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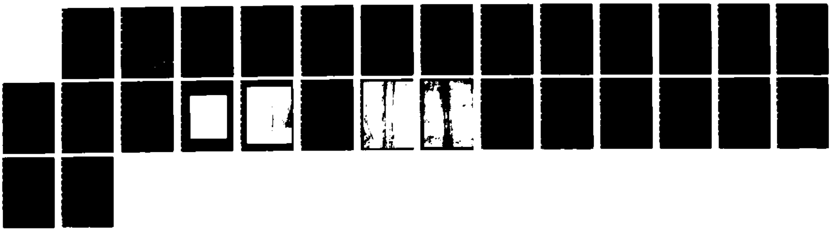

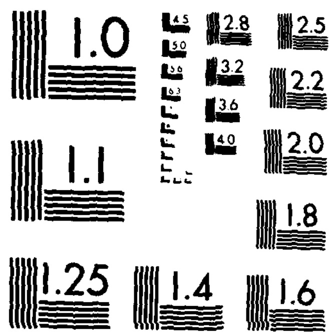

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Technical Report

ANALYSIS OF AERIAL PHOTOGRAPHY FROM ARRAY II (1980)

AD-A172 337

M. B. WALSH
Radar and Optics Division

MAY 1982

Prepared For
U. S. Army Mobility Equipment
Research and Development Command
Ft. Belvoir, VA 22060

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Aerial photography was collected in 1980 over Camp Adair, Oregon, in a pilot operation preceding larger scale tests. The photography was acquired by Mohawk OV-1D aircraft equipped with the KA-76 camera. The imagery was analyzed for its usefulness in detecting minefields. The importance of background types and sun elevation angle is discussed. Specular reflection off surface-laid mines is suggested as a significant factor in detection. Shadows cast by surface-laid mines were found to be important cues for detection.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The deployment of anti-vehicular mines is a well defined element of many scenarios practiced by potential enemy forces. The development and assessment of capabilities to detect such mine arrays is an important task being addressed by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM) and its contractors. The Environmental Research Institute of Michigan (ERIM) is carrying out a portion of that work.

From May to September 1980, imaging flights were made over Test Array No. II of anti-vehicular mines by Oregon National Guard OV-1 Mohawk tactical reconnaissance aircraft. The Array II site is located about ten miles north of Corvallis, Oregon. Imagery was collected with both the KA-76 framing reconnaissance camera and the AN/AAS-24 thermal infrared line scanner system, mostly on separate flights.

In this report, the analysis of 1980 Array II aerial photography is described. A companion report [1] describes the analysis of AAS-24 imagery.

Previously, aerial photography of Array I near Ann Arbor, Michigan was taken by RF-8G and OV-1 aircraft during the summer of 1979. Reference 2 describes RF-8G photographic imagery analysis. Reference 3 describes OV-1 Mohawk photo analysis. The results were positive and the desirability of a more extensive testing program under a closer approximation to operational conditions and under a broader range of environmental and vegetation background conditions was established.

To help in the definition and planning of this expanded program, a pilot operation was conducted during the summer of 1980 over Array II. Several mine arrays were deployed at Camp Adair and were overflown by Mohawk OV-1D aircraft of the Oregon National Guard (ONG) on an unscheduled basis, as supplemental missions to their normal training exercises. The expanded test program is planned to rely extensively on equipment and personnel of the ONG.

The objectives of the effort reported herein were to:

1. Analyze the aerial photography from these exploratory flights over Array II,
2. Compare them to the results obtained under the more closely controlled conditions of Array I overflights,
3. Make a preliminary assessment of the limiting conditions for sensor/PI performance, and
4. Gain initial experience and insight prior to initiation of the larger scale MIDURA (Minefield Detection Using Reconnaissance Assets) tests and develop recommendations for the more extensive follow-on data collection and analysis activities.

These objectives were all met. A good foundation was established for the follow-on program. The details of the data, their analysis, and the results are presented in the remainder of this report.

1.1 BACKGROUND

The Array I flights were made to establish whether or not reconnaissance cameras, like the KA-76, and infrared mapping scanners, like the AN/AAS-24, have the potential to detect surface-laid and buried mines of various types. Although reconnaissance cameras are standard equipment on military aircraft, operational guidelines for their use in mine detection do not exist. Additionally, IR scanners had not been evaluated for minefield detection.

