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DESCRIPTION OF PROGRAM A

(ABLE)

Technical Memorandum

CDC TM-9552-5

# Feasibility Study of a Track-While-Scan Navigation Concept

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Prepared by:

Bruce D. Vannelli

Submitted to:

Joseph E. Carroll
Project Engineer

Research Division
Control Data Corporation
3101 East 80th Street
Minneapolis 20, Minnesota

# DESCRIPTION OF PROGRAM A

## (ABLE)

## I. INTRODUCTION

A FORTRAN-60 program has been written for the Control Data Corporation 1604 computer and used as a first step in developing the complete simulation of an on-board data processor. A brief description of the program (ABLE), its use and its output will be given. Details of the computations involved and physical constraints can be found in Reference 1.

## II. DESCRIPTION

A. ABLE can best be understood by referring to the flow chart in Figure 1. A given number of stars and planets (no more than 100 and 9 respectively, a program parameter) are checked sequentially to determine if the camera can see them. If so, transit times are computed for this target and partial derivative coefficients are evaluated until all targets are checked. Normally distributed errors are added to every transit time and with these transit times plus the partials, the navigation equations determine the best (in a least squares sense) vehicle attitude and position and compares these with those of the true vehicle state. The differences are found and written on tape (in binary after this process has been repeated nine times with different transit time error sets) until NR (the Monte Carlo sample size, a parameter of the program) of these error sets have been found. These errors are analyzed and

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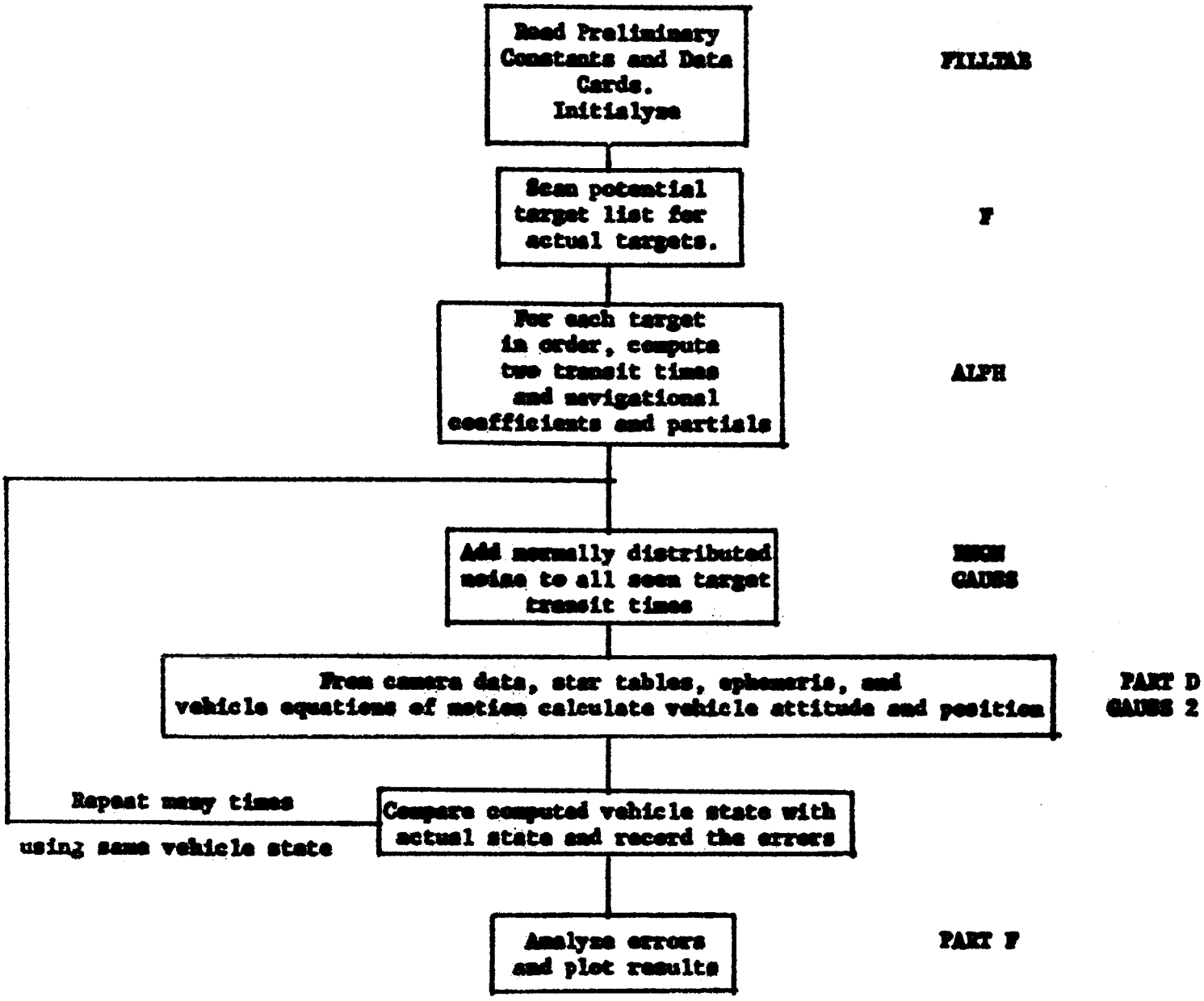
1 Carroll, J. E., "Error Analysis - Program A", CDC TM-9552-2, Contract No. NAS1-2902, June 1963.

Figure 1: Flow Chart - ABLE



distributions plotted exactly as in the analysis for DISTEST.[2]

B. Besides the standard FORTRAN library subroutines (such as SINF, SQRTF, etc.), a number of routines were written explicitly for ABLE. Their usage will be described here in roughly the order in which they appear in the main program.

1. FILLTAB is a very simple routine which fills the star and planet position tables with star right ascension and declination and planet zero longitude and radial distance. It also sets up the table of correspondence between uniformly distributed data and normally distributed data (see Part 5). See Appendix B for the listing.

Size of program: 1985 words

Common storage: 3634

2. F is the truncating function. Supplied with a main program parameter ISHIFT, F(x) simply shifts the quantity x right ISHIFT places (thus dropping the right most ISHIFT bits of the mantissa of a floating point number) and restores x ISHIFT places to the left. Using F in the partial derivative and coefficient computations and the navigational computations thus simulates a smaller (than 48 bits) machine word. Since a 1604 floating point word contains a 36 bit mantissa, one should probably use a shift count of from 0 to not more than 30. See Appendix C for the listing.

Size of program: 39 words

Common storage: 3634 words

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2 Vannelli, B. D., "Description of Preliminary Programs", CDC TM-9552-4, Contract No. NAS1-2902, September 1963.

3. ALPH. Since the FORTRAN inverse tangent routine always finds the principal value of its argument, a routine was written to resolve the arc-tangent into its proper quadrant. ALPH is supplied with two arguments A and B. Their algebraic signs are examined and $x$ = arc-tangent (A/B) is computed. By comparing signs, the angle is put into the proper quadrant ($0 \leq X \leq 2\pi$). See Appendix D for the listing.

Size of program: 137 words

Common storage: None

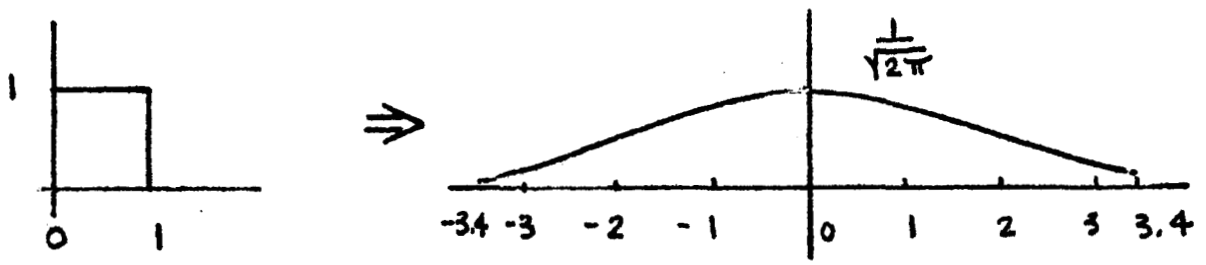
4. RNGN is the random number generator. Repeated usage will produce uniformly distributed random numbers in the interval 0, 1 with mean ½. This routine is used to generate input values to the normally distributed random number generator, GAUSS. See Appendix E for the listing.

