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Impact of Flying Qualities on Mission Effectiveness for Helicopter Air Combat (Vol. I)

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LIST OF ACRONYMS AND SYMBOLS

AO	Area of operations
ATGM	Anti-tank guided missile
ER	Exchange ratio
H	Scout height above ground level
HACES	Helicopter Air Combat Effectiveness Simulation
H_{HOV}	Basic hover height
ΔH_{HOV}	Height above basic hover height
ΔH_{MEAN}	Mean height variation
H_{NOE}	Basic NOE height
ΔH_{NOE}	Height above basic NOE height
MMS	Mast mounted sight
MOE	Measure of effectiveness
$N_K(R)$	Number of Red ground units (tank/BMP's, SAM, AAA) killed per mission
NOE	Nap-of-the-earth
$P_K(B)$	Probability of the Blue scout being killed per mission
t	Time from beginning of simulated scout profile
VFT	Visual free time

In order to tackle the problem it has to be broken into two parts. First, the relationship between flying qualities parameters and such effects as precision of path control, nap-of-the-earth (NOE) speed-altitude relationships and visual free time must be established; then the impact of these effects on mission effectiveness must be assessed. This program concentrated on the latter task, using the unit action Helicopter Air Combat Effectiveness Simulation, HACES, to introduce the important non-flying qualities factors into the problem. Specifically, HACES is a Monte Carlo simulation that has the capability to assess the effects of helicopter characteristics, numbers, tactics and weaponization on the force's ability to accomplish a specified mission against a specified threat as a function of realistic tactical factors.

This report comprises three volumes:

Volume I: Main Report

Volume II: HACES - General Description

Volume III: Description of Scenario Elements.

This primary technical volume - Volume I, describes the work performed and the results obtained. Volume II describes the Helicopter Air Combat Effectiveness Simulation, including the modifications that were incorporated into it to tailor it for this study. Volume III, a classified volume, describes various aspects of the scenarios that supplements the information presented in Section 2 of this volume.

Section 2 of this volume describes the mission, tactics, scenarios, and measures of effectiveness used to assess the impact of the flying qualities effects considered in this study. Section 3 describes the specific flying qualities parameters investigated, how they are manifested, and how they were implemented into the HACES. Section 4 presents the results and an analysis of them. Finally, Section 5 presents the conclusions and recommendations emanating out of the study.

Appendix A describes the specific modifications that were made to the HACES to tailor it to this study. Appendix B presents a set of detection statistics since it is the detection statistics that, probably more than any other factor, drives the problem. Finally, Appendix C presents an example of how to relate flying qualities parameters to task performance (flight path control, etc.) and then relate their effects to mission effectiveness; hence how to directly relate flying qualities parameters to mission effectiveness.

SECTION 1
INTRODUCTION

This report has been prepared in fulfillment of Contract No. NAS-2-11178 with the Aeromechanics Laboratory, U.S. Army Research and Technology Laboratories of the U.S. Army Aviation Research and Development Command, to assess the impact of flying qualities on mission effectiveness. The objective of the study was to directly relate the effects of:

a. precision of flight path control
b. control power, and
c. pilot workload

on the ability of a single Scout helicopter, or helicopter team, to successfully accomplish a specified anti-armor mission.

In order to realistically determine the effects of helicopter stability and control factors on the ability to perform specific tasks, well structured programs using man-in-the-loop simulators are required. However, to realistically assess mission effectiveness, many factors in addition to flying qualities must be considered. These factors include:

a. the scenario, which comprises force size and composition, terrain, available cover, targets, surface defenses and mission
b. helicopter performance, survivability systems, fire control systems and weapons
c. detectability parameters such as helicopter size, contrast, motion, tactics, sensors, weather and time available for the crew to search.

Because there are so many factors, and because there are so many interactions between them, no particular factor or aspect of the total scenario can be modeled in great detail. Specifically, to use a very high fidelity model of a helicopter, including its flight control system and pilot dynamics, would result in a large and complex computer simulation that would be difficult to develop and expensive to run. Thus, there is a real problem in directly relating specific helicopter stability and control characteristics, or flying qualities suitability for specific tasks, to overall mission effectiveness. Yet such relationships should be established to assist flying qualities specialists in defining proper criteria.

SECTION 2

MISSION, SCENARIOS AND MEASURES OF EFFECTIVENESS

2.1 GENERAL SCENARIO

The mission of the Blue Force is to attack the Advance Guard of a Motorized Rifle Division moving through the Fulda Gap area of Central Europe. The Blue Force, which comprises Scout and Attack helicopter, has as primary targets the tanks and BMPs which are defended by armed helicopters, SAMs and AAA. All helicopters, weapons, sensors, and threat defenses are compatible with a near future time frame and are described in Volume III.

The scenario is based on the following principles which are to:

a. Be realistic, but not overly complex - a unit action

b. Analyze a stressful combat engagement that demands full helicopter capability for mission accomplishment

c. Employ realistic, but simple, tactics

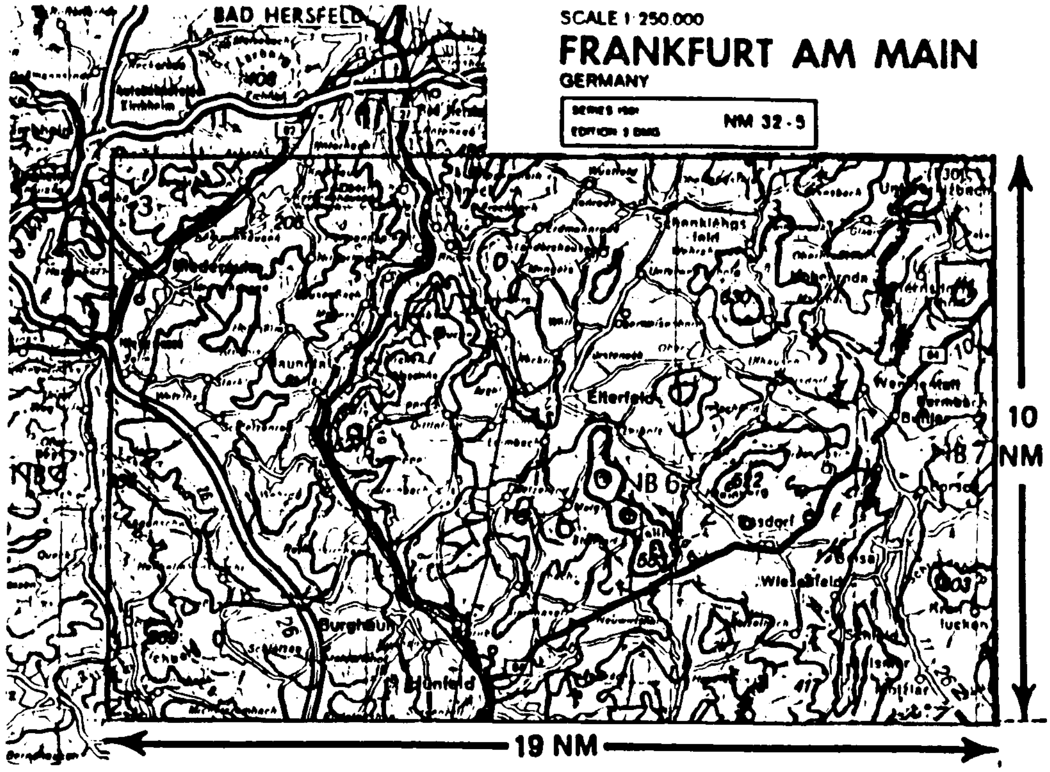
d. Fly the mission to a point where the impact of all flying qualities parameters will be manifested and practical measures of effectiveness can be obtained, then terminate.

e. Ensure that the driving factors of nap-of-the-earth (NOE) flight and hover capability, ability to detect, susceptibility to detection and fire, and the ability to effectively employ air-to-ground and air-to-air weapons are accounted for.

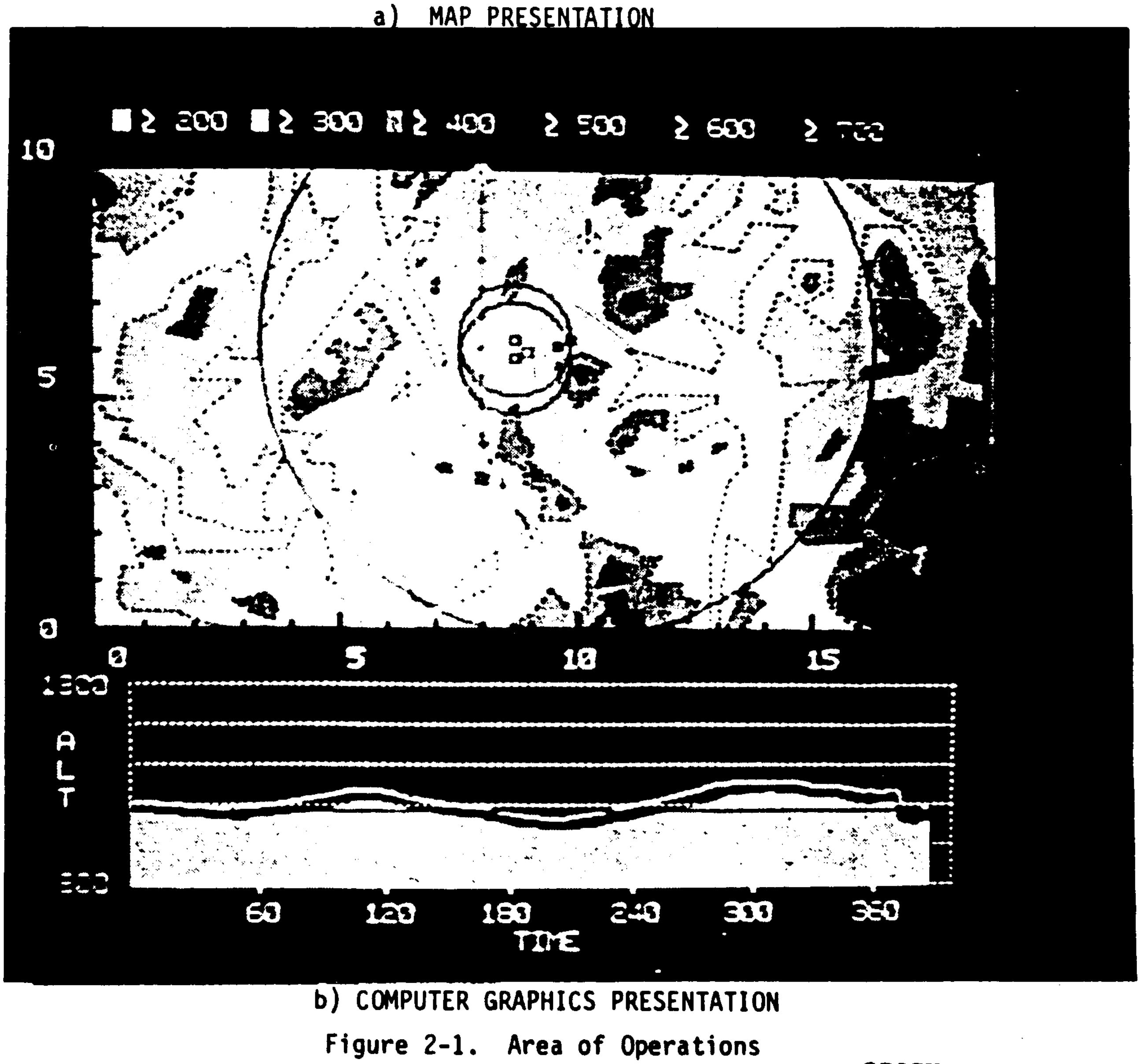
The area of operations is located just north of the town of Fulda, and south of Bad Hersfeld, as indicated in Figure 2-1a. Figure 2-1b highlights the topography, including a typical cross section, of the area as modeled in the HACES simulation.

The Advance Guard of the Motorized Rifle Division, comprises tanks, BMPs, BRDMs, self-propelled artillery and trucks, moving generally west through the area. The column has organic AAA and SAM. Armed helicopters are in support. Figure 2-2 depicts the organization of this force.

The tactics simulated is for the Blue Force to first move the Scouts to a position where they can observe the advance force, then have the Scouts call up and direct the fires of the Attack helicopters against the armour (tanks and BMPs).



a) MAP PRESENTATION



b) COMPUTER GRAPHICS PRESENTATION

Figure 2-1. Area of Operations

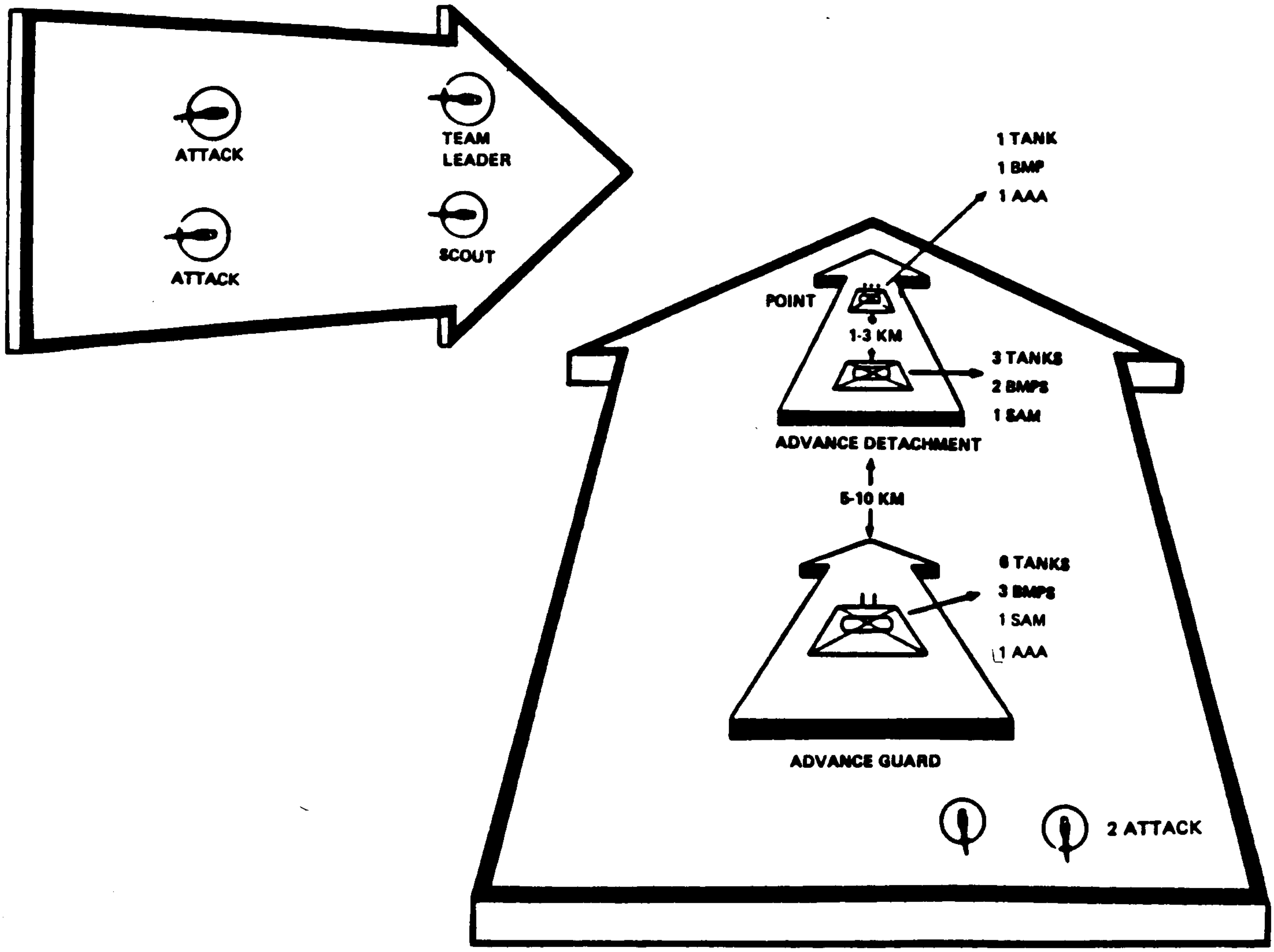


Figure 2-2. Organization of Forces

2.2 SPECIFIC SCENARIOS

The following three scenarios were simulated:

a. Scenario 1: The Advance Guard of a Motorized Rifle Division were moving along arterial highways to the north-northwest extending a distance of approximately ten kilometers at a rate of advance of approximately 40 Km/hr. The Blue helicopter force, comprising two Scouts and two Attack helicopters, working in sections, approached the area of operations from the south-southwest in NOE flight to surveillance positions behind the two prominent hill masses. Figure 2-3 shows the disposition of forces. Atmospheric conditions were representative of a dull hazy day with 5 KM visibility.

b. Scenario 2: The composition of forces is the same as Scenario 1, however, the entire Advance Guard had rounded the hills south of Eiterfeld and were proceeding west-southwest toward Steinbach at a rate of advance of approximately 40 Km/hr. In this scenario, the Blue helicopters attacked from the north-west and had to cross approximately four kilometers of relatively flat terrain to reach good observation points. These observation points were within ATGM range of the Advance Guard. The location of all threat elements, and the tracks flown by the Blue helicopters are presented in Figure 2-4. Atmospheric conditions were as for Scenario 1.

c. Scenario 3: The locale is the same as Scenario 2, however, the Advance Guard and Blue helicopter were reduced in numbers. The Blue force comprised one Scout and one Attack helicopter, while the Red force comprised five tanks/BMPs defended by one SAM, one AAA and one armed helicopter. The location of all threat elements, and the track flown by the Scout are presented in Figure 2-5. Atmospheric conditions were representative of those late on a dull hazy day, with 5 KM visibility.

The study employed these three scenarios to determine the effect of flying qualities on mission effectiveness with representative size units when attacking under ideal conditions (Scenario 1), to determine the effect of flying qualities on mission effectiveness with representative size units when attacking under more difficult conditions (Scenario 2), and to determine the effect of flying qualities on mission effectiveness when attacking under difficult conditions with a small number of units (Scenario 3). Reducing the number of units reduced the number of interactions, hence giving a less complex picture of the relationship between flying qualities and mission effectiveness.

2.3 CONCEPT OF OPERATIONS

The Blue force simulated one or two sections of Scout and Attack helicopters working in concert as described above. The Scouts performed the surveillance function of searching the area of operations, detecting targets,

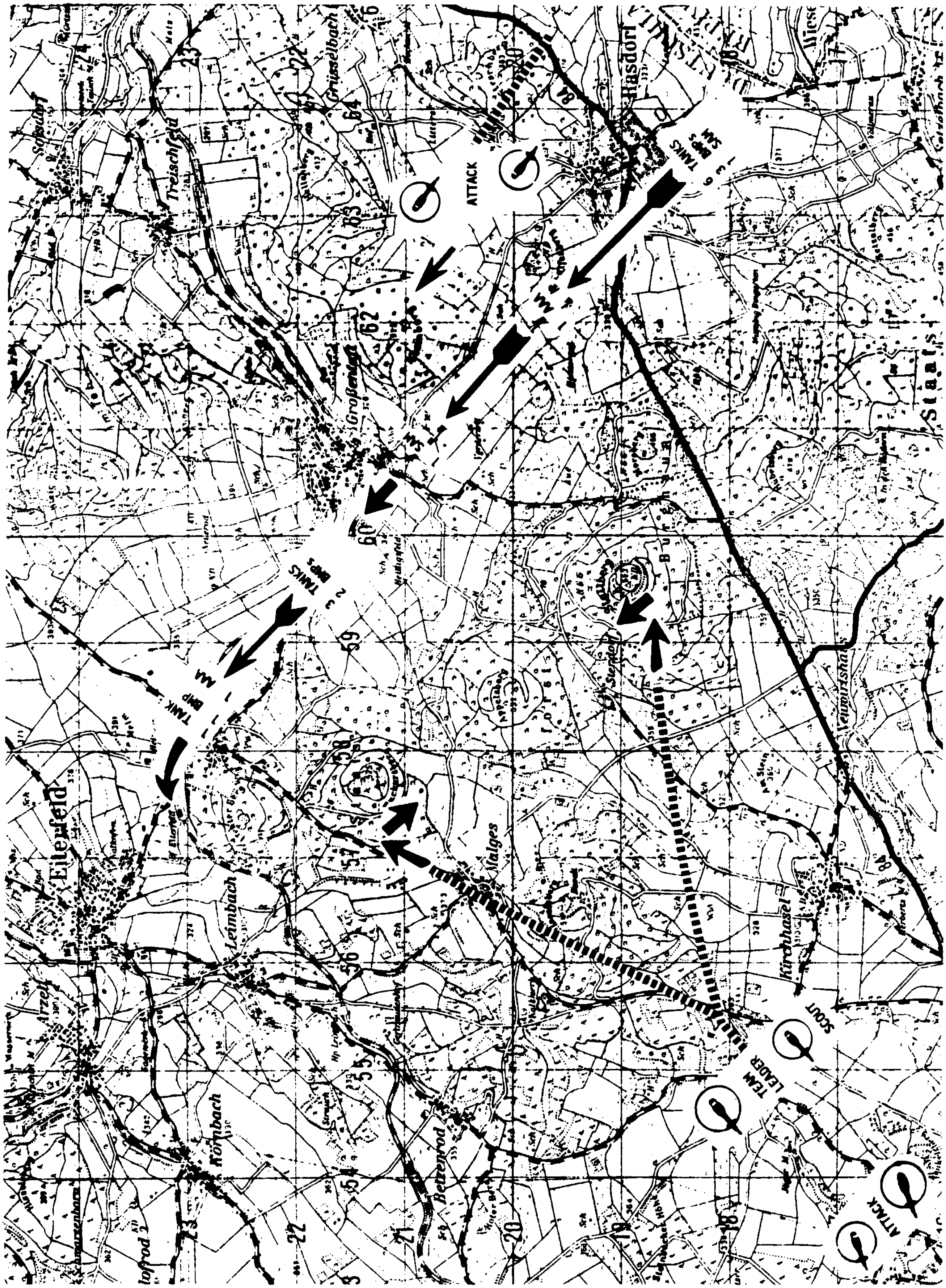


Figure 2-3. Disposition of Forces - Scenario 1

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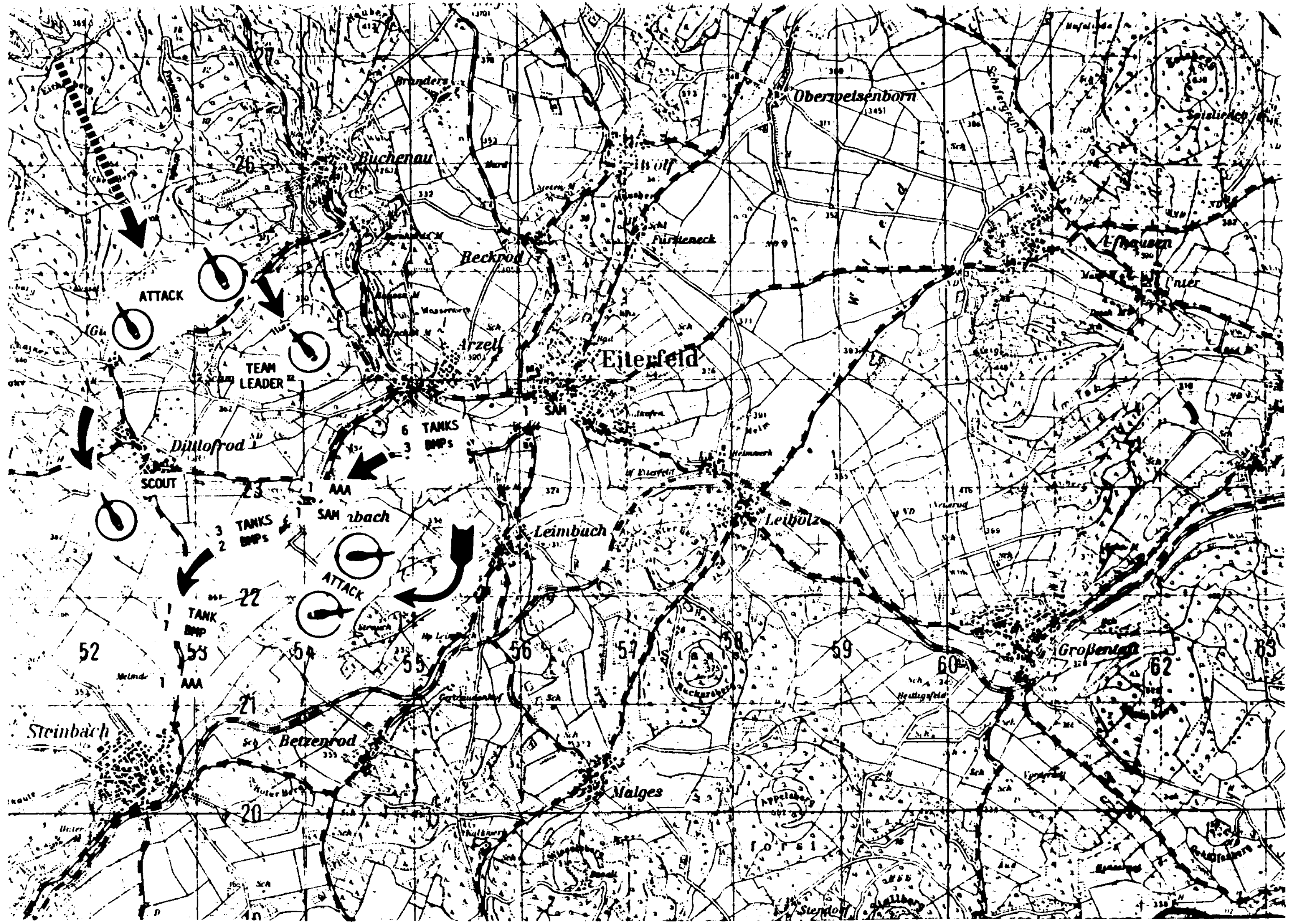

Figure 2-4. Disposition of Forces - Scenario 2

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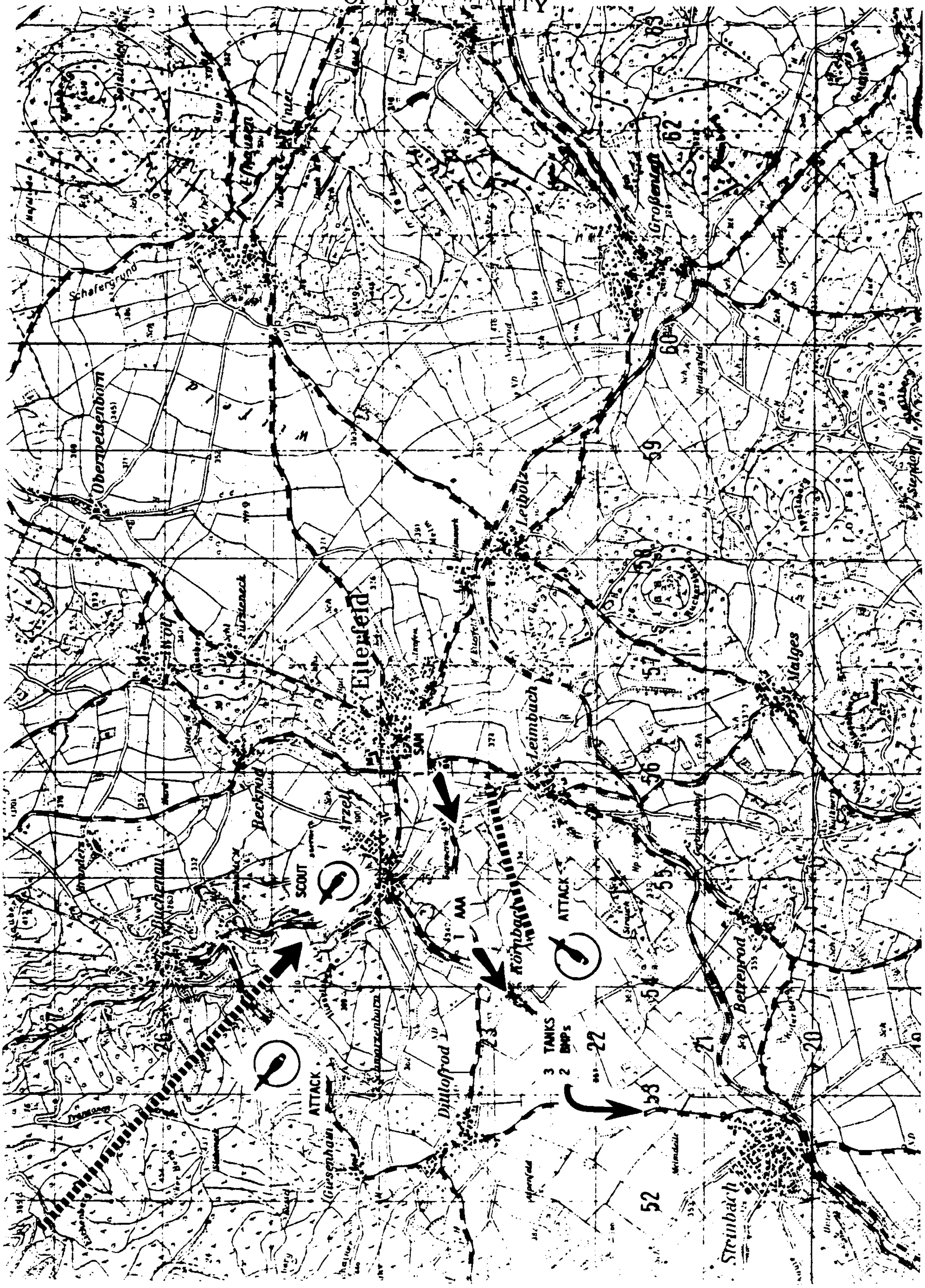


Figure 2-5. Disposition of Forces - Scenario 3

designating targets and directing the fires of the Attack helicopter(s). The purpose of the study was centered about the Scout's ability to perform these tasks as a function of its flying qualities. It was assumed that the Attack helicopter(s) could remain well hidden throughout the mission, and respond to indirect fire commands from the Scout(s). The attack helicopters were therefore not simulated for observation, just for firepower effects.

Figure 2-6 presents a nominal mission profile which allows for low level, contour and NOE flight near the area of operations (AO). Since this study was scoped to investigate the effect of flying qualities near the area of operations, only the NOE and hover (in the area of operations) portions of such a mission were simulated. Nap-of-the-earth (NOE) flight, which is appropriate for the mission simulated, is defined as flight as close to the earth's surface as vegetation or obstacles will permit, while generally following contours of the earth. Airspeed and altitude are varied as influenced by the terrain, weather, and enemy situaton. The pilot preplans a broad corridor of operation, based upon known terrain features, which has a longitudinal axis pointing toward his objective. In flight, the pilot uses a weaving and devious route within his pre-planned corridor while remaining oriented along his general axis of movement in order to take maximum advantage of the cover and concealment afforded by the terrain, vegetation, and man-made features. By gaining maximum cover and concealment from enemy detection, observation, and firepower, NOE flight exploits surprise and allows for evasive action and avoidance of threat weapons systems.

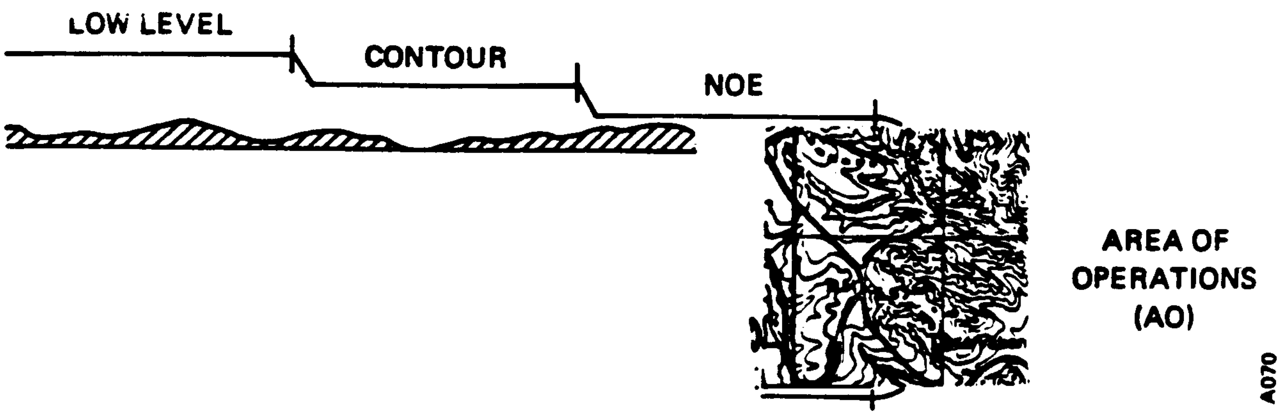


Figure 2-6. Nominal Mission Profile

The simulations commenced at a point where there was a finite probability of being detected and each evaluation (run) ended when one of the following conditions were met:

a. the Scouts reached their observation points and had hovered there for two minutes
b. the Attack helicopters fired all ten of their anti-tank missiles (ATGMs)
c. all tanks and BMPs were destroyed
d. the Scouts were killed.

