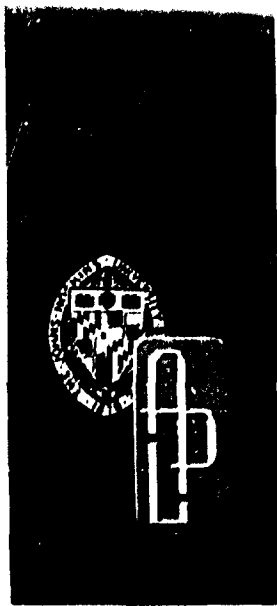


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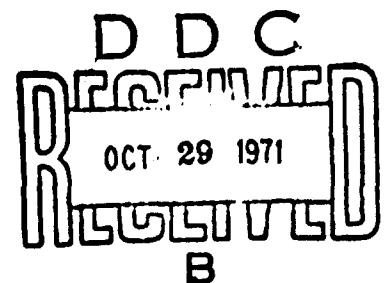


AD 731 663

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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NAVIGATION SOLUTION**

Edited by J. B. MOFFETT

THE JOHNS HOPKINS UNIVERSITY • APPLIED PHYSICS LABORATORY
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Operating under Contract N00017-62-C-0604 with the Department of the Navy

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SILVER SPRING MARYLAND

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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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.

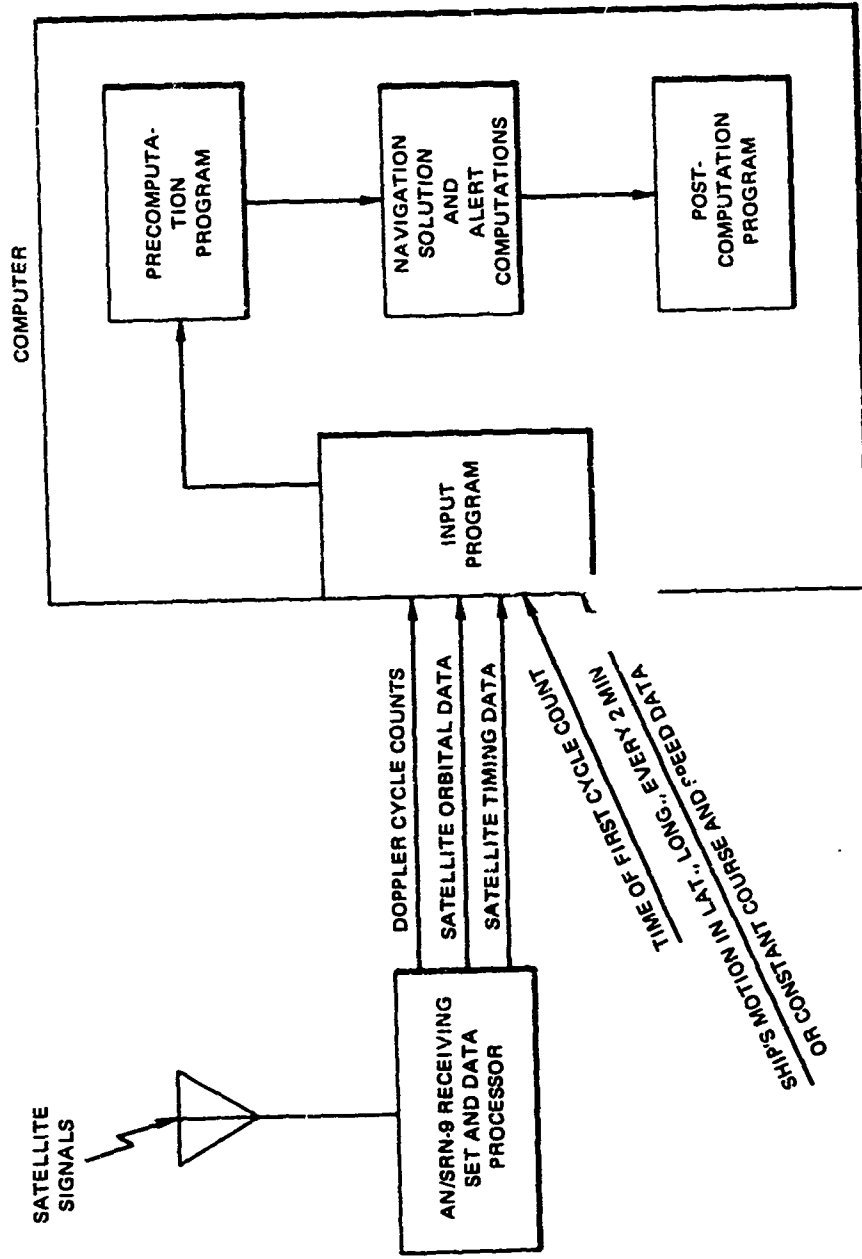


Fig. 2 BLOCK DIAGRAM OF AN/SRN-9 SYSTEM

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 $(f_0 - \bar{f})$ continuously between transmission of two time mark signals (transmitted at times t_k and t_{k-1}) the ground observer will count $(f_0 - \bar{f})X\tau$ 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_0 . A difference frequency therefore exists in the ground receiver of frequency $f_0 - f_R(t)$. 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_0) between receipt of two such successive time marks is therefore:

$$N_k = \int_{t_{k-1} + \frac{S_{k-1}}{c}}^{t_k + \frac{S_k}{c}} (f_0 - f_R(t)) dt = f_0 t \Big|_{t_{k-1} + \frac{S_{k-1}}{c}}^{t_k + \frac{S_k}{c}} - (f_0 - \bar{f}) \tau; \quad (1)$$

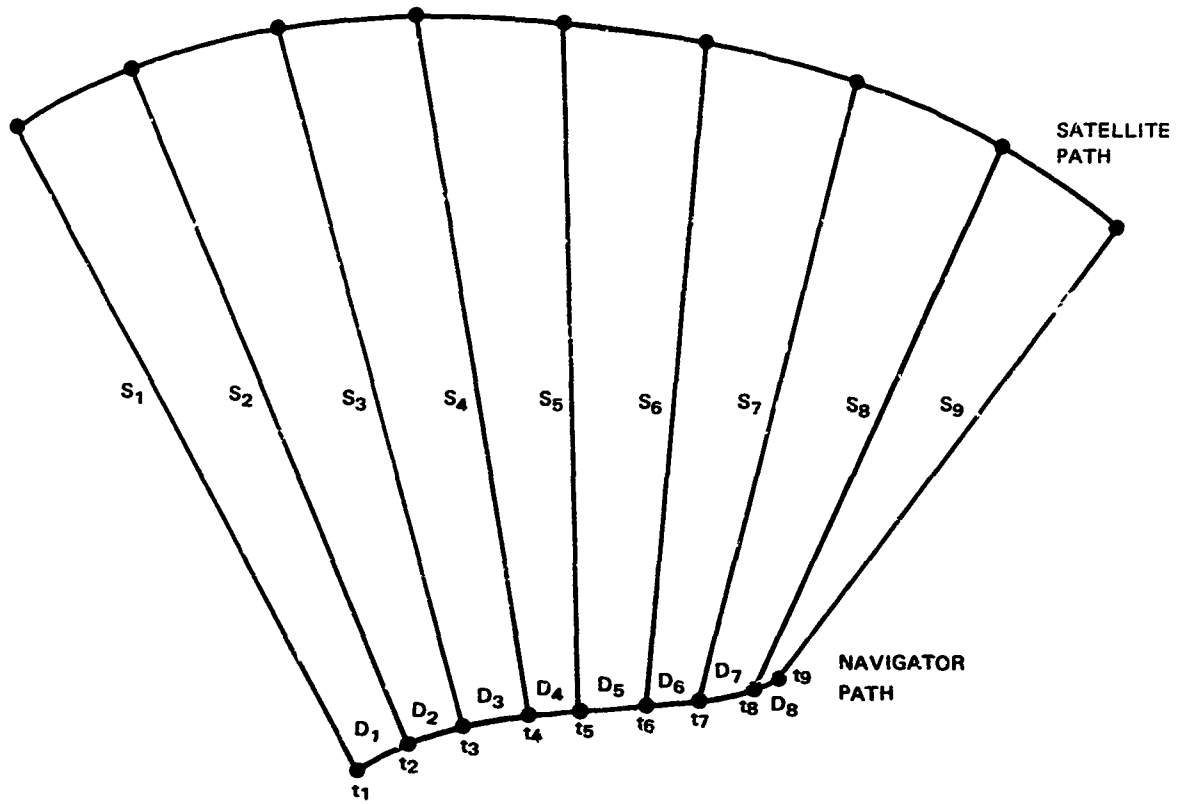


Fig. 3 SLANT RANGE MEASUREMENT

i. e., as noted,

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

where

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

f_o = reference frequency,

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

c = vacuum speed of light.

Therefore

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

from which the apparent slant range change over the k th interval is

$$S_k - S_{k-1} = \frac{\Lambda}{S_k} = L_o N_k - \bar{f} L_o \tau, \quad (4)$$

where

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

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

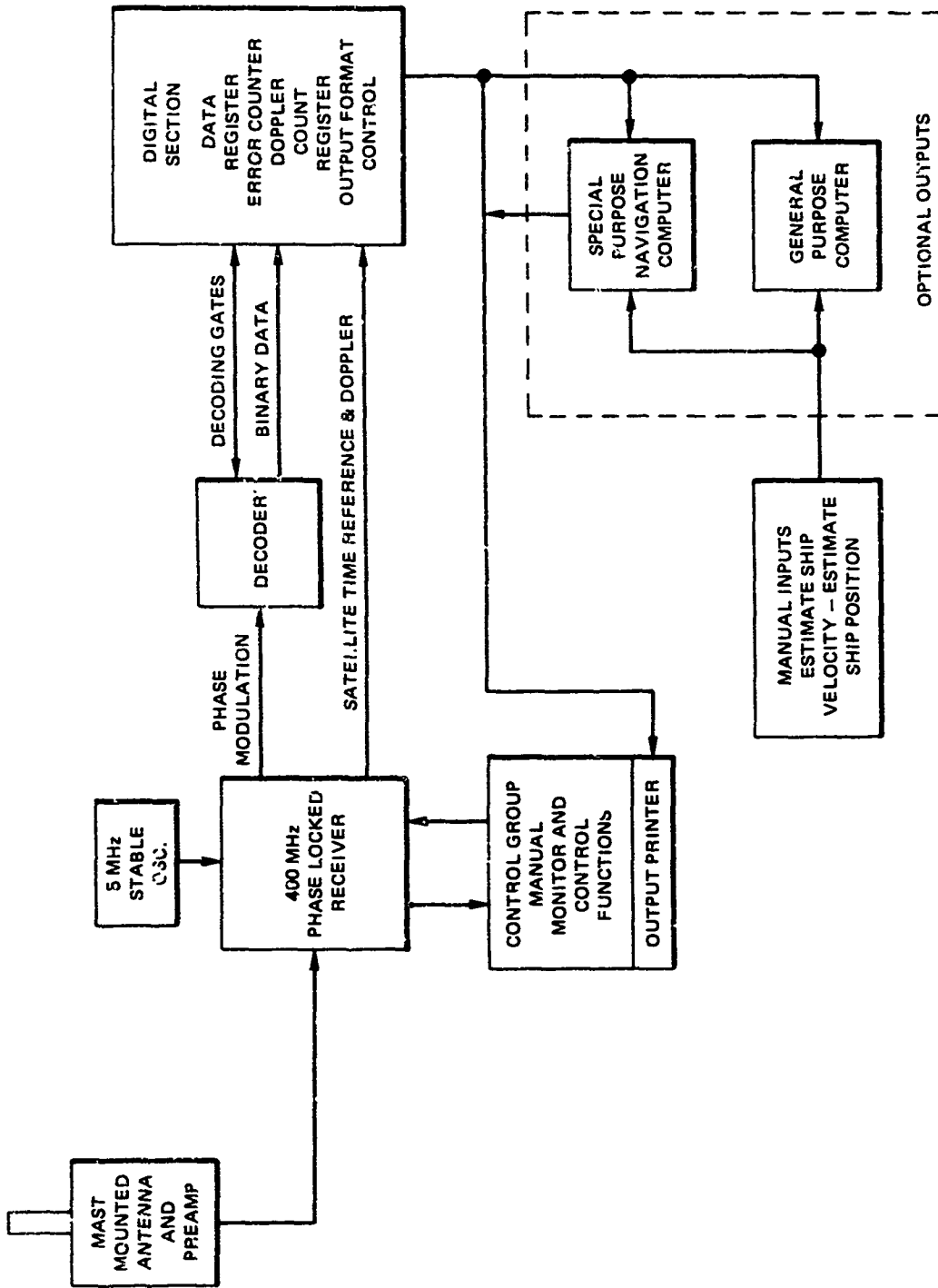


Fig. 4 BLOCK DIAGRAM OF SATELLITE INTEGRATED DOPPLER NAVIGATION EQUIPMENT, SINGLE-FREQUENCY SYSTEM

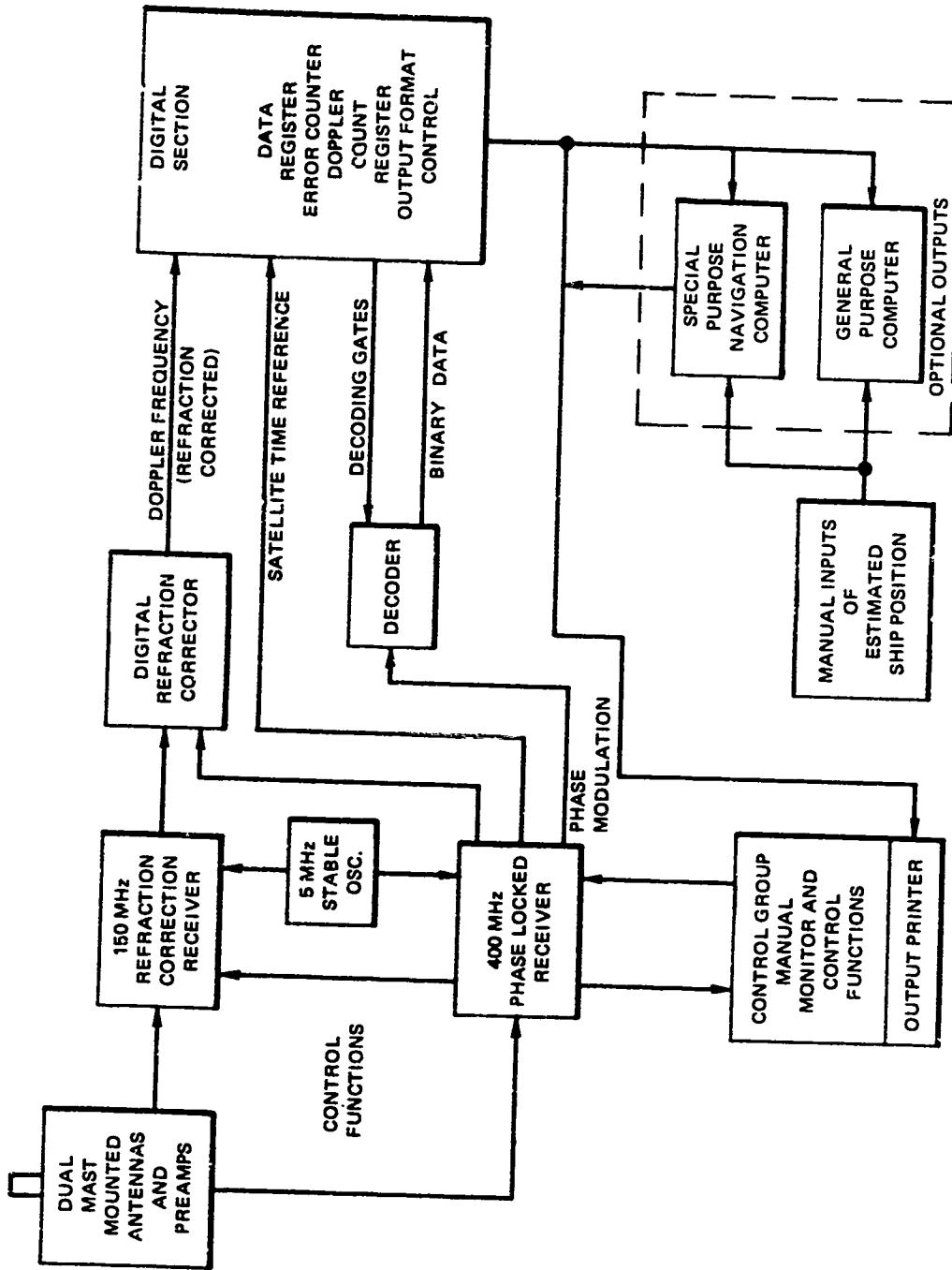


Fig. 5 BLOCK DIAGRAM OF SATELLITE INTEGRATED DOPPLER NAVIGATION EQUIPMENT, DUAL-FREQUENCY SYSTEM

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 $400 \text{ MHz} - f_H$, where $f_H \approx 32 \text{ kHz}$, since the

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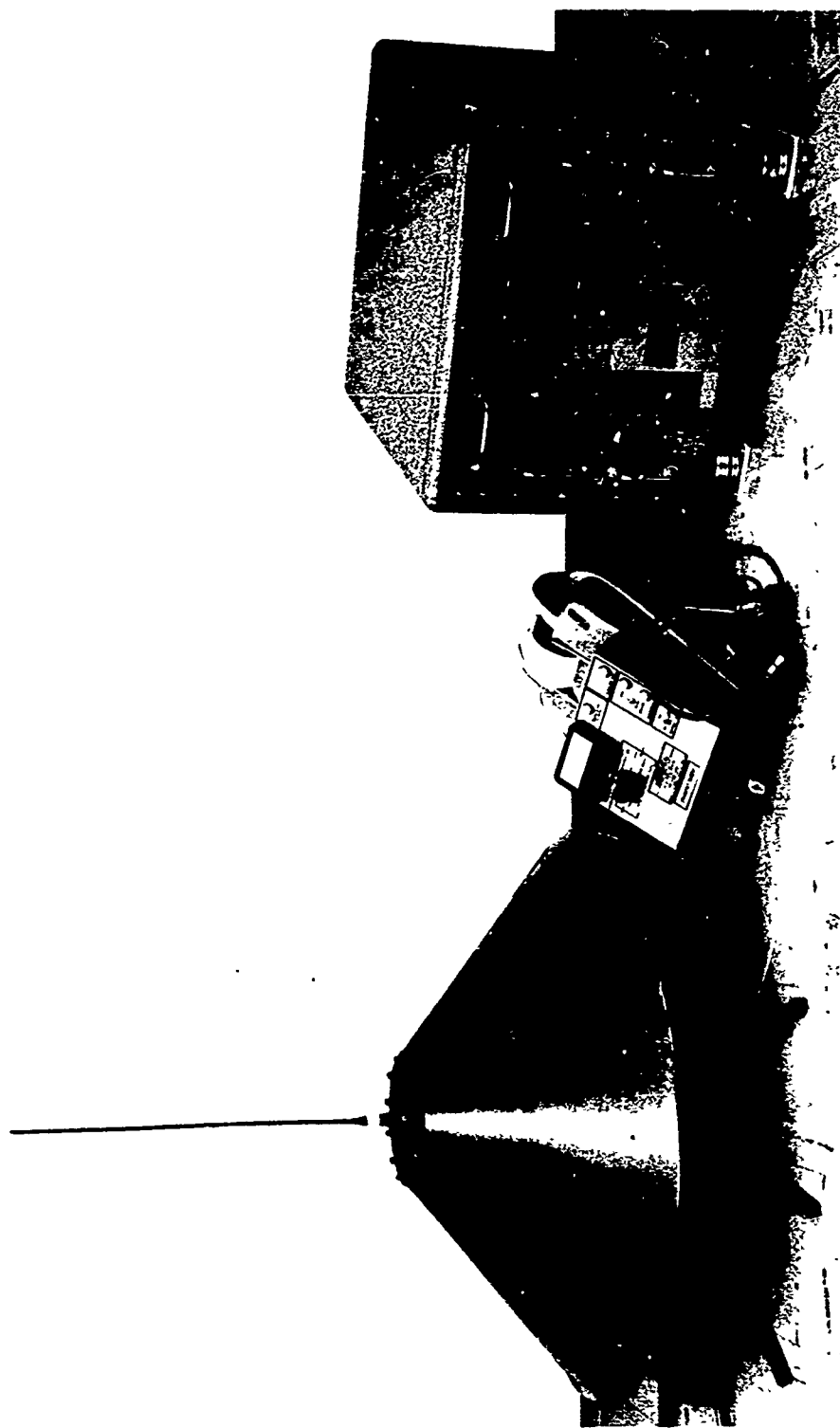
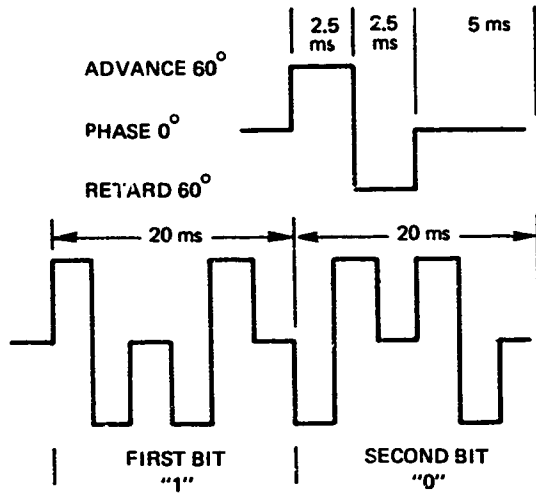


Fig. 6 AN/SRN (XN-5) RECEIVING EQUIPMENT



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 $\cong 50/S$

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 $400 \text{ MHz} - f_H + d_H + \epsilon_H$. 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:

$$3/8 [405 \text{ MHz} - f_H + d_H + \epsilon_H] - [150 \text{ MHz} + 3/8 (-f_H + d_H) +$$

$$8/3 \epsilon_H] = 1.875 \text{ MHz} + [3/8 - 8/3] \epsilon_H = \quad (5)$$

$$1.875 \text{ MHz} - 55/24 \epsilon_H.$$

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.

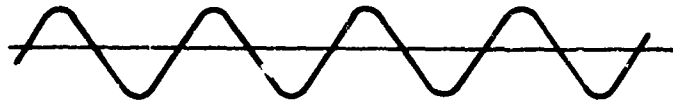
The 400-MHz phase comparator also produces a signal whose voltage excursions versus time are an accurate representation of the phase excursions of the input signal as shown in Fig. 8. The decoder accepts these doublet data from the phase comparator, synchronously detects them, and converts them to a binary format compatible with the digital section. 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 $\pm 500 \mu s$, 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.

A
 PHASE COMPARATOR
 OUTPUT
 $f = \frac{55}{24} \epsilon_h$



B
 FEEDBACK DIVIDER
 INPUT PULSES
 $f = \frac{55}{24} \epsilon_h$



C
 FEEDBACK DIVIDER
 OUTPUT PULSES
 $f = \epsilon_h$



D
 QUADRATURE PHASE
 COMPARATOR OUTPUT
 FOR $+\epsilon$



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

E
 QUADRATURE PHASE
 COMPARATOR OUTPUT
 FOR $-\epsilon$



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.