While the capability of aerial camera systems and photointerpreters to detect many types of military targets is well known, minefields present challenging problems because of the small size of the mines and the photographic target-background contrasts that are achievable. The dimensions of anti-vehicular mines are approximately a foot in diameter and a few inches in height. They often might be placed in vegetation backgrounds which are a foot or more in height. They may be emplaced on the surface or they may be buried. Surface disturbances associated with burying of mines also can contrast with their backgrounds.

Clearly, the spatial resolution of cameras limits the altitudes at which the aircraft can fly and still obtain photography on which mines would be detectable. Also, environmental conditions will influence the times at which mine tones will be sufficiently different from tones of their backgrounds. The Array I tests did indicate a capability for detection under limited conditions. As stated earlier, the objective of this pilot exercise over Array II was to test this capability and explore its limits under a wider range of operating and environmental conditions.

1.2 SUMMARY OF THE ARRAY I TEST

During July and August, 1979, reconnaissance photography was collected over Array I near Ann Arbor, Michigan. Array I consisted of a farm field covered with a mixture of alfalfa and grasses with emplaced military targets and calibration targets [4]. Military targets included surface-laid M-15, M-19, and PM-60 mines and buried mines, both hand-buried and machine-buried. Photographic images were collected by an Oregon National Guard OV-1 Mohawk and by a Naval Reserve RF-8G tactical reconnaissance aircraft at altitudes ranging from 200 to 1,700 feet (scales of 1:430 to 1:3,400). The OV-1 also collected thermal imagery with an infrared line scanning system.

The major conclusion drawn from analysis of Array I photography was that both surface-laid and evidence of buried mines can be detected in photography acquired by conventional framing reconnaissance cameras at realistic reconnaissance altitudes, under the proper conditions. Furrows containing machine-buried mines were detectable in all photography of them, while ground disturbances associated with hand-buried mines were detectable in direct sunlight, but not under an overcast condition. The surface-laid M-19 was easily detected under all conditions encountered, while other types were detected only in direct sunlight and even then, were subject to limiting factors. For example, minimum resolvable ground distance became a factor, as did background. It was suggested that specular reflections from the surface mines may be important to detection, in addition to their tones.

1.3 PLAN FOR ARRAY II

It was planned to use equipment and personnel of the 1042nd Military Intelligence Command Company of the Oregon Air National Guard (ONG) for the implementation of the extended test program of minefield detection capability. Therefore, the Array II pilot operation, discussed in the remainder of this report, was arranged to familiarize them with the program, to uncover unanticipated problems in conducting such a test under a cooperative arrangement, and to provide preliminary data on limiting conditions of minefield detection in the new environment.

The original intent was to immediately follow the Array II pilot operation by an analysis of the test data, planning activities, and the larger scale MIDURA test program. The plan was interrupted by an hiatus in funding, but this report represents a resumption of the program and completion of the analysis effort aimed at developing insights from the 1980 aerial photography collection activity.

2
TECHNICAL DISCUSSION

2.1 ARRAY AND ENVIRONMENTAL CONDITIONS

Array II, located about ten miles north of Corvallis, Oregon at Oak Hill (N 44 43 W 123 16), is part of Camp Adair. The array area is fenced and has been used as a training area for tracked vehicles. Figure 1 is a map of the area. To the south is an access drive, parking lot, and rifle range. To the north and east are active agricultural fields. West of the area is wooded land with an irregular boundary.

The summit of Oak Hill is in the western part of the area. At Oak Hill, the slope is generally between ten and twenty percent. The slope becomes more gradual farther from the hill. Well travelled vehicle trails are depicted in Figure 1. Tracks caused by single tracked vehicles are too numerous to illustrate. The area was probably cleared of trees and used for agriculture or pasture many years ago. Agricultural activity was abandoned and a second growth of natural vegetation has taken hold. The vegetation consists mostly of herbacious plants (2-3 ft high) with scattered shrubs and small trees. The density of vegetation cover varies considerably over small areas.

In early May 1980, six each PM-60's and M-15's were hand buried in a row running east/west directly east of a 80 x 100 foot fenced enclosure (right center part of Figure 1). One "minefield" of PM-60's and one of M-15's were deployed on the surface. The positions of these mines were changed several times during the summer. Each minefield generally consisted of two rows, of ten to twelve mines each, deployed near and parallel to well travelled vehicle trails. Sometimes the rows ran along each side of a trail. Other times the rows were on the same side. Spacing between mines and between rows was generally between four and eight meters. Spacing of ten to twenty meters was observed in two situations.

