

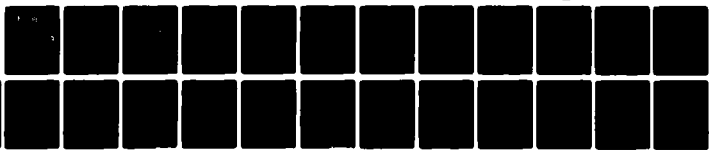
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A COMPUTER ASSISTED METHODOLOGY FOR ALIGNING THE AN/ASN 43 FOR --ETC(U)
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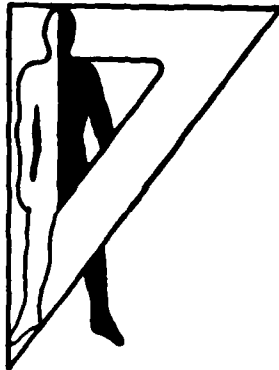
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Technical Memorandum 8-80

A COMPUTER ASSISTED METHODOLOGY FOR ALIGNING
THE AN/ASN 43 FOR DOPPLER (AN/ASN 128)
INSTALLATION AND CALIBRATION

Thomas L. Frezell
Peter J. Grazaitis

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April 1980
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**A COMPUTER ASSISTED METHODOLOGY FOR ALIGNING
THE AN/ASN 43 FOR DOPPLER (AN/ASN 128)
INSTALLATION AND CALIBRATION**

INTRODUCTION

With the procurement of a doppler navigation system by the US Army for installation on certain Army aircraft, it is imperative that maximum fidelity be attained from the aircraft heading reference system. This report deals only with the alignment of an AN/ASN 43; however, the methodology described is appropriate for aligning and calibrating other magnetic reference systems.

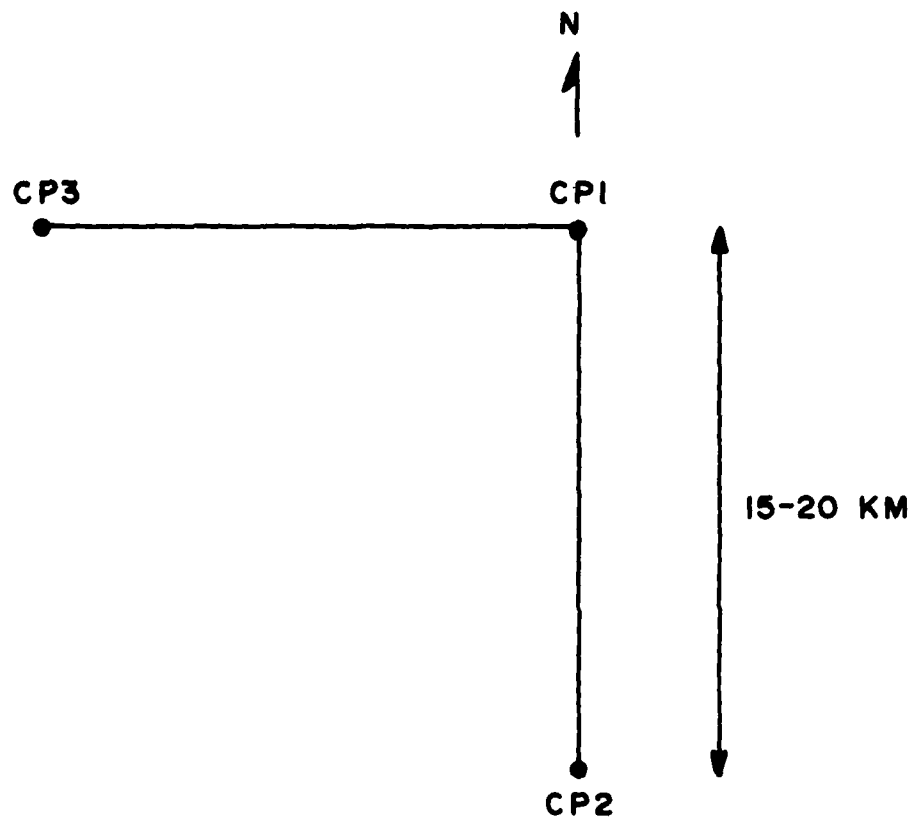
ALIGNMENT

A detailed method for aligning the magnetic flux system is contained in the AN/ASN-128 Doppler Installation and Acceptance Testing Manual.¹ This section will only serve to supplement and enhance the base document.

In initiating an alignment procedure, a precise flight test course should be established for use throughout the entire procedure. Many factors exist which must be considered in establishing a course. Several of these factors are listed below:

1. Select check points (CPs) that can be easily identified at a distance of several kilometers when flying the test course.
2. Select a CP that is easily identified on a large scale map to assure the greatest accuracy in plotting its coordinates.
3. Design the test course so that the CPs selected are close to magnetic North-South and East-West headings. This will help in resolving errors by holding the number of possible variables to a minimum.
4. The CPs should be located approximately 15 to 20 kilometers apart. A graphic presentation of an ideal flight test course is depicted in Figure 1.

¹US Army Avionics Research & Development Activity. Installation and Acceptance Testing of Navigational Set, Doppler AN/ASN-128, Specification Number AV-IT5800-001A, Fort Monmouth, NJ, 9 March 1979.



