DESERT SEARCHES:
EFFECTIVENESS OF HELICOPTERS

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INTRODUCTION

Arizona Revised Statute 11-441C states that the Sheriff of each of the 14 Arizona Counties shall conduct or coordinate search and rescue within their jurisdiction and assist the Sheriffs of other Arizona Counties upon request. The Pima County Sheriff's Department has assumed an active role in both search and rescue. Two Deputies assigned to the Sheriff's Search and Rescue (SAR) section are responsible for the investigation and management of SAR related incidents. This Department has managed 663 search and rescue missions during the period of 1975 through 1980. These missions occurred throughout the State of Arizona and in Mexico; 371 of these SAR missions began as searches for people lost or overdue from a wilderness outing.

Search and rescue in Pima County is a multiagency team effort involving the cooperation of numerous professional and volunteer agencies. A typical search may involve the response of volunteer members of the Search and Rescue Council Incorporated, trackers from the United States Border Patrol, search dogs from local law enforcement agencies, and various air support resources.

In the area of air support resources, the Pima County Sheriff's Department works extensively with the United States Air Force Aerospace Rescue and Recovery Service, the Arizona Department of Public Safety Air-Rescue, the United States Border Patrol, the United States Customs Service, and the United States Army National Guard, each of which has excellent air-search capabilities.

Upon examination of Pima County's historical SAR data involving the helicopter resource (for the period January 1978, through February 1981), it is noted that the median time spent on an air search was 4 hours. An extreme case involved 55 hours of unsuccessful air searching. In daytime mountain searches (elevation 4,000 to 10,000 feet) of all the victims found as a direct result of the SAR effort, 53% were found by the helicopter resource. In daytime desert searches (elevation 1,500 to 4,000 feet) of all the victims found as a direct result of the SAR effort , 78% were found by the helicopter resource. However, it should be noted that clue conscious ground search teams provided significant guidance to the air resources in many of these successful finds. Nevertheless, these data show that the helicopter air-search is a valuable search aid.

The search manager is responsible for attaining maximum levels of effectiveness and efficiency through proper direction of the available resources. The achievement of these goals requires an understanding of the effectiveness (or probability of detection, POD) of SAR resources[1], because an understanding of this resource effectiveness allows the search manager to forecast both the extent of multiple coverage and the search time required to reach an acceptable level of coverage.

Consequently, a knowledge of the PODs for each of the SAR resources would be valuable. Unfortunately almost no information is available on efforts to measure the PODs of SAR resources in the inland search for lost persons. The one exception is the notable contribution of Wartes [1] involving grid search teams in the dense Pacific Northwest forest.

This research is being conducted to establish a conservative measurement of the probability of detection, POD, of the United States Air Force helicopter rescue teams searching Sonoran desert terrain for lost persons. The experiments were designed to simulate average conditions encountered on the desert search. The results of this effort indicate significant

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[1]For an explanation of the terminology, see the Appendix.

differences in helicopter search effectiveness, which depend not only on the vegetation density and the victims' actions, but also, surprisingly, on the cloud coverage of the search area.

Finally, it should be added that the material contained within this study will be useful in applications other than searching for lost persons. Military, law enforcement and corrections agencies can utilize this management aid in air searches of desert terrain for military targets, wanted criminals and escaped prisoners, because these objectives may be in situations similar to those considered in this document.

STRUCTURE OF EXPERIMENT

Description of Search Area.

The particular search area used for all the experiments was rectangular in shape, two miles long by three miles wide. It was selected because it represented desert terrain typical of the Tucson area. It was essentially flat (see contour map, figure 1) with a number of dry washes running through it. The vegetation was a mixture of Palo Verde, Mesquite, Saguaro, Prickly Pear, Cholla, and Creosote. The density of the vegetation varied from sparse to heavy (see figures 2,3,4,6,7). The area was devoid of buildings and mines, but contained typical features such as cattle ponds, unpaved roads, trails, fences, and power lines.

From the point of view of the management of the experiment the search area was attractive for two other reasons. First, it contained sufficient 4WD trails to allow the deployment of the victims with relative ease. Second, it was in a sufficiently remote area that only people associated with the experiment were likely to be present during an experiment.

