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## Supporting Research

September 1982

# PROGRAM TO COMPUTE THE POSITIONS OF THE AIRCRAFT AND OF THE AIRCRAFT SENSOR FOOTPRINTS

Jack F. Paris

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ABSTRACT

The positions of the ground track of the aircraft and of the aircraft sensor footprints, in particular the metric camera and the radar scatterometer on the C-130 aircraft, are estimated by a program called ACTRK. The program uses the altitude, speed, and attitude information contained in the radar scatterometer data files to calculate the positions. The report documents the ACTRK program.

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# PROGRAM TO COMPUTE THE POSITIONS OF THE AIRCRAFT AND OF THE AIRCRAFT SENSOR FOOTPRINTS

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## 1.0 INTRODUCTION

The purpose of the Aircraft Tracks (ACTRK) program, written in FORTRAN, is to calculate the positions of the C-130 aircraft and of the centers of sensor footprints (ground resolution elements or fields of view) during a particular data run. The calculations are possible due to frequent (about every 0.65 sec) information provided in the data files on the altitude, speed, and attitude of the aircraft. In the ACTRK program, it is assumed that the aircraft was flying over level terrain, that no errors exist in the input data, and that changes in aircraft orientation and speed were gradual throughout the flight. These assumptions were valid for the agricultural scenes addressed by the program.

## 2.0 INPUT PARAMETERS

The input parameters (from the computer compatible tape or disk file) are defined as follows:

1. Roll angle (ROLL[1]) - the angle between the line passing through the aircraft wing tips and the horizontal plane. The roll angle is positive when the left wing is above the horizontal plane. The units are degrees.

[1]The name of the parameter in the FORTRAN program is given in all capitals.

2. Pitch angle (PITCH) - the angle between the line passing through the fuselage of the aircraft and the horizontal plane. The pitch angle is positive when the nose of the aircraft is above the horizontal plane. The units are degrees.

3. Heading angle (AHEAD) - the azimuthal orientation of the line passing through the fuselage of the aircraft as seen from above relative to true north. The angle is measured clockwise from true north. The units are degrees.

4. Drift angle (DRIFT) - the difference between the heading angle and the direction of the actual ground track. The drift angle is positive when the ground track is clockwise from the heading angle. The units are degrees.

5. Ground speed (GS) - the speed of the aircraft with respect to the ground. Ground speed is calculated by the onboard navigation system computer from the air speed and the wind speed vectors. The units are knots.

6. Radar altitude (ALT) - the vertical distance between the aircraft and the ground. The units are feet.

The above parameters are given on the first of the four data files versus elapsed time (ET) from the time of the first record. Also, the actual times (Greenwich Meridian Time, GMT) of the acquisition of these data are given on each record in hours (NHR), minutes (NMIN), and seconds (SEC). These time values are used to compute the time in seconds (TIME). The units for time (ET and TIME) are seconds.

## 3.0 LOGIC OF THE PROGRAM

If one follows the logic of the ACTRK program, it is divided into several parts as follows.

Dimensions of arrays are defined at the beginning. Allowances are made to handle up to 300 records (data records) for each aircraft run. This can be increased if necessary.

The program requests an input from the terminal for the orientation of the flight line (FLIGHT) that was being flown (the intended flight line direction measured clockwise from true north as viewed from above). Be sure to include a decimal point in the input from the terminal since the read format is floating point. The units are degrees.

The first three records of the file are read into dummy variables. These records are headers for the remaining data records.

Data records are then read in a loop until the end of file is encountered. Within the loop, the time data are converted to seconds (TIME), and the derived parameters, GTRACK and GAMMA, are calculated. GTRACK is the ground track angle (in degrees from true north in a manner similar to that of AHEAD). GTRACK is given by

$$\text{GTRACK} = \text{AHEAD} + \text{DRIFT} \tag{1}$$

GAMMA is the angle between the flight line direction (FLIGHT) and the ground track (GTRACK) and is given by

$$\text{GAMMA} = \text{FLIGHT} - \text{GTRACK} \tag{2}$$

The ground speed (GS) is converted from knots to feet per second and restored in the same variable name.