- LEG 1 = CP2 - CPI
- LEG 2 = CPI - CP3
- LEG 3 = CP3 - CPI
- LEG 4 = CPI - CP2

Figure 1. Graphic presentation of an ideal flight test course.

5. In using the AN/ASN 128 to enter the magnetic variation of the flight area, the Clark 1866 code of CL6 should be used anywhere within the continental United States. Outside the continental United States, other applicable codes should be used. The Defense Mapping Agency's Index of Grids, Datums and Spheroids² should be used to determine what code is appropriate.

6. The installation and acceptance document suggests using the average value by flying three test patterns and computing a mean value. If good reliability is determined early in the flight pattern, then one trip around the course should provide accurate data to perform the necessary alignment calculations.

7. The same individual should determine the aircraft's exact time over the check point for recording and storage to assure consistency and reliability. This will also eliminate another variable.

8. The alignment procedure is a precise and time consuming task. The accurate alignment of the flux system will yield greater system performance.

ALIGNMENT EQUATIONS AND COMPUTATIONS

This section deals with equations and calculations necessary in aligning the aircraft flux system. The majority of the data provided here is also contained in the installation and acceptance document. Some areas have been clarified to a greater extent, and some of the acceptance document errors have been corrected. It is included to assist those who do not have computer facilities or the background to utilize the computer assisted methodology that will follow this section.

The computations performed will use coordinate values supplied in the installation and acceptance document.

The schematic depicted in Figure 2 would indicate a flight from CP 1 to CP 2 and return to CP 1, thus allowing two sets of data points to be generated; i.e. actual (plotted) and indicated (displayed by doppler upon overflight of plotted point). Table 1 shows the UTM actual and indicated coordinates.

²Defense Mapping Agency Topographic Center. Grid, datum, and spheroid information, Plate I. DMA Stock No. DATMX52411C1. Code 40220, Washington, DC, 20315, 2 September 76.

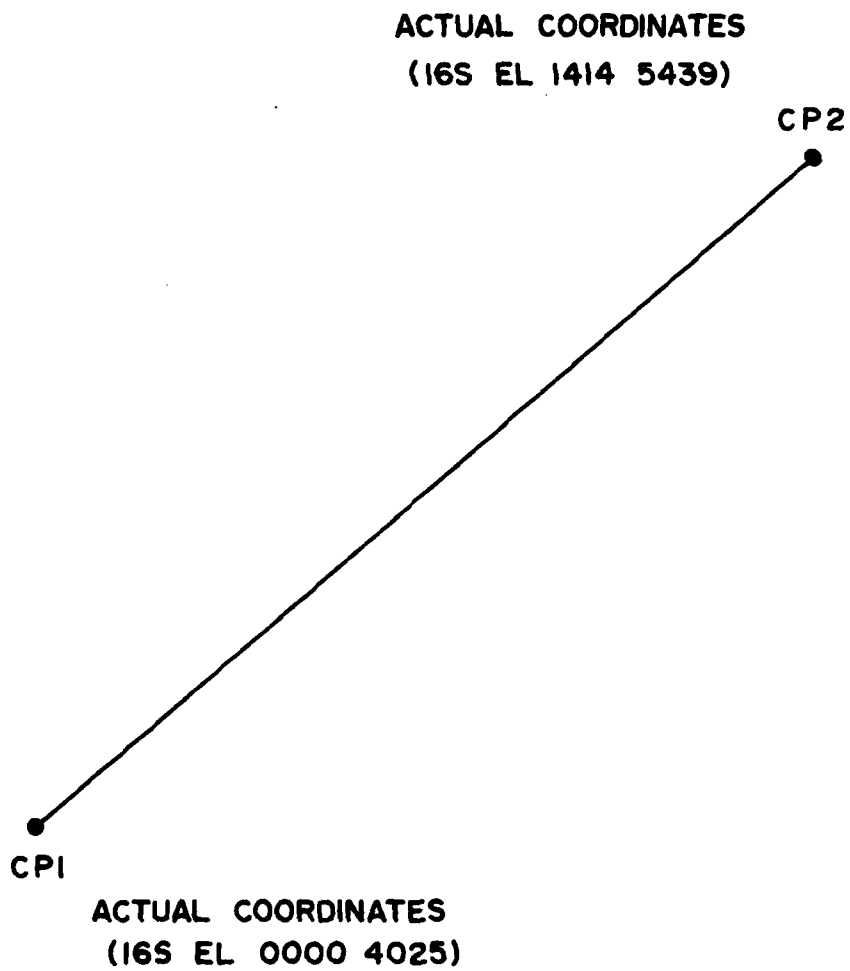


Figure 2. Initial test leg of flight course.

TABLE 1

UTM Actual and UTM Indicated Coordinates

Check Point	UTM Actual Coordinates				UTM Indicated Coordinates			
	Grid Zone	Area	Easting (E)	Northing (N)	Grid Zone	Area	Easting (E)	Northing (N)
1	16S	EL	0000	4025	16S	EL	0006	4022
2	16S	EL	1414	5439	16S	EL	1438	5432
3								
.								
.								
.								
.								