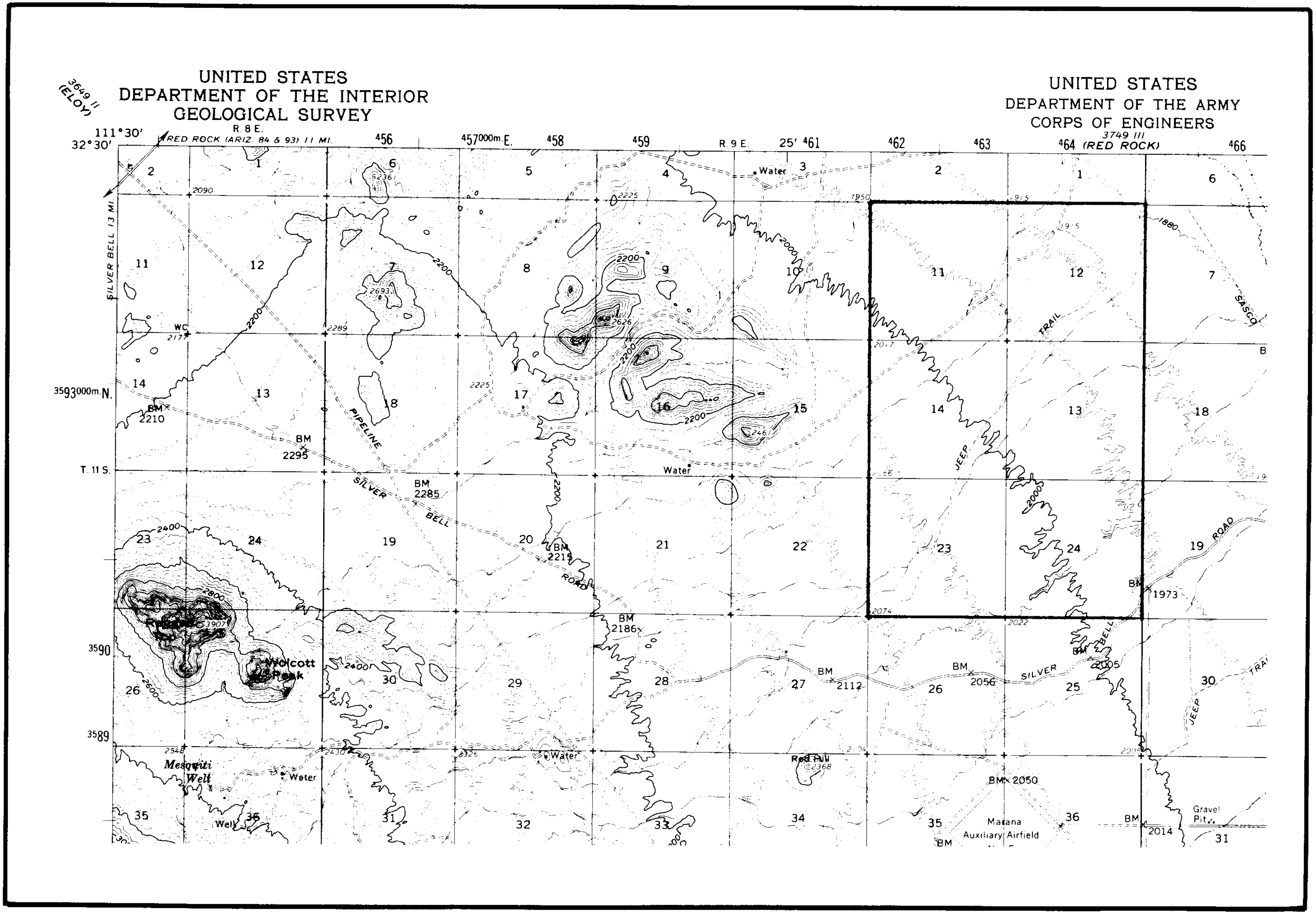

FIGURE 1: A segment of the Silverbell Peak, Arizona, 1959 Quadrangle (15 minute series, contour interval 40 feet) illustrating the six square mile area used for this experiment. Range 9 East, Township 11 South, Sections 11, 12, 13, 14, 23, and 24 outlined in black.

FIGURE 2: Typical Sonoran desert vegetation within the test area.

Description of Victims.

In every experiment the particular position of each of the victims was determined randomly (by a random number generator). It was felt that the victim's location and behavior might have a bearing on his/her being found. Typically a victim might be out in the open or under cover, and, furthermore, the victim might be passive (simulating an unconscious or dead person) or active (simulating a conscious person trying to attract attention by waving, etc.). Of these four possible combinations it seemed that a victim who was unconscious and under cover would be the most difficult to detect, while a victim attracting attention in the open would be the easiest. In view of the fact that in practice the figures obtained from these experiments would be used to decide when to STOP the multiple searching of an area, it was important that the figures obtained should be on the conservative side. Consequently, five out of six experiments performed were devoted entirely to victims who were both unconscious and under cover. The remaining experiment dealt with what was (and is) thought to be the other extreme, victims attracting attention in the open. [In fact, all 8 of the victims were found in this latter experiment, which reinforced the opinion that to be conservative the tables should be derived exclusively from the least favorable situation, viz. the results of the remaining five experiments].

In all experiments victims were asked to wear "everyday" clothing (which ranged from white T-shirts and blue jeans to brown and green checked shirts and khaki trousers) and were not permitted to wear clothing with large areas of orange or bright yellow (thought to be highly visible). The use of any signalling device (e.g. mirror) was prohibited. Finally if a victim's assignment involved being under cover, he/she was instructed not to try to hide, merely to seek cover.

Description of Searchers and Search Pattern.

The particular helicopters used in this experiment were Bell Helicopters Type HH-lH (Iriquois), widely known as "Hueys", crewed by members of Detachment 1, 37th Aerospace Rescue and Recovery Squadron, United States Air Force, stationed at Davis Monthan Air Force Base, Tucson, Arizona[2]. (See figure 3).

A typical crew consisted of a pilot (who devoted his full attention to flying and maintaining the search pattern) and a copilot together with from two to four scanners. The scanners were located midway on each side of the aircraft and would scan at right angles to its flight path, through large open cargo doors. Under extreme adverse weather conditions these doors might be closed. (See figure 3).

Typically a single helicopter would arrive in the test area where the search manager would advise the pilot of the search boundaries. The helicopter would then commence a "creeping line search" (i.e. the helicopter would fly a non-overlapping back and forth pattern moving deeper into the search area with each successive leg until the entire six square miles had been scanned once - called a "single pass"), see figure 5. The speed, altitude, and spacing between the creeping lines were decided on by each helicopter crew. (The average speed was about 60 knots, the altitude 175 feet, and the track spacing 1/4 mile).

The crew were not advised of the number of victims in the search area, nor were they advised whether to expect the victims to be in the open, under cover, attracting attention, or simulating unconsciousness.

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[2] The primary mission of Det. 1 37th A.R.R.S. is to provide helicopter support for the 390th Strategic Missle Wing (SAC) located at Davis-Monthan Air Force Base in Tucson, Arizona. This Detachment is equipped and trained for air search and rescue and provides SAR support for military and civilian agencies within approximately a 100 mile radius of Tucson, Arizona.

