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NRL Memorandum Report 2426  
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# Effects of Briefing Material, Swath Width, and Resolution Upon Target Detection and Designation With a Synthetic Aperture Radar

[Unclassified Title]

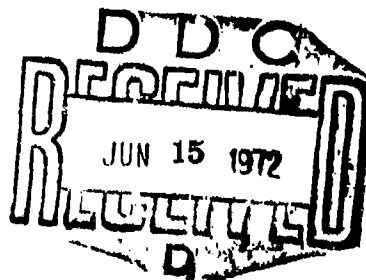
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*Airborne Radar Branch  
Radar Division*

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April 1972

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MEMORANDUM

Subject: A Memorandum on the Effects of Briefing Material, Swath Width, and Resolution upon Target Detection and Designation with a Synthetic Aperture Radar.

Background

(C) The Naval Research Laboratory (NRL) has been investigating techniques for the control of air-to-surface weapons that are compatible with using a high-resolution radar in the launch aircraft for target detection and designation of targets using static and dynamic displays of high-resolution real aperture data.

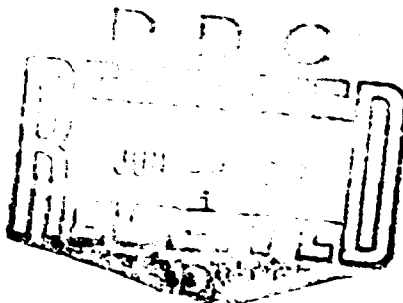
Findings

(C) This report presents the results of an investigation of operator performance in the real-time detection and designation of tactical targets from high-resolution synthetic aperture radar (SAR) data. The data from an airborne reconnaissance radar, which were processed on a ground-based optical processor were used in this study. The results of this report, therefore, should be interpreted as upper-limit performance capabilities of a real time SAR system. Within the scope of the study reported here, the following trends were observed:

1. A 4 nm field of view presentation in the search mode and a 2 nm field of view presentation in the zoom mode, gave optimum target designation probabilities and times.
2. Sectional aeronautical charts and aerial photographs were the best of the briefing materials investigated.
3. Degrading the resolution from 45 to 90 feet did not affect the probability of target designation significantly, however it did increase target designation times.

R & D Implications

(C) Effective tactical utilization of SAR systems depends upon a thorough understanding of the capabilities and limitations of high-resolution SAR in the air-to-surface target detection and designation process. This report presents a preliminary analysis of this process. The trends indicated by these results may be used as guidelines for initial system design. Further detailed analysis is required prior to finalization of system design.



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Recommended Action

(C) The following recommendations are made:

1. A concentrated effort should be made to obtain digitally processed SAR data to permit a detailed statistical analysis. These data should be collected in both the 45° squint mode and the doppler beam sharpened (DBS) mode.

2. Previous studies tend to show that radar imagery is the best type of briefing material. Flight tests of real time SAR systems should be conducted over areas where radar imagery already exists. This will allow a detailed study of the effects of radar imagery as briefing material.

3. Studies should also be performed to determine if the performance of a SAR can be improved by using it in conjunction with other sensors such as infrared and low-light-level television.

*Clair M. Loughmiller*

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ABSTRACT (C)

(C) A human factors simulation was performed to determine the effects of swath width, briefing material, and resolution upon an operator's ability to detect and designate targets from a real-time synthetic aperture radar presentation. It was determined that a 4 nm field of view presentation in the search mode, and a 2 nm field of view presentation in the zoom mode, give the best results in terms of target designation probabilities and times. Aerial photographs, together with sectional aeronautical charts, were found to be the best types of briefing materials. The mean time required to designate a target under the conditions listed above was  $26 \pm \sigma = 6$  seconds with a mean designation probability of  $0.7 \pm \sigma = .1$ .

PROBLEM STATUS (U)

This is an interim report on a continuing problem

AUTHORIZATION

NRL Problem 53D01-03  
A36-5333/652C/1W1118-0000

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EFFECTS OF BRIEFING MATERIAL, SWATH WIDTH, AND RESOLUTION UPON TARGET  
DETECTION AND DESIGNATION WITH A SYNTHETIC APERTURE RADAR

I. INTRODUCTION

(C) The effectiveness of tactical aircraft in delivering a weapon against surface targets can be greatly improved by increasing the capability of accurately detecting targets at long ranges. One potential method of accomplishing accurate real-time, long-range detection is a synthetic aperture radar (SAR). For this reason, the Naval Air Systems Command (NAVAIR) is developing a Multi Mission Radar (MMR) which incorporates a synthetic aperture mode.

(C) Reconnaissance radar systems have used SAR for some time. They have not been used for tactical applications due to the fact that the imagery had to be optically processed on the ground. Recently, however, advances in technology, particularly in the signal processing area, offer the possibility of a real-time SAR. The Hughes Aircraft Company (HAC) and the Westinghouse Aerospace Division, for example, working under NAVAIR contracts, are developing real-time digital processors which are currently being flight tested to evaluate the MMR concept.

(C) There are several obvious advantages associated with the MMR. The first, and possibly most important advantage, is the relatively long-range detection of surface targets afforded by this radar. It is planned that the MMR will allow detection of tactical surface targets at ranges up to 50 nm. If targets are detected at these ranges, it will allow the attacking aircraft to avoid target-area, surface-to-air defenses by either launching a stand-off missile or by descending to low altitude to attack the target. A second advantage which is related to the first, is the relatively long time allowed for weapon delivery by this detection technique. Other sensors having shorter detection ranges do not allow sufficient time for an effective weapon delivery. A third advantage is the improved resolution offered by a SAR. The MMR, for example, is expected to have a resolution of 50 feet which would allow the capability to find a rather large class of tactical targets. A final advantage of SAR over IR or low-light level-television is its capability for all-weather operation.

(C) It is not enough that SAR data be processed in real-time. In order for these data to be tactically useful, they must also be interpreted by a human operator, sufficiently well and in time to allow the aircraft to attack the target. The problem of adapting the SAR to a tactical aircraft divides into two parts, hardware capability and human capability. Human capabilities and limitations are dealt with in this report.

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(C) This is a report of the effects of briefing material, swath width, and resolution on operator performance in a simulated MMR mission. To accomplish this study, high quality reconnaissance SAR imagery which was optically processed, was degraded to the quality expected of digitally processed MMR imagery. This degraded imagery was then used to simulate an MMR mission.

(C) The HAC, under contract to NRL, is conducting a simulation in parallel with this study at their facility. Again, optically processed reconnaissance SAR imagery is degraded to the quality expected of the MMR. The objective of the HAC study is to determine how accurately various classes of targets can be detected at various detection times.

## II. MULTIMISSION RADAR (MMR) DESCRIPTION

(C) The MMR, as its name implies, will have various modes of operation against both airborne and ground-based targets. These modes are:

- o Synthetic array mapping with real-time display
- o Doppler beam sharpening (DBS)
- o Air-to-ground ranging
- o Tracking of fixed ground targets
- o Terrain following or avoidance
- o Detection of moving ground targets
- o Detection of moving airborne targets
- o Tracking of airborne or ground moving targets

The synthetic array mapping mode is the operational mode that will be considered in this study. The various parameters describing this mode are as follows:

- o Squint angle -  $45^{\circ}$
- o Resolution - 50 feet in both range and azimuth
- o Stand off range - 50 nm
- o Swath width - 10 nm
- o Altitude - 30,000 feet

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- o Aircraft speed - up to M 2.0
- o Display - real-time passing scene

(C) The following is a description of a typical mission utilizing the synthetic array mapping mode. The mission is broken up into the 3 phases. A portion of Phase 1 is shown in Fig. 1 together with Phase 2 and Phase 3. In Phase 1, the operator is given a detailed briefing on the target of interest, using maps and aerial photographs. The target coordinates are then fed into the weapon control computer. After take-off from the carrier, there is a cruise phase to within range of enemy defenses. The aircraft then descends to a lower altitude to avoid surface to air missiles (SAM). Navigation at low altitude is accomplished by the on-board, doppler-inertial navigation system. The low altitude penetration is completed when a predetermined check point is detected and designated. This check point is also used to update the aircraft's navigation system. At a selected position relative to the check point, the aircraft then pops up to search altitude to complete Phase 1.

(C) In Phase 2, while the MMR is squinted at  $45^\circ$  with respect to the aircraft's flight path and mapping a swath on the ground at a 50 nm range from the aircraft as shown in Fig. 2, the target is detected and designated. In Phase 3, two options are available. The target coordinates can be fed into the computer of a long-range air-to-surface missile (ASM), or the target coordinates can update the aircraft's navigation system for a low-level delivery of conventional weapons. Only Phase 2 of the MMR mission is simulated in this study.

### III. PROCEDURES FOLLOWED BY A BOMBARDIER/NAVIGATOR (B/N) IN AN ACTUAL MISSION

(U) The planned procedures to be followed by a B/N in Phase 2 of an actual MMR mission will now be described. Later these procedures will be related to those followed by the operator in the simulation.

(C) Prior to the MMR mission, some level of reconnaissance will have been performed. Maps, aerial photographs, and/or radar imagery of the target area may have been collected. The B/N plans his flight path to encounter the minimum of enemy defenses. He studies the briefing material and finds the appropriate check points and cues needed to locate the target.

(C) After the low-altitude navigation and penetration phases have been completed, the aircraft attains search altitude and the MMR, squinted at  $45^\circ$  to the aircraft flight path, maps a wide swath on the ground. The SAR mapping data are collected and stored. The stored data are processed in real-time and displayed to the B/N who searches

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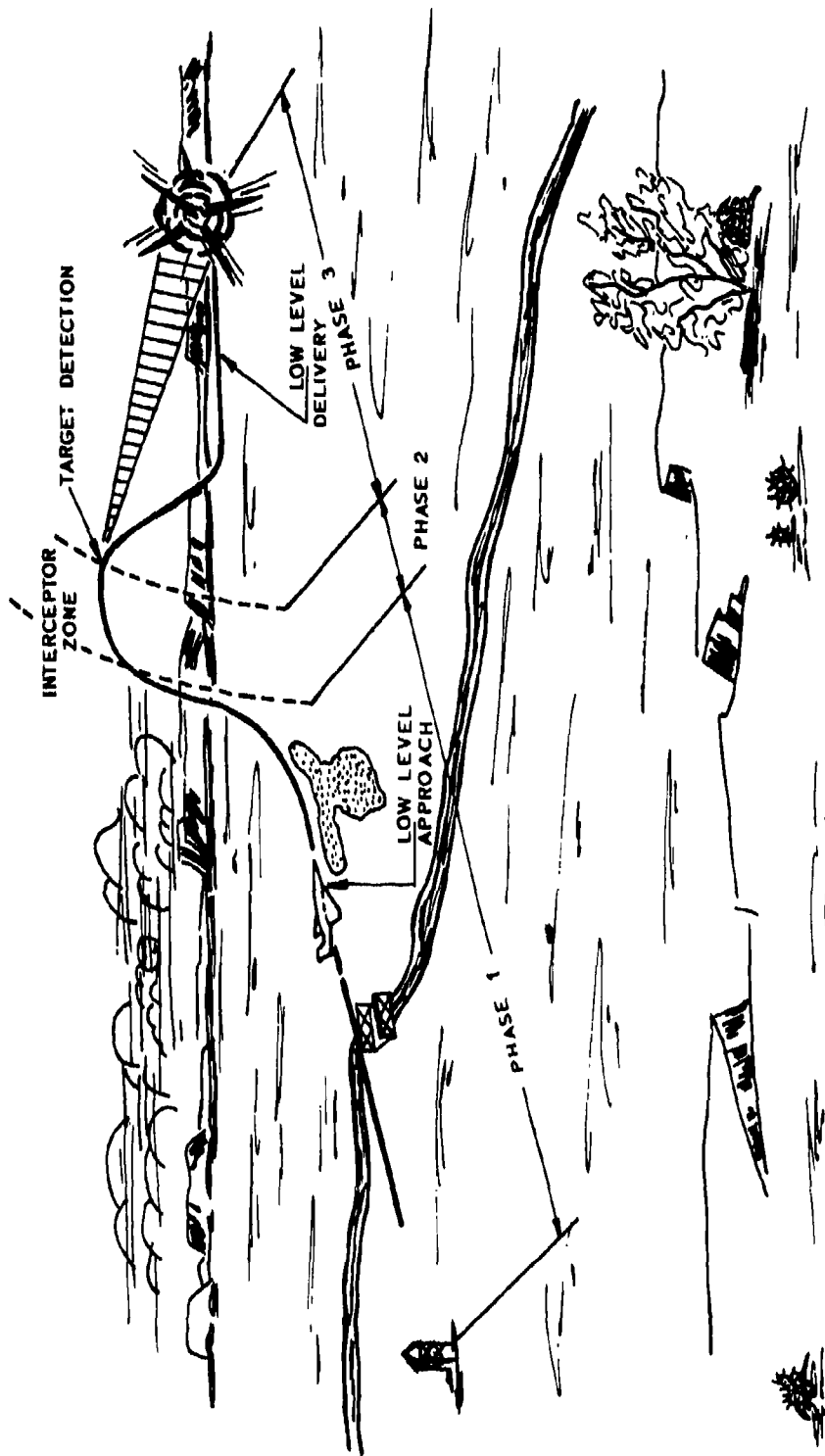


Fig. 1 (U) - Typical MMR mission profile

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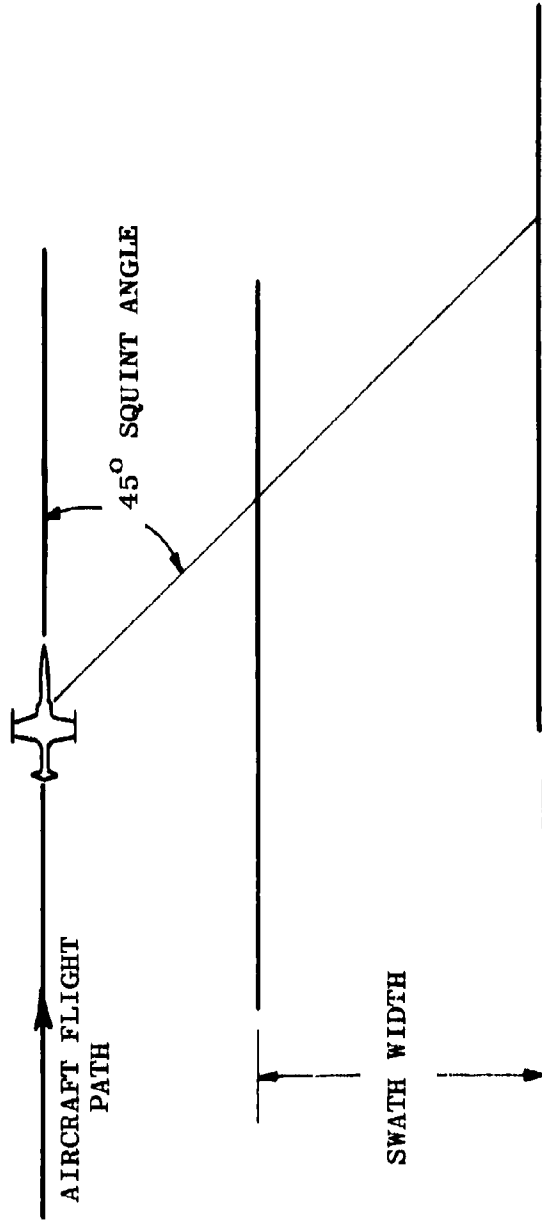


Fig. 2 (U) - Top view of aircraft flight path in target detection phase

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the display for the target. His navigation computer indicates the approximate time when the target will enter the radar field of view (FOV). When the target appears on the display, he places a set of cursors over the target area and activates the freeze and zoom control. A line drawing which represents a typical display presentation in the search mode, prior to activating the freeze and zoom control, appears in Fig. 3. The same target area is shown after zoom in Fig. 4.

(C) In the zoom mode, SAR data are still being collected and stored. The display is frozen and the system electronically zooms to a narrower swath of the stored data centered about the cursor. Various methods of accomplishing zoom are discussed in Ref. 1. Of those, only the following method will be considered in this study. Doppler phase histories are collected, stored, processed and displayed to the B/N. Currently the limiting elements in terms of system resolution are the processor and display. When the zoom operation occurs, a synthetic radar map is obtained for the narrower swath by reprocessing data which is already in store and which is centered about the cursor position. Since the same number of resolution elements are now processed over a narrower swath width, an increase in resolution will occur.

(C) Target designation is performed in the zoom mode while the display is frozen and the narrower swath of the map is displayed. Designation occurs when the B/N places the cursor over the target and activates the designation control. A typical display presentation during zoom is given in Fig. 4. If the B/N cannot designate the target, he reverts to the wide-swath passing scene display by activating the appropriate control. The weapon control system will start the passing scene display at a point consistent with the aircraft's current position. The B/N again attempts to designate the target which has now advanced on his display consistent with the time spent in the zoom mode. The target may also have passed out of the FOV which would result in a non detection.

(C) After the target has been designated, Phase 2 of the mission is completed. The coordinates of the target may now be used for missile launch or to update the aircraft's navigation computer for a descent to low altitude to deliver conventional weapons.

#### IV. DESCRIPTION OF SIMULATOR

(U) The simulator used in this study, designed and built at NRL, consists of three fundamental elements:

- 1) A cockpit mock-up in which the operator interprets a moving scene display of radar imagery for target selection and designation,
- 2) a control center where the operator performance is evaluated, and
- 3) a light table upon which the radar imagery is scanned. A block

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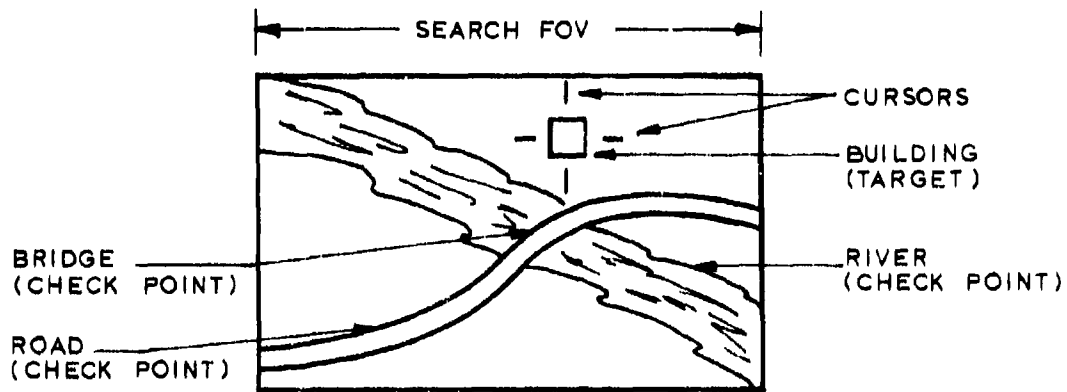


Fig. 3 (U) - Display presentation in search mode

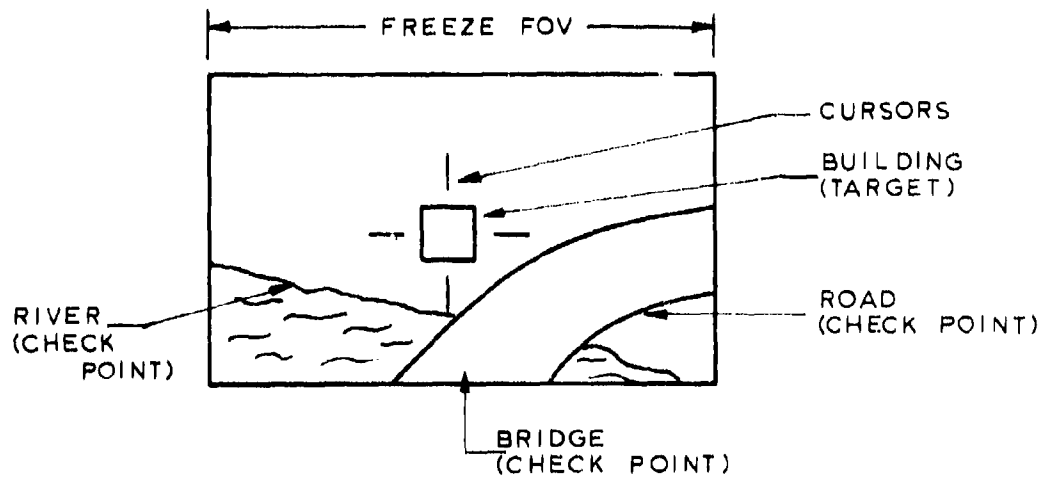


Fig. 4 (U) - Display presentation in freeze mode

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diagram of the flight simulator appears in Fig. 5.

(U) The light table, shown in Fig. 6 illuminates the radar imagery which is viewed by a vidicon camera through a zoom lens. During the search mode, the vidicon is driven by a carriage along the imagery at a rate to simulate a selected aircraft velocity. Simulated velocities up to Mach 5 are possible. When zoom is initiated, the vidicon is disengaged from the carriage and a servo carries the vidicon to a position controlled by the operator's joystick, a clocknut on the light table continues at the aircraft's velocity, and the zoom lens is activated. Zoom ratios of 20:1 are possible. If the operator returns to the search mode, the vidicon catches up to the clocknut and the lens is unzoomed. Three photocells are carried along with the vidicon. These photocells record critical times throughout the simulation from markings on the edge of the imagery.