After the inputting of the data records is completed, the number of data records, ISTOP, is calculated. Then, two more inputs are requested from the terminal. One is the absolute position (XSTART) of the aircraft at the time of the first data record as measured down the flight line (X-axis). The other is the absolute position (YSTART) of the aircraft at the time of the first data record as measured to the left of the flight line (Y-axis) as one faces the flight line direction. Be sure to include decimal points in these parameters entered from the terminal since the format is floating point. The inclusion of XSTART and YSTART allows one to locate the subsequent positions in an absolute frame of reference. The units are feet.

The program proceeds by going through a loop in which the positions (X,Y) of the aircraft are calculated. A simple dead reckoning procedure is used. The aircraft is vectored along at the average ground speed (arithmetic average of two adjacent data record values) in the average direction angle, GAMMA, with respect to the intended flight line, FLIGHT. The time of travel is the difference in the elapsed times (ET) between data records. Elapsed time is used rather than absolute time (TIME) since ET is given to an accuracy of hundredths of a second and TIME is given only to an accuracy of tenths of a second. The results of the aircraft position calculations are stored in the X and Y arrays. The units are feet. The equations for X and Y are as follows:

$$X_{i+1} = X_i + (ET_{i+1} - ET_i) * \overline{GS} * COS(GAMMA) \qquad (3)$$

$$Y_{i+1} = Y_i + (ET_{i+1} - ET_i) * \overline{GS} * SIN(GAMMA) \qquad (4)$$

Given the aircraft positions, X and Y, the program proceeds with the calculation of the positions of the photo centers and the centers of the radar scatterometer footprints (i.e., the areas from which returned and filtered radar scatterometer signals come). Another angle, EPI, is calculated in this procedure. EPI is the difference between the intended flight line direction (FLIGHT) and the heading angle (AHEAD) of the aircraft. EPI is needed due to the fact that the fan-shaped antenna of the radar scatterometer is aligned with the axis of the aircraft and is directed toward the aft of the aircraft. Aircraft roll affects the location of the intersection of the antenna pattern and the ground. It is assumed that the metric camera is hard mounted to the aircraft (i.e., it rolls with the aircraft as the aircraft rolls). In the case of the radar scatterometer, changes in pitch angle

(PITCH) do not affect the position of the radar scatterometer footprint since the incidence angle has been specified according to the Doppler frequency shift filter used in processing the data. Changes in pitch angle do affect the position of the camera photo center. Changes in the roll angle do affect both the camera and radar scatterometer footprint positions. Of course, changes in altitude affect these positions also. In the last computational loop of the program, the equations used to predict the effects of changes in pitch, roll, and drift on these positions are applied. See the attached figures (Figures 2 and 3) for the equations.

The last loop simply writes the results of the calculations out to a file for subseuqent use.

The last plot given in this note shows the results of the application of ACTRK to an actual aircraft flight run over Webster County, Iowa, on August 19, 1980. Note the different tracks of the photo center, aircraft ground track, and radar scatterometer footprints. In some instances, the lateral displacement between pairs of tracks is several hundred feet. This could result in some footprints lying outside a particular field of interest at some or all angles of viewing. It should be noted, in particular, that the use of photography to locate the aircraft and the positions of radar scatterometer footprints could result in some data being included wrongly in a data set that is supposed to be taken over a given field.

## 4.0 CONCLUSION

The program, ACTRK, is explained in this short document. It produces useful estimates of the positions of the aircraft, photo centers, and radar scatterometer footprints where level terrain has been overflown and where changes in the altitude, speed, and attitude of the aircraft are slow enough to be well tracked by the data given in the first data file of the set of four data files produced by the NASA Johnson Space Center before 1982.

If significantly unlevel terrain should be encountered, the user should not use the ACTRK program. The distance from the aircraft position to the sensor footprint position would be in error. Also, the range from the aircraft to the sensor footprint would be in error. Finally, the local incidence angle would not be equal to the sensor look angle. It should be possible to alter the program such that the elevation of the surface along the flight line can be estimated on one pass and used in antoher pass to make these estimates more accurately than does the existing ACTRK program.