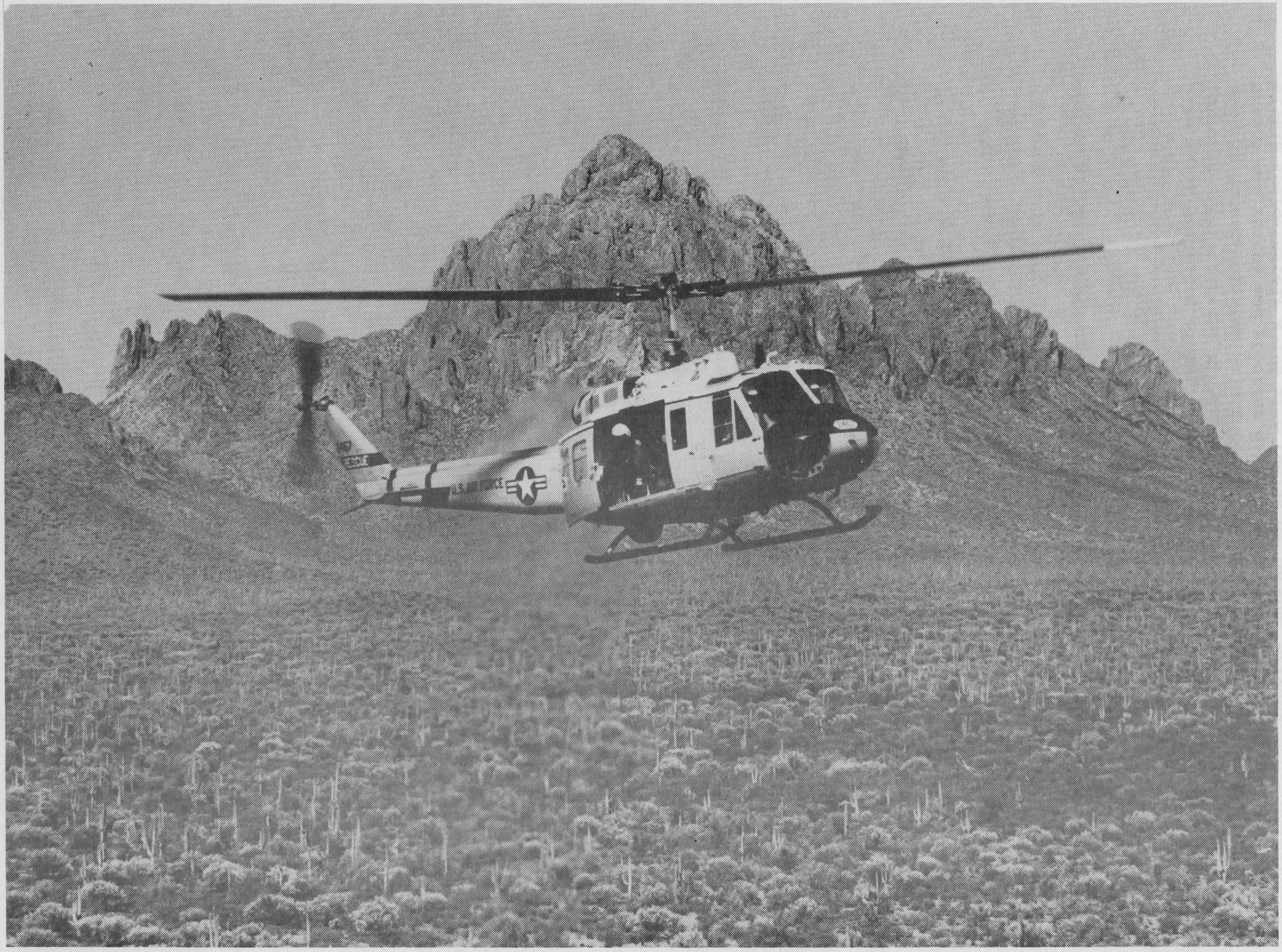
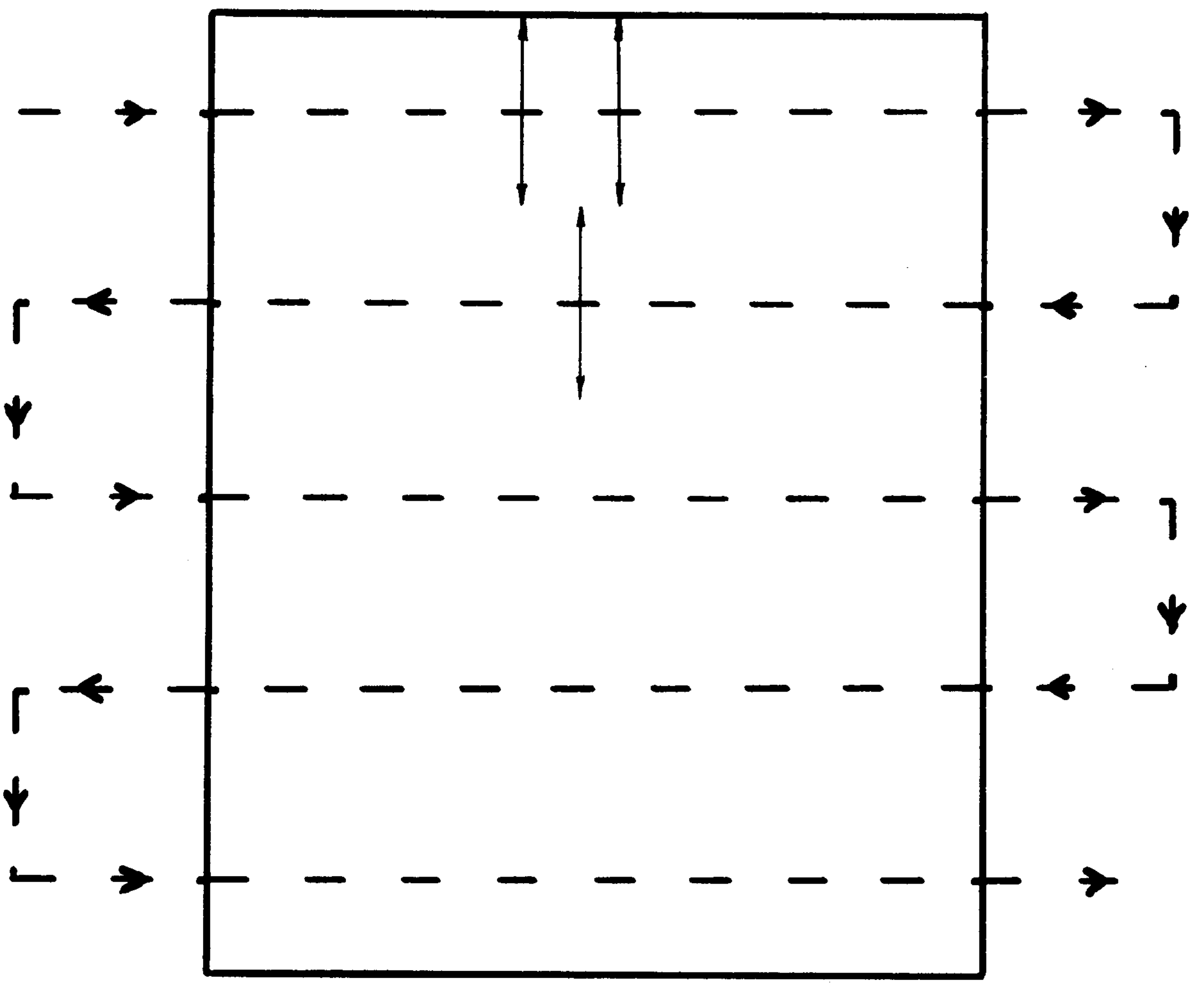


FIGURE 3: An air rescue crew of Detachment 1 37th Aerospace Rescue and Recovery Squadron searching the desert area east of Ragged Top Peak. Note the scanner's superior visibility through the open cargo door.

