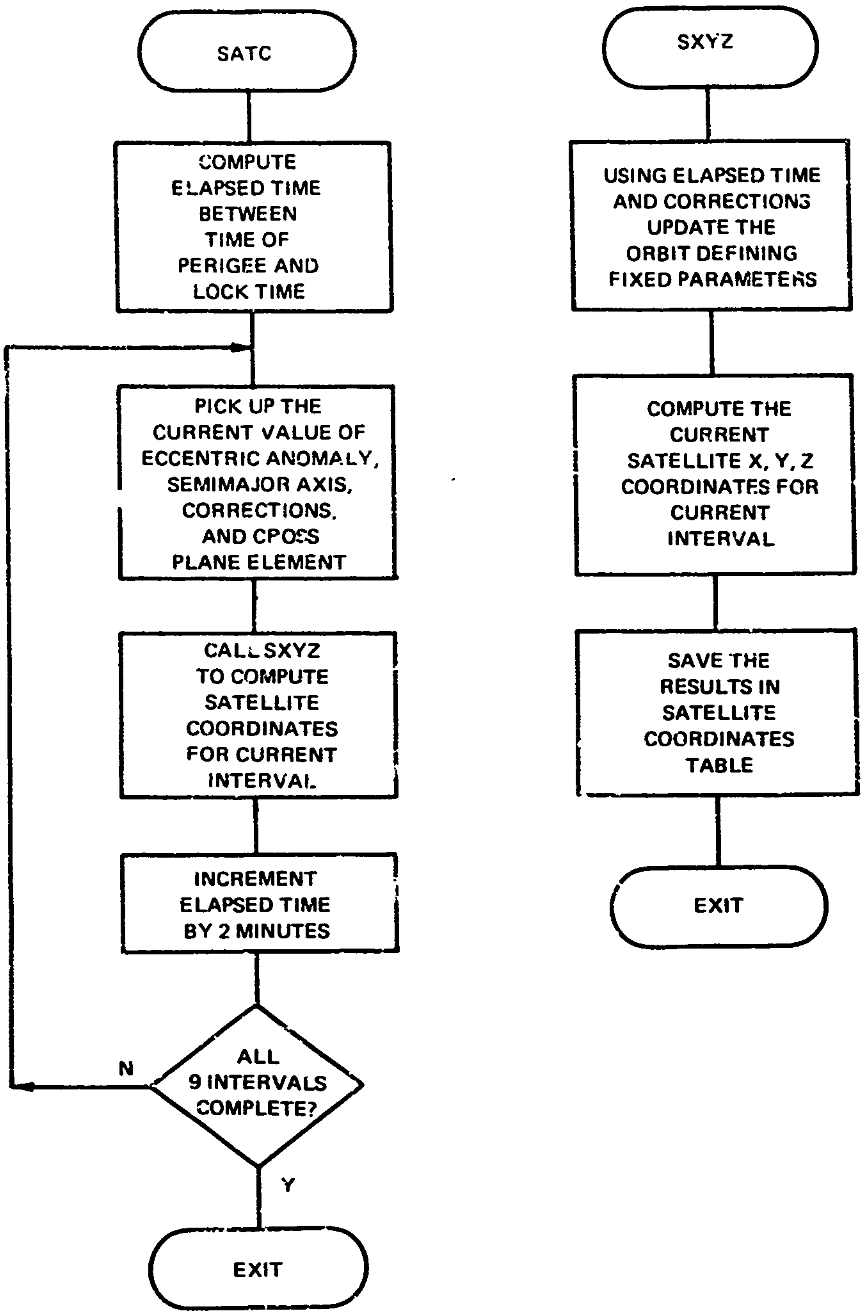


Fig. A-20 SUBROUTINES SATC AND SXYZ

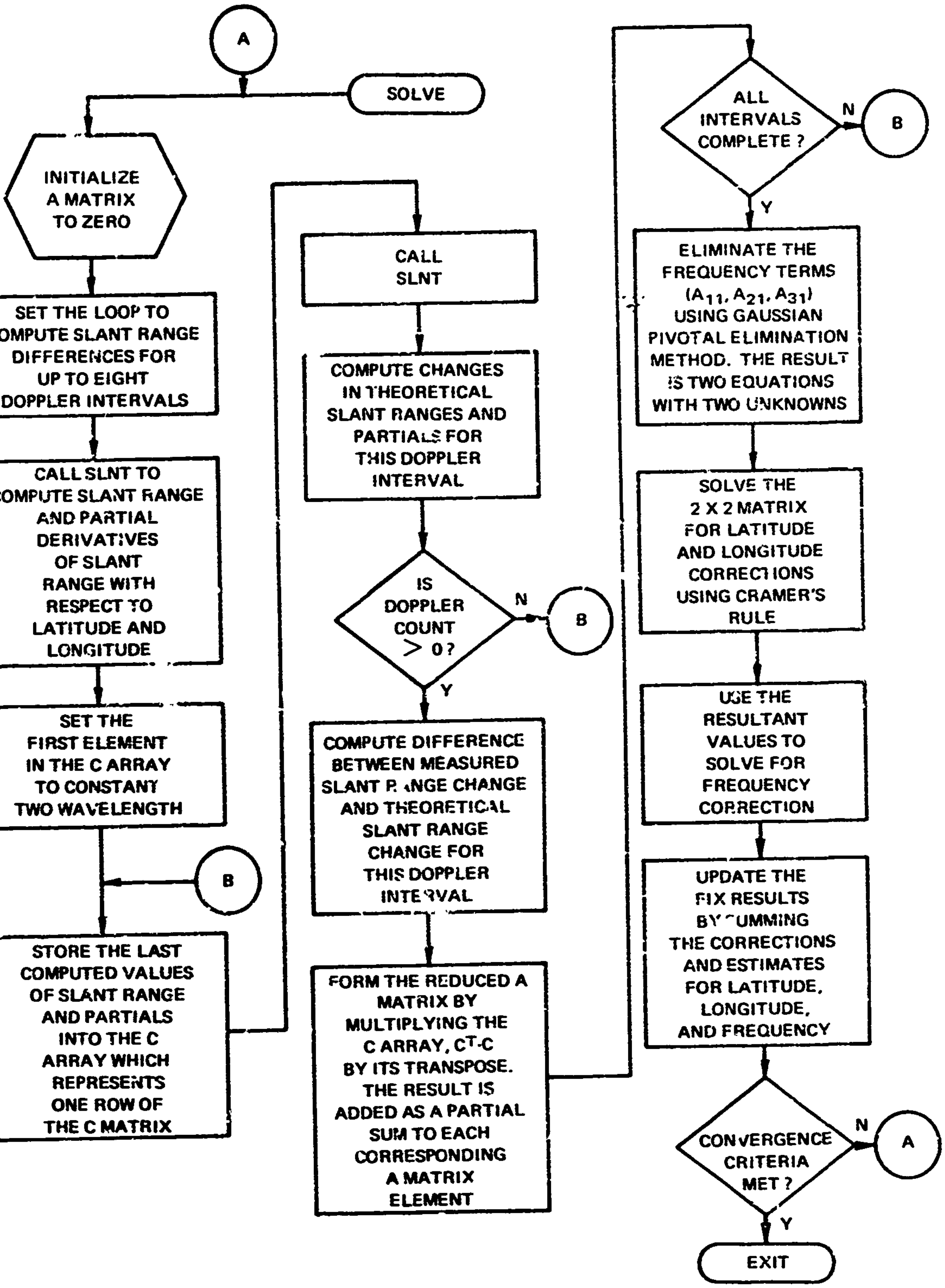


Fig. A-21 SUBROUTINE SOLVE

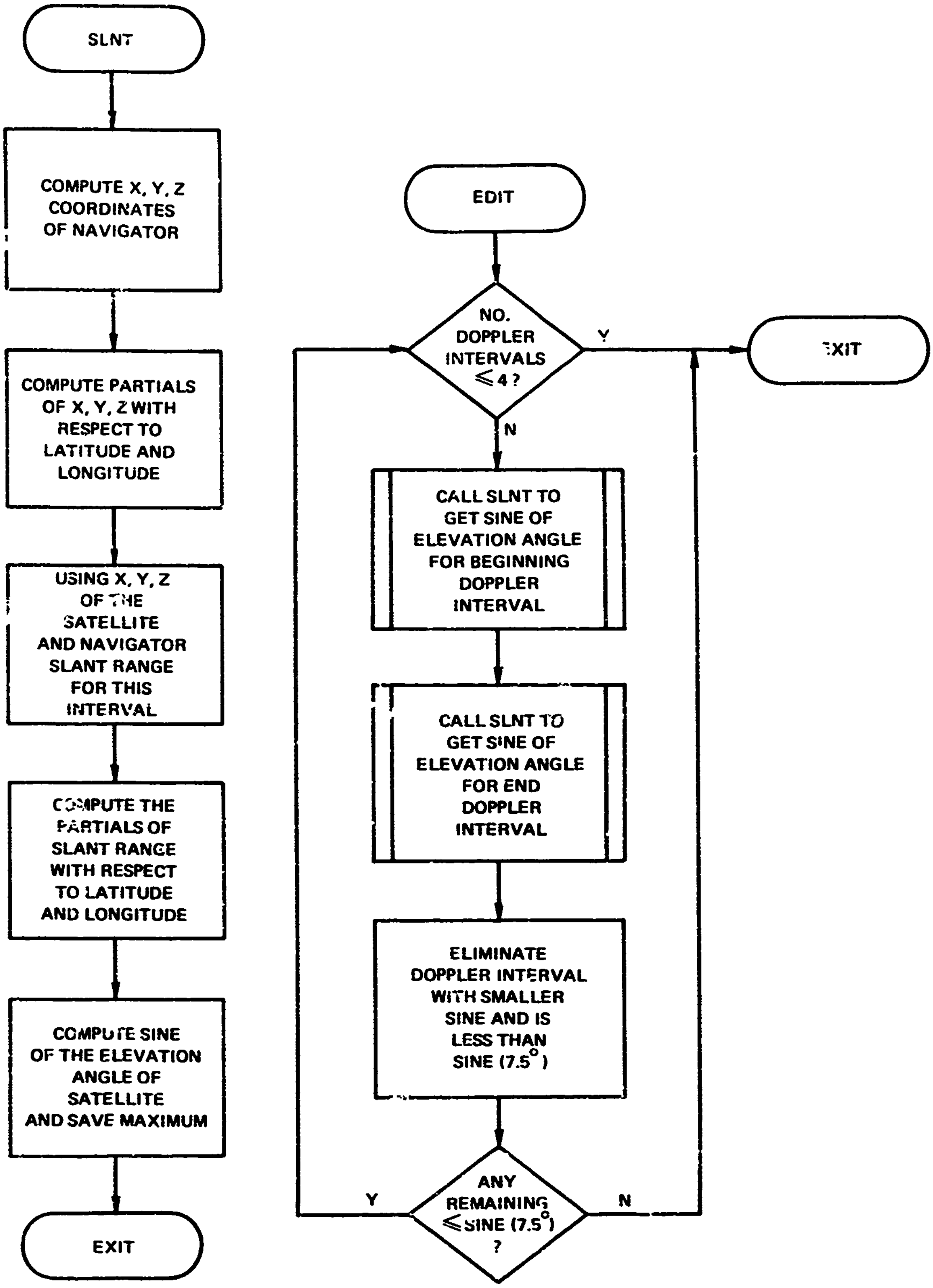


Fig. A-22 SUBROUTINES SLANT AND EDIT

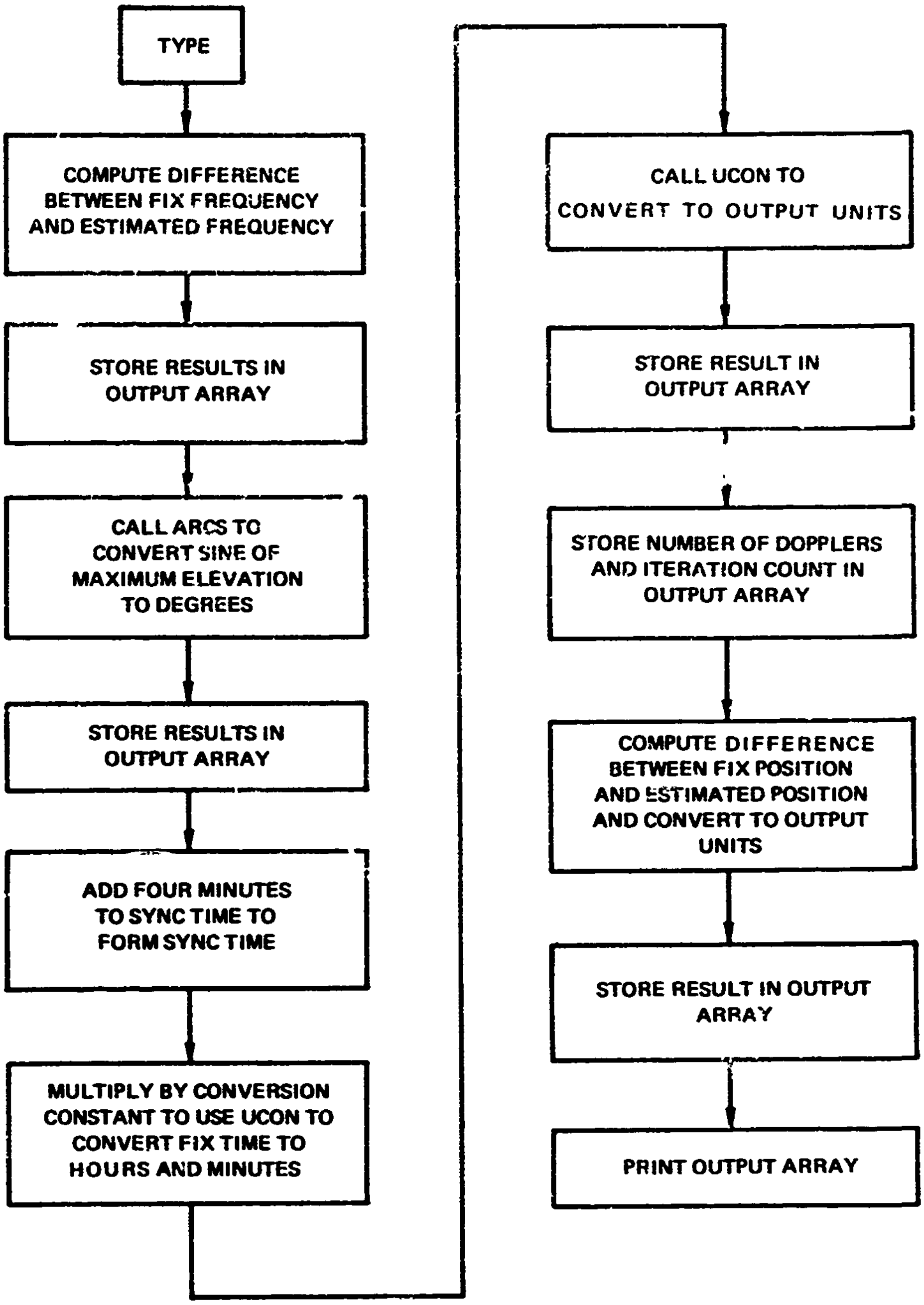


Fig. A-23 SUBROUTINE TYPE

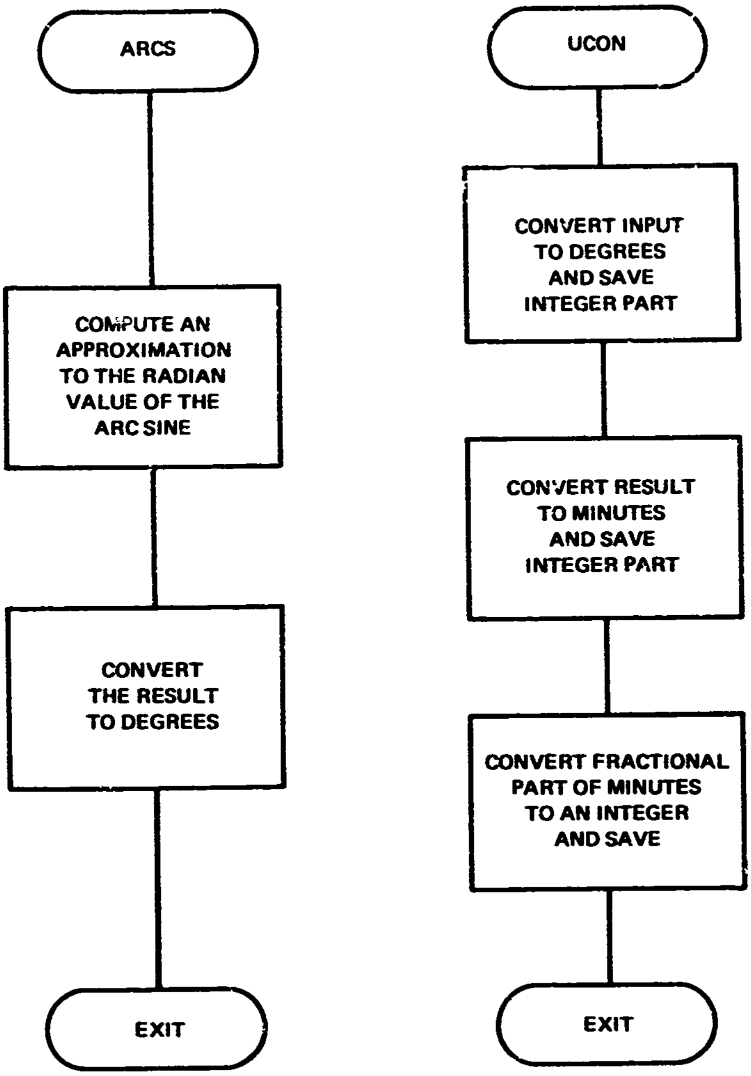


Fig. A-24 SUBROUTINE ARCS AND UCON

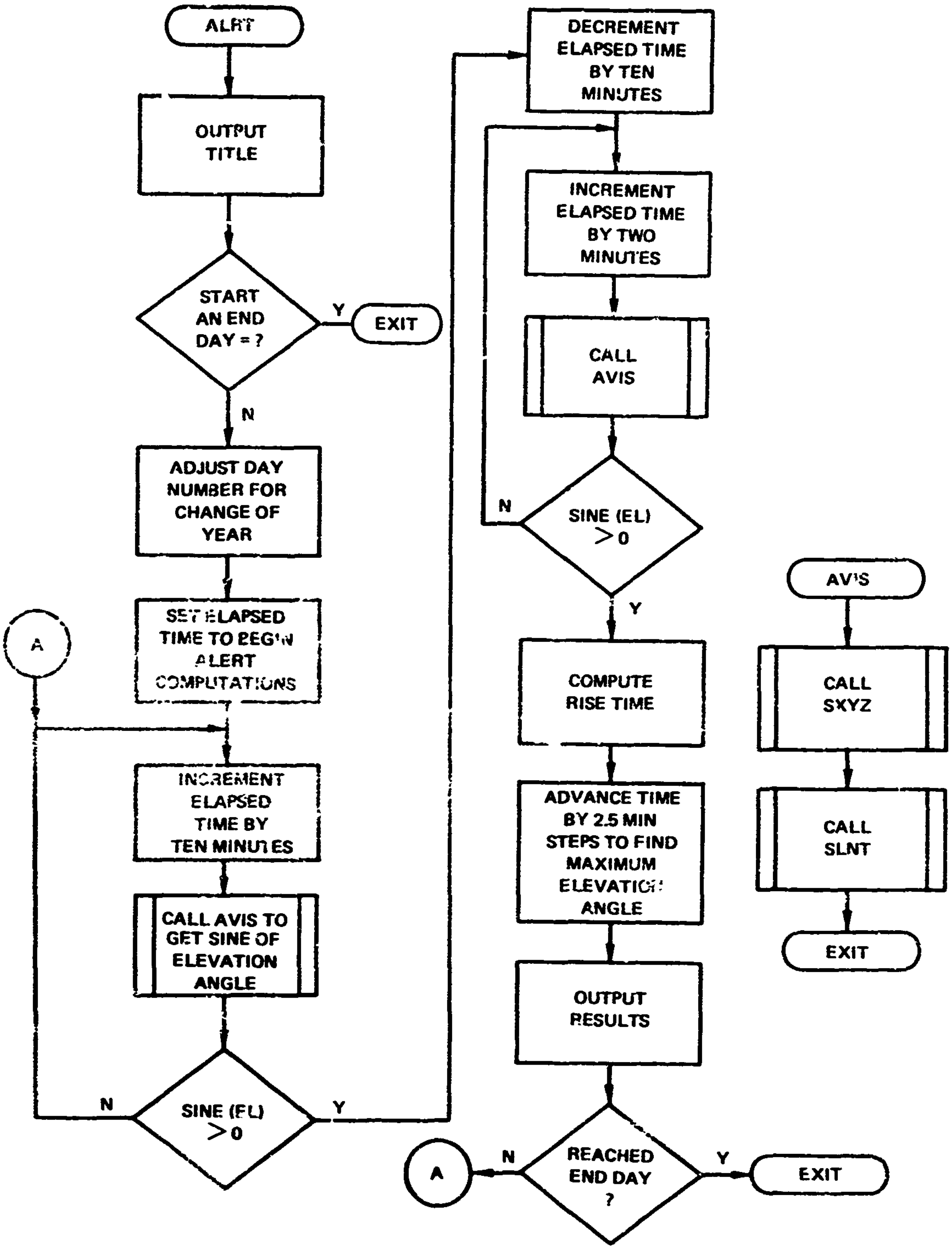


Fig. A-25 SUBROUTINES ALRT AND AVIS

APPENDIX B

FIXED POINT SCALING

The AN/SRN-9 navigation solution equations and the suggested fixed point scaling to be used in the solution are presented in this Appendix. It is assumed that a computer with at least 30-bit word length is available (i.e., sign and 29 bits) and that the error of arithmetic routines is in the 29th bit.

SCALING NOTATION

The register containing the word of interest is considered to have the most significant bit at the left and the least significant bit to the right. The decimal point is normally considered to be at the far left, between the sign bit and most significant data bit. This situation is represented by s0. The letter s is used to indicate a scaling number. If the decimal place is considered to be to the right n places, the scaling is indicated by sn. If the decimal point is considered to be to the left n places, the scaling is indicated by s-n. To scale the number 9 (for example) optimally it should be scaled s4.

9_{10} = 1001 binary

represented in a 30-bit word as

bit position 30 29 28 27 26 25 ....
S. 1 0 0 1. 0
s0 → s4

The number 0.25 would be scaled s-1 optimally.

$$0.25_{10} = 0.01 \text{ binary}$$

$$\underset{s0}{\overset{\curvearrowleft}{0}}\ \underset{s-1}{.}\ \boxed{1\,0\,0\,-\,-\,-} = \underset{s-1}{S.}\ 1\ \ 0\ \ 0\ -\ -$$

In the navigation equations the scaling is written above the variable of concern. Sometimes a shift of the decimal point of the result of a computation is needed to match that of another computation. This is indicated by giving the scaling of the result of the operation with an arrow to the desired scaling.

Example:

$$x = a + by$$

suppose a is scaled s3

b is scaled s2

y is scaled s4

and it is desired to have x scaled s2. This would be indicated by:

$$x = \overset{s3}{a} + \underset{s6 \rightarrow s3}{\overset{s2}{b}\ \overset{s4}{y}} \qquad s3 \rightarrow s2$$

In multiplication, scaling numbers add. In division, scaling numbers are formed by subtracting the denominator scaling from the numerator scaling. In division, it is necessary to adjust the scaling before dividing so that the result of the division will have the proper scaling to insure no overflow (i.e., the answer will fit into the resulting scaling).

INPUTS AND UNITS

The inputs to the navigation computation and the units in which they are expressed are listed below.

Symbol	Units	Scaling
t_p	minutes	s11
n	radians/minute	s-3
ω_o	radians	s4
$\lvert\dot{\omega}\rvert$	radians/minute	s-11
ϵ	dimensionless	s-3
A_o	meters	s24
Ω_o	radians	s4
Ω	radians/minute	s-7
Ci	dimensionless	s-5
Λ_G	radians	s4
Si	dimensionless	s1
ΔE_k	radians	s-2
ΔA_k	meters	s24
ηk	meters	s9
t_o	minutes	s4
T_c	minutes	s11
N_k	cycles	s23
R_k	cycles	s12
φ_e	radians	s4
λe	radians	s4
φ_k	radians	s4
λ_k	radians	s4
$\bar{f}_o$	cycles/minute	s21
f	dimensionless	s6

Symbol	Units	Scaling
δ	dimensionless	s0
R_o	meters	s23
h'	meters	s23
ω_e	radians/minute	s-7
L_o	meters/cycle	s0
v	knots	s9
d	radians	s4

SCALING FOR NAVIGATION FIX SOLUTION AND ALERTS

STEP A – Correct 400-MHz doppler counts for effect of ionospheric refraction.

$$\text{If } N_{k_{400}} \le 2 \times 10^6,\ N_k = 0, \text{ otherwise continue.} \qquad (A.1)$$

$$\text{If } R_k = 2 \times 10^3,\ N_k = 0, \text{ otherwise continue.} \qquad (A.2)$$

$$N_k = \overset{s23}{N_{k_{400}}} + \overset{s0}{\frac{24}{55}}\ \underset{\underline{s12 \rightarrow s23}}{(\overset{s12}{2000} - \overset{s12}{R_k})} \quad s23 \text{ cycles.} \qquad (A.3)$$

STEP B – Compute navigator's relative motion in latitude and longitude.

$$\delta = f\ (2-f) \qquad s0. \qquad (B.1)$$

$$\Delta\lambda_k = \overset{s4}{(k-1)}\ \overset{s9}{v}\ \underset{s1}{\overset{s1}{\frac{\sin d}{\cos\varphi_e}}}\left[\overset{s-13}{\frac{1}{3443.934}}\ \frac{2}{60}\right]\underset{\underline{s1\rightarrow s2}}{\left[(1-0.5\,\overset{s1}{\delta}\,\sin^2\varphi_e)\right]}\ s2 \text{ radians.} \qquad (B.2)$$

$$\Delta\varphi_k = \overset{s4}{(k-1)}\ \overset{s9}{v}\ \overset{s1}{\cos d}\left[\frac{1^{s-13}}{3443.934}\ \frac{2}{60}\right]\left[1+\delta\ \overset{s1}{(1-0.5\delta\ \sin^2\varphi_e}\right] s2 \text{ radians.} \qquad (B.3)$$

<u>STEP C</u> – Compute first fiducial time.

$$K' = \overset{s11}{\underset{s2}{\left[\frac{T_c}{2}\right]}}\ [\,]\text{ means integer part of} \qquad s10 \text{ minutes.} \qquad (C.1)$$

$$\underline{s9\rightarrow s10}$$

$$I = \overset{s2}{2}\ \overset{s10}{K'} \qquad \underline{s12\rightarrow s11} \qquad s11 \text{ minutes.} \qquad (C.2)$$

$$T_c' = \left[\overset{s11}{\underset{s5}{\frac{I}{30}}}\right] \qquad s6 \text{ minutes.} \qquad (C.3)$$

$$J = \overset{s11}{I} - \overset{s5}{30}\ \overset{s6}{T_c'} \qquad s11 \text{ minutes.} \qquad (C.4)$$

$$s6\rightarrow s11$$

$$H = \overset{s2}{2}\ \overset{s4}{t_0} - \overset{s11}{J} \qquad s11 \text{ minutes.} \qquad (C.5)$$

$$T_0 = \overset{s11}{I} + \overset{s11}{H} - \overset{s5}{30}\left[\overset{s11}{\underset{s5}{\frac{H}{15}}}\right] \qquad s11 \text{ minutes.} \qquad (C.6)$$

