STUDY OF SYNTHETIC APERTURE RADAR (SAR) IMAGERY CHARACTERISTICS

CONTRACT NO. NAS 6-2571

SUBMITTED TO
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WALLOPS STATION
WALLOPS ISLAND, VIRGINIA

GERA-2089
30 MAY 1975

GOODYEAR AEROSPACE CORPORATION
ARIZONA DIVISION • • • LITCHFIELD PARK, ARIZONA
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CORPORATION
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Code 99696
This is the final report to NASA Contract NAS 6-2571. Sources of geometric and radiometric fidelity errors in AN/APQ-102A radar imagery are discussed, along with a digital computer program to correct the distortions. The major effort, a computer program which will process digitalized recorded AN/APQ-102A phase histories into imagery, is described. All computer programs are listed.
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SECTION I - INTRODUCTION AND SUMMARY

This report describes the work accomplished on a study program entitled, "Study of Synthetic Aperture Radar Imagery Characteristics," funded under NASA Contract NAS 6-2571. The objective of the program was to analyze the characteristics of synthetic aperture radar (SAR) imagery and develop digital processing techniques to utilize this type of data in conjunction with other sensor data on the NASA earth resources program. Specifically, the major effort was directed toward producing the digital computer programs for the processing of data obtained from the AN/APQ-102A radar system.

The study program consisted of two major tasks: (1) the definition of SAR image characteristics, and (2) the development of digital computer programs to accept phase history data and generate a radar image normalized relative to both intensity and geometry.

Section II discusses the sources and magnitude of errors in the AN/APQ-102A imagery. The theoretical analysis consists of enumerating the known sources contributing to geometric distortion, determining the effect of each source, and combining to yield an overall estimate of the geometric fidelity of the imagery. Sources for geometric distortion fall into three categories: (1) sensing geometry, (2) radar equipment errors, and (3) errors in the aircraft inertial navigation system (INS) and altimeter. In addition to the theoretical analysis, the distortions in an AN/APQ-102A image of Wallops Island flown on 30 August 1973 were measured.

Section III describes the computer programs and procedures developed to process AN/APQ-102A phase history data. These programs and procedures were validated by actually processing imagery at the Wallops Station facility utilizing the Optronics Microdensitometer and the Honeywell 625 computer. This validation effort included the training of Wallops Station personnel, thus giving NASA the capability to process subsequent radar data without contractor support.

Conclusions are given in Section IV, and the appendixes contain program listings of all computer programs generated or used.
SECTION II - DEFINITION OF IMAGERY CHARACTERISTICS

1. GENERAL

The AN/APQ-102A has been quite successful in mapping for tactical purposes; however, its imagery has small geometric and radiometric fidelity errors which it would be desirable to remove when it is being used for cataloging earth resources. Some of the geometric errors are internally generated within the radar; however, these errors are generally small. The major sources of geometric errors are inertial system errors. Since these errors are not known for any particular flight, their effect (geometric distortion) must be measured by comparison with a map or other well-controlled data. This section discusses the error sources, their effect on geometric fidelity, and a method of measuring geometric distortions through the use of terrain features recognizable both in the radar image and on a map.

The basic design of the AN/APQ-102A includes features that minimize radiometric distortions that would be caused by sensing geometry (e.g., $\csc^2 \cos^{1/2}$ vertical antenna pattern). Radiometric distortions can be determined by measuring the deviation of the radar transfer function from the ideal or by imaging a calibrated radiometric range. Only the first of these methods is discussed.

2. GEOMETRIC FIDELITY ANALYSIS

The velocity and flight characteristics of the RF-4 aircraft and its avionics are used in the numerical calculation of the magnitude of the error components. The calculation is typical of the parameters of the flight of 30 August 1973. This analysis includes only fixed target imagery and only the modes listed in Table I.
TABLE I - AN/APQ-102A HIGH-RESOLUTION OPERATING MODES

<table>
<thead>
<tr>
<th>Mode</th>
<th>Altitude (ft)</th>
<th>Type of coverage</th>
<th>Range coverage (NMI)</th>
<th>Velocity (ft/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500 to 5,000</td>
<td>HR</td>
<td>0 to 10 both sides</td>
<td>700 to 1250</td>
</tr>
<tr>
<td>5</td>
<td>30,000 to 50,000</td>
<td>HR</td>
<td>5 to 15 both sides</td>
<td>700 to 2000</td>
</tr>
<tr>
<td>6</td>
<td>30,000 to 50,000</td>
<td>HR</td>
<td>10 to 30 left</td>
<td>700 to 2000</td>
</tr>
<tr>
<td>7</td>
<td>30,000 to 50,000</td>
<td>HR</td>
<td>10 to 30 right</td>
<td>700 to 2000</td>
</tr>
</tbody>
</table>

3. ACROSS-TRACK ERRORS

a. Ground Range Sweeps

The CRT recorder in the AN/APQ-102A employs ground range sweeps. Two characteristics of the sweep are normally considered relative to geometric fidelity, i.e., linearity and stability. Sweep linearity is expressed in terms of percent error in the distance between two points in the sweep interval. The linearity of the sweep of the AN/APQ-102A is ±0.5 percent. The error in position of a target at one edge of the swath with respect to the other for a 10-NMI swath is

\[ \pm (0.005) \times (5) (6080) = \pm 152 \text{ ft} \quad (1) \]

The long-term stability of this error should be good, and the error should be highly correlated between data films using the same recorder on successive missions.

The expected dominant spatial frequency of this range scale factor error is one-half cycle per sweep length, with the error near the center of the sweep trace being very small.

b. Film Thickness Variations

Linear film thickness variations can cause errors on the order of four feet in the range direction. The spatial frequencies of these errors have not been determined.
c. **Range Displacement Error from Target Altitude**

Conversion from slant range measurement to ground range measurement depends on the relative altitude between the radar flightpath and a given target and thus is affected by terrain roughness, earth curvature, etc. No error is attributed to the radar for this operation.

4. **ALONG-TRACK ERRORS**

a. **Recorder Film Drive Error**

The major error in film drive is caused by the error in the measurement of ground-speed. The accuracy of the velocity measuring equipment is about nine feet per second. Thus, the linear error in target location resulting from errors in velocity is

\[ E_V = \frac{V_E}{V_Y} \times D \]

where

- \( V_E \) = error in velocity
- \( V_Y \) = aircraft velocity
- \( D \) = the along-track distance over which error is to be considered.

In a high-speed mode over a five-mile distance, the linear error is

\[ \frac{9}{1500} \times 5 \times 6080 = 180 \text{ ft} \]  

It can be further assumed that a three-mil peak sinusoidal error is present because of eccentricity of the film metering drum. This would be equivalent to a three-foot error.
b. **Film Thickness Variations**

The errors from film thickness variations are estimated to be small (about four feet).

c. **Clutterlock Stability**

The stability of the clutterlock motion compensation loop is about five Hertz and would produce an error in the longitudinal (y) direction according to the following relationship:

\[
d_y = \frac{R y}{2V} \left( \frac{df d\lambda}{d\lambda} \right)_{y},
\]  

where

- frequency error = \( df = 5 \text{ Hz} \)
- wavelength = \( \lambda = 0.1 \text{ ft} \)
- groundspeed = \( V_y = 1500 \text{ ft/s} \)
- \( \epsilon = \text{relative error} \)
  \[ \epsilon = dy_1 - dy_2 \]
  \[ \epsilon = (R_{\min} - R_{\max}) \frac{df d\lambda}{2V} \]
  \[ \epsilon = \frac{30,400 \times 5 \times 0.1}{2 \times 1500} = 5 \text{ ft} \]

This is a skew-type error, and its frequency is estimated to be very low.

d. **Correlator Film Drive Error for Optically Processed Imagery**

Aspect ratio error contributes a small, steady-state error in the image azimuth scale factor. This error is held to less than a resolvable element and is estimated
to be 15 feet. Data film drive error resulting from metering drum eccentricity is the same as that of the recorder and is three feet. The image film metering drum eccentricity permits a maximum sinusoidal error of 23 feet peak at a period of 3.9 NMI.

e. Residual Error from Motion Compensation Instrumentation

Compensation for sideways motion in the AN/APQ-102A radar is achieved in the following manner. An antenna-mounted accelerometer system measures the sideways accelerations which are integrated and combined with the clutterlock-measured velocities. The clutterlock takes an average of range samples at intervals along the entire 10-mile swath. The motion compensation signal thus derived is applied at midrange. Thus, no along-track error exists at this point; however, an error does exist on each side of the midpoint, with maximum error at maximum and minimum ranges.

To obtain an expression for this error, consider a velocity in the X direction, $V_X$. A correction is made so that no error exists at $Y_0$. However, there is a difference between the hyperbola on which mapping is occurring and the straightline correction that is applied. From Figure 1, the following expressions may be written:

$$Y_\psi = (R^2 + h^2)^{1/2} \cos \psi$$  \hspace{2cm} (5)

$$Y_o = \frac{V_X}{V_Y} R_o$$  \hspace{2cm} (6)

$$Y = \frac{V_X}{V_Y} R$$  \hspace{2cm} (7)

$$\frac{V_X}{V_Y} R_o = (R_o^2 + h^2)^{1/2} \cos \psi$$  \hspace{2cm} (8)
\[ \cos \psi = \frac{Y}{(R_o^2 + h^2)^{1/2}} \]  
(9)

\[ Y = (R^2 + h^2)^{1/2} \frac{V_X R_o}{Y} = \frac{(R^2 + h^2)^{1/2}}{(R_o^2 + h^2)^{1/2}} \frac{R_o}{V_Y} V_X \]  
(10)

The along-track error is

\[ Y - Y_\psi = \frac{V_X}{V_Y} R - \frac{V_X R_o}{Y} \frac{(R^2 + h^2)^{1/2}}{(R_o^2 + h^2)^{1/2}} \]

\[ = \left[ R - R_o \frac{(R^2 + h^2)^{1/2}}{(R_o^2 + h^2)^{1/2}} \right] \frac{V_X}{V_Y} \]  
(11)

Figure 1 - Geometry and Motion Compensation Error
If the velocity, \( V_X \), is 10 ft/s, \( V_Y \) is 1500 ft/s, \( R \) is 20 miles, \( R_0 \) is 15 miles, and \( h \) is 40,000 ft, the error is
\[
Y - Y_\psi = 26.7 \text{ ft} 
\] (12)

f. **Effect of Clutterlock and Across-Track Velocity Measurement Error**

An across-track velocity measurement error introduces a squint or skew into the final image. An across-track velocity measurement error of 6 ft/s at 1500 ft/s produces a pointing error of
\[
\text{ANGULAR } \epsilon_{CTV} = \frac{6}{1500} = 4 \times 10^{-3} \text{ radian} 
\] (13)