FIGURE 4: A victim attracting attention of the Air Search crew. All eight victims attracting attention were found in this experiment.

FIGURE 5

BASIC "CREEPING LINE" SEARCH PATTERN



———— denotes the boundary of the search area.

— — — denotes the flight path of the helicopter. The distance between successive horizontal lines is the "track spacing".

—+— denotes the extent that scanners search on either side of the flight path.

NOTE: The actual number of legs flown will depend on the size of the search area together with the track spacing.

Description of a Find.

If a victim was located the scanners in the helicopter would shine a highly visible light on the victim. When the victim was absolutely certain he/she had been found (occasionally victims were about 100 yards apart), that victim would don a bright orange vest, which, until then, had been kept concealed. The crew would then disregard anyone in an orange vest and continue searching.

At the conclusion of each experiment both the crew and the victims were debriefed.

NUMERICAL RESULTS

Actual Results of the Experiments

As mentioned earlier, all victims who were assigned to move about in the open and attempt to attract attention, were found. These numbers were NOT used in the calculation of the probabilities of detection tables because of the desire to obtain conservative results.

ALL COMMENTS AND CALCULATIONS WHICH FOLLOW ARE RELATED TO THE EXTREME SITUATION OF VICTIMS UNDER COVER AND SIMULATING UNCONSCIOUSNESS. Data were collected from 5 separate experiments of this type, 3 performed on bright, sunny days, and 2 performed on overcast days. These data suggested that there might be an important distinction between the results obtained for bright, sunny days and the corresponding results for overcast conditions. This difference was confirmed statistically with over 98% confidence (see Appendix) in an objective fashion, and visually in a subjective manner (see figures 6,7,8).

On bright, sunny days 7 out of a possible 24 victims were found.

On overcast days 11 out of a possible 16 victims were found.

FIGURE 6: Victim in a prone position beneath a Palo Verde tree on a CLOUDY day. This unretouched photograph was taken from a normal search altitude. (Compare with Figure 7.)

FIGURE 7: Victim in a prone position beneath a Palo Verde tree on a SUNNY day. This unretouched photograph was taken from a normal search altitude. (Victim's position is pin pointed in Figure 8).

Probability of Detection for Given Confidence Levels.

On the basis of experimental results and the statistical analysis described in the Appendix, the following SINGLE PASS POD confidence intervals were determined for victims who were under cover and simulating unconsciousness.

TABLE 1

Experimental Data: Confidence Intervals for Single Pass POD BRIGHT, SUNNY CONDITIONS

	Confidence Level										
	.40	.50	.60	.70	.75	.80	.85	.90	.95	.99	.999
Single Pass POD											
is at least	.229	.216	.203	.188	.180	.170	.159	.146	.126	.093	.063
is at most	.366	.380	.397	.417	.428	.442	.458	.479	.511	.573	.643

TABLE 2

Experimental Data: Confidence Intervals for Single Pass POD CLOUDY, SUBDUED LIGHT CONDITIONS

	Confidence Level										
	.40	.50	.60	.70	.75	.80	.85	.90	.95	.99	.999
Single Pass POD											
is at least	.590	.572	.551	.527	.513	.496	.477	.452	.413	.342	.265
is at most	.770	.785	.801	.818	.828	.839	.852	.868	.890	.925	.956

Additional Tables and Examples.

Tables 1 and 2 are experimental values for single pass PODs. The tables included here (Tables 3, 4, 5, and 6) are for use when a helicopter passes over a search area multiple times.

Tables 3 and 4 may be used to determine the range of values for the cumulative POD obtained by searching an area multiple times with a helicopter. In these tables, the column on the left is the number of times the area is searched; the row across the top is the confidence level required. Each square in the body of the table contains two numbers: the cumulative POD corresponding to the smallest and largest interval values for the single pass POD given in Table 1 or Table 2. [The cumulative POD is given by the equation

$$\text{POD(cumulative)} = 1 - (1 - p)^m,$$

where p is the single pass POD and m is the number of passes made over the area].

TABLE 3

Multiple Pass POD For BRIGHT, SUNNY CONDITIONS

No. of passes	Confidence level .40	.50	.60	.70	.75	.80	.85	.90	.95	.99	.999
1	.229	.216	.203	.188	.180	.170	.159	.146	.126	.093	.063
	.366	.380	.397	.417	.428	.442	.458	.479	.511	.573	.643
2	.406	.385	.365	.341	.328	.311	.293	.271	.236	.177	.122
	.598	.616	.636	.660	.673	.689	.706	.729	.761	.818	.873
3	.542	.518	.494	.465	.449	.428	.405	.377	.332	.254	.177
	.745	.762	.781	.802	.813	.826	.841	.859	.883	.922	.955
4	.647	.622	.597	.565	.548	.525	.500	.468	.416	.323	.229
	.838	.852	.868	.884	.893	.903	.914	.926	.943	.967	.984
5	.728	.704	.678	.647	.629	.606	.579	.546	.490	.386	.278
	.898	.908	.920	.933	.939	.946	.953	.962	.972	.986	.994
6	.790	.768	.744	.713	.696	.673	.646	.612	.554	.443	.323
	.935	.943	.952	.961	.965	.970	.975	.980	.986	.994	.998
7	.838	.818	.796	.767	.751	.729	.702	.669	.610	.495	.366
	.959	.965	.971	.977	.980	.983	.986	.990	.993	.997	.999
8	.875	.857	.837	.811	.796	.775	.750	.717	.660	.542	.406
	.974	.978	.983	.987	.989	.991	.993	.995	.997	.999	.999+
9	.904	.888	.870	.847	.832	.813	.790	.758	.702	.585	.443
	.983	.986	.989	.992	.993	.995	.996	.997	.998	.999+	.999+
10	.926	.912	.897	.875	.863	.845	.823	.794	.740	.623	.478
	.990	.992	.994	.995	.996	.997	.998	.999	.999	.999+	.999+
11	.943	.931	.918	.899	.887	.871	.851	.824	.773	.658	.511
	.993	.995	.996	.997	.998	.998	.999	.999	.999+	.999+	.999+
12	.956	.946	.934	.918	.908	.893	.875	.850	.801	.690	.542
	.996	.997	.998	.998	.999	.999	.999	.999+	.999+	.999+	.999+
13	.966	.958	.948	.933	.924	.911	.895	.871	.826	.719	.571
	.997	.998	.999	.999	.999	.999	.999+	.999+	.999+	.999+	.999+
14	.974	.967	.958	.946	.938	.926	.911	.890	.848	.745	.598
	.998	.999	.999	.999	.999+	.999+	.999+	.999+	.999+	.999+	.999+
15	.980	.974	.967	.956	.949	.939	.926	.906	.867	.769	.623
	.999	.999	.999	.999+	.999+	.999+	.999+	.999+	.999+	.999+	.999+