(U) The simulation control center is shown in Fig. 7. All runs are initiated, terminated and evaluated by the controller at this center. Simulated aircraft velocity is controlled by the oscillator at the top of the panel. Two of the six NIXIE counters at the lower left automatically record elapsed time and the time the target enters the operator's FOV using pulses derived from the previously mentioned photocells on the light table. The four other counters indicate the times at first freeze and designate and, if required, for the second zoom and designate. An oscilloscope duplicates the cockpit presentation of the imagery and cursor.

(U) A picture of the simulated cockpit appears in Fig. 8. The radar imagery is presented to the operator in the right seat of a F-111B mock-up on a 14 inch display of a 945 line closed circuit television system. A stop watch is used as a navigational aid and the control stick moves the cursor position over the display to a desired target area for the zoom and designate functions. Two push buttons are provided on the joystick, one on top for zoom control and one on the side for target designation.

(U) A detailed description of the NRL simulation facility is given in Ref. 2.

#### V. PROCEDURES FOLLOWED BY THE OPERATOR IN THE SIMULATION

(U) This section will describe how the MMR mission discussed in Section III was simulated in the NRL facility. The operators are thoroughly briefed on the target of interest with maps and aerial photographs. They are also given the approximate time that the target will enter their FOV. As the vidicon camera passes over the imagery, targets appear on the display and the operator places the cursor over the desired target with the joystick.

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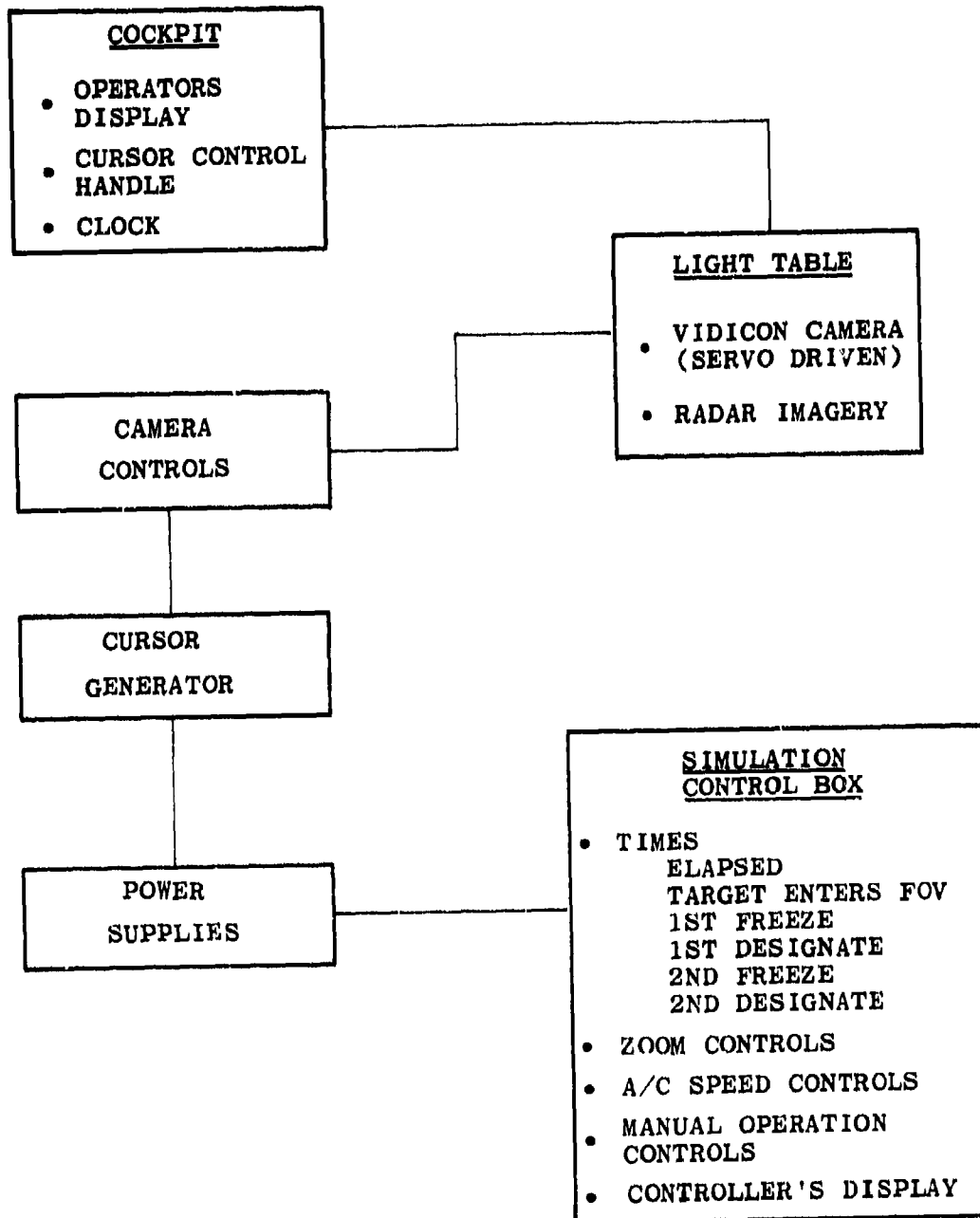


Fig. 5 (U) - Block diagram of NRL flight simulator

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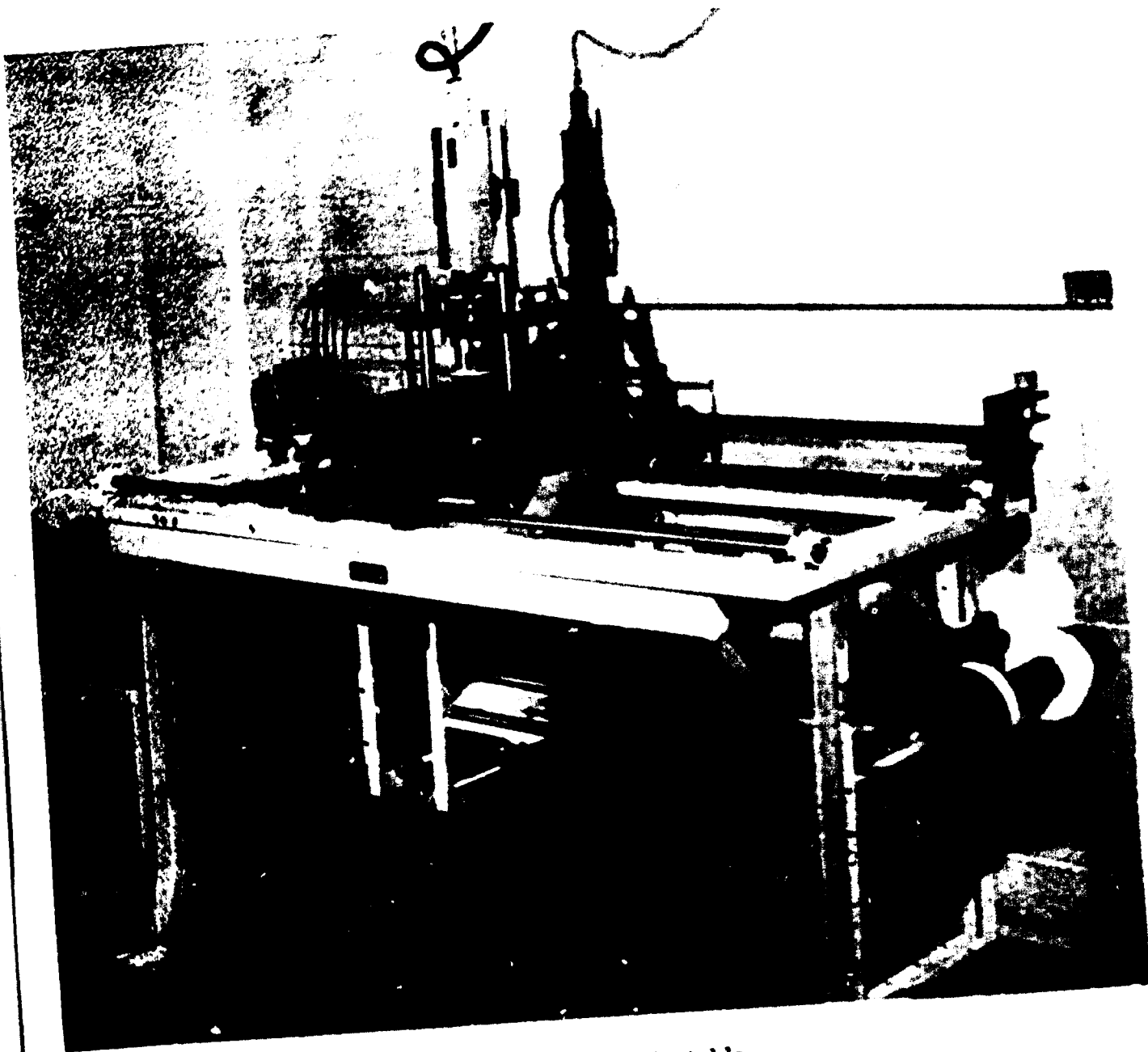


Fig. 6 (U) - Light table

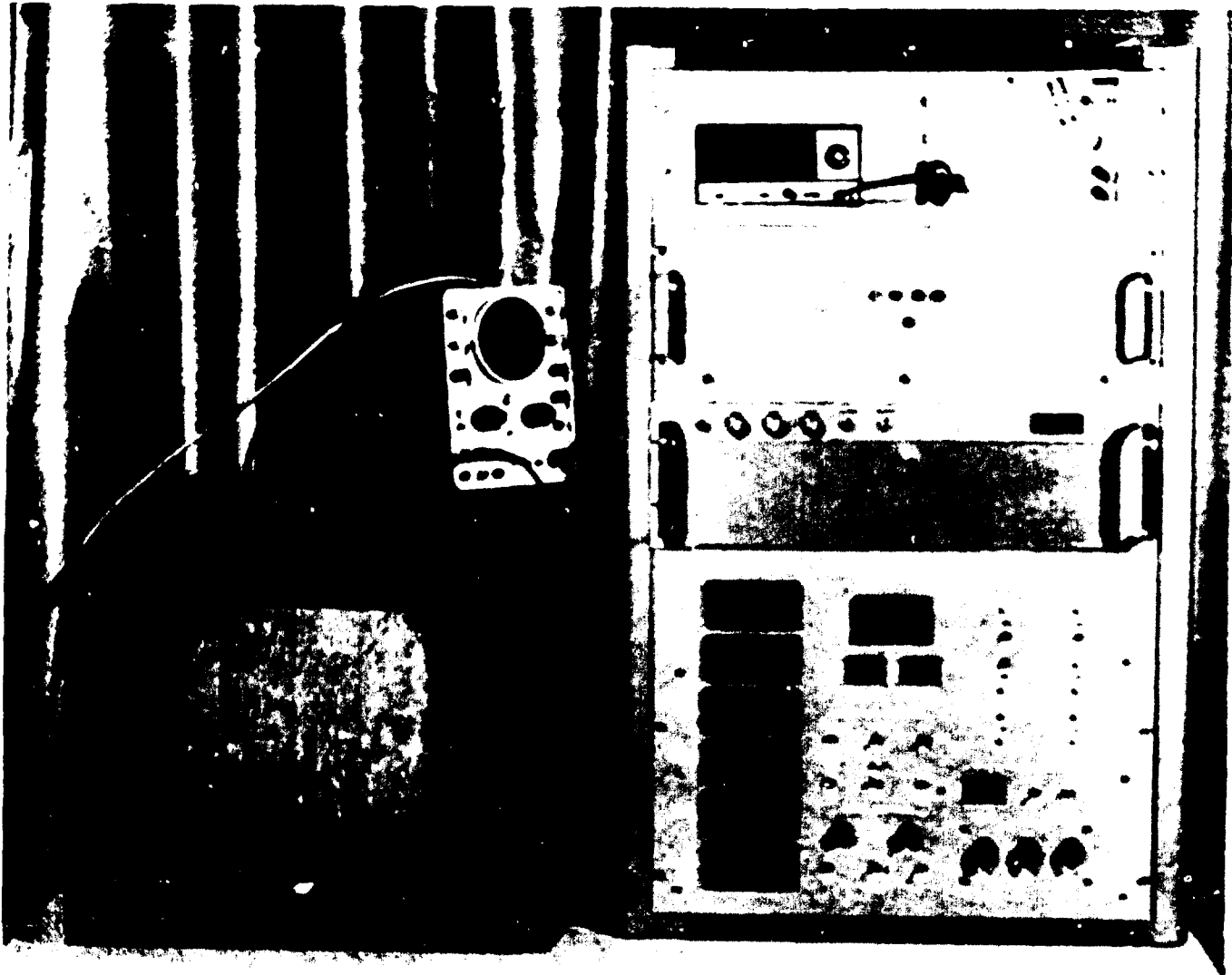


Fig. 7 (U) - Simulation control center

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Fig. 8 (U) - Cockpit simulator

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(U) To initiate zoom, he presses a button on the top of the joystick. This freezes the display by stopping the vidicon camera which is centered about the cursor position and zoomed so that a narrower portion of the film is viewed. Since a narrower portion of the terrain is viewed, the resolution of the scene is increased. The freezing, centering, and zooming of the camera occur simultaneously in less than one second.

(U) The simulator is now in the zoom mode. Target designation occurs when the operator places the cursor over the target and presses the designate button. This action brings the simulated mission to conclusion. His display blanks and he loses control of the cursor. The simulation controller now evaluates the operator's performance.

(U) If the operator cannot designate in the zoom mode, he does not press the designate button. He presses the button on the top of the joystick to revert to the wide-swath/passing-scene display. This unzooms the camera and advances it to the clocknut position which is where the camera would have been if the freeze button had not been pressed. The operator then attempts to perform the zoom and target designation phases of the mission.

## VI. RADAR IMAGERY

(S) The radar imagery used in this study was collected by the AN/APQ-108 radar, a system developed by the Conduccion Corporation. Pertinent parameters of this imagery are:

- o Synthetic aperture radar
- o 90° look angle
- o Optically processed imagery
- o A reconnaissance system
- o Resolution, 10 to 20 ft, in range and azimuth
- o Shades of grey - 7
- o Swath width - 6 nm
- o Area covered - Los Angeles and San Francisco
- o Mapping altitude - 30,000 ft.
- o Range to far edge of swath - 40 nm

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(U) The imagery was collected on 6 recorders, each recording a 3.3 nm swath on 5" film. A contact negative was made from the imagery of two adjacent swaths. A positive was then made on 5" film with a margin for photocell marks. Resolution and contrast were carefully controlled in the reproduction process to insure that they were not degraded.

(U) A total of fifty targets was chosen from the imagery. Eight target classes were established, with five targets in each class. Ten targets were used for operator training. The target classes which were investigated were:

- o Small buildings
- o Large buildings
- o Airfields
- o Highway or railroad intersections
- o Boat docks
- o Small bridges
- o Large bridges
- o Electronic facilities

A description of each target used in the simulation appears in Table 1. Every target was correlated with the following types of briefing material:

- o Sectional aeronautical charts (SAC), 1:500,000 scale
- o 7.5' maps, 1:24,000 scale
- o Aerial photographs, 1:36,000 scale

Samples of each class of target together with the correlated briefing material appear in Figs. 9 to 40.

#### VII. OPERATORS AND OPERATOR BRIEFING

(U) The operators were operational personnel (NAVAIR, Marine Corp Headquarters, Naval Air Station, Oceana) and engineers (NAVAIR, NRL, Westinghouse, Raytheon). A listing of the operator's qualifications appear in Table 2. The number of operators needed for statistical accuracy was thirty, as determined by the results of previous studies and the calculations given in Appendix A.

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<u>Target No.</u>	<u>Target Class</u>	<u>Description</u>
T 1	Intersection	(Training Target) The intersection of a 4- and a 2- lane highway, in the mountains, near a reservoir.
T 2	Large Bldg.	(Training Target) A large building in the mountains near a small town and a county fairground. There is considerable masking around the area.
T 3	Intersection	(Training Target) A "Y" shaped 4-lane highway intersection between a small city and a mountain range.
T 4	Small Bldg.	(Training Target) A small building near a creek and a 4-lane highway. Much of the area around the target is masked by mountains.
T 5	Small Bridge	(Training Target) A small highway bridge across a creek running through a small city.
T 6	Boat Dock	(Training Target) A large boat dock in a bay close to two large bridges.
T 7	Large Bldg.	(Training Target) A large building in a city near a 4-lane highway.
T 8	Intersection	(Training Target) A railroad intersection on the outskirts of a small town.
T 9	Small Bldg.	(Training Target) A small building between a small town and a river in the mountains.
T 10	Large Bldg.	(Training Target) A large building in an isolated mountainous region.
1	Small Bldg.	A small building about 1/4 nm from the coast line.

TABLE 1 - Target Descriptions (U)

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<u>Target No.</u>	<u>Target Class</u>	<u>Description</u>
2	Small Bldg.	A small building along the coast.
3	Small Bldg.	A small building near a bay and a large bridge.
4	Small Bldg.	A small building near a river and a small town.
5	Small Bldg.	A small building at the foothills of a mountain range and near a horseshoe shaped canyon.
6	Large Bldg.	A large building along the coast near a large breakwater.
7	Large Bldg.	A large building along the coast near a large city.
8	Large Bldg.	A large building in an urban area near a race track.
9	Large Bldg.	A large building in an urban area near a large bridge.
10	Large Bldg.	A large building along a coast line at the intersection of two creeks.
11	Airfields	A large airfield in an urban area.
12	Airfields	A large airfield near a good land/water boundary.
13	Airfields	A large airfield near a good land/water boundary.
14	Airfields	A large airfield in an urban area.
15	Airfields	A large airfield in an urban area near a river.
16	Intersection	A highway intersection between two 4-lane highways in an isolated area.

TABLE 1 - Target Descriptions (Cont'd)

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<u>Target No.</u>	<u>Target Class</u>	<u>Description</u>
17	Intersection	A railroad intersection in a large urban area.
18	Intersection	A 2-lane highway intersection between a river and a mountain range.
19	Intersection	A railroad intersection near an airfield.
20	Intersection	A 4-lane highway intersection near an airfield.
21	Boat Dock	A boat dock lying in a bay near a small airfield.
22	Boat Dock	A boat dock lying off an island near a large highway bridge.
23	Boat Dock	A boat dock along the coast.
24	Boat Dock	A boat dock off a point of land which extends into a bay.
25	Boat Dock	A boat dock in a small bay.
26	Small Bridge	A railroad bridge across a small river near a small town.
27	Small Bridge	A highway bridge across a small creek near a small airfield.
28	Small Bridge	A highway bridge across a small creek near a large railroad yard.
29	Small Bridge	A highway bridge across a tidal canal near a large airfield.
30	Small Bridge	A highway bridge over a small creek in an isolated area.
31	Large Bridge	A railroad bridge across a large river.

TABLE 1 - Target Descriptions (Cont'd)

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<u>Target No.</u>	<u>Target Class</u>	<u>Description</u>
32	Large Bridge	A railroad bridge across a large river.
33	Large Bridge	A highway bridge across a large river.
34	Large Bridge	A highway overpass near a large airfield.
35	Large Bridge	A highway bridge over a creek which feeds into a large bay.
36	Electronic Facility	Radio towers near a good land/water boundary.
37	"	Radio towers between a river and a small county airfield.
38	"	Radio towers along a coast line.
39	"	Radio towers between a coast line and a large highway.
40	"	Electrical power generating plant between a river and a 4-lane highway.