The linear error along track of a target on one edge of the swath with respect to the other is
\[
\epsilon_{CTV} = \frac{\Delta V_X}{V_Y} (R_{\text{MAX}} - R_{\text{MIN}}) 
\]
\[
= \frac{6}{1500} (10) (6080) 
\]
\[
= 243 \text{ ft} 
\] (14)

g. **Effect of Vertical Velocity Measurement Error**

An expression relating vertical velocity to along-track error can be developed similar to that for across-track velocity:
\[
\epsilon_{VV} = h \left[ \frac{1}{(R^2 + h^2)^{1/2}} - \frac{1}{(R_0^2 + h^2)^{1/2}} \right] \frac{V_Z}{V_Y} 
\] (15)
For the conditions

\[ V_Z = 3.5 \text{ ft/s} \]
\[ V_Y = 1500 \text{ ft/s} \]
\[ h = 40,000 \text{ ft} \]
\[ R = 20 \text{ NMI} \]
\[ R_0 = 15 \text{ NMI} \]

therefore,

\[ \epsilon_{VV} = 26.9 \text{ ft} \]

**h. Effect of Vertical Velocity Measurement Error**

The along-track effect of vertical velocity measurement error may be determined from the expression

\[ \epsilon \Delta V_Z = \frac{h}{V_Y} \times \Delta V_Z \quad (16) \]

For the parameters

\[ \Delta V_Z = 2 \text{ ft/s} \]
\[ V_Y = 1500 \text{ ft/s} \]
\[ h = 40,000 \text{ ft} \]

the along-track error resulting from vertical velocity measurement error is

\[ \epsilon \Delta V_Z = \frac{40,000}{1500} \times 2 = 53.3 \text{ ft} \quad (17) \]
i. **Antenna Pitch and Yaw Errors**

Errors in antenna pitch and yaw will affect along-track geometric fidelity. The result is that the clutterlock attempts to correct for the error, causing a skew in the imagery. Consider the geometry of Figure 2. The aircraft is flying at velocity with an antenna pitch of \( \theta_p \) and yaw of \( \theta_a \). The error in the along-track direction is the mismatch between the best-fit doppler line and the antenna pattern intersecting the ground. This error is \( Y - Y_\psi \).

From Figure 2, the following expressions may be written:

\[
Y_\psi = (R^2 + h^2)^{1/2} \cos \psi \tag{18}
\]

\[
Y = R\theta_a + h\theta_p \tag{19}
\]

\[
Y_o = R\theta_a + h\theta_p \tag{20}
\]

![Figure 2 - Geometry of Antenna Pitch and Yaw Error](image)
The error in along-track position is

\[ Y - Y_\psi = R\theta_a + h\theta_p - (R_o^2 + h^2)^{1/2} \cos \psi \]

and, substituting for \( \cos \psi \), the following is obtained:

\[ Y - Y_\psi = R\theta_a + h\theta_p - \left[ \frac{R_o^2 + h^2}{(R_o^2 + h^2)^{1/2}} \right] (R_o \theta_a + h\theta_p) \]

The error at \( R_o, Y_o \) is zero but increases as \( R \) increases or decreases from \( R_o \).
Therefore, \( R_o \) is placed at the midswath position, and \( R \) may vary five NMI on either side.

For the following conditions,

- \( R = 20 \text{ NMI} \)
- \( R_o = 15 \text{ NMI} \)
- \( h = 40,000 \text{ ft} \)
- \( \theta_a = 0.25 \text{ deg} \)
- \( \theta_p = 0.25 \text{ deg} \)

an along-track error of 90 ft occurs.
j. Aircraft Turning Error

The inability of the aircraft to fly a perfectly straight path introduces errors in the along-track direction. When the aircraft goes into a slow turn within the time constants of the clutterlock, the clutterlock is able to keep the physical beam oriented on the zero doppler line. However, the radar thinks it is following a straight line flightpath and, as a result, the imagery is skewed. The geometry of this situation is depicted in Figure 3. Here, \( r \) is the uncompensated turning radius of the aircraft, \( R \) is the range of interest of the radar, \( s \) is the length of the ground track in rotating through the angle \( \theta \), and \( S \) is the distorted, recorded length of the flightpath. The error caused by the aircraft turn may be written as

\[
\epsilon_T = \frac{S - s}{s} = \frac{(r + R)\theta - r\theta}{r\theta} = \frac{R}{r}.
\]  

(25)

Figure 3 - Geometry of Errors Resulting from Uncompensated Turn
It is difficult to determine what the minimum uncompensated turning radius for the RF-4 or C-54 is, but the manufacturer of the RF-4 has indicated that it will fly straight with a minimum turn radius of 2650 NMI. Therefore, the error resulting from a turn expressed in percent is

$$\epsilon_T = \frac{R}{r} \frac{10}{2650} = 0.00378 = 0.38 \text{ percent} \quad (26)$$

When one considers a strip five NMI long, the turning error is

$$\epsilon_T = (0.0038) \times 5 \times 6080 = 115 \text{ ft}$$

5. MEASUREMENT OF GEOMETRIC ERRORS

a. General

It can be seen from the foregoing that most of the fidelity errors are random and are irreducible prior to imaging, because they represent the utilization of onboard sensors and their attendant errors. Certain errors such as residual motion compensation error and the skew introduced by use of an offset frequency for demodulation could be removed after flight if the offset frequency and the three-axis translation of the aircraft were recorded during flight. These data, however, are not available in the AN/APQ-102A, and hence the aforementioned errors are not separable from the random errors.

As a postflight procedure, the processed radar image may be rectified by use of a computer program which does a least-square-error fit using precisely imaged points whose geographic coordinates are accurately known. Care must be taken that points utilized are coincident with the points whose coordinates are known.
b. Program Rationale

For the distribution correction program, the following radar image distortions were considered:

1. Scale (range versus track) - caused by the separate scaling mechanisms involved (in the radar) in the track and range directions

2. Skew - caused by either radar antenna or correlator slit misalignment (results in range and track nonorthogonality).

3. Residual distortion - that which remains after items 1, and 2, have been accounted for (caused by height differences between the radar ground plane and the elevation of objects in the ground area being imaged, nonlinearities in the recording CRT, measurement errors, etc.).

c. Program Steps

Since the program determines the distortion relative to (radar) range and track, a prerequisite for the analysis is that the radar image measurements (of identified ground control points) be performed with the X-axis of the measurement device aligned with the track direction of the radar. The steps taken by the program in analyzing distortion are summarized as follows:

1. The ground coordinates of the control points are preliminarily aligned with the image coordinate system. This is done by determining the relative orientation of two designated control points in both the image and ground frames and rotating the ground system to coincidence. For correctly signed printout of scale, skew, and distortion, it is desirable to choose the ground axes to lie within 45 degrees of the image coordinate
system (for an existing system, this is accomplished by controlling the sign and (X-Y) designation of the axes). The designation of alignment points (as a program parameter) prevents the use of points known to have a high probability of substantial relative distortion (e.g., points extremely close together). The selection of two widely spaced points will suffice for the initial alignment.

2. A least-squares fit between image and ground range coordinates is performed. The range errors remaining after the fit are computed, and the linear correlation coefficient between range errors and track coordinates is determined (if a nonzero coefficient exists, it indicates a residual misalignment). The ground coordinates are then rotated to make the coefficient zero. This process prevents individual control point errors from introducing substantial alignment errors.

3. A least-squares fit between the range image and ground coordinates is computed and residual errors determined (at ground scale).

4. Track image and ground coordinates are scaled via a least-squares fit and average error determined. Skew is then introduced into the image coordinate system via two equations:

\[ Y' = Y \]  \hspace{1cm} (27)

and

\[ X'(l) = X(l) + A \cdot Y(l) \]  \hspace{1cm} (28)
where

\[(X, Y) = \text{original image coordinates}\]

\[(X', Y') = \text{skewed coordinates}\]

\[A = \text{tangent of skew angle.}\]

The skew angle is varied (in sign and magnitude) until track errors are minimized (as measured by successive least-squares fits)

5. Several types of analyses are then performed by the program to demonstrate the relative contribution of various error sources. In each of them, the residual error variance and individual point errors (ground scale) are computed (and displayed for examination) after various types of image correction are introduced. The four types of correction are:

a. A magnification equal to the average (range and track) scaling difference between image and ground coordinates

b. Differential scale correction

c. Magnification plus skew correction

d. Differential scale and skew correction.

The image range scale, track scale, and skew are displayed. Plots are created (using CalComp software) which illustrate the ground position and residual error of the control points after the various types of correction.
d. Program Parameters

The program listing is given in Appendix A. The utilization of the results to restitute digitally processed imagery is discussed in Section III.

Program parameters are as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
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<tr>
<td>ALPHA 1 - ALPHA 4</td>
<td>Analysis section headers</td>
</tr>
<tr>
<td>N</td>
<td>Number of control points</td>
</tr>
<tr>
<td>N1, N2</td>
<td>Number (corresponding to program order) of point pair to be used for initial alignment. N1 and N2 should be ordered so that N1 has a smaller track coordinate than N2 (however, N1 &lt; N2 need not be true; i.e., control points may be entered in any order)</td>
</tr>
<tr>
<td>SCPLT</td>
<td>Scale of plots (ground units/inch) which are created of control point positions</td>
</tr>
<tr>
<td>SCERR</td>
<td>Scale of error vectors</td>
</tr>
<tr>
<td>(P(I), Q(I))</td>
<td>Ground coordinates of control point</td>
</tr>
<tr>
<td>(X(I), Y(I))</td>
<td>Image coordinates of Ith control point</td>
</tr>
<tr>
<td>A(I)</td>
<td>Alphanumeric control point designator.</td>
</tr>
</tbody>
</table>
c. Results

A section of the AN/APQ-102 data film which was flown for NASA on the 30 August 1973 flight was optically correlated on a laboratory correlator, and the portion of the imagery around Wallops Island was analyzed. Sixteen points were used, of which coordinates for 6 were from triangulation and 10 from a map. After distortion correction, the mean error along track was zero with a standard deviation of 77.52 meters and mean across-track error of 7.2 meters, with a standard deviation of 87.7 meters.

6. RADIOMETRIC ERRORS

a. General

As mentioned previously, the transfer function of the AN/APQ-102A was designed to compensate for sensing geometry, ideally resulting in no radiometric distortion. To the extent that the radar transmitted power and the receiver gain remain constant (this can be accomplished by disabling the automatic gain control), the radar can be designed to compensate for changes in slant range and depression angle. These compensations are accomplished with sensitivity time control and a vertical antenna pattern designed for uniform illumination as a function of depression angle. Deviations (from the ideal) of these functions can cause radiometric errors.

b. Sensitivity Time Control (STC)

Reference 1\(^a\) contains instructions on how to adjust the STC to give the desired signal. This description includes wave shapes and is considered the best data available. The STC so adjusted requires no correction. The STC is turned off in modes used above 30,000-ft altitude and does not apply to the flight of 30 August 1973.

\(^a\) USAF T.O. 12P3-2APQ102-2-4. Radar Mapping Set, AN/APQ-102 and AN/APQ-102A (Frequency Converter-Transmitter CV 1678/APQ102), Chapter 11.
c. Antenna Illumination

It can be shown that if the vertical antenna pattern has a gain

\[ G = K \csc^2 \theta \cos^{1/2} \theta, \quad (29) \]

then the terrain would be uniformly illuminated as a function of depression angle \( \theta \).