The specific rules of engagements were as follows:

a. The Scouts flew contour to the points where they emerged from behind masking terrain then flew NOE to their observation points.
b. The Scouts were subject to visual detection by the Red helicopters, and to radar detection by the SAM and AAA units. If detected by the SAMs or AAA, they were fired upon when within range. If detected by the Red helicopters, the Red helicopters attacked and fired their two air-to-air missiles.
c. Although detection statistics were computed for the tanks/BMPs vs the Scout(s), they were not employed in the engagement logic to have the tanks take cover, fire upon the Scout(s) or to relay a detection to the defensive units.
d. The Scouts could only be engaged by the SAMs, AAA and armed helicopters. While there was inter-unit communications between the ground defense elements (SAMs and AAA), no communication between helicopters and ground units was simulated. Communication between the SAM and AAA units was simulated through a command and control structure in which all targets are prioritized and assigned to specific units according to prioritization. Communication between the helicopters was simulated by logic which increased the probability of all helicopters in a team making a detection if one of the team members makes a detection. Specifically, it is assumed that the other team members will be told where to look.
e. In Scenarios 1 and 2, four SAM and four AAA units were actually considered to be in the force, moving in a leap-frogging manner, with only two units of each in position to fire at any given time.

f. The Blue attack helicopters maneuvered and positioned themselves for attack in such a manner that they were not subject to detection.

g. When a Scout reached its observation point, it designated any targets detected to permit indirect fire from its accompanying Attack helicopter. Twenty seconds was allocated to designate and perform all indirect fire control functions.

h. Each Scout continued to search for targets and direct fire from its observation point for two minutes.

i. The Scouts were subject to both air-to-air and surface-to-air fire at all times without firing back (unarmed) or taking evasive action (avoid breaking lock).

j. If a Scout was killed, all the missiles associated with the accompanying Attack helicopter were considered lost, including those in flight at the time the Scout was killed.

k. The Attack helicopters carried 10 ATGMs.

l. Although the tanks and BMPs were the primary targets, the SAM and AAA units were attacked first to suppress the defenses.

m. The Blue and Red air team detection logic was such that if one member of a team detected an opponent, the probability of the other team member making a detection was increased by a factor of two. This was to simulate the detecting unit passing the information on to the other team member.

The probability of avoiding detection, hence probability of survival, was directly related to the ability to fly close to the ground while approaching the observation point and in being able to hover precisely while at the observation point.

2.4 MEASURES OF EFFECTIVENESS

Several measures of effectiveness were used in analyzing the data. The basic ones, relating directly to mission effectiveness, were:

a. probability of the Scout(s) getting killed/surviving

b. number of enemy vehicles killed including tanks, BMPs, AAA and SAMs

c. exchange ratio: number of vehicles killed divided by the number of Scouts killed

Kills were computed by drawing a random number against a probability of kill from either a missile or a burst of AAA fire. For example, if a burst of AAA fire resulted in a probability of kill (based on range, vulnerable area, target maneuvers) of 0.2, a random number between 0 and 1.0 was drawn against that number. If the number drawn was 0.2 or less, the unit was killed and removed from the problem. If the number drawn was greater than 0.2, the unit survived and was subject to further fire.

Although in all cases the trends were as expected, under some conditions the effects were not very pronounced or were very non-linear. To obtain insight into such phenomena, some basic detection statistics were also examined; specifically, the probability of detection between the following elements in Scenario 3:

a. Scout vs Red Helicopter

b. Red Helicopter vs Scout

c. Scout vs Tanks/BMPs

d. Tanks/BMPs vs Scout.

The detection of all units is a function of range, macro- and micro-terrain, target and observer height, visibility, size, contrast, scan sector, glimpse rate, motion and numbers, as described in Volume II. The specific values of each parameter pertaining to each unit are specified in Volume III. The helicopters, AAA and SAM units were considered to be sufficiently spread out that they were treated as separate units in computing detection statistics. The sixteen tanks and BMPs of Scenarios 1 and 2 were in formations of two, five and nine. Thus a formation, not a single unit, was detected. The five tanks and BMPs were considered as separate units in the very poor lighting conditions of Scenario 3.

To obtain further insight into the engagement outcomes, several intermediate measures of effectiveness were considered. These included:

a. the probability of either Scout being detected by the Red helicopters

b. the average time from the start of the problem at which the Scouts were detected by the Red helicopters

c. the probability of a Scout being killed by a Red helicopter

d. the average time (from the start of the problem) at which the Scouts were killed by the Red helicopters

e. the average time at which the Scouts were killed by any threat element (SAMs, AAA or helicopters)

f. the probability of the Scouts detecting the tanks/BMPs

g. the average time at which the Scouts detected the tanks/BMPs

h. the average number of tanks/BMPs killed.

Obviously not all of these intermediate measures of effectiveness were of significance under all conditions. Only those which clarify the impact of flying qualities on mission effectiveness have been presented.

SECTION 3

IMPACT OF FLYING QUALITIES ON FLIGHT PATH CONTROL AND PILOT WORKLOAD

3.1 OPERATIONAL CONSIDERATIONS

Two significant tasks for the Scout helicopter are surveillance (targets detected, identified and pinpointed) and directing indirect fire (designation, coordination, etc.). Flying qualities have an effect on the ability of a crew to perform both of these tasks.

For example, workload, which is a function of flying qualities, directly affects the ability to perform these tasks. Specifically, if there is less visual free time available because of poor flying qualities, the less time there will be for the surveillance function, and thus perhaps poorer mission performance. Similarly, the more difficult the helicopter is to fly, the heavier the manipulative workload, and the less free time for weapon control. Poor flying qualities can force a pilot to fly at a higher altitude with the attendant increased risk of being detected and shot down. On the other hand, a pilot may choose not to take the risk of flying at a higher altitude, thus the poor flying qualities coupled with the low altitude will not permit sufficient free time to devote to surveillance and weapon control, thus reducing the probability of mission success.

In summary, two important factors that may have an impact on how well a mission is performed are:

1. flight path control precision; in that it impacts on speed/altitude flown,
2. workload; both visual and manipulative, in that it impacts on the ability to perform surveillance and weapon control functions.

3.2 FLIGHT PATH CONTROL

The ability of a pilot to fly a desired flight path or to hover at a certain three dimensional location is determined by precision of flight path control and control power. The manifestation of poor flight path control is that a pilot cannot fly or hover in a position that optimizes his capability to transit and/or to observe, while minimizing his own probability of detection. Three specific factors were investigated:

a. precision of longitudinal control in forward flight
b. precision of lateral control in forward flight
c. precision of height control in hover.

3.2.1 Precision of Longitudinal Flight Path Control

The primary impact of precision of longitudinal flight path control, be it because of stability or control power factors, is in altitude holding capability. More specifically, in NOE flight, for given terrain characteristics and helicopter agility, there is a direct relationship betweeen speed and altitude. Basic physics, human response time and the nature of micro-terrain all tend to force the helicopter to fly higher as speed is increased as indicated in Figure 3-1.

The curve in Figure 3-1 is predicated upon a certain nominal level of flying qualities. The average altitude for any given speed is that which gives the pilot a sufficient margin of error such that he will always clear all terrain features over which he is flying. This "margin of error" is determined by many factors, one of the foremost being flying qualities. Thus, if the flying qualities are better than nominal, the pilot can fly at a lower average altitude at any speed while still retaining the same level of safety. Conversely, if the flying qualities are poorer than nominal, the pilot must fly higher to maintain the same level of safety, all other factors being equal.

3.2.2 Precision of Lateral Control in Forward Flight

NOE flight requires a great deal of lateral maneuvering to avoid micro-terrain features being used for cover. As a general rule, the closer to the ground the helicopter flies the greater the number of micro-terrain features, so more maneuvering is required. If either because of poor roll control power, or lack of precision of lateral control, the helicopter's lateral maneuverability is degraded, then it will be forced to fly higher to reduce maneuvering requirements if it is to maintain the same speed. Thus, the result is the same as with poor longitudinal precision of control, specifically, the helicopter is forced to fly higher making it more vulnerable to detection and fire.

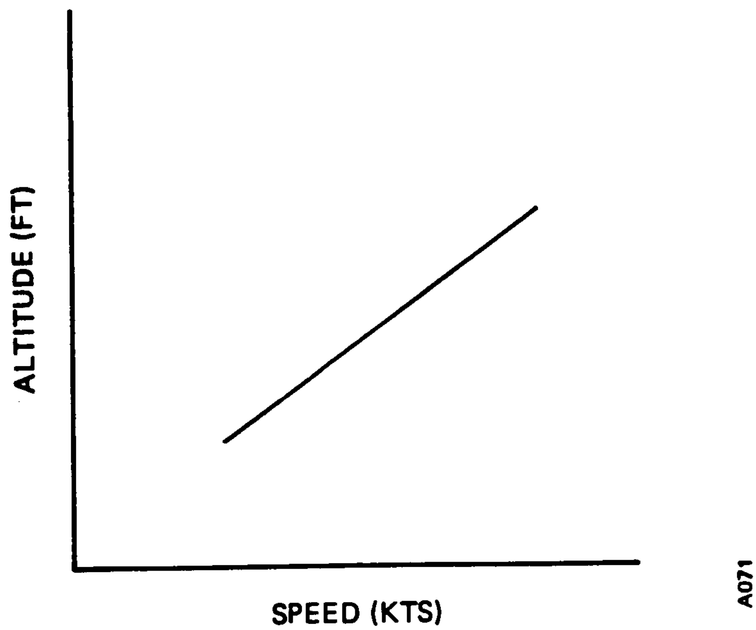


Figure 3-1. MOE Speed/Altitude Relationship

3.2.3 Precision of Altitude Control in Hover

At an observation point, a Scout wishes to observe without being observed. Thus control along, and about, all three axes is critical, but none more critical than that of height control. Specifically, the Scout must unmask to the degree that his observation device(s) (eyes, mast mounted sight, etc.) are exposed, but no more. For example, the purpose of a mast mounted sight (MMS) is to permit the helicopter to remain almost totally masked while still being able to observe. If, however, its hover station keeping capability is so poor that large height excursions occur, many of the benefits of the MMS are lost. If it descends too far while designating a target, it may break lock and any missile in flight may be lost. If it climbs too high, a larger area will be exposed, making it more susceptible to detection and fire.

3.3 WORKLOAD

Workload consists of several types of activities -- visual, manipulative, oral/auditory and cognitive. Some tasks associated with mission performance are listed in Table 3-1. Most of them require all four of the workload activities. If we define Visual Free Time (VFT) as the percentage of time

Table 3-1. Tasks Associated with Mission Performance

TASKS

	Flight Path Control	Navigation	Communications	Surveillance	Fire Direction/ Weapon Control
SUB TASKS	• Hover	• Terrain Avoidance	• Pass to Ground Commander	• Hasty Recon.	• Recall Target Locations
	• Transition	• Select Observation Positions	• Prepare Data Message	• Search W/MMS	• Determine Routes, Firing Positions
	• Flight	• Determine Coord. to Tactical Operations Center	• Transmit Message to Tactical Operations Center	• Identify Targets	• Method of Engagement
	• Maneuver	• Update Doppler/INS		• Store Target Information	• Target Location for Attack Helos
	• Monitor A/C Systems	• Track to New Position		• Monitor Target Position Changes	• Designate Target
		• Cross Check Terrain Against Map		• Maintain Look-out Doctrine	• Coordinate Movement of Attack Helos
				• Initiate Countermeasures	• Assess Damage

that is used to perform those tasks and subtasks unrelated to control of the helicopter, but which contribute to the performance of the mission, it is reasonable to assume that by improving flying qualities VFT would be increased, thus giving the pilot more time to better perform non-flying tasks. Depending on the threat, the tendency will probably be to gravitate toward that combination of VFT, speed, and altitude, which will result in the least probability of getting killed, regardless of the VFT.

This could have a significant impact on mission effectiveness since VFT directly impacts on the pilot's ability to detect threats, hence avoid them; to be detected by threats, hence fired upon by them; and to detect and identify targets, hence direct fire on them. Thus, to relate workload to mission effectiveness it is assumed that increased workload will reduce VFT, and hence VFT was varied in this simulation to determine the resulting effects on mission effectiveness.

3.4 IMPACT ON TASK PERFORMANCE

As can be seen from the preceding discussions, for NOE flight, as flying qualities degrade the pilot must either fly higher, fly slower or work harder, reducing time available to perform other mission functions. Clearly, he can compensate for degraded flying qualities in the above ways either independently or in combination. For example, a pilot flying NOE with degraded flying qualities could fly a little higher, a little slower, and devote more attention to his flying, reducing VFT.

For the purposes of this study, flying qualities are considered to manifest themselves in the following four ways:

a. Determine the basic NOE height at which a helicopter can fly at a given speed. This is primarily determined by control power and type/density of the micro-terrain.

b. Determine the amount and frequency content of excursions in height above the basic NOE height. This is primarily a function of precision of control and presupposes the pilot will not risk descending below some minimum "safe" altitude.

c. Determine the amount and frequency content of height excursions in hover above that required for observation. This presupposes that the pilot will not risk breaking lock on a designated target.

d. Determine the amount of visual free time for surveillance and fire control functions.

3.4.1 Impact on Basic NOE Flight Conditions

Initial analysis of the impact of flying qualities on NOE speed and altitude suggested that as flying qualities degrade, the pilot would fly higher to maintain a given margin of safety. Moreover, judgment, based on operational experience, suggested that the pilot would compensate more at low altitudes than at high altitudes, resulting in curves that converge at the high speed end as illustrated in Figure 3-2.

The HACES algorithm which relates speed, height and maneuverability in NOE flight yields exactly the same trends as helicopter maneuverability is degraded, and in fact, Figure 3-2 was constructed from that algorithm.

Since flying qualities can be viewed as a measure of the degree to which the performance/maneuvering potential of a helicopter can be utilized, a degradation in flying qualities can, to some degree, be equated to a degradation in performance/maneuverability. Thus, it is probably not by chance that the trends subjectively derived in analyzing the effect of flying qualities, closely parallel the trends generated through analyzing the effects of helicopter maneuverability.

As HACES is presently mechanized, the NOE speed/altitude curves are based strictly on the performance/maneuvering potential of the helicopter. This equates to a curve of perfect flying qualities, where the pilot is able to fully exploit the performance potential of the aircraft. To generate non-arbitrary curves of realistic - degraded - flying qualities, advantage has been taken of the correlation between flying qualities and performance/maneuverability. Specifically, the impact on flight condition of two grades of degraded flying qualities have been defined by reducing the performance/maneuverability of the Scout helicopters, and generating speed/altitude curves based on this degraded performance. Although the curves may not be exact, they should certainly be sufficiently close to obtain a meaningful quantitative measure of the impact of flying qualities on mission effectiveness.

The specific curves, corresponding to the three grades of flying qualities are presented in Figure 3-2. The lower curve - Grade 1 Flying Qualities - was generated assuming the full maneuvering potential of the Scout helicopters.

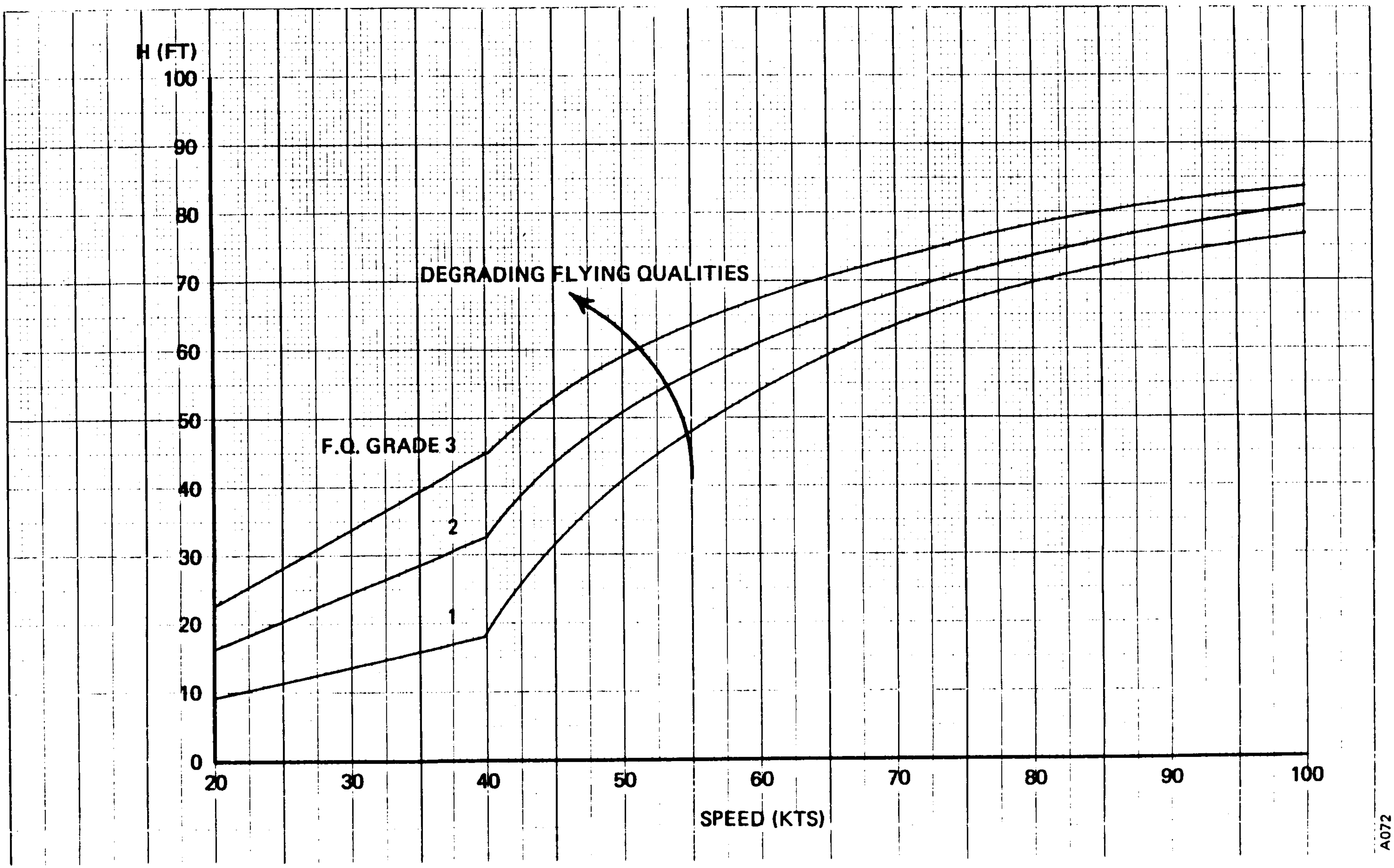


Figure 3-2. Flying Qualities/NOE Flight Relationships

The other two curves, corresponding to Grades 2 and 3 flying qualities, were generated by reducing the maneuverability of the Scout helicopters approximately 15 percent per grade. The primary parameter that determines the speed - altitude relationship in the HACES NOE model (for a given density of micro-terrain) is maximum sustained turn capability, so this is the parameter that was reduced.

As stated in the Introduction, the objective of this program was to relate the effects of flying qualities to mission effectiveness. Thus, to assess the difference in mission effectiveness of two configurations, the user must first assess the difference in the effects of their flying qualities. More specifically, the user must assess the basic NOE height for each, either through experiment or through analysis of the helicopter's stability and control characteristics, and use these heights to enter the effectiveness curves of Section 4. As an example of how this may be achieved, Appendix C considers the impact of roll control effectiveness on basic NOE height.

3.4.2 Impact on NOE Height Variations

As previously discussed, poor lateral and/or longitudinal precision of control can force a helicopter to fly higher than the basic NOE altitude which is determined essentially by control power. Since it is assumed that the pilot will not risk descending below what he perceives to be a "safe" altitude, given the characteristics of the micro-terrain, his speed and his helicopter's "effective" maneuverability; the precision of control factor yields a statistical distribution of height, ΔH, superimposed on the basic NOE height. This can be represented by a Rayleigh distribution, as illustrated in Figure 3-3, whose mean is determined by height keeping capability. Mean values between zero (perfect control) and thirty feet have been considered in this program.

As with the basic NOE height, to assess the impact of flying qualities on mission effectiveness with respect to precision of flight path control, the user must establish what the mean excursion is, then use this to enter the data of Section 4. It is important that this altitude holding capability not be based solely on the physical ability to hold an altitude, when that is the only task, but fully consider such factors as environmental/tactical factors (i.e., terrain roughness, visibility, EW effects), other tasks which must be accomplished (i.e., navigation, communication, maintaining formation integrity,

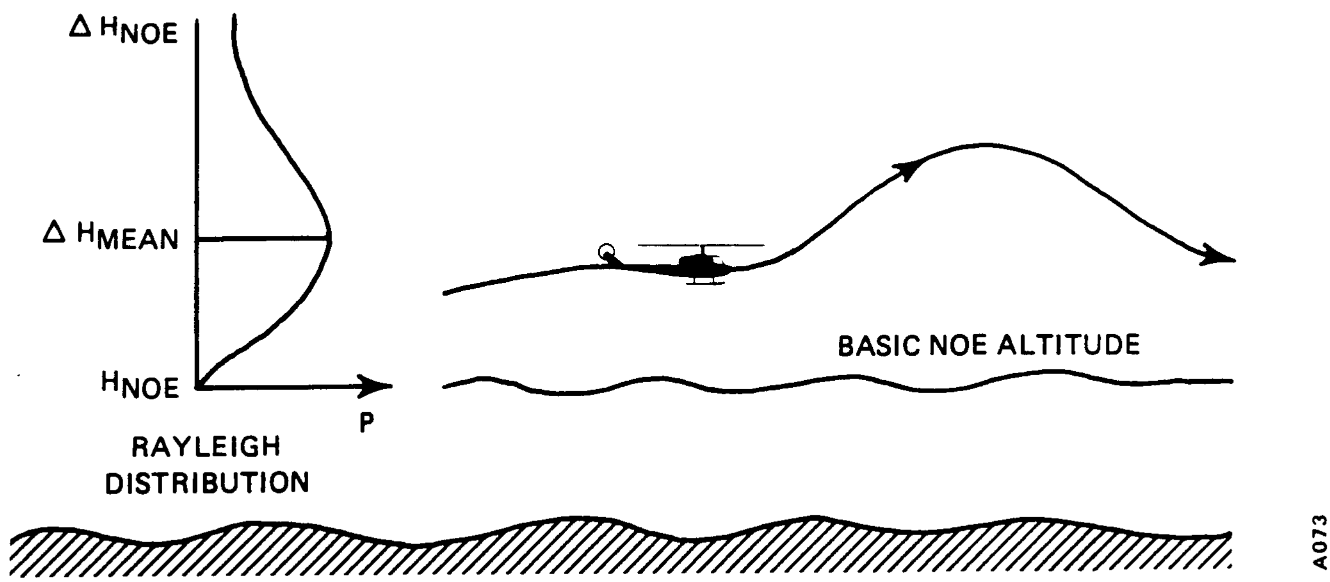


Figure 3-3. Statistical NOE Height Variation

look-out for threat elements) and maintaining a margin of safety (knowledge that striking the ground or other objects either directly below or from either side, could possibly be fatal).

3.4.3 Impact on Hover Height Variations

For a given set of environmental and topographic conditions, a helicopter's hovering precision is almost totally determined by its handling qualities. As with precision of control in NOE flight, the height variations which occur in hover are considered to be above the minimum observation height and can be represented by a Rayleigh distribution as illustrated in Figure 3-4. Mean values between zero (perfect control) and ten feet have been considered in this program.

To enter the data of Section 4 to determine the significance of hover precision, the mean variation in hover altitude must be estimated/calculated/measured.

3.4.4 Impact on Workload

Review of the literature, in particular work done by Dr. Dora Dougherty Strother, Chief, Human Factors Engineering, Bell Helicopter Company, show that

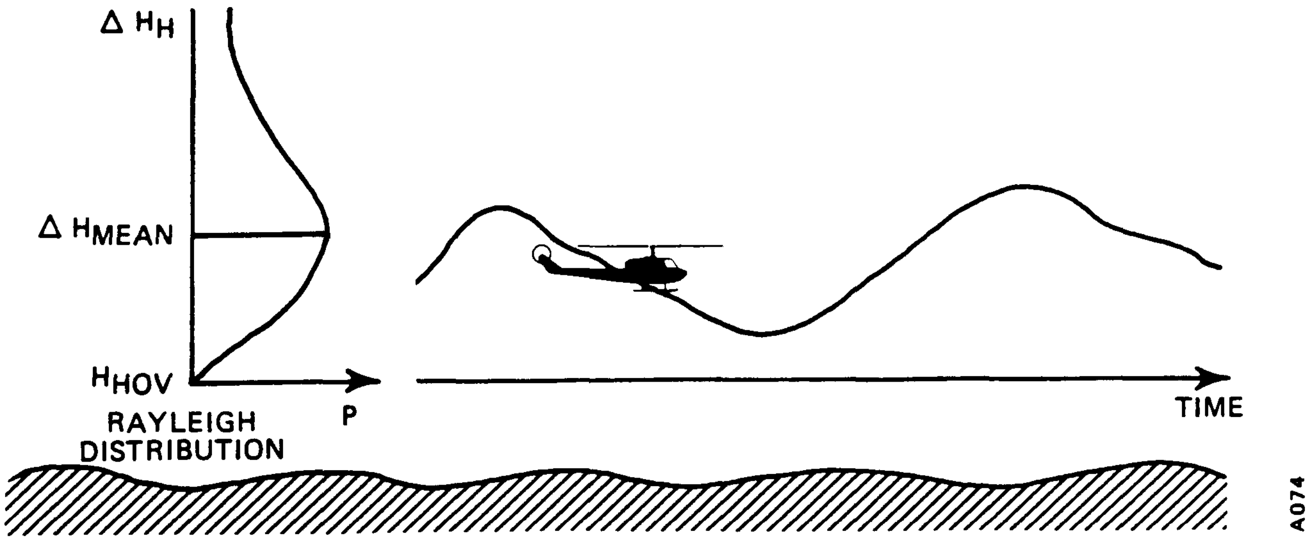


Figure 3-4. Statistical Hover Height Variation

some data have been acquired on the amount of visual free time available to a pilot flying at varying heights above the terrain. Typical data from Dr. Strother, Reference 1, is presented in Figure 3-5.

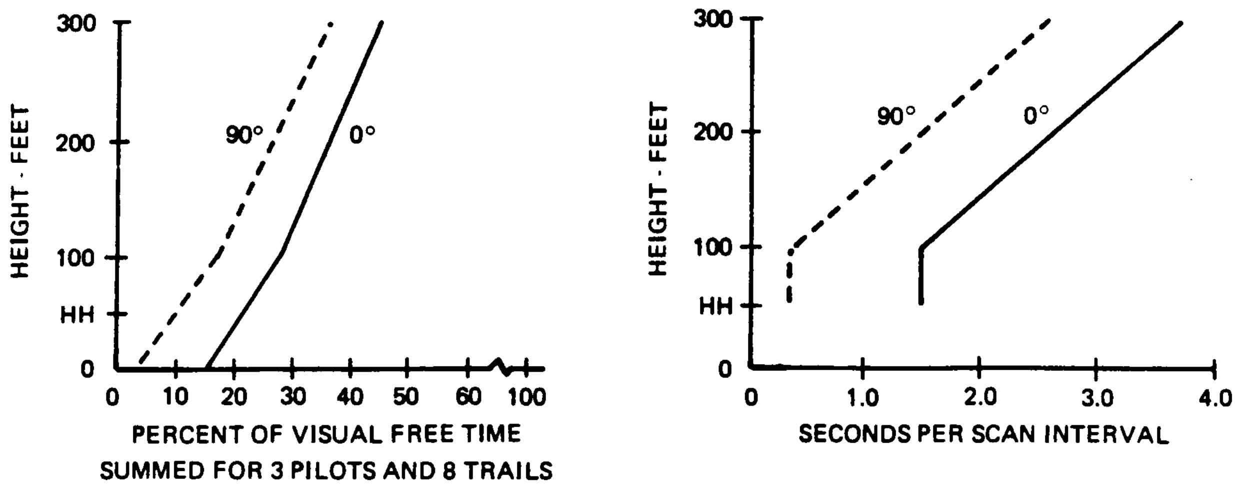
These data show, as would be expected, that VFT increases with height while maintaining a constant speed. The solid curve of Figure 3-5a gives the amount of VFT as determined by looking at objects straight ahead, while the dashed line represents the amount of VFT as determined by having to look at objects 90 degrees to one side of the pilot's normal field of view. Figure 3-5b shows the variation of scan inteval with height. It can be seen from the figures that looking to the side, rather than straight ahead, not only reduces VFT, but reduces the length of each scan period. Both factors degrade a pilot's ability to perform non-flying tasks.

Although these data relate strictly to the amount of time available for non-flying visual activities; and total workload comprises visual, manipulative, oral/auditory and cognitive activities; it is considered to be directly applicable to the Scout surveillance task/mission since the visual activity is paramount.

These data show that for NOE heights of 100 feet and below, VFT ranges from 25 to 15 percent when the pilot spends his "free time" searching in front of him (solid curve), and ranges from 15 to 5 percent when the pilot spends

3-5a

3-5b



Visual Free Time
Plotted Against Altitude

Duration of Visual Scans
Plotted Against Altitude

A075

Figure 3-5. Visual Workload Effects

his "free time" searching to his side. These data are of significance because even in helicopters with two crew members, the co-pilot/gunner is becoming a head-down crew member during search and attack phases.

For the purposes of this study, these data will be taken as minimum times and the amount of VFT considered has been increased above these values. In determining the range of values of VFT to consider in the surveillance mission, three additional factors had to be taken into account: The amount of surveillance which occurs in the processes of visual flight; the contribution of a second crew member; and the contributions of automatic detection devices. Considering all factors, visual free times ranging from 5 percent to 100 percent were considered in this program.

As with the other parameters, estimates of visual free time associated with differing levels of flying qualities must be made to assess the impact on mission effectiveness.

SECTION 4

EXPERIMENTAL DESIGN, RESULTS AND ANALYSIS

4.1 EXPERIMENTAL DESIGN

The scenarios and cases selected for analysis were based on the sometimes conflicting requirements to clearly show cause and effect relationships (necessitating only a few elements - Scenario 3), and to relate flying qualities to mission effectiveness for larger, more realistic, unit actions (Scenarios 1 and 2). The case matrix which was developed and run is presented in Table 4-1. As will be noted, seventeen cases were devoted to Scenario 3 to obtain a basic understanding of the impact of flying qualities on mission effectiveness, thirteen cases were devoted to Scenario 2 to establish relationships in larger unit actions under adverse attack conditions, and two cases (in which data were taken) were devoted to Scenario 1 to establish relationships when attacking under near ideal conditions.

The simulation was run 50 times per case. Fifty Monte Carlo runs were selected as a compromise between keeping costs in bound and in obtaining reasonable convergence. Experience has shown that the accuracy, or repeatability, is nominally within ±5 percent with this number of runs. This is precise enough to show trends quite accurately, but does introduce a little scatter in the data.

4.2 SCENARIO 3 RESULTS

The seventeen Scenario 3 cases permitted the investigation of the following flying qualities effects:

a. Cases 15, 1, 13, 2 and 3 varied the Scout's basic NOE height from 41 to 80 feet for fixed conditions of V=50 kts, ΔH_{NOE} = 0 ft, ΔH_{HOVER} = 2 ft and VFT = 50 percent.

b. Cases 1, 4, 5 and 16 varied the Scout's statistical NOE height variation from 0 to 30 feet for fixed conditions of V = 50 kts, H_{NOE} = 50 ft, ΔH_{HOVER} = 2 ft and VFT = 50 percent.

c. Cases 17, 1, 7 and 6 varied the Scout's statistical hover height variation from 0 to 5 feet for fixed conditions of V = 50 kts, H_{NOE} = 50 ft, ΔH_{NOE} = 0 ft and VFT = 50 percent.

Table 4-1. Case Matrix

Case	Scenario	H_{NOE}(FT)	V_{NOE}(KTS)	ΔH_{NOE}(FT)	ΔH_{HOV}(FT)	VFT(%)
1	3	50	50	0	2	50
2	3	65	50	0	2	50
3	3	80	50	0	2	50
4	3	50	50	10	2	50
5	3	50	50	20	2	50
6	3	50	50	0	5	50
7	3	50	50	0	3.5	50
8	3	50	50	0	2	5
9	3	50	50	0	2	10
10	3	50	50	0	2	25
11	3	50	50	0	2	100
12	3	41	50	0	0	100
13	3	58	50	0	2	50
14	3	58	50	20	5	25
15	3	41	50	0	2	50
16	3	50	50	30	2	50
17	3	50	50	0	0	50
18	2	14	30	0	2	50
19	2	41	50	0	2	50
20	2	50	50	0	2	50
21	2	58	50	0	2	50
22	2	69	80	0	2	50
23	2	50	50	10	2	50
24	2	50	50	20	2	50
25	2	50	50	30	2	50
26	2	50	50	0	2	25
27	2	50	50	0	2	100
28	2	50	50	0	5	50
29	2	50	50	0	10	50
30	2	50	50	0	0	50
31	1	47	50	10	2	50
32	1	64	50	30	10	50

d. Cases 8, 9, 10, 1 and 11 varied the Scout's VFT from 5 to 100 percent for fixed conditions of V = 50 kts, H_{NOE} = 50 ft, ΔH_{NOE} = 0 ft and ΔH_{HOVER} = 2 ft.

e. Cases 12, 4 and 14 varied all the Scout's parameters from near perfect flying qualities to bad flying qualities. In Case 12, the near perfect case; H_{NOE} = 41 ft, ΔH_{NOE} = 0 ft, ΔH_{HOVER} = 0 ft and VFT = 100 percent. In Case 4, the nominal case; H_{NOE} = 50 ft, ΔH_{NOE} = 10 ft, ΔH_{HOVER} = 2 ft and VFT = 50 percent. In Case 14, the bad case; H_{NOE} = 58 ft, ΔH_{NOE} = 20 ft, ΔH_{HOVER} = 5 ft and VFT = 25 percent.