.999+ denotes a number greater than .999 but less than one.

TABLE 4

Multiple Pass POD For CLOUDY, SUBDUED LIGHT CONDITIONS

	Confidence level										
	.40	.50	.60	.70	.75	.80	.85	.90	.95	.99	.999
No. of passes											
1	.590 .770	.572 .785	.551 .801	.527 .818	.513 .828	.496 .839	.477 .852	.452 .868	.413 .890	.342 .925	.265 .956
2	.832 .947	.817 .954	.798 .960	.776 .967	.763 .970	.746 .974	.726 .978	.700 .983	.655 .988	.567 .994	.460 .998
3	.931 .988	.922 .990	.909 .992	.894 .994	.884 .995	.872 .996	.857 .997	.835 .998	.798 .999	.715 .999+	.603 .999+
4	.972 .997	.966 .998	.959 .998	.950 .999	.944 .999	.935 .999	.925 .999+	.910 .999+	.881 .999+	.813 .999+	.708 .999+
5	.988 .999	.986 .999+	.982 .999+	.976 .999+	.973 .999+	.967 .999+	.961 .999+	.951 .999+	.930 .999+	.877 .999+	.785 .999+
6	.995 .999+	.994 .999+	.992 .999+	.989 .999+	.987 .999+	.984 .999+	.980 .999+	.973 .999+	.959 .999+	.919 .999+	.842 .999+
7	.998 .999+	.997 .999+	.996 .999+	.995 .999+	.994 .999+	.992 .999+	.989 .999+	.985 .999+	.976 .999+	.947 .999+	.884 .999+
8	.999 .999+	.999 .999+	.998 .999+	.997 .999+	.997 .999+	.996 .999+	.994 .999+	.992 .999+	.986 .999+	.965 .999+	.915 .999+
9	.999+ .999+	.999+ .999+	.999 .999+	.999 .999+	.998 .999+	.998 .999+	.997 .999+	.996 .999+	.992 .999+	.977 .999+	.937 .999+
10	.999+ .999+	.999+ .999+	.999+ .999+	.999 .999+	.999 .999+	.999 .999+	.998 .999+	.998 .999+	.995 .999+	.985 .999+	.954 .999+
11	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999 .999+	.999 .999+	.999 .999+	.997 .999+	.990 .999+	.966 .999+
12	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999 .999+	.998 .999+	.993 .999+	.975 .999+
13	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999 .999+	.996 .999+	.982 .999+
14	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999 .999+	.997 .999+	.987 .999+
15	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.999+ .999+	.998 .999+	.990 .999+

.999+ denotes a number greater than .999 but less than one.

Example 1. On an overcast day, a helicopter of the type described in this report searches an area 3 times. What is the range of values for the cumulative probability of detection (POD) at a confidence level of .75?

Answer. Using Table 4 (overcast day), the confidence level of .75 is found in the top row. The number of passes (3) is found in the column on the left, and from the body of the table it is seen that the cumulative POD is at least .884 but not more than .995. In other words, one is sure at the 75% confidence level that the area has been covered with a cumulative probability of detection of at least 88.4% but not more than 99.5%.

Tables 5 and 6 may be used to determine how many passes must be made over an area in order to obtain a cumulative POD of at least a desired level. In addition, these tables contain factors in parentheses which, when multiplied by the total size of the search area (in square miles) will yield the approximate number of helicopter hours needed to accomplish a desired cumulative POD. This number is based on a "creeping line" pattern which covers one square mile in 9 minutes.

In Tables 5 and 6, the column on the left is the cumulative POD desired and the row across the top is the confidence level required. The body of the tables consists of squares which contain two numbers, one of which is in parentheses. The number which is not in parentheses is the number of helicopter passes over the search area needed to achieve a cumulative POD of at least the value given in the column at the left. The number in parentheses is the factor by which the total area (in square miles) is multiplied in order to yield the number of helicopter hours needed to produce such a cumulative POD.

TABLE 5

Number of Helicopter Passes and Helicopter Hours
Required to Achieve Given POD for BRIGHT, SUNNY CONDITIONS.