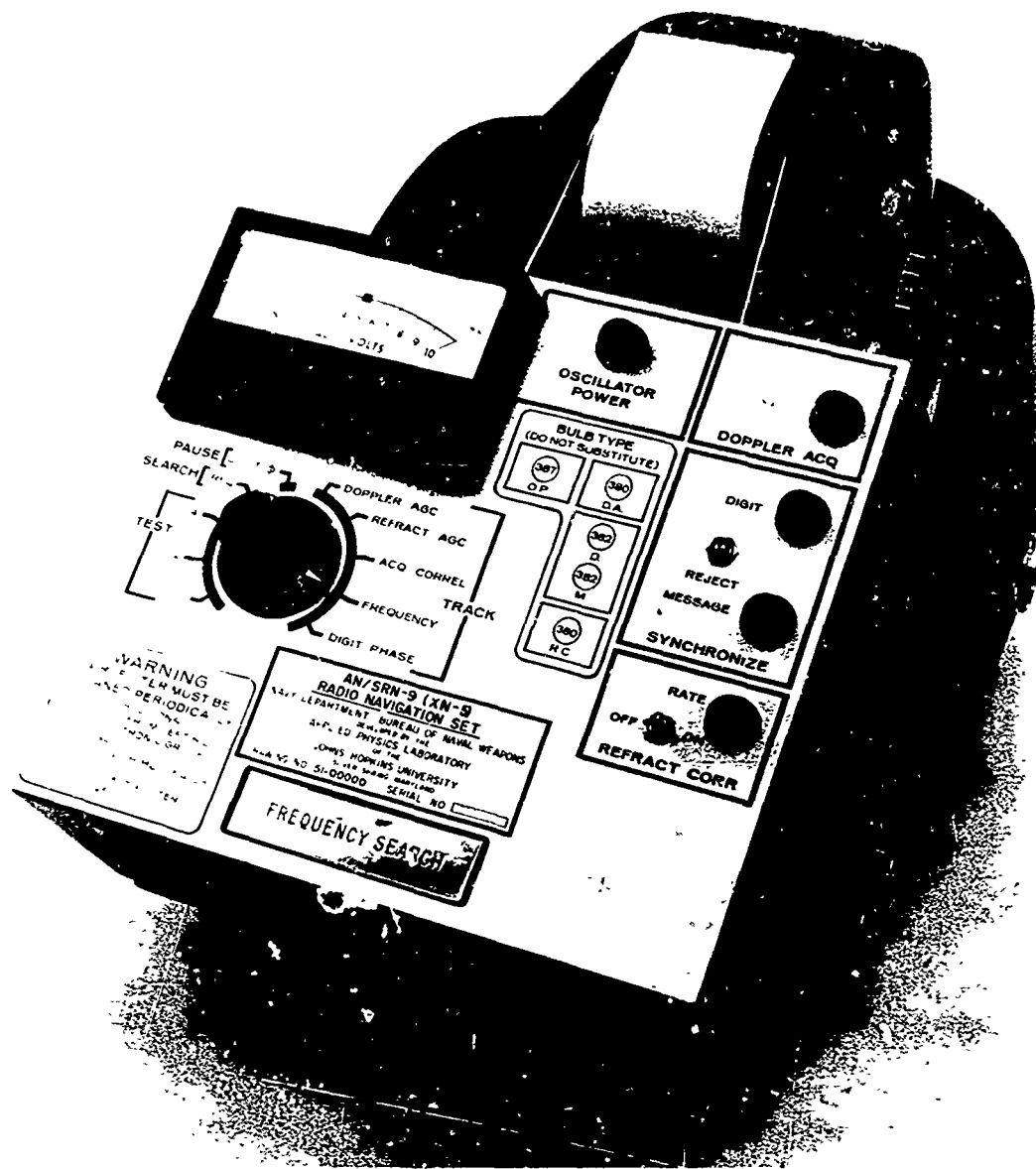


Fig. 9 AN/SRN-9 (XN-5) CONTROL GROUP-PRINTER CONFIGURATION

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
    +-030520205
    +-040430510
    +-050390743
    +-060270900
    ++110391920
    + 36488020
    + 04278850
    + 00196610
    + 00187520
    + 07165340
    + 23720880
    + 00000080
    - 00005880
    + 32350310
    + 20189280
    + 54903120
    + 10000000
    --199870000
    ++000000000
    ++000000000
    ++000000000
    3373172 ← DOPPLER CYCLE COUNT
    ++000370950
    ++010460566
    ++020520170
    +-030520205
    +-040480510
    +-050390743
    +-060270900
    +-070120961
    ++110391920
    + 36488020
    + 04278850
    + 00196610
    + 00187520
    + 07465340
    + 23720880
    + 00000080
    - 00005880
    + 32350310
    + 20189280
    + 54903120
    + 10000000
    --199870000
    ++000000000
    ++000000000
    ++000000000
    4093892 ← DOPPLER CYCLE COUNT
  
```

EPHEMERAL MEMORY READOUT

FIXED MEMORY READOUT

EPHEMERAL READOUT

FIXED MEMORY READOUT

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.

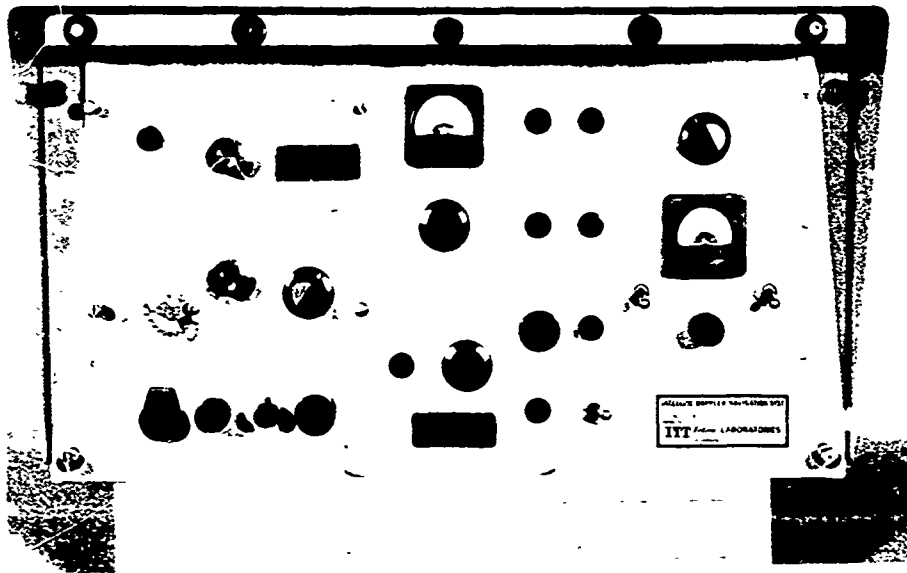
RADIO NAVIGATION SETS AN/SRN-9 AND AN/SRN-9A

Under contract to the Naval Ship Systems Command, ITT has produced shipboard navigation equipment designated Radio Navigation 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

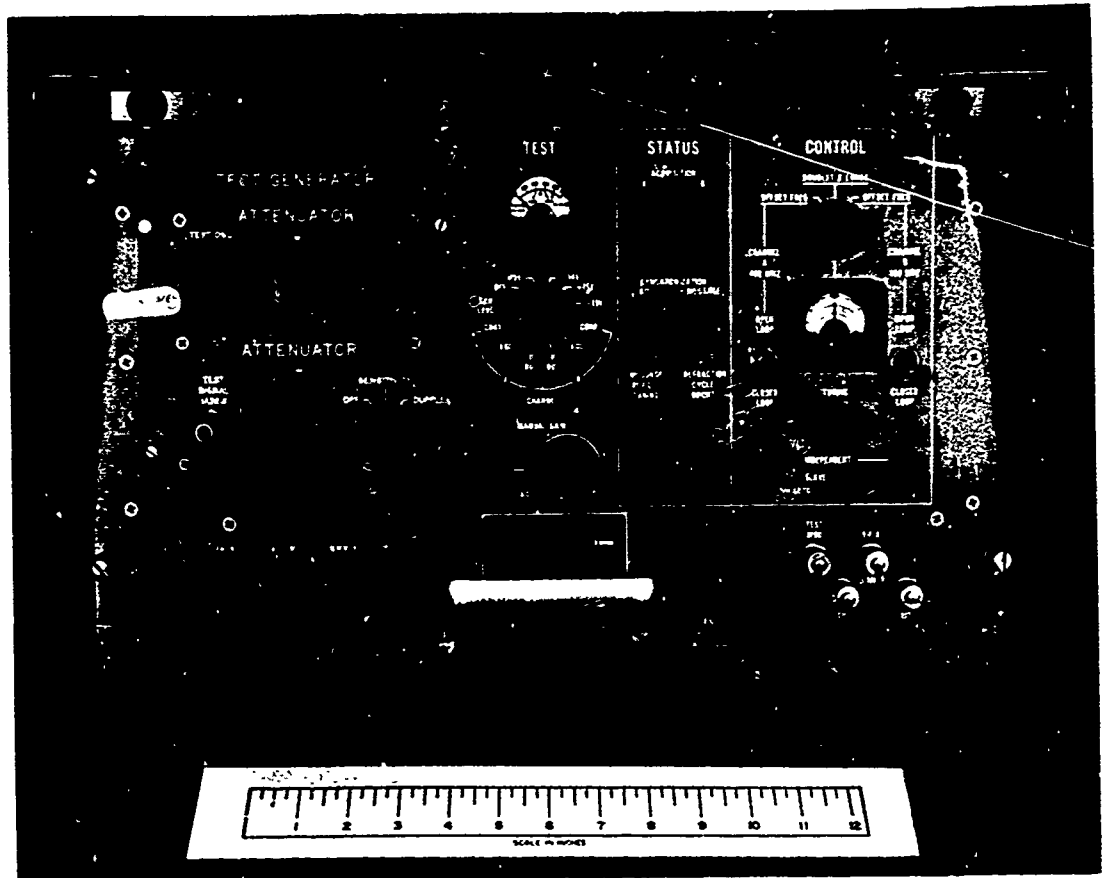


Fig. 12 AN/SRN-9A RADIO NAVIGATION SET

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

$$N_k = N_{k400} - \frac{24}{55} (R_k - 2000) \quad (6)$$

where

N_k = ionospheric refraction corrected doppler count,

N_{k400} = 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.

NOT REPRODUCIBLE

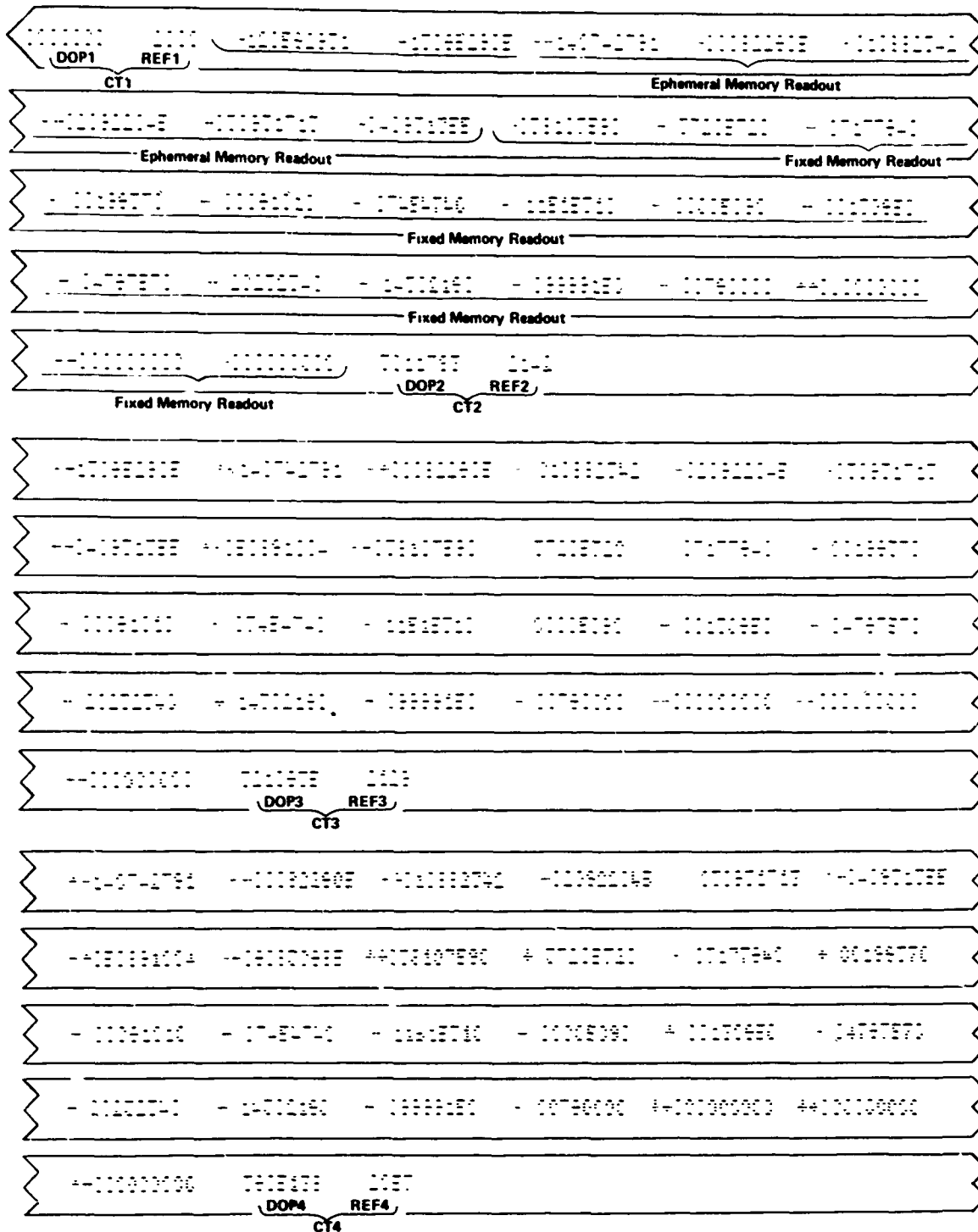


Fig. 13 AN/SRN-9 OR AN/SRN-9A TWO-MINUTE DOPPLER, REFRACTION, AND ORBITAL PARAMETER PRINTOUT

NOT REPRODUCIBLE

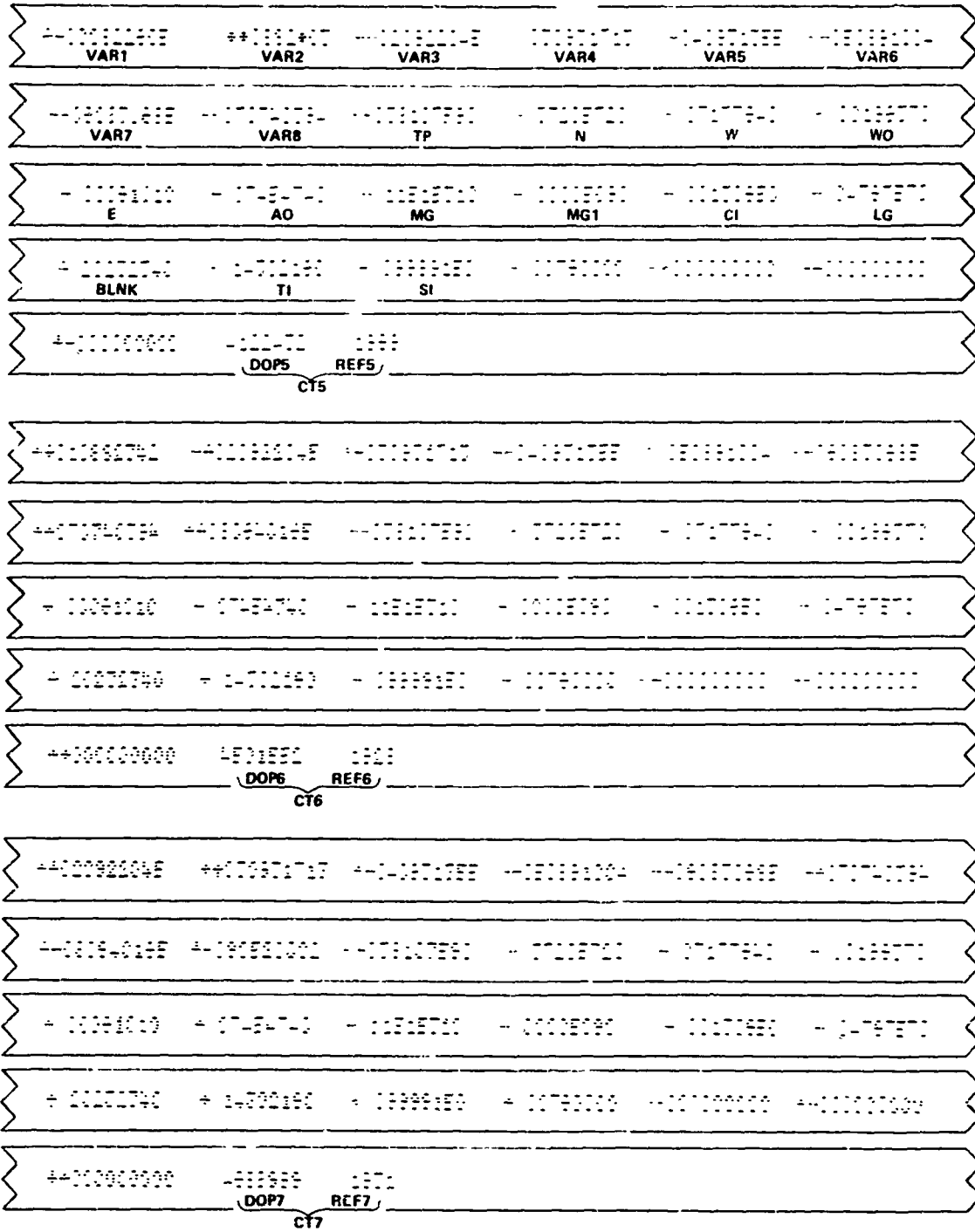


Fig. 13 AN/SRN-9 OR AN/SRN-9A TWO-MINUTE DOPPLER, REFRACTION, AND ORBITAL PARAMETER PRINTOUT (cont'd)

NOT REPRODUCIBLE

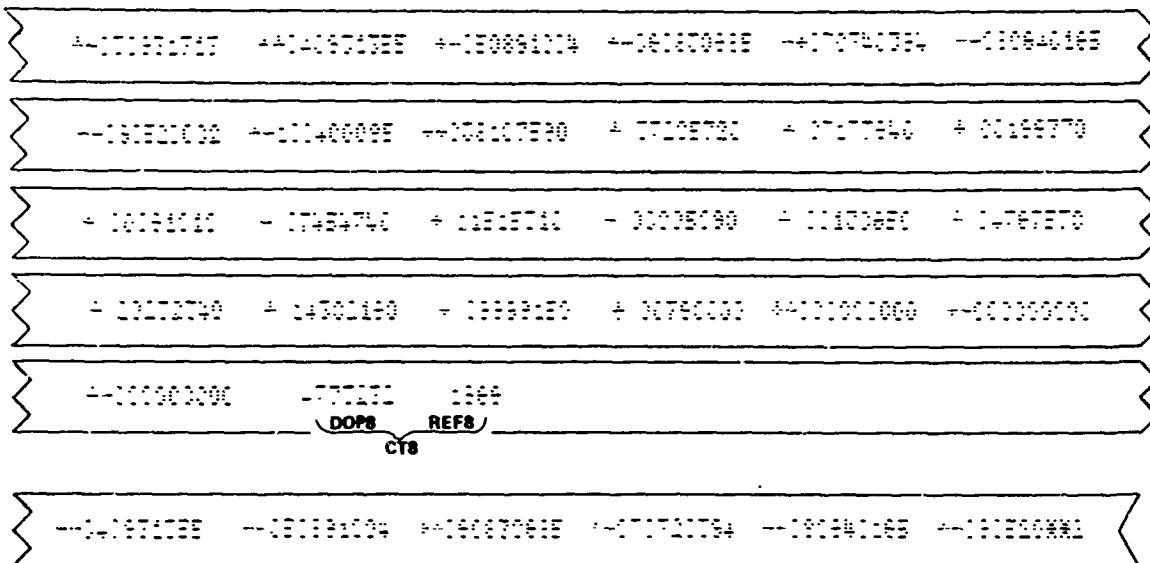


Fig. 13 AN/SRN-9 OR AN/SRN-9A TWO-MINUTE DOPPLER, REFRACTION, AND ORBITAL PARAMETER PRINTOUT (cont'd)

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 API 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

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

where

N_k = ionospheric refraction corrected doppler count,

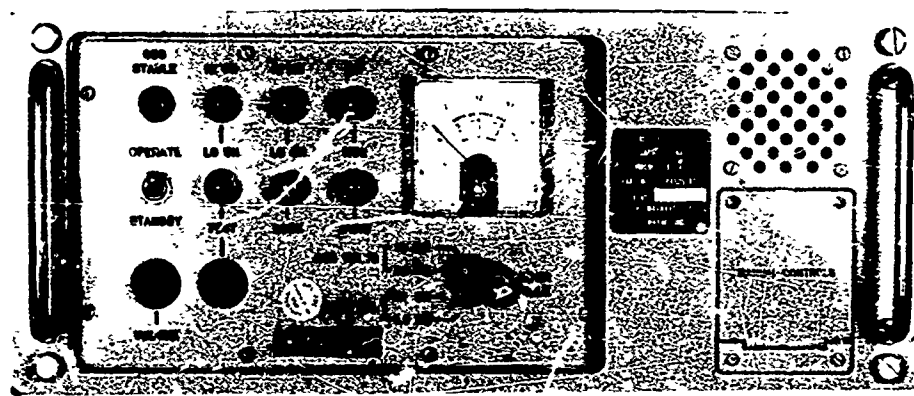
$N_{k_{400}}$ = 400-MHz doppler count, and

$N_{k_{150}}$ = 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
430732990 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 PRINT-OUT 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

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

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_0 , 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

$$\begin{aligned} X &= x' \cos \Omega_0 - y' \cos i \sin \Omega_0 \\ Y &= x' \sin \Omega_0 + y' \cos i \cos \Omega_0 \\ Z &= y' \sin i \end{aligned} \quad (9a)$$

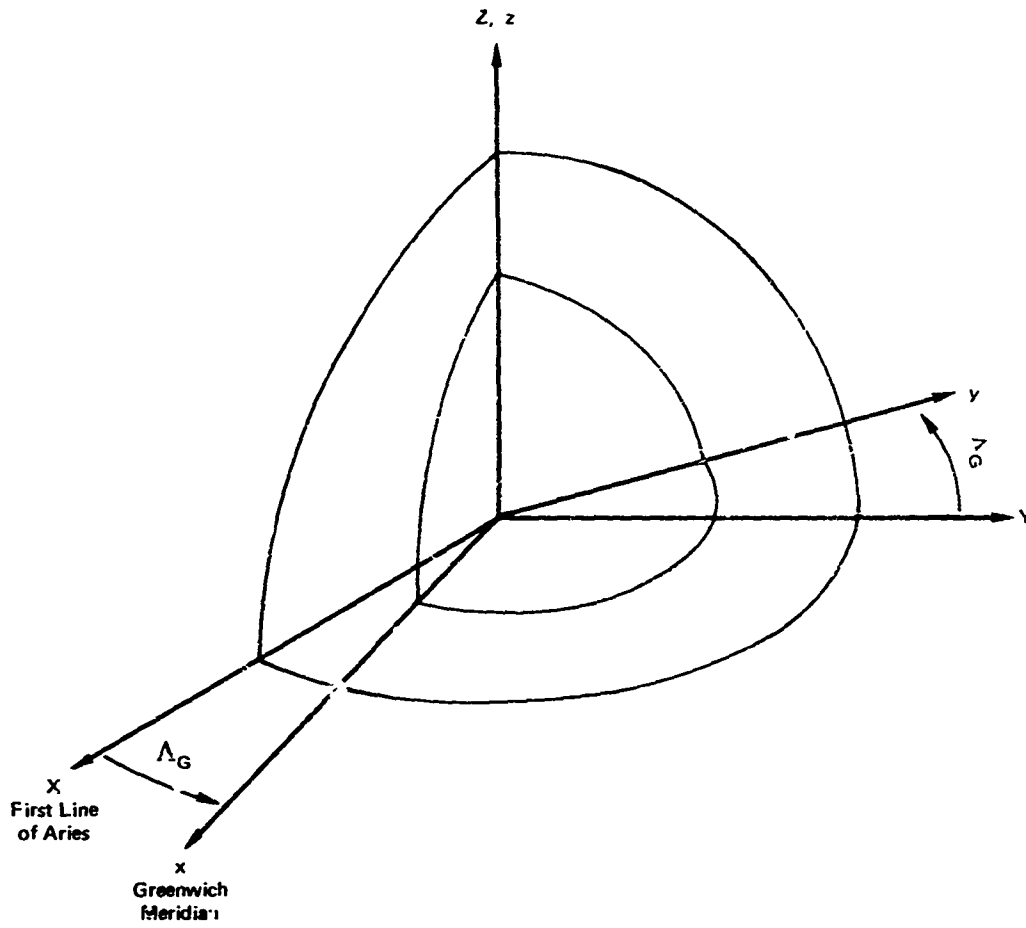


Fig. 16 XYZ AND xyz COORDINATE SYSTEMS

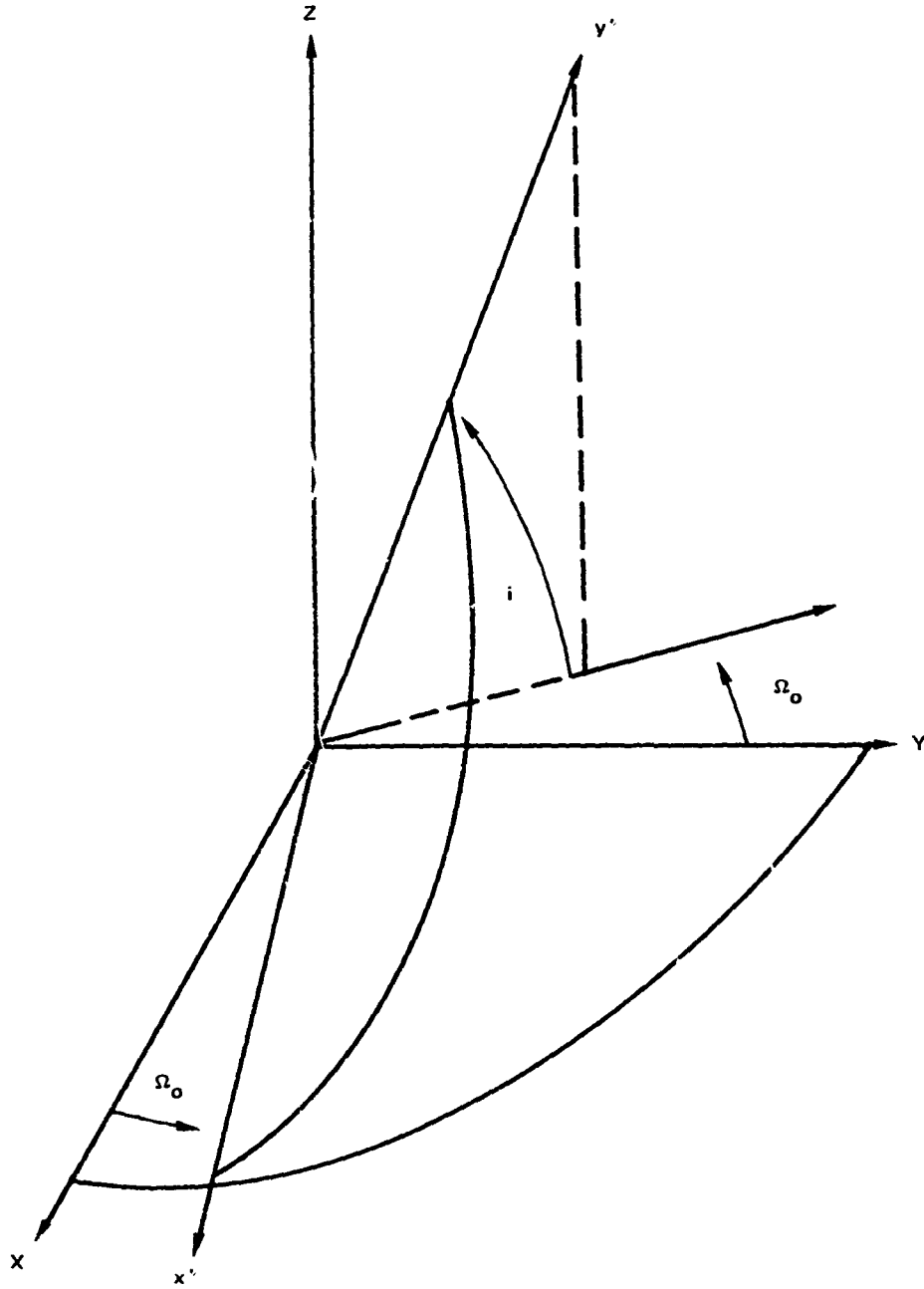


Fig. 17 ORIENTATION OF ORBITAL PLANE

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

$$\begin{aligned} X &= x' \cos \Omega_0 - y' \cos i \sin \Omega_0 + z' \sin i \sin \Omega_0 \\ Y &= x' \sin \Omega_0 + y' \cos i \cos \Omega_0 - z' \sin i \cos \Omega_0 \\ Z &= y' \sin i + z' \cos i . \end{aligned} \quad (9b)$$

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

$$\beta = \Omega_0 - \Lambda_G . \quad (10)$$

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:

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

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

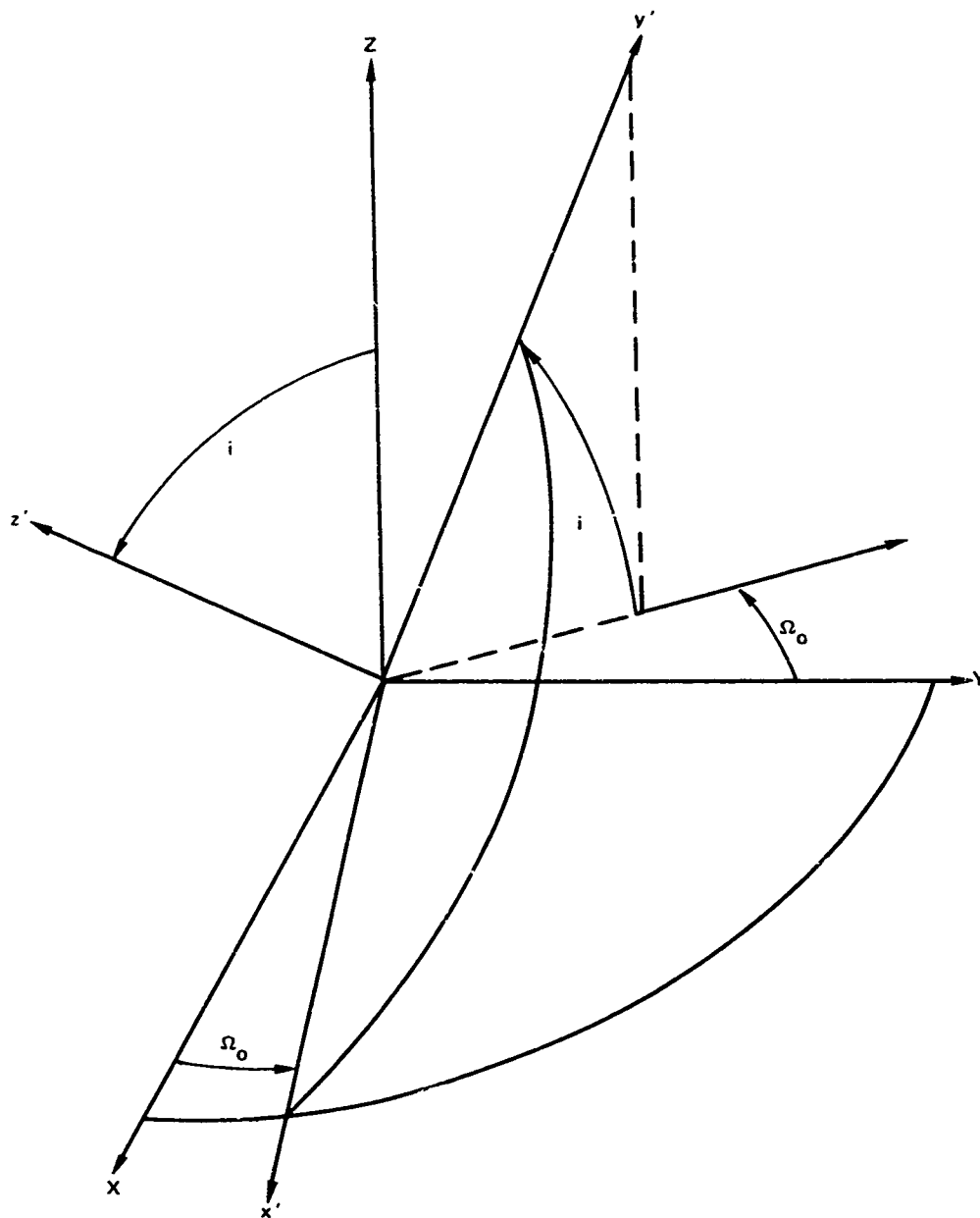


Fig. 18 $x'y'z'$ COORDINATE SYSTEM

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_0 and ω_0 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

$$F(x, y, z) = \frac{x^2 + y^2}{R_0^2} + \frac{z^2}{[R_0(1-f)]^2} - 1 = 0. \quad (15)$$

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

$$\begin{aligned} F_x &= \frac{2x}{R_o^2} \\ F_y &= \frac{2y}{R_o^2} \\ F_z &= \frac{2z}{[R_o (1 - f)]^2} \end{aligned} \quad (16)$$

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

$$\begin{aligned} \cos \varphi \cos \lambda &= F_x / (F_x^2 + F_y^2 + F_z^2)^{1/2} \\ \cos \varphi \sin \lambda &= F_y / (F_x^2 + F_y^2 + F_z^2)^{1/2} \\ \sin \varphi &= F_z / (F_x^2 + F_y^2 + F_z^2)^{1/2} \end{aligned} \quad (17)$$

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_0 , 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

$$\begin{aligned}x' &= u \cos \omega_0 - v \sin \omega_0 \\y' &= u \sin \omega_0 + v \cos \omega_0 \\z' &= w.\end{aligned}\tag{12}$$

Now consider the pictorial representation of the satellite orbit as shown in Fig. 20. The point O' is the center of the ellipse PSA and of the circumscribed circle PCA . The origin of the uvw coordinate system is taken as O . 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_0 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_0 , 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):

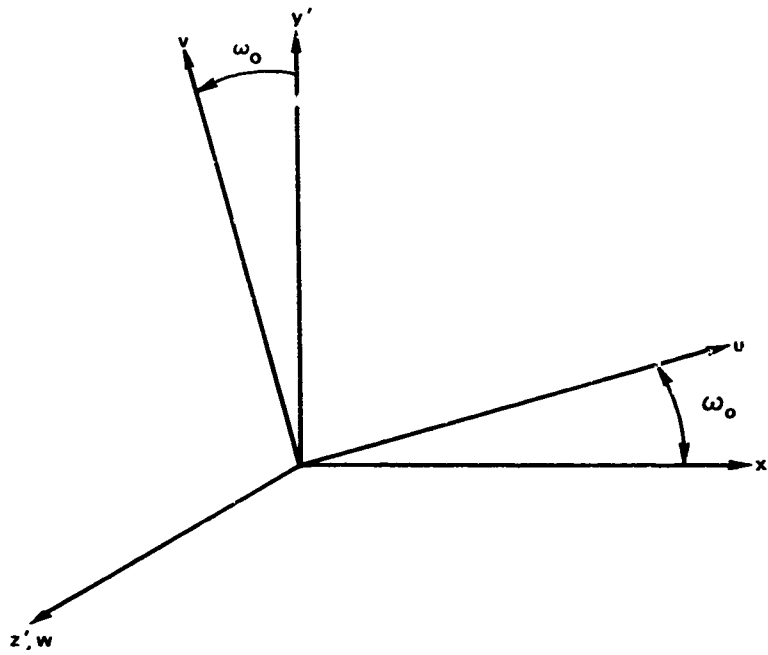


Fig. 19 RELATION BETWEEN $x'y'$ AND uv PLANES

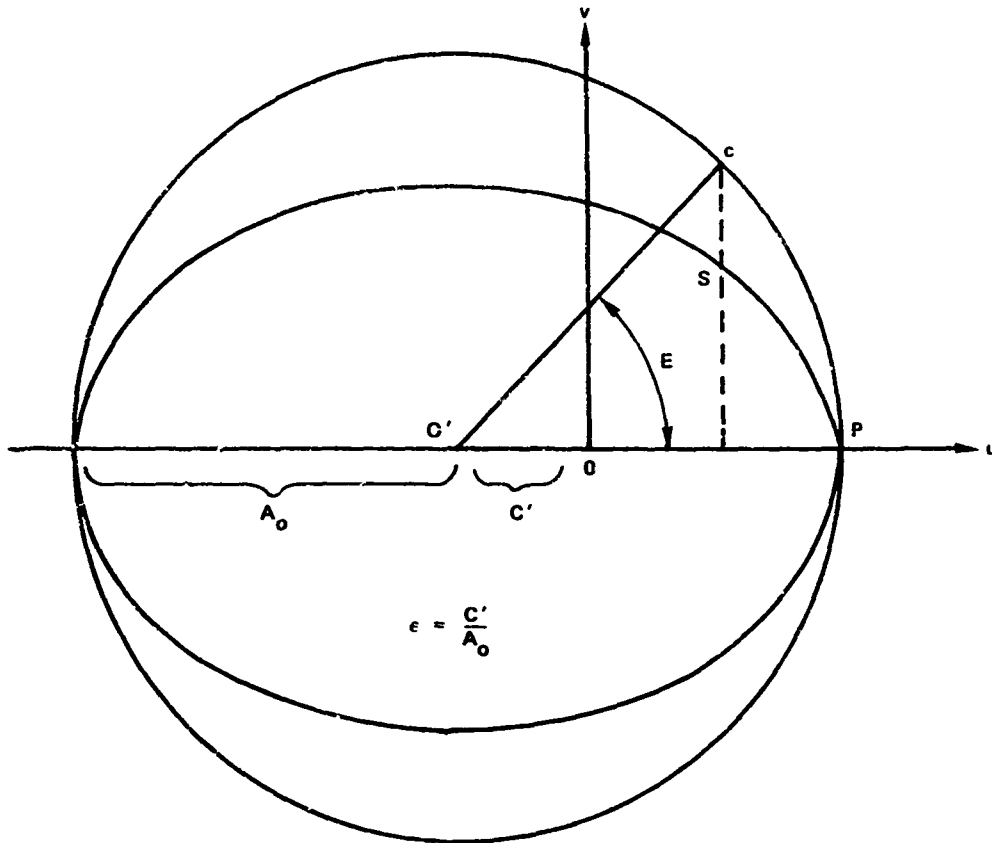


Fig. 20 SATELLITE ORBIT

$$\begin{aligned}
 M(t) &= n(t-t_p) \\
 E(t) &= M(t) + \epsilon \sin E(t) \\
 A &= A_0 \\
 u(t) &= A(\cos E(t) - \epsilon) \\
 v(t) &= A\sqrt{1-\epsilon^2} \sin E(t) \\
 w(t) &\text{ is undefined.}
 \end{aligned}
 \tag{13}$$

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_0 , 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

$$\begin{aligned}
 M_k &= n(t_k - t_p) \\
 E_k &= M_k + \epsilon \sin E_k + \Delta E(t_k) \\
 A_k &= A_0 + \Delta A(t_k) \\
 u_k &= A_k (\cos E_k - \epsilon) \\
 v_k &= A_k \sin E_k \\
 w_k &= \eta(t_k).
 \end{aligned}
 \tag{14}$$

$$\begin{aligned} x/R_0 &= F_x R_0/2 = (R_0/2) (F_x^2 + F_y^2 + F_z^2)^{1/2} \cos \varphi \cos \lambda \\ y/R_0 &= F_y R_0/2 = (R_0/2) (F_x^2 + F_y^2 + F_z^2)^{1/2} \cos \varphi \sin \lambda \\ z/R_0(1-f) &= F_z R_0(1-f)/2 = [R_0(1-f)/2] (F_x^2 + F_y^2 + F_z^2)^{1/2} \sin \varphi . \end{aligned} \quad (18)$$

Now, by Eq. (15)

$$(x/R_0)^2 + (y/R_0)^2 + [z/R_0(1-f)]^2 = 1. \quad (19)$$

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

$$(F_x^2 + F_y^2 + F_z^2) = \frac{4}{R_0^2 \cos^2 \varphi + [R_0(1-f)]^2 \sin^2 \varphi} \quad (20)$$

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

$$\begin{aligned} x(\varphi, \lambda) &= \frac{R_0 \cos \varphi \cos \lambda}{(\cos^2 \varphi + (1-f)^2 \sin^2 \varphi)^{1/2}} \\ y(\varphi, \lambda) &= \frac{R_0 \cos \varphi \sin \lambda}{(\cos^2 \varphi + (1-f)^2 \sin^2 \varphi)^{1/2}} \\ z(\varphi) &= \frac{R_0(1-f)^2 \sin \varphi}{(\cos^2 \varphi + (1-f)^2 \sin^2 \varphi)^{1/2}} \end{aligned} \quad (21)$$

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 the 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, $h' \geq 0$ according to

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

Now let

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

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

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

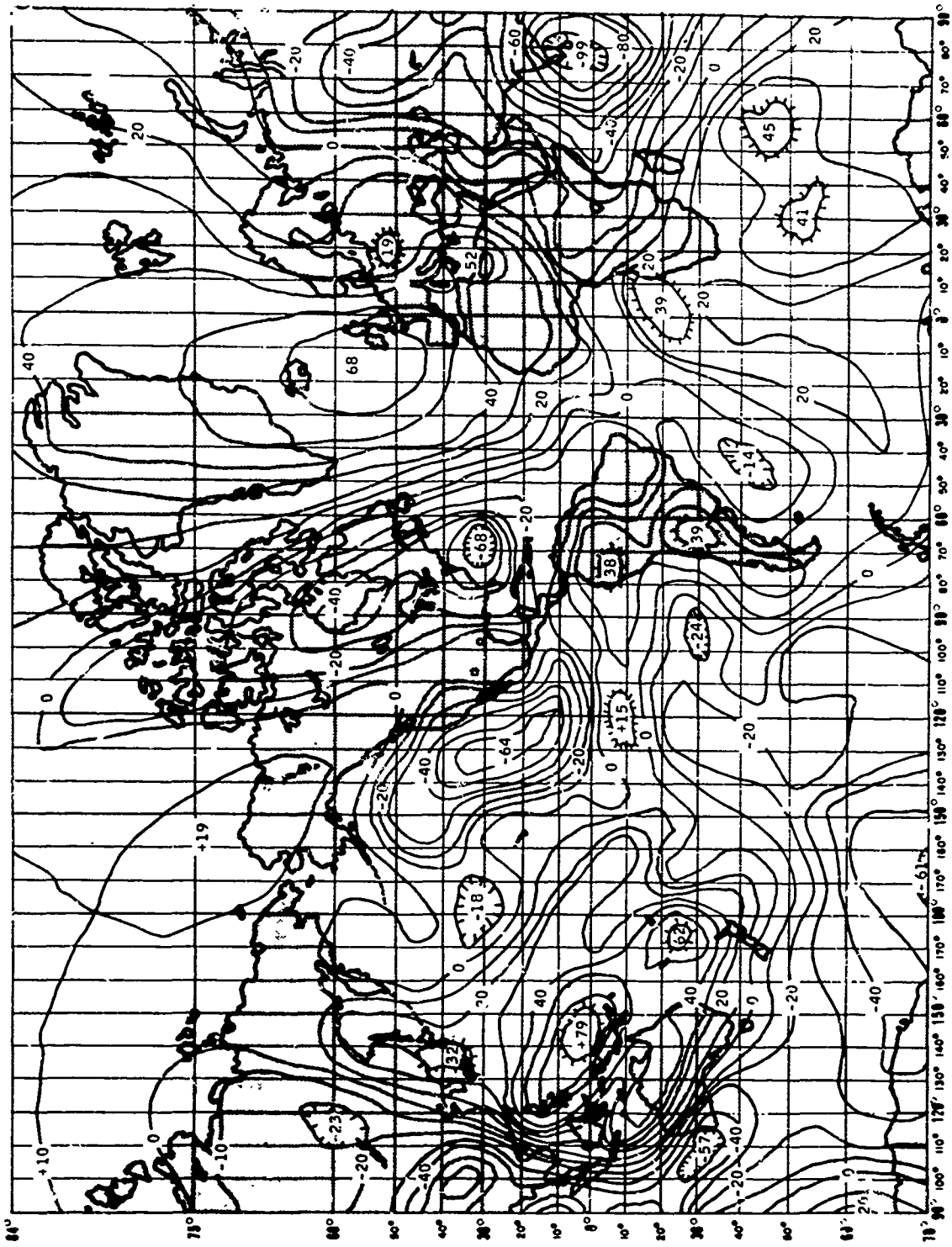


Fig. 21 GEOIDAL HEIGHT (H) CONTOUR MAP (METERS)

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

$$\begin{aligned}x^{(2)}(\varphi, \lambda, h') &= - \left((R_0)^2 [R_0 (1-f)]^2 / D^3(\varphi) + h' \right) \sin \varphi \cos \lambda \\y^{(2)}(\varphi, \lambda, h') &= - \left((R_0)^2 [R_0 (1-f)]^2 / D^3(\varphi) + h' \right) \sin \varphi \sin \lambda \\z^{(2)}(\varphi, h') &= (R_0)^2 [R_0 (1-f)]^2 / D^3(\varphi) + h' \cos \varphi \\x^{(3)}(\varphi, \lambda, h') &= -y(\varphi, \lambda, h') \\y^{(3)}(\varphi, \lambda, h') &= x(\varphi, \lambda, h') .\end{aligned}\tag{24}$$

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
	t_k	Minutes modulo 15	2	2	XX.0	Time in integer even UT minutes following an integer one-half hour of kth transmission
8, 14, 20, 26, 32, 38, 44, and 50	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 ephemeris memory on the day when that perigee occurs
62	n	Degrees/minute minus three ²	9	S.XXXXXXXXX	Mean motion of satellite
68	ω_0	Degrees	9	SXXX.XXXXX ³	Argument of perigee at t_p
74	$\dot{\omega}$	Degrees/minute	9	S.XXXXXXXXX	Precession rate of perigee
80	ϵ	Dimensionless	9	SX.XXXXXXXXX	Eccentricity
86	A_0	Meters	9	SXXXXXXXXX.0 ³	Mean semimajor axis
92	Ω_0	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	C_i	Dimensionless	9	SX.XXXXXXXXX	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	S_i	Dimensionless	9	SX.XXXXXXXXX	Sine of inclination
134	$\Delta \gamma_s$	----	9	----	Satellite frequency offset (unused)
140, 146 and 152	--	----	9	---	Zeros at time of injection ⁴

¹The 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 -.

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

³Always a positive value.

⁴Words 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	$\pm XX^\circ, XX.XXX'$ + = north - = south
Longitude	λ_e	Degrees and minutes	$\pm XXX^\circ, XX.XXX'$ + = east - = west
Antenna height	h	Meters	$\pm XX.X^1$
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.

¹Dependent upon installation; see Fig. 21.

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

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

Table 4
 Program Constants

Parameter	Symbol	Units	Magnitude
System Constants			
Initial value of offset frequency	\bar{f}_0	cycles/second	32,000
Vacuum wavelength at reference frequency	L_0	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_0	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 what 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

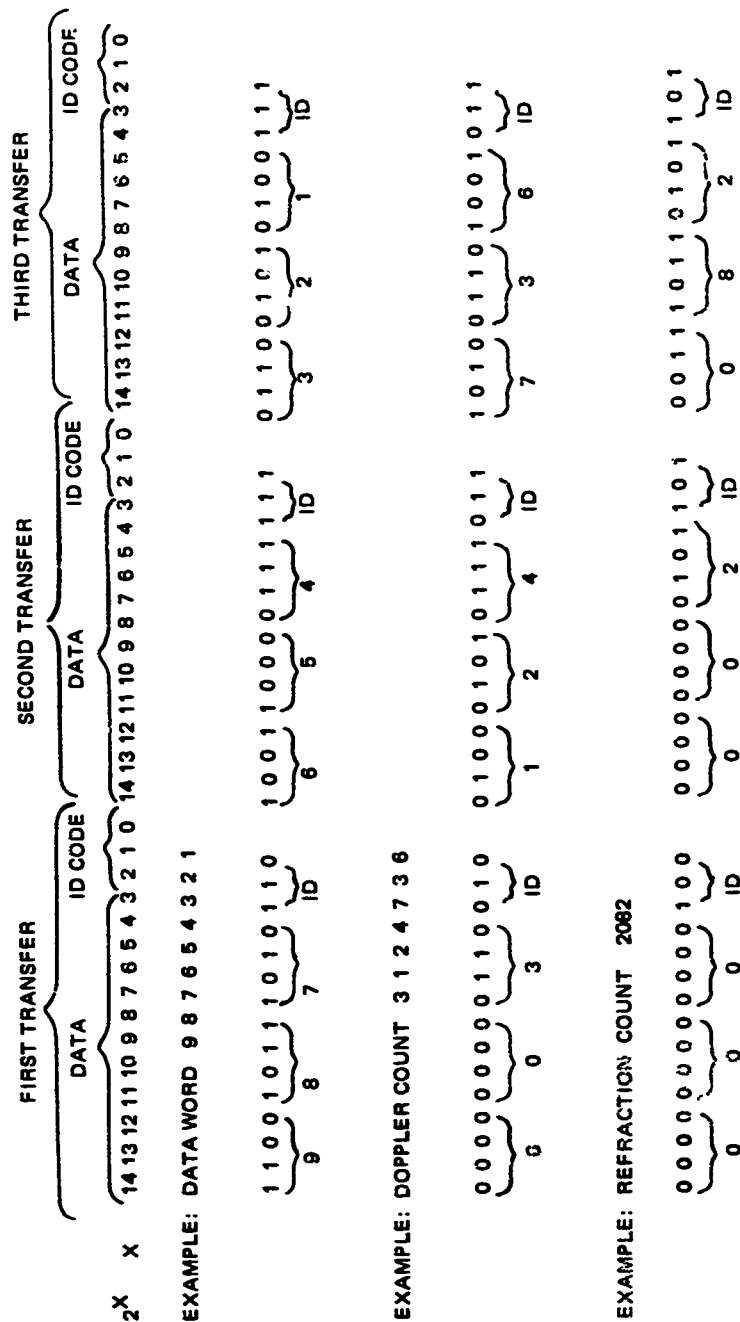
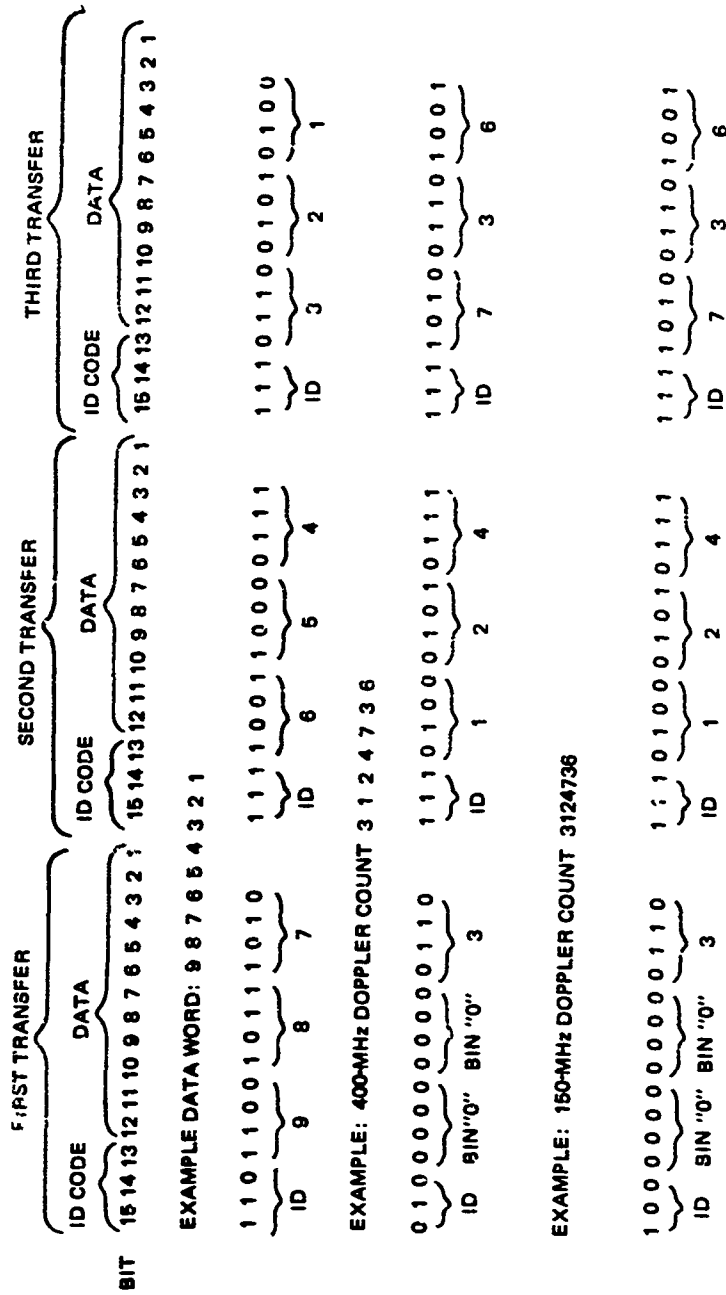


Fig. 22 DATA FORMAT FOR AN/SRN-9 EQUIPMENT



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						SIGN ID	
NO.	SIGN	ID					
1	0 0000 0000	X 010	DOPPLER	0 010	0000 0000	X	
2	0 X X X	X 011	DATA	0 111	X X X		
3	0 X 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	X 101	DATA	0 111	X X X		
1	0 X X X	X 110	ORBITAL	0 110	X X X		
2	0 X X X	X 111	PARAM-	0 111	X X X		
3	0 X X X	X 111	ETER DATA	0 111	X X X		

ITT OUTPUT SATELLITE MAGNAVOX OUTPUT
 DATA
 TYPE

X = BCDX3 CHARACTER

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

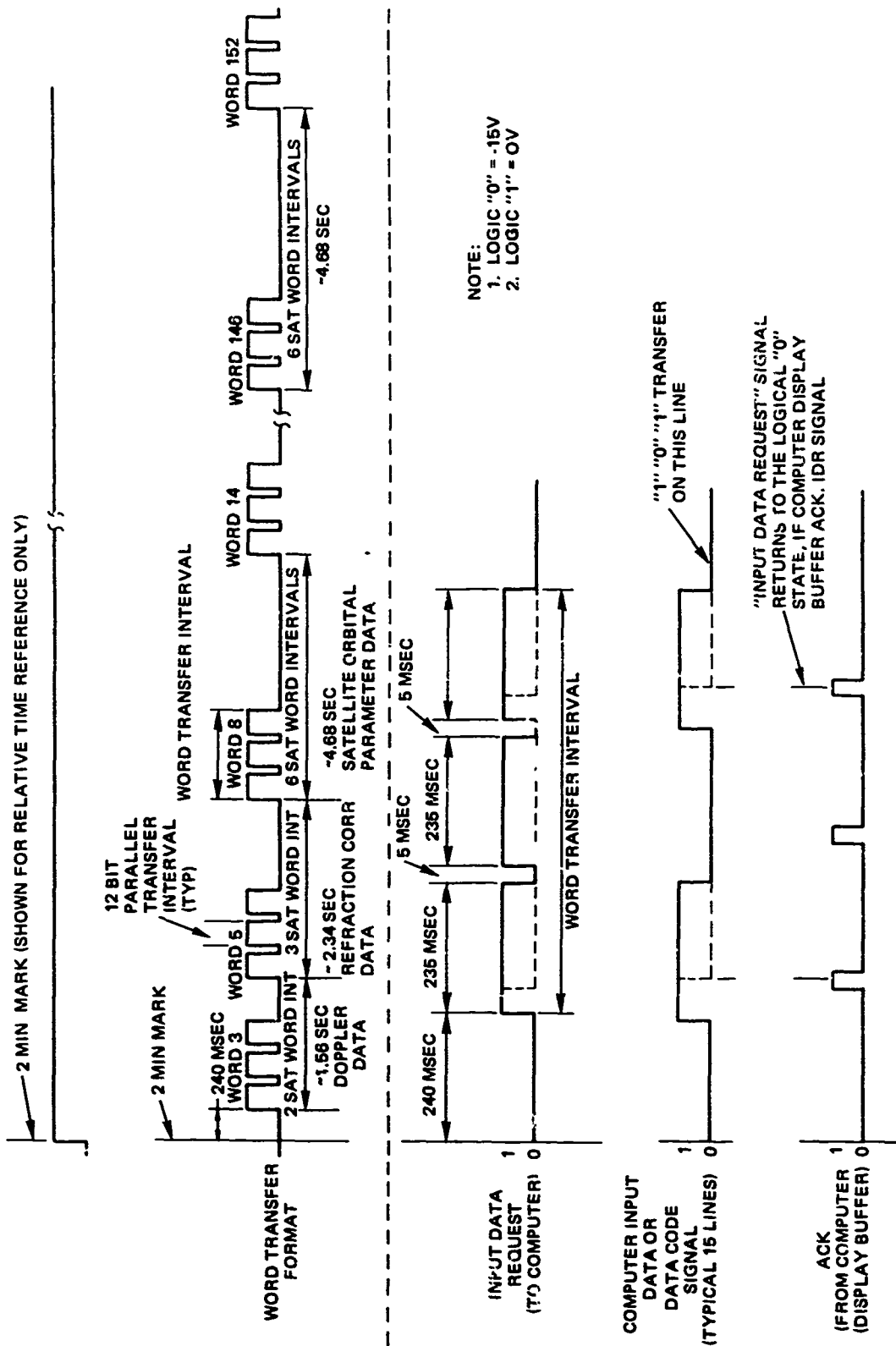


Fig. 25 RECEIVER/COMPUTER INTERFACE TIMING DIAGRAM

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.

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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 (FPV)	FIXED PARAMETER ERROR WORD (FPER)	VARIABLE PARAMETER CURRENT WORD (VPCR)	VARIABLE PARAMETER MAJORITY VOTED WORD (VPV)	VARIABLE PARAMETER ERROR WORD (VPER)	CENTER WORD (CPCS)	REACTION WORD (REFS)
16223 → FPR	16000 → FPV	16416 → FPE	16366 → VPR	16123 → VPV	16106 → VPE	16063 → DOA	16113
16224	16001	16417	16367	16144 BCDX3	16307	16064	16114
16225	16002	16420	16370	16145 Zero	16310	16065	16115
16226	16003	16421	16371	16146	16311	16066	16116
16227	16004	16422	16372	16147	16312	16067	16117
16228	16005	16423	16373	16150	16313	16068	16120
16229	16006	16424	16374	16151	16314	16071	16121
16230	16007	16425	16375	16152	16315	16072	16122
16231	16008	16426	16376	16153	16316	16073	16123
16232	16009	16427	16377	16154	16317	16074	16124
16233	16010	16428	16378	16155	16318	16075	16125
16234	16011	16429	16379	16156	16319	16076	16126
16235	16012	16430	16380	16157	16320	16077	16127
16236	16013	16431	16401	16158	16321	16078	16128
16237	16014	16432	16402	16159	16322	16079	16129
16238	16015	16433	16403	16160	16323	16080	16130
16239	16016	16434	16404	16161	16324	16101	16131
16240	16017	16435	16405	16162	16325	16102	16132
16241	16018	16436	16406	16163	16326	16103	16133
16242	16019	16437	16407	16164	16327	16104	16134
16243	16020	16438	16408	16165	16328	16105	16135
16244	16021	16439	16409	16166	16329	16106	16136
16245	16022	16440	16410	16167	16330	16107	16137
16246	16023	16441	16411	16168	16331	16108	16138
16247	16024	16442	16412	16169	16332	16109	16139
16248	16025	16443	16413	16170	16333	16110 → RE-1	16140
16249	16026	16444	16414	16171	16334	16111	16141
16250	16027	16445	16415	16172	16335	16112	16142
16251	16028	16446	16416	16173	16336		
16252	16029	16447	16417	16174	16337		
16253	16030	16448	16418	16175	16338		
16254	16031	16449	16419	16176	16339		
16255	16032	16450	16420	16177	16340		
16256	16033	16451	16421	16200	16341		
16257	16034	16452	16422	16201	16342		
16258	16035	16453	16423	16202	16343		
16259	16036	16454	16424	16203	16344		
16260	16037	16455	16425	16204	16345		
16261	16038	16456	16426	16205	16346		
16262	16039	16457	16427	16206	16347		
16263	16040	16458	16428	16207	16348		
16264	16041	16459	16429	16208	16349		
16265	16042	16460	16430	16209	16350		
16266	16043	16461	16431	16210	16351		
16267	16044	16462	16432	16211	16352		
16268	16045	16463	16433	16212	16353		
16269	16046	16464	16434	16213	16354		
16270	16047	16465	16435	16214	16355		
16271	16048	16466	16436	16215	16356		
16272	16049	16467	16437	16216	16357		
16273	16050	16468	16438	16217	16358		
16274	16051	16469	16439	16218	16359		
16275	16052	16470	16440	16219	16360		
16276	16053	16471	16441	16220	16361		
16277	16054	16472	16442	16221	16362		
16278	16055	16473	16443	16222	16363		
16279	16056	16474	16444		16364		
16280	16057	16475	16445		16365		
16281	16058	16476	16446		16366		
16282	16059	16477	16447		16367		
16283	16060	16478	16448		16368		
16284	16061	16479	16449		16369		
16285	16062	16480	16450		16370		
16286	16063	16481	16451		16371		
16287	16064	16482	16452		16372		
16288	16065	16483	16453		16373		
16289	16066	16484	16454		16374		
16290	16067	16485	16455		16375		
16291	16068	16486	16456		16376		
16292	16069	16487	16457		16377		
16293	16070	16488	16458		16378		
16294	16071	16489	16459		16379		
16295	16072	16490	16460		16380		
16296	16073	16491	16461		16381		
16297	16074	16492	16462		16382		
16298	16075	16493	16463		16383		
16299	16076	16494	16464		16384		
16300	16077	16495	16465		16385		
16301	16078	16496	16466		16386		
16302	16079	16497	16467		16387		
16303	16080	16498	16468		16388		
16304	16081	16499	16469		16389		
16305	16082	16500	16470		16390		

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

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010	011	011	100	101	101	110	111	111	111	110	111	111	111	110	111	111
DP1	DP2	DP2	RF1	RF2	RF2	MG1	MG2	MG2	MG1	MG2	MG2	MG1	MG2	MG1	MG2	MG2
doppler			refraction			satellite orbital parameter data										
data			data													

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 second 15-bit transfer for orbital parameter word No. 1 directs 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 VPCR, 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, BCDX3, Zero)	VARIABLE PARAMETER ERROR WORD (VPER)	DOPPLER WORD (DOPS)	REFRACTION WORD (REFS)
μ 16223	16000 → FPV	16416	T_0-6 16386	16143 → VPV	16306	16063 → 004	16113
16224	16001	16417	16387	16144 BCDX3	16307	16064	16114
16225	16002	16420	-J370	16145 Zero	16310	16065	16115
η 16226	16003	16421	T_0-4 16371	16146	16311	16066	16116
16227	16004	16422	Contains	16147	16312	16067	16117
16228	16005	16423	8	16150	16313	16070	16120
ω_0 16231	16006	16424	T_0-2 16374	16151	16314	16071	16121
16232	16007	16425	variable	16152	16315	16072	16122
16233	16010	16426	16376	16153	16316	16073	16123
ω 16234	16011	16427	16377	16154	16317	16074	16124
16235	16012	16430	T_0 16400	16155	16320	16075	16125 BCDX3
16236	16013	16431	from	16156	16321	16076	16126
ϵ 16237	16014	16432	T_0+2 16402	16157	16322	16077	16127 Zero
16240	16015	16433	16403	16160	16323	16100	16130
16241	16016	16434	two	16161	16324	16101	16131
16242	16017	16435	minute	16162	16325	16102	16132
16243	16020	16436	T_0+4 16405	16163	16326	16103	16133
16244	16021	16437	message	16164	16327	16104	16134
16245	16022	16440	in	16165	16330	16105	16135
16246	16023	16441	T_0+6 16410	16166	16331	16106	16136
16247	16024	16442	16412	16167	16332	16107	16137
16248	16024	16443	T_0+8 16413	16170	16333	16110 → RE-1	16140
16249	16025	16444	16414	16171	16334	16111	16141
16250	16026	16445	format	16172	16335	16112	16142
16251	16027	16446	BCDX3	16173	16336		
16252	16030	16447	16415	16174	16337		
16253	16031	16448		16175	16340		
16254	16032	16449		16176	16341		
16255	16033	16450		16177	16342		
16256	16034	16452		16200	16343		
16257	16035	16453		16201	16344		
16258	16036	16454		16202	16345		
16259	16037	16455		16203	16346		
16260	16040	16456		16204	16347		
16261	16041	16457		16205	16350		
16262	16042	16460		16206	16351		
16263	16043	16461		16207	16352		
16264	16044	16462		16210	16353		
16265	16045	16463		16211	16354		
16266	16046	16464		16212	16355		
16267	16047	16465		16213	16356		
16268	16048	16466		16214	16357		
16269	16049	16467		16215	16360		
16270	16052	16470		16216	16361		
16271	16053	16471		16217	16362		
16272	16054	16472		16220	16363		
16273	16055	16473		16221	16364		
16274	16056	16474		16222	16365		
16275	16057	16475					
16276	16058	16476					
16277	16059	16477					
16307	16062	16500					
16308							
16309							
16310							
16311							
16312							
16313							
16314							
16315							
16316							
16317							
16318							
16319							
16320							
16321							
16322							
16323							
16324							
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16327							
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16330							
16331							
16332							
16333							
16334							
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16336							
16337							
16338							
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16340							
16341							
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16360							
16361							
16362							
16363							
16364							
16365							

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 DPLG is incremented, and program control transfers 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 (FFCR)	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)	COPLER WORD (COFS)	REFRACTION WORD (REFS)
16223 → FPR	t_p 16000 → FPV	16416 → FPE	T_0-6 16366 → VPR	T_0-6 16143	16306	16063	16113 → RE:1
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 → 004	16116
16227	16004	16422	16372	16147	16312	16067	16117
16230	16005	16423	16373	Contains 8 variable para-	16313	16070	16120
16231	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
16235	16011	16427	16377	16154	16317	16074	16124
16236	16012	16430	16400	16155	16320	16075	16125
16237	16013	16431	16401	16156	16321	16076	16126
16240	ϵ 16014	16432	T_0+2 16402	T_0+2 16157	16322	16077	BCDX3 Zero
16241	16015	16433	16403	16100	16323	16100	16130
16242	16016	16434	16404	16161	16324	16101	16131
16243	16017	16435	T_0+4 16405	16162	16325	16102	16132
16244	16020	16436	16406	16163	16326	16103	16133
16245	16021	16437	16407	16164	16327	16104	16134
16246	16022	16440	T_0+6 16408	16165	16330	16105	16135
16247	16023	16441	16409	16166	16331	16106	16136
16248	16024	16442	16410	16167	16332	16107	16137
16250	16025	16443	16411	16168	16333	16110	16140
16251	16026	16444	16412	16169	16334	16111	16141
16252	16027	16445	16413	16170	16335	16112	16142
16253	16030	16446	16414	16171	16336		
16254	16031	16447	16415	16172	16337		
16255	16032	16450		16174	16340		
16256	16033	16451		16175	16341		
16257	16034	16452		16176	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	16044	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	16051	16471		16216	16361		
16300	16054	16472		16217	16362		
16101	16055	16473		16218	16363		
16102	16056	16474		16219	16364		
16103	16057	16475		16220	16365		
16104	16060	16476		16221	16366		
16105	16061	16477		16222	16367		
	16062	16480					

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 (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 tp	16000	16416	T ₀₋₄	T ₀₋₆	16306	16053	16113
16224	16001	16417	16386	16143	16307	16064	16114
16225	16002	16420	16387	16144	16310	16065	16115
16226	16003	16421	T ₀₋₂	T ₀₋₄	16311	16065	16116
16227	16004	16422	16371	16145	16312	16070	16117
16230	16005	16423	16372	16147	16313	16070	16120
16231	16006	16424	T ₀	T ₀₋₂	16314	16071	16121
16232	16007	16425	Contains &	16150	16315	16072	16122
16233	16010	16426	Variable	16152	16316	16073	16123
16234	16011	16427	T ₀₊₂	T ₀	16317	16074	16124
16235	16012	16430	para-	T ₀	16317	16075	16125
16236	16013	16431	meters	16155	16321	16076	16126
16237	16014	16432	from	16156	16322	16077	16127
16240	16015	16433	T ₀₊₄	T ₀₊₂	16323	16077	16130
16241	16016	16434	second	16160	16324	16078	16131
16242	16017	16435	two-	16161	16325	16079	16132
16243	Contains	16436	minute	16162	16326	16080	16133
16244	17 fixed	16437	message	T ₀₊₄	16327	16102	16134
16245	para-	16440	in	16164	16330	16103	16135
16246	meters	16441	BCDX3	T ₀₊₆	16331	16104	16136
16247	from	16442	format	16167	16332	16105	16137
16250	16024	16443	T ₀₊₈	16170	16333	16110	16140
16251	16025	16444	format	16171	16334	16111	16141
16252	16026	16445	BCDX3	16172	16335	16112	16142
16253	16027	16446	format	16173	16336		
16254	16030	16447	format	16174	16337		
16255	16031	16448	format	16175	16340		
16256	16032	16449	format	16176	16341		
16257	16033	16451	format	16177	16342		
16258	16034	16452	format	16200	16343		
16259	16035	16453	format	16201	16344		
16260	16036	16454	format	16202	16345		
16261	16037	16455	format	16203	16346		
16262	16038	16456	format	16204	16347		
16263	16039	16457	format	16205	16350		
16264	16040	16458	format	16206	16351		
16265	16041	16459	format	16207	16352		
16266	16042	16460	format	16208	16353		
16267	16043	16461	format	16209	16354		
16268	16044	16462	format	16210	16355		
16269	16045	16463	format	16211	16356		
16270	16046	16464	format	16212	16357		
16271	16047	16465	format	16213	16358		
16272	16048	16466	format	16214	16359		
16273	16049	16467	format	16215	16360		
16274	16050	16468	format	16216	16361		
16275	16051	16469	format	16217	16362		
16276	16052	16470	format	16218	16363		
16277	16053	16471	format	16219	16364		
16278	16054	16472	format	16220	16365		
16279	16055	16473	format	16221			
16280	16056	16474	format	16222			
16281	16057	16475	format				
16282	16058	16476	format				
16283	16059	16477	format				
16284	16060	16478	format				
16285	16061	16479	format				
16286	16062	16480	format				
16287	16063	16481	format				
16288	16064	16482	format				
16289	16065	16483	format				
16290	16066	16484	format				
16291	16067	16485	format				
16292	16068	16486	format				
16293	16069	16487	format				
16294	16070	16488	format				
16295	16071	16489	format				
16296	16072	16490	format				
16297	16073	16491	format				
16298	16074	16492	format				
16299	16075	16493	format				
16300	16076	16494	format				
16301	16077	16495	format				
16302	16078	16496	format				
16303	16079	16497	format				
16304	16080	16498	format				
16305	16081	16499	format				
16306	16082	16500	format				

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.

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	16306 → VPR	16143	16306 BCD	16061	16111
16224	16001	16417	16367	16144	16307	16064	16114
16225	16002	16420	16370	16145	16310	16065	16115
16226	16003	16421	16371	16146	16311	16066	16116 → RE-1
16227	16004	16422	16372	16147	16312	16067	16117
16230	16005	16423	16375	16150	16313	16070	16120
16231	16006	16424	16374	16151 → VPV	16314 → VPE	16071	16121
16232	16007	16425	16375	16152	16315	16072	16122
16233	16010	16426	16376	Contains 8 variable para-meters	16316	16073	16123
16234	16011	16427	16377	8 meters from	16317	16074	16124
16235	16012	16430	16400	16157 from	16320	16075	16125
16236	16013	16431	16401	16158	16321	16076	16126
16237	16014	16432	16402	16159	16322	16077	16127
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	16412	16167	16332	16107	16137
16250	16025	16443	16413	16168	16333	16110	16140
16251	16026	16444	16414	16169	16334	16111	16141
16252	16027	16445	16415	16170	16335	16112	16142
16253	16030	16446		16171	16336		
16254	16031	16447		16172	16337		
16255	16032	16448		16173	16338		
16255	16033	16449		16174	16339		
16256	16034	16450		16175	16340		
16257	16035	16451		16176	16341		
16260	16036	16452		16177	16342		
16261	16037	16453		16200	16343		
16262	16038	16454		16201	16344		
16263	16040	16455		16202	16345		
16264	16041	16456		16203	16346		
16265	16042	16457		16204	16347		
16266	16043	16460		16205	16350		
16267	16044	16461		16206	16351		
16270	16045	16462		16207	16352		
16271	16046	16463		16208	16353		
16272	16047	16464		16209	16354		
16273	16048	16465		16210	16355		
16274	16050	16466		16211	16356		
16275	16051	16467		16212	16357		
16276	16052	16470		16213	16358		
16277	16053	16471		16214	16359		
16300	16054	16472		16215	16360		
16301	16055	16473		16216	16361		
16302	16056	16474		16217	16362		
16303	16057	16475		16220	16363		
16304	16058	16476		16221	16364		
16305	16059	16477		16222	16365		

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) 321(g). The example assumes that in the first 2-minute message this entry is received as 5321(g), 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

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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 16224 16225 16226 16227 16230 16231 16232 16233 16234 16235 16236 16240 16241 16242 16244 16245 16246 16247 16250 16251 16252 16253 16254 16255 16256 16257 16260 16261 16262 16263 16264 16265 16266 16267 16270 16271 16272 16273 16274 16275 16276 16277 16278 16279 16280 16281 16282 16283 16284	Γ_p 16000 16001 16002 η 16003 16004 16005 ω_0 16006 16007 16010 $\hat{\omega}$ 16011 16012 16013 ϵ 16014 16015 16016 16017 A_0 16017 16020 16021 Ω_0 16022 16023 16024 $\hat{\Omega}$ 16025 16026 16027 16028 C_1 16030 16031 16032 16033 16034 16035 16036 16037 16040 16041 16042 16043 16044 16045 16046 16047 16048 16049 16050 16051 16052 16053 16054 16055 16056 16057 16058 16059 16060 16061 16062 16063	16416 16417 16420 16421 16422 16423 16424 16425 16426 16427 16430 16431 16432 16433 16434 16435 16436 16437 16440 16441 16442 16443 16444 16445 16446 16447 16450 16451 16452 16453 16454 16455 16456 16457 16460 16461 16462 16463 16464 16465 16466 16467 16470 16471 16472 16473 16474 16475 16476 16477 16478 16479 16480	T_0+10 16366 16367 16370 T_0+12 16371 16372 16373 T_0+14 16374 16375 16376 T_0+16 16377 16378 16400 T_0+18 16402 16403 16404 T_0+20 16405 16406 16407 T_0+22 16410 16411 16412 T_0+24 16413 16414 16415	T_0-6 16143 16144 16145 T_0-4 16146 16147 16150 T_0-2 16151 16152 16153 T_0 16154 16155 16156 T_0+2 16157 16160 16161 T_0+4 16162 16163 16164 T_0+6 16165 16166 16167 T_0+8 16170 16171 16172 T_0+10 16173 16174 16175 T_0+12 16176 16177 16200 T_0+14 16201 16202 16203 T_0+16 16204 16205 16206 T_0+18 16207 16210 16211 T_0+20 16212 16213 16214 T_0+22 16215 16216 16217 T_0+24 16220 16221 16222	16306 BCD 16307 16310 16311 16312 16313 16314 16315 16316 16317 16320 16321 16322 16323 16324 16325 16326 16327 16330 16331 16332 16333 16334 16335 16336 16337 16340 16341 16342 16343 16344 16345 16346 16347 16350 16351 16352 16353 16354 16355 16356 16357 16360 16361 16362 16363 BCD 16364 16365	16063 16064 16065 16066 16067 16070 16071 16072 16073 16074 16075 16076 16077 16100 16101 16102 16103 16104 16105 16106 16107 16110 16111 16112	16113 16114 16115 16116 16117 16120 16121 16122 16123 16124 16125 16126 16127 16130 16131 16132 16133 16134 16135 16136 16137 16140 16141 16142

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 content of registers SYNC and CLOC become equal, 2 minutes have elapsed and subroutine TES2 will check doppler flag DPLG 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 INF3 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 ($\Delta\phi$), longitude ($\Delta\lambda$), 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

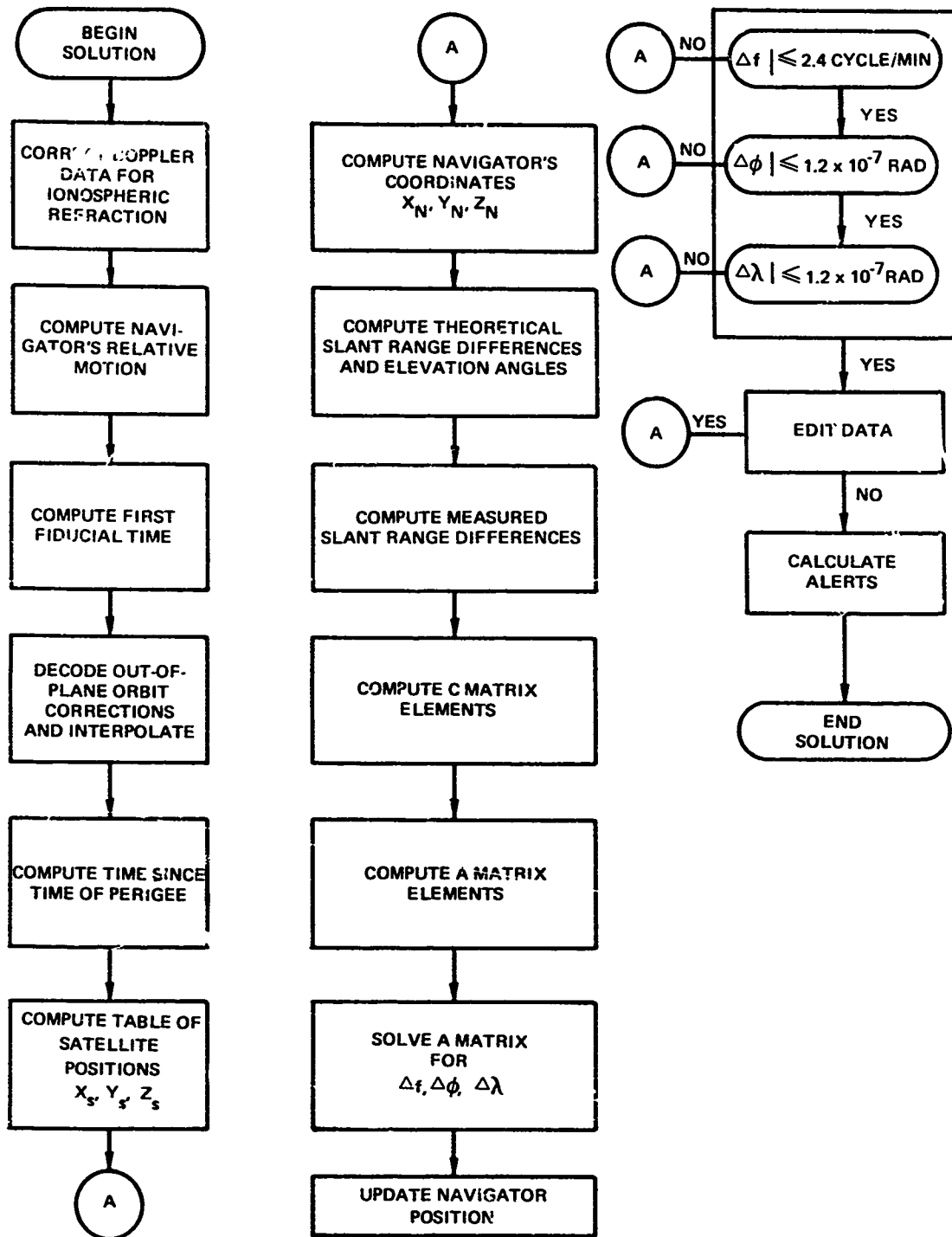


Fig. 34 BLOCK DIAGRAM OF NAVIGATION SOLUTION

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:

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

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

$$- a_{30} + a_{31} \Delta f + a_{32} \Delta \varphi + a_{33} \Delta \lambda = 0.$$

6. By Cramer's method 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_1 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_{k400} - 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_{k400} doppler counts were received.

KM-1 - Number of cycle counts.

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

$$\text{If } N_{k400} \leq 2 \times 10^6, N_k = 0, \text{ otherwise continue. (A.1)}$$

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

$$N_k = N_{k400} + \frac{24}{55} (2000 - R_k). \quad (\text{A.3})$$

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):

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

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

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

OUTPUT: $\Delta\phi_k, \Delta\lambda_k$ - Table of navigator's relative motion in latitude ($\Delta\phi$) and longitude ($\Delta\lambda$) at 2-minute intervals (radians).

STEP C - Compute first fiducial time.

INPUTS: T_c - Navigator's estimate for first fiducial time (minutes GMT).

t_0 - Two-minute interval number from first variable parameter in satellite message.

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

$$I = 2 K' \quad (C.2)$$

$$T'_c = \left[\frac{I}{30} \right] \quad (C.3)$$

$$J = I - 30 T'_c \quad (C.4)$$

$$H = 2 t_0 - J \quad (C.5)$$

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

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 ($k = 1, 2, 3, \dots, 11$) 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 $T_0 - 2$.

KM - Number of fiducial times, etc.

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

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

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

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

If $\eta_k - 5 \geq 0$ then

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

and $CPT(l) = k$.

If $\eta_k - 5 < 0$ and
 $\eta_k \neq 0$ then (D. 4)
 $CP(l) = 100(\eta_k - 5) - 10\eta_{k+1}$
 and $CPT(l) = k$.

If $\eta_k - 5 < 0$ and
 $\eta_k = 0$ then (D. 5)
 $CP(l) = -10\eta_{k+1}$
 and $CPT(l) = k$

where $l = 1, 2, 3, \dots, OP$.

If $OP \leq 2$ then
 $\eta_k = 0$ for $k = 1, 2, 3, \dots, KM$. (D. 6)

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

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

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

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 $k = 6, 7, 8, \dots, KM$.

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 $k = 5, 6, 7, \dots, KM$.

(D. 7)

$$\eta_v = \left[\frac{(K+1) - CPT(2)}{CPT(1) - CPT(2)} \cdot \frac{(K+1) - CPT(3)}{CPT(1) - CPT(3)} \right] CP(1) \quad (D. 7-a)$$

$$+ \left[\frac{(K+1) - CPT(1)}{CPT(2) - CPT(1)} \cdot \frac{(K+1) - CPT(3)}{CPT(2) - CPT(3)} \right] CP(2)$$

$$+ \left[\frac{(K+1) - CPT(1)}{CPT(3) - CPT(1)} \cdot \frac{(K+1) - CPT(2)}{CPT(3) - CPT(2)} \right] CP(3),$$

$$\eta_k = \left[\frac{(K+1) - CPT(3)}{CPT(2) - CPT(3)} \cdot \frac{(K+1) - CPT(4)}{CPT(2) - CPT(4)} \right] CP(2) \quad (D. 7-b)$$

$$+ \left[\frac{(K+1) - CPT(2)}{CPT(3) - CPT(2)} \cdot \frac{(K+1) - CPT(4)}{CPT(3) - CPT(4)} \right] CP(3)$$

$$+ \left[\frac{(K+1) - CPT(2)}{CPT(4) - CPT(2)} \cdot \frac{(K+1) - CPT(3)}{CPT(4) - CPT(3)} \right] CP(4),$$

$$\eta_k = \left[\frac{(K+1) - CPT(4)}{CPT(3) - CPT(4)} \cdot \frac{(K+1) - CPT(5)}{CPT(3) - CPT(5)} \right] CP(3) \quad (D. 7-c)$$

$$+ \left[\frac{(K+1) - CPT(3)}{CPT(4) - CPT(3)} \cdot \frac{(K+1) - CPT(5)}{CPT(4) - CPT(5)} \right] CP(4)$$

$$+ \left[\frac{(K+1) - CPT(3)}{CPT(5) - CPT(3)} \cdot \frac{(K+1) - CPT(4)}{CPT(5) - CPT(4)} \right] CP(5).$$

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

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 mes-
 sage (minutes).

n - Satellite mean motion (radians/minute).

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

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

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

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

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

OU - UT: 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):

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

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

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

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

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

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

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

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

$$x'_k = u_k \cos \omega_k - v_k \sin \omega_k, \quad (\text{F. 8})$$

$$y'_k = u_k \sin \omega_k + v_k \cos \omega_k, \quad (\text{F. 9})$$

$$z'_k = \eta_k, \quad (\text{F. 10})$$

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

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

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

$$Z_{Sk} = y'_k \text{Si} + z'_k \text{Ci}. \quad (\text{F. 14})$$

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: $\Delta\phi_k$ - 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 ($k = 1, 2, 3, \dots, \text{KM}$):

$$\cos \phi_k = \cos (\phi_f + \Delta\phi_k), \quad (\text{G. 1})$$

$$\sin \phi_k = \sin (\phi_f + \Delta\phi_k), \quad (\text{G. 2})$$

$$\cos \lambda_k = \cos (\lambda_f + \Delta \lambda_k), \quad (G. 3)$$

$$\sin \lambda_k = \sin (\lambda_f + \Delta \lambda_k), \quad (G. 4)$$

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

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

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

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

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

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

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

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

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

OUTPUTS: 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.

STEP H - Compute theoretical slant range differences, partial derivatives, and elevation angle.

INPUTS: 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):

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

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

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

$$S_k^2 = X_k^2 + Y_k^2 + Z_k^2, \quad (\text{H. 4})$$

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

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

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

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

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

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

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

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

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

$\frac{\partial S_k}{\partial \phi}, \frac{\partial S_k}{\partial \lambda}$ - 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 ($k = 1, 2, 3, \dots, KM-1$):

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

OUTPUT: ΛS_{ko} - Table of measured slant range differences (meters) for KM points.

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

$$\Lambda S_{ko} = 0.$$

STEP J - Form the C matrix.

INPUTS: ΛS_{ko} - Table of (KM-1) measured slant range differences (meters).

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

$\frac{\partial S_k}{\partial \phi}, \frac{\partial S_k}{\partial \lambda}$ - 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 ($k = 1, 2, 3, \dots, \text{KM}-1$), for which

$$\Lambda S_{ko} \neq 0:$$

$$C_{J0} = - \Lambda S_{ko} + [S_{k+1} - S_k], \quad (J.1)$$

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

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

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

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.

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

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

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

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

$$a_{21} = \sum_{m=1}^J C_{m2} C_{m1}, \quad \text{Note: } a_{21} = a_{12} \quad (K. 5)$$

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

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

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

$$a_{12} = a_{21}', \quad (K. 7)$$

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

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

$$a_{13} = a_{31}', \quad (K. 10)$$

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

$$a_{33} = \sum_{m=1}^J C_{m3} C_{m3}'. \quad (K. 12)$$

OUTPUT: A matrix

where

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

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

$$- a_{30} + a_{31} \Delta f + a_{32} \Delta \varphi + a_{33} \Delta \lambda = 0.$$

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

INPUT: A matrix elements.

$$B_{11} = a_{22} - a_{12} \frac{a_{12}}{a_{11}}, \quad (L. 1)$$

$$B_{12} = a_{23} - a_{13} \frac{a_{12}}{a_{11}}, \quad (L. 2)$$

$$B_{10} = a_{20} - a_{10} \frac{a_{12}}{a_{11}}, \quad \text{Note: } \begin{aligned} a_{12} &= a_{21} \\ a_{13} &= a_{31} \\ a_{32} &= a_{23} \end{aligned} \quad (L. 3)$$

$$B_{22} = a_{33} - a_{13} \frac{a_{13}}{a_{11}}, \quad (L. 4)$$

$$B_{20} = a_{30} - a_{10} \frac{a_{13}}{a_{11}}, \quad (L. 5)$$

$$\Delta = B_{11} B_{22} - B_{12} B_{21}, \quad (L. 6)$$

$$\Delta\phi = (B_{22} B_{10} - B_{12} B_{20})/\Delta, \quad (L. 7)$$

$$\Delta\lambda = (B_{11} B_{20} - B_{12} B_{10})/\Delta, \quad (L. 8)$$

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

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

$$\phi_f = \phi_f + \Delta\phi, \text{ and} \quad (L. 11)$$

$$\lambda_f = \lambda_f + \Delta\lambda. \quad (L. 12)$$

- 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}_0 - 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).

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

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

$$FRQ = f - \bar{f}_0, \text{ and} \quad (M. 3)$$

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

OUTPUTS: 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).
 $\Delta\phi$ - Incremental change in navigator's latitude (radians).
 $\Delta\lambda$ - Incremental change in navigator's estimated longitude (radians).
ITER - Number of the present iteration.
If $\Delta f > 2.4$ cycle/min, (N. 1)
or if $\Delta\phi > 1.2 \times 10^{-7}$ radian, *
or if $\Delta\lambda > \frac{1.2 \times 10^{-7} *}{\cos \phi_f}$,

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.

* 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 3×10^{-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 $\sin E_{KM - k+1} \leq \sin 7.5^\circ$ 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 $\sin E_{KM - k+1} > \sin 7.5^\circ$ and (O.2)

$\sin E_k \leq \sin 7.5^\circ$ 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, (P. 2)

I = 1, 2, 3, ---, ISTP, KDAY = I + IDAY.

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 $T_0 - 2 = \text{RISE}$, $E_k = E_A$, $T_0 = T_0 + 0.25$ 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 $E_A = \text{maximum elevation for that pass}$. (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 $I > \text{ISTP}$ indicating that (P. 9)
all alerts through the end of MDAY have been ob-
tained.

OUTPUTS: KDAY - Day number of alert day.
RISE - Time of rise (hours and min-
utes) 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 $\times 10^4$	Radians		1	Navigator
ELON	Estimated Longitude	FP	Min $\times 10^4$	Radians		1	Navigator
HEOU	Antenna Height	FP	Meters	Meters		1	Navigator
ELTM	Estimated Lock Time	FP	Minutes	Minutes		1	Navigator
HEAD	Ship's Heading	FP	Minutes	Radians		1	Navigator
RVLE	Ship's Speed	FP	Knots $\times 10$	Radians/Min $\times 2$		1	Navigator
HDAY	Day of Pass	Integers	Days	Days	15 bit dressed Rt	1	Navigator
MEAY	Alert End Day	Integers	Days	Days	15 bit dressed Rt	1	Navigator
DOPL(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 $\times 10^3$	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	$\frac{\text{Meters}}{10 \text{ or } 100}$	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 $\times 10^5$	Minutes		1	Satellite Message
NNDI	Mean Motion	FP	Deg/Min $\times 10^8 - 3$	Rad/Min		1	Satellite Message
SOME	Argument of Perigee	FP	Degrees $\times 10^5$	Radians		1	Satellite Message
SOMD	Precession Rate of Perigee	FP	Deg/Min $\times 10^8$	Rad/Min		1	Satellite Message
E	Eccentricity	FP	Deg/Min $\times 10^7$	Dimensionless		1	Satellite Message
AO	Mean Semimajor Axis	FP	Meters	Meters		1	Satellite Message
COME	Right Ascension of Ascending Node	FP	Degrees $\times 10^5$	Radians		1	Satellite Message
COMD	Precession Rate of Node	FP	Deg/Min $\times 10^8$	Rad/Min		1	Satellite Message
CI	Cosine Inclination	FP	Deg/Min $\times 10^7$	Dimensionless		1	Satellite Message
NLMG	Greenwich Long. at TP	FP	Degrees $\times 10^5$	Radians		1	Satellite Message
SI	Sine Inclination	FP	Degrees $\times 10^7$	Dimensionless		1	Satellite Message
DLAT(K)	Relative Lat. Motion			Radians	Calculated from Head	9	Navigator
DLOX(K)	Relative Long. Motion			Radians		9	Navigator
STIM	Correct Mag. 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.

* 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.