TABLE 1 - Target Descriptions (Cont'd)

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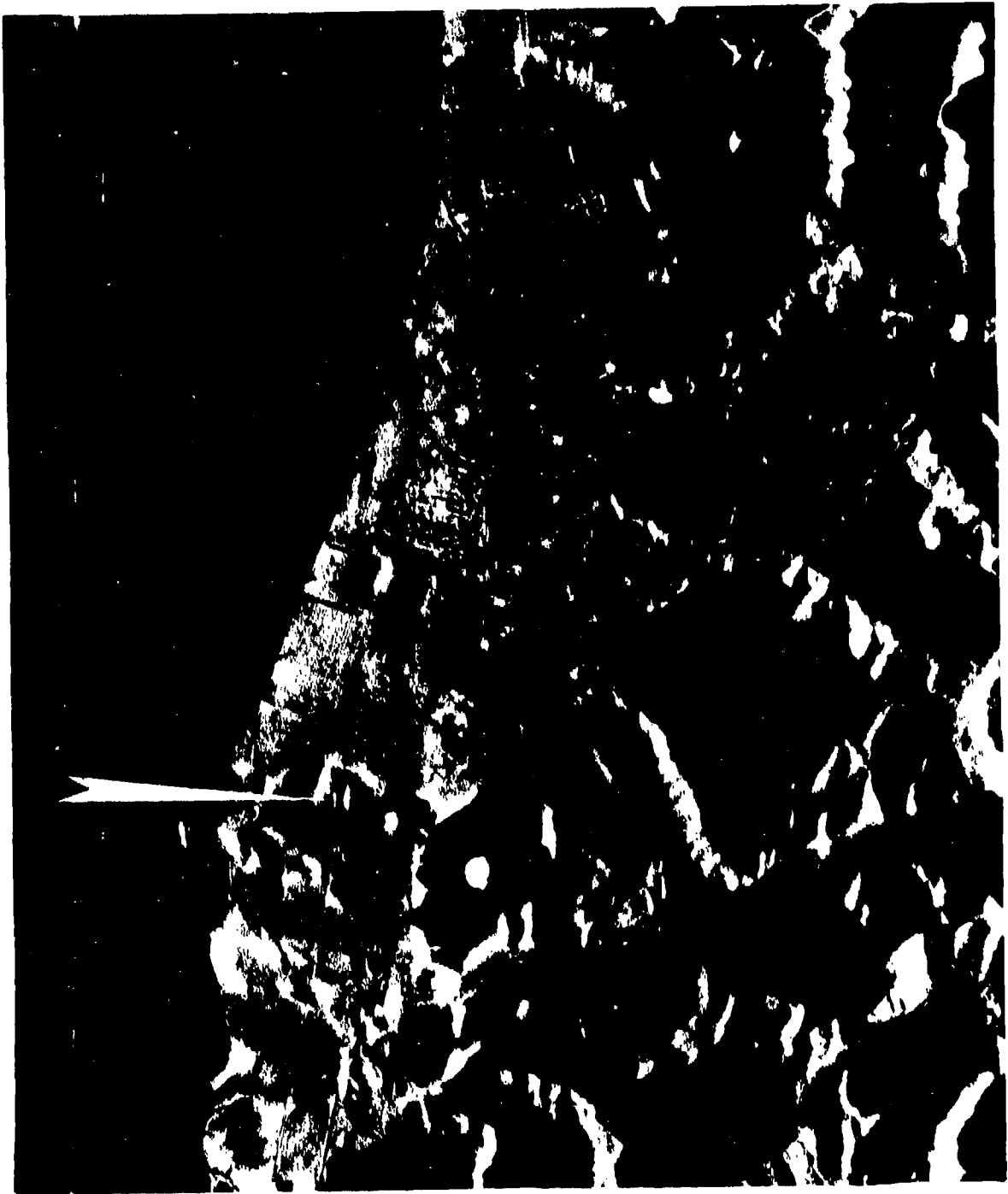


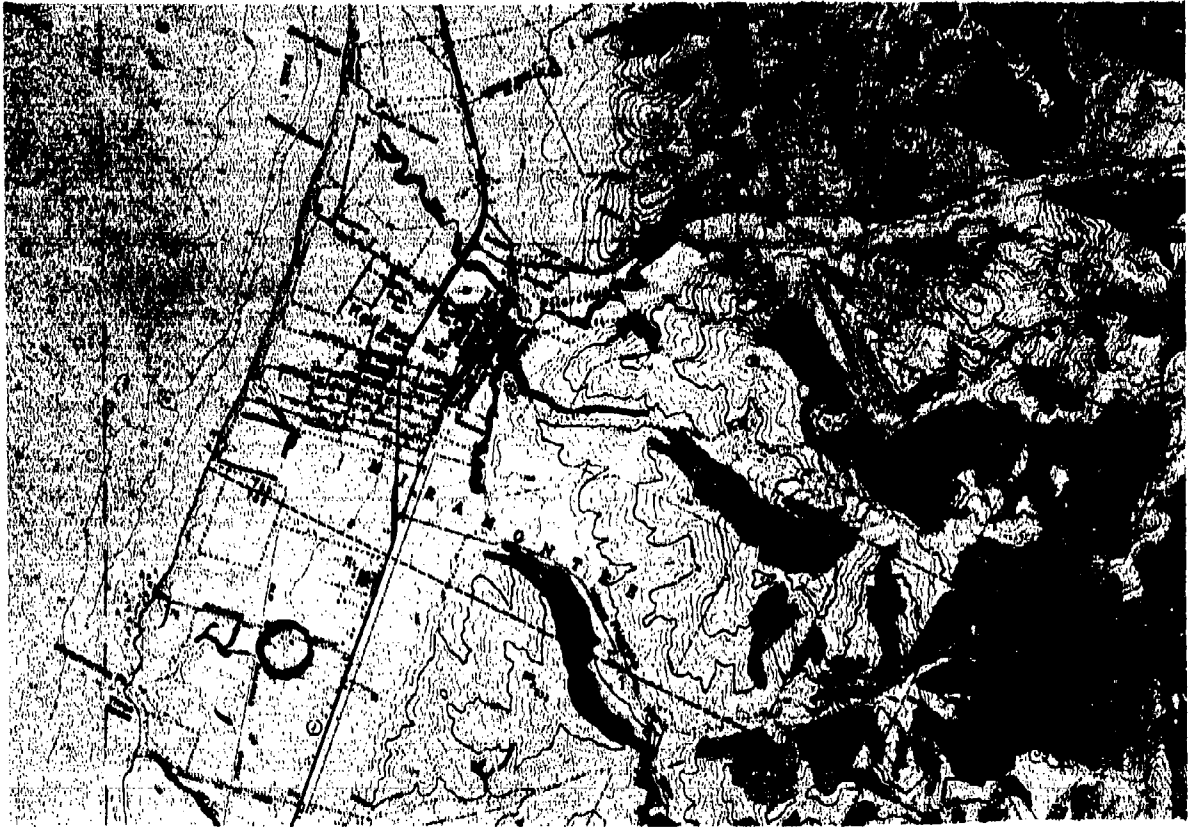
Fig. 9 (S) - Radar imagery of a small building lying  
along the coast

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Fig. 10 (U) - Sectional aeronautical chart of a small building lying along the coast

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**Fig. 11 (U) - 7.5 Min. map of a small building lying  
along the coast**

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Fig. 12 (U) - Aerial photo of a small building lying  
along the coast

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Fig. 13 (S) - Radar imagery of a large building along a coast  
line at the intersection of two creeks

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Fig. 14 (U) - Sectional aeronautical chart of a large building along a coast line at the intersection of two creeks

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Fig. 15 (U) - 7.5 Min. map of a large building along a coast  
line at the intersection of two creeks

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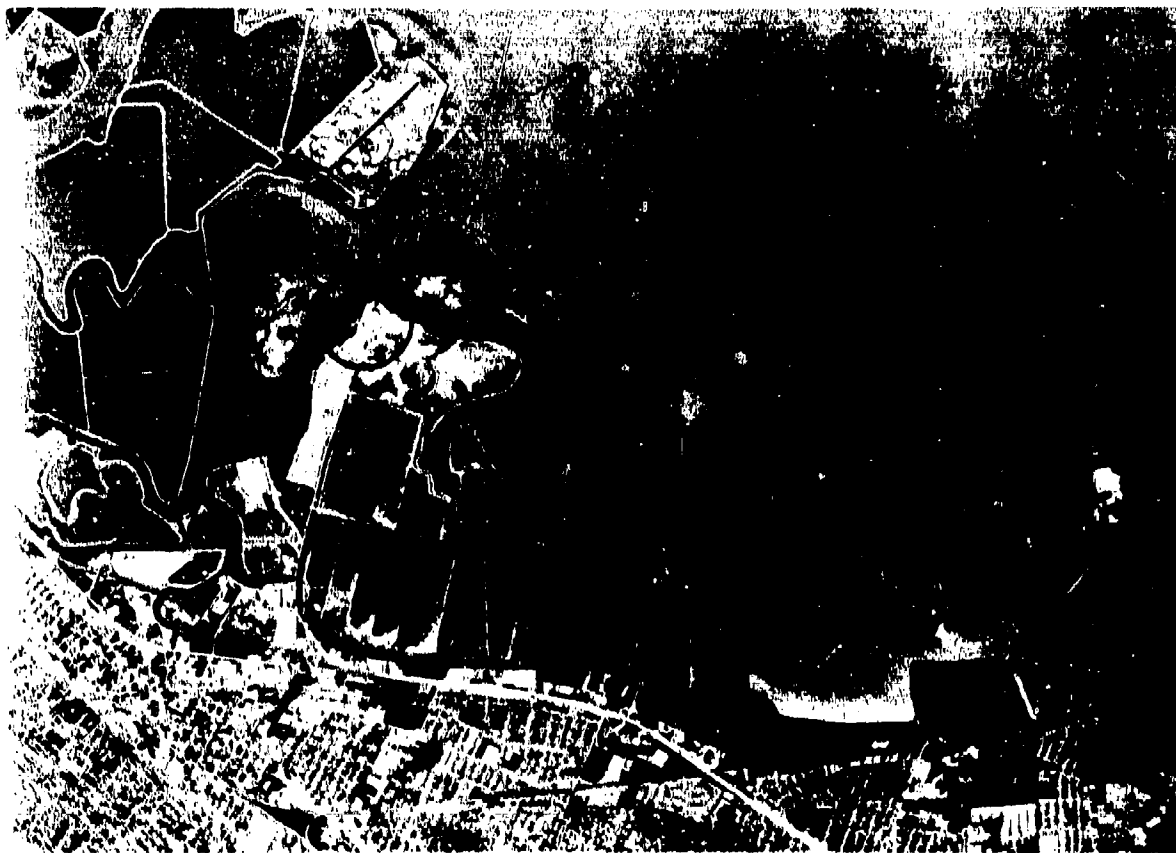


Fig. 16 (U) - Aerial photo of a large building along a coast at the intersection of two creeks

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Fig. 17 (S) - Radar imagery of a large airfield near a  
good land water boundary

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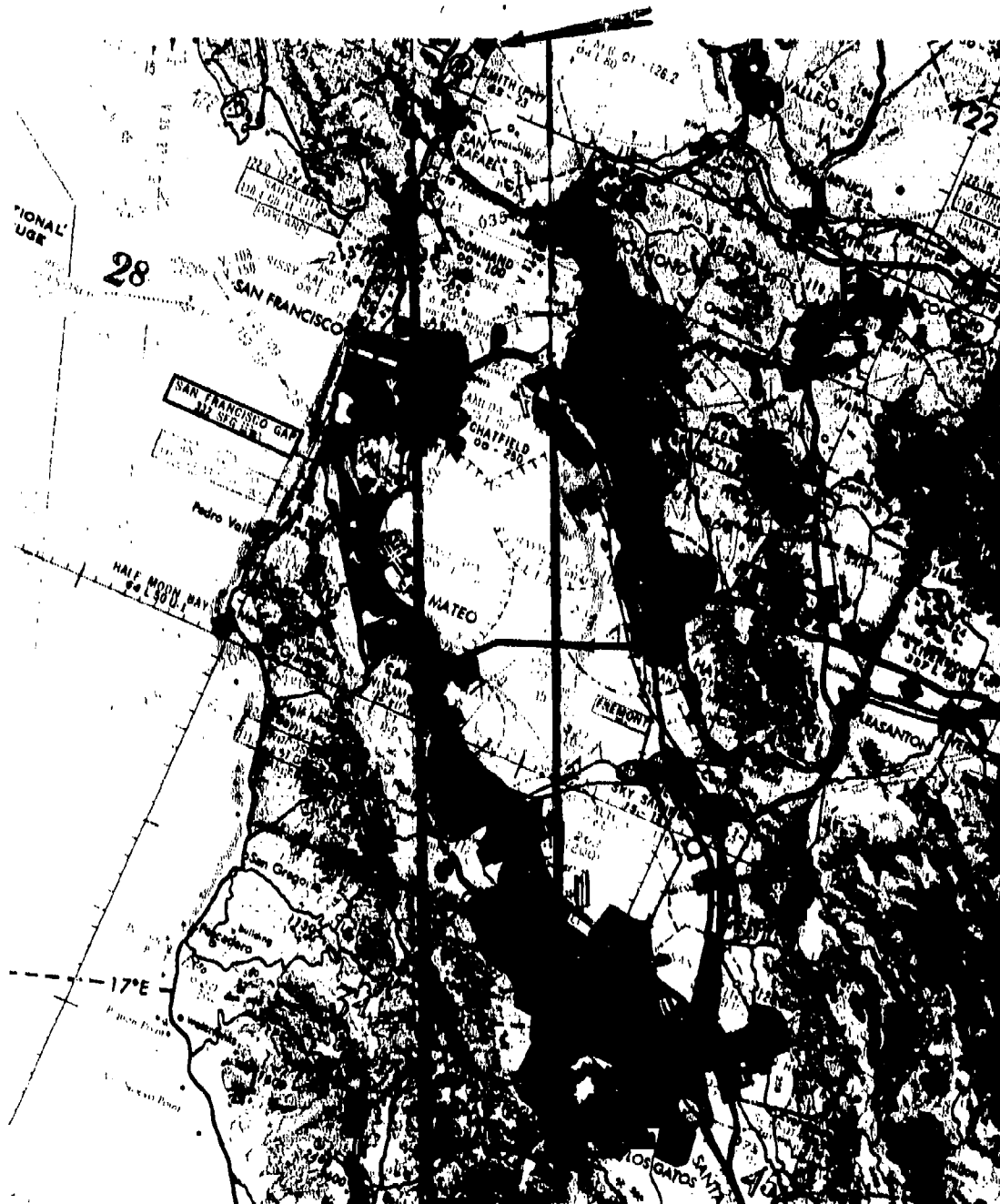


Fig. 18 (U) - Sectional aeronautical chart of a large airfield near a good land water boundary

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Fig. 19 (U) - 7.5 Min. map of a large airfield near a good land water boundary

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**Fig. 20 (U) - Aerial photo of a large airfield near a  
good land water boundary**

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Fig. 21 (S) - Radar imagery of a two lane highway intersection  
between a river and a mountain range

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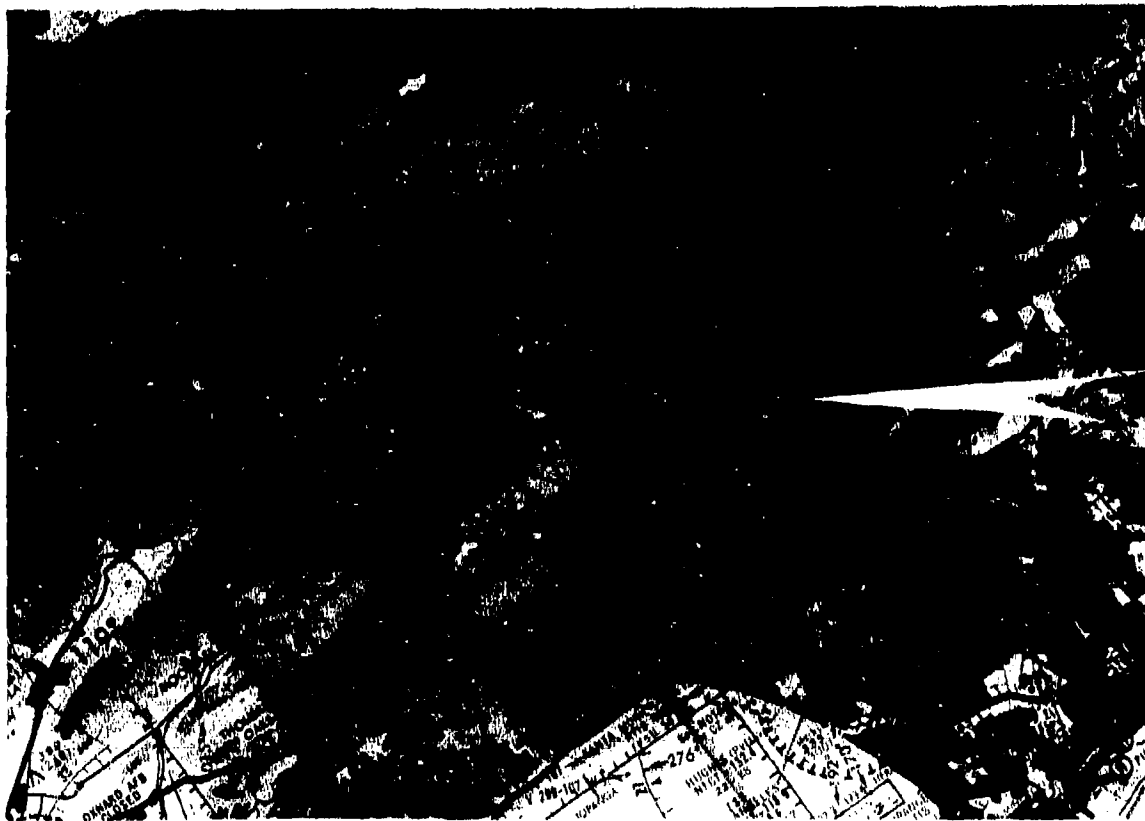


Fig. 22 (U) - Sectional aeronautical chart of a two lane highway intersection between a river and a mountain range

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Fig. 23 (U) - 7.5 Min. map of a two lane highway intersection  
between a river and a mountain range

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Fig. 24 (U) - Aerial photo of a two lane highway intersection  
between a river and a mountain range

SECRET

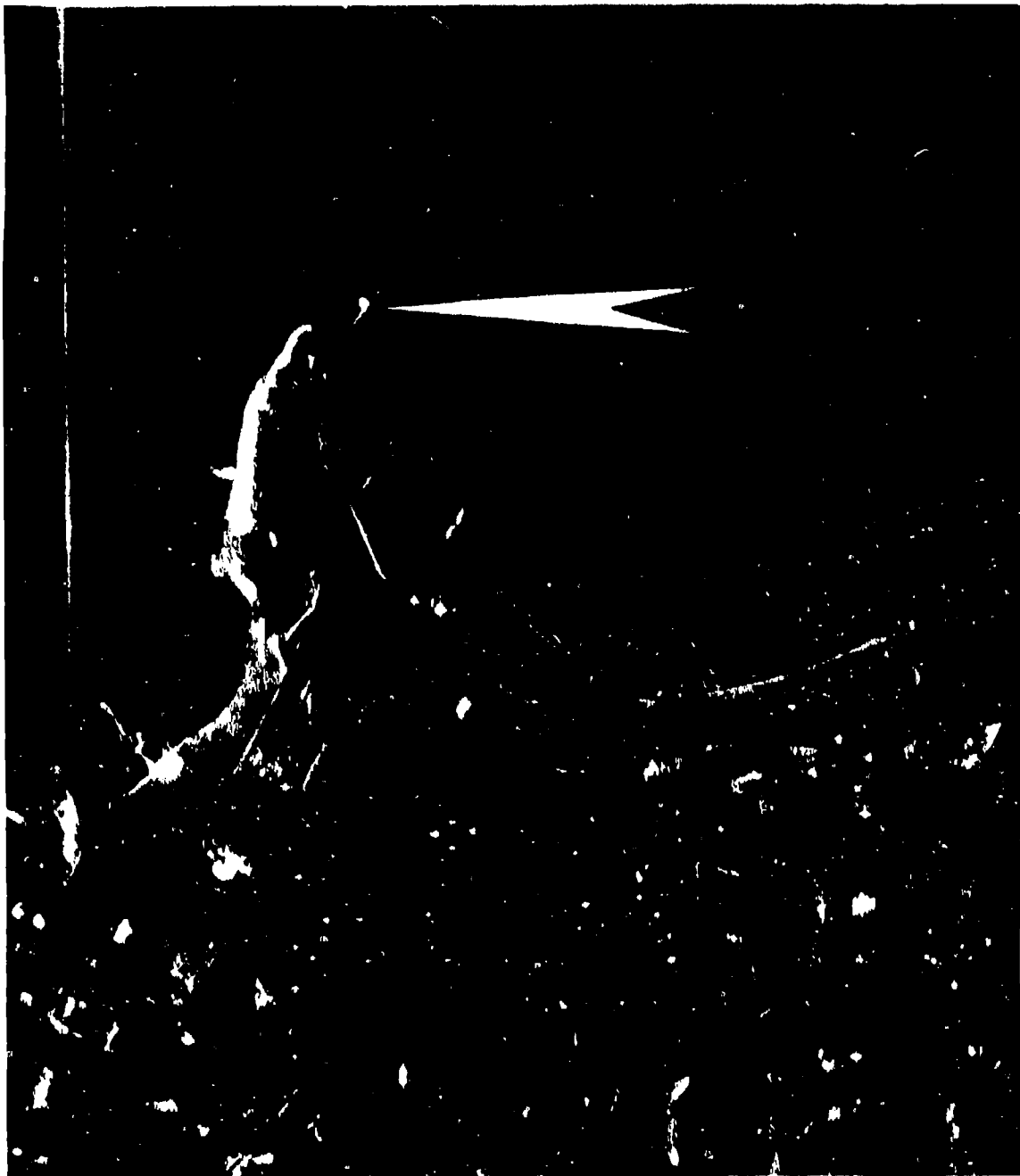


Fig. 25 (S) - Radar imagery of a boat dock off a point of land which extends into a bay

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Fig. 26 (U) - Sectional aeronautical chart of a boat dock  
off a point of land which extends into a bay

**SECRET**



**Fig. 27 (U) - 7.5 Min. map of a boat dock off a point of  
land which extends into a bay**

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Fig. 28 (U) - Aerial photo of a boat dock off a point of land which extends into a bay

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Fig. 29 (S) - Radar imagery of a small highway bridge  
over a small creek in an isolated area

