1.0

1.1

1.25   1.4   1.6

45   2.8   2.5
50   3.2   2.2
36
40   2.0

1.8

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

RAPID DAMAGE ASSESSMENT

VOLUME I: METHODOLOGY FOR SELECTING REPAIR AREA OF ORDNANCE-DAMAGED PAVEMENTS

(12) LEVEL

NEW MEXICO ENGINEERING RESEARCH INSTITUTE
ALBUQUERQUE, NEW MEXICO 87131

SEPTEMBER 1980

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JUNE 1977 - AUGUST 1979

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Crater	Image Manipulation	
Camouflet	Bomb-Damaged Runway	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report introduces and provides detailed information on four damage assessment and data reduction systems. The functions of these systems are to locate and assess the magnitude and location of the damage sustained by an airbase pavement during an attack using conventional weaponry and to select the section of the runway requiring the least amount of repair time to make operational. The primary system utilizes a linear photodiode array camera (1728 elements) to scan the runway and a microcomputer and video processing equipment to reduce the data and select the repair area. Three backup systems are recommended which

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20.   ABSTRACT (CONCLUDED)

require more time to assess the damage and reduce the data. Recommendations are made by the New Mexico Engineering Research Institute (NMERI) for the development of the four systems. This report is Volume I of two volumes.

PREFACE

This report was prepared by the New Mexico Engineering Research Institute, University of New Mexico, Box 25, University Station, Albuquerque, New Mexico 87131, under contract F29601-76-C-0015 with the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida 32403. The work described here was performed at the Eric H. Wang Civil Engineering Research Facility, Kirtland Air Force Base, New Mexico.

This report consists of two volumes. This is Volume I which summarizes work done between 1 June 1977 and 31 August 1979.
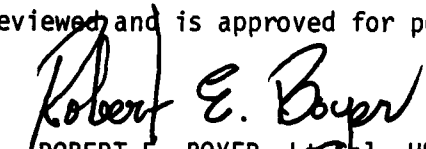
This report has been reviewed by the Public Affairs Office (PA) and it is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

The findings and recommendations in this document are not to be construed as an official Department of the Air Force position. The use of trade names in this report does not constitute an official endorsement or approval of commercial products. This report may not be cited for purposes of advertisement.

This technical report has been reviewed and is approved for publication.

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SECTION I
INTRODUCTION

OBJECTIVE

The main objective of this effort was to develop a system which can be used to locate and identify runway damage resulting from an attack with conventional weaponry and to select that particular 5,000- by 50-foot section of runway which would require the least amount of time to repair. The reconnaissance and data analysis should be completed within 30 minutes.

PROPOSED MEANS OF MEETING OBJECTIVE

A system consisting of an airborne electronic line-scan camera and a computerized image-analysis system is proposed as the primary system for runway damage assessment. A number of alternate systems which cannot meet the time requirement are proposed for interim use and backup for the primary system.

OVERVIEW OF PROPOSED SYSTEMS

The recommended primary system consists of two major subsystems: an airborne package consisting of a linear photodiode array electronic camera, a stabilized platform, a lighting system, and an aerial reconnaissance vehicle and a ground-based video processing system used to analyze the imagery data. The ground system consists of a microcomputer process controller, a bulk storage disk and controller, an interactive digital refresh console, and display stations. A data link, either a video recorder or telemetry link, transfers imagery data from the camera to the video processing equipment.

The complete damage assessment system would function in the following manner. Following an attack the electronic camera is placed aboard the aerial reconnaissance vehicle and flown over the damaged pavements. The aircraft must be able to operate from unimproved surfaces and fly within certain flight parameters of speed, altitude, and heading. The stabilized platform compensates for rotational motion of the aircraft. The lighting system provides illumination for the camera during darkness and low light level conditions. The video output of the electronic camera is transferred to the video processing equipment. There it is loaded onto a bulk storage disk. Portions of the imagery data are then presented to an operator on a display screen. The

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operator interactively classifies, sizes, and locates damages using the digital
refresh console. The microcomputer tabulates the type, size, and location
data. When the damage-identification process is completed, the microcomputer
then scans the runway surfaces for the 5,000- by 50-foot area that can be made
operational in the least amount of time.

REPORT OUTLINE

General background information and effort requirements as well as
detailed objectives are discussed in Section II. Section III contains a dis-
cussion of the types of damages expected and defines these types. Techniques
to estimate the time required to repair these various types of damage are
discussed in Section IV. A review of the damage assessment and reconnais-
sance techniques considered here is presented in Section V. Section VI con-
tains the recommendations relevant to the development of a linear photodiode
array system for damage reconnaissance.

SECTION II
BACKGROUND INFORMATION

GENERAL BACKGROUND

The dependency of modern jet aircraft on high quality airfield surfaces makes the airfield runway a high priority target. The probability of attack on vulnerable airfield runways is further increased by the United States Air Force (USAF) use of hardened aircraft shelters. However, at present the USAF does not have a system for rapidly locating and evaluating the magnitude of damage which would result from an enemy attack on the runway surfaces with conventional weaponry.

The possibility of finding the most suitable launch and recovery area for emergency repair is complicated by the multiplicity of targets in an airfield facility, i.e., main runway, alternate runways, main taxiway, alternate taxiways, stabilized areas, and main access highways in the vicinity. The problem then is to find a system which can rapidly scan the entire airfield complex to determine the most suitable area for repair. Once the damage had been located and classified, the system would scan the least damaged areas to determine that section of runway, main taxiway, or alternate runway area which could most rapidly be made operational. The system would locate and categorize damage and determine the repair effort required.

In selecting the repair area, several damage assessors must consider several parameters which have a bearing on any repair effort:
1. The time required to clear the area of unexploded ordnance.
2. The possibility of encountering unexploded ordnance which cannot be removed.
3. The distance and access time from the aircraft to the selected repair area.
4. The proximity of construction materials to the selected repair area.

5. The difficulty of accurately determining the type and magnitude of damage.

6. The quantity of data which must be classified and reduced.

The system which is selected must permit evaluation of all of these parameters in order to determine accurately the best area for repair.

Several assumptions have been made which bear on this initial investigation. First, no relationship or process had been developed to determine the required repair effort for combinations of different types of damages such as craters, camo-heaves, camouflets, spalls, and unexploded ordnance. The repair of major craters has received the greatest amount of attention in determining equipment for Rapid Runway Repair (RRR) which would enable the RRR team to meet a 4-hour time requirement for the repair of the runway. However, several studies show that certain combinations of small craters, spalls, camo-heaves, camouflets, unexploded ordnance, and large craters may require more time to repair than the three 750-pound bomb craters which are currently used as the design criteria (References 1, 2, and 3).

Second, the effort statement suggested that conventional surveying and photogrammetric systems be investigated prior to the examination of alternate systems. Due to the adverse conditions which may exist following an enemy attack, it is not recommended that a ground method of assessment be utilized. The quantity of data which must be gathered would eliminate conventional surveying techniques as a viable method of locating damage. The use of an electronic distance-measuring device with a theodolite cannot practically be used in this scheme for several reasons. First, the postulated attack for purposes

References

1. Hokanson, L. D., and Rollings, R. S., *Field Test of Standard Bomb Damage Repair Techniques for Pavements*, AFWL-TR-75-148, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, October 1975.

2. Hokanson, L. D., *Tyndall Air Force Base Bomb Damage Repair Field Test Documentation and Analysis*, AFWL-TR-74-266, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, October 1975.

3. Brooks, G. W., Cunningham, J. E., and Mayer, P. W., *Bomb Damage Repair (BDR) Damage Prediction*, Volumes I and II, AFCEC-TR-75-24, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, October 1975.

of design is 125 separate, locatable damages. In daytime and with no adverse conditions, it could take approximately 4 minutes to locate and record each damage. This corresponds to a required time of 8-1/2 hours to locate and assess the magnitude of damage. The time allotted for the entire operation, however, is 30 minutes. If the location procedure must be conducted at night and under adverse conditions, the time required to locate and assess the damage may exceed this estimate by two to three times. Also, if antipersonnel mines have been dropped on the airfield pavement, a manual, ground-based system such as this may be unnecessarily delayed while explosive ordnance disposal (EOD) personnel clear the area of the unexploded ordnance.

It was initially believed that the volume of fill required to backfill a crater would be the prime factor in determining the time required to repair the crater. This is not true. The backfill operation takes only 10 percent of the total repair time. The most time-consuming and difficult portion of the repair effort is the removal of moderately upheaved pavement. A relationship between the apparent diameter of the crater, the area of the moderately upheaved pavement, and the time required to make expedient or semipermanent repair based on dimensional analysis was found by the University of New Mexico's Engineering Research Institute (NMERI). (*Expedient repair* is defined as removing all pavement which has a slope of greater than 4 inches in 20 feet. *Semipermanent repair* is defined as replacing all pavement which has a slope of greater than 1 inch in 20 feet.)

The effort statement states that the system which is devised should be conducive to data reduction by hand. The reduction of damage data by hand is a lengthy procedure. However, such data reduction can be expeditiously done by a small computer or desktop calculator. If a manual data-reduction system is utilized, the resolution in the selection process is severely affected. A manual system analyzing a given quantity of data would have, for example, a resolution of 500 feet longitudinally, 50 feet laterally, and would require a data-reduction time of approximately 2 hours. However, a small computer could have a selection resolution of 50 feet longitudinally and 5 feet laterally and a data-reduction time of approximately 30 minutes. It is recommended that the manual system serve only as a backup in the event that the primary system is damaged or destroyed during the attack.

LIMITATIONS

In the original effort statement eight limitations were placed on the system. These limitations are listed in Table 1. The first limitation is that the system must operate independent of base facilities. This means that if a system depends on electricity, it must operate independent of any base power and must be backed up by more than one power source. The system should not depend on the base computer, photogrammetric or photo processing laboratories, nor on any equipment which is not specifically designated for RRR.

The second limitation is that the total time required for the collection and reduction of data not exceed 30 minutes. Obviously, the total time required to make an airfield pavement operational depends on the amount of time needed to locate and assess the damage, reduce the data, and select the repair area. The 30-minute time limit is an arbitrary but necessary constraint because pavement repair work cannot be started until the repair area is selected.

The third limitation is that the system should depend mainly upon manpower and simple equipment. The original effort statement stated that the system should be relatively simple to implement by a technician or professional and that no highly sophisticated apparatus or equipment should be employed. Specifically prohibited were the use of electronic cameras, sensing devices, elevation or optical monitoring equipment, and computers.

The last of the limitations is that the system must function in an adverse environment such as an airfield where antipersonnel mines have been scattered, or in a hostile chemical, radiological, or biological environment. The system must operate efficiently day or night and in adverse weather conditions.

Research was conducted for approximately three months. This NMERI effort attempted unsuccessfully to devise a system which met all of the above constraints. At the conclusion of the research, NMERI presented a briefing to the Air Force which demonstrated seven systems which had been investigated in detail. None of the systems, however, conformed to all of the limitations of the original subtask statement.

TABLE 1. INITIAL LIMITATIONS

- MUST FUNCTION INDEPENDENT OF BASE FACILITIES

- MUST NOT EXCEED THIRTY-MINUTE MAXIMUM

- MUST USE LIMITED MANPOWER AND SIMPLE EQUIPMENT

- MUST NOT EMPLOY ELECTRONIC CAMERAS

- MUST NOT REQUIRE SENSING DEVICES

- MUST NOT REQUIRE ELEVATION OR OPTICAL MONITORING EQUIPMENT

- MUST NOT EMPLOY COMPUTERS

- MUST FUNCTION IN ADVERSE ENVIRONMENTS

As a result of this briefing, the limitations in the effort statement were changed. Instead of all the previous limitations, only two constraints were placed on the system. First, the system should take as little time as possible to locate and assess the magnitude of damage and select the repair area. Second, the system should be as simple as possible consistent with the time constraint imposed for selecting repair areas. In these new guidelines the time requirement was considered to be the single most important variable in choosing the most effective system of reconnaissance and selection of repair areas.

The research conducted under this effort was based on the assumption that an enemy attack would utilize conventional weapons. These weapons could be detonated by contact; by time-delay fuze; or by seismic, acoustic, or magnetic signals. In addition, kinetic-energy penetrating weapons could conceivably be used.

The damage assessment system devised should include a technique to locate unexploded ordnance and estimate the size of the explosive head. A system of trade-offs should be incorporated in the selection process which would provide

launch and recovery capability in the least amount of time while deferring
the disarmament of unexploded ordnance. The system should also include pro-
visions to locate and assess ordnance adjacent to the runway which might
damage the aircraft or injure repair personnel should a weapon detonate. The
area to be considered is that portion of the runway complex which is 225 feet
or less from the centerline of the repair area. The weapons which must be
considered in the design of the system are listed in Table 2.

TABLE 2. TYPES OF WEAPONS

• GENERAL PURPOSE BOMBS

• CANNON FIRE

• KINETIC ENERGY PENETRATORS

• ANTIPERSONNEL MINES

The hypothetical damages of an assumed enemy attack used by NMERI in the
evaluation of the damage assessment system are as follows:

125 Discrete Damages

62	Spalls (large enough to require repair)	50 Percent
4	Unexploded Ordnance (not including antipersonnel mines)	3 Percent
15	Large Craters (36-foot diameter or greater)	12 Percent
31	Small or Intermediate Craters	25 Percent
9	Camo-Heaves	7 Percent
4	Camouflets	3 Percent
125		100 Percent

The quantity and types of damage which might be sustained by an airfield
pavement may vary considerably from those used in the design of the system,
but NMERI determined that the system should be capable of handling at least
this quantity of data. The quantity of damage represents approximately 1/40
of the damage sustained, for example, at the airport in Cyprus during the
Greek and Turkish conflict of 1975.

SECTION III
DAMAGE DEFINITIONS

In this study a hypothetical attack is modeled in terms of the number of discrete damages inflicted and the kinds of ordnance causing them. Further, four types of damage are postulated and defined (Figure 1).

Type I damage is designated as the *standard crater*. The diameter of a standard crater may range from 3 to 4 feet for a small explosive head to 50 feet for a 750-pound bomb. The weapon penetrates the pavement and possibly into the subgrade before detonating. The explosion creates an open crater which exposes the subgrade. The concrete pavement immediately surrounding the open area of the crater is radically upheaved. A large volume of the subgrade material may be displaced upward and outward. A portion of this displaced subgrade material falls back into the crater, and the remainder is strewn radially about the perimeter of the crater. The depth of the displaced subgrade material decreases approximately exponentially with the distance away from the lip of the crater. The pavement beyond the radically upheaved pavement may be moderately upheaved and require removal before the crater can be repaired. The subgrade material immediately adjacent to the displaced subgrade material is disturbed and fractured and must also be excavated if permanent repair is desired.

There are several terms which are useful in describing a standard crater. The *true depth* of the standard crater is the depth from the original surface of the pavement to the deepest point of the surface of the undisplaced subgrade material. The *apparent depth* of the crater is the vertical distance from the original surface of the pavement to the deepest point on the surface of the subgrade material which has fallen back into the crater. The *true radius* of the crater is the distance from the center of the crater to the point at which the original surface of the pavement intercepts the surface of the undisplaced subgrade material. The *apparent radius* is the distance from the center of the crater to the point at which the original surface of the pavement intercepts the displaced subgrade material which has fallen back into the crater. Generally the only distances which are readily distinguishable to an observer are the apparent radius and the apparent depth.
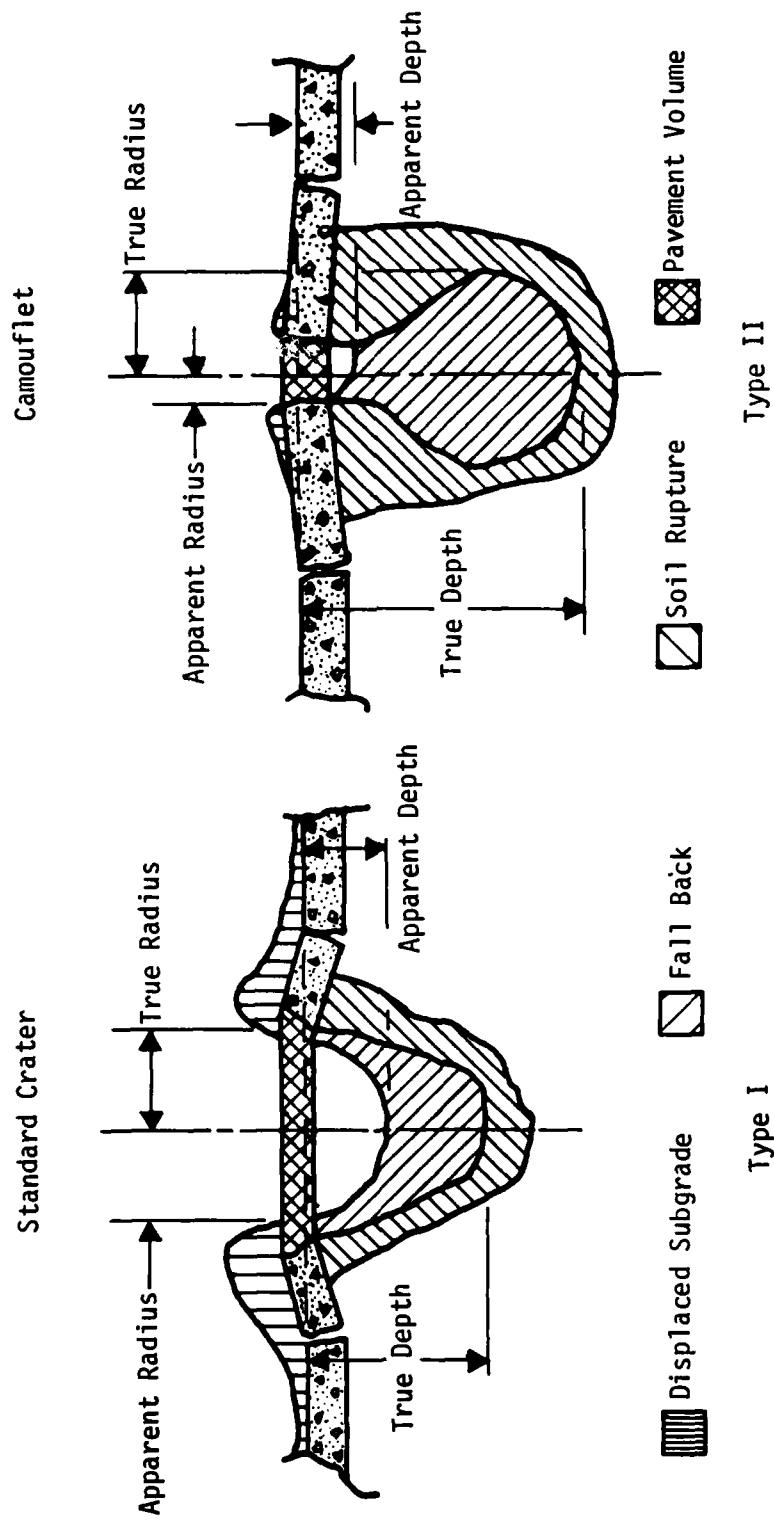
9

Camouflet

True Radius

Apparent Radius

Apparent Depth

True Depth

Type II

Standard Crater

True Radius

Apparent Radius

Apparent Depth

True Depth

Type I

⊠ Pavement Volume

▨ Soil Rupture

▨ Displaced Subgrade

▨ Fall Back

Figure 1. Types of Damages

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Spalling

Diameter

Type IV

Unexploded Ordnance
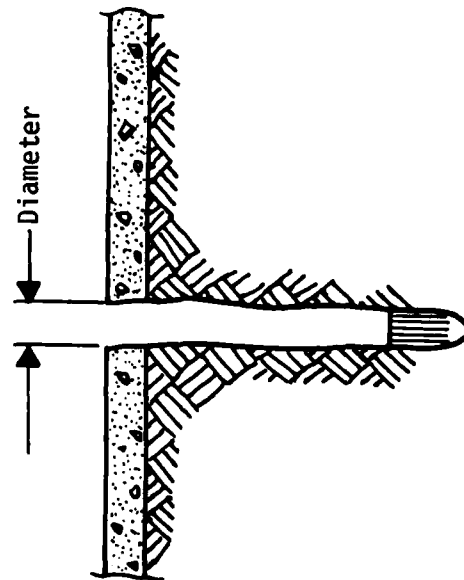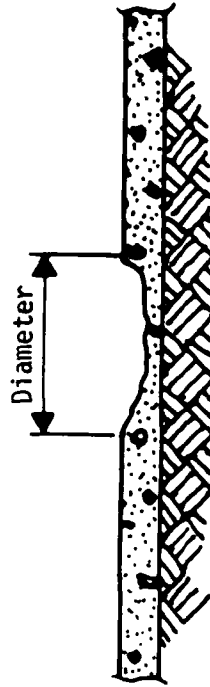
Diameter

Type III

Figure 1. Types of Damages (Concluded)

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The second type of damage is the *camouflet* which is designated as Type II damage. The camouflet may have a diameter of 4 inches to approximately 18 inches depending on the weight of the explosive head, the depth of burst, and the thickness and strength of the pavement. A weapon which forms a camouflet or a camo-heave penetrates the pavement--sometimes cleanly--and detonates at some distance below the surface of the pavement in the subgrade. The result of the explosion is a crater formed beneath the pavement. The pavement which immediately surrounds the port of entry of the explosive device may be moderately to radically upheaved, in which case the damage is known as a *camo-heave*. In other cases the surface of the pavement may not be disrupted. This type of damage is known as a *true camouflet*. The pavement which surrounds the port of the entry of the weapon may also be fractured or displaced, which fact aids in distinguishing between unexploded ordnance and the true camouflets. Spalling may also occur around the port of entry due to the impact of the weapon on the pavement or the explosion of the weapon beneath the subgrade.

The *true depth of the camouflet* is the distance from the original surface of the pavement to the deepest point of the undisplaced surface of the soil. The *apparent depth of the camouflet* is the distance from the original surface of the pavement to the deepest point of the surface of the displaced subgrade soil which has fallen back into the cavity. The *true radius of the camouflet* is the distance from the center of the port of entry to the outside edge of the surface of the displaced subgrade soil. The *apparent radius* is the distance from the center of the port of entry to the outside edge of the port of entry. The only parameter which is readily distinguishable by an observer is the apparent radius of the camouflet or camo-heave.

Type III damage is known as *unexploded ordnance*. Unexploded ordnance may be any of the types of weapons listed in Table 2 which penetrate the pavement and come to rest in the subgrade without detonating. The weapon could be a kinetic energy penetrator with a small explosive head (5 to 50 pounds), or it could be a larger weapon with an explosive head in excess of 386 pounds. The larger weapon could be equipped with a contact detonation device which failed to detonate, or it could be a weapon which is detonated by

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time-delay fuze, seismic impulse, magnetic signal, or acoustic signal. The diameter of the port of entry is a direct indication of the size of the explosive head of the weapon. If the diameter of the port of entry is 6 inches, the device is in the approximate 25-pound range, while if the diameter is 13 inches the weapon may be in the 750-pound range. The damage assessment system must be capable of determining the diameter of the port of entry to the nearest 2 inches in order to assess adequately the potential danger of any kind of unexploded ordnance.

The distinguishing characteristics of any unexploded ordnance are very similar to those of the camouflet with the exception that the explosive device is still below the surface of the pavement. It is extremely difficult to distinguish between camouflets and unexploded ordnance if there are no cracks in the surface of the pavement, no upheavals, and no displacements at the joints of the pavement around the port of entry. In order to make that distinction, the cavity created by the weapon has to be closely examined.

If there is a large cavity with evidence of displaced or highly disturbed soil, the damage is most likely a camouflet. However, the walls of the cavity created by the penetration of an unexploded piece of ordnance may collapse and give the appearance of the displaced subgrade soil of a camouflet. There is also the possibility that kinetic-energy penetrators may have been used. Such weapons may have a rocket-assist engine to propel them through the subgrade after they have penetrated the pavement. These devices may even travel beneath the surface parallel to the pavement and come to rest some distance from the port of entry. Determining the type of unexploded ordnance, as well as locating the final resting place of these devices, is beyond the scope of this project.

Type IV damage is the *surface spall*. A surface spall is defined as a rupture in the pavement surface which does not penetrate to the subgrade. Surface spalls may be caused by surface detonation of explosive devices or by small cannon fire. In any real attack it is anticipated that there would be a large number of surface spalls which may require repair.

SECTION IV
REPAIR EQUATIONS

There are several important parameters which affect the time required to provide expedient, semipermanent, or permanent repair of any type of runway damage. The most significant of these parameters affecting repair time is the area of moderately upheaved pavement. It has been demonstrated in tests conducted at Tyndall Air Force Base that approximately 60 percent of the total repair effort is spent in the removal of the upheaved pavement: 15 percent for the removal of radically upheaved pavement around the lip of the crater and 45 percent for removal of moderately upheaved pavement (References 1 and 2).

If the areas of moderately upheaved pavement are to be determined, several parameters must be known. The compressive strength of the concrete affects the extent of damage inflicted on the pavement, the size of the resulting crater, and the volume of pavement which must be removed. The apparent radius of the crater is one of only two parameters readily observable in a standard crater and is the *only* observable parameter for camo-heaves, camouflets, and unexploded ordnance.

The square of the apparent radius of the crater is directly proportional to the area of moderately upheaved pavement for standard craters and camo-heaves. The apparent radius is also directly proportional to the weight of the explosive head of a piece of unexploded ordnance. In determining the repair time for a given section of the total runway, it is essential to know the radius of the port of entry of an unexploded bomb. Then, if it is not possible to defuse the weapon, an estimate can be made as to how far the repair section must be from the unexploded weapon to eliminate the danger of detonation during the repair of the runway or during the later launch or recovery of aircraft from the repaired section of runway. The area selected for repair should not be within a given distance of an unexploded weapon; thus, large portions of the runway could be eliminated from consideration if the diameters or explosive weights of all unexploded weapons were known. This information would also decrease the time required for the data reduction process.

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The weight of the explosive head of the weapon also affects the area of the moderately upheaved pavement. There is no direct relationship, however, between the weight of the explosive head of the weapon and the parameters which are readily observable for the standard crater. However, the estimated weight of the explosive head can vary appreciably from the true weight of the explosive without having a significant effect on the predicted repair time.

There are several other parameters which would have a significant effect on the predicted repair time for any given crater. Unfortunately there are not enough data to examine the effects of these parameters on the predicted repair time. Some of these other important parameters which were not considered because of lack of reliable data are

1. Experience of the RRR team.

2. Depth of burst of the explosive head.

3. Angle of obliquity of the explosive head.

4. Thickness of the pavement.

5. Thickness of the asphalt overlay.

6. Density of the subgrade soil.

7. Type of subgrade soil.

8. Void ratio, porosity, and saturation of the subgrade soil.

9. Cohesive strength of the subgrade soil.

10. Distance of the repair materials from the repair area.

Dimensional analysis was used to determine the relationship between the area of the moderately upheaved pavement (A), the weight of the explosive head (W), the ultimate compressive strength of the concrete (f_c'), and the apparent radius of the crater (R). Since there are four independent variables

and two fundamental dimensions, two *pi* (π) terms are required to describe the relationship. The derivation of the required *pi* terms was conducted in the following manner:

$$A = f(W, f'_c, R)$$

$$L^2 = g(F, F/L^2, L)$$

Variables	Fundamental Dimensions	π_1	π_2
A	L^2		X
W	F	X	
f'_c	F/L^2	X	
R	L	XX	XX

$$\pi_1 = \frac{f'_c R^2}{W} \quad (1)$$

$$\pi_2 = \frac{A}{R^2} \quad (2)$$

Because there is a significant difference between the area of moderately upheaved pavement which must be removed for expedient repair (A_E) and that which must be removed for semipermanent repair (A_{SP}), separate relationships exist for each of the conditions. It is also necessary to distinguish between standard craters, camo-heaves, and camouflets, and to derive separate equations for each of the different types of damages.

