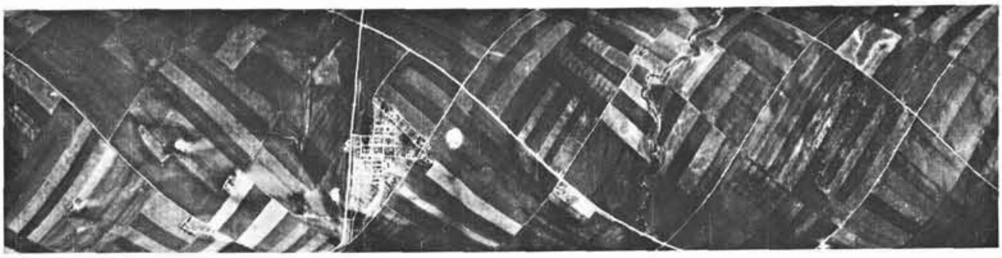
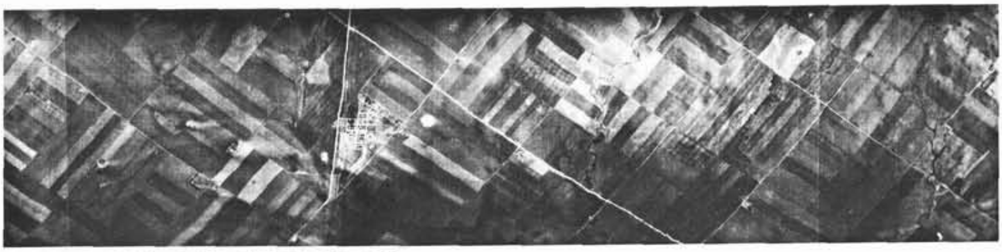


A. CONVENTIONAL PLAYBACK WITH TYPICAL SCANNER DISTORTION



B. RECTILINEAR PLAYBACK WITH DISTORTION ELIMINATED

FRONTISPIECE. Conventional and rectilinear playbacks of imagery with 120° scan angle recorded on magnetic tape. 8-14 μm nighttime imagery at 4,000 feet above terrain.

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Recording and Processing Thermal IR Imagery

Normal production imagery may contain defects or irregularities caused by aircraft motion, weather, electronic noise and processing problems.

(*Abstract on page* 840)

INTRODUCTION

PREVIOUS PAPERS have described applications and interpretations of thermal IR imagery (Sabins, 1967, 1969). A recent paper by Sabins (1973) described methods of flight planning and navigation for these surveys. Relatively little attention has been given to the recording and processing methods for obtaining optimum imagery. By processing we mean the conversion of scanner magnetic tape records into film imagery. This is the manner in which most imagery is produced today. Some computerized imagery processing has been described, but we are concerned with direct tape-to-film methods.

Most remote-sensing papers, including my own, are illustrated with the highest quality imagery available. Normal *production* imagery, however, may contain defects or irregularities caused by aircraft motion, weather, electronic noise and processing problems. Experienced workers recognize the cause and prevention of these irregularities, but students and new workers lack this background. Examples of common imagery irregularities are illustrated here together with a discussion of their cause and prevention.

IMAGE RECORDING AND RECTILINEARIZATION

MAGNETIC TAPE RECORDING

The development of magnetic tape recording and playback methods has greatly im-

ABSTRACT: *Thermal IR scanner imagery was formerly recorded directly on film, but most modern scanners record on magnetic tape which is played back onto film. The tapes may be replayed to obtain correct image scale and optimum contrast and density. The imagery may be rectilinearized to eliminate marginal distortion inherent in scanner recording. Typical imagery irregularities caused by aircraft motion, weather, electronic noise and processing problems are illustrated along with suggestions for their prevention. Image enhancement methods such as digitized gray scale, level slicing and color display are aids to the interpreter.*

proved the quality of IR scanner imagery. Earlier scanners recorded directly on film and any operator errors in setting film speed, density and contrast were indelibly recorded. Also any mishap in processing the original film could ruin a night of flying. Magnetic tapes may be replayed if necessary to obtain optimum image quality and correct scale.