For POD of at least	Confidence level .40	.50	.60	.70	.75	.80	.85	.90	.95	.99	.999
.50	3 (0.3)	3 (0.3)	4 (0.4)	4 (0.4)	4 (0.4)	4 (0.4)	4 (0.4)	5 (0.6)	6 (0.7)	8 (0.9)	11 (1.2)
.60	4 (0.4)	4 (0.4)	5 (0.6)	5 (0.6)	5 (0.6)	5 (0.6)	6 (0.7)	6 (0.7)	7 (0.8)	10 (1.1)	15 (1.7)
.70	5 (0.6)	5 (0.6)	6 (0.7)	6 (0.7)	7 (0.8)	7 (0.8)	7 (0.8)	8 (0.9)	9 (1.0)	13 (1.4)	19 (2.1)
.75	6 (0.7)	6 (0.7)	7 (0.8)	7 (0.8)	7 (0.8)	8 (0.9)	8 (0.9)	9 (1.0)	11 (1.2)	15 (1.7)	22 (2.4)
.80	7 (0.8)	7 (0.8)	8 (0.9)	8 (0.9)	9 (1.0)	9 (1.0)	10 (1.1)	11 (1.2)	12 (1.3)	17 (1.9)	25 (2.8)
.85	8 (0.9)	8 (0.9)	9 (1.0)	10 (1.1)	10 (1.1)	11 (1.2)	11 (1.2)	12 (1.3)	15 (1.7)	20 (2.2)	30 (3.3)
.90	9 (1.0)	10 (1.1)	11 (1.2)	12 (1.3)	12 (1.3)	13 (1.4)	14 (1.6)	15 (1.7)	18 (2.0)	24 (2.7)	36 (4.0)
.95	12 (1.3)	13 (1.4)	14 (1.6)	15 (1.7)	16 (1.8)	17 (1.9)	18 (2.0)	19 (2.1)	23 (2.6)	31 (3.4)	46 (5.1)
.99	18 (2.0)	19 (2.1)	21 (2.3)	23 (2.6)	24 (2.7)	25 (2.8)	27 (3.0)	30 (3.3)	35 (3.9)	48 (5.3)	71 (7.9)
.999	27 (3.0)	29 (3.2)	31 (3.4)	34 (3.8)	35 (3.9)	38 (4.2)	40 (4.4)	44 (4.9)	52 (5.8)	71 (7.9)	107 (11.9)

TABLE 6

Number of Helicopter Passes and Helicopter Hours
Required to Achieve Given POD for CLOUDY, SUBDUED LIGHT.

For POD of at least	Confidence level .40	.50	.60	.70	.75	.80	.85	.90	.95	.99	.999
.50	1 (0.1)	1 (0.1)	1 (0.1)	1 (0.1)	1 (0.1)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	3 (0.3)
.60	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	3 (0.3)	3 (0.3)
.70	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	3 (0.3)	3 (0.3)	4 (0.4)
.75	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	2 (0.2)	3 (0.3)	3 (0.3)	3 (0.3)	3 (0.3)	4 (0.4)	5 (0.6)
.80	2 (0.2)	2 (0.2)	3 (0.3)	3 (0.3)	3 (0.3)	3 (0.3)	3 (0.3)	3 (0.3)	4 (0.4)	4 (0.4)	6 (0.7)
.85	3 (0.3)	3 (0.3)	3 (0.3)	3 (0.3)	3 (0.3)	3 (0.3)	3 (0.3)	4 (0.4)	4 (0.4)	5 (0.6)	7 (0.8)
.90	3 (0.3)	3 (0.3)	3 (0.3)	4 (0.4)	4 (0.4)	4 (0.4)	4 (0.4)	4 (0.4)	5 (0.6)	6 (0.7)	8 (0.9)
.95	4 (0.4)	4 (0.4)	4 (0.4)	4 (0.4)	5 (0.6)	5 (0.6)	5 (0.6)	5 (0.6)	6 (0.7)	8 (0.9)	10 (1.1)
.99	6 (0.7)	6 (0.7)	6 (0.7)	7 (0.8)	7 (0.8)	7 (0.8)	8 (0.9)	8 (0.9)	9 (1.0)	11 (1.2)	15 (1.7)
.999	8 (0.9)	8 (0.9)	9 (1.0)	9 (1.0)	10 (1.1)	10 (1.1)	11 (1.2)	11 (1.2)	13 (1.4)	17 (1.9)	23 (2.6)

Example 2. It is bright and sunny, and the search area is 15 square miles. How many passes of the helicopter and how many helicopter hours will be required to achieve a cumulative probability of detection (POD) of at least .7 with a confidence level of .85?

Answer. From Table 5 (bright, sunny) the confidence level (.85) is found along the top row and the cumulative POD of at least .7 is found in the left most column. From the table it is seen that 7 passes of the helicopter are needed. To determine the approximate number of helicopter hours required, the number in parentheses (0.8) is multiplied by the size of the search area (15 square miles): $(0.8) \times (15) = 12$ hours.

DISCUSSION

Aerial photographs were taken to demonstrate the conditions encountered by air search teams on sunny and cloudy days (with victims under cover and immobile), see figures 6,7,8. These photographs clearly illustrate how significant the difference is between these contrasting conditions. In fact, the photographer (who knew the location of the victim) experienced notable difficulty in spotting the subject on sunny days. He had no such difficulty on cloudy days.

It is evident that lighting conditions influence the effectiveness of air search teams. The harsh contrast of dark shadows with bright, reflecting open areas makes it difficult for scanners to adjust their vision for simultaneous searching in both lighting extremes. Also when the sun is low on the horizon shadows are longer and scanners commonly have to cope with looking into bright sunlight. These observations indicate that searchers may be most successful on overcast days with high levels of light but minimum contrast, or just

FIGURE 8: Yes, Virginia, there really is a victim here!

before sunrise or just after sunset on bright, sunny days. As the level of light decreases to darkness search effectiveness will also decrease.

Regardless of cloud cover it was exceptionally difficult to detect victims on the opposite side of bushy vegetation. This difficulty would presumably increase with distance from the aircraft. Immobile victims in the open were easier to detect than those under cover, and detectability increased dramatically with added motion.

The scanners noted that sitting victims were generally more difficult to detect than those lying in a prone position. This may be because the sitting victim exposes less surface area to the scanner.

It was found that scanners have difficulty in anticipating the relative size the victim will appear to be in the search area. Many scanners commented that at the onset of a search they were looking for something much smaller than the victim subsequently turned out to be. They stated that it would be helpful to provide a visual size reference at the beginning of a search mission to aid them.

Natural features within the search area have the potential of reducing scanner effectiveness. For example white flowers, the light crown of cholla and saguaro cactus, reflections from puddles, and moving wildlife are among the many desert inhabitants that could, for an instant, distract the scanners from their objective. Although the distractions require brief examination by the scanner to confirm their insignificance, such brief inspections may disrupt the scanner's normal searching procedure, and the victim could easily be passed over during this period.