```

COMPILER OPTIONS - NAME = MAIN,OPT=02,LINECNT=90,SIZE=0000K,
SOURCE,EOI,EOIC,NULIST,NOJEC4,LJAD,MAP,NXC,DIT,IO,NOXREF
-----EXEC DEBUG-----
C
C
C
ISN 0002      1 FORMAT ('H ,(3F15.1//))      EXEC
C
C          DOUBLE PRECISION TA,WAVE,CVCG,EFHQ,UMGE,XDSQ,ZOSQ      EXEC
ISN 0003          DOUBLE PRECISION ONE,TWO,THREE,FIVE,ATE,TEN,D60,HUND,C480,S7PS      EXEC
ISN 0004          DOUBLE PRECISION TQPI,DTRA,DTUM,TM1,TM4,TM5,TM8,CMTR,CKRM      EXEC
ISN 0005          DOUBLE PRECISION ZERO,FOUR,SEVEN,CZK,CZM,REFC      EXEC
ISN 0006          DOUBLE PRECISION DOP,REF,DE,DA,DN,ELAT,ELON,GEOM,ETIM,HEAD,RATE      EXEC
ISN 0007          DOUBLE PRECISION DTA,TP,XNDT,SJME,SUMD,E,AD,COME,COMD,C1,XLNG      EXEC
ISN 0008          DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5      EXEC
ISN 0009          DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN      EXEC
ISN 0010          DOUBLE PRECISION T,TEMP,A,DUM      EXEC
ISN 0011          C
C          C-DIMENSION
ISN 0012          DIMENSION DOP(8),REF(8),DE(9),DA(11),DLAT(9),DLON(9)      EXEC
ISN 0013          DIMENSION AT(4),DJM(10)      EXEC
C
C          C-COMMON
ISN 0014          COMMON TP,XNDT,COME,SOMD,E,AD,COME,COMD,C1,XLNG      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,NDAY,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
ISN 0021          COMMON /COMC/MUL,NONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF      EXEC
ISN 0022          COMMON /COMC/TAW,WAVE,CVCG,EFHQ,UMGE,XDSQ,ZOSQ,ZERO      EXEC
ISN 0023          COMMON /COMC/ONE,TWO,THREE,FOUR,FIVE,ATE,TEN,D60,HUND      EXEC
ISN 0024          COMMON /COMC/C480,S7PS,TQPI,DTRA,DTUM      EXEC
ISN 0025          COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CMTR,CKRM,CZK,CZM,REFC      EXEC
C
C          C-----CONSTANTS-----
C          C---SYSTEM CONSTANTS
C          TAM=2.0+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 *M      EXEC
C          FFRQ=1.92D+6      EXEC
C          I=M+9      EXEC
C          IM=8      EXEC
C          KF=3      EXEC
C          C---EARTH CONSTANTS
C          OMGE=4.37526951D-3      EXEC
C          RAC/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          ACSI=XO*XO      EXEC
C          ONE=1.0+0      EXEC
C          ZO=XO*(ONE-ONE/EFLT)      EXEC
C
C          C          ZOSQ=ZO*ZO      EXEC
C          C-----UNIT CONVERSIONS AND MISCELLANEOUS
C          C          NULL=0      EXEC
C          C          IONE=1      EXEC
C          C          ITWO=2      EXEC
C          C          IFOR=4      EXEC
C
ISN 0026          REMIND 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

```

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	C	R08	N.R.	E	C	R08	N.R.	I	C	I04	N.R.	J	C	I04	N.R.
K	C	I04	N.R.	L	C	I04	N.R.	M	C	I04	N.R.	N	C	I04	N.R.
T	C	R08	N.R.	AG	C	R08	N.R.	CI	C	R08	N.R.	DA	C	R08	N.R.
DE	C	R08	N.R.	DY	C	R08	N.R.	IP	C	I04	N.R.	KF	C	I04	N.R.
4M	C	I04	N.R.	SI	C	R08	N.R.	CZM	C	R08	N.R.	YN	C	R08	N.R.
ATE	C	R08	N.R.	CZK	C	R08	N.R.	000	C	R08	N.R.	00P	C	R08	N.R.
DTK	C	R08	N.R.	DUM	C	R08	N.R.	REF	C	R08	N.R.	119	C	I04	N.R.
170	C	I04	N.R.	ONE	C	R08	N.R.	TM1	C	R08	N.R.	RSQ	C	R08	N.R.
TAM	C	R08	N.R.	TEM	C	R08	N.R.	TM8	C	R08	N.R.	TM4	C	R08	N.R.
TMS	C	R08	N.R.	TRM	C	R08	N.R.	COMD	C	R08	N.R.	TMO	C	R08	N.R.
CXRN	C	R08	N.R.	CVTM SF	XF	R08	000000	C400	C	R08	N.R.	COME	C	R08	N.R.
CVCG	C	R08	N.R.	OTOM	C	R08	N.R.	DTRA	C	R08	N.R.	DLAT	C	R08	N.R.
DLUN	C	R08	N.R.	DUM3	C	R08	N.R.	DUM4	C	R08	N.R.	DJMI	C	R08	N.R.
DUMP	C	R08	N.R.	EFRO	C	R08	N.R.	ELAT	C	R08	N.R.	DUM5	C	R08	N.R.
EDIT SF	XF	R04	000000	FFRU	C	R08	N.R.	FILE	C	R08	N.R.	ELON	C	R08	N.R.
ETIM	C	R08	N.R.	FOUR	C	R08	N.R.	GEUM	C	R08	N.R.	FLAT	C	R08	N.R.
FLJY	C	R08	N.R.	IDAY	C	I04	N.R.	IFM SF	C	I04	000000	HEAD	C	R08	N.R.
HUND	C	R08	N.R.	ITER SF	C	I04	000314	ITM.	C	I04	N.R.	IFOR	C	I04	N.R.
IONE	C	I04	N.R.	NDOP	C	I04	N.R.	NJLL	C	I04	N.R.	1305	C	I04	N.R.
NDAY	C	I04	N.R.	RATE	C	R08	N.R.	REFC	C	R08	N.R.	DFST	C	R08	N.R.
QNGE	C	R08	N.R.	SMXE	C	R08	N.R.	SJMD	C	R08	N.R.	SATC SF	XF	R04	000000
SELY	C	R08	N.R.	TEMP	C	R08	N.R.	THRE	C	R08	N.R.	SOME	C	R08	N.R.
S7P5	C	R08	N.R.	WAVE	C	R08	N.R.	XLNG	C	R08	N.R.	TOP1	C	R08	N.R.
TYPE SF	XF	R04	000000	ZERO	C	R08	N.R.	ZOSQ	C	R08	N.R.	XNDT	C	R08	N.R.
XOSQ	C	R08	N.R.	IBCC# F	XF	R04	000000					INPUT SF	XF	I04	000000
SOLVE SF	XF	R04	000000												

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

NAME OF COMMON BLOCK *				* SIZE OF BLOCK 0003D: HEXADCEMAL BYTES							
VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R08	N.R.	XNDT	R08	N.R.	SOME	R08	N.R.	SOMD	R08	N.R.
E	R08	N.R.	AU	R08	N.R.	COME	R08	N.R.	COMD	R08	N.R.
CI	R08	N.R.	XLNG	R08	N.R.	DJMI	R08	N.R.	DJMI	R08	N.R.
SI	R08	N.R.	DFST	R08	N.R.	DUM3	R08	N.R.	DUM4	R08	N.R.
DUM5	R08	N.R.	DOP	R08	N.R.	DTK	R08	N.R.	DE	R08	N.R.
DA	R08	N.R.	DY	R08	N.R.	HEAD	R08	N.R.	ELAT	R08	N.R.
FLU4	R08	N.R.	GEUM	R08	N.R.	ETIM	R08	N.R.	RATE	R08	N.R.
IDAY	I04	N.R.	NDAY	I04	N.R.	SELY	R08	N.R.	DLAT	R08	N.R.
FLO4	R08	N.R.	SMXE	R08	N.R.	RSQ	R08	N.R.	FLAT	R08	N.R.
FLO4	R08	N.R.	FFRU	R08	N.R.	K	R08	N.R.	V4	R08	N.R.
I	I04	N.R.	J	I04	N.R.	XNDT	I04	N.R.	L	I04	N.R.
W	I04	N.R.	H	I04	N.R.	A	R08	N.R.	ITER	I04	000314
T	R08	N.R.	TEMP	R08	N.R.				DUM	R08	N.R.

NAME OF COMMON BLOCK * COMC*				SIZE OF BLOCK 003126 HEXADCEMAL BYTES							
VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NJLL	I04	N.R.	IONE	I04	N.R.	ITND	I04	N.R.	IFOR	I04	N.R.
115	I04	N.R.	13D	I04	N.R.	1305	I04	N.R.	IM	I04	N.R.
K4	I04	N.R.	KF	I04	N.R.	TAM	R08	N.R.	WAVE	R08	N.R.
CVCG	R08	N.R.	EFRO	R08	N.R.	DNGE	R08	N.R.	XOSQ	R08	N.R.
ZOSQ	R08	N.R.	ZERO	R08	N.R.	ONE	R08	N.R.	TMO	R08	N.R.
THRE	R08	N.R.	FOUR	R08	N.R.	FIVE	R08	N.R.	ATE	R08	N.R.
TEM	R08	N.R.	D60	R08	N.R.	HUND	R08	N.R.	C400	R08	N.R.
S7P5	R08	N.R.	TOP1	R08	N.R.	DTRA	R08	N.R.	DTOR	R08	N.R.
TM1	R08	N.R.	TR4	R08	N.R.	TMS	R08	N.R.	TM7	R08	N.R.
TM8	R08	N.R.	CRTR	R08	N.R.	CXRN	R08	N.R.	TM7	R08	N.R.
CZM	R08	N.R.	REFC	R08	N.R.				CZK	R08	N.R.

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

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=99,SIZE=0000K,
SOURCE,ERCDIC,MULIST,NJDECK,LUAJ,MAP,NUEEDIT,IO,NJXREF

```

ISN 0002      BLOCK DATA                                BKDATA
ISN 0003      DOUBLE PRECISION TAM,WAVE,CVCG,EFRQ,UMGE,XOSC,ZOSQ    BKDATA
ISN 0004      DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,MUND C480,STPS  BKDATA
ISN 0005      DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CNTR,CKRM  BKDATA
ISN 0006      DOUBLE PRECISION ZERO,FOUR,TH7,C2K,C2M,REFC           BKDATA
C
C---COMMON
ISN 0007      COMMON /COMC/MULL,IDVE,ITWD,IFOR,115,130,1365,TK,KM,KF    BKDATA
ISN 0008      COMMON /COMC/TAM,WAVE,CVCG,EFRQ,UMGE,XOSC,ZOSQ,ZERO      BKDATA
ISN 0009      COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,MUND     BKDATA
ISN 0010      COMMON /COMC/C480,STPS,TOPI,DTRA,DTOM                      BKDATA
ISN 0011      COMMON /COMC/TM1,TM4,TM5,TH7,TM8,CNTR,CKRM,C2K,C2M,REFC  BKDATA
C
ISN 0012      DATA NULL ,IDNE ,ITWD ,IFOR ,115 ,130 ,1365 /          BKDATA
ISN 0013      DATA IM ,KM ,KF /                                        BKDATA
ISN 0014      DATA TAM ,WAVE ,CVCG /                                BKDATA
ISN 0015      DATA EFRQ ,UMGE /                                     BKDATA
ISN 0016      DATA XOSC ,ZOSQ /                                    BKDATA
ISN 0017      DATA ZERO ,ONE ,TWO ,THRE ,FOUR /                  BKDATA
ISN 0018      DATA FIVE ,ATE ,TEN ,D60 /                         BKDATA
ISN 0019      DATA MUND ,C480 ,STPS /                             BKDATA
ISN 0020      DATA TOPI ,DTOM /                                   BKDATA
ISN 0021      DATA DTOM ,TM1 ,TM4 ,TM5 /                          BKDATA
ISN 0022      DATA TM7 ,TM8 ,CNTR /                               BKDATA
ISN 0023      DATA CKRM ,C2K ,C2M /                               BKDATA
ISN 0024      DATA REFC ,FOUR /                                   BKDATA
C---MORE CONSTANTS
C 115=15
C 130=30
C 1365=365
C ZERO=0.D+0
C TWO=2.D+0
C THRE=3.D+0
C FOUR=4.D+0
C FIVE=5.D+0
C TEN=1.D+1
C ATE=8.D+0
C D60=6.D+1
C MUND=1.D+2
C C480=4.60+2
C STPS=-13953D+0
C
C TOPI=6.2831853072D+0      BKDATA
C DTRA=1.7453292519943D-2  BKDATA
C DTOM=1.44D+3             BKDATA
C TK1=1.D-1               BKDATA
C TM4=1.D-4               BKDATA
C TM5=1.D-5               BKDATA
C TH7=1.D-7               BKDATA
C TM8=1.D-8               BKDATA
C CNTR=2.90888208D-4      BKDATA
C =PI/180*60 MINUTES TO RADIAN  BKDATA
C CKRM=9.6788536D-7       BKDATA
C =2/60*10*3443.934 KNOTS TO RAD/2MIN BKDATA
ISN 0025      END

```


NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
IM	C	I04	N.R.	KF	C	I04	N.R.	KM	C	I04	N.R.	ATE	C	R08	N.R.
C2K	C	R08	N.R.	C2M	C	R08	N.R.	D60	C	R08	N.R.	I15	C	I04	N.R.
I30	C	I04	N.R.	ONE	C	R08	N.R.	TAM	C	R08	N.R.	TEN	C	R08	N.R.
TM1	C	R08	N.R.	TM4	C	R08	N.R.	T45	C	R08	N.R.	TM7	C	R08	N.R.
TM8	C	R08	N.R.	TW0	C	R08	N.R.	CKRM	C	R08	N.R.	CMFR	C	R08	N.R.
CVCG	C	R08	N.R.	C480	C	R08	N.R.	DTOM	C	R08	N.R.	DTRA	C	R08	N.R.
EFRQ	C	R08	N.R.	FIVE	C	R08	N.R.	FOUR	C	R08	N.R.	MUND	C	R08	N.R.
IFOR	C	I04	N.R.	IUNE	C	I04	N.R.	ITW0	C	I04	N.R.	I305	C	I04	N.R.
NULL	C	I04	N.R.	UMGE	C	R08	N.R.	REFC	C	R08	N.R.	STP5	C	R08	N.R.
TMPE	C	R08	N.R.	TOPI	C	R08	N.R.	WAVE	C	R08	N.R.	XOSU	C	R08	N.R.
ZERO	C	R08	N.R.	ZOSU	C	R08	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	I04	N.R.	I04E	I04	N.R.	ITW0	I04	N.R.	IFOR	I04	N.R.
I15	I04	N.R.	I30	I04	N.R.	I305	I04	N.R.	IM	I04	N.R.
KM	I04	N.R.	KF	I04	N.R.	TAM	R08	N.R.	WAVE	R08	N.R.
CVCG	R08	N.R.	EFRQ	R08	N.R.	OMGE	R08	N.R.	XOSU	R08	N.R.
ZOSU	R08	N.R.	ZERO	R08	N.R.	ONE	R08	N.R.	TM0	R08	N.R.
THRE	R08	N.R.	FOUR	R08	N.R.	FIVE	R08	N.R.	ATE	R08	N.R.
TEN	R08	N.R.	D60	R08	N.R.	HUND	R08	N.R.	C480	R08	N.R.
STP5	R08	N.R.	TOPI	R08	N.R.	DTRA	R08	N.R.	DTOM	R08	N.R.
TM1	R08	N.R.	TM4	R08	N.R.	T45	R08	N.R.	TM7	R08	N.R.
TM8	R08	N.R.	CMFR	R08	N.R.	CKRM	R08	N.R.	C2K	R08	N.R.
C2M	R08	N.R.	REFC	R08	N.R.						

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

OPTIONS IN EFFECT SOURCE=,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,IO,NOXREF

STATISTICS SOURCE STATEMENTS = 24 ,PROGRAM SIZE = 8

STATISTICS NO DIAGNOSTICS GENERATED

***** END OF COMPILATION *****

61K BYTES OF CORE NOT USED

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=56,SIZE=J000,
SOURCE=FBCDIC,NOLIST,VJDLCK,LOAD,MAP,NOEDIT,ID,NOXREF

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15X 0002      SUBROUTINE INPUT                                INPUT
C
C
15X 0003      DOUBLE PRECISION TA,NAVE,CVC,EFK,DPGE,X7SQ,Z0SQ    INPUT
15X 0004      DOUBLE PRECISION LNE,TNG,THPE,FIVE,ATE,TEN,060,HUND,C480,STPS  INPUT
15X 0005      DOUBLE PRECISION TUPT,DTRA,DTJ4,TH4,TH5,TH6,CNTR,TRPM    INPUT
15X 0006      DOUBLE PRECISION ZERO,FOUR,TH7,C2K,C2M,REFC    INPUT
15X 0007      DOUBLE PRECISION DDP,REF,JE,DA,UN,ELAT,ELON,GEOM,ETIM,H,AD,RATE  INPUT
15X 0008      DOUBLE PRECISION DTK,TP,XNDT,SOME,SUM,JE,AD,COME,COMD,C1,XLW  INPUT
15X 0009      DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5    INPUT
15X 0010      DOUBLE PRECISION DLAT,DLUN,SMXE,SELV,FLAT,FLUN,FFRQ,RSQ,VN    INPUT
15X 0011      DOUBLE PRECISION T,TEMP,A                                INPUT
15X 0012      DOUBLE PRECISION DUM9                                INPUT
C
C---DIMENSIONS
15X 0013      DIMENSION DOP(8),REF(8),DE(9),DA(9),JN(11),DLAT(9),DLUN(9)  INPUT
15X 0014      DIMENSION A(3,4)                                       INPUT
15X 0015      DIMENSION DUM9(17)                                       INPUT
C
C---COMMON
15X 0016      COMMON TP,XNDT,SOME,SOMD,E,AD,COME,COMD,C1,XLW    INPUT
15X 0017      COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DOP    INPUT
15X 0018      COMMON REF                                           INPUT
15X 0019      COMMON DE,DA,UN,DTK,ELAT,ELON,GEOM,HEAD,RATE,IDAY,NDAY,ETIM  INPUT
15X 0020      COMMON DLAT,DLUN,SMXE,SELV,FLAT,FLUN,FFRQ,RSQ,VN    INPUT
15X 0021      COMMON I,J,K,L,M,N,A,XL,JP,ITER                      INPUT
15X 0022      COMMON T,TEMP,A                                       INPUT
15X 0023      COMMON /COMC/NULL,IONE,AD,IFDR,125,130,1365,14,XM,KF    INPUT
15X 0024      COMMON /COMC/TA,NAVE,CVC,EFK,DPGE,X7SQ,Z0SQ,ZERO    INPUT
15X 0025      COMMON /COMC/TNG,THPE,FOUR,FIVE,ATE,TEN,060,HUND    INPUT
15X 0026      COMMON /COMC/C480,STPS,TUPT,DTRA,DTJ4            INPUT
15X 0027      COMMON /COMC/TH4,TH5,TH7,TH8,CNTR,C2K,C2M,REFC    INPUT
C
C
15X 0029      EQUIVALENCE (TP,DUM9(1))                                INPUT
C
15X 0030      12 FORMAT(A4,2(I3),I4)                                    INPUT
15X 0031      11 FORMAT(5A8)                                          INPUT
15X 0032      READ(5,12) ISTA,ISAT,IDAY,ITIM                          INPUT
15X 0033      IF(ISTAT) 30,31,31                                       INPUT
15X 0034      30 WRITE(8,12) ISTA,ISAT,IDAY,ITIM                      INPUT
15X 0035      REWIND 8                                                 INPUT
15X 0036      CALL EXIT                                               INPUT
15X 0037      31 READ(5,11) DUM1,DUM2,DUM3,DUM4,DUM5                  INPUT
15X 0038      WRITE(8,12) ISTA,ISAT,IDAY,ITIM                          INPUT
15X 0039      WRITE(8,11) DUM1,DUM2,DUM3,DUM4,DUM5                    INPUT
15X 0040      READ(5,10) TP,XNDT,SOME,SOMD,E,AD,COME,COMD            INPUT
15X 0041      1  ,C1,XLW,DUM1,DUM2,SI,OFST,DUM3,DUM4                INPUT
15X 0042      2  ,DUM5,(DE(K),K=1,9),(DA(K),K=1,9),                INPUT
15X 0043      3  (JN(K),K=1,11),DTK,GEOM,ELAT,ELON,                INPUT
15X 0044      4  HEAD,RATE,(DOP(K),K=1,8),(REF(K),K=1,8),          INPUT
15X 0045      5  ETIM                                                INPUT
15X 0046      10 FORMAT (1A,09,0)                                     INPUT
C
15X 0047      DUM1=ELAT*TH4                                           INPUT
15X 0048      I=DUM1/060                                              INPUT
15X 0049      DUM1=DABS(DUM1-(DBLE(FLOAT(I))*060))                    INPUT
15X 0050      WRITE(8,13) I,DUM1                                       INPUT
15X 0051      13 FORMAT(I4,F4.4)                                       INPUT
15X 0052      DUM1=ELON*TH4                                           INPUT
15X 0053      I=DUM1/060                                              INPUT
15X 0054      DUM1=DABS(DUM1-(DBLE(FLOAT(I))*060))                    INPUT
15X 0055      WRITE(8,13) I,DUM1                                       INPUT
15X 0056      14 FORMAT(F9.0)                                          INPUT
15X 0057      15 FORMAT(F10.0,F5.0,F5.0,F3.0,F9.0,F6.0)              INPUT
15X 0058      16 FORMAT(F10.0,F5.0,F5.0,F3.0)                          INPUT
15X 0059      17 FORMAT(F3.0)                                          INPUT
15X 0060      222 FORMAT(F10.0,F9.0,F6.0)                               INPUT
15X 0061      DO 26 K=1,12                                             INPUT
15X 0062      IF(K-1) 21,21,18                                         INPUT
15X 0063      18 IF(K-8) 22,22,19                                       INPUT
15X 0064      19 IF(K-10) 23,23,20                                       INPUT
15X 0065      20 IF(K-11) 24,24,25                                       INPUT
15X 0066      21 WRITE(8,222) DUM9(K),DOP(K),REF(K)                   INPUT
15X 0067      GO TO 26                                                 INPUT
15X 0068      22 I=K-1                                                INPUT
15X 0069      WRITE(8,114) DUM9(K),DE(I),DA(I),JN(I),DOP(K),REF(K)  INPUT
15X 0070      GO TO 26                                                 INPUT
15X 0071      23 I=K-1                                                INPUT
15X 0072      WRITE(8,15) DUM9(K),DE(I),DA(I),DN(I)                  INPUT
15X 0073      GO TO 26                                                 INPUT
15X 0074      24 I=K-1                                                INPUT
15X 0075      WRITE(8,16) SI,DN(I)                                       INPUT
15X 0076      GO TO 26                                                 INPUT
15X 0077      25 I=K-1                                                INPUT
15X 0078      WRITE(8,17) DN(I)                                       INPUT
15X 0079      26 CONTINUE                                             INPUT
15X 0080      I=HEAD/060                                              INPUT
15X 0081      WRITE(8,27) I,RATE                                       INPUT
15X 0082      27 FORMAT(I4,F5.1)                                       INPUT
15X 0083      RETURN                                                INPUT
15X 0084      END                                                    INPUT

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/ INPUT / SIZE OF PROGRAM 000730 HEXADECIMAL BYTES PAGE 003

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	C	R06	N.R.	E S	C	R08	000020	I SFA	C	I04	0002F8	J	C	I04	N.R.

K SF	C	I04	000300	L	C	I04	N.R.	M	C	I04	N.R.	N	C	I04	N.R.	
T	C	R08	N.R.	AD S	C	R08	000028	CI S	C	R08	000040	DA SF	C	R08	000151	
DE SF	C	R08	000108	DN SF	C	R08	000198	IM	C	I04	N.R.	KF	C	I04	N.R.	
KM	C	I04	N.R.	SI SF	C	R08	000060	IP S	CE	R08	000000	VN	C	R08	N.R.	
ATE	C	R08	N.R.	C2K	C	R08	N.R.	C2M	C	R08	N.R.	DUP SF	C	R08	000088	
DTR S	C	R08	0001F0	U60 FA	C	R08	0000A0	I15	C	I04	N.R.	I30	C	I04	N.R.	
ONE	C	R08	N.R.	REF SF	C	R08	0000C8	H50	C	R08	N.R.	T7n	C	R08	N.R.	
TEN	C	R08	N.R.	TM1	C	R08	N.R.	TM4 F	C	R08	0000E0	TNS	C	R08	N.R.	
TM7	C	R08	N.R.	TK8	C	R08	N.R.	TMD	C	R08	N.R.	CKRM	C	R08	N.R.	
CMTR	C	R08	N.R.	CUMD S	C	R08	000038	CUME S	C	R08	000030	CVCG	C	R08	N.R.	
C480	C	R08	N.R.	DLAT	C	R08	N.R.	DLUN	C	R08	N.R.	DTM	C	R08	N.R.	
DTRA	C	R08	N.R.	DUM1 SFA	C	R08	000050	DUM2 SF	C	R08	00005E	DUM3 SF	C	R08	000070	
DUM4 SF	C	R08	000078	DUM5 SF	C	R08	000080	DUM9 F	CE	R08	000090	EFM3	C	R08	N.R.	
ELAT SF	C	R08	0001F8	ELGN SF	C	R08	000200	ETIM S	C	R08	000228	EXIT SF	AF	I04	N.R.	
FFRQ	C	R08	N.R.	FIVE	C	R08	N.R.	FLAT	C	R08	N.R.	FLUN	C	R08	N.R.	
FOUR	C	R08	N.R.	GEOM SF	C	R08	000208	H-AD SF	C	R08	000210	M40	C	R08	N.R.	
IDAY SF	C	I04	000220	IFDR	C	I04	N.R.	IGNE	C	I04	N.R.	ISAT SF	C	I04	N.R.	
I365	C	I04	N.R.	ITER	C	I04	N.R.	ITIM SF	C	I04	000124	ITAU	C	I04	N.R.	
OPST S	C	R08	000088	MDAY	C	I04	N.R.	MDUP	C	I04	N.R.	MULL	C	I04	N.R.	
SELV	C	R08	N.R.	SMXE	C	R08	N.R.	RATE SF	C	R08	000218	RIFC	C	R08	N.R.	
STP5	C	R08	N.R.	TEMP	C	R08	N.R.	SMUD S	C	R08	000018	S7FE S	C	R08	N.R.	
WAVE	C	R08	N.R.	XLMG S	C	R08	000048	THRE	C	R08	N.R.	TUPI	C	R08	N.R.	
ZERO	C	R08	N.R.	ZUSQ	C	R08	N.R.	XSDT S	C	R08	000008	UN	C	R08	N.R.	
								INPUT	C	I04	000118	ULCUM	F	AF	I04	000100

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

NAME OF COMMON BLOCK *				* SIZE OF BLOCK 000388 HEXADECIMAL BYTES											
VARIABLE	TYPE	REL. ADDR.		VARIABLE	TYPE	REL. ADDR.		VARIABLE	TYPE	REL. ADDR.		VARIABLE	TYPE	REL. ADDR.	
P	R08	000000		XNDT	R08	000008		SOME	R08	000010		SLMU	R08	000118	
E	R08	000020		AU	R08	000028		CUME	R08	000030		CGM	R08	000038	
C7	R08	000040		XLMG	R08	000048		DUM1	R08	000050		BMP2	R08	000058	
SI	R08	000060		GFST	R08	000068		DUM3	R08	000070		JUM4	R08	000078	
DUM5	R08	000080		GDP	R08	000088		REF	R08	0000C8		LE	R08	000118	
DA	R08	000150		DV	R08	000198		DTK	R08	0001F0		ELAT	R08	0001F8	
ELON	R08	000200		GECH	R08	000208		HEAD	R08	000210		RATE	R08	000218	
IDAY	I04	000220		MDAY	I04	N.R.		ETIM	R08	000228		DLAT	R08	N.R.	
DLUN	R08	N.R.		SMXE	R08	N.R.		SELV	R08	N.R.		FLAT	R08	N.R.	
FLON	R08	N.R.		FFRQ	R08	N.R.		R3Q	R08	N.R.		VN	R08	N.R.	
I	I04	0002F8		J	I04	N.R.		Y	I04	00030C		L	I04	N.R.	
M	I04	N.R.		N	I04	N.R.		'DDP	I04	N.R.		ITER	I04	N.R.	
T	R08	N.R.		TEMP	R08	N.R.		A	R08	N.R.					

EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK
 VARIABLE OFFSET VARIABLE OFFSET

VARIABLE OFFSET

VARIABLE OFFSET

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

PAGE 004

VARIABLE	TYPE	REL. ADDR.	VARIABLE	TYPE	REL. ADDR.	VARIABLE	TYPE	REL. ADDR.	VARIABLE	TYPE	REL. ADDR.
NULL	I04	N.R.	IONE	I04	N.R.	ITW0	I04	N.R.	IFR	I04	N.R.
I15	I04	N.R.	I30	I04	N.R.	I365	I04	N.R.	IM	I04	N.R.
KM	I04	N.R.	KF	I04	N.R.	TAW	R08	N.R.	WAVE	R08	N.R.
CVCG	R08	N.R.	EFRQ	R08	N.R.	CMGE	R08	N.R.	XSDT	R08	N.R.
ZOSQ	R08	N.R.	ZERO	R08	N.R.	UNE	R08	N.R.	TMD	R08	N.R.
THRE	R08	N.R.	FOUR	R08	N.R.	FIVE	R08	N.R.	ATE	R08	N.R.
TEN	R08	N.R.	D60	R08	0000A0	HUND	R08	N.R.	C480	R08	N.R.
STP5	R08	N.R.	'PI	R08	N.R.	DTRA	R08	N.R.	DTM	R08	N.R.
TM1	R08	N.R.	TK8	R08	0000E0	TMS	R08	N.R.	TM7	R08	N.R.
TM4	R08	N.R.	C	R08	N.R.	CKRM	R08	N.R.	C2K	R08	N.R.
C2M	R08	N.R.	RLIC	R08	N.R.						

LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	PAGE
10	00019E	11	0001EA	16	00055A	19	000562	005
20	00056A	21	000578	22	000540	23	000606	
24	00064A	25	00067A	26	00069E			

OPTIONS IN EFFECT NAME= MAIN,OPT=32,LINECNT=58,SIZE=0000K,

OPTIONS IN EFFECT SOURCE,F9C,IC,NULIST,NODECK,LUAD,MAP,NOEDIT,IO,NXREF

STATISTICS SOURCE STATEMENTS = 79 ,PROGRAM SIZE = 184P

STATISTICS NO DIAGNOSTICS GENERATED

***** END OF COMPILATION *****

49K BYTES OF CORE NOT USED

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=50,SIZE=00907,
SOURCE,EBCDIC,NOLIST,MODECK,LOAD,MAP,NOEDIT,IO,N,XREF

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ISN 0002 SUBROUTINE CVTM 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 TAM, WAVE, CVCG, EFRQ, OYGE, XOSQ, ZOSQ CVTM
ISN 0004 DOUBLE PRECISION ONE, TWO, THREE, FIVE, ATE, TEN, D60, HUND, C480, S7PS 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, KEF, DE, DA, DN, ELAT, ELON, GECH, STIM, HEAD, RATE CVTM
ISN 0008 DOUBLE PRECISION DTK, TP, XNDT, SOME, SUM, E, AD, COME, CMD, CI, XLNG CVTM
ISN 0009 DOUBLE PRECISION DUM1, DUM2, S1, OFST, DUM3, DUM4, DUM5 CVTM
ISN 0010 DOUBLE PRECISION DLAT, DLON, SHKE, SELV, FL, FLOW, FFRQ, RSQ, VN CVTM
ISN 0011 DOUBLE PRECISION TMS, 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(6), 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, AD, COME, CMD, CI, XLNG CVTM
ISN 0016 COMMON DUM1, DUM2, S1, OFST, DUM3, DUM4, DUM5, DOP CVTM
ISN 0017 COMMON REF CVTM
ISN 0018 COMMON DE, DA, DN, DTK, ELAT, ELON, GECH, HEAD, RATE, IDP, MOAY, STIM CVTM
ISN 0019 COMMON DLAT, DLON, SHKE, SELV, FLAT, FLOW, FFRQ, RSQ, VN CVTM
ISN 0020 COMMON I, J, K, L, M, N, MDOP, TP CVTM
ISN 0021 COMMON TI, P, CP, CPT, CHSD, CLSD, TEMP, TEMA CVTM
C CVTM
ISN 0022 COMMON /COMC/MULL, IONE, ITNU, IFOR, I15, I30, I365, IM, KM, KF CVTM
ISN 0023 COMMON /COMC/YAW, WAVE, CVCG, EFRQ, OYGE, XOSQ, ZOSQ, ZERO CVTM
ISN 0024 COMMON /COMC/ONE, TWO, THREE, FOUR, FIVE, I7E, TEN, D60, HUND CVTM
ISN 0025 COMMON /COMC/C480, S7PS, TOPI, DTRA, DTOM CVTM
ISN 0026 COMMON /COMC/TM1, TM4, TM5, TM7, TM8, CMTR, CKRM, C2K, C2M, REFC CVTM
C CVTM
C CONVERT CONSTANT ORBIT PARAMET. CVTM
C CVTM
ISN 0027 TP=TP*THS CVTM
ISN 0028 XNDT=(XNDT+.3D+9)*DTRA*TH8 CVTM
ISN 0029 SOME=SOME*DTRA*TH5 CVTM
ISN 0030 SOMD=SOMD*DTRA*TH8 CVTM
ISN 0031 E=E*TH7 CVTM
C CVTM
ISN 0032 AD IS IN METERS CVTM
ISN 0033 COME=COME*DTRA*TH5 CVTM
ISN 0034 COND=COND*DTRA*TH8 CVTM
ISN 0035 CI=CI*TH7 CVTM
ISN 0036 XLNG=XLNG*DTRA*TH5 CVTM
SI=SI*TH7 CVTM
C CVTM