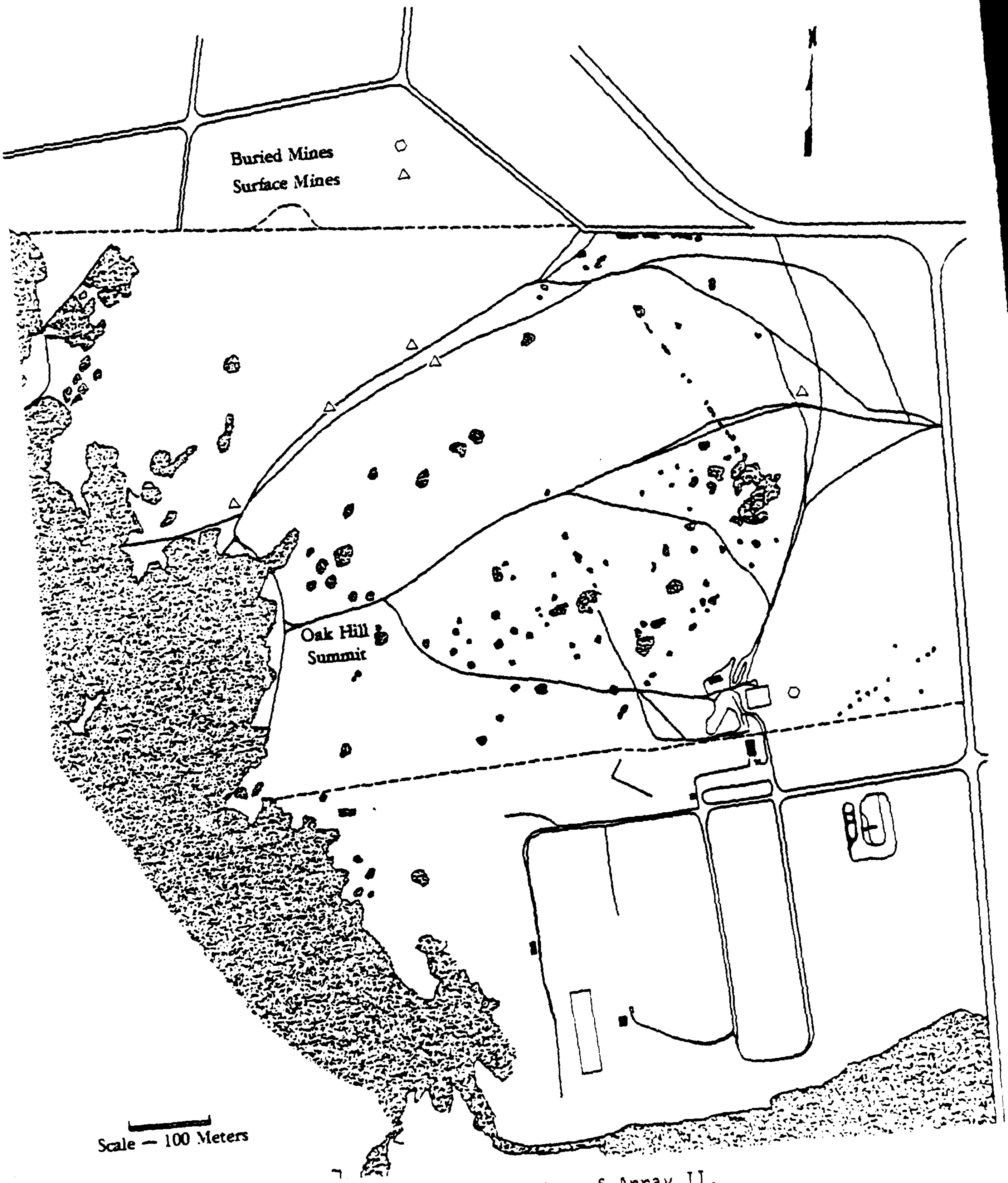

Figure 1. Map of Array II.

Some of the PM-60's were replicas, but essentially identical for photographic purposes. The M-15's, normally black (with patches of rust), had been painted olive drab to simulate TM-46 coloration.

Photographic calibration targets such as resolution targets and gray scales were not installed in 1980.

