Impact of Flying Qualities on Mission Effectiveness for Helicopter Air Combat

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A computer simulation to investigate the impact of flying qualities on mission effectiveness was conducted. 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 antiarmor mission successfully. The model used in the actual engagements was a Monte Carlo simulation that had 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 was the simulation of microterrain features (trees, etc.) and their effects on detection, exposure, and masking for nap-of-the-Earth (NOE) flight. Variations in threat, NOE height and speed, hover height, and pilot visual free time were investigated. The program generated a significant amount of data relating flying qualities effects to the ability to perform several specific mission tasks. The flying qualities parameter most critical to the aeroscout mission was the precision of hover control. In addition, the more demanding the mission was, the more important good flying qualities became.

Nomenclature

D = rotor diameter, ft
d = diameter of microterrain features (50 ft in model)
h_0 = height of highest microterrain feature, ft
N_Z = sustained load factor, g
P_{ss} = steady state roll rate, deg/s
R = turn radius based on helicopter speed and sustained turn capability, ft
S = required spacing between microterrain features, ft
S_{eff} = effective spacing ($S_{eff} = S + \Delta S_{tr}$), ft
S_0 = nominal spacing between microterrain features at ground level ($h = 0$), ft
ΔS_{tr} = required spacing due to turn reversals, ft
t_{turn} = time required to complete the turn reversal, s
V = helicopter speed, ft/s
$V/2$ = two times the clearance between rotor tip and microterrain features, ft
τ_R = roll mode time constant, s
ϕ_t = helicopter bank angle when in coordinated turn $\approx \cos^{-1}(1/N_Z)$, deg
ψ = relative flight-path direction at the time of turn reversal, deg

Introduction

BATTLEFIELD nap-of-the-Earth (NOE) helicopter operations involve agile flight at extremely low altitudes (below treetop level if possible) to take advantage of the cover afforded by trees, creek beds, ridges, etc., in order to reduce the possibility of detection and vulnerability to sophisticated weapons. The anticipated role of the Advanced Scout helicopter will change with the future incorporation of target acquisition and display (TADS), multipurpose missile systems, holographic sighting, speech command-auditory/display systems, advanced digital and optical control systems, and multifunctional displays. The scout, operating out of unprepared landing zones, will provide close combat support, reconnaissance, security, target acquisition/designation, fire support, command, and control along with self-defense under day, night, and adverse weather conditions in all intensities of warfare (Fig. 1).

Also, to enhance its combat mission effectiveness in a high-threat environment, the scout should have the capability of improved agility during NOE flight. Excellent NOE flying qualities would allow the pilot to concentrate his attention on aspects outside the cockpit or to engage in battlefield management tasks. The pilot's workload in this flight regime is very high, and the effect of the helicopter's handling qualities on overall performance is significant.

Digital war-game simulators previously have been utilized for combat helicopter scenarios, but the simulations[1] were deterministic and had difficulty with the war scenarios of today. Technically, they did not "simulate," but calculated.

In order to determine realistically the effects of helicopter flying qualities on the ability to perform specific tasks, well-structured programs using man-in-the-loop simulators primarily can be utilized. However, to assess total mission effectiveness realistically, other factors in addition to flying qualities must be considered and modeled. These factors include: 1) helicopter performance, survivability systems, fire control systems, and weapons; 2) the scenario, which comprises forces force size and composition, terrain, available cover, targets, surface defenses, and the mission; and 3) detectability parameters, such as helicopter size, contrast, motion, tactics, sensors, weather, and time available for the crew to do ground and air searches.

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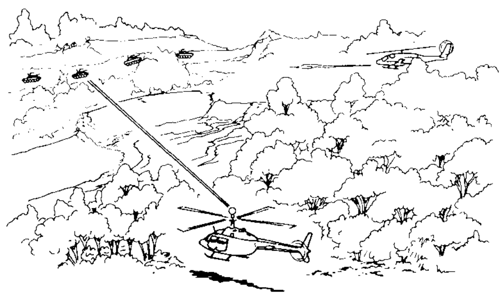


Fig. 1 Target acquisition and designation for attack helicopters.