STEP D – Decode out-of-plane orbit corrections and interpolate for missing corrections.

$$N = \overset{s11}{T_0} - \overset{s3}{4} \underset{s3}{\overset{s11}{\left[\frac{T_0}{4}\right]}} \quad [\,]\ \text{means integer part of}\ s11\ \text{minutes.} \qquad (D.1)$$

Eqs. (D.3) through (D.5) shall be executed for

$k = 2, 4, 6, \text{---}$ if $N = 0$ or for $k = 1, 3, 5, \text{---}$ if $N \neq 0$. (D.2)

If $\eta_k - 5 \geq 0$ then (D.3)

$CP(\ell) = 100\,(\eta_k - 5) + 10\,\eta_{k+1}$ s9

and $CPT\,(\ell) = k$. s5

If $\eta_k - 5 < 0$ and (D.4)

$\eta_k \neq 0$ then

$CP\,(\ell) = 100\,(\eta_k - 5) - 10\,\eta_{k+1}$ s9

and $CPT\,(\ell) = k$. s5

If $\eta_k - 5 < 0$ and (D.5)

$\eta_k = 0$ then

$CP\,(\ell) = -10\,\eta_{k+1}$ s9

and $CPT\,(\ell) = k$ s5

where $\ell = 1, 2, 3, \text{---}, OP$.

If OP $\leq$ 2 then (D.6)

$$\eta_k = 0 \text{ for } k = 1, 2, 3, \cdots, KM.$$

If OP = 3, execute Eq. (D. 7-a) for k = 1, 2, 3, ---, KM.
If OP = 4 and N = 0 execute Eq. (D. 7-a) for
k = 1, 2, 3 and Eq. (D. 7-b) for k = 4, 5, 6, ---, KM.
If OP = 4 and N $\neq$ 0 execute Eq. (D. 7(a) for
k = 1, 2 and Eq. (D. 7-b) for k = 3. 4, 5, ---, KM. (D. 7)
If OP = 5 and N = 0 execute Eq. (D. 7-a) for
k = 1, 2, 3, Eq. (D. 7-b) for k = 4, 5, and
Eq. (D. 7-c) for k = 6, 7, 8, ---, KM.
If OP = 5 and N $\neq$ 0 execute Eq. (D. 7-a) for k =
1, 2, 3. Eq. (D. 7-b) for k = 4, and Eq. (D. 7-c) for
k = 5, 6, 7, ---, KM.

$$\eta_k = \left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(2)}}{\underset{s5}{CPT(1)} - \underset{s5}{CPT(2)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(3)}}{\underset{s5}{CPT(1)} - \underset{s5}{CPT(3)}} \right]_{\underline{s10 \to s7}} \overset{s9}{CP(1)} \qquad \underline{s12 \to s9}\ s9$$

$$+ \left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(1)}}{\underset{s5}{CPT(2)} - \underset{s5}{CPT(1)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(3)}}{\underset{s5}{CPT(2)} - \underset{s5}{CPT(3)}} \right]_{\underline{s10 \to s7}} \overset{s9}{CP(2)} \qquad \underline{s12 \to s9}\ s9 \tag{D. 7-a}$$

$$+ \left[\frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(1)}}{\underset{s5}{CPT(3)} - \underset{s5}{CPT(1)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{CPT(2)}}{\underset{s5}{CPT(3)} - \underset{s5}{CPT(2)}} \right]_{\underline{s10 \to s7}} \overset{s9}{CP(3)} \qquad \underline{s12 \to s9}\ s9.$$

$$
\begin{aligned}
\eta_k = {} & \underset{\underline{\text{s10-s7}}}{\left[\frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(3)}}{\underset{s5}{\text{CPT}(2)} - \underset{s5}{\text{CPT}(3)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(4)}}{\underset{s5}{\text{CPT}(2)} - \underset{s5}{\text{CPT}(4)}} \right]} \overset{s9}{\text{CP}(2)} \qquad \underline{\text{s12-s9}}\ \text{s9} \\
& + \underset{\underline{\text{s10-s7}}}{\left[\frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(2)}}{\underset{s5}{\text{CPT}(3)} - \underset{s5}{\text{CPT}(2)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(4)}}{\underset{s5}{\text{CPT}(3)} - \underset{s5}{\text{CPT}(4)}} \right]} \overset{s9}{\text{CP}(3)} \qquad \underline{\text{s12-s9}}\ \text{s9} \qquad \text{(D. 7-b)} \\
& + \underset{\underline{\text{s10-s7}}}{\left[\frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(2)}}{\underset{s5}{\text{CPT}(4)} - \underset{s5}{\text{CPT}(2)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(3)}}{\underset{s5}{\text{CPT}(4)} - \underset{s5}{\text{CPT}(3)}} \right]} \overset{s9}{\text{CP}(4)} \qquad \underline{\text{s12-s9}}\ \text{s9}.
\end{aligned}
$$

$$
\begin{aligned}
\eta_k = {} & \underset{\underline{\text{s10-s7}}}{\left[\frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(4)}}{\underset{s5}{\text{CPT}(3)} - \underset{s5}{\text{CPT}(4)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(5)}}{\underset{s5}{\text{CPT}(3)} - \underset{s5}{\text{CPT}(5)}} \right]} \overset{s9}{\text{CP}(3)} \qquad \underline{\text{s12-s9}}\ \text{s9} \\
& + \underset{\underline{\text{s10-s7}}}{\left[\frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(3)}}{\underset{s5}{\text{CPT}(4)} - \underset{s5}{\text{CPT}(3)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(5)}}{\underset{s5}{\text{CPT}(4)} - \underset{s5}{\text{CPT}(5)}} \right]} \overset{s9}{\text{CP}(4)} \qquad \underline{\text{s12-s9}}\ \text{s9} \qquad \text{(D. 7-c)} \\
& + \underset{\text{s10-s7}}{\left[\frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(3)}}{\underset{s5}{\text{CPT}(5)} - \underset{s5}{\text{CPT}(3)}} \cdot \frac{\overset{s5}{(k+1)} - \overset{s5}{\text{CPT}(4)}}{\underset{s5}{\text{CPT}(5)} - \underset{s5}{\text{CPT}(4)}} \right]} \text{CP}(5) \qquad \underline{\text{s12-s9}}\ \text{s9}.
\end{aligned}
$$

<u>STEP E</u> – Compute time between time of perigee and first fiducial time.

$$t = \overset{s11}{T_0} - \overset{s11}{t_p} \qquad \text{s11 minutes.} \qquad (E.1)$$

$$t_R = \overset{s11}{1440} - 2\,\overset{s4}{\Pi}/\underset{s-3}{n} \quad \underline{s7 \rightarrow s11} \qquad \text{s11 minutes.} \qquad (E.2)$$

$$\left.\begin{array}{l} \text{If } t \leq -480 \text{ then } \Delta t_p = \overset{s11}{t} + \overset{s11}{1440} \\ \text{If } -480 < t < t_R \text{ then } \Delta t_p = \overset{s11}{t} \\ \text{If } t_R \leq t \text{ then } \Delta t_p = \overset{s11}{t} - \overset{s11}{1440} \end{array}\right\} \text{ s11 minutes.} \qquad (E.3)$$