```

```

C---CHECK AND REFRACTON CORRECT THE DOPPLERS
C----- J DOPPLER, NOT USED IN SOLUTION
C
ISN 0037      AODP=AOULL
ISN 0038      DO 30 I=1,1M
ISN 0039      IF (DCP(11)-C2M) 29,29,21
ISN 0040      21 IF (REF(11)-C2K) 22,29,22
ISN 0041      22 (LPI1)=DCP(11)+(C2K-REF(11))*REFC
ISN 0042      AODP=AODP+IONE
ISN 0043      GO TO 30
ISN 0044      29 DCP(11)=ZERO
ISN 0045      30 CONTINUE

C
C---CONVERT HEADING AND SPEED
C
ISN 0046      HEAD=HEAD*CMTR
ISN 0047      RATC=RATE*CKRM

C
C CONVERT DE(K),DA(K) AND COMPUTE INCREMENTAL LAT AND LON
C
ISN 0048      DO 1 K=1,KM
ISN 0049      DE(K)=DE(K)+DTRA*TH4
ISN 0050      DA(K)=DA(K)+TEN
ISN 0051      TEMP=K-KF
ISN 0052      TEMP=TEMP*RATC
ISN 0053      DLON(K)=TEMP*DSIN(HEAD)
ISN 0054      1 DLAT(K)=TEMP*DCOS(HEAD)
C---CONVERT AND SET INITIAL ESTIMATES
ISN 0055      EFRQ=(OFST* 471)*2.4D+6
ISN 0056      FFRQ=EFRQ
ISN 0057      ELAT=ELAT*CMTR*TH4
ISN 0058      FLAT=ELAT
ISN 0059      ELON=ELON*CMTR*TH4
ISN 0060      FLON=ELON
C---RESOLVE TRUE LOCK TIME
ISN 0061      IP=ITMD/ITMO
ISN 0062      IP=ITMD*IP
ISN 0063      I=IP/130
ISN 0064      I=IP-130*I
ISN 0065      K=TMD*DTK
ISN 0066      K=K-I
ISN 0067      I=K/115
ISN 0068      K=IP*K-130*I
ISN 0069      STIM=K
C---CONVERT CROSS PLANE ELEMENTS
ISN 0070      I=K/IFDP
ISN 0071      K=K-IFDP*I
ISN 0072      IP=NULL
ISN 0073      L=ITMD
ISN 0074      IF (K) 2,3,2
ISN 0075      2 L=IONE
ISN 0076      3 DO 10 I=1,5
ISN 0077      CPI(I)=ZERO
ISN 0078      CLSD=DM(IONE+L)
ISN 0079      CMSD=DM(L)
ISN 0080      IF (CMSD) 11,11,11

11 IF (CLSD) 9,4,4
ISN 0081      4 CMSD=CMSD-FIVE
ISN 0082      IF (CMSD) 5,8,8
ISN 0083      5 CLSD=CLSD
ISN 0084      IF (CMSD+FIVE) 8,6,8
ISN 0085      6 CMSD=ZERO
ISN 0086      8 IP=IP+IONE
ISN 0087      CPI(IP)=MIND*CMSD+TEN*CLSD
ISN 0088      CPT(IP)=L
ISN 0089      9 L=L+ITMD
ISN 0090      10 CONTINUE
C---INTERPOLATE FOR MISSING CROSS PLANE ELEMENTS
ISN 0092      TI=TMG
ISN 0093      DO 20 K=1,KM
ISN 0094      DN(K)=ZERO
ISN 0095      IF (IP-ITMD) 20,20,31
ISN 0096      31 ITA=IONE
ISN 0097      I=CPT(I)
ISN 0098      J=CPT(J)
ISN 0099      J=J-IFDP
ISN 0100      IF (K-I) 16,16,12
ISN 0101      12 ITA=IP-ITMD
ISN 0102      IF (K-J) 13,16,16
ISN 0103      13 ITA=K/ITMD
ISN 0104      16 DO 19 L=1,3
ISN 0105      J=L*ITA-IONE
ISN 0106      P=ONE
ISN 0107      DO 18 M=1,3
ISN 0108      I=M+ITA-IONE
ISN 0109      IF (I-J) 17,18,17
ISN 0110      17 P=P*(I-CPT(I))/(CPT(J)-CPT(I))
ISN 0111      18 CONTINUE
ISN 0112      DN(K)=DN(K)+P*CPT(J)
ISN 0113      19 TI=TI+ONE
ISN 0114      RETURN
ISN 0115      END

```

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
E SF	C	R#0	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	A SF	C	I#4	000308	N	C	I#4	N.R.	P SF	C	R#0	000320
AO	C	R#0	N.R.	CI SF	C	R#0	000040	CP SF	C	R#0	000328	DA SF	C	R#0	000150
DE SF	C	R#0	000038	DN SF	C	R#0	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#0	000060	TI SF	C	R#0	000318
TP SF	C	R#0	000000	VN	C	R#0	N.R.	ATE	C	R#0	N.R.	TI SF	C	R#0	000350
C2K F	C	R#0	000110	G2M	C	R#0	000118	DDP SF	C	R#0	000088	OPT F	C	R#0	000150
D60	C	R#0	N.R.	ITA SF	C	I#4	0000AC	I15 F	C	I#4	000010	I30 F	C	I#4	000014
DNE F	C	R#0	000068	REF F	C	R#0	0000C8	RSQ	C	R#0	N.R.	TAM	C	R#0	N.R.
TEN F	C	R#0	000098	YMI	C	R#0	N.R.	TM4 F	C	R#0	0000E0	TM5 F	C	R#0	0000E8
TN7 F	C	R#0	0000F0	TM9 F	C	R#0	0000F8	TW0 F	C	R#0	000070	CKRM F	C	R#0	000108
CLSD SF	C	R#0	000380	CMSD SF	C	R#0	000378	CMTR F	C	R#0	000100	CMND SF	C	R#0	000038
COMF SF	C	R#0	000030	CVCG	C	R#0	N.R.	RATE	C	R#0	000080	C480	C	R#0	N.R.
DLAT S	C	R#0	000230	DLON S	C	R#0	000278	DTJM	C	R#0	N.R.	DTRA F	C	R#0	0000C8
DUMI	C	R#0	N.R.	DJM2	C	R#0	N.R.	DUM3	C	R#0	N.R.	DJW4	C	R#0	N.R.
DUM5	C	R#0	N.R.	EFRQ SF	C	R#0	000040	ELAT SF	C	R#0	0001F8	ELON SF	C	R#0	000200
FFRQ S	C	R#0	0002E0	FIVE F	C	R#0	000088	FLAT S	C	R#0	0002D0	FLDN S	C	R#0	000208
FOUR	C	R#0	N.R.	GEOM	C	R#0	N.R.	HEAD SFA	C	R#0	000210	HIND F	C	R#0	0000A8
IDAY	C	I#4	N.R.	IFOR F	C	I#4	00000C	IONE F	C	I#4	000004	ITD F	C	I#4	000008
I365	C	I#4	N.R.	MDAY	C	I#4	N.R.	NDOP SF	C	I#4	000310	NULL F	C	I#4	000000
OFST F	C	R#0	000068	OMGE	C	R#0	N.R.	RATE SF	C	R#0	000218	REFC F	C	R#0	000120
SELV	C	R#0	N.R.	SMXE	C	R#0	N.R.	SOMD SF	C	R#0	000018	SOME SF	C	R#0	000010
STIM SF	C	R#0	000228	STP5	C	R#0	N.R.	TEMA	C	R#0	N.R.	TEMP SF	C	R#0	000388
THRE	C	R#0	N.R.	TOP1	C	R#0	N.R.	WAVE	C	R#0	N.R.	XLMP SF	C	R#0	000048
XNDT SF	C	R#0	000008	XDSG	C	R#0	N.R.	ZERO F	C	R#0	000060	ZOSG	C	R#0	N.R.
DCOS	XF	R#0	000000	DSIN	XF	R#0	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#0	000000	XNDT	R#0	000008	SOME	R#0	000010	SOMD	R#0	000018
E	R#0	000020	AO	R#0	N.R.	COMF	R#0	000030	CMND	R#0	000038
CI	R#0	000040	XLMP	R#0	000048	DUM1	R#0	N.R.	DJM2	R#0	N.R.
SI	R#0	000060	OFST	R#0	000068	DJM3	R#0	N.R.	DUM4	R#0	N.R.
DUM5	R#0	N.R.	DDP	R#0	000088	REF	R#0	0000C8	DE	R#0	000108
DA	R#0	000150	DN	R#0	000198	DTK	R#0	0001F8	ELAT	R#0	0001F8
ELON	R#0	000200	GEOM	R#0	N.R.	HEAD	R#0	000210	RATE	R#0	000218
IDAY	I#4	N.R.	MDAY	I#4	N.R.	STIM	R#0	000228	DLAT	R#0	000230
DLON	R#0	000278	SMXE	R#0	N.R.	SELV	R#0	N.R.	FLAT	R#0	0002D0
FLON	R#0	0002E0	FFRQ	R#0	0002E0	RSQ	R#0	N.R.	V4	R#0	N.R.
I	I#4	0002F8	J	I#4	0002FC	X	I#4	000300	L	I#4	000304
M	I#4	000304	N	I#4	N.R.	NDOP	I#4	000310	IP	I#4	000314
TI	R#0	000318	P	R#0	000320	CP	R#0	000328	CPT	R#0	000350
CMSD	R#0	000378	CLSD	R#0	000380	TEMP	R#0	000388	TEMA	R#0	N.R.

NAME OF COMMON BLOCK * * 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	ITW0	I#4	000008	IFCR	I#4	00000C
I15	I#4	000010	I30	I#4	000014				IM	I#4	00001C

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KM	I#4	000020	KF	I#4	000024	TAM	R#0	N.R.	WAVE	R#0	N.R.
CVCG	R#0	N.R.	EFRQ	R#0	000040	OMGE	R#0	N.R.	XOSC	R#0	N.R.
ZOSG	R#0	N.R.	ZERO	R#0	000060	FIVE	R#0	000068	TW0	R#0	000070
THRE	R#0	N.R.	FOUR	R#0	N.R.	HIND	R#0	0000A8	ATE	R#0	N.R.
TEN	R#0	000098	D60	R#0	N.R.	DTRA	R#0	0000C8	C480	R#0	N.R.
STP5	R#0	N.R.	TOP1	R#0	N.R.	TM5	R#0	0000E8	DTM	R#0	N.R.
YMI	R#0	N.R.	TM4	R#0	0000F8	CKRM	R#0	000108	TM7	R#0	0000F0
TM9	R#0	0000F8	CMTR	R#0	000100				C2K	R#0	000110
REFC	R#0	000120									

LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	PAGE	NO.
01	0001EC	22	0001FE	29	000214	30	00021C		
7	00020E	2	00040E	3	000412	11	000486		
4	000490	5	000498	6	0004AC	8	0004BD		
9	0004F2	10	0004FA	31	0005A6	12	0005BF		
13	0005D2	16	0005F2	17	00067E	18	00065A		
14	00066A	20	000696						

OPTIONS IN EFFECT NAME= MAIN,OPT=02,LINLEN=56,SIZE=0000K,

OPTIONS IN EFFECT SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,IO,NUNDEF

STATISTICS SOURCE STATEMENTS = 114 ,PROGRAM SIZE = 1778

STATISTICS A. DIAGNOSTICS GENERATED

***** END OF COMPILATION *****

49% BYTES OF CORE WERE USED

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=58,SIZE=0000K, SOURCE, EBCDIC, NOLIST, NODECK, LOAD=MAP, NOEDIT, ID, NOXREF

```
ISN 0002 SUBROUTINE SATC
C
C-USES XYZ TO COMPUTE SATELLITE COORDINATES
C DRIVER TO SET TIME AND VARIABLE PARAMETERS AND STORING PARAMETER K
C
ISN 0003 DOUBLE PRECISION TAM,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSO SATC
ISN 0004 DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D6C,MUND,C48D,S7P5 SATC
ISN 0005 DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TH4,TM5,TAB,CNTR,CKRM SATC
ISN 0006 DOUBLE PRECISION ZERO,FOUR,THY,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,AD,COME,CUMD,CI,XLMG SATC
ISN 0009 DOUBLE PRECISION DUM1,DUM2,S1,DFST,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 COMMON F TEMP SATC
C
C---DIMENSION
ISN 0013 DIMENSION DOP(8),DJM(5),DE(9),DA(9),DN(11),DLAT(9),DLON(9), SATC
C
C---COMMON
ISN 0014 COMMON TP,XNDT,SOME,SOMD,E,AD,COME,CUMD,CI,XLMG SATC
ISN 0015 COMMON DUM1,DUM2,S1,DFST,DUM3,DUM4,DUM5,DOP SATC
ISN 0016 COMMON DEK,DAK,DNK SATC
ISN 0017 COMMON DJM SATC
ISN 0018 COMMON DE,DA,DN,DTA,FLAT,ELON,GEOH,HEAD,RATE,ICAY,MDAY,STIM SATC
ISN 0019 COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN SATC
ISN 0020 COMMON I,J,K,L,M,N,P,Q,R,S,T SATC
ISN 0021 COMMON T,TEMP SATC
C
ISN 0022 COMMON /COM1/MUL,ICNE,IFW0,IFOR,I15,'30,I365,IN,RY,KF SATC
ISN 0023 COMMON /COM2/TAM,WAVE,CVCG,EFRQ,OMGE,XOSQ,ZOSO,ZEPO SATC
ISN 0024 COMMON /COM3/ONE,TWO,THRE,FIVE,ATE,TEN,D6C,MUND SATC
ISN 0025 COMMON /COM4/C48D,S7P5,TOPI,DTRA,DTOM SATC
ISN 0026 COMMON /COM5/TM1,TH4,TH5,TH6,CNTR,CKRM,C2K,C2M,REFC SATC
C
C---COMPUTE TIME SINCE PERIGEE
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) 3,3,3 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 XYZ SATC
ISN 0038 5 T=T+T0 SATC
ISN 0039 RETURN SATC
ISN 0040 END SATC
```

SIZE OF PROGRAM: 000164 HEXADECIMAL BYTES PAGE 002

Table with columns: NAME, TAG, TYPE, ADDR., NAME, TAG, TYPE, ADDR., NAME, TAG, TYPE, ADDR., NAME, TAG, TYPE, ADDR. It lists various variables and their attributes.

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

Table with columns: NAME OF COMMON BLOCK, SIZE OF BLOCK, DD-32M HEXADECIMAL BYTES. It provides details for common blocks like TP, E, CI, SI, JUM5, DNK, UN, GEOH, MDAY, SMXE, FFRQ, J, N, TEMP.

NAME OF COMMON BLOCK			NAME OF BLOCK			QUANTITY MANUFACTURED			TYPE		
VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
VJLL	I*	N.R.	IJNC	I*	N.R.	ITWD	I*	N.R.	IFOR	I*	N.R.
IIS	I*	N.R.	IJD	I*	N.R.	I365	I*	N.R.	IM	I*	N.R.
K4	I*	000C20	KF	I*	N.R.	TAM	R*	N.R.	WAVE	R*	N.R.

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CVGG	R*	N.R.	EFRJ	R*	N.R.	UMGE	R*	N.R.	XGSQ	R*	N.R.
LOSQ	R*	N.R.	LERD	R*	N.R.	ONE	R*	N.R.	TWD	R*	0J0070
THRE	R*	N.R.	FJUR	R*	N.R.	FIVE	R*	N.R.	ATE	R*	N.R.
TEN	R*	N.R.	D6D	R*	N.R.	HJND	R*	N.R.	C460	R*	0000E0
S7P5	R*	N.R.	TOPI	R*	0000C0	DTRA	R*	N.R.	DTGM	R*	0000D0
TMI	R*	N.R.	T4	R*	N.R.	TMS	R*	N.R.	TW7	R*	N.R.
T4B	R*	N.R.	CMTR	R*	N.R.	CKRM	R*	N.R.	C2K	R*	N.R.
C24	R*	N.R.	REFC	R*	N.R.						

LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	PAGE
1	0000C2	2	0000D2	3	0000EC	4	0000F0	004
5	00011E							

>OPTIONS IN EFFECT* NAME= MAIN,OPT=02,LINECNT=50,SIZE=0000K,
OPTIONS IN EFFECT SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,IO,NXREF

STATISTICS SOURCE STATEMENTS = 39 ,PROGRAM SIZE = 356

STATISTICS NO DIAGNOSTICS GENERATED

***** END OF COMPILATION *****

61K BYTES OF CORE NOT USED

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=58,SIZE=0000K,
SOURCE,EBCDIC,NOLIST,NOOCHK,LOAD,MAP,NOEDIT,IO,NOXREF
SUBROUTINE SKYZ

```

ISN 0002      C
              C COMPUTE SATELLITE COORDINATES FOR TIME T CORRESPONDING TO POINT K
              C
ISN 0003      DOUBLE PRECISION TAN,WAVE,CVCG,EFRQ,UMGE,XOSQ,ZOSQ
ISN 0004      DOUBLE PRECISION UME,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,STP5
ISN 0005      DOUBLE PRECISION TUPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CHTR,CKRM
ISN 0006      DOUBLE PRECISION ZERO,FOUR,THY,C2K,C2M,REFC
ISN 0007      DOUBLE PRECISION DOP,XS,YS,ZS,ELAT,ELON,GEOM,STIM,HEAD,RATE
ISN 0008      DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AD,COME,COMD,C1,ALMG
ISN 0009      DOUBLE PRECISION DJM1,DJM2,SI,DFST,DUM3,DUM4,DUM5
ISN 0010      DOUBLE PRECISION DUM,T,TEMP
ISN 0011      DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN
ISN 0012      DOUBLE PRECISION DEK,DAK,DNK
ISN 0013      DOUBLE PRECISION XMK,EK,AK,UK,VK,WK,CWK,SWK,SKP,YKP,BK,CEK,SBK
              C
ISN 0014      C---DIMENSION
              DIMENSION DOP(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9)
ISN 0015      DIMENSION DUM(4)
              C
ISN 0016      C---COMMON
              COMMON TP,XNDT,SOME,SOMD,E,AD,COME,COMD,C1,ALMG
ISN 0017      COMMON DJM1,DJM2,SI,DFST,DUM3,DUM4,DUM5,DOP
ISN 0018      COMMON DEK,DAK,DNK,XMK,DUM
ISN 0019      COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOM,HEAD,RATE,IDAY,MDAY,STIM
ISN 0020      COMMON DLAT,DLON,SMXF,SELV,FLAT,FLON,FFRQ,RSQ,VN
ISN 0021      COMMON I,J,K,L,M,N,ADOP,ITER
ISN 0022      COMMON T,TEMP,Ef,AK,UK,VK,WK,CWK,SWK,SKP,YKP,BK,CEK,SBK
              C
ISN 0023      COMMON /COMC/NULL,IONE,ITWO,IFOP,I15,I30,I365,IM,KM,KF
ISN 0024      COMMON /COMC/TAN,WAVE,CVCG,UME,UMGE,XOSQ,ZOSQ,ZERO
ISN 0025      COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND
ISN 0026      COMMON /COMC/C480,STP5,TUPI,DTRA,DTOM
ISN 0027      COMMON /COMC/TM1,TP4,TM5,TM7,TM8,CHTR,CKRM,C2K,C2M,REFC
              C
ISN 0028      XMK=T*XND1
ISN 0029      EK=E*DSIN(XMK)+XMK*DEK
ISN 0030      AK=AD*DEK
ISN 0031      VK=AI*DSIN(EK)
ISN 0032      UK=(SCOS(EK)-E)*AK
ISN 0033      WK=SOME-T*SCMD
ISN 0034      CWK=DCOS(WK)
ISN 0035      SWK=DSIN(WK)
ISN 0036      XKP=UR*CWK-VK*SWK
ISN 0037      YKP=VK*CWK+UK*SWK
ISN 0038      BK=(COMD-DMGE)*T+COME-
ISN 0039      CBK=DCOS(BK)
ISN 0040      SBK=DSIN(BK)
ISN 0041      TEMP=YKP*CI-DNK*SI
ISN 0042      XS(K)=XKP*CBK-TEMP*SBK
ISN 0043      YS(K)=XKP*SBK+TEMP*CBK
ISN 0044      ZS(K)=YKP*SI+DNK*CI
ISN 0045      RETURN
              SKYZ

```

ISN 0046 END SKYZ

/ SKYZ / SIZE OF PROGRAM 900204 HEXADECIMAL BYTES PAGE 013

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	<	F	C	I#4	000330						
L		C	I#4	N.R.	M	C	I#4	N.R.	N	C	I#4	T	F	C	R#8	000118						
AK	SFA	C	R#8	000330	AO	F	C	R#8	000028	BK	SFA	C	R#8	000370	CI	F	C	R#8	000140			
EK	SFA	C	R#8	000328	IM	C	I#4	N.R.	KF	C	I#4	KN	C	I#4	N.R.	KN	C	I#4	N.R.			
SI	F	C	R#8	000060	IP	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.	CAK	SF	C	R#8	000378	CAK	SF	C	R#8	000350				
CZK		C	R#8	N.R.	C2M	C	R#8	N.R.	DAK	F	C	R#8	000000	UEK	F	C	R#8	000008				
DNK	F	C	R#8	000008	DOP	C	R#8	N.R.	DTK	C	R#8	N.R.	DUM	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.	ONE	C	R#8	N.R.		
NSQ		C	R#8	N.R.	SBK	SF	C	R#8	000380	SMK	SF	C	R#8	000358	TAM	C	R#8	N.R.	TAM	C	R#8	N.R.
TEN		C	R#8	N.R.	YPI	C	R#8	N.R.	TN4	C	R#8	N.R.	TN5	C	R#8	N.R.	TN5	C	R#8	N.R.		
TM7		C	R#8	N.R.	YMB	C	R#8	N.R.	YND	C	R#8	N.R.	XKP	SF	C	R#8	000360	XKP	SF	C	R#8	000360
XMK	SFA	C	R#8	0000E0	YKP	SF	C	R#8	00036?	CAKM	C	R#8	N.R.	CMTR	C	R#8	N.R.	CMTR	C	R#8	N.R.	
COMD	F	C	R#8	000038	CUME	F	C	R#8	000030	CVCG	C	R#8	N.R.	C480	C	R#8	N.R.	C480	C	R#8	N.R.	
DLAT		C	R#8	N.R.	DLOM	C	R#8	N.R.	DTOM	C	R#8	N.R.	LTRA	C	R#8	N.R.	LTRA	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.	DUM4	C	R#8	N.R.		
DUM5		C	R#8	N.R.	EFKQ	C	R#8	N.R.	FLAT	C	R#8	N.R.	FLON	C	R#8	N.R.	FLON	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.	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.	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.	ITER	C	I#4	N.R.		
IT#D		C	I#4	N.R.	I365	C	I#4	N.R.	MDAY	C	I#4	N.R.	NDGP	C	I#4	N.R.	NDGP	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.	RATE	C	R#8	N.R.	
REFC		C	R#8	N.R.	SELV	C	R#8	N.R.	SMXE	C	R#8	N.R.	SGMD	F	C	R#8	000018	SGMD	F	C	R#8	000018
SOME	F	C	R#8	000010	STIM	C	R#8	N.R.	SKYZ		R#8	000090	S7P5	C	R#8	N.R.	S7P5	C	R#8	N.R.		
TEMP	SF	C	R#8	000320	THRE	C	R#8	N.R.	TOP1	C	R#8	N.R.	WAVE	C	R#8	N.R.	WAVE	C	R#8	N.R.		
XLNG	F	C	R#8	000048	XNDT	F	C	R#8	000008	XDSQ	C	R#8	N.R.	ZERO	C	R#8	N.R.	ZERO	C	R#8	N.R.	
ZOSQ		C	R#8	N.R.	DCOS	XF	R#8	000000	DS14	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	AD	R#8	000028	CUME	R#8	000030	COMD	R#8	000038
CI	R#8	000040	XLNG	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	000008	DAK	R#8	000000
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.	NDUP	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	CK	R#8	000350
SMX	R#8	000358	XK	R#8	000360	YKP	R#8	000368	BK	R#8	000370
CBK	R#8	000378	SBK	R#8	000380						

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.
NJLL	I04	N.R.	IONE	I04	N.R.	ITW0	I04	N.R.	IFUR	I04	N.R.
I15	I04	N.R.	I30	I04	N.R.	I365	I04	N.R.	IM	I04	N.R.
KM	I04	N.R.	KF	I04	N.R.	TAN	R08	N.R.	WAVE	P05	N.R.
CVCG	R08	N.R.	EFKJ	K08	N.R.	OMGE	R08	000048	XUSU	R08	N.R.
ZOSQ	R08	N.R.	ZERD	K08	N.R.	ONE	R08	N.R.	TW0	R08	N.R.
THRE	R08	N.R.	FOUR	R08	N.R.	FIVE	R08	N.R.	ATE	R08	N.R.
TEN	R08	N.R.	D60	X08	N.R.	MUND	R08	N.R.	C480	R08	N.R.
STPS	R08	N.R.	TOPI	R01	N.R.	DTRA	R08	N.R.	DTUM	R08	N.R.
TM1	R08	N.R.	TM6	R01	N.R.	TMS	R08	N.R.	TP7	P05	N.R.
TMB	R08	N.R.	CMTR	R08	N.R.	CKRM	R08	N.R.	CZK	R08	N.R.
C2H	R08	N.R.	KEFC	R01	N.R.						

OPTIONS IN EFFECT NAME= MAIN,OPT=02,LINELN=50,SIZE=1000K,

OPTIONS IN EFFECT SOURCE=ICDIC,NJLIST,NODECA,LOAD,MAP,NUEJIT,10,NXREF

STATISTICS SOURCE STATEMENTS = 45 ,PROGRAM SIZE = 612

STATISTICS NO DIAGNOSTICS GENERATED

***** END OF COMPILATION *****

61K BYTES OF CORE NOT USED

COMPIER OPTIONS - NAME= MAIN,OPT=02,LINENR=58,SIZE=6000K,
SOURCE,ERCOIC,NOLIST,QUECK,LLAO,MAP,NUEDIT,LD,NJXREF

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ISN 0002      SUBROUTINE SOLVE                                SOLVE
C                                                     SOLVE
C-USES SLNT WHICH CALCULATES NAVIGATOR COORDINATES AND SLANT RANGE SOLVE
C                                                     SOLVE
ISN 0003      DOUBLE PRECISION TAM, WAVE, CVC, EFR, UMGE, XDSQ, ZDSQ SOLVE
ISN 0004      DOUBLE PRECISION UME, TMD, THRE, FIVE, ATE, TEN, D60, HUND, C460, S7P5 SOLVE
ISN 0005      DOUBLE PRECISION TJPI, DTR, DUM, TM1, TM4, TM5, TMB, CMTR, CKRM SOLVE
ISN 0006      DOUBLE PRECISION ZER, FOUR, TIT, C2K, C2M, REFC SOLVE
ISN 0007      DOUBLE PRECISION DDP, XS, Y, ZS, ELAT, LGN, GEUM, STIM, HEAD, RATE SOLVE
ISN 0008      DOUBLE PRECISION DTR, TP, XDT, SUME, SUME, E, AU, COME, COMD, CI, XLMG SOLVE
ISN 0009      DOUBLE PRECISION DUM, 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, FLON, XFRQ SOLVE
ISN 0015      DOUBLE PRECISION DET SOLVE
C                                                     SOLVE
C---DIMENSION SOLVE
DIMENSION A(3,4) SOLVE
DIMENSION DDP(8), XS(9), YS(9), ZS(1), DLAT(9), DLON(9) SOLVE
DIMENSION C(4) SOLVE
C                                                     SOLVE
C---COMMON SOLVE
COMMON TP, XDT, SUME, SUMD, E, AU, COME, COMD, CI, XLMG SOLVE
COMMON DUM, DUM2, SI, OFST, DUM3, DUM4, DUM5, DDP SOLVE
COMMON B11, B12, B22, B10, B20, XLAT, FLON, XFRQ SOLVE
COMMON XS, YS, ZS, DTK, ELAT, DLON, GEUM, HEAD, RATE, IDAY, NDAY, STIM SOLVE
COMMON DLAT, DLON, SMXE, SELV, FLAT, FLON, FFRQ, RSQ, VN SOLVE
COMMON I, J, K, L, M, N, NDDP, ITER SOLVE
COMMON JN T, TEMP, A SOLVE
COMMON C SOLVE
C                                                     SOLVE
ISN 0027      COMMON /COMC/NULL, IONE, ITMD, IFDR, ILS, ISQ, IS65, IM, IM, KF SOLVE
ISN 0028      COMMON /COMC/TAM, WAVE, CVC, EFR, UMGE, XDSQ, ZDSQ, ZERO SOLVE
ISN 0029      COMMON /COMC/ONE, TMD, THRE, FIVE, ATE, TEN, D60, HUND SOLVE
ISN 0030      COMMON /COMC/C460, S7P5, TJPI, DTR, DUM SOLVE
ISN 0031      COMMON /COMC/TM1, TM4, TM5, TM7, TMB, 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
DO 1 I=1,3 SOLVE
DO 1 J=1,4 SOLVE
1 A(I,J)=ZERO SOLVE
SMXE=ZERO SOLVE
RSQ=ZERO SOLVE
NDDP=NULL SOLVE
K=IONE SOLVE
C---FORM THE A MATRIX SOLVE
CALL SLNT SOLVE
ISN 0041      C(I)=WAVE*TAM SOLVE
ISN 0042
C                                                     SOLVE
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 (DDP(N) 4,4,2 SOLVE
ISN 0053      2 NDDP=NDCP*IONE SOLVE
ISN 0054      C(4)=WAVE*DDP(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
DET=A(1,2)/A(1,1) SOLVE
B11=A(2,2)-A(1,2)*DET SOLVE
B12=A(2,3)-A(1,3)*DET SOLVE
B10=A(2,4)-A(1,4)*DET SOLVE
B22=A(3,3)/A(1,1) SOLVE
B20=A(3,3)-A(1,3)*DET SOLVE
B20=A(3,4)-A(1,4)*DET SOLVE
DET=B11*B22-B12*B12/DET SOLVE
XLAT=(B22*B10-B12*B20)/DET SOLVE
XLOM=(B11*B20-B12*B10)/DET SOLVE
XFRQ=( A(1,4)-A(1,2)*XLAT-A(1,3)*XLOM)/A(1,1) SOLVE
C---UPDATE NEW ESTIMATE SOLVE
FLAT=FLAT+XLAT SOLVE
FLON=FLON+XLOM SOLVE
FFRQ=FFRQ+XFRQ SOLVE
C---CONVERGENCE CRITERIA = .0004 NM AND 2.4 CPM SOLVE
DZP4=2.4D0 SOLVE
DET=CVC/DCOS(FLAT) SOLVE
IF (DABS(XLAT)-C(4)) 7,7,9 SOLVE
7 IF (DABS(FLON)-DET) 8,8,9 SOLVE
8 IF (DABS(XFRQ)-DZP4) 10,10,9 SOLVE
9 CONTINUE SOLVE
10 RETURN SOLVE
ISN 0081      END SOLVE

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NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	SF	C	R08	000378	E	C	R08	N.R.	I	SF	C	I04	0002F8		
J	SF	C	I04	0002FC	L	C	I04	N.R.	M	C	I04	N.R.			
N	SF	C	I04	00030C	S	F	CE	R08	N.R.	AO	C	R08	N.R.		
CI	C	R08	N.R.	IM	F	C	I04	00000C	KF	C	I04	N.R.			
SI	C	R08	N.R.	S7	F	CE	R08	000000	S3	F	CE	R08	000008		
VN	C	R08	N.R.	XS	C	R08	N.R.	YS	C	R08	N.R.				
ATE	C	R08	N.R.	210	SF	C	R08	0000E0	B11	SF	CE	R08	0000C8		
R20	SF	C	R08	0000E8	222	SF	CE	R08	0000D8	C2K	C	R08	N.R.		
DEF	SF	CE	R08	000320	UOP	F	C	R08	000388	DTK	C	R08	N.R.		
I15	C	I04	N.R.	I30	C	I04	N.R.	UNE	C	R08	N.R.				
TAM	F	C	R08	000028	TEN	C	R08	N.R.	TH1	C	R08	N.R.			
TMS	C	R08	N.R.	TH7	C	R08	N.R.	TH8	C	R08	N.R.				
CKRM	C	R08	N.R.	CMTR	C	R08	N.R.	COMD	C	R08	N.R.				
CVCG	F	C	R08	000038	C480	C	R08	N.R.	ULAT	C	R08	N.R.			
DTOM	C	R08	N.R.	DTM4	C	R08	N.R.	DUM1	C	R08	N.R.				
DUM3	C	R08	N.R.	DUM4	C	R08	N.R.	DUM5	C	R08	N.R.				
EF72	C	R08	N.R.	ELAT	C	R08	N.R.	ELUN	C	R08	N.R.				
FIVE	C	R08	N.R.	FLAT	SFA	C	R08	0002D0	FLUN	SF	C	R08	0002D8		
GEC1	C	R08	N.R.	HEAD	C	R08	N.R.	HUND	C	R08	N.R.				
IFOP	C	I04	N.R.	IONE	F	C	I04	000004	ITER	SF	C	I04	000314		
I365	C	I04	N.R.	MDAY	C	I04	N.R.	NDDP	SF	C	I04	000210			
OFST	C	R08	N.R.	OMGE	C	R08	N.R.	RATE	C	R08	N.R.				
SELY	C	R08	N.R.	SLNT	SF	XF	R08	000070	SME	S	C	R08	0002C0		
SOME	C	R08	N.R.	STIM	C	R08	N.R.	S7P5	C	R08	N.R.				
THRE	C	R08	N.R.	TOPI	C	R08	N.R.	WAVE	F	C	R08	000030			
XLAT	SFA	C	R08	0000F0	XLNG	C	R08	N.R.	XLON	SFA	C	R08	0000F8		
XDSQ	C	R08	N.R.	ZEND	F	C	R08	000060	XNDT	C	R08	N.R.			
DCDS	XF	R08	000000					ZISQ	C	R08	N.R.	SOLVE	K04	00009C	

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

NAME OF COMMON BLOCK * * SIZE OF BLOCK 0003AB HEXADESIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R08	N.R.	XNDT	R08	N.R.	SOME	R08	N.R.	SQMD	R08	N.R.
E	R08	N.R.	AD	R08	N.R.	COME	R08	N.R.	COMD	R08	N.R.
CI	R08	N.R.	XLNG	R08	N.R.	DUM1	R08	N.R.	COM2	R08	N.R.
SI	R08	N.R.	OFST	R08	N.R.	DUM3	R08	N.R.	COM4	R08	N.R.
DUM5	R08	N.R.	DOP	R08	000088	B11	R08	0000C8	B12	R08	0000D0
B22	R08	0000D8	B10	R08	0000E0	B20	R08	0000E8	XLAT	R08	0000F0
XLON	R08	0000F8	XFRO	R08	000100	XS	R08	N.R.	YS	R08	N.R.
ZS	R08	N.R.	DTK	R08	N.R.	HAT	R08	N.R.	ELON	R08	N.R.
GEOM	R08	N.R.	HEAD	R08	N.R.	LATE	R08	N.R.	IDAY	R08	N.R.
MDAY	R08	N.R.	STIM	R08	N.R.	DLAT	R08	N.R.	DLON	R08	N.R.
SME	R08	0002C0	SELY	R08	N.R.	FLAT	R08	0002D0	FLON	R08	0002D8
FRQ	R08	0002E0	RSQ	R08	0002F0	VN	R08	N.R.	I	R08	0002F8
J	R08	0002FC	K	R08	000300	L	R08	N.R.	M	R08	N.R.
N	R08	00030C	NDDP	R08	000310	ITER	R08	000314	T	R08	N.R.
TEMP	R08	000320	A	R08	000328	C	R08	000388			

EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK
 VARIABLE S OFFSET 0000C8
 VARIABLE S2 OFFSET 000000

VARIABLE S3 OFFSET 000008

VARIABLE DET OFFSET 000320

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

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
NULL	I04	000000	IONE	I04	000004	ITWD	I04	N.R.	IFUR	I04	N.R.
I15	I04	N.R.	I30	I04	N.R.	I365	I04	N.R.	IM	I04	000010
KM	I04	N.R.	KF	I04	N.R.	TAM	R08	000028	WAVE	R08	000030
CVCG	R08	000038	EFRO	R08	N.R.	OMGE	R08	N.R.	XDSQ	R08	N.R.
ZISQ	R08	N.R.	ZEND	R08	000060	ONE	R08	N.R.	ITWD	R08	N.R.
THPE	R08	N.R.	FOUR	R08	N.R.	FIVE	R08	N.R.	ATE	R08	N.R.
TEN	R08	N.R.	O60	R08	N.R.	HUND	R08	N.R.	C480	R08	N.R.
S7P5	R08	N.R.	TOPI	R08	N.R.	DTRA	R08	N.R.	DTOP	R08	N.R.
TH1	R08	N.R.	TH4	R08	N.R.	TMS	R08	N.R.	TH7	R08	N.R.
TH8	R08	N.R.	CMTR	R08	N.R.	CKRM	R08	N.R.	C2K	R08	N.R.
C2M	R08	N.R.	REFC	R08	N.R.						

LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	PAGE
1	00016E	2	000242	3	0002A2	4	0002CC	005
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,NOICF,LOAD,MAP,NOEDIT,LD,NOXREF

STATISTICS SOURCE STATEMENTS = 80 ,PROGRAM SIZE = 1144

STATISTICS NO DIAGNOSTICS GENERATED

***** END OF COMPILATION *****

53K BYTES OF CORE NOT USED

COMPILER OPTIONS - NAME= 'A1',OPT=02,LINECT=58,SIZE=000K,
SOURCE,EB,0IC,NOLIST,NOCHECK,LOAD,MAP,NOEDIT,LD,NXREF

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ISN 0002      SUBROUTINE SLNT
C
C---COMPUTE SLANT RANGE AND DERIVATIVES FOR POINT K AND ELEVATION
C
ISN 0003      DOUBLE PRECISION TA,TA0,AVE,CVCG,EFK,UMGE,XDSQ,ZDSQ
ISN 0004      DOUBLE PRECISION UME,TW0,THRE,FIVE,ATE,TEN,DBU,HND,C6BG,STP5
ISN 0005      DOUBLE PRECISION TJP1,OTRA,DT,M,TM1,TH4,TH5,TM8,CHTR,CKRM
ISN 0006      DOUBLE PRECISION ZCR0,FOUK,TM7,C2K,C2M,REFC
ISN 0007      DOUBLE PRECISION DDP,XS,YS,ZS,ELAT,ELUN,GEOM,STIM,HEAD,RATE
ISN 0008      DOUBLE PRECISION DTK,TP,XNDI,SJMI,SUMPE,AC,CUME,CUMDCI,XLHG
ISN 0009      DOUBLE PRECISION DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5
ISN 0010      DOUBLE PRECISION DLAT,DLUN,SMXE,SELV,FLAT,FLUN,FFRQ,RSQ,VN
ISN 0011      DOUBLE PRECISION T,TEMP
ISN 0012      DOUBLE PRECISION A
ISN 0013      DOUBLE PRECISION XN,YN,ZN,XN2,YN2,ZN2,X,Y,Z
ISN 0014      DOUBLE PRECISION CLAT,SLAT,SLUN,CLUN,LC
ISN 0015      DOUBLE PRECISION S,S2,S3
C
C---DIMENSIONS
ISN 0016      DIMENSION DU(8),XS(9),YS(9),ZS(11),U AT(9),DLON(9)
ISN 0017      DIMENSION A(3,4),C(4)
C
C---COMMON
ISN 0018      COMMON TP,XNDI,SUME,SUMLE,EAU,CJML,CJND,CI,XLHG
ISN 0019      COMMON DUM1,DUM2,SI,OFST,DUM3,DUM4,DUM5,DDP
ISN 0020      COMMON CLAT,SLAT,SLUN,CLUN,XN,YN,ZN
ISN 0021      COMMON XS,YS,ZS,DTK,ELAT,ELUN,GEOM,HEAD,RATE,IDAY,MDAY,STIM
ISN 0022      COMMON DLAT,DLUN,SMXE,SELV,FLAT,FLUN,FFRQ,RSQ,VN
ISN 0023      COMMON T,J,K,L,M,N,NDOP,ITER
ISN 0024      COMMON T,TEMP,A
ISN 0025      COMMON C,X,Y,Z,XN2,YN2,ZN2
C
ISN 0026      COMMON /CONC/MULL,IONE,ITW,IFUN,115,130,1365,IM,NM,KF
ISN 0027      COMMON /CUMC/TA,AVE,CVCG,EFK,UMGE,XDSQ,ZDSQ,ZERO
ISN 0028      COMMON /CONC/DTA,TW0,THRE,FOUR,FIVE,ATE,TEN,DBU,HND
ISN 0029      COMMON /C/OTRA,STP5,TJP1,OTRA,DTOM
ISN 0030      COMMON /CUMC/TM1,TH4,TH5,TM7,TM8,CHTR,CKRM,C2K,C2M,REFC
C
ISN 0031      EQUIVALENCE (CLAT,S) ((AT,S2),(CLUN,S3))
C
C---NAVIGATORS COORDINATES AND DERIVATIVES
ISN 0032      TEMP=CLAT+DLAT*(K)
ISN 0033      CL=TEMP*(TEMP)
ISN 0034      SLA=DSIN(TEMP)
ISN 0035      TEMP=FLON+DT*(K)/ZCLAY
ISN 0036      CLJ=LCOS(SL*SRP)
ISN 0037      SLON=DSIN(TEMP)
ISN 0038      D=ZDSQ*(AT-CLAT)+ZDSQ*SLAT*SLAT
ISN 0039      D=ZDSQ*(D)
ISN 0040      TEMP=XDSQ/ZDSQ*GEOM
ISN 0041      XN=TEMP*FLAT
ISN 0042      YN=TEMP*SLUN
C
ISN 0043      XN=XN*CLON
ISN 0044      ZN=ZDSQ/D*GEOM*SI*AT
ISN 0045      XN2=TEMP*SLAT
ISN 0046      YN2=XN2*CLON
ISN 0047      XN2=XN2*CLON
ISN 0048      ZN2=TEMP*CLAT
C---SLANT RANGE AND DERIVATIVES
ISN 0049      X=XS(K)-XN
ISN 0050      Y=YS(K)-YN
ISN 0051      Z=ZS(K)-ZN
ISN 0052      S2=X*X+Y*Y+Z*Z
ISN 0053      S=DSQRT(S2)
ISN 0054      S2=-IX*XN2+Y*YN2+Z*ZN2/15
ISN 0055      S3=IX*YN-Y*XN/15
C---COMPUTE SIN(ELEV) AND SAVE MAXIMUM
ISN 0056      SELV=(X*XN+Y*YN+Z*ZN)/S*DI
ISN 0057      IF (SELV-SMXE) 2,Z,1
ISN 0058      1 SMXE=SELV
ISN 0059      2 RETURN
ISN 0060      END

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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	R08	N.R.	C	C	R08	N.R.	D	SFA	C	R08	E	C	R08	N.R.
M	C	I04	N.R.	J	C	I04	N.R.	K	F	C	I04	L	C	I04	N.R.
N	C	I04	N.R.	N	C	I04	N.R.	S	SF	CE	R08	T	C	R08	N.R.
CI	SF	C	R08	Y	SF	C	R08	Z	SF	C	R08	AD	C	R08	N.R.
SI	C	R08	N.R.	IM	C	I04	N.R.	KF	C	I04	N.R.	KM	C	I04	N.R.
VH	C	R08	N.R.	S2	SFA	CE	R08	S3	S	CE	R08	TP	C	R08	N.R.
YS	F	C	R08	XN	SF	C	R08	XS	F	C	R08	YN	SF	C	R08
C2K	C	I08	N.R.	ZN	SF	C	R08	ZS	F	C	R08	ATE	C	R08	N.R.
D60	C	R08	N.R.	C2M	C	R08	N.R.	DDP	C	R08	N.R.	DTK	C	R08	N.R.
RSQ	C	R08	N.R.	I15	C	I04	N.R.	I30	C	I04	N.R.	UNE	C	R08	N.R.
TM4	C	R08	N.R.	TAM	C	R08	N.R.	TEN	C	R08	N.R.	TM1	C	R08	N.R.
TMO	C	R08	N.R.	TM5	C	R08	N.R.	TM7	C	R08	N.R.	TM8	C	R08	N.R.
CKRM	C	R08	N.R.	XN2	SF	C	R08	YN2	SF	C	R08	ZN2	SF	C	R08
COMD	C	R08	N.R.	CLAT	SF	CE	R08	CLON	SF	C	R08	CMTR	C	R08	N.R.
DLAT	F	C	R08	COME	C	R08	N.R.	CVCG	C	R08	N.R.	C680	C	R08	N.R.
DUM1	C	I08	N.R.	DLON	F	C	R08	DTQM	C	R08	N.R.	DTRA	C	R08	N.R.
DUM5	C	R08	N.R.	DUM2	C	R08	N.R.	DJM3	C	R08	N.R.	DUM4	C	R08	N.R.
FFRQ	C	R08	N.R.	EFRQ	C	R08	N.R.	ELAT	C	R08	N.R.	ELON	C	R08	N.R.
FOUR	C	R08	N.R.	FIVE	C	R08	N.R.	FLAT	F	C	R08	FLON	F	C	R08
IDAY	C	I04	N.R.	GEUH	F	C	R08	HEAD	C	R08	N.R.	HUND	C	R08	N.R.
ITWQ	C	I04	N.R.	IFOR	C	I04	N.R.	IONE	C	I04	N.R.	ITER	C	I04	N.R.
NULL	C	I04	N.R.	I305	C	I04	N.R.	MDAY	C	I04	N.R.	NDDP	C	I04	N.R.
REFC	C	R08	N.R.	OFST	C	R08	N.R.	UMGE	C	R08	N.R.	RATE	C	R08	N.R.
SLON	SF	CE	R08	SELV	SF	C	R08	SLAT	SF	CE	R08	SLNT	C	R08	N.R.
STIM	C	R08	N.R.	SMXE	S	C	R08	SOMD	C	R08	N.R.	SOME	C	R08	N.R.
TOPI	C	R08	N.R.	S7P5	C	R08	N.R.	TEMP	SFA	C	R08	THRE	C	R08	N.R.
XDSQ	F	C	R08	WAVE	C	R08	N.R.	XLMG	C	R08	N.R.	XNDT	C	R08	N.R.
DSIN	XF	R08	000000	ZERO	C	R08	N.R.	ZOSQ	F	C	R08	OSQT	XF	R08	000000
				DCOS	XF	R08	000000								

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

NAME OF COMMON BLOCK *				* SIZE OF BLOCK 000308 HEXADECIMAL BYTES							
VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TI	R08	N.R.	XNUT	R08	N.R.	SOME	R08	N.R.	SOMD	R08	N.R.
E	R08	N.R.	AD	R08	N.R.	COME	R08	N.R.	CUMD	R08	N.R.
CI	R08	N.R.	XLMG	R08	N.R.	DUM1	R08	N.R.	DUP2	R08	N.R.
SI	R08	N.R.	OFST	R08	N.R.	DUM5	R08	N.R.	DUP4	R08	N.R.
DUM5	R08	N.R.	DDP	R08	N.R.	CLAT	R08	0000C8	SLAT	R08	0000D0
SLON	R08	0000D8	CLON	R08	0000E0	D	R08	0000E8	XN	R08	0000F0
YN	R08	0000F8	ZN	R08	000100	XS	R08	000108	YS	R08	000110
ZS	R08	000198	DTK	R08	N.R.	ELAT	R08	N.R.	ELUN	R08	N.R.
GEUH	R08	000208	HEAD	R08	N.R.	RATE	R08	N.R.	IDAY	R08	N.R.
MDAY	I04	N.R.	STIM	R08	N.R.	DLAT	R08	000230	DLON	R08	000278
SMXE	R08	0002C0	SELV	R08	0002C8	FLAT	R08	0002D0	FLGN	R08	0002D8
FFRQ	R08	N.R.	RSQ	R08	N.R.	VN	R08	N.R.	I	R08	N.R.
J	I04	N.R.	K	I04	00030C	L	I04	N.R.	M	I04	N.R.
N	I04	N.R.	NDDP	I04	N.R.	ITER	I04	N.R.	T	R08	N.R.
TEMP	R08	000320	A	R08	N.R.	C	R08	N.R.	X	R08	0003A8
Y	R08	000380	Z	R08	000368	>N2	R0E	0003C0	YN2	R08	0003C8