Contemporary search theory is that hasty, non-thorough search methods are among the most profitable tactics at the onset of the search mission. Air crews participating in this experiment believe that it is a sound procedure to initiate the air search at a high altitude and air speed in order to scan the entire area with close attention to natural attractions and obvious routes of travel. This enables the team to quickly find the easily detectable victim or clues. More thorough methods involving lower altitudes and air speeds can follow the hasty search, increasing coverage in high probability areas. Furthermore, the work of Wartes [1], where it is found that "nonthorough" searching with multiple passes produces a higher probability of success per hour spent in the search, will apply to the "creeping line" search used in this experiment. Therefore, it may be more advantageous to use a broader gridded creeping line and conduct as many multiple passes as possible if there is a choice.

These experiments were conducted using a specific type of military helicopter with a full search crew. Other types of aircraft (such as smaller helicopters and fixed wing aircraft) will probably have lower detection probabilities due to decreased crew size, fewer scanners, higher speed, and poorer visibility.

During the experiment it was found that the area immediately below and slightly to the side of the helicopter is an area of reduced detectibility. In fact 8 out of the 22 victims not found stated that the helicopter flew directly overhead. (This reduced detectibility is evidently consistent with what has also been observed in maritime search applications [2]). It is felt that the effect of this area of lower detectibility could be reduced a great deal by conducting multiple passes which are perpendicular to the original path of the aircraft.

With the belief that the successful SAR manager should constantly strive to increase his/her understanding of the search resource's limitations and effectiveness, this initial survey of helicopter search effectiveness suggests that further research of this type should be conducted involving not only helicopters, but also other resources.

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APPENDICES

Appendix 1: Explanation of Terminology

The term "Probability of Detection", or POD, refers to the probability that a search team (such as a helicopter and crew) finds a victim in a given area given that the victim is in that area. Thus, the term POD, used in search terminology is a conditional probability with the conditioning event that of the victim being assumed to be in the area. This conditional probability, POD, is thus a true measure of a team's ability to detect independent of the possibility that the victim may not be in the area.

The term "Cumulative probability of detection" refers to the increased measure of detection produced by the given (or another) search team conducting multiple searches of the same given area. If p is the "single pass", or single search, probability of detection for a team such as a helicopter with scanning crew, then the cumulative probability of detection produced by two passes of that team over the same area is given by

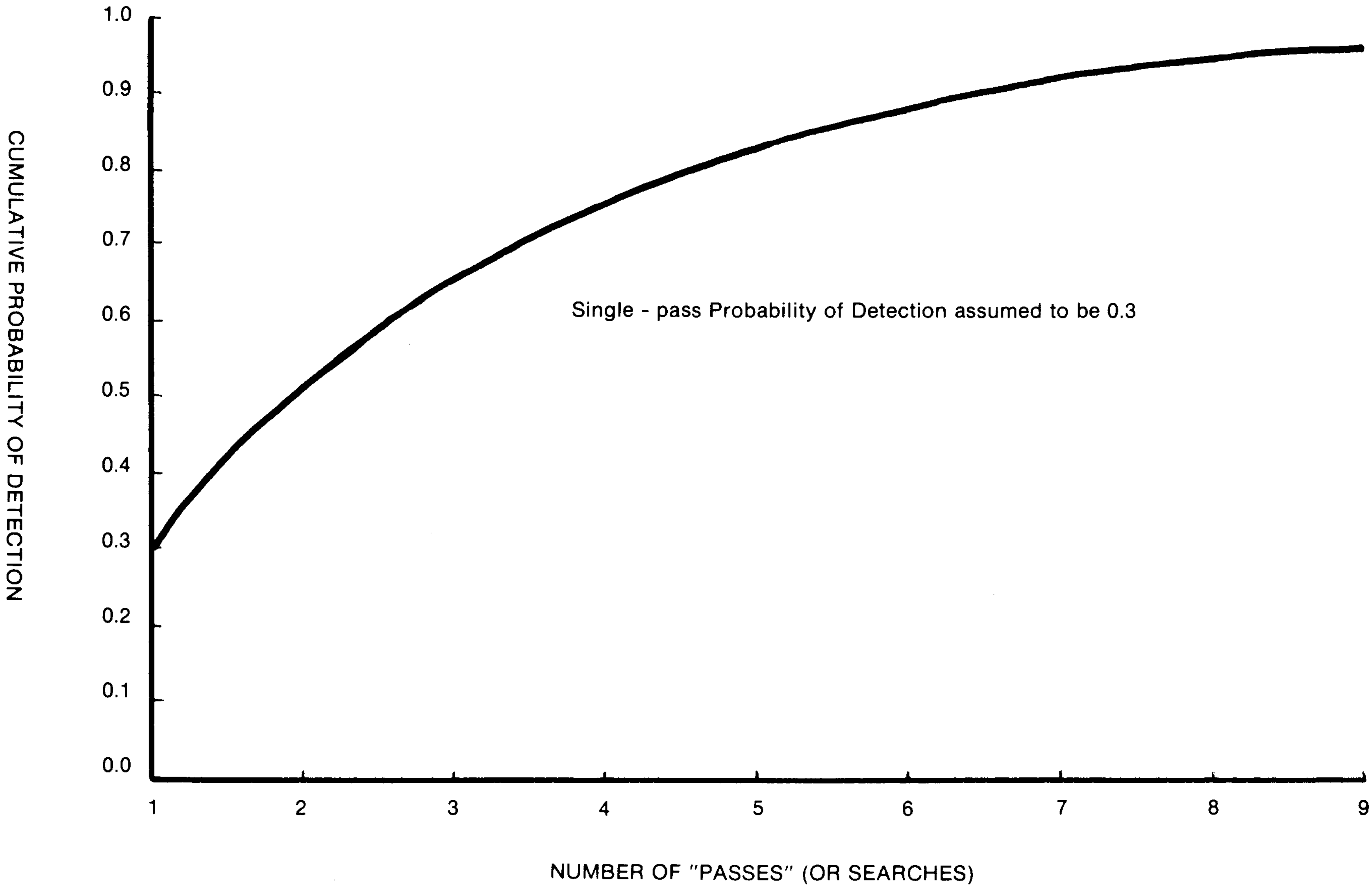
$$POD = 1-(1-p)^2.$$

If the team searches the area three times, then the cumulative probability of detection increases to

$$POD = 1-(1-p)^3,$$

and so on. The benefit of searching an area multiple times is qualitatively demonstrated by figure 9 where the single pass probability, p, is assumed to

FIGURE 9
CUMULATIVE PROBABILITY OF DETECTION
AS A FUNCTION OF NUMBER OF PASSES



be 0.3. It is typical and instructive to note that the major gain in the cumulative probability of detection occurs with the first several "passes" of the search team. The gain in cumulative POD is not as high with later passes. This fact is borne out in the numerical tables in this document.