<u>STEP F</u> – Compute satellite coordinates at 2-minute intervals.

$$\Delta t_k = \overset{s11}{\Delta t_p} + 2\,\overset{s11}{(k-1)} \qquad \text{s11 minutes.} \qquad (F.1)$$

$$M_k = \overset{s-3}{n}\,\Delta \overset{s11}{t_k} \quad \underline{s8 \rightarrow s7} \qquad \text{s7 radians.} \qquad (F.2)$$

$$E_K = \overset{s7}{M_k} + \underset{s-2 \rightarrow s7}{\left[\overset{s-3}{\epsilon}\sin \overset{s1}{M_k} + \Delta \overset{s-2}{E_k}\right]} \qquad \text{s7 radians.} \qquad (F.3)$$

$$A_k = \overset{s24}{A_0} + \Delta \overset{s24}{A_k} \qquad \text{s24 meters.} \qquad (F.4)$$

$$u_k = \underset{s25 \rightarrow s24}{\left[\overset{s24}{A_k}\left(\cos \overset{s1}{E_k} - \overset{\underline{s-3 \rightarrow s1}}{\epsilon}\right)\right]} \qquad \text{s24 meters.} \qquad (F.5)$$

$$v_k = \overset{s24}{A_k}\ \overset{s1}{(\sin E_k)}\ \ s25 \rightarrow s24 \qquad \text{s24 meters.} \qquad \text{(F. 6)}$$

$$\omega_k = \overset{s4}{\omega_0} - \begin{bmatrix} s\text{-}11s11 \\ \dot{\omega}\,\Delta\, t_k \end{bmatrix} s0 \rightarrow s4 \qquad \text{s4 radians.} \qquad \text{(F. 7)}$$

$$x'_k = \overset{s24}{u_k}\ \overset{s1}{\cos\omega_k} - \overset{s24}{v_k}\ \underset{s25\rightarrow s24}{\overset{s1}{\sin\omega_k}} \qquad \text{s24 meters.} \qquad \text{(F. 8)}$$

$$y'_k = \overset{s24}{u_k}\ \overset{s1}{\sin\omega_k} + \overset{s24}{v_k}\ \overset{s1}{\cos\omega_k} \qquad \text{s25 meters.} \qquad \text{(F. 9)}$$

$$z' = \overset{s9}{\eta_k} \qquad \text{s9 meters.} \qquad \text{(F. 10)}$$

$$\beta_k = (\overset{s4}{\Omega_0} - \overset{s4}{\Lambda_G}) + (\overset{s^{-7}}{\dot{\Omega}} - \overset{s_{-7}}{\omega_e})\ \overset{s11}{\Delta t_k} \qquad \text{s4 radians.} \qquad \text{(F. 11)}$$

$$X_{Sk} = \underset{\underline{s25\rightarrow s24}}{\begin{bmatrix} s24 & s1 \\ x'_k & \cos\beta_k \end{bmatrix}} - \underset{\underline{s21\rightarrow s24}}{\begin{bmatrix} s25 & s\text{-}5 & s1 \\ y'_k & Ci & \sin\beta_k \end{bmatrix}} \qquad \text{(F. 12)}$$

$$+ \underset{\underline{s11\rightarrow s24}}{\begin{bmatrix} s9 & s1 & s1 \\ z'_k & Si & \sin\beta_k \end{bmatrix}} \qquad \text{s24 meters.}$$

$$Y_{Sk} = \underset{\underline{s25\rightarrow s24}}{\begin{bmatrix} s24 & s1 \\ x'_k & \sin\beta_k \end{bmatrix}} + \underset{\underline{s21\rightarrow s24}}{\begin{bmatrix} s25 & s\text{-}5 & s1 \\ y'_k & Ci & \cos\beta_k \end{bmatrix}} \qquad \text{(F. 13)}$$

$$- \underset{\underline{s11\rightarrow s24}}{\begin{bmatrix} s9 & s1 & s1 \\ z'_k & Si & \cos\beta_k \end{bmatrix}} \qquad \text{s24 meters.}$$

$$Z_{Sk} = \overset{s25}{y'_k}\ \overset{s1}{Si} + \underset{\underline{s4 \rightarrow s26}}{\left[\overset{s9}{z'_k}\ \overset{s-5}{Ci}\right]} s26 \rightarrow s24 \qquad s24 \text{ meters.} \qquad (F.14)$$

STEP G – Compute navigator's coordinates and partial derivatives.

$$\cos\varphi_k = \cos(\varphi_f + \Delta\varphi_k) \qquad s1. \qquad (G.1)$$

$$\sin\varphi_k = \sin(\varphi_f + \Delta\varphi_k) \qquad s1. \qquad (G.2)$$

$$\cos\lambda_k = \cos(\lambda_f + \Delta\lambda_k) \qquad s1. \qquad (G.3)$$

$$\sin\lambda_k = \sin(\lambda_f + \Delta\lambda_k) \qquad s1. \qquad (G.4)$$

$$D_k^2 = \overset{s46}{R_0^2} \underset{\underline{s48 \rightarrow s46}}{\left[\overset{s2}{\cos^2\varphi_k} + \overset{s0}{(1-f)^2}\overset{s2}{\sin^2\varphi_k}\right]} s46 \text{ (meters)}^2. \qquad (G.5)$$

$$X_{Nk} = \left[\underset{s23}{\overset{s46}{(R_0^2/D_k)}} + h'\right]^{s23} \underset{\underline{s25 \rightarrow s24}}{\overset{s1}{\cos\varphi_k}\ \overset{s1}{\cos\lambda_k}} \quad s24 \text{ meters.} \qquad (G.6)$$

$$Y_{Nk} = \left[\underset{s23}{\overset{s46}{(R_0^2/D_k}} + h'\right]^{s23} \underset{\underline{s25 \rightarrow s24}}{\overset{s1}{\cos\varphi_k}\ \overset{s1}{\sin\lambda_k}} \quad s24 \text{ meters.} \qquad (G.7)$$

$$Z_{Nk} = \left[\underset{s23}{\frac{\overset{s46}{R_0^2}\ \overset{s0}{(1-f)^2}}{D_k}} + \overset{s23}{h'}\right] \overset{s1}{\sin\varphi_k} \qquad s24 \text{ meters.} \qquad (G.8)$$

$$\frac{\partial X_{Nk}}{\partial \varphi} = -\left[\frac{\overset{s92}{R_0^{\,4}}\,\overset{s0}{(1-f)^2}}{\underset{s69}{D_k^{\,3}}} + h'\right]^{s23} \underset{\underline{s25 \to s23}}{\overset{s1}{\sin\varphi}\;\overset{s1}{\cos\lambda_k}} \qquad s23\ \text{meters/ radian} \qquad (G.9)$$

$$\frac{\partial Y_{Nk}}{\partial \varphi} = -\left[\frac{\overset{s92}{R_0^{\,4}}\,\overset{s0}{(1-f)^2}}{\underset{s69}{D_k^{\,3}}} + h'\right]^{s23} \underset{\underline{s25 \to s23}}{\overset{s1}{\sin\varphi_k}\;\overset{s1}{\sin\lambda_k}} \qquad s23\ \text{meters/ radian} \qquad (G.10)$$

$$\frac{\partial Z_{Nk}}{\partial \varphi} = \left[\frac{\overset{s92}{R_0^{\,4}}\,\overset{s0}{(1-f)^2}}{\underset{s69}{D_k^{\,3}}} + h'\right]^{s23} \underset{\underline{s24 \to s23}}{\cos\varphi_k} \qquad s23\ \text{meters/ radian} \qquad (G.11)$$

$$\frac{\partial X_{Nk}}{\partial \lambda} = -\overset{s24}{Y_{Nk}} \qquad s24\ \text{meters/ radian} \qquad (G.12)$$

$$\frac{\partial Y_{Nk}}{\partial \lambda} = \overset{s24}{X_{Nk}} \qquad s24\ \text{meters/ radian} \qquad (G.13)$$

STEP H – Compute theoretical slant range differences, partial derivatives, and elevation angle.

$$X_k = \overset{s24}{X_{Sk}} - \overset{s24}{X_{Nk}} \qquad s24\ \text{meters.} \qquad (H.1)$$

$$Y_k = \overset{s24}{Y_{Sk}} - \overset{s24}{Y_{Nk}} \qquad s24\ \text{meters.} \qquad (H.2)$$

$$Z_k = \overset{s24}{Z_{Sk}} - \overset{s24}{Z_{Nk}} \qquad \text{s24 meters.} \qquad \text{(H. 3)}$$

$$S_k^2 = \overset{s48}{X_k^2} + \overset{s48}{Y_k^2} + \overset{s48}{Z_k^2} \qquad \text{s48 (meters)}^2. \qquad \text{(H. 4)}$$

$$S_k = \left[\overset{s48}{X_k^2} + \overset{s48}{Y_k^2} + \overset{s48}{Z_k^2} \right]^{1/2} \qquad \text{s24 meters.} \qquad \text{(H. 5)}$$

$$R_k^2 = \overset{s48}{X_{Sk}^2} + \overset{s48}{Y_{Sk}^2} + \overset{s48}{Z_{Sk}^2} \qquad \text{s48 (meters)}^2. \qquad \text{(H. 6)}$$

$$r_k^2 = \overset{s48}{X_{Nk}^2} + \overset{s48}{Y_{Nk}^2} + \overset{s48}{Z_{Nk}^2} \qquad \text{s48 (meters)}^2. \qquad \text{(H. 7)}$$

$$r_k = \underset{s24 \rightarrow s23}{\left[\overset{s48}{X_{Nk}^2} + \overset{s48}{Y_{Nk}^2} + \overset{s48}{Z_{Nk}^2} \right]^{1/2}} \qquad \text{s23 meters} \qquad \text{(H. 8)}$$

$$\frac{\partial S_k}{\partial \varphi} = \frac{-1}{\underset{s24}{S_k}} \left[\overset{s24}{X_k} \overset{s23}{\frac{\partial X_{Nk}}{\partial \varphi}} + \overset{s24}{Y_k} \overset{s23}{\frac{\partial Y_{Nk}}{\partial \varphi}} + \overset{s24}{Z_k} \overset{s23}{\frac{\partial Z_{Nk}}{\partial \varphi}} \right] \qquad \text{(H. 9)}$$

s23 meters/
radian.

$$\frac{\partial S_k}{\partial \lambda} = \frac{-1}{\underset{s24}{S_k}} \left[\overset{s24}{X_k} \overset{s24}{\frac{\partial X_{Nk}}{\partial \lambda}} + \overset{s24}{Y_k} \overset{s24}{\frac{\partial Y_{Nk}}{\partial \lambda}} \right] \qquad \text{s24 meters/radian.} \qquad \text{(H. 10)}$$

$$\sin E_k = \left[\frac{\overset{s24}{X_k} \overset{s24}{X_{Nk}} + \overset{s24}{Y_k} \overset{s24}{Y_{Nk}} + Z_k \overset{s24}{Z_{Nk}}}{\underset{s24}{S_k} \underset{s23}{r_k}} \right] \qquad \text{s1.} \qquad \text{(H. 11)}$$

If $\sin E_{k+1} < \sin E_k$ then $\sin E_{max} = \sin E_k$. (H. 12)

STEP I – Compute refraction corrected measured slant range differences.

$$\hat{S}_{ko} = \overset{s23}{N_k}\ \overset{s0}{L_o} - \overset{s2}{2.0}\ \overset{s21}{\bar{f}_o}\ \overset{s0}{L_o} \qquad \text{s23 meters.} \qquad \text{(I. 1)}$$

STEP J – Form the C matrix.

$$C_{J0} = -\overset{s23}{\hat{S}_{ko}} + \underbrace{\left[\overset{s23}{S_{k+1}} - \overset{s23}{S_{k+1}}\right]}_{s23 \rightarrow s20} \qquad \text{s20 meters.} \qquad \text{(J. 1)}$$

$$C_{J1} = -\underbrace{\begin{bmatrix}\overset{s2}{2.0} & \overset{s0}{L_o}\end{bmatrix}}_{s2 \rightarrow s1} \qquad \text{s1 } \frac{\text{meters-minutes}}{\text{cycle}} \qquad \text{(J. 2)}$$

$$C_{J2} = -\frac{\partial \overset{s23}{S_{k+1}}}{\partial \varphi} + \frac{\partial \overset{s23}{S_k}}{\partial \varphi} \qquad \text{s23 meters/ radian.} \qquad \text{(J. 3)}$$

$$C_{J3} = \underbrace{\left[-\frac{\partial \overset{s24}{S_{k+1}}}{\lambda} + \frac{\partial \overset{s24}{S_k}}{\partial \lambda}\right]}_{s24 \rightarrow s23} \qquad \text{s23 meters/ radian.} \qquad \text{(J. 4)}$$

STEP K – Form the A matrix.

J - Number of rows in C matrix.

$$a_{10} = \sum_{m=1}^{J} \overset{s1}{C_{m1}}\ \overset{s20}{C_{m0}} \qquad \underline{s21 \rightarrow s23}\ \ \text{s23.} \qquad \text{(K. 1)}$$

$$a_{20} = \sum_{m=1}^{J} \overset{s23}{C_{m2}}\ \overset{s20}{C_{m0}} \qquad \underline{s43 \rightarrow s45}\ \ \text{s45.} \qquad \text{(K. 2)}$$

$$a_{30} = \sum_{m=1}^{J} C_{m3}^{s23}\, C_{m0}^{s20} \quad \underline{s43 \rightarrow s42} \quad s42. \tag{K. 3}$$

$$a_{11} = \sum_{m=1}^{J} C_{m1}^{s1}\, C_{m1}^{s1} \quad \underline{s2 \rightarrow s5} \quad s5\,. \tag{K. 4}$$

$$a_{21} = \sum_{m=1}^{J} C_{m2}^{s23}\, C_{m1}^{s1} \quad \underline{s24 \rightarrow s27} \quad s27. \tag{K. 5}$$

$$a_{31} = \sum_{m=1}^{J} C_{m3}^{s23}\, C_{m1}^{s1} \quad \underline{s24 \rightarrow s23} \quad s23. \tag{K. 6}$$

$$a_{12} = a_{21}. \tag{K. 7}$$

$$a_{22} = \sum_{m=1}^{J} C_{m2}^{s23}\, C_{m2}^{s23} \quad \underline{s46 \rightarrow s49} \quad s49. \tag{K. 8}$$

$$a_{32} = \sum_{m=1}^{J} C_{m3}^{s23}\, C_{m2}^{s23} \quad \underline{s46 \rightarrow s45} \quad s45. \tag{K. 9}$$

$$a_{13} = a_{31}. \tag{K. 10}$$

$$a_{23} = a_{32}. \tag{K. 11}$$

$$a_{33} = \sum_{m=1}^{J} C_{m3}^{s23}\, C_{m3}^{s23} \quad \underline{s46 \rightarrow s43} \quad s43. \tag{K. 12}$$

STEP L – Solve for Δf, $\Delta\varphi$, $\Delta\lambda$ and update estimates of f, φ, and λ.

$$B11 = \overset{s49}{a_{22}} - \overset{s27}{a_{12}}\ \underset{s5}{\overset{s27}{\frac{a_{12}}{a_{11}}}} \qquad s49. \qquad (L.1)$$

$$B12 = \overset{s45}{a_{23}} - \overset{s23}{a_{13}}\ \underset{s5}{\overset{s27}{\frac{a_{12}}{a_{11}}}} \qquad s45. \qquad (L.2)$$

$$B10 = \overset{s45}{a_{20}} - \overset{s23}{a_{10}}\ \underset{s5}{\overset{s27}{\frac{a_{12}}{a_{11}}}} \qquad s45. \qquad (L.3)$$

$$B22 = \overset{s43}{a_{33}} - \left[\overset{s23}{a_{13}}\ \underset{s5}{\overset{s23}{\frac{a_{13}}{a_{11}}}}\right]_{\underline{s41\to s43}} \qquad s43. \qquad (L.4)$$

$$B20 = \overset{s42}{a_{30}} - \left[\overset{s23}{a_{10}}\ \underset{s5}{\overset{s23}{\frac{a_{13}}{a_{11}}}}\right]_{\underline{s41\to s42}} \qquad s42. \qquad (L.5)$$

$$\Delta = \begin{bmatrix} \overset{s49}{B11}\ \overset{s43}{B22} \\ s92\to s91 \end{bmatrix} - \begin{bmatrix} \overset{s45}{B12}\ \overset{s45}{B12} \\ s90\to s91 \end{bmatrix} \qquad s91. \qquad (L.6)$$

$$\Delta\varphi = \frac{(\overset{s88\to s87}{\overline{\overset{s43}{B22}\ \overset{s45}{B10}}} - \overset{s45}{B12}\ \overset{s42}{B20})}{\underset{s91}{\Delta}} \qquad s\text{-}4 \text{ radians.} \qquad (L.7)$$

$$\Delta\lambda = \frac{(\overset{s91\to s90}{\overline{\overset{s49}{B11}\ \overset{s42}{B20}}} - \overset{s45}{B12}\ \overset{s45}{B10})}{\underset{s91}{\Delta}} \qquad s\text{-}1 \text{ radian.} \qquad (L.8)$$

$$\Delta f = \frac{\overset{s23}{a_{10}} - \overset{s27}{(a_{12})}\overset{s-4}{(\Delta\varphi)} - \overset{s22\to s23}{\overline{\overset{s23}{(a_{13})}\overset{s-1}{(\Delta\lambda)}}}}{\underset{s5}{a_{11}}}$$

s18 cycles/minute. (L. 9)

$\overset{s21}{f} = \overset{s18\to s21}{f + \Delta f}$ where $f = \bar{f}_o$ on first iteration s21 cycles/minute. (L. 10)

$\overset{s4}{\varphi_f} = \varphi_f + \overset{s-4\to s4}{\Delta\varphi}$ s4 radian. (L. 11)

$\overset{s4}{\lambda_f} = \lambda_f + \overset{s-1\to s4}{\Delta\lambda}$ s4 radian. (L. 12)

STEP M – Write out results.