Such a pattern can be synthesized over a limited angle. In the AN/APQ-102A, the pattern is normalized at 18 deg. Figure 4 shows the theoretical vertical antenna pattern of the AN/APQ-102A, together with the tolerances in gain. The standard deviation of the one-way gain from uniform illumination is less than 0.5 dB. The antenna pattern of the arrays to be used can be measured and the deviation between measured values and the ideal \( \csc^2 \theta \cos^{1/2} \theta \) determined. It was anticipated that the measured antenna pattern could be used to make radiometric corrections to the imagery of Wallops Island made on 30 August 1973. However, it has been determined that USAF records do not make this possible. Therefore, no corrections for the antenna pattern were made. The image distortion program discussed in Section III has such provisions.
SECTION III - DIGITAL PROCESSING OF IMAGERY

1. DIGITAL AZIMUTH PROCESSING

The processing described in this section will accommodate AN/APQ-102 radar data which has been range compressed, recorded optically, scanned, and digitized for processing. The azimuth compression will be performed by a high-speed digital computer. The data flow diagram is given in Figure 5. The processing will be performed to obtain 30-ft-resolution imagery with the option of either one or two azimuth looks. If more rapid processing of the data is desired, the azimuth resolution may be degraded.

The data will be processed for an azimuth offset that is nominally PRF/4. In actuality, the azimuth offset frequency is not exactly known, and the data processing must take this into account. To maintain low sidelobe levels, an oversampling factor of at least four will always be maintained. The sampling rate of the input data will be not be reduced until azimuth compression is being performed.

The implications of the foregoing may be better understood by examining the fundamental formulas for azimuth compression. The synthetic aperture length which must be flown to attain a desired 3-dB azimuth resolution, \( W_A \), is

\[
L_{\text{SYN}} = \frac{0.88\lambda R}{2W_A},
\]

where \( R_s \) is the slant range to the target measured on a line perpendicular to the flight-path, and \( \lambda \) is the wavelength of the transmitted signal.

However, when the phase history of a point target which has been collected over the required \( L_{\text{SYN}} \) is compressed (i.e., processed in a matched filter), the resultant sidelobes of the \( \sin(x)/x \) compressed waveform have a -13.6-dB peak and decay slowly.
SECTION III

Figure 5 - Digital Processing of SAR Data-Flow Diagram (Sheet 1 of 2)
Figure 5 - Digital Processing of SAR Data - Flow Diagram (Sheet 2 of 2)
These sidelobes present a problem in that the sidelobes of a large target may have larger amplitudes than the mainlobe of a target, and hence mask it. To prevent this from occurring, a weighting function is applied to the return phase history. Basically, the weighting function reduces the sidelobes by the application of a symmetrical taper across the azimuth phase history of a target. This symmetrical attenuation, however, causes a broadening of the mainlobe of the target when azimuth compression is performed. To maintain the desired resolution, yet achieve a low sidelobe level, excess azimuth bandwidth is required.

Typical of the weighting functions which may be applied are Taylor aperture functions. A Taylor aperture function which suppresses the peak sidelobe to -30 dB will broaden a point target's mainlobe by a factor of 1.42. When this weighting function is used,

$$L_{\text{SYN}} = \frac{1.25\lambda R}{2W_A} \quad (31)$$

Processing is being performed for a finer resolution than is specified, with the knowledge that the weighting function is being utilized and will broaden the mainlobe to that desired.

If the antenna's real azimuth beamwidth, $\beta_s$ (here considered to be 3-dB beamwidth) is capable of illuminating more azimuth extent than is required for a desired resolution, i.e., if

$$R_s \beta_s > L_{\text{SYN}} \quad (32)$$

then the excess illuminated area may be used to form more than one synthetic aperture. For the AN/APQ-102A system, the 2-way 3-dB beamwidth is approximately 1 degree, which would theoretically imply that 8 synthetic apertures for 30-foot resolution exist between the 3-dB points of the antenna beam:

$$\frac{R_s \beta_s}{L_{\text{SYN}}} = \frac{R_s (1 \text{ deg})/K\lambda R_s}{57.3/2W_A} = 8.37 \quad (33)$$

-26-
However, because the limitations of the motion compensation INS, azimuth recorder bandwidth, etc., blurring of the image will possibly occur if more than two looks are combined. Thus, for this problem,

\[
L_{\text{SYN}} = 2.083 \times 10^{-3} \times R \times \text{number of looks},
\]

where \( L_{\text{SYN}} \) is the synthetic aperture length in feet, \( R \) is the slant range in feet, and the number of looks is either one or two.

The AN/APQ-102 radar has a PRF of 1,1 V, where \( V \) is the aircraft velocity in feet per second. Therefore, a sample of the terrain is collected once per 0.9091 ft of aircraft travel. This sampling is greatly in excess of that necessary for 30-ft resolution, which is

\[
\text{minimal sample spacing} = \frac{30}{2 \times 1.25 \times \text{number of looks}} \text{ ft}.
\]

(The factor of 1.25 in the denominator accounts for the excess bandwidth required to preserve resolution when using the weighting function.) It is necessary to have this high PRF to keep the spectrum which lies within the antenna's mainbeam unambiguous.

The unambiguous bandwidth of the sampled spectrum lies from zero frequency to 1/2 PRF, or 0.55 cycle/ft. The clutterlock, however, keeps the antenna, and hence the doppler spectrum within its mainlobe, centered on zero doppler. Therefore, it is necessary to translate the return mainlobe spectrum up in frequency so that a frequency of -0.275 cycle/ft will lie at zero frequency, and a frequency of +0.275 cycle/ft will lie at 0.55 cycle/ft. This is accomplished by mixing the return with an azimuth offset frequency of 1/4 PRF. The translated return spectrum is illustrated in Figure 5. Energy at frequencies above ±0.275 cycle/ft will fold back into the spectrum of interest. However, as is illustrated by the dashed lines in Figure 6, this energy is heavily attenuated by the rolloff of the antenna's mainlobe. The peak sidelobes of the AN/APQ-102A 2-way antenna pattern are more than 26 dB down, and thus the energy in them will contribute little to the processing noise.
The spatial bandwidth required to process 1 look for 30-ft, 3-dB resolution with 30-dB peak sidelobes is $(1.42)(0.88)/(30) = 0.04617$ cycle/ft. The factor of 1.42 is the excess bandwidth ratio required for the sidelobe control. Thus, the bandwidth of the spectrum which will enter the processor is in excess of that necessary to process one look by the ratio of $(0.55)/(0.04167) = 13.2$. As will be detailed later, the input bandwidth can be reduced by filtering to reduce the excess bandwidth and improve the signal-to-noise ratio. (Note that only $8.37/13.2$ of the unambiguously sampled data lies within the 3-dB antenna beamwidth, as was shown in Equation (33)).

The radar's azimuth bandwidth and sampling rates having been examined, the effects of scanning the optically recorded data and digitizing samples will be considered. For each range element, an azimuth sample has been taken and recorded on film for each 0.9091 ft of aircraft travel. When this data is scanned, however, a sample is taken from the film at the equivalent of once for each 0.826 ft of aircraft travel, which introduces

Figure 6 - Antenna Azimuth Frequency Response
an effective increase in the azimuth sampling of a factor of 1.10. It must be understood that no increase in the information bandwidth has occurred, that having been restricted by the original PRF. However, there is a translation of all frequencies because of the resampling. All data must be treated as though the spatial bandwidth were \((0.55)(1.1) = 0.605\) cycle/ft, even though no information lies in the portion of the unambiguous spectrum resulting from the different input and output data rates.

The digitized data will be treated as if the original PRF produced a factor of \((13.2)(1.1) = 14.52\) in excess bandwidth over that required for a single azimuth look. Each azimuth look will thus occupy \((0.04167/0.605) \times 100 = 6.9\) percent of the unambiguous sampled bandwidth.

The first operation in the digital processing of the data is to bandpass only those frequencies necessary for azimuth compression, and thereby improve the signal-to-noise ratio by reducing the noise bandwidth. This is done in the azimuth prefilter, which has been designed (described below) to have a nominal center frequency of \(0.4545\) (i.e., \(\text{PRF}/4/1.1\)) of the sampled bandwidth and have \(0.04167\) and \(0.08334\) cycle/ft spatial bandwidths for the one- and two-look cases, respectively.

The two azimuth prefilter functions are 'window function' designs.\(^{a}\) To produce a window function with a desired center frequency and bandwidth, the following procedure is employed (the steps are illustrated in Figure 7):

1. In the frequency domain, place an impulse at the desired fraction of the bandwidth for which the filter's center frequency is to lie, and at the corresponding negative frequency

2. Take the inverse discrete Fourier transform (IDFT) of this spectrum.

The result will be a sampled cosine in the time domain having an integer number of cycles over the time extent of the IDFT output

Figure 7 - Window Filter Design
3. A weighting function, in this case, a 40-dB Taylor function, is point by point multiplied with the sampled cosine. This is the filter function.

4. A discrete Fourier transform (DFT) is taken of the product. This shows the bandpass of the filter. Note that if no window function were applied, the step 4 output would have the shape of \( \sin(x)/x \), which is the transform of a pulsed cosine.

The selection of the number of points in the window function design depends essentially upon three factors:

1. The accuracy to which the center frequency of the filter must be positioned
2. The bandwidth of the filter
3. The rolloff rate and minimum stop-band attenuation of the filter.

For the two azimuth prefilter functions, the desired center frequency of both is \( 0.4545 = 5/11 \). Thus, as an impulse is needed at both positive and negative frequency, the length of the reference function should be a multiple of \( 2 \times 11 = 22 \) points.

The bandwidths desired are 0.04167 and 0.08334 cycle/ft spatial bandwidths. As the 3-dB width of the \( \sin(x)/x \) function mentioned in step 4 of the foregoing is \( 0.88 \times 2/N \) of the bandwidth, where \( N \) is the number of points in the sampled cosine, and as the 40-dB Taylor weighting broadens this by a factor of 1.42, then for the 0.04107 cycle/ft filter,

\[
0.88 \times 2 \times 1.42 \frac{N}{N} = \frac{0.069}{1.1} \rightarrow N = 40
\]  

and for the 0.08334 cycle/ft filter,

\[
0.88 \times 2 \times 1.42 \frac{N}{N} = \frac{0.138}{1.1} \rightarrow N = 20
\]
Thus, for the filters, \( N = 44 \) and \( N = 22 \) provide excellent choices, with the impulses at (10, 34) for the first and at (5, 17) for the second. The taper over the amplitude of the filter's output spectrum will be used as part of the weighting to control the azimuth sidelobes (described in Equation (31)).

The two filters are readily translatable to different center frequencies simply by changing the position of the impulses in step 1. The narrow bandwidth filter can be stepped in increments of 0.04545 of the sampled bandwidth and the wider bandwidth filter in steps of 0.9091 of the sampled bandwidth. Finer steps can be obtained by increasing the number of points in the reference function and changing the window function accordingly.

The azimuth prefilter is a nonrecursive, convolution filter. In nonrecursive filters, the output is not fed back to the input. Although filters with feedback (i.e., recursive filters) have shorter reference functions than do nonrecursive filters, they suffer in that they allow a noise buildup because of signal quantization and do not offer the truly linear phase characteristic which nonrecursive filters provide. Hence, nonrecursive designs are considered superior for this application.