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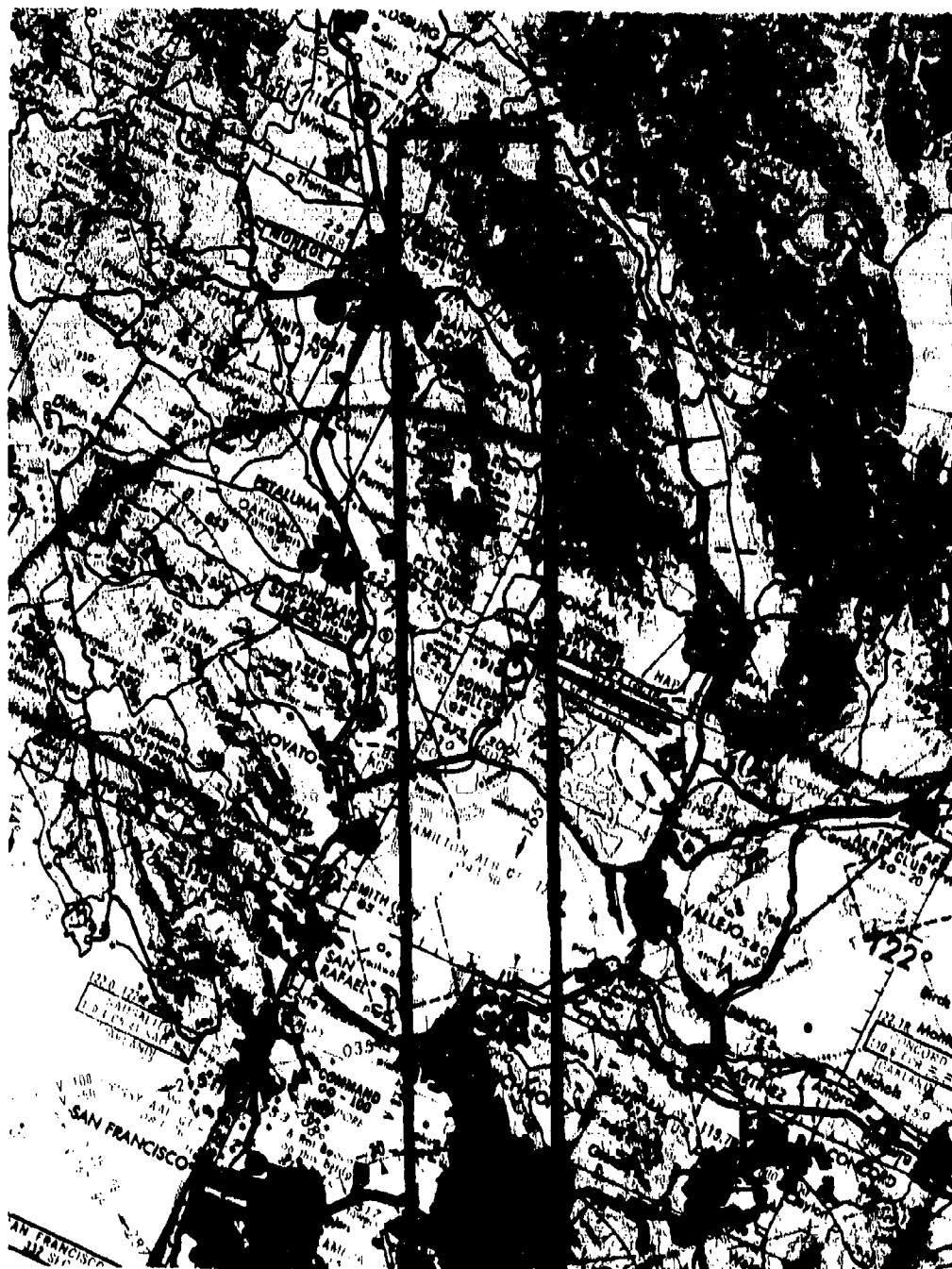
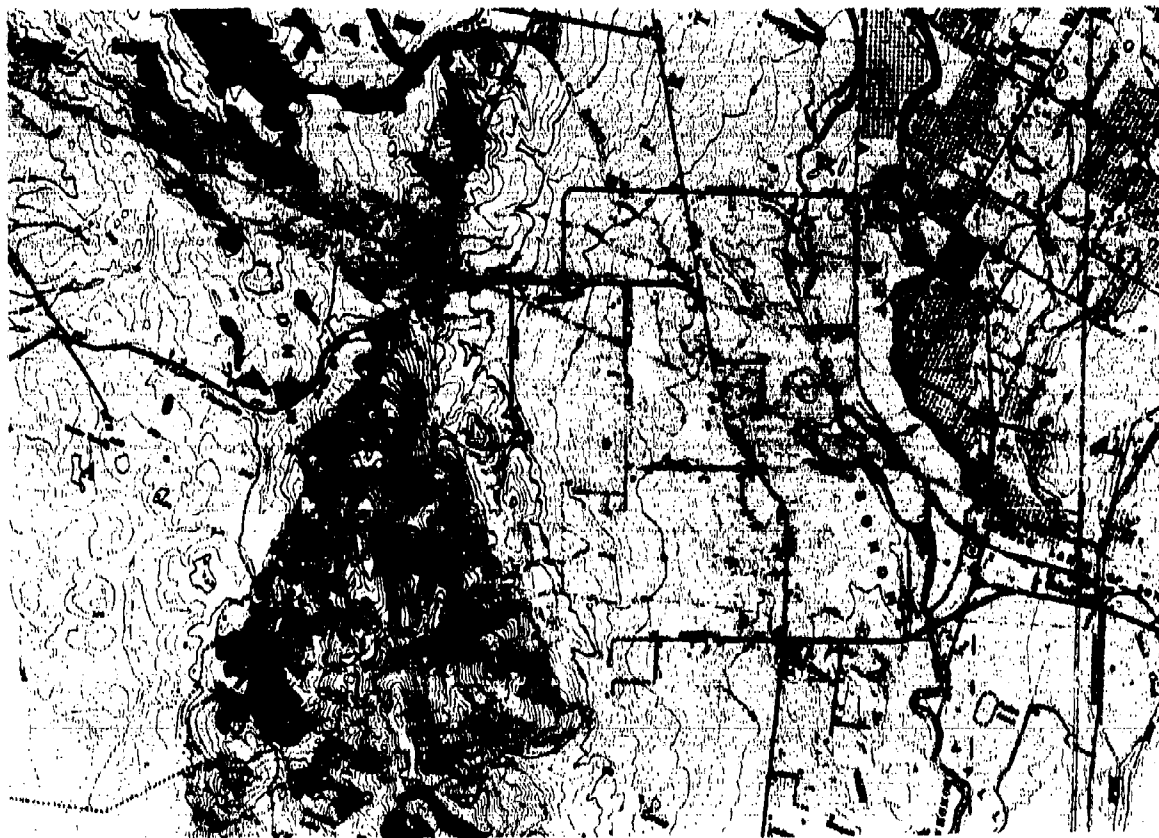


Fig. 30 (U) - Sectional aeronautical chart of a small highway bridge over a small creek in an isolated area

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**Fig. 31 (U) - 7.5 Min. map of a small highway bridge  
over a small creek in an isolated area**

SECRET

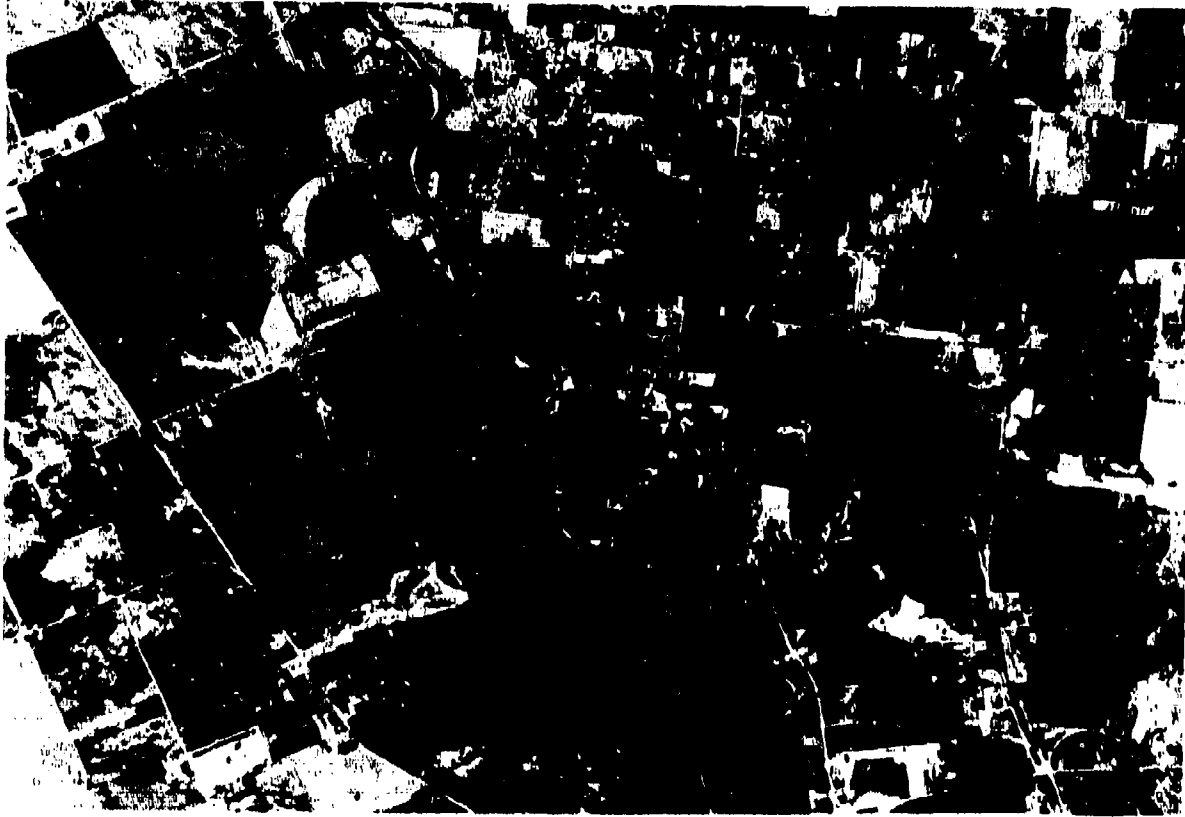


Fig. 32 (U) - Aerial photo of a small highway bridge  
over a small creek in an isolated area

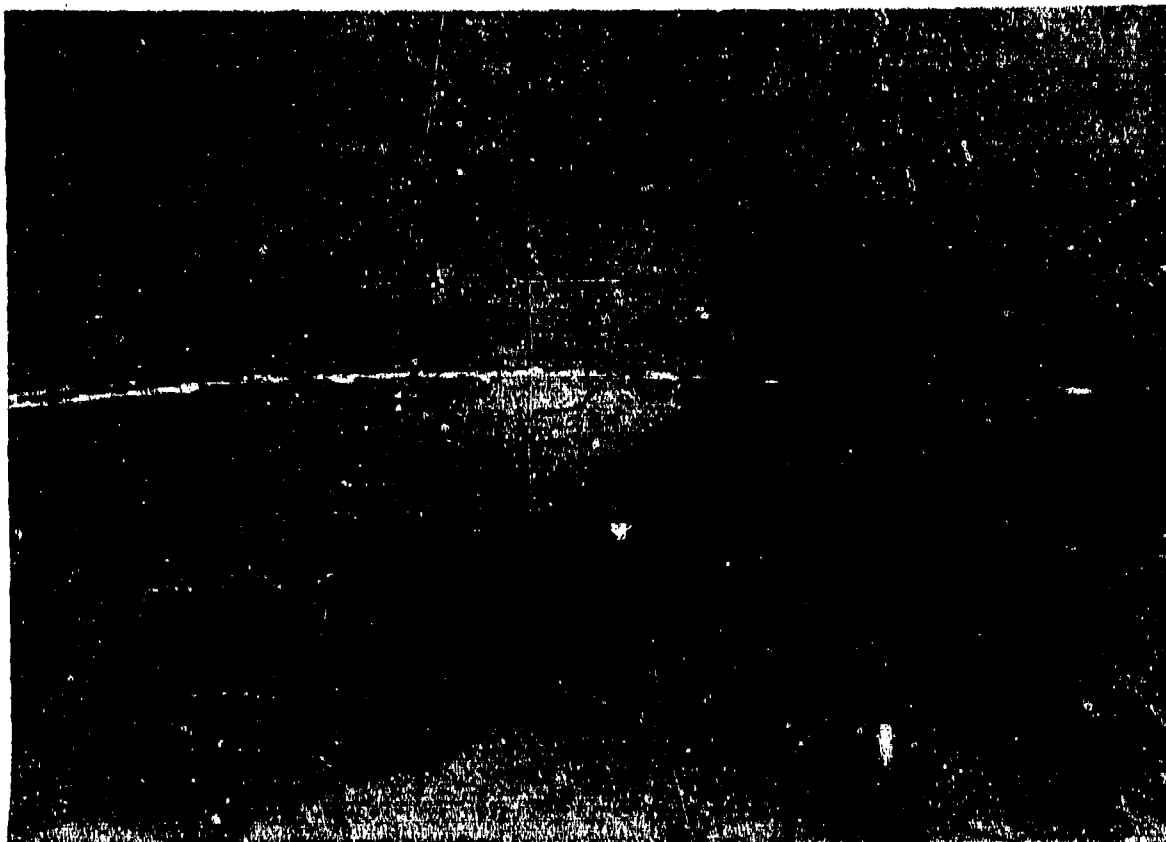
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Fig. 33 (S) - Radar imagery of a large highway bridge  
over a creek which feeds into a large bay



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**Fig. 35 (U) - 7.5 Min. map of a large highway bridge  
over a creek which feeds into a large bay**

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Fig. 36 (U) - Aerial photo of a large highway bridge  
over a creek which feeds into a large bay

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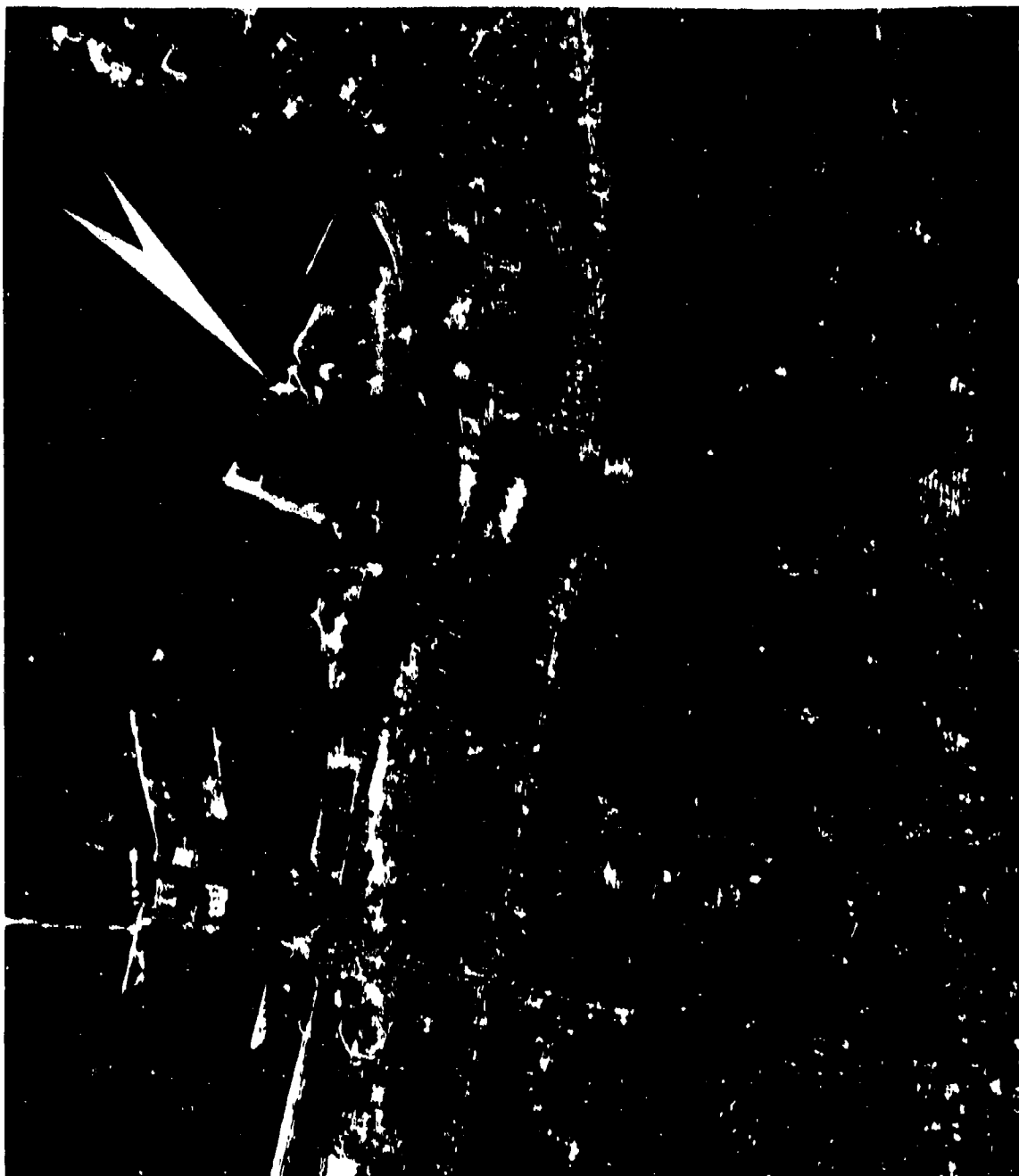


Fig. 37 (S) - Radar imagery of a electronic facility  
(radio towers) along a coast

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Fig. 38 (U) - Sectional aeronautical chart of a electronic facility (radio towers) along a coast line

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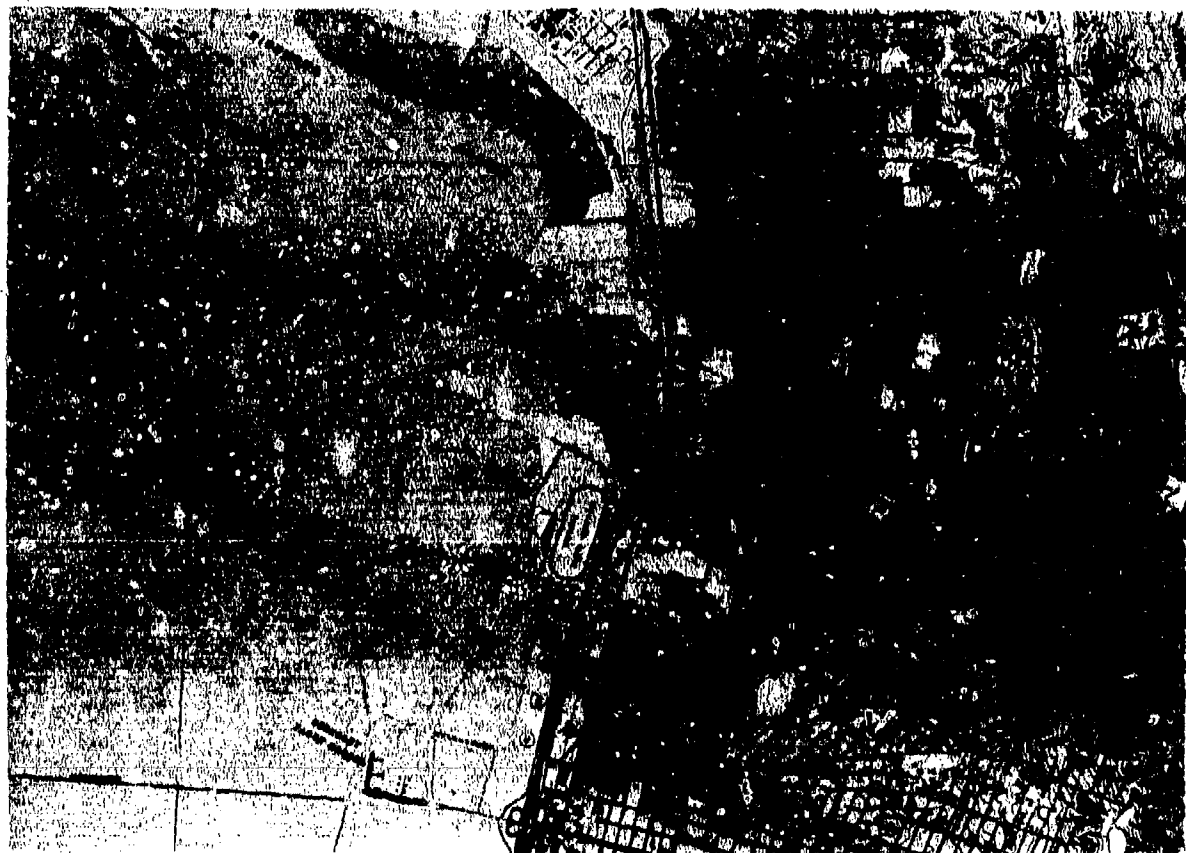


Fig. 39 (U) - 7.5 Min. map of a electronic facility  
(radio towers) along a coast line

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**Fig. 40 (U) - Aerial photo of a electronic facility  
(radio towers) along a coast line**

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Operator Type	Number of Operators	Average Years of Experience	Radar Systems Most Familiar With
Pilot	5	16	AN/APQ-92, AN/AWG-10, AN/APQ-112, AN/APQ-102, AN/APQ-116
B/N	7	9	AN/APQ-92, ASB-7, ASB-1
Engineers	18	11	MMR, FARS, AN/AWG-10, AN/APQ-72, AN/APQ-92

TABLE 2 - OPERATORS QUALIFICATIONS (U)

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(U) The operator briefing was at both the group level and at the individual level. The group level briefing was a general introduction to the simulation, its objectives, and operational procedures. A copy of the training manual was given to the operators during this briefing. The individual level briefing, which occurred just before the start of the training runs covered the following:

- o The simulator and its operation
- o The controls and the display
- o Measurements of system resolution and contrast
- o The brightness of the operator's display using a sample of the imagery
- o A description of briefing material and the run-in-time
- o An explanation of imagery and display scale sizes

(U) After the individual briefing, the operators practiced on ten training targets. The mean operator performance was calculated, considering such parameters as probability of target area detection, probability of target designation, target area detection time, and target designation time. After reviewing the performance of the various operators on the training targets, it was decided not to include the data from any operator whose performance was below a certain level. During the training period, it was stressed to the operator that both time and accuracy were important; the target should be designated quickly, but it should be the correct target.