$\text{DLA} = \overset{s4}{\varphi_f} - \overset{s4}{\varphi_e}$ s4 radians. (M. 1)

$\text{DLO} = \overset{s4}{\lambda_f} - \overset{s4}{\lambda_e}$ s4 radians. (M. 2)

$\text{FRQ} = \overset{s21}{f} - \overset{s21}{\bar{f}_o}$ s21 cycles/minute. (M. 3)

$\text{TIME} = \overset{s11}{T_0} + \overset{s3\to s11}{4}$ s11 minutes. (M. 4)

STEP N – Test for convergence.

If $\Delta f > 2.4$ cycle/minute

or if $\Delta\varphi > 1.2 \times 10^{-7}$ radian or if $\Delta\lambda > \dfrac{1.2 \times 10^{-7}}{\cos \varphi_f}$ radian

and if ITER $<$ 10 then return to Step G. Otherwise go to Step O to edit doppler data or Step P to compute alerts.

STEP O – Edit doppler data.

If $\sin E_{KM-k+1} \leq \sin 7.5°$ and (O.1)

$\sin E_{KM-k+1} \leq \sin E_k$ and

$N_{KM-k} > 0$ then

$N_{KM-k} = 0$ and

$NDOP = NDOP - 1.$

Or if $\sin E_{KM-k+1} > \sin 7.5°$ and (O.2)

$\sin E_k \leq \sin 7.5°$ and

$N_{k+1} > 0$ then

$N_{k+1} = 0$ and

$NDOP = NDOP - 1.$

Otherwise make no changes in the N_k table.

STEP P – Compute alerts.

ISTP = MDAY-IDAY. If ISTP $<$ 0, let ISTP = ISTP + 365. (P.1)

Let $T_0 = T_0 - 18$, KM = 1, DE(K) = 0, DA(K) = 0, DN(K) = 0, I = 1, 2, 3, ---, ISTP, KDAY = I + IDAY. (P. 2)

Execute Steps F, G, and H. (P. 3)

If $E_k \leq 0$ let $T_0 = T_0 + 10$, and repeat Step P. 3 increasing T_0 by 10 each repetition until $E_k > 0$. (P. 4)

When $E_k > 0$ let $T_0 = T_0 - 10$, repeat Step P. 3, and then execute Step P. 6. (P. 5)

If $E_k \leq 0$, let $T_0 = T_0 + 2$, repeat Step P. 3 increasing T_0 by 2 each time until $E_k \geq 0$, and then execute Step P. 7. (P. 6)

When $E_k \geq 0$ let $T_0 - 2$ = RISE, $E_k = E_A$, $T_0 = T_0 + 0.25$ and repeat Step P. 3 increasing T_0 by 0.25 and letting the new value of $E_k = E_A$ each time until $E_k < E_A$. Then E_A = maximum elevation for that pass. (P. 7)

Write out day number of alert day, RISE time (hours and minutes), and maximum elevation angle for the alert pass. (P. 8)

Let $T_0 = T_0 + 10$ then repeat Steps P. 3 through P. 8 incrementing I and K until I > ISTP indicating that all alerts through the end of MDAY have been obtained. (P. 9)

Appendix C

FOUR-VARIABLE (VELOCITY NORTH) NAVIGATION

Section 7 does not include equations to solve for velocity north or equations for relative motion inputs other than those obtained from an inertial system (i.e., latitude and longitude) or a system providing course and speed data. This Appendix provides these equations and also presents a method of assigning numbers to satellite 2-minute messages when a real-time clock is not available. This method may be used to determine missing messages due to loss of lock.

EQUATIONS FOR SHIP'S MOTION FOR CONSTANT VELOCITY OR DISTANCE TRAVELED

A table of navigator's latitudes (φ_k) and navigator's longitudes (λ_k) is assumed available from Step B of Section 7. These table values may be provided by an inertial system or from calculations based on a knowledge of course and speed. However, there are situations where these types of data are not present and therefore these tables may also be constructed from information on either the navigator's velocity (north and east) or from distance traveled using certain approximations. No study has been done on the effects of these approximations. However, for the relatively small velocities encountered in shipboard navigation their effects are negligible.

Equations for Constant Velocity North and East

$$\varphi_k = \varphi_j + 2\,\frac{(k-j)\,V_N}{R_0}\,[(1 + \delta\,(1 - 0.5\delta\,\sin^2\varphi_j)]$$

$$\lambda_k = \lambda_j + 2\,\frac{(k-j)\,V_E}{R_0}\,\left(\frac{1 - 0.5\delta\,\sin^2\varphi_j}{\cos\varphi_j}\right)$$

$\delta = f(2-f)$.

f = the value given in the table of program constants.

φ_j = and λ_j are initial estimates for the position at time t_j.

j is the value k = 3.

V_N and V_E are the constant north and east components of ship's velocity given in nautical miles per minute. R_o = 3443.934 nautical miles.

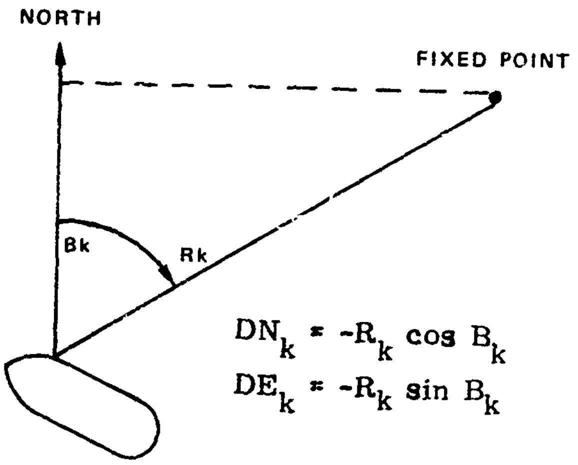
The factor of 2 appears because the fiducial time points denoted by k are 2 minutes apart. The approximations are caused by assuming that $\dot{\varphi}$ and $\dot{\lambda}$ are constant velocity north and east and ignoring changes in the earth radius during the time of the pass.

Equations for Distance Traveled

$$\varphi_k = \varphi_j + \frac{DN_k - DN_j}{R_0} [1 + \delta (1 - 0.5\delta \sin^2 \varphi_j)]$$

$$\lambda_k = \lambda_j + \frac{DE_k - DE_j}{R_0} \left[\frac{1 - 0.5\delta \sin^2 \varphi_j}{\cos \varphi_j}\right]$$

DN_k and DE_k are measured from any fixed arbitrary point. These distances may be obtained from a DRT plot, or as the range (R_k) and bearing (B_k) to a fixed point, as follows:



$$DN_k = -R_k \cos B_k$$

$$DE_k = -R_k \sin B_k$$

Additions to Section 7 to Solve for Velocity North Error

STEP G

Replace φ_k by $\varphi_k + 2\ \dot{\phi}_j\,(k-j)$ in Eqs.(G. 5) through (G. 11) where j is the value $k = 3$.

Additional Input: Estimate of velocity north (V_N) to get estimate of

$$\dot{\phi}_j = \frac{V_N \text{ (knots)}}{3443. \times 60} = \frac{\text{rad}}{\text{min}}$$

$$\left.\begin{array}{l} \dfrac{\partial X_{Nk}}{\partial \dot{\varphi}_j} = 2\,(k-j)\,\dfrac{\partial X_{Nk}}{\partial \varphi} \\[2ex] \dfrac{\partial Y_{Nk}}{\partial \dot{\varphi}_j} = 2\,(k-j)\,\dfrac{\partial Y_{Nk}}{\partial \varphi} \\[2ex] \dfrac{\partial Z_{Nk}}{\partial \dot{\varphi}_j} = 2\,(k-j)\,\dfrac{\partial Z_{Nk}}{\partial \varphi} \end{array}\right\} \quad = \frac{\partial \varphi_k}{\partial \varphi_j}\,\frac{\partial X_{Nk}}{\partial \varphi_k} \qquad \text{(G. 14)}$$

These steps are not necessary in the computation but are included for background. (G. 15)

(G. 16)

STEP H

$$\frac{\partial S_k}{\partial \dot{\varphi}_j} = 2\,(k-j)\,\frac{\partial S_k}{\partial \varphi}\,. \tag{H.13}$$

STEP J

$$C_{J4} = \frac{-\partial S_{k+1}}{\partial \dot{\varphi}_j} + \frac{\partial S_k}{\partial \dot{\varphi}_j}\,. \tag{J.5}$$

OUTPUT: The C matrix for velocity north

$$\begin{bmatrix} C_{10} & C_{11} & C_{12} & C_{13} & C_{14} \\ C_{20} & C_{21} & C_{22} & C_{23} & C_{24} \\ . & . & & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ C_{J0} & C_{J1} & C_{J2} & C_{J3} & C_{J4} \end{bmatrix}$$

STEP K

$$a_{40} = \sum_{m=1}^{J} C_{m4}\; C_{m0}\,. \tag{K.3.1}$$

$$a_{41} = \sum_{m=1}^{J} C_{m4}\; C_{m1}\,. \tag{K.6.1}$$

$$a_{42} = \sum_{m=1}^{J} C_{m4}\; C_{m2}\,. \tag{K.9.1}$$

$$a_{43} = \sum_{m=1}^{J} C_{m4} \; C_{m3}. \qquad \text{(K. 12. 1)}$$

$$a_{14} = a_{41}. \qquad \text{(K. 12. 2)}$$

$$a_{24} = a_{42}. \qquad \text{(K. 12. 3)}$$

$$a_{34} = a_{43}. \qquad \text{(K. 12. 4)}$$

$$a_{44} = \sum_{m=1}^{J} C_{m4} \; C_{m4}. \qquad \text{(K. 12. 5)}$$

<u>OUTPUT</u>: A Matrix

$$-a_{10} + a_{11} \Delta f + a_{12} \Delta\varphi + a_{13} \Delta\lambda + a_{14} \Delta\gamma = 0$$

$$-a_{20} + a_{21} \Delta f + a_{22} \Delta\varphi + a_{23} \Delta\lambda + a_{24} \Delta\gamma = 0$$

$$-a_{30} + a_{31} \Delta f + a_{32} \Delta\varphi + a_{33} \Delta\lambda + a_{34} \Delta\gamma = 0$$

$$-a_{40} + a_{41} \Delta f + a_{42} \Delta\varphi + a_{43} \Delta\lambda + a_{44} \Delta\gamma = 0$$

STEP L

$$\Delta\gamma = \frac{a_{40} - \left[a_{41} \Delta f + a_{42} \Delta\varphi + a_{43} \Delta\lambda\right]}{a_{44}} \qquad \text{(L. 0)}$$

Eliminate $\Delta\gamma$ by redefining the A matrix at the end of Step K and used in Step L.

$i = 1, 2, 3$

$$a_{i0} = a_{i0} - \frac{a_{40}}{a_{44}} a_{i4} \qquad a_{i2} = a_{i2} - \frac{a_{42}}{a_{44}} a_{i4}$$

$$a_{i1} = a_{i1} - \frac{a_{41}}{a_{44}} a_{i4} \qquad a_{i3} = a_{i3} - \frac{a_{43}}{a_{44}} a_{i4} .$$

Solve for $\Delta\varphi$, $\Delta\lambda$, Δf as in Steps (L. 1) to (L. 9).

Then solve

$\Delta\gamma$ from (L. 0), (L. 9), (L. 7), (L. 8)

$$\phi_j = \dot{\varphi}_j + \Delta\gamma . \qquad \text{(L. 13)}$$

STEP N

$$\text{If } |\Delta\gamma| > \frac{0.02}{3443. \times 60.} \quad \text{continue iterating at Step G} \qquad \text{(N. 2)}$$

after convergence

$$V_N = 3443.934 \left(\cos^2 \varphi_j + (1-f)^2 \sin^2 \varphi_j\right)^{1/2} \phi_j \times 60.$$

Programming Method

Figure C-1 is a flow chart of a direct search method for implementing the velocity north solution. In this method the 3 × 3 solution is obtained together with the value of the sum of the square of the residual between the theoretical and measured slant range difference. The value for velocity north is increased from an initial value of zero by an amount Δv, a new fix solution obtained, and a new value calculated for the sum of the residuals. The process is repeated with

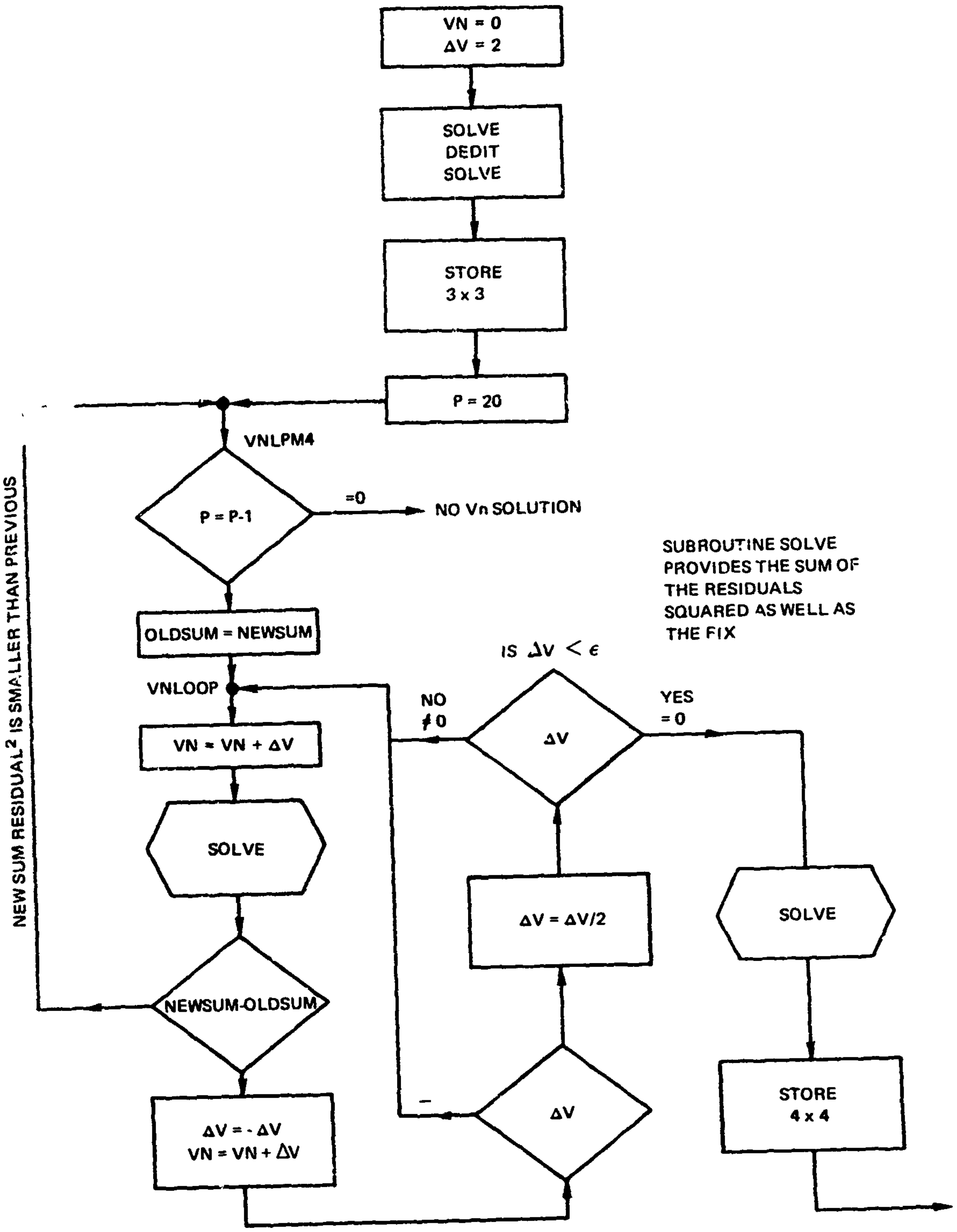


Fig. C-1 VELOCITY NORTH SOLUTION BY DIRECT SEARCH

Δv being incremented so long as the residuals continue to decline in value. The method provides for both positive and negative values of Δv.

NUMBER ASSIGNMENT TO SATELLITE 2-MINUTE MESSAGES TO DETERMINE MISSING MESSAGES

In order to majority vote the words from the satellite messages, it is necessary to keep track of which words represent the same parameter. The words which represent constant parameters do not change their position in the satellite message. However, words which represent the time varying parameters do change their position from one 2-minute message to the next. Whenever 2-minute messages are missing due to loss of lock it is necessary to know how many are missing. Otherwise the relative position of similar words will not be known between any two messages. Keeping track of missing messages is easy when messages are stored according to a clock. However, when a clock is not available some other means of determining missing messages must be used. The satellite data may be used to assign numbers to each message using the technique discussed later. These numbers are sequential with missing numbers for missing messages and therefore they accomplish the purpose of determining missing messages. Once this is done, majority voting of the time-varying words may be accomplished. From these results and an estimate of time (correct to 14 minutes) the correct time of the first doppler interval is calculated. The doppler counts stored during the pass may now be associated with the correct time interval by use of the message number assignments.