To use the calculated aircraft and aircraft sensor positions with the measured data, the author makes the following comments. One can use the aircraft positions versus time of flight (TIME) or elapsed time (ET) as given as a basis for other comparisons. The sensors, however, acquire data over an area that is not, in general, directly below the aircraft. For example, at nominal ground speeds (160 knots), at an altitude of 460 meters (1500 feet), and with a pitch angle of one degree, the center of the photos <u>leads</u> the aircraft position by 8 meters (26 feet) or 0.1 seconds. The position of the radar scatterometer footprint taken at a sensor look angle of 15 degrees <u>lags</u> the aircraft position by 123 m (402 ft.) or 1.5 sec. At a sensor look angle of 50 degrees, the <u>lag</u> is 548 m (1788 ft) or 6.6 sec. Reportedly, in the case of the radar scatterometer data, the measurements have been adjusted such that the radar backscattering coefficient value reported at a given time is of the area under the aircraft (or to the left of right of the aircraft when nonzero roll and drift angles existed) at the time reported. This is the so-called nadir time correction. Nevertheless, the data are actually acquired several seconds later (1.5 and 6.6 seconds, respectively, for 15 and 50 degree data) when the aircraft was in a different attitude than at the time of the overflight of the area in question. The author has noted, also, that the apparent time that the airplane crosses a field boundary according to the photography can be as much as 1.5 seconds before that boundary is crossed by the radar scatterometer even though the data have been nadir time corrected. The explanation of this observation has not been found by the author.