(U) Since engineers were easier to obtain than operational personnel, most of the operators were engineers with experience in interpreting radar imagery. The mean performance of the operational personnel was compared with the mean performance of the engineers in the training runs. The engineer level of performance was 80% of that of the operational personnel. The operational personnel, however, were very experienced and should be classified as above average. It was concluded that engineers could be used in the simulations with only a slight degradation of performance.

#### VIII. SIMULATION INPUTS

(S) The simulation inputs included both fixed parameters and variables. The fixed parameters were:

- o Velocity - 1000 ft/sec
- o Display mode - Continuous with freeze and zoom

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- o System Contrast - 7 shades of grey
- o Navigation error - see below

The ability of an operator to find a target on a display is greatly enhanced if he has an estimate of the time when the target will appear on his display. This time is a function of the aircraft's navigation errors. A calculation performed in Ref. 4 considered the effects of the following navigation errors on the variability of this time:

- o Aircraft navigation system accuracy - 0.5 nm/hr
- o The error in check point acquisition with a preliminary sensor- 0.05 nm
- o The error associated with inserting the check point into the navigation system - 0.04 nm
- o The error of locating the check point on a map - 0.017 nm
- o The error of locating the target on a map - 0.017 nm
- o The error between aircraft carrier and map geoid reference 0.5 nm

The results of these calculations showed that the error in the time that the target is expected to enter the FOV had a Poisson distribution of mean 1.9 seconds and 3 $\sigma$  value of 3 seconds. The run-in-time for each of the targets was modified by the errors from this distribution and the resultant time was given to the operators in the briefing.

(U) The variables in the simulation were swath width, briefing material, and resolution. They were presented to the operators as the various conditions listed in Table 3.

#### IX. SIMULATION OUTPUTS

(C) To obtain an accurate statistical analysis of operator performance under the various conditions outlined in Section VIII, the following parameters were recorded by the simulation controller.

- o Target area detection time - the time between the target entering the FOV and freeze/zoom.
- o Target area detection probability - if the target appeared on the display in the zoom mode, the probability was unity. If it did not appear, the probability was zero.

CONDITION	FOV		BRIEFING MATERIAL			RESOLUTION	
	SEARCH (N.M.)	FREEZE (N.M.)	SAC CHARTS	7.5' MAPS	AERIAL PHOTOS	SEARCH (FT)	FREEZE (FT)
I	6	2	✓	✓	✓	45	20
II	6	1	✓	✓	✓	45	20
III	4	2	✓	✓	✓	45	20
IV	6	2	✓	✓		45	20
V	6	2	✓		✓	45	20
VI	6	2	✓	✓	✓	90	30

TABLE 3 - EXPERIMENTAL VARIABLES

\*Five operators were used in each condition with forty targets presented to each of the operators..

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- o Target designation time - the time between the target entering the FOV and designation.
- o Target designation probability - if the operator designated the correct target, the probability was unity. If the operator designated the wrong target, the probability was zero.

X. RESULTS

A. Target Area Detection

(U) The number of correct target area detections, in various time intervals, was determined as a function of the six conditions and eight target types indicated in Table 3. The probabilities of target area detection,  $P_A$ , are plotted as a function of time in Figs. 41 to 48. The asymptotic or (maximum) values of probability of detection ( $P_A$ ), taken from Fig. 41 to 48 along with their corresponding times, appear in Table 4. Table 4 indicates that:

- o Condition III, which had the smallest search FOV (4 nm), gave the highest probability of detection in the shortest time. With a high quality navigation system and good briefing, the operator does not require a large FOV in the search mode. Less time is required to search the smaller FOV.

- o The operators performance was fairly uniform in Conditions I, IV, and V. The detection times were slightly longer in Condition I which implies it took longer for the operators to use both the 7.5' maps and the aerial photos than either alone. Nor, did having the two types of briefing material improve  $P_A$  significantly.

- o Condition II, which had the smallest FOV in zoom (1 nm) gave the lowest  $P_A$  and the longest detection times. The longer times are the result of the operators having to be extremely careful in placing the cursor over the target area in the search mode since, when they went into the zoom mode, they had a FOV of only 1 nm. They were unable to "guess" in the search mode and this resulted in lower values of  $P_A$ .

(S) The easiest target areas to locate under all conditions were airfields, boat docks, large bridges, and electronic facilities. The hardest were small and large buildings, intersections, and small bridges. The boat docks and large bridges were easy to locate due to the good land/water boundaries. The airfields were generally large and the  $\gamma$  shades of grey made them easily distinguishable. The electronic facilities, located in outlying areas, generally were easy to locate.

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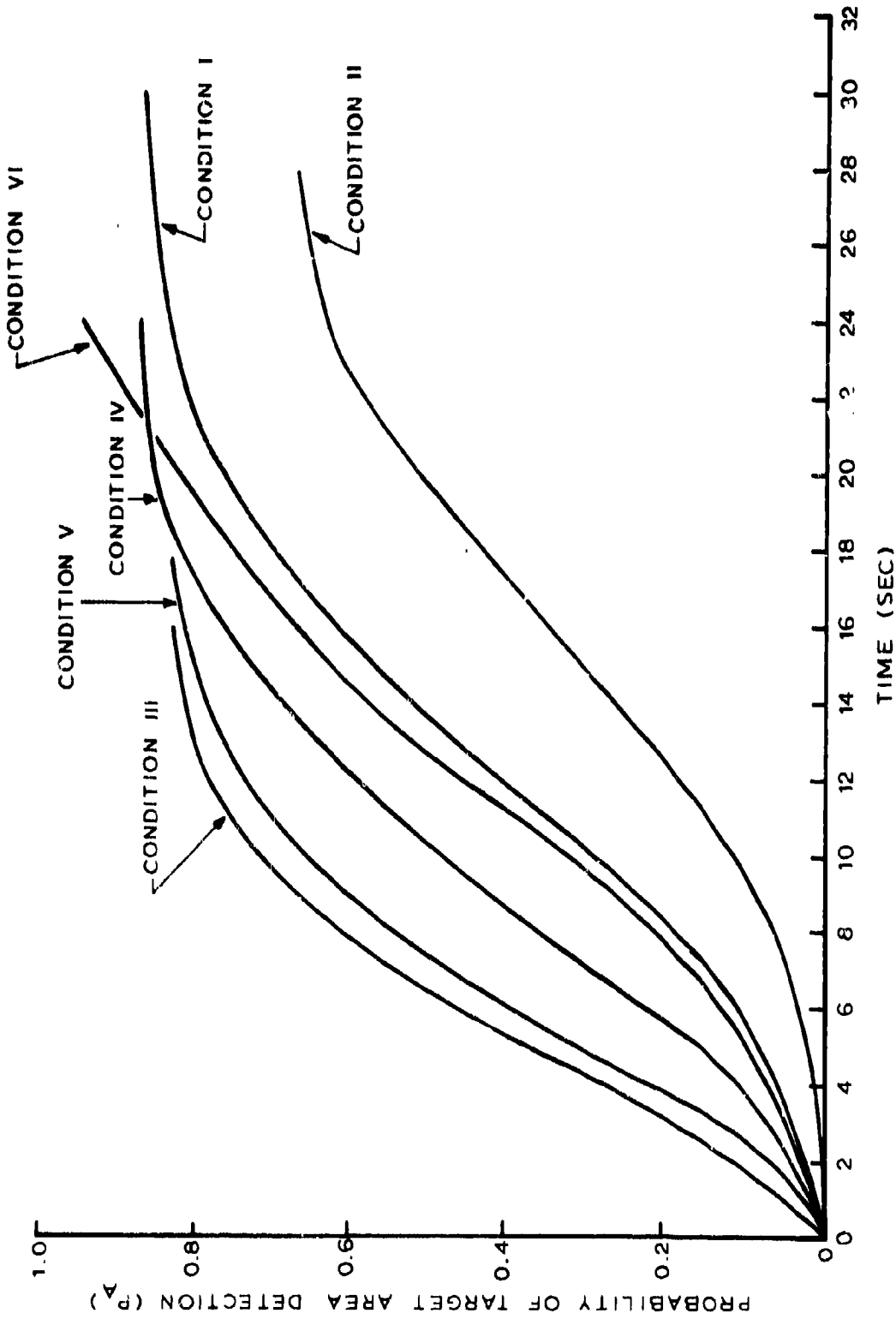


Fig. 41 (U) - Probability of target area detection ( $P_A$ ) vs. time (large building)

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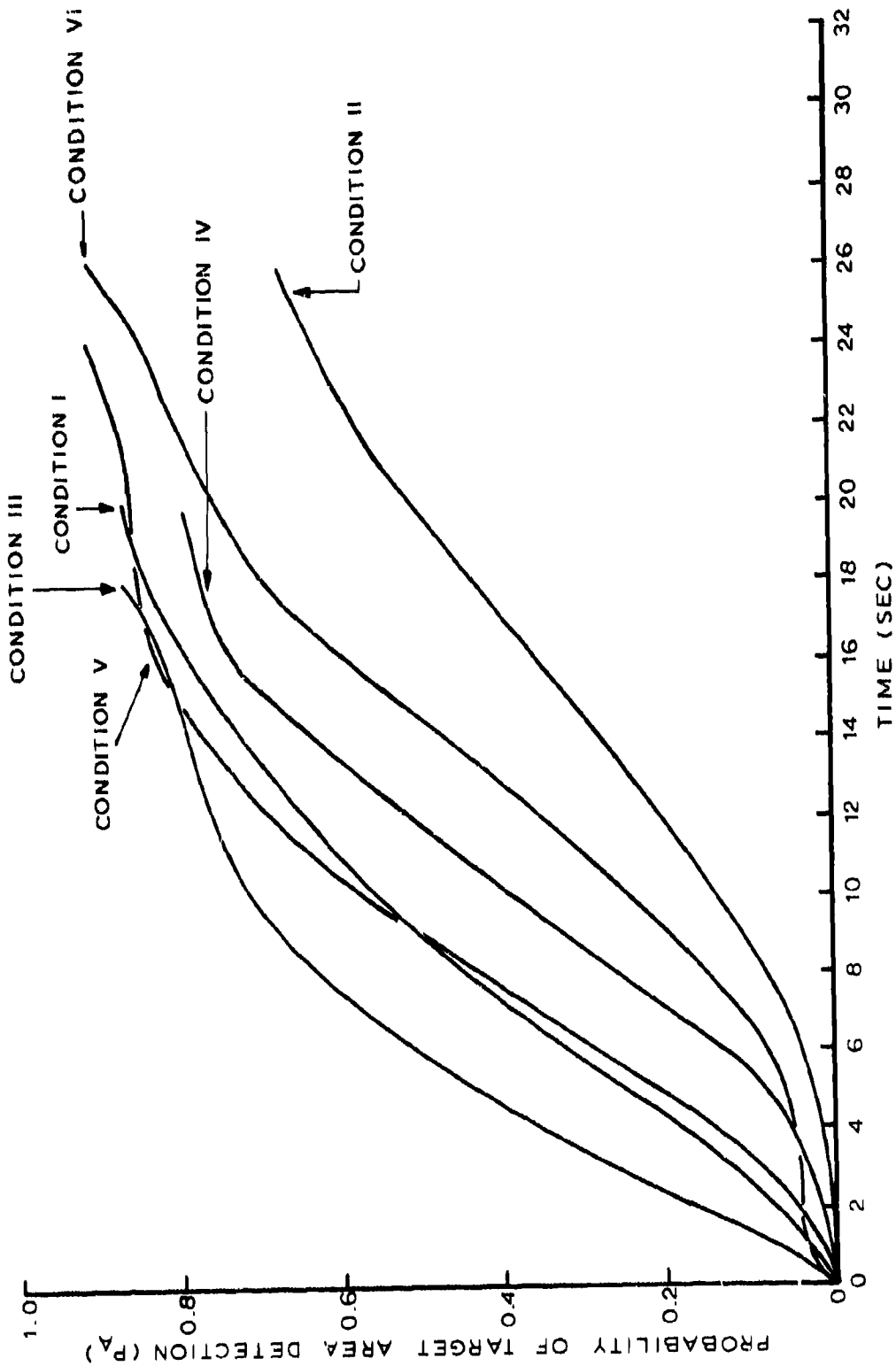


Fig. 42 (U) - Probability of target area detection ( $P_A$ ) vs. time (large building)

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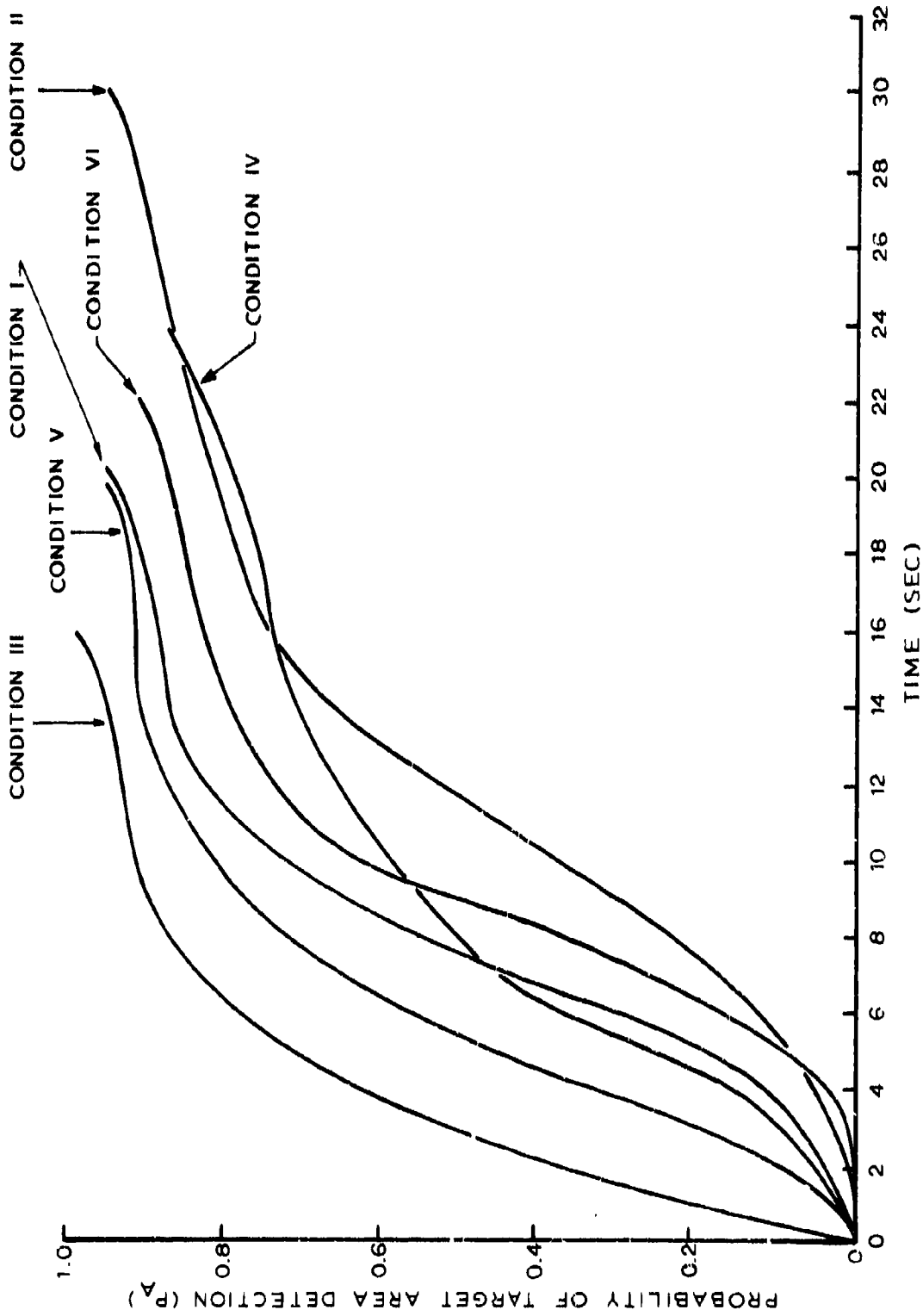


Fig. 43 (U) - Probability of target area detection ( $P_A$ ) vs. time (airfield)

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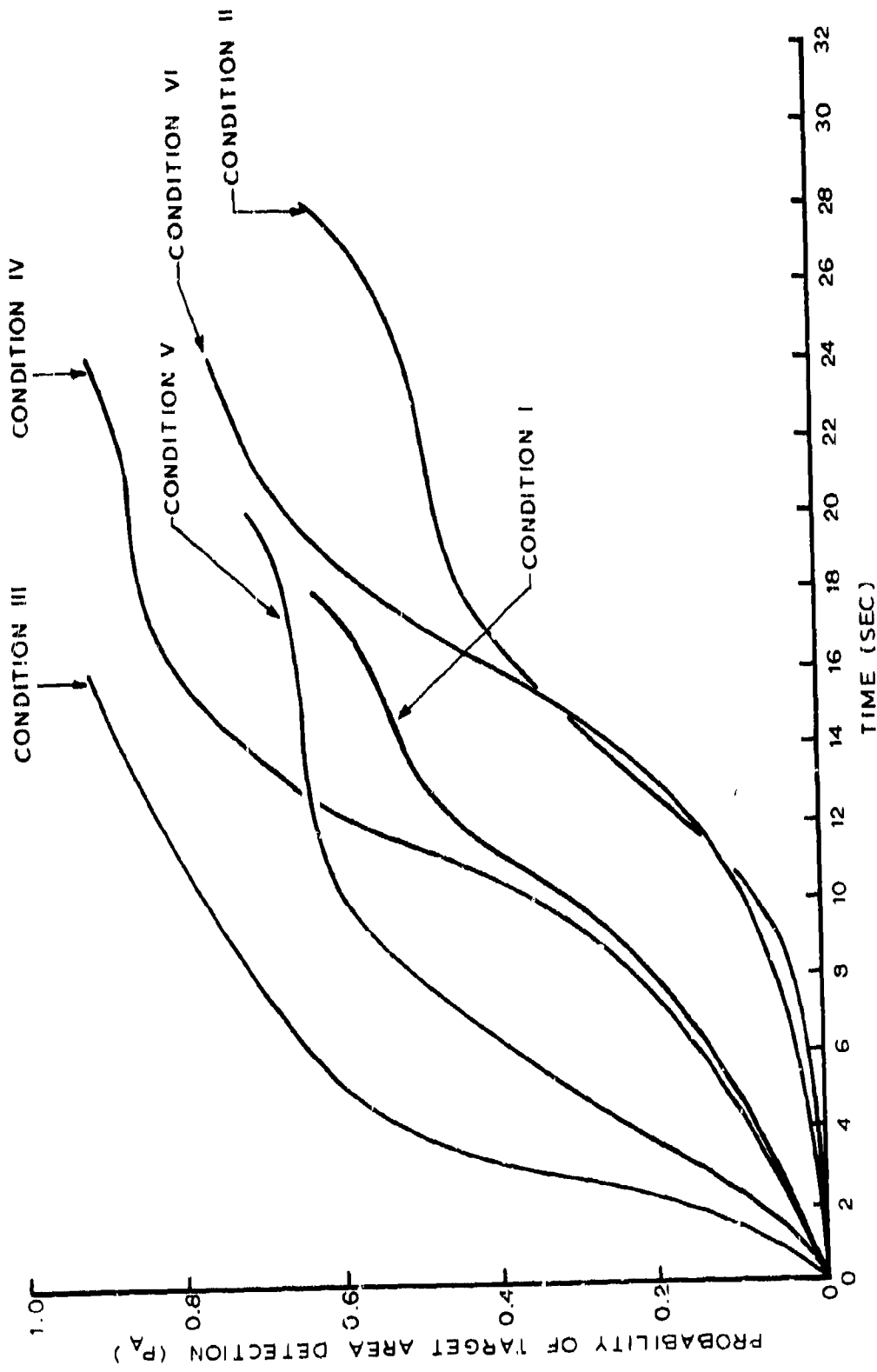


Fig. 44 (U) - Probability of target area detection ( $P_A$ ) vs. time (intersection)