Equations and Calculations

Actual Distance Traveled CP1 → CP2

- D_T = Distance traveled
- (m) = Meters
- Δ = Delta; i.e., change or difference

$$\begin{aligned}
 D_T(m) &= c = \sqrt{a^2 + b^2} \times 10 \text{ where } a = \begin{array}{l} \text{CP2(E)}=1414 \\ \text{CP1(E)}=0000 \\ \Delta E = -1414 \end{array} \quad b = \begin{array}{l} \text{CP2(N)}=5439 \\ \text{CP1(N)}=4025 \\ \Delta N = -1414 \end{array} \\
 &= \sqrt{(1414)^2 + (1414)^2} \times 10 \\
 &= \sqrt{3998792} \times 10 \\
 &= 20,000\text{m} \\
 &= 20\text{km}
 \end{aligned}$$

Using the Easting and Northing error values, as well as the actual bearing angle, we now compute the Along Track Error (ϵ_{AT}) and the Cross Track Error (ϵ_{CT}) in meters and percent.

Where

$$\begin{aligned}\epsilon_{AT}(m) &= \epsilon_{P_N} \cos \beta + \epsilon_{P_E} \sin \beta \\ &= -40 \cos 45^\circ + 180 \sin 45^\circ\end{aligned}$$

$$\epsilon_{AT}(m) = 98.980 \text{ meters}$$

$$\epsilon_{AT}(\%) = \frac{\epsilon_{AT}(m)}{D_T(m)} \times 100 = \frac{98.980}{20,000} = .49\%$$

The $\epsilon_{AT}\%$ should not exceed 2.0% of D_T . Repair or realignment should be considered if error is much more than 1.0% of D_T .

Cross Track Error:

$$\begin{aligned}\epsilon_{CT}(m) &= -\epsilon_{P_N} \sin \beta + \epsilon_{P_E} \cos \beta \\ &= -(-40) \sin 45^\circ + 180 \cos 45^\circ \\ &= 155.54\end{aligned}$$

$$\epsilon_{CT}(\%) = \frac{\epsilon_{CT}(m)}{D_T(m)} \times 100$$

$$= \frac{155.54}{20,000} \times 100$$

$$\epsilon_{CT}(\%) = .77\%$$

$\epsilon_{CT}\%$ should not exceed 5.0% of D_T . The authors believe that the $\epsilon_{CT}\%$ should not exceed 2.5% of D_T in order to consider the system reliable enough for accurate navigation.

FLIGHT TEST DATA REDUCTION AND ERROR DETERMINATION

This section will present the calculation methodology for reducing the flight data. All the equations used are taken from the Installation and Acceptance Testing Document.

1. Calculate the azimuth angle flown on each leg by computing the change in northing ΔN and easting ΔE . In order to compute this angle in the correct direction, we must use the following values:

$$\text{If } \Delta E \geq 0 \text{ then } \theta = 90^\circ - \tan^{-1} \frac{\Delta N}{\Delta E} + \text{Magnetic Variation}$$

$$\text{If } \Delta E < 0 \text{ then } \theta = 270 - \tan^{-1} \frac{\Delta N}{\Delta E} + \text{Magnetic Variation}$$

2. If using more than one set of values, group the azimuth angles into north, south, east, and west groups.

3. Determine the error for each leg by subtracting the calculated true azimuth from doppler read values.

$$\text{i.e. } \epsilon = \theta - \theta \text{ true}$$

4. Calculate the mean error for each leg; i.e. (N,S,E,W):

$$\bar{\epsilon} = \frac{1}{N} \sum \epsilon$$

5. Once the mean is calculated for each leg, determine that the error (ϵ) in each leg is not greater than 1° from the calculated mean ($\bar{\epsilon}$). The acceptance document recommends that the mean be recalculated leaving out the leg with the mean error difference of $>1^\circ$, or re-flying the course to obtain a new set of data points.

6. Calculate the index error by:

$$\bar{\epsilon}_I = \frac{\bar{\epsilon}_N + \bar{\epsilon}_S + \bar{\epsilon}_E + \bar{\epsilon}_W}{4}$$

7. Calculate the N/S and E/W compensation displacement by:

$$\epsilon_{N/S} = \frac{\bar{\epsilon}_N - \bar{\epsilon}_S}{2}$$

$$\text{and } \epsilon_{E/W} = \frac{\bar{\epsilon}_E - \bar{\epsilon}_W}{2}$$

8. The value calculated for the index error ($\bar{\epsilon}_I$) must now be corrected from the AN/ASN 43. Accuracy to be obtained should be within $\pm 0.1^\circ$.

9. The N/S and E/W compensation displacement error should be corrected to within $\pm 0.1^\circ$.

One will quickly realize that the alignment procedure is a very time consuming process. Not only must one spend many hours in flight, but the calculations required to determine system error and compass alignment and compensation values are arduous and prone to error.

In the process of installing and aligning two doppler systems, the US Army Human Engineering Laboratory developed a computer program that will do all calculations and print out all information described thus far.

NOTE: All calculations are based on a flight within one 100,000 meter square. If the flight area should include more than one 100,000 meter square, one should take this into account when entering coordinate values. Neither program will recognize a change in the 100,000 meter square.