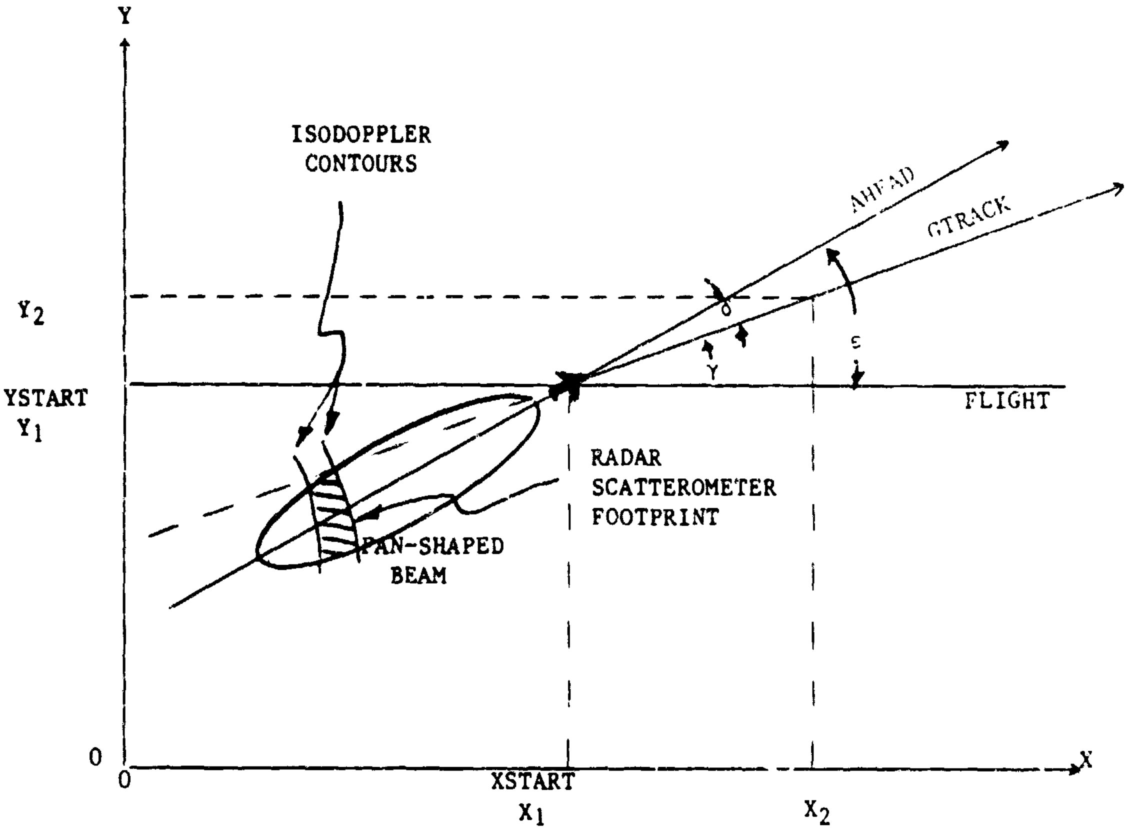


FIGURE 1. GEOMETRY OF AIRCRAFT ATTITUDE

γ = GAMMA ANGLE
ε = EPI ANGLE
δ = DRIFT ANGLE

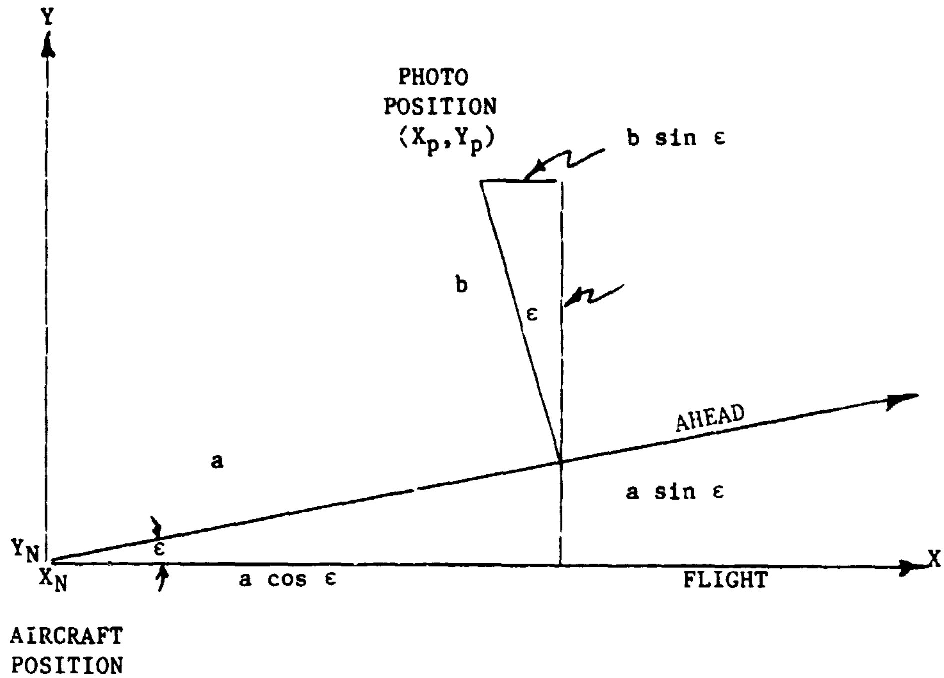


FIGURE 2. RELATIONSHIP BETWEEN PHOTO CENTER AND AIRCRAFT POSITION

A = ALTITUDE (FEET)
p = PITCH ANGLE (DEG)
r = ROLL ANGLE (DEG)
$a = A \tan p$
$b = A \tan r$
$X_p = X_N + a \cos \varepsilon - b \cos \varepsilon$
$Y_p = Y_N + a \sin \varepsilon + b \cos \varepsilon$