CRATER EQUATIONS, UPHEAVED PAVEMENT

The data which were used to determine the equations were extracted from References 1, 2, and 3, and also from tests conducted both by the U.S. Army Waterways Experiment Station (WES), and by the USAF at Eglin and Tyndall Air Force Bases for large craters (Table 3). These data, contained in Table 3, are plotted in Figure 2. Regression techniques were used initially to determine the relationship between the *pi* terms. However, these resulting equations were dominated by the small crater data and tended to underestimate the true value of the area of the moderately upheaved pavement. The curves which are plotted in Figure 2 are the upper limits for expedient and semipermanent repair. These curves were found by assuming the form of the curve and solving for the constants by trial and error. The resulting equations

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TABLE 3. STANDARD CRATER EXPEDIENT REPAIR

Test Number	A_E, in^2	R, in	f'_c, psi	W, lb	A/R^2	$\frac{f'_c R^2}{W} \times 10^{-6}$	Calculated A_E, in^2
23	750	12.0	10,022	5	5.21	0.29	5,640
89	2,880	120.0	10,520	15	0.20	10.10	3,347
90	7,200	42.0	10,520	15	4.08	1.24	15,254
106	25,100	84.0	4,240	15	3.56	1.99	33,572
111	20,900	84.0	4,501	15	2.96	2.12	33,148
117	8,000	84.0	5,385	15	1.13	2.53	26,669
126	79,330	159.0	10,022	100	3.14	2.53	95,526
128	98,180	44.1	10,022	100	50.48	0.19	112,821
140	411,400	223.1	10,022	386	8.27	1.29	410,305

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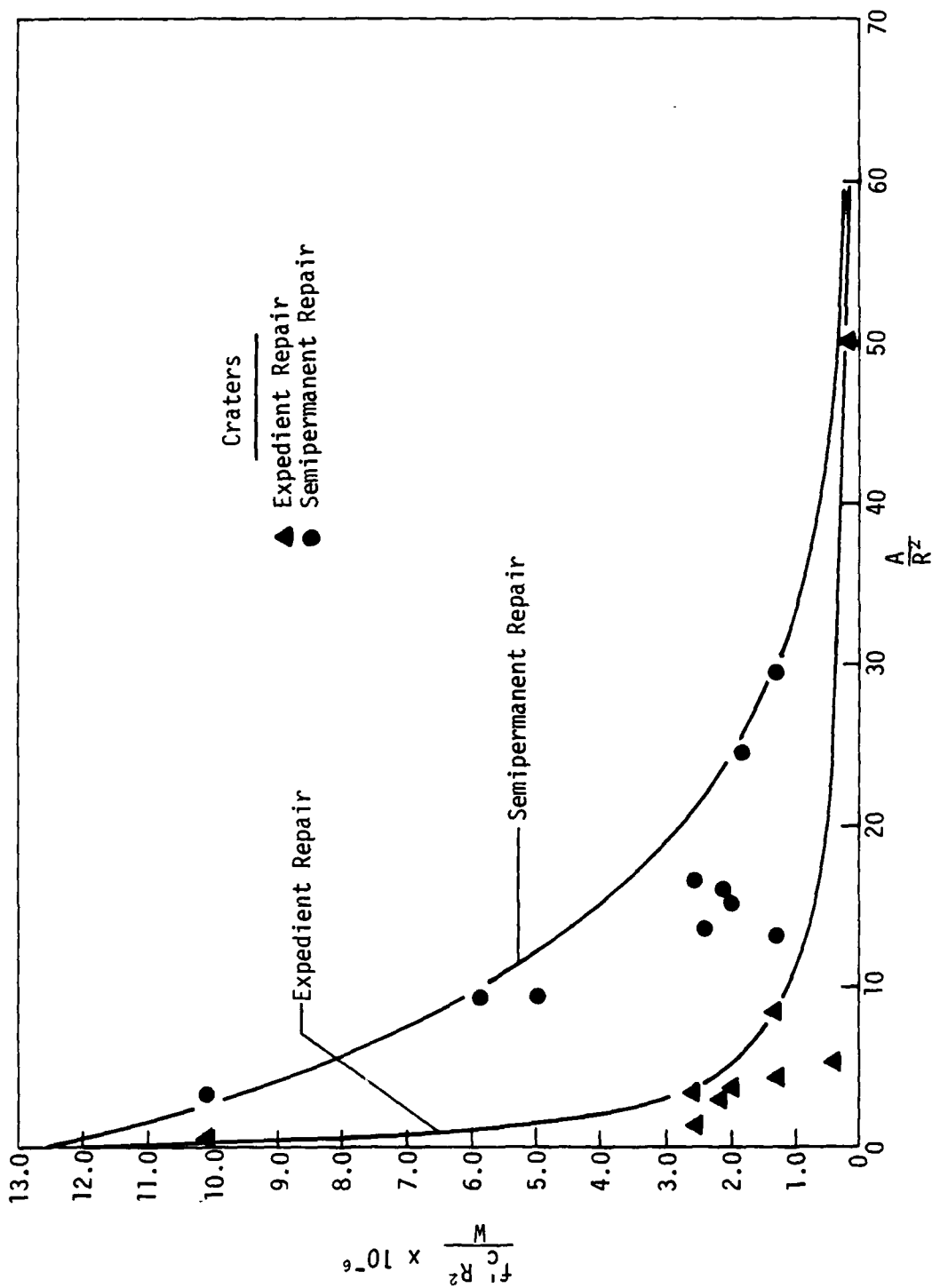
Figure 2. Pi-Term Graph for Data Points in Tables 3 and 4

give better results in the medium- and large-crater range; they are conservative in the estimation of the area of moderately upheaved pavement for small craters. The derivation of the equation for the expedient repair of standard craters is shown below:

$$\frac{f'_c R^2}{W} = (12.5 \times 10^6)\, C_1^{\left[\left\{C_2 \ln\left(\frac{A}{R^2} + 1\right)\right\}\right]}$$

$$\ln\left\{\frac{f'_c R^2}{W(12.5 \times 10^6)}\right\} = \left(C_2 \ln C_1\right) \ln\left(\frac{A}{R^2} + 1\right)$$

Let $C = \dfrac{1}{C_2 \ln C_1}$

$$\ln\left\{\frac{f'_c R^2}{W(12.5 \times 10^6)}\right\}^C = \ln\left(\frac{A}{R^2} + 1\right)$$

$$A_E = R^2\left[\left\{\frac{f'_c R^2}{W(12.5 \times 10^6)}\right\}^C - 1\right] \tag{3}$$

$C = -0.98$ (By trial and error)

The equation for the prediction of the area of the moderately upheaved pavement for semipermanent repair was derived in the same manner as the equation for expedient repair. The form of the semipermanent repair equation differs slightly from the expedient repair equation in that the natural logarithm of the A/R^2 term does not appear in the semipermanent repair equation. The data which were used in the formulation of the equation are listed in Table 4. The plot of the equation is also shown in Figure 2. The derivation of the equation for the semipermanent repair of standard craters is shown below.

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TABLE 4. STANDARD CRATER SEMIPERMANENT REPAIR

Test Number	A_{SP}, in^2	R, in	f'_c, psi	W, lb	$\frac{A}{R^2}$	$\frac{f'_c R^2}{W} \times 10^{-6}$	Calculated A_{SP}, in^2
8	26,880	54	10,022	5	9.22	5.84	29,083
31	63,830	51	10,022	15	24.54	1.74	67,332
79	23,260	42	10,500	15	13.19	1.23	53,573
80	46,860	59	10,520	15	13.46	2.44	74,589
83	64,230	84	10,520	15	9.10	4.95	85,782
89	46,210	120	10,520	15	3.21	10.10	40,293
90	52,060	42	10,520	15	29.51	1.24	53,529
106	106,500	84	4,240	15	15.09	1.99	169,906
111	112,800	84	4,501	15	15.99	2.12	164,376
117	115,300	84	5,385	15	16.34	2.53	147,775

$$\frac{f_c' R^2}{W} = (12.5 \times 10^6)\left[C_1^{\{C_2(A/R^2)\}}\right]$$

$$\ln\left\{\frac{f_c' R^2}{W(12.5 \times 10^6)}\right\} = (C_2 \ln C_1)\left(\frac{A}{R^2}\right)$$

$$A_{SP} = CR^2 \ln\left\{\frac{f_c' R^2}{W(12.5 \times 10^6)}\right\} \tag{4}$$

$$C = \frac{1}{C_2 \ln C_1} = -13.12 \qquad \text{(By trial and error)}$$

CAMO-HEAVE EQUATIONS, UPHEAVED PAVEMENT

The repair of camouflets does not require the removal of moderately up-heaved pavement. Therefore, a distinction must be made between camouflets and camo-heaves, which may have a significant amount of moderately upheaved pavement to be removed. The damage assessment system selected by the USAF must be capable of making this distinction.

The data which were used to predict the area of moderately upheaved pavement for expedient repair are compiled in Table 5. These data are plotted in Figure 3. The form of the equation was selected, and then the constants in the equation were evaluated by trial and error. The calculations for the derivation of the equation for the prediction of the area of the moderately upheaved pavement for the expedient repair of camo-heaves are given below.

$$\frac{f_c' R^2}{W} = 7.395 \times 10^6 \left(\frac{A}{R^2}\right)^{-0.89}$$

$$\left(\frac{A}{R^2}\right)^{-0.89} = \frac{f_c' R^2}{W(7.395 \times 10^6)}$$

TABLE 5. CAMO-HEAVE EXPEDIENT REPAIR

Test Number	A_E, in²	R, in	f'_c, psi	W, lb	$\frac{A}{R^2}$	$\frac{f'_c R^2}{W}$	Calculated A_E, in²
33	16,000	3	10,022	15	1,778	6,013	26,743
35	36,000	3	10,022	15	4,000	6,013	26,743
36	36,000	3	10,022	15	4,000	6,013	26,743
37	24,000	3	10,022	15	2,667	6,013	26,743
38	36,000	3	10,022	15	4,000	6,013	26,743
47	24,000	3	10,022	15	2,667	6,013	26,743
48	36,000	3	10,022	15	4,000	6,013	26,743
49	36,000	3	10,022	15	4,000	6,013	26,743
52	36,000	3	10,022	15	4,000	6,013	26,743
56	32,400	6	10,022	25	900	14,432	39,987
57	36,000	6	10,022	25	1,000	14,432	39,987
58	36,000	6	10,022	25	1,000	14,432	39,987
59	34,130	6	10,022	25	948	14,432	39,987
60	57,600	6	10,022	25	1,600	14,432	39,987
61	43,200	6	10,022	25	1,200	14,432	39,987
71	17,280	3	10,022	5	1,920	18,936	7,370
75	28,800	6	10,520	15	800	25,248	21,825
81	40,320	9	10,520	15	498	56,808	19,285
82	28,800	3	10,520	15	3,200	6,312	25,325
84	14,400	8	10,520	15	225	44,885	19,856
85	14,400	7	10,520	15	294	34,365	20,525
105	43,000	3	5,202	15	4,778	3,121	55,887
118	59,800	3	3,479	15	6,644	2,087	87,840
119	54,700	3	3,593	15	6,078	2,156	84,710
120	40,800	3	4,292	15	4,533	2,575	69,371
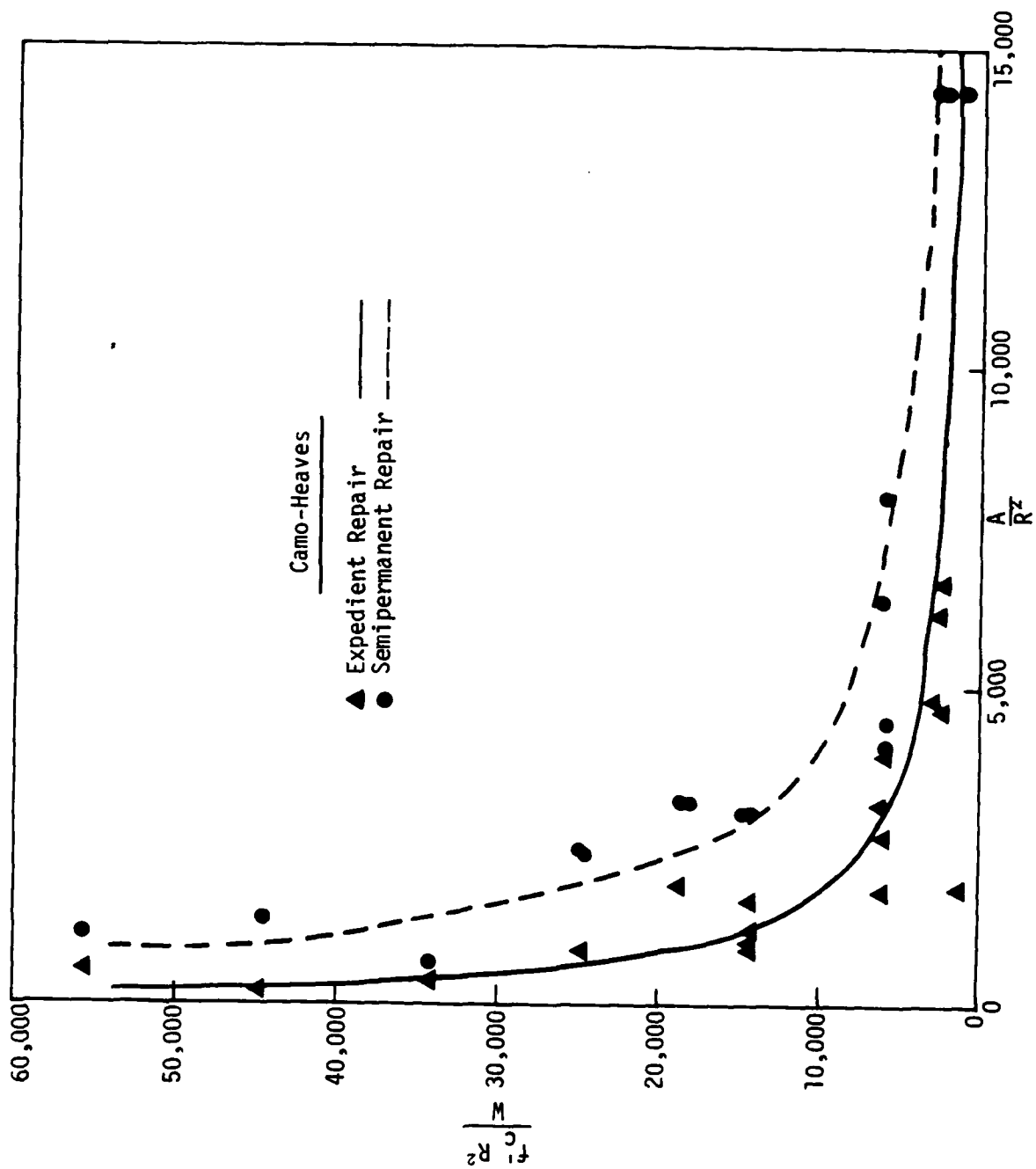
Figure 3. Pi-Term Graph for Data Points in Tables 4 and 5

$$-0.89 \ln\left(\frac{A}{R^2}\right) = \ln\left[\frac{f'_c R^2}{W(7.395 \times 10^6)}\right]$$

$$A_E = R^2\left[\frac{f'_c R^2}{W(7.395 \times 10^6)}\right]^{-1.124} \tag{5}$$

The equation used to predict the area of moderately upheaved pavement for expedient repair is extremely sensitive to the estimated diameter of the port of entry of the weapon. The damage assessment system which is ultimately selected must be able to determine the diameter of the port of entry to the nearest 2 inches, or the predicted repair time for the crater will be inaccurate.

The data used to determine the relationship between the pi terms for semipermanent repair are contained in Table 6. These data are plotted in Figure 3. Because the equation which predicts the area of the moderately upheaved pavement for semipermanent repair is also very sensitive to the estimated size of the port of entry of the weapon, the same precautions must be taken in determining the diameter of the port of entry. The derivation of the equation which predicts the area of moderately upheaved pavement for the semipermanent repair of camo-heaves is given below.

$$\frac{f'_c R^2}{W} = 4.133 \times 10^7 \left(\frac{A}{R^2}\right)^{-1.002}$$

$$\left(\frac{A}{R^2}\right)^{-1.002} = \frac{f'_c R^2}{W(4.133 \times 10^7)}$$

$$\frac{A}{R^2} = \left[\frac{f'_c R^2}{W(4.133 \times 10^7)}\right]^{-1.002}$$

$$A_{SP} = R^2\left[\frac{f'_c R^2}{W(4.133 \times 10^7)}\right]^{-1.002} \tag{6}$$

TABLE 6. CAMO-HEAVE SEMIPERMANENT REPAIR

Test Number	A_{sp}, in²	R, in	f'_c, psi	W, lb	A/R^2	$\dfrac{f'_c R^2}{W}$	Calculated A_{sp}, in²
33	71,970	3	10,022	15	7,997	6,013	62,962
35	71,970	3	10,022	15	7,997	6,013	62,962
36	71,970	3	10,022	15	7,997	6,013	62,962
37	71,960	3	10,022	15	7,996	6,013	62,962
38	35,970	3	10,022	15	3,997	6,013	62,962
47	35,970	3	10,022	15	3,998	6,013	62,962
48	36,000	3	10,022	15	4,000	6,013	62,962
49	71,980	3	10,022	15	7,998	6,013	62,962
52	71,970	3	10,022	15	7,997	6,013	62,962
56	107,900	6	10,022	25	2,997	14,432	104,753
57	107,900	6	10,022	25	2,997	14,432	104,753
58	107,900	6	10,022	25	2,997	14,432	104,753
59	108,000	6	10,022	25	3,000	14,432	104,753
60	107,900	6	10,022	25	2,997	14,432	104,753
61	108,000	6	10,022	25	3,000	14,432	104,753
71	28,770	3	10,520	5	3,197	18,936	19,948
75	86,290	6	10,520	15	2,397	25,248	59,809
81	86,140	9	10,520	15	1,063	56,808	59,712
82	57,570	3	10,520	15	6,397	6,312	59,975
84	86,200	8	10,520	15	1,347	44,885	59,741
85	28,670	7	10,520	15	585	34,365	59,772
105	129,600	3	5,202	15	14,400	3,121	121,459
118	129,600	3	3,479	15	14,400	2,087	181,759
119	129,600	3	3,593	15	14,400	2,156	175,981
120	129,600	3	4,292	15	14,400	2,575	147,268

CRATER REPAIR TIME EQUATION

As stated previously, the repair time is a function of the area of the moderately upheaved pavement. The data used to derive the relationship are contained in Table 7 and plotted in Figure 4. The equation of the curve is found by regression techniques using a least-squares method. For the relationship which is shown in Figure 4 there is approximately a 99-percent probability that the equation is valid. The scatter of the data about the curve is attributed to the wide range of repair crew experience. The scatter can be reduced by a significant amount if an experience factor is included in the equation. The form of the equation, the constants, and the factor are given below.

$$t = aA^b$$
$$a = 59.9 \quad b = 0.16$$
$$t = (59.9) A^{0.16} \tag{7}$$

TABLE 7. REPAIR TIME

Test Designation	Repair Time, min	Area of Moderately Upheaved Pavement, ft^2
TYD T-1	283	1,771.1
TYD T-2	221	1,302.2
TYD 1-4NE	150	281.3
TYD 1-3	140	1,503.5
AFCEC LC$_a$	238	2,322.6
AFCEC LC$_b$	175	1,701.8
AFCEC LC$_d$	120	1,503.5
AFCEC SC$_a$	150	328.3
AFCEC SP	29	0.0
Theoretical Limit	240	2,150.0

REPAIR TIME NOMOGRAPHS

Nomographs have been developed to assist in the determination of repair time (Figures 5 and 6). The curves for prediction of the area of the moderately upheaved pavement for expedient repair have been superimposed on the
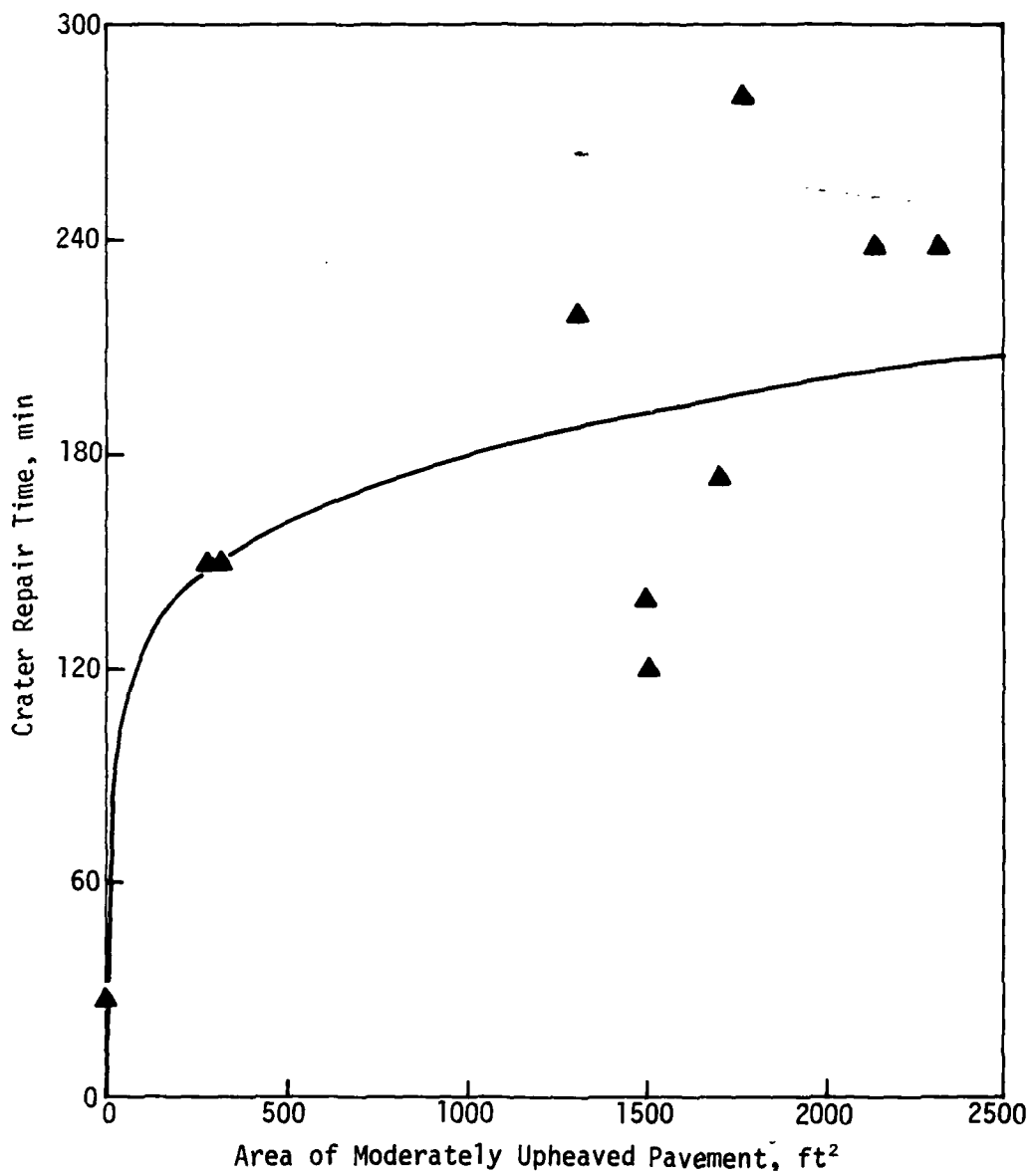
Figure 4.   Crater Repair Time versus Area of Moderately Upheaved Pavement
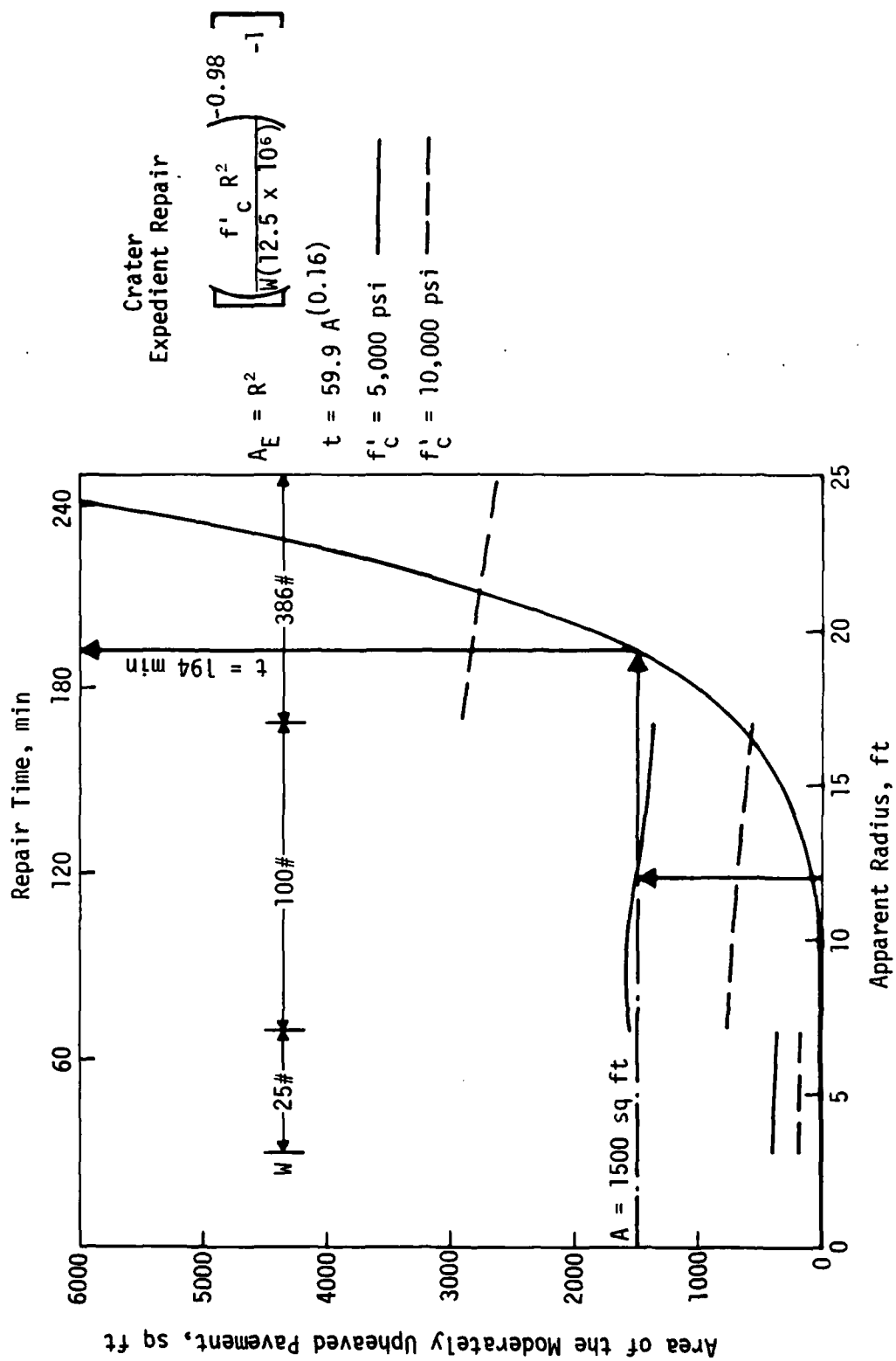
Figure 5. Standard Crater Nomograph for Expedient Repair

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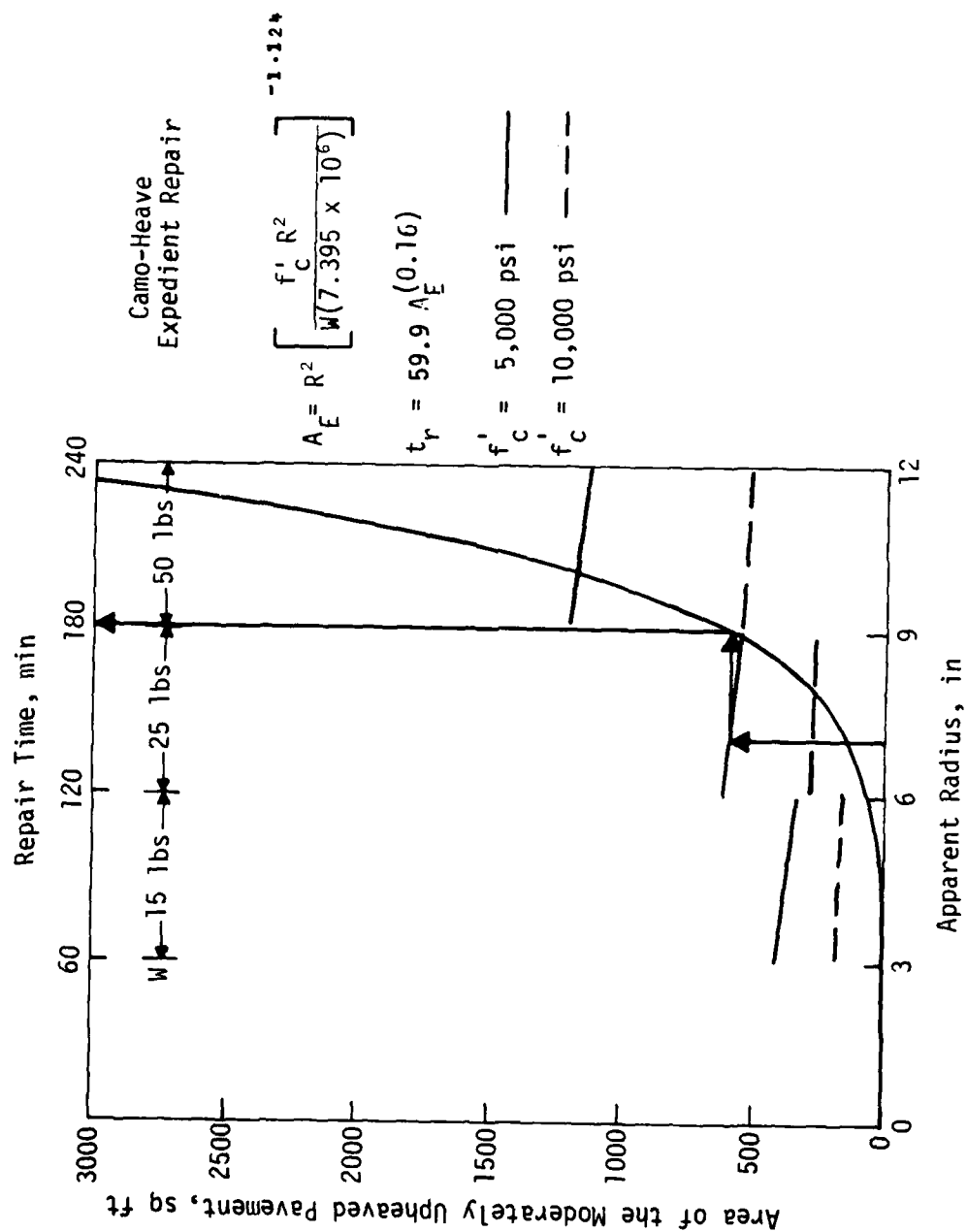
Figure 6. Camo-Heave Nomograph for Expedient Repair

repair time prediction curve for both standard craters and camo-heaves. In order to obtain the repair time for a given crater, one must know the apparent radius. The magnitude of the apparent radius is located on the horizontal axis of the nomograph. A line is then plotted vertically which intersects the curve for the given value of the ultimate compressive strength (f'_c) of the concrete. From this point a horizontal line can be drawn which intersects both the vertical axis and the repair-time prediction curve. The area of the moderately upheaved pavement can be read from the vertical axis and added to the area of the crater to determine the volume of base course required to repair the crater. A vertical line can then be extended from the point of intersection of the repair-time prediction curve to the horizontal repair-time axis, and the required repair time in minutes can be read from the chart. Arrows representing the steps of this procedure are shown in Figures 5 and 6. In Figure 5, the apparent radius is assumed to be 12 feet, and a port of entry of 7 inches is assumed in Figure 6. Figure 5 indicates that 194 minutes would be required to repair the crater. Figure 6 indicates a repair time of 180 minutes for the camo-heave. These repair times correspond to the amount of time it would take one-third of the RRR team to effect expedient repair on the given damages. The apparent radius of the standard crater or the apparent diameter of the camo-heave must be provided by the damage assessment system, and the ultimate compressive strength of the concrete, usually contained in base pavement evaluation reports, must be known. The weight of the explosive head of the weapon is estimated from the diameter of the crater at the port of entry.