Size of program: 37 words

Common storage: None

5. GAUSS is the routine used to transform a number taken from a uniform distribution into a number taken from a normal distribution with mean zero, standard deviation one. Given the uniform number, GAUSS does a table lookup plus a linear extrapolation to produce the normal number for input values in the range $.0003 \leq x \leq .9997$. Since the tails of a normal distribution must be clipped somewhere (in a finite length computer word), the values -3.4 and +3.4 were chosen as these limits. Hence, for $0 \leq x < .0003$ and $.9997 < x \leq 1$, a flag is set, indicating that the normally distributed number would be outside this range and a new input number should be generated.

Symbolically, the mapping is represented as shown below.




See Appendix F for the listing.

Size of program: 109 words

Common storage: 3634 words

6. PART D is the navigation computation subroutine. ABLE supplies the number of stars and planets that can be seen to PART D and through the use of common storage, this subroutine computes attitude and position deviations from the true vehicle state and returns them to the main program. No details of the computations need be given here as they are explained fully in Reference 1. See Appendix G for the listing.

Size of program: 2872 words not including GAUSS 2.

Common storage: 3634 words

7. GAUSS 2 is included in PART D and is a standard CO-OP User's FORTRAN-60 subroutine (F2 UTEX GAUSS 2 "Solution of Simultaneous Linear Algebraic Equations"). This routine is used to solve a system of three equations and three unknowns for attitude errors and a similar system for vehicle position (which are subtracted from the true position to obtain errors). Parameters supplied to GAUSS 2

indicate the size and designation of the coefficient and constant matrices and the designation of the solution. Also, as part of the output, a flag is set to indicate whether the coefficient matrix is singular (flag set $\neq$ 1) or not (= 1). See Appendix G for the listing.

Size of program: 160 words

Common storage: None

8. PART F is the statistical analysis subroutine and can be used with very little modification for the analysis of many different kinds of data sets. This routine must be supplied with two parameters, the tape unit number where the sample data is stored (NTAPE) and the sample size (NR). The data can be thought of as being written in a NR x 6 matrix and is in binary. Data is analyzed by columns from left to right and nine rows are read in at a time and stored away until all NR rows are stored (NR need not be a multiple of 9). Then the mean and the second, third, and fourth moments about zero are computed followed by the second, third, and fourth moments about the mean. Next the standard deviation, the coefficient of skewness, and the coefficient of excess.

Following this, a cumulative distribution is printed and plotted. The interval between the smallest data point and the largest is divided into a convenient number of intervals (more than 49, but less than 401) and the percentage of points in each interval is accumulated and printed along with a number of asterisks (equal to ten times the interval percentage) to form a rough bar graph of the distribution. Finally, the number of intervals, the interval

size, the degrees of freedom, $\chi^2$ and $t_\chi$ (all related to the chi-squared test for normal distributions) are printed. Several examples of output from PART F are shown in Appendix A. See Appendix H for the listing.

Size of program: 7496 words

Common storage: None

## III. OPERATION

ABLE is operated exactly as AJAX 1 and AJAX 2[2] with the following exceptions.

1) No error card (card 6 in the minimal list is necessary nor required.
2) A tape unit must be specified in position C, card 1.
3) A transit time error standard deviation must be specified in position A, card 5.
4) The Monte Carlo sample size (NR) must be specified in position B, card 5.

ABLE takes up 17571 memory locations plus 3634 common storage locations.

To estimate the running time for a particular vehicle data set and a given sample size, one may use the formula

$$T = \frac{A\left(\left[NR/9\right]+1\right)}{60} + B + C$$

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2 Vannelli, B. D., "Description of Preliminary Programs", CDC TM-9552-4, Contract No. NAS1-2902, September 1963.

where

T is the length of time in minutes,

A is the time in seconds to generate nine sets of errors,

NR is the sample size,

B is the time in minutes to call ABLE from the tape,

C is the statistical analysis time in minutes for 6 variables, and

[ ] indicates "integer less than or equal to".

Nominally, A = 16, B = 1, C = 3. For example, to calculate how long a run with NR equal to 1000 will take, we have

$$T = \frac{16\left(\left[1000/9\right]+1\right)}{60} + 1 + 3$$

$$= \frac{16\left(111+1\right)}{60} + 4$$

$$\cong 34 \text{ minutes.}$$

## APPENDIX A

### TABLE OF CORRESPONDENCE PROGRAM ABLE

| SYMBOL | FORTRAN |
|---|---|
| $\pi$ | PI |
| G | G |
| M | SM |
| $\epsilon$ | ECLIP |
| $T_o$ | TZ |
| $k_1, k_2, k_3$ | K1, K2, K3 |
| Tape Number | NTAPE |
| Star Number (1-100) | NSTAR |
| Right Ascension | RA |
| Declination | DEC |
| Planet Number (1-9) | NPLANET |
| $\lambda_o$ | XLAMEZ $\longrightarrow$ PLANPOS (I, 1) |
| a | RAD $\longrightarrow$ PLANPOI (I, 2) |
| $\theta$ | VEH (1) |
| $\phi$ | VEH (2) |
| t | VEH (3) |
| x | VEH (4) |
| y | VEH (5) |
| z | VEH (6) |
| T | T |
| $\tau$ | TAU |
| $\sigma$ | ISIG |
| $M_R$ | NR |
| $\Gamma$ | GAMMA |
| H | CH |
| r' | RP |
| $\lambda$ | XLAMB |
| 86,400/MG | FAC |
| $M_h$ | D |
| $\sin\theta$ | STHETA |
| $\cos\theta$ | CTHETA |
| $\sin\phi$ | SPHI |
| $\cos\phi$ | CPHI |
| $K_g$ | KS |
| $A_h$ | A |
| $B_h$ | B |
| $\chi_1$ | PSI(J) |
| $\cos\eta$ | CADA |
| $t_h$ (+) | TT |
| Step 3 | Error in $\chi$. $1 \geq \cos\eta \geq \cos H$ is not satisfied for any of the $\chi$'s. |
| $\tan\Gamma$ | TANGAM |
| $\cos(\theta + \Delta)$ | CT |
| $\sin(\theta + \Delta)$ | ST |
| $\cos(\phi + \Delta)$ | CP |
| $\sin(\phi + \Delta)$ | SP |
| $\sin(\alpha_h)$ | SRA |
| $\cos(\alpha_h)$ | CRA |
| $\sin(\delta_h)$ | SDEC |

| SYMBOL | FORTRAN |
|---|---|
| $\cos(\delta_h)$ | CDEC |
| $\sin(\epsilon)$ | SECLIP |
| $\cos(\epsilon)$ | CECLIP |

| NUMBERED STOPS | CAUSE |
|---|---|
| 1 | Error in TARGET or NOMINAL card |
| 2 | Error in STAR or PLANET card |
| 3 | Error in $\chi$, $\cos H \leq \cos\eta < 1$ is not satisfied for any of the $\chi$'s. |
| 4 | $\cos\eta > 1$ |
| 11 | Error in GAUSS 2, x, y, z solution could not be found |
| 12 | Error in GAUSS 2, $\Delta\theta$, $\Delta\phi$, $\Delta t$ solutions could not be found. |
| 21 | Input random number r is greater than 1. |