The time-varying words have contained within them a time integer modulo 15 that represents the time in some half hour for which that particular correction is to be applied. These time integers are sequential from 0 to 14 as time goes from 0 to 30 minutes. Each message contains eight sequential time varying words (see Fig. 10 and Table 1). These time integers could be used directly to assign message numbers. However, there is no assurance that they are correct because of noise in transmission or receiving. The following technique is used to assign numbers to the messages and will work when the bit error rate is less than or equal to 1 out of 8, which is much higher than normally encountered.

Procedure

Strip off the least significant time digit (4 bits) from each of the eight time-varying words in the message of interest. This sequence of eight numbers may have errors, but it will be a subset of the sequence:

01234567890123401234560123456.

This eight-digit (32-bit) sequence is compared to a known, error-free sequence. The known sequence is shifted a digit at a time until the number of bit errors between the two sequences is less than five. The number of shifts required to do this is the number assigned to that message.

Table C-1 shows the number of bit errors between any two (BCDX3) digits from 0 - 9. By adding the eight numbers along the diagonal starting at the point defined by the starting digit of the known and satellite time sequence, one immediately gets the number of errors between the two sequences.

Table C-2 gives the results of doing this calculation on Table C-1.

Assuming the satellite message is error-free there will be no errors when the two sequences are the same; otherwise there are at least nine bit errors (by observing Table C-2).

The sequences are compared on the basis of less than 5-bit errors to handle the case when there are 4-bit errors in a sequence which would normally mismatch by 9 bits.

Table C-1

Number of Bit Errors between any Two BCDX3 Digits

	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	0	1	2	3	4	5	6
0	0	3	2	2	1	3	2	2	1	4	0	3	2	2	1	0	3	2	2	1	3	2
1	3	0	1	1	2	2	3	3	4	1	3	0	1	1	2	3	0	1	1	2	2	3
2	2	1	0	2	1	3	2	4	3	2	2	1	0	2	1	2	1	0	2	1	3	2
3	2	1	2	0	1	3	4	2	3	2	2	1	2	0	1	2	1	2	0	1	3	4
4	1	2	1	1	0	4	3	3	2	3	1	2	1	1	0	1	2	1	1	0	4	3
5	3	2	3	3	4	0	1	1	2	1	3	2	3	3	4	3	2	3	3	4	0	1
6	2	3	2	4	3	1	0	2	1	2	2	3	2	4	3	2	3	2	4	3	1	0
7	2	3	4	2	3	1	2	0	1	2	2	3	4	2	3	2	3	4	2	3	1	2
8	1	4	3	3	2	2	1	1	0	3	1	4	3	3	2	1	4	3	3	2	2	1
9	4	1	2	2	3	1	2	2	3	0	4	1	2	2	3	4	1	2	2	3	1	2
0	0	3	2	2	1	3	2	2	1	4	0	3	2	2	1	0	3	2	2	1	3	2
1	3	0	1	1	2	2	3	3	4	1	3	0	1	1	2	3	0	1	1	2	2	3
2	2	1	0	2	1	3	2	4	3	2	2	1	0	2	1	2	1	0	2	1	3	2
3	2	1	2	0	1	3	4	2	3	2	2	1	2	0	1	2	1	2	0	1	3	4
4	1	2	1	1	0	4	3	3	2	3	1	2	1	1	0	1	2	1	1	0	4	3
0	0	3	2	2	1	3	2	2	1	4	0	3	2	2	1	0	3	2	2	1	3	2
1	3	0	1	1	2	2	3	3	4	1	3	0	1	1	2	3	0	1	1	2	2	3
2	2	1	0	2	1	3	2	4	3	2	2	1	0	2	1	2	1	0	2	1	3	2
3	2	1	2	0	1	3	4	2	3	2	2	1	2	0	1	2	1	2	0	1	3	4
4	1	2	1	1	0	4	3	3	2	3	1	2	1	1	0	1	2	1	1	0	4	3
5	3	2	3	3	4	0	1	1	2	1	3	2	3	3	4	3	2	3	3	4	0	1
6	2	3	2	4	3	1	0	2	1	2	2	3	2	4	3	2	3	2	4	3	1	0

Table C-2

Number of Errors when Comparing Two Eight-Digit Sequences Made up of the Least Significant Digits of the BCDX3 Modulo 15 Time Sequence

Beginning Digit of the Other Sequence		Beginning Digit of One Sequence															Errors
		0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	Min-Max
	0	0	15	14	20	15	26	17	22	14	20	10	14	18	15	15	10 - 26
	1	15	0	15	13	22	17	26	17	21	17	19	13	13	18	14	13 - 26
	2	14	15	0	18	13	22	17	26	18	18	18	18	16	13	19	13 - 26
	3	20	13	18	0	19	14	21	16	22	18	18	18	18	19	13	13 - 22
	4	15	22	13	19	0	19	12	19	17	19	17	17	19	18	22	13 - 22
	5	26	17	22	14	19	0	17	10	18	16	16	18	16	21	19	10 - 26
	6	17	26	17	21	12	17	0	17	11	17	17	13	17	16	22	11 - 26
	7	22	17	26	16	19	10	17	0	16	12	16	16	10	19	15	10 - 26
	8	14	21	18	22	17	18	11	16	0	18	12	16	14	9	19	9 - 21
	9	20	17	18	18	19	16	17	12	18	0	16	12	14	13	9	9 - 20
	0	10	19	18	18	17	16	17	16	12	16	0	14	12	15	13	10 - 19
	1	14	13	18	18	17	18	13	16	16	12	14	0	12	13	17	12 - 18
	2	18	13	16	18	19	16	17	10	14	14	12	12	0	15	15	10 - 19
	3	15	18	13	19	18	21	16	19	9	13	15	13	15	0	14	9 - 21
	4	15	14	19	13	22	19	22	15	19	9	13	17	15	14	0	9 - 22

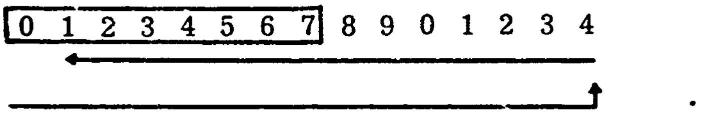
Example

Applying the above procedure to the data shown in Fig. 10 the following time sequences are obtained:

4 0 1 2 3 4 5 6 for the first message,

0 1 2 3 4 5 6 7 for the second message.

Now if a left end around shift is done to the following known sequence and the first eight digits are compared to the above sequences, it will be seen that 14 shifts are required for the first and 0 for the second.



If a match to less than 5-bit errors is not obtained in 14 shifts that message should not be used since it contains data that are too noisy.

Appendix D

TROPOSPHERIC REFRACTION CORRECTION

This Appendix presents the equations developed in Ref. 11 that are to be used if it is desired to correct the integrated doppler data obtained from the satellite for the effects of tropospheric refraction. The correction for tropospheric refraction $\Delta\rho_{tro}$ is to be subtracted from every slant range measurement. The expression for $\hat{S}_{ko}$, the measured slant range difference (Eq. (I.1) in Section 7), would thus be modified as follows:

$$\hat{S}_{ko_{corr}} = \hat{S}_{ko} - (\Delta\rho_{tro_{k+1}} - \Delta\rho_{tro_k}) \qquad (D.1)$$

where k = 1, 2, 3, ---, KM .

The tropospheric refraction correction $\Delta\rho_{tro}$ is defined as follows:

$$\Delta\rho_{tro} = \sum_{i=1,2} \Delta\rho_i \qquad (D.2)$$

where

$$\Delta\rho_i = 10^{-6} N_{T_i} \left[-\ell_1 + \frac{4}{h_{tro_i}^4} \left\{ \frac{1}{3} r_T^2 \ell_1^3 - \frac{2}{15} \ell_1^5 - \frac{3}{4} r_T r_{tro_i} \ell_1 (\ell_1^2 + \frac{1}{2} \ell_2^2) \right. \right.$$

$$+ r_{tro_i}^2 \ell_1^3 - \frac{1}{2} r_{tro_i}^3 r_T \ell_1 - \frac{1}{3} r_{tro_i}^2 \ell_{3_i}^3 + \frac{2}{15} \ell_{3_i}^5$$

$$+ \frac{3}{4} r_{tro_i}^2 (\ell_{3_i}^3 + \frac{1}{2} \ell_{3_i} \ell_2^2) - r_{tro_i}^2 \ell_{3_i} (\ell_{3_i}^2 - \frac{1}{2} r_{tro_i}^2)$$

$$\left. \left. + \frac{1}{2} r_{tro_i} \ell_2^2 (\frac{3}{4} \ell_2^2 + r_{tro_i}^2) \ln \frac{r_T + \ell_1}{r_{tro_i} + \ell_{3_i}} \right\} \right]$$

and

i = subscript indicating dry (d) and wet (w) refractivity terms,

N_{T_i} = ith component of tropospheric refractivity evaluated at a location near the navigator's antenna,

ℓ_1 = $r_T \sin E$,

h_{tro_i} = $h_{o_i} - h_T$,

r_T = distance from center of earth to navigator's antenna (km),

r_{tro_i} = $r_T + h_{tro_i}$,

ℓ_2 = $r_T \cos E$,

ℓ_{3_i} = $(r_{tro_i}^2 - \ell_2^2)^{1/2}$,

h_{o_i} = height of ith component of the troposphere above the geoid (km),

h_T = height of navigator's antenna above the geoid (km)

(on ships, negligible error is introduced by assuming $h_T = 0$), and

E = elevation angle of satellite at instant of slant range measurement (radians).

The dry and wet components of the tropospheric refractivity N_{T_i} are determined as follows:

$$N_{T_d} = \frac{77.6\,P}{T_K} \tag{D.3}$$

$$N_{T_w} = \frac{77.6\,(4810\,e)}{T_K^2} \tag{D.4}$$

where T_K = temperature (degrees Kelvin), P is total atmospheric pressure (millibars), and e is the partial pressure of water vapor (millibars) measured at the navigator's location. Alternatively, seasonal values for these parameters may be used as obtained from standard marine atlases (Refs. 12 and 13).

The determination of tropospheric height h_{o_i} is based on the assumption that the height of the wet component h_{o_w} is invariant with latitude, but that the height of the dry component h_{o_d} is a function of the navigator's latitude φ_T, as given in the following expression,

$$h_{o_d} = h_{o_{d(eq)}} + A_d \sin^2 \varphi_T , \tag{D.5}$$

where $h_{o_{d(eq)}}$ is the dry height at the equator and A_d is the amplitude of the variation of h_{o_d} with latitude. Values of these parameters for three values of h_{o_w} are given in Table D-1. A value of h_{o_w} = 12 km is generally satisfactory for use in all tropospheric refraction calculations.

Table D-1

Height Parameters for Two-Quartic N Profile (km)

h_{o_w}	$h_{o_{d(eq)}}$	A_d
10	43.858	-5.986
12	43.130	-5.206
14	42.402	-4.426

ALTERNATIVE FORMS TO ELIMINATE ROUNDING ERRORS

At high satellite elevation angles, significant rounding errors occur in the computation of the expression for $\Delta\rho_{tro}$ given in the preceding section, even in double precision. Alternative forms have been developed, therefore, to eliminate the rounding error problem and the need for double precision computation. These forms, which are presented in Ref. 14, are based upon the integral expression

$$\Delta\rho_{tro} = \frac{N_{T_i} \cdot 10^{-6}}{\left(h_{tro_i}\right)^4} \int_{-h_{tro_i}}^{0} \frac{\left(r_{tro_i} + x\right) x^4 \, dx}{\left[\left(r_{tro_i} + x\right)^2 - \ell_2^2\right]^{1/2}} . \quad \text{(D. 6)}$$

Although this equation may be integrated in closed form, it results in inacceptable rounding errors, as stated above. An alternative form is obtained by expanding the integrand in series form and then performing the integration. This approach eliminates the problem of rounding errors. Two solutions are of interest: one for large values of E and one for small values. Their respective regions of rapid convergence sufficiently overlap so that the crossover value of E can be left to the discretion of the user. In addition to the two solutions presented below, a formula is given for estimating the error in truncating the series to a fixed number of terms. For convenience, the following parameters are defined:

$$W_1 = r_{tro_i} + \ell_2 ,$$

$$W_2 = r_{tro_i} - \ell_2 ,$$

$$W = W_1 \, W_2 .$$

Large Elevation Angles

$$\Delta\rho_{tro} = N_{T_i}\, 10^{-6}$$

$$\cdot \left\{ W^{1/2} - \ell_1 - \frac{0.8\, h_{tro_i}\, r_{tro_i}}{W^{1/2}} \right.$$

$$- W^{1/2} \sum_{p=0}^{\infty} \frac{1}{p+6} \left(\frac{h_{tro_i}}{W_2} \right)^{p+2} \qquad \text{(D. 7)}$$

$$\cdot \left[2F\,(p+1) \left[1 + \left(\frac{W_2}{W_1} \right)^{p+2} \right] \right.$$

$$\left. \left. - \sum_{n=0}^{p} F(n)\, F(p-n) \left(\frac{W_2}{W_1} \right)^{n+1} \right] \right\}$$

where $F(k) = \binom{2k}{k} \frac{1}{(k+1)2^{2k}}$.

The recursive relationship

$$F(k) = 1/2 \quad \frac{(2k-1)}{k+1} \quad F(k-1) \qquad \text{(D. 8)}$$

may be used to generate the F(k) for any desired range of values of k and eliminates having to compute factorials. The remainder in the expression for $\Delta\rho_{tro}$ after $p = 2^k - 2$ terms have been used may be estimated by

$$R_{\Delta\rho} < 4 \times 10^{-6}\, N_{T_i}\, W^{1/2}\, 2^{-3k/2} \left(\frac{h_{tro_i}}{W_2} \right)^{(2^k + 1)} \quad . \qquad \text{(D. 9)}$$

Small Elevation Angles

$$\Delta\rho = N_{T_i} \times 10^{-6}$$

$$\cdot \left\{ -\ell_1 + 4\,\frac{W_2^{\,5}}{h_{tro_i}^{\,4}} \left(\frac{W_1}{W_2} - 1\right)^{1/2} \right.$$

$$\cdot \sum_{n=0}^{3} (-1)^n \binom{3}{n}$$

$$\cdot \left[\frac{2}{2n+3} \left[1 - \left(1 - \frac{h_{tro_i}}{W_2} \right)^{(2n+3)/2} \right] \right. \qquad \text{(D-10)}$$

$$+ \sum_{p=0}^{\infty} (-1)^p \, \frac{F(p)}{(2p+2n+5)} \; \frac{1}{\left(\frac{W_1}{W_2} - 1\right)^{p+1}}$$

$$\left. \cdot \left\{ 1 - \left(1 - \frac{h_{tro_i}}{W_2} \right)^{(2p+2n+5)/2} \right\} \right] \right\} .$$

The remainder after $p = 2^k - 1$ terms is given by

$$R_{\Delta\rho} < N_{T_i} \times 10^{-6} \left(\frac{W_2^{\,5}}{h_{tro_i}^{\,4}} \right) 2^{-3k/2} \left(\frac{W_2}{W_1 - W_2} \right)^{(2^k + 3/2)} \qquad \text{(D.11)}$$

APPROXIMATION FOR SMALL COMPUTERS

The computations of the full expression for tropospheric range correction presented above require a fairly large computer. The following greatly simplified expressions have been developed for use where the computing facilities are limited.

The total range correction $\Delta\rho_{tro}$ at any elevation angle (i. e., any data point) is computed as the sum of the so-called "dry" and "wet" components, here subscripted d and w:

$$\Delta\rho_{tro} = (\Delta\rho_{tro})_d + (\Delta\rho_{tro})_w \ . \qquad (D.12)$$

The simplest available approximations for the components are based on Ref. 15 and are as follows:

$$\left.\begin{aligned} (\Delta\rho_{tro})_d &= 2.31 \times 10^{-3} \csc\sqrt{E^2 + \theta_d^2} \ \text{km} \\ (\Delta\rho_{tro})_w &= 0.20 \times 10^{-3} \csc\sqrt{E^2 + \theta_w^2} \ \text{km} \end{aligned}\right\} \qquad (D.13)$$

where E is the elevation angle of the satellite slant range vector and θ_d and θ_w are empirical parameters (angles); values will be given below. Equation (D. 13) should be used only at sea level stations (ships or near-sea level land installations); the dry component of Eq. (D. 13) is based on standard sea level pressure and the wet component on a marine rather than a continental climate.

For a little more accuracy, the following can be used instead of Eq. (D. 13):

$$\left.\begin{aligned} (\Delta\rho_{tro})_d &= K_d \, P \csc\sqrt{E^2 + \theta_d^2} \\ (\Delta\rho_{tro})_w &= K_w \csc\sqrt{E^2 + \theta_w^2} \end{aligned}\right\} . \qquad (D.14)$$

Here P is the observed local pressure (near antenna height). The parameter K_d is a constant and its value has been quite precisely determined from upper atmosphere data and theoretical considerations. Its current best value is $K_d = 2.278 \times 10^{-6}$ km/millibar. Using this value and the pressure P expressed in millibars, $(\Delta\rho_{tro})_d$ will be in kilometers.

The parameter K_w is not a constant but varies with latitude, season, and weather. An estimate may be made on the basis of qualitative observations and the observed average values presented in Table D-2.