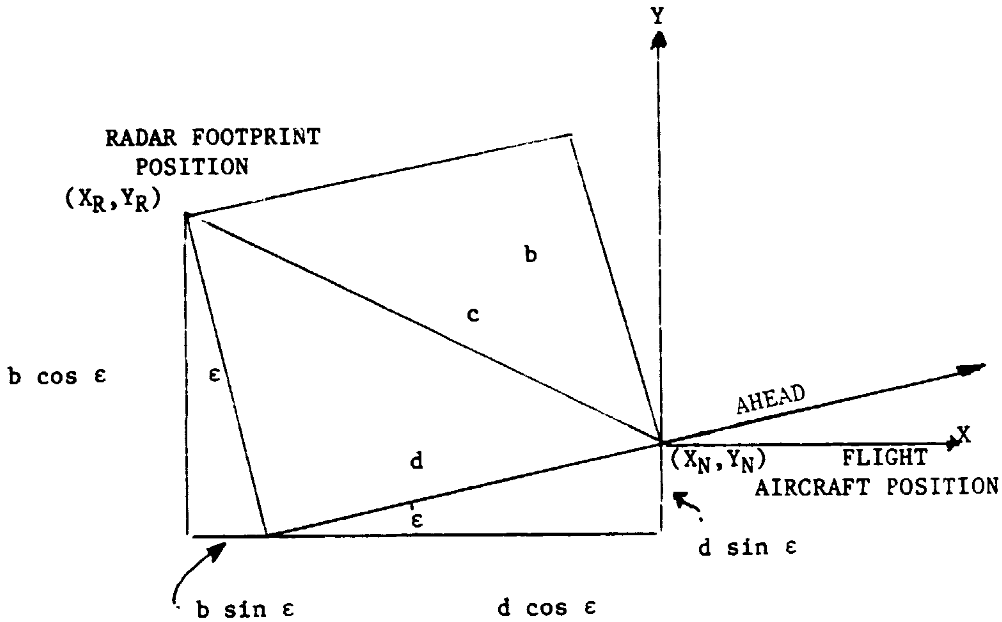


FIGURE 3. RELATIONSHIP BETWEEN RADAR FOOTPRINT POSITION AND AIRCRAFT POSITION

A = ALTITUDE (FEET)
r = ROLL ANGLE (DEG)
Θ = RADAR LOOK ANGLE (DEG)