The term "Probability of Area", or POA, refers to the probability that a victim is actually in the area being searched. Exactly how this quantity is to be determined is not the subject of this particular document. In practice, POA can be determined by using past statistical information on previous victims behavior (e.g. "50% of previous lost persons starting at this point wandered into a certain region and were found there"); however, in the absence of such organized data, the consensus estimate of a small group of experienced, knowledgable individuals can produce a distribution of POAs for principal search areas.

The term "Probability of Success", or POS, refers to the quantity that a search manager must strive to maximize. Mathematically, POS = POA × POD. That is, the probability of finding the victim equals the probability that the victim is in the area being searched multiplied by the probability that the victim can be found in that area if he/she were in the area. Again, this latter probability, the POD, is strictly a measure of effectiveness for a given team; obviously the team could be perfect, with a POD = 1.00, and yet the POS could be quite small due to the fact that the POA is small.

The term "Confidence Level" is a technical term in mathematical probability theory which essentially refers to the level of "sureness" or "confidence" that the search manager is willing to use. Unfortunately, there are only very few things in life that are certain; everything else has uncertainty associated with it. For the search manager, it would, of course, be optimum for him/her to be certain of all decisions. In particular, it would be simpler if when a helicopter crew searches a given area, the POD for that search is known to be exactly, say 0.7. Because of unavoidable uncertanties in data collection for any experiment, it is not possible to present data in this exact form.

More realistically, the search manager must use the experimental data presented in this report in the following way.

As an example, consider the experimental data supplied by table 4. The "Confidence Level" chosen may be used to assign the "confidence" one may have in using these data. Hence, one may say (see table 4) that "with one helicopter pass over the area, the probability is 0.8 that the POD for that pass lies between .496 and .839". In other words, the search manager may be 80% sure that the one helicopter pass has "covered the area" with a coverage (POD) of at least 49.6% but at most 83.9%. If the search manager uses two helicopter passes over the same area, he/she can be 80% sure that the cumulative POD (or total coverage) is at least 74.6% but not more than 97.4%. Notice that the search manager can also say that he/she is 40% sure that the cumulative POD is at least 83.2% and not more than 97.4%.

The search manager, in referring to the detailed tables found in this document, will find that it is possible to obtain a very high level of coverage (POD of less than 99.8% but more than 99.7%) with a very high confidence level (99%) if he/she has the helicopter-hours to spend on a particular area. This, of course, is rarely the case, and the proper, optimal use of helicopter time is subject to many other considerations which are not addressed here.

Appendix 2: Statistical Analysis of Experimental Data

For the data gathered above, it is seen that 7 out of 24 victims were located during bright, sunny days, while 11 out of 16 were located during overcast days. To estimate the probability of detection (POD) and to test whether these data indicate a statistically significant difference in POD between bright, sunny days and overcast days the following procedure was used.

The data gathered during bright, sunny days may be represented as 7 successes in 24 trials of a Bernoulli random variable with unknown parameter p_s. In a similar way the data gathered during overcast days may be thought of as 11 successes in 16 trials of a Bernoulli random variable with unknown parameter p_o, see [3].

The approximate 95% confidence intervals for p_s and p_o are determined such that (see [4], pp 108-117)

$$P(B(24,p_{\ell,s}) > 7) = .025$$

and

$$P(B(24,p_{u,s}) < 7) = .025 ,$$

where $P(a > b)$ is the probability that the random variable a exceeds b, and where $B(n,p)$ is a Binomial random variable with parameters n and p. The interval $(p_{\ell,s}, p_{u,s})$ is then an approximate 95% confidence interval for the unknown POD p_s. Likewise $p_{\ell,o}$ and $p_{u,o}$ are determined such that

$$P(B(16,p_{\ell,o}) > 11) = .025$$

and

$$P(B(16,p_{u,o}) < 11) = .025$$

and $(p_{\ell,o}, p_{u,o})$ represents an approximate 95% confidence interval for the POD p_o. It is noted that the endpoints of these confidence limits may be randomized to obtain exact confidence intervals.

To test whether $p_s = p_o$, the UMP (uniformly most powerful unbiased test) is used on the null hypothesis $p_s = p_o$ as described in [3], pp. 141-143. This requires the computation of

$$P\{Y \geq y | X + Y = t\} = \sum_{z=y}^{t} \binom{m}{t-z}\binom{n}{z} / \binom{m+n}{t},$$

where X and Y are independent Binomial random variables with parameters m and n, and common probability p and

$$\frac{y}{n} \geq \frac{t-y}{m} .$$

In the present case, m = 24, n = 16, y = 11, and t = 18, in which case

$$P\{Y \geq 11 | X + Y = 18\} = 0.0157,$$

see [5].

Thus the null hypothesis that $p_s = p_o$ is rejected at a level of .0157, or in everyday language, there is over 98% confidence that the difference is significant.

REFERENCES

[1] Wartes, J. : An Experimental Analysis of Grid Sweep Searching, 1974, Explorer Search and Rescue (Western Region), 790 Lucerne Dr., Sunnyvale, CA 94086.

[2] National SAR Manual, Air Force Manual 64-2, July 1, 1973, U.S. Government Printing Office, Washington, D.C.

[3] Lehmann, E. : Testing Statistical Hypotheses, 1959, John Wiley and Sons.

[4] Clopper, C. J., and Pearson, E. S. : The Use of Confidence in Fiducial Limits Illustrated in the Case of the Binomial, Biometrika, Vol. 26, pp. 108-117.

[5] Finney, D. A. : Tables for Testing Significance in a 2 x 2 Contingency Table, 1963, Cambridge University Press.