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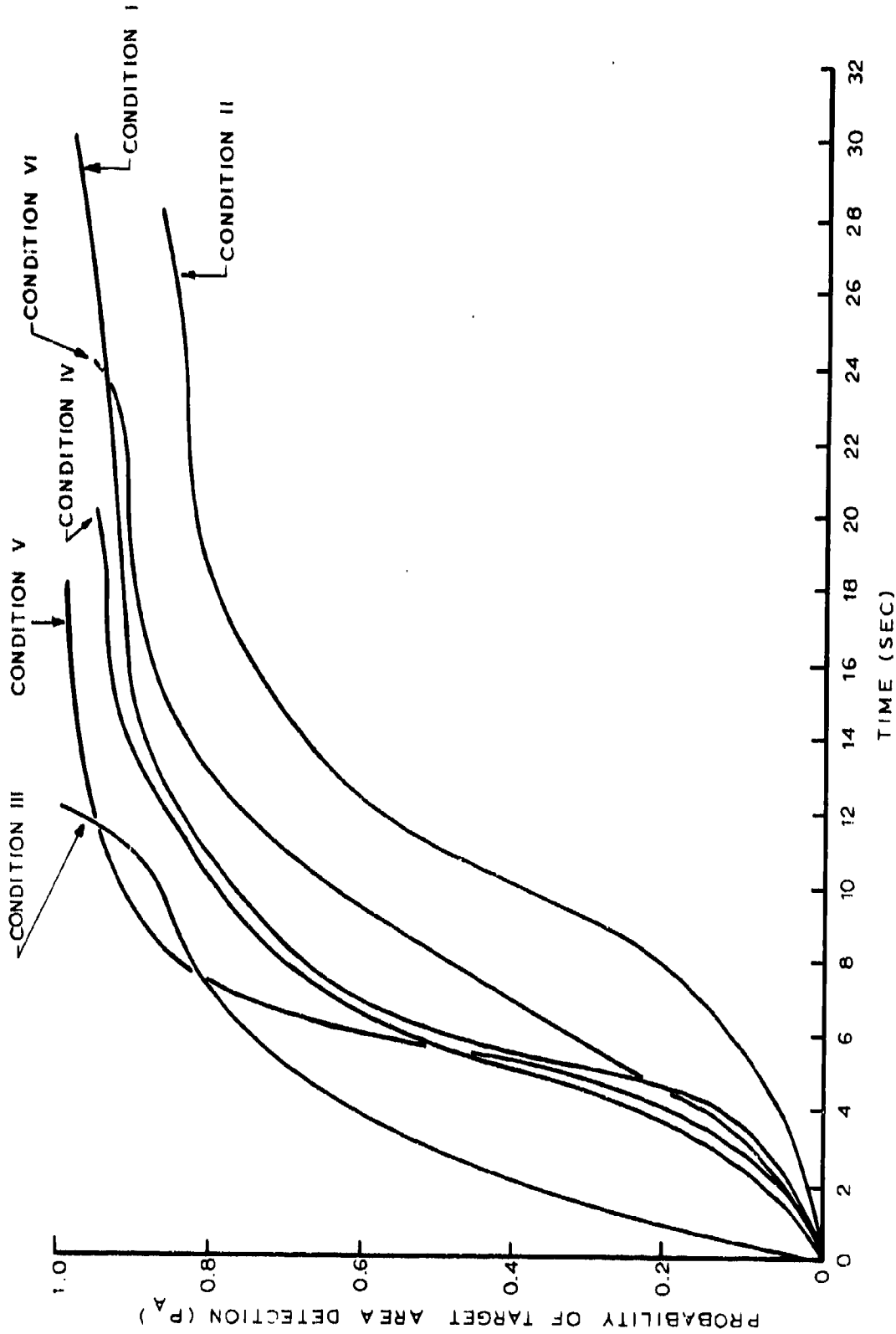


Fig. 45 (U) - Probability of target area detection ( $P_A$ ) vs. time (boat dock)

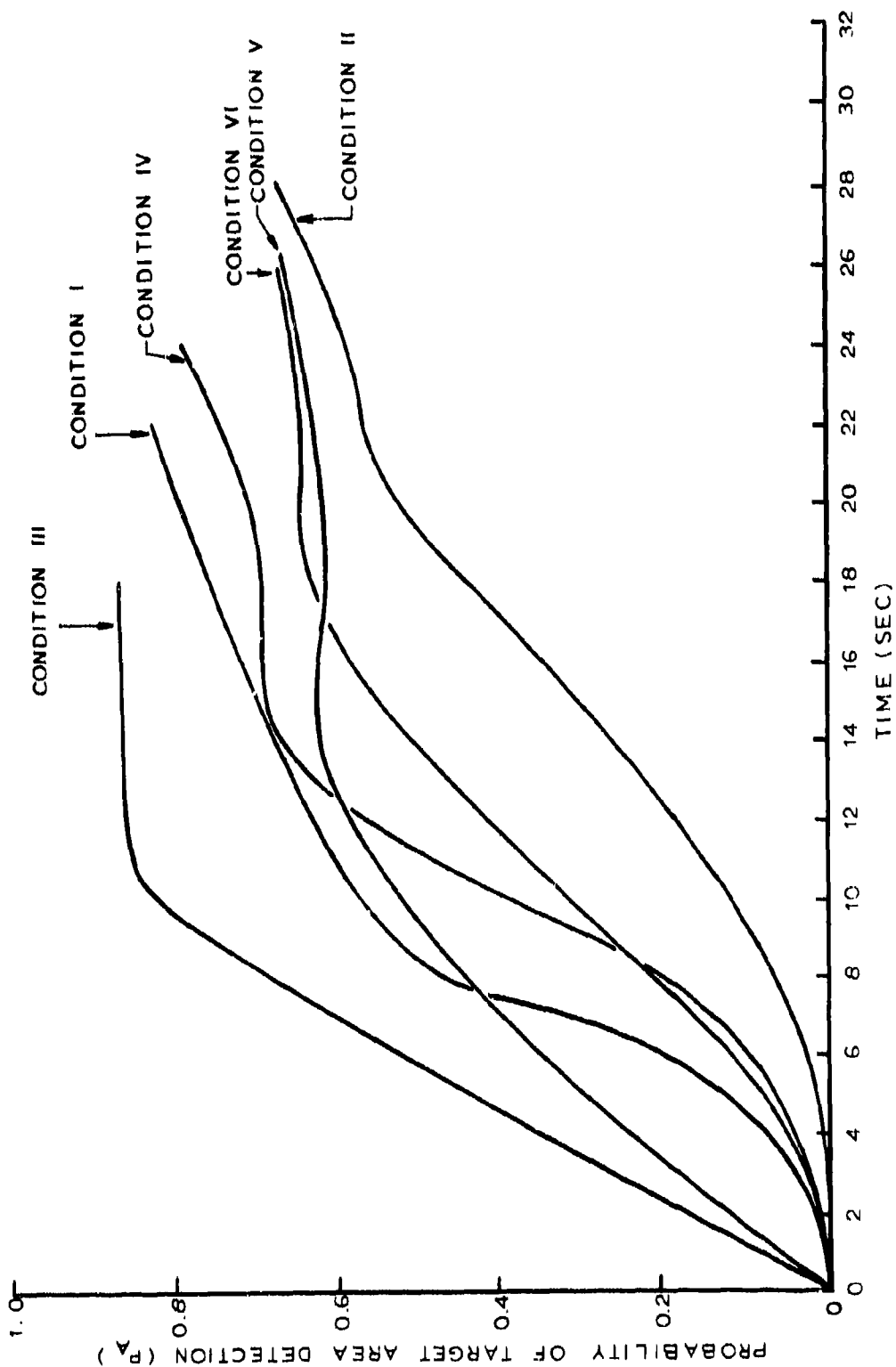


Fig. 46 (U) - Probability of target area detection ( $P_A$ ) vs. time (small bridge)

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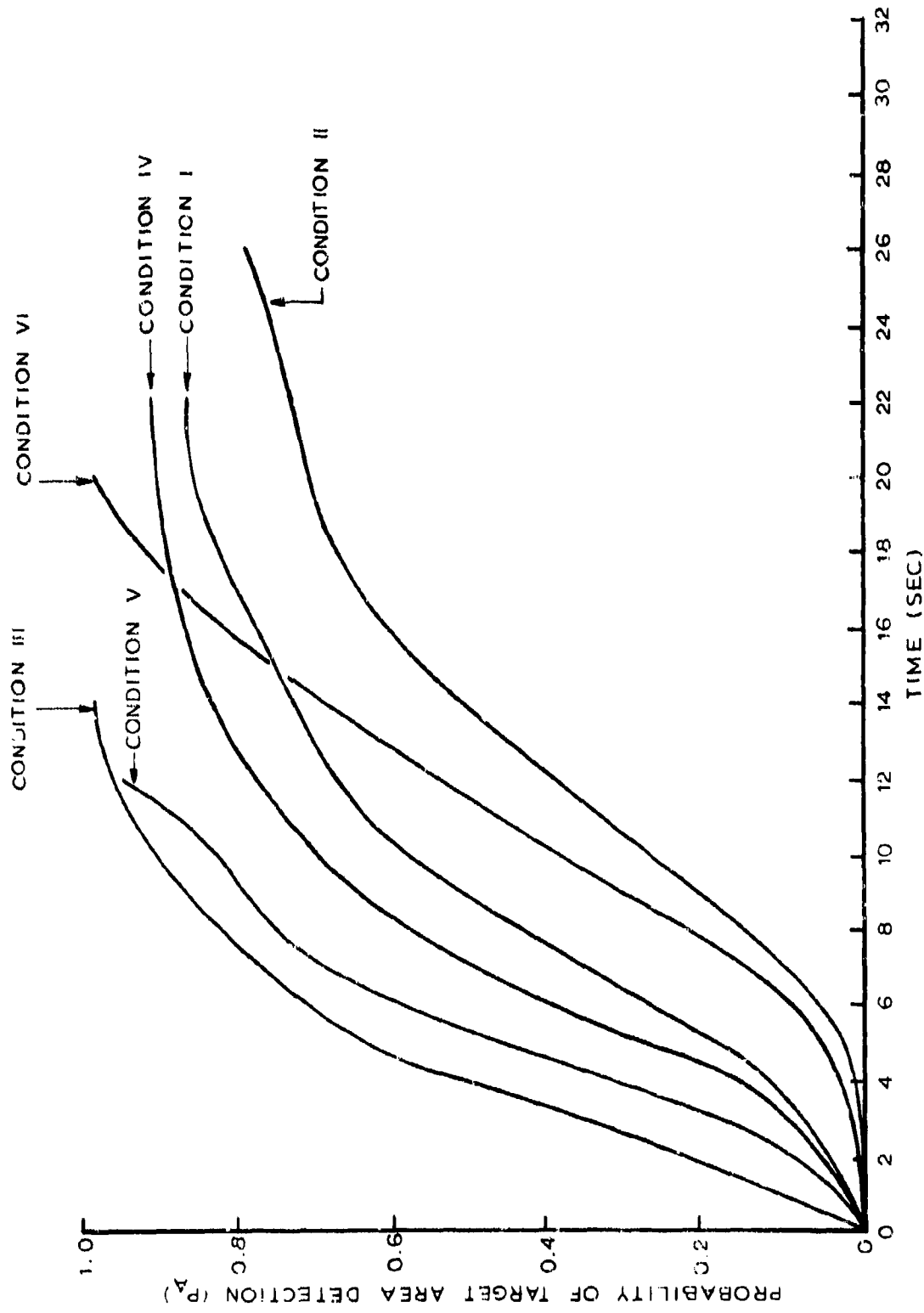


Fig. 47 (U) - Probability of target area detection ( $P_A$ ) vs. time (large bridge)

SECRET

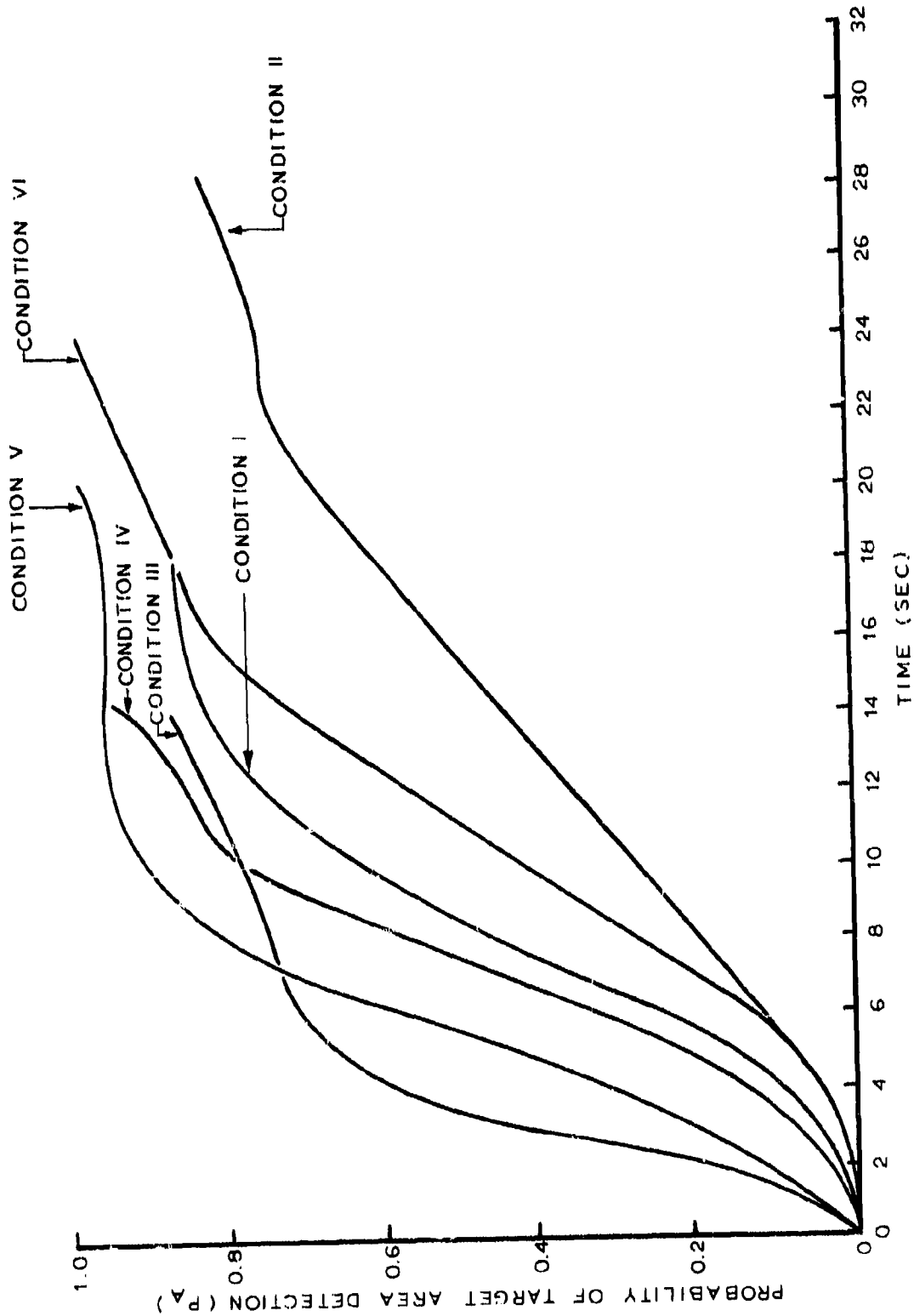


Fig. 48 (U) - Probability of target area detection ( $P_A$ ) vs. time (electronic facility)

Target Class	CONDITION #												Mean (Target Class)				
	I	II	III	IV	V	VI	P' A		t (sec)		P' A		t (sec)				
Small Building	0.84 24	0.64 24	0.80 12	0.84 18	0.80 14	0.96 24	0.84	18	0.80	14	0.96	24	0.84	18	0.96	24	.8 ± .1 19.5-5
Large Building	0.88 20	0.68 26	0.88 18	0.76 16	0.84 16	0.92 22	0.76	16	0.84	16	0.92	22	0.84	16	0.92	22	.83 ± .03 20.5-5
Airfield	0.96 20	0.96 30	0.92 10	0.98 24	0.92 14	0.92 22	0.98	24	0.92	14	0.92	22	0.92	14	0.92	22	.93 ± .04 20.5-7
Intersection	0.94 18	0.64 28	0.92 16	0.84 16	0.64 12	0.76 24	0.84	16	0.64	12	0.76	24	0.84	16	0.76	24	.7 ± .1 19.5-6
Boat Dock	0.88 12	0.80 18	1.00 12	0.92 14	0.96 12	0.92 18	0.92	14	0.96	12	0.92	18	0.92	14	0.92	18	.9 ± .1 14.5-3
Small Bridge	0.84 22	0.68 28	0.84 10	0.68 14	0.60 12	0.64 18	0.68	14	0.60	12	0.64	18	0.68	14	0.64	18	.7 ± .1 17.5-7
Large Bridge	0.84 18	0.80 26	1.00 14	0.80 16	0.96 12	1.00 20	1.00	16	0.96	12	1.00	20	0.80	16	1.00	20	.5 ± .1 17.5-5
Electronic Facility	0.84 14	0.76 22	0.88 14	0.96 14	0.96 12	1.00 24	0.96	14	0.96	12	1.00	24	0.96	14	1.00	24	.9 ± .1 16.5-5
Mean (Condition)	.84 ± .09 18.5-4	.75 ± .05 25.5-3	.91 ± .07 13.5-3	.85 ± .09 16.5-3	.82 ± .1 13.5-2	.8 ± .1 22.5-3	.85	16.5-3	.82 ± .1	13.5-2	.8 ± .1	22.5-3	.85	16.5-3	.8 ± .1	22.5-3	

Table 4 (U) - Asymptotic probability of target area detection (P' A) vs. detection time (knee or maximum point on the curve as appropriate)

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(C) The buildings were hard to detect. They were generally situated in urban complexes with a variety of similar returns in the same area. The poorer resolution in the search mode made detection extremely difficult. Similarly, road intersections and small bridges over creeks about the size of an average highway, were hard to detect in the search mode because of the poorer resolutions.

B. Target Designation

(C) The number of correct designations, in various time intervals, were determined as a function of the six condition numbers and eight target types. The probabilities of target designation,  $P_D$ , are plotted as a function of time in Figs. 49 - 57. The asymptotic or maximum values of  $P_D$  ( $P_D^1$ ), taken from Figs. 49 - 57, along with the corresponding designation times, appear in Table 5. Table 5 indicates that:

o Condition III again gave the highest  $P_D^1$  in the shortest time. Thus the accurate target area detections discussed earlier were reflected in the ability to accurately designate the target.

o Condition I and V rated second in performance. Although the aerial photos and 7.5' maps gave comparable performances in target area detection, the aerial photos enabled the operators to designate the targets quicker.

o Condition VI rated third. The degraded resolution in both search (90') and zoom (30') modes did not degrade  $P_D^1$ , but forced the operators to take longer to detect and designate the targets. Care should be exercised in interpreting the results with degraded resolution. In this experiment, the optics were defocused to degrade the resolution. The same information content was present but only defocused. Another method of resolution degradation is to optically reprocess the imagery and physically take out information. It is believed that  $P_D^1$  would be significantly reduced if optically reprocessed imagery was used.

o Condition IV rated fourth. The 7.5' maps and SAC were not adequate in the zoom mode. The operators required longer periods to correlate the imagery with the maps due to the high resolution (20') and added detail in the imagery which was not present on the maps.

o The worst results were obtained with Condition II. The 1 nm FOV in the zoom mode allowed only a small error in placing the cursors in the search mode. Many targets that would appear in a 2 nm FOV are not in the 1 nm FOV. As a result,  $P_D^1$  is low and the operators took longer to designate the targets. The longer detection times mentioned earlier, are reflected in larger designation times.