EQUIVALENCED VARIABLES WITHIN THIS COMMON BLOCK
 VARIABLE OFFSET VARIABLE OFFSET
 5 0000C9 52 0000D0

VARIABLE OFFSET
 53 0000D0

VARIABLE OFFSET

NAME OF COMMON BLOCK * C1MC* 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.	I0VE	I*4	N.R.	ITWD	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.
AM	I*4	N.R.	AF	I*4	N.R.	TAM	R*8	N.R.	WAVE	R*8	N.R.
CVCG	I*4	N.R.	EFRQ	R*8	N.R.	ONGE	R*8	N.R.	XOSQ	R*8	000050
ZDSJ	R*8	000058	ZERG	R*8	N.R.	ONE	R*8	N.R.	TWD	R*8	N.R.
THRE	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TEY	R*8	N.R.	D60	R*8	N.R.	HUND	R*8	N.R.	C480	R*8	N.R.
S7P5	R*8	N.R.	TUPI	R*8	N.R.	DTRA	R*8	N.R.	DIGH	R*8	N.R.
T41	R*8	N.R.	T44	R*8	N.R.	TMS	R*8	N.R.	TM7	R*8	N.R.
T4B	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	OOD
1	000272	2	0002CA						
*OPTIONS IN EFFECT: NAME= MAIN,OPT=02,LINECNT=50,SIZE=0300K,									
*OPTIONS IN EFFECT: SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,IO,NOKREF									
STATISTICS SOURCE ELEMENTS = 59, PROGRAM SIZE = 750									
STATISTICS NO DIAGNOSTICS GENERATED									
***** END OF COMPILATION *****									

617 BYTES OF CORE NOT USED

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COMPILER OPTIONS - NAME= MAIN,DPT=02,LINECN=58,SIZE=000K,
SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,LD,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 TAM,WAVE,CVCG,EFREQ,UMGE,XDSQ,ZDSQ EDIT
ISN 0004 DOUBLE PRECISION ONE,TWO,THRE,FIVF,ATE,TEN,D60,HUND,C48J,S7P5 EDIT
ISN 0005 DOUBLE PRECISION TOP1,DTRA,DTOM,TM1,TM4,TM5,TM8,CNTR,CKRM EDIT
ISN 0006 DOUBLE PRECISION ZERO,FOUR,THY,C2K,C2M,REFC EDIT
ISN 0007 DOUBLE PRECISION DUP,REF,XS,YS,ZS,ELAT,ELON,GEOM,STIM,HEAL,RATE EDIT
ISN 0008 DOUBLE PRECISION DTK,TP,XNDT,SOME,SUMU,E,AD,COME,COMD,CI,XLMG EDIT
ISN 0009 DOUBLE PRECISION DUM1,DUM2,S1,OFST,DUM3,DUM4,DUM5 EDIT
ISN 0010 DOUBLE PRECISION DLAT,DLON,SMXE,SELY,FLAT,FLON,FFRQ,RSQ,VM 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,AD,COME,CUMD,CI,XLMG EDIT
ISN 0015 COMMON DUM1,DUM2,S1,OFST,DUM3,DUM4,DUM5,DUP EDIT
ISN 0016 COMMON REF EDIT
ISN 0017 COMMON XS,YS,ZS,DTK,ELAT,ELON,HEAL,RATE,IOAY,MDAY,STIM EDIT
ISN 0018 COMMON DLAT,DLON,SMXE,SELY,FLAT,FLON,FFRQ,RSQ,VM 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,IT=0,IFUR I15,I30,I365,IM,KM,KF EDIT
ISN 0022 COMMON /COMC/TAM,WAVE,CVCG,EFREQ,UMGE,XDSQ,ZDSQ,ZERO EDIT
ISN 0023 COMMON /COMC/ONE,TWO,THRE,FOUR,FIVF,ATE,TEN,D60,HUND EDIT
ISN 0024 COMMON /COMC/C48J,S7P5,TOPI,DTRA,DTOM EDIT
ISN 0025 COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CNTR,CKRM,C2K,C2M,REFC EDIT
C EDIT
ISN 0026 I=IDLE 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=SELY EDIT
ISN 0032 K=J EDIT
ISN 0033 CALL SLNT EDIT
ISN 0034 EE=SELY 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)=ZEPO EDIT

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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NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	
I	SF	C	104	I	SF	C	104	J	SF	C	104	K	S	C	104	
AD	C	R08	N.R.	LI	C	R08	N.R.	N	C	104	N.P.	T	C	R08	N.R.	
IN	C	104	N.R.	XF	C	104	N.R.	FB	S	C	R08	EE	S	C	R08	
TP	C	R08	N.R.	VN	S	R08	N.R.	KM	F	C	104	SI	C	R08	N.R.	
ZS	C	R08	N.R.	ATE	C	R08	N.R.	XS	C	R08	N.R.	YS	C	R08	N.R.	
DDP	S	C	R08	DTA	C	R08	N.R.	CZK	C	R08	N.R.	CZM	C	R08	N.R.	
F30	C	104	N.R.	ONE	C	R08	N.R.	D00	C	R08	N.R.	I15	C	104	N.R.	
I15	C	R08	N.R.	TEN	C	R08	N.R.	REF	C	R08	N.R.	RSQ	C	R08	N.R.	
CKRM	C	R08	N.R.	TW7	C	R08	N.R.	TMI	C	R08	N.R.	TM4	C	R08	N.R.	
CVCG	C	R08	N.R.	CTR	C	R08	N.R.	TMB	C	R08	N.R.	TW0	C	R08	N.R.	
DTOM	C	R08	N.R.	C480	C	R08	N.R.	UNO	C	R08	N.R.	CUME	C	R08	N.R.	
DUM3	C	R08	N.R.	UTPA	C	R08	N.R.	DLAT	C	R08	N.R.	DLUN	C	R08	N.R.	
EFRT	C	R08	N.R.	DUM4	C	R08	N.R.	DUM1	C	R08	N.R.	DUM2	C	R08	N.R.	
FIVE	C	R08	N.R.	ELAT	C	R08	N.R.	SJMS	C	R08	N.R.	EDIT	C	R08	N.R.	
GEOM	C	R08	N.R.	FLAT	C	R08	N.R.	TLON	C	R08	N.R.	FFRQ	C	R08	N.R.	
IFOR	C	104	00000C	HEAD	C	R08	N.R.	FLUN	C	R08	N.R.	FOUR	C	R08	N.R.	
I365	C	104	N.R.	JUNE	F	C	104	HUND	C	104	N.R.	IDAY	C	104	N.R.	
OFST	C	R08	N.R.	MDAY	C	104	N.R.	ITER	C	104	N.R.	ITW0	C	104	N.R.	
SELY	F	C	R08	UNGE	C	R08	N.R.	NDOP	SF	C	104	000310	NULL	C	104	N.R.
SOIE	C	R08	N.R.	SLNG	SF	XF	R04	RATE	C	R08	N.R.	REFC	C	R08	N.R.	
THRE	C	R08	N.R.	STIM	C	R08	N.R.	SMXE	C	R08	N.R.	SOMD	C	R08	N.R.	
XNDT	C	R08	N.R.	TOPI	C	R08	N.R.	STPS	C	R08	N.R.	TEMP	C	R08	N.R.	
				XU'V	C	R08	N.R.	UNGE	C	R08	N.R.	XLMG	C	R08	N.R.	
								ZERO	F	C	R08	000060	ZOSQ	C	R08	N.R.

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

NAME OF COMMON BLOCK * SIZE OF BLOCK 000330 HEXADECIMAL BYTES

VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R08	N.R.	XNDT	R08	N.R.	SOME	R08	N.R.	SOMD	R08	N.R.
E	R08	N.R.	AD	R08	N.R.	COME	R08	N.R.	COMD	R08	N.R.
CI	R08	N.R.	XLMG	R08	N.R.	DUM1	R08	N.R.	DUM2	R08	N.R.
SI	R08	N.R.	OFST	R08	N.R.	DUM3	R08	N.R.	DUM4	R08	N.R.
OUM5	R08	N.R.	DDP	R08	0000BB	REF	R08	N.R.	XS	R08	N.R.
YS	R08	N.R.	ZS	R08	N.R.	DTK	R08	N.R.	ELAT	R08	N.R.
ELUN	R08	N.R.	GEOM	R08	N.R.	HEAD	R08	N.R.	RATE	R08	N.R.
IDAY	104	N.R.	MDAY	104	N.R.	STIM	R08	N.R.	DLAT	R08	N.R.
DLON	R08	N.R.	SMXE	R08	N.R.	SELY	R08	0002C8	FLAT	R08	N.R.
FLUN	R08	N.R.	FFRQ	R08	N.R.	RSQ	R08	N.R.	VN	R08	N.R.
I	104	0002F8	J	104	0002FC	K	104	000300	L	104	000304
M	104	N.R.	N	104	N.R.	NDOP	104	000310	ITER	104	N.R.
T	R08	N.R.	TEMP	R08	N.R.	EE	R08	000328	EB	R08	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	104	N.R.	IONE	104	000004	ITW0	104	N.R.	IFOR	104	00000C
I15	104	N.R.	I30	104	N.R.	I365	104	N.R.	IM	104	N.R.
CVCG	R08	N.R.	XF	104	N.R.	TAM	R08	N.R.	WAVE	R08	N.R.
			EFRQ	R08	N.R.	UNGE	R08	N.R.	XOSQ	R08	N.R.
ZOSQ	R08	N.R.	ZERO	R08	000060	ONE	R08	N.R.	TW0	R08	N.R.
THRE	R08	N.R.	FOUR	R08	N.R.	FIVE	R08	N.R.	ATE	R08	N.R.
TEN	R08	N.R.	D00	R08	N.R.	HUND	R08	N.R.	C480	R08	N.R.
STPS	R08	0000BB	TOPI	R08	N.R.	DTRA	R08	N.R.	DTOM	R08	N.R.
TMI	R08	N.R.	TM4	R08	N.R.	TM5	R08	N.R.	TM7	R08	N.R.
TM8	R08	N.R.	CMTR	R08	N.R.	CKRM	R08	N.R.	CZK	R08	N.R.
CZM	R08	N.R.	REFC	R08	N.R.						

LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	LABEL	ADDR	PAGE	CUS
1	0000A8	2	0000B8	4	0000F8	5	00010*		
6	000114	7	00012C	8	000140	9	000152		
10	00016A	11	00016E						

OPTIONS IN EFFECT NAME * MAIN,OPT=02,LINCOLT=59,SIZE=0000F,

OPTIONS IN EFFECT SOURCE,ENCOC,NO LIST,NO DLK,LUAG,MAP,NOEDIT,IO,NOXREF

STATISTICS SOURCE STATE * 47, PROGRAM SIZE * 402

STATISTICS NO DIAGNOSTICS GEN. *TD

***** END OF COMPILATION *****

61K BYTES OF CORE NOT USED

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=58,SIZE=0000K,
SOURCE,EBCDIC,NOLIST,NODECK,LUAD,MAP,NOEDIT,TD,NOXREF

```

ISN 0002      SUBROUTINE ALRT
C
C-USES AVIS WHICH USES SLNT AND SKVZ
C
ISN 0003      DOUBLE PRECISION TAM,WAVE,CVCG,EFKQ,OMGE,XDSQ,ZDSQ
ISN 0004      DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,S7P5
ISN 0005      DOUBLE PRECISION TOPI,DTRA,DTOM,TM1,TM4,TM5,TM8,CNTR,CKRM
ISN 0006      DOUBLE PRECISION ZERO,FOUR,SEV,C2K,C2M,REFC
ISN 0007      DOUBLE PRECISION DOP,XS,YS,ZS,ELAT,ELUN,GEOM,STIM,HEAD,RATE
ISN 0008      DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AD,COME,COMD,C1,XLMG
ISN 0009      DOUBLE PRECISION DUM1,DUM2,S1,OFST,DUM3,DUM4,DUM5
ISN 0010      DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN
ISN 0011      DOUBLE PRECISION T,TEMP,A
ISN 0012      DOUBLE PRECISION DCK,DAK,DMK
ISN 0013      DOUBLE PRECISION DUM
ISN 0014      DOUBLE PRECISION AELV
ISN 0015      DOUBLE PRECISION TO ,RISE,XMIN
C
C---DIMENSIONS
ISN 0016      DIMENSION DOP(8),YS(9),ZS(11),DLAT(9),DLON(9)
ISN 0017      DIMENSION DUM(5),A(3,4)
C
C---COMMON
ISN 0018      COMMON TP,XNDT,SOME,SOMD,F,AD,COME,COMD,C1,XLMG
ISN 0019      COMMON DUM1,DUM2,S1,OFST,DUM3,DUM4,DUM5,DUP
ISN 0020      COMMON DCK,DAK,DMK,DUM
ISN 0021      COMMON XS,YS,ZS,DTK,ELAT,ELUN,GEOM,HEAD,RATE,IDAY,MDAY,STIM
ISN 0022      COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FFRQ,RSQ,VN
ISN 0023      COMMON I,J,K,L,M,N,NDOP,ITER
ISN 0024      COMMON T,TEMP,A
ISN 0025      COMMON TO ,RISE,AELV,XMIN
C
ISN 0026      COMMON /COMC/NULL,IONE,ITW,IFOR,I15,I30,I70,IM,KM,KF
ISN 0027      COMMON /COMC/TAM,WAVE,CVCG,EFKQ,OMGE,XDSQ, ,Q,ZERO
ISN 0028      COMMON /COMC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND
ISN 0029      COMMON /COMC/C480,S7P5,TOPI,DTRA,DTOM
ISN 0030      COMMON /COMC/TM1,TM4,TM5,TM7,TM8,CNTR,CKRM,C2K,C2M,REFC
C
ISN 0031      EQUIVALENCE (ISTP,NDOP),(IELV,ITER)
ISN 0032      1 FORMAT (1H,3MDAY,3X,4HRIS,3X,4HELEV)
ISN 0033      ISTD=MDAY-IDAY
ISN 0034      IF (ISTP) 2,13,3
ISN 0035      2 ISTD=ISTP-I365
ISN 0036      3 TO=T-18.000
ISN 0037      T=T-TO
ISN 0038      WRITE (6,1)
ISN 0039      4 T=T+TEN
ISN 0040      CALL AVIS
ISN 0041      IF (SELV) 4,4,5
ISN 0042      5 T=T-TEN
ISN 0043      6 T=T+TWO
ISN 0044      CALL AVIS
ISN 0045      IF (SELV) 6,7,7

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

```

NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.
A	C	R#B	N.R.	E	C	R#B	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#B	000318	AD	C	R#B	N.R.	CI	C	R#B	N.R.	IN	C	I#4	N.R.
KF	C	I#4	N.R.	KM	C	I#4	N.R.	SI	C	R#B	N.R.	TO SF	C	R#B	000388
TP	C	R#B	N.R.	VN	C	R#B	N.R.	XS	C	R#B	N.R.	YS	C	R#B	N.R.
ZS	C	R#B	N.R.	ATE	C	R#B	N.R.	CZK	C	R#B	N.R.	CZM	C	R#B	N.R.
DAK	C	R#B	N.R.	DEK	C	R#B	N.R.	DNK	C	R#B	N.R.	DOP	C	R#B	N.R.
DYK	C	R#B	N.R.	DUM	C	R#B	N.R.	D60	C	R#B	N.R.	I15	C	I#4	N.R.
13J	C	I#4	N.R.	UNE	C	R#B	N.R.	RSQ	C	R#B	N.R.	TAW	C	R#B	N.R.
TEN F	C	R#B	000098	TM1	C	R#B	N.R.	TM6	C	R#B	N.R.	TMS	C	R#B	N.R.
TM7	C	R#B	N.R.	TM8	C	R#B	N.R.	TW0 F	C	R#B	000070	AELV SFA	C	R#B	000398
ALRT	R#4	0000CC		ARCS SF	XF	R#4	000000	AVIS SF	XF	R#4	000000	CKRM	C	R#B	N.R.
CMTR F	C	R#B	000100	CUMD	C	R#B	N.R.	CUME	C	R#B	N.R.	CVCG	C	R#B	N.R.
C480	C	R#B	N.R.	DLAT	C	R#B	N.R.	DLOM	C	R#B	N.R.	DTDM F	C	R#B	000000
OTRA	C	R#B	N.R.	DUM1	C	R#B	N.R.	DUM2	C	R#B	N.R.	DUM3	C	R#B	N.R.
UM44	C	R#B	N.R.	DUM5	C	R#B	N.R.	FFRQ	C	R#B	N.R.	ELAT	C	R#B	N.R.
FLOM	C	R#B	N.R.	FFKQ	C	R#B	N.R.	FIVE	C	R#B	N.R.	FLAT	C	R#B	N.R.
FLOM	C	R#B	N.R.	FQQA	C	R#B	N.R.	GEOM	C	R#B	N.R.	HEAD	C	R#B	N.R.
MUND	C	R#B	N.R.	IDAY F	C	I#4	000220	IELV SF	CE	I#4	000314	IFOR	C	I#4	N.R.
IU F	C	I#4	N.R.	ISTP SF	CE	I#4	000310	ITER	CE	I#4	000314	ITWO	C	I#4	N.R.
1365 F	C	I#4	000018	MDAY F	C	I#4	000314	NOOP	CE	I#4	000310	NULL	C	I#4	N.R.
OFST	C	R#B	N.R.	UMLE	C	R#B	N.R.	RATF	C	R#B	N.R.	REFC	C	R#B	N.R.
RISE SF	C	R#B	000390	SELV F	C	R#B	0002C8	SAME	C	R#B	N.R.	SOMD	C	R#B	N.R.
SUME	C	R#B	N.R.	STIM F	C	R#B	000228	STPS	C	R#B	N.R.	TEMP SF	C	R#B	000320
THRE	C	R#B	N.R.	TQPI	C	R#B	N.R.	UCON SF	XF	R#4	000000	WAVE	C	R#B	N.R.
XLNG	C	R#B	N.R.	XMIN	C	R#B	N.R.	XNDT	C	R#B	N.R.	XOSO	C	R#B	N.R.
ZERD	C	R#B	N.R.	ZUSD	C	R#B	N.R.	XNDT F	XF	R#4	000000				

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

NAME OF COMMON BLOCK *				* SIZE OF BLOCK 0003A8 HEXADECIMAL BYTES							
VAP. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAP. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
TP	R#B	N.R.	XNDT	R#B	N.R.	SOME	R#B	N.R.	SHMD	R#B	N.R.
E	R#B	N.R.	AD	R#B	N.R.	COM1	R#B	N.R.	CUMD	R#B	N.R.
CI	R#B	N.R.	XLNG	R#B	N.R.	DUM1	R#B	N.R.	DUM2	R#B	N.R.
SI	R#B	N.R.	OFST	R#B	N.R.	DUM3	R#B	N.R.	DUM4	R#B	N.R.
DUM5	R#B	N.R.	DDP	R#B	N.R.	DEK	R#B	N.R.	DAK	R#B	N.R.
UNK	R#B	N.R.	DUM	R#B	N.R.	XS	R#B	N.R.	YS	R#B	N.R.
ZS	R#B	N.R.	DTR	R#B	N.R.	ELAT	R#B	N.R.	ELON	R#B	N.R.
GEDH	R#B	N.R.	HEAD	R#B	N.R.	RATE	R#B	N.R.	IDAY	I#4	000220
MDAY	I#4	000224	STIP	R#B	000228	DLAT	R#B	N.R.	DLOM	R#B	N.R.
SXKE	R#B	N.R.	SELV	R#B	0002C8	FLAT	R#B	N.R.	FLOM	R#B	N.R.
FFRQ	R#B	N.R.	RSQ	R#B	N.R.	VN	R#B	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.	NOOP	I#4	000310	ITER	I#4	000314	T	R#B	000318
TEMP	R#B	000320	A	R#B	N.R.	TO	R#B	000368	RISE	R#B	000390
AELV	R#B	0003C8	XMIN	R#B	N.R.						

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

NAME OF COMMON BLOCK * COMC* SIZE OF BLOCK 00J126 HEXADECIMAL BYTES											
VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.	VAR. NAME	TYPE	REL. ADDR.
LULL	I*4	N.R.	IONE	I*4	N.R.	ITWD	I*4	N.R.	IFOR	I*4	N.R.
Y15	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.	ZERD	R*8	N.R.	ONE	R*8	N.R.	TWD	R*8	000070
TH.E	R*8	N.R.	FOUR	R*8	N.R.	FIVE	R*8	N.R.	ATE	R*8	N.R.
TFV	R*8	000098	DE7	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	000000
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	CKRM	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
2	000110	3	000120	4	00014C	5	000170	0
6	000180	7	0001AC	8	0001BC	9	0001EE	
10	000254	11	000258	13	0002EC			

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

OPTIONS IN EFFECT SOURCE,EBODIC,NJLIST,NODECK,LOAD,MAP,NOEDIT-1-0,NORREF

STATISTICS SOURCE STATEMENTS = 64 ,PROGRAM SIZE = 784

STATISTICS NO DIAGNOSTICS GENERATED

***** END OF COMPILATION *****

61K BYTES OF CORE NOT USED

FORM	LEVEL	DATE	11/06/10	PAGE 0001
0001	DOUBLE PRECISION	AVIS		
0002	DOUBLE PRECISION	AVIS		
0003	DOUBLE PRECISION	AVIS		
0004	DOUBLE PRECISION	AVIS		
0005	DOUBLE PRECISION	AVIS		
0006	DOUBLE PRECISION	AVIS		
0007	DOUBLE PRECISION	AVIS		
0008	DOUBLE PRECISION	AVIS		
0009	DOUBLE PRECISION	AVIS		
0010	DOUBLE PRECISION	AVIS		
0011	DOUBLE PRECISION	AVIS		
0012	DOUBLE PRECISION	AVIS		
0013	C---DIMENSIONS	AVIS		
0014	DIMENSION LUP(8),...	AVIS		
0015	C---CONSTANT	AVIS		
0016	CONSTANT TP, XNOT,...	AVIS		
0017	CONSTANT DUM,...	AVIS		
0018	CONSTANT DAK,...	AVIS		
0019	CONSTANT KS, TS,...	AVIS		
0020	CONSTANT DEAT,...	AVIS		
0021	CONSTANT T, TEMP,...	AVIS		
0022	CONSTANT TO	AVIS		
0023	C---CONSTANT	AVIS		
0024	CONSTANT /CORC/...	AVIS		
0025	CONSTANT /CORC/...	AVIS		
0026	CONSTANT /CORC/...	AVIS		
0027	CONSTANT /CORC/...	AVIS		
0028	C---CONSTANT	AVIS		
0029	CONSTANT DAK=ZERO	AVIS		
0030	CONSTANT DAK=ZERO	AVIS		
0031	CONSTANT DAK=ZERO	AVIS		
0032	CONSTANT CALL SAYE	AVIS		
0033	CONSTANT CALL SLMT	AVIS		
0034	CONSTANT RETURN	AVIS		
0035	CONSTANT END	AVIS		

		COMMON BLOCK /		/ MAP SIZE		390			
SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
TP	0	INPT	8	SUNE	10	SUSD	18	E	20
AP	28	CONF	30	CONF	38	CI	40	ILRG	48
DUR1	50	DUR2	58	SI	60	OFST	68	DURJ	70
DUR3	78	DUR5	80	DOP	88	DEK	88	DAK	80
DNK	D*	DUB	80	KS	108	IS	150	ZS	158
DTK	170	ELAT	178	ELON	200	GECH	208	HEAD	210
RATE	218	IDAY	220	SDAY	224	STIM	228	GLAT	230
DLOW	278	SMIE	280	SELY	288	FLAT	280	FLOW	288
TRQ	280	MSQ	288	YB	298	I	298	J	298
K	300	L	304	S	308	A	308	NDUP	310
ITER	314	T	318	TEMP	320	A	328	TO	368

		COMMON BLOCK /COMMON		/ MAP SIZE		128			
SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
SULL	0	IONE	4	ITAG	0	IECA	0	I15	10
I10	14	J	18	IN	10	AE	20	K2	24
L4	28	AVE	30	CVLC	30	LEFQ	40	ONG	48
TRQ	50	CDQ	58	ZERU	60	ONE	68	I40	70
TRR2	78	FOUR	80	FIVE	88	ATE	90	LS	94
TR5	AC	SUSD	18	CMB0	80	STP0	88	TOP1	80
TR8A	18	LTOM	80	TH1	88	TR*	80	TR5	88
TR7	FC	TR8	88	CTR	100	TRK	108	TRK	110
TR8	118	REFC	120						

		COMMON BLOCK /COMMON		/ MAP SIZE		128			
SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION	SYMBOL	LOCATION
S130L	90	SLAT	90						

OPTIONS IN EFFECT ID,ESCDIC,SOURCE,UNITSI,MODECK,LOAD,MAP
 OPTIONS IN EFFECT NAME = AV15 , WILDCAT = 58
 STATISTICS SOURCE STATEMENTS = 15, PROGRAM SIZE = 362
 STATISTICS NO DIAGNOSTICS GENERATED

LEVEL 10 : SEPT 60 :