THEORY AND OPERATION OF THE PROGRAM

The program is written in Basic for the Hewlett Packard Model HP-9830A programmable desktop calculator. The calculator will calculate and print pertinent data for calibration purposes. A copy of the Basic program is included in Appendix A. A sample of the Basic program printout is contained in Appendix B.

It is assumed that you are flying to three points in a manner similar to the figure below (Figure 3).

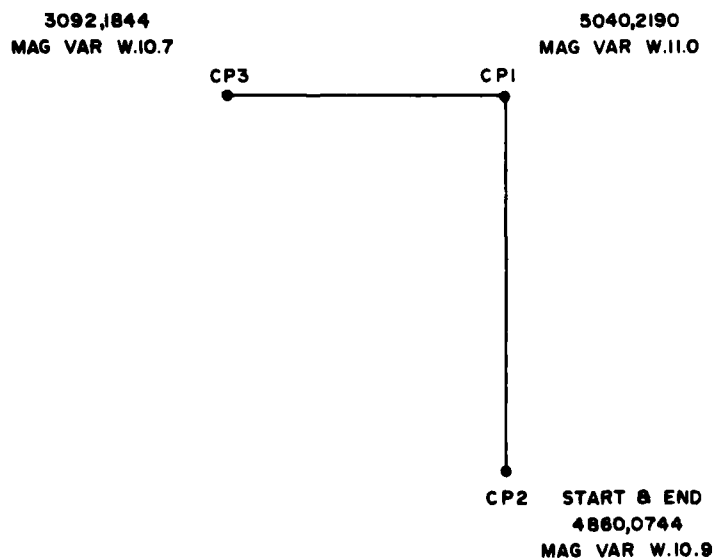


Figure 3. Flight test course and associated coordinate and magnetic variations.

The easting and northing coordinates and the magnetic variance associated with the three flight points must be known (Figure 3).

The flight pattern is as follows: Take off from point 2, proceed to point 1, proceed to point 3, return to point 1, and return to point 2 where the flight ends. As the flight proceeds to the various points, the doppler coordinates should be recorded. The coordinate values will probably be different from the reference coordinates. The doppler and reference coordinates should be set up in a table (Table 2) for ease in entering the needed data into the computer for processing.

TABLE 2

Doppler and Reference Coordinates Setup

<u>Point</u>	<u>Plotted Reference Points</u>		<u>Recorded Doppler Points</u>		<u>Magnetic Var. of End Point</u>
	<u>Easting</u>	<u>Northing</u>	<u>Easting</u>	<u>Northing</u>	
2-1	4860	0744	5010	2124	11.0
1-3	5040	2190	3187	1935	10.7
3-1	3092	1844	4930	2274	11.0
1-2	5040	2190	4840	0833	10.9

Table 2 relates directly to the flight path taken. This information is keyed into the computer for processing but in a slightly different line order. When the program is executed, the program will prompt the user four times for input data. A typical prompt is listed below:

Input PT1 to PT2 & Magnetic Variation

The user would type in the known easting and northing coordinates for point 1, then the doppler easting and northing coordinates, and the magnetic variation associated with point 2 (the point one is flying to). The input stream is keyed in via the keyboard followed by an execute (carriage return). The user's response to the prompt is taken from Table 2 and appears below:

5040,2190,4840,0833,10.9(ex)

The user must take care to input the data correctly according to the prompts. A sample of the four computer prompts and the proper user responses are given in the exact order as they will appear below. The responses are based on sample data contained in Table 2.

(Computer Prompt)	Input PT1 to PT2 & Magnetic Variation
(User Response)	5040,2190,4840,0833,10.9(ex)
(Computer Prompt)	Input PT2 to PT1 & Magnetic Variation
(User Response)	4860,0744,5010,2124,11.0(ex)
(Computer Prompt)	Input PT1 to PT3 & Magnetic Variation
(User Response)	5040,2190,3187,1935,10.7(ex)
(Computer Prompt)	Input PT3 to PT1 & Magnetic Variation
(User Response)	3092,1844,4930,2274,11.0(ex)

A large portion of the program is made up of output statements. The program should be suitable for a handheld programmable calculator, such as the HP-41C, provided that it has sufficient memory. This would be ideal for use directly in the field; however, no attempt has been made to convert it. Although the HP-9830A is somewhat portable, the name is misleading. It is more of a minicomputer than a calculator. It is not battery operated and runs on a 110V AC line making it difficult to use in the field.

It should be very easy to convert the program written for the HP-9830A calculator into standard Basic. Most of the statements do not require modification. The changes that are necessary should be both minor and obvious. Since everyone does not use Basic, the program was converted to Fortran. The Fortran program was written for the PDP-11 series computer from Digital Equipment Corporation under the RT-11 operating system. This machine uses a 16-bit word length. There should be no major problem in running this program on any other machine using the Fortran program. A minor formatting problem might occur where the real variable Array C is used to output some character data on the A4 format. On machines with larger word lengths, this A4 format should be changed to accommodate the larger character storing capacity.

The Fortran program directs all messages and all inputs via logical unit 5. On the PDP-11 series machine, this is the consol terminal. All output is directed to logical unit 6 which is the system line printer on the PDP-11 series machines. If your machine uses another logical unit numbers for the terminal and line printer, change the variables LO (Logical Output) and LI (Logical Input) to what they should be for your machine.