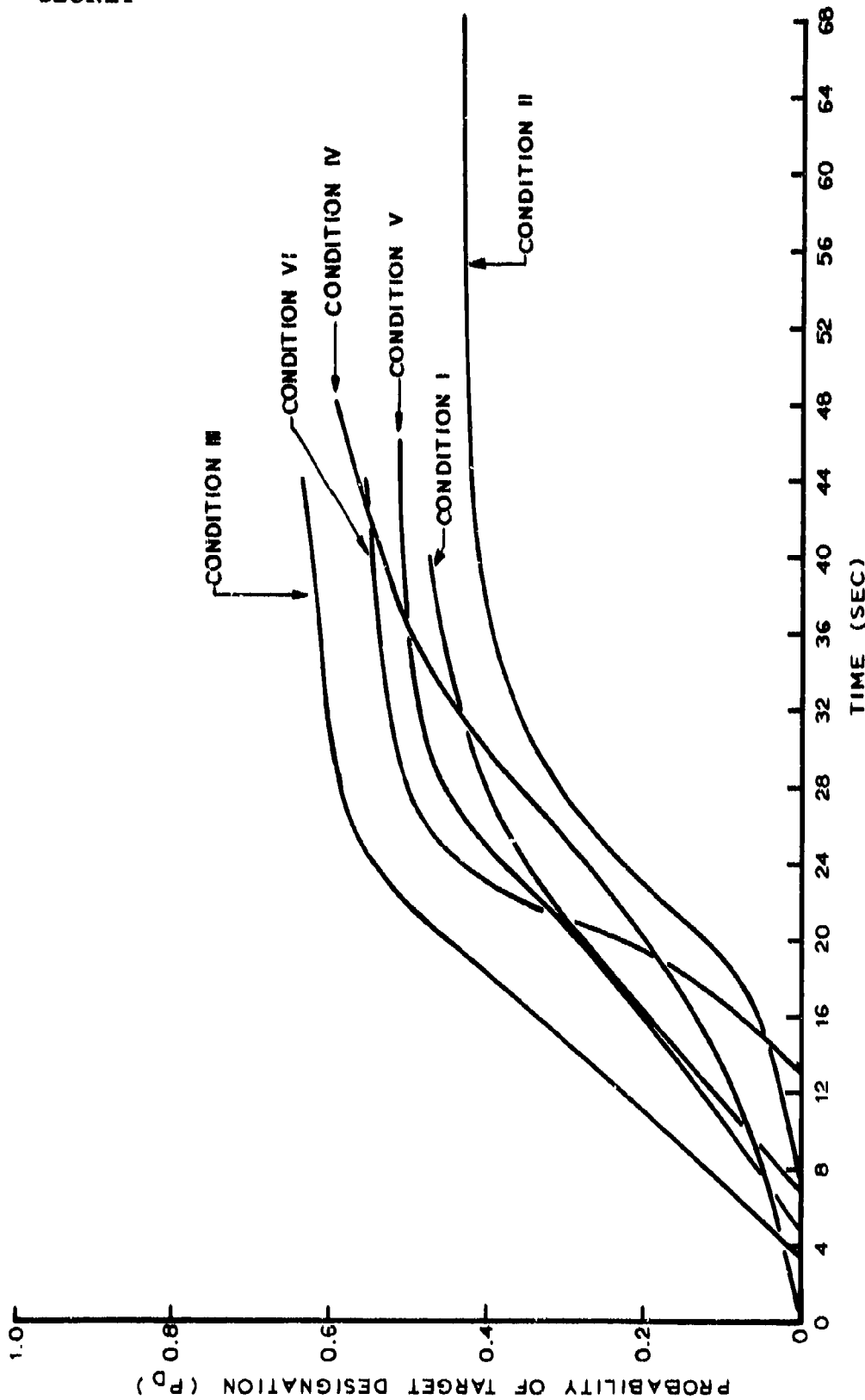


Fig. 49 (U) - Probability of target designation ( $P_D$ ) vs. time (small building)

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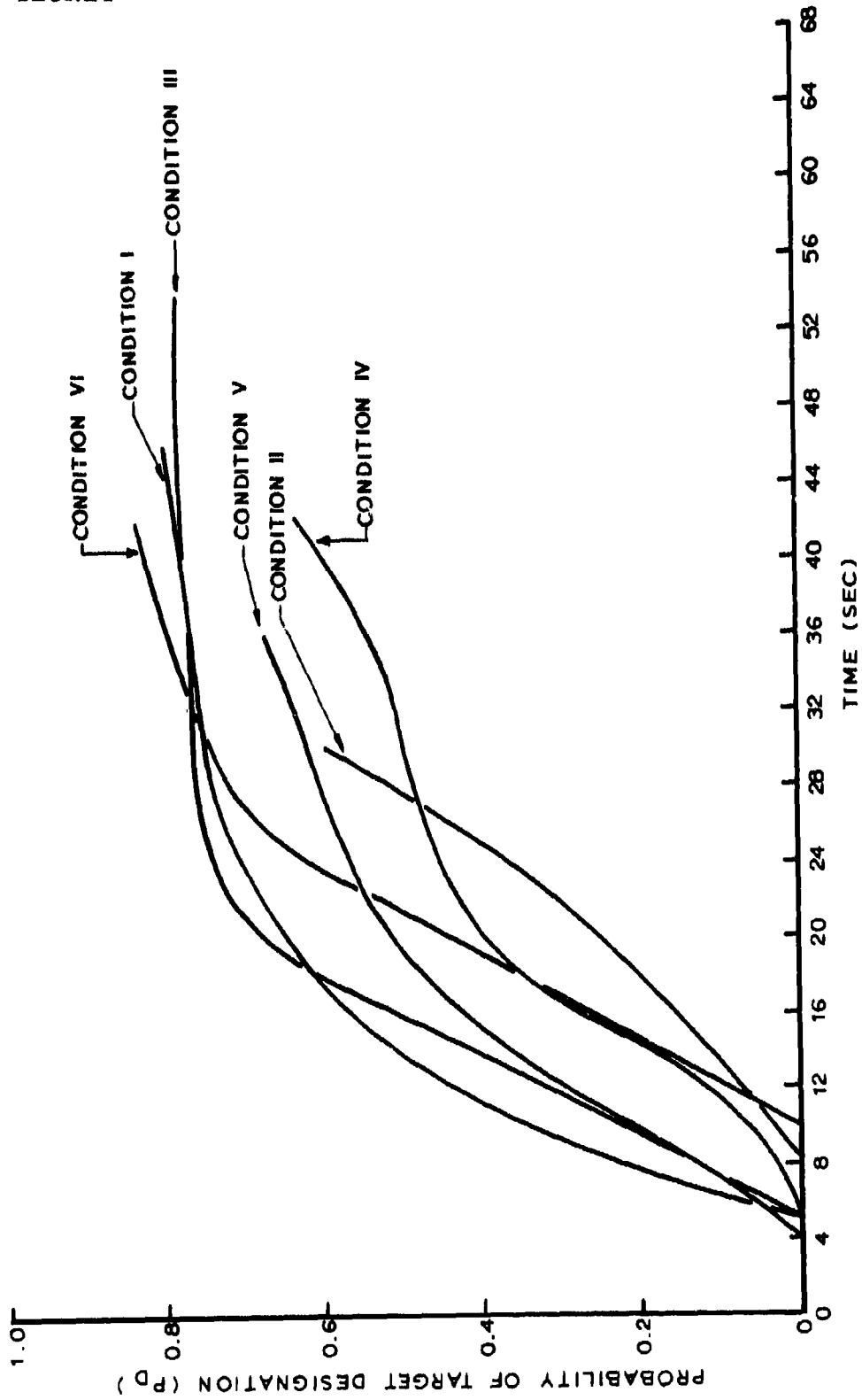


Fig. 50 (U) - Probability of target designation ( $P_D$ ) vs. time (large building)

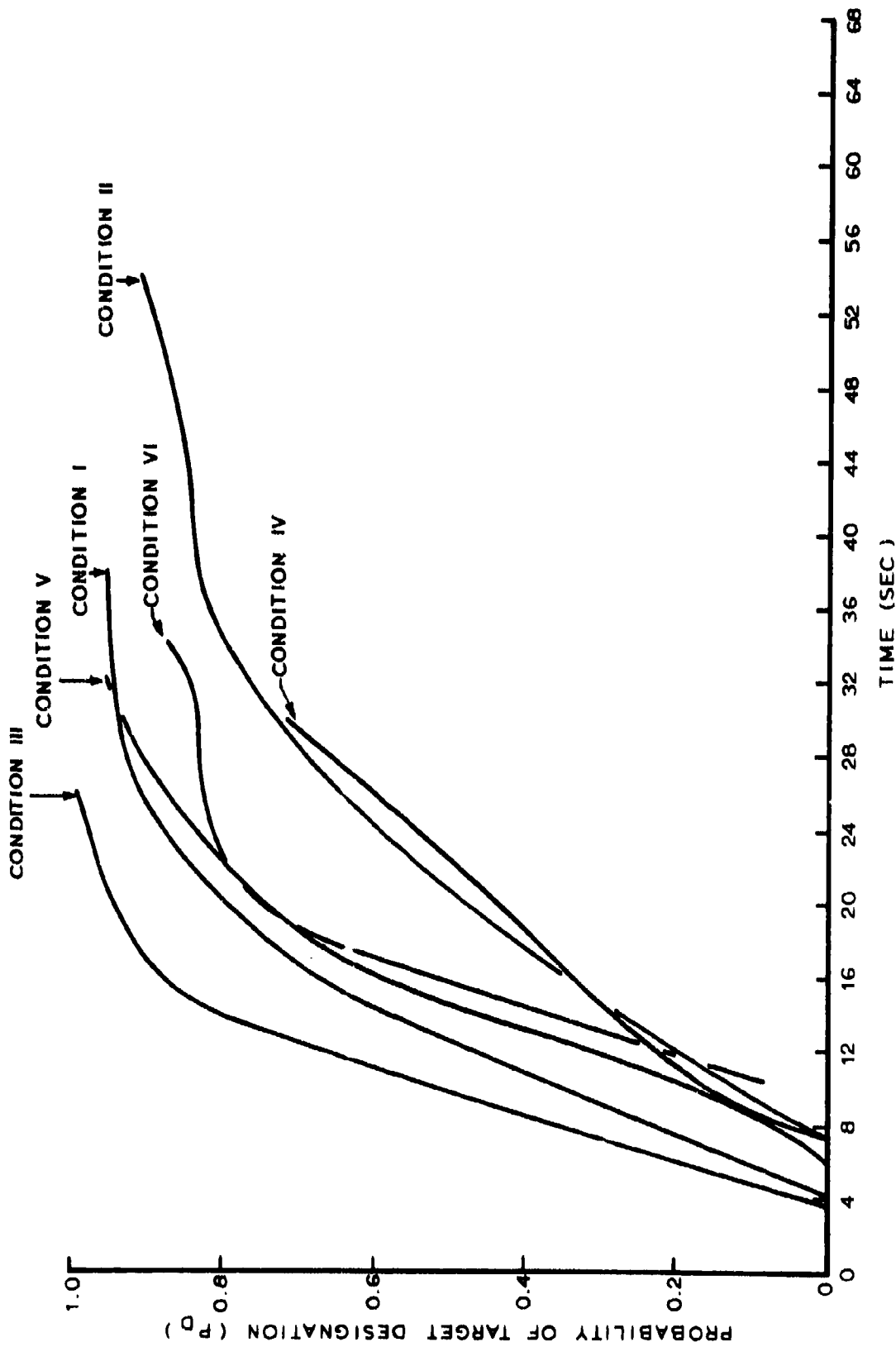


Fig. 51 (U) - Probability of target designation ( $P_D$ ) vs. time (airfield)

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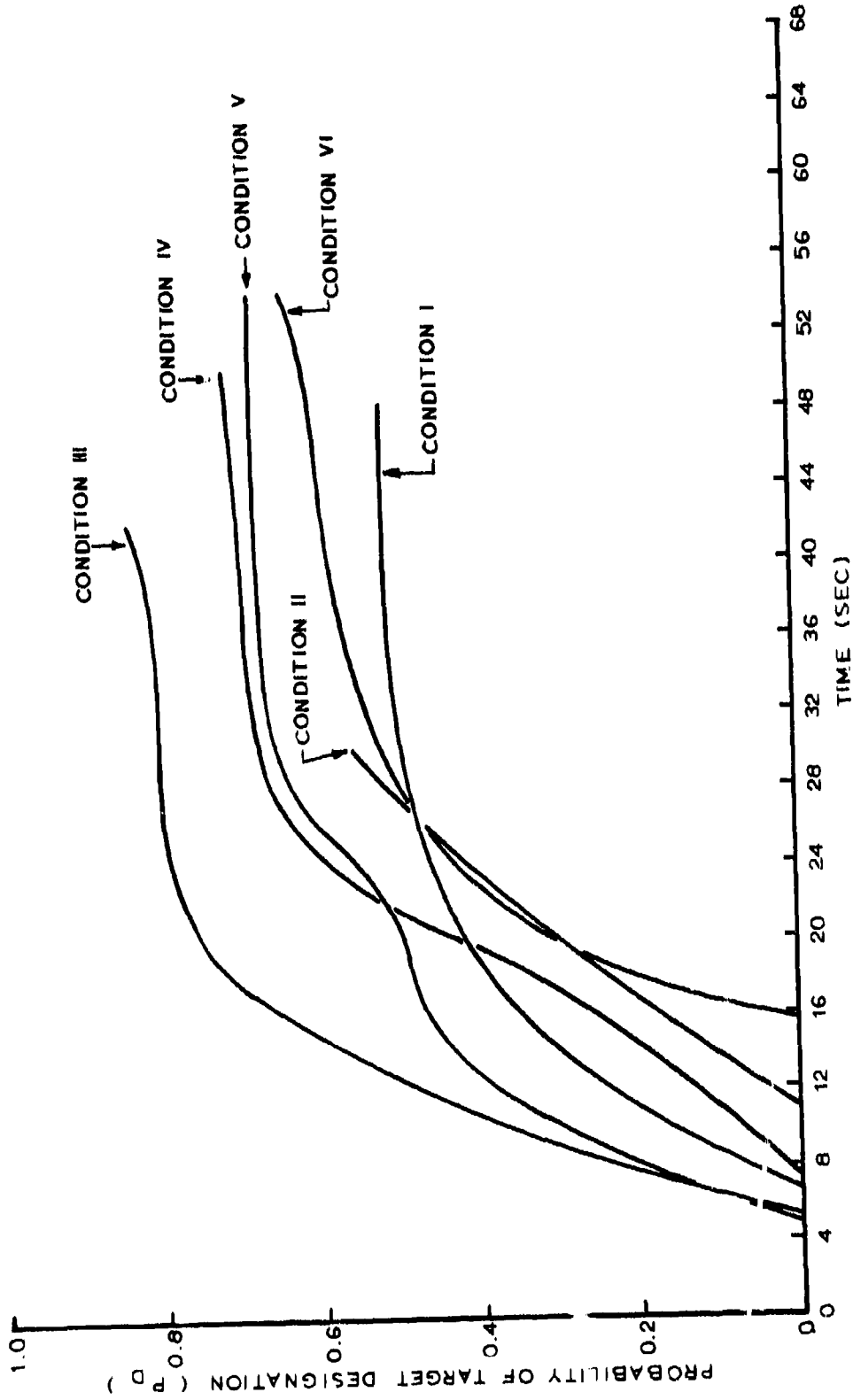


Fig. 52 (U) - Probability of target designation ( $P_D$ ) vs. time (intersection)

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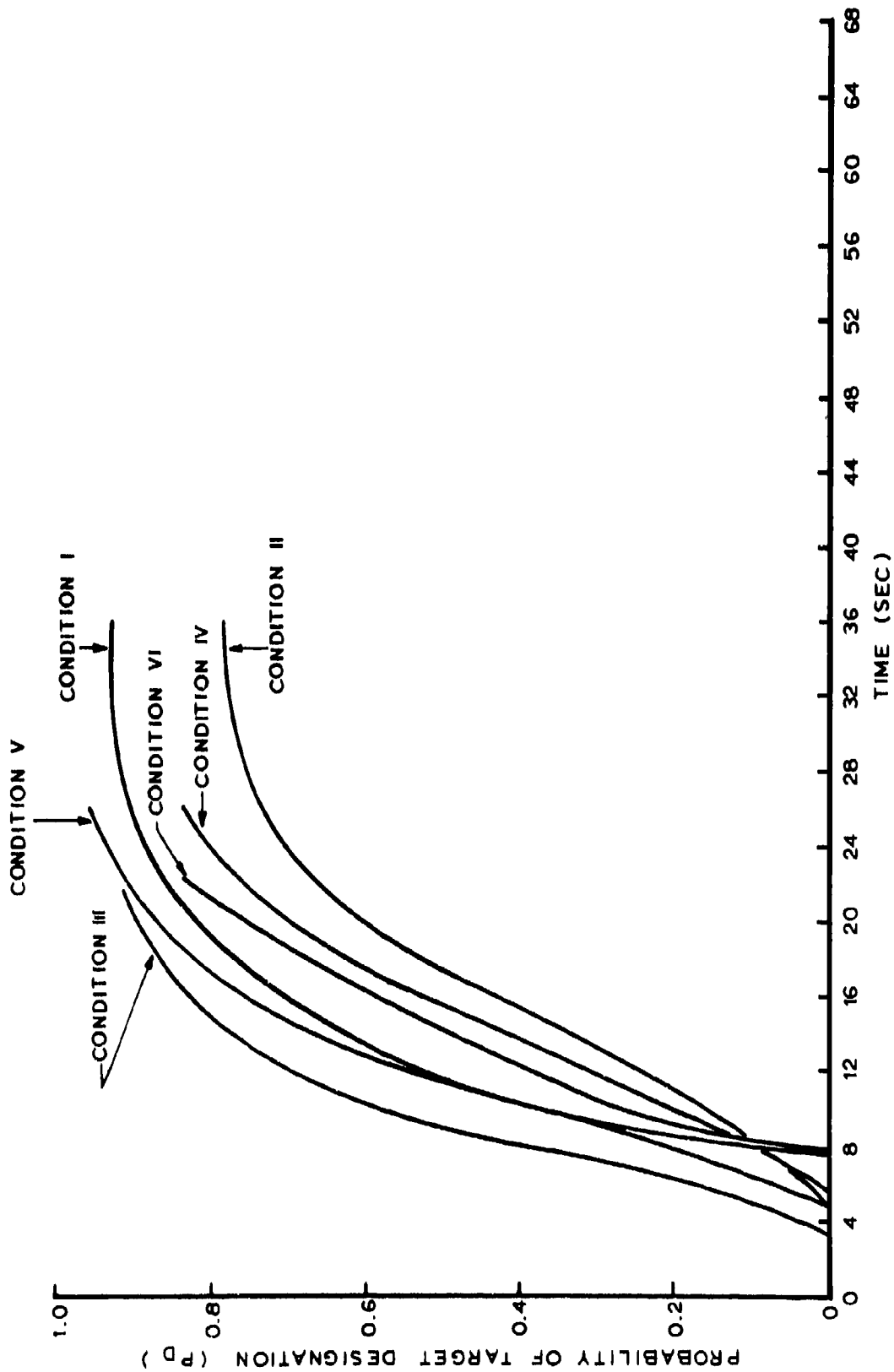


Fig. 53 (U) - Probability of target designation ( $P_D$ ) vs. time (boat dock)

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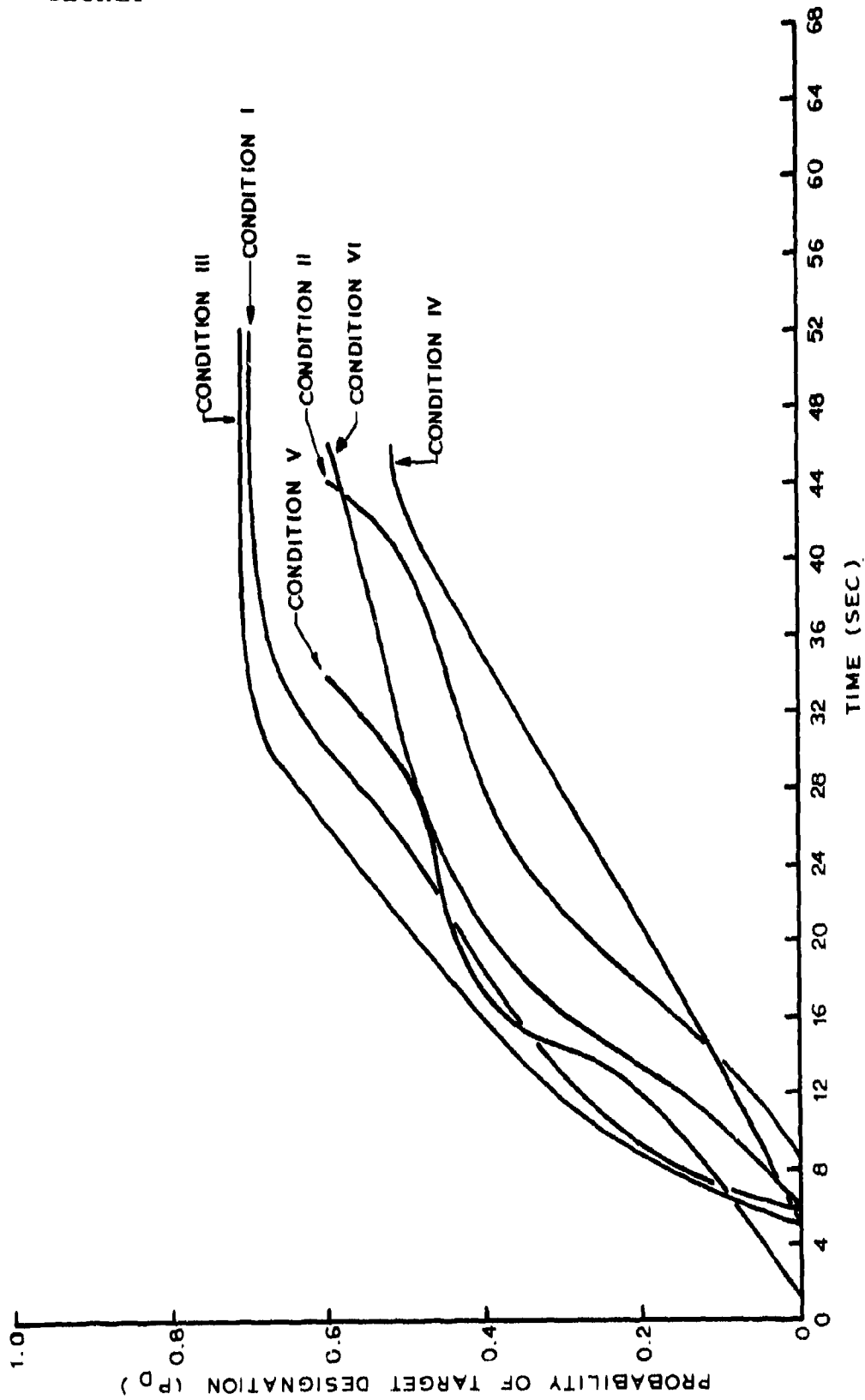


Fig. 54 (U) - Probability of target designation ( $P_D$ ) vs. time (small bridge)