IDENTIFICATION OF CAMOUFLETS

There are several factors which may assist in the identification of camouflets. First, there may be a small amount of displaced subgrade material strewn about the port of entry of the weapon. Second, there may be a significant amount of surface spalling around the port of entry of the weapon due to the blast. Third, it is possible that large cracks radiating out from the port of entry of the weapon may be observed. Fourth, displacements of 1 to 3 inches may be observed between pavement slabs. It should be noted, however, that these factors may not be readily observable. Displacement of subgrade material and surface spalling around the port of entry of the weapon do not always occur; and even if they do occur, the displaced subgrade material may cover up all signs of the camouflet if the camouflet is in the proximity of a

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crater. The pavement displacements and the cracks which may radiate out from the port of entry may be too small to observe, or they may not even exist. In summary, it may not always be possible to distinguish between camouflets and unexploded ordnance. Therefore, it is extremely important that the damage assessment system be capable of accurately determining the apparent diameter of the port of entry of the weapon in order that the size of the explosive head of an unexploded weapon can be estimated with confidence.

. At present a standard method for the repair of surface spalls and small craters has not been developed. In order to handle the large number of surface spalls in the design attack, an average repair time of 30 minutes is assigned to each surface spall regardless of size. This time is assigned in order that all of the proposed systems can be evaluated fairly and representatively. When a standard method for the repair of surface spalls is introduced, the repair time estimate can be revised; or a formula can be used which will predict an accurate repair time.

SECTION V
DAMAGE ASSESSMENT AND DATA REDUCTION METHODS

PRELIMINARY

The original subtask statement required that many different types of damage assessment methods be investigated. Conventional surveying and topographical methods were to be researched, and if these methods could not be used, other methods were to be investigated. Several limitations were placed on the damage assessment and data reduction methods. These methods are discussed in detail in Section II and are included here for reference:

1. The system must function independently of base facilities.

2. The system must observe a 30-minute time limit for damage assessment and data reduction.

3. The system should be as simple as possible, consistent with the time constraint imposed for selecting a repair area.

Other factors also play an important role in the determination of the best system. The system should accurately distinguish between camouflets and unexploded ordnance, where such a distinction can be made. The on-the-ground resolution of the system should be small enough to distinguish between debris on the runway and perforations in the runway. The economics of the system should be considered. (Is the increased cost for higher resolution justifiable?) Another factor which must be considered is whether the system can provide fast and accurate information on the degree of damage sustained by other base facilities. This assessment would have bearing on the selection of the repair area because the aircraft must be able to get to launch site as quickly as possible.

MANUAL METHODS

Several manual methods were investigated. These methods propose using USAF personnel who are not highly skilled but who have been trained to complete the investigation. Manual methods would be cheap, could be implemented

quickly, and would use equipment and personnel already dedicated to the RRR. However, the manual methods are extremely slow in both damage assessment and data reduction.

The first manual method utilizes conventional electronic distance-measuring and surveying equipment to locate the damage. As stated before, the postulated attack consists of 125 discrete damages. Under ideal circumstances (unobstructed and long-sight distances, daytime, cool temperatures, no anti-personnel mines, no chemical, biological, nor radiological environment), the individual damages could be located in an estimated average time of 4 minutes per damage. This corresponds to a damage assessment time in excess of 8-1/2 hours, which violates the required limit of 15 minutes. The system would be inexpensive and easy to implement because personnel with the required skills would be readily available. This system, however, would be extremely suscep-tible to adverse environmental conditions such as antipersonnel mines or chemi-cal, biological, or radiological contamination. If clusters of antipersonnel mines have been dropped on the runway, it is questionable whether the system could function at all because the area would have to be cleared by EOD per-sonnel before the system could even be initiated.

The second manual method involves the use of teams of jeeps, each equipped with a two-way radio, a driver, and an observer. The jeeps (two per runway) would then be driven down the edges of the runway (where possible) and the location and magnitude of the damage would be relayed by radio to a base station. The observer would have to determine the type of damage and estimate the longitudinal station and its distance from the side of the pavement. This system would be inexpensive, would utilize equipment, personnel, and skills al-ready in the RRR package, and could be implemented in a relatively short period of time. There are, however, several disadvantages to this system. The average area of the runway which must be evaluated is 250 feet wide and 10,000 feet long. If it takes 4 minutes for each jeep to locate each damage site and relay the information to the base station, the damage assessment would take just 4 hours. If damage assessment must be accomplished at night, it would be difficult to locate the camouflets and unexploded ordnance. The probability of missing a large, unexploded weapon which could damage an aircraft or hinder the repair

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effort would be extremely high. It would also be difficult to estimate the longitudinal stationing and the lateral location of bomb damage with sufficient accuracy. Adverse environmental conditions could also delay this manual reconnaissance effort. If it were necessary to find unexploded ordnance in the adjacent grassed areas, it is questionable whether such a system could be utilized without loss of personnel. NMERI recommends that these manual methods of reconnaissance be used only as backup for a more rapid and dependable system.

The third manual method involves the visual observation of damage from an aerial platform such as a helicopter or small aircraft. The location and magnitude of damage could be relayed by radio to a base station or recorded on computer cards or tabulated and taken back to the base station for reduction. This system would require a helicopter, a pilot, and two observers. This system would not be curtailed by adverse environmental conditions at the surface. However, approximately the same amount of time to locate and assess damage would be required as the second manual system. It is recommended by CERF that this system be used in conjunction with another aerial system which has better on-the-ground resolution. The observer could then be used to make a rapid determination of a runway area which had not sustained any damage or significantly less damage than any other runway area. This information could then be used to select an alternate runway or to assist the computer reduction method in the selection of the repair area.

There are two basic methods for the manual reduction of data. First, the damage can be plotted on a scaled plan view of the runway. A transparency representing the relative size of the repair area could then be manipulated around the damage areas until the area with the least amount of damage is located. This method was tested by NMERI and found to be effective with the following reservations:

1.   The reduction method is very slow. It takes experienced personnel at least 2 minutes per alternate runway area investigated. If longitudinal increments of 500 feet and lateral increments of 50 feet are used and if no inclined areas are investigated, data-reduction time would be approximately 3-1/2 hours. Unless part of the runway area can be eliminated from consideration by aerial observation, NMERI recommends that this system be used only as a backup for a computer-based system.

2. Manual entry of data into a desktop calculator (comparable in size
to an HP 9825) could accomplish the data-reduction procedure for longitudinal
increments of 100 feet and lateral increments of 25 feet. It could also
investigate inclined sections, all in approximately 30 minutes.

PHOTOGRAMMETRIC METHODS

Two aerial-based photogrammetric methods were investigated. The first
photogrammetric method utilizes conventional photogrammetric film in a stand-
ard camera. The camera is flown at a constant rate of speed and a constant
altitude. The film is then brought back to the base film-processing facility
where it is developed. The data supplied by the film can then be reduced by
the manual methods explained previously or by scanning the film with a video
or vidicon camera and processing the information with video processing equip-
ment similar to that described under Primary System Recommendation in this
report. The reconnaissance could be accomplished in approximately 10 minutes,
but there would be a delay of at least 2 hours while the film was being devel-
oped. After the film has been developed, it would take approximately 30 min-
utes per runway to scan the photographs and select the repair area.

The second method is identical to the first with the exception that Quick-
Strike Reconnaissance (QSR) telemetry data could be used to provide the
reconnaissance data. This would eliminate the 2-hour minimum time requirement
for film processing if the base had its own data link and recorder. This
method would be fast, accurate, and would not be curtailed by adverse environ-
mental conditions. The data could be reduced rapidly, and the on-the-ground
resolution should be sufficient. For instance, the system should be able to
distinguish between camo-heaves and unexploded ordnance and to determine the
diameter of the port of entry of an unexploded weapon with the required accu-
racy. The system, however, does not meet the 30-minute time limit requirement
for reconnaissance and data reduction. It is also questionable whether the
reconnaissance aircraft can provide QSR telemetry data of the required airport
facilities and runways immediately after an attack. NMERI recommends that
the QSR system be used only as a backup for the linear photodiode array system
recommended in this report.

VIDICON TECHNIQUES

There are three basic methods which fall under the general category of vidicon techniques. The first system is a high-frequency, low-light-level video or vidicon camera which would operate at approximately 50 megahertz and have a frame size of approximately 1,500 by 1,100 picture elements or *pixels*. The second system would use three conventional low-light-level vidicon cameras mounted in parallel. The third system would use a linear photodiode array of 1,728 elements mounted perpendicular to the centerline of the runway.

There are several reasons why vidicon techniques should be used for the damage assessment system:

1. The time required to collect the data is reduced from 2 to 8 hours to 10 minutes. The vidicon camera or the linear photodiode array is mounted on a stabilized platform in a helicopter or small aircraft and flown at 60 mph above the centerlines of the selected runways, main taxiway, and alternate runway. At that speed it would take approximately 2 minutes to scan each individual runway. A scan can also be made of the entire airport facility from a greater height to provide information on repair routes.

2. The resolution is good (1.9-inch-square element size on the ground for a linear photodiode array and a 3-inch-square for the other vidicon cameras).

3. The time required to reduce the data and select the runway section would be reduced from 2 to 4 hours to 20 minutes if the data reduction were accomplished by operator interaction with video processing equipment and automatic feature extraction software.

4. The runway selection process utilizing a minicomputer to analyze the data is fast and accurate.

5. The reconnaissance system would not be curtailed by antipersonnel mines or a biological, chemical, or radiological environment.

6. The system utilizes personnel already involved with damage assessment.

7. The system can determine the diameters of the ports of entry of unexploded ordnance and thus eliminate unsafe areas from consideration in the selection process.

8. The system would be capable of locating large antipersonnel mines located on the runways and in the adjacent grassed areas.

9. The system can pinpoint the locations where unexploded ordnance may have penetrated the earth in the grassed areas adjacent to the runway, provided the grass is not so tall that it covers the ports of entry.

10. The system can be used to provide a quick, low-resolution scan of the entire airbase facility.

11. It would be relatively easy to train qualified personnel to operate the video processing equipment.

In order to permit a better understanding of the operation of a conventional vidicon camera, a brief description of its operation is included here.

The conventional vidicon camera utilizes an electron beam to scan a photoconductive target (Figure 7). A light pattern is focused on the target by means of a conventional photographic lens. The electron beam scans the photoconductive target, charging it to a negative potential. When the target is illuminated, the conductivity increases, and the back side of the target changes to a more positive value. The electron beam then reads the signal by depositing a proportionate charge on the positive areas, resulting in a capacitively-coupled signal to the signal electrode.

The vidicon is extremely useful because of its simplicity, good quantum efficiency, low cost, and small size. However, the vidicon camera requires a vacuum tube which limits the types of environments in which the camera may be used. It is also limited in its low-light-level applications because it becomes laggy as the light level decreases and its dark current begins to dominate the signal. High light levels are also difficult to handle with a vidicon camera because of blooming effects. However, the most serious limitation of the vidicon camera is the user's inability to predict the exact position of its beam. Most vidicon cameras use magnetic deflection to control the position of the beam. The positional accuracy can be influenced by magnetic materials in the proximity of the deflection yokes. Therefore, to determine the stationing of the image accurately, it is necessary to do on-line calibration each time the magnetic environment changes.
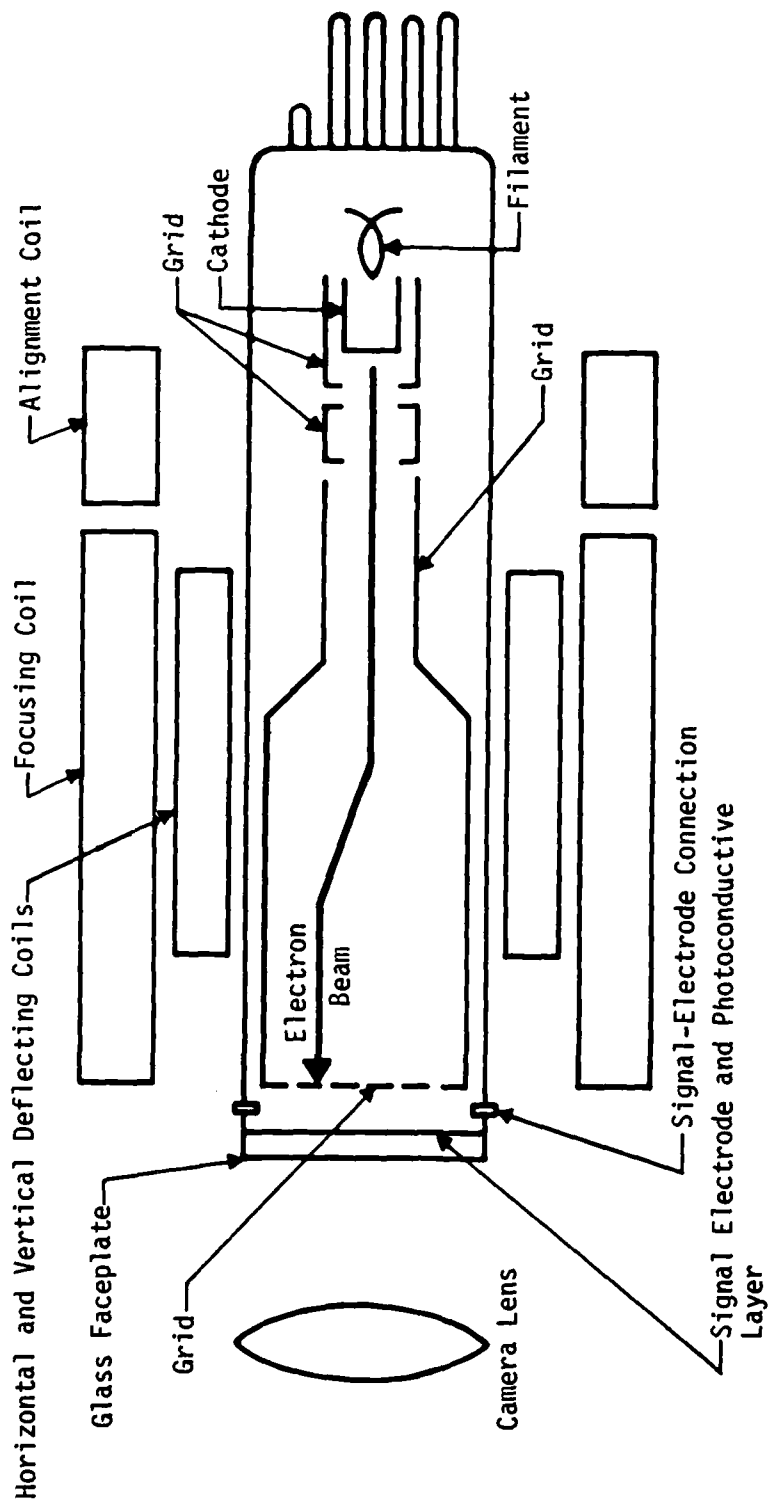
Figure 7. Vidicon Camera

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Other problems associated with tube type vidicon cameras which would limit their usefulness in a reconnaissance effort of this type are:

1. The inability of the system to utilize a variable scan rate controlled by the ground speed of the helicopter.

2. The frequency of operation which would be required to yield the required resolution.

3. The unavailability of vidicon and data-processing equipment which operate at the required data transfer rate (50 megahertz).

4. The large quantity of unusable data which would be generated by the camera.

5. The reduction in resolution due to the vibrational frequencies and motion of the helicopter.

The third vidicon technique considered by CERF involves the use of a linear photodiode array sensor (Figure 8) in the place of the conventional vidicon camera. The linear photodiode array is a self-scanning image sensor which utilizes a silicon chip containing a row of photodiodes and a parallel shift register. A more detailed description is given below.

The principle necessary for development of a linear photodiode array sensor was first discovered by Reynolds (Reference 4), who described a beam-scanned silicon target comprised of a multiplicity of *pn* junctions. Summers (Reference 5) analyzed the possible use of silicon targets for use as solid state image sensors and concluded that the technology did not exist in 1963 to produce vidicons comparable to those already in existence.

In 1965 the first practical use of storage mode operation in a monolithic integrated structure was realized. A device was developed that used 200 photodiodes on 2.5-mil centers. Each photodiode was associated with a metal oxide semiconductor-field effect transistor (MOS-FET). The gates of the MOS-FETs were brought off the chip and connected to an external scan generator. The

References

4. Reynolds, F. W., U.S. Patent 3041089.

5. Summers, H. S., Jr, "Response of Photoconducting Image Devices with Floating Electrodes," *Journal of Applied Physics*, Vol. 34, No. 10, pp. 2923-2934, October 1963.
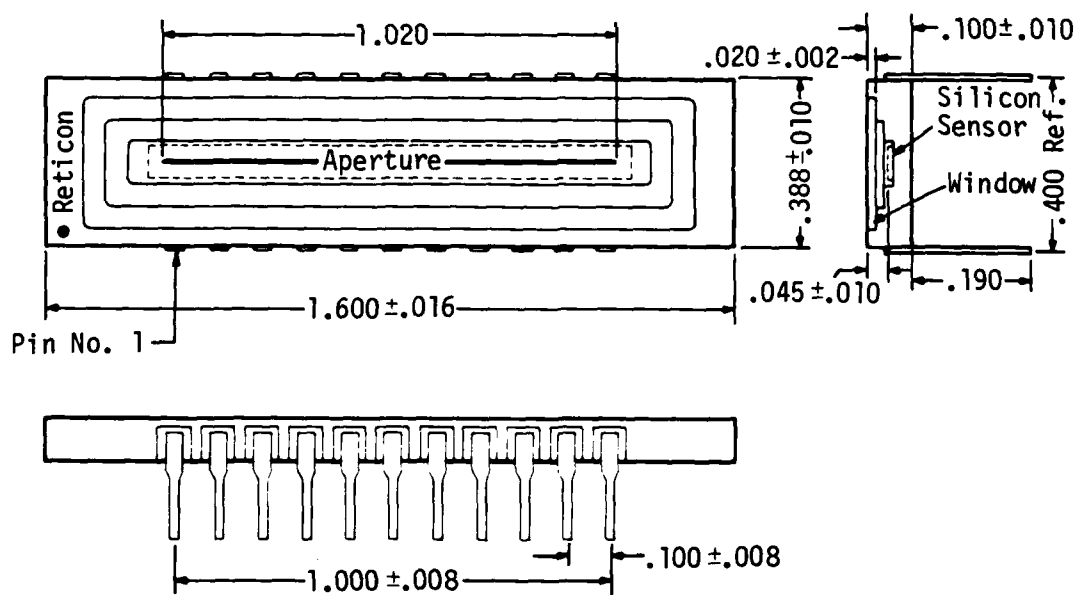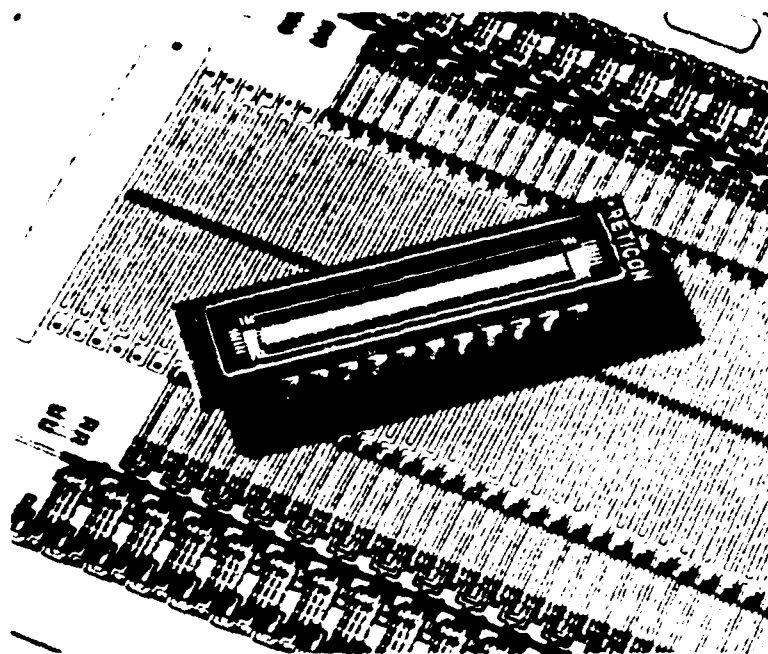
Figure 8. Linear Photodiode Array

array was used in a camera with a rotating mirror and was extremely fragile.
The photodiode MOS-FET combination was later replaced by a phototransistor
operating in the storage mode. This decision was made due to the face that the
transistor technology was much further advanced than MOS-FET technology. Some
of the advantages of using phototransistors were: (1) lower operating voltages,
(2) signal enhancement due to transistor gain, and (3) ease of fabrication.
The major difficulty of the phototransistor--and the reason that the develop-
ment of the phototransistor was later abandoned in favor of the photodiode--
was the random variations in transistor gain and low-level threshold due to
the emitter offset. However, several years were spent trying to overcome these
difficulties, and both linear and area arrays which use phototransistors were
developed. These arrays required external scan generators. This interface
between the array and the external scan generator increased cost, decreased
reliability, and degraded performance. The next generations of arrays would
incorporate the scanning function as well as the sensors on the same monolithic
chip.

During the period when phototransistor technology was being developed, MOS
technology made tremendous advances. The marriage between MOS circuit tech-
nology and the photodiode array led to present day self-scanning photodiode
image sensors.

Modern solid state image sensors utilize highly developed integrated cir-
cuit technology. The image is detected by absorption in the silicon of pho-
tons within an energy range from 1.1 to about 6 electrovolts (eV). This
corresponds to electromagnetic waves with wavelengths from 0.2 micron (μ)
to 1.1 μ (Figure 9). The absorption of a photon by the silicon generates an
electron hole pair. The electron hole pair is separated, and the charge equi-
valent to one electron appears on the depletion region capacitance. Once
the charge has been detected, the information must be detected at the terminal.
There are many different methods to detect this information in solid state
detector design. The two most commonly used methods are shown in Figure 10.
The first linear photodiode array utilizes a digital shift register to access
a transfer switch sequentially which connects individual picture elements or

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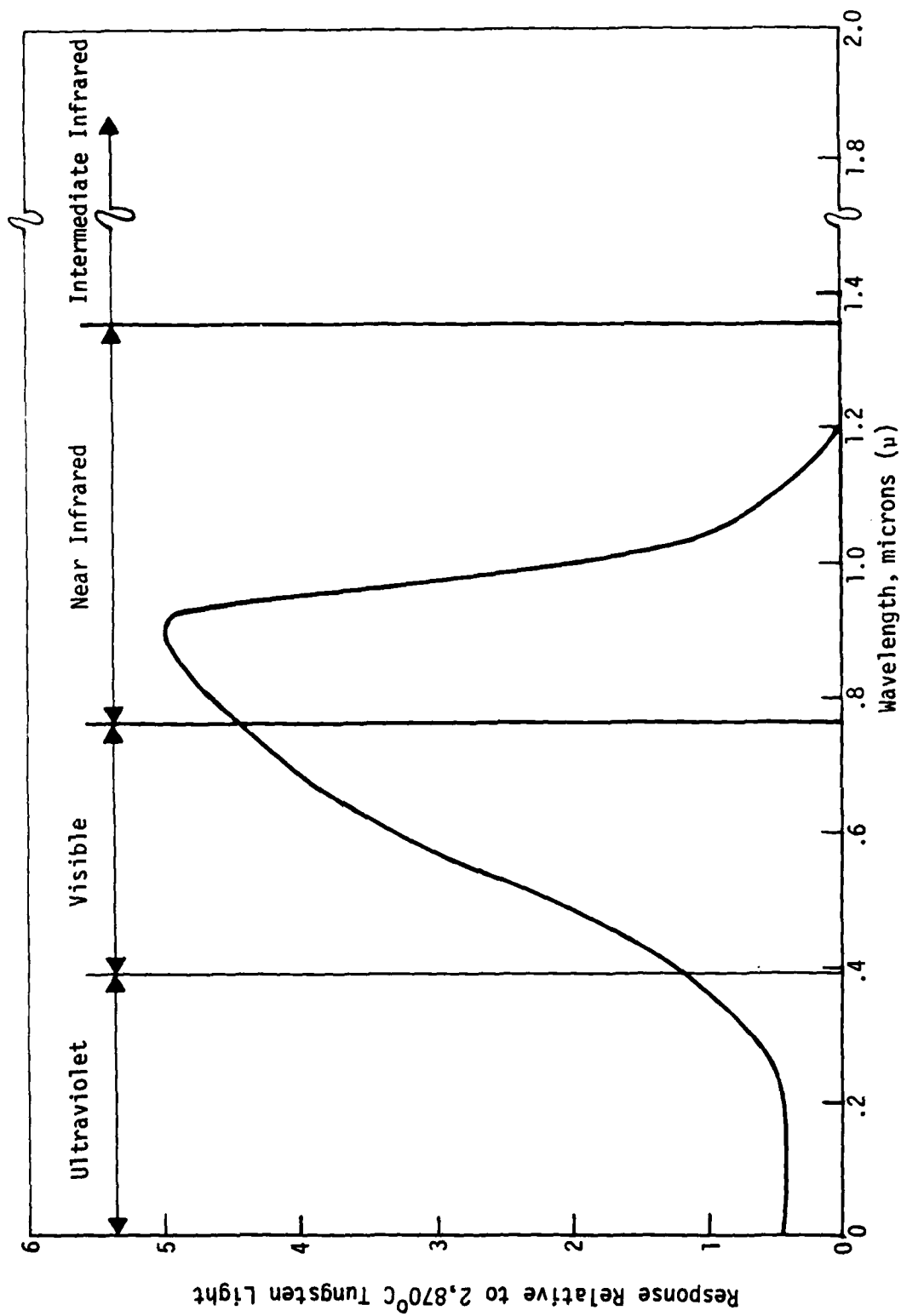
Figure 9. Spectral Response of Solid State Image Sensor

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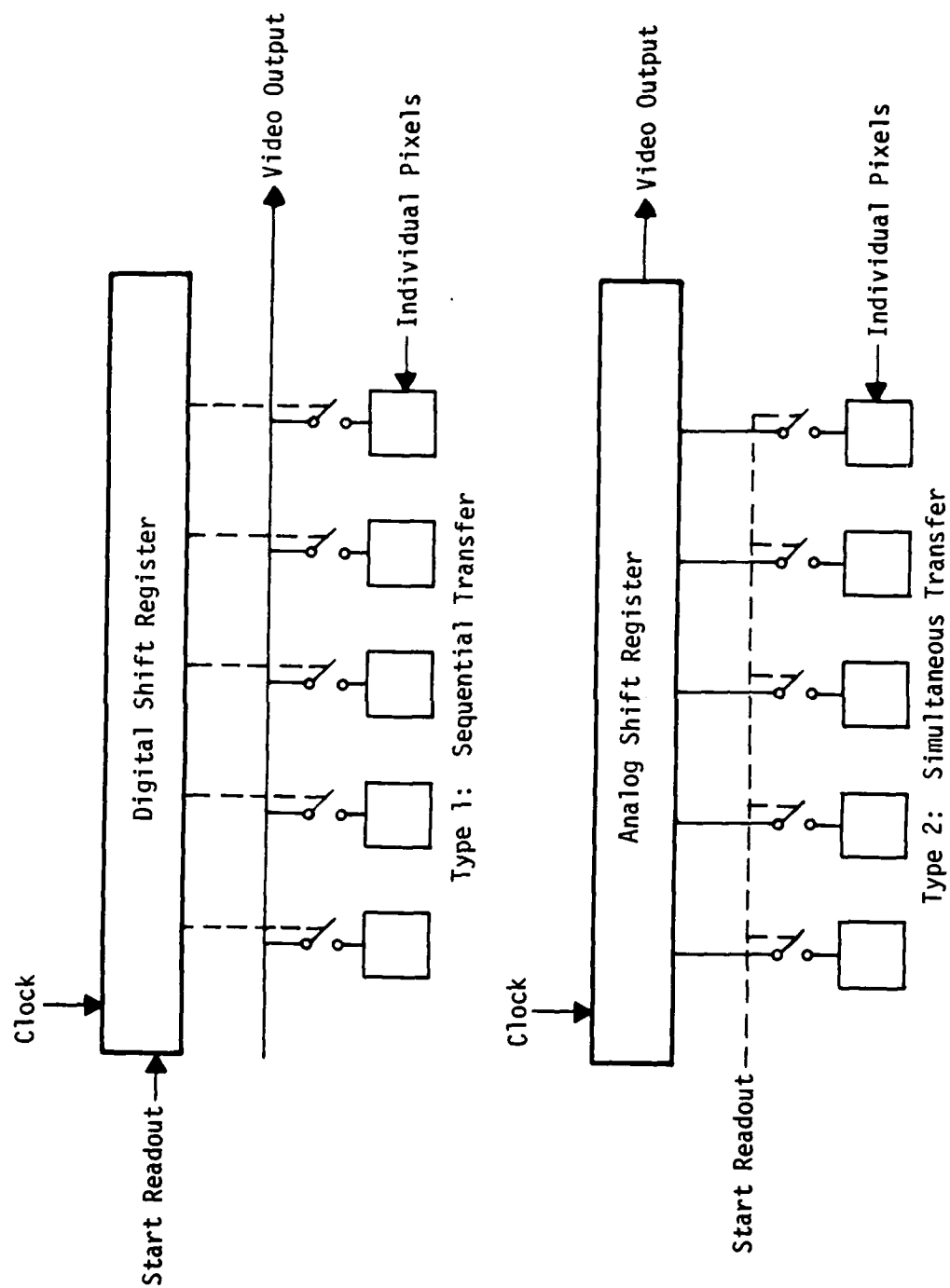
Figure 10. Most Commonly Used Readout Techniques

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pixels to a common terminal. The second method utilizes a transfer switch for each pixel, but the pixels are sampled simultaneously, transferring the information in parallel to an analog shift register. The type of application described in this report favors the sequentially sampled photodiode array because of its higher uniformity and freedom from blooming.