Table D-2

Values of K_w for Selected Places and Times

K_w	Place, Time
0.28×10^{-3} km	Tropics or midlatitude summer
0.20×10^{-3} km	Midlatitude spring or fall
0.12×10^{-3} km	Midlatitude winter
0.05×10^{-3} km	Polar regions

The needed total range correction $\Delta\rho_{tro}$ for a single arriving ray is approximately 2.5 meters in the zenith direction and 90 meters at the horizon. The simplified expressions of Eqs. (D.13) and (D.14) are not very good at the horizon but are very good approximations at elevation angles higher than 5° and quite good as low as 2°, with the following parameter values:

$$\theta_d = 2.5^\circ$$

$$\theta_w = 1.5^\circ .$$

Uncorrected tropospheric errors do not affect navigation in the along-track direction unless there is a preponderance of data at one end of the pass. When symmetrical amounts of data are present at both ends, the uncorrected troposphere affects only the apparent slant range (or coordinates dependent on it).

The average tropospheric effect, if uncorrected, pushes the navigator's position, obtained from a whole pass, approximately 20 meters toward the orbit in slant range for a high pass, and nearly 80 meters for a 15° pass (elevation 15° at closest approach). An error of 1% (10 millibars) in the pressure P used for the dry component in Eq. (D. 14) affects the total range correction by not quite 1% (both the point-by-point correction and the effect on navigated range). An error of 0.1×10^{-3} in the magnitude of K_w (e.g., 0.20×10^{-3} instead of 0.10×10^{-3}) affects the total range correction by approximately 4% (both point-by-point and the effect on navigation).

The dry component generally contributes 90% or more of the total tropospheric correction at the higher angles (though the relative importance of the wet contribution increases at lower angles, especially below 5°). If local pressure is known to a millibar, the error in the dry component is negligible aside from the cosecant factor, and that error is small. Most of the uncertainty is due to the wet component, which (fortunately) is itself much the smaller component. The residual error in using Eq. (D. 14) should be under 10% on the average.

Appendix E

COMPUTER PROGRAM FOR GEODETIC COORDINATE TRANSFORMATION

The following section is a paper which describes a technique for performing Geodetic Coordinate Transformations between ellipsoids. Although the procedure that has been developed employs approximations, it is felt that any inaccuracy introduced by these approximations is outweighed by the simplicity of the resulting equations.

The technique described has been programmed in Fortran for the 7094 computer, the Hewlett Packard 2115A computer, and also the Honeywell H-21 computer.

In order to improve the accuracy of the computation some minor modifications have been made to the equations. These modifications are described. A Fortran listing of the program and a sample printout generated by the program are also presented.

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NOTICES

The purpose of this paper is to disseminate results of technical research to activities engaged in geodesy and related subjects.

The opinions expressed in this report are those of the writer and should not be construed as necessarily coinciding with Air Force doctrine. The writer alone assumes the responsibility for the validity and accuracy of mathematical data contained herein.

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LIST OF APPENDIXES

A. Notation.
B. Formula for Transformation of Coordinates.
C. Formula for Changes in Distance and Azimuths.
D. Results of Transformation of Coordinates.
E. Results of Transformation of Azimuths and Distances.
F. References.

1. Purpose. The purpose of the tests was to determine the accuracy and the adaptability to electronic and machine computing of two formulas for transformation of geodetic data between reference ellipsoids. These formulas are designed for:

a. Transformation of latitude, longitude, and geodetic height (ref. [5] and App. B).

b. Computation of changes in geodetic distance and azimuths due to transformation of coordinates (ref. [6] and App. C).

2. Participating Organizations. The 1373rd Mapping and Charting Squadron (Data Control Division) provided position and inverse computations performed on RECOMP II computer. The 1381st Geodetic Survey Squadron (Data Reduction Division) performed hand computations as well as electronic transformations of coordinates on RPC 4000 computer.

3. General Information.

a. The formulas of Appendixes B and C constitute a projective method of change of ellipsoid, as distinguished from development methods of earlier days. The characteristics of the two kinds of solution are summarized below.

b. Figure 1 shows points P and Q in space and a profile of a perpendicular section through these points. Curved lines represent ellipsoid and geoid surfaces and straight lines represent normals to ellipsoids, dashed lines referring to the old ellipsoid. The axes of the two ellipsoids are assumed to be mutually parallel. P_o and Q_o are the projections of P and Q upon the old ellipsoid and P_n and Q_n are their projections upon the new ellipsoid. The separation of ellipsoid surfaces at P is given by the distance $P_nP_o \doteq P_nP_o$, with a similar situation existing at Q. The geodetic distance on the old ellipsoid is the arc P_oQ_o and on the new ellipsoid it is P_nQ_n. The straight

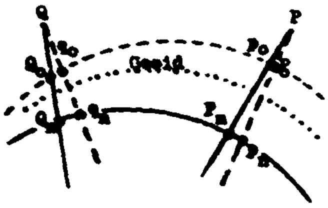

Figure 1.

line (spatial) distance PQ remains obviously the same before and after the transformation.

c. It is seen from Figure 1 that the effect of a projective method of transformation is to replace and reorient the reference ellipsoid, leaving all points in the same position in space as they were before the change took place. It follows that the angle between any two straight lines joining points in space must be the same before and after the transformation.

d. Thus the projective methods approach the problem in a truly rigorous way but they cannot remove the errors existing in the net due to errors of the survey, which includes errors caused by the reduction of distances to the geoid instead of the ellipsoid.*

e. Errors due to reduction of bases to the geoid instead of the ellipsoid are negligible in geodetic nets of limited extent if the ellipsoid fits the geoid reasonably well and if the two surfaces coincide at the origin. Herring, ref. [2], states that in the United States the geoid departs from the ellipsoid by only 1 meter at the distance of 30° from Meades Ranch. Taking 0.5 m as the average departure, we can calculate the error in geodetic distance due to this separation as less than 0.3 m at 3000 km, or 1 part in 10 million. This is much less than the expected error in measurement of a single line in Hiran trilateration and certainly much less than the error expected to accumulate through random errors of observation even in a most precise geodetic survey.

f. The development methods of transformation, such as are given in ref. [3] and [7], disregard the separation of geoid and ellipsoid surfaces and consider the distances and angles as the same on both ellipsoids. The effect of a development method is to recompute the net point by point on the new ellipsoid using old observational data. Any point taken at random cannot be transformed until the conversion

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*The rise or fall of the geoid with respect to the ellipsoid may be obtained by astronomic or gravimetric surveys or by a combination of both methods. Astronomic determination of geoid heights requires observations for astronomic latitude and longitude at numerous stations.

has been extended to it from the origin. The new net will not match the old one, that is spatial distances and plane angles will be changed in transformation. The development method may be considered proper for local nets when the new ellipsoid is assumed to fit the geoid better than the old one but, when viewed as a transformation method, it is an approximation and an inconvenient one. It fails in transformations of global extent, in which case the departure of the geoid from an earth-centered ellipsoid of best fit may be quite large in any given area, such as 50 meters or more.

4. Testing Procedures.

a. Starting from stations 20, 50, and 80 in latitudes 20°, 50°, and 80°N respectively and in longitude 65°E, position computations were performed on Clarke 1866 Ellipsoid at distances 2000 km and in azimuths 90°, 135°, and 180° as shown in Figure 2.

b. In each group the ends of the lines were connected by inverse computations to form a quadrilateral with diagonals.

c. All stations were transformed to International Ellipsoid oriented with δx = 90.904 m, δy = 108.335 m, and δz = 100.000 m. This separation of ellipsoid centers was computed from arbitrary data at the origin chosen at φ = 40°N, λ = 5°E. Geodetic heights at stations 22, 52, and 82 were assumed as 1000 m and at all other stations as zero. The transformation formula used was that of ref. [5] as shown in Appendix B. Results are shown in Appendix D.

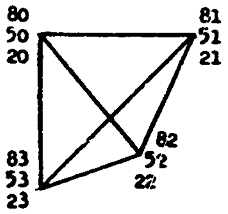

Figure 2.

d. Changes in distance and azimuth were computed over all lines, using the formula of reference [6] as shown in Appendix C. Then, using the International Ellipsoid values, rigorous inverse computations were performed over all lines. Results are shown in Appendix E.

e. The 1381st Geodetic Survey Squadron additionally tested the coordinate transformation formula against the Vening Meinesz formula by translating all stations from North American 1927 Datum to WGS 60, using both programs. The differences in results are shown in Appendix D.

5. Analysis of Results.

a. Ref. [2] analyses three projective methods of coordinate transformation; the space coordinate transformation formula, Baldini formula (ref. [1]), and Vening Meinesz formula (ref. [4]). One of the conclusions reached is that the Vening Meinesz formula is the least accurate of the three.

b. Ref. [5] compares a proposed formula with the Baldini and Vening Meinesz formulas and concludes that it is the simplest and the most accurate of the three. Its simplicity for both electronic and machine computing is due chiefly to the fact that it takes advantage of several constants which are precomputed once and for all for any particular change of ellipsoid. In addition, it permits accumulation of products without the necessity for recording intermediate results. Its accuracy in such cases as may occur in practice is shown to be of an order of 0.05 m at a distance halfway around the world from the origin (excluding areas in the immediate vicinity of the poles), with errors varying very slowly between distant points.

c. Appendix E shows the largest errors for a 2000-km line to be 0.010 m in distance and 0".0014 in azimuth, which represents proportional errors of 1:200 million and 1:140 million respectively. However, in rigorous computations the disagreement between forward and inverse computation results was found to be up to 0.005 m in distance and up to 0".0007 in azimuth, therefore the values in column (3) cannot all be correct to the last figure given. Consequently, actual errors should be smaller than those shown in column (5). Slightly larger errors are to be expected when the change of the ellipsoid is more violent than that shown in this example.

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d. The coordinate transformation formula of Appendix B is very well suited for both electronic and machine computing. It was programmed for the RPC 4000 computer by the 1381st Geodetic Survey Squadron quickly and without difficulty. That squadron rated hand computations involving this formula on a scale of increasing difficulty from 1 (represented by Hiran minimum sum computation) to 10 (represented by Hiran ΔH and ΔN computation) and gave it a rating of 3. The average time for completing the computation form was determined as about 25 minutes.

e. The formula of Appendix C is easy for use with a calculator because of few significant figures and no interpolation required. The 1381st Squadron gave it a rating of 5 on the same scale of difficulty as in paragraph 5d after determining that the average time necessary to complete the form was about 40 minutes. It is believed that this rating is a little too pessimistic and that computations should be completed within 30 minutes, particularly for short lines or when lesser accuracy is acceptable, as in Hiran trilateration.

f. No programming of the formula of Appendix C was undertaken, but it is believed that this should present no difficulties. The computer time should be a fraction of the time required to run an inverse computation. If this formula were to be programmed separately in the form as given here, it would require an input of several quantities (old positions and elevations, changes in ϕ, λ, and H, old distance, and old azimuths). However, it could be programmed in one package together with the coordinate transformation formula, in which case the only additional input data would be old distance and old azimuths.

6. Conclusions.

a. The formulas of Appendixes B and C can be advantageously adopted for hand computing when the electronic computer is inoperative or in use for higher priority projects. In this case all constants should be precomputed and printed on the computation form.

Alternatively, if the activity concerned has contact with several ellipsoids, the several sets of constants can be shown on a separate sheet.

b. The formula of Appendix B can be programmed for an electronic computer in a few hours, or in much less time than it took to type this report. From the accuracy point of view the Vening Meinesz formula which many activities now use is satisfactory. However, after a new world geodetic system is prescribed, as will certainly happen in the future, there will be no reason for using the Vening Meinesz formula, since easier and more accurate methods are now available.

c. The formula of Appendix C can be evaluated by each activity concerned to determine whether it would be more profitable to program it or to continue to use inverse computations, depending on operational requirements.

APPENDIX A

NOTATION

ϕ, λ = geodetic latitude and longitude. λ positive east.

H = height of point above ellipsoid (geodetic height).

α = azimuth of the geodesic, clockwise from north.

S = geodetic distance.

a, b = major and minor semiaxes of the ellipsoid.

e = $(a^2 - b^2)^{\frac{1}{2}}/a$ = first eccentricity.

ε = $e^2/(1 - e^2)$ = the square of second eccentricity.

N = radius of curvature in the prime vertical = $a(1-e^2\sin^2\phi)^{-\frac{1}{2}}$.

R = approximate radius of the Earth.

$\bar{a}$ = $\frac{1}{2}(a_o + a_n)$.

$\bar{\varepsilon}$ = $\frac{1}{2}(\varepsilon_o + \varepsilon_n)$.

x, y, z = rectangular space coordinates, i.e.

$x = (N + H)\cos\phi \cos\lambda$

$y = (N + H)\cos\phi \sin\lambda$

$z = [N(1 - e^2) + H]\sin\phi$.

$\delta\phi$, $\delta\lambda$, δH = $\phi_n - \phi_o$ etc. = shifts in latitude, longitude and geodetic height. δH is the height of the old ellipsoid above the new one.

δx, δy, δz = rectangular components of separation of ellipsoid centers.

δa, δe^2 = $a_n - a_o$ and $e_n^2 - e_o^2$.

$\delta\alpha$, δS = $\alpha_n - \alpha_o$ and $S_n - S_o$.

Subscripts o and n refer to the old and the new ellipsoid respectively. Subscripts 1 and 2 refer to the ends of a geodetic line. α_1 is the forward azimuth and α_2 is the back azimuth.

APPENDIX B

FORMULA FOR TRANSFORMATION OF COORDINATES

To compute changes in latitude, longitude, and geodetic height:

$$\delta\phi'' = [\,(A_1\cos\lambda + A_2\sin\lambda)\sin\phi + A_3\cos\phi]V + (A_4\sin^2\phi + A_5)\sin\phi\cos\phi \qquad (1a)$$

$$\delta\lambda'' = (A_1\sin\lambda - A_2\cos\lambda)W\sec\phi \qquad (1b)$$

$$\delta H = (B_1\cos\lambda + B_2\sin\lambda)\cos\phi + B_3\sin\phi + B_4\sin^2\phi + B_5\sin^4\phi + B_6 \qquad (1c)$$

To compute the separation of ellipsoid centers if changes in latitude, longitude, and geodetic height are known at any point:

$$\delta x = \frac{1}{V}(C_1\sin\phi\,\cos\phi + C_2\delta\phi'')\sin\phi\,\cos\lambda + \left[\frac{1}{W}C_2\delta\lambda''\sin\lambda + (\delta H + C_3)\cos\lambda\right]\cos\phi \qquad (2a)$$

$$\delta y = \frac{1}{V}(C_1\sin\phi\,\cos\phi + C_2\delta\phi'')\sin\phi\,\sin\lambda + \left[-\frac{1}{W}C_2\delta\lambda''\cos\lambda + (\delta H + C_3)\sin\lambda\right]\cos\phi \qquad (2b)$$

$$\delta z = -\frac{1}{V}(C_1\sin\phi\,\cos\phi + C_2\delta\phi'')\cos\phi + (\delta H + D_1 + D_2\sin^2\phi + D_3\sin^4\phi)\sin\phi \qquad (2c)$$

The following are constants which may be precomputed:

$A_1 = -(\csc 1''/a)\,\delta x$

$A_2 = -(\csc 1''/a)\,\delta y$

$A_3 = (\csc 1''/a)\,\delta z$

$A_4 = -\frac{1}{2}\,\epsilon\,\csc 1''\,\delta e^2$

$A_5 = [(\epsilon/a)\delta a + (1+\epsilon)\delta e^2]\csc 1''$

$B_1 = \delta x$

$B_2 = \delta y$

$B_3 = \delta z$

$B_4 = \frac{1}{2}\,\epsilon\,\delta a + \frac{1}{2}\,a\,\delta e^2$

$B_5 = \frac{1}{2}\,\epsilon^2\delta a + \frac{1}{4}\,a\,\epsilon\,\delta e^2$

$B_6 = -\delta a$

$C_1 = \frac{1}{2}\,\epsilon\,\delta a + \frac{1}{2}(1+\epsilon)a\,\delta e^2$

$C_2 = -a\sin 1''$

$C_3 = \delta a$

$D_1 = [1 - \frac{1}{2}\epsilon(1-\epsilon)]\delta a - \frac{1}{2}a\,\delta e^2$

$D_2 = -B_5$

$D_3 = -\frac{1}{2}\,\epsilon^2\delta a$

Additionally, $V = 1 + \epsilon(1 - \frac{3}{2}\sin^2\phi)$ and $W = 1 - \frac{1}{2}\,\epsilon\,\sin^2\phi$.

Above equations are applicable to a point on the surface of the ellipsoid. In a general case of a point at height H, multiply each term in $\delta\phi$ and $\delta\lambda$ in eq. (2) by $(1+H/R)$ and the results of eq. (1a) and (1b) by $(1-H/R)$, where $1/R \doteq 0.157 \times 10^{-6}$ meters. Elevation above geoid may be substituted for H without introducing an appreciable error. Five-figure computations are sufficient.