4.2.1 Effect of Basic NOE Height

Figure 4-1 presents the basic measures of mission effectiveness: probability of the Blue Scout getting killed per mission (P_k (B)), number of Red ground units (tanks/BMPs, SAM, AAA) killed per mission (N_k(R)), and exchange ratio (ER) which equals the number of Red units killed per mission divided by the number of Scouts killed per mission.

From this figure it can be seen that although, as would be expected, the probability of the Scout being killed increased and the number of targets killed decreased as NOE altitude increased, the trends are not very pronounced, particularly at the lower NOE heights. This is a direct result of the scenario which caused the effects in hover to dominate the effects in NOE. This was caused by the fact that because of the geometry of the problem (reference Figure 2-5), in general most of the detecting and killing of the Scout occurred in hover. Thus, changes that occurred in the NOE portion of the mission only affected a small part of the problem. Had, for example, the Scout to fly by one or more defense sites to reach its hover point, surviving the NOE portion of the mission would have been much more difficult, making the measures of effectiveness much more sensitive to NOE parameters. This in no way invalidates the results, only suggests that many different missions and geometries must be examined to really pin down the criticality of height control in NOE flight.

Since all engagements were dominated by which side made the first detection, it is of interest to examine the probability of detection statistics. Figure 4-2a presents the cumulative probability of the Scout detecting the Red helicopter as a function of time for the different NOE heights. From these

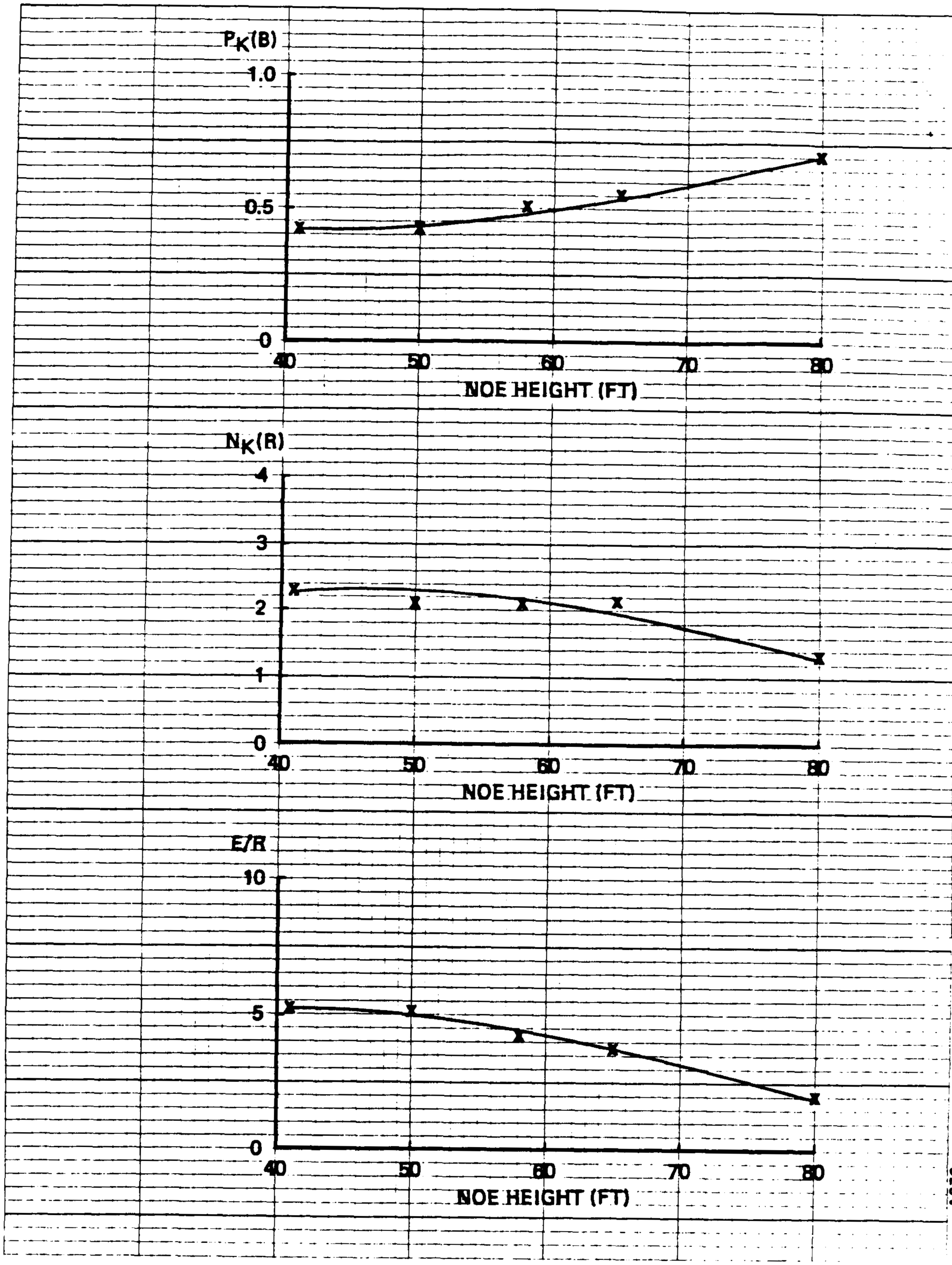


Figure 4-1. Basic NOE Height Variation MOEs

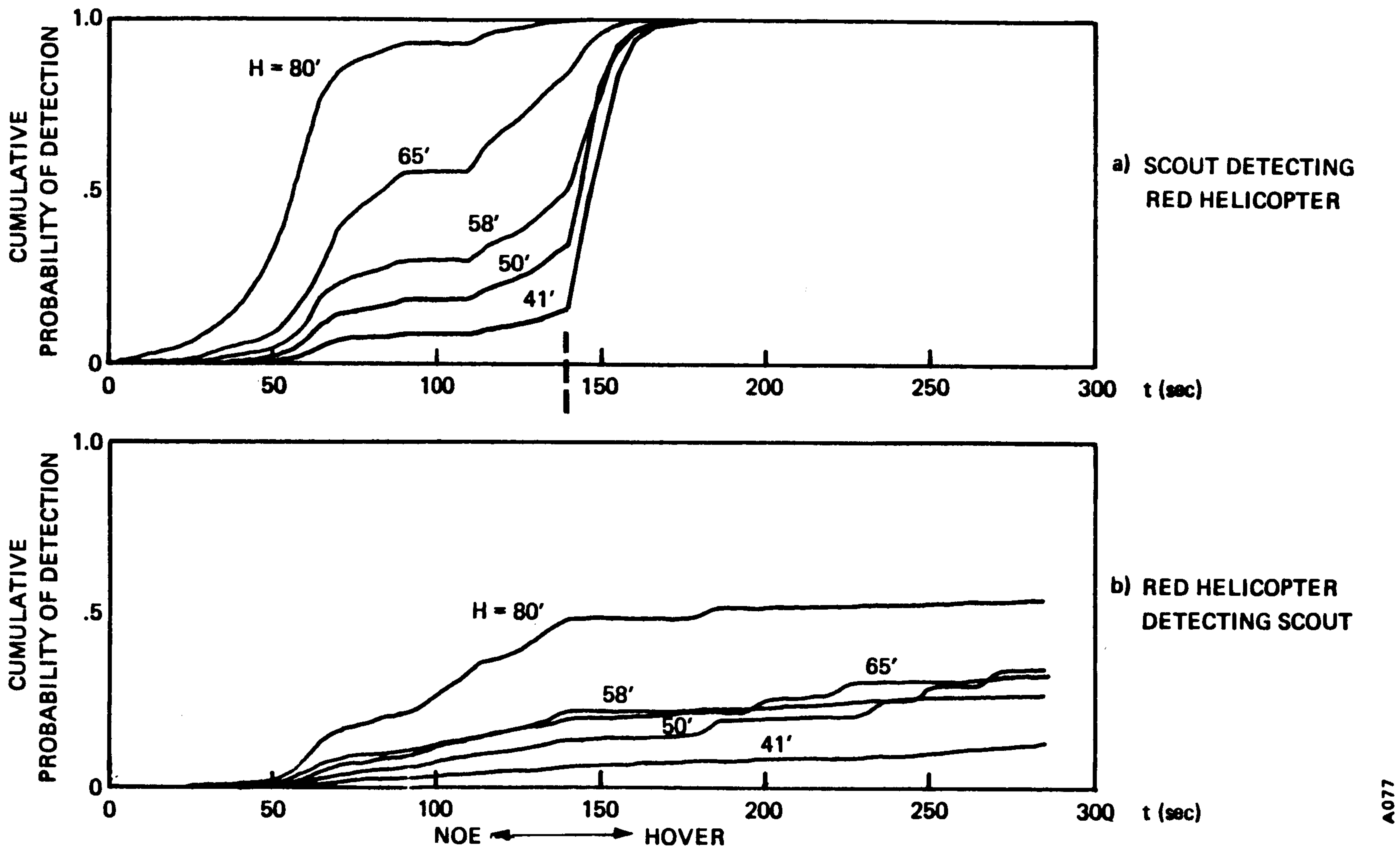


Figure 4-2. Impact of Basic NCE Height on Helicopter Probability of Detection

figures, it can be seen that as the Scout NOE height was increased (with speed, hover height variations, and VFT remaining constant), the Scout could see better, hence its probability of detecting the Red helicopter increased. Or put another way, as Scout height increased any specified level of probability of detection was reached sooner. It should be noted that the Scout reached its Observation Point at 140 seconds from the start of the problem. Since the Scout had a clear line-of-sight at its Observation Point, its probability of detecting the Red helicopter increased very rapidly from that point on for those NOE heights where probability of detection was not already high.

Figure 4-2b, which shows the probability of the Red helicopter detecting the Scout, indicates the same trend, only much less pronounced. The main reason that the Red helicopter has a lower probability of detecting the Scout than vice versa, is because of the Scout's much smaller size (reference Volume III). That the probability of detection for the 58 foot and 65 foot profiles is so close, could be due to imprecise "flying" of the 65 foot profile. That none of the curves parallel each other for times greater than 140 seconds is due to the fact that each curve was taken from one of the 50 Monte Carlo runs in each case. Since hover height varies differently for each run (ΔH_{HOVER} = 2 feet), variations between cases is to be expected.

In order to better estimate how NOE altitude affected the NOE portion of flight, consider Figure 4-3 which presents the probability of the Scout being detected by the Red helicopter prior to reaching its observation point at t = 140 seconds. From this figure, it can be seen that the probability of being detected at 50 feet is two times as great as at 41 feet (perfect flying qualities), and that flying at 58 feet the probability of detection is four times as great as at 41 feet.

One final measure of effectiveness that was examined was the average time at which the Scout was detected by the Red helicopter. This curve, which is presented in Figure 4-4, indicates that at the highest altitude considered (80 feet), on the average the Scout was detected 62 seconds prior to reaching its observation point . At 50 knots, this translates to the Scout being 0.86 miles short of the observation point, on the average, when and if detected. In fact it was detected 48 percent of the time. At 58 feet, the Scout just made it to the hover point (on the average), and was detected 24 percent of the time. At 41 feet, the data show that the average time of detection was eight seconds

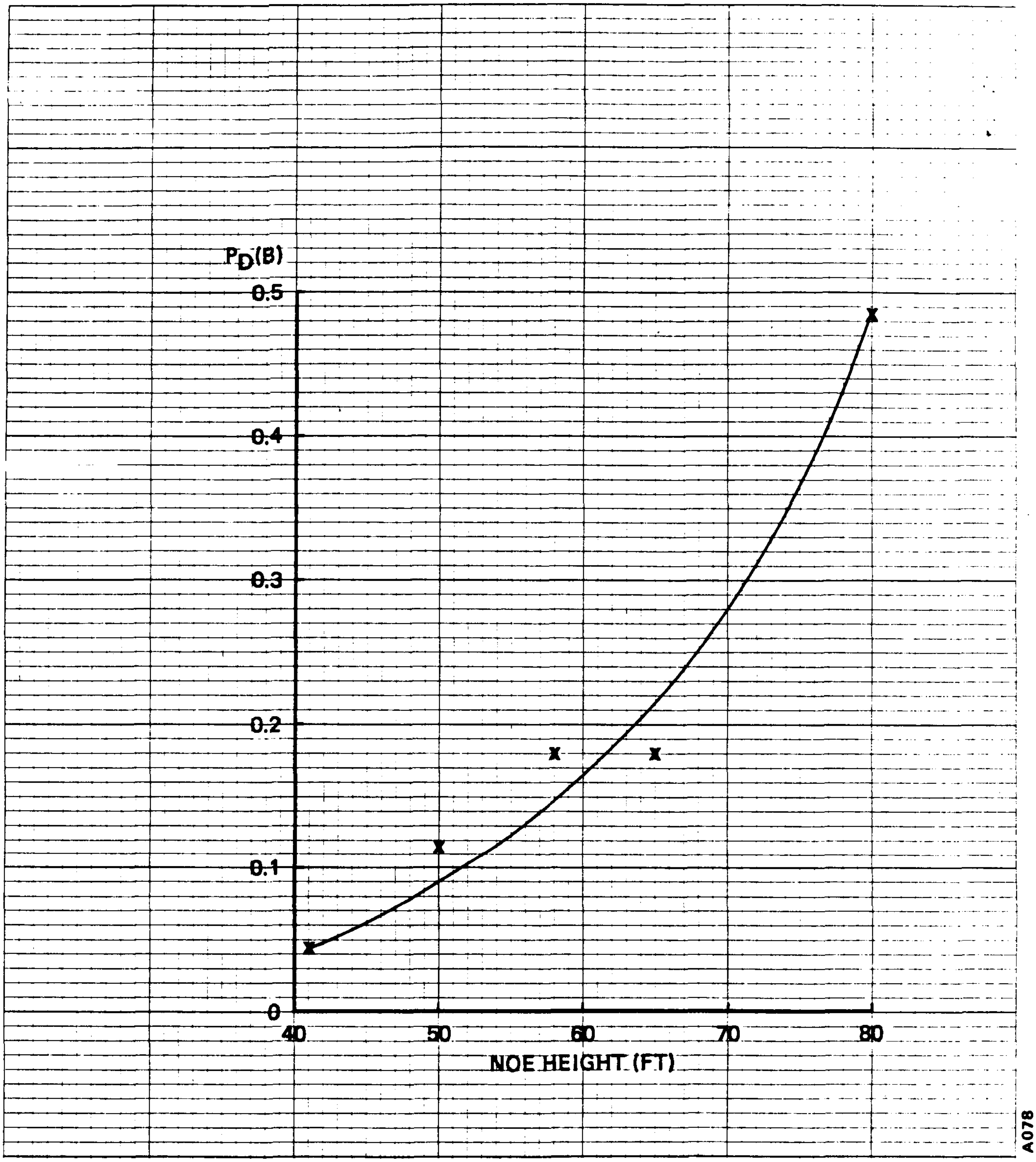


Figure 4-3. Probability of Scout Being Detected by Red Helicopter in NOE Flight

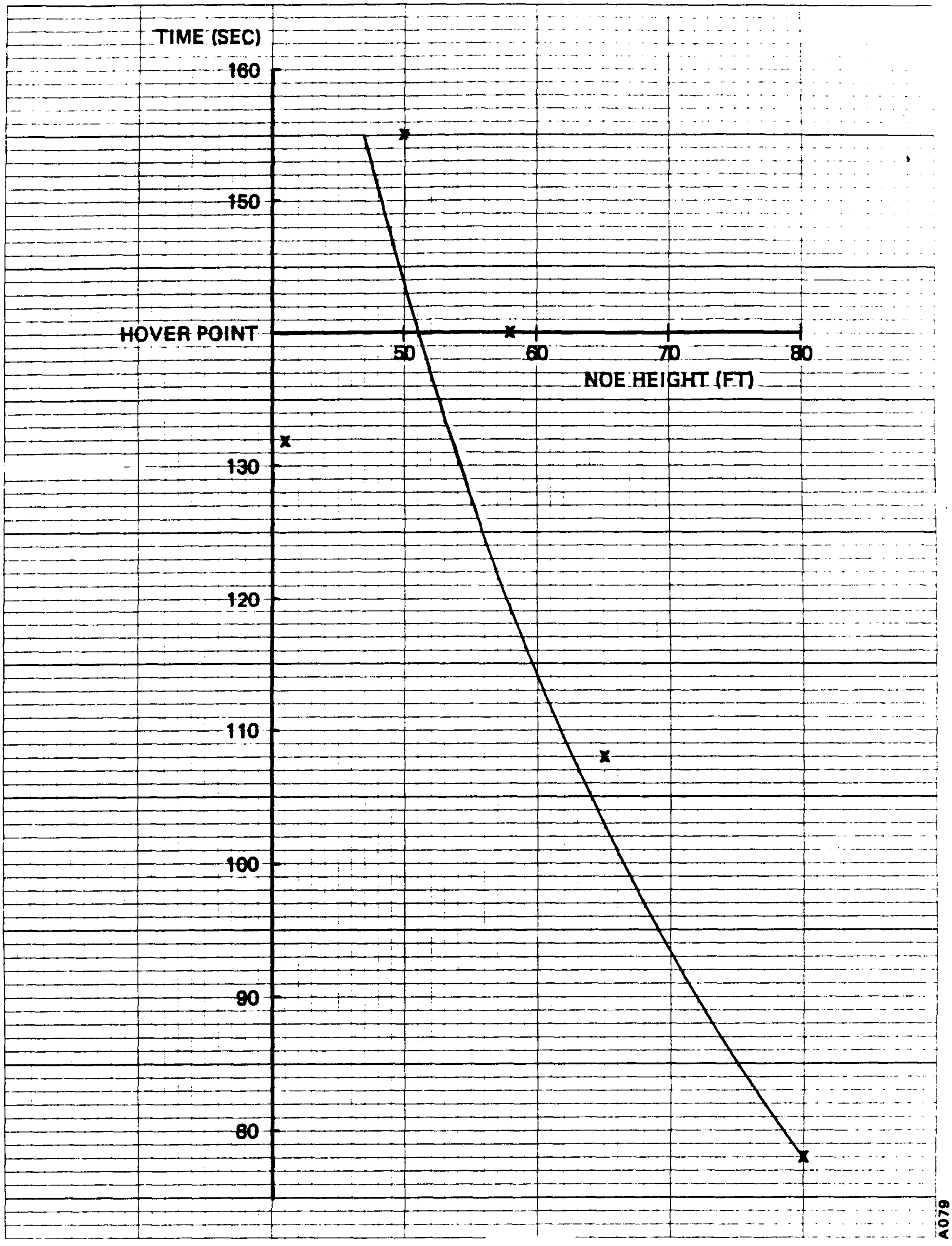


Figure 4-4. Average Time of Detection by Red Helicopter

prior to reaching the hover point. However, since the helicopter was only detected 12 percent of the time, the data sample is small. Analysis of the detection statistics indicates that had a larger number of runs been made, the average expected time of detection would almost certainly have been well after the observation point was reached.

It is believed that these intermediate MOEs give a great deal more insight into the importance of NOE height control than do the primary MOEs alone.

4.2.2 Effect of Statistical NOE Height Variations

Figure 4-5 presents the basic measures of mission effectiveness: $P_k(B)$, $N_k(R)$ and ER, as the mean height of the helicopter varied between 0 and 30 feet above the basic NOE height of 50 feet. As can be seen from these data, the spread on the measures of effectiveness is similar to that for the variations in basic NOE height, but the curves are less linear. Specifically, for ΔH between 0 and 10 feet little change occurred, for ΔH between 10 and 20 feet a large change occurred in all parameters, and for ΔH between 20 and 30 feet little further change occurred.

This non-linear behavior is also reflected in the probabilities of detection and the average times of detection. For ΔH = 0 and 10 feet, the probability of the Scout being detected by the Red helicopter was approximately 0.25, and the average time of detection was approximately 15 seconds after reaching the observation point. For ΔH = 20 and 30 feet, the probability of the Scout being detected by the Red helicopter was approximately 0.60, and the average time of detection was approximately 50 seconds prior to reaching the observation point. At 50 kts, this meant that the Scout was detected 0.7 miles short of the observation point over half the time.

The underlying detection statistics are presented in Figure 4-6. In Figure 4-6b, which presents the cumulative probability of the Red helicopter detecting the Scout, it can be seen that as the Scout's mean NOE altitude increased, its probability of being detected increased. A partial explanation for the non-linear behavior of the measures of effectiveness may be seen in that in going from a ΔH of 10 feet, to a ΔH of 20 feet, a very large change in the detection statistics occurs. It cannot be said for certain if this is the case, however, because each curve represents the probability of detection time

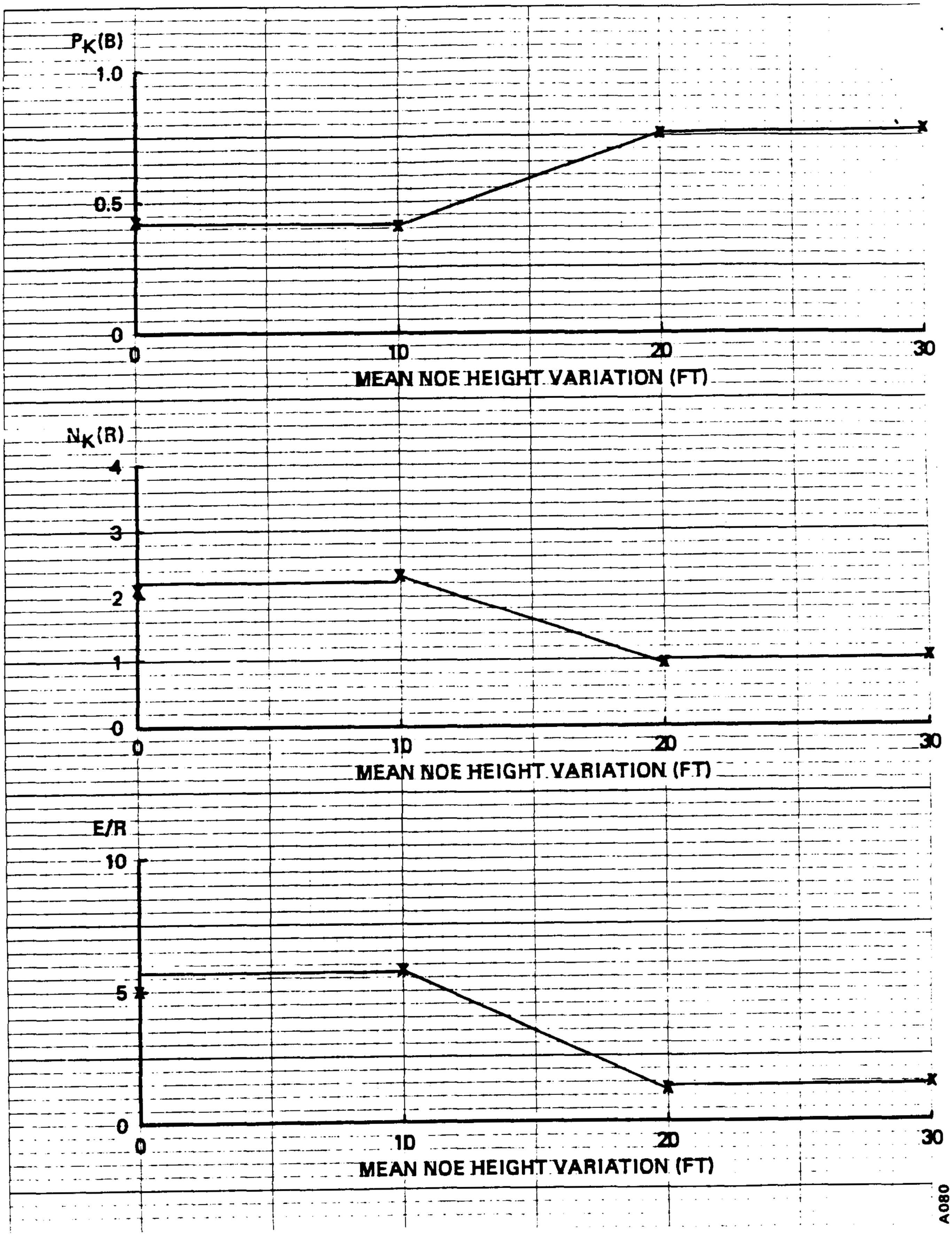


Figure 4-5. Statistical NOE Height Variation MOEs

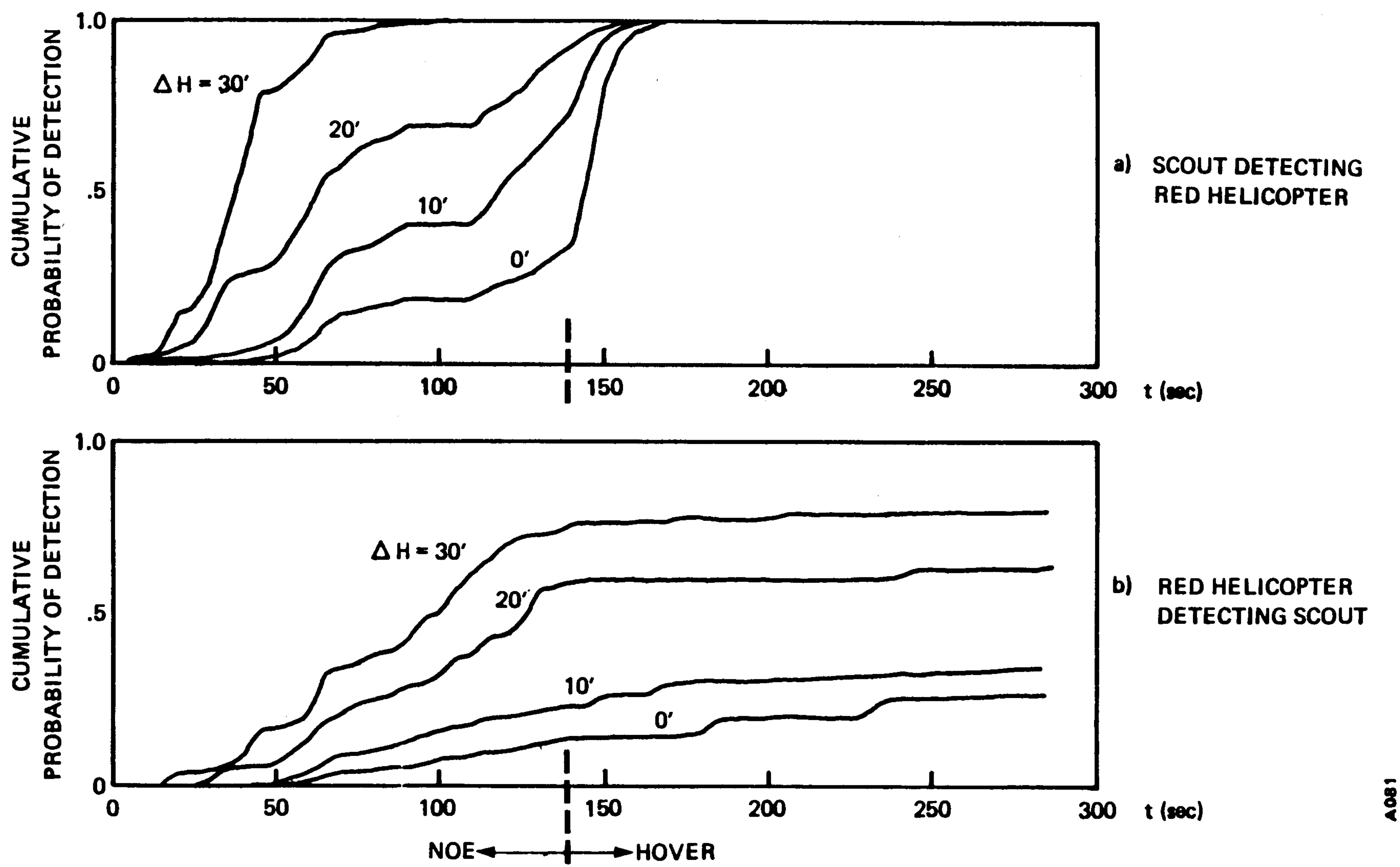


Figure 4-6. Impact of Statistical NOE Height Variations on Helicopter Probability of Detection

history for only one of the fifty runs for each case. Since the variations are statistical, each run for each case is different. However since each case has a specified mean, the differences from run-to-run are generally relatively small.

In Figure 4-6a, which presents the cumulative probability of the Scout detecting the Red helicopter, it can be seen that, holding speed and VFT constant, as the Scout gets higher its probability of detecting the Red helicopter increased significantly. Thus, if the Scout could have evaded or fired back, the effects of higher NOE altitude vis-a-vis the Red helicopter would have been mitigated. However, since most of the killing of the Scout was done by the surface anti-air defense (primarily the AAA units), the outcome would not have changed significantly.

4.2.3 Effect of Statistical Hover Height Variations

Figure 4-7 presents the basic measures of mission effectiveness: $P_k(B)$, $N_k(R)$ and ER, as the mean hover height of the helicopter varied between zero and five feet above the height required to just expose the mast mounted sight. As described in Appendix A, the simulation had been modified to compute the amount of surface area exposed as a function of hover height with respect to some masking feature. For example, with just the MMS exposed, the exposed surface area for the Scout is four square feet, but with five additional feet of exposure, the exposed area increases to 54 square feet. The actual exposed area as a function of the degree to which the Scout is unmasked is presented in Volume III.

As can be seen from Figure 4-7, simulation of this effect showed the great significance of precision of hover control on mission effectiveness. With perfect hover control and only the MMS exposed, the probability of Scout survival was 0.9 and the number of enemy units killed averaged 3.6 per mission. The number of units killed was limited by the number of anti-armor missiles which could be fired, and their P_k. The number of missiles which could be fired was in turn limited by the two minute hover time, the time taken for the Scout to coordinate with the Attack helicopter and direct its fire, and the flight time of the missiles (only one target designated at a time and one missile fired at a time). This high probability of survival and relatively large number of targets destroyed resulted in a very high exchange ratio.

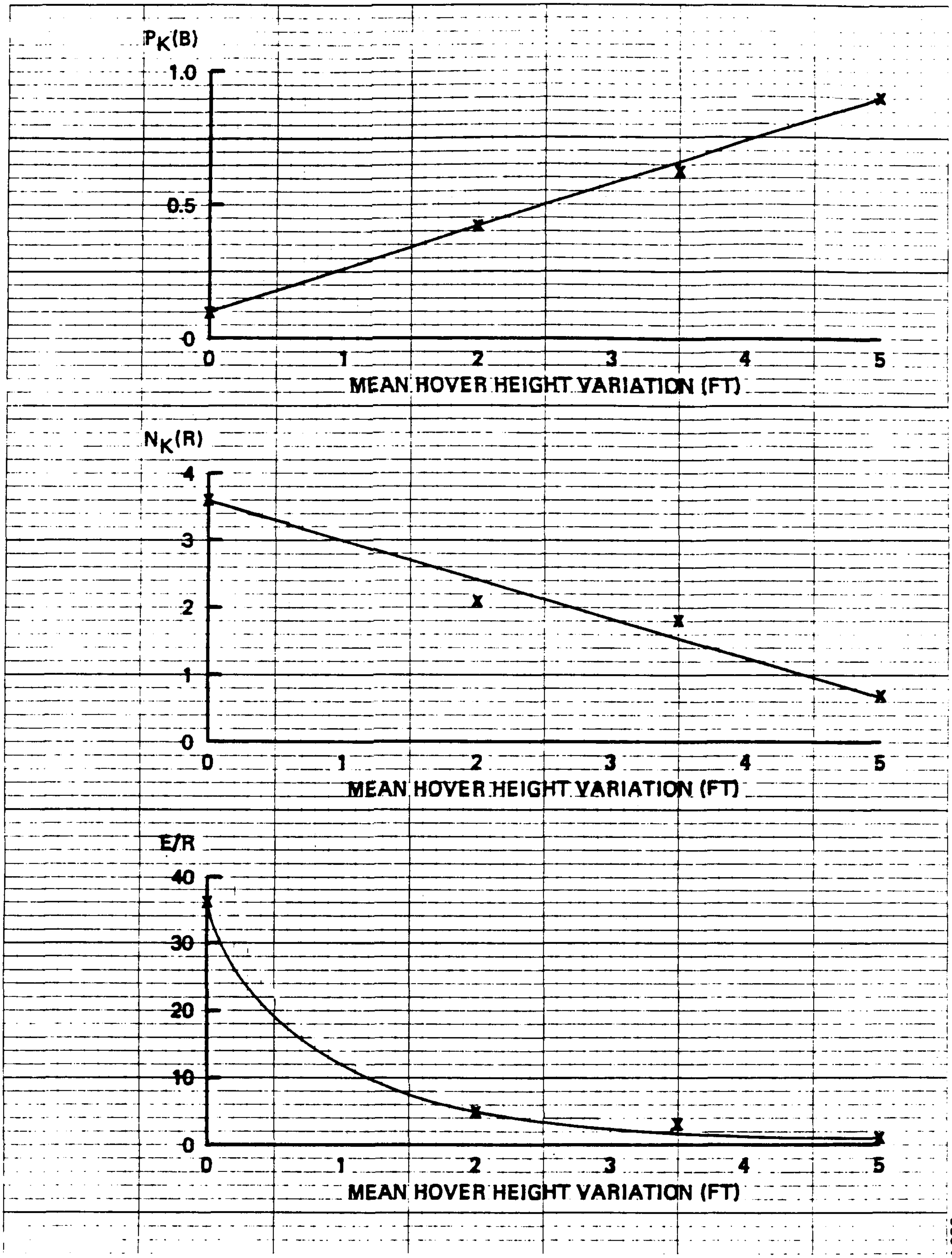


Figure 4-7. Statistical Hover Height Variation MOEs

As hover precision decreased, and the time varying height of the Scout increased, the Scout's probability of being killed increased, the number of targets killed decreased, hence exchange ratio decreased. It is of interest to note that the Scout's probability of survival decreased almost linearly with the decrease in precision of control. At the point where the mean height variation was about half the height of the helicopter (the Scout is 12 feet high), the probability of survival had reached a very low value.