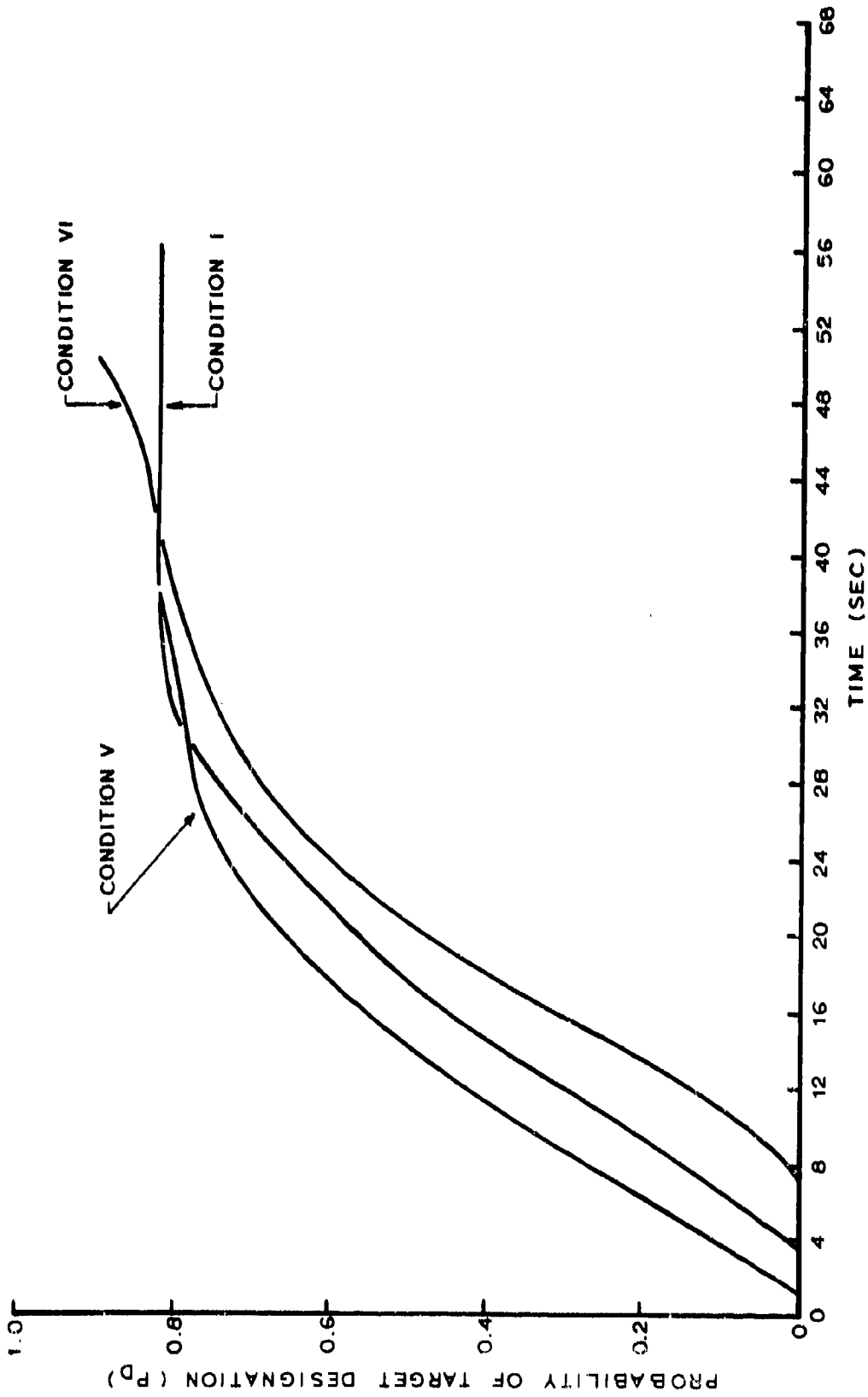


Fig. 55 (U) - Probability of target designation ( $P_D$ ) vs. time (large bridge)

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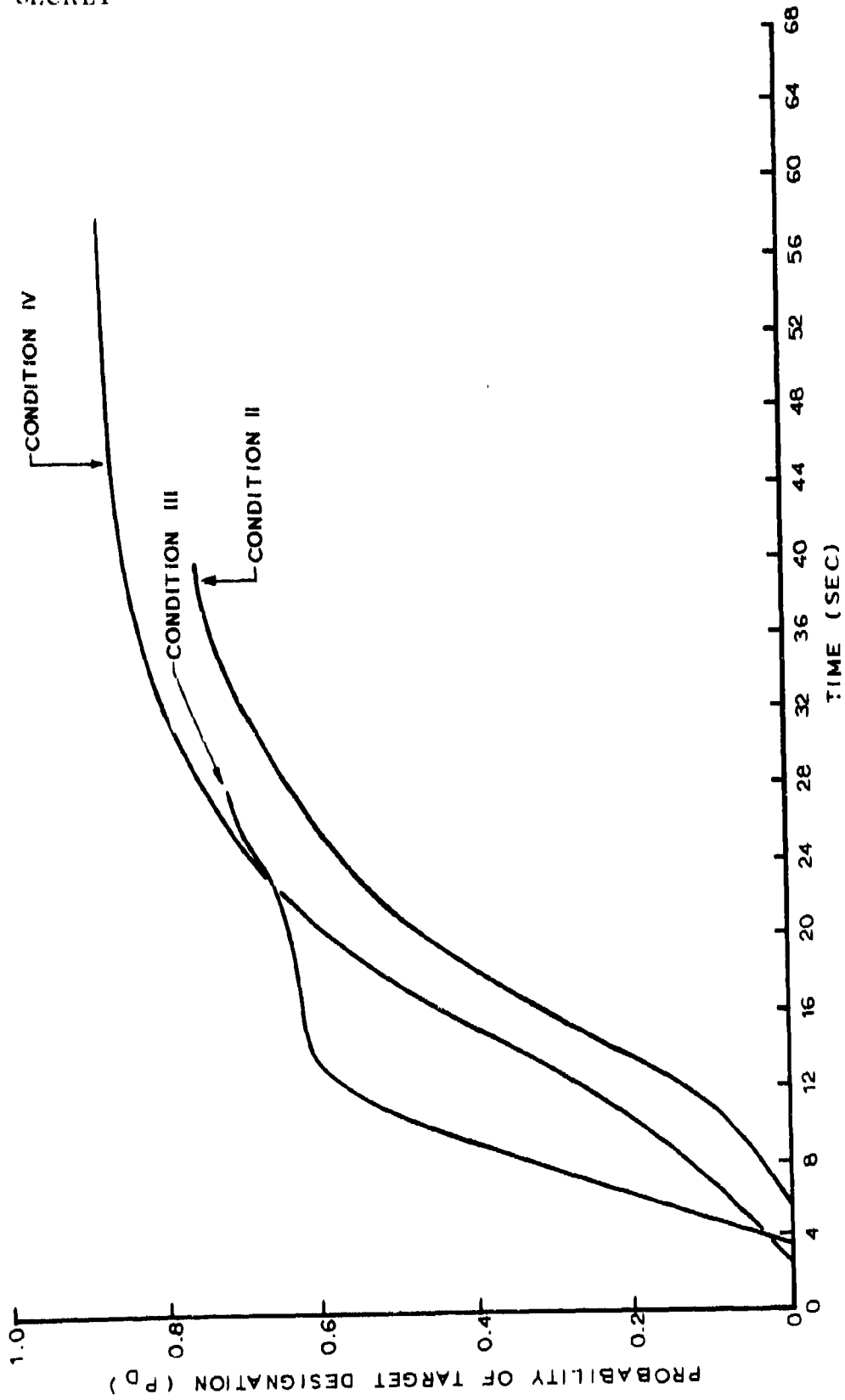


Fig. 56 (U) - Probability of target designation ( $P_D$ ) vs. time (large bridge)

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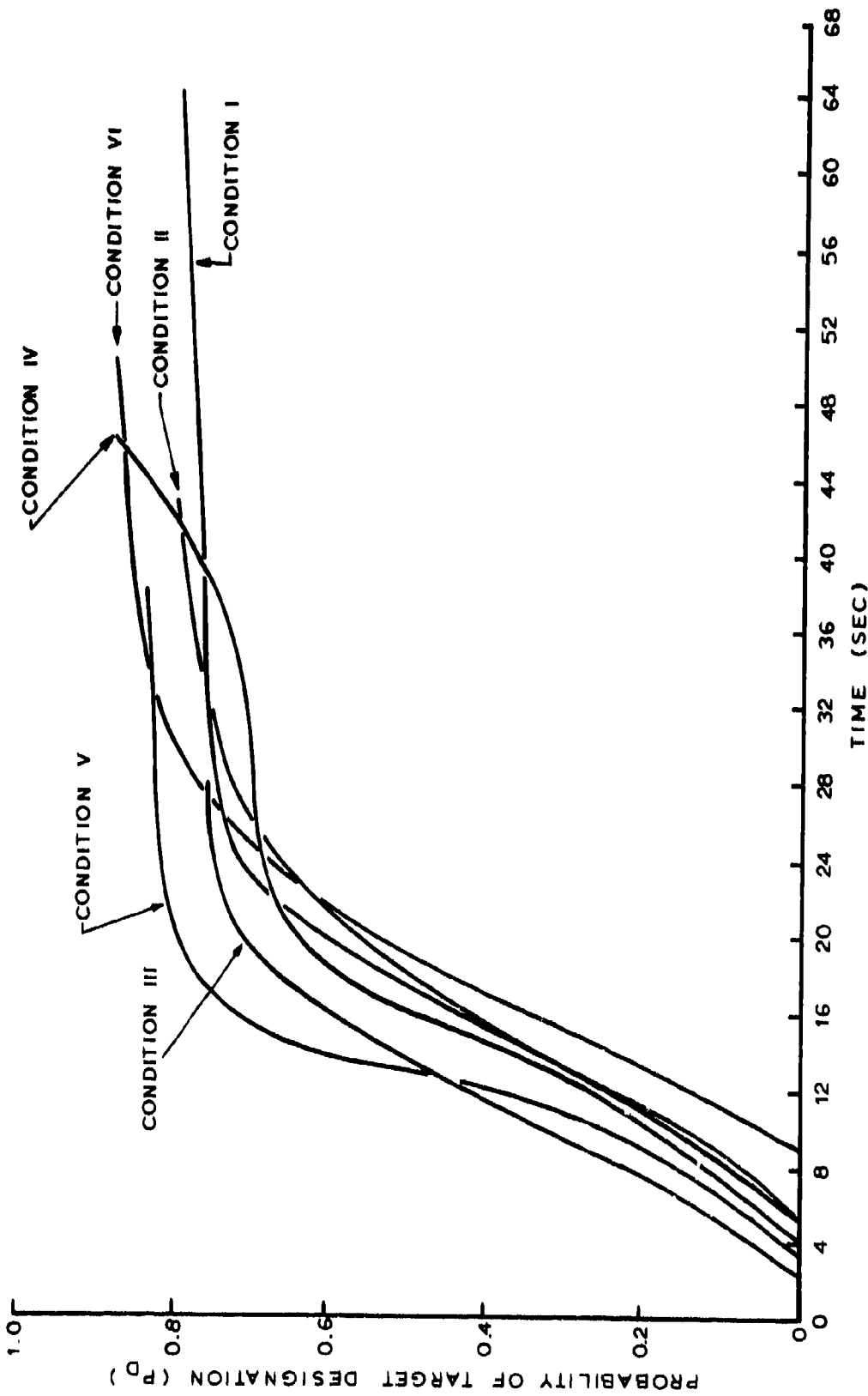


Fig. 57 (U) - Probability of target designation ( $P_D$ ) vs. time (electronic facility)

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Target Class	CONDITION #										Average (Target Class)	
	I	II	III	IV	V	VI	Average					
	P <sub>D</sub> t (sec)	P <sub>D</sub> t (sec)	P <sub>D</sub> t (sec)	P <sub>D</sub> t (sec)	P <sub>D</sub> t (sec)	P <sub>D</sub> t (sec)	P <sub>D</sub> t (sec)	P <sub>D</sub> t (sec)	P <sub>D</sub> t (sec)	P <sub>D</sub> t (sec)	P <sub>D</sub> t (sec)	
Small Building	0.48 40	0.40 36	0.60 30	0.60 48	0.48 30	0.52 30	0.52 30	0.52 30	0.52 30	0.52 30	0.52 30	.52 ± .1 36 ± 5
Large Building	0.72 22	0.64 30	0.76 32	0.64 42	0.68 36	0.84 42	0.84 42	0.84 42	0.84 42	0.84 42	0.84 42	.62 ± .1 34 ± 8
Airfield	0.96 32	0.84 38	1.00 26	0.72 30	0.92 26	0.80 22	0.80 22	0.80 22	0.80 22	0.80 22	0.80 22	.92 ± .1 29 ± 6
Intersection	0.48 26	0.56 30	0.75 20	0.68 30	0.64 28	0.56 34	0.56 34	0.56 34	0.56 34	0.56 34	0.56 34	.62 ± .1 28 ± 5
Boat Dock	0.92 30	0.76 26	0.92 22	0.84 26	0.96 26	0.84 22	0.84 22	0.84 22	0.84 22	0.84 22	0.84 22	.92 ± .1 26 ± 3
Small Bridge	0.68 36	0.60 44	0.68 32	0.52 46	0.60 34	0.60 46	0.60 46	0.60 46	0.60 46	0.60 46	0.60 46	.61 ± .1 40 ± 3
Large Bridge	0.80 30	0.76 40	0.76 28	0.84 36	0.80 30	0.84 40	0.84 40	0.84 40	0.84 40	0.84 40	0.84 40	.80 ± .1 34 ± 8
Electronic Facility	0.72 24	0.76 32	0.72 20	0.88 46	0.80 20	0.84 34	0.84 34	0.84 34	0.84 34	0.84 34	0.84 34	.79 ± .1 29 ± 10
Mean (Condition)	.72 ± .2 30 ± 8	.62 ± .1 35 ± 3	.72 ± .1 26 ± 7 = 6	.72 ± .1 36 ± 10	.72 ± .1 29 ± 3 = 3	.72 ± .1 34 ± 7 = 8	.72 ± .1 34 ± 7 = 8	.72 ± .1 34 ± 7 = 8	.72 ± .1 34 ± 7 = 8	.72 ± .1 34 ± 7 = 8	.72 ± .1 34 ± 7 = 8	.72 ± .1 34 ± 7 = 8

Table 5 (U) - Asymptotic probability of target designation (P<sub>D</sub><sup>i</sup>) vs. designation time (knee or maximum point on the curve as appropriate)

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o As observed from Table 5, the variation in  $P'_D$  is small between the various conditions. The variation in target designation time, however, is significant, considering the fact that the aircraft is at high altitude and in the range of enemy surface to air missiles (SAM) during this time. The small variations in  $P'_D$  over the conditions implies that most of the operators sacrificed target designation time for a positive designation.

o Boat docks were the easiest target class to designate. The good land/water boundaries were very helpful.

o Airfields were the second easiest target class to designate. After being accurately detected, the designation followed easily, since runways and hanger facilities showed up well in the zoom mode.

o Electronic facilities, rated third, tended to give good returns in both the search and zoom modes which made designation easy.

o Large bridges, rated fourth, were generally across rivers in urban areas. The land/water interface was helpful, but it was difficult to find the right bridge in a heavily populated area.

o Intersections, rated fifth, were hard to locate with the poorer resolution of the search mode. In the zoom mode, the resolution improved, and intersections were easier to designate.

o Large buildings, rated sixth, were hard to find in the search mode in cluttered urban developments. In the zoom mode, they showed up well and were easily designated.

o Small bridges, rated seventh, were generally over small creeks which were hard to locate with the poorer resolution of the search mode. In the zoom mode the creeks and bridges were distinguishable, but it was difficult to find the right bridge.

o Small buildings, rated eight, were difficult in both the search and zoom mode because of the degraded resolution.

#### XI. CONCLUSIONS & RECOMMENDATIONS

(C) If a highly accurate navigation system and enough contextual information are available, a 4 nm FOV in the search mode and a 2 nm FOV in the zoom mode give the best probability and least times for target detection and designation. Aerial photographs, together with sectional aeronautical charts, are the best briefing materials. The time required to designate an average target under the conditions listed above is  $26 \pm \sigma = 6$  seconds with a probability of  $.7 \pm \sigma = .1$ .

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(C) The resolution was degraded from 45 to 90 ft. by defocusing the optics. This resolution increased target designation times by 13%, but it did not significantly affect the probability of target designation. Boat docks, airfields, electronic facilities, and large bridges were the easiest targets to designate while intersections, large buildings, small buildings, and small bridges were the most difficult.

(C) The imagery used in this study was good quality optically processed reconnaissance imagery which was degraded to the format expected of a real time system. This process could not completely degrade all parameters of the optically processed imagery. Therefore, the results obtained from this imagery suggest upper-limit performance of the MMR in a real-time tactical environment. To obtain more realistic data on expected MMR performance, a comprehensive simulation should be conducted using digitally processed real-time SAR imagery such as is being collected in the Hughes and Westinghouse programs.

(U) Simulations should include the navigation, target detection, and weapon delivery phases of the total mission. Of particular interest is the trade-off between the target detection in the 45° squint mode and terminal detection in the doppler-beam-sharpened mode. Studies should also be performed to determine if the performance of the MMR can be improved by using it in conjunction with other sensors such as infrared and low-light-level-television.

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APPENDIX A (U)

A Determination of the Number of Operators  
and Targets Needed in the Simulation (U)

(U) It is assumed in this analysis that if an infinite amount of data was taken the results would yield a normal distribution with a true mean ( $\mu$ ) and a true standard deviation ( $\sigma$ ). Since this study will not yield an infinite amount of data, the results when plotted will yield a distribution which will approximate the normal with a sample mean  $M$  and a sample standard deviation  $S$ . By comparing  $M$  and  $\mu$ , it can be determined if enough data was taken to establish certain confidence limits.

(U) Let  $z$  equal a random variable having a normal distribution as shown in Fig. A-1.

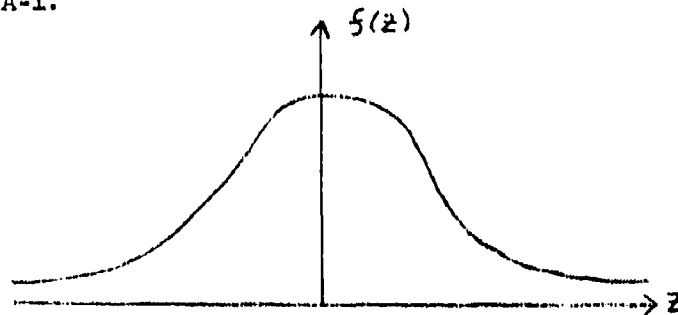


Fig. A-1 A Typical Normal Distribution (U)

$Z$  is given by:

$$Z = \frac{M - \mu}{\sigma / \sqrt{n}} \quad \text{A-1}$$

Where:  $n$  = the number of data samples taken

If it is assumed that  $\sigma$  can be approximated by  $S$ ,  $Z$  becomes

$$Z = \frac{M - \mu}{S / \sqrt{n}}$$

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Since Z follows a normal distribution, there is a confidence of  $1 - \alpha$  that Z is in the interval:

$$-Z_{\alpha/2} < \frac{M - \mu}{S/\sqrt{n}} < Z_{\alpha/2} \quad A-3$$

$$\text{or: } \left| \frac{M - \mu}{S/\sqrt{n}} \right| < Z_{\alpha/2} \quad A-4$$

Let E, which is the error in estimating  $\mu$  by M be given by:

$$E = |M - \mu| \quad A-5$$

$$E < Z_{\alpha/2} \frac{S}{\sqrt{n}} \quad A-6$$

$$n < \frac{Z_{\alpha/2}^2 S^2}{E^2} \quad A-7$$

Therefore, it can be asserted with a probability of  $1 - \alpha$  that the error of estimating  $\mu$  by M will be less than E if a sample size of n is used.

$$\text{Where: } n = \frac{Z_{\alpha/2}^2 S^2}{E^2} \quad A-8$$

(C) A-8 can be used to determine the number of runs needed for accurate target area detection times and target designation time. E and S are determined from a similar study conducted earlier, Ref. 3. The number of runs needed for target area detection are given by the following relationships:

$M_A$  = mean target area detection time for all targets in Ref. 3.

= 10.7 sec.

$S_A^2$  = variance of target area detection time for all targets in Ref. 3 = 32.2 sec<sup>2</sup>.

Let the confidence level  $(1 - \alpha) = 0.95$

$Z_{0.95} = 1.96$  (from normal distribution tables)

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$E_A$  = target area detection time error interval

Let  $E_A = 25\%$  of  $M_A = 2.7$  sec

The total number of runs needed for a .95 confidence that  $M_A$  lies in the interval  $8.0 \text{ sec} \leq M_A \leq 13.4 \text{ sec}$  is 17. The number of runs needed for target designation are given by the following relationships.

$M_D$  = mean target designation time for all targets in Ref. 3

= 27.9 sec

$s_D^2$  = variance of target designation time for all targets in Ref. 3

= 269.5 sec<sup>2</sup>

Let the confidence level  $(1 - \alpha) = .95$

$Z_{.95} = 1.96$  (from normal distribution tables)

$E_D$  = target designation time error interval

Let  $E_D = 25\%$  of  $M_D = 7$  sec.

$$n = \frac{s_D^2 Z^2 .95}{E_D^2} \quad \approx \quad 21$$

The total number of runs needed for a .95 confidence that  $M_D$  lies in the interval  $20.9 \text{ sec} \leq M_D \leq 34.9 \text{ sec}$ . is 21.

(U) There are 8 target classes with 5 targets per class. If 5 operators are run against each target class a total of  $n = 25$  runs will be completed which exceeds the  $n = 17$  and  $n = 21$  determined by the above analysis. There are also 6 conditions which are varied. Five operators are required for each of the conditions. Therefore, a total of 30 operators are needed for the simulation.

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