The Fortran program prompts the user interactively as before, but the input must adhere to the input format listed below. A copy of the Fortran program and its output appears in Appendixes C and D.

XXXXX,XXXXX,XXXXX,XXXXX,XX.X(CR)

05040,02190,04840,00833,10.9(CR)

APPENDIX A

THE BASIC PROGRAM

```

5 DIM A(4,13),A$(80),B(4,5)
10 DISP "INPUT PT1 TO PT2 & MAG. VARIANCE"
15 INPUT A(1,1),A(1,2),A(1,3),A(1,4),A(1,5)
20 DISP "INPUT PT2 TO PT1 & MAG. VARIANCE"
25 INPUT A(2,1),A(2,2),A(2,3),A(2,4),A(2,5)
30 DISP "INPUT PT1 TO PT3 AND MAG. VARIANCE"
35 INPUT A(3,1),A(3,2),A(3,3),A(3,4),A(3,5)
40 DISP "INPUT PT3 TO PT1 & MAG. VARIANCE"
45 INPUT A(4,1),A(4,2),A(4,3),A(4,4),A(4,5)
50 DEG
55 FOR J=1 TO 4
60 IF J=2 OR J=4 THEN 75
65 A(J,6)=SQR((A(J,1)-A(J+1,1))^2+(A(J,2)-A(J+1,2))^2)*10
70 A(J+1,6)=A(J,6)
75 B1=SQR((A(J,2)-A(J+(-1)^(J+1),2))^2)
80 B2=SQR((A(J,1)-A(J+(-1)^(J+1),1))^2)
85 IF A(J+(-1)^(J+1),1)>A(J,1) AND A(J+(-1)^(J+1),2)>A(J,2) THEN 105
90 IF A(J+(-1)^(J+1),2)>A(J,2) AND A(J+(-1)^(J+1),1)>A(J,1) THEN 115
95 IF A(J+(-1)^(J+1),2)>A(J,2) AND A(J+(-1)^(J+1),1)>A(J,1) THEN 125
100 IF A(J+(-1)^(J+1),2)>A(J,2) AND A(J+(-1)^(J+1),1)>A(J,1) THEN 135
105 A(J,7)=ATN(B2/B1)+A(J,5)
110 GOTO 140
115 A(J,7)=ATN(B2/B1)+A(J,5)+270
120 GOTO 140
125 A(J,7)=ATN(B2/B1)+A(J,5)+180
130 GOTO 140
135 A(J,7)=ATN(B2/B1)+A(J,5)+90
140 A(J,8)=((A(J,3)-A(J+(-1)^(J+1),3))-(A(J+(-1)^(J+1),3)-A(J,1)))*10
145 A(J,9)=((A(J,4)-A(J+(-1)^(J+1),4))-(A(J+(-1)^(J+1),4)-A(J,2)))*10
150 A(J,10)=A(J,9)*COS(A(J,7))+A(J,8)*SIN(A(J,7))
155 A(J,11)=A(J,10)/A(J,6)*100
160 A(J,12)=A(J,8)*COS(A(J,7))-A(J,9)*SIN(A(J,7))
165 A(J,13)=A(J,12)/A(J,6)*100
170 NEXT J
175 WRITE (15,180)
180 FORMAT 34X,"CALCULATIONS",2/,36X,"TABLE 1",/
185 A$(1,74)="
190 A$(66,80)="EAST ACTUAL INDICATED MAGNETIC ACTUAL BEARING"
195 WRITE (15,200)A$
200 FORMAT 8
205 A$(1,61)="LEG COORDINATE COORDINATE DIFFERENCE DISTANCE ANGLE"
210 A$(62,80)="
215 WRITE (15,220)A$
220 FORMAT 8,/
225 PRINT
230 WRITE (15,235)A(1,1),A(1,2),A(1,3),A(1,4),A(1,5),A(1,6),A(1,7),A(1,8),A(1,9)
235 FORMAT "1-2",F8.0,"-",F5.0,F7.0,"-",F5.0,F9.1,7X,F6.0,F9.1,F10.1,F8.1
240 WRITE (15,245)A(2,1),A(2,2),A(2,3),A(2,4),A(2,5),A(2,6),A(2,7),A(2,8),A(2,9)
245 FORMAT "2-1",F8.0,"-",F5.0,F7.0,"-",F5.0,F9.1,7X,F6.0,F9.1,F10.1,F8.1
250 WRITE (15,255)A(3,1),A(3,2),A(3,3),A(3,4),A(3,5),A(3,6),A(3,7),A(3,8),A(3,9)
255 FORMAT "1-3",F8.0,"-",F5.0,F7.0,"-",F5.0,F9.1,7X,F6.0,F9.1,F10.1,F8.1
260 WRITE (15,265)A(4,1),A(4,2),A(4,3),A(4,4),A(4,5),A(4,6),A(4,7),A(4,8),A(4,9)
265 FORMAT "3-1",F8.0,"-",F5.0,F7.0,"-",F5.0,F9.1,7X,F6.0,F9.1,F10.1,F8.1
270 WRITE (15,275)