$b = A \tan r$

$c = A \tan \Theta$

$d = \sqrt{c^2 - b^2}$

$X_R = X_N - d \cos \varepsilon - b \sin \varepsilon$

$Y_R = Y_N - d \sin \varepsilon + b \cos \varepsilon$

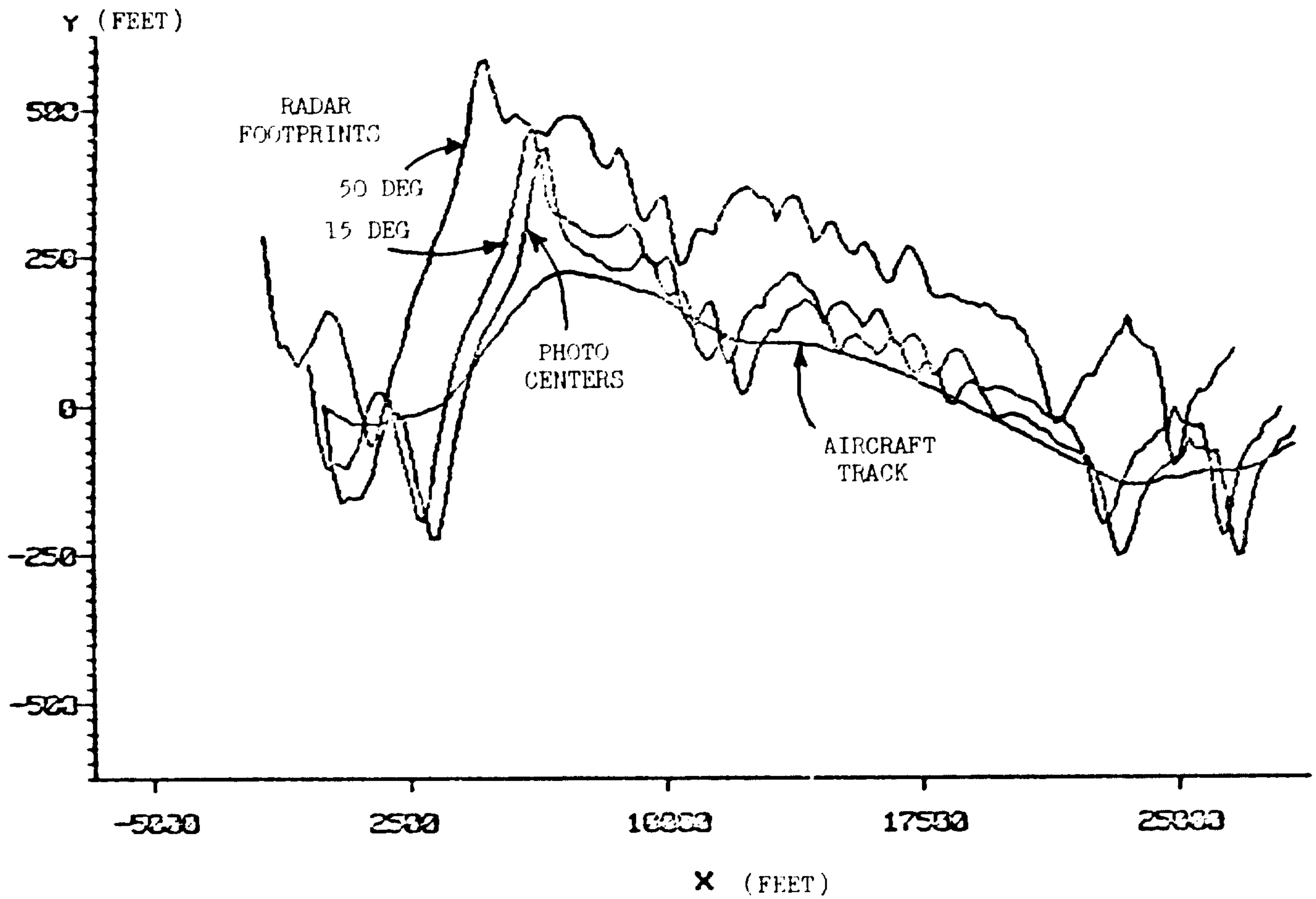


Figure 4. Example of Calculated Positions of the Aircraft and Aircraft Sensor Footprints for Data taken over Webster County, Iowa, on August 19, 1980.