# APPENDIX A

## - ABLE -

## Program Listing

```
      PROGRAM ABLE
      DIMENSION DELT(6),R(3),P(3),TARLIST(110,2),PSI(4),SAVEP(9,2),
     1SAVES(100,2),DELTA(9,6)
      DIMENSION VEH(6),PAREF(100,7,4),PLANCO(9,5,4),ERR(6),SEENS(100,3),
     1SEENP(9,3),PMAG(9),FN(69),STARPOS(100,2),PLANPOS(9,2)
      COMMON PI,K1,K2,K3,NTAPE,ISHIFT,VEH,ISIG,NR,PAREF,PLANCO,T,ERR,FN,
     1SEENS,SEENP,PMAG,STARPOS,PLANPOS
C
C
C          IF SENSE SWITCH 1 IS ON, THE PROGRAM BRANCHES IMMEDIATELY TO
C     THE STATISTICAL ANALYSIS SUBROUTINE PART F.  IF IT IS OFF, COMP-
C     UTATION PROCEEDS NORMALLY THROUGH THE GENERATION OF NR SETS OF
C     ERRORS.  ONCE THIS IS COMPLETED, THE NUMBER OF VEHICLE SETS (K3)
C     IS TESTED.  IF THIS NUMBER IS GREATER THAN 1, THEN PART F IS AUTO-
C     MATICALLY EXECUTED --- IF EQUAL TO 1, THEN SENSE SWITCH 2 DETER-
C     MINES WHETHER TO TERMINATE (ON), OR ENTER PART F (OFF).
C
C
      PRINT 1
    1 FORMAT(1H1,/,4X,112HABLE    ADDED TO THE AREOSPACE RESEARCH MASTER
     1 TAPE ON 20 SEPTEMBER 1963.  THE DATE OF THIS RUN IS              .
     2////,4X,106HABLE IS A FORTRAN 60 PROGRAM DESIGNED TO GENERATE AND
     3ANALYZE POSITION AND ATTITUDE ERRORS WHEN ERRORS ARE,//,2X,111HADD
     4ED TO THE TRUE TRANSIT TIMES.  TIME ERRORS ARE NORMALLY DISTRIBUTE
     5D ABOUT ZERO WITH STANDARD DEVIATION ISIG.,//,2X,43HFOR THE PROGRA
     6M DESCRIPTION, SEE TM-9552-6.)
      PI=3.1415926536
      G=1.996E-47
      ECLIP=.40916094
      SM=1.99E+33
C     READ INITIALIZING DATA
      READ 5,TZ,K3,NTAPE,ISHIFT
    5 FORMAT (F15.2,4I10)
C     TEST FOR STATISTICAL ANALYSIS ONLY (SS 1 ON)
      IF(SENSE SWITCH 1)1510,10
   10 CALL FILLTAB
      READ 15, NORT
   15 FORMAT (A8,I10)
C     TEST FOR CORRECTIONS TO NOMINAL TABLE (NORT=8HTARGET   )
      IF(NORT-8HTARGET   )20,40,20
   20 IF(NORT-8HNOMINAL )30,120,30
   30 STOP 1
   40 K=0
   42 READ 15,NORT,NN
C     TEST FOR PLANET OR STAR DATA
      IF(NORT-8HSTAR     )50,70,50
   50 IF(NORT-8HPLANET   )60,100,60
   60 STOP 2
   70 DO 80 I=1,NN
C     READ STAR NUMBER, RIGHT ASCENSION, AND DECLINATION (IN RADIANS)
      READ 25,NSTAR,RA,DEC
   25 FORMAT (I5,5X,F10.8,10X,F10.7)
      STARPOS(NSTAR,1)=RA
   80 STARPOS(NSTAR,2)=DEC
      IF(K)120,90,120
   90 K=7
```

```
      GO TO 42
  100 DO 110 I=1,NN
C     READ PLANET NUMBER, ZERO LONGITUDE, AND RADIAL DISTANCE
      READ 25,NPLANET,XLAMBZ,RAD
      PLANPOS(NPLANET,1)=XLAMBZ
  110 PLANPOS(NPLANET,2)=RAD
      IF(K)120,90,120
C     READ VEHICLE DATA, PERIOD, AND TIME
  120 READ 35,((VEH(I),I=1,6),T,TAU)
   35 FORMAT (6F10.6,F4.0,F16.2)
C     READ DECISION PARAMETERS K1,K2
      READ 45,K1,K2
   45 FORMAT (6I8)
C     READ CAMERA AND STATISTICAL DATA
      READ 55,ISIG,NR,GAMMA,CH
   55 FORMAT (2I10,2F10.8)
      PRINT 75,TZ,K3,NTAPE,ISHIFT,VEH(1),VEH(2),VEH(3),VEH(4),VEH(5),
     1VEH(6),T,TAU,ISIG,NR,GAMMA,CH,K1,K2
   75 FORMAT(1H1/,5X,6HT ZERO,10X,2HK3,6X,5HNTAPE,3X,6HISHIFT,/,
     1   F15.2,3X,I5, 4X,I5,3X,I5,//,6X,5HTHETA,8X,3HPHI,10X,2HTO,11X,
     21HX,12X,1HY,12X,1HZ, 8X,6HPERIOD,9X,4HTIME,/,3X,F10.6,3X,F10.6,3X,
     3F10.6,3X,F10.6,3X,F10.6,3X,F10.6,3X,F4.0,2X,F16.2,//,5X,5HSIGMA,
     43X,2HNR,6X,5HGAMMA,8X,1HH,/,3X,I5,3X,I5,3X,F10.8,3X,F10.8,//,
     55X,38HNUMBER OF STARS AND PLANETS CONSIDERED,/,14X,I5, 3X,I5,////)
      TANG=F(TANF(F(GAMMA)))
      PI2T=F(F(2.*F(PI))/F(T))
      FAC=86400.*SQRTF(SM*G)
      TANGAM=TANF(GAMMA)
      STHETA=SINF(VEH(1))
      CTHETA=COSF(VEH(1))
      SPHI=SINF(VEH(2))
      CPHI=COSF(VEH(2))
      SECLIP=SINF(ECLIP)
      CECLIP=COSF(ECLIP)
      NP=0
      NS=0
      CP=F(COSF(VEH(2)))
      SP=F(SINF(VEH(2)))
      CT=F(COSF(VEH(1)))
      ST=F(SINF(VEH(1)))
      NNN=1
      MMM=K1
      CALL TIME (1HP)
  990 DO 1300 J=NNN,MMM
      IF(J-100)1000,1000,1010
 1000 SRA=SINF(STARPOS(J,1))
      CRA=COSF(STARPOS(J,1))
      SDEC=SINF(STARPOS(J,2))
      CDEC=COSF(STARPOS(J,2))
      P(1)=CRA*CDEC
      P(2)=CECLIP*CDEC*SRA+SECLIP*SDEC
      P(3)=-SECLIP*CDEC*SRA+CECLIP*SDEC
      RP=1.
      GO TO 1020
 1010 MM=J-100
      XLAMB=PLANPOS(MM,1)+FAC*(TAU-TZ)/PLANPOS(MM,2)**1.5
```

```
      R(1)=PLANPOS(MM,2)*COSF(XLAMB)
      R(2)=PLANPOS(MM,2)*SINF(XLAMB)
      R(3)=0.
      DO 1018 K=1,3
 1018 P(K)=R(K)-VEH(K+3)
      RP=SQRTF(R(1)**2+R(2)**2+R(3)**2+VEH(4)**2+VEH(5)**2+VEH(6)**2-
     12.*(R(1)*VEH(4)+R(2)*VEH(5)+R(3)*VEH(6)))
 1020 D=P(1)*STHETA*SPHI-P(2)*STHETA*CPHI+P(3)*CTHETA
      IF(ABSF(D)/RP-COSF(GAMMA)*SINF(CH))1030,1030,1300
 1030 A=-P(1)*CPHI-P(2)*SPHI
      B=-P(1)*CTHETA*SPHI+P(2)*CTHETA*CPHI+P(3)*STHETA
      DEL=ALPH(B,A)
      TEMP=D*TANGAM/SQRTF(A*A+B*B)
C     COMPUTE THE FOUR VALUES OF PSI
      PSI(1)=ASINF(TEMP)-DEL
      PSI(2)=ASINF(-TEMP)-DEL
      PSI(3)=PI-PSI(1)-2.*DEL