It must be noted at this point that, in the same way that the scenario and geometry de-emphasized the effects of NOE height control, so it amplified the effects of hover height control. However, even bearing this in mind, there is little doubt that precision of hover control, as influenced by flying qualities and other parameters, is a powerful factor in determining mission effectiveness.

Figure 4-8 presents the detection statistics underlying the previous results. Figure 4-8a presents the probability of the Red helicopter detecting the Scout as a function of time, while Figure 4-8b presents the probability of an armored unit (tanks and BMPs) detecting the Scout as a function of time. Nominal visual detection statistics of all ground units were computed for completeness, but were not used in the engagement logic. The probability statistics of the Scout against all threat units remained invariant with hover excursions, since the logic (reference Section 3.4.3) was that the Scout would not break lock on a target, hence any excursions would be above the desired height, not below, where line-of-sight would be broken. The figures clearly point out how much easier, and how much more quickly, both air and surface units could detect the Scout as its precision of hover control degraded.

4.2.4 Effect of Visual Free Time

Figure 4-9 presents the basic measures of mission effectiveness: $P_k(B)$, $N_k(R)$ and ER, as visual free time varied between five percent and 100 percent. Only a small increase in Scout probability of survival occurred as visual free time increased, because the only defensive action that the Scout took upon detecting the Red helicopter was to use the micro-terrain in such a way that decreased probability of detection by the Red helicopter. Since the AAA and SAM did most of the killing anyway, only a small effect was expected and noted.

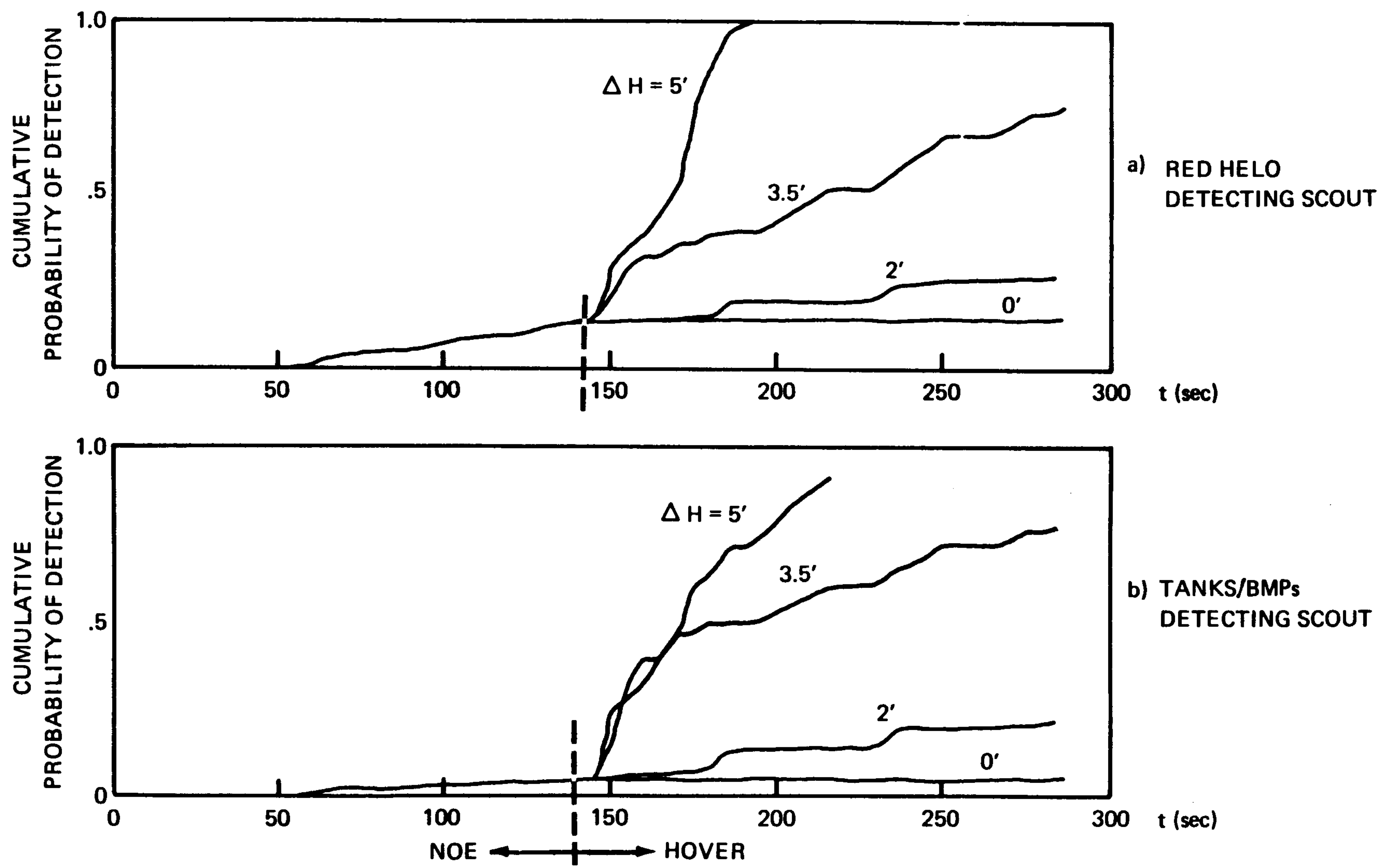


Figure 4-8. Impact of Statistical Hover Height Variations on Threat Detection of Scout

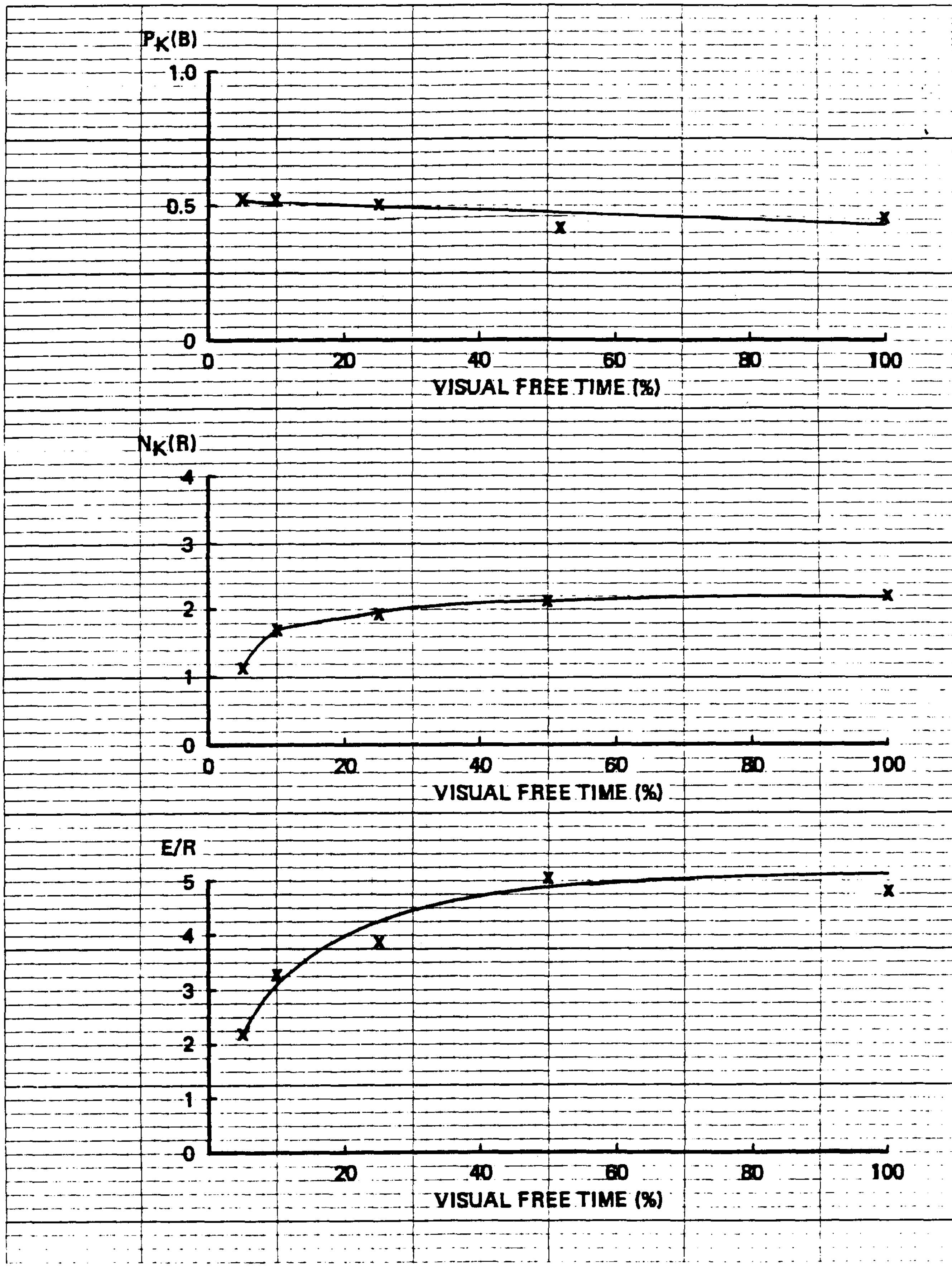


Figure 4-9. Visual Free Time MOEs

Although some variation is seen in the number of Reds killed, a significant variation only occurs at low values of VFT. This follows since the AAA and the SAM always had to be killed before the tanks were attacked (they were higher priority targets). Since the SAM and AAA essentially always detected the Scout and fired at it, the Scout always detected the SAM and AAA and had the simulated Attack helicopter return their fire. Thus, most of the engagement time was with units that were readily detectable, so not much impact on that measure of effectiveness was expected or occurred.

Better insight into the effects of VFT is gained by examining intermediate measures of effectiveness. Figure 4-10 presents the probability of detecting the armored vehicles, and the number of vehicles killed, as a function of VFT. These measures of effectiveness show a much stronger correlation with the amount of VFT available for surveillance. As will be seen from the detection statistics, the point of diminishing returns is reached at VFT = 50 percent in this scenario, since at that point the probability of detecting the tanks (if the Scout survives) is near unity. The inference is clear, however, that for any object (or group of objects) that is hard to see, the greater the amount of visual free time, the greater the probability of detecting that object; and that the amount of VFT required to achieve a given probability of detection is a function of the geometry, the size and contrast of the object, and time on station.

One other factor that has not been introduced, but has a bearing on the problem, is the relationship between VFT and the length of time that a crewmember can scan at any time. As was pointed out in Section 3.4.4, as VFT decreases, so too does the length of each scan interval. Thus, as VFT decreases, not only does the crewmember have a smaller fraction of his total time available for surveillance, but because he must interrupt this activity more often, his search will be less efficient. This would amplify the effects demonstrated by the data.

Figure 4-11 presents the detection statistics of the Scout detecting the Red helicopter and the tanks/BMPs. A clear relationship between probability of detection and VFT is evident. It will be noted that because the Red helicopter is relatively high, variations in the detection statistics against it begin during the NOE portion of the mission. On the other hand, because the tanks/BMPs are obviously low, there is almost no probability of detecting them during the NOE portion of the mission. Thus, all variations in the detection statistics occur after the observation point is reached.

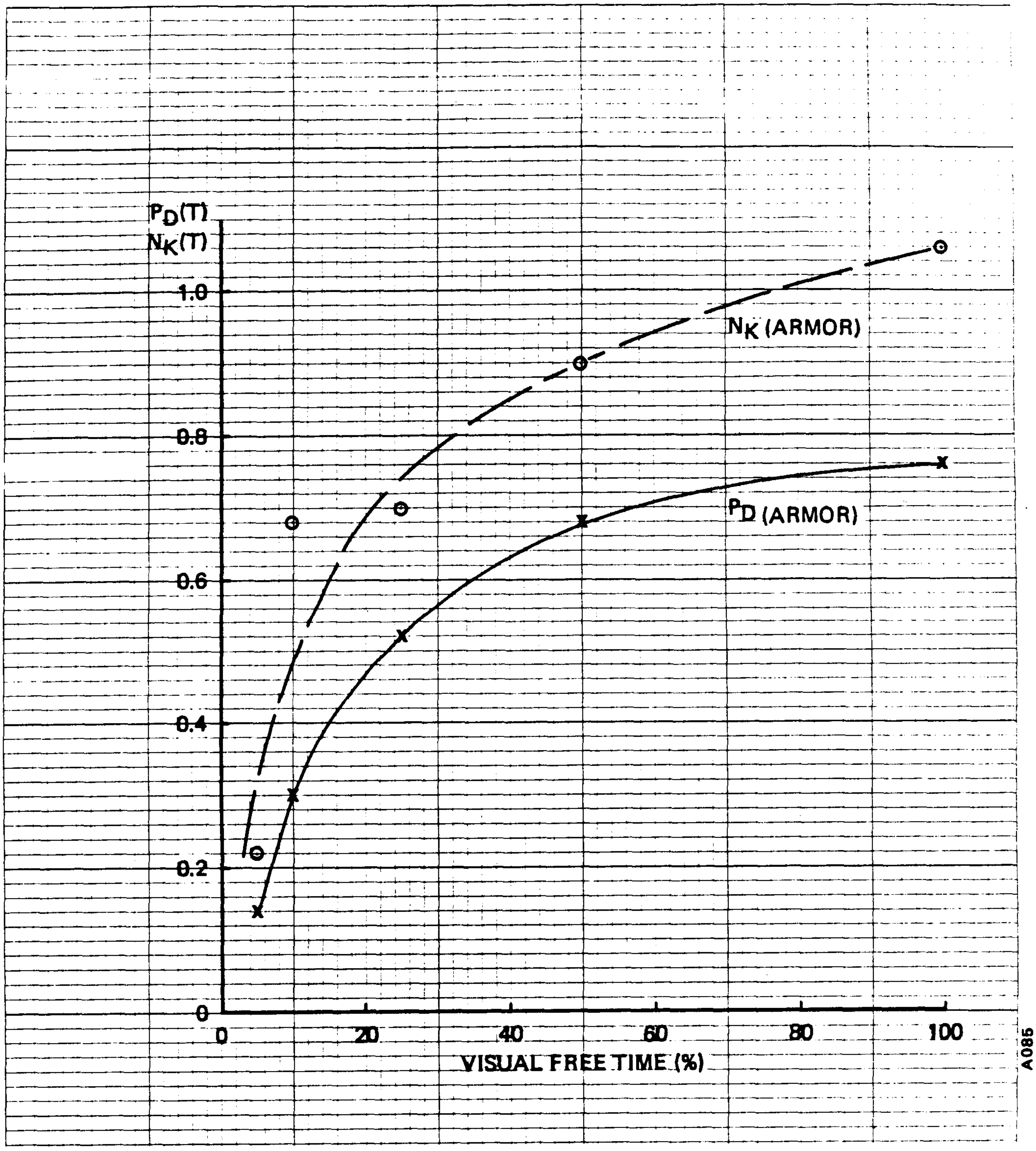


Figure 4-10. Probability of Detecting Armor and Number Vehicles Killed

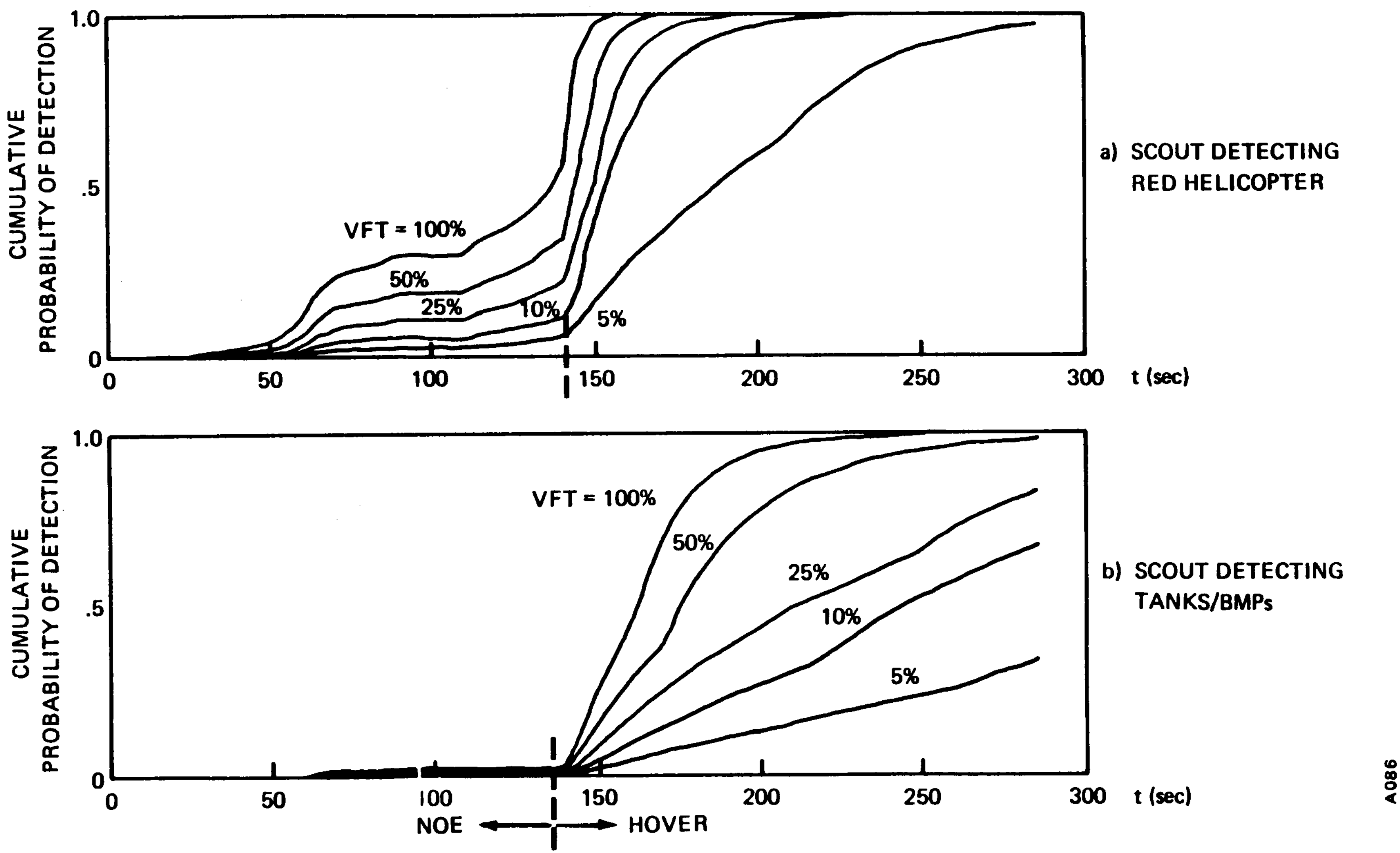


Figure 4-11. Impact of Statistical Height Variations on Threat Detection of Scout

4.2.5 Combined Effect of All Parameters

To obtain some insight as to the combined effect of all the parameters considered, three levels of flying qualities were defined as follows:

a. Perfect:
H_{NOE} = 41 feet (at 50 kts)
ΔH_{NOE} = 0
ΔH_{HOVER} = 0
VFT = 100%

b. Fair:
H_{NOE} = 50 feet (at 50 kts)
ΔH_{NOE} = 10 feet
ΔH_{HOVER} = 2 feet
VFT = 50%

c. Bad:
H_{NOE} = 58 feet (at 50 kts)
ΔH_{NOE} = 20 feet
ΔH_{HOVER} = 5 feet
VFT = 25%.

Figure 4-12 presents the basic measures of mission effectiveness: $P_K(B)$, N_K (R) and ER, as the flying qualities were varied from perfect to bad as just defined. With perfect flying qualities, probability of survival was very high, four threat units were killed on the average, hence exchange ratio was very high. With bad flying qualities, just the reverse was true. With fair flying qualities, intermediate results were obtained.

Quantitative analysis of the results indicates that the effects of individual parameters are independent and additive. Specifically, the increase in probability of Blue kill going from perfect to bad flying qualities, considering the four parameters independently, were computed and multiplied together. This number (18) was within 20 percent of the number (15) obtained by dividing $P_K(B)$ for perfect flying qualities by $P_K(B)$ for bad flying qualities when all parameters were varied simultaneously. Similarly, the decrease in the number of threats killed in going from perfect to bad flying qualities, considering the four parameters independently, were computed and multiplied together. This number (0.08) was also within 20 percent of the number (0.07) obtained by dividing $N_K(R)$ for perfect flying qualities with $N_K(R)$ for bad flying qualities when all parameters were varied simultaneously. That the sum of the effects when considered independently is essentially the same as when they are considered collectively, may, or may not, have been intuitively obvious.

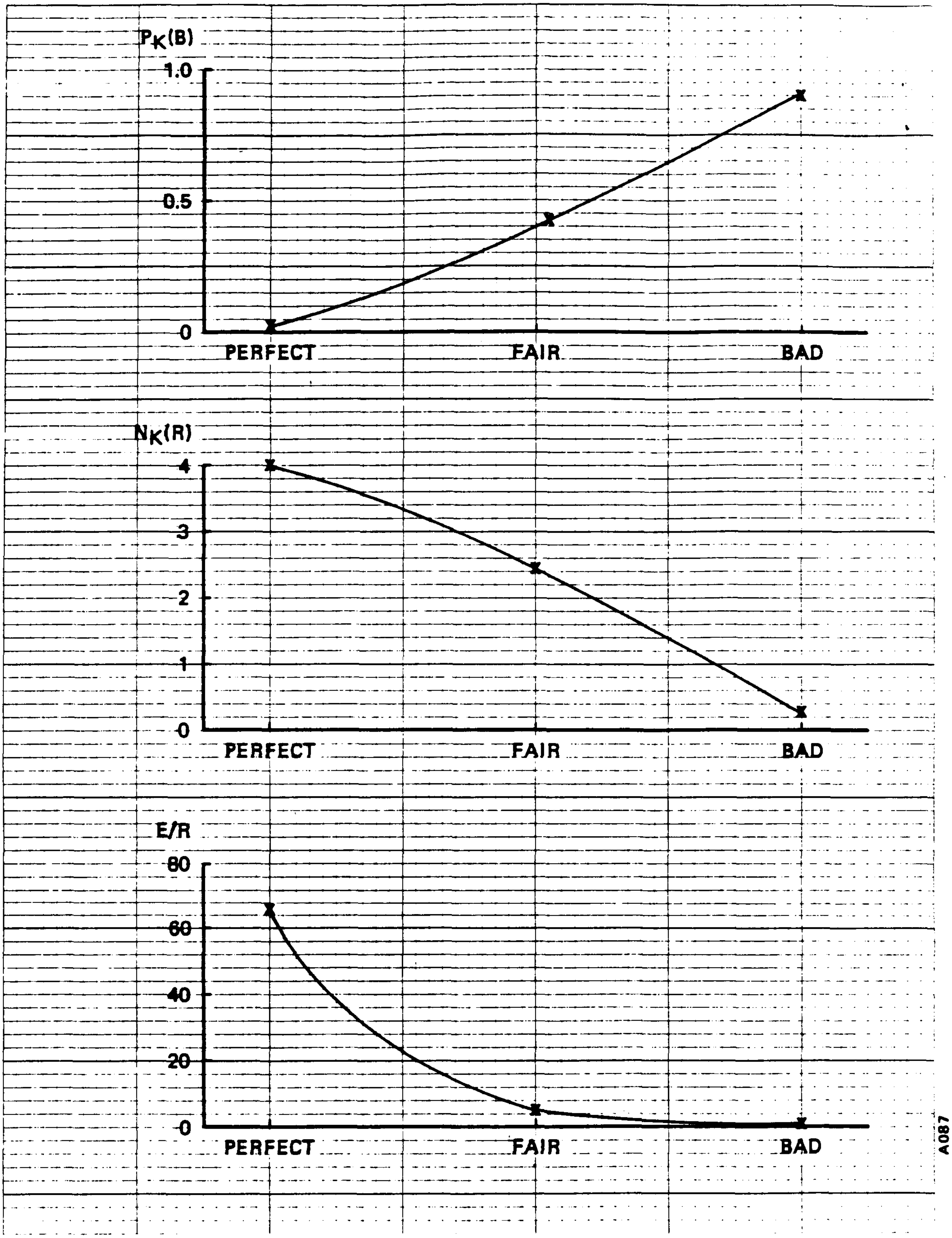


Figure 4-12. Combined Effect of all Parameters MOEs

It is also of interest to note that even though the value of the degradation in flying qualities effects in going from perfect flying qualities to bad flying qualities was not extreme, the probability of the Scout getting killed with bad flying qualities was 15 times as great as with perfect flying qualities, and only 1/14th the number of targets were killed.

The detection statistics, presented for the three levels of flying qualities in Figure 4-13, indicate strong, obvious trends.

4.3 SCENARIO 2 RESULTS

Scenario 2 was the same as Scenario 3, only more elements were added. Specifically, Scenario 2 had two Scout/Attack elements, two SAM's, two AAA's, and three tank/BMP formations. This increased the number of interactions considerably, which made the results more difficult to interpret.

The thirteen Scenario 2 cases permitted the investigation of the following flying qualities effects:

a. Cases 19, 20, and 21 varied the Scouts' basic NOE height from 41 to 58 feet for fixed conditions of V = 50 kts, $\Delta H_{NOE} = 0$, $\Delta H_{HOVER} = 2$ feet and VFT = 50%.

b. Cases 20, 23, 24 and 25 varied the Scouts' statistical NOE height variation from 0 to 30 feet for fixed conditions of V = 50 kts, $H_{NOE} = 50$ feet, $\Delta H_{HOVER} = 2$ feet and VFT = 50%.

c. Cases 30, 20, 28 and 29 varied the Scouts' statistical hover height variation from 0 to 10 feet for fixed conditions of V = 50 kts, $H_{NOE} = 50$ feet, $\Delta H_{NOE} = 0$ and VFT = 50%.

d. Cases 26, 20 and 27 varied the Scouts' VFT from 25% to 100% for fixed conditions of V = 50 kts, $H_{NOE} = 50$ feet, $\Delta H_{NOE} = 0$ and $\Delta H_{HOVER} = 2$ feet.

e. Cases 18, 19 and 22 varied the Scouts' basic NOE flight conditions from 30 kts at 12 feet, to 50 kts at 41 feet, to 80 kts at 69 feet for fixed conditions of $\Delta H_{NOE} = 0$, $\Delta H_{HOVER} = 2$ feet and VFT = 50%.

4.3.1 Effect of Basic NOE Height

Figure 4-14 presents the basic measures of mission effectiveness: $P_K(B)$, N_K (R) and ER, as basic NOE height of the Scouts varied from 41 to 58 feet. As discussed in Section 4.2, the scenario results were dominated by the hover portion of the mission. For that reason, and because only a relatively small

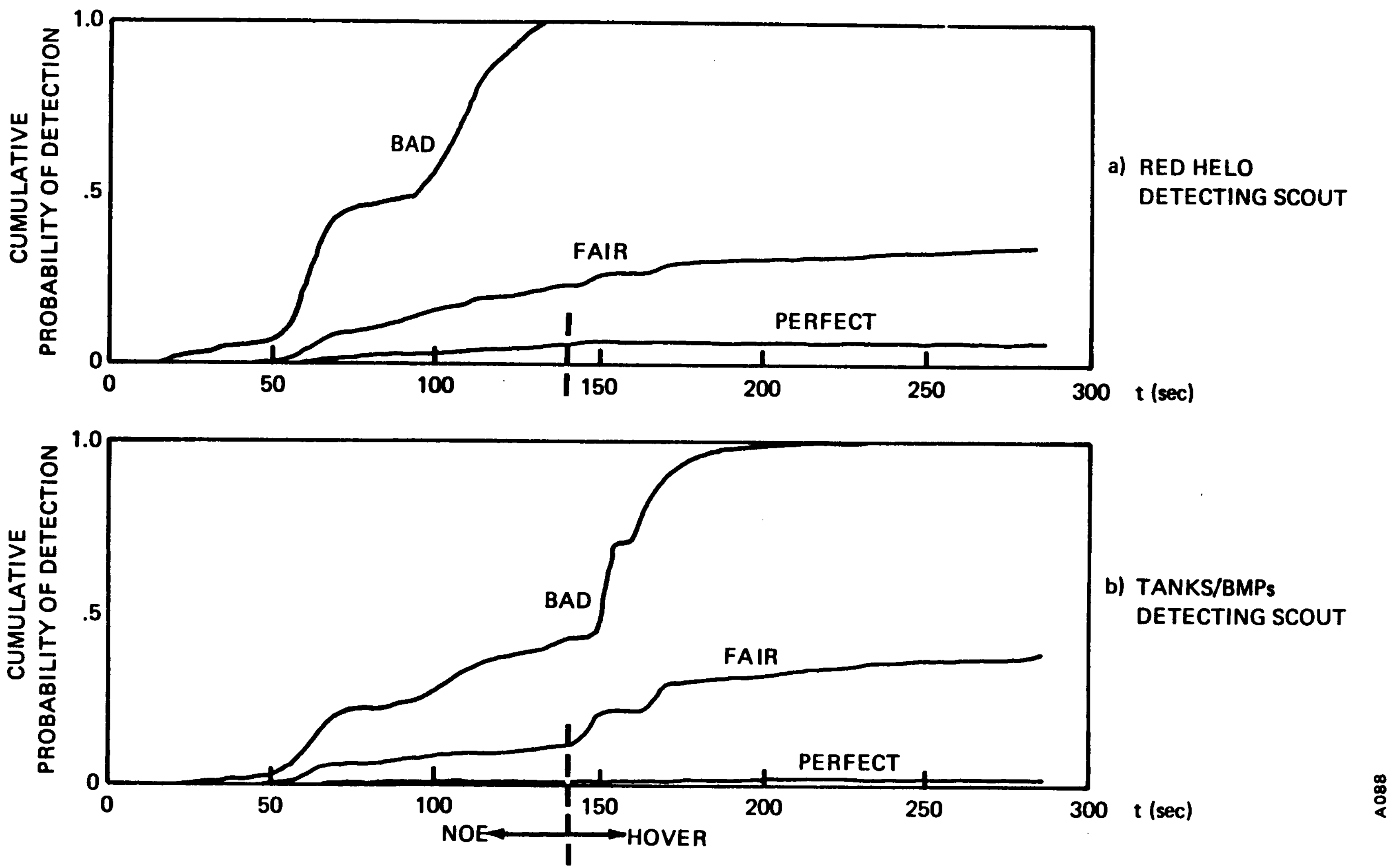


Figure 4-13. Impact of all Parameters Combined on Threat Detection of Scout

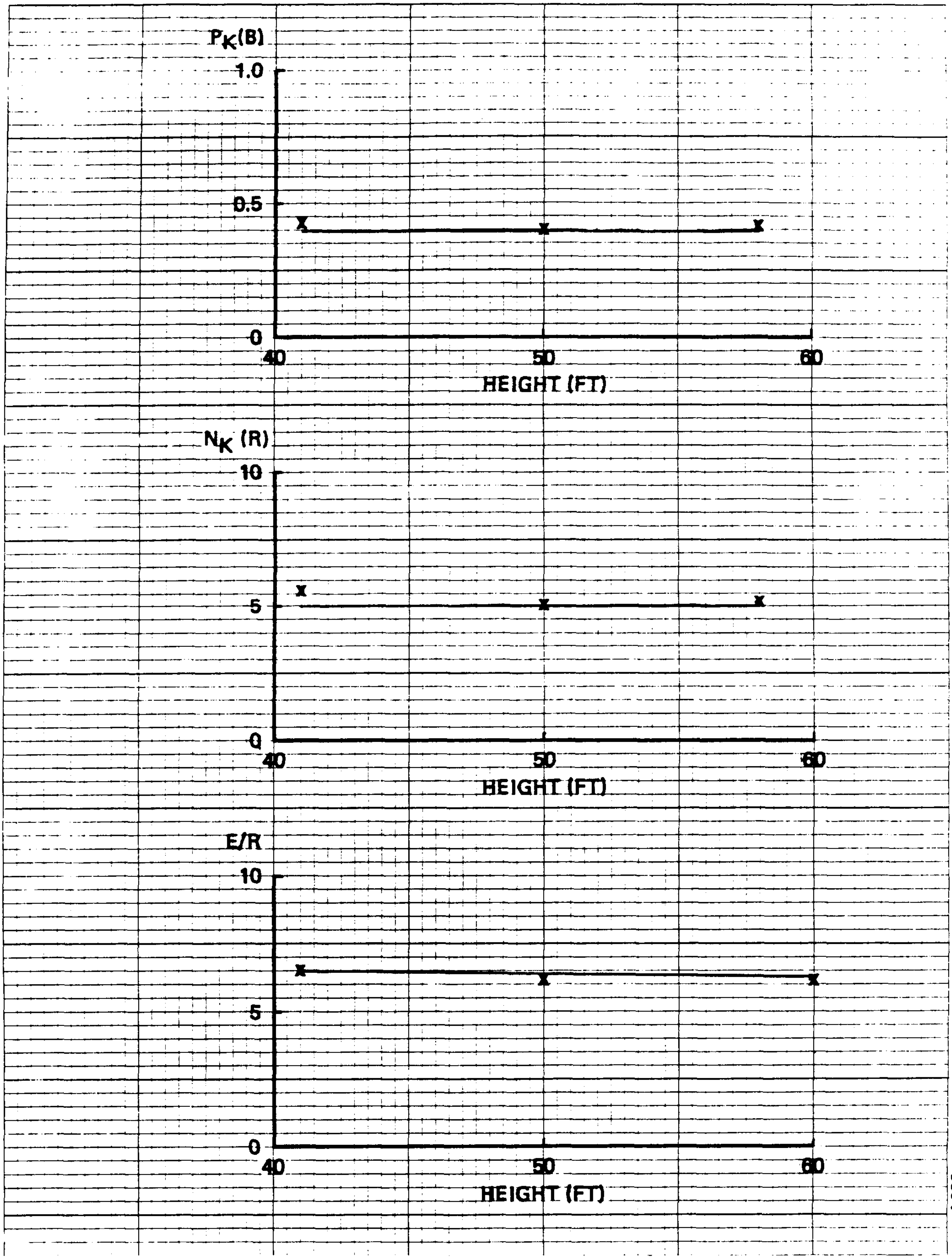


Figure 4-14. Basic NOE Altitude - $P_K(B)$; $N_K(R)$; E/R -

variation in NOE altitude was considered (the 65 foot and 80 foot points were omitted), any variations are lost in the noise and the curves are flat. Thus, to identify the impact of the basic NOE altitude, intermediate measures of effectiveness had to be analyzed.