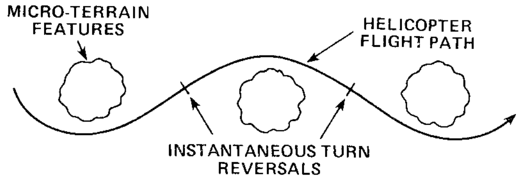


Fig. 2 Basic NOE flight.

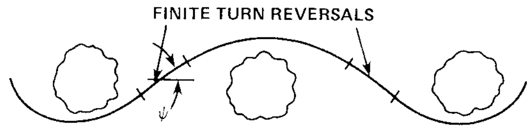


Fig. 3 NOE flight considering finite time for turn reversals.

Effects of Helicopter Performance

In determining overall mission effectiveness, flying qualities and their interaction with other parameters are important. First, consider a helicopter advancing for attack using NOE tactics. In this simulation the advance speed is dependent upon two performance parameters: turn capability, and the capability to enter and roll out of the turns rapidly.

As initially mechanized, the simulation program models NOE flight by assuming a continuous series of turns around microterrain obstacles as indicated in Fig. 2.

The spacing of the microterrain features required to allow NOE flight is a function of the terrain, helicopter speed, and helicopter maneuverability. The program also has algorithms that relate this required spacing of microterrain features to a required height above the ground for NOE flight.

The effective spacing of the microterrain features increases as height above ground increases. Therefore, the greater the turn radius of the helicopter, the higher it must fly to avoid the obstacles. The finite time required to perform the turn reversals in this simulated serpentine course must also be considered. The additional required time and distance are functions of the roll mode time constant, roll rate, and precision of control.

Clearly, under these conditions and for this terrain with constant helicopter speed and given maneuvering capability, the microterrain features must be spaced farther apart if the helicopter is to avoid striking them. This requirement dictates that the helicopter must fly higher, thus increasing its probability of being detected and killed.

The equation used by the program to compare required spacing S between microterrain features is

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

If the effect of finite turn reversal time is also considered, an additional distance, ΔS_{tr}, must be computed. This additional distance is approximated by the straight line portion of the flight path (Fig. 3). A mathematical relation for this distance is given by the expression

$$\Delta S_{tr}=Vt_{turn}\cos\psi \approx V(2\phi_T/P_{ss})+1.5\tau_R\cos\psi \qquad (2)$$

Thus $S_{eff}=S+\Delta S_{tr}$.

The algorithm relating microterrain spacing to required height h is

$$h=h_0(1-S_0/S_{eff}) \qquad (3)$$

Thus, Eq. (3) is a mechanization of the assumption that as a helicopter's height increases, the spacing between microterrain features increases.

For the baseline case in the sensitivity studies presented herein, the following performance and geometry parameters were used: $V=50$ knots, $N_Z=1.46\ g$ ($\phi_T=\pm 46.8$ deg), $D=35$ ft, and $d=50$ ft. These parameters yielded a turn radius of 208 ft, a required microterrain spacing of 300 ft [Eq. (1)], and a required height of 50 ft [Eq. (3)].

Consider now the impact of a 30- and 60-deg/s roll rate, both with a 1-s roll mode time constant.