To better understand the operation of a linear photodiode array, it would be helpful to examine the circuit diagram in Figure 11. The device consists of a row of photodiodes mounted on a silicon chip and a parallel shift register. The gate of a MOS switch, which couples the adjacent photodiode to a common video line, is connected to each stage of the parallel shift register. The shift register is driven by complementary-square wave voltages. Each scan is initiated by a start pulse which loads a pulse that is clocked through the register, thus sequentially opening and closing the switches. In this manner each individual photodiode is connected to the video line. When the photodiodes are sampled, they are charged to the video line potential and are left open circuited until the next scan. Between scans the photodiodes accumulate a charge equal to the instantaneous photocurrent integrated over the line-scan time. The integrated charge on each photodiode is then discharged through the video line as it is sampled during the line scan. The output video signal is of charge pulses which have magnitudes proportional to the intensity of the incident light. This particular mode of operation is called the *charge storage mode*.

The sensitivity of the sensor is directly proportional to the scan rate because the lower the scan rate, the longer the photodiodes can integrate the charge. Sensitivity is defined in terms of charge per unit of exposure, where *exposure* is defined as the light intensity multiplied by the time interval between scans. The relationship between relative output and exposure is shown in the graph in Figure 12. The dynamic range (the ratio of maximum signal to the noise level) may be enhanced using pixel-by-pixel computer correction. The dynamic range for an individual pixel may be in excess of 30,000:1. The grey-scale requirements for the system would dictate that the array have a dynamic range of 50:1, which is easily achieved at the specific scan rate. The

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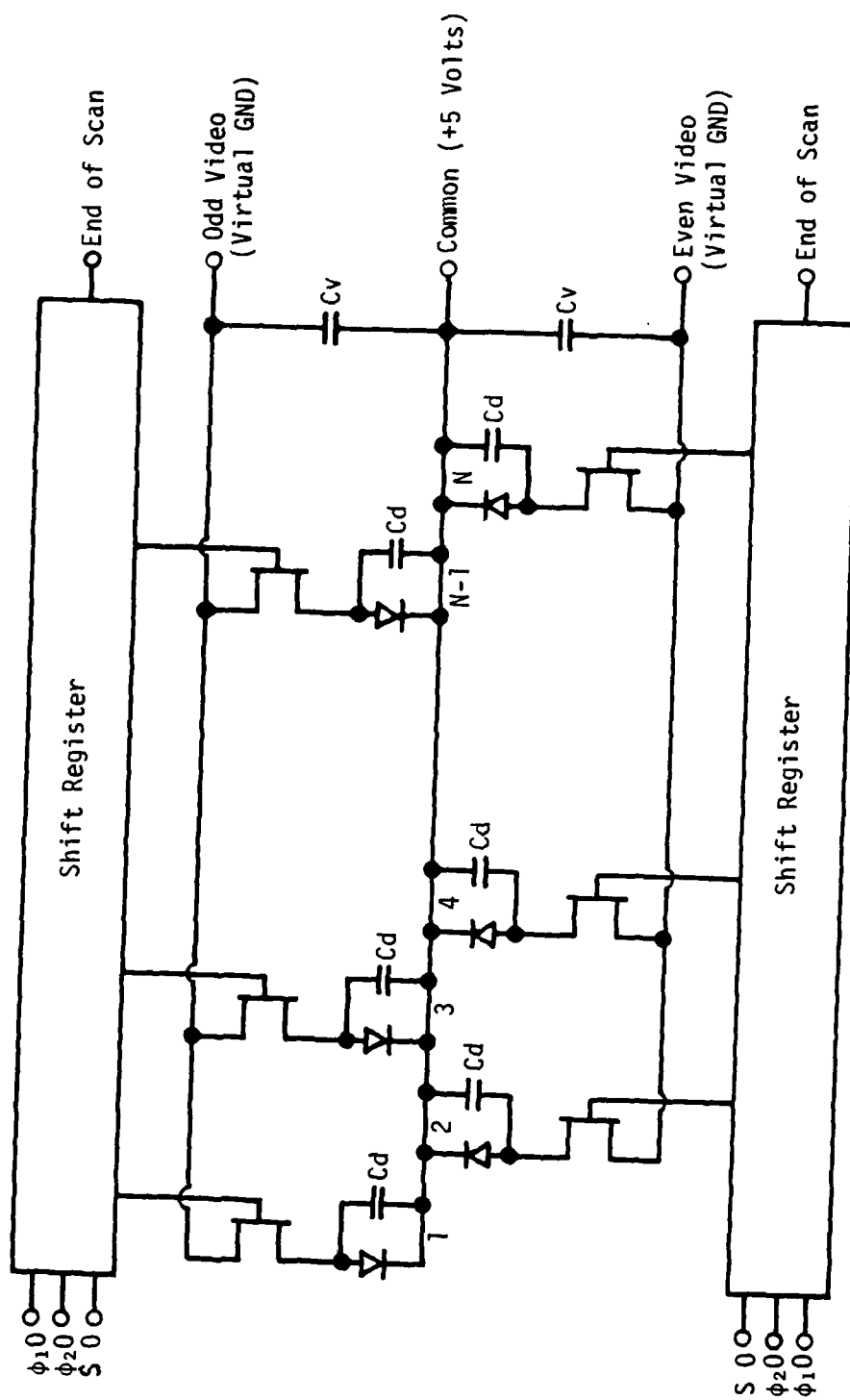
Figure 11. Linear Photodiode Array Diagram

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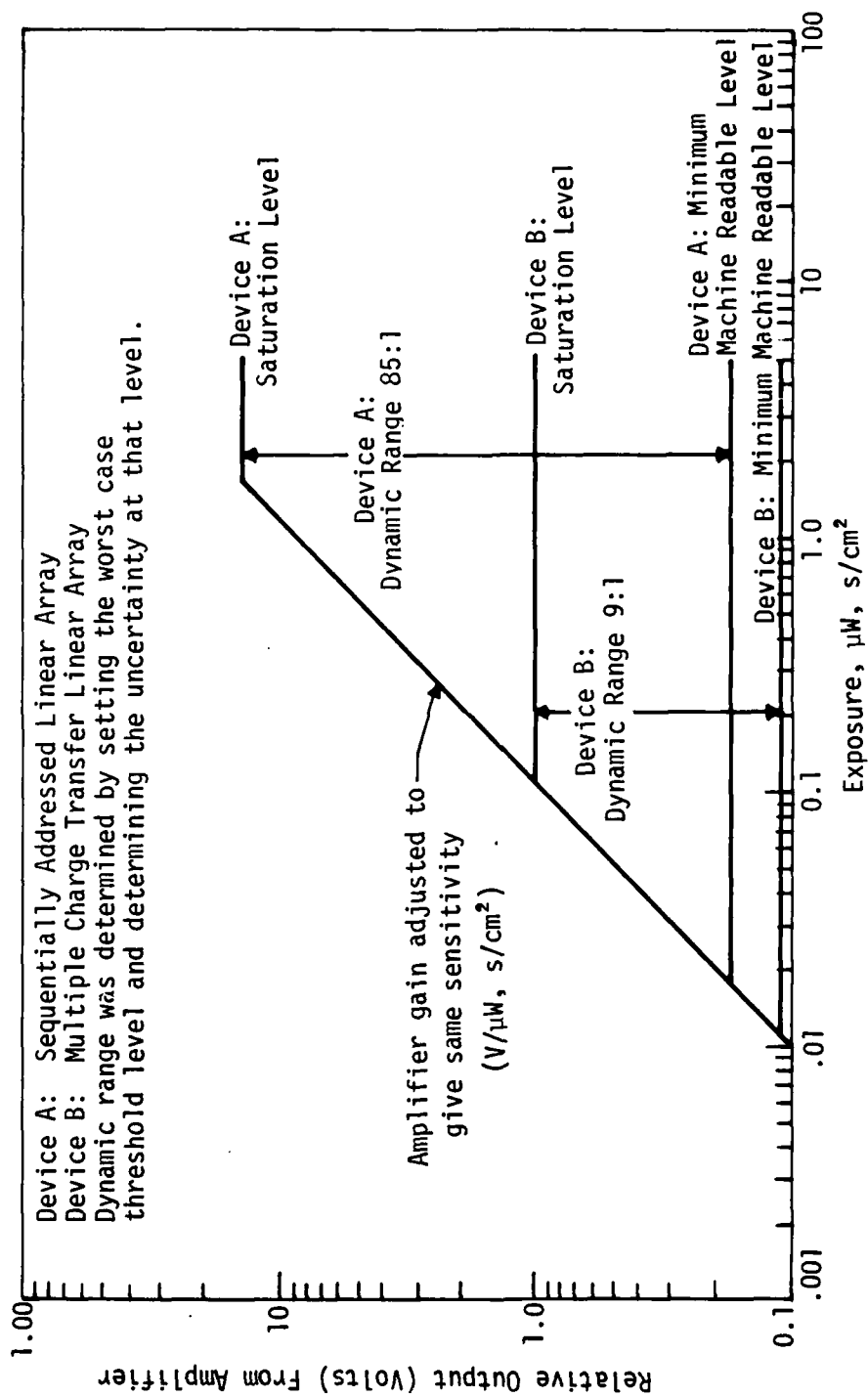
Figure 12. Dynamic Range

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scan rate for the linear photodiode array is calculated as follows:

Velocity of helicopter (v_H) = 88 feet per second

Number of elements per array (n) = 1728

Width of viewing area (w_A) = 270 feet

Width of resolution on the ground (w_R) = $\frac{270}{1,728}$ (12) = 1.875 inches

Number of lines per second required (N) = $\frac{88(12)}{1.875}$ = 563.2 lines per second

Scanning rate (R) = (1728) (563.2) = 973,209.6 hertz

Use: R = 975 kilohertz

A comparison of the three vidicon systems is given in Table 8. The first two systems generate an excessive amount of redundant data whereas the linear photodiode array does not. The on-the-ground resolution of the linear photo-diode array is almost twice that possible with the conventional vidicon cameras. For these reasons and because of the previously listed problems associated with the conventional vidicon cameras, NMERI recommends that a linear photodiode array with at least 1,728 elements be used for the application discussed in this report.

INFRARED TECHNIQUES

There are many different types of sensors available commercially today which detect infrared waves at different wavelengths. Some of these methods are conventional photography or photogrammetry using infrared film, the vidi-con camera, photothermionic image converters, evaporographs, and infrared-sensitive phosphors. A list of other infrared detectors which are available commercially are contained in Table 9.

Infrared radiation can be divided into three principal regions (Figure 13). The first region is the near-infrared region. This region begins with electro-magnetic waves with a wavelength of 0.76 micron (μ) and extends to wavelengths of 1.35 μ. This corresponds to temperatures of 3,577°C - 1,847°C. Inter-mediate infrared radiation goes from 1.35 to 40 μ, corresponding to tempera-tures of 1,847°C to -200°C, and the far infrared region extends from 40 to 1,000 μ, corresponding to temperatures of -200°C to near absolute zero.

TABLE 8. DATA STORAGE REQUIREMENTS

Description	LSI 8850	Three Conventional LLL	Linear Array Photodiode
Runway Size	250 ft x 10,000	Same	Same
Minimum Resolution	3-in Square on Ground	Same	Same
Minimum Number of Points Per Line	1,000	1,000	1,000
Aspect Ratio	4:3	1:1	1:1,728
Operating Frequency	50 MHz	3 x 10 MHz	1.00 MHz
Frame Size	1,500 x 1,110 pixels	3(575 x 575) pixels	1 x 1,728 pixels
Resolution on the Ground	2.5 in	2.3 in	1.9 in
Number of Data Points Generated Per Runway	5.70×10^9	3.42×10^9	1.14×10^8
Number of Nonusable Data Points Generated	5.64×10^9	3.35×10^9	0
Cost of Camera	$25,000	$30,000	$6,000
Cost of Storage Device	$100,000	$25,000	$15,000
Cost of Vidicon and Data Processing Equipment	$500,000	$250,000	$170,000

TABLE 9. CHARACTERISTICS OF INFRARED DETECTORS

Detector Material	Operating Mode[a]	Useful Wavelength Range[b], μ	Wavelength of Peak Response, μ	Resistance, Ω[c]	Time Constant, μs	D*(500 K Blackbody), cm(Hz)$^{1/2}$ W^{-1} (at Frequency Indicated)[d]	D*(at Peak Response), cm(Hz)$^{1/2}$ W^{-1} (at Frequency Indicated)[d]
Thermal Detectors							
Room-Temperature Operation							
Thermocouple	Thermoelectric	1-40	--	1-10	25,000	$3\text{-}12 \times 10^8(5)$	$6\text{-}15 \times 10^8(5)$
Evaporated Thermopile	Thermoelectric	1-40	--	100	5,000	$1 \times 10^8(20)$	$2 \times 10^8(20)$
Thermistor Bolometer	Bolometer	0.2-40	--	$1\text{-}5 \times 10^6$	2,000	$0.3\text{-}1.2 \times 10^8(15)$	$1\text{-}3 \times 10^8(15)$
Ferroelectric Bolometer	Bolometer	1-12	--	--	--	$1.1 \times 10^8(15)$	--
Golay Cell	Gas Expansion	5-1000	--	--	20,000	$1\text{-}5 \times 10^9(10)$	$5\text{-}10 \times 10^9(10)$
Low-Temperature Operation							
Niobium Nitride Bolometer (16°K)	Superconducting	--	--	0.2	550	$5 \times 10^9(360)$	$5 \times 10^9(360)$
Carbon Bolometer (2.1°K)	Bolometer	40-100	--	0.12×10^6	10,000	$4 \times 10^{10}(13)$	$4 \times 10^{10}(13)$
Germanium Bolometer (2.1°K)	Bolometer	5-2000	--	12×10^3	400	$8 \times 10^{11}(200)$	$8 \times 10^{11}(200)$
Photon Detectors							
Room-Temperature Operation							
Silicon	PV	0.5-1.05	0.84	$0.1\text{-}1 \times 10^5$	100	$10^{10}\text{-}10^{11}(90)$	$1\text{-}5 \times 10^{11}(90)$
Lead Sulfide (PbS)	PC	0.6-3.0	2.3-2.7	$0.5\text{-}10 \times 10^7$	50-500	$1\text{-}7 \times 10^9(800)$	$50\text{-}100 \times 10^9(800)$
Indium Arsenide (InAs)	PV	1-3.7	3.2	20	1	$1\text{-}3 \times 10^8(900)$	$3\text{-}7 \times 10^9(900)$
Indium Arsenide (InAs)	PEM	1.4-3.8	3.4	--	1	--	$6 \times 10^9(1000)$
Lead Selenide (PbSe)	PC	0.9-4.6	3.8	$1\text{-}10 \times 10^6$	2	$0.7\text{-}2 \times 10^8(800)$	$1\text{-}4 \times 10^8(800)$
Indium Antimonide (InSb)	PEM	0.5-7.5	6.2	20	0.1	$0.8 \times 10^8(1000)$	$0.3 \times 10^9(1000)$
Operation at 195°K							
Lead Sulfide (PbS)	PC	0.5-3.3	2.6	$0.5\text{-}5 \times 10^7$	800-4000	$0.7\text{-}7 \times 10^9(800)$	$20\text{-}70 \times 10^{10}(800)$
Indium Arsenide (InAs)	PV	0.5-3.5	3.2	--	1	$1\text{-}5 \times 10^9(1800)$	$3\text{-}25 \times 10^{10}(1800)$
Indium Arsenide (InAs)	PEM	1.3-3.6	3.2	--	1	$3 \times 10^9(1000)$	$20 \times 10^{10}(1000)$
Lead Selenide (PbSe)	PC	0.8-5.1	4.2	10×10^6	30	$2\text{-}4 \times 10^9(800)$	$1\text{-}4 \times 10^{10}(800)$
Indium Antimonide (InSb)	PC	0.5-6.5	5.1	20	1	$1 \times 10^9(800)$	$0.5\text{-}0.9 \times 10^{10}(800)$

[a] PV = photovoltaic, PC = photoconductive, PEM = photoelectromagnetic.

[b] Wavelengths between which D* exceeds 0.2 of its peak value.

[c] Value shown is for a square element. For PV detectors, the value is the dynamic impedance dV/dI.

[d] All D* values given for a detector viewing a hemispherical surround at a temperature of 300°K.
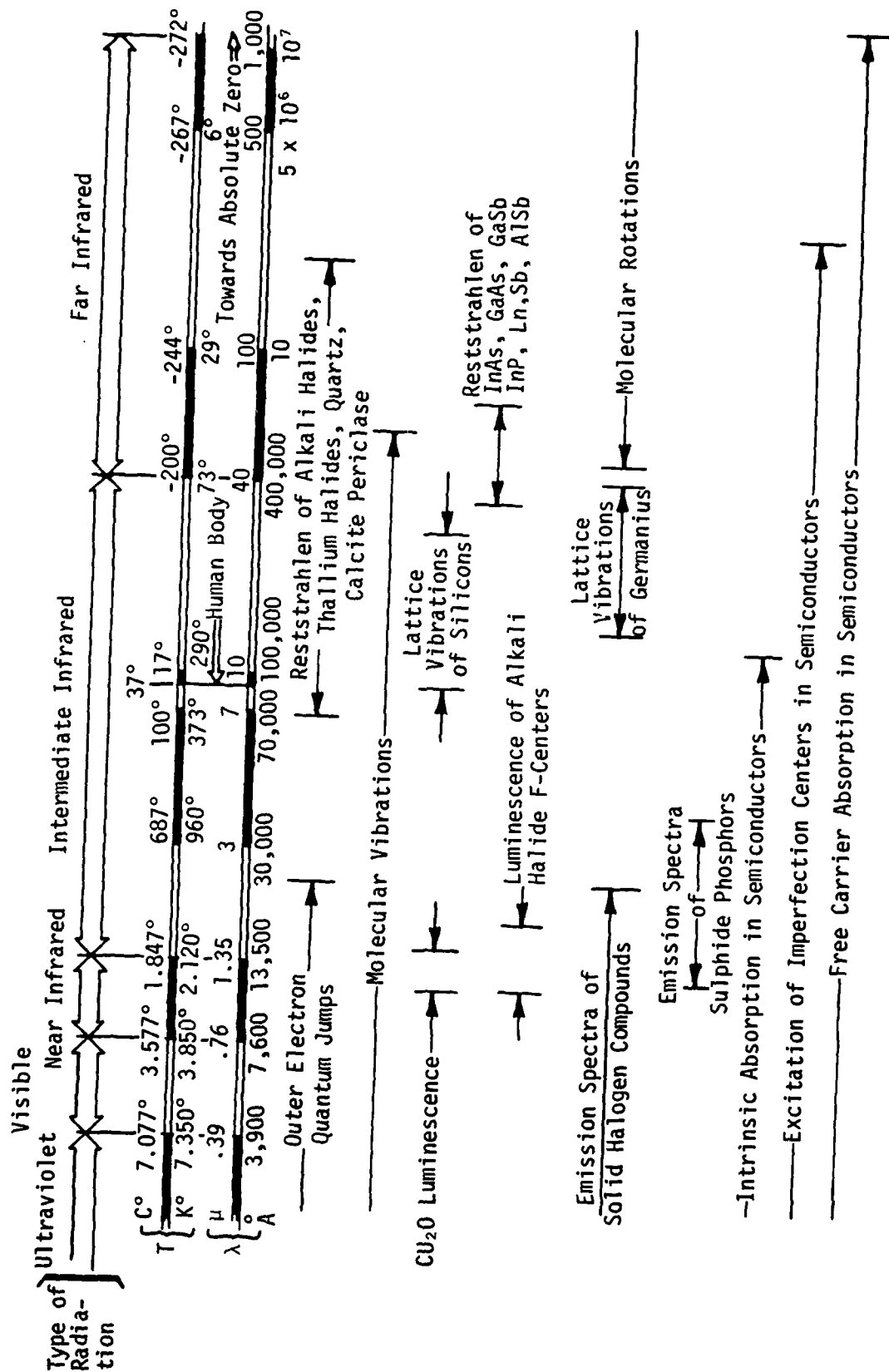
Figure 13. Visible and Infrared Spectrum

Two infrared techniques were investigated in detail. The first is photo-
grammetry using conventional infrared film. A conventional camera is used with
infrared film and filters to screen out the light in the ultraviolet and visi-
ble ranges. The value of using a film which is sensitive in the near-infrared
region is that infrared sensitive films have the capability of recording tonal
gradations not visible to the naked eye nor recordable with normal photographic
films. Often it is possible to obtain an infrared signature of certain events
because of the variations in their reflectivity. There is a possibility that
a camouflet may leave an infrared signature different from the unexploded
ordnance. The system would also function well at night, be relatively unaf-
fected by haze, and would be fast, accurate, and inexpensive. However, there
are several problems associated with such a system. First, the infrared film
is difficult to work with. It must be maintained at a cool temperature and
is affected by variances from optimum humidity (45 to 50 percent). As with
the conventional photogrammetric system, there would be a 2-hour delay while
the film is being developed. Not all bases have the capability to develop
infrared film. The data would be reduced in the same manner as the conven-
tional photogrammetric method. Thus this method violates two of the three
requirements: it uses base facilities, and it exceeds the time limit. For
these reasons, NMERI recommends that this system not be developed further.

The second infrared system is a vidicon system which operates in the inter-
mediate range and is sensitive to minute variations in temperature. As a body
is heated, its atoms become excited and begin to emit electromagnetic waves
at many wavelengths. The warmer the body, the shorter the wavelength. Bodies
at temperatures between 1,847°C and -200°C emit waves which are predominantly
in the intermediate infrared range. The vidicon camera can be fitted with
filters which allow only a narrow band of waves to pass through. The result-
ing image is a measure of the variations in temperature of the body and its
surroundings. This technique is called *thermal scanning* and is used for the
plotting of temperature profiles of effluents from large factories into lakes
or oceans and for detecting heat loss from buildings, etc.

The thermal scanning system was initially investigated because it was
hoped that the high-temperature gases and the air, which are both emitted from
a camouflet, might be used to distinguish between camouflets and unexploded

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ordnance. However, large temperature differentials would only exist for a short period of time after an attack. The detection of small temperature differentials (2°C to 5°C) would be extremely difficult or impossible in the environment likely to exist immediately after an attack. If the reconnaissance is to take place during the day, thermal cushioning and pluming from adjacent craters would most likely cover all traces of the camouflets. NMERI recommends that this system be given no further consideration.

MAGNETOMETER TECHNIQUES

Four types of magnetometers are commonly in use today: fluxgate, proton precession, Schmidt field balance, and dip needle. The Schmidt and dip-needle magnetometers are rapidly being replaced because they are mechanical systems that are cumbersome to operate and less accurate than fluxgate and proton magnetometers. The proton magnetometer is also gradually replacing the fluxgate magnetometer because of its greater sensitivity (1 gamma or better), absolute accuracy, nonmoving parts, and its ability to measure absolute field intensity without orientation errors. The proton magnetometer utilizes a precession of spinning protons or nuclei of hydrogen atoms emersed in a hydrocarbon field. The spinning protons act as tiny dipoles. These magnets are temporarily aligned by the introduction of a uniform magnetic field generated by a current in a coil. When the current in the coil is removed, the spinning protons precess about the ambient magnetic field and generate a current in the coil originally used to align them. This current is directly proportional to the magnetic field intensity and is independent of the orientation of the coil.

The proton magnetometer can be used to measure small differences in the ambient magnetic field caused by any unexploded metallic ordnance which has penetrated the pavement. However, the proton magnetometer is affected only by the ferrous materials and alternating currents which may be in the area. If the unexploded ordnance is nonferrous, the magnetometer will not detect it. It is also questionable whether the magnetometer could detect the presence of unexploded ordnance through a thick concrete pavement. NMERI recommends that a magnetometer be used to assist in detecting unexploded ordnance only in cases such as a port of entry where no visual distinction can be made between unexploded ordnance and camouflets.

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REMOTE SENSING METHODS

Remote sensing methods detect reflected electromagnetic waves from a location removed by some distance from the body being observed (Figure 14). The following systems were investigated but were found to be impractical for the reconnaissance applications under consideration: radiometry, multispectral scanners, radar, optical radar, holography, acoustics (sonar), longwave radar, microwave, passive microwave, and seismic systems. Table 10 contains a list of the advantages and disadvantages of each system.
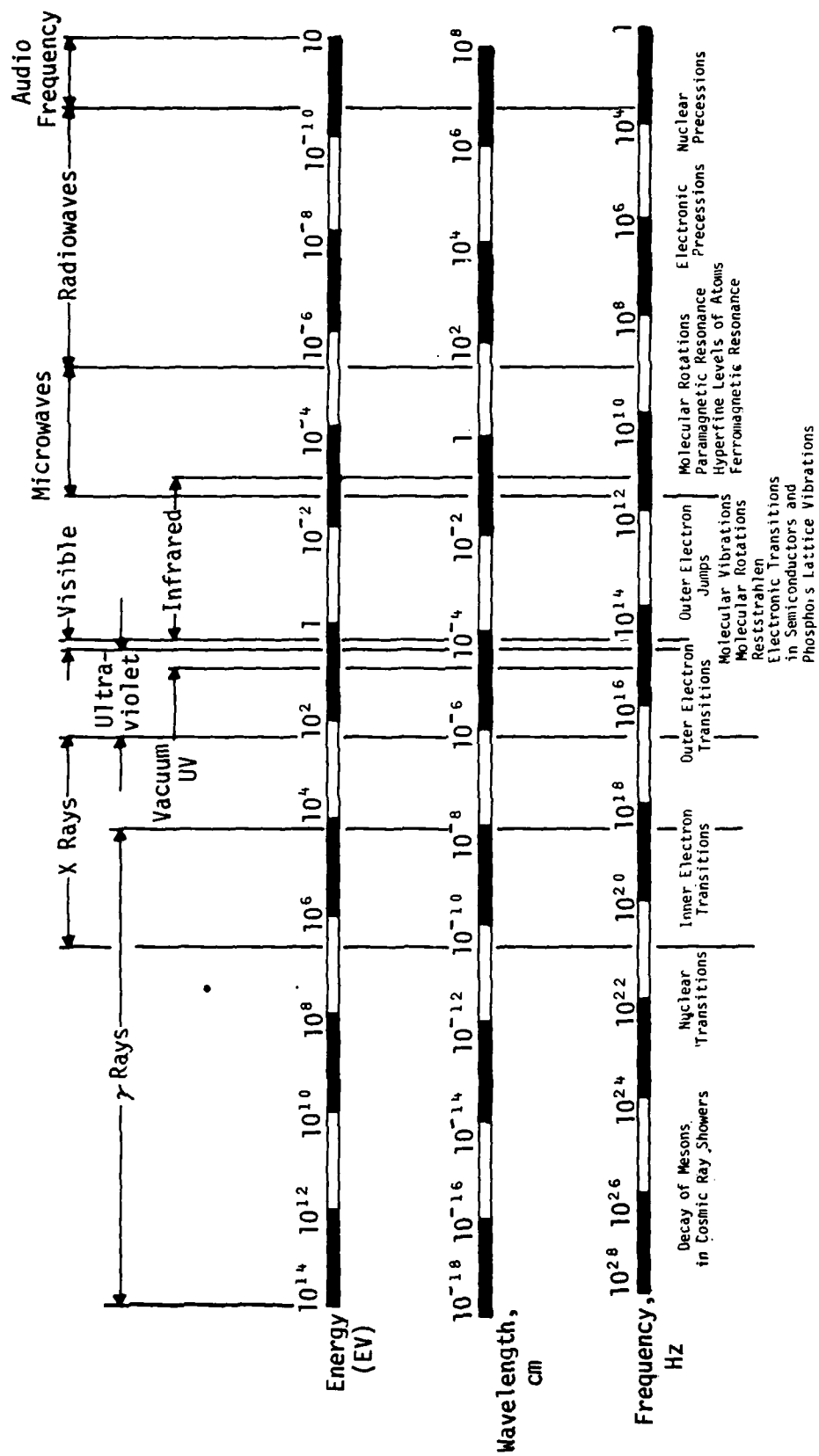
Figure 14. Electromagnetic Spectrum

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TABLE 10. REMOTE SENSING METHODS

METHOD	Radiometry	Multispectral Scanners	Radar	Optical Radar	Acoustics (Sonar)	Longwave Radar	Passive Microwave	Magnetometer	
DESCRIPTION	Imagery by Reflected Electromagnetic Waves	Photographic Technique (0.1 to 1.3.)	R-Band X-Band C-Band P-Band	Imaging by Reflected Electromagnetic Energy	Reflection of Acoustical Signal	Increased Wavelength	Remote Sensing of Reflected Microwaves	Detection of Metal and Changes in Magnetic Field	Detection of Reflected waves in concrete and subgrade
ADVANTAGES	None	1) Can be used in day or night application. 2) Reconnaissance is easy to operate and inexpensive. 3) Fast method of reconnaissance.	1) Reconnaissance is fast and accurate.	None	None	1) Penetrates pavement for detection of unexploded ordnances.	1) Penetrates pavement for detection of unexploded ordnances. 2) Very accurate and fast reconnaissance.	1) Possible to detect unexploded ordnances.	
DISADVANTAGES	1) Very expensive. 2) Not conducive to remote sensing. 3) Requires sophisticated equipment. 4) Requires personnel with specialized training. 5) Violates most of the project limitations.	1) Requires personnel with specialized skills for data reduction. 2) 2-hr delay for film processing. 3) Requires expensive, sophisticated equipment for data reduction. 4) Utilizes optical monitoring equipment. 5) Data Reduction is very slow. 6) Won't distinguish between unexploded ordnance and camouflets.	1) Very expensive. 2) Requires highly skilled personnel. 3) Requires computer for data processing. 4) Data cannot be processed or reduced by hand. 5) Won't distinguish between unexploded ordnance and camouflets.	1) Very expensive. 2) Not conducive to remote sensing. 3) Violates the project limitations.	1) The air is not a good carrier of sonar signals. 2) Not conducive to remote sensing. 3) Violates the project limitations.	1) Very expensive. 2) Requires highly skilled personnel. 3) Requires computer for data processing. 4) Data cannot be processed or reduced by hand. 5) Won't distinguish between unexploded ordnance and camouflets.	1) Very expensive. 2) Requires highly skilled personnel. 3) Requires computer for data processing. 4) Data cannot be reduced by hand. 5) Requires stationary platform. 6) Requires long exposure times.	1) Very slow reconnaissance. 2) Won't find craters, camouflets, or spalls. 3) No electronics, metal, or motorized equipment can be in vicinity. 4) Requires highly skilled personnel for data reduction. 5) Utilizes sensing devices.	1) Not feasible for this application.