2.2 CAMERA AND FILM CHARACTERISTICS

The OV-1D Mohawk carries the KA-76 framing reconnaissance camera, which produces 4.5 x 4.5-inch images on 5-inch film. Vertical photography was collected for mine detection missions. Like other mission reconnaissance cameras, the KA-76 has a focal plane shutter, forward motion compensation, automatic exposure control, and space for data annotation. Annotation was absent for all but one photographic flight.

Although optics of several focal lengths can be installed on the KA-76, the focal length used for these flights was assessed to be six inches, based on the amount of horizontal displacement observed near image edges. The six-inch focal length is "normal" for the 4.5-inch format, providing an angle of view of about 41 degrees. Due to $\cos^4$ fall-off, vignetting, and reduced resolution, the corners and edges of the image format are not adequate for mine detection. An area centered in the image with a 4-inch diameter is judged adequate (33 degree field of view). At 700 feet altitude, a swath 127 meters wide (~ 400') on the ground can be expected.

Three types of film were used. GAF 2914 is a medium speed, black-and-white panchromatic film with extended red sensitivity on 4-mil base. This film was commonly used by the Oregon National Guard and was used during most photographic flights over Array II. Exposure appeared to be fair. Contrast was low.

Kodak 3411 Plus-X Aerocon is a fine grain, high contrast, medium speed, panchromatic black-and-white reconnaissance film with extended red sensitivity and a 2.5-mil base. Imagery was collected on this film during four flights. Film from two flights was either overexposed or overprocessed (high density). Contrast was low to fair for these two missions. The other two flights exhibit much better contrast, probably better than the 2914 film.

Kodak 2424 Infrared Aerographic is a negative, black-and-white film with near infrared, visible, and ultraviolet sensitivity (4-mil base). Normally, a filter is used to block out the visible and ultraviolet spectrum during exposure. This film was utilized during one flight. Contrast was low. Filter type or specifications were not documented with the processed film.

Resolution over Array II was judged qualitatively to be better than the resolution obtained by the OV-1 Mohawk that overflew Array I. It cannot, however, be determined quantitatively without a resolution target.

The problem of superimposed frames observed in Array I Mohawk photography was not present in Array II photography.

2.3 SCALE, ALTITUDE AND TIME DETERMINATION

Scale was determined for each pass over the Array II area by measuring distances on the images and comparing these with "known" ground distances or with a map (Figure 1). The map scale was calibrated by measuring similar features on the USGS 15' Corvallis topographic quadrangle map. Known distances were determined in the vicinity of the fenced enclosure and caretaker's trailer. A ladder, several 4' x 3' plywood sheets, and several vehicles were useful for calibration.

Altitudes were calculated from image scales assuming a six-inch focal length.

Times over target (TOT) were provided with the film for most flights. Whether the time represents the time of the first, middle, or last pass over Array II was not specified. Times were calculated for several flights without provided times by measuring azimuths of shadows. Sun elevation figures were obtained during these calculations. Apparent sun time was adjusted for daylight saving and the location of Array II with respect to the time zone central meridian.

2.4 PHOTOINTERPRETATION APPROACH

The original negative film was first viewed quickly without magnification and without knowledge of mine locations. With this type of search, most of the Array I minefields could be detected. However, at Array II no mines were found.

The film was sequentially studied with a 7X tube magnifier and crude ground truth maps. Surface mines were detected using this approach. Enlarged prints (2X) were made of frames with detections. These prints were studied side by side to interpret cues permitting detection.

2.5 RESULTS

Twelve photographic flights were flown, one without coverage of Array II. Photographic imagery was obtained for 46 passes including part of Array II. Surface-laid mines were detected on eleven occasions in nine passes. In 22 passes, it is reasonably certain that minefields were not covered within useable parts of the image format. In the remaining passes, either the coverage of minefields is not known with confidence or the image scale is beyond 1:4000, too small for detecting these mines under these conditions.

Detections are listed in Table 1. Direct sunlight and distinct shadows were present during the five flights and nine passes where minefields were detected. Sun elevation varied between about 45 and 60 degrees. The shadow-to-height ratio represents shadow length in proportion to object height for a given sun elevation angle.