In the nonrecursive filter, \( N \) consecutive data points are multiplied by the \( N \) corresponding filter reference function points; the \( N \) products are summed, and the result is obtained. The oldest input data point is discarded, the remaining \( N - 1 \) data points are shifted one position, a new data point is entered, and the multiplication and summation process is repeated. Thus, for every data point entered, there is one data point output.

After azimuth prefiltering has been performed, the data will be compressed to its ultimate azimuth resolution. The length of the synthetic aperture required to compress an azimuth return was shown in Equation (34) to be equal to \( 2.083 \times 10^{-3} \times R_s \times \text{number of looks} \), where \( R_s \) is the slant range to the target in feet. A digitized data sample is taken from the data film once for every 0.826 ft of aircraft travel. The number of data points contained in the synthetic aperture length, \( N \), is given by
\[ N = 2.52 \times 10^{-3} \times R_s \times \text{number of looks} \]  

where \( R_s \) is in feet.

The azimuth compression filter function with which the prefiltered data will be correlated will next be determined. Consider an isolated point target at a slant range, \( R_s \). The ground range to this target, \( R_g \), is

\[ R_g = (R_{go} + 32.8 \times M) \text{ ft} \]  

where \( R_{go} \) is the ground range (in feet) to the near edge of the swath being mapped, 32.8 is the conversion factor from film scan to feet on the ground, and \( M \) is the number of the range cell in which the target lies (\( M \) equaling zero for the first range cell). The slant range and ground range are related by the equation

\[ R_s = \left[ h^2 + R_g^2 \right]^{1/2} \]  

where \( h \) is the aircraft altitude.

As the aircraft flies past the point target, the phase of the return, \( \phi \), is equal to

\[ \phi = \frac{4\pi R_s}{\lambda} \]  

where \( R_s \) is the slant range to the target, and \( \lambda \) is the radar wavelength. The range \( R \) may be expressed as

\[ R_s = \left[ R_{so}^2 + X^2 \right]^{1/2} \]  

where \( R_{so} \) is the slant range to the target when measured on a line perpendicular to the flightpath (i.e., at the point closest to the aircraft), and \( X \) is the along-track displacement of the aircraft from the point at which \( R_s \) is measured. As \( R_{so} \gg X \), Equation (42) may be approximated as
\[ R_s \approx R_{so} + \frac{x^2}{2R_{so}} \]  \hspace{1cm} (43)

with a high degree of accuracy. Hence,

\[ \phi = \frac{4\pi}{\lambda} \left[ R_{so} + \frac{x^2}{2R_{so}} \right] = \phi_0 + \frac{2\pi x^2}{\lambda R_{so}} \]  \hspace{1cm} (44)

where \( \phi_0 \) is a constant.

To Equation (44), the azimuth offset frequency (shown previously to be \( \text{PRF}/4/1.1 \), where the factor of 1.1 results from the digitizing process) has been added. Thus, the azimuth phase history of the signal presented to the azimuth compression filter is

\[ \phi = \frac{4\pi}{\lambda} \left[ (0.826n)^2 \right]^{1/2} - 2\pi \cdot (0.227n) + \phi_0 \]  \hspace{1cm} (45)

where

\[ n = \text{azimuth sample number}, \quad n = 0 \text{ occurring at } X = 0 \]

\[ 0.227 = \text{azimuth offset frequency in cycles per foot on the ground after digitizing} \]

\[ 0.826 = \text{distance between samples in feet} \]

The azimuth compression reference function (ACF) which will compress the point target to the desired resolution is

\[ \text{ACF} = \exp[j\phi] = \cos \phi + j \sin \phi \]  \hspace{1cm} (46)

The value of \( \phi_0 \) for the reference is set to zero as it is an arbitrary constant. The value of \( N \) has been determined in Equation (38). The value \( n \) in Equation (45) will be stepped from \(-n/2\) to \(N/2\) for generation of the reference function. The compression is performed by the complex convolution of the data and the reference function, although the data quadrature component is always zero, and hence no multiplication is performed with this term.
The computed ACF will be weighted by a Taylor aperture function to reduce the azimuth sidelobes. (Recall that the broadening of the mainlobe of the compressed pulse has already been compensated for by the factor of 1.42 in the aperture length formula, Equation (31).) The Taylor aperture function has only real, positive coefficients. The product of the weighting function and the ACF will result in a function

\[
\text{ACF}_{\text{weighted}} = A(n) \exp(j\phi)
\]

where \(A(n)_{\text{max}} = 1\) when \(n = 0, -N/2 \leq n \leq N/2\).

The output of the azimuth compression convolution will be generated having 7.5-ft spacings, or equivalently at one-ninth of the input data rate. This will reduce the data rate and hence the number of calculations by a factor of nine, yet retains a sufficient number of data samples to preserve the processed resolution after detection.

Detection of the compressed data is accomplished by forming \(I^2 + Q^2\) of the azimuth processed image; i.e., by squaring the real and quadrature components of the data and then summing them. Detection produces information which contains only magnitude information, the magnitude being proportional to the power of the return over the aperture length from a point target.

To obtain two looks in azimuth, the ACF will be twice the length as that used for one-look processing. The weighting function is applied in the same manner; however, twice as many sample functions are taken over the Taylor aperture function. The two looks are formed after azimuth compression and detection by passing the data through a post-detection filter. The postdetection filter's impulse response is equivalent to 30-ft resolution. This filter is formed by summing four consecutive azimuth compression filter outputs and dividing by four; i.e.,

\[
E_{\text{Out}} = 0.25 \sum_{i=1}^{4} E(i)_{\text{In}}
\]

For every output of the azimuth compression filter, there will be one output of the post-detection filter.
For the azimuth compression, it has been shown that the phase of the ACF varies with range as shown in Equation (45), and that a new ACF can be computed for each range increment. Experience has shown, however, that satisfactory results may be achieved even if the phase difference between the signal and the ACF varies by as much as ±22-1/2 degrees. Hence,

\[ \phi = \frac{4\pi R}{\lambda} = \phi_0 + \frac{2\pi x^2}{\lambda R_0}, \]

\[ \frac{d\phi}{dR_0} = -\frac{2\pi x^2}{\lambda R_0^2} \frac{dR_0}{\lambda R_0} = \frac{\pi}{4}, \]

\[ x = \frac{1}{2} \frac{L_{\text{SYN}}}{\lambda} = \frac{K\lambda R_0}{4wA}, \]

Therefore,

\[ 2\pi \frac{K\lambda^2}{\lambda R_0^2} \frac{\Delta R}{4wA} = -\frac{K^2\lambda}{8wA} \Delta R = \frac{\pi}{4}, \]

\[ |\Delta R| = \frac{2w^2}{A} \frac{11,520}{K^2 \lambda \text{(number of looks)}^2} \text{ ft} \quad (49) \]

For one look, \( \Delta R = 5760 \text{ ft} \); and for two looks, \( \Delta R = 1440 \text{ ft} \).

2. REMOVAL OF IMAGE SKEW

Because of such factors as aircraft across-track motion, antenna pointing errors, errors in scanning the data from the film, etc., the output data may be at a skew angle. The skew is corrected by the image distortion correction program.
The skew removal is accomplished by a "zero data" addition procedure. From the
gometry shown in Figure 8, where $\phi$ is the skew angle, it is seen that the data must be
rotated to orient the data's range vector with the vector perpendicular to the flightpath.
To accomplish this, data points with magnitudes of zero are inserted at near and far
range to form a rectangular data block, as illustrated in Figure 9. (The all-zero
columns at near and far range are for computational convenience.)

The number of zeros added to each range return is given by the equation

$$NZ = NRG \sin (|\phi|) + 2,$$

where

- $NZ = \text{the number of zeros added for skew correction}$
- $NRG = \text{the number of ground range sweeps}$
- $|\phi| = \text{the absolute value of the skew angle}$.

The skew correction is calculated by

$$Y = AX + B,$$

where

- $Y = \text{the corrected ground range}$
- $X = \text{the along-track distance relative to the patch being deskewed}$
- $A = \frac{NZ}{NRG} \times \text{SIGN} (\phi)$
- $B = 1$ if $\text{SIGN} (\phi)$ is positive
- $NZ$ if $\text{SIGN} (\phi)$ is negative.

Finally, it is noted that the number of zeros added to each range return must be an
integer. If the number of zeros added to the $i$th range return is $IZ_i$, and the number of
zeros added to the same return at far range is $JZ_i$, then
Figure 8 - Geometry of Data Skew

Figure 9 - Format of Data after Skew Correction
I_{Z_i} = \left[ (A)(i) + B \right]_{\text{ROUNDED}} \quad (52)

J_{Z_i} = N_Z - I_{Z_i} \quad (53)

The placement of the zeros is illustrated in Figure 10.

3. SCALE FACTOR CORRECTION

Upon completion of the azimuth compression, the output data sample points may be spaced differently in range and azimuth. The image will consequently appear distorted because of the differing range and azimuth resolution. To compensate for this, a scale factor correction may be necessary.

Scale factor correction is accomplished by linear interpolation on the azimuth data. For example, assume that an azimuth sample was calculated every 12 feet, and that 30 feet was desired between samples in both dimensions. Then, to achieve azimuth samples spaced by 30 feet,
\[ Y_1' = Y_1 \]
\[ Y_2' = \frac{1}{4}(Y_3 + Y_4) \]
\[ Y_3' = Y_6 \]  

(54)

It is observed that data points \( Y_2 \) and \( Y_5 \) are not utilized in the foregoing calculation. Therefore, an increase in the processing rate is possible, because these points need not be calculated.
SECTION IV - CONCLUSIONS

The results of the geometric distortion analysis indicate that the distortions in AN/APQ-102A imagery are primarily the result of navigation system errors that are external to the radar system itself. These distortions can be rather high in magnitude (e.g., one percent), but have a low spatial frequency. As such, it is a relatively simple task to measure and remove the geometric distortion. Measurement is accomplished by comparing image distances (obtained from a map) between known ground features with good distances. Using this technique, the residual distortions were under 100 meters. Computer programs to measure and correct these distortions were delivered as part of the contract effort.