*Near infrared or image intensifier eliminates thermal cushion and pluming effects.

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SECTION VI
PRIMARY SYSTEMS RECOMMENDATIONS

The recommended RRR damage assessment system is composed of four subsys-
tems: a primary system and three backup systems. The primary system is the
linear photodiode array system discussed under vidicon techniques with video
processing equipment for data reduction. The first backup system utilizes
quick-strike reconnaissance data which are reduced by video processing equip-
ment. The second backup system is a manual system which utilizes men and
equipment from the existing RRR team plus a helicopter to obtain data. The
data are then reduced using the microcomputer from the video processing equip-
ment. The third backup system is a variation of the second in which the
video processing equipment is assumed to have been destroyed and no aircraft
is available for reconnaissance. Here the data-reduction process is carried
out by graphical methods.

LINEAR PHOTODIODE ARRAY SYSTEM

The linear photodiode array system is a 1,728-element, charge-coupled
device. The array is mounted in a lightweight camera designed to withstand
the extreme environmental conditions to which this system will be subjected.
The camera is mounted on a stabilized platform. All of the electronic equip-
ment necessary to operate the sensor is housed in the camera head. This equip-
ment includes the timing logic board for clock signal generation and the sig-
nal processing board for conditioning the linear photodiode array sensor
output. The analog video output is available on the camera head, and the
binary video output signal is available from the camera control unit. The
camera control unit houses the power supply for the camera with the controls
necessary to set the camera at the appropriate conditions for operation. The
following capabilities are included in the camera control box: variable
exposure time, variable video data rate, input and output signals for synchro-
nization purposes, as well as threshold adjustment for generation of the
binary video signal. A conceptual illustration of the complete airborne

reconnaissance system including platform and lighting system is shown in Figure 15. A standard C-mount lens adapter mounted on the camera head allows a wide range of lenses to be used with the system. The video output from the control box is recorded on a video tape recording device. The camera control box and the video tape recording device are mounted in an equipment rack inside the helicopter.

An alternative to the videotape recording device is a microwave or RF telemetry device. The video output from the camera control box would be input to a transmitter which would transmit the data directly to the video processing equipment by means of receiver. The cost of a transmitter and receiver would be approximately $75,000.00. The telemetry system would give real-time, data-processing capability to the system and would eliminate the problems associated with the videotape recording device.

AERIAL RECONNAISSANCE VEHICLES

There are several helicopters which have been specified by the USAF as possible carriers for the system. These helicopters, which are presently in use in Europe, are the CH-53, HH-38, CH-3, UH-1N, and the HH-1H. The USAF requires that all equipment used in damage assessment efforts be designed so that it may be attached to any or all of these aircraft.

The USAF requested that the feasibility of using a single-engine Cessna-type aircraft (Figure 16), a three-man helicopter, or a remotely piloted vehicle (RPV) be investigated to determine their potential for use in the system. The carrier of the system must fly at 60 mph (±5 mph) ground speed in a wide variety of environmental and weather conditions. It must also fly at a constant altitude of 245 feet (±10 feet) and maintain a constant trajectory (±10 feet from the centerline of the runway). The single-engine Cessna can meet these criteria and is low in cost. However, there are several disadvantages to the use of a single-engine aircraft. First, it must have a clear area approximately 500 feet long and 40 feet wide for its launch and recovery. Second, the weight of the equipment which the aircraft must carry may exceed the cargo limitations of aircraft having a low enough stall speed to carry out the mission.

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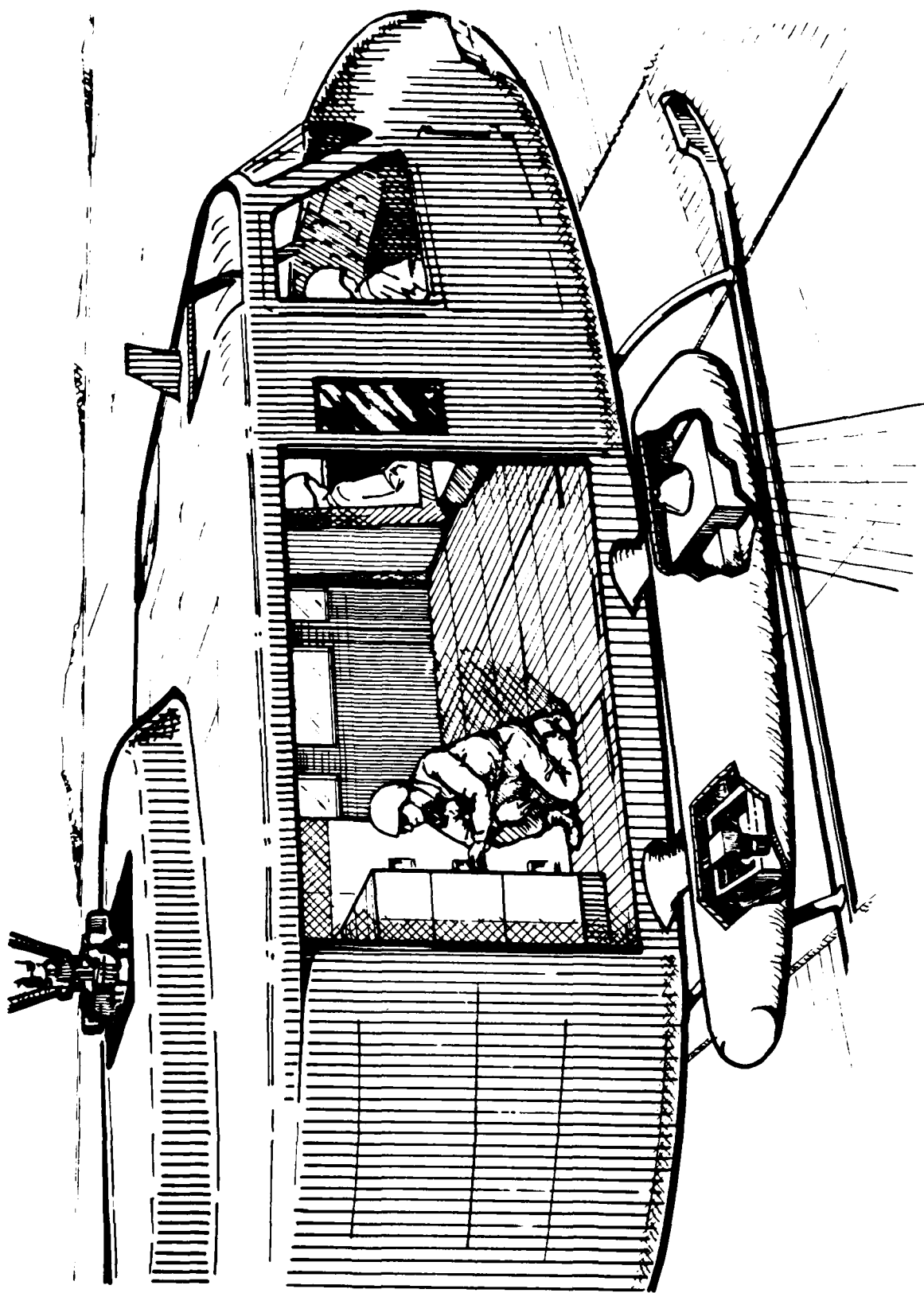
Figure 15. Airborne Reconnaissance System
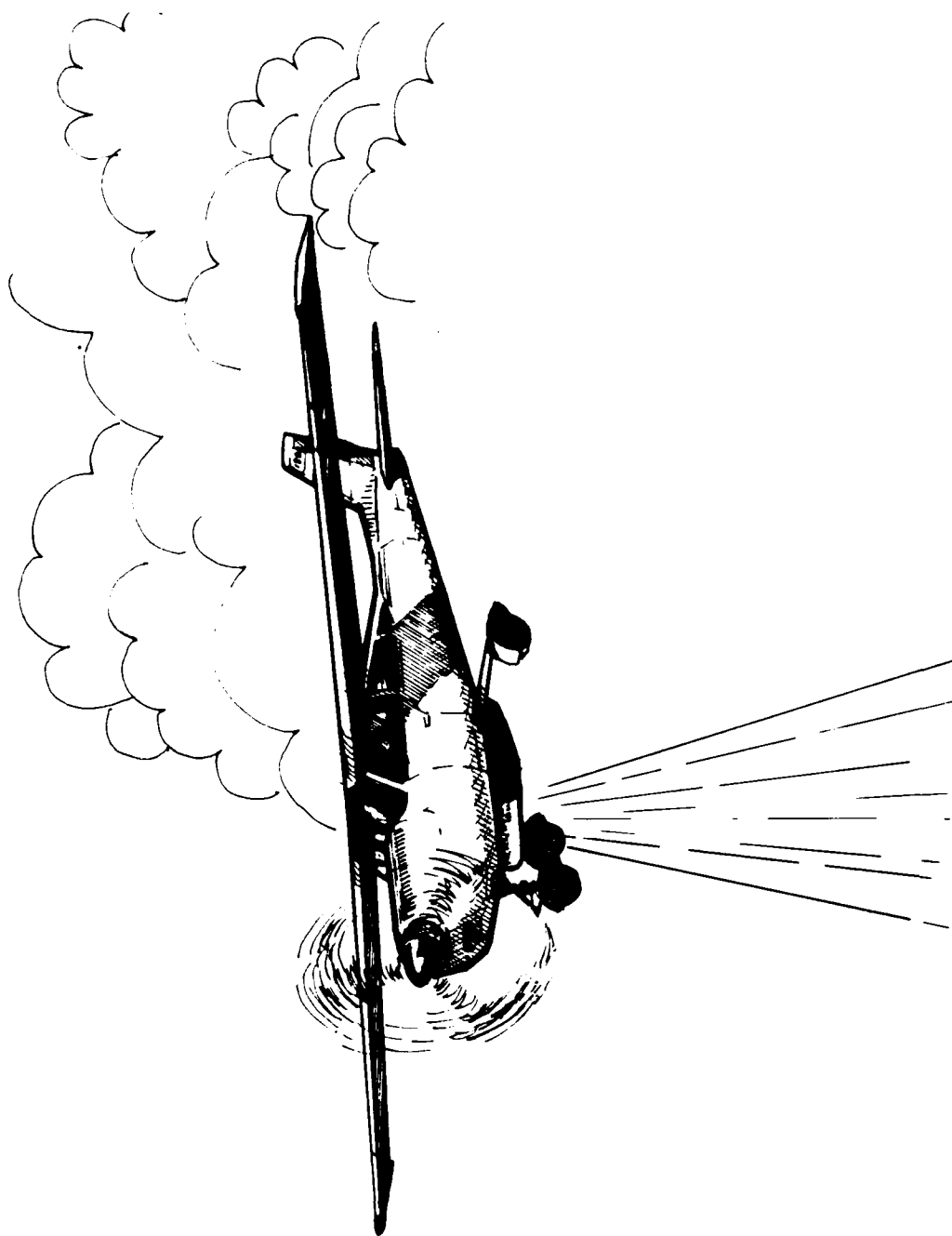
Figure 16. Single-Engine Aircraft

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The three-man helicopter would be similar in size and appearance to the Enstron F-280, which has been modified for use as a dispersal machine in agriculture. The small helicopter system would meet the basic criteria, would be relatively low in cost, and would not require a large area for launch and recovery. However, the cargo area for the helicopter is only 18 inches by 18 inches by 3 feet high. If the stabilized platform were to be mounted in the cargo area, significant modification of the fuselage would be required. In addition to these problems, it is questionable whether the cargo weight limitations would be sufficient to transport all of the necessary hardware for the reconnaissance equipment.

Several RPV systems were investigated to determine the feasibility of using them to transport the reconnaissance equipment. Some of the existing systems investigated were the Lockheed Aquila System, the E-55 and E-100 Melpar Systems, and the Wideye Supervisor RPV (Reference 6) which is presently under development by Marconi-Elliott Avionics. The RPV systems are catapult launched, net recovered, and are guided by a computerized automatic flight-control system. The Remotely Piloted Helicopter (RPH) can be launched and recovered without a catapult or net and also uses a computerized, automatic flight-control system.

These systems require at least five highly trained professionals as operators. The cost of all three systems is in excess of $1,000,000.00 each, and none of the systems can carry a large enough payload to carry the lighting equipment. As a result, the system could only be operated during the day when natural lighting is adequate. Due to the present high cost of the RPV and RPH systems, it is recommended that they receive no further consideration as carriers for the damage assessment system at this time.

The lighting system, which provides night lighting and shadowing, consists of high intensity lamps and focusing reflectors. The entire system is to be designed so that it can be rapidly mounted on the carrier aircraft. An auxiliary power source may be required for the lighting system. The lighting system and its power supply may be large enough to eliminate the single-

Reference

6. "British Remotely-Piloted Helicopter Progress," *International Defense Review*, June 1977, p. 1087.

engine aircraft and the small helicopter from consideration as carrier air-
craft. NMERI recommends that the lighting system be designed and that the
power supply be sized as a part of the subsequent investigation.

GROUND ANALYSIS SYSTEM

After the reconnaissance portion of the mission takes place, the video
data would be analyzed on video processing equipment. The video processing
equipment is composed of the following hardware components:

1. Microcomputer process controller with interfaces
2. Bulk storage disc/controller
3. Digital refresh console
4. Display station

NMERI recommends that the digital refresh portion of this system be
similar to the Video Display Interface (VDI) 300, manufactured by Interpreta-
tion Systems Incorporated. A list of suggested generalized specifications for
the digital refresh console are provided below:

1. Imagery data should be stored in digital, random-access memory.
2. System should be capable of storing image data in the refresh memory
array with a capacity of 1 megabyte. It should be possible to store a single-
image array within this total capacity, or alternatively, to store multiple
image arrays of variable resolution and variable pixel precision- within the
constraints of maximum memory capacity.

3. The allowable pixel precisions for display of stored image data
arrays should be 1, 2, 4, 8, or 16. The allowable image array resolution X
x Y should be any integer values between 1 and 512. Both precision and resolu-
tion should be programmable.

4. The display system should permit the host to read or update refresh
memory contents, all Look-Up Tables (LUTs), and status of all switches and
registers governing display activity.

5. Transfers of image array data should occur at rates of up to 3 mega-
bytes per second.

6. Display system should have the capacity to generate "false color"
video signals.

7. It should be possible independently to alter the variables control-
ling the perceived color display: namely; intensity, hue, and saturation.
The altering of one of these variables should in no way result in a change to
the other variables.

8. The display should be capable of scrolling up or down.

9. A flexible zooming effect or magnification feature should be provided. It is desirable that magnification be controllable by a trackball or similar manual device. It is desirable that the vertical and horizontal scales be independently alterable. That is, it is desirable that a resultant display be capable of being produced which has a horizontal scale factor of, say, 2 while the vertical scale has a different factor, say, 4.

10. All scaling or magnification operations should be performed with the minimum intervention of the host microcomputer.

11. All function or remapping tables should be capable of being read and written by the microcomputer.

12. It should be possible to define a window within the displayed array which can be remapped through an alternate function other than that which is assigned the data surrounding the window. It should be possible to alter the video output parameters for the window data at the same rate as for the background data.

13. The system should have both a 525 TV synchronous format and a 559 TV synchronous format which can be program switchable.

14. It should be possible to display rectangular subarrays which originate at any address in the refresh memory and to translate this subarray to any screen location. Again, no change to the stored refresh memory contents should be required. It should be possible to display multiple subarrays (i.e., > 2) simultaneously.

15. The system must be capable of loading refresh memory by means of a digitized facility at video rates. It should be possible to pass the digitized signal through the LUT section of the display system without storing the data in the refresh memory.

16. It is desirable to display a pseudo-3D presentation of the contents of the refresh memory. This could be done on a separate XY-display oscilloscope. The resultant image should be program variable in terms of tilt, rotation, relief, and intensity and should be independent of the color image manipulations.

17. It is desirable that the system be modular in design and be able to support optional display capabilities.

18. The system should be capable of building a display by assigning a line array for each displayed line. This should be accomplished without altering the original stored data or required additional buffer memory. Appropriate

control signals should be provided to allow programming of all image changes without causing image flicker, flashing, or noise (i.e., the only change to be perceived is in the desired data).

It is very difficult to make a meaningful comparison of the Interpretation Systems Inc. (ISI) video/digital interactive display processor (VDI) system with other video processing systems now marketed. To assist in comparing, a technical summary of the features and performance of the VDI system is included below.

Essentially, the VDI system discussed here is an innovative, unique television raster-based device capable of producing dynamic color, monochrome, and pseudo-3D images from random-access memory. These images are presented on standard television monitors and raster-scanned, large-screen oscilloscope displays. The VDI approach to digital image display, known as *raster graphics*, has many advantages over the *stroke writing* approach generally referred to as *vector graphics*. Some of these advantages are:

1. Ability to deal easily with continuous surfaces, solid objects, and very dense data arrays. Since only line drawings can be displayed by vector writing systems, complex images become very cumbersome to generate and manage.

2. Ability to modify the refresh memory and/or the displayed image dynamically on a pixel basis without annoying flicker. For complex displays, vector systems suffer from flicker due to refresh update requirements.

3. Displayed images are generated directly from data arrays. With vector systems, cumbersome display lists or other intermediate representations are required to generate images.

4. Ability to utilize full-color displays as well as monochrome. Vector systems are typically monochromatic in nature; only a few systems now offer a very limited color capability through use of penetration phosphor cathode ray tubes (CRTs).

The VDI has several significant advantages over other existing raster display systems. These advantages result primarily from the use of random-access memory for refresh of the displayed image and from the manner in which array addressing is accomplished, specifically:

1. The VDI allows the displayed image resolution, scale, starting location, orientation, and window-of-view to be altered within the standard television refresh cycle without having to alter the stored refresh memory.

2. The stored refresh memory data are program accessible as numeric values for each resolution cell. These values may be transferred to the refresh memory from the host machine as blocks, submatrices, or random points.

3. The VDI maintains independence between the stored refresh memory data and resultant image display parameters. The only obvious requirement is that there be at least as much available refresh memory as is defined by the display parameters. Refresh memory addressing for display purposes (i.e., the starting location, the sequence of lines, and the number of total lines) is completely arbitrary.

4. The VDI's OPTICOLOR● technique for encoding display data makes it a "color thinking" machine. All other raster systems employ multiple monochrome LUTs which can be circumstantially cabled to the red+green+blue (RGB) phosphor drives of a color monitor. The VDI is the only raster system which employs a rational LUT color coding scheme.

Some additional significant features of the VDI are:

1. The ability to either digitize directly through to the display CRT or into the refresh memory. This is done in real time using standardized sources.

2. Its modularity and configuration flexibility. While standardized versions have been defined, the plug-in type, wide-communications bus allows for duplication of certain paths and an ability to add new modules readily as they are developed.

3. Programmable display resolutions up to 1,000 x 1,000 pixels. For the standard 525/60 synchronous format, the maximum full-precision color display resolution is 640 x 480 pixels; for 599/60 synchronous format, the maximum full-precision color display resolution is 640 x 512 pixels; for 625/50 synchronous format, the maximum full-precision color display resolution is 766 x 575 pixels.

4. Switchable synchronous formats by means of software command (i.e., 525/60 or 559/60); the 625/50 synchronous format is also available.

5. Program switchable pixel aspect ratio between 1:1 and 4:3 (H:V.).

6. Programmable display data precisions of 1, 2, 4, 8, or 16 bits per pixel. (Pixel precisions of 16 bits require an optional higher-speed refresh memory.)

7. The ability to accept command and data strings from a host at a rate in excess of 3 megabytes per second.

8.   Multiple display data-encoding LUTs that can yield over 60,000 programmable color-intensity combinations and up to 256 monochrome grey levels simultaneously.

9.   The ability to superimpose, for display purposes, standard video input imagery with the digitally generated display data. This superimposition can take the form of (a) standard video input display only, (b) digitally generated display only, or (c) ANDing of these two display channels.

10.   The capability of being driven by an external composite synchronous source or from a standard composite video signal.

11.   The availability of a pseudo-3D display generator, with dynamically variable "tilt," "rotate," "relief," and "intensity" parameters. This output generation is connected to a large screen XY-display CRT.

12.   The availability of a movable cursor, a movable window, and 1- or 2-bit overlay-generation modules.

Figure 17 provides a diagram of the generalized function of the VDI.

One of the most significant features of the VDI is the manner in which the refresh memory is organized. When employing other digital raster display systems with high-speed random-access memories, the user is required to organize his data as bit planes. The spatial limits of his refresh memory (number of lines, number of pixels per line) correspond directly with his display parameters. The data to be displayed may or may not be passed through LUTs for remapping purposes. The VDI, on the other hand, employs a unique method with respect to how refresh memory is managed.

For the VDI user, the refresh memory is managed in much the same way that the host computer memory is managed. The user has the flexibility of utilizing the refresh memory in less restrictive ways. The size of the refresh memory in terms of total bytes can be greater than that which the user is able to,or desires to,have displayed. Total address lines within the VDI permit up to 1 megabyte of refresh memory to be available to the VDI for display purposes. This maximum size is partitioned into two 1/2-megabyte banks.

Diagram

(CI)
Control Interface to/from Host

(RMC)
Refresh Memory Controller

(RM)
Refresh Memory (64 Kilobytes Minimum)

(RMP)
Refresh Memory Processor

(DFP)
Dynamic Function Processor

(OPT)
Video Output Gen. (OPTICOLOR®) → RGB → Mono

Ext. Video

(STC)
Sync and Timing Controller ← Ext. Synchronous

(Options)
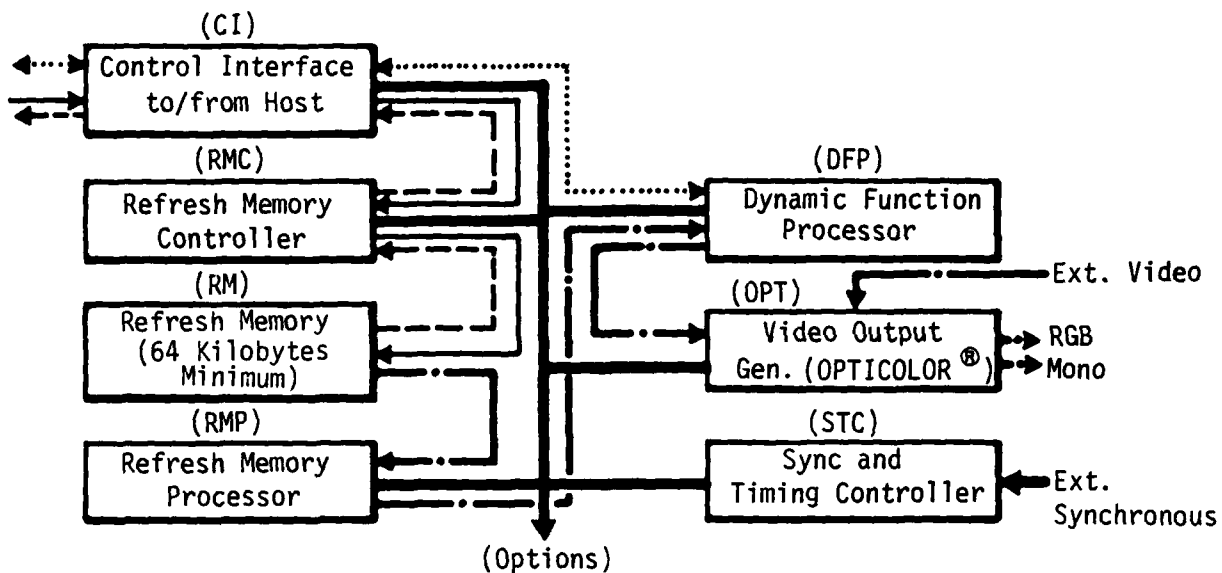
Legend	Description
CI	Control interface module which serves interface signal control to/from host computer.
RMC	Refresh memory controller module enables the refresh memory or the reading of memory status.
RM	Refresh memory array; minimum allowable size is 64 kilobytes while maximum is 1 megabyte.
RMP	Refresh memory processor module provides addressing and pixel precision organization for display.
DFP	Dynamic function processor module provides four remapping look-up tables and generates at 16-bit data stream to the OPTICOLOR® module for display; permits host read/write of look up tables through CI.
OPT	OPTICOLOR® output generator module encodes the DFP generated data stream into the OPTICOLOR® scheme (i.e., each display pixel is assigned a calibrated value representing one of over 60,000 "color intensity" combinations for an RGB output signal, and one of 256 grey levels for a simultaneous monochrome output signal).
STC	Synchronous and timing controller module.

Command, control and timing bus; note that the STC module will accept:
An external synchronous source (standard).
Refresh memory write (update)
Display refresh path
Refresh memory read (status read by host)
Display refresh read or write (applies to look-up tables)

Figure 17. Generalized Functional Diagram of the VDI
(Mimimum Standard Configuration)

The basic "word" size of the VDI refresh memory is 64 bits. The rate at which the VDI will accept commands and/or image data is 3.2 megabytes per second. This rate is faster than most 16-bit host computers can sustain over their data channels. Because of the way the refresh-memory chips are organized on their planar plug-in cards, the VDI minimum level of memory is 64 kilobytes.

The VDI refresh memory resides in a separate matching chassis with its own power supplies and cables to the VDI electronics. Two memory chassis sizes are available. Since the VDI will support two data memory banks of 1/2 megabyte each, ISI offers a 1-megabyte capacity chassis and power supply option into which the plug-in memory cards can be inserted. The standard refresh-memory chassis will contain up to 256 kilobytes of memory. Thus, up to four of these standard chasses can subsequently be added to a VDI package as needed.

The standard VDI uses refresh memory cards which are populated with 4,000 static random access memory (RAMs). While this quantity necessitates somewhat higher power requirements, and to a certain extent, increases cost-per-bit factors, the trade-offs resulting from improved reliability and especially the elimination of pattern sensitivity attributable to other RAM technologies are justified. The VDI refresh-memory chips are mounted in plug-in sockets, not soldered directly to the board. This feature makes any chip replacement a simple task.

Referring to the generalized functional diagram (Figure 17), it is seen that the refresh memory serves several functions: it is written (or updated) under the control of the refresh-memory controller (RMC). For the update function, refresh-memory data are transmitted as four 16-bit words (considering a 16-bit host machine interface).