First, the average time of detection and kill by the Red helicopters was examined, as presented in Figure 4-15. From this figure it can be seen that Scout No. 1 was always detected and killed before Scout No. 2, when it was detected and killed. Average detection and kill times occurred earlier for both aircraft as NOE height increased, with the exception of the kill time for Scout No. 2 at 58 feet. The reason for this is not totally clear, but could be related to the fact that as NOE altitude increased, the Red helicopters detected, attacked and killed Scout No. 1 more and more often. Because of this shift in attack, Scout No. 2 was only killed ten percent of the time by the Red helicopters at 58 feet. With this small a sample size, considerable variation in average time of kill is expected, so the shift could be accounted for by noise. On the other hand, the shift in time could be real, being related to the shift in level of intensity of attack. There was also a change in probability, time and intensity of attack by the four ADA units against each of the Scouts. This could well also have been a factor. In summary, although no trends in the basic mission measures of effectiveness are evident, Figure 4-15 does indicate that change in NOE altitude was having many effects, and in general, average detection and kill times by the Red helicopters decreased as Scout NOE altitude increased. It is also evident that there are so many interactions between the two Scouts, the two Red helicopters, the two SAMs and the two AAAs, that to obtain a clear insight into exactly what happened and why is almost impossible, and does little to further the objectives of this program.

Since there are 28 sets of detection statistics for each case [(two Scouts vs. three groups of armor, plus two SAMs, plus two AAAs) x 2 = 2 x 7 x 2 = 28], only a lmited number of sets of data were analyzed, specifically the probability of detection of Red helicopter No. 1 vs. Scout No. 1 and Scout No. 2 for the three NOE altitudes. These data (not presented) show a progression of increased probability of detection as basic NOE height increases similar to that of Scenario 1, and also show the higher probability of the Red helicopters detecting (and killing) Scout No. 1 more than Scout No. 2, which flew a less exposed profile.

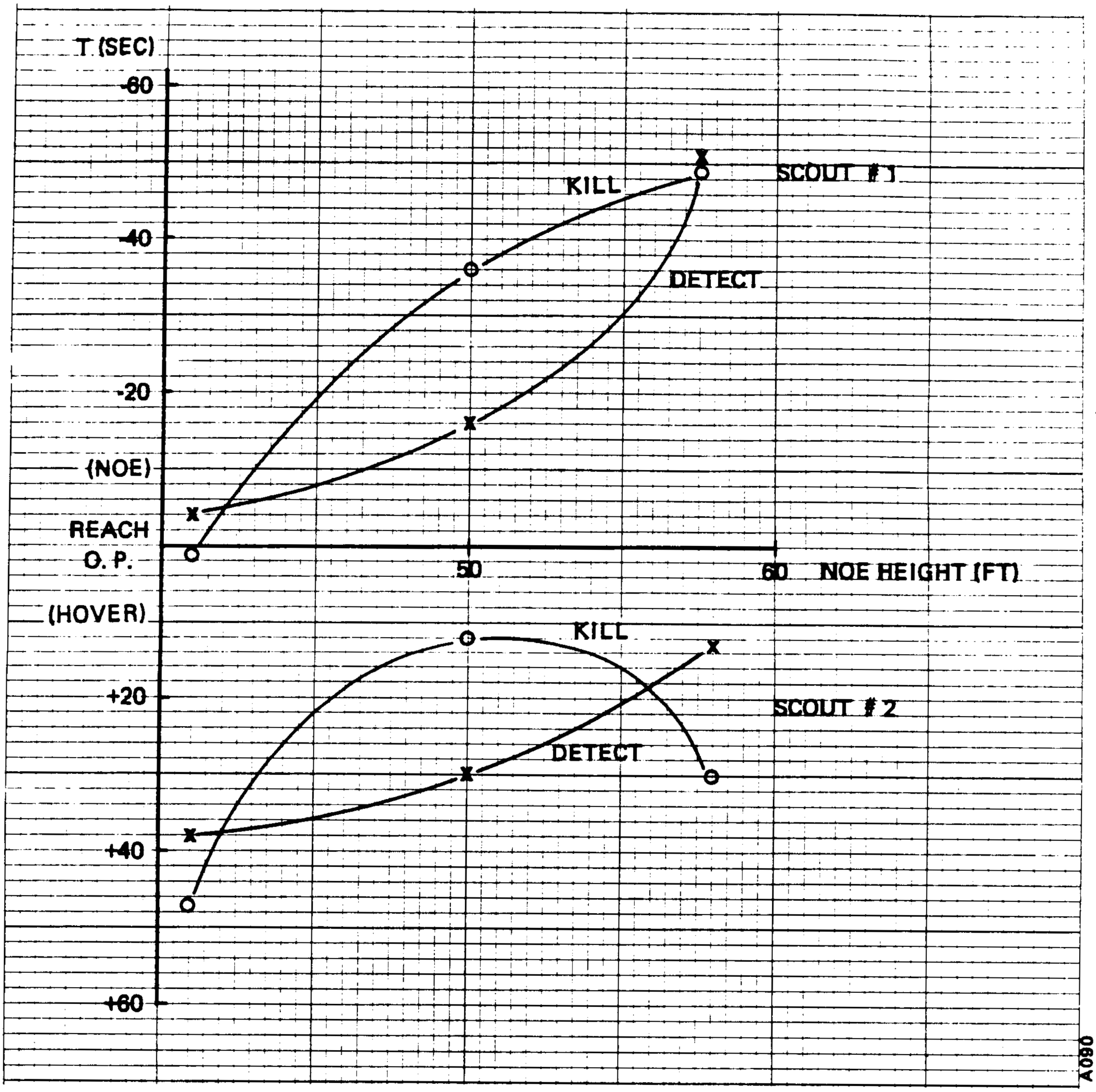


Figure 4-15. Basic NOE Altitude - Average Time of First Detection/Kill by Red Helos

4.3.2 Effect of Statistical NOE Height Variations

Figure 4-16 presents the basic measures of mission effectiveness: $P_K(B)$, $N_K(R)$ and ER, as the mean height of the Scouts varied between 0 and 30 feet above the basic NOE height of 50 feet. Here, because height variations are much larger and are of a different nature than for the basic NOE height investigation, the change in the primary measures of mission effectiveness are well

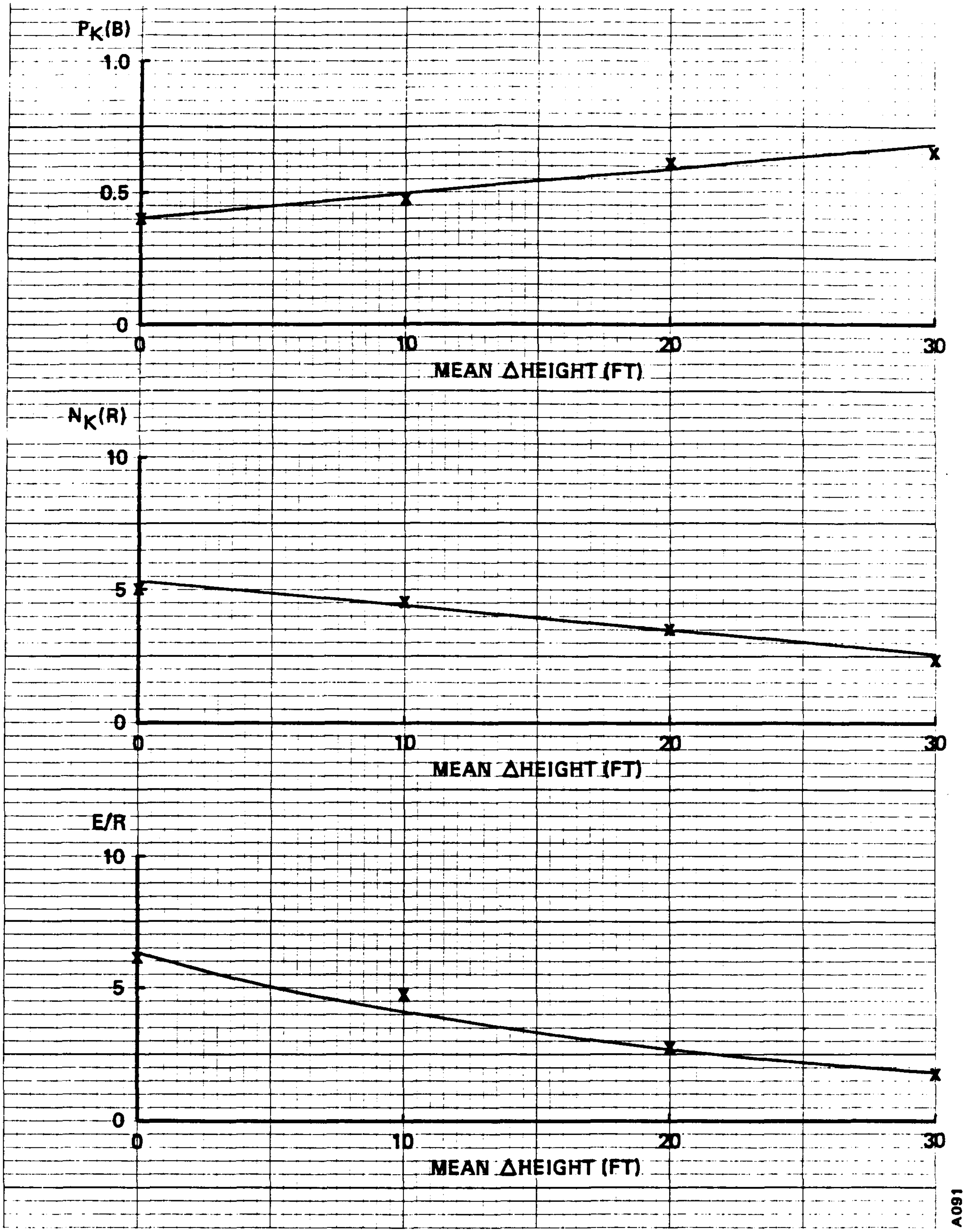


Figure 4-16. Statistical NOE Height Variation
- $P_K(B)$; N_K (R); E/R -

defined. As a matter of fact, the size of the variations are almost exactly the same as for Scenario 3, only the curves are much smoother. As will be recalled, in Scenario 3 there was a large discontinuity between ΔH_{NOE} = 10 and 20 feet, whereas here the curves are essentially linear. This is due to the greater number of players and interactions which has a smoothing effect on the data.

Figure 4-17 presents some intermediate results showing the average time of first detection of each Scout by either Red helicopter, and the average time of first kill by any threat unit. The trends of earlier detection and kill times with increased mean height variation are obvious.

4.3.3 Effect of Statistical Hover Height Variations

Figure 4-18 presents the basic measures of mission effectiveness: $P_K(B)$, $N_K(R)$ and ER, as the mean hover height of the Scouts varied between 0 and 10 feet above the height required to just keep their mast mounted sights exposed. A large variation in the parameters is noted between 0 and 5 feet, but at that point the Scouts are essentially always detected, so little additional variation occurs when the mean hover height variation equals 10 feet. This is consistent with the Scenario 3 results (which only considered variations up to five feet) which showed a very low probability of Scout survival when the mean variation was five feet.

For zero variation, it will be noted that in this scenario the probability of each Scout getting killed is 0.2, whereas in Scenario 3 the probability of the Scout getting killed was 0.1 . Analysis of the attrition matricies indicates that most of the killing was being done by the Red helicopters which killed five times the number of Scouts in Scenario 2 than in Scenario 3. This difference is due to the fact that in Scenario 2 there are two Red helicopters searching for two Scouts, which increases the probability of at least one Red helicopter detecting a Scout by a factor of four. Moreover, with the logic that once a detection is made by a member of a formation, the probability of the other member of the formation detecting is increased (assuming communication between the two), the probability of the Scout being detected is further increased. This increased detection capability, coupled with the increased firepower, explains why the probability of survival against a larger force is poorer, even though the force ratios are the same.

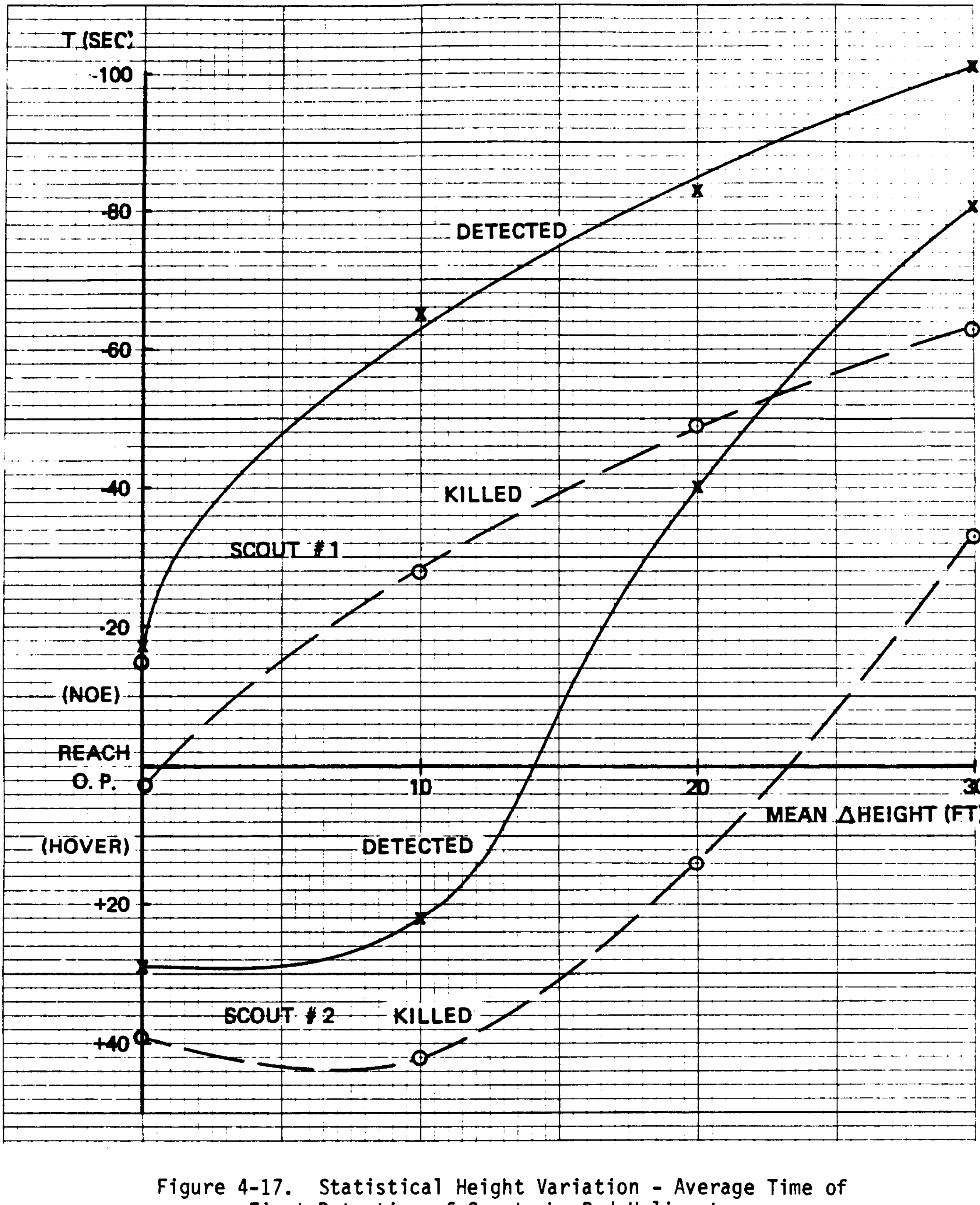


Figure 4-17. Statistical Height Variation - Average Time of
First Detection of Scouts by Red Helicopters
and of Kill by any Threat Unit

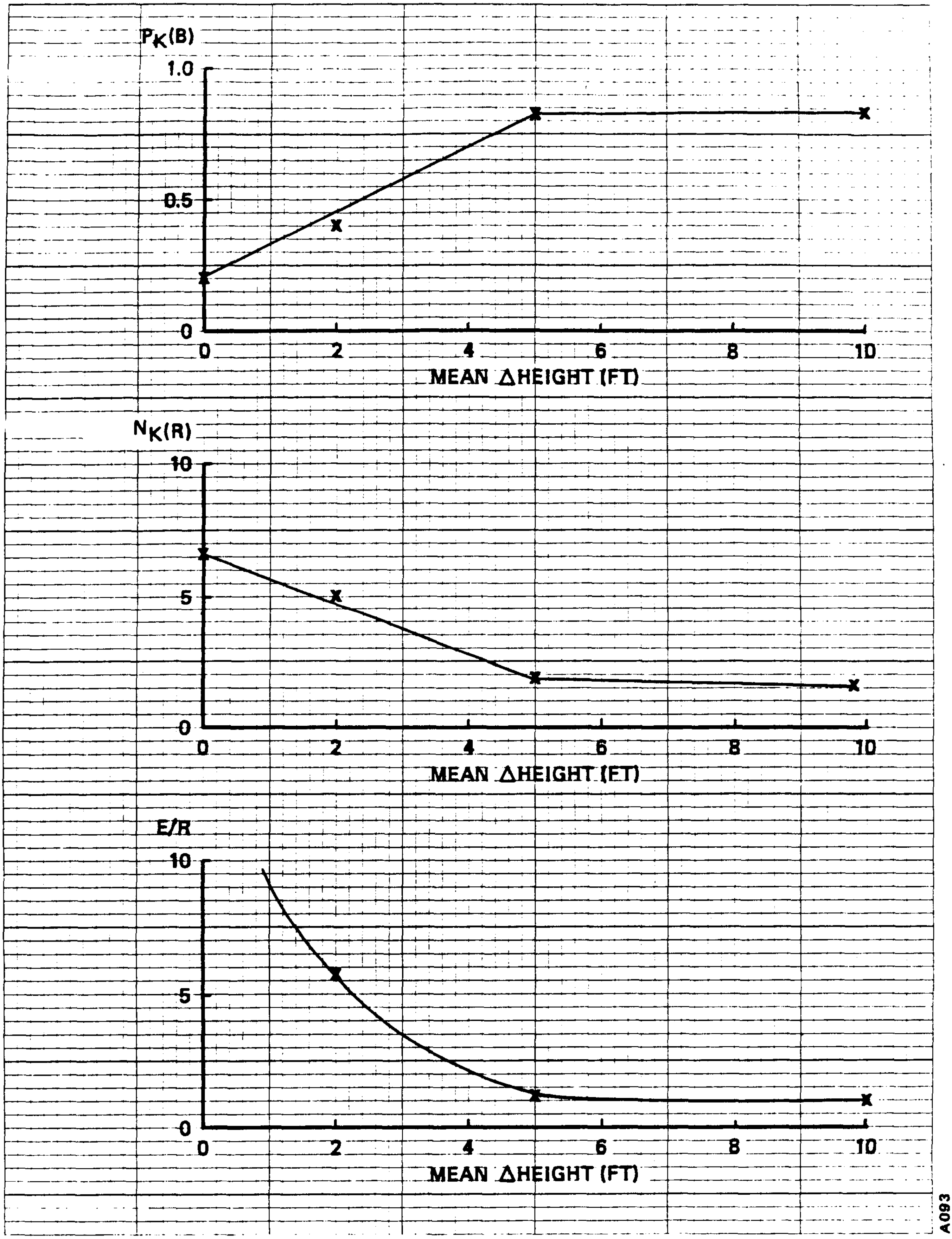


Figure 4-18. Statistical Hover Height Variation
- $P_K(B)$; $N_K(R)$; E/R -

4.3.4 Effect of Visual Free Time

Figure 4-19 presents the basic measures of mission effectiveness: $P_K(B)$, $N_K(R)$ and ER, as the visual free time of the Scouts varied from 25 percent to 100 percent. As can be readily seen, in this scenario no measurable variation in mission effectiveness occurred as a function of visual free time. The reason for this is that in this scenario there were not only a large number of armored vehicles that were close to the observation points, but they had high contrast. Because of this the Scouts always detected the armor regardless of the value of VFT.

The other effect of VFT is defensive in nature. Specifically, the simulation has logic that decreases the probability of one element detecting another if the other element detects it first. Thus, as visual free time increased, the probability of the Scouts detecting the Red helicopters increased, hence the probability of the Red helicopters detecting the Scouts decreased. This is illustrated in Figure 4-20. Since the change in probabilities were not large, the effect of this factor on the primary MOEs was lost in the noise.

In summary, if objects are very easy to detect (specifically, the armored formations in Scenario 2), then little variation in measures of effectiveness with VFT are to be expected. On the other hand, if objects are difficult to detect (specifically the armored units in Scenario 3 which were fewer in number, were treated individually and had low contrast with their background), then significant variations in measures of effectiveness with VFT are to be expected.

4.3.5 Effect of NOE Flight Condition

Figure 4-21 presents the basic measures of mission effectiveness: $P_K(B)$, $N_K(R)$ and ER, for three NOE speed/altitude combinations. The flight conditions were 30 knots at 14 feet, 50 knots at 41 feet and 80 knots at 69 feet. The level of flying qualities (Grade 1)was the same at each flight condition (reference Figure 3-2).

The purpose of making this set of runs was to give some insight as to the magnitude of variations experienced when other (non-flying qualities) parameters were varied, to put the variations experienced with flying quality parameters in perspective. A second purpose was to assess the speed regime of

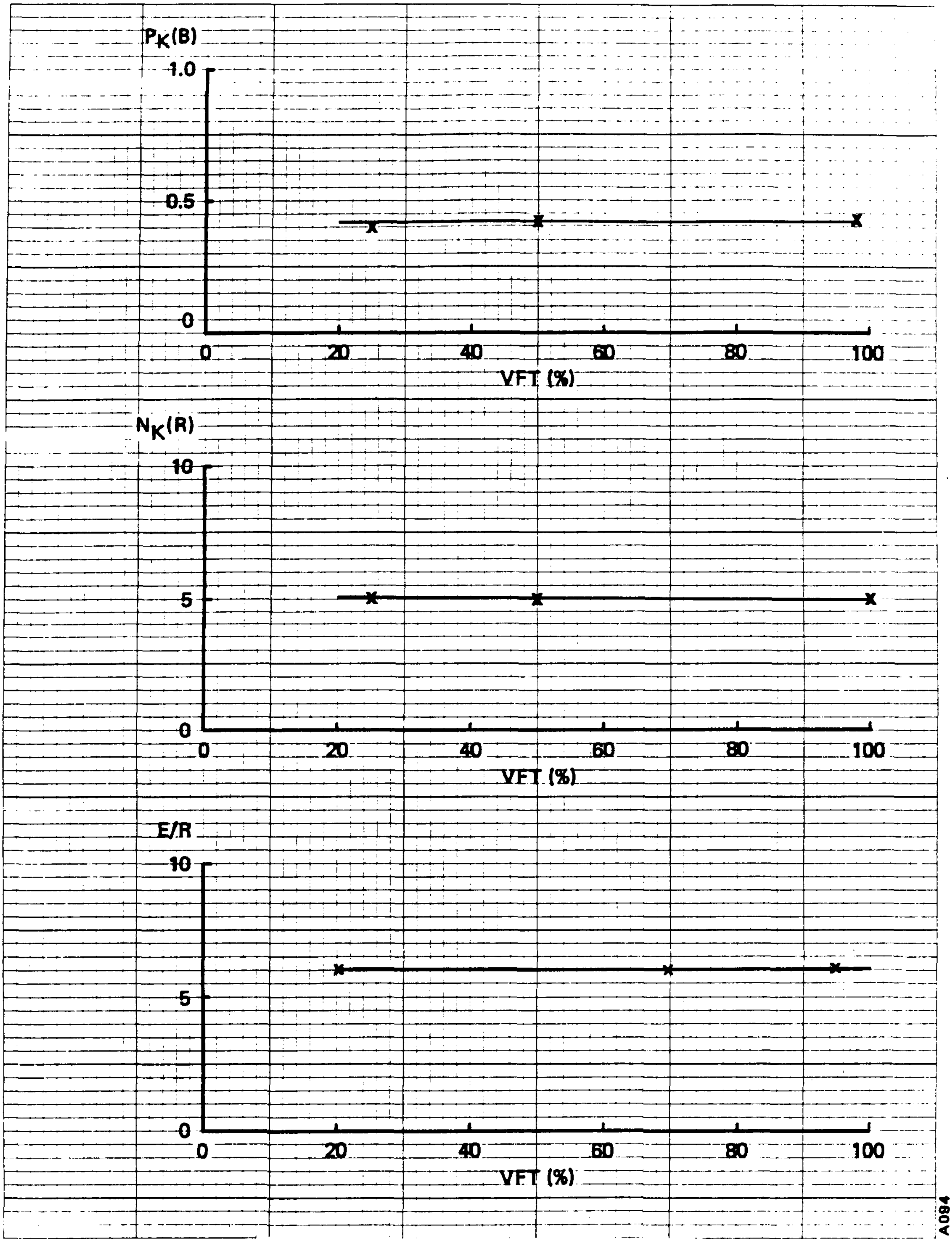


Figure 4-19. Visual Free Time (VFT)
\- $P_K(B)$; $N_K(R)$; E/R -

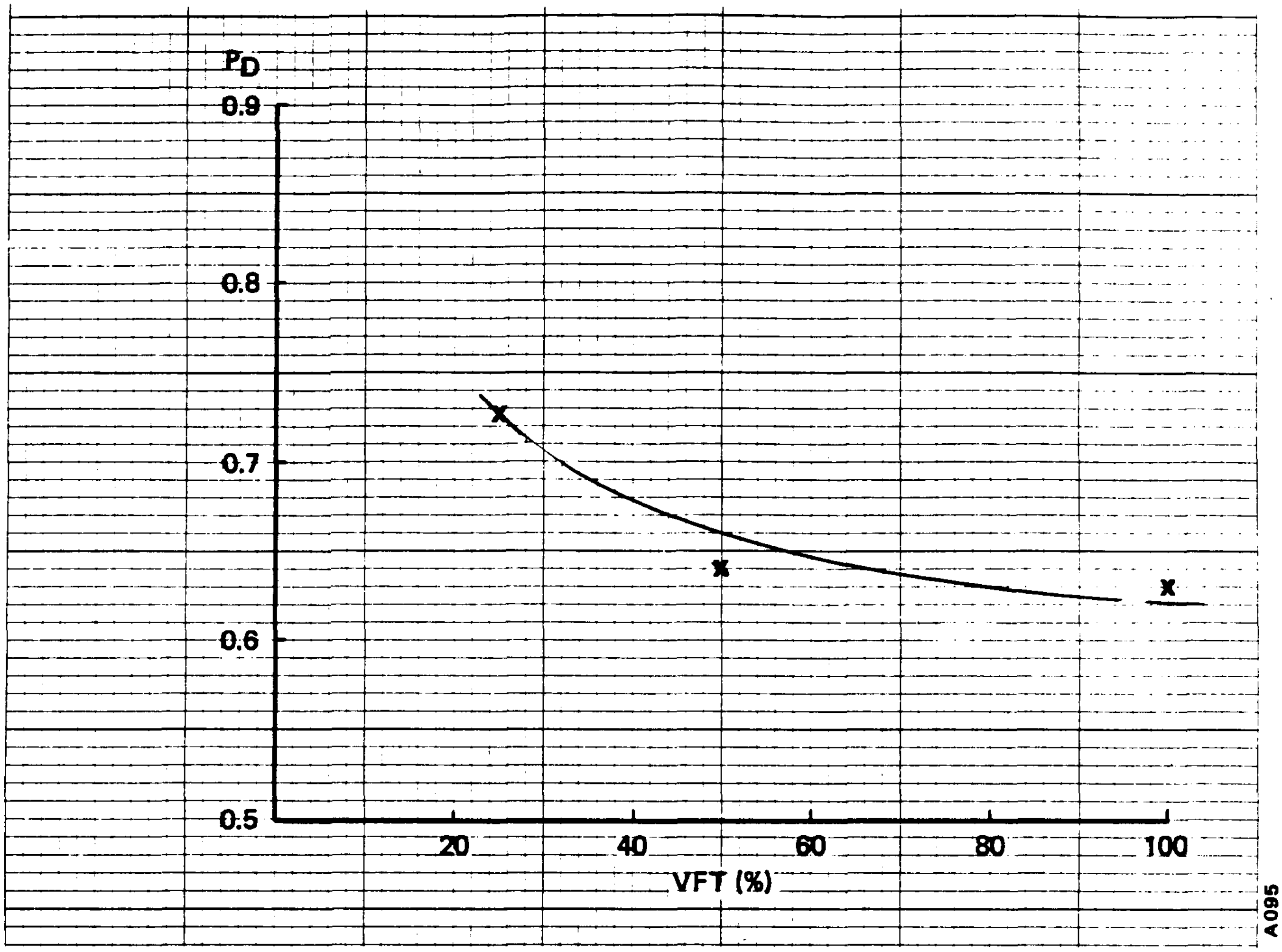


Figure 4-20. Visual Free Time (VFT) Variation - Probability of the Scouts Being Detected by the Red Helicopters

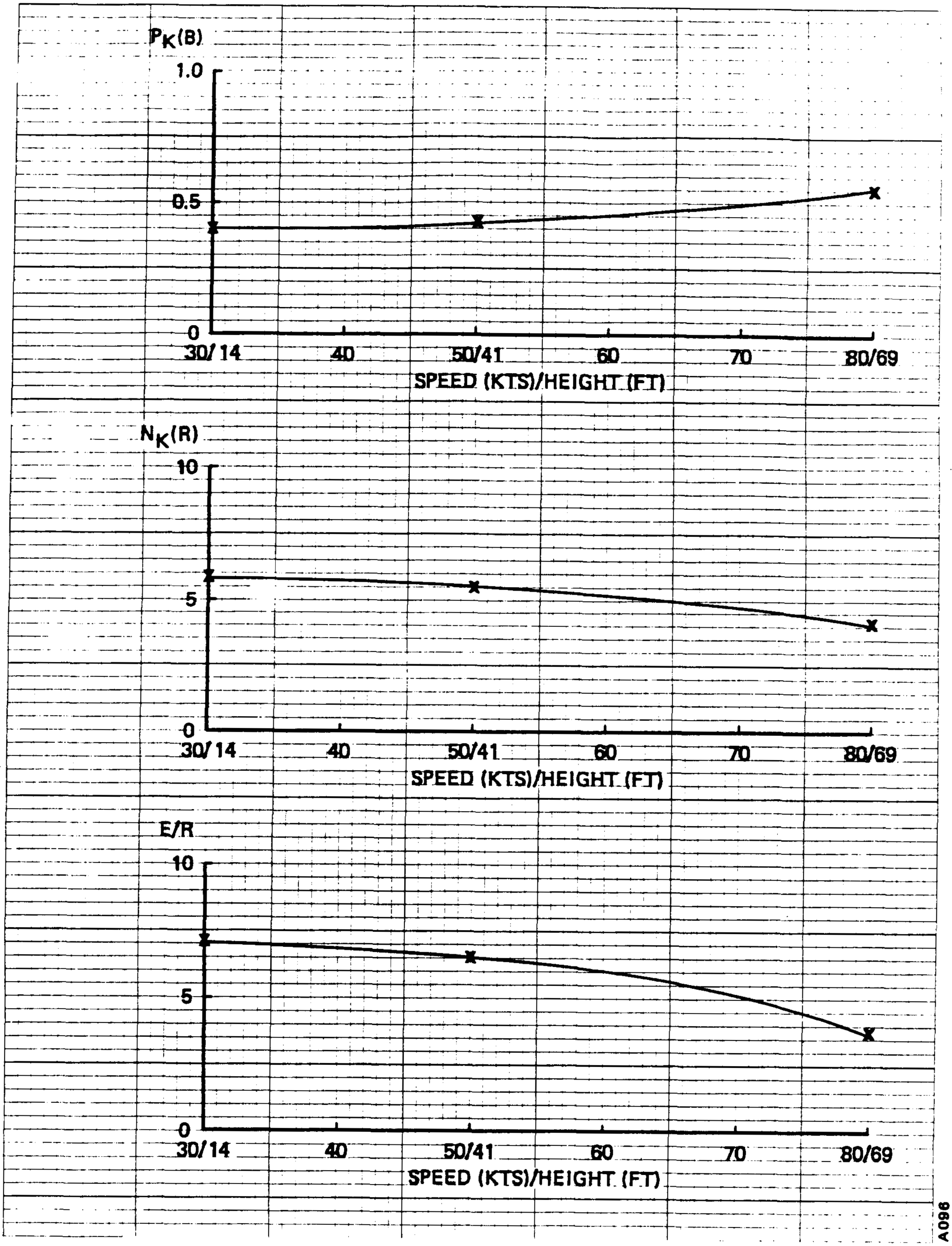


Figure 4-21. NOE Speed and Altitude - P_K(B); N_K(R); E/R -

primary interest. From the curves of Figure 4-21, it can be seen that as the Scouts increased their NOE speed and altitude, their probability of survival decreased. This effect has been noted in other simulation studies. Assuming that this observation is fact, at least over some types of terrain, then the implication is that to have good flying qualities at the higher speeds is certainly no less important than to have good flying qualities at low speed.