      PSI(4)=PI-PSI(2)-2.*DEL
      K=1
      ILAG=0
      IDICAT1=0
      IDICAT2=0
      IF(J-100)1034,1034,1036
 1034 NS=NS+1
      GO TO 1038
 1036 NP=NP+1
 1038 CADA=(-A*COSF(PSI(K))+B*SINF(PSI(K)))/RP
      IF(ABSF(CADA)-1.00000001)1040,1040,1042
 1042 STOP 4
 1040 IF(COSF(CH)-CADA)1050,1050,1082
 1050 TT=VEH(3)+T*PSI(K)/(2.*PI)
      IF(J-100)1054,1054,1056
 1054 SEENS(NS,1)=J
      GO TO 1058
 1056 SEENP(NP,1)=J
 1058 IF(XABSF(K-2)-1)1070,1060,1070
 1060 IF(IDICAT1)1064,1062,1064
 1062 IF(J-100)1063,1063,1066
 1063 SEENS(NS,2)=TT
      GO TO 1068
 1066 SEENP(NP,2)=TT
 1068 IDICAT1=1
      GO TO 1080
 1070 IF(IDICAT2)1064,1072,1064
 1072 IF(J-100)1074,1074,1076
 1074 SEENS(NS,3)=TT
      GO TO 1078
 1076 SEENP(NP,3)=TT
 1078 IDICAT2=1
 1080 ILAG=ILAG+1
      IF(ILAG-2)1082,1090,1090
 1064 PRINT 1065,(PSI(M),M=1,4)
 1065 FORMAT (///,3X,14HPSI(J),J=1,4   ,4E20.8,/)
      STOP
 1082 IF(K-4)1084,1086,1086
 1084 K=K+1
```

```
      GO TO 1038
 1086 STOP 3
 1090 IF(J-100)1094,1094,1200
 1094 K=NS
      SRA=F(SINF(F(STARPOS(J,1))))
      CRA=F(COSF(F(STARPOS(J,1))))
      SDEC=F(SINF(F(STARPOS(J,2))))
      CDEC=F(COSF(F(STARPOS(J,2))))
      P(1)=F(CRA*CDEC)
      P(2)=F(F(F(F(CECLIP)*CDEC)*SRA)+F(F(SECLIP)*SDEC))
      P(3)=F(F(F(F(-SECLIP)*CDEC)*SRA)+F(F(CECLIP)*SDEC))
      PAREF(K,1,1)=F(F(P(1)*F(CT*SP))-F(P(2)*F(CT*CP))-F(P(3)*ST))
      PAREF(K,1,2)=F(F(P(1)*CP)+F(P(2)*SP))
      PAREF(K,1,3)=F(F(F(P(1)*F(ST*SP))-F(P(2)*F(ST*CP))+F(P(3)*CT))
     1*TANG)
      PAREF(K,1,4)=F(-PAREF(K,1,3))
      PAREF(K,2,1)=F(F(-P(1)*F(ST*SP))+F(P(2)*F(ST*CP))-F(P(3)*CT))
      PAREF(K,2,2)=0.
      PAREF(K,2,3)=F(F(F(P(1)*F(CT*SP))-F(P(2)*F(CT*CP))-F(P(3)*ST))
     1*TANG)
      PAREF(K,2,4)=F(-PAREF(K,2,3))
      PAREF(K,3,1)=F(F(P(1)*F(CT*CP))+F(P(2)*F(CT*SP)))
      PAREF(K,3,2)=F(F(-P(1)*SP)+F(P(2)*CP))
      PAREF(K,3,3)=F(F(F(P(1)*F(ST*CP))+F(P(2)*F(ST*SP)))*TANG)
      PAREF(K,3,4)=F(-PAREF(K,3,3))
      PAREF(K,4,1)=F(-PAREF(K,1,2)*PI2T)
      PAREF(K,4,2)=F(PAREF(K,1,1)*PI2T)
      PAREF(K,4,3)=0.
      PAREF(K,4,4)=0.
      GO TO 1300
 1200 L=NP
      MM=J-100
      XLAMB=F(F(PLANPOS(MM,1))+F(F(F(FAC)*F(TAU-TZ))/F(PLANPOS(MM,2)
     1**1.5)))
      R(1)=F(F(PLANPOS(MM,2))*F(COSF(XLAMB)))
      R(2)=F(F(PLANPOS(MM,2))*F(SINF(XLAMB)))
      R(3)=0.0
      DO 1204 K=1,3
 1204 P(K)=F(R(K)-F(VEH(K+3)))
      A=F(F(-P(1)*F(COSF(F(VEH(2)))))-F(P(2)*F(SINF(F(VEH(2))))))
      B=F(F(-P(1)*F(F(COSF(F(VEH(1))))*F(SINF(F(VEH(2))))))+F(P(2)*F(
     1F(COSF(F(VEH(1))))*F(COSF(F(VEH(2))))))+F(P(3)*F(SINF(F(VEH(1))))
     2))
      PLANCO(L,1,1)=F(-CT*SP)
      PLANCO(L,1,2)=F(-CP)
      PLANCO(L,1,3)=F(F(-ST*SP)*TANG)
      PLANCO(L,1,4)=F(-PLANCO(L,1,3))
      PLANCO(L,2,1)=F(CT*CP)
      PLANCO(L,2,2)=F(-SP)
      PLANCO(L,2,3)=F(F(ST*CP)*TANG)
      PLANCO(L,2,4)=F(-PLANCO(L,2,3))
      PLANCO(L,3,1)=F(ST)
      PLANCO(L,3,2)=0.
      PLANCO(L,3,3)=F(-CT*TANG)
      PLANCO(L,3,4)=F(-PLANCO(L,3,3))
      PLANCO(L,4,1)=F(F(-R(1)*F(CT*SP))+F(R(2)*F(CT*CP))+F(R(3)*ST))
```

```
      PLANCO(L,4,2)=F(F(-R(1)*CP)+F(-R(2)*SP))
      PLANCO(L,4,3)=F(F(F(-R(1)*F(ST*SP))+F(R(2)*F(ST*CP))-F(R(3)*CT))
     1*TANG)
      PLANCO(L,4,4)=F(-PLANCO(L,4,3))
      PLANCO(L,5,1)=F(PI2T*A)
      PLANCO(L,5,2)=F(-PI2T*B)
 1300 CONTINUE
      CALL TIME (1HP)
      IF(NNN-1)1310,1302,1310
 1302 NNN=101
      MMM=K2+100
      GO TO 990
 1310 PRINT 1285
 1285 FORMAT (////////,5X,31HTABLE OF STARS THAT CAN BE SEEN,//,3X,6HNUMB
     1ER,9X,10HT.T. NO. 1,10X,10HT.T. NO. 2,/)
      PRINT 1295,((SEENS(J,K),K=1,3),J=1,NS)
      PRINT 1275
 1275 FORMAT (1H1,///,5X,33HTABLE OF PLANETS THAT CAN BE SEEN,//,3X,6HNU
     1MBER,9X,10HT.T. NO. 1,10X,10HT.T. NO. 2,/)
      PRINT 1295,((SEENP(J,K),K=1,3),J=1,NP)
 1295 FORMAT(///,(3X,F5.0,2X,2E20.8))
      CALL TIME (1HP)
      DO 1410 J=1,2
      L=J+1
      DO 1400 I=1,NS
 1400 SAVES(I,J)=SEENS(I,L)
      DO 1410 I=1,NP
 1410 SAVEP(I,J)=SEENP(I,L)
      TTCONST=.5*T/PI*4.8481E-06*FLOATF(ISIG)
      MR=NR/9+1
      DO 1500 K=1,MR
      DO 1450 L=1,9
      DO 1440 J=1,2
      N=J+1
      DO 1430 I=1,NS
 1428 CALL RNGN (QQ)
      QQ=GAUSS (QQ,III)
      IF(III)1428,1430,1428
 1430 SEENS(I,N)=SAVES(I,J)+TTCONST*QQ
      DO 1440 I=1,NP
 1438 CALL RNGN (QQ)
      QQ=GAUSS (QQ,III)
      IF(III)1438,1440,1438
 1440 SEENP(I,N)=SAVEP(I,J)+TTCONST*QQ
      CALL PART D (NP,NS)
      DO 1450 M=1,6
 1450 DELTA(L,M)=ERR(M)
 1500 WRITE TAPE NTAPE,((DELTA(I,J),J=1,6),I=1,9)
      END FILE NTAPE
      CALL TIME (1HP)
      REWIND NTAPE
      IF(K3-1)1520,1530,1510
 1510 CALL PART F (NTAPE,NR)
      CALL TIME (1HP)
      IF(SENSE SWITCH 1)2010,1520
 1520 K3=K3-1
```

```
      IF(K3)2010,2010,120
1530  IF(SENSE SWITCH 2)1520,1510
2010  END
      END
```