For $P_{ss}=30$ deg/s, from Eq. (2),

$$\Delta S_{tr}=320 \text{ ft}$$

where ψ is computed iteratively and can be approximated to be 35 deg based upon

$$\psi=2\tan^{-1}\frac{D+d+V/2}{S_{eff}}$$

and

$$S_{eff}=S+\Delta S_{tr}$$

$$=300+320$$

$$=620 \text{ ft}$$

Therefore,

$$h(P_{ss}=30 \text{ deg}/S)=100(1-S_0/S_{eff})$$

$$=100(1-150/620)$$

$$=76 \text{ ft}$$

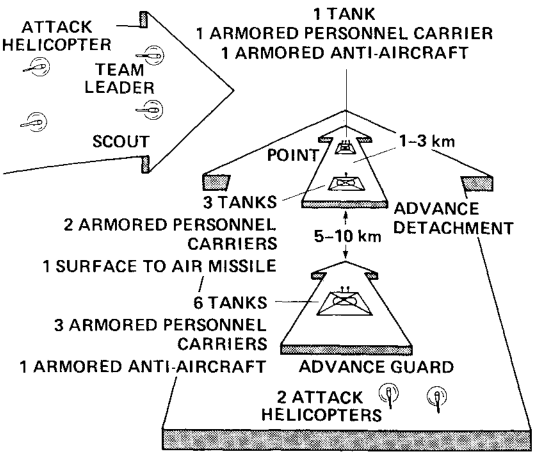
By performing similar computations for $P_{ss}=60$ deg/s ($\Delta S_{tr}=212$ ft), $S_{eff}=572$ ft. The resulting height is 71 ft. Thus, two different helicopters with different roll rates operating with the same speed capabilities will be able to fly at different NOE heights. This altitude difference then can be evaluated in the detection and engagement algorithms to yield measures of effectiveness for the two scouts conducting the given mission. Therefore, in general, measures of effectiveness that are calculated based upon aircraft dynamic characteristics can be examined to bound these parameters in the formulation of mission-oriented criteria.

This computer-engagement model was based on information gathered from U.S. Army, Marine, and Air Force organizations involved in helicopter air combat. The results of the survey are presented in Ref. 2, and a description of the resulting helicopter air combat model is presented in Ref. 3.

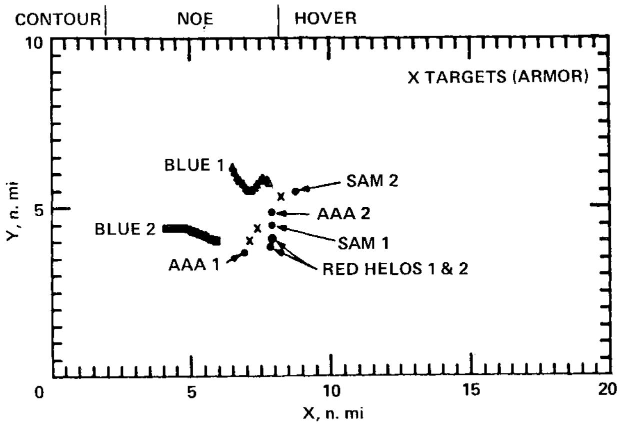
Experimental Design

Engagement Scenario

The simulated Blue Force (BF) consisted of one or two sections of scout and attack helicopters working in concert against the Red air and ground forces (Fig. 4a). The scouts performed the surveillance function of searching the area of operations, detecting Red Force (RF) targets, designating



a) Organization of forces.



b) Area of operations.

Fig. 4 General mission scenario.

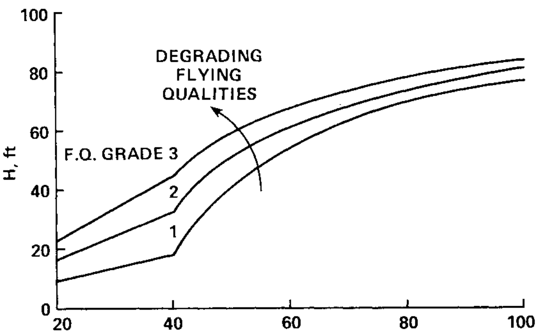


Fig. 5 Flying qualities/NOE flight relationships.

targets, and directing the fire of the attack helicopters. The study concentrated on the scout's ability to perform these tasks as a function of its flying qualities. It was assumed that the attack helicopters could remain well hidden throughout the mission and respond to indirect fire commands from the scouts. The attack helicopters were, therefore, simulated only for their firepower effects. Figure 4b presents a nominal mission profile which allows for low level, contour, and NOE flight in the area of operations (AO). Since this study was scoped to investigate the effect of flying qualities in the AO, only NOE and hover (in the area of operations) portions of the mission were simulated. More specifically, the evaluations commenced at a point where there was a finite probability of being detected (at 8 km from hover positions). Each evalua-