4.4 SCENARIO 1 RESULTS

Only a very limited amount of "production" running was done with Scenario 1, since Scenario 1 was used primarily to shake out the program, explore the types of effects that occurred as various flying qualities parameters were varied, and establish the specific parameters to be investigated and their range of variation. Also, at that time no Scout performance data was available so AH-1S data were used instead.

One of the first things that was learned was that the position of attack and tactics employed - while excellent from a military standpoint -did little to show the effects of flying qualities. Specifically, since the Scouts attacked under cover of the hills, wide variations in NOE flight had no effect on the results. The helicopters were hidden from all the threat elements so it didn't matter how they flew. This simply pointed out the obvious, but did nothing to address the question on the impact of flying qualities on mission effectiveness. For that reason, Scenarios 2 and 3 were set up, which were more demanding and more representative of engagement conditions.

Another difference between Scenario 1 and Scenarios 2 and 3 was that in Scenario 1 the Scouts were considered to be armed with two air-to-air missiles. Thus, their tactics called for them to return the fire of the threat helicopters if they were attacked by them. This resulted in a lot of air-to-air engagements, with the Scouts spending little time performing their primary mission of surveillance and directing fire. For that reason, the Scouts were unarmed in Scenarios 2 and 3.

In summary, Scenario 1 was important in setting up more representative scenarios, in establishing flying qualities parameters of interest and in obtaining insight as to the types of effects caused by variations in flying qualities parameters. It also pointed out the obvious importance of employing sound tactics and attacking from a position of strong advantage. Under these highly favorable conditions, flying qualities were not very important. Conversely, the more demanding the mission, the more important good flying qualities became to successful mission accomplishment.

4.5 UTILITY OF RESULTS IN DETERMINING IMPACT OF ROLL RATE

The thrust of this report has been to relate the effects of flying qualities parameters, such as precision of flight path control, to mission effectiveness. To directly relate the impact of flying qualities parameters to mission effectiveness, the impact of flying qualities parameters must be quantitatively related to their effects. As an example of how this can be done, this section relates the impact of steady state roll rate on basic NOE height, then from the results of Section 4.2.1, directly relates the impact of roll rate to mission effectiveness.

The analysis is presented in full in Appendix C. In short, the following steps are taken:

a. The time taken for turn reversals when flying NOE is computed for a range of maximum steady state roll rates for a fixed roll mode time constant.

b. From these times and helicopter speed, turn reversal distances are calculated for the range of roll rates.

c. These turn reversal distances are added to the required distance between micro-terrain features as determined by the basic HACES NOE algorithm.

d. The new required micro-terrain spacings are used to compute new (higher) heights at which the helicopter must fly to avoid striking the micro-terrain features. Thus each roll rate is directly related to a required NOE height.

e. Figure 4-3 is used to compute the probability of the Scout being detected by the Red helicopter for each NOE height/roll rate.

f. Figure 4-22, which relates the probability of the Scout being detected to its steady state roll rate, was constructed from the data obtained in Step e.

Figure 4-22 indicates that, as expected, the greater the steady state roll rate the lower the Scout could fly, hence the lower its probability of being detected. This illustrates the ability to determine the impact, or sensitivity, of specific flying quality parameters to measures of mission effectiveness.

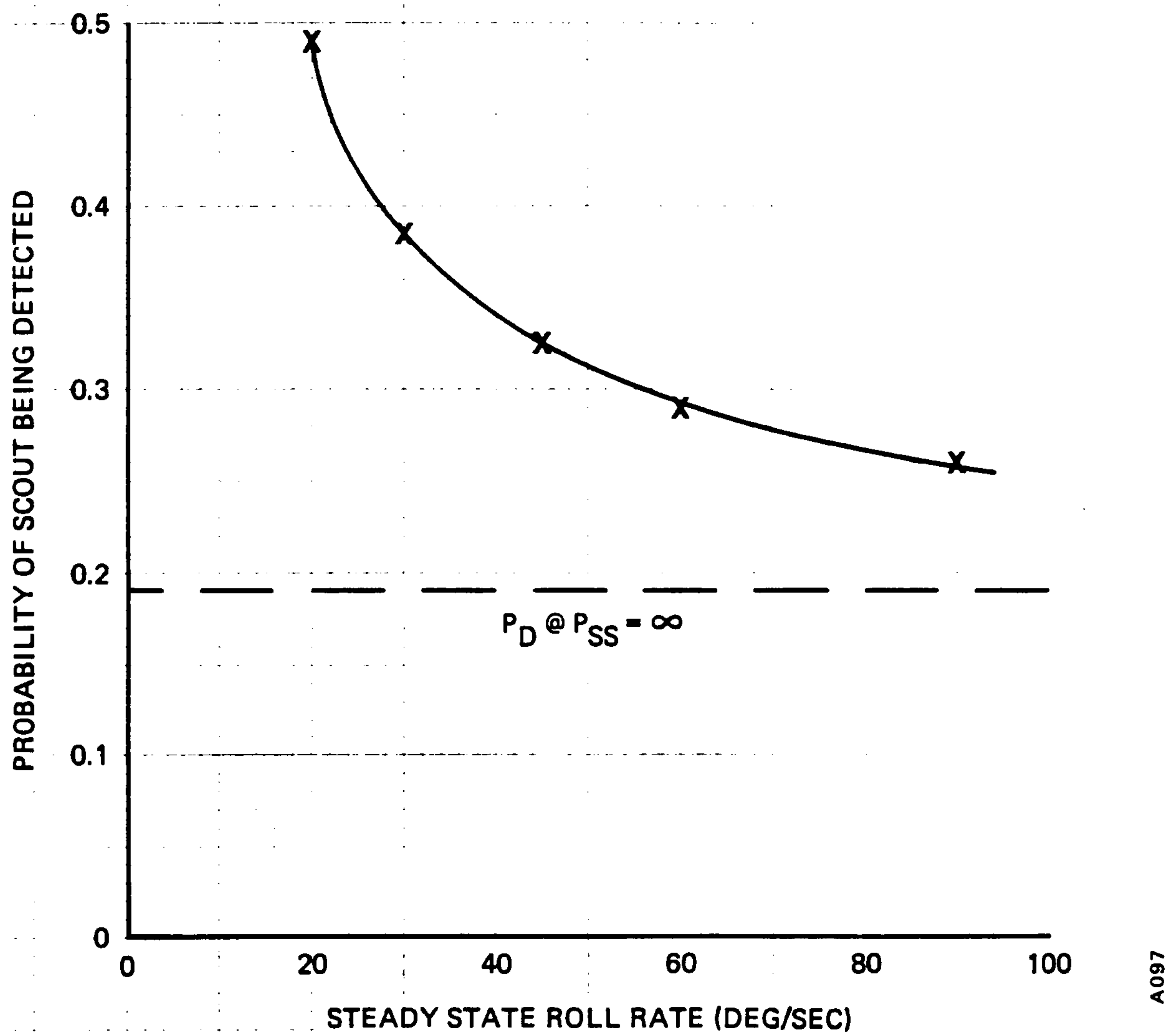


Figure 4-22. Probability of Detection by Red Helicopter as a Function of Roll Rate

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The primary purpose of this study was to determine the feasibility of relating helicopter flying quality parameters to mission effectiveness using a digital combat simulation. In such a simulation, so many factors and elements are considered that no single element can be simulated with a high degree of fidelity - often just "effects" are simulated. Since this holds for modeling of the helicopters as well as other elements, the problem has to be broken into two parts. First, the relationship between flying qualities parameters and such effects as precision of flight path control, NOE speed-altitude relationships and visual free time must be established; then the impact of these effects on mission effectiveness must be assessed.

This program concentrated on the latter task, using the unit action Helicopter Air Combat Effectiveness Simulation; HACES. Only one example of relating a flying qualities parameter to an effects parameter was presented (reference Section 4.5 and Appendix C). However, that example demonstrated that specific flying qualities parameters do impact the ability to perform specific mission tasks and that effect can be quantified. To systematically and rigorously relate flying qualities parameters to mission effectiveness will require that many mission tasks in many scenarios be examined, and much more work in determining effects will have to be performed.

The program did more than just show proof of concept; it generated a significant amount of data relating flying qualities effects to the ability to perform several specific mission taks, and permitted the following conclusions to be drawn in context of the scenarios studied:

a. Flying qualities do have a major impact on the ability to perform a specific mission - affecting both primary and intermediate measures of effectiveness.

b. The impact of flying qualities on mission effectiveness resulted primarily from the impact on the helicopter's probability of being detected.

c. The flying qualities effect that was most critical to the chosen Scout mission was precision of hover control.

d. The greater the required precision of flight to reduce probability of exposure, the more important good flying qualities become.

e. The data generated in Section 4 can be used to relate specific flying qualities parameters to specific mission tasks.

In summary, a powerful new approach - with attendant tools - is available for relating flying qualities parameters to mission effectiveness and the ability to perform specific mission tasks. Since the results are quantitative, the approach can be used to perform sensitivity studies, trade-off analyses, evaluation of concepts/configurations and in bounding flying qualities criterion.

REFERENCES

1. Strother, Dr. Dora Dougherty, Visual and Manual Workload of the Helicopter Pilot, Presented at the 30th Annual National Forum of the American Helicopter Society, May 1974.

HACES MODIFICATIONS

This study was conducted using the existing Helicopter Air Combat Effectiveness Simulation (HACES), however a number of modifications were necessary to meet specific needs. The following sections discuss the changes made to the HITS and ENGAGE programs of HACES.

1. HITS MODIFICATIONS

The HITS program generates the Blue and Red helicopter flight profiles which are used in the engagement model. The program models the flying characteristics of the desired helicopter type based on performance data. For NOE flight, helicopter maneuverability affects the minimum altitude which can be safely held while maintaining a given speed. To sho the effects of degraded flying qualities, provision was made to decrease the nominal maneuverability. This forces the helicopter to fly at a higher NOE altitude to maintain safe terrain clearance.

1.2 PILOT MODELING

The effect of the pilot in the helicopter control loop was modeled in two ways: firstly, first order filters were applied to the commanded accelerations $\ddot{x}$, $\ddot{y}$, and $\ddot{\psi}$ in forward flight, and to $\ddot{z}$ and $\ddot{x}$ in hover. Previously, these commands consisted of the error between the actual state and desired state, multiplied by a gain factor. The lag that was introduced models the effect that humans cannot respond instantaneously to correct system errors.

Secondly, the simulation was modified so that the state erro sampling rate (hence commands) could be delayed. This effectively simulates a pilot with increased workload. In flying a prescribed profile, the pilot must continuously visually check his flight, path and instruments and make appropriate corrections. As his overall workload increases, the pilot's sample rate decreases.

These modifications were implemented and verified, however, when typical values for the filters, and the sample rate delay were introduced, the HITS simulation went unstable. This was probably due to the fact that the lags and higher-order system created by the additional filters could not be handled at the current simulation frame rate. A fix can be effected by modifying the frame rate and fine tuning all of the system filter characteristics. It was determined to leave out the pilot model for the purposes of this study.

2. ENGAGE MODIFICATIONS

The ENGAGE program produces th scenario detection statistics, performs Monte Carlo engagement sequences, and summarizes the results.

2.1 ALTITUDE VARIATION

The HITS program provides a baseline flight profile with NOE and hover modes of flight. The ENGAGE simulation superimposes noise on the altitude profile to model the effect of varying precision of altitude-hold capability. Different noise magnitudes are used during NOE and hover since the flight characteristics are different.

The noise model consists of Rayleigh-distributed random variables which are passed through a first-order filter to smooth the resulting altitude profile. The altitude deviations from the nominal profile is, by necessity, always positive (up).

During hover the mast-mounted sight must maintain a continuous line of sight in order to designate the target. The helicopter will fly as low into cover as possible, but any altitude deviations must be up only. During NOE flight an absolute minimum altitude must be maintained to avoid striking obstacles. Again, any errors must be up only.

Using this noise model, each Monte Carlo run produces a slightly different profile. As the helicopter altitude changes, the detection statistics, and hence the attrition by air and ground forces, change.

2.2 PROBABILITY OF DETECTION

Previously, the nominal HITS profile was used to generate one set of detection statistics. This was done by a separate "DETECT" program, and the results were read into ENGAGE. With altitude noise, the detection statistics must be calculated for each Monte Carlo run. This was accomplished by placing the entire DETECT program within ENGAGE.

With this change, each Monte Carlo run produces a different curve for the probability of detection, corresponding to the geometry of a slightly different altitude profile.

2.3 EXPOSED HELICOPTER AREA

The probability of the scout helicopter being detected by hostile helicopters is a function of the exposed area as well as the relative geometry. Ideally, the Scout will hover within the micro-terrain with only the mast-mounted sight exposed. Without perfect altitude-hold capability, however, the Scout will "bounce" above the observation point, exposing more total area. This makes it more susceptible to detection and more vulnerable to hostile fire.

This effect was modeled and was used when the Scout was hovering at the observation point. The area visible above the micro-terrain is varied as a function of the Scout's altitude and physical height, as well as the height of the micro-terrain.

The exposed area is used to calculate the probability of being visually detected by the hostile helicopters, to vary the radar cross section obtained by the SAM and AAA units, and to vary the vulnerable area.

2.4 VISUAL FREE TIME

In order to make visual detections, the Scout pilot and/or observer must be free to look outside the aircraft, scanning the sector visible from the cockpit.

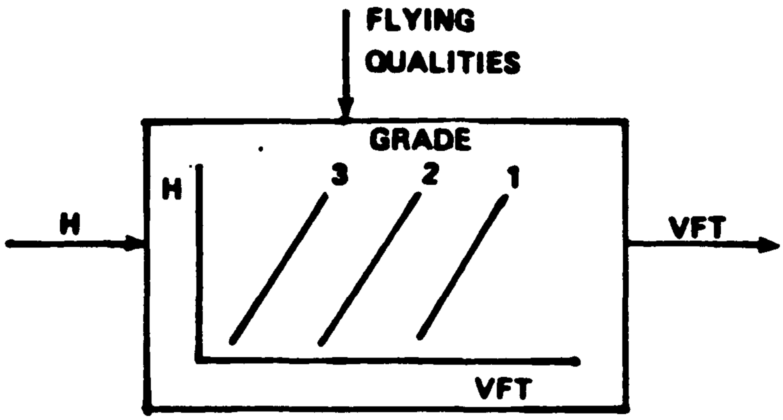
For this study, a variable visual free time (VFT) algorithm was implemented so that as VFT varied, the effective glimpse rate also varied, and the probability of detection changed as a result. The form of the VFT algorithm is shown in Figure 1.

Given a baseline VFT curve (50%, for example) the VFT was modeled to vary slightly with altitude in the range of zero to one hundred feet AGL. Within this range a low altitude yields a lower VFT, and a high altitude yields a higher VFT. This is in accordance with the workload data referenced in Section 3.4.4.

2.5 HELICOPTER TEAM DETECTION LOGIC

For scenarios with more than one Red or Blue helicopter a "team" detection effect was implemented. If any Blue helicopter detects a Red element, the probability of all Blue helicopters detecting that Red element is doubled. This assumes that communications can direct all helicopter to look in the general direction where the first detection was made. The same logic holds for the Red helicopters in trying to detect the Blue helicopters.

- **DATA SHOWS VISUAL FREE TIME A FUNCTION OF FLYING QUALITIES AND HEIGHT**
- **COMPUTATION OF GLIMPSE RATE FOR DETECTION STATISTICS**



$$\text{SCAN TIME} = \frac{\text{SCAN SECTOR}}{\text{SCAN RATE X SCAN RATE FACTOR X VFT}}$$

GLIMPSE RATE = 1/SCAN TIME

Figure 1. Program Modifications - Visual Free Time

Another effect modeled was that if a Blue helicopter detects a Red helicopter, the probability of that Red helicopter detecting any of the Blue helicopters is decreased by a factor of two. This assumes that the Blue helicopters will use the local micro-terrain to greater effect to better conceal their position after the Red helicopter is spotted.

2.6 INTERMEDIATE MOEs

The ENGAGE program nominally prints a summary of the Monte Carlo runs which shows Blue helicopter attrition, the damage inflicted on the Red elements, and the exchange ratio.

For this study several other MOE printouts were necessary to illustrate sensitivities to parameter variations. For Red helicopters detecting Blue helicopters the program now prints the average time of first detection, the average range from the Red column and the number of runs in which Blue was detected. For Blue helicopters detecting the tank groups, the average time of first detection and the number of runs in which detections were made is printed out. For Blue helicopter attrition, the kills by Red helicopters are broken out of the total kills (air and ground elements). The average time of kill, range and number of times killed are printed.

APPENDIX B

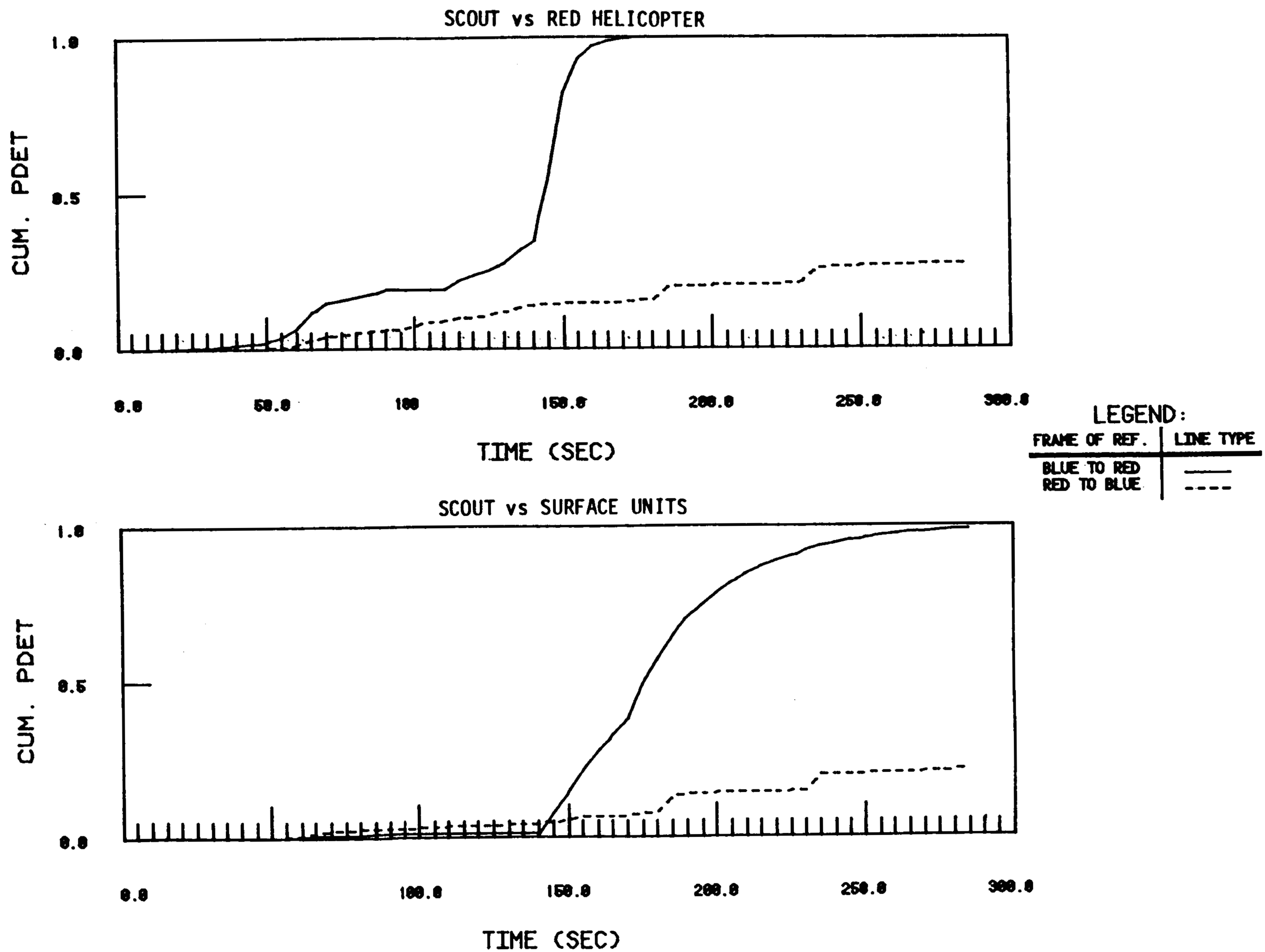
SCENARIO 3 VISUAL DETECTION STATISTICS
SCOUT DETECTING RED HELICOPTER

AND

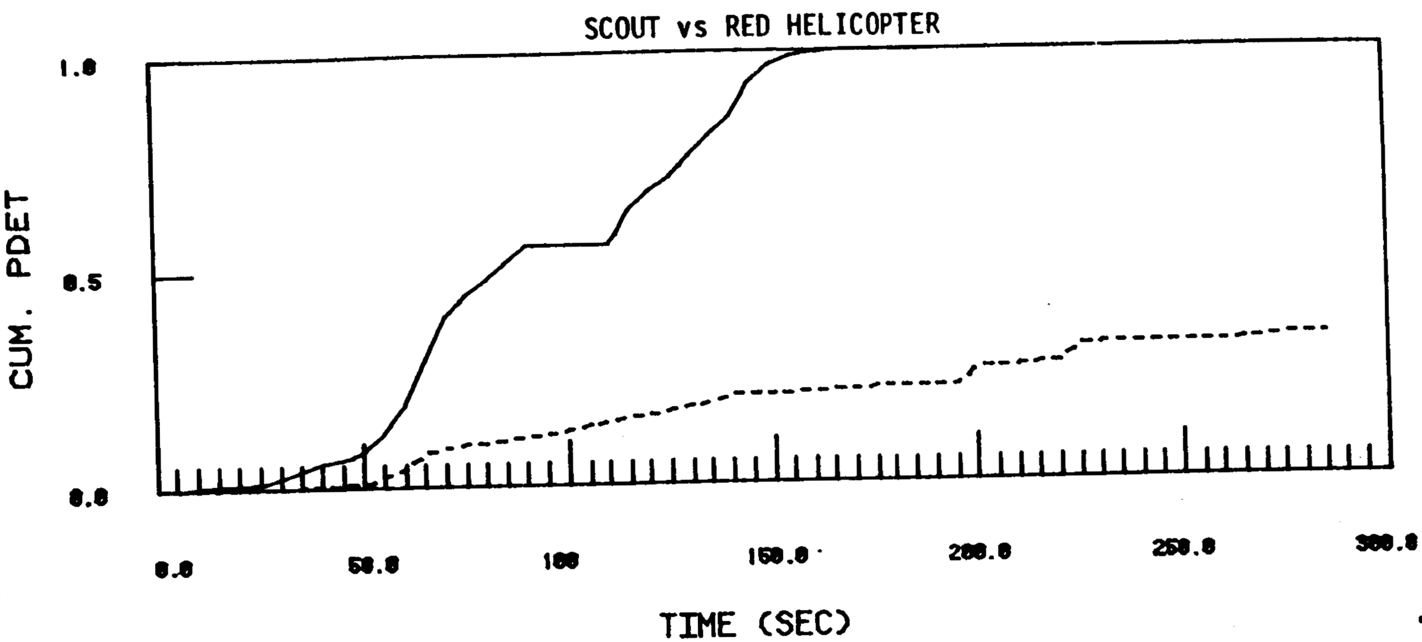
SCOUT DETECTING A TYPICAL SURFACE UNIT (A TANK)

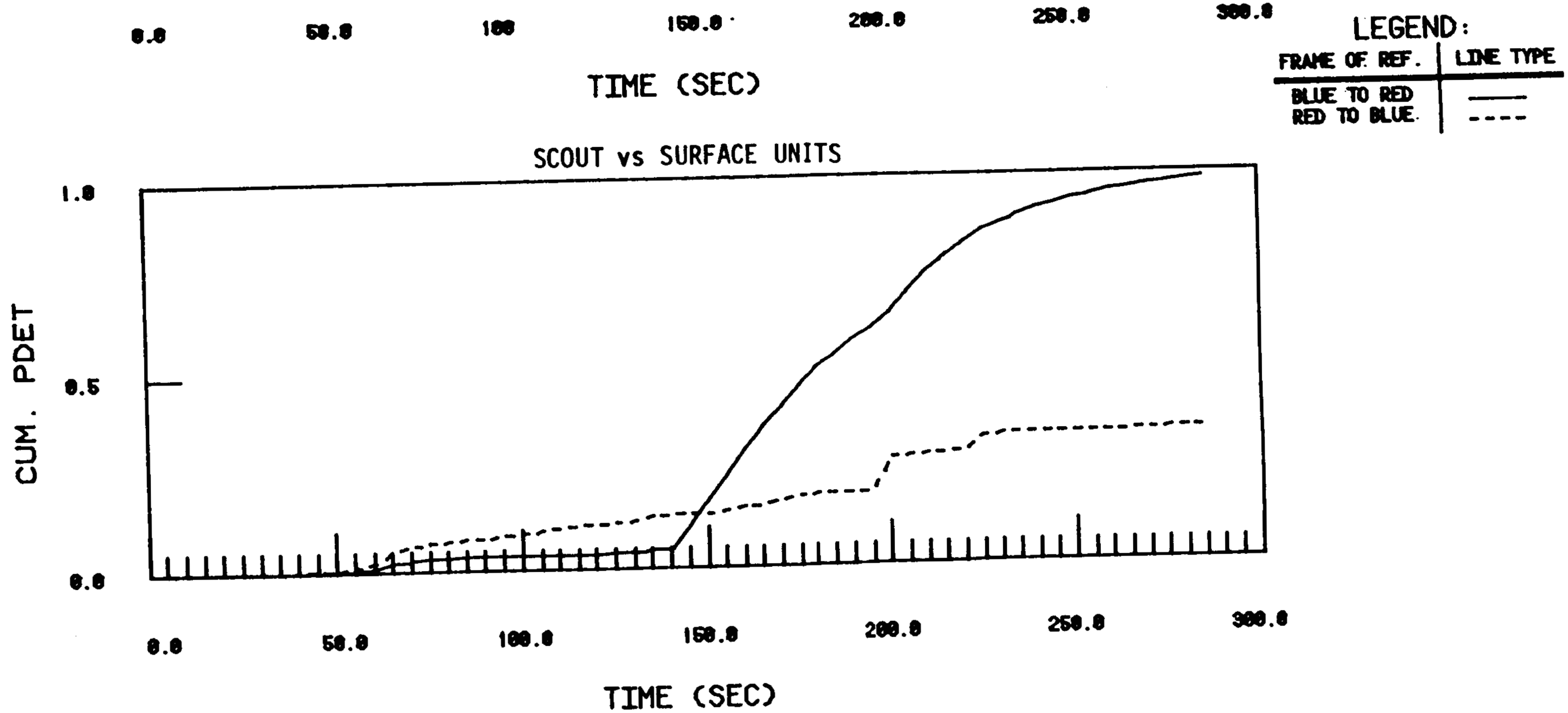
FOR

CASE NUMBERS DEFINED IN TABLE 4-1

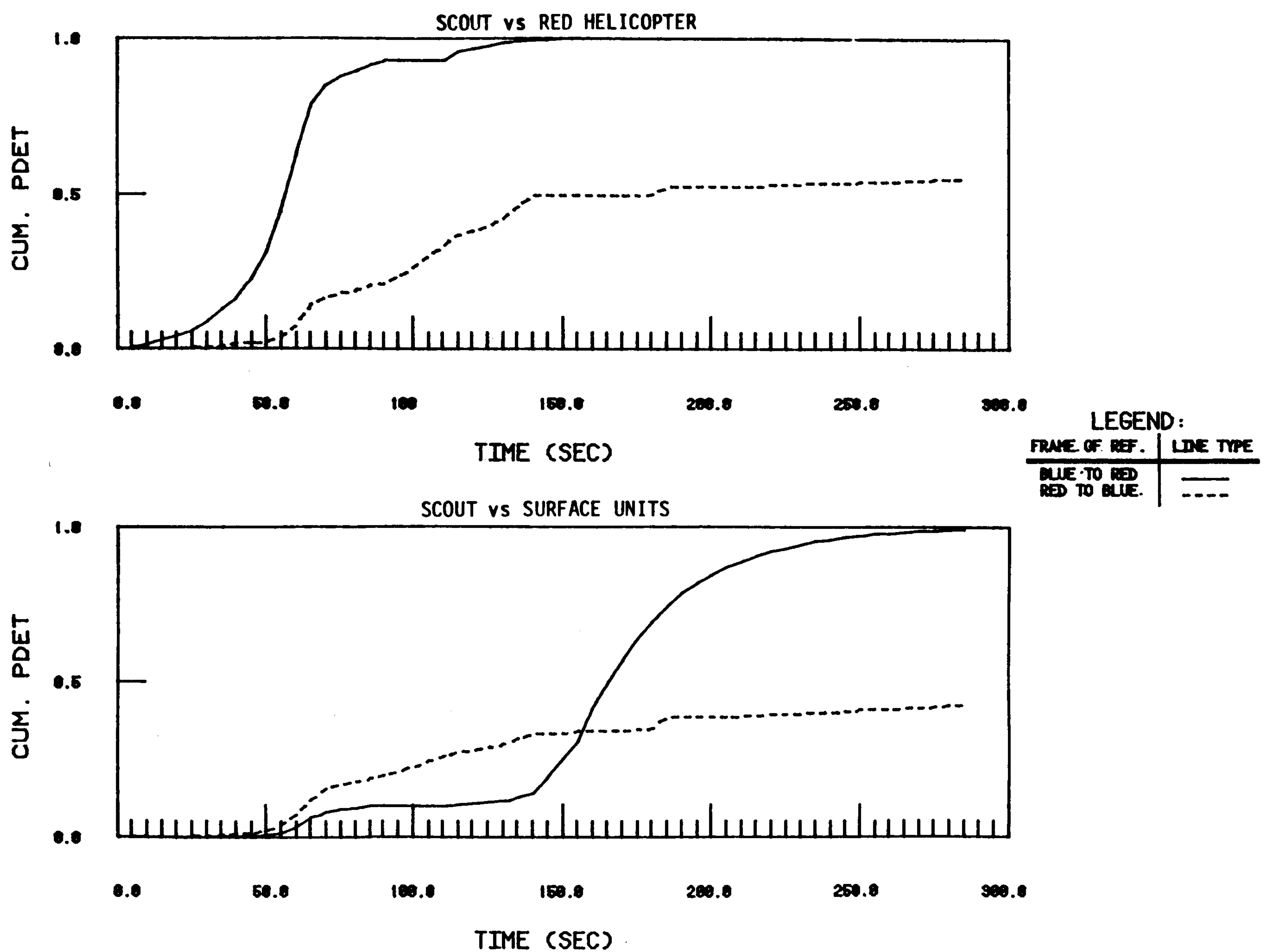


CASE NO. 1: H_{NOE} = 50 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 2 FT; VFT = 50%