J37300 FUKIYAN H

DATE 70.196/18.54.52

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COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=50,SIZE=0000K,  
SOURCE,EBCDIC,NULIST,NJDECK,LOAD,MAP,NCEUIT,TD,NXREF  
ISN 0002 SUBROUTINE ARCS (ARG) AKCS  
ISN 0003 DOUBLE PRECISION ARG,X AKCS  
ISN 0004 X=.5D+0 AKCS  
C--THE ACCURACY IS DEPENDENT UPON THE NUMBER OF ITERATIONS AKCS  
ISN 0005 DO 1 I=1,6 AKCS  
ISN 0006 1 X=X+(ARG-DSIN(X))/DCOS(X) AKCS  
ISN 0007 ARG=X*.572957795131D+2 AKCS  
ISN 0008 RETURN AKCS  
ISN 0009 END AKCS
```


/ 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	R*	000098	X	SFA	R*	0000A0	ARG	SF	R*	0000AB	ARCS		R*	00009C
UCOS	XF	R*	000000	DSIN	XF	R*	000000								

LABEL ADDR

LABEL ADDR

LABEL ADDR

LABEL ADDR

PAGE 003

1 00000C

OPTIONS IN EFFECT NAME= MAIN,OPT=02,LINECNT=50,SIZE=0000K,

OPTIONS IN EFFECT SOURCE,EMCDIC,NULIST,NODECK,LOAD,MAP,NOEDIT,IO,NUXPE<

STATISTICS SOURCE STATEMENTS = 8 ,PROGRAM SIZE = 358

STATISTICS NO DIAGNOSTICS GENERATED

***** END OF COMPILATION *****

65K BYTES OF CORE NOT USED

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COMPILER OPTIONS - NAME= MAIN,DPT=02,LIVECNT=58,SIZE=0000K,
SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,IO,NOXREF
ISN 0002 SUBROUTINE TYPE
C
ISN 0003 DOUBLE PRECISION TAN,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 T0P1,DTRA,DT0M,TM1,TM4,TM5,TM8,CNTR,CKRM TYPE
ISN 0006 DOUBLE PRECISION ZERO,FOUR,TM7,C2K,C2M,REFC TYPE
ISN 0007 DOUBLE PRECISION DDP,REF,XS,YS,ZS,ELAT,ELON,GEOM,STIM,HEAD,RATE TYPE
ISN 0008 DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AQ,COME,CMD,C1,XLNG TYPE
ISN 0009 DOUBLE PRECISION DUM1,DUM2,S1,OFST,DUM3,DUM4,DUM5 TYPE
ISN 0010 DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FRQ,RSQ,VN TYPE
ISN 0011 DOUBLE PRECISION T,TEMP,A TYPE
C
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,M,DLATS,DLONS,C4PB TYPE
ISN 0015 DOUBLE PRECISION TEMP4,TEMP5 TYPE
C
C---DIMENSION
ISN 0016 DIMENSION A(3,4) TYPE
ISN 0017 DIMENSION DDP(8),REF(8),XS(9),YS(9),ZS(11),DLAT(9),DLON(9) TYPE
C
C---COMMON
ISN 0018 COMMON TP,XNDT,SOME,SOMD,E,AQ,COME,CMD,C1,XLNG TYPE
ISN 0019 COMMON DUM1,DUM2,S1,OFST,DUM3,DUM4,DUM5,DDP TYPE
ISN 0020 COMMON REF TYPE
ISN 0021 COMMON XS,YS,ZS,DTK,ELAT,ELON,GEOM,HEAD,RATE,1DAY,MUAY,STIM TYPE
ISN 0022 COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FRQ,RSQ,VN TYPE
ISN 0023 COMMON I,J,K,L,M,N,NDOP,ITER TYPE
ISN 0024 COMMON T,TEMP,A TYPE
C
ISN 0025 COMMON /CONC/NULL,IONE,ITWO,IFOR,I15,I30,I365,IM,KM,KF TYPE
ISN 0026 COMMON /CONC/TAN,WAVE,CVCG,EFRQ,OMGE,OSQ,ZOSQ,ZERO TYPE
ISN 0027 COMMON /CONC/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND TYPE
ISN 0028 COMMON /CONC/C480,S7P5,TU1,DTRA,DTOM TYPE
ISN 0029 COMMON /CONC/TM1,TM4,TM5,TM7,TM8,CNTR,CKRM,C2K,C2M,REFC TYPE
C
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),M) 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
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 0043 WRITE(8,111) TEMP TYPE
ISN 0044 111 FORMAT(F5.1) TYPE

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ISN 0045 TEMP=(STIM*FOUR)*CNTR TYPE
ISN 0046 CALL UCOS 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-SLAT)/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,TEMP4,TEMP5,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.E7393780D-02 TYPE
ISN 0064 A1=-0.93137062D+0 TYPE
ISN 0065 A2=0.2134908D+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=1.4D+TEMP TYPE
ISN 0074 V=ONE+TGT*(ONE-THRE*S2LAT/TWO) TYPE
ISN 0075 M=ONE-EDOT*S2LAT/TWO TYPE
ISN 0076 DLATS=((A1)*TEMP3+A2*TEMP2)*TEMP+A3*TEMP1)*V TYPE
ISN 0077 *((A4)*S2LAT+A5)*TEMP*TEMP1 TYPE
ISN 0078 DLONS=(A1)*TEMP2-A2*TEMP3)*TEMP1 TYPE
ISN 0079 C1=4.369136811D-06 TYPE
ISN 0080 FLAT=FLAT+C4PB*DLATS TYPE
ISN 0081 FLON=FLON+C4PB*DLONS TYPE
ISN 0082 I=-1 TYPE
ISN 0083 GO TO 190 TYPE
ISN 0084 103 RETURN TYPE
ISN 0085 END TYPE

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NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	NAME	TAG	TYPE	ADD.	
A	CE	R#B	000328	E	C	R#B	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#B	N.R.	V SF	CE	R#B	000360	W SF	CE	R#B	000378	AO	C	R#B	N.R.	
A1 SF	R#B	000120	A2 SF	R#B	000128	A3 SF	R#B	000130	A4 SF	R#B	000138	KF	C	I#4	N.R.	
A5 SF	R#B	000140	CI	C	R#B	N.R.	IM	C	I#4	N.R.	VN	C	R#B	N.R.		
X	C	I#4	N.R.	SI	C	R#B	N.R.	TP	C	R#B	N.R.	ATE	C	R#B	N.R.	
YS	C	R#B	N.R.	YS	C	R#B	N.R.	ZS	C	R#B	N.R.	DTK	C	R#B	N.R.	
C2K	C	R#B	N.R.	C2M	C	R#B	N.R.	USP	C	R#B	N.R.	JNE F	C	R#B	000068	
U60	FA	C	0000A0	I15	C	I#4	N.R.	I30	C	I#4	N.R.	TEN	C	R#B	N.R.	
FF	C	R#B	N.R.	RSQ	C	R#B	N.R.	TAM	C	R#B	N.R.	TM7	C	R#B	N.R.	
T#1	C	R#B	N.R.	TM4	C	R#B	N.R.	TM5	C	R#B	N.R.	CKPM	C	R#B	N.R.	
TM8	C	R#B	N.R.	THD F	C	R#B	000070	ARCS SF	XF	R#B	000000	CVCG	C	R#B	N.R.	
CMTR	F	C	000100	COMD	C	R#B	N.R.	COME	C	R#B	N.R.	DLUN	C	R#B	N.R.	
C4P8 SF	R#B	000148	C4B0	C	R#B	N.R.	DLAT	C	R#B	N.R.	DUM2	C	R#B	N.R.		
DTUM	C	R#B	N.R.	DTRA F	C	R#B	0000C8	DUM1	C	R#B	N.R.	EDGT SF	CE	R#B	000328	
DUM3	C	R#B	N.R.	DUM4	C	R#B	N.R.	DUM5	C	R#B	N.R.	FFRQ F	C	R#B	0002E0	
FRQ	F	C	000040	ELAT F	C	R#B	0001F8	ELGN F	C	R#B	0002C0	FOUR F	C	R#B	000080	
FIVE	C	R#B	N.R.	FLAT SFA	C	R#B	0002U0	FLOM SFA	C	R#B	0002D8	ITER	C	I#4	N.R.	
GEUH	C	R#B	N.R.	HEAD	C	R#B	N.R.	HUND	C	R#B	0000A8	NULL	C	I#4	N.R.	
IFOR	C	I#4	N.R.	IONE	C	I#4	N.R.	ITER	F	C	I#4	000314	REFC	C	R#B	N.R.
I365	C	I#4	N.R.	MDAY	C	I#4	N.R.	NDOP	F	C	I#4	000310	SOME	C	R#B	N.R.
OFST	C	R#B	N.R.	MGGE	C	R#B	N.R.	RATE	C	R#B	N.R.	THRE	F	C	R#B	000078
SELV	C	R#B	N.R.	SMXE F	C	R#B	0002C0	SUND	C	R#B	N.R.	WAVE	C	R#B	N.R.	
STIM F	C	R#B	000278	S7P5	C	R#B	N.R.	TEMP SFA	C	R#B	000320	ZERU	C	R#B	N.R.	
TOPI	C	R#B	N.R.	TYPE	C	R#B	N.R.	UCON SF	XF	R#B	000000	ITER	C	I#4	000314	
XLNG	C	R#B	N.R.	XNDT	C	R#B	N.R.	XDSQ	C	R#B	N.R.	S2LAT SF	CE	R#B	000348	
ZOSQ	C	R#B	N.R.	DLATS SF	CE	R#B	000338	DLNS SF	CE	R#B	000350	TEMP4 SFA	CE	R#B	000368	
TEMP1 SF	CE	R#B	000358	TEMP2 SF	CE	R#B	000370	TEMP3 SFA	CE	R#B	000380	IBCCM#	F	XF	R#B	000000
TEMP5 SF	CE	R#B	000380	USIN	XF	R#B	000000	DCUS	XF	R#B	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#B	N.R.	XNDT	R#B	N.R.	SOME	R#B	N.R.	SOMD	R#B	N.R.
E	R#B	N.R.	AU	R#B	N.R.	COME	R#B	N.R.	COMD	R#B	N.R.
CI	R#B	N.R.	XLNG	R#B	N.R.	DUM1	R#B	N.R.	DUM2	R#B	N.R.
SI	R#B	N.R.	OFST	R#B	N.R.	DUM3	R#B	N.R.	DUM4	R#B	N.R.
DUM5	R#B	N.R.	DOP	R#B	N.R.	REF	R#B	N.R.	XS	R#B	N.R.
YS	R#B	N.R.	ZS	R#B	N.R.	DTK	R#B	N.R.	ELAT	I#B	0001F8
ELON	R#B	000200	GEDH	R#B	N.R.	HEAD	R#B	N.R.	RATE	R#B	N.R.
IDAY	I#4	N.R.	MDA:	I#4	N.R.	STI1	R#B	000228	DLAT	R#B	N.R.
DLON	R#B	N.R.	SMXE	R#B	0002C0	SELV	R#B	N.R.	FLAT	R#B	0002D0
FLOM	R#B	0002D8	FFRQ	R#B	0002E0	RSQ	R#B	N.R.	VN	R#B	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#B	N.R.	TEMP	R#B	000320	A	R#B	000328			

EQUIVALENCED VARIABLE	VAR. NAME	OFFSET	VAR. NAME	OFFSET	VARIABLE	OFFSET	VARIABLE	OFFSET
EDOT	EDOT	000328	TEMP1	000358	TEMP2	000370	TEMP3	000380

PAGE 004

S2LAT	000348	V	000360	M	000378	DLATS	000338
DLUNS	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.
VULL	I#4	N.R.	IUNE	I#4	N.R.	ITND	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.	TAM	R#B	N.R.	WAVE	R#B	N.R.
CVCG	R#B	N.R.	EFRO	R#B	000040	DMGE	R#B	N.R.	XOSQ	R#B	N.R.
ZOSQ	R#B	N.R.	ZERU	R#B	N.R.	ONE	R#B	000068	THD	R#B	000070
THRE	R#B	000078	FOUR	R#B	000080	FIVF	R#B	N.R.	ATE	R#B	N.R.
TEN	R#B	N.R.	D60	R#B	0000A0	HUND	R#B	0000A8	C480	R#B	N.R.
S7P5	R#B	N.R.	TOPI	R#B	N.R.	DTRA	R#B	0000C8	DTOM	R#B	N.R.
TM1	R#B	N.R.	TM4	R#B	N.R.	TM5	R#B	N.R.	TM7	R#B	N.R.
TM8	R#B	N.R.	CMTR	R#B	000100	CKRM	R#B	N.R.	C2K	R#B	N.R.
C2M	R#B	N.R.	REFC	R#B	N.R.						

LABEL ADDR	LABEL ADDR	LABEL ADDR	LABEL ADDR	PAGE 005
10 000180 NR	190 0J028A	102 000*1E	103 00052C	

OPTIONS IN EFFECT NAME= MAIN,CPT=02,LINECNT=56,SIZE=0000K,

OPTIONS IN EFFECT SOURCE,FBCDIC,NJLIST,MODECK,LOAD,MAP,NOEDIT,IO,NOXREF
STATISTICS SOURCE STATEMENTS = 83 ,PROGRAM SIZE = 1360
STATISTICS NO DIAGNOSTICS GENERATED
***** END OF COMPILATION *****

57K BYTES OF CORE NOT USED

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINECNT=58,SIZE=0000K,
SOURCE,EBCDIC,NULIST,NUDECK,LUAU,MAP,NUEDIT,IO,NOXREF

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ISN 0002      SUBROUTINE UCON                                UCON
               C                                            UCON
ISN 0003      DOUBLE PRECISION TAN,WAVE,CVCG,EFREQ,OMGE,XDSQ,ZDSQ  UCON
ISN 0004      DOUBLE PRECISION ONE,TWO,THRE,FIVE,ATE,TEN,D60,HUND,C480,STPS  UCON
ISN 0005      DOUBLE PRECISION TUPI,DTRA,DTUN,TM1,TM4,TM5,TM6,CMTR,CKRM      UCON
ISN 0006      DOUBLE PRECISION ZERO,FOUR,TM7,CZK,C2M,REFC                UCON
ISN 0007      DOUBLE PRECISION DUP,REF,DF,DA,DN,ELAT,ELON,GEO,1,ETIM,HEAD,RATE  UCON
ISN 0008      DOUBLE PRECISION DTK,TP,XNDT,SOME,SOMD,E,AD,COME,COMD,C1,XLMG  UCON
ISN 0009      DOUBLE PRECISION DUM1,DUM2,S1,DFST,DUM3,DUM4,DUM5            UCON
ISN 0010      DOUBLE PRECISION DLAT,DLON,SMXE,SELV,FLAT,FLON,FRQ,RSG,VN     UCON
ISN 0011      DOUBLE PRECISION T,TEMP,A,DUM                                  UCON
ISN 0012      DOUBLE PRECISION Y,Z                                          UCON
               C                                            UCON
ISN 0013      C---DIMENSIONS                                                UCON
ISN 0014      DIMENSION DDP(8),REF(8),DE(9),DA(9),DN(11),DLAT(9),DLON(9)  UCON
               DIMENSION AT(3,4),DUM(10)                                    UCON
               C                                            UCON
ISN 0015      C---COMMON                                                    UCON
ISN 0016      COMMON TP,XNDT,SOME,SOMD,E,AD,COME,COMD,C1,XLMG             UCON
ISN 0017      COMMON DUM1,DUM2,S1,DFST,DUM3,DUM4,DUM5,DDP                 UCON
ISN 0018      COMMON REF                                                    UCON
ISN 0019      COMMON DE,DA,DN,DTK,ELAT,ELON,GEO,HEAD,RATE,1,DAY,MDAY,ETIM  UCON
ISN 0020      COMMON DLAT,DLON,SMXE,SELV,FLAT,FLON,FRQ,RSG,VN            UCON
ISN 0021      COMMON I,J,K,L,M,N,NDOP,ITEK                                   UCON
ISN 0022      COMMON T,TEMP,A,DUM                                           UCON
               C                                            UCON
ISN 0023      COMMON /COMMON/NULL,1ONE,ITWO,IFUR,I15,I30,I365,IM,KM,KF     UCON
ISN 0024      COMMON /COMMON/TAN,WAVE,CVCG,EFREQ,OMGE,XDSQ,ZDSQ,ZERO      UCON
ISN 0025      COMMON /COMMON/ONE,TWO,THRE,FOUR,FIVE,ATE,TEN,D60,HUND      UCON
ISN 0026      COMMON /COMMON/C480,STPS,TUPI,DTRA,DTUN                       UCON
               C                                            UCON
ISN 0027      COMMON /COMMON/TM1,TM4,TM5,TM7,TM6,CMTR,CKRM,CZK,C2M,REFC    UCON
               C                                            UCON
ISN 0028      EQUIVALENCE (REF(1),Y),(REF(2),Z),                            UCON
ISN 0029      Y=(TEMP/DTRA)+TM7                                             UCON
ISN 0030      L=Y                                                            UCON
ISN 0031      Z=L                                                            UCON
ISN 0032      Y=DABS((Y-Z)*D60)                                             UCON
ISN 0033      M=Y                                                            UCON
ISN 0034      M=(M-Z)/TM6                                                  UCON
ISN 0035      RETURN                                                         UCON
ISN 0036      END                                                            UCON

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NAME	TAG	TYPE	ADDR.	NAME	TAG	TYPE	ADDR.	NAME	TAG	TYPE	ADDR.	NAME	TAG	TYPE	ADDR.		
A	C	R#8	N.R.	F	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	CL	R#8	0000C8	Z SFA	CE	R#8	0000D0	AO	C	R#8	N.R.		
CI	C	R#8	N.R.	(A	C	R#8	N.R.	UE	C	R#8	N.R.	UN	C	R#8	N.R.		
IM	C	I#4	N.R.	NI	C	I#4	N.R.	KM	L	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.	CZK	C	R#8	N.R.		
CZM	C	R#8	N.R.	ULP	C	R#8	N.R.	DTK	C	R#8	N.R.	DUM	C	R#8	N.R.		
DOJ	FA	C	R#8	ILS	C	I#4	N.R.	I30	C	I#4	N.R.	JNE	C	R#8	N.R.		
REF	C	R#8	0000C8	MSQ	C	R#8	N.R.	TAM	C	R#8	N.R.	TEN	C	R#8	N.R.		
TM1	C	R#8	N.R.	TM4	F	C	R#8	0000E0	TMS	C	R#8	N.R.	TM7	F	C	R#8	0000F0
TM8	C	R#8	N.R.	TM0	C	R#8	N.R.	CKRM	C	R#8	N.R.	CMTR	C	R#8	N.R.		
COMD	C	R#8	N.R.	CJME	C	R#8	N.R.	CVCG	C	R#8	N.R.	C480	C	R#8	N.R.		
DLAT	C	R#8	N.R.	DLUM	L	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.		
LUM5	C	R#8	N.R.	LFHQ	C	R#8	N.R.	ELAT	C	R#8	N.R.	ELUN	C	R#8	N.R.		
FLUN	C	R#8	N.R.	IFRQ	C	R#8	N.R.	FIVE	C	R#8	N.R.	FLAT	C	R#8	N.R.		
HUND	C	R#8	N.R.	FJUR	C	R#8	N.R.	GEOR	C	R#8	N.R.	HEAD	C	R#8	N.R.		
ITER	C	I#4	N.R.	IDAY	C	R#8	N.R.	IFOR	C	I#4	N.R.	IGNE	C	I#4	N.R.		
NDOP	C	I#4	N.R.	ITWD	C	R#8	N.R.	I365	C	I#4	N.R.	NDAY	C	I#4	N.R.		
KATE	C	R#8	N.R.	NULL	C	R#8	N.R.	UFST	C	R#8	N.R.	UMGE	C	R#8	N.R.		
SMD	C	R#8	N.R.	REFC	C	R#8	N.R.	SELY	C	R#8	N.R.	SMXE	C	R#8	N.R.		
THRE	C	R#8	N.R.	SCME	C	R#8	N.R.	S7P5	C	R#8	N.R.	TEMP	F	C	R#8	000320	
XLHG	C	R#8	N.R.	TOPJ	C	R#8	N.R.	UCON	R#4	00008C	NAVE	C	R#8	N.R.			
ZOSQ	C	R#8	N.R.	XNDT	C	R#8	N.R.	XOSQ	C	R#8	N.R.	ZERO	C	R#8	N.R.		

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

NAME OF COMMON BLOCK *				* SIZE OF BLOCK				000308 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.	SCME	R#8	N.R.	SCMD	R#8	N.R.
E	R#8	N.R.	AO	R#8	N.R.	CJME	R#8	N.R.	COMD	R#8	N.R.
CI	R#8	N.R.	XLHG	R#8	N.R.	DUM1	R#8	N.R.	DUM2	R#8	N.R.
SI	R#8	N.R.	UFST	R#8	N.R.	DUM3	R#8	N.R.	DUM4	R#8	N.R.
DUM5	R#8	N.R.	DDP	R#8	N.R.	REF	R#8	0000C8	UE	R#8	N.R.
DA	R#8	N.R.	DN	R#8	N.R.	DTK	R#8	N.R.	ELAT	R#8	N.R.
FLUN	R#8	N.R.	GEOR	R#8	N.R.	HEAD	R#8	N.R.	KATE	R#8	N.R.
IDAY	I#4	N.R.	PDAY	I#4	N.R.	ETIM	R#8	N.R.	DLAT	R#8	N.R.
DLON	R#8	N.R.	SMXE	R#8	N.R.	SELY	R#8	N.R.	FLAT	R#8	N.R.
FLUN	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	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.	VAR. NAME	TYPE	REL. ADDR.	
NULL	I#4	N.R.	JNE	I#4	N.R.	ITWD	I#4	N.R.	IFCR	I#4	N.R.				
I35	I#4	N.R.	I30	I#4	N.R.	I365	I#4	N.R.	IM	I#4	N.R.				
KM	I#4	N.R.	MF	I#4	N.R.	TAM	R#8	N.R.	NAVE	R#8	N.R.				
CVCG	R#8	N.R.	EFHQ	R#8	N.R.	UMGE	R#8	N.R.	XOSQ	R#8	N.R.				
ZOSQ	R#8	N.R.	ZERU	R#8	N.R.	JNE	R#8	N.R.	TM0	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.	TOPJ	R#8	N.R.	DTRA	R#8	0000C8	DTOM	R#8	N.R.				
TM1	R#8	N.R.	TM4	R#8	0000E0	TMS	R#8	N.R.	TM7	R#8	0000F0				
TM8	R#8	N.R.	CMTR	R#8	N.R.	CKRM	R#8	N.R.	CZK	R#8	N.R.				
CZM	R#8	N.R.	REFC	R#8	N.R.										

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

OPTIONS IN EFFECT SOURCE,EBCDIC,LIST,MODECK,LOAD,MAP,NOEDIT,IO,NUSREF

STATISTICS SOURCE STATEMENTS = 35 ,PROGRAM SIZE = 42K

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.
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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.

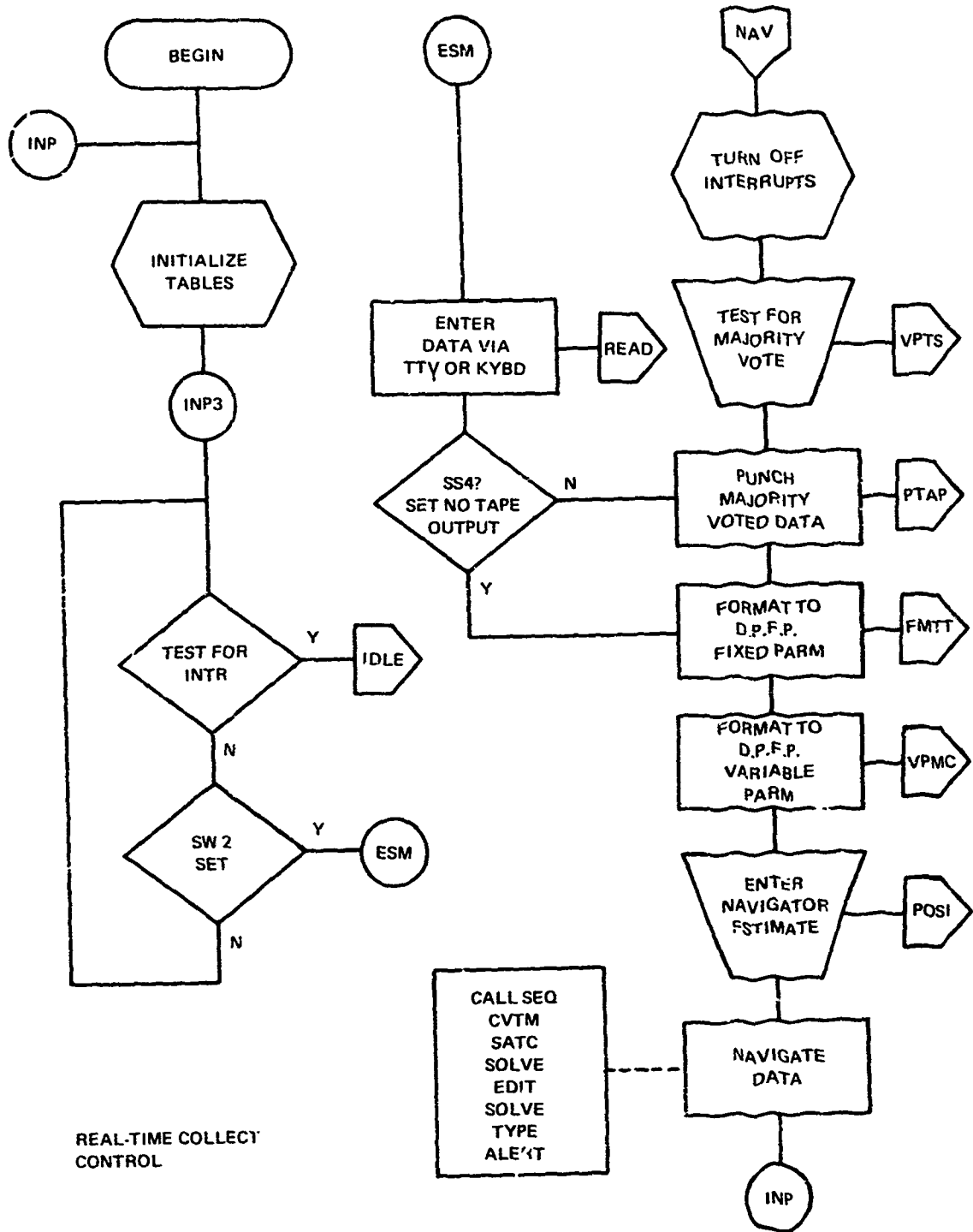


Fig. A-1 SUBROUTINES INP3, ESM, AND NAV

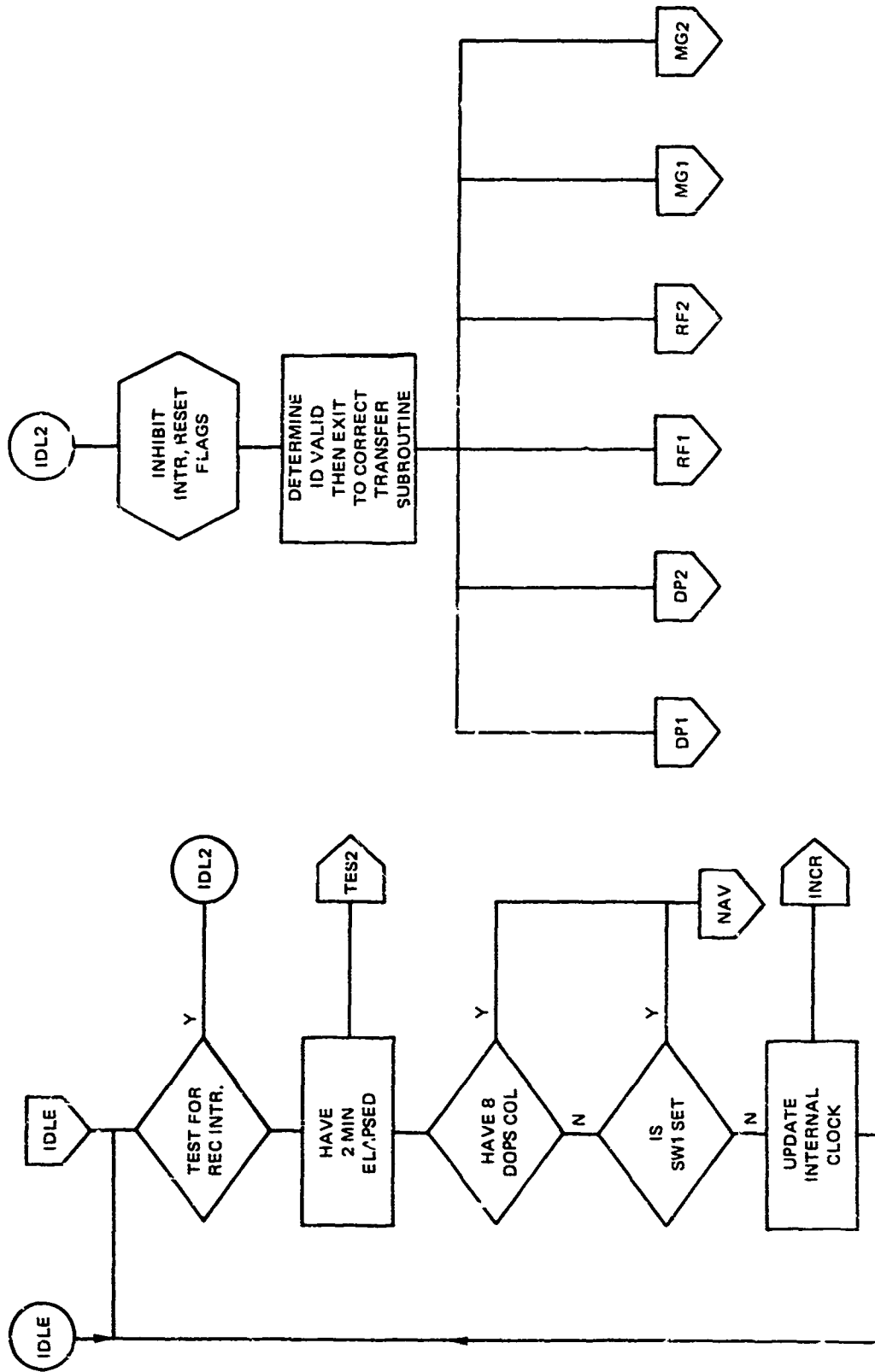


Fig. A-2 SUBROUTINES IDLE AND IDL2

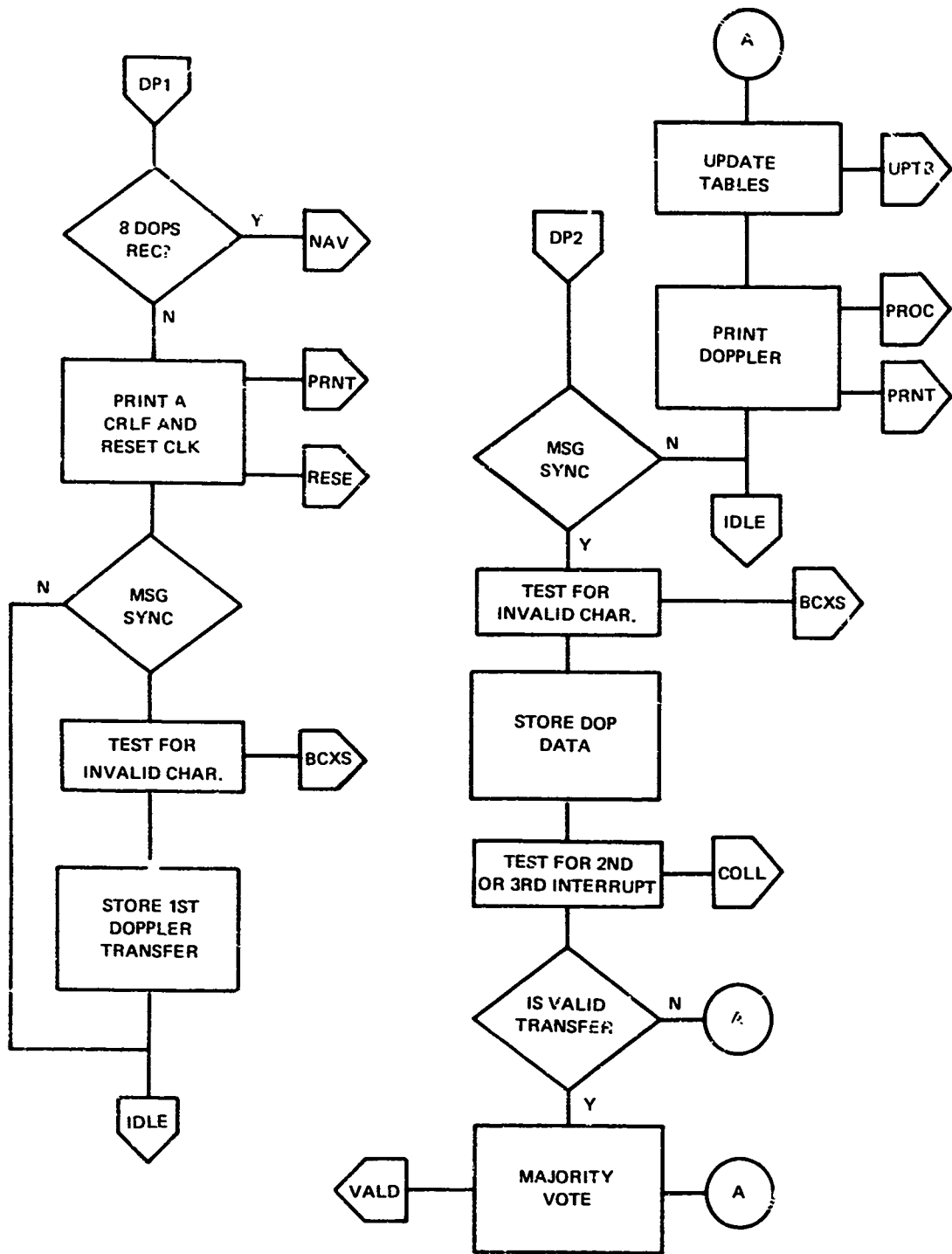


Fig. A-3 SUBROUTINES DP1 AND DP2

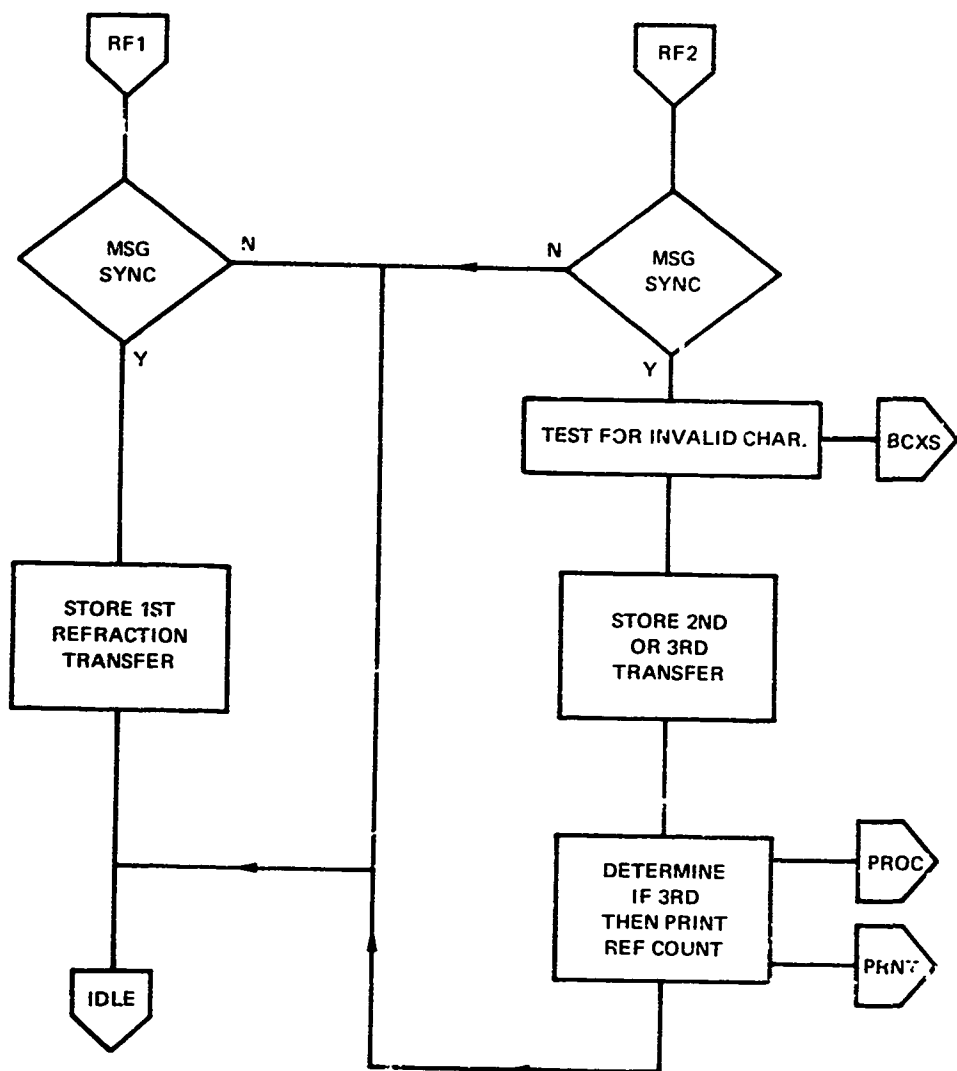


Fig. A-4 SUBROUTINES RF1 AND RF2

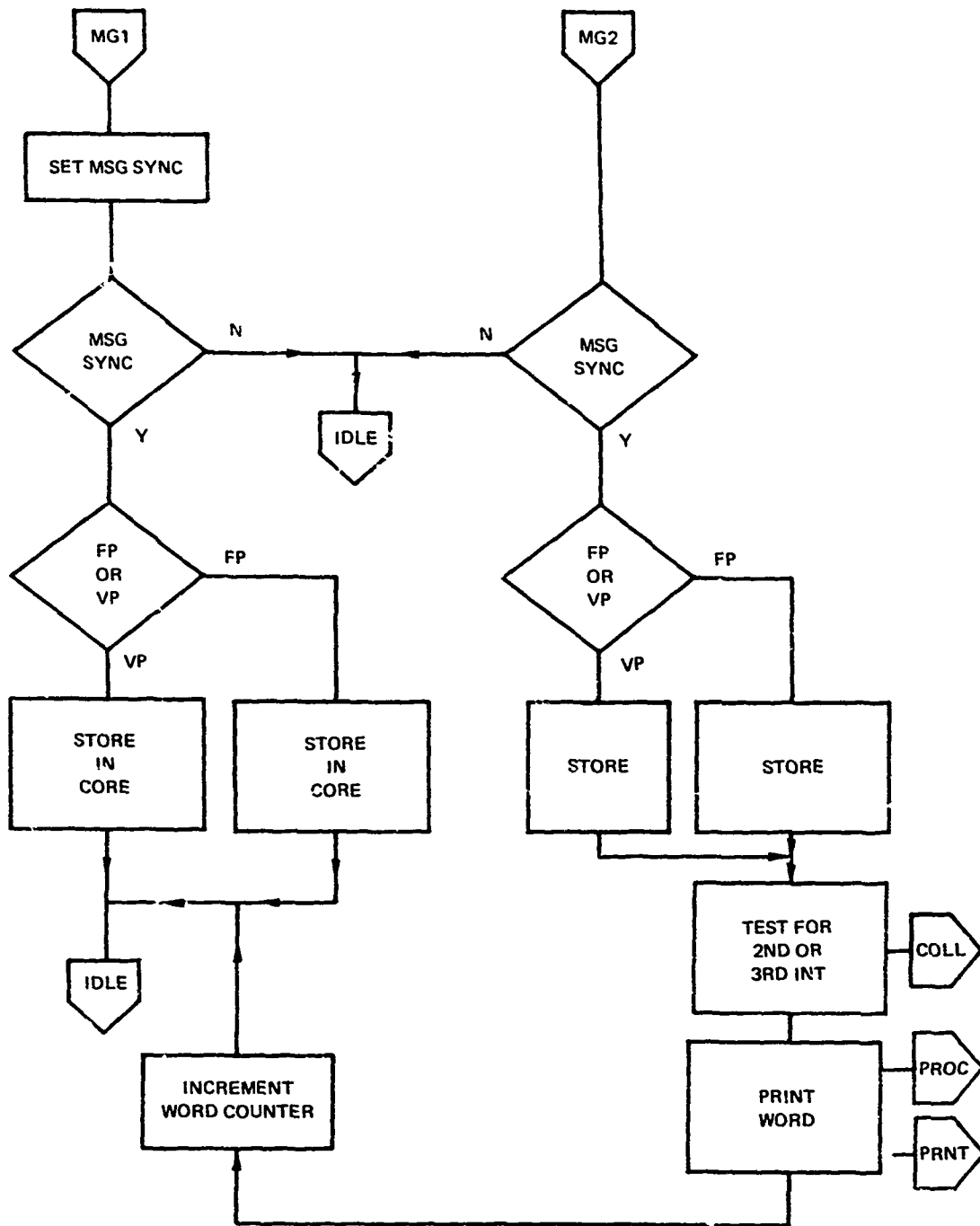


Fig. A-5 SUBROUTINES MG1 AND MG2

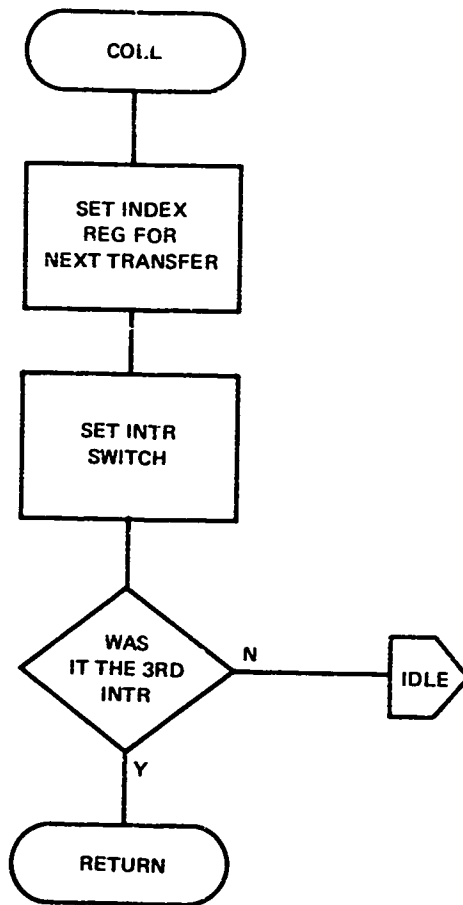


Fig. A-6 SUBROUTINE COLL

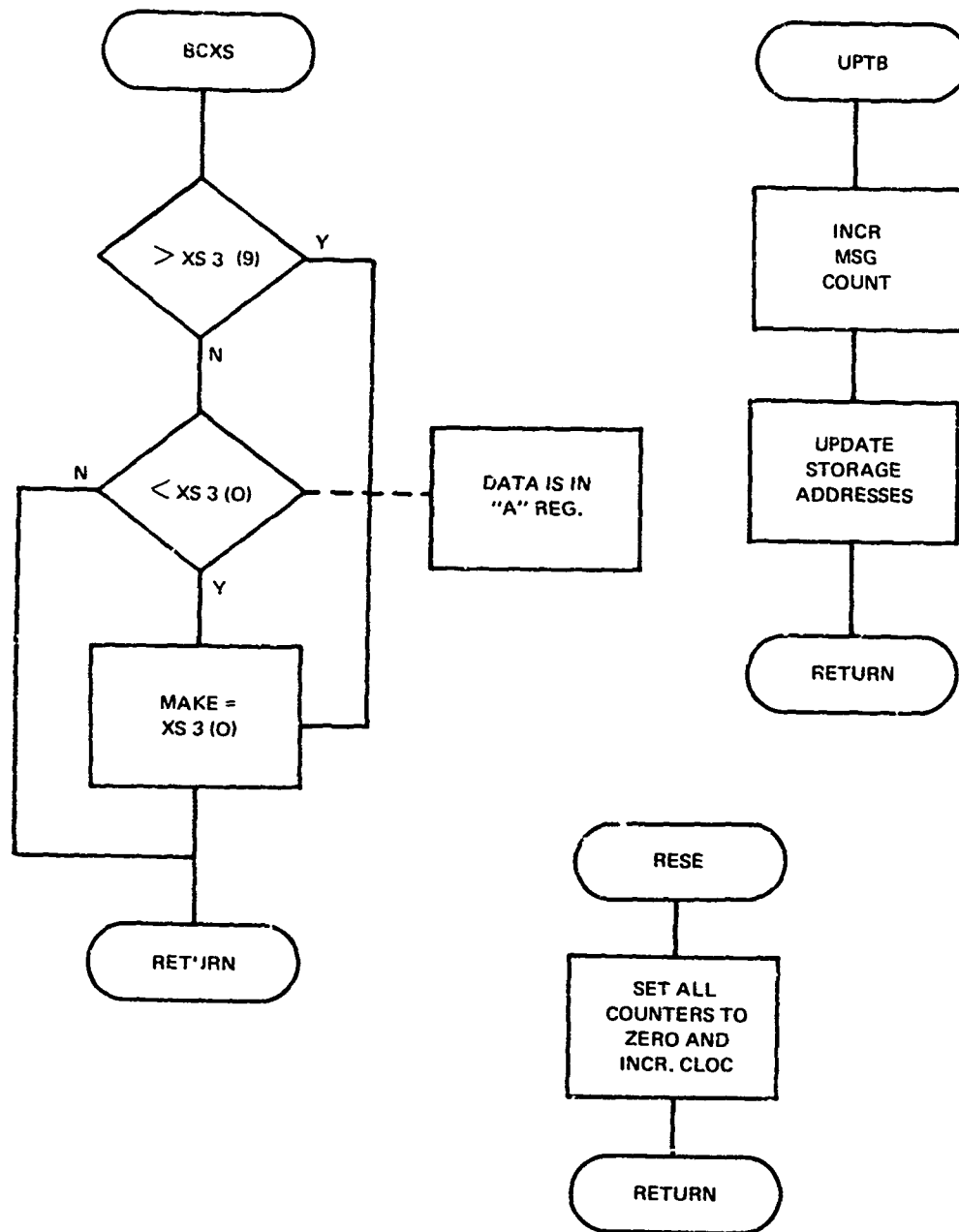


Fig. A-7 SUBROUTINES BCXS, UPTB, AND RESE

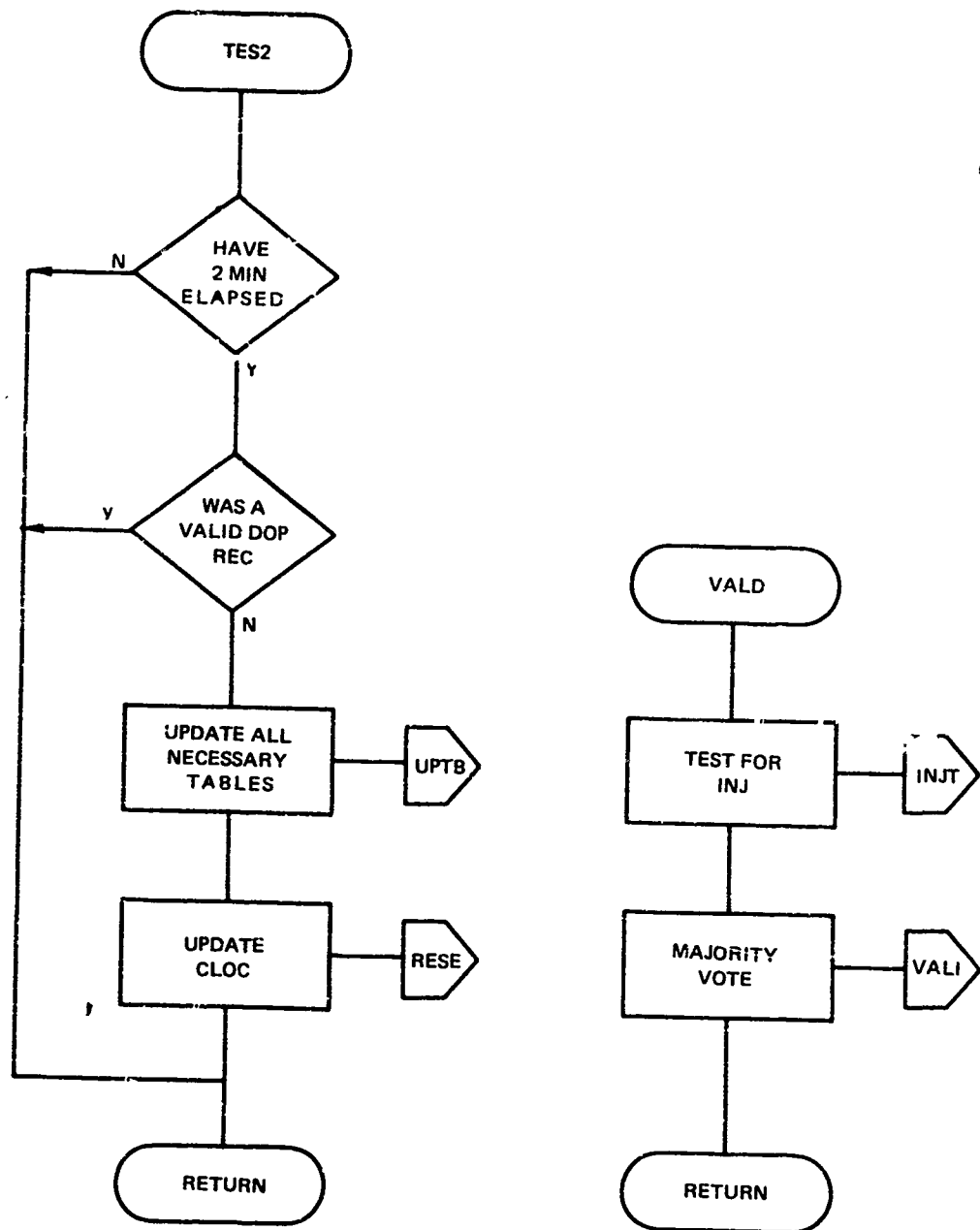


Fig. A-8 SUBROUTINES TES2 AND VALD

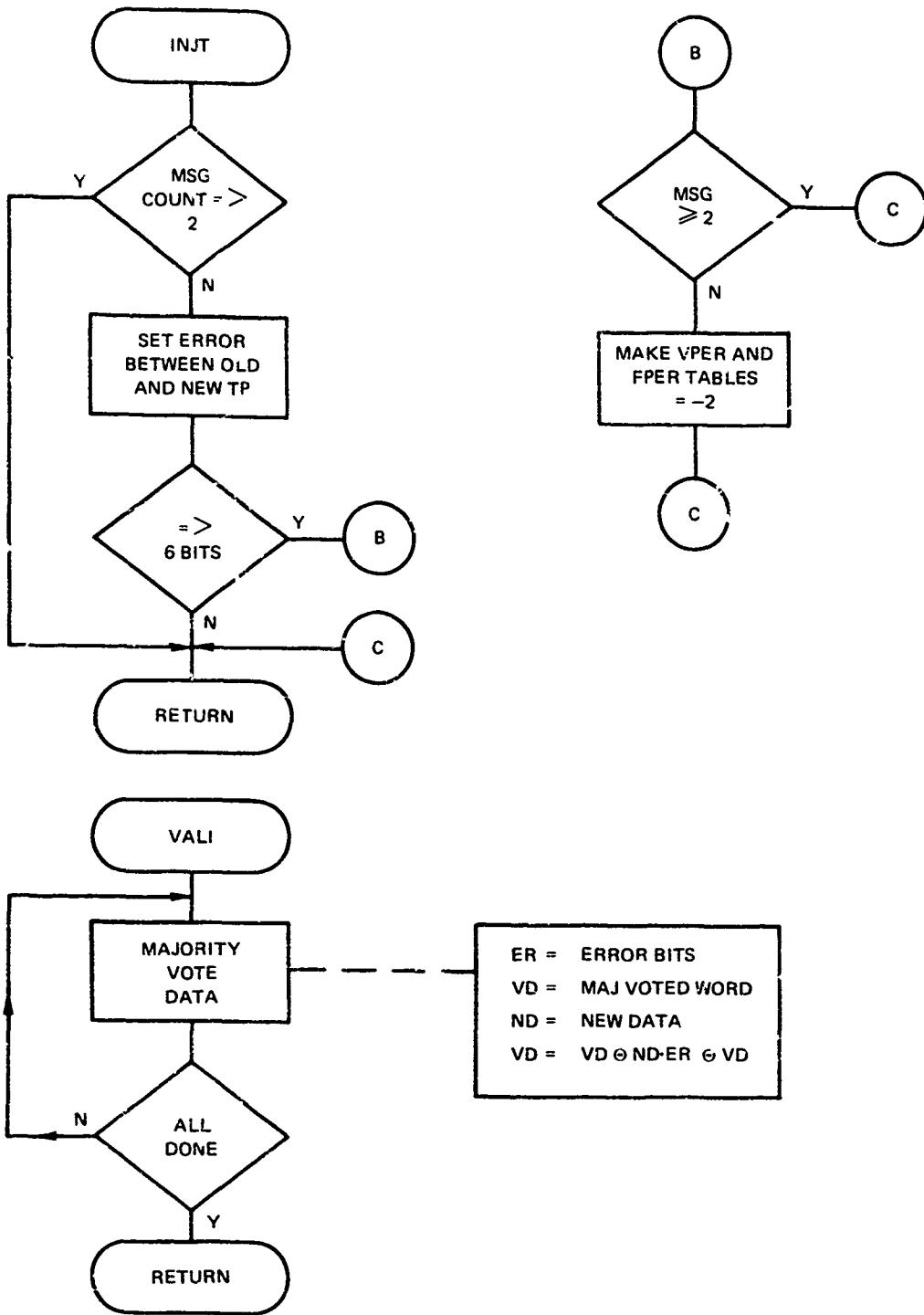


Fig. A-9 SUBROUTINES INJT AND VALI

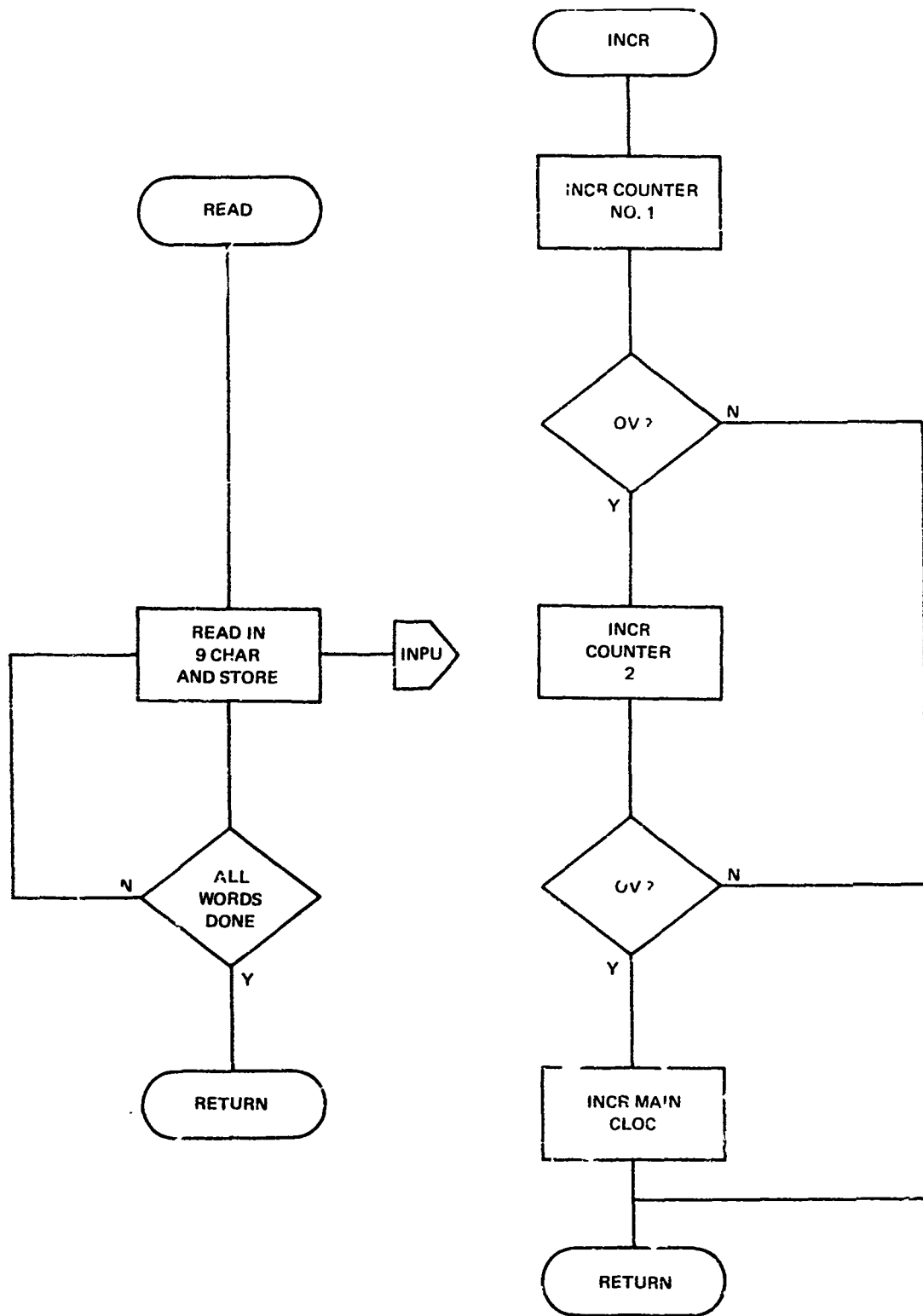


Fig. A-10 SUBROUTINES READ AND INCR

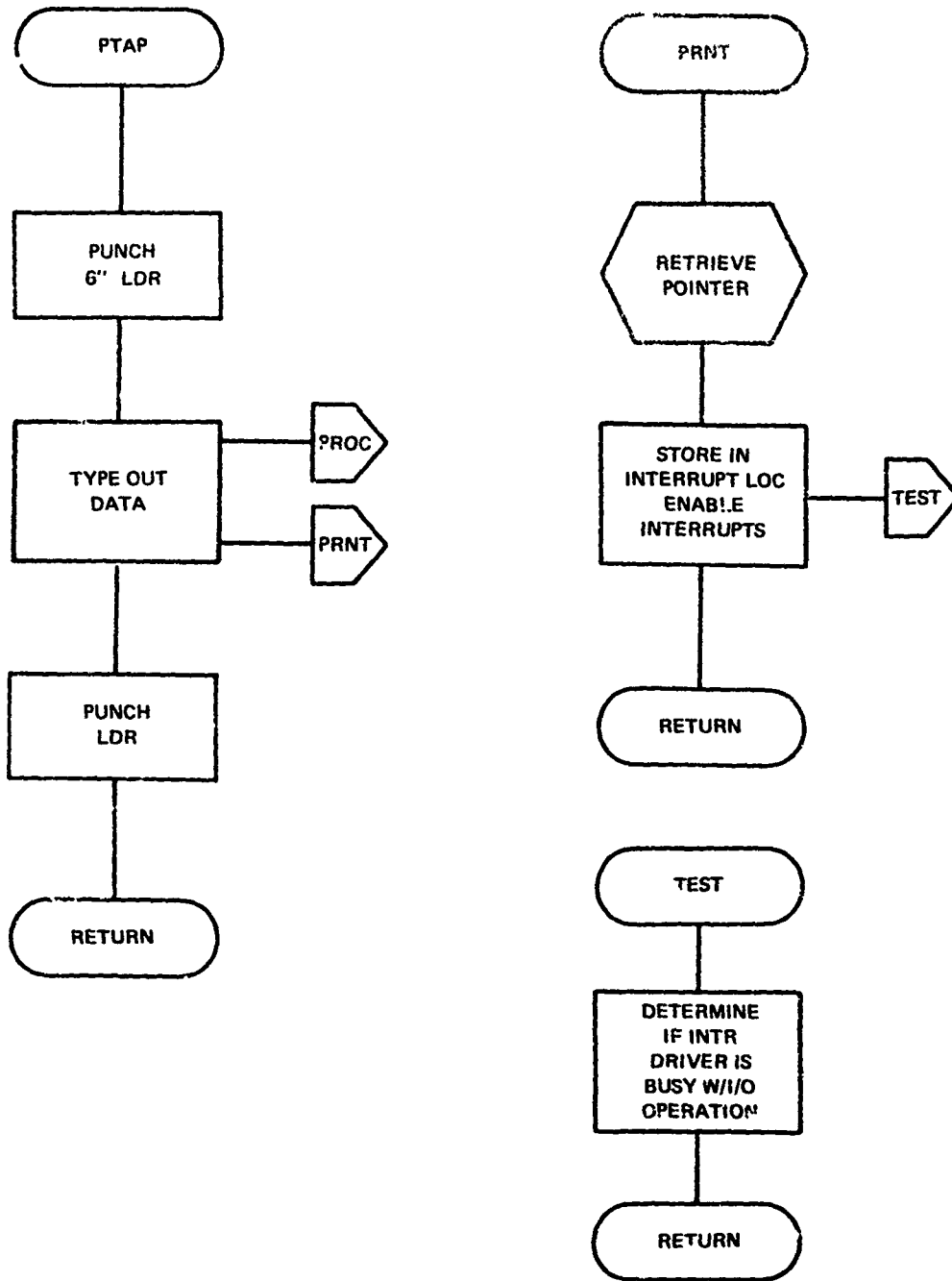


Fig. A-11 SUBROUTINES PTAP, PRNT, AND TEST

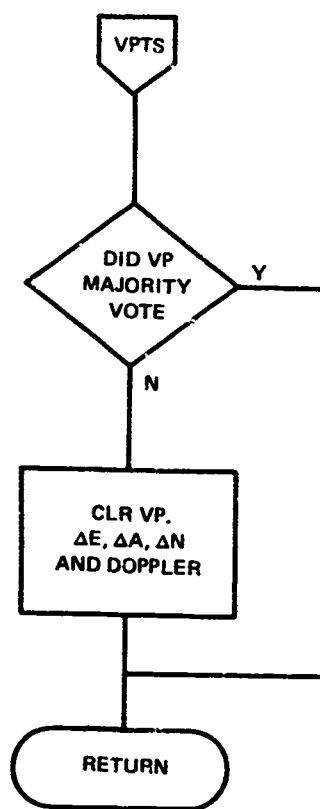


Fig. A-12 SUBROUTINE VPTS

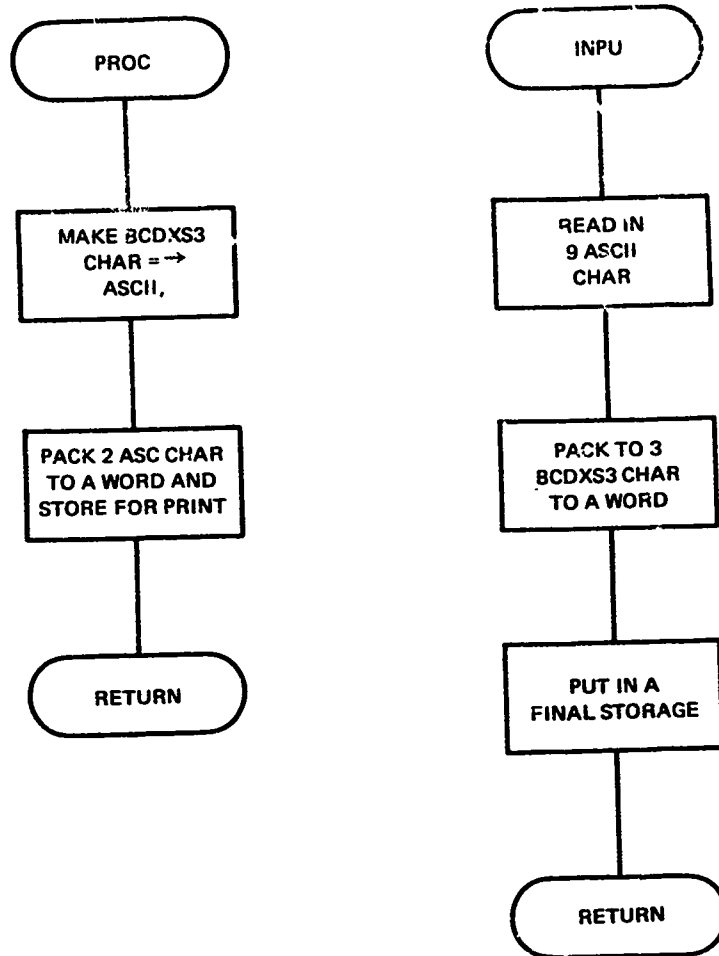


Fig. A-13 SUBROUTINES PROC AND INPU

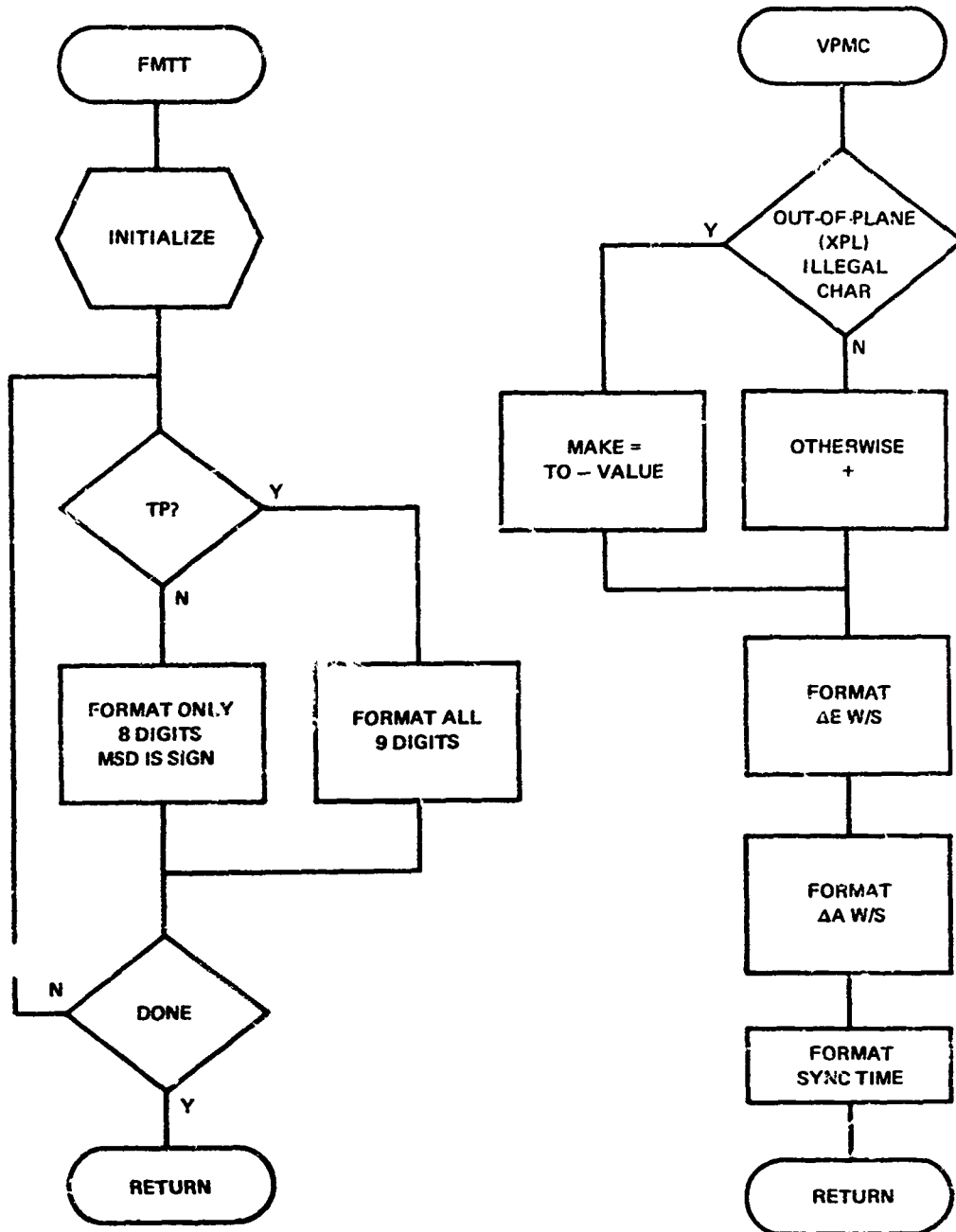


Fig. A-14 SUBROUTINES FMTT AND VPMC

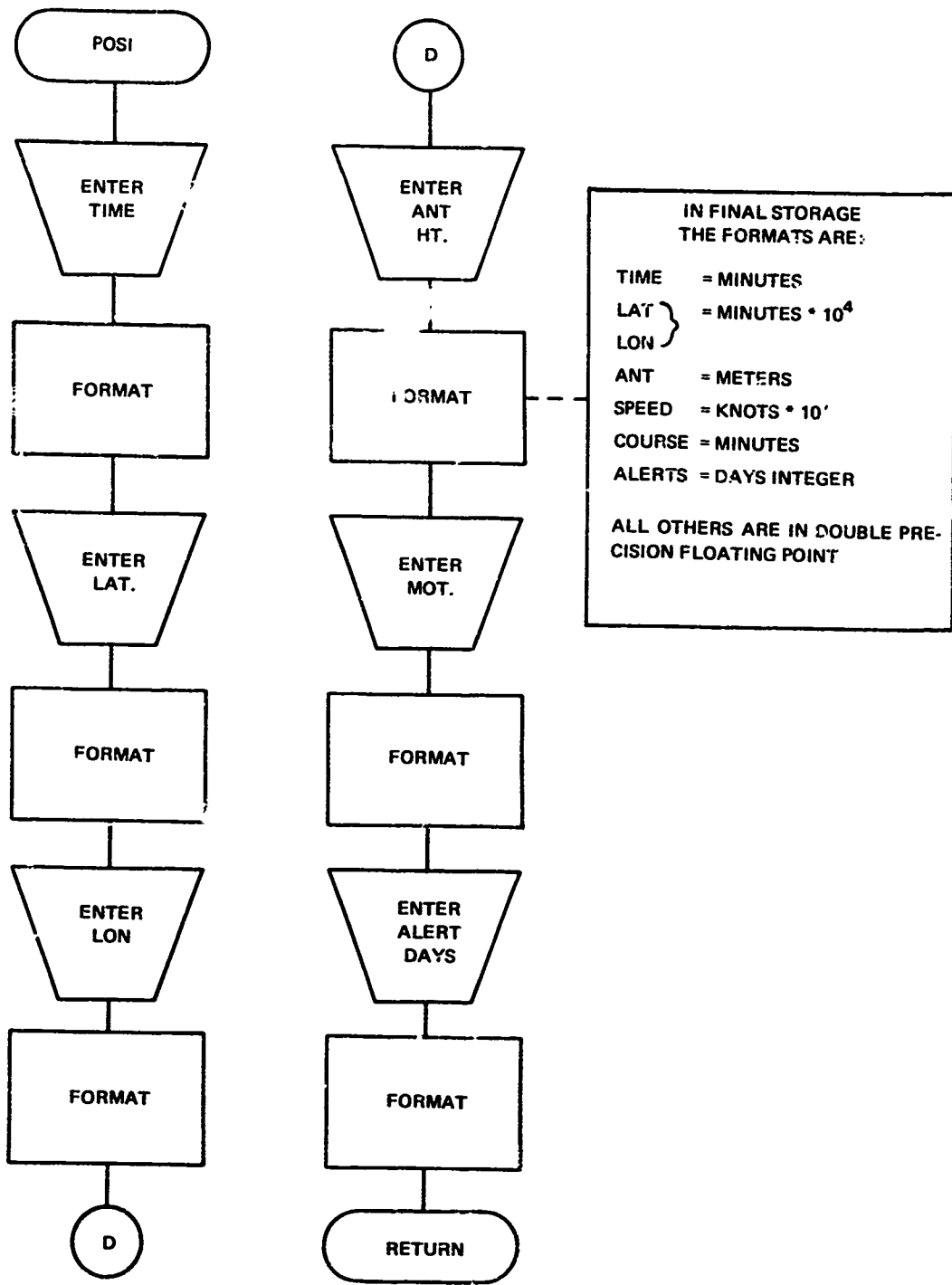


Fig. A-15 SUBROUTINE POSI

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

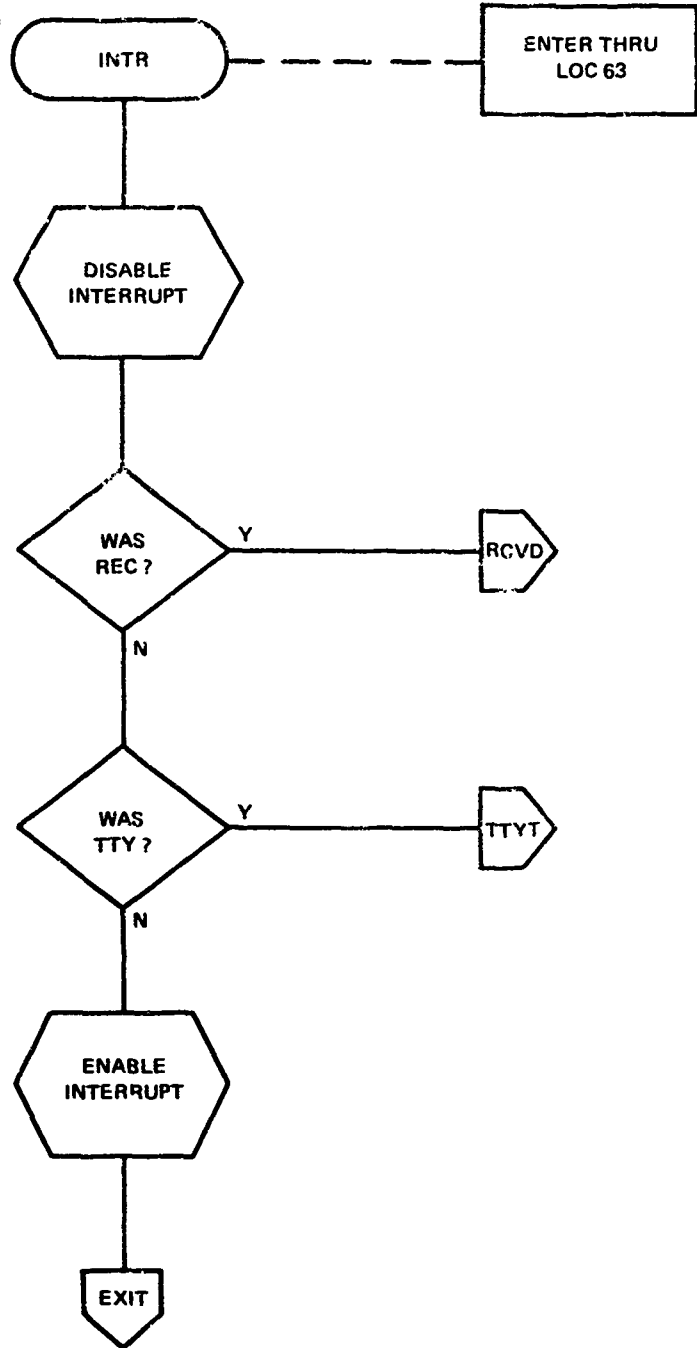


Fig. A-16 SUBROUTINE INTR

SUBROUTINE RCVD

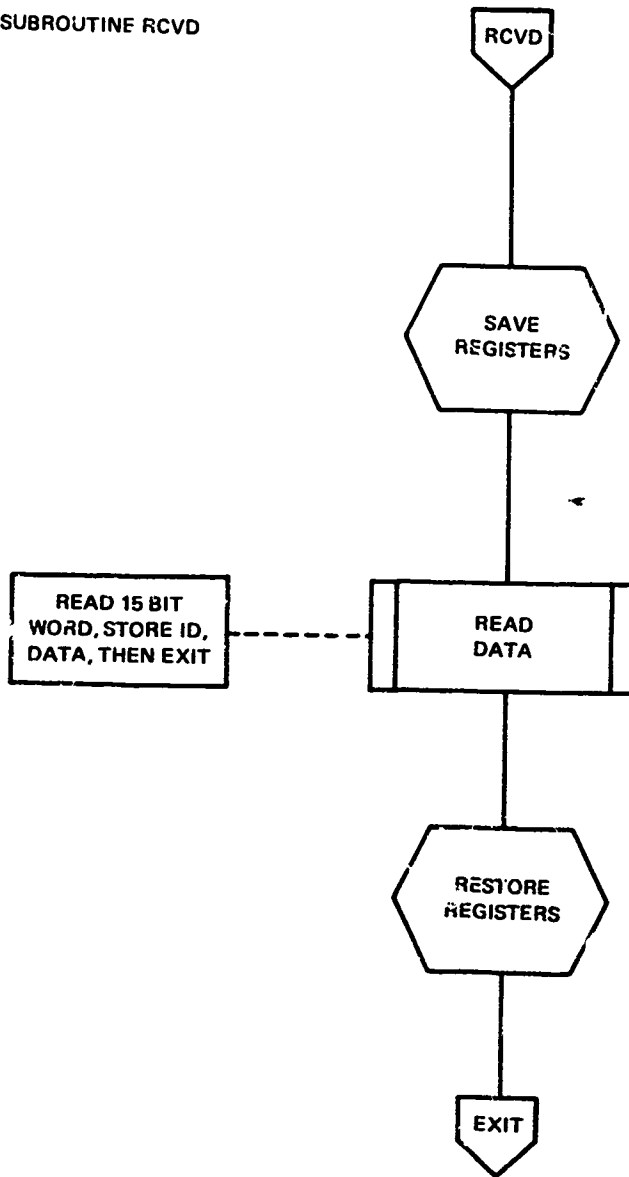


Fig. A-17 SUBROUTINE RCVD

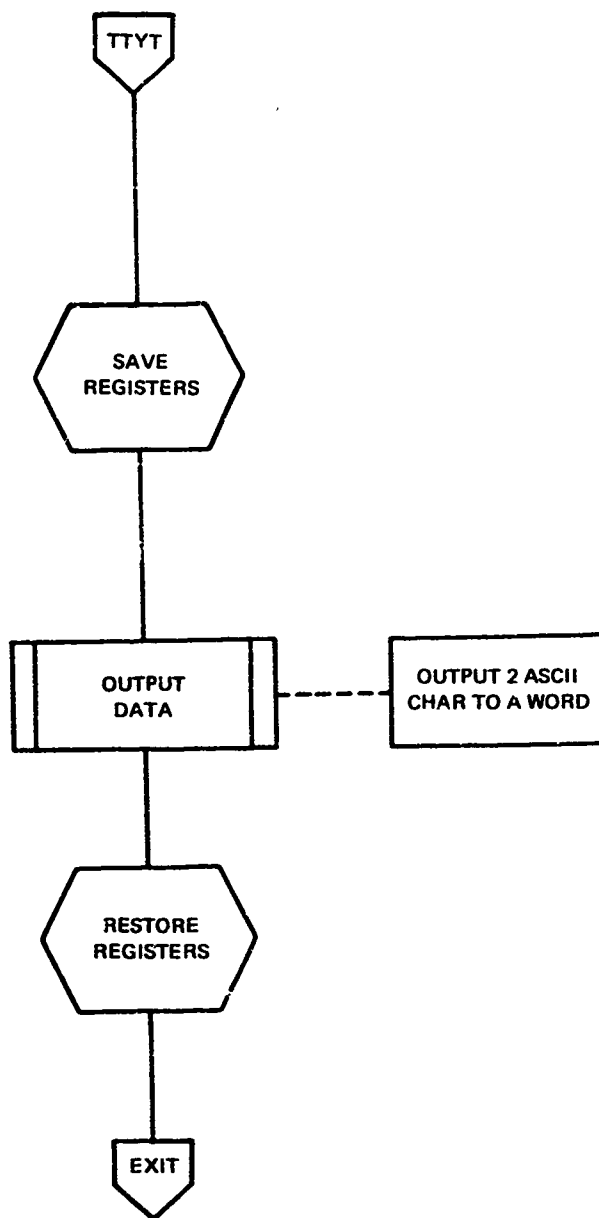


Fig. A-18 SUBROUTINE TTYT

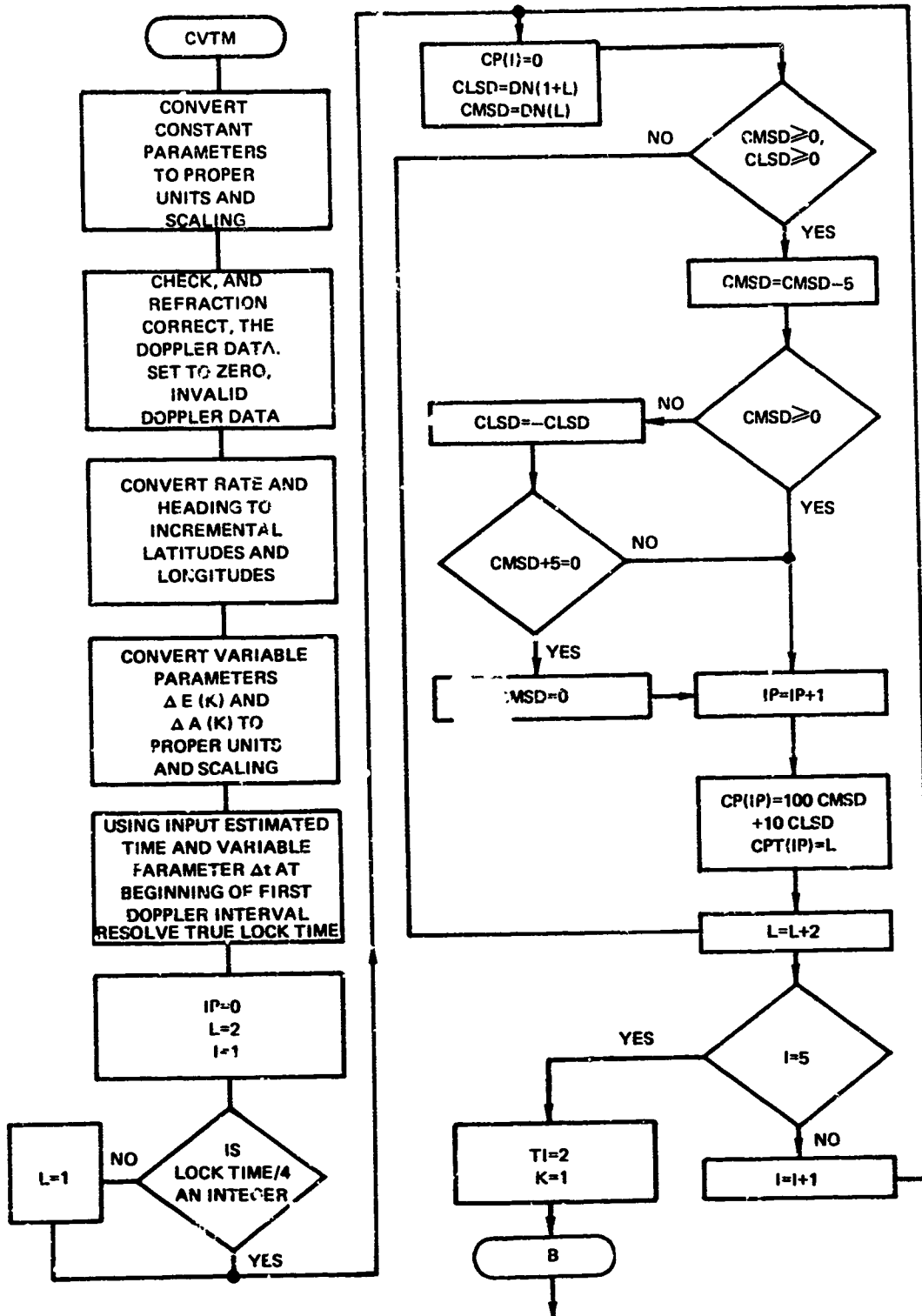


Fig. A-19 SUBROUTINE CVTM
 - 192 -

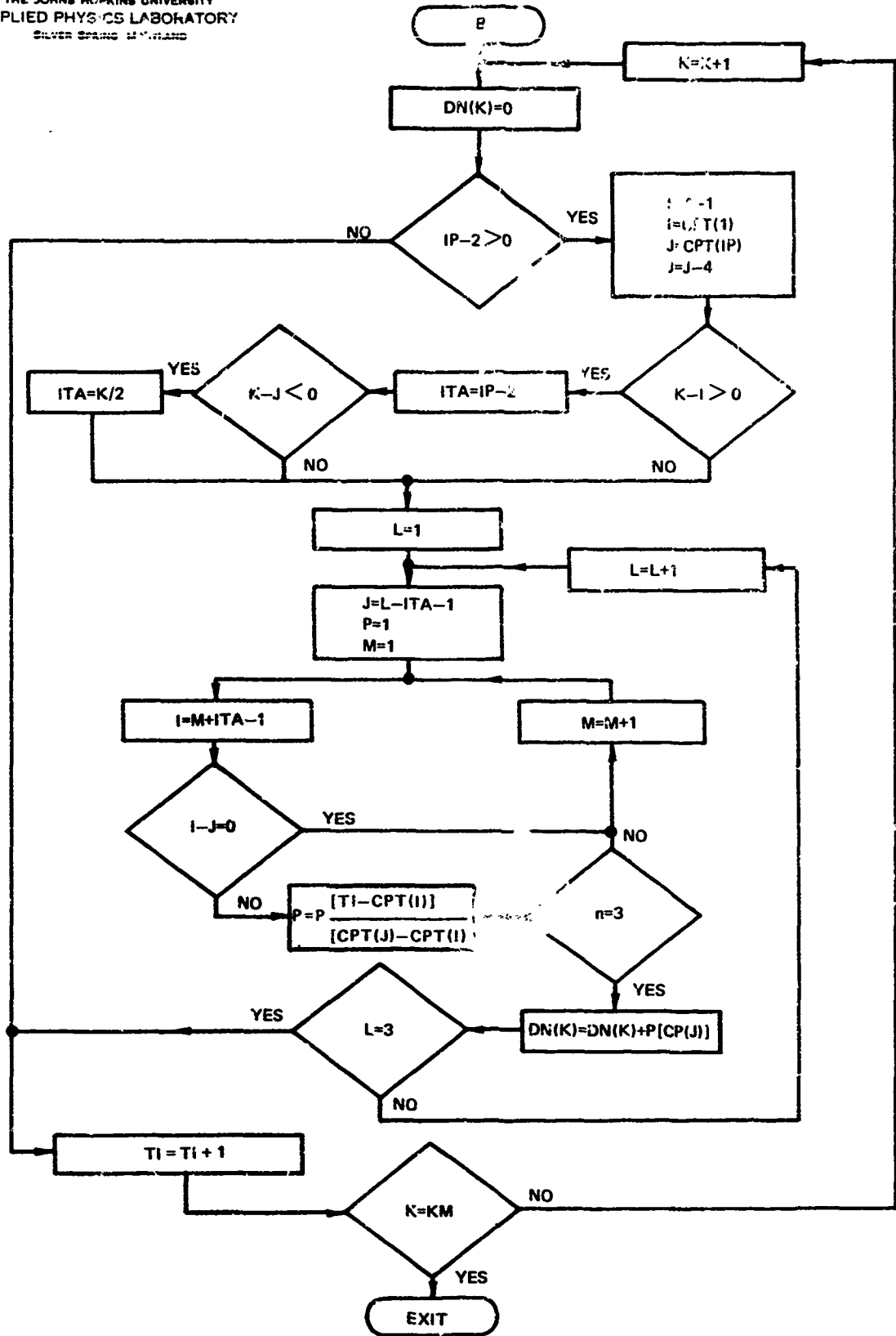


Fig. A-19 SUBROUTINE CVTM (cont'd)

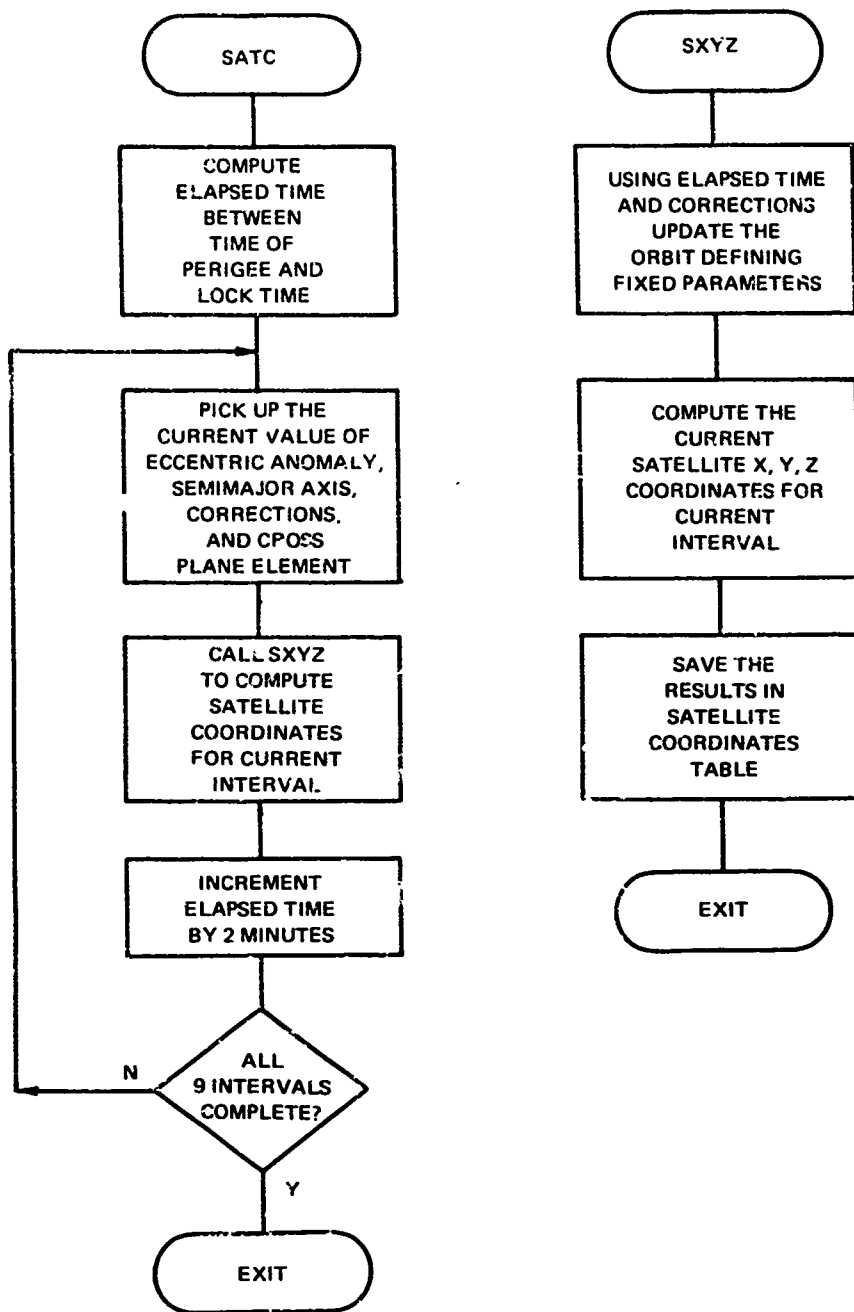


Fig. A-20 SUBROUTINES SATC AND SXYZ

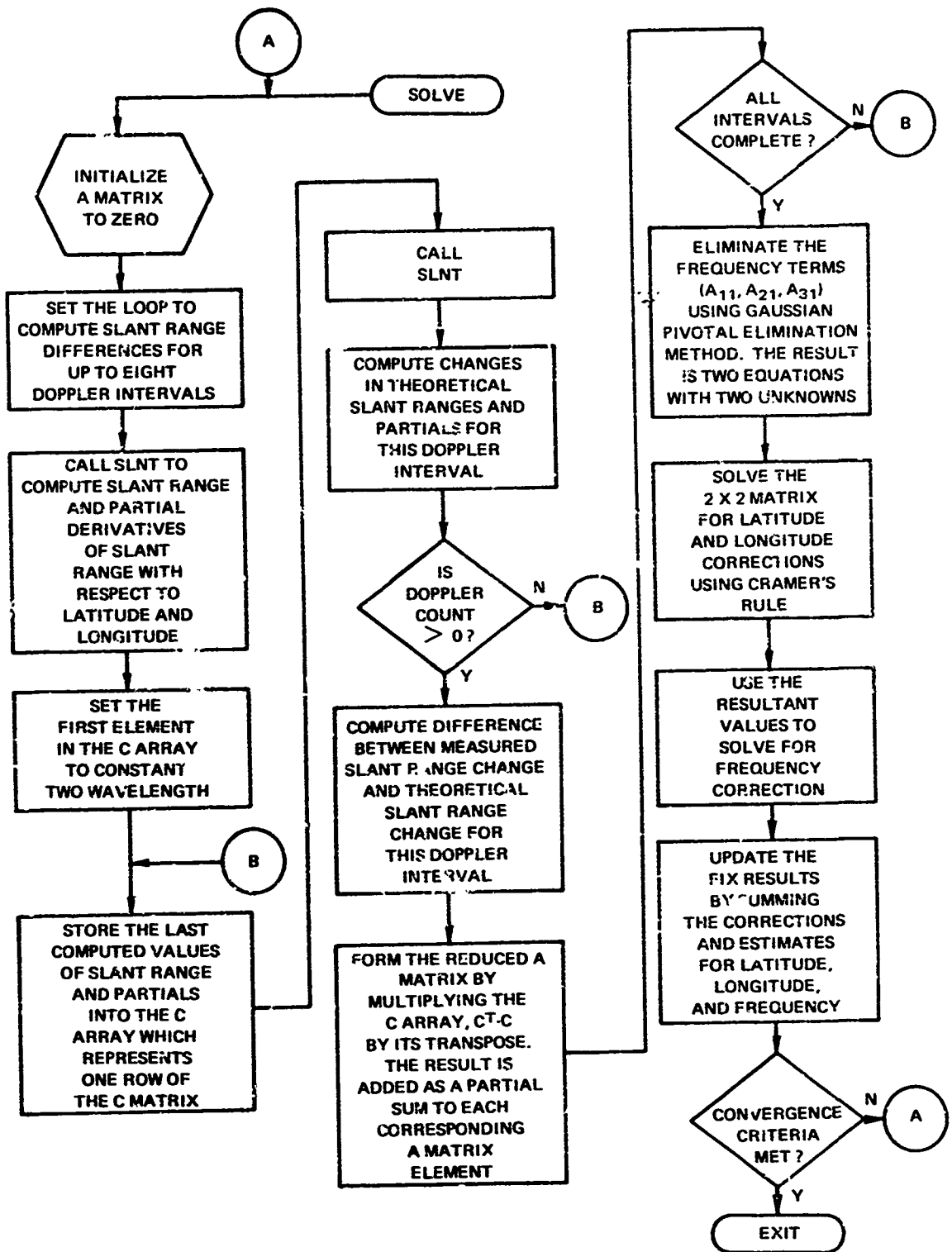


Fig. A-21 SUBROUTINE SOLVE

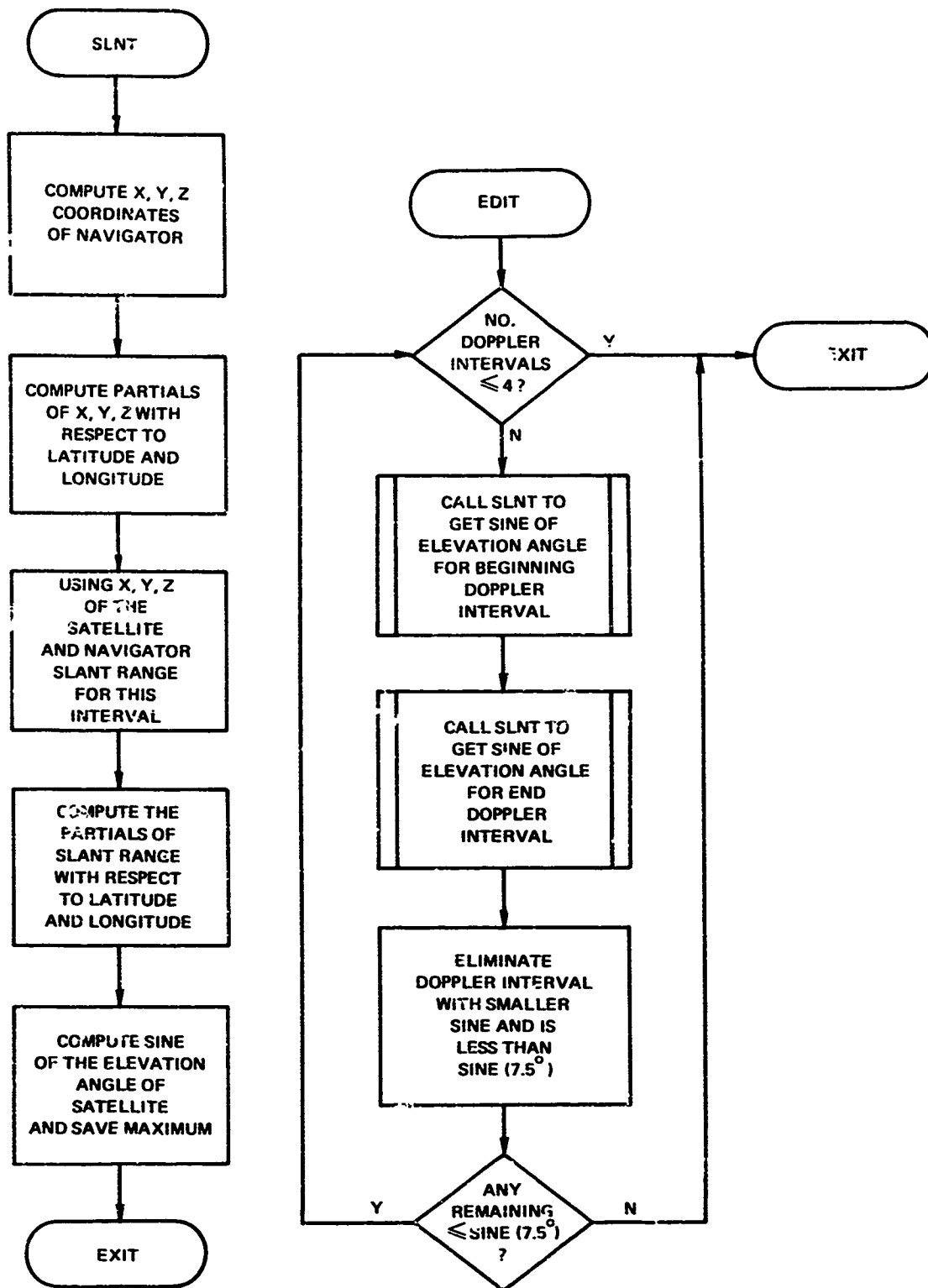


Fig. A-22 SUBROUTINES SLANT AND EDIT

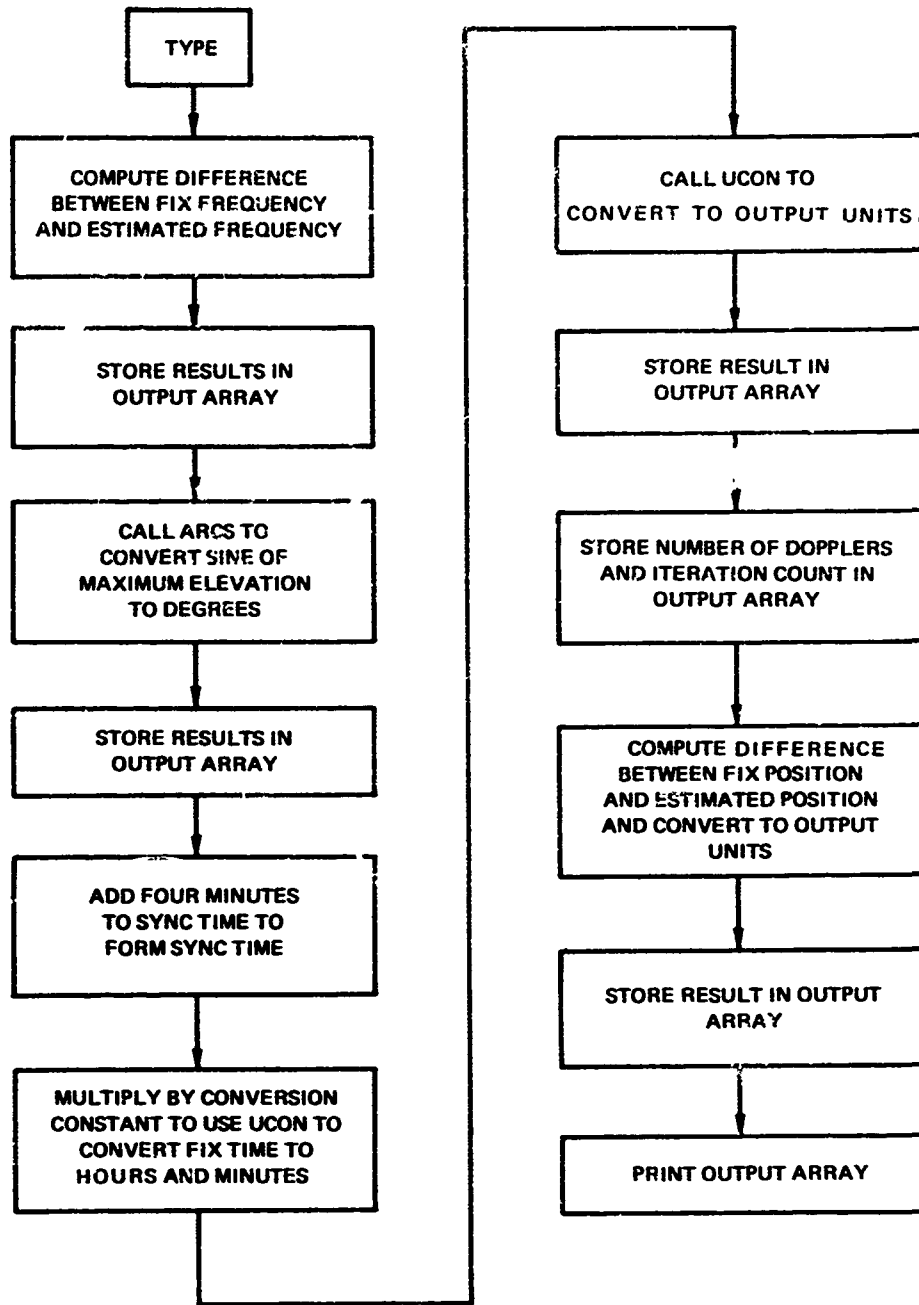


Fig. A-23 SUBROUTINE TYPE

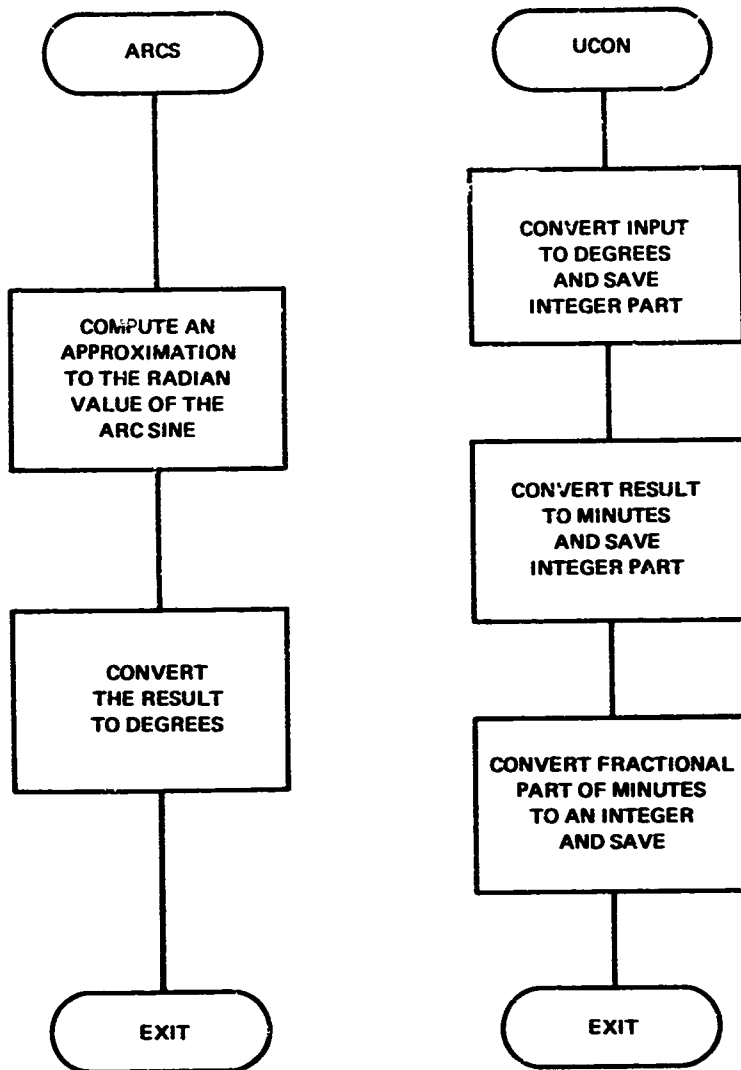


Fig. A-24 SUBROUTINE ARCS AND UCON

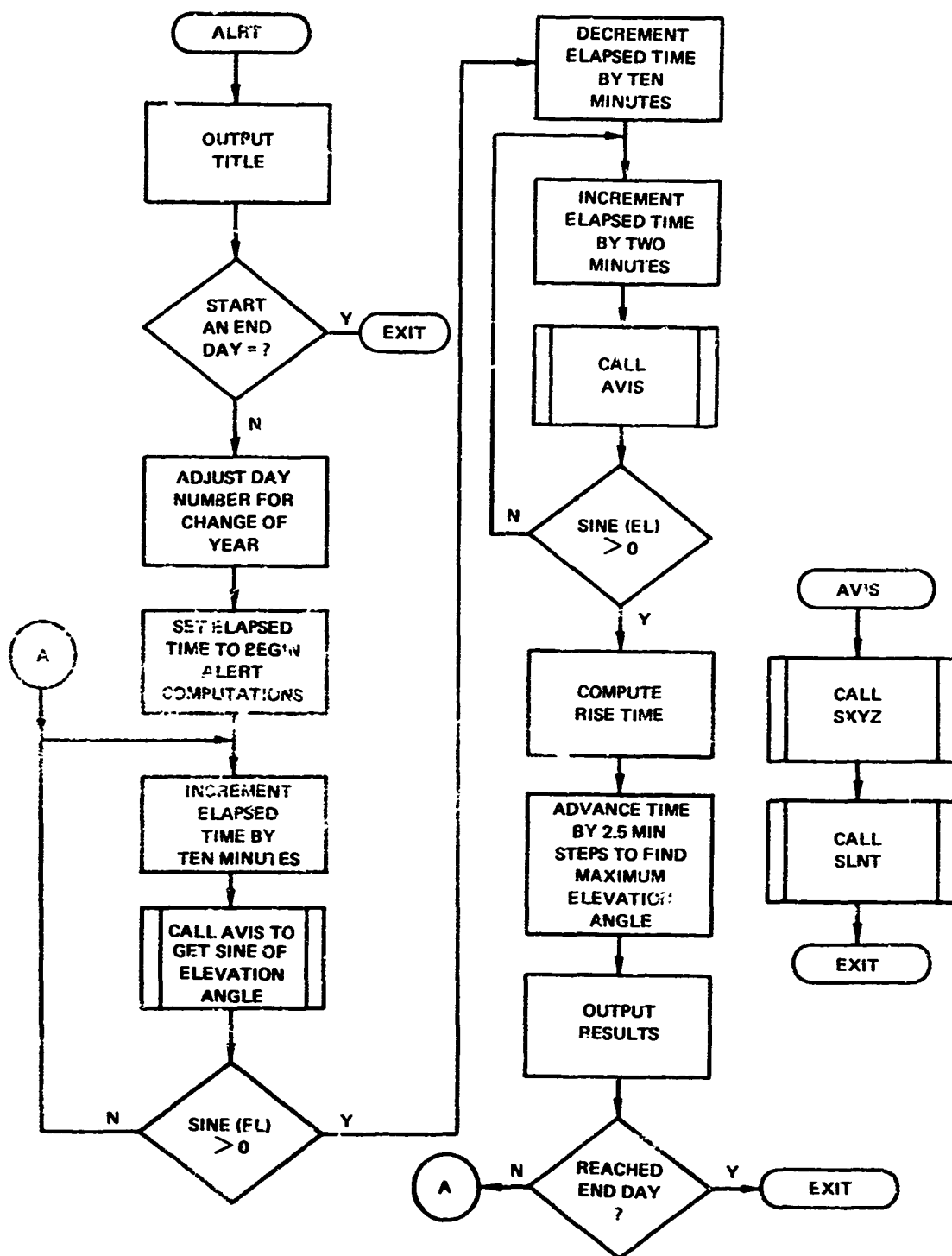


Fig. A-25 SUBROUTINES ALRT AND AVIS

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 s_0 . 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 s_n . 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 s_4 .

$$9_{10} = 1001 \text{ binary}$$

represented in a 30-bit word as

bit position 30 29 28 27 26 25

S.	1	0	0	1.	0
s_0	—————			s_4	

PRECEDING PAGE BLANK

The number 0.25 would be scaled s-1 optimally.

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

$$\begin{array}{c} \overset{0}{\curvearrowright} \\ s_0 \end{array} \cdot \boxed{100 \text{ ---}} = \underset{s-1}{S. 100 \text{ ---}}$$

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:

$$s_3 \quad s_2 \quad s_4$$

$$x = a + by \quad s_3 \rightarrow s_2$$

$$s_6 \rightarrow s_3$$

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
$ \dot{\omega} $	radians/minute	s-11
ϵ	dimensionless	s-3
A_o	meters	s24
Ω_o	radians	s4
Ω	radians/minute	s-7
C_i	dimensionless	s-5
Λ_G	radians	s4
S_i	dimensionless	s1
ΔE_k	radians	s-2
ΔA_k	meters	s24
η_k	meters	s9
t_o	minutes	s4
T_c	minutes	s11
N_k	cycles	s23
R_k	cycles	s12
φ_e	radians	s4
λ_e	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.

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

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

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

s12 → s23

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

$$\delta = f(2-f) \quad s0. \quad (\text{B. 1})$$

$$\Delta\lambda_k = \frac{s^4}{(k-1)} \frac{s^9}{v} \frac{s^1 \sin d}{\cos \varphi_e} \left[\frac{s^{-13}}{3443.934} \frac{2}{60} \right] \left[\frac{s^1}{(1 - 0.5 \delta \sin^2 \varphi_e)} \right] \frac{s^2 \text{ radians. (B. 2)}}{s^1 \rightarrow s^2}$$

$$\Delta\varphi_k = \frac{s^4}{(k-1)} \frac{s^9}{v} \frac{s^1}{\cos d} \left[\frac{s^{-13}}{3443.934} \frac{2}{60} \right] \left[1 + \delta \frac{s^1}{(1 - 0.5 \delta \sin^2 \varphi_e)} \right] s^2 \text{ radians. (B. 3)}$$

STEP C - Compute first fiducial time.

$$K' = \left[\frac{T}{\frac{c}{s_2}} \right] \left[\right] \text{ means integer part of } \frac{s^{10} \text{ minutes. (C. 1)}}{s^9 \rightarrow s^{10}}$$

$$I = \frac{s^2 s^{10}}{2 K'} \frac{s^{11} \text{ m. } \rightarrow \text{s. (C. 2)}}{s^{12} \rightarrow s^{11}}$$

$$T'_c = \left[\frac{s^{11}}{\frac{I}{30}} \right] \frac{s^6 \text{ minutes. (C. 3)}}{s^5}$$

$$J = \frac{s^{11} s^5 s^6}{I - 30 T'_c} \frac{s^{11} \text{ minutes. (C. 4)}}{s^6 \rightarrow s^{11}}$$

$$H = \frac{s^2 s^4 s^{11}}{2 t_0} - J \frac{s^{11} \text{ minutes. (C. 5)}}{s^2 \rightarrow s^{11}}$$

$$T_0 = I + H - 30 \left[\frac{s^{11}}{\frac{H}{15}} \right] \frac{s^{11} \text{ minutes. (C. 6)}}{s^5}$$

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

$$N = T_0 - 4 \begin{matrix} s11 \\ s3 \end{matrix} \left[\begin{matrix} T_0 \\ 4 \end{matrix} \right] \quad [] \text{ means integer part of } \quad (D.1)$$

s11 minutes.

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

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

$$\text{If } \eta_k - 5 \geq 0 \text{ then} \quad (D.3)$$

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

$$\text{and } CPT(l) = k. \quad s5$$

$$\text{If } \eta_k - 5 < 0 \text{ and} \quad (D.4)$$

$$\eta_k \neq 0 \text{ then}$$

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

$$\text{and } CPT(l) = k. \quad s5$$

$$\text{If } \eta_k - 5 < 0 \text{ and} \quad (D.5)$$

$$\eta_k = 0 \text{ then}$$

$$CP(l) = -10 \eta_{k+1} \quad s9$$

$$\text{and } CPT(l) = k \quad s5$$

where $l = 1, 2, 3, \dots, OP.$

If $OP \leq 2$ then (D. 6)

$$\eta_k = 0 \text{ for } k = 1, 2, 3, \dots, KM.$$

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

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

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

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 $k = 5, 6, 7, \dots, KM$.

$$\eta_k = \left[\frac{s_5}{CPT(1) - CPT(2)} \cdot \frac{s_5}{CPT(1) - CPT(3)} \right]_{s_{10}-s_7}^{s_9} \text{ CP(1)} \quad \frac{s_{12}-s_9}{s_9}$$

$$+ \left[\frac{s_5}{CPT(2) - CPT(1)} \cdot \frac{s_5}{CPT(2) - CPT(3)} \right]_{s_{10}-s_7}^{s_9} \text{ CP(2)} \quad \frac{s_{12}-s_9}{s_9} \text{ (D. 7-a)}$$

$$+ \left[\frac{s_5}{CPT(3) - CPT(1)} \cdot \frac{s_5}{CPT(3) - CPT(2)} \right]_{s_{10}-s_7}^{s_9} \text{ CP(3)} \quad \frac{s_{12}-s_9}{s_9}$$

$$\eta_k = \left[\frac{s_5}{(k+1) - CPT(2) - CPT(3)} \cdot \frac{s_5}{(k+1) - CPT(4)} \right]_{\substack{s_5 \\ s_{10}-s_7}} \begin{matrix} s_9 \\ CP(2) \end{matrix} \quad \underline{s_{12}-s_9} \quad s_9$$

$$+ \left[\frac{s_5}{(k+1) - CPT(3) - CPT(2)} \cdot \frac{s_5}{(k+1) - CPT(4)} \right]_{\substack{s_5 \\ s_{10}-s_7}} \begin{matrix} s_9 \\ CP(3) \end{matrix} \quad \underline{s_{12}-s_9} \quad s_9 \quad (D. 7-b)$$

$$+ \left[\frac{s_5}{(k+1) - CPT(4) - CPT(2)} \cdot \frac{s_5}{(k+1) - CPT(3)} \right]_{\substack{s_5 \\ s_{10}-s_7}} \begin{matrix} s_9 \\ CP(4) \end{matrix} \quad \underline{s_{12}-s_9} \quad s_9.$$

$$\eta_k = \left[\frac{s_5}{(k+1) - CPT(3) - CPT(4)} \cdot \frac{s_5}{(k+1) - CPT(5)} \right]_{\substack{s_5 \\ s_{10}-s_7}} \begin{matrix} s_9 \\ CP(3) \end{matrix} \quad \underline{s_{12}-s_9} \quad s_9$$

$$+ \left[\frac{s_5}{(k+1) - CPT(4) - CPT(3)} \cdot \frac{s_5}{(k+1) - CPT(5)} \right]_{\substack{s_5 \\ s_{10}-s_7}} \begin{matrix} s_9 \\ CP(4) \end{matrix} \quad \underline{s_{12}-s_9} \quad s_9 \quad (D. 7-c)$$

$$+ \left[\frac{s_5}{(k+1) - CPT(5) - CPT(3)} \cdot \frac{s_5}{(k+1) - CPT(4)} \right]_{\substack{s_5 \\ s_{10}-s_7}} \begin{matrix} s_9 \\ CP(5) \end{matrix} \quad \underline{s_{12}-s_9} \quad s_9.$$

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

$$t = T_0 - t_p \quad \text{s11 minutes. (E. 1)}$$

$$t_R = 1440 - 2 \frac{\pi}{n} \frac{s_7 \rightarrow s_{11}}{s-3} \quad \text{s11 minutes. (E. 2)}$$

$$\left. \begin{array}{l} \text{If } t \leq -480 \text{ then } \Delta t_p = t + 1440 \\ \text{If } -480 < t < t_R \text{ then } \Delta t_p = t \\ \text{If } t_R \leq t \text{ then } \Delta t_p = t - 1440 \end{array} \right\} \text{s11 minutes. (E. 3)}$$

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

$$\Delta t_k = \Delta t_p + 2(k-1) \quad \text{s11 minutes. (F. 1)}$$

$$M_k = n \Delta t_k \frac{s_8 \rightarrow s_7}{s-3} \quad \text{s7 radians. (F. 2)}$$

$$E_k = M_k + \left[\epsilon \sin M_k + \frac{\Delta E_k}{s-2 \rightarrow s_7} \right] \quad \text{s7 radians. (F. 3)}$$

$$A_k = A_0 + \Delta A_k \quad \text{s24 meters. (F. 4)}$$

$$u_k = \left[\frac{s_{24}}{A_k} \left(\cos E_k - \frac{s_{-3} \rightarrow s_1}{\epsilon} \right) \right] \quad \text{s24 meters. (F. 5)}$$

s25 → s24

$$v_k = A_k (\sin E_k) \quad s^{24} \text{ meters.} \quad (F. 6)$$

$$\omega_k = \omega_0 - \left[\dot{\omega} \Delta t_k \right] \quad s^4 \text{ radians.} \quad (F. 7)$$

$$x'_k = u_k \cos \omega_k - \frac{s^{24}}{v_k} \sin \omega_k \quad s^{24} \text{ meters.} \quad (F. 8)$$

$$y'_k = u_k \sin \omega_k + v_k \cos \omega_k \quad s^{25} \text{ meters.} \quad (F. 9)$$

$$z' = \eta_k \quad s^9 \text{ meters.} \quad (F. 10)$$

$$\beta_k = (\Omega_0 - \Lambda_G) + (\dot{\Omega} - \omega_e) \Delta t_k \quad s^4 \text{ radians.} \quad (F. 11)$$

$$X_{Sk} = \left[\frac{x'_k \cos \beta_k}{s^{25} \rightarrow s^{24}} \right] - \left[\frac{y'_k \text{ Ci} \sin \beta_k}{s^{21} \rightarrow s^{24}} \right] \quad (F. 12)$$

$$+ \left[\frac{z'_k \text{ Si} \sin \beta_k}{s^{11} \rightarrow s^{24}} \right] \quad s^{24} \text{ meters.}$$

$$Y_{Sk} = \left[\frac{x'_k \sin \beta_k}{s^{25} \rightarrow s^{24}} \right] + \left[\frac{y'_k \text{ Ci} \cos \beta_k}{s^{21} \rightarrow s^{24}} \right] \quad (F. 13)$$

$$- \left[\frac{z'_k \text{ Si} \cos \beta_k}{s^{11} \rightarrow s^{24}} \right] \quad s^{24} \text{ meters.}$$

$$Z_{Sk} = y'_k \overset{s25}{Si} + \overset{s1}{\left[\overset{s9}{z'_k} \quad \overset{s-5}{Ci} \right]} \overset{s26 \rightarrow s24}{\underset{s4 \rightarrow s26}{}} \quad s24 \text{ meters.} \quad (F. 14)$$

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

$$\cos \varphi_k = \cos (\varphi_f + \Delta\varphi_k) \quad s1. \quad (G. 1)$$

$$\sin \varphi_k = \sin (\varphi_f + \Delta\varphi_k) \quad s1. \quad (G. 2)$$

$$\cos \lambda_k = \cos (\lambda_f + \Delta\lambda_k) \quad s1. \quad (G. 3)$$

$$\sin \lambda_k = \sin (\lambda_f + \Delta\lambda_k) \quad s1. \quad (G. 4)$$

$$D_k^2 = R_0^2 \overset{s46}{\left[\overset{s2}{\cos^2 \varphi_k} + \overset{s0}{(1-f)^2} \overset{s2}{\sin^2 \varphi_k} \right]} \overset{s46 \text{ (meters)}^2}{\underset{s48 \rightarrow s46}{}} \quad (G. 5)$$

$$X_{Nk} = \overset{s46}{\left[\overset{2}{(R_0 / D_k)} + h' \right]} \overset{s23}{\cos \varphi_k} \overset{s1}{\cos \lambda_k} \overset{s1}{s24 \text{ meters.}} \quad (G. 6)$$

$\underset{s23}{\quad} \quad \quad \quad \underset{s25 \rightarrow s24}{\quad}$

$$Y_{Nk} = \overset{s46}{\left[\overset{2}{(R_0 / D_k)} + h' \right]} \overset{s23}{\cos \varphi_k} \overset{s1}{\sin \lambda_k} \overset{s1}{s24 \text{ meters.}} \quad (G. 7)$$

$\underset{s23}{\quad} \quad \quad \quad \underset{s25 \rightarrow s24}{\quad}$

$$Z_{Nk} = \overset{s46}{\left[\overset{s0}{\frac{R_0^2 (1-f)^2}{D_k}} + h' \right]} \overset{s23}{\sin \varphi_k} \overset{s1}{s24 \text{ meters.}} \quad (G. 8)$$

$\underset{s23}{\quad}$

$$\frac{\partial X_{Nk}}{\partial \phi} = - \left[\frac{R_0^4 (1-f)^2}{D_k^3} + h' \right] \frac{s1 \quad s1}{s25 \rightarrow s23} \quad \begin{matrix} s23 \text{ meters/} \\ \text{radian} \end{matrix} \quad \text{(G. 9)}$$

$$\frac{\partial Y_{Nk}}{\partial \phi} = - \left[\frac{R_0^4 (1-f)^2}{D_k^3} + h' \right] \frac{s1 \quad s1}{s25 \rightarrow s23} \quad \begin{matrix} s23 \text{ meters/} \\ \text{radian} \end{matrix} \quad \text{(G. 10)}$$

$$\frac{\partial Z_{Nk}}{\partial \phi} = \left[\frac{R_0^4 (1-f)^2}{D_k^3} + h' \right] \frac{\cos \phi_k}{s24 \rightarrow s23} \quad \begin{matrix} s23 \text{ meters/} \\ \text{radian} \end{matrix} \quad \text{(G. 11)}$$

$$\frac{\partial X_{Nk}}{\partial \lambda} = - \frac{s24}{Y_{Nk}} \quad \begin{matrix} s24 \text{ meters/} \\ \text{radian} \end{matrix} \quad \text{(G. 12)}$$

$$\frac{\partial Y_{Nk}}{\partial \lambda} = \frac{s24}{X_{Nk}} \quad \begin{matrix} s24 \text{ meters/} \\ \text{radian} \end{matrix} \quad \text{(G. 13)}$$

STEP H - Compute theoretical slant range differences, partial derivatives, and elevation angle.

$$X_k = X_{Sk} - X_{Nk} \quad \begin{matrix} s24 \\ s24 \text{ meters.} \end{matrix} \quad \text{(H. 1)}$$

$$Y_k = Y_{Sk} - Y_{Nk} \quad \begin{matrix} s24 \\ s24 \text{ meters.} \end{matrix} \quad \text{(H. 2)}$$

$$Z_k = Z_{Sk} - Z_{Nk} \quad s_{24} \text{ meters.} \quad (H. 3)$$

$$S_k^2 = X_k^2 + Y_k^2 + Z_k^2 \quad s_{48} (\text{meters})^2. \quad (H. 4)$$

$$S_k = \left[X_k^2 + Y_k^2 + Z_k^2 \right]^{1/2} \quad s_{24} \text{ meters.} \quad (H. 5)$$

$$R_k^2 = X_{Sk}^2 + Y_{Sk}^2 + Z_{Sk}^2 \quad s_{48} (\text{meters})^2. \quad (H. 6)$$

$$r_k^2 = X_{Nk}^2 + Y_{Nk}^2 + Z_{Nk}^2 \quad s_{48} (\text{meters})^2. \quad (H. 7)$$

$$r_k = \left[X_{Nk}^2 + Y_{Nk}^2 + Z_{Nk}^2 \right]^{1/2} \quad s_{23} \text{ meters} \quad (H. 8)$$

$s_{24} \rightarrow s_{23}$

$$\frac{\partial S_k}{\partial \phi} = \frac{-1}{S_k} \left[X_k \frac{\partial X_{Nk}}{\partial \phi} + Y_k \frac{\partial Y_{Nk}}{\partial \phi} + Z_k \frac{\partial Z_{Nk}}{\partial \phi} \right] \quad s_{23} \text{ meters/} \\ s_{24} \quad \text{radian.} \quad (H. 9)$$