TABLE 1

SURFACE MINE DETECTIONS

DATE	LOCAL TIME	SUN ELEVATION (DEGREES)	SHADOW/ HEIGHT	APPROX. ALTITUDE (FEET)	SCALE	MINE TYPE	NO. MINES DETECTED
7 May 80	1420	59	.6	2300	4600	PM-60	2
7 May 80	1420	59	.6	1500	3078	PM-60	3
7 May 80	1420	59	.6	950	1905	PM-60	9
8 Aug 80	1050	50	.85	800	1633	M-15	7
8 Aug 80	1050	50	.85	700	1380	PM-60 /M-15	11/4
8 Aug 80	1050	50	.85	700	1380	M-15	5
28 Aug 80	1240	50	.85	750	1466	PM-60	8
29 Aug 80	1110	45	1.00	550	1122	M-15	11
3 Sep 80	1430	50	.85	650	1345	M-15	7
3 Sep 80	1430	50	.85	900	1400	PM-60	20

The three minefield detections for May 7 were imaged in three passes over the same minefield. The detections at the two higher altitudes were possible due to prior detection of the same mines on photographs obtained at lower altitude (950 ft). Detection of the mines in the higher two passes would be doubtful without ground truth. The May 7 detections differ from detections later in the year because the mines appear substantially brighter than their surroundings, whereas later in the year, the mines match in tone with their backgrounds to a greater extent. Shadows are barely perceptible in the May 7 detections. Of the nine mines detected in the lowest altitude pass, six are readily apparent. The other three are detectable by careful examination after extrapolating to their locations from the location of the other six. These three mines have backgrounds that are lighter in tone and that present numerous potential false targets.

Detections in August and September images are different from the May detections. The PM-60's in the May images appear as round bright spots, whereas the tones of the M-15's and PM-60's in the later images are much closer to their surroundings. In many cases, the tones of the tops of the mines match their immediate surroundings. Such mines are detectable from dark crescent-shaped shadows or dark rings, consisting of shadows and mine edges. Tones of both mine surface signatures and backgrounds vary within rows of mines.

Figures 2 and 3 illustrate examples of Array I and Array II backgrounds, respectively. The upper field in Figure 2 had been planted with soybeans three years before. The texture and tone of vegetation is uniform, except for vehicle tracks and bare patches. Surface-laid M-15's stand out in the right section of this field. Surface-laid PM-60's are less evident to the left. Below the hedgerow is a six-year old soybean field with a higher proportion of weeds and grasses and with hand buried mines. Figure 3 in Array II illustrates diverse natural vegetation from grasses and other herbaceous plants to