RECTILINEAR IMAGERY

Scanner imagery, whether recorded on tape or film, has a characteristic distortion which is diagrammed on Figure 1. Because of the longer slant distance, the detector spot size (instantaneous field of view) is larger at either edge of the sweep than in the center directly beneath the aircraft. The scanner operates at a constant *angular* rate, but the imagery is recorded at a constant *linear* rate so that each instantaneous field of view is recorded equally, causing compression toward the edges of the image. This compression results in imagery distortion shown diagrammatically on Figure 1-B and with a real example in the Frontispiece (A). The *sigmoid* curvature of straight roads trending diagonally across the flight path is a typical form of scanner distortion. On film-recorded imagery, interpreters commonly work only with the central two-thirds of the strip where distortion is less severe.

Tape-recorded imagery may be played back onto film with an electronic correction to produce rectilinear imagery free from distortion. The Frontispiece compares examples of the same tape played back with and without the rectilinear processing. There are several advantages to rectilinear imagery, particularly for compiling mosaics. Also, the full width of usable imagery allows wider spacing of flight lines.

IMAGERY IRREGULARITIES

In addition to the normal scanner distortion, imagery irregularities may result from various causes, some of which are illustrated on Figure 2. This description of image problems is intended to be useful to other investigators rather than a cause of discouragement. The overall high yield of good imagery is encouraging, especially considering that scanners are installed in vibrating unpressurized aircraft with numerous potentially interfering electrical circuits and are operated at the mercy of the weather by fallible humans.

AIRCRAFT MOTION DISTORTIONS

Most scanners incorporate a system to compensate for aircraft roll but, if this system is not operating, imagery distortion may occur. On Figure 2-A the roll compensation failure is obvious in the distortion of the straight road. In other types of terrain, it may be more difficult to recognize this irregularity. On imagery of dipping sedimentary rock outcrops, roll compensation failure has produced patterns that resemble plunging folds. Some scanner systems incorporate a warning device that alerts the operator to roll compensation malfunctions.

Aircraft bank and turn is another cause of image distortion because roll compensation systems can only correct for about 10° of roll. If an aircraft maneuver exceeds this, the imagery will be distorted in a curving pattern. Such maneuvers may occur while the pilot is lining up the beginning of the flight line or breaking off at the end. This is avoided by correct flight planning which programs adequate maneuvering room beyond the ends of the flight line (Sabins, 1973).

Yaw (also called *crab*) results from aircraft rotation about a vertical axis so that the aircraft longitudinal axis is not parallel with the flight direction. Yaw results from crosswinds and causes distortion from end to end of the image strip unlike the intermittent motions described earlier. Williams and Ory (1967, p. 1378) described the effects of yaw on imagery. Some scanners are installed in a conventional camera ringmount which may be rotated in the horizontal plane. Camera drift sights are useless at night but the pilot can determine any difference between aircraft heading and flight line direction. The operator can rotate the scanner mount to compensate for this yaw angle. This compensation must be reversed, of course, on alternate lines with opposite headings.

WEATHER EFFECTS ON IMAGERY

In some instances remote sensing flights must be conducted even though weather conditions are less than ideal. Some scattered clouds below the flight altitude may have to be tolerated. Clouds typically have the patchy warm and cool pattern illustrated on Figure 2-B where the dark tones are relatively cool and the bright tones are relatively warm. Scattered rain showers produce a pattern of streaks parallel with the scan lines. It is generally believed that a heavy overcast layer will greatly reduce thermal contrasts because of re-radiation of energy between the terrain and cloud layer. We have avoided flying under these conditions, even though the base of the overcast layer was above the planned flight altitude. Another investigator, however, has obtained excellent nighttime imagery (unpublished) of an urban area under these conditions. The typical high thermal contrast between urban targets may have compensated for overcast re-radiation effects, or we may have overestimated these effects.