APPENDIX C

FORMULA FOR CHANGES IN DISTANCE AND AZIMUTHS

$$\alpha_m = \alpha_1 + \alpha_2 \qquad (3)$$

$$r = A\left(1 - \tfrac{1}{2}e[(2 - \cos\alpha_m)\cos^2\tfrac{1}{2}(\phi_1+\phi_2) - 1]\right) \qquad (4)$$

$$\theta = S/r \qquad (5)$$

$$\sin\phi_m = \sin\phi_1\cos\tfrac{1}{2}\theta + \cos\phi_1\sin\tfrac{1}{2}\theta\,\cos\alpha_1 \qquad (6)$$

$$\sin\Delta\lambda = \sin\tfrac{1}{2}\theta\,\sin\alpha_1\sec\phi_m \qquad (7)$$

$$\lambda_m = \lambda_1 + \Delta\lambda \qquad (8)$$

Now compute δH_m for (ϕ_m, λ_m) by eq. (1o). Then

$$\delta\bar{H} = (\delta H_1 + 4\delta H_m + \delta H_2)/6 \qquad (9)$$

$$\delta S = -\theta\,\delta\bar{H} + H_1\cos\alpha_1\delta\phi_1 + H_2\cos\alpha_2\delta\phi_2 + (H_1\delta\lambda_1 - H_2\delta\lambda_2)\cos\phi_1\sin\alpha_1 \qquad (10)$$

$$T = (H_2 - H_1)/S - \tfrac{1}{2}\theta\,(1 + \tfrac{1}{12}\theta^2) \qquad (11)$$

$$U = \sin\alpha_1\delta\phi_1 - \cos\phi_1\cos\alpha_1\delta\lambda_1 \qquad (12)$$

$$\delta\alpha_1 = \sin\phi_1\delta\lambda_1 + TU - \tfrac{1}{6}\theta^2\cos\phi_1\sin\alpha_1(\cos\phi_1\cos\alpha_1 - \tfrac{1}{4}\theta\sin\phi_1)\delta e^2$$
$$- \tfrac{1}{2}e\cos^2\tfrac{1}{2}(\phi_1+\phi_2)\sin\alpha_m\delta H_2/R \qquad (13)$$

To compute $\delta\alpha_2$, use (11), (12), and (13) with subscripts 1 and 2 reversed.

$\delta\phi$ and $\delta\lambda$ are in radians.

For lines up to 250 km omit the θ^3 term in eq. (11) and use

$$\delta\alpha_1 = \sin\phi_1\delta\lambda_1 + TU + \tfrac{1}{12}\theta^2\cos^2\tfrac{1}{2}(\phi_1+\phi_2)\sin\alpha_m\delta e^2$$
$$- \tfrac{1}{2}e\,\cos^2\tfrac{1}{2}(\phi_1+\phi_2)\sin\alpha_m d\bar{H}/R \qquad (13')$$

For ground triangulation lines omit (6), (7), and (8) and use

$$\delta\bar{H} = \tfrac{1}{2}(\delta H_1 + \delta H_2) \qquad (9')$$

For lesser accuracy, as in aerial electronic trilateration, use only the first term of eq. (10), omit the term in θ^3 in eq. (11), and omit the last term of eq. (13).

Five-figure computations are sufficient.

A more convenient form of equation (6), not used in test computations, is

$$\sin\phi_m = \tfrac{1}{2}(\sin\phi_1 + \sin\phi_2)\sec\tfrac{1}{2}\theta \qquad (6_1)$$

Further simplifications of equations (6) and (7) are achieved by using for lines of intermediate length

$$\sin\phi_m = \tfrac{1}{2}(\sin\phi_1 + \sin\phi_2)(1 + \tfrac{1}{8}\theta^2) \qquad (6')$$

$$\sin\Delta\lambda = \tfrac{1}{2}\,\theta\,\sin\alpha_1\sec\phi_m(1 - \tfrac{1}{24}\theta^2) \qquad (7')$$

Equations (6') and (7') were not tested extensively but it is believed that the errors in δR_m due to their approximations will not change the final result by more than 0.005 m at 1000 km.

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APPENDIX D

RESULTS OF TRANSFORMATION OF COORDINATES

I. From Clarke 1866 to International Ellipsoid by Vincenty method. δx = 90.904 m, δy = 108.335 m, δz = 100.000 m.

STA	ϕ	λ	H	$\delta\phi$	$\delta\lambda$	δH
20	20°00'00".0000N	65°00'00".0000E	0 m	-1".5188	-1".2591	-36.124 m
21	18 58 51.7574	84 01 51.1926	0	-1.0883	-2.7056	-53.702
22	6 50 01.2011	77 41 18.3625	1000	+1.6234	-2.1398	-47.432
23	1 55 10.2032	65 00 00.0000	0	+2.7863	-1.1843	-41.888
50	50 00 00.0000	65 00 00.0000	0	-5.9800	-1.8378	-103.062
51	46 46 45.2454	91 43 14.1278	0	-5.0107	-4.4364	-114.136
52	36 01 24.5469	80 37 35.9501	1000	-4.2157	-2.8769	-74.939
53	31 59 26.3418	65 00 00.0000	0	-3.8651	-1.3943	-53.794
80	80 00 00.0000	65 00 00.0000	0	-5.3982	-6.7941	-201.505
81	69 33 49.1212	126 44 47.5999	0	-2.9561	-12.7110	-205.195
82	64 03 27.2886	94 49 06.5703	1000	-5.2304	-7.3474	-166.210
83	62 04 27.4728	65 00 00.0000	0	-6.3107	-2.5208	-143.585

II. From Clarke 1866 to International Ellipsoid by Vincenty and exact space coordinate methods. δx, δy, and δz as above. ϕ = 40°00'00".0000S, λ = 95°00'00".0000E, H = 0.000 m. (The exact method uses equations for x, y, and z as shown in Appendix A and their inverse forms, e. g. [5]).

		$\delta\phi$	$\delta\lambda$	δH
(1)	Vincenty	+9".2440	-4".2156	-229.701 m
(2)	Exact	+9.2442	-4.2156	-229.696
	Error	0.0002	0.0000	0.005 (Total error = 0.007 m)

III. From North American 1927 Datum to WGS 60 by Vincenty and Vening Meinesz methods. Only the differences in results (Vincenty minus Vening Meinesz) are given.

STA	$\Delta\delta\phi$	$\Delta\delta\lambda$	STA	$\Delta\delta\phi$	$\Delta\delta\lambda$
20	+0".0029	+0".0006	52	-0".0039	+0".0011
21	+0.0028	+0.0010	53	-0.0038	+0.0006
22	+0.0016	+0.0008	80	-0.0023	+0.0031
23	+0.0009	+0.0005	81	-0.0022	+0.0040
50	-0.0042	+0.0008	82	-0.0032	+0.0026
51	-0.0039	+0.0016	83	-0.0037	+0.0012

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APPENDIX E

RESULTS OF TRANSFORMATION OF AZIMUTHS AND DISTANCES

Line	Clarke 1866 Fwd. Az. Back Az. Geod. Distance (1)	Intern. Fwd. Az. Back Az. Geod. Dist. (2)	Change (2)-(1) (3)	Vincenty Formula (4)	Error (4)-(3) (5)
20-21	90°00'00".0000	59".8060	-0".1940	-0".1940	0".0000
	276 2[illegible] 09.3789	08.2714	-1.1075	-1.1073	0.0002
	2 000 000.000 m	13.762 m	13.762 m	13.765 m	0.002 m
20-22	135 00 00.0000	59.8040	-0.1960	-0.1955	0.0005
	317 58 31.2446	30.8384	-0.4062	-0.4048	0.0014
	2 000 000.000	12.417	12.417	12.427	0.010
20-23	180 00 00.0000	59.7576	-0.2424	-0.2424	0.0000
	0 00 00.0000	59.7720	-0.2280	-0.2280	0.0000
	2 000 000.000	11.213	11.213	11.205	0.008
21-22	207 54 07.8411	07.1994	-0.6417	-0.6421	0.0005
	26 28 33.6267	33.0881	-0.5386	-0.5396	0.0010
	1 509 168.813	80.450	11.637	11.635	0.001
21-23	229 57 45.3834	44.8287	-0.5547	-0.5590	0.0043
	46 26 25.4873	24.9637	-0.5236	-0.5280	0.0044
	2 804 710.238	29.445	19.207	19.187	0.020
22-23	249 28 27.3893	27.4314	+0.0421	+0.0426	0.0005
	68 30 04.0390	03.6669	-0.3721	-0.3711	0.0010
	1 509 158.629	69.019	10.390	10.385	0.005
50-51	90 00 00.0000	50.5315	-0.4685	-0.4684	0.0001
	290 08 48.8458	44.6888	-4.1570	-4.1563	0.0007
	2 000 000.000	34.001	34.001	34.009	0.008
50-52	135 00 00.0000	59.3588	-0.6412	-0.6415	0.0003
	325 46 29.9818	27.5698	-2.4120	-2.4115	0.0005
	2 000 000.000	27.606	27.606	27.610	0.004
50-5	180 00 00.0000	58.7793	-1.2207	-1.2206	0.0001
	0 00 00.0000	59.0739	-0.9260	-0.9260	0.0000
	2 000 000.000	24.108	24.108	24.108	0.000
51-52	221 39 08.1528	04.8215	-3.3413	-3.3404	0.0009
	34 16 12.2452	10.6256	-1.6196	-1.6193	0.0003
	1 509 296.352	18.582	22.230	22.227	0.003
51-53	243 42 55.0029	51.1367	-3.8662	-3.8674	0.0012
	46 25 56.9819	56.7810	-0.2009	-0.2032	0.0023
	2 804 850.319	86.531	36.212	36.222	0.010
52-53	257 16 44.4955	42.3868	-2.1087	-2.1094	0.0007
	68 29 46.0656	45.7173	-0.3483	-0.3489	0.0006
	1 509 276.249	91.386	15.137	15.140	0.003

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	①	②	③	④	⑤
80-81	90 00 00".0000	54".1592	-5".8408	-5".8410	0".0002
	330 10 00.3747	47.6204	-12.7542	-12.7542	0.0001
	2 000 000.000 m	63.966 m	63.966 m	63.965 m	0.001 m
80-82	135 00 00.0000	54.0378	-5.9622	-5.9622	0.0000
	243 41 24.3278	16.9954	-7.3324	-7.3320	0.0004
	2 000 000.000	57.779	57.779	57.773	0.006
80-83	180 00 00.0000	53.4949	-6.5051	-6.5048	0.0003
	0 00 00.0000	57.5863	-2.4137	-2.4134	0.0003
	2 000 000.000	54.216	54.216	54.211	0.005
81-82	261 40 39.0634	26.8843	-12.1791	-12.1789	0.0002
	152 10 46.2197	39.8743	-6.3454	-6.3454	0.0000
	1 509 414.654	58.589	43.935	43.934	0.001
81-83	283 44 36.1541	23.3688	-12.7853	-12.7849	0.0004
	46 25 25.4062	24.0379	-1.3682	-1.3686	0.0004
	2 804 987.582	64.874	77.292	77.297	0.005
82-83	275 12 01.2084	53.9452	-7.2632	-7.2631	0.0001
	168 29 23.3547	21.7720	-1.5827	-1.5826	0.0001
	1 509 407.176	43.844	36.668	36.672	0.004

APPENDIX F

REFERENCES

[1] BALDINI, A. A. "New formulas useful when changing ellipsoidal parameters or orientation". GIMRADA Research Note No 2, 1962.

[2] HERRING, J. C. "Changes in the geodetic coordinates due to a change in the reference ellipsoid". A thesis, The Ohio State University, 1965.

[3] MacTAVISH, W. H. "The transfer of geodetic data from one ellipsoid to another". Publication No. 59, Geodetic Service of Canada, 1939.

[4] VENING MEINESZ, F. A. "New formulas for systems of deflections of the plumb-line and Laplace's theorem" and "Changes of deflections of the plumb-line brought about by a change of reference ellipsoid". Bulletin Geodesique 15, 1950.

[5] VINCENTY, T. "Transformation of co-ordinates between geodetic systems". 8th Reconnaissance Technical Squadron technical report, 1965, with change dated 8 June 1965.

[6] VINCENTY, T. Unpublished notes. 1965.

[7] ZAKATOV, P. S. "A course in higher geodesy". 1953. Translation from Russian.

FORMULA FOR TRANSFORMATION OF GEODETIC COORDINATES

There are seven parameters used in this computation which specify the datums involved in the transformation. They are:

1. Aφ – The semimajor axis of the reference ellipsoid in the original datum.
2. Fφ – The reciprocal flattening of the reference ellipsoid of the original datum.
3. AN – The semimajor axis of the reference ellipsoid in the new datum.
4. FN – The reciprocal flattening of the reference ellipsoid of the new datum.
5. DX – The x-axis origin offset between the two geodetic systems.
6. DY – The y-axis origin offset between the two geodetic systems.
7. DZ – The z-axis origin offset between the two geodetic systems.

The equations which have been implemented in the program, GEOCN (Geodetic Coordinate Conversion Program) are:

$$\delta\varphi'' = \Big[\big[(A_1 \cos\lambda + A_2 \sin\lambda) \sin\varphi + A_3 \cos\varphi\big] \; V + (A_4 \sin^2\varphi + A_5) \sin\varphi \cos\varphi \Big] \left[1 - \frac{H}{A\varphi}\right]$$

$$\delta\lambda'' = \left[(A_1 \sin\lambda - A_2 \cos\lambda) \frac{w}{\cos(\varphi)}\right] \left[1 - \frac{H}{A\varphi}\right]$$

$$\delta H = (DX \cos\lambda + DY \sin\lambda) \cos\varphi + DZ \sin\varphi + B_4 \sin^2\varphi + B_5 \sin^4\varphi + B$$

where

$$A_1 = -\frac{\csc(1'')}{\dot{a}} DX$$

$$A_2 = -\frac{\csc(1'')}{\dot{a}} DY$$

$$A_3 = \frac{\csc(1'')}{\dot{a}} DZ$$

$$A_4 = -0.5\,(\dot{\epsilon}\,\csc(1'')\,de^2)$$

$$A_5 = \left[\left(\frac{\dot{\epsilon}}{\dot{a}}\right) da + (1+\dot{\epsilon})\,de^2\right] \csc(1'')$$

$$B_4 = 0.5\,(\dot{a}\,de^2 - \dot{\epsilon}\,da)$$

$$B_5 = B_4 \cdot \dot{d}e^2 - (0\ 25)(\dot{a} \cdot \dot{\epsilon} \cdot de^2)$$

$$B_6 = A\varphi - AN$$

$$V = 1 + \dot{\epsilon}(1 - 1.5\sin^2(\varphi))$$

$$W = 1 - 0.5\ \dot{\epsilon}\sin^2(\varphi)$$

φ = Latitude of reference position in original datum.

λ = Longitude of reference position in original datum.

H = Height of reference position above reference ellipsoid in original datum.

From the preceding paper:

$$\dot{a} = 0.5\,(A\varphi + AN)$$

$$e = \frac{(a^2-b^2)^{1/2}}{a}$$

$$\epsilon = \frac{e^2}{(1-e^2)}$$

$\dot{\epsilon} \quad - \frac{1}{2}(\epsilon_{\varphi} + \epsilon_{n})$

$da = a_n - a_{\varphi}$

$de^2 = e_n^2 - e_o^2$

But for an ellipse:

$b = a\left(1 - \frac{1}{f}\right)$

a = Semimajor axis

b = Semiminor axis

f = Reciprocal flattening.