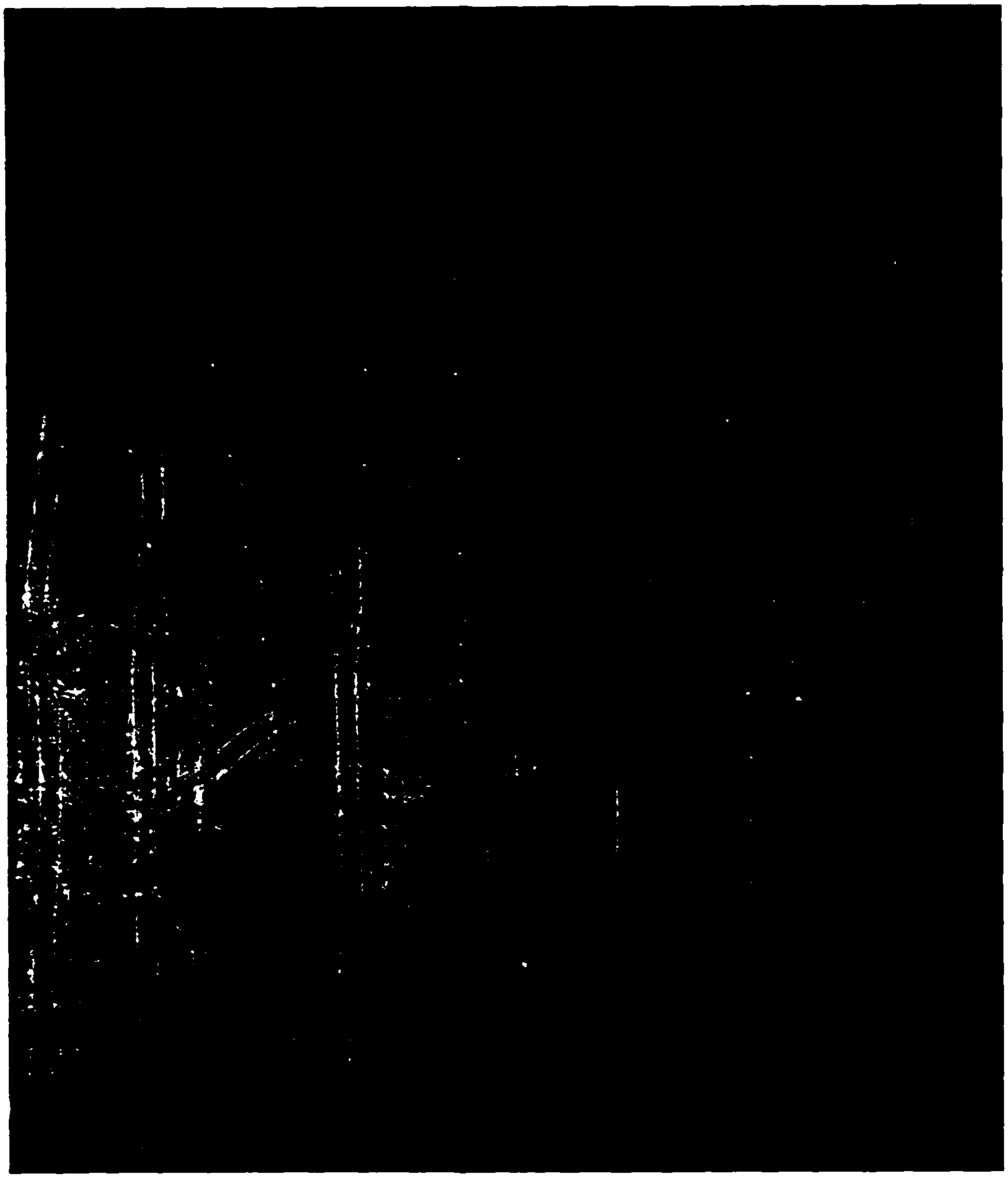

Figure 2. Array I Background

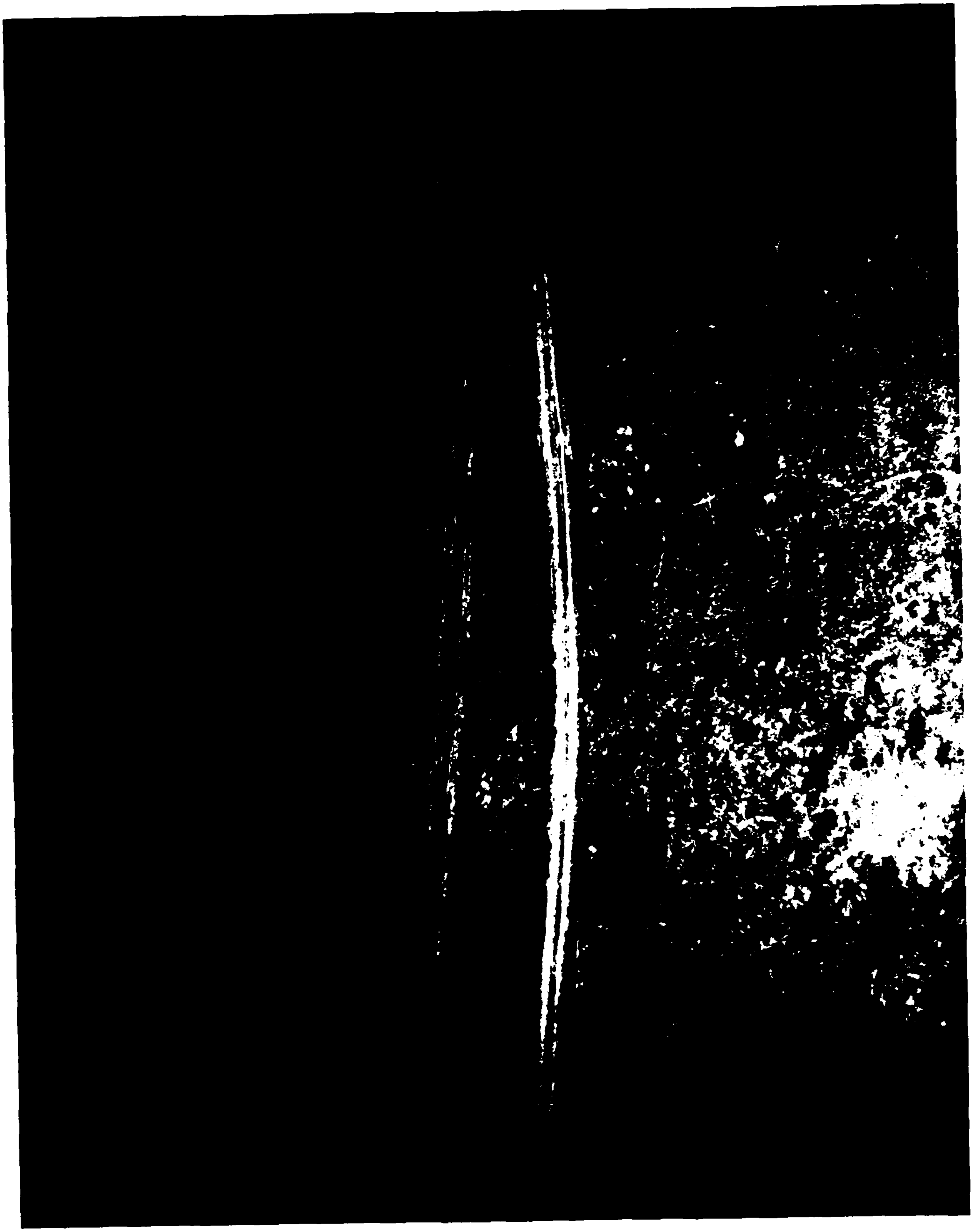

Figure 3. Array II Background

shrubs. Note the dark shadows of shrubs. Light spots are due to bare ground and lighter vegetation. Some of the vegetation has lost its chlorophyll in this August 29 image. Surface-laid M-15's are along both sides of the vehicle trail in the right half of Figure 3.

Figure 4 is a highly enlarged section of the same August 29 image. Eight M-15's, about three millimeters across, are present along the trail edges. The thin horizontal white lines are film scratches. Surroundings of individual mines vary from light in tone to dark. The tones of the mines also differ among themselves. The importance of shadows as detection cues can be discerned. Looking closely, subtle evidence of the raised inner section of M-15s can be perceived.

Eight PM-60 surface-laid mines are illustrated in Figure 5 of a 3 September pass. Overall, the PM-60's appear darker than the M-15's in Figure 4. Shadows of the PM-60's are also helpful detection cues.

In the late summer images, most PM-60's match their backgrounds in tone fairly closely. A smaller number are darker than their immediate surroundings. Shadows are more important than tone differences in detection of about two-thirds of the cases. Most M-15's also match their backgrounds in tone. Another set are lighter in tone than their surroundings. Only a handful are darker. Shadow cues are most important in almost three-quarters of the M-15 detection cases.

2.6 DISCUSSION

Detection of mines in Array II photographic images was significantly more difficult than in Array I images. Most of the mines in Array I could be detected on the original negative with the naked eye, whereas magnification was necessary for Array II. The background of Array II, more variable in texture and tone than Array I, is probably partially responsible. Background variations, however,