Surface winds produce characteristic *smears* and *streaks* on imagery. Wind smears (Figure 2-C) are parallel curving lines of alternating warmer and cooler signature which may extend over wide expanses of imagery. Wind streaks occur downwind from obstructions on flat terrain and typically appear as the warm (bright) plumes shown on Figure 2-D. On this example the obstructions are clumps of trees which image warm and one distinct building with a cold-imaging metal roof in the lower right part of Figure 2-D. The obvious solution to wind effects is to fly only on still nights, but in many areas surface winds persist for much of the year and their effects must simply be endured.

ELECTRONIC NOISE

Transmissions from many aircraft radios may cause strong interference patterns on imagery. On the example of Figure 2-E, the interference occurs as bands of electronic noise which obscure the underlying image pattern. Radio transmissions may also produce a wavy moiré interference pattern. Electronic shielding of the scanner equipment may prevent this interference but the simplest solution is to observe radio silence during image runs and communicate with the ground during turns and offset legs.

Cyclic repetition of discrete signal patterns (Figure 2-F) is an annoying, but not serious, form of electronic interference. In this example the noise occurs as positive (bright) dots but it may also have a negative signa-

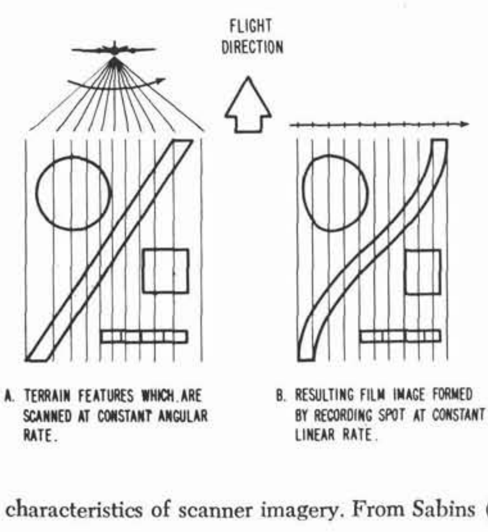


FIG. 1. Distortion characteristics of scanner imagery. From Sabins (1969, Figure 3).