The major program effort consisted of generating a computer program to digitally process AN/APQ-102A phase history data. This program was checked out and validated at the customer's facility—thus providing a capability of processing subsequent AN/APQ-102A data without contractor support.
APPENDIX A -

TARGET SIMULATOR
APPENDIX A

C PROGRAM PRINT TARGET GENERATOR
C
C DIMENSION IDATA (8800), MTR1(27)
C
C IDATA = 2
BIS = 316
ALGF = 4.342944819032
PI = 3.1415926535897
ALAM = 1.022
ND = 5 * PI / 180
FPAL = 4 * PI / ALAM
REKIND 2

C 200 CONTINUE
READ 98, MTR1
PRINT 101
PRINT 102
PRINT 99, MTR1

C OUTPUT RECORD 1 ON TAPE

C CALL TAPE R1(MTR1)

C DAZ DISTANCE PER AZIMUTH SAMPLE
C DRG DISTANCE PER RANGE SAMPLE
C AZF0S AZIMUTH OFFSET
C HF ALTITUDE IN FEET
C R8 RANGE IN FEET
C PH10 PHASE ANGLE

C READ 100, DAZ, DRG, AZF0S
PRINT 103, DAZ, DRG, AZF0S
READ 104, HF, R8, PH10
PRINT 104, HF, R8, PH10

201 CONTINUE
C M RG ELEMENT
C N AZ ELEMENT

ORIGINAL PAGE IS
OF POOR QUALITY

PRECEDING PAGE BLANK NOT FILMED
C NRNP NUMBER OF RANGES
C
READ 105,M,N,NRNP
IF(NRNP) 198, 198, 199
198 CONTINUE
CALL EXIT
199 CONTINUE
PRINT 106,M,N,NRNP
IX=1
XM=M
XA=A
RG LOOP
C
DA 202 I^=1,NRNP
DI 203 I^=1,8800
IPDA(I^)=C
203 CONTINUE
C CALCULATE AZ INDEX LIMITS
C
RS=SQR(HF*HF+(RB+XM*DRG)**2)
NAZ=SIN(BW)*RS/CAZ
NAZ1=NAZ
NAZ2=NAZ
C LIMIT INDICES
C
NAZ1=MAX(1,NAZ1)
NAZ2=MIN(NAZ2,17600)
PRINT 107,NAZ1,NAZ2
C END OF BOOK KEEPING, DO THE CALCULATIONS
C
A=NAZ1
AN=NAZ
AA=5*FPAL*DAZ*DAZ/RS
BB=2*PI*AZBFS
PRINT 109,AA,BB
IY=C
IF(NAZ1=8800)208,209,209
C OUTPUT FIRST HALF OF AZ SWEEP

ORIGINAL PAGE IS
OF POOR QUALITY
209 CONTINUE
CALL TAPEN2 ( IDATA, IX, IY )
IY=28CO
JAZ=NAZ1=R800
208 CONTINUE

C 204  IAZ=NAZ1=NAZ2
PHI=(AA*AN+BB)*AN+PHIB
C TAKF CBS,ADD BIAS AND SCALE
C
T=SCN*CBS(PHI)+BIS
C CONVERT TRANSMISSION TO DENSITY
C
D=ALGF*ALPG(1/T)
C NOW SCALE TO 8 BITS
C
ID=T*128+++5
IDATA( JAZ )=ID
C
95 TO 197
PRINT 108,AN,PHI,T,D,ID
197 CONTINUE
AN=AN+1.
JAZ=JAZ+1
C
IF (.AZ-R800)204,204,205
205 CONTINUE
C OUTPUT HALF OF AZ SWEEP
C
CALL TAPEN2 ( IDATA, IX, IY )
DO 206 I=1,R800
IDATA(I)=0
206 CONTINUE
IY=R800
JAZ=1
C
204 CONTINUE
210 CONTINUE
OUT PUT SECOND HALF OF AZ SWEEP

CALL TAP E W 2 ( IDATA , IX , IY )
IF ( IY ) > 2 1 2, 2 1 2 , 2 1 1
2 1 2 CONTINUE
IY = 8 8 0 0
2 1 3 CONTINUE
GR TA 2 1 0
2 1 1 CONTINUE

C
IX = IX + 1
IX = IX + 1
2 0 2 CONTINUE

C
GR TA 2 0 1
9 8 F R M A T ( 8 C A 1 )
9 9 F R M A T ( 6 X 8 0 A 1 )
1 0 0 F R M A T ( 8 E 1 0 * 4 )
1 0 1 F R M A T ( 6 X 1 4 H P H 8 G R A M 9 = 7 5 , 2 0 X 3 0 H G 0 0 D Y E A R A E R O S P A C E C O R P O R A T I O N , / )
1 0 2 F R M A T ( 6 X 2 2 H P B I N T T A R G E T G E N E R A T O R , / )
1 0 3 F R M A T ( 6 X 5 H P A 2 = E 1 2 . 5 , 5 X 5 H D R G = E 1 2 . 5 , 5 X 5 H A Z 0 F S , E 1 2 . 5 , / )
1 0 4 F R M A T ( 6 X 5 H W F = F 1 2 , 1 , 5 X 5 H W R 0 = F 1 2 , 1 , 5 X 5 H P H 1 6 * F 1 2 . 3 , / )
1 0 5 F R M A T ( 1 6 I 5 )
1 0 6 F R M A T ( 6 X , 3 H P = I 7 , 5 X , 3 H P = I 7 , 5 X 3 H N R B , I 7 , / )
1 0 7 F R M A T ( 6 X 2 1 H A 2 I M U T H S A M P L E L I M I T S , 2 1 1 0 , / )
1 0 8 F R M A T ( 4 F 1 2 , 4 , 1 5 )
1 0 9 F R M A T ( 6 X 4 H A A = E 1 2 , 6 , 6 X 4 H B B = E 1 2 , 6 , / )
END
SUBROUTINE TAPE1(MTR1)
DIMENSION MTR1 (27)
C THIS ROUTINE IS FOR WRITING RECORD 1 ON MAG TAPE
C FORMAT (27 CHARACTERS)
C 27 CHARACTERS OF WHICH 20 OR 22 ARE NEEDED
WRITE TAPE 2, MTR1
RETURN
END

SUBROUTINE TAPE2(IDATA,IX,IY)
C THIS ROUTINE IS FOR OUTPUT TO MAGNETIC TAPE FOR THE SECOND AND SUBSEQUENT RECORDS
DIMENSION IDATA(8800)
WRITE TAPE 2, IDATA
RETURN
100 FORMAT(16,1X,4013)
RETURN
END
APPENDIX B -
AZIMUTH PROCESSING
AZIMUTH PROCESSING PROGRAM

START

2 CARDS

INITIALIZATION, CONSTANTS, TAPES, PLOTS, ETC.

1 CARD

INITIALIZATION FOR INTENSITY TO TRANSMISSION TO BI-POLAR ROUTINE

2 CARDS

INITIALIZATION FOR AZIMUTH PREFILTER PROCESSING ROUTINE

2 CARDS

INITIALIZATION FOR AZIMUTH REFERENCE FUNCTION GENERATOR ROUTINE

INPUT DATA

READ 1 SET OF RANGE DATA

TRANSFORM DATA, DENSITY TO TRANSMISSION TO BI-POLAR

AZIMUTH PREFILTER CONVOLUTION

SCALE BY SHIFTING DATA RIGHT n (9) BITS

INITIALIZATION OF AZIMUTH COMPRESSION REFERENCE FUNCTION FOR THIS RANGE

AZIMUTH COMPRESSION CONVOLUTION

WRITE 1 SET OF PROCESSED RANGE DATA

OUTPUT DATA

1 > Nrg

END
Card Input to the Azimuth Processing Program

Card 1  80 column description card.

Card 2  N number of data points/record.
        (2 values)  (Azimuth samples per range bin.)

        NRG number of range bins to be processed.

Card 3  (3 values)
        SCL = density represented by a value of 255.
        TMEAN = mean transmission for bipolar calculations.
        SCL2 = second scale to convert to integer.

        These are for Initialization of the Density to
        Transmission to Bipolar Routine.

        Typical Data:  SCL = 2 or 3, TMEAN = .38, SCL2 = 64 or 128.

Card 4  (3 values)
        NLOOK = number of looks, 1 or 2.
        K = K in COS[2PI K I/N], (see azimuth prefilter formula).
        NB = number of bits in the quantized output.

Card 5  (1 value)
        PHIO = phase offset in degrees. (This is an arbitrary input.)

        Cards 4 and 5 are for the azimuth prefilter reference function
        generator routine.

Card 6  (3 values)
        DAZ = distance per azimuth sample in feet.
        DRG = distance per range sample in feet.
        AZOFS = azimuth offset frequency in cycles/ft on ground.

Card 7  (3 values)
        HF = altitude in feet.
        RO = range in feet.
        PHIO = phase angle in radians.

        Cards 6 and 7 are for initialization of the compression
        reference generator routine.
C MAIN LINE PROCESSING OF IMAGERY
C
DIMENSION IP(44), JD(45)
DIMENSION MM(20), RR(44)
C
DIMENSION ID(17600)
DIMENSION KD(931)
DIMENSION ICR(930), ICQ(930)
C
EQUIVALENCE (ID(1), JD(44))
EQUIVALENCE (KD(931), ID(1))
N = 17600
JT=1
IT=2
C TAPE 2 IN, TAPE 1 OUT
200 CONTINUE
RE WIND IT
RE WIND JT
C AN = 20 CPL DISCRIPTION
READ 99,AN
PRINT 101
PRINT 98,NN
READ 100,N,NRG
PRINT 102,N,NRG
MT=*
K = C
CALL CNTRBP (ID,K)
CALL REFGFN (IR,NPR)
C
NL=9K = 1
IF(NPR-22) 220, 220, 221
220 CONTINUE
NL=9K = 2
221 CONTINUE
M = -NL=9K
CALL CMPREF (ICR,ICQ,M)
C
C LOOP ON RG
C MAX=0
D0 201 MRG=1,NRG
N = NT
CALL TAPEIN (ID,NT)
K = N
CALL DNTRRP (ID,K)
CALL PRINTD (ID,N)
C
NP = N
CALL AZPRF (ID,IR,N,NPR,JD,NP)
C
C SHIFT DATA BY 9 BITS
C
D0 207 I = 1, NP
JD(1) = JD(1)/512
207 CONTINUE
CALL PRINTD (JD,NP)
CALL PLOTD (JD,NP)
C
M = MRG
CALL CMPREF (ICR,ICQ,M)
NR = M
CALL PRINTD (ICR,M)
CALL PRINTD (ICG,M)
C
NS = 9
CALL AZC8MP (JD,ICR,ICQ,NP,NR,NS,KD)
N = NP/NNS
GO TO (224,222), NL66K
222 CONTINUE
C
C TWO L90K CALCULATIONS
C
NP = N-3
D0 223 I = 1, NP
KC(I) = KC(I)+KC(I+1)+KD(I+2)+KD(I+3)
223 CONTINUE
N = NP
224 CONTINUE
CALL PRINTD (KD, N)

IF (MAX = KD(1)) 205, 206, 206
205 CONTINUE
MAX = KD(I)
PRINT 104, NRG, I, MAX
206 CONTINUE
NP = N + 1
203 CONTINUE
KD(I) = 1
CALL PRTMO (KD/N)

CALL PL6TC (I0*O
93 FORMAT (6X20A4//
99 FORMAT (20A4)
100 FORMAT (8E10.4)
101 FORMAT (36X35IMAGE PROCESSING GA.C PR0G 9-75,//
102 FORMAT (6X19NUMBER OF SAMPLES =,17,5X22NUMBER OF RANGE BINS =17
12/
104 FORMAT (110, 2X1C19)
END
SUBROUTINE DNTFIP (ID, M)

DENSITY TO TRANSMISSION TO BI POLAR

DIMENSION ID(17600)
DIMENSION JD(256)