cannot be the entire answer. Mines in Array I were detectable due to higher reflectances than their backgrounds in most cases. The mines even appear brighter than nearby vehicle tracks. Array II mines, on the other hand, appeared intermediate in tone to the lightest and darkest parts of their backgrounds. The same M-15's and PM-60's were used in both arrays. Either the overall background of Array II is brighter or the reflections from the mines in Array II are less bright than their Array I counterparts. Both appear to be true.

The inherent colors of the mines were the same in both arrays. Differences in reflection could have been due to specular components of reflection. The potential for specular reflection is clear. Good examples can be viewed in hand-held color photographs of mines in Figure 2-2 of Reference 2. Noticeable differences in tone of the same mine photographed from different positions, such as successive frames during a pass, observed in imagery from both arrays, are attributable to specular reflection differences.

For vertical aerial photography, specular reflection is much higher at high sun elevation angles (60°-90°) than at medium angles (45°-50°). Reflections from vegetation and the ground do not increase to the same extent at high sun angles because vegetative backgrounds are, in large part, diffuse reflectors. Therefore, mines appear brighter than their surroundings. Black-and-white photography illuminated by direct sunlight in both arrays, was evaluated with respect to sun angle. Array I OV-1 Mohawk photography was collected at sun elevation angles of about 66 to 69 degrees and Array I RF-8G photography was collected with the sun at about 66 degrees. The May 7 Array II OV-1 photography, exhibiting brighter mines than surroundings, was taken with the sun about 59 degrees above the horizon. Array II images with mines and backgrounds more closely matched were collected at sun angles of 45 to 50 degrees.