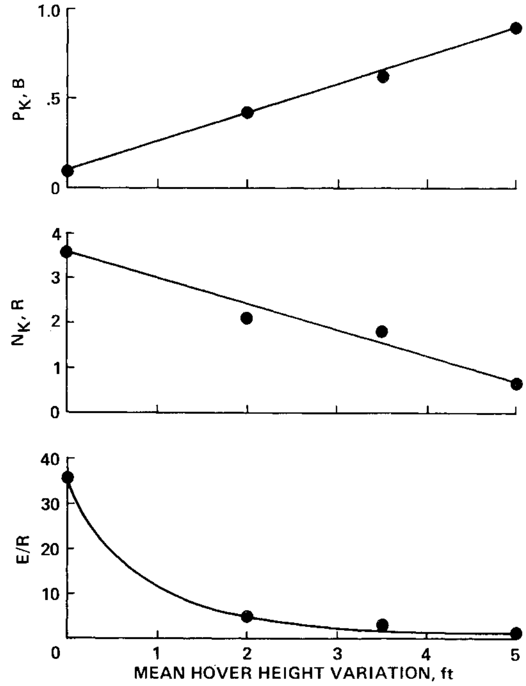


Fig. 6 Statistical hover height variation MOEs.

tion (run) ended when one of the following conditions was met: 1) the scouts reached their observation points and hovered there for 2 min; 2) the attack helicopters fired all ten of their antitank missiles; 3) all tanks and armored vehicles were destroyed; and 4) the scouts were killed.

The atmospheric conditions were representative of a hazy day with 5-km visibility. The scenarios were set up from operational experience, guided by the U.S. Army and Soviet operations doctrine contained in Refs. 4-6.

Flying Qualities Effects and Experimental Variables

Two significant tasks for the scout helicopter are surveillance and directing the indirect fire from the attack helicopters. Flying qualities have an effect on the ability of a crew to perform both of these tasks.

For example, pilot workload (which is a function of flying qualities) directly affects the ability to perform these tasks. Specifically, if there is less visual free time (VFT) available to the crew 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 elect 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 time to be devoted to surveillance and weapon control, thus reducing the probability of mission success.

In summary, two important factors related directly to flying qualities that may have an impact on how well a mission is performed are: 1) flight-path control precision, in that it has an impact on the speed and altitude flown; and 2) workload, both visual and manipulative, in that it has an impact on the ability to perform surveillance and weapon control functions.

For the purposes of this study, the scout flying qualities were considered to manifest themselves in four ways: 1) the basic NOE height (H_{NOE}) at which a helicopter can fly at a given speed (V_{NOE}). This relationship is determined primarily by control power and type/density of the terrain features as

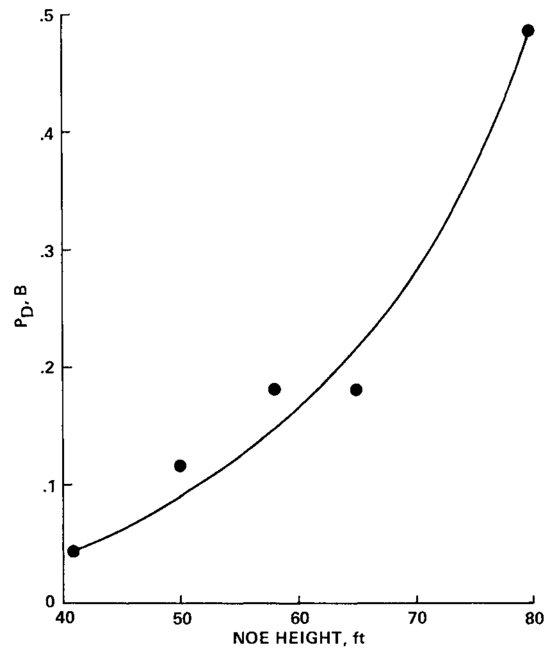


Fig. 7 Probability of scout being detected by Red Force helicopter in NOE flight.

indicated by the introductory example (Fig. 5); 2) the amount and frequency content of excursions in height above the basic NOE height. This stochastically derived mean absolute altitude error (ΔH_{NOE}) is primarily a function of precision of control and presupposes the pilot will not risk descending below some minimum "safe" altitude; 3) the amount and frequency content of height excursions in hover above that required for observation. This stochastic altitude perturbation (ΔH_{hov}) presupposes that the pilot will not risk breaking lock on a designated target; and 4) the amount of visual free time (VFT%) available to the aircrew for surveillance and fire control functions. (The importance of this parameter is discussed in more detail in Ref. 7)

Accordingly, these four parameters were selected as the primary experimental variables for this study.