$$\frac{\partial S_k}{\partial \lambda} = \frac{-1}{S_k} \left[X_k \frac{\partial X_{Nk}}{\partial \lambda} + Y_k \frac{\partial Y_{Nk}}{\partial \lambda} \right] \quad s_{24} \text{ meters/} \\ s_{24} \quad \text{radian.} \quad (H. 10)$$

$$\sin E_k = \left[\frac{X_k X_{Nk} + Y_k Y_{Nk} + Z_k Z_{Nk}}{S_k r_k} \right] \quad s_{24} \quad s_{23} \quad (H. 11)$$

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

STEP I - Compute refraction corrected measured slant range differences.

$$\Lambda_{S_{ko}} = N_k \frac{s_{23} s_0}{L_o} - 2.0 \frac{s_2 s_{21} s_0}{f_o L_o} \quad s_{23} \text{ meters.} \quad (\text{I. 1})$$

STEP J - Form the C matrix.

$$C_{J0} = - \frac{\Lambda_{S_{ko}}}{s_{23}} + \left[\frac{s_{23} \quad s_{23}}{S_{k+1} - S_k} \right] \quad s_{20} \text{ meters.} \quad (\text{J. 1})$$

$\frac{s_{23} \rightarrow s_{20}}$

$$C_{J1} = - \left[\frac{s_2 \quad s_0}{2.0 L_o} \right] \quad s_1 \frac{\text{meters-minutes}}{\text{cycle}} \quad (\text{J. 2})$$

$\frac{s_2 \rightarrow s_1}$

$$C_{J2} = - \frac{\frac{s_{23}}{\partial S_{k+1}}}{\partial \phi} + \frac{\frac{s_{23}}{\partial S_k}}{\partial \phi} \quad s_{23} \text{ meters/} \quad (\text{J. 3})$$

radian.

$$C_{J3} = \left[- \frac{\frac{s_{24}}{\partial S_{k+1}}}{\lambda} + \frac{\frac{s_{24}}{\partial S_k}}{\partial \lambda} \right] \quad s_{23} \text{ meters/} \quad (\text{J. 4})$$

$\frac{s_{24} \rightarrow s_{23}}$
radian.

STEP K - Form the A matrix.

J - Number of rows in C matrix.

$$a_{10} = \sum_{m=1}^J C_{m1} \frac{s_1}{C_{m0}} \frac{s_{20}}{s_{21} \rightarrow s_{23}} \quad s_{23}. \quad (\text{K. 1})$$

$$a_{20} = \sum_{m=1}^J C_{m2} \frac{s_{23}}{C_{m0}} \frac{s_{20}}{s_{43} \rightarrow s_{45}} \quad s_{45}. \quad (\text{K. 2})$$

$$a_{30} = \sum_{m=1}^J C_{m3} \frac{s_{23}}{C_{m0}} \frac{s_{20}}{\underline{s_{43} \rightarrow s_{42}}} s_{42}. \quad (\text{K. 3})$$

$$a_{11} = \sum_{m=1}^J C_{m1} \frac{s_1}{C_{m1}} \frac{s_1}{\underline{s_2 \rightarrow s_5}} s_5. \quad (\text{K. 4})$$

$$a_{21} = \sum_{m=1}^J C_{m2} \frac{s_{23}}{C_{m1}} \frac{s_1}{\underline{s_{24} \rightarrow s_{27}}} s_{27}. \quad (\text{K. 5})$$

$$a_{31} = \sum_{m=1}^J C_{m3} \frac{s_{23}}{C_{m1}} \frac{s_1}{\underline{s_{24} \rightarrow s_{23}}} s_{23}. \quad (\text{K. 6})$$

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

$$a_{22} = \sum_{m=1}^J C_{m2} \frac{s_{23}}{C_{m2}} \frac{s_{23}}{\underline{s_{46} \rightarrow s_{49}}} s_{49}. \quad (\text{K. 8})$$

$$a_{32} = \sum_{m=1}^J C_{m3} \frac{s_{23}}{C_{m2}} \frac{s_{23}}{\underline{s_{46} \rightarrow s_{45}}} s_{45}. \quad (\text{K. 9})$$

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

$$a_{23} = a_{32}. \quad (\text{K. 11})$$

$$a_{33} = \sum_{m=1}^J C_{m3} \frac{s_{23}}{C_{m3}} \frac{s_{23}}{\underline{s_{46} \rightarrow s_{43}}} s_{43}. \quad (\text{K. 12})$$

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

$$B_{11} = a_{22} - a_{12} \frac{s_{27} a_{12}}{a_{11} s_5} \quad s_{49}. \quad (L. 1)$$

$$B_{12} = a_{23} - a_{13} \frac{s_{23} s_{27} a_{12}}{a_{11} s_5} \quad s_{45}. \quad (L. 2)$$

$$B_{10} = a_{20} - a_{10} \frac{s_{23} s_{27} a_{12}}{a_{11} s_5} \quad s_{45}. \quad (L. 3)$$

$$B_{22} = a_{33} - \frac{s_{43} \begin{bmatrix} s_{23} & s_{23} \\ a_{13} & a_{11} \end{bmatrix}}{s_5} \quad s_{43}. \quad (L. 4)$$

s41-s43

$$B_{20} = a_{30} - \frac{s_{42} \begin{bmatrix} s_{23} & s_{23} \\ a_{10} & a_{11} \end{bmatrix}}{s_5} \quad s_{42}. \quad (L. 5)$$

s41-s42

$$\Delta = \begin{bmatrix} s_{49} & s_{43} \\ B_{11} & B_{22} \\ s_{92} \rightarrow s_{91} \end{bmatrix} - \begin{bmatrix} s_{45} & s_{45} \\ B_{12} & B_{12} \\ s_{90} \rightarrow s_{91} \end{bmatrix} \quad s_{91}. \quad (L. 6)$$

$$\Delta\phi = \frac{\frac{s_{88} \rightarrow s_{87}}{s_{43} \ s_{45}} \quad s_{45} \ s_{42}}{(B_{22} \ B_{10} - B_{12} \ B_{20})} \quad s-4 \text{ radians.} \quad (L. 7)$$

$$\Delta\lambda = \frac{\frac{\Delta}{s_{49} \ s_{42}} \quad s_{45} \ s_{45}}{(B_{11} \ B_{20} - B_{12} \ B_{10})} \quad s-1 \text{ radian.} \quad (L. 8)$$

$\frac{\Delta}{s_{91}}$

$$\Delta f = \frac{\begin{matrix} s23 & s27 & s-4 & s22 \rightarrow s23 \\ a_{10} & - (a_{12}) & (\Delta\phi) & - (a_{13}) & (\Delta\lambda) \end{matrix}}{\begin{matrix} a_{11} \\ s5 \end{matrix}} \quad \begin{matrix} s18 \text{ cycles/} \\ \text{minute.} \end{matrix} \quad (\text{L. 9})$$

$$f = i + \Delta f \text{ where } f = \bar{f}_0 \text{ on first iteration } \begin{matrix} s21 \text{ cycles/} \\ \text{minute.} \end{matrix} \quad (\text{L. 10})$$

$$\phi_f = \phi_f + \Delta\phi \quad \begin{matrix} s4 \text{ radian.} \\ \end{matrix} \quad (\text{L. 11})$$

$$\lambda_f = \lambda_f + \Delta\lambda \quad \begin{matrix} s4 \text{ radian.} \\ \end{matrix} \quad (\text{L. 12})$$

STEP M - Write out results.

$$\text{DLA} = \phi_f - \phi_e \quad \begin{matrix} s4 \text{ radians.} \\ \end{matrix} \quad (\text{M. 1})$$

$$\text{DLO} = \lambda_f - \lambda_e \quad \begin{matrix} s4 \text{ radians.} \\ \end{matrix} \quad (\text{M. 2})$$

$$\text{FRQ} = f - \bar{f}_0 \quad \begin{matrix} s21 \text{ cycles/} \\ \text{minute.} \end{matrix} \quad (\text{M. 3})$$

$$\text{TIME} = T_0 + 4 \quad \begin{matrix} s11 \text{ minutes.} \\ \end{matrix} \quad (\text{M. 4})$$

STEP N - Test for convergence.

If $\Delta f > 2.4 \text{ cycle/minute}$

or if $\Delta\phi > 1.2 \times 10^{-7} \text{ radian}$

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

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.

$$\text{If } \sin E_{KM-k+1} \leq \sin 7.5^\circ \text{ and} \quad (\text{O. 1})$$

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

$$N_{KM-k} > 0 \text{ then}$$

$$N_{KM-k} = 0 \text{ and}$$

$$\text{NDOP} = \text{NDOP} - 1.$$

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

$$\sin E_k \leq \sin 7.5^\circ \text{ and}$$

$$N_{k+1} > 0 \text{ then}$$

$$N_{k+1} = 0 \text{ and}$$

$$\text{NDOP} = \text{NDOP} - 1.$$

Otherwise make no changes in the N_k table.

STEP P - Compute alerts.

$$\text{ISTP} = \text{MDAY} - \text{IDAY}. \text{ If } \text{ISTP} < 0, \text{ let } \text{ISTP} = \text{ISTP} + 365. \quad (\text{P. 1})$$

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

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

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

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

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

When $E_k \geq 0$ let $T_0 - 2 = RISE$, $E_k = E_A$, $T_0 =$ (P. 7)
 $T_0 + 0.25$ 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 eleva-
tion for that pass.

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

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

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 ship-board navigation their effects are negligible.

Equations for Constant Velocity North and East

$$\phi_k = \phi_j + 2 \frac{(k-j) V_N}{R_0} [(1 + \delta (1 - 0.5\delta \sin^2 \phi_j))$$

$$\lambda_k = \lambda_j + 2 \frac{(k-j) V_E}{R_0} \left(\frac{1 - 0.5\delta \sin^2 \phi_j}{\cos \phi_j} \right)$$

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$$\delta = f(2-f).$$

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. $R_0 = 3443.934$ nautical miles.

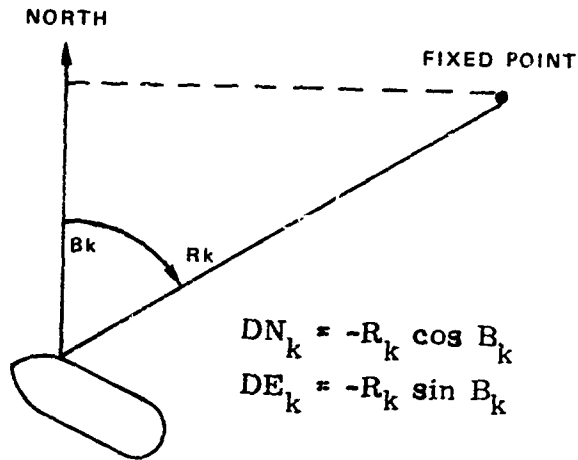
The factor of 2 appears because the fiducial time points denoted by k are 2 minutes apart. The approximations are caused by assuming that $\dot{\varphi}$ and $\dot{\lambda}$ are constant velocity north and east and ignoring changes in the earth radius during the time of the pass.

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:



Additions to Section 7 to Solve for Velocity North Error

STEP G

Replace ϕ_k by $\phi_k + 2 \phi_j (k-j)$ 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

$$\phi_j = \frac{V_N \text{ (knots)}}{3443. \times 60} = \frac{\text{rad}}{\text{min}}$$

$$\left. \frac{\partial X_{Nk}}{\partial \dot{\phi}_j} = 2(k-j) \frac{\partial X_{Nk}}{\partial \phi} \right\} = \frac{\partial \phi_k}{\partial \phi_j} \frac{\partial X_{Nk}}{\partial \phi_k} \quad (\text{G. 14})$$

$$\left. \frac{\partial Y_{Nk}}{\partial \dot{\phi}_j} = 2(k-j) \frac{\partial Y_{Nk}}{\partial \phi} \right\} \quad (\text{G. 15})$$

$$\left. \frac{\partial Z_{Nk}}{\partial \dot{\phi}_j} = 2(k-j) \frac{\partial Z_{Nk}}{\partial \phi} \right\} \quad (\text{G. 16})$$

These steps are not necessary in the computation but are included for background.

STEP H

$$\frac{\partial S_k}{\partial \dot{\phi}_j} = 2(k-j) \frac{\partial S_k}{\partial \phi} \quad (\text{H. 13})$$

STEP J

$$C_{J4} = \frac{-\partial S_{k+1}}{\partial \dot{\phi}_j} + \frac{\partial S_k}{\partial \dot{\phi}_j} \quad (\text{J. 5})$$

OUTPUT: The C matrix for velocity north

$$\begin{bmatrix} C_{10} & C_{11} & C_{12} & C_{13} & C_{14} \\ C_{20} & C_{21} & C_{22} & C_{23} & C_{24} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ C_{J0} & C_{J1} & C_{J2} & C_{J3} & C_{J4} \end{bmatrix}$$

STEP K

$$a_{40} = \sum_{m=1}^J C_{m4} C_{m0} \quad (\text{K. 3. 1})$$

$$a_{41} = \sum_{m=1}^J C_{m4} C_{m1} \quad (\text{K. 6. 1})$$

$$a_{42} = \sum_{m=1}^J C_{m4} C_{m2} \quad (\text{K. 9. 1})$$

$$a_{43} = \sum_{m=1}^J C_{m4} C_{m3} \quad (\text{K. 12. 1})$$

$$a_{14} = a_{41} \quad (\text{K. 12. 2})$$

$$a_{24} = a_{42} \quad (\text{K. 12. 3})$$

$$a_{34} = a_{43} \quad (\text{K. 12. 4})$$

$$a_{44} = \sum_{m=1}^J C_{m4} C_{m4} \quad (\text{K. 12. 5})$$

OUTPUT: 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

$$\Delta \gamma = \frac{a_{40} - [a_{41} \Delta f + a_{42} \Delta \varphi + a_{43} \Delta \lambda]}{a_{44}} \quad (\text{L. 0})$$

Eliminate $\Delta \gamma$ by redefining the A matrix at the end of Step K and used in Step L.

$$i = 1, 2, 3$$

$$\begin{aligned} a_{i0} &= a_{i0} - \frac{a_{40}}{a_{44}} a_{i4} & a_{i2} &= a_{i2} - \frac{a_{42}}{a_{44}} a_{i4} \\ a_{i1} &= a_{i1} - \frac{a_{41}}{a_{44}} a_{i4} & a_{i3} &= a_{i3} - \frac{a_{43}}{a_{44}} a_{i4} \end{aligned}$$

Solve for $\Delta\phi$, $\Delta\lambda$, Δf as in Steps (L. 1) to (L. 9).

Then solve

$\Delta\gamma$ from (L. 0), (L. 9), (L. 7), (L. 8)

$$\phi_j = \dot{\phi}_j + \Delta\gamma. \quad (\text{L. 13})$$

STEP N

$$\text{If } |\Delta\gamma| > \frac{0.02}{3443. \times 60.} \quad \text{continue iterating at Step G} \quad (\text{N. 2})$$

after convergence

$$V_N = 3443.934 (\cos^2 \phi_j + (1-f)^2 \sin^2 \phi_j)^{1/2} \phi_j \times 60.$$

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

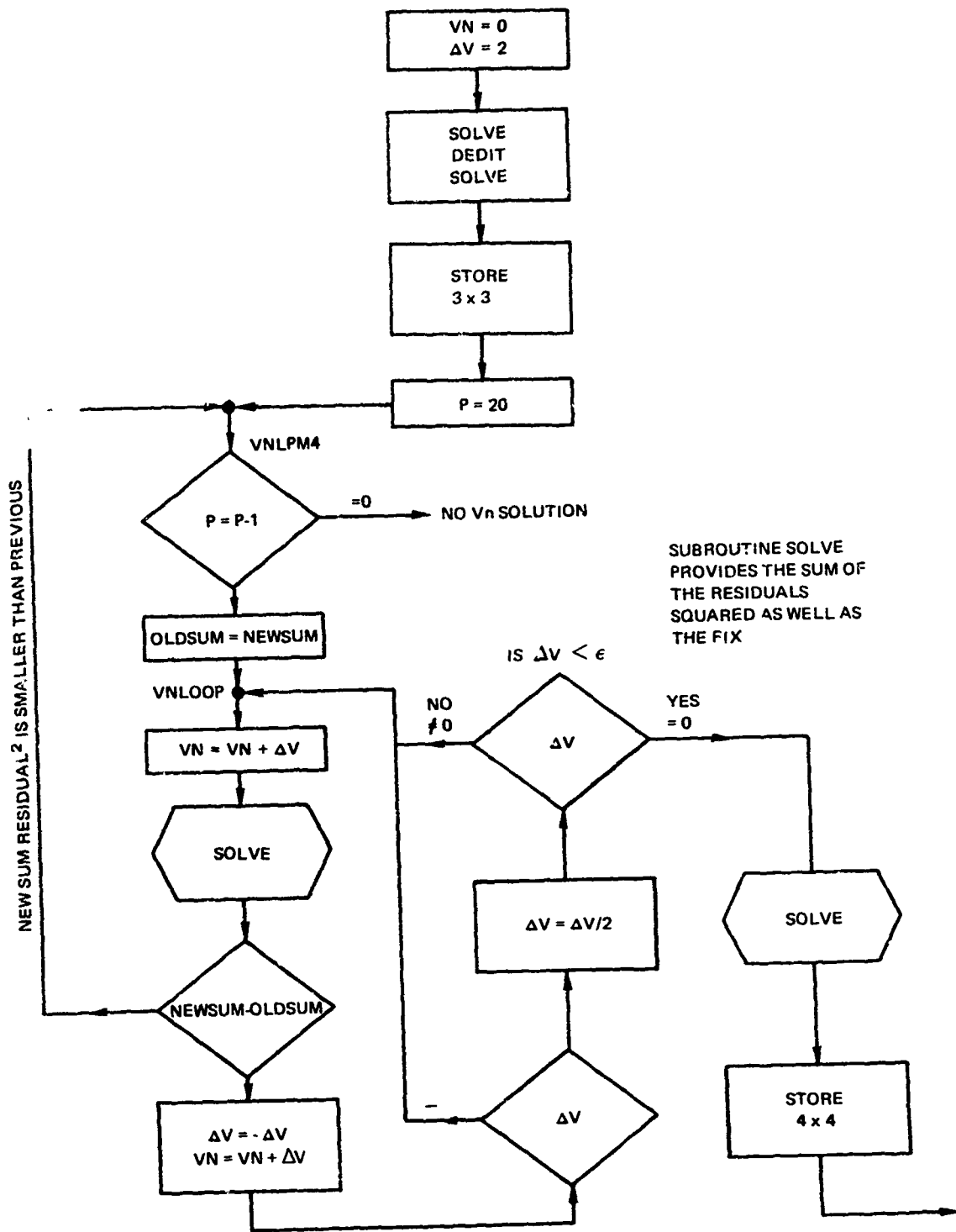


Fig. C-1 VELOCITY NORTH SOLUTION BY DIRECT SEARCH

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:

0123456789012340123456.

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	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 One Sequence															Errors Min - Max
	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	
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

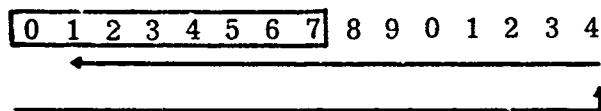
Example

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 Λ every slant range measurement. The expression for S_{ko} , the measured slant range difference (Eq. (I.1) in Section 7), would thus be modified as follows:

$$S_{ko\text{ corr}}^\Lambda = S_{ko}^\Lambda - (\Delta\rho_{tro_{k+1}} - \Delta\rho_{tro_k}) \quad (D.1)$$

where $k = 1, 2, 3, \dots, KM$.

The tropospheric refraction correction $\Delta\rho_{tro}$ is defined as follows:

$$\Delta\rho_{tro} = \sum_{i=1, 2} \Delta\rho_i \quad (D.2)$$

where

$$\begin{aligned} \Delta\rho_i = 10^{-6} N_{T_i} \left[-l_1 + \frac{4}{h_{tro_i}} \left\{ \frac{1}{3} r_T^2 l_1^3 - \frac{2}{15} l_1^5 - \frac{3}{4} r_T r_{tro_i} l_1 (l_1^2 + \frac{1}{2} l_2^2) \right. \right. \\ + r_{tro_i}^2 l_1^3 - \frac{1}{2} r_{tro_i}^3 r_T l_1 - \frac{1}{3} r_{tro_i}^2 l_3^3 + \frac{2}{15} l_3^5 \\ + \frac{3}{4} r_{tro_i}^2 (l_3^3 + \frac{1}{2} l_3 l_2^2) - r_{tro_i}^2 l_3 (l_3^2 - \frac{1}{2} r_{tro_i}^2) \\ \left. \left. + \frac{1}{2} r_{tro_i} l_2^2 \left(\frac{3}{4} l_2^2 + r_{tro_i}^2 \right) \ln \frac{r_T + l_1}{r_{tro_i} + l_3} \right\} \right] \end{aligned}$$

and

i = subscript indicating dry (d) and wet (w) refractivity terms,

N_{T_i} = i th 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} = $(r_{tro_i}^2 - l_2^2)^{1/2}$,

h_{o_i} = height of i th 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:

$$N_{T_d} = \frac{77.6 P}{T_K} \quad (D. 3)$$

$$N_{T_w} = \frac{77.6 (4810 e)}{T_K^2} \quad (D. 4)$$

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_{oi} is based on the assumption that the height of the wet component h_{ow} is invariant with latitude, but that the height of the dry component h_{od} is a function of the navigator's latitude ϕ_T , as given in the following expression,

$$h_{od} = h_{od(eq)} + A_d \sin^2 \phi_T, \quad (D.5)$$

where $h_{od(eq)}$ is the dry height at the equator and A_d is the amplitude of the variation of h_{od} with latitude. Values of these parameters for three values of h_{ow} are given in Table D-1. A value of $h_{ow} = 12$ km is generally satisfactory for use in all tropospheric refraction calculations.

Table D-1
 Height Parameters for Two-Quartic N Profile (km)

h_{ow}	$h_{od(eq)}$	A_d
10	43.858	-5.986
12	43.330	-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 $\Delta\rho_{\text{tro}}$ 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

$$\Delta\rho_{\text{tro}} = \frac{N_{T_i} \cdot 10^{-6}}{(h_{\text{tro}_i})^4} \int_{-h_{\text{tro}_i}}^0 \frac{(r_{\text{tro}_i} + x)^4 dx}{[(r_{\text{tro}_i} + x)^2 - l_2^2]^{1/2}} \quad (\text{D. 6})$$

Although this equation may be integrated in closed form, it results in unacceptable 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:

$$W_1 = r_{\text{tro}_i} + l_2,$$

$$W_2 = r_{\text{tro}_i} - l_2,$$

$$W = W_1 W_2.$$

Large Elevation Angles

$$\Delta\rho_{\text{tro}} = N_{T_i} 10^{-6} \left\{ W^{1/2} - t_1 - \frac{0.8 h_{\text{tro}_i} r_{\text{tro}_i}}{W^{1/2}} - W^{1/2} \sum_{p=0}^{\infty} \frac{1}{p+6} \left(\frac{h_{\text{tro}_i}}{W_2} \right)^{p+2} \cdot \left[2F(p+1) \left[1 + \left(\frac{W_2}{W_1} \right)^{p+2} \right] - \sum_{n=0}^p F(n) F(p-n) \left(\frac{W_2}{W_1} \right)^{n+1} \right] \right\} \quad (\text{D. 7})$$

where $F(k) = \binom{2k}{k} \frac{1}{(k+1)2^{2k}}$.

The recursive relationship

$$F(k) = 1/2 \frac{(2k-1)}{k+1} F(k-1) \quad (\text{D. 8})$$

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 $\Delta\rho_{\text{tro}}$ after $p = 2^k - 2$ terms have been used may be estimated by

$$R_{\Delta\rho} < 4 \times 10^{-6} N_{T_i} W^{1/2} 2^{-3k/2} \left(\frac{h_{\text{tro}_i}}{W_2} \right)^{(2^k+1)} \quad (\text{D. 9})$$

Small Elevation Angles

$$\Delta\rho = N_{T_i} \times 10^{-6} \cdot \left\{ -\ell_1 + 4 \frac{W_2^5}{h_{tro_i}^4} \left(\frac{W_1}{W_2} - 1 \right)^{1/2} \right.$$

$$\cdot \sum_{n=0}^3 (-1)^n \binom{3}{n} \left[\frac{2}{2n+3} \left[1 - \left(1 - \frac{h_{tro_i}}{W_2} \right)^{(2n+3)/2} \right] \right.$$

$$\left. + \sum_{p=0}^{\infty} (-1)^p \frac{F(p)}{(2p+2n+5)} \left(\frac{W_1}{W_2} - 1 \right)^{p+1} \right.$$

$$\left. \cdot \left[1 - \left(1 - \frac{h_{tro_i}}{W_2} \right)^{(2p+2n+5)/2} \right] \right\} .$$

(D-10)

The remainder after $p = 2^k - 1$ terms is given by

$$R_{\Delta\rho} < N_{T_i} \times 10^{-6} \left(\frac{W_2^5}{h_{tro_i}^4} \right) 2^{-3k/2} \left(\frac{W_1 - W_2}{W_1 + W_2} \right)^{(2^k + 3/2)}$$

(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:

$$\Delta\rho_{tro} = (\Delta\rho_{tro})_d + (\Delta\rho_{tro})_w \quad (D.12)$$

The simplest available approximations for the components are based on Ref. 15 and are as follows:

$$\left. \begin{aligned} (\Delta\rho_{tro})_d &= 2.31 \times 10^{-3} \text{ csc} \sqrt{E^2 + \theta_d^2} \text{ km} \\ (\Delta\rho_{tro})_w &= 0.20 \times 10^{-3} \text{ csc} \sqrt{E^2 + \theta_w^2} \text{ km} \end{aligned} \right\} \quad (D.13)$$

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):

$$\left. \begin{aligned} (\Delta\rho_{tro})_d &= K_d P \text{ csc} \sqrt{E^2 + \theta_d^2} \\ (\Delta\rho_{tro})_w &= K_w \text{ csc} \sqrt{E^2 + \theta_w^2} \end{aligned} \right\} \quad (D.14)$$

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 APPENDICES

- A. Notation.
- B. Formula for Transformation of Coordinates.
- C. Formula for Change 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 ESOOLP II computer. The 1381st Geodetic Survey Squadron (Data Reduction Division) performed hand computations as well as electronic transformations of coordinates on EPC 4000 computer.

3. General Information.

a. The formulas of Appendices 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_0 and Q_0 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 $P_n P_0 = P_n' P_0'$, with a similar situation existing at Q. The geodetic distance on the old ellipsoid is the arc $P_0 Q_0$ and on the new ellipsoid it is $P_n Q_n$. The straight

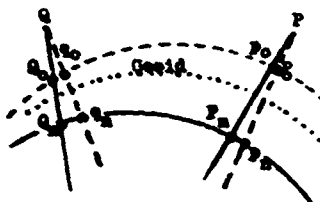


Figure 1.

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

*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 70 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 $\delta x = 90.904$ m, $\delta y = 108.339$ m, and $\delta z = 100.000$ m.

This separation of ellipsoid centers was computed from arbitrary data at the origin chosen at $\phi = 40^\circ$ N, $\lambda = 7^\circ$ 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.

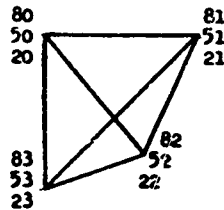


Figure 2.

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.

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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 NGS 60, using both programs. The differences in results are shown in Appendix D.

5. Analysis of Results.

a. Ref. [2] analyzes 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 Appendices 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.

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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 Meiness 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 Meiness 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 - $(a^2 - b^2)/a$ = first eccentricity.
 e^2 - $e^2/(1 - e^2)$ = the square of second eccentricity.
 R - radius of curvature in the prime vertical = $a(1 - e^2 \sin^2 \phi)^{-1/2}$.
 R - approximate radius of the Earth.
 \bar{a} - $\frac{1}{2}(a_0 + a_n)$.
 \bar{e} - $\frac{1}{2}(e_0 + e_n)$.
 x, y, z - rectangular space coordinates, i.e.
 $x = (R + H) \cos \phi \cos \lambda$
 $y = (R + H) \cos \phi \sin \lambda$
 $z = [R(1 - e^2) + H] \sin \phi$.
 $\delta \phi, \delta \lambda, \delta H$ - $\phi_n - \phi_0$ etc. = shifts in latitude, longitude and geodetic height. δH is the height of the old ellipsoid above the new one.
 $\delta x, \delta y, \delta z$ - rectangular components of separation of ellipsoid centers.
 $\delta a, \delta e^2$ - $a_n - a_0$ and $e_n^2 - e_0^2$.
 $\delta S, \delta S$ - $S_n - S_0$ and $S_n - S_0$.
 Subscripts 0 and n refer to the old and the new ellipsoid respectively.
 Subscripts 1 and 2 refer to the ends of a geodesic 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:

$$\delta\phi'' = [(A_1 \cos\lambda + A_2 \sin\lambda) \sin\phi + A_3 \cos\phi] W + (A_4 \sin^2\phi + A_5) \sin\phi \cos\phi \quad (1a)$$

$$\delta\lambda'' = (A_1 \sin\lambda - A_2 \cos\lambda) W \cos\phi \quad (1b)$$

$$\delta H = (B_1 \cos\lambda + B_2 \sin\lambda) \cos\phi + B_3 \sin\phi + B_4 \sin^2\phi + B_5 \sin^4\phi + W_6 \quad (1c)$$

To compute the separation of ellipsoid centers if changes in latitude, longitude, and geodetic height are known at any point:

$$\delta x = \frac{1}{W} (C_1 \sin\phi \cos\phi + C_2 \delta\phi'') \sin\phi \cos\lambda + \left[\frac{1}{W} C_2 \delta\lambda'' \sin\lambda + (\delta H + C_3) \cos\lambda \right] \cos\phi \quad (2a)$$

$$\delta y = \frac{1}{W} (C_1 \sin\phi \cos\phi - C_2 \delta\phi'') \sin\phi \sin\lambda + \left[-\frac{1}{W} C_2 \delta\lambda'' \cos\lambda + (\delta H + C_3) \sin\lambda \right] \cos\phi \quad (2b)$$

$$\delta z = -\frac{1}{W} (C_1 \sin\phi \cos\phi + C_2 \delta\phi'') \cos\phi + (\delta H + D_1 + D_2 \sin^2\phi + D_3 \sin^4\phi) \sin\phi \quad (2c)$$

The following are constants which may be precomputed:

$A_1 = -(\cos 1''/\Delta) \delta x$	$C_1 = \frac{1}{2} \epsilon \delta a + \frac{1}{2} (1+\epsilon) \delta \delta a^2$
$A_2 = -(\cos 1''/\Delta) \delta y$	$C_2 = -\delta \sin 1''$
$A_3 = (\cos 1''/\Delta) \delta z$	$C_3 = \delta a$
$A_4 = -\frac{1}{2} \epsilon \cos 1'' \delta a^2$	$D_1 = [1 - \frac{1}{2} \epsilon (1-\epsilon)] \delta a - \frac{1}{2} \delta \delta a^2$
$A_5 = [(\epsilon/\Delta) \delta a + (1+\epsilon) \delta a^2] \cos 1''$	$D_2 = -B_5$
$B_1 = \delta x$	$D_3 = -\frac{1}{2} \epsilon^2 \delta a$
$B_2 = \delta y$	
$B_3 = \delta z$	
$B_4 = \frac{1}{2} \epsilon \delta a + \frac{1}{2} \delta \delta a^2$	
$B_5 = \frac{1}{2} \epsilon^2 \delta a + \frac{1}{4} \delta \delta a^2$	
$B_6 = -\delta a$	

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 $1/R \approx 0.157 \times 10^{-6}$ 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

$$a_m = a_1 + a_2 \quad (3)$$

$$r = \frac{1}{2} S \left[1 - \frac{1}{2} \theta \left[(2 - \cos a_m) \cos^2 \frac{1}{2} (\beta_1 + \beta_2) - 1 \right] \right] \quad (4)$$

$$\theta = S/r \quad (5)$$

$$\sin \beta_m = \sin \beta_1 \cos \theta + \cos \beta_1 \sin \theta \cos a_1 \quad (6)$$

$$\sin \Delta \lambda = \sin \theta \sin a_1 \sec \beta_m \quad (7)$$

$$\lambda_m = \lambda_1 + \Delta \lambda \quad (8)$$

Now compute δH_m for (β_m, λ_m) by eq. (10). Then

$$\delta \bar{H} = (\delta H_1 + 4\delta H_m + \delta H_2)/6 \quad (9)$$

$$\delta S = -\theta \delta \bar{H} + H_1 \cos a_1 \delta \beta_1 + H_2 \cos a_2 \delta \beta_2 + (H_1 \delta \lambda_1 - H_2 \delta \lambda_2) \cos \beta_1 \sin a_1 \quad (10)$$

$$T = (H_2 - H_1)/S - \frac{1}{2} \theta \left(1 + \frac{1}{12} \theta^2 \right) \quad (11)$$

$$U = \sin a_1 \delta \beta_1 - \cos \beta_1 \cos a_1 \delta \lambda_1 \quad (12)$$

$$\delta a_1 = \sin \beta_1 \delta \lambda_1 + TU - \frac{1}{6} \theta^2 \cos \beta_1 \sin a_1 (\cos \beta_1 \cos a_1 - \frac{1}{2} \theta \sin \beta_1) \delta \theta^2 - \frac{1}{2} \theta \cos^2 \frac{1}{2} (\beta_1 + \beta_2) \sin a_m \delta H_m / R \quad (13)$$

To compute δa_2 , use (11), (12), and (13) with subscripts 1 and 2 reversed.

$\delta \beta$ and $\delta \lambda$ are in radians.

For lines up to 250 km omit the θ^3 term in eq. (11) and use

$$\delta a_1 = \sin \beta_1 \delta \lambda_1 + TU + \frac{1}{12} \theta^2 \cos^2 \frac{1}{2} (\beta_1 + \beta_2) \sin a_m \delta \theta^2 - \frac{1}{2} \theta \cos^2 \frac{1}{2} (\beta_1 + \beta_2) \sin a_m \delta \bar{H} / R \quad (13')$$

For ground triangulation lines omit (6), (7), and (8) and use

$$\delta \bar{H} = \frac{1}{2} (\delta H_1 + \delta H_2) \quad (9')$$

For lesser accuracy, as in aerial electronic trilateration, use only the first term of eq. (10), omit the term in θ^2 in eq. (11), and omit the last term of eq. (13).

Five-figure computations are sufficient.

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A more convenient form of equation (6), not used in test computations, is

$$\sin \delta_m = \frac{1}{2} (\sin \delta_1 + \sin \delta_2) \sec \delta_0 \quad (6')$$

Further simplifications of equations (6) and (7) are achieved by using for lines of intermediate length

$$\sin \delta_m = \frac{1}{2} (\sin \delta_1 + \sin \delta_2) \left(1 + \frac{1}{8} \theta^2\right) \quad (6'')$$

$$\sin \Delta = \frac{1}{2} \theta \sin \delta_1 \sec \delta_0 \left(1 - \frac{1}{24} \theta^2\right) \quad (7'')$$

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.
 $\delta x = 90.904$ m, $\delta y = 108.335$ m, $\delta z = 100.000$ m.

STA	ϕ	λ	H	δx	δy	δz
20	20°00'00"000000N	65°00'00"000000E	0 m	-15.188	-12.591	-36.124
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 39 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	52 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. $\phi = 40°00'00"000000S$, $\lambda = 95°00'00"000000E$, $H = 0.000$ m. (The exact method uses equations for x , y , and z as shown in Appendix A and their inverse forms, e. g. [5]).

	δx	δy	δz
(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 NAD 83 by Vincenty and Vening Meinesz methods. Only the differences in results (Vincenty minus Vening Meinesz) are given.

STA	$\Delta \delta x$	$\Delta \delta y$	STA	$\Delta \delta x$	$\Delta \delta y$
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		Intern. Fed. As. Beck As.	Change	Vincenty Formula	Error
	Fed. As. Beck As.	Geod. Dist.				
	(1)	(2)	(2)-(1)	(3)	(4)	(4)-(3)
20-21	90 00 00.0000	59.8060	-0.1940	-0.1940	0.0000	
	276 2 09.3789	08.2714	-1.1075	-1.1073	0.0002	
	2 000 000.000	13.762	13.762	13.765	0.002	
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 00.000	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 42.3834	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 21.3893	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 42.8458	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	-0.6412	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	59.5739	-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	-1.6153	0.0002	
	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	-5.8438	-5.8410	0.0002
	330 10 00.3147	47.6204	-12.7542	-12.7542	0.0001
	2 000 000.000	63.966	63.966	63.965	0.001
90-82	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	-2.5827	-1.5826	0.0001
	1 509 407.176	43.844	36.668	36.672	0.004

App. E, PG 2

APPENDIX F

REFERENCES

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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. $A\phi$ - The semimajor axis of the reference ellipsoid in the original datum.
2. $F\phi$ - 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:

$$\delta\phi'' = \left[[(A_1 \cos\lambda + A_2 \sin\lambda) \sin\phi + A_3 \cos\phi] \sqrt{1 + (A_4 \sin^2\phi + A_5) \sin\phi \cos\phi} \right] \left[1 - \frac{H}{A\phi} \right]$$

$$\delta\lambda'' = \left[(A_1 \sin\lambda - A_2 \cos\lambda) \frac{w}{\cos(\phi)} \right] \left[1 - \frac{H}{A\phi} \right]$$

$$\delta H = (DX \cos\lambda + DY \sin\lambda) \cos\phi + DZ \sin\phi + B_4 \sin^2\phi + B_5 \sin^4\phi + B_6$$

where

$$A_1 = - \frac{\text{csc}(1'')}{\dot{a}} DX$$

$$A_2 = - \frac{\text{csc}(1'')}{\dot{a}} DY$$

$$A_3 = \frac{\text{csc}(1'')}{\dot{a}} DZ$$

$$A_4 = -0.5 (\dot{\epsilon} \text{csc}(1'') de^2)$$

$$A_5 = \left[\left(\frac{\dot{\epsilon}}{\dot{a}} \right) da + (1 + \epsilon) de^2 \right] \text{csc}(1'')$$

$$B_4 = 0.5 (\dot{a} de^2 - \dot{\epsilon} da)$$

$$B_5 = B_4 \cdot de^2 - (0.25) (\dot{a} \cdot \dot{\epsilon} \cdot de^2)$$

$$B_6 = A\phi - AN$$

$$V = 1 + \dot{\epsilon} (1 - 1.5 \sin^2(\phi))$$

$$W = 1 - 0.5 \dot{\epsilon} \sin^2(\phi)$$

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:

$$\dot{a} = 0.5 (A\phi + AN)$$

$$e = \frac{(a^2 - b^2)^{1/2}}{a}$$

$$\epsilon = \frac{e^2}{(1 - e^2)}$$

$$\epsilon = \frac{1}{2}(\epsilon_{\phi} + \epsilon_n)$$

$$da = a_n - a_{\phi}$$

$$de^2 = e_n^2 - e_{\phi}^2$$

But for an ellipse:

$$c = a \left(1 - \frac{1}{f}\right)$$

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

$$\frac{a}{b} = \frac{f}{f-1}$$

$$e^2 = \frac{a^2 - b^2}{a^2} = 1 - \frac{b^2}{a^2} = 1 - \left(\frac{f-1}{f}\right)^2$$

$$\epsilon = \frac{e^2}{1 - e^2} = \frac{1 - \left(\frac{f-1}{f}\right)^2}{1 - 1 + \left(\frac{f-1}{f}\right)^2}$$

$$\epsilon = \frac{1 - \left(\frac{f-1}{f}\right)^2}{\frac{f-1}{f}} = \left(\frac{f}{f-1}\right)^2 - 1$$

$$\dot{\epsilon} = \frac{1}{2} \left[\left(\frac{F\phi}{F\phi-1}\right)^2 + \left(\frac{FN}{FN-1}\right)^2 \right] - 1$$

$$de^2 = \left[\frac{F\phi-1}{F\phi}\right]^2 - \left[\frac{FN-1}{FN}\right]^2$$

FORTRAN LISTING

C
C
C

--- 1/3/69 VERSION ---

NOT REPRODUCIBLE