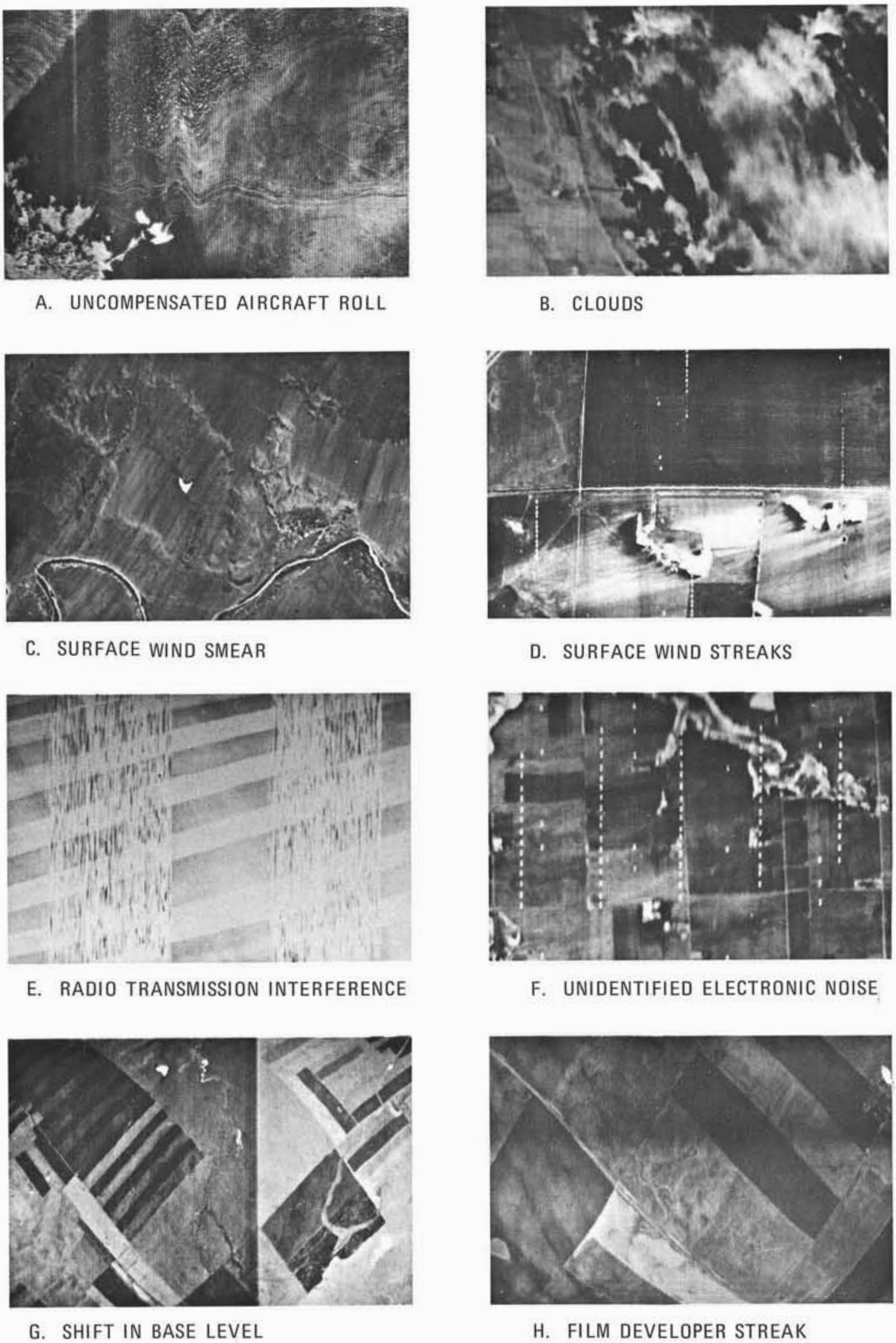


FIG. 2. Imagery irregularities. In all examples, scan lines run from bottom to top.

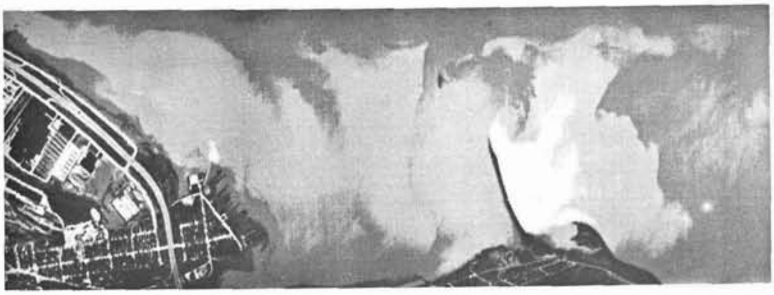
ture and occur as dashes. We have observed variations of this noise on imagery from a wide range of scanners, aircraft, and localities. It seems to occur sporadically and does not hinder image interpretation. It has been suggested, but not established, that outside sources such as air traffic radars may be responsible. Electronic shielding of the scanner installation may reduce the effect.