```

(Continued)

```

275 FORMAT /,36X,"TABLE 2",/
280 WRITE (15,285)
285 FORMAT 13X,"ALONG TRACK ERROR",19X,"CROSS TRACK ERROR"
290 WRITE (15,295)
295 FORMAT "LEG",9X,"(M)",13X,"(%)",17X,"(M)",13X,"(%)",/
300 WRITE (15,305)A[1,10],A[1,11],A[1,12],A[1,13]
305 FORMAT "1-2",7X,F7.1,10X,F6.2,13X,F7.1,10X,F6.2
310 WRITE (15,315)A[2,10],A[2,11],A[2,12],A[2,13]
315 FORMAT "2-1",7X,F7.1,10X,F6.2,13X,F7.1,10X,F6.2
320 WRITE (15,325)A[3,10],A[3,11],A[3,12],A[3,13]
325 FORMAT "1-3",7X,F7.1,10X,F6.2,13X,F7.1,10X,F6.2
330 WRITE (15,335)A[4,10],A[4,11],A[4,12],A[4,13]
335 FORMAT "3-1",7X,F7.1,10X,F6.2,13X,F7.1,10X,F6.2
340 FOR J=1 TO 4
345 B1=A[J+(-1)^(J+1),2]-A[J,2]
350 B2=A[J+(-1)^(J+1),1]-A[J,1]
355 IF B2<0 THEN 370
360 B[J,4]=90-ATN(B1/B2)+A[J,5]
365 GOTO 375
370 B[J,4]=270-ATN(B1/B2)+A[J,5]
375 B[J,1]=A[J,4]-A[J,2]
380 B[J,2]=A[J,3]-A[J,1]
385 IF B[J,2]<0 THEN 400
390 B[J,3]=90-ATN(B[J,1]/B[J,2])+A[J,5]
391 IF B[J,3]<360 THEN 405
392 B[J,3]=B[J,3]-360
395 GOTO 405
400 B[J,3]=270-ATN(B[J,1]/B[J,2])+A[J,5]
401 IF B[J,3]<360 THEN 405
402 B[J,3]=B[J,3]-360
405 B[J,5]=B[J,3]-B[J,4]
410 NEXT J
415 PRINT
420 WRITE (15,425)
425 FORMAT 36X,"TABLE 3",/
430 A#[1,80]="LEG DIRECTION DEL NORTH DEL EAST THETA"
435 A#[50,80]=" THETA TRUE ERROR"
440 WRITE (15,445)A#
445 FORMAT B
450 PRINT
455 WRITE (15,460)B[1,1],B[1,2],B[1,3],B[1,4],B[1,5]
460 FORMAT "1-2",5X,"SOUTH",8X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1
465 WRITE (15,470)B[2,1],B[2,2],B[2,3],B[2,4],B[2,5]
470 FORMAT "2-1",5X,"NORTH",8X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1
475 WRITE (15,480)B[3,1],B[3,2],B[3,3],B[3,4],B[3,5]
480 FORMAT "1-3",5X,"EAST",9X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1
485 WRITE (15,490)B[4,1],B[4,2],B[4,3],B[4,4],B[4,5]
490 FORMAT "3-1",5X,"WEST",9X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1,2/
495 WRITE (15,500)(B[2,5]-B[1,5])/2
500 FORMAT "ERROR-N/S",5X,F10.2,/
505 WRITE (15,510)(B[3,5]-B[4,5])/2
510 FORMAT "ERROR-E/W",5X,F10.2,/
515 WRITE (15,520)(B[1,5]+B[2,5]+B[3,5]+B[4,5])/4
520 FORMAT "INDEX ERROR",5X,F10.2
525 END

```

APPENDIX B

BASIC PROGRAM PRINTOUT

CALCULATIONS

TABLE 1

LEG	ACTUAL COORDINATE	INDICATED COORDINATE	MAGNETIC DIFFERENCE	ACTUAL DISTANCE	BEARING ANGLE	EAST ERROR	NORTH ERROR
1-2	5040.-2190.	4840.- 833.	10.9	14572.	198.0	100.0	1550.0
2-1	4860.- 744.	5010.-2124.	11.0	14572.	18.1	-100.0	-1550.0
1-3	5040.-2190.	3187.-1935.	10.7	19785.	270.6	2050.0	70.0
3-1	3092.-1844.	4930.-2274.	11.0	19785.	90.9	-2050.0	-70.0

TABLE 2

LEG	ALONG TRACK ERROR		CROSS TRACK ERROR	
	(M)	(%)	(M)	(%)
1-2	-1505.1	-10.33	383.7	2.63
2-1	-1504.4	-10.32	386.4	2.65
1-3	-2049.1	-10.36	92.3	0.47
3-1	-2048.6	-10.35	103.1	0.52

TABLE 3

LEG	DIRECTION	DEL NORTH	DEL EAST	THETA	THETA TRUE	ERROR
1-2	SOUTH	-1357.0	-200.0	199.3	198.0	1.3
2-1	NORTH	1380.0	150.0	17.2	18.1	-0.9
1-3	EAST	-255.0	-1853.0	272.9	270.6	2.2
3-1	WEST	430.0	1838.0	87.8	90.9	-3.1
ERROR-N/S		-1.09				
ERROR-E/W		2.67				
INDEX ERROR		-0.12				