# APPENDIX B

## - FILLTAB -

## Program Listing

```
      SUBROUTINE FILLTAB
      DIMENSION VEH(6),PAREF(100,7,4),PLANCO(9,5,4),ERR(6),SEENS(100,3),
     1SEENP(9,3),PMAG(9),FN(69),STARPOS(100,2),PLANPOS(9,2)
      COMMON PI,K1,K2,K3,NTAPE,ISHIFT,VEH,ISIG,NR,PAREF,PLANCO,T,ERR,FN,
     1SEENS,SEENP,PMAG,STARPOS,PLANPOS
      FN(1) =.0003
      FN(2) =.0005
      FN(3) =.0007
      FN(4) =.0010
      FN(5) =.0013
      FN(6) =.0019
      FN(7) =.0026
      FN(8) =.0035
      FN(9) =.0047
      FN(10)=.0062
      FN(11)=.0082
      FN(12)=.0107
      FN(13)=.0139
      FN(14)=.0179
      FN(15)=.0228
      FN(16)=.0287
      FN(17)=.0359
      FN(18)=.0446
      FN(19)=.0548
      FN(20)=.0668
      FN(21)=.0808
      FN(22)=.0968
      FN(23)=.1151
      FN(24)=.1357
      FN(25)=.1587
      FN(26)=.1841
      FN(27)=.2119
      FN(28)=.2420
      FN(29)=.2743
      FN(30)=.3085
      FN(31)=.3446
      FN(32)=.3821
      FN(33)=.4207
      FN(34)=.4602
      FN(35)=.5000
      FN(36)=.5398
      FN(37)=.5793
      FN(38)=.6179
      FN(39)=.6554
      FN(40)=.6915
      FN(41)=.7257
      FN(42)=.7580
      FN(43)=.7881
      FN(44)=.8159
      FN(45)=.8413
      FN(46)=.8643
      FN(47)=.8849
      FN(48)=.9032
      FN(49)=.9192
      FN(50)=.9332
      FN(51)=.9452
```

```
FN(52)=.9554
FN(53)=.9641
FN(54)=.9713
FN(55)=.9772
FN(56)=.9821
FN(57)=.9861
FN(58)=.9893
FN(59)=.9918
FN(60)=.9938
FN(61)=.9953
FN(62)=.9965
FN(63)=.9974
FN(64)=.9981
FN(65)=.9987
FN(66)=.9990
FN(67)=.9993
FN(68)=.9995
FN(69)=.9997
STARPOS(  1,  1)=   1.7620189629
STARPOS(  1,  2)=   -.2910045640
STARPOS(  2,  1)=   1.6723963058
STARPOS(  2,  2)=   -.9194200574
STARPOS(  3,  1)=   3.8290196683
STARPOS(  3,  2)=  -1.0596427184
STARPOS(  4,  1)=   3.7275578611
STARPOS(  4,  2)=    .3375127404
STARPOS(  5,  1)=   4.8691268192
STARPOS(  5,  2)=    .6763975035
STARPOS(  6,  1)=   1.3721269524
STARPOS(  6,  2)=    .8023278571
STARPOS(  7,  1)=   1.3661273831
STARPOS(  7,  2)=   -.1437230158
STARPOS(  8,  1)=   1.9972311685
STARPOS(  8,  2)=    .0925606280
STARPOS(  9,  1)=    .4214824699
STARPOS(  9,  2)=  -1.0016202170
STARPOS( 10,  1)=   3.6725581731
STARPOS( 10,  2)=  -1.0512021122
STARPOS( 11,  1)=   1.5426383481
STARPOS( 11,  2)=    .1292125423
STARPOS( 12,  1)=   5.1893874649
STARPOS( 12,  2)=    .1533708080
STARPOS( 13,  1)=   1.1964013856
STARPOS( 13,  2)=    .2871115101
STARPOS( 14,  1)=   3.2502975773
STARPOS( 14,  2)=  -1.0983938759
STARPOS( 15,  1)=   4.3090579346
STARPOS( 15,  2)=   -.4601948424
STARPOS( 16,  1)=   3.5064028283
STARPOS( 16,  2)=   -.1920831805
STARPOS( 17,  1)=   6.0039108101
STARPOS( 17,  2)=   -.5197881401
STARPOS( 18,  1)=   2.0223275487
STARPOS( 18,  2)=    .4904423679
STARPOS( 19,  1)=   5.4122878271
STARPOS( 19,  2)=    .7884088563
```

```
STARPOS( 20,  1)=   3.3421091681
STARPOS( 20,  2)=  -1.0389120854
STARPOS( 21,  1)=   2.6475553922
STARPOS( 21,  2)=    .2114369426
STARPOS( 22,  1)=   1.8214546961
STARPOS( 22,  2)=   -.5049237526
STARPOS( 23,  1)=   1.9752254755
STARPOS( 23,  2)=    .5577296588
STARPOS( 24,  1)=   4.5883251592
STARPOS( 24,  2)=   -.6472359606
STARPOS( 25,  1)=   1.4116295712
STARPOS( 25,  2)=    .1103823789
STARPOS( 26,  1)=   1.4154329346
STARPOS( 26,  2)=    .4988829741
STARPOS( 27,  1)=   2.4124013643
STARPOS( 27,  2)=  -1.2146328041
STARPOS( 28,  1)=   3.2702597805
STARPOS( 28,  2)=   -.9938922870
STARPOS( 29,  1)=   1.4603533462
STARPOS( 29,  2)=   -.0212833206
STARPOS( 30,  1)=   5.7872936333
STARPOS( 30,  2)=   -.8221809774
STARPOS( 31,  1)=   3.3716052324
STARPOS( 31,  2)=    .9795224095
STARPOS( 32,  1)=   1.4802355552
STARPOS( 32,  2)=   -.0341551238
STARPOS( 33,  1)=    .8821330372
STARPOS( 33,  2)=    .8684079619
STARPOS( 34,  1)=   4.8091674873
STARPOS( 34,  2)=   -.6004078071
STARPOS( 35,  1)=   2.8880472187
STARPOS( 35,  2)=   1.0805963657
STARPOS( 36,  1)=   2.1319560424
STARPOS( 36,  2)=   -.8246195902
STARPOS( 37,  1)=   1.8638880136
STARPOS( 37,  2)=   -.4597924470
STARPOS( 38,  1)=   3.6056684294
STARPOS( 38,  2)=    .8632786331
STARPOS( 39,  1)=   4.6040040338
STARPOS( 39,  2)=   -.7501570569
STARPOS( 40,  1)=   1.5591317096
STARPOS( 40,  2)=    .7844721693
STARPOS( 41,  1)=   1.7277886930
STARPOS( 41,  2)=    .2866945703
STARPOS( 42,  1)=   2.2858431768
STARPOS( 42,  2)=   -.9529158346
STARPOS( 43,  1)=   4.3871905076
STARPOS( 43,  2)=  -1.2038505478
STARPOS( 44,  1)=   5.3375804627
STARPOS( 44,  2)=   -.9919287916
STARPOS( 45,  1)=   2.1899518789
STARPOS( 45,  2)=  -1.0369437418
STARPOS( 46,  1)=   1.6640696309
STARPOS( 46,  2)=   -.3131072197
STARPOS( 47,  1)=    .5474879697
STARPOS( 47,  2)=    .4070350222
```

```
STARPOS( 48,  1)=     .6013822826
STARPOS( 48,  2)=    -.0543330692
STARPOS( 49,  1)=     .4804818709
STARPOS( 49,  2)=    1.5555731772
STARPOS( 50,  1)=    2.6979372299
STARPOS( 50,  2)=     .3489640395
STARPOS( 51,  1)=     .1836231817
STARPOS( 51,  2)=    -.3167918037
STARPOS( 52,  1)=    3.8867246167
STARPOS( 52,  2)=    1.2963966314
STARPOS( 53,  1)=    2.4701354014
STARPOS( 53,  2)=    -.1488329520
STARPOS( 54,  1)=    1.5111642440
STARPOS( 54,  2)=    -.1689236309
STARPOS( 55,  1)=     .0298014970
STARPOS( 55,  2)=     .5048364862
STARPOS( 56,  1)=    4.5969281781
STARPOS( 56,  2)=     .2195721162
STARPOS( 57,  1)=    3.6866080735
STARPOS( 57,  2)=    -.6322164327
STARPOS( 58,  1)=     .2969023224
STARPOS( 58,  2)=     .6189325379
STARPOS( 59,  1)=    4.9454122521
STARPOS( 59,  2)=    -.4596470029
STARPOS( 60,  1)=    3.2503484826
STARPOS( 60,  2)=   -1.0984035722
STARPOS( 61,  1)=     .8124944000
STARPOS( 61,  2)=     .7128215553
STARPOS( 62,  1)=    3.5025412873
STARPOS( 62,  2)=     .9613515927
STARPOS( 63,  1)=    3.0871820141
STARPOS( 63,  2)=     .2572615318
STARPOS( 64,  1)=     .2394519012
STARPOS( 64,  2)=    1.0568792804
STARPOS( 65,  1)=    3.3154783525
STARPOS( 65,  2)=    -.8516431048
STARPOS( 66,  1)=     .5325290436
STARPOS( 66,  2)=     .7363010819
STARPOS( 67,  1)=    5.9379737254
STARPOS( 67,  2)=    -.8210416652
STARPOS( 68,  1)=    1.4419619392
STARPOS( 68,  2)=     .0060989561
STARPOS( 69,  1)=     .1692605764
STARPOS( 69,  2)=     .9838954289
STARPOS( 70,  1)=    4.6945284442
STARPOS( 70,  2)=     .8986991207
STARPOS( 71,  1)=    4.0727985316
STARPOS( 71,  2)=     .4680003427
STARPOS( 72,  1)=    5.3282647679
STARPOS( 72,  2)=     .7009145313
STARPOS( 73,  1)=    2.1054343099
STARPOS( 73,  2)=    -.6966918042
STARPOS( 74,  1)=    2.3862650588
STARPOS( 74,  2)=    -.7559117953
STARPOS( 75,  1)=    2.4272657518
STARPOS( 75,  2)=   -1.0323428600
```

```
STARPOS( 76,  1)=    .0330012673
STARPOS( 76,  2)=   1.0294776111
STARPOS( 77,  1)=   4.3991751018
STARPOS( 77,  2)=   -.5976104322
STARPOS( 78,  1)=   4.1824852028
STARPOS( 78,  2)=   -.3933584283
STARPOS( 79,  1)=   3.5690746929
STARPOS( 79,  2)=   -.9305174426
STARPOS( 80,  1)=   2.8799896152
STARPOS( 80,  2)=    .9868721849
STARPOS( 81,  1)=    .1082249580
STARPOS( 81,  2)=   -.7412267889
STARPOS( 82,  1)=   5.6841519471
STARPOS( 82,  2)=    .1699320434
STARPOS( 83,  1)=   4.6269042081
STARPOS( 83,  2)=   -.6809741446
STARPOS( 84,  1)=   3.8117627252
STARPOS( 84,  2)=   -.7335134032
STARPOS( 85,  1)=   3.8557668390
STARPOS( 85,  2)=    .4747198603
STARPOS( 86,  1)=   1.9325449030
STARPOS( 86,  2)=   -.5103924509
STARPOS( 87,  1)=   3.1078205325
STARPOS( 87,  2)=    .9400634240
STARPOS( 88,  1)=   5.5757306392
STARPOS( 88,  2)=   1.0901035620
STARPOS( 89,  1)=   4.4883541542
STARPOS( 89,  2)=   -.2738373115
STARPOS( 90,  1)=   2.4486314907
STARPOS( 90,  2)=   -.9578754786
STARPOS( 91,  1)=   5.4323227525
STARPOS( 91,  2)=    .5909151552
STARPOS( 92,  1)=   6.0356321694
STARPOS( 92,  2)=    .2625605453
STARPOS( 93,  1)=   3.8393825608
STARPOS( 93,  2)=   -.8248619971
STARPOS( 94,  1)=   6.0314942845
STARPOS( 94,  2)=    .4872862309
STARPOS( 95,  1)=   4.2048835949
STARPOS( 95,  2)=   -.3442710431
STARPOS( 96,  1)=    .7884961228
STARPOS( 96,  2)=    .0693429008
STARPOS( 97,  1)=   2.9344002547
STARPOS( 97,  2)=    .3610795334
STARPOS( 98,  1)=   4.3436954480
STARPOS( 98,  2)=   -.1834001674
STARPOS( 99,  1)=   4.9772645110
STARPOS( 99,  2)=   -.5222946268
STARPOS(100,  1)=   3.2038209136
STARPOS(100,  2)=   -.3032606538
PLANPOS(1,1)=2.032716
PLANPOS(1,2)=.387099
PLANPOS(2,1)=5.009707
PLANPOS(2,2)=.723332
PLANPOS(3,1)=1.974492
PLANPOS(3,2)=1.0
```

```
      PLANPOS(4,1)=.481677
      PLANPOS(4,2)=1.52369
      PLANPOS(5,1)=3.550211
      PLANPOS(5,2)=5.2028
      PLANPOS(6,1)=.662074
      PLANPOS(6,2)=9.540
      PLANPOS(7,1)=3.238145
      PLANPOS(7,2)=19.18
      PLANPOS(8,1)=4.162384
      PLANPOS(8,2)=30.07
      PLANPOS(9,1)=3.222018
      PLANPOS(9,2)=39.44
      END
      END
```