IF(M) 200, 200, 210

200 CONTINUE

SCL = DENSITY REPRESENTED BY A VALUE OF 255
TMEAN = MEAN TRANSMISSION FOR BIPOLAR CALCULATIONS
SCL2 = SECOND SCALE TO CONVERT TO INTEGER

TYPICAL DATA: SCL=2 OR 3, TMEAN=38, SCL2=64 OR 128

READ 100, SCL, TMEAN, SCL2
PRINT 101
PRINT 102, SCL, TMEAN, SCL2
PRINT 103.
SCL = SCL/256.
D2 PC1 I = 1, 256
X = I-1
X = X
X = X*SCL
X = IC**((-X))
X = X-TMEAN
JD(I) = X * SCL2
PRINT 104, K, JD(I)

201 CONTINUE
RETURN

210 CONTINUE
K = M
BIAS = 0.
D9 211 I = 1, K
K = ID(I)+1
IF(K) 212, 212, 213

213 CONTINUE
IF(K=255) 214, 214, 212
212 CONTINUE
   PRINT 105, ID(I)
214 CONTINUE
   ID(I) = JD(K)
   X = ID(I)
   BIAS = BIAS + X
211 CONTINUE
   X = N
   BIAS = BIAS/X
   PRINT 106, BIAS
   RETURN

C
100 FORMAT (8E10.4)
101 FORMAT (78H7H DENSITY TO TRANSMISSION TO BI POLAR DATA, /)
102 FORMAT (6X,5HSCL =,F10.4,5X5HTMEAN,F10.4,5X5HSCL2,F10.4,/,)
103 FORMAT (25X7HDATA IN,10X6HRESULT,/,)
104 FORMAT (25X15,1C15)
105 FORMAT (6X33H*** INPUT DATA OUT OF RANGE ***I5)
106 FORMAT (6X31HAVERAGE BIAS FOR THIS RANGE WAS,F10.4)
END
SUBROUTINE REGEN (IR,N)
AZIMUTH PREFILTER REFERENCE FUNCTION GENERATOR
TWO DATA CARDS REQUIRED

DIMENSION IR(44)
DIMENSION RR(44)

NLBRK = NUMBER OF LAAKS
K = K IN C0S(2PI K I/N)
NF = NUMBER OF BITS IN THE QUANTIZED OUTPUT

PI = 3.14159265535897
READ 103, NLBRK, K, NB
PRINT 104, NLBRK, K, NB
READ 100, PHI9
PRINT 105, PHI9
SC = (2**NE)-1
N = 27
GO TO (201, 202), NLBRK

201 CONTINUE
N = 44
202 CONTINUE

X1 = X
PRINT 106
XMIN = C*
XMAX = D -1
A = 4C*
NB = 6
X = C*
CALL TAYLOR (XMIN, XMAX, A, NB, X, WTN, 0)
DB 203 I = 1, N
A = (I-1)*K
A = 2**PI*A/XN*PHI9
X = I-1
CALL TAYLOR (XMIN, XMAX, A, NB, X, WTN, 1)
RR(I) = WTN*COS(A)
203 CONTINUE

C C C PUT AMPLITUDE WIGHTING HERE

D9 204 I = 1, N
F5 = .5
IF(PR(I)) 205, 205, 206
205 CONTINUE
F5 = -.5
206 CONTINUE
IR(I) = RF(I)*SC*P5
PRINT 107, I, IR(I)
204 CCONTINUE
RETURN
100 FORMAT (8E10.4)
103 FORMAT (1615)
104 FORMAT (6X7HNL6PK =,13,5X3HK =,13,5X4HN8 =,13,/)
105 FORMAT (6X7PH19 =,F10.4,/,)
106 FORMAT (//,6X9HRFFERENCE,10X1HI,10X1HR,/) 107 FORMAT(15X2I11)
END
SUBROUTINE AZPRF (ID, IR, N, NPR, JD, NP)
AZIMUTH PREFILTER WALLBPS DATA
DIMENSION IR(44), JD(45)
DIMENSION ID(17600)

C
NP=N=NPR
C3 202  I=1,NP
IS=0
C3 203  J=1,NPR
K = I+J-1
IS=ID(K)*IR(J)+IS
C3 203 CONTINUE
JD(1)=IS
C3 202 CONTINUE
RETURN
END
SUBROUTINE CMREFE (IR, IQ, M)
COMPRESSION REFERENCE GENERATOR
DIMENSION IR(IQ(930)), IQ(IQ(930))

M = -1 OR -2 FOR INITIALIZATION  ABS(M) = NL00KS
M RETURNED AS NUMBER OF POINTS IN THE REF

IF(M) 200, 210, 210
200 CONTINUE
PI = 3.1415926535897
ALAM = -1022
RA = 30.
SNF = .88
TWF = 1.42
XK = SNF*TWF
XLK = IAHS(M)
FPAL = 4.*PI/ALAM

DAZ = DISTANCE PER AZIMUTH SAMPLE
DRG = DISTANCE PER RANGE SAMPLE
AZIFS = AZIMUTH OFFSET
HF = ALTITUDE IN FEET
R8 = RANGE IN FEET
PHIO = PHASE ANGLE

ND3C = DB DOWN FOR TAYLOR WEIGHTING (40)
NPAR = NEAR FOR TAYLOR WEIGHTING (6)
NBITS = NUMBER OF BITS IN REF FUNCTIONS 6,7,8

READ 100, DAZ, DRG, AZIFS
PRINT 103, DAZ, DRG, AZIFS
READ 100, HF, R8, PHIO
PRINT 104, HF, R8, PHIO
ND3C = 40
NPAR = 6

ORIGINAL PAGE IS OF POOR QUALITY
APPENDIX B

```fortran
NPITS = 8
PRINT 105, NDBD, NBAR, NBITS
DDB = NDBD
SC = (2**NPITS)**1
PN = 5*XK*ALAM/(WA*DAZ)
FN = PN*XLB9K
201 CONTINUE
RETURN
210 CONTINUE
XM = M
RS = SGRT(HF*HF+(R8+XM*DRG)**2)
NAZ = RS*PN/2**.5
AN = -NAZ
N = NAZ+NAZ+1
M = N
XMIN = -NAZ
XMAX = NAZ
AA = 5*FPAL*DAZ*DAZ/RS
BB = -2.*PI*AZFS
PRINT 106, AA, BB
CALL TAYLOR (XM1N,XMAX,DDB,NBAR,AN,AMP,0)
211 I = 1
CALL TAYLOR (XM1N,XMAX,DDB,NBAR,AN,AMP,1)
PHI = (AA*AN+BB)*AN+PH19
AN = AN+1
R = AMP*SC*COS(PHI)
G = AMP*SC*SIN(PHI)
IF (I) = R
IF (I) = G
211 CONTINUE
RETURN
100 FORMAT (8E10.4)
101 FORMAT (1l0,4E1P+6,2I10)
102 FORMAT (16I5)
103 FORMAT (6X5HDAZ =E12.5,5X5HDRT =E12.5,5HXHAZB6FS,E12.5/,)
104 FORMAT (6X5PHF =F12.1,5X5HRG =F12.1,5X5PH16FS,F12.3/)
105 FORMAT (6XHNDDB =I5,5X6HNBAR =I5,5X6HNBITS =I5,/
106 FORMAT (6X4HAA =E12.5,5X4HBB =E12.5/,)
END
```

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OF POOR QUALITY
SUBROUTINE AZCEMP (ID, IR, IQ, N, NR, NS, JD)

AZIMUTH COMPRESSION FILTER

C DIMENSION ID(17600)
C DIMENSION JD(45)
C DIMENSION IR(930), IQ(930)

N = NUMBER OF POINTS IN THE DATA
NR = NUMBER OF POINTS IN THE REFERENCE
NS = NUMBER OF POINTS FROM OUTPUT SAMPLE TO NEXT OUTPUT SAMPLE

ID IS DATA
JD IS OUTPUT
IR IS REAL REF CHANNEL
IQ IS QUAD REF CHANNEL

K = 1

C 200 I = 1, N, NS
ISR = 0
ISG = 0

C 201 J = 1, NR
L = J+1-1
JR = IR(J)*ID(L)/256
JC = IQ(J)*ID(L)/256

ISR = ISR+JR
ISQ = ISQ+JC

201 CONTINUE

KK = 128

KK = 64

ISG = ISG/KK
ISR = ISR/KK
IS = ISR*ISR*ISQ*ISQ

JD(k)*IS

C = CD+1

200 CONTINUE

RETURN

END
SUBROUTINE TAYLOR (XMIN, XMAX, A, NB, X, ANS, JEB)

THIS SUBROUTINE CALCULATES THE TAYLOR APERTURE

XMIN, XMAX = RANGE OF APERTURE

A = DB DOWN OF FIRST SIDELobe in TAYLOR ANTENNA PATTERN

NR = N-Par (TAYLOR'S CONSTANT)

X = VALUE AT WHICH ONE POINT OF APERTURE IS WANTED

ANS = THE RETURNED ANSWER

JEB = 0 THIS IS A NEW XMIN, XMAX, A AND NB DATA SET

1 USE PREVIOUS XMIN, XMAX, A AND NB DATA CALCULATIONS

DIMENSION F(20), C(10), FF(2)

EQUIVALENCE (FF(2), F(1))

IF (JEB) 11, 11, 12

11 CONTINUE

12 D = XMAX-XMIN

PI = 3.1415926535897

TPI = 2.*PI

F(0) = 1.

DO 10 I = 1, 20

ARG = I

F(I) = F(I-1)*ARG

10 CONTINUE

AA = 10.0*(ABS(A)/20.0)

CALL ARCOSH (AA, ETA)

AA = ETA/PI

A2 = AA*AA

ENB = N

NB = NR-1

SIG = ENB/SQRT(A2+(ENB-.5)**2)

DO 20 N = 1, NB

EN = N

EN2 = EN*EN

S = 1.