Experimental Matrix

Thirty-two cases (Table 1) were selected for analysis. The three specific scenarios selected were based on the requirement to investigate the appropriate cause-and-effect relationships both for a few combat elements (scenario 3) and for larger, more realistic, unit actions (scenarios 1 and 2). The Monte Carlo simulation was run 50 times per case.

Only two scenario 1 cases were run because the mission route was so well chosen that the scouts were hardly ever detected regardless of how they were flown. On the other hand, in scenarios 2 and 3 in which the scouts were far more exposed, the flying qualities parameters generally had a significant impact on probability of survival and ability to perform the mission.

Results

Measures of Effectiveness

Several measures of effectiveness (MOEs) were used to analyze the data. The basic ones, relating directly to mission effectiveness, were: 1) probability of the scout(s) being killed: $P_K(B)$; 2) number of enemy vehicles killed including tanks, personnel carriers (BMPs), antiaircraft artillery (AAA), and surface-to-air missiles (SAM): $N_K(R)$; and 3) exchange ratio: number of enemy vehicles killed divided by the number of scouts killed: E/R.

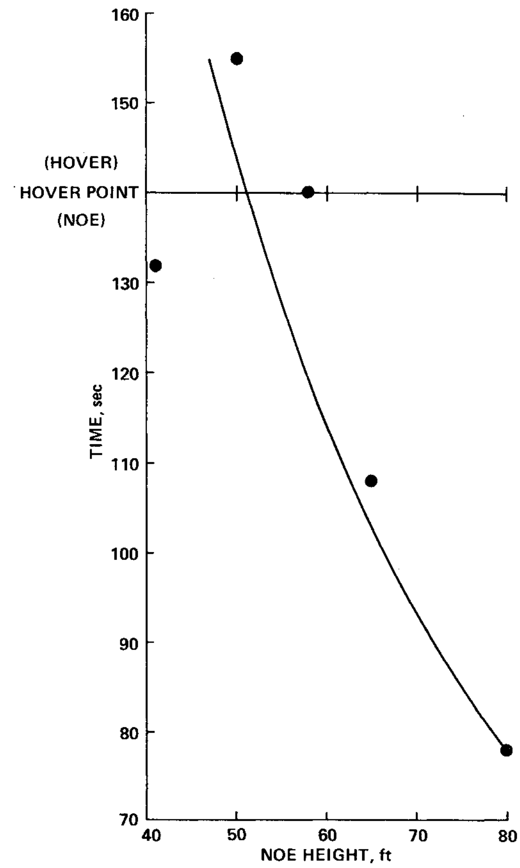


Fig. 8 Average time of detection by Red Force helicopter.

Table 1 Primary experimental variables

Case No.	Scenario No.	H_{NOE}, ft	V_{NOE}, knots	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

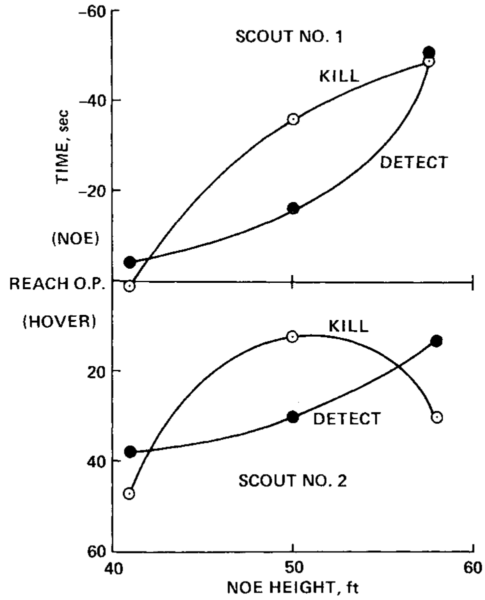


Fig. 9 Basic NOE altitude—average time of first detection by Red Force helicopters and kill by any threat element.