# APPENDIX C

- F -

## Program Listing

```
      FUNCTION F(X)
C     F FUNCTION FIRST RIGHT SHIFTS A QUANTITY (TO DROP OFF RIGHT-HAND
C     BITS) ISHIFT PLACES AND THEN LEFT SHIFTS TO TRUNCATE.
      DIMENSION VEH(6),PAREF(100,7,4),PLANCO(9,5,4),ERR(6),SEENS(100,3),
     1SEENP(9,3),PMAG(9),FN(69),STARPOS(100,2),PLANPOS(9,2)
      COMMON PI,K1,K2,K3,NTAPE,ISHIFT,VEH,ISIG,NR,PAREF,PLANCO,T,ERR,FN,
     1SEENS,SEENP,PMAG,STARPOS,PLANPOS
      I=ISHIFT
      LDA (X)      ARS1(N)
      ALS1(N)      STA (F)
      F=F+0.0
      END
      END
```

# APPENDIX D

## - ALPH -

## Program Listing

```
      FUNCTION ALPH(X,Y)
C     ALPH COMPUTES THE ARC TANGENT OF THE QUOTIENT OF TWO NUMBERS AND
C     RESOLVES THE ANGLE TO THE PROPER QUADRANT BY EXAMINING THE
C     NUMERATOR AND DENOMINATOR SIGNS.
      PI=3.1415926536
      IF(Y)10,30,20
   10 IF(X)11,12,11
   11 ALPH=PI+ATANF(X/Y)
      RETURN
   12 ALPH=PI
      RETURN
   20 IF(X)21,23,22
   21 ALPH=2.*PI+ATANF(X/Y)
      RETURN
   22 ALPH=ATANF(X/Y)
      RETURN
   23 ALPH=0.0
      RETURN
   30 IF(X)31,33,32
   31 ALPH=1.5*PI
      RETURN
   32 ALPH=.5*PI
      RETURN
   33 ALPH=2.*PI
      END
      END
```