If detection is consistently higher at high sun angles, the timing of flights could be selected to take advantage of this phenomenon. However, this would be useful only in scenarios with minefields in place for long periods of time. Also, at high latitudes the likelihood of high sun angles is low. For example, at 50 degrees latitude, the sun doesn't appear above 60 degrees sun elevation for ten months of the year.

At intermediate and low sun angles, the inherent mine color and shadows appear to be more important than specular reflections. Tonal contrast between the mine and surroundings are comparatively lower than at higher sun angles with bright, specular mines against the same background. Lower flying altitudes and increased interpretation time are probably necessary for detection. As sun elevation angle is reduced, shadow extent is increased, but distinguishing the shadow from its background is difficult due to lower illumination. Image blur is increased at lower sun angles due to longer exposure times. At low sun angles, slow speed films are precluded.

Another approach for taking advantage of mine specularity at low sun angles has been suggested. This approach would be to fly offset flight paths and view the mines obliquely at the specular reflection angle, looking toward the sun, using a panoramic or oblique camera. This approach could be employed where there is little vegetation (winter) or early in spring or late in the fall when vegetation is short.

If shadows are an important cue, the M-15 mine is not a good substitute for the TM-46 since the height of the TM-46 is only about three-fifths that of the M-15.

Under overcast conditions, three factors detract from detectability of surface mines: absence of shadows, absence of specular reflections, and an increase in image blurring due to longer exposure times.

3 CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

The results derived from this pilot operation over Array II during the summer of 1980 substantiate the results obtained from the previous Array I test, extending them to a different and wider range of background and weather conditions. They support the previous recommendations for a larger scale test program and provide useful insights for the design and conduct of that program.

Both M-15 and PM-60 surface-laid mines were detected at several locations in Array II aerial photography. Hand buried mines were not detected in the one array element present. The surface-laid mines were significantly more difficult to detect than the same types of mines in Array I images. Detection in Array II images required careful search with the aid of magnification, whereas no magnification was necessary for most detections in Array I images. Array I mines were more easily detectable, partly due to a more homogeneous background than Array II. Specular reflection and sun elevation angle are proposed as other contributors to detection differences. Array I was photographed at high sun angles, whereas Array II was photographed at lower sun angles. Strong specular reflections from mines at higher sun angles could be one reason for improved detection in Array I. Another could be the generally darker tone of vegetation in Array I.

In most cases at Array II, mines were photographed at intermediate sun angles. The tones of mine reflections were close to background tones. Shadows of mines proved to be the most important detection cue in these images. All images with detected mines were taken in direct sunlight conditions. The above observations hold for specific background, sun angle and lighting conditions. Under other conditions, cues for detection would differ.

3.2 RECOMMENDATIONS

In future flights a wide distribution of conditions is recommended. Altitude, sun angle, lighting quality, and background appear to be the most important variables for photographic missions. Altitude is closely related to ground-resolved distance. Ranges of altitudes flown should depend on other factors such as background type and sun angle. For any set of sun angle, lighting quality, and background conditions, different altitudes should be flown to produce imagery with detectability varying from probable to improbable. This could be accomplished during any particular flight, since the other conditions are likely to be static during that short time.

Differences in sun angle and lighting quality must be accomplished by scheduling flights at suitable times. Sun angles are highest at and near summer solstice (ca. June 22). In this report, the importance of specular reflection at high sun angles (above 60°) was suggested. These angles are only possible in the weeks close to summer solstice. In addition, low and intermediate sun angles are needed to ascertain the relationship of detectability with sun elevation angle. Flights should also be flown in overcast and hazy skys. The importance of direct sunlight should be studied. The conditions necessary for detection of mines in overcast/hazy environments could be determined.

Different backgrounds should be utilized. Seasonal changes affect the background at a particular location. Different locations could provide even greater background differences. The importance of mine color, shadows, specular reflection, and vegetative obscuration would vary with respect to location.

When different films, filters, and techniques are tried, care should be taken to collect imagery under lighting, altitude, and background conditions equivalent to imagery used for comparison.

When vegetative obscuration is not a problem and when suitable flight tracks are available, some flights should be made photographing surface mines, both at vertical angles (mines at nadir) and at oblique angles (oblique-oriented framing camera or panoramic camera). The oblique photography should be pointed towards the sun in azimuth and at a depression angle equal to the solar elevation angle. The mines imaged at oblique angles should appear much brighter than the same mines photographed vertically. This would be particularly useful in areas with dark backgrounds.

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