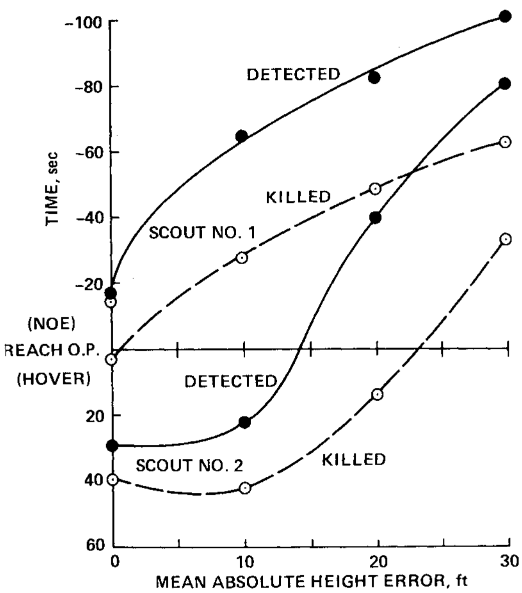


Fig. 10 Statistical height variation (from 50 ft basic NOE altitude)—average time of first detection of scouts by Red Force helicopters and kill by any threat element.

Figure 6 presents these basic measures of mission effectiveness as a function of the mean value of the hover height excursions.

As can be seen from Fig. 6, the study demonstrated that, for the mission simulated, precision of hover control has a significant impact on mission effectiveness. Even though the other three flying qualities parameters also had an impact on mission effectiveness, none had as significant an effect for the simulated mission as hover control precision.

To obtain further insight into the engagement results, several intermediate measures of effectiveness were evaluated. These included: 1) the probability of the Blue Force being detected by the Red Force helicopters $P_D(B)$ (Fig. 7) as NOE basic height changes; 2) the average time (from the start of the problem) at which the scouts were detected by the Red Force helicopters (Fig. 8) as NOE basic height changes; 3) the average time (from the start of the problem) at which each scout was detected by a Red Force helicopter and killed by any enemy element (Fig. 9) due to change in basic NOE height; 4) the average time at which the scouts were killed by any threat element (SAMs, AAA, or helicopters) (Fig. 10) due to a change in height variation from a 50-ft basic altitude; 5) the probability of the scouts detecting the tanks/BMPs, $P_D(T)$, (Fig. 11), as VFT changes; and 6) the average number of tanks/BMPs killed, N_K(T), (Fig. 11), as general flying qualities were varied.

These figures all show that as the parameters relating to flying qualities degrade, the intermediate MOEs also generally degrade. Considerable emphasis has been placed on showing the relationship between the flying qualities parameters and probability (and time) of detection. It was found that this was the primary mechanism whereby the impact of flying qualities on mission effectiveness was manifest. Most of the figures are self-explanatory; however, there is some scatter in the data, which is explained as follows: In Fig. 8 it can be seen that the lower the scout flew, the later (into the mission) the average time of detection, with the exception of the 41-ft NOE height point. However, from Fig. 7 it was seen that as scout altitude decreased, its probability of detection also decreased, which resulted in a very small sample size at the lowest (41-ft) altitude. Thus, even two or three "good" draws at the lowest altitude, yielding early detections, could easily cause an apparent reversal of the observed dominant trend.

Figure 9 shows that as NOE height increased, each scout was detected earlier and, in general, was also killed sooner. The two scouts' detection and kill results were not the same because as the scouts flew higher, the flight paths and threat deployment were such that Scout 1 took more of the fire; thus, attrition was later and less for Scout 2.

Also, in some cases, the scouts were destroyed by the AAA and SAM units before they were detected by the threat helicopters (Fig. 9). In short, the detect and kill curves in Fig. 9 cannot be compared directly.