# APPENDIX E

## - ENGN -

## Program Listing

```
      SUBROUTINE RNGN (R)
C         RNGN IS A RANDOM NUMBER GENERATOR WHICH (BY REPEATED USE) WILL
C     PRODUCE UNIFORMLY DISTRIBUTED RANDOM NUMBERS IN THE RANGE (0,1).
C     THIS IS A FORTRAN SYMBOLIC VERSION OF THE MACHINE LANGUAGE CO-OP
C     PROGRAM G5 CODA RNGN.
C     CALLING SEQUENCE --- CALL RNGN (Z)
      IF(M)2,1,2
    1 M=2
B     X=3625176463724015
B     Y=3625176463724015
B     Z=2000000000000000
    2 LDA (X)        MUI (Y)
      STA (X)        ARS (12)
      ADD (Z)        FAD (Z)
      STA (R)
      R=R+0.0
      END
      END
```

# APPENDIX F

## - GAUSS -

## Program Listing

```
      FUNCTION GAUSS (RR,JECT)
C         GAUSS TAKES A UNIFORMLY DISTRIBUTED NUMBER RR IN THE RANGE
C     (0,1) AND CONVERTS IT TO A GAUSSIAN DISTRIBUTED NUMBER (RR) WITH
C     MEAN ZERO AND STANDARD DEVIATION ISIG.  JECT IS SET IF RR IS
C     IN THE RANGE (0,.0003) OR (.9997,1).  WHEN THIS HAPPENS,
C     REGENERATE A NEW RR.
      DIMENSION VEH(6),PAREF(100,7,4),PLANCO(9,5,4),ERR(6),SEENS(100,3),
     1SEENP(9,3),PMAG(9),FN(69),STARPOS(100,2),PLANPOS(9,2)
      COMMON PI,K1,K2,K3,NTAPE,ISHIFT,VEH,ISIG,NR,PAREF,PLANCO,T,ERR,FN,
     1SEENS,SEENP,PMAG,STARPOS,PLANPOS
      IF(RR-1.)3,1,2
    1 JECT=1
      RETURN
    2 STOP 21
    3 IF(RR)2,1,4
    4 IF(RR-.9997)5,5,1
    5 IF(RR-.0003)1,10,10
   10 DO 11 I=1,69
      IF(RR-FN(I))12,13,11
   11 CONTINUE
   12 I=I-1
   13 TT=(FLOATF(I-35)+(RR-FN(I))/(FN(I+1)-FN(I)))*.1
      GAUSS=TT
      JECT=0
      END
      END
```

# APPENDIX G

## - PART D, GAUSS 2 -

Program Listing

```
      SUBROUTINE PART D (NP,NS)
      DIMENSION A(20),B(20),C(20),D(20),XM(3,4),SOL(3),PSI(100,2),
     1FF(4,200)
      DIMENSION VEH(6),PAREF(100,7,4),PLANCO(9,5,4),ERR(6),SEENS(100,3),
     1SEENP(9,3),PMAG(9),FN(69),STARPOS(100,2),PLANPOS(9,2)
      COMMON PI,K1,K2,K3,NTAPE,ISHIFT,VEH,ISIG,NR,PAREF,PLANCO,T,ERR,FN,
     1SEENS,SEENP,PMAG,STARPOS,PLANPOS
      IF(NP-2)10,20,20
   10 PRINT 15,NP
   15 FORMAT(///,3X,31HHALT IN PART D, WE CAN ONLY SEE,I3,9H PLANETS.)
      STOP
   20 Q=F(F(2.*PI)/T)
      DO 30 I=1,NP
      DO 30 J=1,2
   30 PSI(I,J)=F(Q*F(SEENP(I,J+1)-VEH(3)))
      DO 40 I=1,NP
      DO 40 J=1,2
      K=2*I+J-2
      CPSI=F(COSF(PSI(I,J)))
      SPSI=F(SINF(PSI(I,J)))
      DENOM=F(F(PLANCO(I,5,1)*CPSI)+F(PLANCO(I,5,2)*SPSI))
      A(K)=F(F(F(PLANCO(I,1,1)*CPSI)+F(PLANCO(I,1,2)*SPSI)
     1+PLANCO(I,1,J+2))/DENOM)
      B(K)=F(F(F(PLANCO(I,2,1)*CPSI)+F(PLANCO(I,2,2)*SPSI)
     1+PLANCO(I,2,J+2))/DENOM)
      C(K)=F(F(F(PLANCO(I,3,1)*CPSI)+PLANCO(I,3,J+2))/DENOM)
   40 D(K)=F(F(F(PLANCO(I,4,1)*CPSI)+F(PLANCO(I,4,2)*SPSI)
     1+PLANCO(I,4,J+2))/DENOM)
C     FORM THE MATRIX ELEMENTS XM
      NPTT=2*NP
      DO 50 I=1,3
      DO 50 J=1,4
   50 XM(I,J)=0.
      DO 60 I=1,NPTT
      XM(1,1)=F(XM(1,1)+F(A(I)*A(I)))
      XM(1,2)=F(XM(1,2)+F(A(I)*B(I)))
      XM(1,3)=F(XM(1,3)+F(A(I)*C(I)))
      XM(2,2)=F(XM(2,2)+F(B(I)*B(I)))
      XM(2,3)=F(XM(2,3)+F(B(I)*C(I)))
      XM(3,3)=F(XM(3,3)+F(C(I)*C(I)))
      XM(1,4)=F(XM(1,4)+F(A(I)*D(I)))
      XM(2,4)=F(XM(2,4)+F(B(I)*D(I)))
   60 XM(3,4)=F(XM(3,4)+F(C(I)*D(I)))
      XM(2,1)=XM(1,2)
      XM(3,1)=XM(1,3)
      XM(3,2)=XM(2,3)
      CALL GAUSS2 (3,1,1.E-12,XM,SOL,IERR)
      IF(IERR-1)70,80,70
   70 STOP 11
   80 DO 90 I=1,3
   90 ERR(I+3)=F(F(SOL(I))-VEH(I+3))
      IF(NS-2)110,120,120
  110 PRINT 115,NS
  115 FORMAT(///,3X,31HHALT IN PART D, WE CAN ONLY SEE,I3,7H STARS.)
      STOP
  120 DO 130 I=1,NS
```

```
      DO 130 J=1,2
  130 PSI(I,J)=F(Q*F(SEENS(I,J+1)-VEH(3)))
      DO 140 I=1,NS
      DO 140 J=1,2
      CPSI=F(COSF(PSI(I,J)))
      SPSI=F(SINF(PSI(I,J)))
      K=2*I+J-2
      DO 140 L=1,4
  140 FF(L,K)=F(F(PAREF(I,L,1)*CPSI)+F(PAREF(I,L,2)*SPSI)
     1+PAREF(I,L,J+2))
C     FORM THE MATRIX ELEMENTS XM
      NSTT=2*NS
      DO 150 I=1,3
      DO 150 J=1,4
  150 XM(I,J)=0.
      DO 160 J=1,4
      IF(J-4)158,156,158
  156 L=1
      GO TO 159
  158 L=J+1
  159 DO 160 I=1,3
      DO 160 K=1,NSTT
  160 XM(I,J)=F(XM(I,J)+F(F(FF(I+1,K)*FF(L,K))/F(FF(4,K)**2)))
      DO 162 I=1,3
  162 XM(I,4)=F(-XM(I,4))
      CALL GAUSS2 (3,1,1.E-12,XM,SOL,IERR)
      IF(IERR-1)170,180,170
  170 STOP 12
  180 DO 190 I=1,3
  190 ERR(I)=F(SOL(I))
      END


      SUBROUTINE   GAUSS2(N,M,EP,A,X,KER)
      DIMENSION A(3,4),X(3)
      NPM=N+M
   10 DO 34 L=1,N
      KP=0
      Z=0.0
      DO 12 K=L,N
      IF(Z-ABSF(A(K,L)))11,12,12
   11 Z=ABSF(A(K,L))
      KP=K
   12 CONTINUE
      IF(L-KP)13,20,20
   13 DO 14 J=L,NPM
      Z=A(L,J)
      A(L,J)=A(KP,J)
   14 A(KP,J)=Z
   20 IF(ABSF(A(L,L))-EP)50,50,30
   30 IF(L-N)31,40,40
   31 LP1=L+1
      DO 34 K=LP1,N
      IF(A(K,L))32,34,32
   32 RATIO=A(K,L)/A(L,L)
      DO 33 J=LP1,NPM
```

```
33   A(K,J)=A(K,J)-RATIO*A(L,J)
34   CONTINUE
40   DO 43 I=1,N
     II=N+1-I
     DO 43 J=1,M
     JPN=J+N
     S=0.0
     IF(II-N)41,43,43
41   IIP1=II+1
     DO 42 K=IIP1,N
42   S=S+A(II,K)*X(K,J)
43   X(II,J)=(A(II,JPN)-S)/A(II,II)
     KER=1
     GO TO 75
50   KER=2
75 CONTINUE
   END
   END
```