DO 30 M = 1, NB

EM = M

ZM = SIG*SQRT(A2+(EM-.5)**2)

S = S*(1-EM*/(ZM*ZM))
30 CONTINUE
   C(N) = S*F(NBM)*F(NBM)/(F(NBM+N)*F(NBM-N))
20 CONTINUE
12 CONTINUE
   F = (X-XMIN)/D*TPI/PI
   ANS = C*
   CP 4C N = 1, NBM
   EN = N
   ANS = ANS+C(N)*COS(EN*P)
40 CONTINUE
   ANS = 1.0+2.0*ANS
   RETURN
C
   PRINT 100, A, SIG
   PRINT 103, A, SIG
   PRINT 101, N, C(N)
   PRINT 102
100 FORMAT (5X17HSSUBROUTINE TAYLOR/,/5X17HFIRST SIDEBE = 1.0,,F6.1,
      1 3H DE,10X8H=BAR = 1.,12,,/10X12HC6EFFICIENTS)
101 FORMAT (5X15,5XF15.8)
102 FORMAT (1H1)
103 FORMAT (18X2HAA,17X3HSIG/,2(5XE15.8))
END
SUBROUTINE ARCSIN (U, A)

C

U2 = U*U
IF(U2-1.0) 11, 11, 12

12 CONTINUE
A = ALG(SQRT(U2-1.0))
RETURN

11 CONTINUE
A = 0.
PRINT 101
RETURN

101 FORMAT (1HO,5X56H*** TAKING ARCSIN OF A NUMBER LESS THAN 1 IMPOSSI
IBLE ***,/)
APPENDIX C -

DISTORTION ANALYSIS
Page intentionally left blank
1 DOUBLE PRECISION EX(512), EY(512)
2 DOUBLE PRECISION X(512), Y(512), P(512), Q(512), A(512), B(512), C(512), E(512), D(512), F(512), X1
3 DOUBLE PRECISION A(20), B(20), C(20), D(20), N(20), PI(20)
4 COMMON /P1/ A(20), B(20), C(20), E(512), D(512), X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
5 COMMON /P2/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
6 COMMON /P3/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
7 COMMON /P4/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
8 COMMON /P5/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
9 COMMON /P6/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
10 COMMON /P7/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
11 COMMON /P8/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
12 COMMON /P9/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
13 COMMON /P10/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
14 COMMON /P11/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
15 COMMON /P12/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
16 COMMON /P13/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
17 COMMON /P14/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
18 COMMON /P15/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
19 COMMON /P16/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
20 COMMON /P17/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
21 COMMON /P18/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
22 COMMON /P19/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
23 COMMON /P20/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
24 COMMON /P21/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
25 COMMON /P22/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
26 COMMON /P23/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
27 COMMON /P24/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
28 COMMON /P25/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
29 COMMON /P26/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
30 COMMON /P27/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
31 COMMON /P28/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
32 COMMON /P29/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
33 COMMON /P30/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
34 COMMON /P31/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
35 COMMON /P32/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
36 COMMON /P33/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
37 COMMON /P34/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
38 COMMON /P35/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
39 COMMON /P36/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
40 COMMON /P37/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
41 COMMON /P38/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
42 COMMON /P39/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
43 COMMON /P40/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
44 COMMON /P41/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
45 COMMON /P42/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
46 COMMON /P43/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
47 COMMON /P44/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
48 COMMON /P45/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
49 COMMON /P46/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
50 COMMON /P47/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
51 COMMON /P48/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
52 COMMON /P49/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
53 COMMON /P50/ X(512), Y(512), P(512), Q(512), E(512), D(512), F(512)
54  \( \frac{x}{y} + \frac{z}{w} \) \( \frac{a}{b} \) \( \frac{c}{d} \)

55 \( \begin{align*}
C & = \text{PLOT SCALING SECTION} \\
P & = 10 \times 10
\end{align*} \)

56 \( \begin{align*}
& 6 \quad \text{COMPILER-2089} \\
& 5 \quad \text{C.ERA-2089}
\end{align*} \)

57 \( \begin{align*}
& 3 \quad \text{19.35 APR 03/75}
\end{align*} \)

58 \( \begin{align*}
& 2 \quad \text{DO 200 I=1,4}
\end{align*} \)

59 \( \begin{align*}
& 1 \quad \text{IF(P(I),LT,P(I))P(I)=P(I)}
\end{align*} \)

60 \( \begin{align*}
& 4 \quad \text{DO 300 I=1,4}
\end{align*} \)

61 \( \begin{align*}
& 3 \quad \text{CALL PLOT(0,1,x,y})
\end{align*} \)

62 \( \begin{align*}
& 2 \quad \text{CALL LSF(I,Y,X,Q,P,A,B)}
\end{align*} \)

63 \( \begin{align*}
& 1 \quad \text{A=1}
\end{align*} \)

64 \( \begin{align*}
& 1005 \quad \text{BY=B}
\end{align*} \)

65 \( \begin{align*}
& 10 \quad \text{AL=B}
\end{align*} \)

66 \( \begin{align*}
& 9 \quad \text{CALL LSF(I,Y,X,Q,P,A,B)}
\end{align*} \)

67 \( \begin{align*}
& 8 \quad \text{C.ERA-2089}
\end{align*} \)

68 \( \begin{align*}
& 7 \quad \text{TEPORARY SECTION TO MEASURE IMAGERY DISTORTION AFTER CORRECT ALIGNMENT}
\end{align*} \)

69 \( \begin{align*}
& 6 \quad \text{DO 51 I=1,4}
\end{align*} \)

70 \( \begin{align*}
& 5 \quad \text{X(I)=A2*X(I)}
\end{align*} \)

71 \( \begin{align*}
& 4 \quad \text{Y(I)=A2*Y(I)}
\end{align*} \)

72 \( \begin{align*}
& 3 \quad \text{A=0}
\end{align*} \)

73 \( \begin{align*}
& 2 \quad \text{DO 53 I=1,4}
\end{align*} \)

74 \( \begin{align*}
& 1 \quad \text{X(I)=X(I)-A3}
\end{align*} \)

75 \( \begin{align*}
& 0 \quad \text{Y(I)=Y(I)-A3}
\end{align*} \)

76 \( \begin{align*}
& 93 \quad \text{CALL LSF(I,Y,X,Q,P,A,B)}
\end{align*} \)

77 \( \begin{align*}
& 92 \quad \text{A=0}
\end{align*} \)

78 \( \begin{align*}
& 91 \quad \text{DO 725 I=1,4}
\end{align*} \)

79 \( \begin{align*}
& 90 \quad \text{X(I)=A3*X(I)}
\end{align*} \)

80 \( \begin{align*}
& 89 \quad \text{Y(I)=A3*Y(I)}
\end{align*} \)

81 \( \begin{align*}
& 88 \quad \text{DO 710 I=1,4}
\end{align*} \)

82 \( \begin{align*}
& 87 \quad \text{X(I)=X(I)-A3}
\end{align*} \)

83 \( \begin{align*}
& 86 \quad \text{Y(I)=Y(I)-A3}
\end{align*} \)

84 \( \begin{align*}
& 85 \quad \text{WRITE(3,561,A(A))}
\end{align*} \)

86 \( \begin{align*}
& 84 \quad \text{CALL EPLQT(P,Q,KE,YE,EX,AA1,AA2)}
\end{align*} \)

87 \( \begin{align*}
& 83 \quad \text{GO TO 56}
\end{align*} \)

88 \( \begin{align*}
& 82 \quad \text{CALL EPLQT(P,Q,KE,YE,EX,AA1,AA2)}
\end{align*} \)

89 \( \begin{align*}
& 81 \quad \text{GO TO 56}
\end{align*} \)

90 \( \begin{align*}
& 80 \quad \text{X(I)=A3*X(I)}
\end{align*} \)

91 \( \begin{align*}
& 79 \quad \text{Y(I)=A3*Y(I)}
\end{align*} \)

92 \( \begin{align*}
& 78 \quad \text{DO 725 I=1,4}
\end{align*} \)

93 \( \begin{align*}
& 77 \quad \text{X(I)=A3*X(I)}
\end{align*} \)

94 \( \begin{align*}
& 76 \quad \text{Y(I)=A3*Y(I)}
\end{align*} \)

95 \( \begin{align*}
& 75 \quad \text{DO 710 I=1,4}
\end{align*} \)

96 \( \begin{align*}
& 74 \quad \text{X(I)=X(I)-A3}
\end{align*} \)

97 \( \begin{align*}
& 73 \quad \text{Y(I)=Y(I)-A3}
\end{align*} \)

98 \( \begin{align*}
& 72 \quad \text{DO 725 I=1,4}
\end{align*} \)

99 \( \begin{align*}
& 71 \quad \text{X(I)=X(I)-A3}
\end{align*} \)

100 \( \begin{align*}
& 70 \quad \text{Y(I)=Y(I)-A3}
\end{align*} \)

101 \( \begin{align*}
& 69 \quad \text{WRITE(3,56,A(A))}
\end{align*} \)

102 \( \begin{align*}
& 68 \quad \text{CALL EPLQT(P,Q,KE,YE,EX,AA1,AA2)}
\end{align*} \)

103 \( \begin{align*}
& 67 \quad \text{CONTINUE}
\end{align*} \)

104 \( \begin{align*}
& 66 \quad \text{CONTINUE}
\end{align*} \)

105 \( \begin{align*}
& 65 \quad \text{CONTINUE}
\end{align*} \)

106 \( \begin{align*}
& 64 \quad \text{CONTINUE}
\end{align*} \)

107 \( \begin{align*}
& 63 \quad \text{CONTINUE}
\end{align*} \)

108 \( \begin{align*}
& 62 \quad \text{CONTINUE}
\end{align*} \)
107. C = COS
108. D = 0.
109. DO 7 I = 1,N
110. E(I) = A*X(I) + B = P(I)
111. 7 J = 2*ABS(E(I))
112. AL = C
113. F = 0.
114. DO 8 I = 1,N
115. 8 X(I) = X(I) + AL*Y(I)
116. CALL LSFR(I,N,X1,Y,P,2,A,B)
117. DO 9 I = 1,N
118. 9 F = F + CA3S(A*X(I) + B = P(I))
119. IF (F = 0) 11, 15
120. 12 AL = AL
121. C = C
122. 11 AL = AL + C
123. DO 12 I = 1,N
124. 12 X(I) = X(I) + AL*Y(I)
125. 1006 B = B
126. CALL LSFR(I,N,X1,Y,P,2,A,B)
127. 3 = 0.
128. DO 13 I = 1,N
129. 13 G = 2*ABS(A*X(I) + B = P(I))
130. 13 IF (G = 0) 16, 19
131. 16 F = 3
132. GC TO 11
133. 14 AL = AL + C
134. C X T E M P O R A R Y SECTION 2
135. 43 = 0.
136. 43 = C
137. DO 71 I = 1,N
138. Y1(I) = A2*Y(I)
139. Y1(I) = A2*X(I)
140. 71 X(I) = X(I) + AL*Y1(I)
141. DO 72 I = 1,N
142. 43 = A3*X(I) - P(I)
143. 72 A = A3 - Y1(I) = G(I)
144. A3 = 0.
145. A = 0.
146. 72 73 I = 1,N
147. X1(I) = X1(I) + A3
148. 73 Y1(I) = Y1(I) = A4
149. CALL FCPI(X1,Y1,P,Q,R,S,T,V1,V2,V3,V4,V5,V6,V7,V8,C1,M)
150. 31, 56 = A3
151. CALL EPILOT(P,G,XE,YES,EX,VE,AA3,AA)
152. GC TO 54
153. 68 CO = TIME
154. DO 74 I = 1,N
155. 74 X1(I) = X1(I) + AL*Y(I)
156. 74 X1(I) = A*X1(I)
157. 74 Y1(I) = A1*Y(I)
158. 43 = 0.
159. A = 0.
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161 I = 1, N
162 3 = 3 * XI(I) * PI(I)
163 3 = 3 / A
164
165 XI(I) I = 1, N
166 YI(I) I = 1, N
167 YI(I) = YI(I) * A
168 CALL CPM(XI, YI, PI, QA, V, V1, VE, YE, CI, M)
169 WRITE(3, 56) A
170 CALL EPLT(P, QA, V, VE, EX, EY, A, A)
171 GO TO 50
172 CONTINUE
173 AL = 57 + 296
174 C SCALE CARDS GO HERE
175 WRITE(3, 35) A
176 WRITE(3, 35) A
177 FORMAT(10X, 'THE TRACK DIRECTION SCALE FACTOR IS 11.0/12.4X', ' THE'
178 'RANGE DIRECTION SCALE FACTOR IS 11.0/12.4X', ' THE SHEAR IS 1
179 2.4/1.6 DEGREES')
180 FORMAT(10X, 'STANDARD DEVIATION', A, A)
181 GO TO 25
182 CONTINUE
183 C STANDARD WRITE SECTION
184 GO TO 75
185
186 WRITE(3, 58)
187 58 FORMAT(10X, 'TABLE I = RESIDUAL ERRORS', '/17X', 'POINT NUMBER', '10X', 'TR
188 'ACK ERROR', '10X', 'RANGE ERROR')
189 WRITE(3, 59) XI, YE(I), YE(I), YE(I), YE(I), YE(I), YE(I), YE(I)
190 60 FORMAT(10X, 'SUM', A, A)
191 SUM = 0
192 SUM = 0
193 SUM = SUM + XI
194 SUM = SUM + YE(I)
195 SUM = SUM + YE(I)
196 SUM = SUM + YE(I)
197 SUM = SUM + YE(I)
198 SUM = SUM + YE(I)
199 SUM = SUM + YE(I)
200 WRITE(3, 22) SUM, SUM
201 22 FORMAT(10X, 'X VARIANCE = ', '10X', 'Y VARIANCE = ', '10X', '10X', '10X', '10X', '10X')
202 GO TO(57, 67, 69, 75, 77, 79, 71, 73, 75)
203 CONTINUE
204 CALL PLOT(12, 0, 0, 999)
205 CALL EXIT
206 END
APPENDIX C