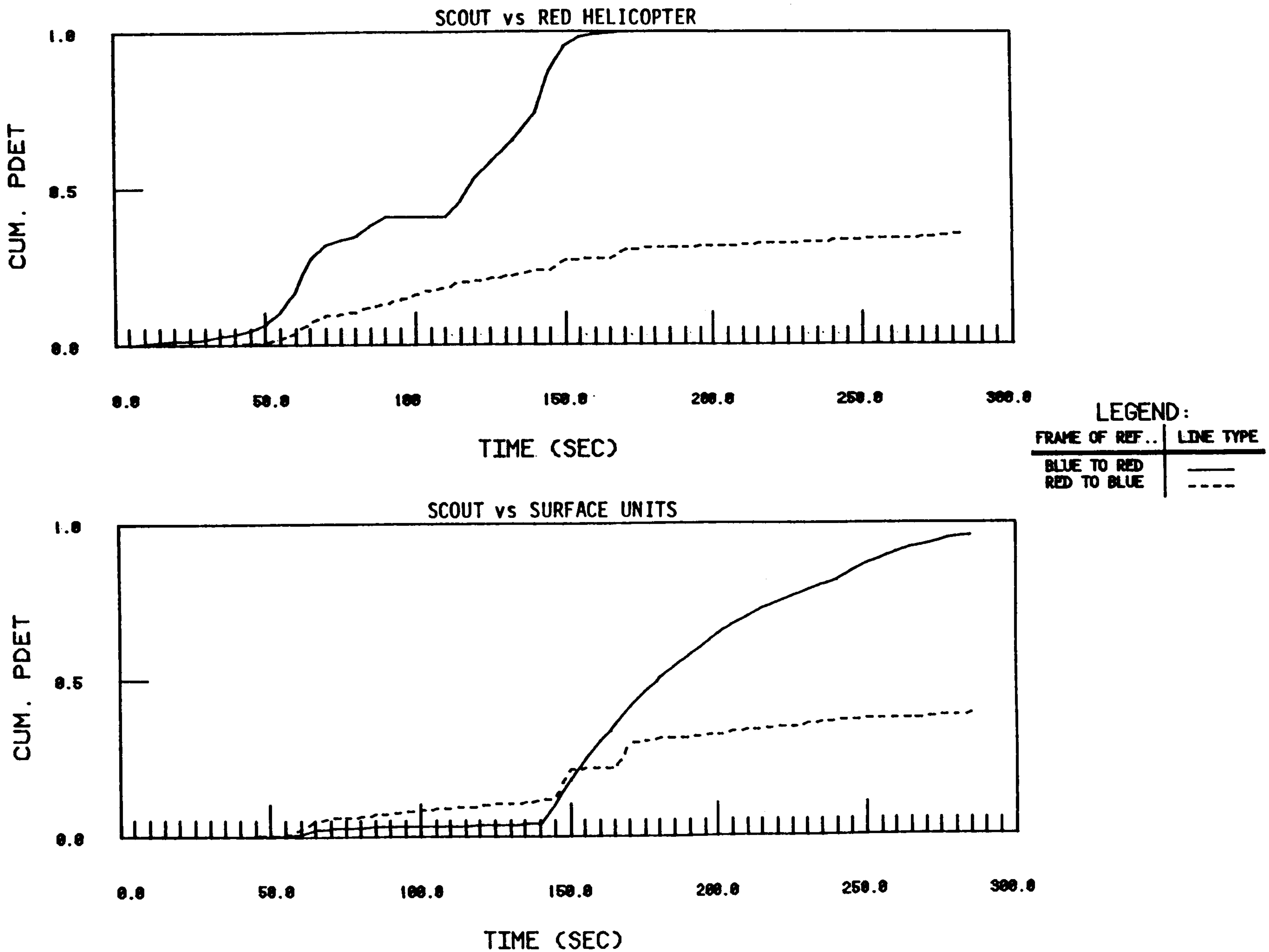




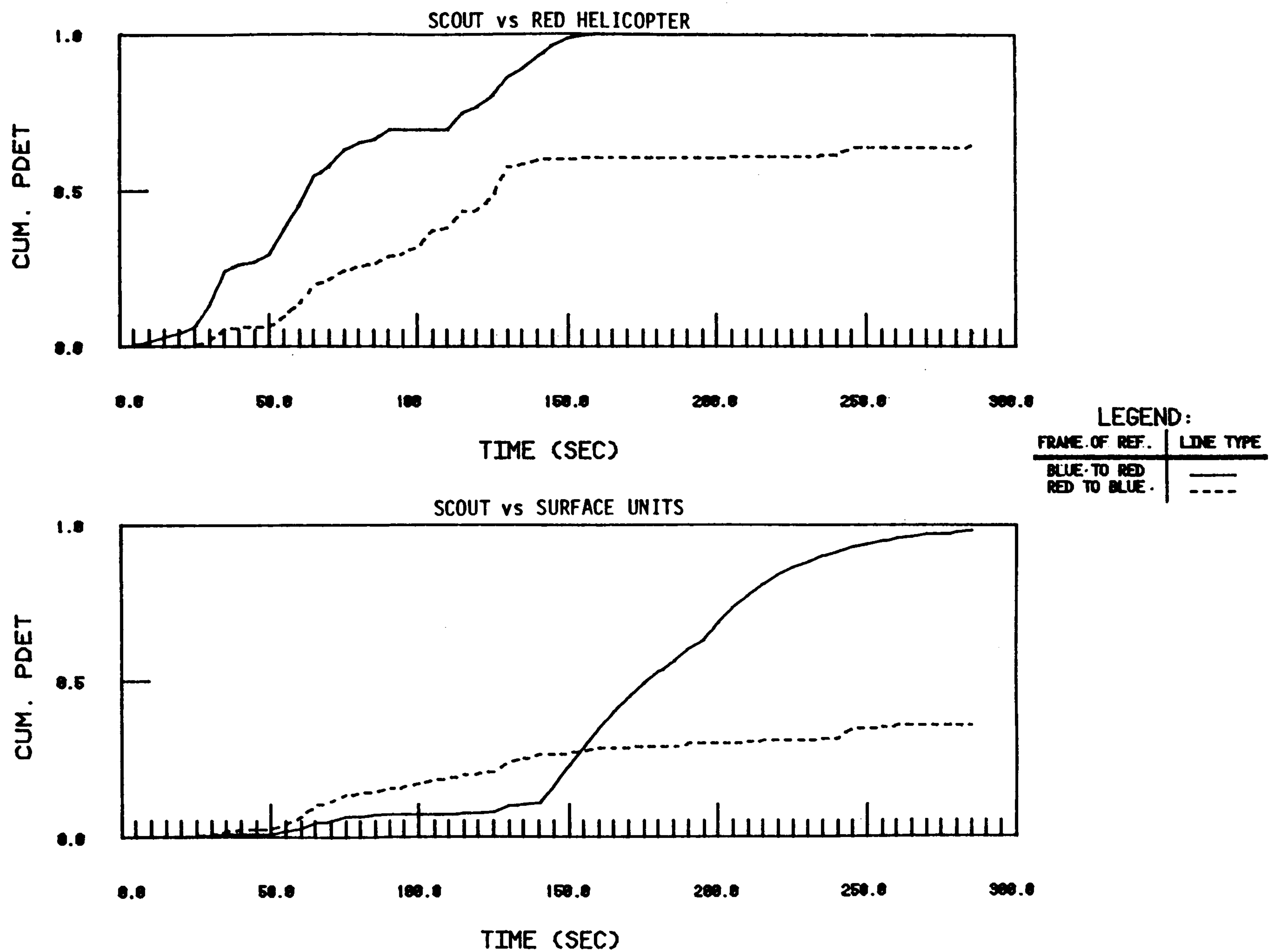
CASE NO. 2: H_{NOE} = 65 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 2 FT; VFT = 50%



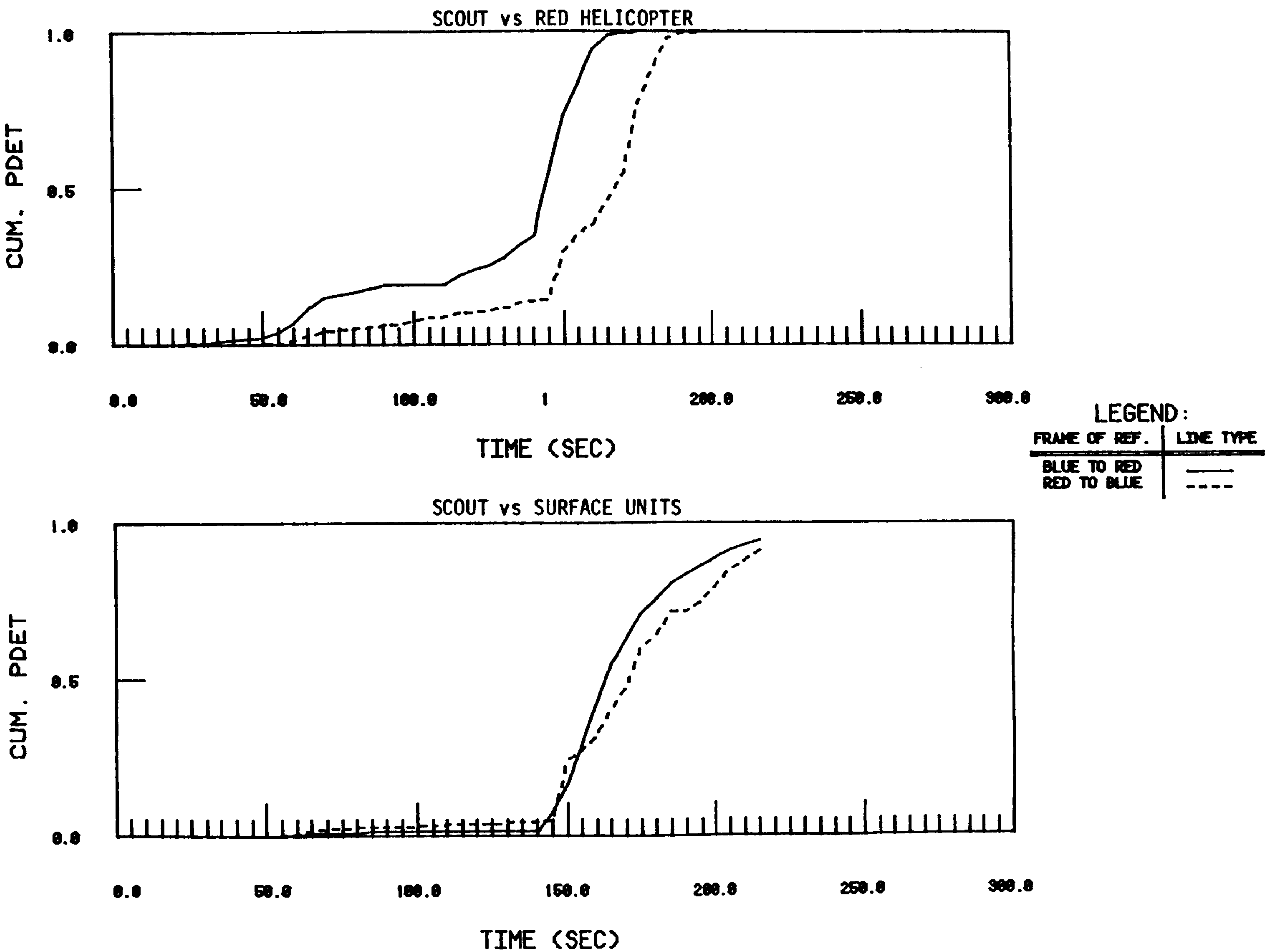
CASE NO. 3: H_{NOE} = 80 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 2 FT; VFT = 50%



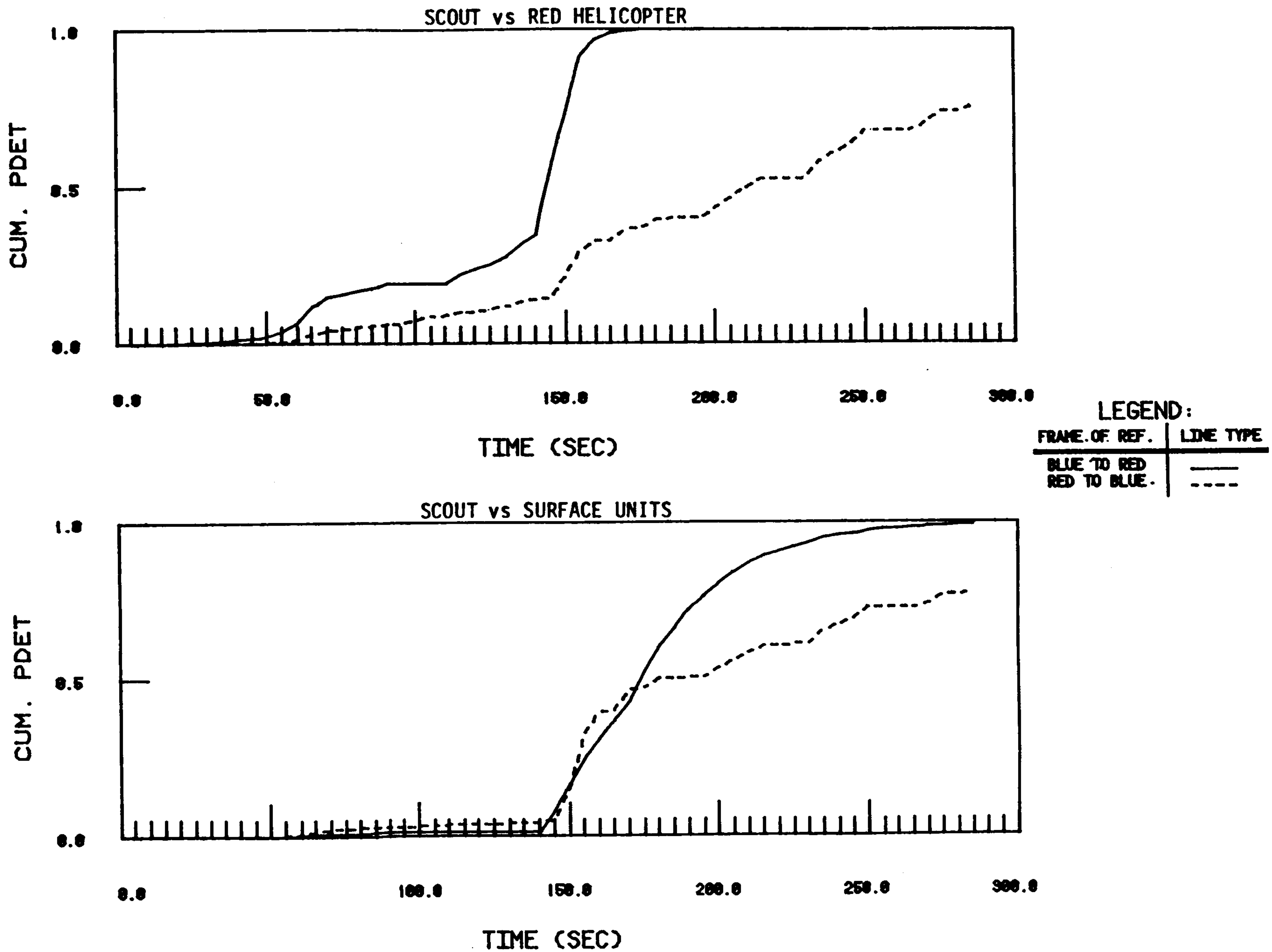
CASE NO. 4: H_{NOE} = 50 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 10 FT; ΔH_{HOV} = 2 FT; VFT = 50%



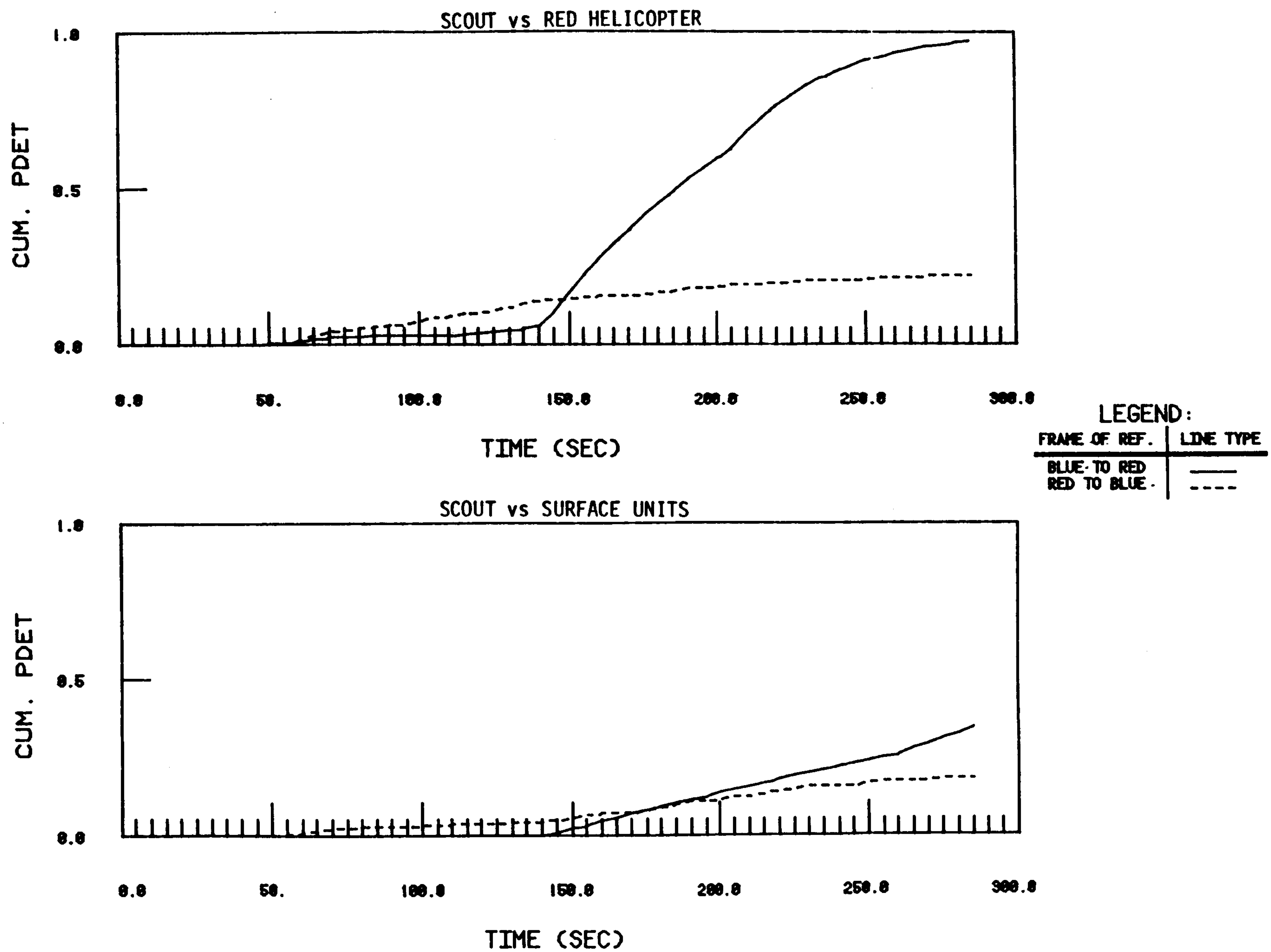
CASE NO. 5: H_{NOE} = 50 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 20 FT; ΔH_{HOV} = 2 FT; VFT = 50%



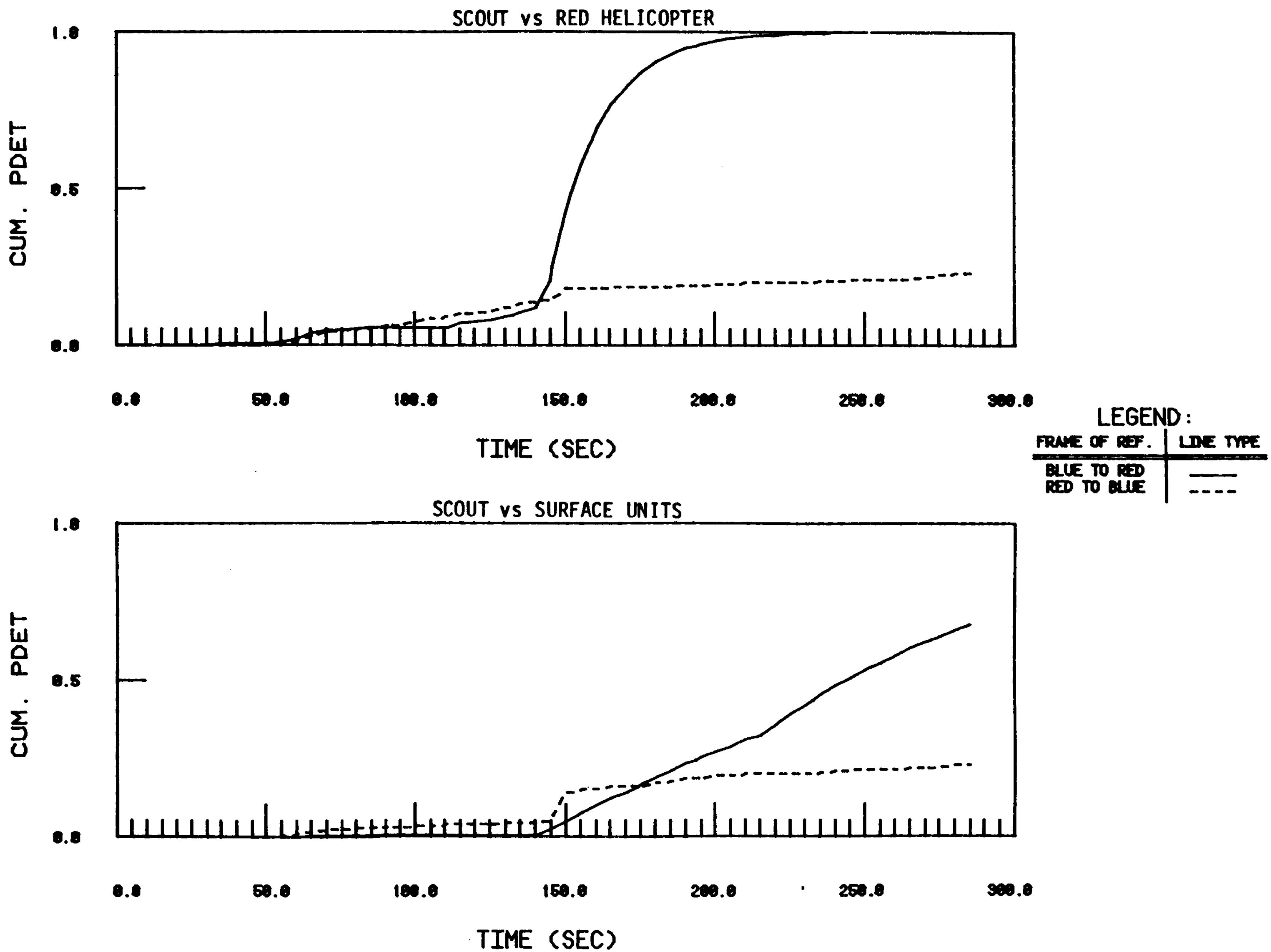
CASE NO. 6: $H_{NOE} = 50$ FT; $V_{NOE} = 50$ KTS; $\Delta H_{NOE} = 0$ FT; $\Delta H_{HOV} = 5$ FT; VFT = 50%



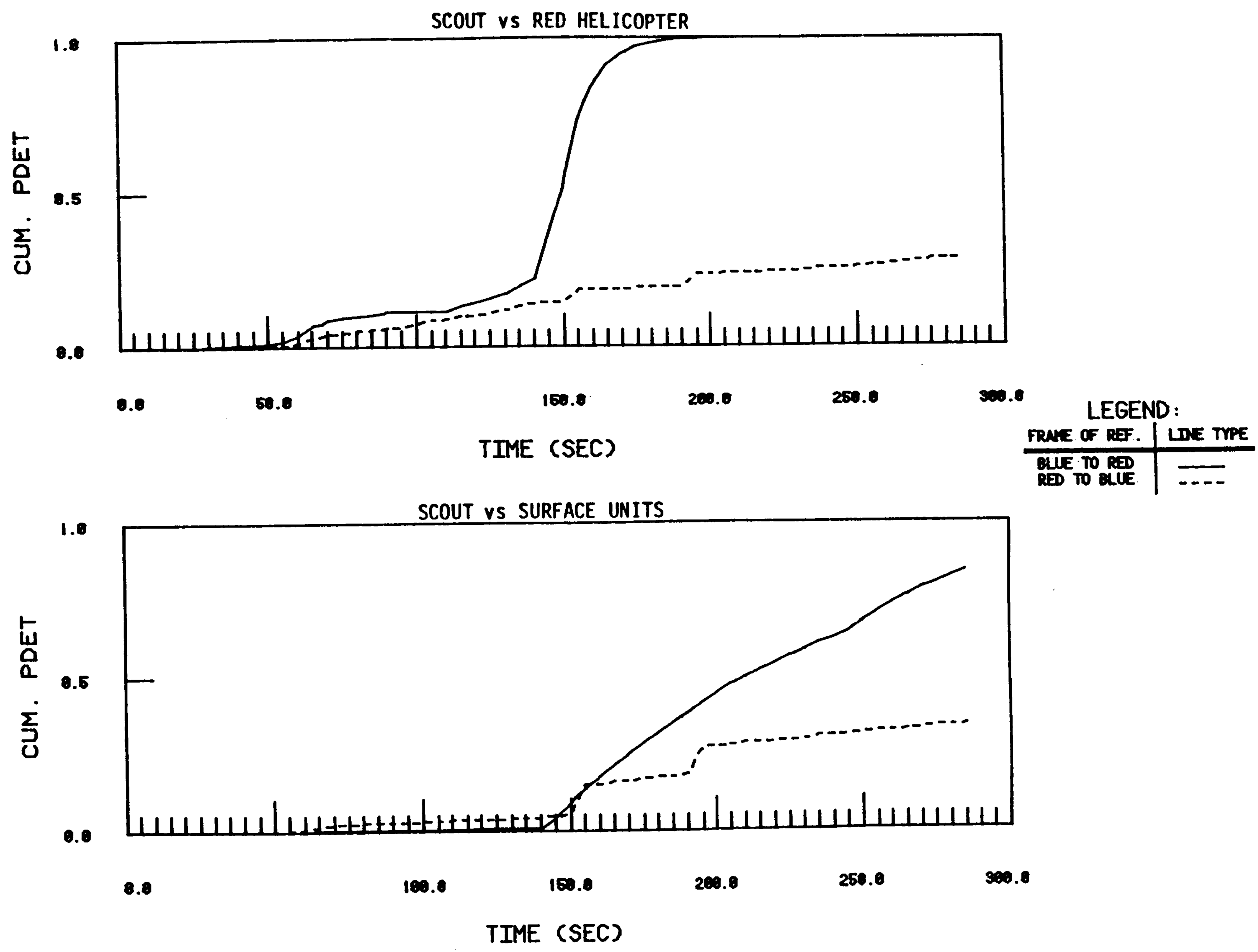
CASE NO. 7: H_{NOE} = 50 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 3.5 FT; VFT = 50%



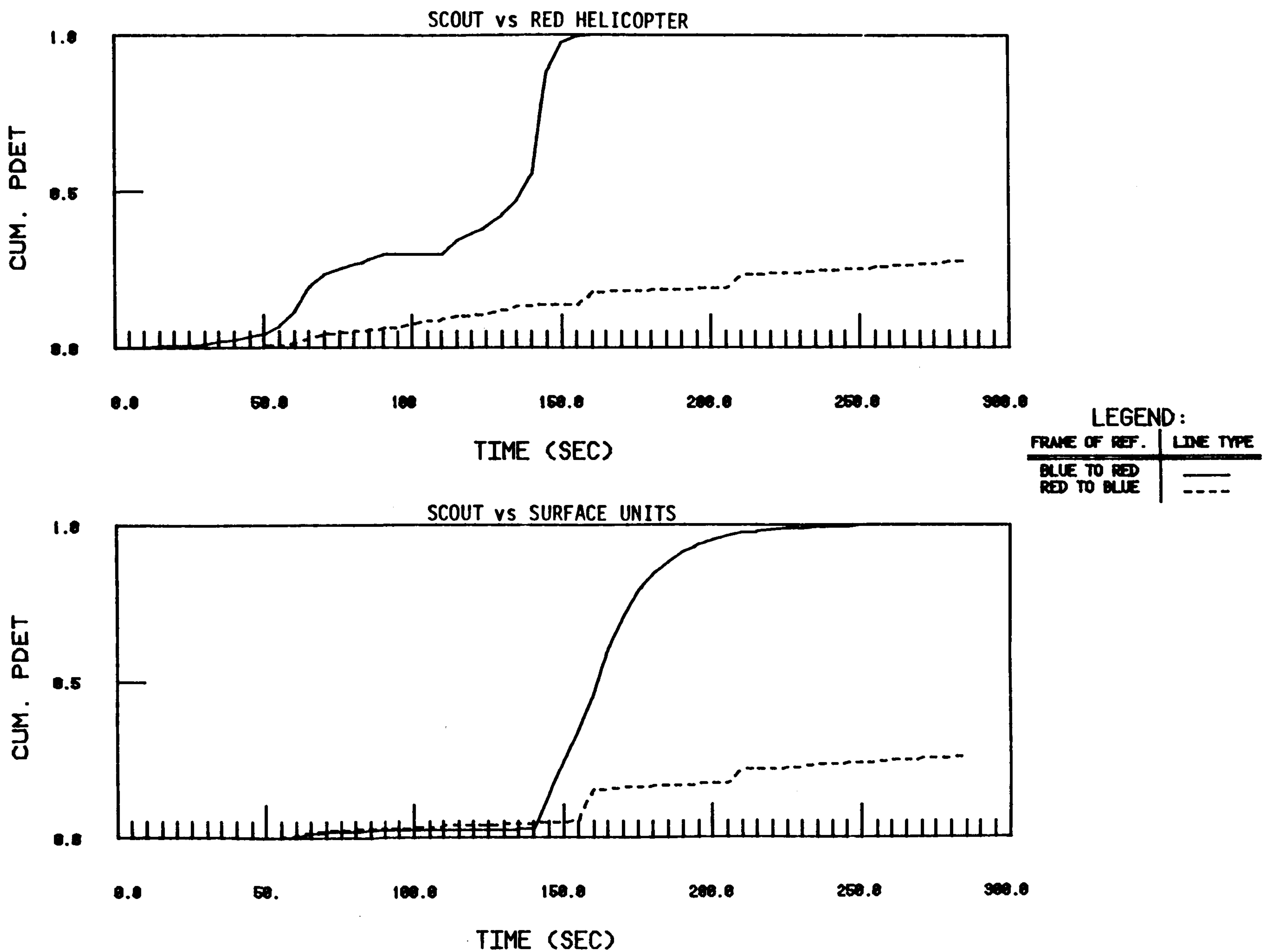
CASE NO. 8: H_{NOE} = 50 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 2 FT; VFT = 5%



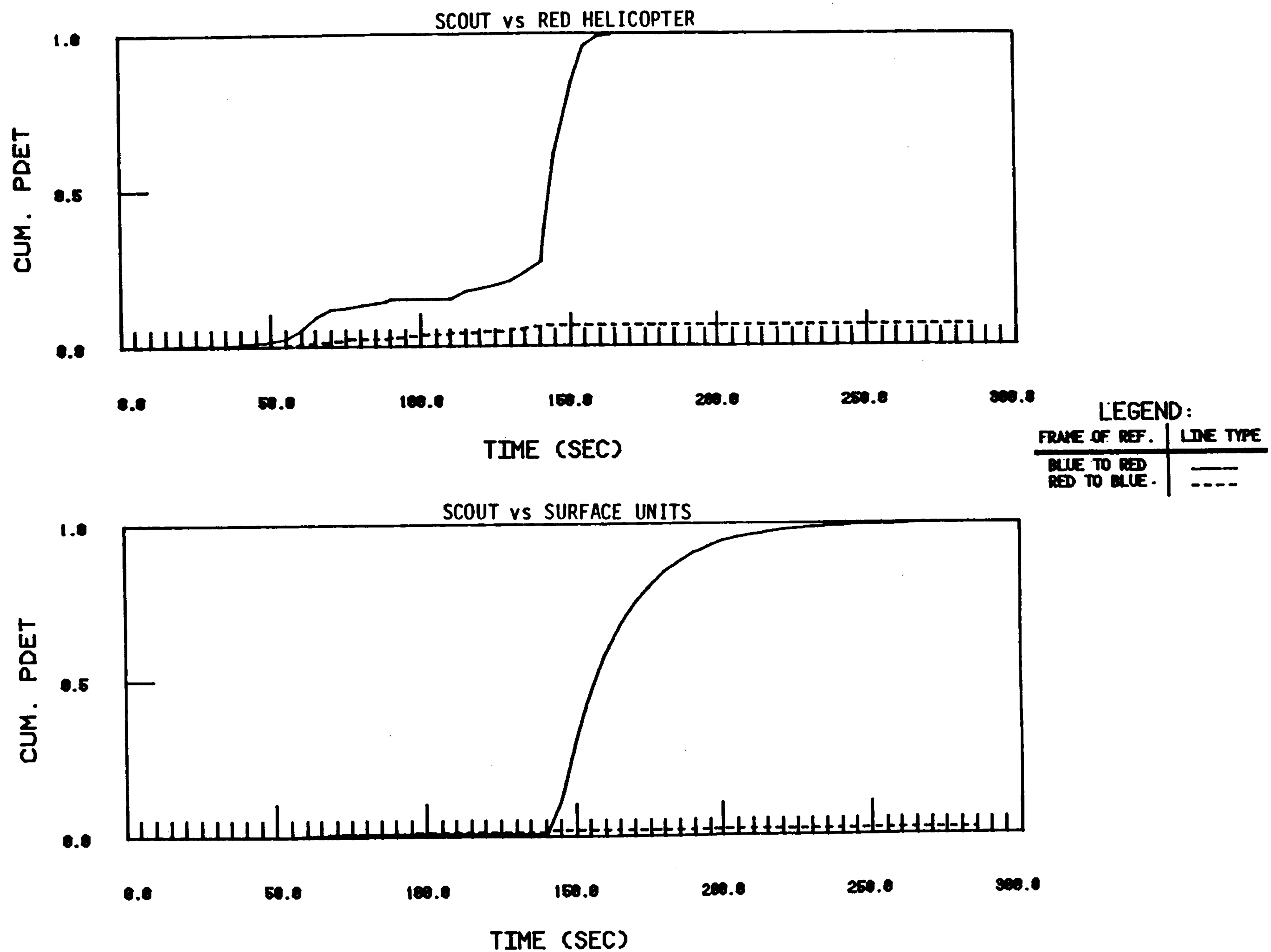
CASE NO. 9: H_{NOE} = 50 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 2 FT; VFT = 10%