It should be noted that the RMC also enables the host computer to read the contents of the refresh memory. This feature is quite useful in a number of ways, such as allowing the host to make use of the refresh memory as if it were auxiliary memory, thus permitting the host to perform refresh-memory edits to correct or isolate certain values for subsequent display requirements, etc.

Again, referring to the previous functional diagram, it is seen that the refresh process for display purposes is under the control of the refresh-memory processor (RMP). Line addressing and pixel precision are processed by 'he RMP and the display data organized as pixels which are sent to the dynamic-function processor (DFP).

By way of illustrating the flexibility available to the VDI user, assume a VDI system with a refresh memory containing 256 kilobytes. For most image processing applications, the user might consider organizing these 256 kilobytes as a single image of 512 lines, each line containing 512 pixels and each pixel having a precision of 8 bits. Later, however, user may wish to re-organize his refresh memory data as, say, four 256 x 256 images in order to operate on any one of these 8-bit images instead of one 512 x 512 image. The user could then select the lower right image and display it anywhere on the CRT screen with or without independent scaling or magnification in either the horizontal or vertical direction. The VDI allows the existence of more refresh memory than is possible to display in two dimensions. For example, 512 kilobytes of refresh memory could be displayed in the form of a panning opera-tion resulting in scrolling or fly-over displays.

This flexible memory organization capability is not restricted with respect to size to quadrants or powers of two as the above example illustrates. The VDI user can organize the refresh memory to have a number of contiguous images of varying lines, pixel widths, and pixel precisions, if desired.

With regard to image display manipulations, the VDI allows the user to alter the display parameters *with no modification* to the stored refresh-memory array. Because viewable display manipulations occur in the refresh path, it is not necessary to read out the contents of the refresh memory to the host machine (or worse, to an auxiliary intermediate memory), reorganize the data as a new image, and send it back to the refresh memory prior to display. In this example, if the user wanted to return to the original image, it is appar-ent that the original has to be buffered away somewhere for subsequent re-trieval or regenerated. With the VDI, the original stored refresh memory re-mains undisturbed throughout the various manipulations the user may wish to employ. It should be noted that updates to the refresh memory can occur independently of the refresh function.

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Image display manipulations by the VDI consist of varying resolution, windowing, translating, scaling, and scrolling. Any of these manipulations can be implemented by simply changing the VDI control information. No change is required to the stored refresh memory.

The generation of video output for display purposes in the standard VDI is a two-stage process involving the DFP and OPTICOLOR® modules. First, the digital data values are received by the DFP from the RMP with pixel precision organized as 1-, 2-, 4-, 8-, or 16-bits. These data values are then used to address cells in any one of four program loadable (and host-computer readable) LUTs. Each table has 256 entries. Which table the user elects to use can be determined by direct VDI commands, or table selection can be under the logical operation control of the standard window feature of the VDI as well as the optional digital overlay channels. Using the window and/or digital overlay control for table selection permits switching between tables at pixel rates.

The second step of the display operation is to generate video signals from the 16-bit words derived from the DFP. The step is accomplished by the OPTICOLOR® module. Both color and monochrome video display are controlled by the OPTICOLOR® module. Color video output is generated by specifying three components: hue, saturation, and intensity. This technique, which ISI refers to as OPTICOLOR®, is considerably more effective in the control and presentation of perceived color values on properly calibrated RGB color monitors than is the traditional method of specifying proportional combinations of RGB data values from three separate monochrome LUTs.

The VDI's OPTICOLOR® module accepts 16-bit data values ("words") from the DFP and decodes them as follows:
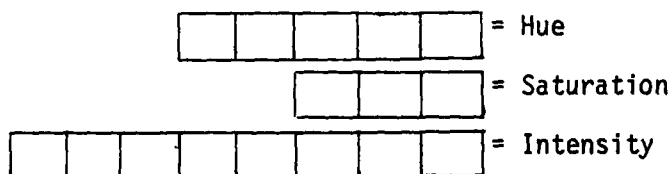
The hue component specifies 1 of 30 color values which have been uniformly distributed and selected from around the periphery of the international CIE color chromaticity scale. The remaining two values are used to denote *black,*

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white, and special calibrating pulses. The saturation component specifies one of eight saturation levels for each of the hue values, progressing from the most saturated value at the periphery of the CIE scale towards white. The intensity component likewise specifies 1 of 256 intensity values. This coding technique greatly facilitates the user's ability to invoke changes in the perceived display at the pixel level. It also optimizes the full-color space available to the user even when working with limited precision pixel arrays.
The color data space available to the user is always 61,442 (including white and black) color-intensity combinations.

Several significant display features,which are not easy to achieve using the other traditional combinational RGB technique,are easily generated by OPTICOLOR®:

1. The ability to change any portion of the display array from one hue to another *without* changing its perceived saturation and intensity.

2. The ability to change any portion of the display array perceivably from one saturation level to another *without* changing its perceived hue and intensity.

3. The ability to change any portion of the display array perceivably from one intensity level to another *without* changing its hue and saturation.

The independent nature of these three variables corresponds directly with normal human visual processes. It should be noted that any one or more of the above modifications to the perceived value displayed on the RGB color monitor can occur from a single command issued to the VDI, and the command can be implemented at refresh rates. OPTICOLOR® further considers the phosphor characteristics of available color CRT monitors and optimizes the response for uniform distribution of hue values and for linear intensities.

None of the easily performed changes described above can be readily achieved with the traditional RGB encoding method used by other systems since hue and saturation are determined by the relative proportions of red, green, and blue; and the perceived intensity is determined by the *sum* of these primary values. Unless a complex algorithm is used, changes to color values typically result in changes in brightness whether desired or not.

OPTICOLOR® is also capable of providing for two other standard types of video outputs. One of these outputs is generated from the intensity field of the 16-bit OPTICOLOR® data values. The second is derived from an external monochrome video signal. This external video signal can replace or, more typically, be ANDed with the digital intensity field for both color and/or monochrome presentations.

Finally, brief mention of one additional form of video generation is included here. Commands from the VDI can be sent to the optional isometric projection generator module to produce on a large-screen oscilloscope display (electrostatic beam deflection CRT) a pseudo-3D presentation of the contents stored in the refresh memory. This display has variable parameters of tilt, rotation, and relief, the sum of which results in a perceptible orientation on the CRT. This orientation can be dynamically changed under VDI control for a unique, independent way of displaying the contents of the stored refresh memory.

The mechanical and electrical characteristics of the VDI-300 are as follows:

Top View: VDI-100

Rear

= 7-inch Power Supply

= 6-inch Available for Backplane Expansion

= 5-inch Analog Backplane

= 5-inch Digital Backplane

Front
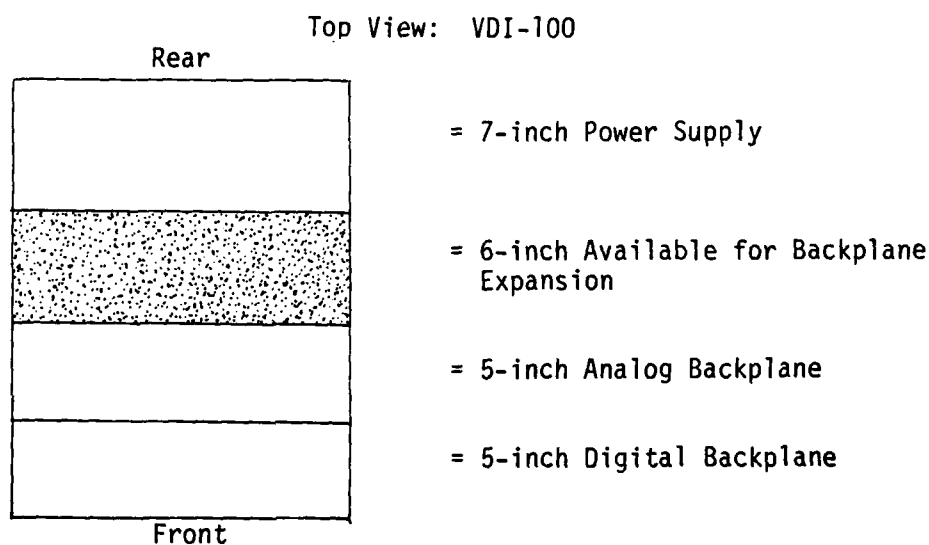
Each of the 5-inch backplanes contains six plug-in slots. The digital section contains five cards in the standard configuration while the analog section contains three cards. One of the remaining three slots in the analog section is reserved for input/output connections while the remaining two slots are reserved for options.

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Dimensions and weights of the VDI-300 with its refresh-memory section are:

	Display Processor Section	Memory Section (256 kilobytes)
Width	19 inches	19 inches
Height	10-1/2 inches	5 inches
Depth	24 inches	23 inches
Weight	30 kilograms	25 kilograms

The front panel of the refresh memory section is designed to match the main VDI electronics chassis visually. Thus, the combined vertical rack space required by a VDI configuration is 22 inches minimum, and without excessive backplane requirements, a maximum of 32-1/2 inches.

The VDI-300 will support a number of options. These options, for the most part, can be readily installed with limited instructions in the field.

The prototype configuration for the linear photodiode array system is shown in Figure 18. The system allows for a high degree of operator interaction in data recognition and classification. Several features of the system assist the operator in recognizing different types of distress. Figure 19 defines the parameters used to described the image-manipulation features of the system. Figure 20 shows several operations which can be performed with the system without altering the original video data. The scaling feature of the system enables the operator to take a closer look at the damage to make a possible distinction between camouflets and unexploded ordnance. The system also has the capability of locating and assigning the longitudinal stationing and lateral displacement of spalls in the system once the first spall has been identified. This feature saves a tremendous amount of time in the recognition process.

The same feature would also make it possible to locate other camouflets and unexploded ordnance after the initial distress had been located and classified. The operator can then go to these specific locations to determine the magnitude of the damage.

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        ┌─────────────────────────┐
        │   Mounted in Aerial     │
        │ Reconnaissance Aircraft │
        │   ┌───────────────────┐ │
        │   │ Linear Photodiode │ │
        │   │Array Camera Mounted│ │
        │   │   on Stabilized   │ │
        │   │     Platform      │ │
        │   ├───────────────────┤ │
        │   │    Video Tape     │ │
        │   │ Recording Device  │ │
        │   └───────────────────┘ │
        └─────────────────────────┘
```

Mounted in Aerial Reconnaissance Aircraft

Linear Photodiode Array Camera Mounted on Stabilized Platform

Video Tape Recording Device

Command Station Configuration

CPU With 28,000 "Words" Memory

Display Generator

Dual Monitor Display

Image Diskette System
1 2 3 4

256 Kilobytes

ASCII Keyboard

In the Level III configuration provision is made for the IMAGE COMPUTER SYSTEM to support pixel precisions of 16 bits (Version ICS-2). Version ICS-1 supports 8-bit pixel precision.

Function Keys/ Trackball

Magnetic Tape Drive/Controller

RGB Color Monitor

Line Printer

XY-Display Monitor

Figure 18.   Prototype Configuration

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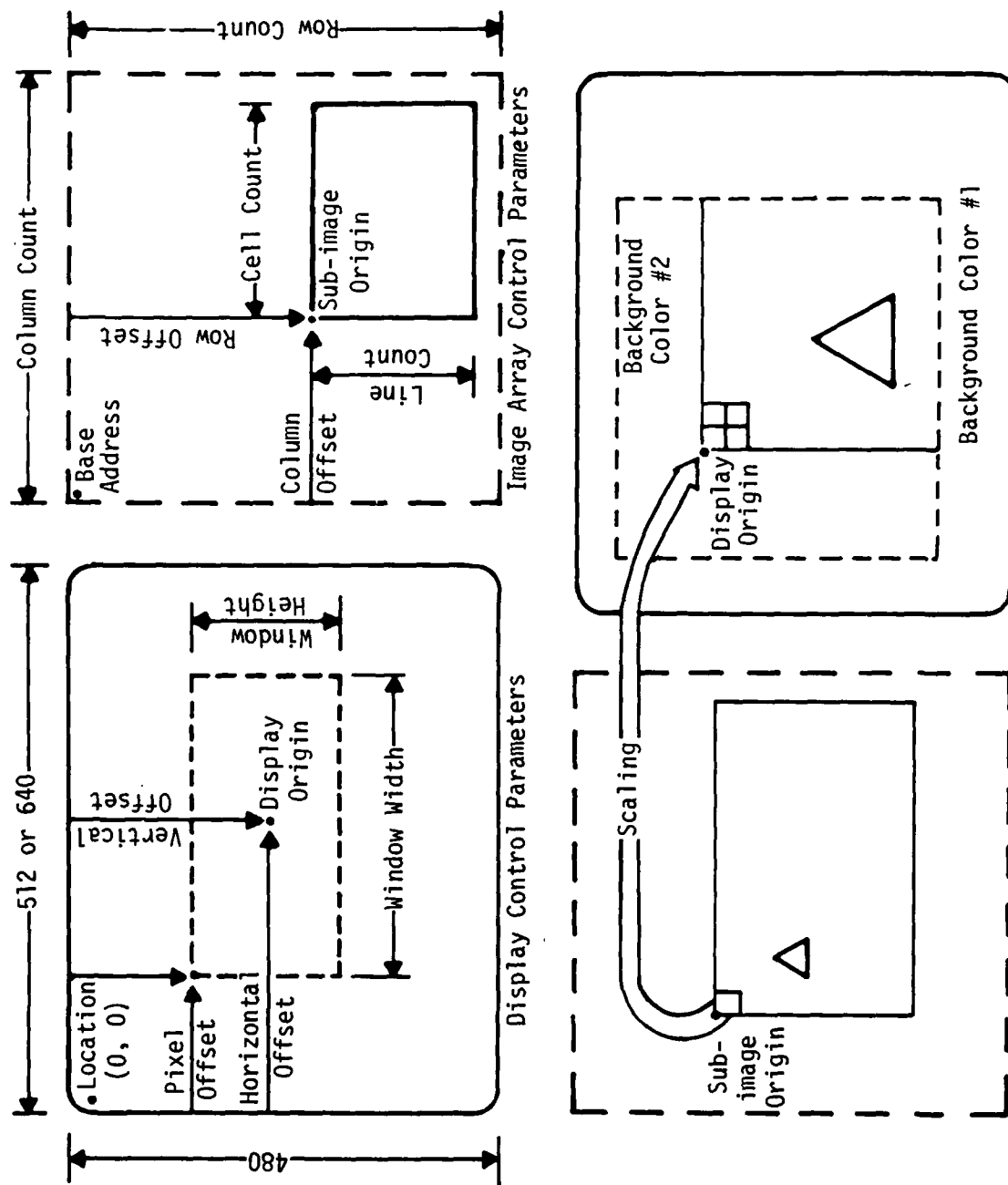
Image Array/Display Relationship

Figure 19.   Image Manipulation Control Parameters

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Legend

A) 1:1 Scaling
B) 1:1 Scaling with Translation
C) 1:2 Scaling
D) 1:3 Horizontal and
   1:1 Vertical Scaling
E) 1:1 Scaling with Win-
   dowing and Mask
F), F') Scaling of a Subimage
G) 2:1 Scaling
H) 2:1 Scaling with Translation
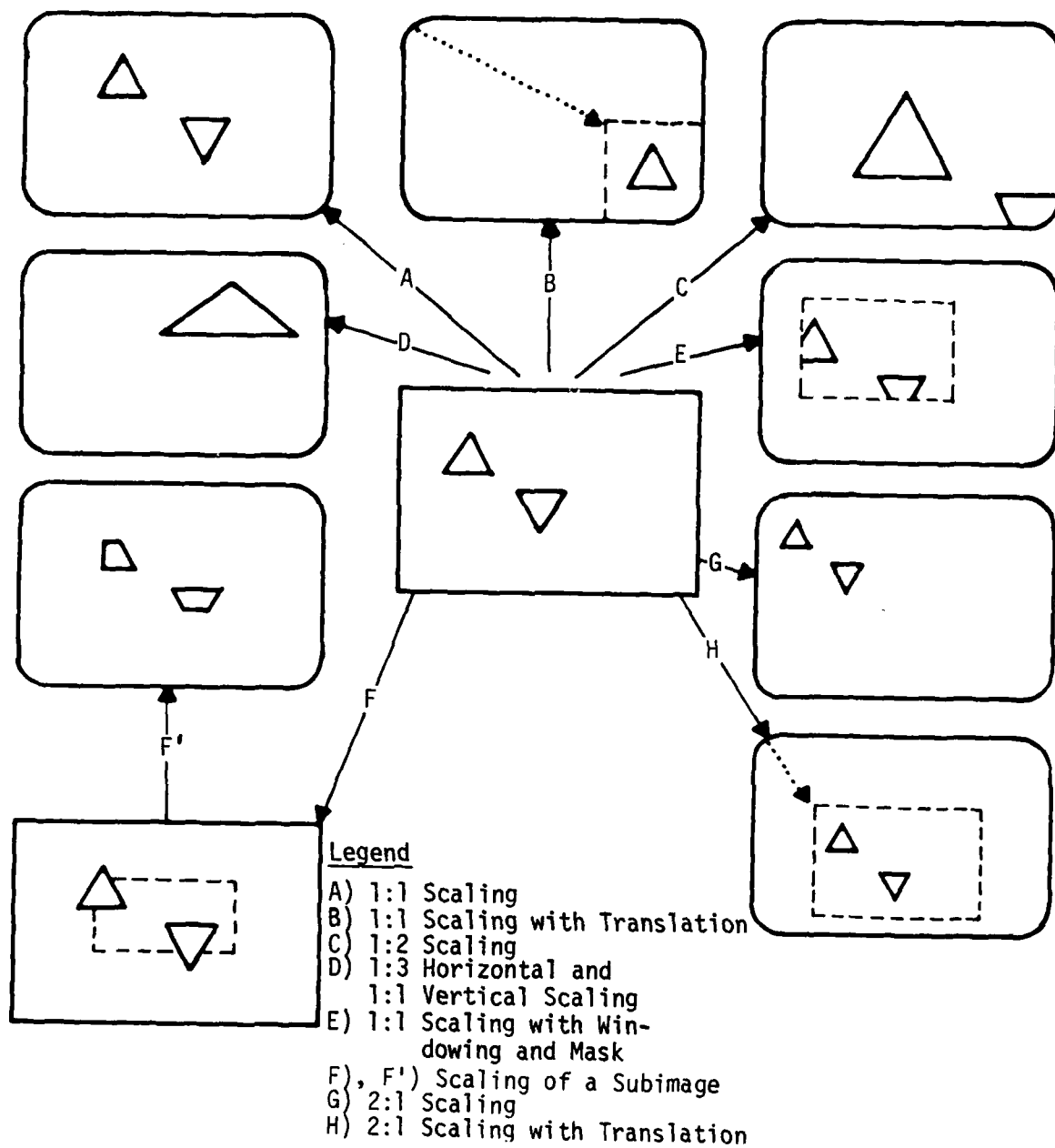
Figure 20.   Image Manipulation Visual Effects

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A useful feature of the system is the isometric projection generator (Figure 21). This creates a three-dimensional picture from the intensity of the light at each individual pixel. These projections can be rotated 360 degrees and tilted 90 degrees. This feature would assist the operator in differentiating between camouflets and unexploded ordnance in cases where this distinction would otherwise be difficult to make. A false color generator can be used to assign a color to a particular shade of grey. This feature would assist the operator in rapidly distinguishing specific characteristics of the damage. These system features combine to make the data classification fast, accurate, and reliable. It is possible to scan an entire runway and classify the damage in less than 10 minutes when no distinction between camouflets and unexploded ordnance is required. The operator could examine the data more closely after the classification process had been completed and the microcomputer had begun the selection process (Figure 22).

The data recognition procedure is carried out by the VDI system with assistance from the operator. The procedure is outlined below:

1. The operator loads the image into the VDI memory and displays it.

2. The cross hair is located over the center of the damage with the trackball.

3. The operator specifies the type of damage which changes the color of the cross hair. The cross hair remains over the center of the damage permanently to prevent the operator from duplicating his effort.

4. A shaded circle converges on the cross hair until the operator stops it by pressing a single button. The operator stops the converging circle when its diameter approximates the diameter of the distress (Figure 22).

5. The microcomputer scans the data and selects that portion of the runway area which requires the least amount of time to make operational.

6. A hard-copy printout is provided which shows the location of the repair area and the locations of the individual damages.

7. The microcomputer generates the personnel and equipment distributions and a hard-copy printout is provided.
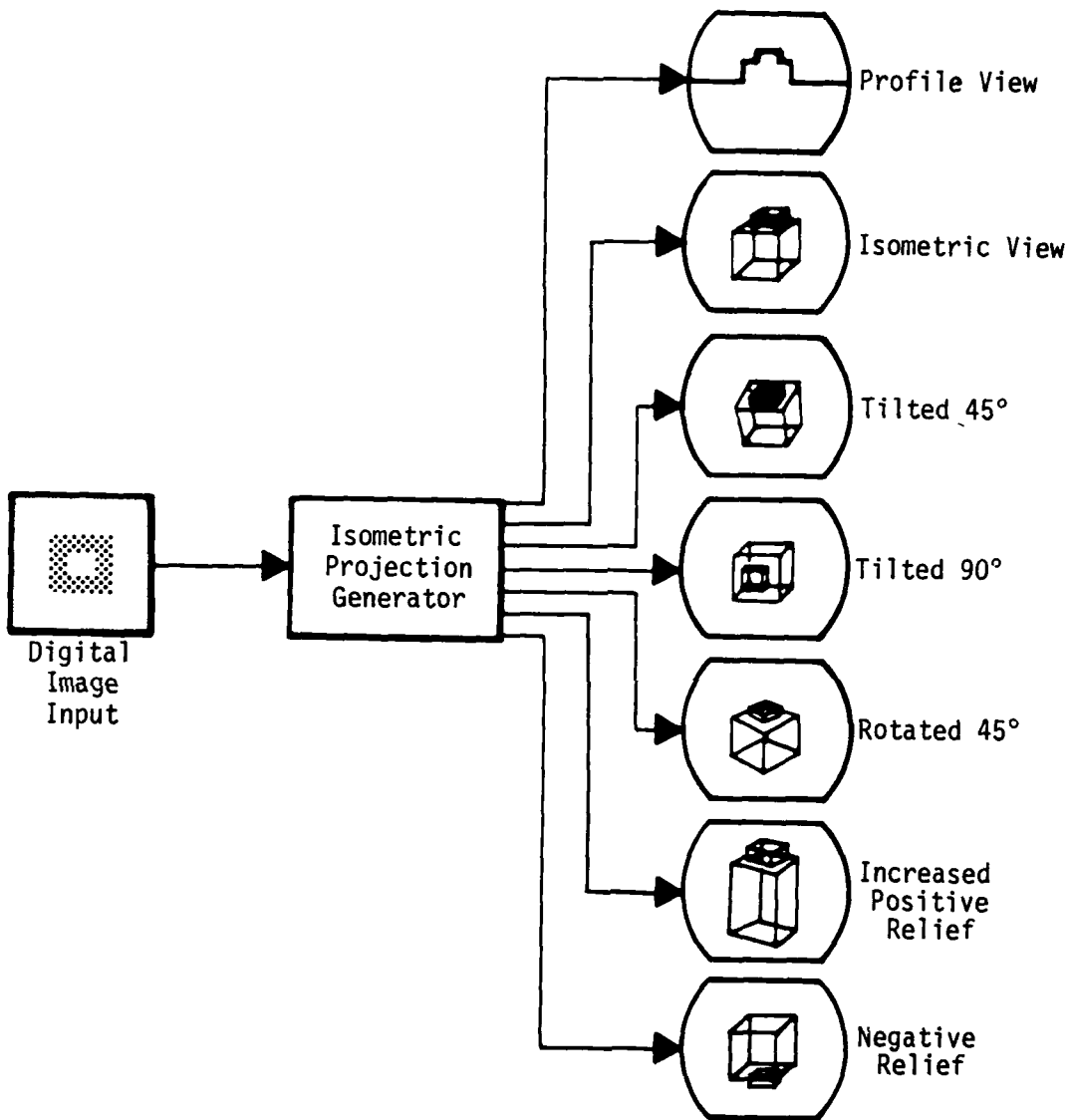
Figure 21. Isometric Projection Capabilities
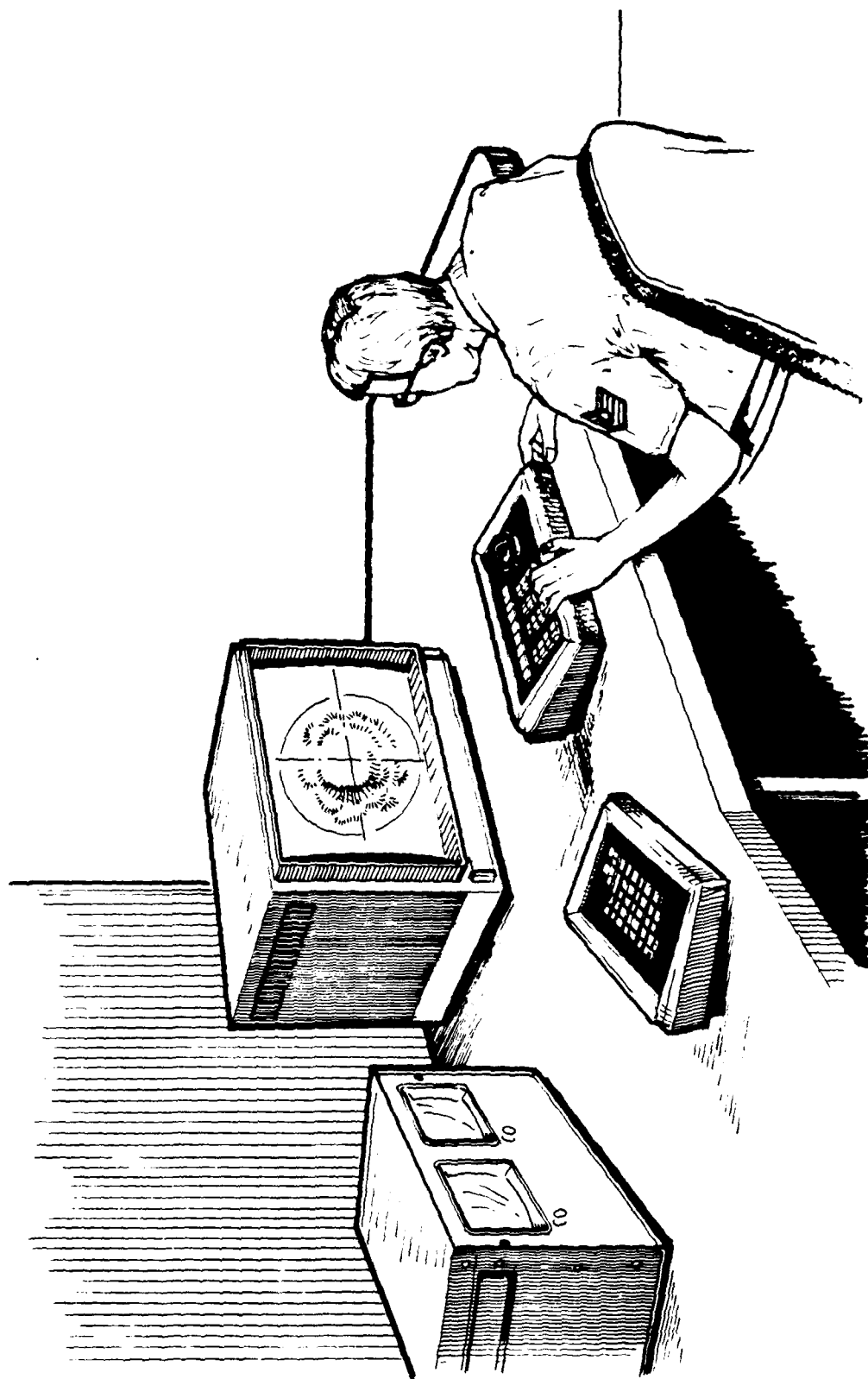
Figure 22. Video Processing Equipment

Since the video processing equipment is relatively small, it can be housed in a central command station (Figure 23). The time required to classify and reduce the data can be shortened further by providing multiple display stations with the unit. In this manner the classification process can be conducted concurrently for each of the runway locations.

A typical scenario for the system is presented graphically in Figure 24. The airfield facilities are originally intact. The runway is attacked with conventional weapons. The RRR team is assembled. The lighting equipment, stabilized platform with the linear photodiode array camera, and the support electronic equipment are attached to the reconnaissance aircraft. The reconnaissance aircraft flies above the centerline of the runway at 60 mph and at 244 feet (Figure 25). The main taxiway and an alternate runway are scanned in the same manner. The aircraft flies to a higher, predetermined altitude and makes a pass over the entire airbase. The reconnaissance aircraft returns to the central command station with the video data which have been recorded on magnetic tape or video disc. The data are processed by the video processing equipment with operator interaction. The microcomputer selects the area of the runway requiring the least repair time. A computer printout is made showing the locations of the repair area and the damages to be repaired. A printout is also made of the personnel and equipment distribution required for the repair effort.

This system has the capability of locating antipersonnel mines on the runways and in grassed areas adjacent to the runways. If it is determined that this capability is not required, the lens in the camera can be changed so that the camera scans an area 438 feet wide. This lens adjustment would give the system an on-the-ground resolution of 3 x 3 inches and would enable the system to scan the grassed areas adjacent to the runway at the same time the runway is being scanned, but it would not be possible to differentiate between camouflets and unexploded ordnance. Also, it would not be possible to locate antipersonnel mines.

The disadvantages of the linear photodiode array system are as follows:
1. The system is untested.
2. The system requires a helicopter or some other aircraft.
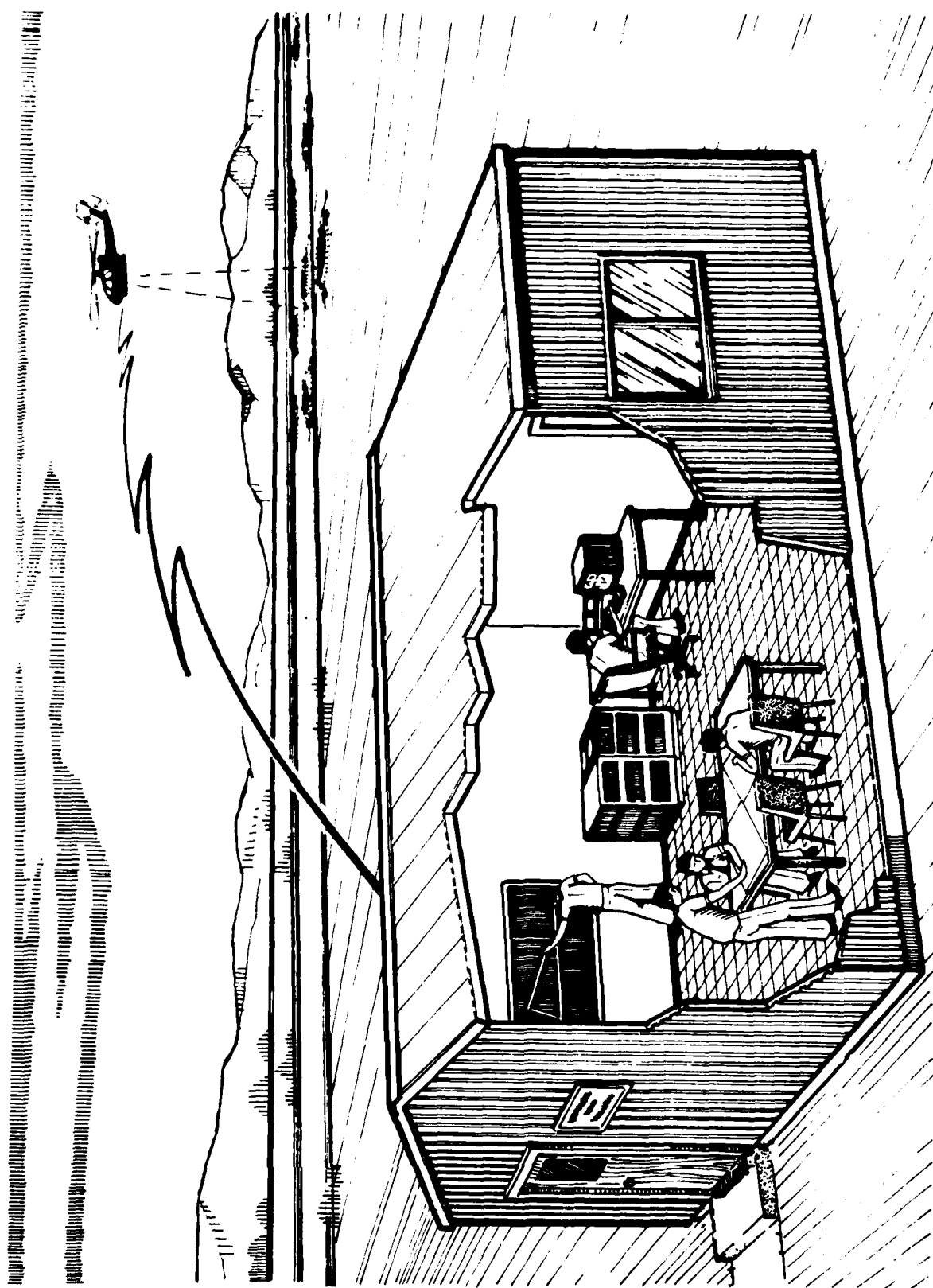
Figure 23. Command Station

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          ┌─────────────────────┐
          │   Attack With       │
          │ Conventional Weapons│
          └─────────────────────┘
                    │
                    ▼
          ┌─────────────────────┐
          │  Reconnaissance by  │
          │  Helicopter using   │
          │ a Linear Photodiode │
          │    Array Camera     │
          └─────────────────────┘
                    │
                    ▼
          ┌─────────────────────┐
          │   Recorded Data     │
          │   Digitized and     │
          │   Stored on Tape    │
          └─────────────────────┘
                    │
                    ▼
          ┌─────────────────────┐
          │Data Input into Vidicon│
          │ Processing Equipment│
          └─────────────────────┘
                    │
                    ▼
          ┌─────────────────────┐
          │  Operator Identifies│
          │ and Classifies Data │
          └─────────────────────┘
                    │
                    ▼
          ┌─────────────────────┐
          │ Microcomputer Selects│
          │  Area To Be Repaired│
          └─────────────────────┘
                    │
                    ▼
          ┌─────────────────────┐
          │Equipment and Personnel│
          │    Distribution     │
          │   Determined by     │
          │    Microcomputer    │
          └─────────────────────┘
                    │
                    ▼
          ┌─────────────────────┐
          │     RRR Team        │
          │    Dispatched       │
          └─────────────────────┘
```