1  ROUTINE LSF(J, M, X, Y, P, Q, R, A, B)
2  REAL X(J), Y(J), P(J), Q(J), R, A, B
3  C THIS SECTION DOES A LEAST SQUARES FIT OF M POINTS, STARTING FROM
4  C THE JTH POINT WITH X AND P
5  K=1
6  A=0
7  S=0
8  R=0
9  B=0
10  T=0
11  U=0
12  DO 1 I=J,K
13     S=S+X(I)
14     R=R+P(I)
15     T=T+X(I)*P(I)
16     U=U+X(I)*Q(I)
17     A=(U-((S*R)/M))/(T-((S*S)/M))
18     B=(R*A*S)/M
19     RETURN
20  END
APPENDIX C
GERA-2089

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1* SUBROUTINE COMP(X,Y,L,P,QA,VA;VE,VE,VE,VE,C,Y)
2* REAL X(1),Y(1),L(1),P(1),QA(1),VA(1),VE(1),VE(1),VE(1),Y(1)
3* C THIS SUBROUTINE COMPUTES THE HISTOGRAM OF THE LENGTH DIFFERENCES BETWEEN
4* C THE RAYS AND "AP POINTS", AS WELL AS THE ABSOLUTE ERRORS AND CEP(C1)
5* CC 3 I=1,20
6* 3 A(I)=C
7* 7 CC 4 I=1,N
8* 8 XE(I)=X(1)P(I)
9* 9 Y(I)=Y(1)Q(I)
10* 10 CC 5 I=1,N
11* 15 AG(I)=AG(I)+ABS(XE(I))
12* 12 5 AG(2)=AG(2)+ABS(Y(I))
13* 13 AG(1)/AG(1)/N
14* 14 AG(2)/AG(2)/N
15* RETURN
16* END
APPENDIX D -

IMAGE DISTORTION CORRECTION
IMAGE DISTORTION CORRECTION PROGRAM

START

2 CARDS

INITIALIZATION CONSTANTS, TAPES, ETC.

CALCULATE SKEW CORRECTION INDEX'S

READ 1 SET OF RANGE DATA

TRANSFORM DATA FROM INTENSITY TO DENSITY

SHIFT DATA FOR SKEW CORRECTION

CORRECT DATA BY SCALING IN AZIMUTH DIRECTION

AMPLITUDE WEIGHT FOR THIS RANGE IF ANTENNA PATTERN ERRORS ARE KNOWN

WRITE 1 SET OF PROCESSED RANGE DATA

OUTPUT TAPE

! > Nrg

YES

END

INPUT TAPE

No

PRECEDING PAGE BLANK NOT FILMED

D-3
Card input to the Image Distortion Correction program.

Card 1  (4 values)
ITN = Tape unit input.
ITO = Tape unit output.
NAZ = Number of azimuth samples per record.
NRG = Number of range elements.

Card 2  (3 values)
SAZ = Azimuth scale.
SRG = Range scale.
SKEW = Skew or shear angle in degrees.
MAIN LINE PART TWO, INTENSITY TO DENSITY, SKEW REMOVED ROUTINE, SCALE IN AZIMUTH, AND WEIGHT IN RANGE

DIMENSION ID(2100)
DIMENSION NN(20)
DIMENSION JD(2100)

PI = 3.1415926535897

CONTINUE
READ 99, NN
PRINT 101
PRINT 102
PRINT 99, NN

ITN TAPE UNIT INPUT
IT9 TAPE UNIT OUTPUT
NAZ NUMBER OF AZIMUTH SAMPLES PER RECORD
NRG NUMBER OF RANGE ELEMENTS

READ 103, ITN, IT9, NAZ, NRG
PRINT 104, ITN, IT9, NAZ, NRG

SAZ AZIMUTH SCALE
SRG RANGE SCALE
SKEW SHEAR OR SHEAR ANGLE

READ 100, SAZ, SRG, SKEW
PRINT 105, SAZ, SRG, SKEW
REWIND IT9
REWIND ITN
RATIO = SAZ/SRG
AZN = NAZ
AZP = AZN*RATIO
RGN = NRG
NZ = ABS(FG*SIN(SKEW*PI/180.))
AZP = AZN
NAZP = NAZP+AZ
BRNZ
AA*NRG

ORIgINAL PAGI IS OF POOR QUALITY
AA = BB / AA
IF (SKW) E20,220,221
220 CONTINUE
BB = 1.
AA = AA
221 CONTINUE
CALL INTO DN (ID, -1)
NZ = NZ + 2
C
ONE ON EACH SIDE ALWAYS
201 RNG = 1, NRG
READ TAPE INTO, (ID(K), K=1, NAZ)
CALL INTO DN (ID, NAZ)
XING = RNG
IZ = AA + XING + BB + 5
IZ = MAX (IZ, 1)
JZ = NZ - IZ
K = 1
222 CONTINUE
DB 222 II = 1, IZ
JD (K) = 0
K = K + 1
223 CONTINUE
DB 223 II = 1, NAZ
JD (K) = ID (II)
K = K + 1
224 CONTINUE
DB 224 II = 1, JZ
JD (K) = 0
K = K + 1
224 CONTINUE
NZ = NAZ
CALL FILL (JD, ID, N, RAT10)
CALL RGT (ID, IRG, N)
WRITE TAPE INTO, (ID(K), K=1, N)
N = MIN (130, N)
PRINT 106, (ID(K), K=1, N)
201 CONTINUE
END FILE ITA
RENEW ITA
PRINT 134
GR TO 20C
95 FORMAT (6X2CA4/)
99 FORMAT (2CA4)
100 FORMAT (8F10.4)
101 FORMAT (6X14HPROGRAM, 9-75, 20X3OHG66DYEAR AEROSPACE CORPORATION,/
102 FORMAT (6X33HSCALE CORRECTION AND SCALE PROGRAM,/
103 FORMAT (16I5)
104 FORMAT (6X10HINPUT TAPE, 15, 6X11HOUTPUT TAPE, 14,/
1 6X28HNUMBER OF AZIMUTH SAMPLES IS, 15, 6X27HNUMBER OF RANGE ELEMENTS IS, 15,/
105 FORMAT (6X7HAZ SCALE, F12.1, 5X8HRG SCALE F12.1, 5X10HSKEW ANGLE F12.5/
106 FORMAT (1X, 13C11).
134 FORMAT (1H1)
END

ORIGINAL PAGE IS OF POOR QUALITY
SUBROUTINE FILL (ID, JD, N, R)

C
C  ID IS THE INPUT ARRAY
C  JD IS THE OUTPUT ARRAY
C  N IS THE NUMBER OF POINTS IN THE INPUT ARRAY
C  R IS THE INCREMENT RATIO
C
C  N WILL BE RETURNED AS THE NUMBER OF OUTPUT POINTS
C

DIMENSION ID(2100)
DIMENSION JD(2100)

I = 1
X = 1.
XN = N
J = 2
200 CONTINUE
   IF(X-XN) .LT. 201.
   201 CONTINUE
   XJ = X
   IF(Y-XJ) .LT. 203.
   203 CONTINUE
   J = J+1
   309 TO 201
   205 CONTINUE
   JD(I) = Y+5
   609 TO 207
   206 CONTINUE
   JD(I) = Y+5
   207 CONTINUE
   X = X+R
   I = I+1
   509 TO 200

203 CONTINUE
   XJ = X
   IF(Y-XJ) .LT. 205.
   205 CONTINUE
   JD(I) = Y+5
   609 TO 207
   206 CONTINUE
   JD(I) = Y+5
   207 CONTINUE
   X = X+R
   I = I+1
   509 TO 200

202 CONTINUE
   N = I-1
   RETURN
END
SUBROUTINE INTGEN (ID, M)
INTENSITY TO DENSITY

DIMENSION ID(2100)
DIMENSION JD(256)

IF SCALE IS NOT KNOWN USE M=N FOR FIRST CALL
IF(V) 200, 210, 210

200 CONTINUE
K = ABS(M)
K = ID(1)
DO 201 I = 1, N
K = MAX(K, ID(I))
201 CONTINUE

KIS = INTENSITY SCALAR USE 0 IF THE SCALE IS NOT KNOWN
KDS = DENSITY SCALAR USE 128 FOR D=2

READ 103, KIS, KDS
IF(KIS) 202, 203, 203

202 CONTINUE

KIS = K*64

203 CONTINUE
PRINT 102, KIS, KDS
ALGF = 1/ALOG(255.)
XS = KDS
DO 204 I = 1, 256
X = I
C = ALGF*ALOG(X)
JD(I) = D*X^5*0.5

204 CONTINUE
RETURN

210 CONTINUE
DS 211 I = 1, M
K = ID(1)/KIS
K = MIN(K, 256)
K = MAX(1, K)
JD(I) = JD(K)
211 CONTINUE
RETURN

102 FORMAT (6X5HKIS =,IR,10X5HKDS =,I10,/
103 FORMAT (F11.0)
END
SUBROUTINE RGWGT (ID, M, N)

C RANGE WEIGHTING FOR VERTICAL ANTENNA PATTERN CORRECTION
C M = RANGE BIN
C NEG M FOR INITIALIZATION IF REQUIRED
C
C DIMENSION ID(2100)

C IF (M) 200, 201, 201
200 CONTINUE
RETURN
201 CONTINUE
RETURN
DA 202 I = 1, N
C
C PUT WEIGHTING HERE
C
202 CONTINUE
RETURN
END