# APPENDIX H

## - PART F -

## Program Listing

```
      SUBROUTINE PART F (NTAPE, NR)
      DIMENSION X(6000),DELTA(9,6), STAR(8), STAR1(8)
      PI=3.1415926536
      PI2D=1./SQRTF(2.*PI)
B      STAR(1)=2020202020202020
       STAR1(1)= STAR(1)
      DO 10 I=2,8
B  10  STAR (I)=5454545454545454
B      STAR1(2)=5420202020202020
B      STAR1(3)=5454202020202020
B      STAR1(4)=5454542020202020
B      STAR1(5)=5454545420202020
B      STAR1(6)=5454545454202020
B      STAR1(7)=5454545454542020
B      STAR1(8)=5454545454545420
      TOT=NR
      MR=NR/9+1
      DO 140 I=1,6
      DO 30 J=1,MR
      READ TAPE NTAPE,((DELTA(K,L),L=1,6),K=1,9)
      M=9*J-9
      DO 30 K=1,9
   30 X(M+K)=DELTA(K,I)
      REWIND NTAPE
      XMEAN=0.
      XSIG2=0.
      XSIG3=0.
      XSIG4=0.
      DO 70 J=1,NR
      XMEAN=XMEAN+X(J)
      ZQ=X(J)*X(J)
      ZR=ZQ*X(J)
      XSIG2=XSIG2+ZQ
      XSIG3=XSIG3+ZR
   70 XSIG4=XSIG4+ZR*X(J)
      XMEAN=XMEAN/TOT
      XSIG2=XSIG2/TOT
      XSIG3=XSIG3/TOT
      XSIG4=XSIG4/TOT
      XMEAN2=XMEAN**2
      U2=XSIG2-XMEAN2
      U3=XSIG3-3.*XSIG2*XMEAN+2.*XMEAN2*XMEAN
      U4=XSIG4-4.*XSIG3*XMEAN+6.*XSIG2*XMEAN2-3.*XMEAN2**2
      SIGMA=SQRTF(U2)
      G1=U3/(SIGMA*U2)
      G2=U4/(U2*U2)-3.
      XM=X(1)
      XL=X(1)
      DO 90 J=1,NR
      IF(XL-X(J))84,84,82
   82 XL=X(J)
   84 IF(XM-X(J))86,90,90
   86 XM=X(J)
   90 CONTINUE
      IF(XM-XL)92,92,96
   92 PRINT 95,XM,XL
```

```
   95 FORMAT (//,33HDISCREPANCY IN X MAX AND X MIN---,3X,5HXM = ,E12.6,
     13X,5HXL = ,E12.6,/)
      GO TO 140
   96 N=0
      NA=0
      NB=0
   98 ISTEP=(XM-XL)/50.*10.**N
      IF(ISTEP)110,110,100
  100 IF(NA)115,102,115
  102 N=N-1
      NB=5
      GO TO 98
  110 IF(NB)114,112,114
  112 N=N+1
      NA=3
      GO TO 98
  114 N=N+1
      ISTEP=(XM-XL)/50.*10.**N
  115 IF(ISTEP-5)116,118,118
  116 STEP=10.**(-N)
      ISTEP=1
      IZ=XL*10.**N
      GO TO 120
  118 STEP=5.*10.**(-N)
      ISTEP=5
      IZ=XL*10.**(N-1)
      IZ=IZ*10-5
  120 Z=FLOATF(IZ)*10.**(-N)
      NNNN=-N
      PRINT 125,I,NR,XL,XM,Z,STEP,N,XMEAN,XSIG2,XSIG3,XSIG4,U2,U3,U4,
     1SIGMA,G1,G2,NNNN
  125 FORMAT(1H1,//,3X,15HVARIABLE NUMBER,I3,6X,16HNUMBER OF POINTS,I6//
     1,3X,14HSMALLEST VALUE,E15.5,6X,13HLARGEST VALUE,E15.5,/,3X,14HSTAR
     2TING VALUE,E15.5,6X,9HSTEP SIZE,E15.5,6X,6HN USED,I6,///
     325HMOMENTS ABOUT THE ORIGIN.,//,3X,4HMEAN,
     4E15.5,6X,8H2ND MOM.,E15.5,6X,8H3RD MOM.,E15.5,6X,8H4TH MOM.,E15.5,
     5///,23HMOMENTS ABOUT THE MEAN.,//,3X,8HVARIANCE,E15.5,6X,8H3RD MOM
     6.,E15.5,6X,8H4TH MOM.,E15.5,6X,8HST. DEV.,E15.5,/,3X,18HCOEFF. OF
     7SKEWNESS,E15.5,6X,16HCOEFF. OF EXCESS,E15.5,//
     8//,4X,8HX (*10**,I3,1H),2X,19HPERCENT LESS THAN X,3X,14H1ST DIFFER
     9ENCE,3X,12HDISTRIBUTION,/)
      LTHANP=0
      PERP=0.
      NOINT=0
      CHI2=0.
      AMGIS=1./SIGMA
  128 LTHAN=0
      IF(Z-XM-STEP)130,130,138
  130 DO 134 J=1,NR
      IF(X(J)-Z)132,134,134
  132 LTHAN=LTHAN+1
  134 CONTINUE
      PER=FLOATF(LTHAN)*100./TOT
      DIFF=PER-PERP
      MM=10.*(DIFF+.05)
      IF(MM-60)144,142,142
```

```
142   JJ=8
      KK=5
      GO TO 146
144   JJ=MM/8+1
      KK=MM-8*(JJ-1)+1
146   PRINT 145,IZ,PER,DIFF,( STAR(L),L=1,JJ), STAR1(KK)
145   FORMAT (2X,I10,8X,F10.2,8X,F10.2,9A8)
      NI=LTHAN-LTHANP
      ZMP=Z-.5*STEP
      TI=AMGIS*(ZMP-XMEAN)
      PPI=STEP*AMGIS*PI2D*EXPF(-TI*TI*.5)
      CHI2=CHI2+((FLOATF(NI)-TOT*PPI)**2)/PPI
      PERP=PER
      Z=Z+STEP
      IZ=IZ+ISTEP
      NOINT=NOINT+1
      LTHANP=LTHAN
      GO TO 128
138   CHI2=CHI2/TOT
      TOINT=NOINT-3
      TX=SQRTF(2.*CHI2)-SQRTF(2.*TOINT-1.)
      PRINT 155,NOINT,STEP,TOINT,CHI2,TX
155   FORMAT (///, 56HDATA FOR CHI-SQUARED TEST OF FIT TO NORMAL DISTRIB
     1UTION.,//,3X,16HNO. OF INTERVALS,I10,6X,13HINTERVAL SIZE,E15.5,6X,
     215HDEG. OF FREEDOM,F15.0,/,3X,11HCHI-SQUARED,E15.5,6X,5HT-CHI,
     3E15.5)
140   CONTINUE
      END
      END
```