Figure 24.   Damage Assessment Procedure Using the Linear
Photodiode Array System

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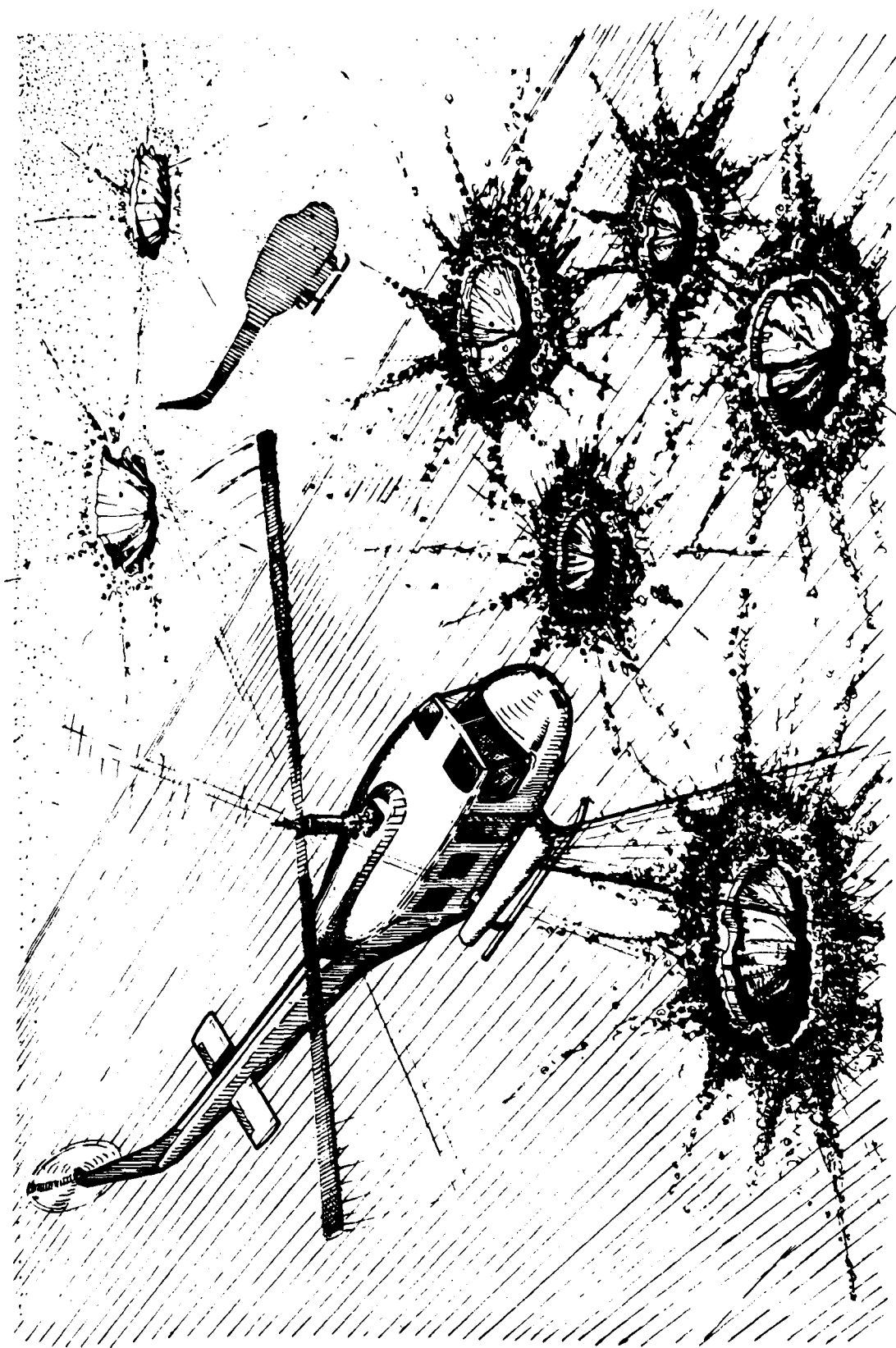
Figure 25.   Linear Photodiode Array System Reconnaissance Aircraft

3.   The system is expensive.

4.   Artificial lighting is required to provide nighttime reconnaissance capability.

5.   A minimum of three years is required for system development.

The advantages of the linear photodiode array system are as follows:

1.   The time required for the reconnaissance of three runway areas is approximately 10 minutes.

2.   The on-the-ground resolution may be good enough to enable the operator to locate antipersonnel mines.

3.   The time required for data reduction is approximately 20 minutes.

4.   The runway selection process is fast and accurate.

5.   Reconnaissance should not be curtailed by an adverse environment.

6.   Personnel already included on the RRR team can be used to operate the system.

7.   The system has the potential to distinguish between camouflets and unexploded ordnance.

8.   The system accurately determines the diameter of the ports of entry of the weapon for unexploded ordnance.

9.   The system pinpoints the locations where any unexploded ordnance may have penetrated the earth in the grassed areas adjacent to the runways.

10.   The system provides a quick scan of the entire airfield facility.

11.   Personnel can be trained to operate the video processing equipment in a short period of time.

SUMMARY

The linear photodiode array system recommended here should be developed as the principal RRR system. The system meets the imposed restrictions and provides the most accurate and rapid assessment of damage of any of the systems investigated.

QUICK-STRIKE RECONNAISSANCE (QSR) SYSTEM

The QSR system is a photogrammetric method which is presently being developed by the USAF. A sophisticated, high-speed jet aircraft provides the aerial platform for the photogrammetric equipment. The aircraft would be based in an area not considered to be a primary target. In the event of an attack on an airfield, the reconnaissance aircraft would be dispatched to the damaged airbase. The photogrammetric data could then be sent back to a central data processing area by means of telemetry, or the aircraft could return to base and the photographs could be hand carried to the data processing station.

The QSR system provides high-resolution photographs immediately after they are taken so that there is no delay for film development. These high-resolution photographs can then be placed on a transparency illuminator and scanned by a conventional vidicon camera as shown in Figure 26. The video data is digitized and fed directly into an image analyzer. The video data can then be analyzed by the same equipment which is used in the linear photodiode array method (Figure 27).

A scenario of the operation of the QSR method is shown in block diagram form in Figure 28. The airbase facilities are initially intact. The airfield runway is attacked with conventional weapons. A message is sent to the reconnaissance airbase informing them that an attack has taken place. The reconnaissance aircraft is dispatched and flies over the airbase runway, main taxiway, and a predetermined alternate runway. The reconnaissance aircraft makes a single pass over the entire airport facility from a greater altitude. The QSR data are then returned to the central data processing station where the photographs are mounted on a transparency illuminator and scanned by a vidicon camera. The video data are then input into the video processing equipment where they are processed by an operator. The reduced data are fed directly into a microcomputer which systematically scans them and selects the area of the pavement requiring the least amount of time to make operational. A hard-copy printout is provided showing the location of the repair area and the individual damages to be repaired. A printout is also provided giving the equipment and personnel distribution for the RRR effort.
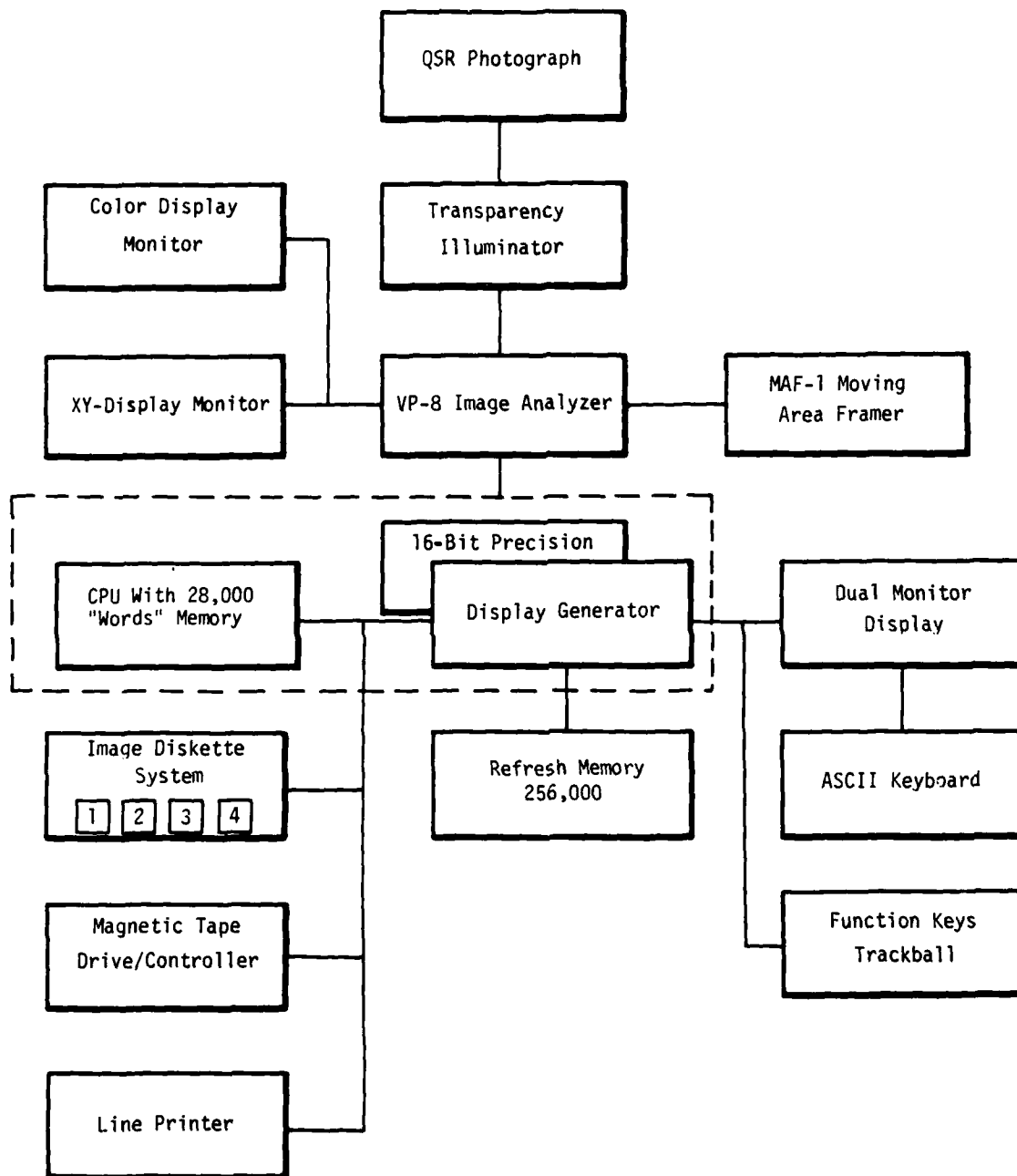
Figure 26. Quick-Strike Reconnaissance System Configuration
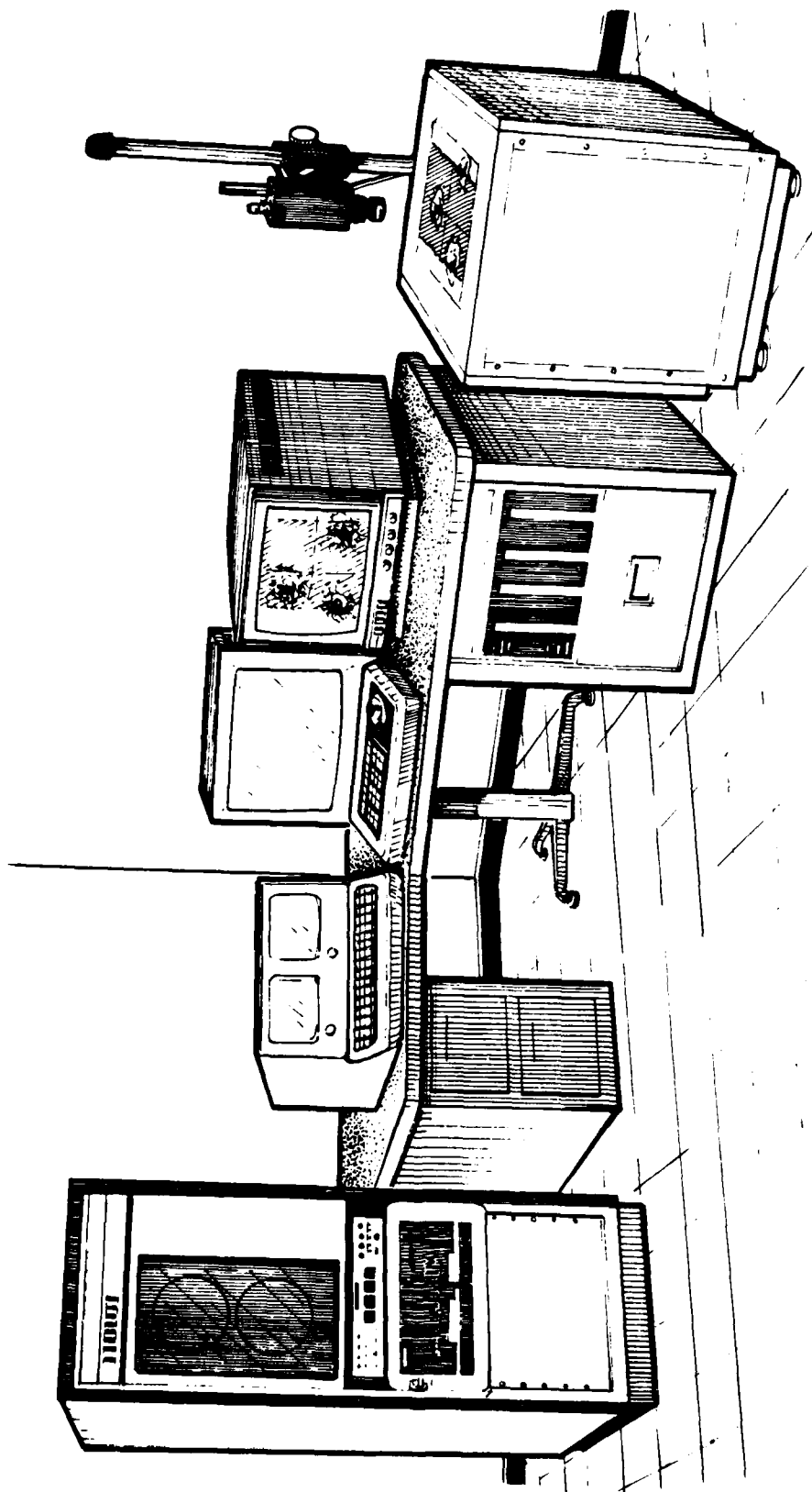
Figure 27. Single-Image Analysis System

86
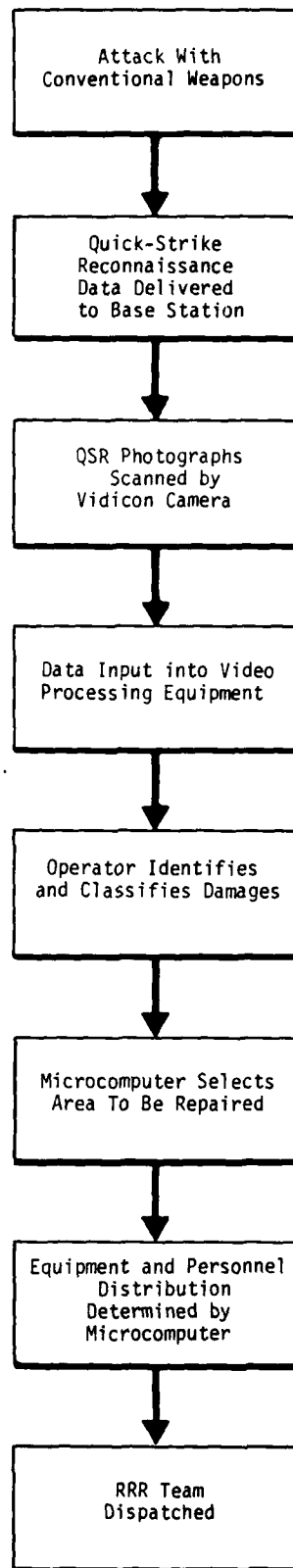
Figure 28. Damage Assessment Procedure Using the Quick-Strike
Reconnaissance Photogrammetric Method

The advantages of the QSR system are as follows:

1. The reconnaissance is fast and accurate.

2. The daytime on-the-ground resolution is adequate.

3. The data reduction process, although it does not meet the time limitation, is fast and accurate.

4. Reconnaissance should not be curtailed by an adverse environment such as antipersonnel mines or chemical, biological, or radiologial contaimination.

5. It may be possible to distinguish between camouflets and unexploded ordnance.

6. The system accurately determines the diameter of the port of entry of the unexploded ordnance.

7. The system locates antipersonnel mines.

8. The system pinpoints the locations of unexploded ordnance which have penetrated the earth in the grassed areas adjacent to the runways.

9. Equipment operators can be trained in a short period of time.

10. The system does not require a dedicated aircraft at each base.

11. The system can provide quick-look data.

Four disadvantages of the QSR method are as follows:

1. It is questionable whether the reconnaissance aircraft can be dispatched to the airport facility in a short time, particularly if more than one base is damaged in the attack.

2. The system does not meet the time limitation for data reduction.

3. The system is expensive.

4. It is questionable whether the system can provide adequate on-the-ground resolution for nighttime reconnaissance.

SUMMARY

The QSR system is fast and accurate. The reconnaissance portion of the system has already been developed. The data reduction process is accurate and can be completed in approximately 30 minutes per runway area analyzed. NMERI recommends that this system be used as the primary backup until the research work has been completed on the linear photodiode array system.

1.0

1.1

1.25

2.8 2.5
3.2 2.2
3.6
4.0 2.0

1.8

1.4 1.6
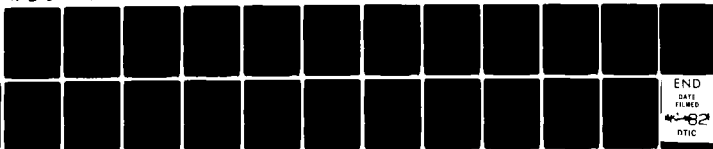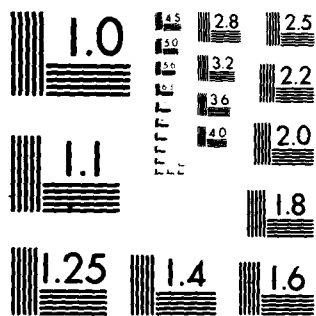
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

MANUAL METHODS

Two manual reconnaissance methods, one airborne and one ground-based, could provide backup for the linear photodiode array at QSR systems. The first method would provide reconnaissance from a helicopter carrying a pilot and two observers. The second would provide reconnaissance using teams of jeeps, each with a driver and observer. Data could be relayed from the helicopter or jeeps to the command post by radios, or the data could be recorded by the observers and hand carried to the command post when the reconnaissance was completed.

Two methods of data reduction can be used. The first is the manual entry of the data into the microcomputer of the video processing equipment. It would be necessary to input the size and type of the crater and its longitudinal station and lateral displacement. The microcomputer could then systematically scan the data and select the repair area which would require the least amount of time to make operational. The printer could then provide a printout of the location of the repair area with the individual locations of the damages to be repaired. A printout of the equipment and personnel distribution for the repair effort could also be provided. The second method calls for the data to be plotted on a 1,000:1 scale drawing of the runway. The drawing is then scanned with a scaled 5,000 x 50-foot overlay and the repair time for each location assessed with the aid of a HP-67 calculator.

A flow chart depicting the manual methods of reconnaissance with both methods of data reduction is shown in Figure 29. The runway facilities are intact. The base is attacked with conventional weapons. The damage assessment team is assembled and operates in one of the following ways:

1. Two observers and a pilot go by helicopter to survey the damage sustained by the runway, main taxiway, and one, predetermined alternate site. One man observes damages while the other radios their location, size, and type to the command post.

2. Six jeeps, each equipped with a two-way radio and two men, are driven along the damaged areas. One man observes the damage and radios in the required information to a central command post.
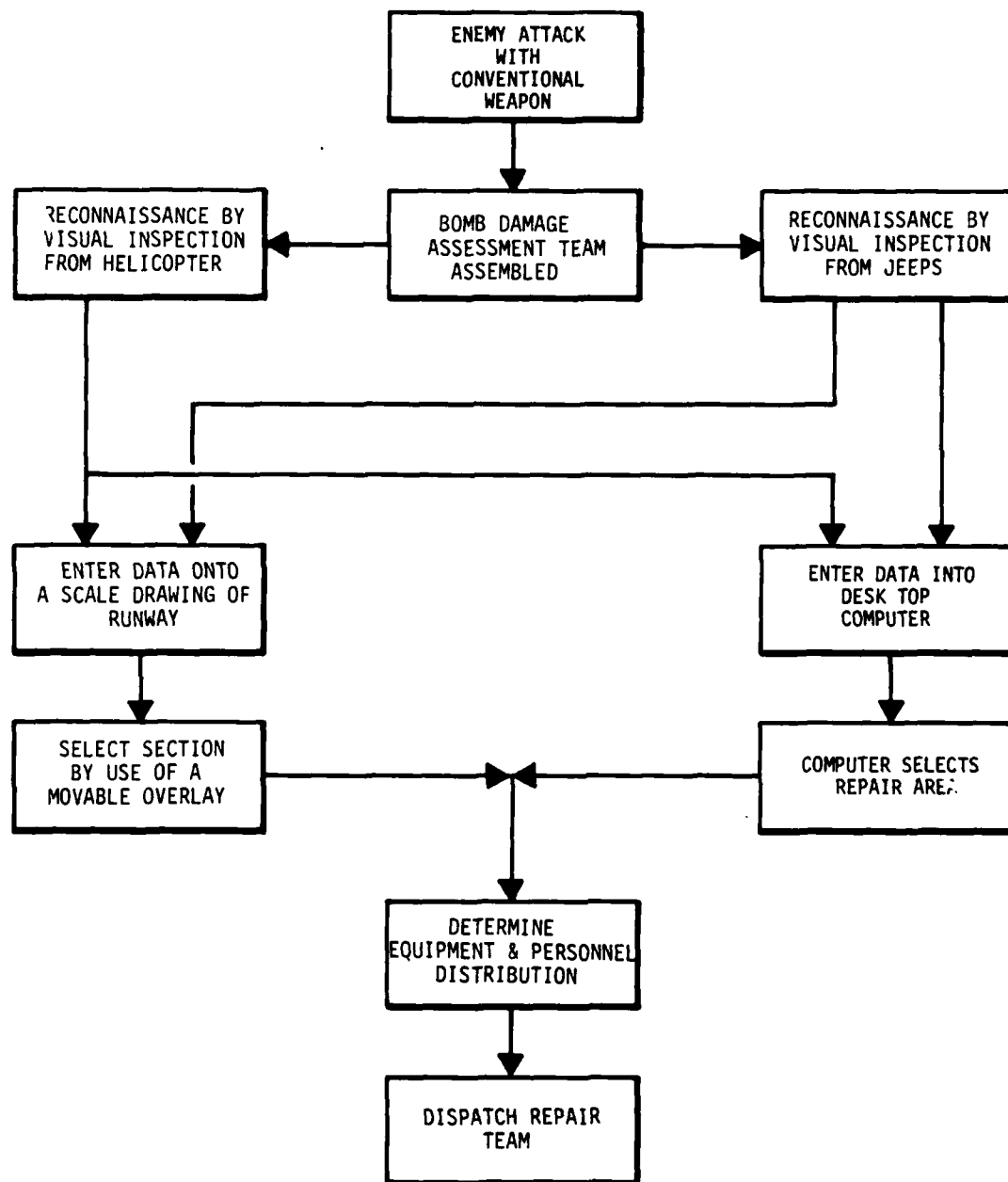
Figure 29.   Manual Methods

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As the data are received at the command post, they are either entered directly into a microcomputer or plotted on a 1000:1-scale drawing of the runway. If the data are entered in the microcomputer, the microcomputer scans the data and selects the repair area. A listing of an HP-9825 program to perform this task is provided in Appendix A. If the data are plotted on the scale drawing of the runway (Figure 30), the entire runway should be scanned systematically with a 1,000:1 scale 5,000- by 50-foot overlay. Lateral increments of 50 feet and 500-foot longitudinal increments should be used. Angular alignments should be examined only if it appears evident that a particular section might require substantially less repair time. For each section the detailed instructions on the use of the HP-67 calculator program (Table 11) should be followed. The repair time for each individual section should be determined and recorded in the table entitled, "Log of Bomb Damage" (Figure 31). Two men and one calculator minimum should be used. If it is apparent that a particular section will require more repair time than the two best previous sections, it should be abandoned and the next section examined. The two sections requiring the least amount of repair time to make them operational should be selected. The data in Table 12, entitled "Alternate Runway Repair Data," should be entered and the HP-67 program used to provide the necessary information. The required data from the best runway section can now be entered in the tables entitled "Bomb Damage Repair Equipment and Personnel Requirements" (Tables 13 and 14). The RRR repair teams should then be dispatched to the appropriate stations of the runway to repair the damage. A listing of the HP-67 program is included in Appendix B.