# APPENDIX A

# PROGRAM LISTING

FILE: ACTRK FORTRAN A EODL / JOHNSON SPACE CENTER

```
C
C**********************************************************************
C
C     THE OBJECTIVE OF THIS PROGRAM IS TO CALCULATE THE POSITIONS OF THE
C     AIRCRAFT (APPARENT GROUND TRACK), OF THE PRINCIPAL POINT (CENTER)
C     OF THE METRIC CAMERA, AND OF THE RADAR SCATTEROMETER FOOTPRINTS AT
C     SPECIFIC ANGLES.  THE INPUT DATA CONSIST OF AIRCRAFT ATTITUDE,
C     SPEED, AND ALTITUDE INFORMATION LOCATED IN THE FIRST FILE OF
C     RADAR SCATTEROMETER DATA PROVIDED ON COMPUTER COMPATIBLE TAPES BY
C     THE NASA JOHNSON SPACE CENTER BEFORE 1982.
C
C     THE PROGRAM WAS WRITTEN BY DR. JACK F. PARIS, NASA/JSC, HOUSTON,
C     TEXAS, ON SEPTEMBER 7, 1982.
C
C**********************************************************************
C
C
C                       DEFINITION OF PARAMETERS
C
C
C   PARAMETER                        DEFINITION
C
C     ET               ELAPSED TIME (SEC) SINCE RUN START
C     TIME             CLOCK TIME (SEC) FROM GMT TIME ON DATA RECORDS
C     ROLL             ROLL ANGLE (DEG) (POSITIVE IS RIGHT WING DOWN)
C     PITCH            PITCH ANGLE (DEG) (POSITIVE IS NOSE UP)
C     DRIFT            DRIFT ANGLE (DEG), GROUND TRACK HEADING MINUS
C                      AIRCRAFT HEADING
C     ALT              ALTITUDE OF AIRCRAFT (FEET) MEASURED BY RADAR
C                      ALTIMETER (ALONG VERTICAL TO GROUND)
C     GS               GROUND SPEED (KNOTS) CALCULATED BY ON-BOARD
C                      NAVIGATION SYSTEM
C     AHEAD            AIRCRAFT HEADING (DEG) MEASURED FROM TRUE NORTH
C                      (0 - 360 DEG), IS NOT THE SAME, IN GENERAL,
C                      AS THE GROUND TRACK
C     FLIGHT           THE INTENDED GROUND TRACK OF THE AIRCRAFT OR THE
C                      DIRECTION (DEG) OF THE FLIGHT LINE MEASURED FROM
C                      TRUE NORTH (0 - 360 DEG)
C     GTRACK           AIRCRAFT HEADING PLUS DRIFT (DEG), THE ACTUAL
C                      DIRECTION THE AIRCRAFT MAKES RELATIVE TO THE
C                      GROUND MEASURED FROM TRUE NORTH (0 - 360 DEG)
C     GAMMA            FLIGHT MINUS GROUND TRACK (DEG)
C     EPI              FLIGHT MINUS AIRCRAFT HEADING (DEG)
C     XSTART           ABSOLUTE POSITION OF THE AIRCRAFT ALONG THE
C                      FLIGHT LINE AT THE TIME OF THE FIRST DATA
C                      RECORD FOR THE RUN (FEET)
C     YSTART           ABSOLUTE POSITION OF THE AIRCRAFT PERPENDICULAR
C                      TO THE FLIGHT LINE AT THE TIME OF THE FIRST DATA
C                      RECORD FOR THE RUN (FEET)
C     X                POSITION OF THE AIRCRAFT MEASURED ALONG THE
C                      FLIGHT LINE (FEET)
C     Y                POSITION OF THE AIRCRAFT MEASURED PERPENDICULAR
C                      TO THE FLIGHT LINE (FEET)
C     XP, YP           POSITION OF THE CENTER OF THE METRIC PHOTO (FEET)
C     X15, Y15         POSITION OF THE 15 DEG RADAR SCATTEROMETER
C                      FOOTPRINT (FEET)
C     X50, Y50         POSITION OF THE 50 DEG RADAR SCATTEROMETER
C                      FOOTPRINT (FEET)
C
C**********************************************************************
C
      DIMENSION ET(300),ROLL(300),PITCH(300),ALT(300),GS(300),AHEAD(300)