APPENDIX C

FORTRAN PROGRAM

```

0001     DIMENSION A(4,13),B(4,5),C(4)
0002     DATA C/'1-2 ','2-1 ','1-3 ','3-1 '/
0003     LI=5
0004     LO=6
0005     WRITE(LI,1)
0006 1     FORMAT(1H,'INPUT PT1 TO PT2 & MAGNETIC VARIANCE?')
0007     READ(LI,2)(A(1,J),J=1,5)
0008 2     FORMAT(4(F5.0,X),F4.1)
0009     WRITE(LI,3)
0010 3     FORMAT(1H,'INPUT PT2 TO PT1 & MAGNETIC VARIANCE?')
0011     READ(LI,2)(A(2,J),J=1,5)
0012     WRITE(LI,4)
0013 4     FORMAT(1H,'INPUT PT1 TO PT3 & MAGNETIC VARIANCE?')
0014     READ(LI,2)(A(3,J),J=1,5)
0015     WRITE(LI,5)
0016 5     FORMAT(1H,'INPUT PT3 TO PT1 & MAGNETIC VARIANCE?')
0017     READ(LI,2)(A(4,J),J=1,5)
0018     DO 100 J=1,4
0019     IF(J.EQ.2.OR.J.EQ.4)GOTO 75
0021     A(J,6)=SQRT((A(J,1)-A(J+1,1))**2+(A(J,2)-A(J+1,2))**2)*10.0
0022     A(J+1,6)=A(J,6)
0023 75     B1=SQRT((A(J,2)-A(J+(-1)**(J+1),2))**2)
0024     B2=SQRT((A(J,1)-A(J+(-1)**(J+1),1))**2)
0025     IF(A(J+(-1)**(J+1),1).GT.A(J,1).AND.A(J+(-1)**(J+1),2).GT.
*     A(J,2))GOTO 105
0027     IF(A(J+(-1)**(J+1),2).GT.A(J,2).AND.A(J+(-1)**(J+1),1).LT.
*     A(J,1))GOTO 115
0029     IF(A(J+(-1)**(J+1),2).LT.A(J,2).AND.A(J+(-1)**(J+1),1).LT.
*     A(J,1))GOTO 125
0031     IF(A(J+(-1)**(J+1),2).LT.A(J,2).AND.A(J+(-1)**(J+1),1).GT.
*     A(J,1))GOTO 135
0033 105    A(J,7)=ATAN(B2/B1)*57.2958+A(J,5)
0034     GOTO 140
0035 115    A(J,7)=ATAN(B2/B1)*57.2958+A(J,5)+270.0
0036     GOTO 140
0037 125    A(J,7)=ATAN(B2/B1)*57.2958+A(J,5)+180.0
0038     GOTO 140
0039 135    A(J,7)=ATAN(B2/B1)*57.2958+A(J,5)+90.0
0040 140    A(J,8)=((A(J,3)-A(J+(-1)**(J+1),1))-(A(J+(-1)**(J+1),3)-
*     A(J,1)))*10.0
0041     A(J,9)=((A(J,4)-A(J+(-1)**(J+1),2))-(A(J+(-1)**(J+1),4)-
*     A(J,2)))*10.0
0042     A(J,10)=A(J,9)*COS(A(J,7)*.017453)+A(J,8)*
*     SIN(A(J,7)*.017453)
0043     A(J,11)=(A(J,10)/A(J,6))*100.0
0044     A(J,12)=A(J,8)*COS(A(J,7)*.017453)-A(J,9)*
*     SIN(A(J,7)*.017453)
0045     A(J,13)=(A(J,12)/A(J,6))*100.0
0046 100    CONTINUE
0047     WRITE(LO,6)
0048 6     FORMAT(1H,34X,'CALCULATIONS',//,36X,'TABLE 1'//)
0049     WRITE(LO,7)
0050 7     FORMAT(1H,9X,'ACTUAL',5X,'INDICATED',4X,'MAGNETIC',6X,
*     'ACTUAL',2X,'BEARING',4X,'EAST',4X,'NORTH')