PROCESSING EFFECTS

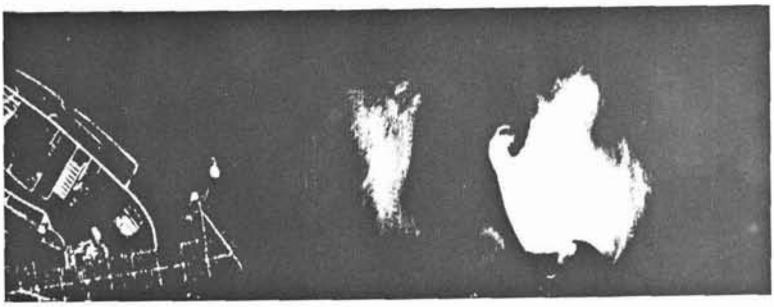
During image recording of a flight line, on either tape or film, a progressive change may occur in the overall radiant temperature level. The operator may have to shift the recording base level to stay within the optimum range, resulting in an abrupt change in image density as shown on Figure 2-G. With direct film recording, base level shifts may be partially compensated by printing the denser and thinner negatives with different exposures. With magnetic tape, the compensation may be accomplished during playback by monitoring the signal level and adjusting for base level shifts to obtain a uniform film density.

The photographic development of the image film (either directly recorded or played back from tape) is another potential source

A. CONVENTIONAL PLAYBACK WITH CONTINUOUS GRAY SCALE



B. DIGITIZED GRAY SCALE WITH SIX DISCRETE LEVELS



C. DISCRETE LEVEL SLICE

FIG. 3. Image enhancement methods. Courtesy of Daedalus Enterprises, Inc.

of image irregularities. The developer streak on Figure 2-H resulted from uneven alignment of a pressure roller in an automatic film processor, which was corrected before further use.

INCORRECT IMAGE SCALE

Image scale is determined by elevation above terrain and the geometry of the scanner (Sabins, 1973). To achieve correct scale in the flight direction, the recording film speed must be related to the aircraft ground speed and elevation (V/h-ratio). Scanner manufacturers supply tables relating V/h to film speed, and average elevation is determined during flight planning. Incorrect ground speed information is the main source of scale errors, which cannot be corrected on direct film recording. Magnetic tapes may be replayed with a corrected film speed to obtain correct scale.

The very low-frequency (VLF) navigation system described by Sabins (1973) provides ground speed information with three-minute updating. We have been surprised at the ground speed variations that can occur during a 45-mile flight line. In order to determine average ground speed, elapsed time is recorded and divided into the flight length given by the VLF distance indicator.

Image Enhancement

GENERAL

It is well known that the average human eye is incapable of discriminating more than a narrow range of gray shades between the extremes of black and white. For this reason, most black-and-white imagery of any type has a higher information content than the interpreter is able to recognize. A number of techniques have been developed to enhance the imagery into a more readily interpreted form. Enhancement operations may be done during the playback of an original magnetic tape record which is the method discussed here. Alternatively, the imagery film (whether recorded originally on film or played back from tape) may be enhanced by scanning densitometer methods which may be adversely affected by film processing irregularities.

DIGITIZED GRAY SCALE

As illustrated on Figure 3-A, conventional imagery has a continuous-tone gray scale. During processing, however, the imagery may be digitized and displayed in a series of separate discontinuous gray values.

The example on Figure 3-B employs a six-level gray scale that covers the entire range of the taped signal but any radiant temperature range could be selected, such as the range represented by the water. This method is particularly useful if applied to calibrated imagery so that apparent temperature values can be assigned to the gray scale steps.

DISCRETE LEVEL SLICE

The taped signal may be *sliced* at a desired amplitude, or temperature level, to produce an image in which all targets warmer than the selected level are white and colder targets are black (Figure 3-C). This may be useful in isolating specific temperature ranges of interest to the investigator.

COLOR DISPLAY

Colors may be substituted for the digitized gray scale by displaying the imagery on a color cathode ray tube and recording the results on color film. Some systems reportedly can provide up to 32 color separations which is a marked improvement over the discrimination that can be accomplished with shades of gray. Because of the increased reproduction cost, this enhancement method will probably be reserved for suspected anomalies or areas of special interest within a larger survey area.

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