     1,DRIFT(300),GTRACK(300),GAMMA(300),X(300),Y(300),XP(300),YP(300)
     2,X15(300),Y15(300),X50(300),Y50(300),TIME(300)
C
C     INPUT OF FLIGHT LINE DIRECTION FROM THE TERMINAL
C
      WRITE(16,200)
  200 FORMAT(' ENTER INTENDED AIRCRAFT FLIGHT LINE HEADING (DEG):')
      READ(15,100)FLIGHT
  100 FORMAT(F10.2)
C
C     CONVERT ANGLES FROM DEGREES TO RADIANS
C
      PI=3.1415927
      THE15R=15.*PI/180.
      THE50R=50.*PI/180.
C
C     DUMMY READ FIRST THREE RECORDS (HEADERS) OF THE DATA FILE
```

```
C
C     ALSO, DUMMY READ FIRST DATA RECORD SINCE ET DIFFERENCE BETWEEN
C     FIRST AND SECOND DATA RECORD IS ALSO TOO LARGE
C
      READ(20,101)AA,BB,CC,DD
  101 FORMAT(A5/A5/A5/A5)
C
C     BEGIN LOOP TO READ DATA RECORDS FROM THE DISK FILE
C
      DO 20 I=1,300
      READ(20,102,END=300)ET(I),NHR,NMIN,SEC,ROLL(I),PITCH(I),DRIFT(I)
     1,ALT(I),GS(I),AHEAD(I)
  102 FORMAT(F7.2,1X,I2,1X,I2,1X,F5.2,F12.2,5F10.2)
C
C     CONVERT HR-MIN-SEC TO SECONDS (GMT)
C
      TIME(I)=3600.*FLOAT(NHR) + 60.*FLOAT(NMIN) + SEC
C
C     WRITE INPUT DATA TO LINE PRINTER TO VERIFY CORRECT INPUT
C     *** NOTE *** USER MAY ELIMINATE THIS STEP
C
      WRITE(6,500)ET(I),NHR,NMIN,SEC,ROLL(I),PITCH(I),DRIFT(I),ALT(I)
     1,GS(I),AHEAD(I)
  500 FORMAT(F8.2,2I3,F5.1,6F8.2)
C
C     CALCULATE GROUND TRACK AND GAMMA ANGLE
C
      GTRACK(I)=AHEAD(I) + DRIFT(I)
      GAMMA(I)=FLIGHT - GTRACK(I)
C
C     CONVERT GROUND SPEED TO FEET PER SECOND FROM KNOTS
C
      GS(I)=GS(I)*6080./3600.
   20 CONTINUE
C
C     ISTOP IS NUMBER OF DATA RECORDS (ASSUMED TO BE LESS THAN 300)
C
  300 ISTOP=I- 1
C
C     ENTER ABSOLUTE POSITION OF AIRCRAFT AT TIME OF FIRST DATA RECORD
C
      WRITE(16,201)
  201 FORMAT(' ENTER XSTART (FEET):')
      READ(15,100)XSTART
      WRITE(16,202)
  202 FORMAT(' ENTER YSTART (FEET):')
      READ(15,100)YSTART
      X(1)=XSTART
      Y(1)=YSTART
C
C     CALCULATE INCREMENT OF TIME, AVERAGE GROUND SPEED, AVERAGE GAMMA
C     ANGLE, AND NEXT AIRCRAFT POSITION
C
      DO 21 I=2,ISTOP
      IM1=I - 1
      DELTAT=ET(I) - ET(IM1)
      GSAVG=0.5*(GS(I) + GS(IM1))
      GAAVG=0.5*(GAMMA(I) + GAMMA(IM1))
      GAAVGR=GAAVG*PI/180.
      DELX=GSAVG*DELTAT*COS(GAAVGR)
      DELY=GSAVG*DELTAT*SIN(GAAVGR)
      X(I)=X(IM1) + DELX
      Y(I)=Y(IM1) + DELY
   21 CONTINUE
C
C     CALCULATE PHOTO POSITION AND RADAR SCATTEROMETER FOOTPRINT
C     POSITIONS (15 AND 50 DEGREES)
C
      DO 30 I=1,ISTOP
      EPI=FLIGHT - AHEAD(I)
      EPIR=EPI*PI/180.
      SEPIR=SIN(EPIR)
      CEPIR=COS(EPIR)
      PR=PITCH(I)*PI/180.
      RR=ROLL(I)*PI/180.
      A=ALT(I)*TAN(PR)
      B=ALT(I)*TAN(RR)
      C15=ALT(I)*TAN(THE15R)
      C50=ALT(I)*TAN(THE50R)
      D15=SQRT(C15*C15 - B*B)
```

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```
      D50=SQRT(C50*C50 - B*B)
      XP(I)=X(I) + A*CEPIR - B*SEPIR
      YP(I)=Y(I) + A*SEPIR + B*CEPIR
      X15(I)=X(I) - D15*CEPIR - B*SEPIR
      X50(I)=X(I) - D50*CEPIR - B*SEPIR
      Y15(I)=Y(I) - D15*SEPIR + B*CEPIR
      Y50(I)=Y(I) - D50*SEPIR + B*CEPIR
   30 CONTINUE
C
C     WRITE RESULTS OF CALCULATIONS TO DISK FILE
C
      DO 22 I=1,ISTOP
      WRITE(30,203)X(I),Y(I),XP(I),YP(I),X15(I),Y15(I),X50(I),Y50(I)
  203 FORMAT(1X,8F9.0)
   22 CONTINUE
      STOP
      END
```