Tables 11 through 14 provide a method of determining the equipment and personnel distribution and an accurate estimate of the total time required for the project. The RRR equipment is not continually in use during the repair of a single major crater. There are large blocks of time during which each piece of equipment could be utilized to perform another function while the major operation continued unaffected. Tables 13 and 14 can be used to determine what combinations of damages can be repaired during the 4-hour repair effort. If the number of minutes under the column entitled "Total" exceeds the number of minutes under the column entitled "Maximum for 4-Hour Repair" for any given piece of equipment, the true repair time can be found by dividing the difference between the two columns by the number of pieces of equipment in the package.

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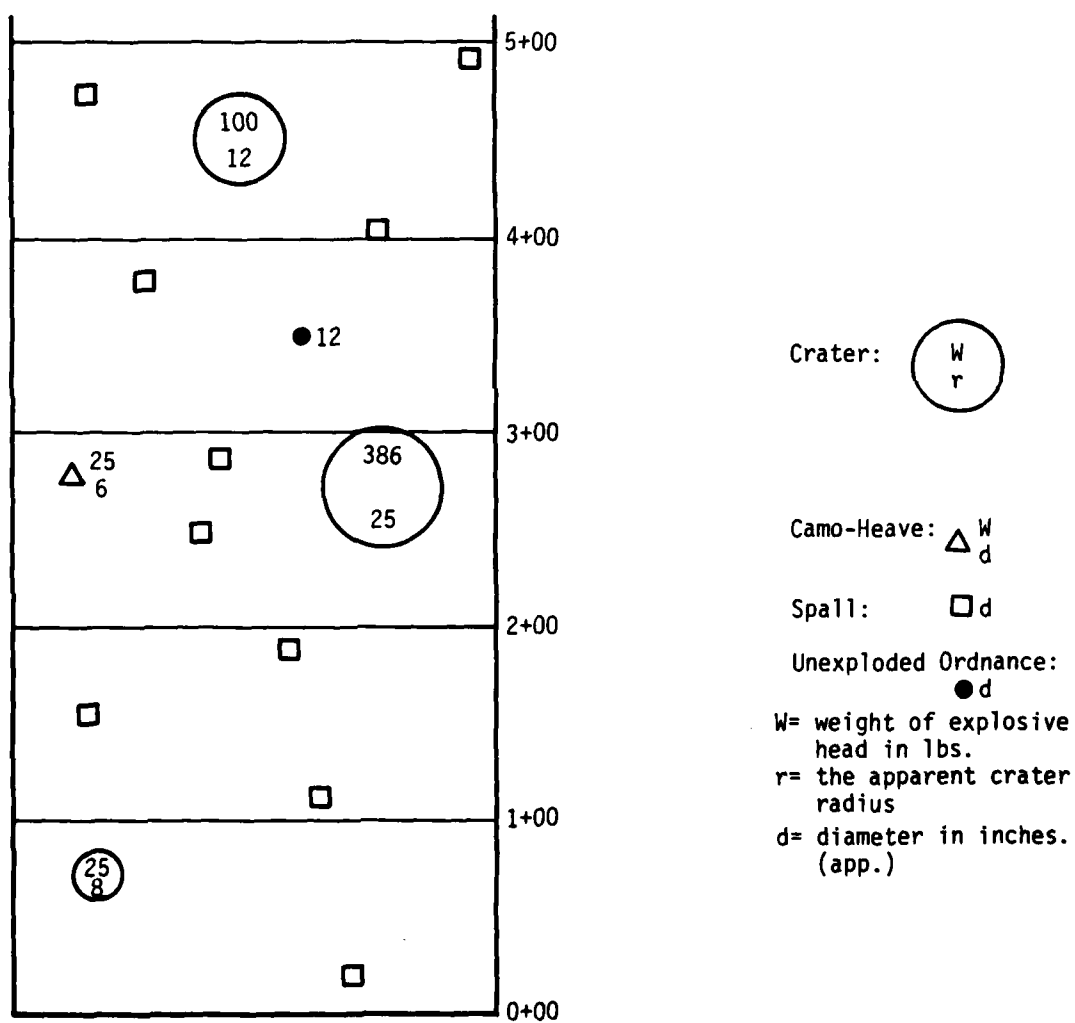
Figure 30. Graphical Data Coding

TABLE 11. HP-67 PROGRAM FOR REPAIR TIME CALCULATION

Step	Description
1.	Read in both sides of RRR card.
2.	Push $\boxed{A}$. If the calculator displays 0.00, then only the calculated repair time will be displayed. If the calculator displays 1.00, then the area of pavement to be removed, the repair time, and the volume of untreated base course required for a 1-foot thickness will be displayed in that order. Successive depressions of $\boxed{A}$ will alternately display 0.00 and 1.00.
3.	Input the following data: Craters: Apparent Radius $\boxed{B}$ ft Camo-Heave: Apparent Diameter $\boxed{C}$ in Spall: $\boxed{D}$ (t = 30 min)
4.	$\boxed{E}$ The total repair time for the given section.

Note: The "0" storage register must be zeroed for each successive alternate runway. $\boxed{f}$ $\boxed{E}$

Automatic weapons sizing from apparent radius craters:

Apparent Radius	Explosive Head	C.H.	Dapp	We
1-7	25		3-8.9	25
8-15	100		9	50
15-20	225			
20	386			

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Beginning Station	*Distance Beginning	*Distance End	Repair Time		Unexploded Ordnance
			Minutes	Hours	

*From Right Edge of Runway

Figure 31.   Log of Bomb Damage

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TABLE 12. ALTERNATE RUNWAY REPAIR DATA

Station of Beginning:
Distance of Beginning from Right Side:
Station of Ending:
Distance of Ending from Right Side:

Station	Distance, ft	Radius, ft	Estimated Repair Time, min	Volume UBC, yd^3
Craters				
1. 55+00	10	10	169	26
2. 73+35	35	25	221	150
3. 86+95	40	21	213	113
4. 91+15	25	16	196	66
5. 96+25	15	15	193	59

Station	Distance, ft	Diameter, in	Estimated Repair Time, min	Volume UBC, yd^3
Camo-Heaves				
1. 51+16	21	6	190	34
2. 78+97	12	12	203	62
3. 91+38	38	10	207	64

Station	Distance, ft	Station	Distance, ft
Spalls			
1. 51+01	47	12. 69+12	19
2. 54+08	6	13. 71+18	32
3. 57+68	29	14. 71+93	49
4. 58+93	41	15. 78+67	23
5. 58+99	12	16. 80+35	39
6. 59+17	42	17. 83+77	2
7. 59+35	9	18. 89+21	27
8. 59+88	25	19. 91+64	33
9. 64+14	36	20. 91+88	12
10. 64+77	21	21. 95+34	48
11. 65+50	44	22. 99+44	5

TABLE 13. BOMB DAMAGE REPAIR EQUIPMENT REQUIREMENTS.

Equipment	Type of Distress	Number of Units Required	Total Repair Time Required, %	Subtotal	Total	Maximum Time for 4-hr Repair, min
Pickup (PU)	CR	1	16	150	313	480
	CH	1	8	48		
	SP	1	16			
Tractor, Truck (TT)	CR	1	50	496	646	1,720
	CH	1	25	150		
	SP	0	--	--		
Semi-Trailer Low Boy (STL)	CR	1	25	248	504	720
	CH	1	25	150		
	SP	1	16	106		
Tracked Dozer (TD)	CR	1	57	565	865	720
	CH	1	50	300		
	SP	0	--	--		
Motorized Grader (GDR)	CR	1	52	516	714	720
	CH	1	33	198		
	SP	0	--	--		
Dump Trucks (DPT)	CR	5	30	298	602	3,600
	CH	2	33	198		
	SP	1	0-16	106		
Industrial Tractor (IT)	CR	1	37	367	517	720
	CH	1	25	150		
	SP	0	--	--		
Rotary Sweeper (SR)	CR	1	20	198	352	480
	CH	1	8	48		
	SP	1	16	106		
Vibratory Sweeper (SV)	CR	1	6	60	214	480
	CH	1	8	48		
	SP	1	16	106		
Front-End Loader (LDR)	CR	3	65	645	1215	1,680
	CH	2	75	450		
	SP	1	20	120		

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TABLE 14. BOMB DAMAGE REPAIR PERSONNEL REQUIREMENTS

Personnel /	Type of Distress	Number of Personnel Required	Total Repair Time Required, %	Maximum Time for 4-hour Repair, min
LT	CR	1	33	
	CH	--	--	
	SP	--	--	240
CMSgt	CR	1	--	
	CH	1	33	
	SP	1	0-5	240
New Centerline Crew	CR			
	CH			
	SP			240
Rotary Sweeper Operator	CR	1	20	
	CH	1	8	
	SP	1	16	480
Vacuum Sweeper Operator	CR	1	6	
	CH	1	8	
	SP	1	16	480
Hauling Crew Supervisor	CR			
	CH			
	SP			240
Front-End Loader Operator	CR	1	62	
	CH	2	60	
	SP	1	20	1,680
Tractor/Trailer Operator	CR	1	37	
	CH	1	25	
	SP	0	--	720
Crater Supervisor	CR	1	50	
	CH	1	25	
	SP	1	0-5	720
Grader Operator	CR	1	52	
	CH	1	33	
	SP	0		720
Tracked Dozer Operator	CR	1	57	
	CH	1	50	
	SP	0		720
Compactor/Vibrator Operator	CR	1	37	
	CH	1	25	
	SP	0	--	720
Crater Laborers	CR	6	75	
	CH	0	25	
	SP	0-1	0-67	4,320
Matting Supervisor	CR	1	50	
	CH	0	--	
	SP	0-1		720
Matting Laying Crew	CR	16	50	
	CH	0	--	
	SP	0-1	0-67	11,520
Dump Truck Operator	CR	5	30	
	CH	2	33	
	SP	1	5-15	3,600

The graphical data reduction system was tested on 29 July 1978 at CERF. A description of the test is included in Appendix B. It was found from the test in Appendix B and in subsequent investigations that it takes at least 2 minutes to investigate any given section of the runway. If the runway is scanned sequentially by 100-foot longitudinal increments and 25-foot lateral increments and if no inclined sections are investigated, it would take approximately 13-1/2 hours to scan an entire runway. Some of this time can be eliminated by visual inspection and by graphing the unsafe areas which surround the unexploded ordnance, but no time was included in this estimate for the reduction of the data from the adjacent grassed areas, for the investigation of repair routes, and for the effects of fatigue on the data reduction personnel.

NMERI recommends that the manual methods of reconnaissance and data reduction be used only as backup systems for the linear photodiode array system and the quick-strike reconnaissance system. Summaries of the equipment and personnel requirements and the advantages and disadvantages of each system are included in Table 15.

TABLE 15. PRIMARY METHODS OF RECONNAISSANCE

SYSTEM	LINEAR PHOTODIODE ARRAY	QSR PHOTOGRAMMETRIC	MANUAL FROM HELICOPTER	MANUAL FROM JEEPS
RECONNAISSANCE	Linear Photodiode Array Camera Mounted on Gyro-Stabilized Platform in Helicopter	Real-Time Developed Photographs Provided by Aircraft and Equipment Already in the USAF Inventory	Visual Observation of Damage from Helicopter	Visual Observation of Damage from Jeeps
DATA RECORDER	Video Magnetic Tape Recording Device	Transparency	Computer Cards or Tables	Data Radioed to Base Station
HARDWARE	Helicopter Linear Photodiode Array Camera Linear Photodiode Array Camera Support Equipment Gyro-Stabilized Platform High-Intensity Strobe Lights Recording Device Analog-to-Digital Device VDI 300 Hardware & Software Building to House Equipment Electrical Generators	Light Table Vidicon Camera with Self-Deflection Yoke Vidicon Support Equipment VDI 300 Hardware & Software Building to House Equipment Electrical Generator QSR Photographs	Helicopter Base Station Radio Desk-Top Computer Building to House Equipment Electrical Generator	Jeeps (6) Multiple Frequency Radios (6) Base Station Radios (6) HP67 (1) Building to House Equipment Electrical Generator
PERSONNEL	Helicopter Pilot Operators (2) Computer Technician (1) Camera Operator (1)	Pilot Operators (2) Computer Technician (1)	Pilot (1) Observers (1) Recorders (1) Operator (1)	Drivers (6) Observers (6) Recorders (6) System Operators (2)
COST	$200,000.00	$200,000.00	$25,000.00	$1,000.00
TIME: Reconnaissance Reduction Total	10 min 20 min 30 min (minimum)	30 min (?) 20 min 2 hr (minimum)	4 hr 30 min 4 1/2 hr (minimum)	4 hr 3 1/2 hr 7 1/2 hr (minimum)
TIME REQUIRED TO IMPLEMENT	3 Years	2 Years	6 Months	6 Months

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TABLE 15. PRIMARY METHODS OF RECONNAISSANCE (Concluded)

ADVANTAGES			
1) Reconnaissance takes 10 minutes to complete. 2) On-the-ground resolution of 1.9 inch by 1.9 inch square. 3) 20-minute data reduction time. 4) Runway selection process is fast and accurate. 5) Reconnaissance is not curtailed by adverse environment. 6) Personnel already included with the BDR team can be used to operate the system. 7) Accurately determines the diameter of the port of entry of the unexploded ordnance. 8) Locates antipersonnel mines. 9) Pinpoints location where unexploded ordnance have penetrated earth in grasses areas. 10) Provides quick scan of entire airport facility. 11) Personnel can be trained to operate vidicon processing equipment in a short period of time. 12) The system can be easily implemented.	1) Fast reconnaissance. 2) Good on-the-ground resolution. 3) Fast data reduction. 4) Accurate data reduction. 5) Reconnaissance is not curtailed by adverse environment. 6) Accurately determines diameter of port of entry for unexploded ordnance. 7) Locates antipersonnel mines. 8) Locates unexploded ordnance in grassed areas. 9) Easy to train equipment operators. 10) Implemented in less than two years. 11) Does not require a helicopter.	1) Could use microcomputer from primary system. 2) Inexpensive. 3) Can be implemented in a very short period of time. 4) Difficult to curtail operation.	1) Inexpensive. 2) Can be implemented in a very short period of time. 3) Difficult to curtail operation. 4) Not affected by adverse environment.
DISADVANTAGES			
1) 3-yr development time. 2) The system is untested. 3) The system requires a helicopter or other transport vehicle. 4) The system is expensive. 5) Requires artificial lighting.	1) Questionable whether reconnaissance aircraft can be dispatched in a short period of time. 2) Does not meet time limitation. 3) The system is expensive. 4) Questionable if the system can function properly at night and under adverse weather conditions.	1) Does not meet time requirement. 2) Inaccurate location and classification of data. 3) Fatigue in reconnaissance.	1) Does not meet time requirement. 2) Inaccurate reconnaissance and data reduction. 3) Fatigue in reconnaissance and data reduction. 4) Does not provide quick-look capability.

REFERENCES

1. Hokanson, L. D., and Rollings, R. S., *Field Test of Standard Bomb Damage Repair Techniques for Pavements*. AFWL-TR-75-148. Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, October 1975.

2. Hokanson. L. D., *Tyndall Air Force Base Bomb Damage Repair Field Test Documentation and Analysis*, AFWL-TR-74-226, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, October 1975.

3. Brooks, G. W., Cunningham. J. E., and Mayer, P. W., *Bomb Damage Repair (BDR) Damage Prediction*. Volumes I and II, TRW-75-24. Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico.

4. Reynolds, F. W., U.S. Patent 3041089.

5. Summers, H. S., Jr., "Response of Photoconducting Image Devices with Floating Electrodes," *Journal of Applied Physics*, Vol. 34, No. 10, pages 2923-2934, October 1963.

6. *International Defense Review*, June 1977, page 1087, "British Remotely-Piloted Helicopter Progress."

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APPENDIX A

MOS SELECTION PROGRAM FOR HP-9825 CALCULATOR

VARIABLES

A = Area of moderately upheaved pavement (ft²)

B = Station at beginning of runway

C = Station of runway distress

D = Loop operator

E = Station at end of runway

F = fc'

G = Loop operator

H = Loop operator

I = Loop operator

J = Intermediate step

K = Intermediate step

L = Intermediate step

M = Alpha

N = dt

O = 1'

P = Counter

Q = Sum of the repair time for given runway section

R = radius of total repair area

S = A [I,4]

T = flg 0

U = flg 1

V

W = Weight of explosive head

X

Y = Width

Z

ARRAYS

A [1000,6]   1) CL Sta   2) Dist Frm CL   3) Type damage   4) Radius   5) Rep. time
             6) Area of Total Repair

B [6,4]   1) Tot Repair Time   2) Beginning STA   3) Beg. Dist. from Alpha
             4) Alpha

f0: sfg 0; ret
f1: sfg 1; ret

```
 0:  dim A[100,6], B [6,4]
 1:  ldt 0,F,B,E,Y; 1→P; B→C
 2:  for I=1 to 100
 3:  C/100→K; int(K)→L; int (frc(K)100)→J; fxd 0
 4:  dsp "Are you at station", L, "t", J; stp
 5:  if flg0: dsp "Yes"; wait 1000; C→A [I,1]
 6:  if flg1; dsp "No"; wait 1000; ent "sta", A [I,1]
 7:  cfg 0; cfg 1; A [I,1] + 5→C
 8:  ent "Distance from Centerline =", A [I,2]
 9:  ent "Type Damage 1=CR 2=CH 3=SP 4=UO", A [I,3]
10:  ent "Rad of CR(ft) or Diam of CH(in)", A [I,4]
11:  if A [I,3]=1; gto "50"; if A [I,4]>= 8; gto "225"; if A [I,4]>=16; gto "386"
12:  if A [I,3]=2; gto "25"; if A [I,4]>=9 gto "50"
13:  gto "Cont"
14:  "50": 50→W; gto "Cont"
15:  "225": 225→W; gto "Cont"
16:  "386": 386→W; gto "Cont"
17:  "25": 25→W; gto "Cont"
18:  "Cont":  if A [I,3]=1; gto "Crater"
19:  if A [I,3]=2; gto "CH"
20:  if A [I,3]=3; gto "SP"
21:  if A [I,3]=4; gto "UO"
22:  dsp "Pay more attention"; wait 750; dsp "to the task at hand"; wait 750
23:  dsp "Push the error button"; wait 750; dsp "and reenter the data"; wait 750
24:  dsp "for this point"; stp
25:  "Crater":  A [I,4]↑2 log ((144 FA [I,4]↑2/W1.25e7)↑ (1/log(.46)))→A
26:  πA [I,4]↑2 + A→A [I,6]; gto "Time"
27:  "CH": ((A [I,4]/12)↑2/1.55 e⁻9) (FA [I,4]↑2/W)↑(-1.41)→A
28:  π(A [I,4]/12)↑2 + A→A [I,6]; gto "Time"
29:  "SP": 30→A [I,5]; gto 32
30:  "UO": 240→A [I,5]; gto 32
31:  "Time":  65.04A↑.16→A [I,5]
32:  if I=P100; ldt P; P+1→P
33:  next I
34:  stp
```

```
35:  "error": dsp "Sorry Charlie, you blew it"; wait 750
36:  dsp "Did the error occur,"; wait 750
37:  dsp "on this point...answer""Yes"""; wait 1000
38:  dsp "or the previous point, ans ""No"""; wait 750; stp
39:  if flg 0; dsp "Yes"; cfg 0; gto 5
40:  if flg 1; C-5→C; I-1→I; disp "No"; cfg 1; gto 4
41:  "Compute":  0→P
42:  for I=1 to (E-B)/50
43:  for D=1 to (Y-50)/25
44:  for G=1 to (Y-50)/25
45:  deg; atn ((25G-25D)/5000)→M
46:  P+1→P; 0→Q
47:  for H=1 to 100
48:  (25(5-D)-A [H,2]) cos (M)-A [H,1] sin (M)→N
49:  (25(5-D)-A [H,2]) sin (M)+A [H,1] cos (M)→O
50:  if O>5000; gto 62
51:  if A [H,3]=1 and N>25+A [H,4]; gto 62
52:  if A [H,3]=1 and N<=25+A [H,4] and N>=25-A [H,4]; gto "Tot"
53:  if A [H,3]=1 and N<25-A [H,4]; A [H,5] + Q→Q; gto 62
54:  if A [H,3]=3; A [H,5] + Q→Q; gto 62
55:  if A [H,3]+4; A [H,5] + Q→Q; gto 62
56:  if A [H,3]=2; Γ(A [H,6]/π)→R
57:  if N>25+R; gto 62
58:  if N<=25+R and N>=25-R; gto "totl"
59:  if N<25-R; A [H,5]+Q→Q; gto 62
60:  "totl":  ((R+25-N)/2R) A [H,5] + Q→Q; gto 62
61:  "tot": ((A [H,3]↑25-n/2A [H,3]) A [H,5] + Q→Q
62:  next H
63:  next G
64:  next D
65:  next O
*6499
```

APPENDIX B
THE MANUAL REPAIR AREA SELECTION TEST

TEST CONDUCTED: July 29, 1977

BEGINNING AT: 8:28

ENDING AT: 9:35

PURPOSE: The purpose of the test was to determine the feasibility of hand reducing the BDR data. As the time requirements were important in reducing the data, a careful and accurate time log was kept. The bomb damage was randomly spaced so as to simulate data which might be expected from reconnaissance reports following an actual enemy attack.

TYPES OF DAMAGE: The damage was proportioned from data on previous attacks on U.S. and foreign bases in war zones. The following is a list of the amounts and types of damages used in the test:

750 pound bombs	4
500 pound bombs	6
100 pound bombs	14
Spalls	450
Camo-heaves	16
Unexploded ordance	10

SUMMARY OF METHOD EMPLOYED: The test was (10,00 feet by 250 feet) conducted by Neil D. Williams and Glenn Baird. A typical runway (10,000 feet by 250 feet) was drawn at a 1,000:1 scale. The various types of bomb damage were then entered to scale on the runway drawing. A transparent overlay (5,000 feet by 50 feet) drawn to scale was placed over the runway drawing and moved in increments so as to cover the entire runway. As seen in Table B-1, the longitudinal increment was 1,000 feet, while the transverse increment was 50 feet. No angular displacments were made. The repair time for the various types of damage is a function of the apparent radius. The formulae for the calculation of the repair time were fed into an HP-67 programmable calculator. This program requires that the type of damage and the apparent radius of the crater be input. It then yields the repair time. If desired, the program will also output the area of the pavement to be removed, the area and

diameters of the total repair, and the number of cubic yards of base course required for the backfill. One person calculated the repair times due to the major distresses, and the other person accumulated the total repair time on another calculator.

SUGGESTION

It is suggested that the use of three people could reduce the time to about 80 percent of the test time.

TABLE B-1. LOG OF BOMB DAMAGE

BEGINNING STATION	DIST. OF BEG. FROM RT. EDGE	DIST. OF END FROM RT. EDGE	REPAIR MIN	TIME HR	UNEXPLODED ORDNANCE
0+00	225	225	2,923	48.7	1
	175	175	3,132	52.2	-
	125	125	1,467	24.5	1
	75	75	2,777	46.3	11
	25	25	2,801	46.7	1
10+00	225	225	2,629	43.8	1
	175	175	2,807	46.8	-
	125	125	1,875	31.3	11
	75	75	2,699	45.0	11
	25	25	2,298	38.3	1
20+00	225	225	2,500	41.7	11
	175	175	3,081	51.4	-
	125	125	1,463	24.4	1
	75	75	3,353	56.0	11
	25	25	2,505	42.0	1
30+00	225	225	2,694	45.0	11
	175	175	2,914	49.0	11
	125	125	4,646	77.0	11
	75	75	3,145	52.0	1
	25	25	2,055	34.0	1
40+00	225	225	2,531	42.0	1
	175	175	2,977	50.0	-
	125	125	2,036	34.0	1
	75	75	2,800	47.0	1
	25	25	1,857	31.0	1
50+00	225	225	1,986	33.0	11
	175	175	2,119	35.0	-
	125	125	1,659	28.0	1
	75	75	2,664	44.0	11
	25	25	1,748	29.0	-

HP-67 PROGRAM

REPAIR TIMES FOR DAMAGE ASSESSMENT

STEP	1st Key	2nd Key	3rd Key
000			
001	f	LBL	A
002	h	F?	0
003	GTO	0	
004	h	SF	0
005	1		
006	h	RTN	
007	f	LBL	0
008	h	CF	0
009	0		
010	h	RTN	
011	f	LBL	B
012	1		
013	2		
014	X		
015	ENTER		
016	g	x^2	
017	STO	0	
018	h	X≤Y	
019	8		
020	4		
021	g	X>Y	
022	GTO	1	
023	2		
024	0		
025	0		
026	GTO	7	
027	f	LBL	1
028	2		
029	5		
030	GTO	7	
031	xf	xLBL	x2
032	3		
033	8		
034	6		
035	f	LBL	7
036	h	1/x	
037	RCL	0	
038	x		
039	RCL	9	
040	x		

REPAIR TIMES FOR DAMAGE ASSESSMENT
(Continued)

STEP	1st Key	2nd Key	3rd Key
041	1		
042	2		
043	.		
044	5		
045	EEX		
046	6		
047	÷		
048	.		
049	9		
050	8		
051	CHS		
052	h	y^x	
053	1		
054	–		
055	RCL	0	
056	X		
057	STO	1	
058	f	GSB	3
059	f	GSB	4
060	h	RTN	
061	f	LBL	C
062	2		
063	÷		
064	ENTER		
065	g	x^2	
066	STO	0	
067	h	$X \leq Y$	
068	6		
069	g	$X > Y$	
070	GTO	5	
071	9		
072	g	$X \leq Y$	
073	GTO	6	
074	2		
075	5		
076	GTO	8	
077	f	LBL	5
078	1		
079	5		
080	GTO	8	
081	f	LBL	8

HP 67 PROGRAM

REPAIR TIMES FOR DAMAGE ASSESSMENT
(Continued)

STEP	1st Key	2nd Key	3rd Key
082	f	LBL	6
083	5		
084	0		
085	f	LBL	8
086	h	1/x	
087	RCL	0	
088	x		
089	RCL	9	
090	x		
091	7		
092	.		
093	3		
094	9		
095	5		
096	EEX		
097	6		
098	÷		
099	1		
100	.		
101	1		
102	2		
103	4		
104	CHS		
105	h	y^x	
106	RCL	0	
107	X		
108	STO	1	
109	f	GSB	3
110	f	GSB	4
111	h	RTN	
112	f	LBL	D
113	3		
114	0		
115	STO	+	8
116	h	RTN	
117	f	LBL	D
118	RCL	8	
119	h	RTN	
120	g	LBLF	E

REPAIR TIMES FOR DAMAGE ASSESSMENT

(Concluded)

STEP	1st Key	2nd Key	3rd Key
122	0		
123	STO	8	
124	5		
125	0		
126	0		
127	0		
128	STO	9	
129	h	RTN	
130	f	LBL	3
131	.		
132	1		
133	6		
134	h	y^x	
135	5		
136	9		
137	.		
138	9		
139	X		
140	STO	2	
141	STO	+	8
142	h	RTN	
143	f	LBL	4
144	RCL	2	
145	h	F?	0
146	h	RTn	
147	R/S		
148	RCL	1	
149	1		
150	4		
151	4		
152	÷		
153	R/S		
154	2		
155	7		
156	÷		
157	h	RTN	

DTIC-DDA-2	12
HQ AFSC/DLWM	1
HQ AFSC/SDNE	1
HQ USAFE/EUROPS (DEXD)	1
HQ USAFE/DEX	1
AFATL/DLJK	1
AD/IN	1
USAFTAWC/THL	1
USAFTAWC/THLA	1
AFATL/DLODL (Tech Library)	1
EOARD/LNS	1
SHAPE TECHNICAL CENTER	1
HQ PACAF/DEM	1
HQ PACAF/DEPR	1
AUL/LSE 71-249	1
HQ SAC/DEM	1
US Navy Civil Engineering Lab	1
HQ ATC/DED	1
HQ MAC/DEM	1
HQ AFESC/DEMP	1
HQ AFESC/DEO	1
HQ AFESC/TST	1
HQ AFESC/RDCR	10
USAE WESGF	1
USAE WES	1
HQ USAF/LEEX	1
HQ USAF/LEYW	1
HQ USAF/RDPX	1
AFWAL/FIEM	1
AFIT/DET	1
HQ AFLC/DEMG	1
AFIT/LDE	1
ASD/RWRS	15

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