```

1 FORMAT (5X,F9.3,6X,F10.4)
2 FORMAT (9X,F9.6,1X,F9.6,1X,F9.6)
3 FORMAT (13,3X,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 SDDC. MM.MMMM SS.SSSS ,
4 36HSDDD. MM.MMMM SS.SSSS SMMMM.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,16HGEODIDAL HEIGHT = ,F8.1,7H METERS,4/)
19 FORMAT ( 5X,7HEDDT = ,E15.8,5X,6HDEE = ,E15.8,8/)
20 FORMAT ( 5X,10HSTATION ,13,/)
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,GHD
PAUSE - 264 -
IF(KSTA) 99,101,101
101 TEMP=ABS(RLATD)
PLATE=SIGNI(TEMP*60.+RLATM)*60.+RLATS,RLATD)

```

NOT REPRODUCIBLE

```
CLATR=CLATS*CON  
CLONR=CLONS*CON  
ADJT=(AO+AN)/2.  
DFO=((FO-1.)/FO)  
DFN=((FN-1.)/FN)  
DFO2=DFO*DFO  
DFN2=DFN*DFN  
EDJT=((1./DFO2)+(1./DFN2))/2.-1.  
DE2=DFO2-DFN2  
CONA=CON*ADJT  
CONE2=DE2/CON  
GHCON=(1.-(GH)*1.E-3)/AO  
A1=-DX/CONA  
A2=-DY/CONA  
A3=DZ/CONA  
A4=-0.5*EDJT*CONE2  
A5=(EDJT/CONA)*(AN-AO)+(1.+EDJT)*CONE2  
CLAT=COS(CLATR)  
SLAT=SIN(CLATR)  
CLON=COS(CLONR)  
SLON=SIN(CLONR)  
S2LAT=SLAT*SLAT  
V=1.+EDJT*(1.-1.5*S2LAT)  
W=1.-0.5*EDJT*S2LAT  
DLAT=((A1*CLON+A2*SLON)*SLAT+A3*CLAT)*V  
1 DLAT=DLAT*GHCON  
DLON=(A1*SLON+A2*CLON)*W/CLAT  
DLON=DLON*GHCON  
B6=(AO-AN)  
B4=(ADJT*DE2-EDJT*B6)*0.5  
B5=B4*EDJT-0.25*ADJT*EDJT*DE2  
DHKM=(DX*CLON+DY*SLON)*CLAT+DZ*SLAT  
1 DHKM=DHKM+0.5*(S2LAT*B5*(S2LAT*S2LAT)+B6  
DHM=DHKM*1.E+3  
GHN=GH+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(K,4)  
WRITE(K,6)  
WRITE(K,7) AO,FO  
WRITE(K,8) AN,FN  
WRITE(K,9) DY,DY,DZ  
123 WRITE(K,20) KSTA  
124 WRITE(K,10)  
WRITE(K,11) RLATD,RLATM,RLATS  
WRITE(K,12) RLOND,RLONM,RLONS  
WRITE(K,13) GH
```

NOT REPRODUCIBLE

```
WRITE(KO,12) FLOND,FLONM,FLONS  
WRITE(KO,18) G4N  
WRITE(KO,14) DLAT,DLON,DHM  
WRITE(KO,15) DLATN,DLONN  
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

NOT REPRODUCIBLE

INPUT ELLIPSOID PARAMETERS

SEMI AXIS	REC. FLAT.
KKKK.KKKK	FFF.FFFF
6378.206	294.978
6378.144	298.230

INPUT ORIGIN OFFSETS

EX - KM	DY - KM	DZ - KM
SX.XXXXXX	SX.XXXXXX	SX.XXXXXX
-0.025	.173	.183

INPUT STATION POSITION

STA	LATITUDE	LONGITUDE	ANT. HEIGHT
NNN	SDD. MM.MMM SS.SSS	SDD. MM.MMM SS.SSS	SMMM.M
1	+039. 9.6165	-076. 53.8643	+ 145.
PAUSE			

GEODEIC COORDINATE TRANSFORMATION

ORIGINAL DATUM - A = 6375.206 KM F = 1/294.978

TRANSFORMED DATUM - A = 6375.144 KM F = 1/298.239

DX = -.02500 KM DY = .17399 KM DZ = .18399 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 9.9999 MIN 49.6875 SEC

LONGITUDE - -76. DEG 53.9999 MIN 51.2498 SEC

GEOIDAL HEIGHT - 94.1 METERS

DLAT = .6799 SEC DLON = .6193 SEC DH = -50.9 METERS

DLAT = .0113 MIN DLON = .9103 MIN

DLAT = .0113 MIN DLON = .0983 MIN

A1 = .80847895E+00

A2 = -.55946750E+01

A3 = .59169660E+01

A4 = .51494971E-01

A5 = -.15312492E+02

- 268 -

EDOT = .67775249E-02 DE2 = -.73671341E-04

Appendix F

GLOSSARY OF TERMS FOR NAVIGATION SOLUTION
 COMPUTATION

<u>Term or Symbol</u>	<u>Fortran Name</u>	<u>Meaning</u>
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.
$C_{ko}(f, \phi, \lambda)$		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).

<u>Term or Symbol</u>	<u>Fortran Name</u>	<u>Meaning</u>
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,, 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 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 ephemerical data.

<u>Term or Symbol</u>	<u>Fortran Name</u>	<u>Meaning</u>
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 .
$\Delta \varphi$		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.

<u>Term or Symbol</u>	<u>Fortran Name</u>	<u>Meaning</u>
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).
$\dot{\Omega}$	COME	Right ascension of ascending node.
$\ddot{\Omega}$	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

$$C_1 = 1.570\ 796\ 318\ 47$$

$$C_3 = -0.645\ 963\ 711\ 06$$

$$C_5 = 0.079\ 689\ 679\ 28$$

$$C_7 = -0.004\ 673\ 765\ 27$$

$$C_9 = 0.000\ 151\ 484\ 19$$

$$\sum_{i=0}^4 C_{2i+1} = 1.000\ 000\ 005\ 31.$$

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 $0 \leq X \leq 1$. 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

$$\psi(X) = a_0 + a_1 X + a_2 X^2 + a_3 X^3 + \dots + a_7 X^7$$

$$a_0 = 1.5707 \quad 965 \quad 050$$

$$a_1 = -0.2145 \quad 988 \quad 016$$

$$a_2 = 0.0889 \quad 789 \quad 874$$

$$a_3 = -0.0501 \quad 743 \quad 046$$

$$a_4 = 0.0308 \quad 918 \quad 810$$

$$a_5 = -0.0170 \quad 881 \quad 256$$

$$a_6 = 0.0066 \quad 700 \quad 901$$

$$a_7 = -0.0012 \quad 624 \quad 911 .$$

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:

$$A_0 = \frac{X}{2} + \frac{1}{2}.$$

- b. Then compute by Newton's method

$$A_1 = \left(\frac{X}{A_0} + A_0 \right) \cdot \frac{1}{2}$$

$$A_2 = \left(\frac{X}{A_1} + A_1 \right) \cdot \frac{1}{2}$$

$$A_3 = \left(\frac{X}{A_2} + A_2 \right) \cdot \frac{1}{2} .$$

c. Then $Y = \sqrt{X} = A_3 .$