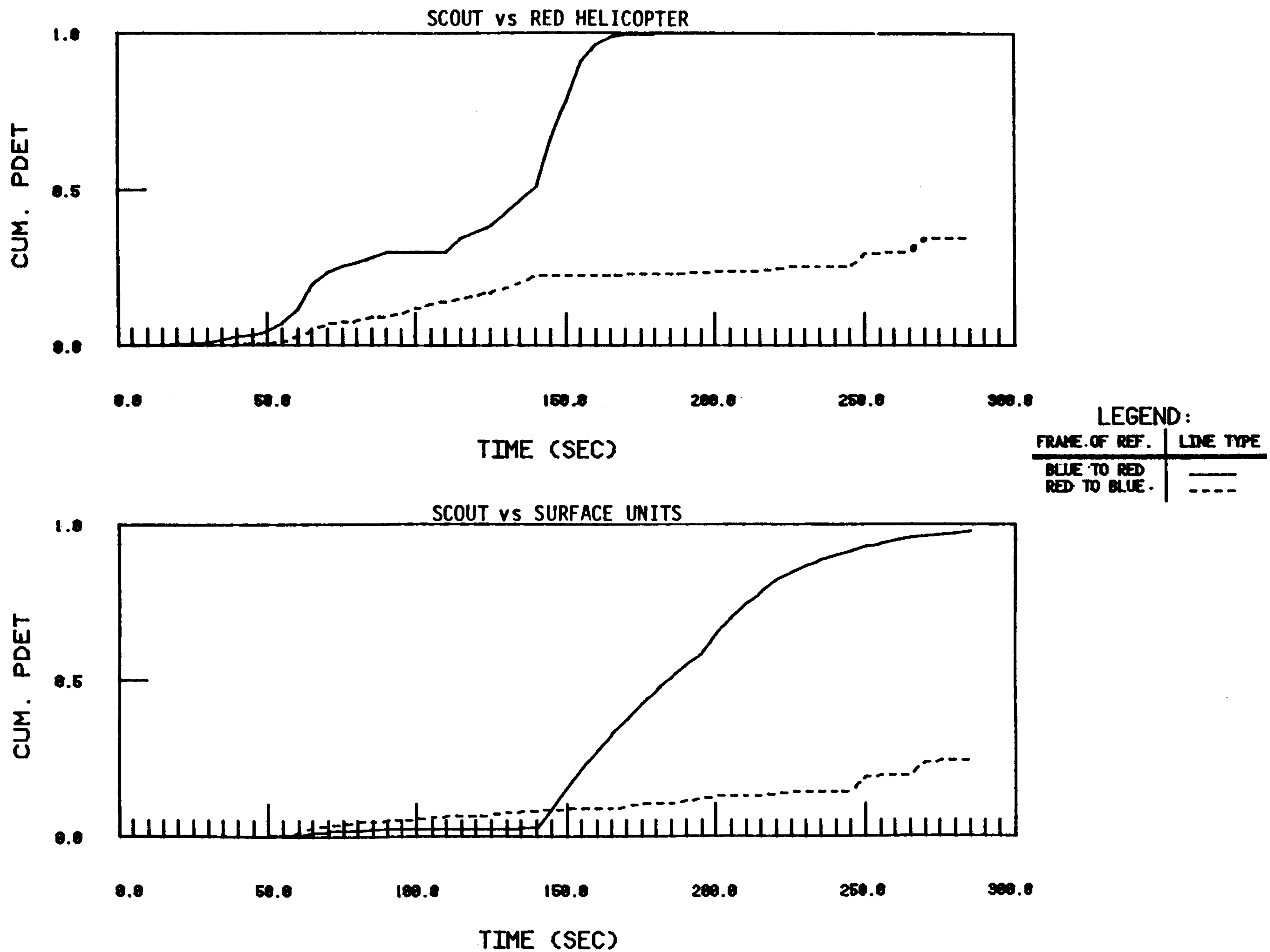
CASE NO. 10: H_{NOE} = 50 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 2 FT; VFT = 25%



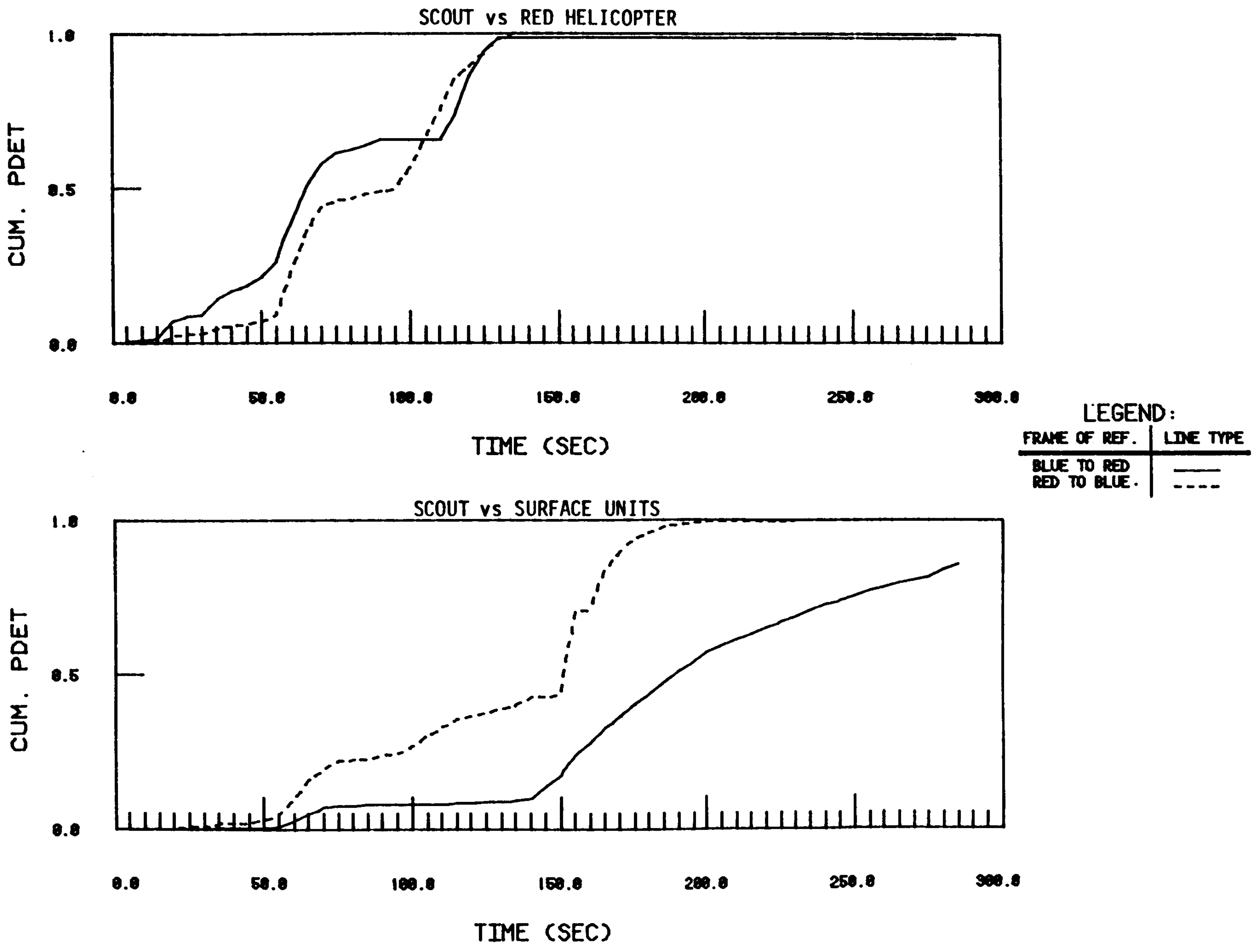
CASE NO. 11: H_{NOE} = 50 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 2 FT; VFT = 100%



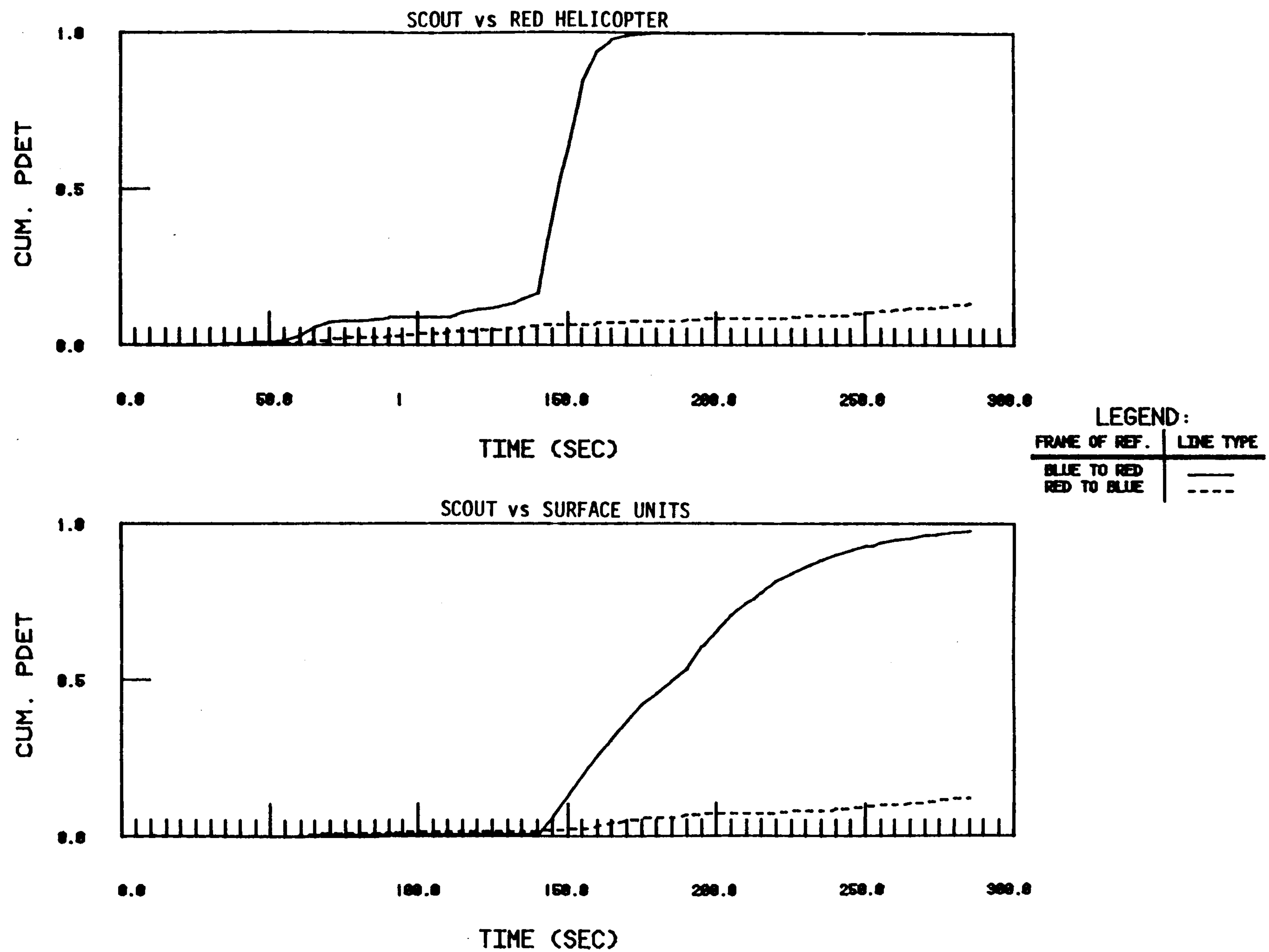
CASE NO. 12: H_{NOE} = 41 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 0 FT; VFT = 100%



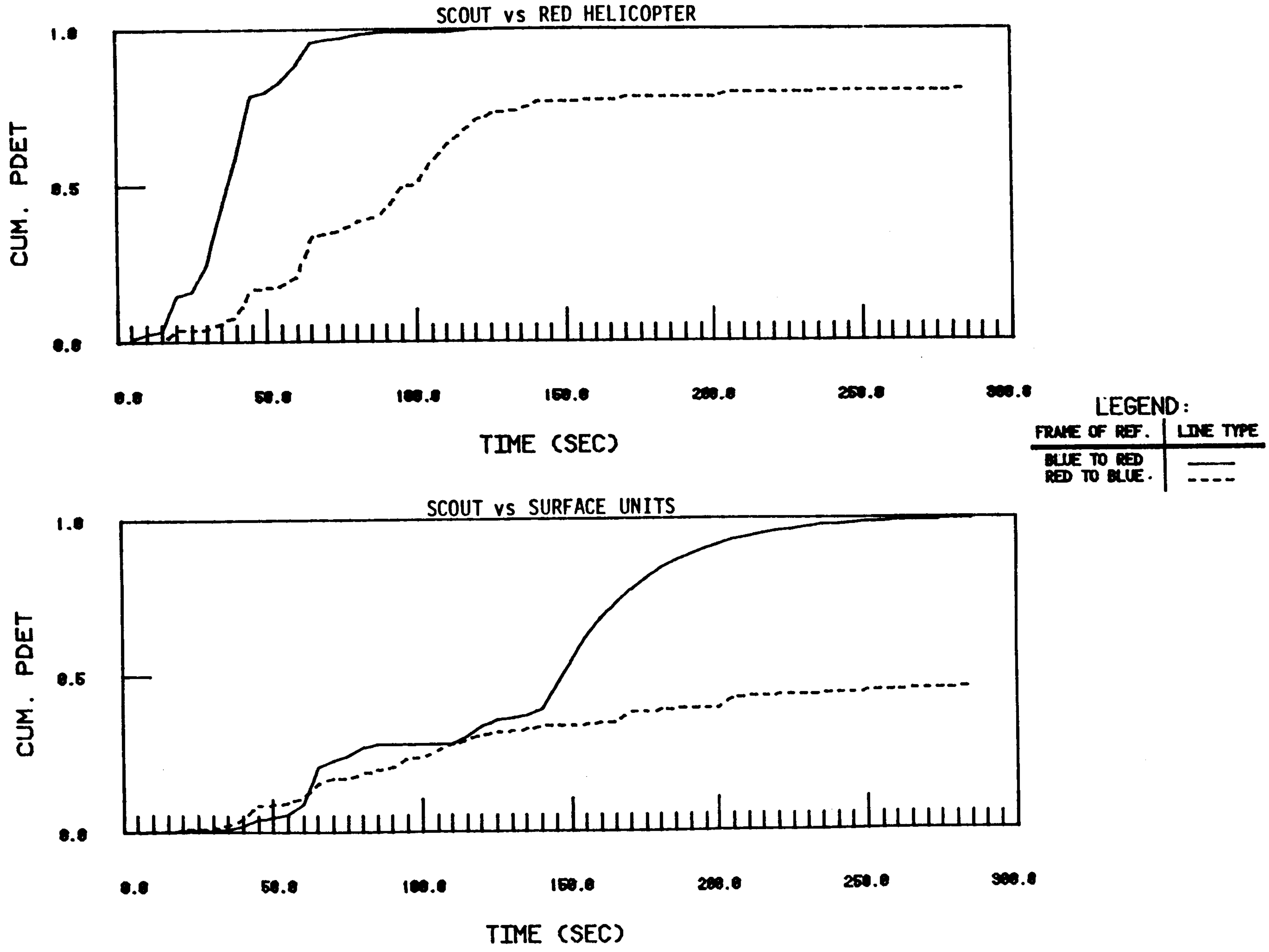
CASE NO. 13: H_{NOE} = 58 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 2 FT; VFT = 50%



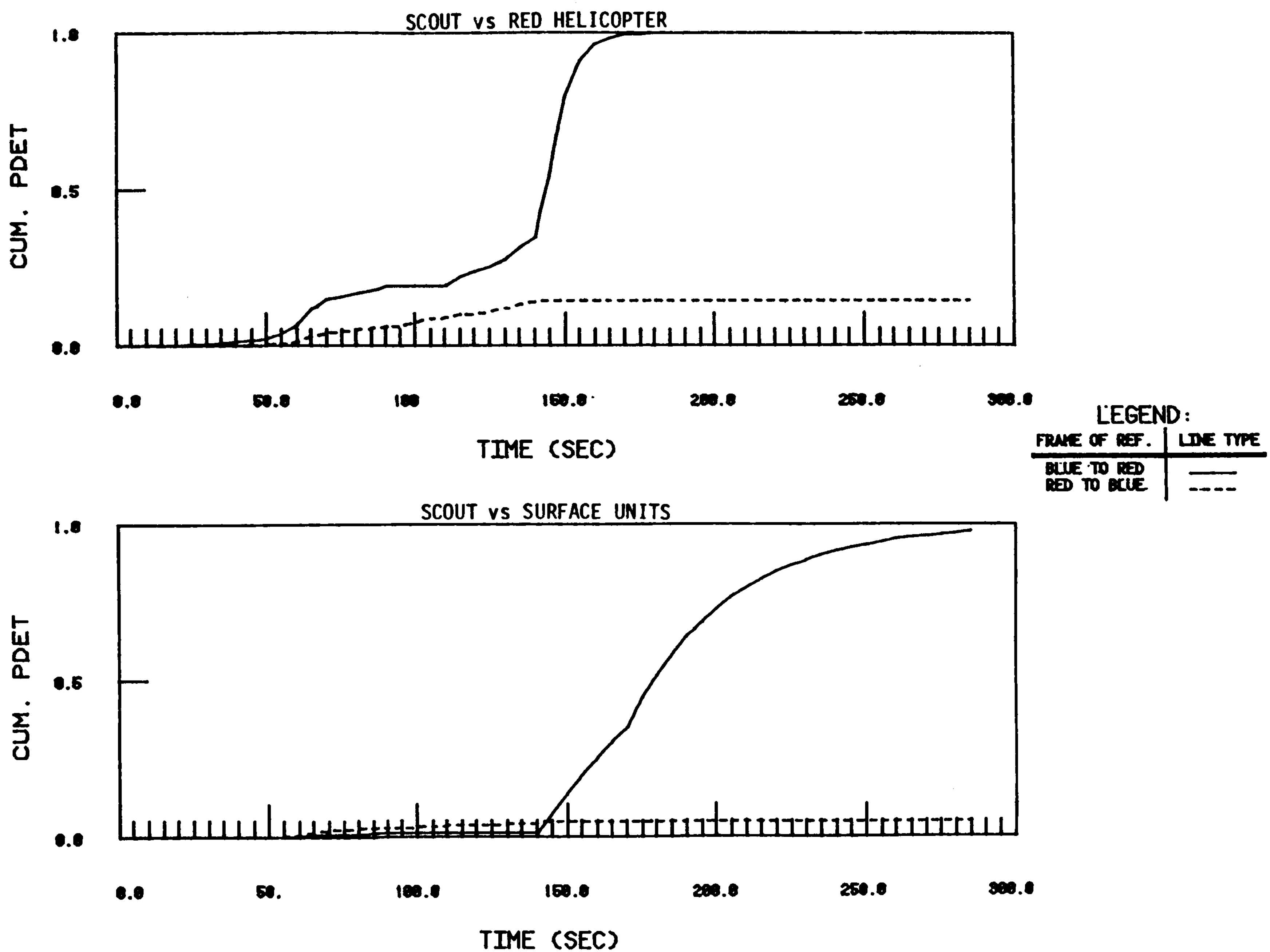
CASE NO. 14: H_{NOE} = 58 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 20 FT; ΔH_{HOV} = 5 FT; VFT = 25%



CASE NO. 15: H_{NOE} = 41 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 2 FT; VFT = 50%



CASE NO. 16: H_{NOE} = 50 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 30 FT; ΔH_{HOV} = 2 FT; VFT = 50%



CASE NO. 17: H_{NOE} = 50 FT; V_{NOE} = 50 KTS; ΔH_{NOE} = 0 FT; ΔH_{HOV} = 0 FT; VFT = 50%

APPENDIX C

IMPACT OF ROLL CONTROL PARAMETERS ON MISSION EFFECTIVENESS

1. INTRODUCTION

The thrust of this report has been to relate the effects of flying qualities parameters, such as precision of flight path control, to mission effectiveness. To directly relate the impact of flying qualities parameters to mission effectiveness, the impact of flying qualities parameters must be quantitatively related to their effects. As an example of how this can be done, this Appendix relates the impact of steady state roll rate on basic NOE height, then from the results of Section 4, directly relates the impact of roll rate to mission effectiveness.

2. IMPACT OF ROLL CONTROL EFFECTIVENESS ON BASIC NOE HEIGHT

As presently mechanized, the HACES simulates NOE flight by assuming a continuous series of turns around obstacles as indicated in Figure 1, below.

The required spacing of the micro-terrain features is a function of the terrain, helicopter speed and helicopter maneuverability. HACES also has algorithms that relate required spacing of micro-terrain features to required height above the ground.

Since the spacing of the micro-terrain features increases as height above ground increases, the greater the turn radii of the helicopter, the higher it must fly to avoid the obstacles. However, what is not modeled is the time taken to perform the turn reversals in this simulated serpentine course. If the roll mode time constants, roll rate and precision of control were all taken into account, the turn reversals would take a finite amount of time/distance, and the flight path of Figure 1 would approximate the flight path of Figure 2.

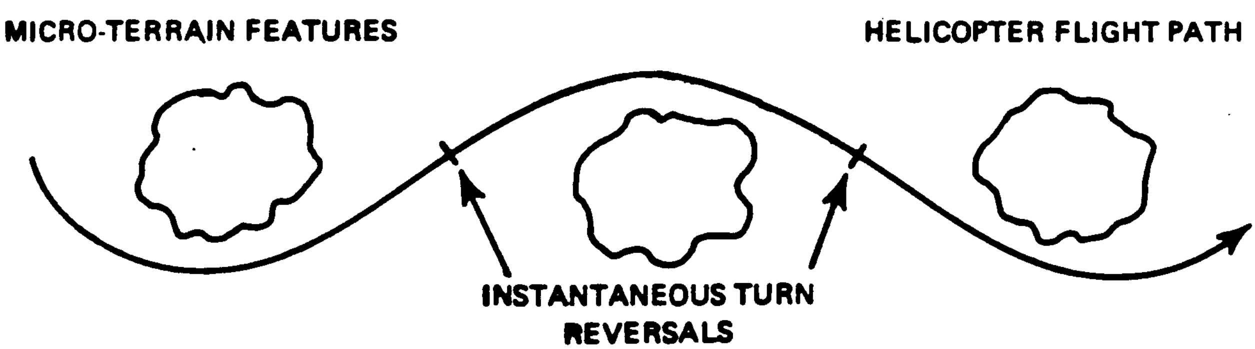


Figure 1. Basic NOE Flight

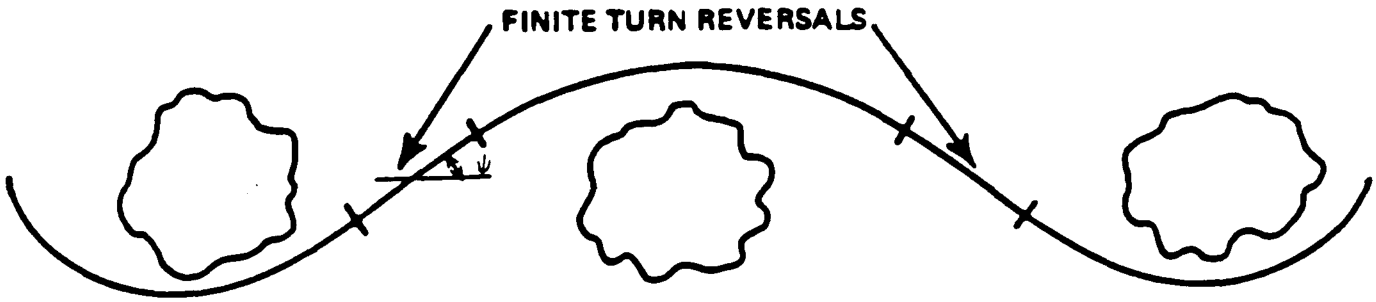


Figure 2. NOE Flight Considering Finite Time for Turn Reversals

Clearly, under these conditions, for the same terrain, helicopter speed and maneuvering capability; the micro-terrain features must be spaced further apart if the helicopter is to avoid striking them. This dictates that the helicopter must fly higher, increasing its probability of detection and kill.

The equation used to compute required spacing, S, between micro-terrain features is given by the equation:

$$S = [4R(D+d+V/2) - (D+d+V/2)^2]^{1/2}$$

where:

- R = turn radius based on helicopter speed and sustained turn capability (feet)
- D = rotor diameter (feet)
- d = diameter of micro-terrain features (50 feet used in model)
- V/2 = 2 x the clearance between rotor tip and micro-terrain features (feet)

If we are to consider the impact of finite turn reversal time, an additional distance, ΔS_{TR} - approximated by the straight line part of the flight path of Figure 2 - must be computed. An approximation for this distance is given by the expression:

$$\Delta S_{TR} = V t_{TURN} \cos\psi$$

$$= V \left(\frac{2\phi_T}{P_{ss}} + 1.5\,\tau_R\right) \cos\psi$$

where:

- V = helicopter speed (fps)
- t_{TURN} = time required to complete the turn reversal (sec)

ψ = relative flight path direction at the time of turn reversal (deg)

$$= 2 \tan^{-1} \left[\frac{D+d+V/2}{S_{EFF}}\right]$$

ϕ_t = helicopter bank angle when in turn (deg)

$= \cos^{-1} (1/N_z)$

P_{ss} = maximum steady state roll rate (deg/sec)

τ_R = roll mode time constant (sec)

Thus $S_{EFF} = S + \Delta S_{TR}$

The algorithm relating required height, h, to required micro-terrain spacing is:

$$h = h_o (1-S_o/S_{EFF})$$

where

h_o = height of highest micro-terrain feature (feet)

S_o = nominal spacing between micro-terrain features at ground level ($h = 0$) (feet)

3. <u>EXAMPLE OF EFFECT OF ROLL RATE ON NOE HEIGHT</u>

For the baseline case in the sensitivity studies presented in this report:

V = 50 kts

N_z = 1.46 g

D = 35 feet

d = 50 feet

This yields a turn radius of 208 feet, a required micro-terrain spacing of 300 feet, and a required height of 50 feet. Consider now the impact of a 30 deg/sec and a 60 deg/sec roll rate, both with a 1 second roll mode time constant.

<u>P_{ss} = 30 deg/sec</u>

$$S = V\left[\frac{2\phi_T}{P_{ss}} + 1.5\,\tau_R\right] \cos\psi$$

$$\phi_T = \cos^{-1}(1/N_z)$$
$$= \cos^{-1}(1/1.46)$$
$$= 48^o$$
$$\tau_R = 1 \text{ sec (assumed)}$$

Since we are solving for S_{EFF}, ψ must be computed iteratively. ψ is approximately 35 deg, so assume $\psi = 35^o$

Therefore

$$\Delta S_{TR} = 1.69\ (50) \left[\frac{2(48)}{30} + 1.5(1)\right] \cos(35)$$
$$= 84.5\ (3.2 + 1.5)\ 0.82$$
$$= 325 \text{ feet.}$$

Therefore

$$S_{EFF} = S + \Delta S_{TR}$$
$$= 300 + 325$$
$$= 625 \text{ feet.}$$

Therefore

$$h(P_{ss} = 30^o/s) = 100 \left[1 - \frac{So}{S_{EFF}}\right]$$
$$= 100 \left[1 - \frac{150}{625}\right]$$
$$= 76 \text{ Feet.}$$

P_{ss} = 60 deg/sec

$$\Delta S_{TR} = 1.69\ (50) \left[\frac{2(48)}{60} + 1.5(1)\right] \cos(35)$$
$$= 84.5\ (1.6 + 1.5)\ 0.82$$
$$= 215 \text{ feet.}$$

Therefore

$$S_{EFF} = 300 + 215$$
$$= 515 \text{ feet}$$

Therefore

$$h(P_{ss} = 60^o/s) = 100 \left[1 - \frac{150}{515}\right]$$

$$= 71 \text{ Feet}$$

4. EXAMPLE OF EFFECT OF ROLL RATE ON MISSION EFFECTIVENESS

Thus an increase in roll rate from 30 ^{o}/S to 60 ^{o}/S reduced basic NOE height from 76 to 71 feet.

Entering Figure 4-1, which presents the impact of NOE height on various measures of effectiveness, it can be seen that the probability of the Scout surviving at 76 feet is 0.34 and of surviving at 71 feet is 0.40. This represents an increase of probability of survival of 18%. However, as mentioned in the main text, most of the detecting and killing in Scenario 3 occurred in the hover portion of the mission. Since $P_K(B)/P_S(B)$ is for the complete mission, and we are just addressing the NOE portion of it, large changes are not to be expected.

To get a better understanding of the relationship between maximum steady state roll rate and mission effectiveness, the intermediate measure of effectiveness of probability of Scout detection during NOE flight, presented in Figure 4-3 was analyzed. Referring to Figure 4-3, the probability of being detected in NOE flight at 76 feet equals 0.39; and at 71 feet, P_D = 0.30. This represents a reduction in probability of detection of 30% which, for a Scout, is very significant. Performing calculations for a range of roll rates, a curve of the probability of the Scout being detected prior to its reaching its observation point, as a function of roll rate, was constructed and is presented in Figure 3. From a control criteria standpoint, figures such as these can be examined to determine the point of diminishing returns to bound maximum steady state roll rate as a function of the task being performed.

In summary, it can be seen that it is possible to directly relate flying qualities parameters to mission effectiveness parameters. Moreover, even in this scenario in which hover, rather than NOE flight, dominated, it can be seen that flying qualities do have a significant impact on the ability of a pilot to perform his mission. Finally, the data can be used to at least bound parameters in the formulation of criteria.

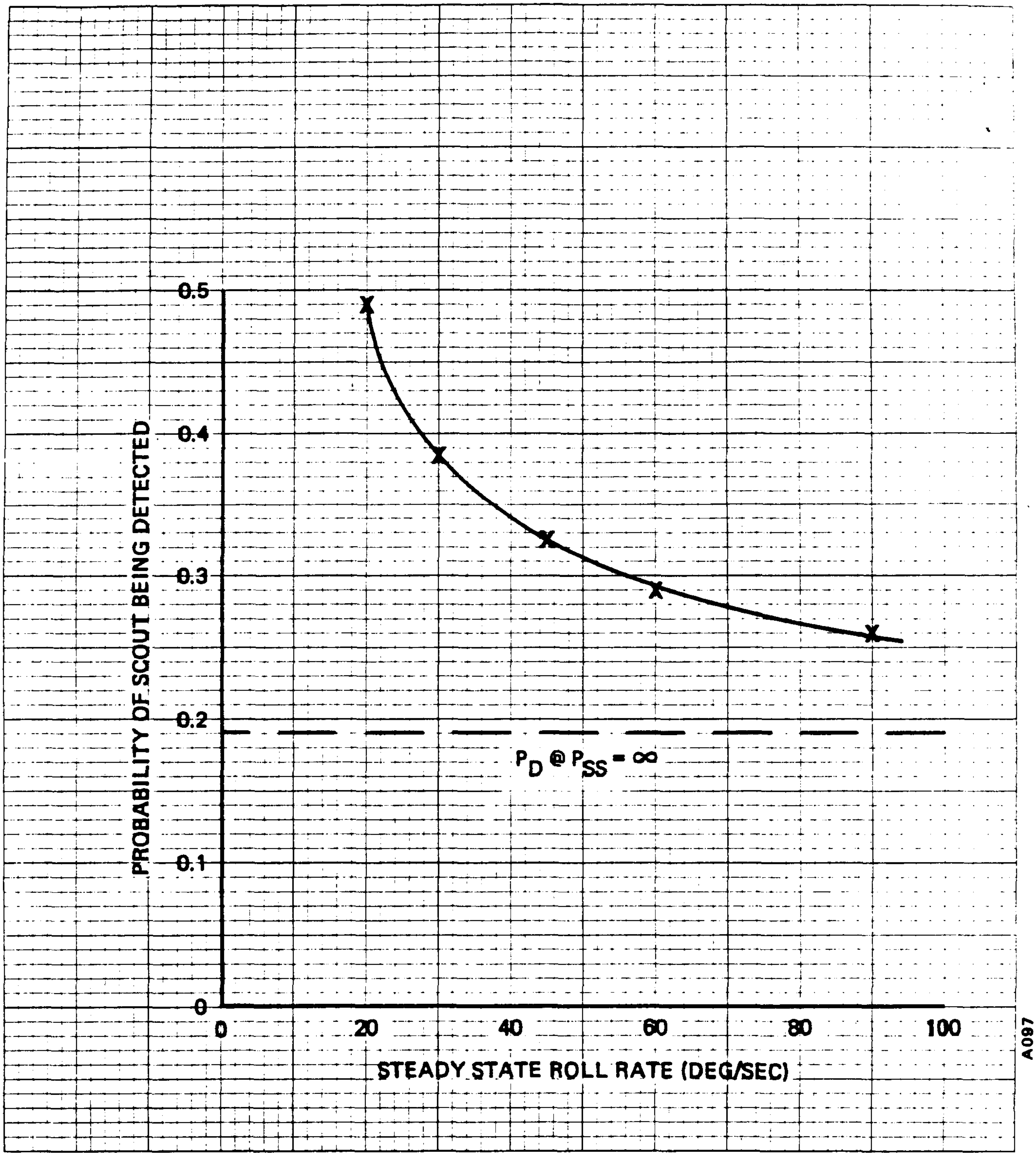


Figure 3. Probability of Detection by Red Helicopter as a Function of Roll Rate

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16. Abstract

A computer simulation to investigate the impact of flying qualities on mission effectiveness is described. The objective of the study was to relate the effects of flying qualities, such as precision of flight path control and pilot workload, to the ability of a single Scout helicopter, or helicopter team, to accomplish a specified anti-armor mission successfully.

The model of the actual engagements is a Monte Carlo simulation that has the capability to assess the effects of helicopter characteristics, numbers, tactics and weaponization on the force's ability to accomplish a specific mission against a specified threat as a function of realistic tactical factors. A key feature of this program is a simulation of micro-terrain features and their effects on detection, exposure, and masking for nap-of-the-earth (NOE) flight.

17. Key Words (Suggested by Author(s))
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