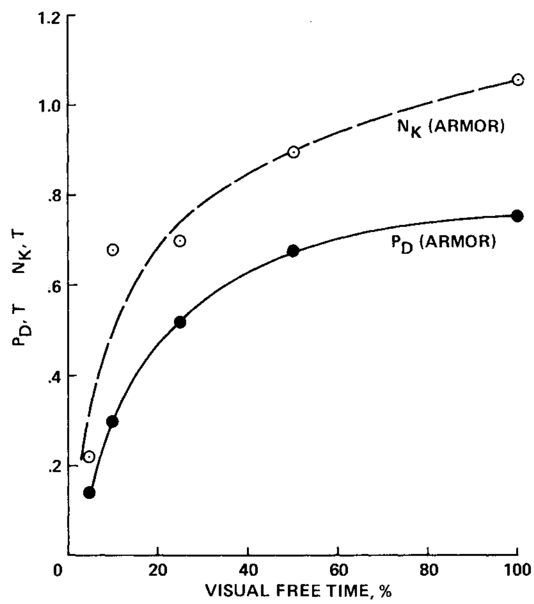


Fig. 11 Probability of detecting armor and number of vehicles killed.

Of particular interest to the scout mission is Fig. 11, which presents the probability of detecting the armored vehicles $P_D(T)$ and the number of armored vehicles killed $N_K(T)$ as a function of visual free time (VFT%). These intermediate measures of effectiveness show a strong correlation with the amount of VFT available for surveillance and acquisition. Further, as will be seen from the detection statistics, the point of diminishing returns is reached at VFT = 50% in this scenario, since at that point the probability of detecting the

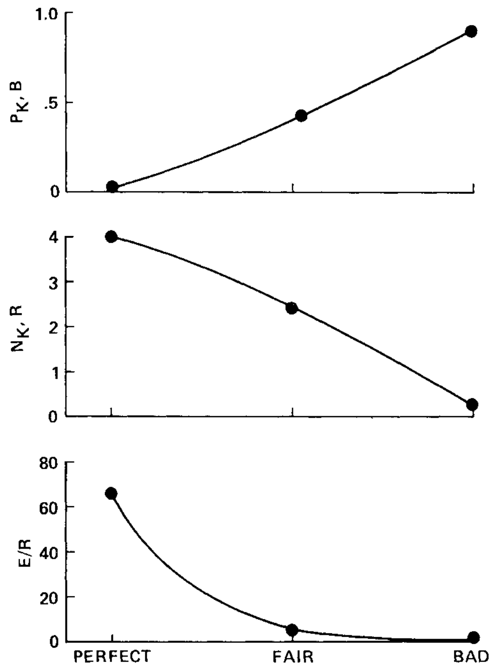


Fig. 12 Combined effects of all-parameter MOEs.

tanks (if the scout survived) is near unity. The inference is clear, however, that for any hard-to-see object (or group of objects), 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.

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

1) Perfect:

H_{NOE} = 41 ft (at 50 knots)
ΔH_{NOE} = 0
ΔH_{hov} = 0
VFT = 100%

2) Fair:

H_{NOE} = 50 ft (at 50 knots)
ΔH_{NOE} = 10 ft
ΔH_{hov} = 2 ft
VFT = 50%

3) Bad:

H_{NOE} = 58 ft (at 50 knots)
ΔH_{NOE} = 20 ft
ΔH_{hov} = 5 ft
VFT = 25%

Figure 12 presents the basic measures of mission effectiveness—$P_K(B)$, $N_K(R)$, and E/R—as the flying qualities, were varied from "perfect" to "bad". With "perfect" flying qualities, probability of survival was very high. Four threat units were killed on the average, hence, the exchange ratio was very high. With "bad" flying qualities, the scout's survival probability approached zero.

Conclusions

This study generated a significant amount of data relating the importance of flying qualities to the ability to perform several specific mission tasks, and has permitted the following conclusions to be drawn in the context of the three scenarios studied.

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

2) The impact of flying qualities on scout mission effectiveness resulted primarily from the probability of being detected.

3) The flying qualities effect most critical to the chosen scout mission was precision of hover altitude control.

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

In summary, a powerful new approach, with attendant tools, is available for relating flying qualities parameters to mission effectiveness and to the ability to perform specific mission tasks.[7,8] Since the results are quantitative, the approach can be used to perform sensitivity studies, tradeoff analyses, evaluation of concepts/configurations, and in bounding flying qualities criteria.

Acknowledgments

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