Then:

$b = a\left(\frac{f-1}{f}\right)$

$\frac{b}{a} = \frac{f-1}{f}$

and

$\frac{a}{b} = \frac{f}{f-1}$

$$e^2 = \frac{a^2-b^2}{a^2} = 1 - \frac{b^2}{a^2} = 1 - \left(\frac{f-1}{f}\right)^2$$

$$\epsilon = \frac{e^2}{1-e^2} = \frac{1 - \left(\frac{f-1}{f}\right)^2}{1 - 1 \div \left(\frac{f-1}{f}\right)^2}$$

$$\epsilon = \frac{1 - \left(\frac{f-1}{f}\right)^{2}}{{\frac{f-1}{f}}^{2}} = \left(\frac{f}{f-1}\right)^{2} - 1$$

$$\dot{\epsilon} = \frac{1}{2}\left[\left(\frac{F\varphi}{F\varphi-1}\right)^{2} + \left(\frac{FN}{FN-1}\right)^{2}\right] - 1$$

$$de^{2} = \left[\frac{F\varphi-1}{F\varphi}\right]^{2} - \left[\frac{FN-1}{FN}\right]^{2}$$

NOT REPRODUCIBLE

FORTRAN LISTING

```
C
C      --- 1/3/69 VERSION ---
C
    1 FORMAT (5X,F9.3,6X,F10.4)
    2 FORMAT (9X,F9.6,1X,F9.6,1X,F9.6)
    3 FORMAT (I3,3X,F5.0,1X,F7.4,1X,F7.4,2X,
     1        F5.0,1X,F7.4,1X,F7.4,4X,F8.1)
    4 FORMAT (2/)
    5 FORMAT ( 5X,23HINPUT STATION POSITION ,///,
     1         29HSTA   LATITUDE                ,
     2         36HLONGITUDE                   ANT. HEIGHT ,/,
     3         29HNNN   SDDD. MM.MMMM SS.SSSS   ,
     4         36HSDDD. MM.MMMM SS.SSSS    SMMMMM.M     )
    6 FORMAT ( 5X,34HGEODETIC COORDINATE TRANSFORMATION,
     1         5/)
    7 FORMAT ( 5X,24HORIGINAL    DATUM - A = ,F8.3,
     1         12H KM   F = 1/,F7.3,3/)
    8 FORMAT ( 5X,24HTRANSFORMED DATUM - A = ,F8.3,
     1         12H KM   F = 1/,F7.3,3/)
    9 FORMAT ( 5X,5HDX = ,F7.5,4H  KM,5X,5HDY = ,
     1         F7.5,4H  KM,5X,5HDZ = ,F7.5,4H  KM,3/)
   10 FORMAT ( 5X,22HREFERENCE POSITION IN ,
     1         16HORIGINAL DATUM -,//)
   11 FORMAT ( 5X,12HLATITUDE  - ,F5.0,5H DEG ,F7.4,
     1         5H MIN ,F7.4,5H SEC ,/)
   12 FORMAT ( 5X,12HLONGITUDE - ,F5.0,5H DEG ,F7.4,
     1         5H MIN ,F7.4,5H SEC ,/)
   13 FORMAT ( 5X,22HREFERENCE POSITION IN ,
     1         19HTRANSFORMED DATUM -,//)
   14 FORMAT ( 5X,7HDLAT = ,F8.4,4H SEC,5X,7HDLON = ,
     1         F8.4,4H SEC,5X,5HDH = ,F7.1,7H METERS,/)
   15 FORMAT ( 5X,7HDLAT = ,F8.4,4H MIN,5X,7HDLON = ,
     1         F8.4,4H MIN,/)
   16 FORMAT ( 5X,7HDLAT = ,F8.4,4H NM ,5X,7HDLON = ,
     1         F8.4,4H NM ,/)
   17 FORMAT ( 5X,5HA1 = ,E15.8,/, 5X,5HA2 = ,E15.8,/,
     1          5X,5HA3 = ,E15.8,/, 5X,5HA4 = ,E15.8,/,
     2          5X,5HA5 = ,E15.8,//)
   18 FORMAT ( 5X,18HGEOIDAL HEIGHT -  ,F8.1,7H METERS,4/)
   19 FORMAT ( 5X,7HEDOT = ,E15.8,5X,6HDE2 = ,E15.8,8/)
   20 FORMAT ( 5X,10HSTATION    ,I3,//)
   21 FORMAT ( 5X,27HINPUT ELLIPSOID PARAMETERS   ,/,
     1          5X,27HSEMI AXIS      REC. FLAT.   ,/,
     2          5X,27HKKKK.KKKK      FFF.FFFFF       )
   22 FORMAT ( 5X,27HINPUT ORIGIN OFFSETS          ,/,
     1          9X,29HDX - KM   DY - KM   DZ - KM  ,/,
     2          9X,30HSX.XXXXXX SX.XXXXXX SX.XXXXXX  )
      KI=1
      KO=2
      CON=4.848136811E-6
   92 WRITE(KO,21)
      READ(KI,1) AO,FO
      READ(KI,1) AN,FN
      WRITE(KO,22)
      READ(KI,2) DX,DY,DZ
  100 WRITE(KO,5)
      READ(KI,3) KSTA,RLATD,RLATM,RLATS,RLOND,RLONM,
     1           RLONS,GHO
      PAUSE
      IF(KSTA) 99,101,101
  101 TEMP= ABS(RLATD)
      CLATS=SIGN((TEMP*60.+RLATM)*60.+RLATS,RLATD)
```

```
      CLATR=CLATS*CON
      CLONR=CLONS*CON
      ADOT= (AO+AN)/2.
      DFO= ((FO-1.)/FO)
      DFN= ((FN-1.)/FN)
      DFO2= DFO*DFO
      DFN2= DFN*DFN
      EDOT= ((1./DFO2)+(1./DFN2))/2.-1.
      DE2= DFO2-DFN2
      CONA= CON*ADOT
      CONE2= DE2/CON
      GHCON= (1.-(GHO*1.E-3)/AO)
      A1= -DX/CONA
      A2= -DY/CONA
      A3=  DZ/CONA
      A4= -0.5*EDOT*CONE2
      A5= (EDOT/CONA)*(AN-AO)+(1.+EDOT)*CONE2
      CLAT= COS(CLATR)
      SLAT= SIN(CLATR)
      CLON= COS(CLONR)
      SLON= SIN(CLONR)
      S2LAT= SLAT*SLAT
      V= 1.+EDOT*(1.-1.5*S2LAT)
      W= 1.-0.5*EDOT*S2LAT
      DLAT= ((A1*CLON+A2*SLON)*SLAT+A3*CLAT)*V
     1      +(A4*S2LAT+A5)*SLAT*CLAT
      DLAT= DLAT*GHCON
      DLON= (A1*SLON-A2*CLON)*W/CLAT
      DLON= DLON*GHCON
      B6= (AO-AN)
      B4= (ADOT*DE2-EDOT*B6)*0.5
      B5= B4*EDOT-0.25*ADOT*EDOT*DE2
      DHKM= (DX*CLON+DY*SLON)*CLAT+DZ*SLAT
     1      +B4*S2LAT+B5*(S2LAT*S2LAT)+B6
      DHM= DHKM*1.E+3
      GHN= GHO+DHM
      DLATM= DLAT/60.
      DLATN= DLATM
      DLONM= DLON/60.
      DLONN= DLONM*CLAT
      ELATS=CLATS+DLAT
      ELONS=CLONS+DLON
      TEMP=ELATS/3600.
      FLATD=IFIX(TEMP)
      TEMP1=ABS(ELATS-FLATD*3600.)/60.
      FLATM=IFIX(TEMP1)
      FLATS=(TEMP1-FLATM)*60.
      TEMP2=ELONS/3600.
      FLOND=IFIX(TEMP2)
      TEMP3=ABS(ELONS-FLOND*3600.)/60.
      FLONM=IFIX(TEMP3)
      FLONS=(TEMP3-FLONM)*60.
  122 CONTINUE
      WRITE(KO,4)
      WRITE(KO,6)
      WRITE(KO,7) AO,FO
      WRITE(KO,8) AN,FN
      WRITE(KO,9) DY,DY,DZ
  123 WRITE(KO,20) KSTA
  124 WRITE(KO,10)
      WRITE(KO,11) RLATD,RLATM,RLATS
      WRITE(KO,12) RLOND,RLONM,RLONS
      WRITE(KO,18) GHO
```

NOT REPRODUCIBLE

```
      [illegible]
      WRITE(KO,12) FLOND,FLONM,FLONS
      WRITE(KO,18) G4N
      WRITE(KO,14) DLAT,DLON,DHM
      WRITE(KO,15) DLATM,DLONM
      WRITE(KO,16) DLATN,DLONN
      WRITE(KO,17) A1,A2,A3,A4,A5
      WRITE(KO,19) EDOT,DE2
      GO TO 100
      END
 END OF TAPE
```

E.4 SAMPLE PRINTOUT

```
INPUT ELLIPSOID PARAMETERS
SEMI AXIS       REC. FLAT.
KKKK.KKKK       FFF.FFFFF
6378.206        294.978
6378.144        298.230
INPUT ORIGIN OFFSETS
    DX - KM   DY - KM   DZ - KM
    SX.XXXXXX SX.XXXXXX SX.XXXXXX
    -0.025      .173      .183
INPUT STATION POSITION

STA  LATITUDE                  LONGITUDE                  ANT. HEIGHT
NNN  SDDD. MM.MMMM SS.SSSS    SDDD. MM.MMMM SS.SSSS      SMMMMM.M
1    +039.  9.8165             -076. 53.8643              +  145.
PAUSE
```

```
GEODETIC COORDINATE TRANSFORMATION


ORIGINAL     DATUM - A = 6378.206 KM   F = 1/294.978


TRANSFORMED DATUM - A = 6378.144 KM   F = 1/298.239


DX = -.02500  KM      DY = .17300  KM      DZ = .18300  KM


STATION      1

REFERENCE POSITION IN ORIGINAL DATUM -

LATITUDE  -   39. DEG  9.8165 MIN   .0000 SEC
LONGITUDE -  -76. DEG 53.8643 MIN   .0000 SEC
GEOIDAL HEIGHT -      145.0 METERS


REFERENCE POSITION IN TRANSFORMED DATUM -

LATITUDE  -   39. DEG  9.0000 MIN 49.6875 SEC
LONGITUDE -  -76. DEG 53.0000 MIN 51.2493 SEC
GEOIDAL HEIGHT -       94.1 METERS


DLAT =     .6799 SEC      DLON =     .6193 SEC      DH =    -50.9 METERS
DLAT =     .0113 MIN      DLON =     .0103 MIN
DLAT =     .0113 NM       DLON =     .0983 NM
A1 =    .80847895E+00
A2 =   -.55946750E+01
A3 =    .59169660E+01
A4 =    .51494971E-01
A5 =   -.15312490E+02
```

```
EDOT =    .67775249E-02     DE2 =  -.73671341E-04
```

Appendix F

GLOSSARY OF TERMS FOR NAVIGATION SOLUTION COMPUTATION

Term or Symbol	Fortran Name	Meaning
A_o	AO	Semimajor axis of orbit ellipse.
ΔA_k	DA(K)	Incremental length of semimajor axis of orbit ellipse.
a_{nj}		Coefficients in the navigation equation, constant for any interval for which a doppler count is obtained.
c		Speed of light in a vacuum.
$C_{ko}(f, \varphi, \lambda)$		Difference between measured slant range difference and theoretical slant range difference.
d	HEAD	Navigator's heading at estimated first fiducial time.
ΔE_k	DE(K)	Incremental eccentric anomaly.
ϵ	E	Eccentricity of satellite orbit.
$\bar{f}_o$	EFRQ	Initial value of offset frequency.
$\bar{f}$	EFRQ	Improved estimate of offset frequency resulting from navigation operations.
GMT		Greenwich Mean Time.
h		Station's antenna height above mean sea level.
H		Height of sea level above reference geoid at station's position.
h'	GEOH	Station's antenna height above geoid (= h + H).

Term or Symbol	Fortran Name	Meaning
KM-1	KM-1	Total number of intervals for which doppler counts have been obtained during a given satellite pass.
k	K	Index identifying the intervals during a given satellite pass ($k = 1, 2, \ldots, KM-1$).
J		Numbering integer for fiducial times, i.e., the number of 2-minute intervals between first fiducial interrupt and previous GMT midnight.
L_o	WAVE	Vacuum wavelength associated with the frequency $\overline{f}_o$. $(L_o = \frac{c}{f_o})$
n	XNDT	Mean motion of satellite ($n = \frac{2\pi}{T}$).
M(t)	XMK	Mean anomaly of satellite.
N_k	DOP(K)	Cycle (doppler) count during kth interval.
R_k	REF(K)	Refraction correction count during kth interval.
R_o		Radius of the earth.
S_k		Theoretical slant range difference for kth interval.
$\hat{S}_{ko}$		Measured slant range difference for kth interval.
T		Orbital period of the satellite.
T_c	ETIM	Reading of navigator's clock (GMT) at first fiducial interrupt.
t_o		Time corresponding to the first fiducial time interrupt from ephemeral data.

Term or Symbol	Fortran Name	Meaning
t_f	STIM+4	Time at which navigator's position is computed (time of fix).
t_p	TP	Time of satellite perigee (GMT).
Δt_p	T	Time between satellite perigee and first fiducial interrupt.
u, v, w		Coordinate system fixed with respect to satellite orbit ellipse.
V		Navigator's speed at estimated first fiducial time.
X, Y, Z		Coordinate system fixed with respect to inertial space.
x, y, z		Coordinate system fixed with respect to the rotating earth.
x', y', z'		Coordinate system of satellite with respect to inertial space.
β	B	Angle between right ascension of ascending node and right ascension of Greenwich.
φ_e	ELAT	Navigator's estimate of his latitude.
φ_{fix}	FLAT	True geodetic latitude coordinate of the navigator at time of fix.
φ_k		Navigator's geodetic latitude at end of interval k.
Δ_{φ}		Improvement to geodetic latitude resulting from navigation equations.
ω	SOME	Argument of perigee of satellite orbit.
$\dot{\omega}$	SOMD	Rate of change of argument of perigee.

Term or Symbol	Fortran Name	Meaning
i		Angle of inclination of orbit plane with respect to equatorial plane.
λ_e	ELON	Navigator's estimate of his longitude.
λ_{fix}	FLON	True geodetic longitude coordinate of the navigator at time of fix.
λ_k		Navigator's geodetic longitude at end of interval k.
Δ_λ		Improvement to geodetic longitude resulting from navigation equations.
Λ_G	XLMG	Right ascension of Greenwich at time of satellite perigee (i. e., hour angle of Greenwich).
Ω	COME	Right ascension of ascending node.
$\dot{\Omega}$	COMD	Rate of change of right ascension of ascending node.
X_{sk}, Y_{sk}, Z_{sk}	XS, YS, ZS	Satellite coordinates in X, Y, Z system at interval k.
X_{nk}, Y_{nk}, Z_{nk}	XN, YN, ZN	Navigator's coordinates in X, Y, Z system at interval k.
η_k	DN(K)	Incremental out-of-plane (cross plane) component of satellite.
$\Delta\bar{f}$		Improvement to offset frequency resulting from navigation equations.
ω_e	OMGE	Rotational rate of the earth.
f		Flattening of the reference ellipsoid.
PDAY	PDAY	Day (GMT) of first fiducial interrupt.
TPDAY	TPDAY	Day (GMT) of satellite perigee (t_p).
T_o	STIM	Time (GMT) of first fiducial interrupt (i. e., corrected value of T_c).

Appendix G

NONSTANDARD NUMERICAL COMPUTATION ROUTINES

In order to write a digital computer program to implement the navigation solution computations and alert computations provided in this document, several special numerical routines other than those available in a standard computer command repertoire must be written. These special routines are:

a. Sine,
b. Cosine,
c. Square root,
d. Arc sine,
e. Arc cosine, and
f. Arc tangent.

This Appendix will provide information which will allow implementation of these routines using standard computer instructions of add, multiply, and divide.

SINE, COSINE

The algorithm given here determines $Y = \sin \frac{\pi}{2} X$ for $-1 < X < +1$. The algorithm given is that given on page 140 of Ref. 16. The $\cos \frac{\pi}{2} X$ is determined by use of the equation,

$$\cos \frac{\pi}{2} X = \sin \frac{\pi}{2} (1 - X) .$$

In consideration of the above, the theoretical error is only discussed in terms of the sine function.

The algorithm to be used in the solution for $\sin\frac{\pi}{2}X$ is the Hastings polynomial approximation for the sine function,

$$\sin\frac{\pi}{2}X = \sum_{i=0}^{4} C_{2i+1}\, X^{2i+1} \,,$$

where

$$C_1 = 1.570\ 796\ 318\ 47$$

$$C_3 = -0.645\ 963\ 711\ 06$$

$$C_5 = 0.079\ 689\ 679\ 28$$

$$C_7 = -0.004\ 673\ 765\ 27$$

$$C_9 = 0.000\ 151\ 484\ 19$$

$$\sum_{i=0}^{4} C_{2i+1} = 1.000\ 000\ 005\ 61\,.$$

As can be seen by the value of $\sum_{i=0}^{4} C_{2i+1}$ in the above table, the error in sin y at $y = \frac{\pi}{2}$ for the Hastings approximation is 5×10^{-9} if all coefficients can be used as given. However, since a minimum word length of 37 bits would be necessary to achieve this minimum error, the error presently achieved with a 30-bit computer would provide a more realistic error. For a 30-bit computer the coefficients can be expressed such that

$$\sum_{i=0}^{4} C_{2i+1} = 0.000\ 000\ 011$$

giving an expected error of 1.1×10^{-8}. This error is within the required accuracy for the computations required by this document.

ARC SINE, ARC COSINE

The algorithm given here determines $Y = \sin^{-1}(X)$ for $0 \le X \le 1$. The algorithm is that given in Ref. 16 on page 163. The arc cosine is determined by

$$\cos^{-1} X = \frac{\pi}{2} - \sin^{-1} X .$$

The algorithm to be used in the solution for $\sin^{-1} X$ is the Hastings polynomial approximation for the arc sine function,

$$\text{arc sin } X = \frac{\pi}{2} - \sqrt{1 - X}\ \psi(X) ,$$

where

$$\psi(X) = a_o + a_1 X + a_2 X^2 + a_3 X^3 \cdot \ldots\ldots + a_7 X^7$$

$a_0 = 1.5707\ 963\ 050$

$a_1 = -0.2145\ 988\ 016$

$a_2 = 0.0889\ 789\ 874$

$a_3 = -0.0501\ 743\ 046$

$a_4 = 0.0308\ 918\ 810$

$a_5 = -0.0170\ 881\ 256$

$a_6 = 0.0066\ 700\ 901$

$a_7 = -0.0012\ 624\ 911 .$

ARC TANGENT

The algorithm given here determines $Y = \tan^{-1}(X)$ for $-1 \leq X \leq 1$. The algorithm is that given in Ref. 16 on page 134. The algorithm is the Hastings polynomial approximation for the arc tangent function,

$$\arctan X = \sum_{i=0}^{4} C_{2i+1} X^{2i+1},$$

where

$C_1 = 0.999\ 8660$

$C_3 = -0.330\ 2995$

$C_5 = 0.180\ 1410$

$C_7 = -0.085\ 1330$

$C_9 = 0.020\ 8351$

SQUARE ROOT

The algorithm given here determines $Y = \sqrt{X}$ for all ranges of X. The algorithm to be solved is given as follows:

a. Compute an initial approximation to $\sqrt{X}$ as:

$$A_o = \frac{X}{2} + \frac{1}{2}.$$

b. Then compute by Newton's method

$$A_1 = \left(\frac{X}{A_o} + A_o\right) \cdot \frac{1}{2}$$

$$A_2 = \left(\frac{X}{A_1} + A_1\right) \cdot \frac{1}{2}$$

$$A_3 = \left(\frac{X}{A_2} + A_2\right) \cdot \frac{1}{2} .$$

c. Then $Y = \sqrt{X} = A_3$.