```

(Continued)

```

0051      WRITE(LO,8)
0052  8    FORMAT(1H , 'LEG',X,2(3X,'COORDINATE'),2X,'DIFFERENCE',4X,
*        'DISTANCE',2X,'ANGLE',4X,'ERROR'3X,'ERROR'/)
0053      WRITE(LO,9)C(1),(A(1,J),J=1,9)
0054  9    FORMAT(1H ,A4,F7.0,'-',F5.0,F7.0,'-',F5.0,F9.1,7X,F6.0,
*        F9.1,F10.1,F8.1)
0055      WRITE(LO,9)C(2),(A(2,J),J=1,9)
0056      WRITE(LO,9)C(3),(A(3,J),J=1,9)
0057      WRITE(LO,9)C(4),(A(4,J),J=1,9)
0058      WRITE(LO,10)
0059  10   FORMAT(1H ,/,37X,'TABLE 2',/)
0060      WRITE(LO,11)
0061  11   FORMAT(1H ,13X,'ALONG TRACK ERROR',19X,'CROSS TRACK ERROR')
0062      WRITE(LO,12)
0063  12   FORMAT(1H , 'LEG',9X,2(' (M)',13X,' (X)',17X)/)
0064      WRITE(LO,13)C(1),(A(1,J),J=10,13)
0065  13   FORMAT(1H ,A4,7X,F7.1,10X,F6.2,13X,F7.1,10X,F6.2)
0066      WRITE(LO,13)C(2),(A(2,J),J=10,13)
0067      WRITE(LO,13)C(3),(A(3,J),J=10,13)
0068      WRITE(LO,13)C(4),(A(4,J),J=10,13)
0069      DO 200 J=1,4
0070      B1=A(J+(-1)**(J+1),2)-A(J,2)
0071      B2=A(J+(-1)**(J+1),1)-A(J,1)
0072      IF(B2.LT.0.0)GOTO 370
0074      B(J,4)=90.0-ATAN(B1/B2)*57.2958+A(J,5)
0075      GOTO 375
0076  370  B(J,4)=270.0-ATAN(B1/B2)*57.2958+A(J,5)
0077  375  B(J,1)=A(J,4)-A(J,2)
0078      B(J,2)=A(J,3)-A(J,1)
0079      IF(B(J,2).LT.0.0)GOTO 400
0081      B(J,3)=90.0-ATAN(B(J,1)/B(J,2))*57.2958+A(J,5)
0082      IF(B(J,3).LT.360.0)GOTO 405
0084      B(J,3)=B(J,3)-360.0
0085      GOTO 405
0086  400  B(J,3)=270.0-ATAN(B(J,1)/B(J,2))*57.2958+A(J,5)
0087      IF(B(J,3).LT.360.0)GOTO 405
0089      B(J,3)=B(J,3)-360.0
0090  405  B(J,5)=B(J,3)-B(J,4)
0091  200  CONTINUE
0092      WRITE(LO,14)
0093  14    FORMAT(1H )
0094      WRITE(LO,15)
0095  15    FORMAT(1H ,36X,'TABLE 3'/)
0096      WRITE(LO,16)
0097  16    FORMAT(1H , 'LEG',3X,'DIRECTION',5X,'DEL NORTH',4X,'DEL EAST',
*        3X,'THETA',5X,'THETA TRUE',3X,'ERROR'/)
0098      WRITE(LO,17)C(1),(B(1,J),J=1,5)
0099  17    FORMAT(1H ,A4,4X,'SOUTH',8X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1)
0100      WRITE(LO,18)C(2),(B(2,J),J=1,5)
0101  18    FORMAT(1H ,A4,4X,'NORTH',8X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1)
0102      WRITE(LO,19)C(3),(B(3,J),J=1,5)
0103  19    FORMAT(1H ,A4,4X,'EAST',9X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1)
0104      WRITE(LO,20)C(4),(B(4,J),J=1,5)
0105  20    FORMAT(1H ,A4,4X,'WEST',9X,F7.1,5X,F7.1,F9.1,7X,F6.1,F10.1)

0106      WRITE(LO,21)(B(2,5)-B(1,5))/2.0
0107  21    FORMAT(1H , 'ERROR-N/S',5X,F10.2/)
0108      WRITE(LO,22)(B(3,5)-B(4,5))/2.0
0109  22    FORMAT(1H , 'ERROR-E/W',5X,F10.2/)
0110      WRITE(LO,23)(B(1,5)+B(2,5)+B(3,5)+B(4,5))/4.0
0111  23    FORMAT(1H , 'INDEX ERROR',5X,F10.2)
0112      END

```

APPENDIX D

FORTRAN PRINTOUT

CALCULATIONS

TABLE 1

LEG	ACTUAL COORDINATE	INDICATED COORDINATE	MAGNETIC DIFFERENCE	ACTUAL DISTANCE	BEARING ANGLE	EAST ERROR	NORTH ERROR
1-2	5040- 2190	4840- 833	10.9	14572	198.0	100.0	1550.0
2-1	4860- 744	5010- 2124	11.0	14572	18.1	-100.0	-1550.0
1-3	5040- 2190	3187- 1935	10.7	19785	270.6	2050.0	70.0
3-1	3092- 1844	4930- 2274	11.0	19785	90.9	-2050.0	-70.0

TABLE 2

LEG	ALONG TRACK ERROR		CROSS TRACK ERROR	
	(M)	(%)	(M)	(%)
1-2	-1505.1	-10.33	383.8	2.63
2-1	-1504.4	-10.32	386.4	2.65
1-3	-2049.1	-10.36	92.5	0.47
3-1	-2048.6	-10.35	103.2	0.52

TABLE 3

LEG	DIRECTION	DEL NORTH	DEL EAST	THETA	THETA TRUE	ERROR
1-2	SOUTH	-1357.0	-200.0	199.3	198.0	1.3
2-1	NORTH	1380.0	150.0	17.2	18.1	-0.9
1-3	EAST	-255.0	-1853.0	272.9	270.6	2.2
3-1	WEST	430.0	1838.0	87.8	90.9	-3.1

ERROR-N/S	-1.09
ERROR-E/W	2.67
INDEX ERROR	-0.12