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A PILOTED SIMULATION OF ONE-ON-ONE
HELICOPTER AIR COMBAT AT NOE FLIGHT LEVELS *

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Abstract

A piloted simulation designed to examine the effects of terrain proximity and control system design on helicopter performance during one-on-one air combat maneuvering (ACM) is discussed. The NASA Ames Vertical Motion Simulator (VMS) and Computer Generated Imagery (CGI) systems were modified to allow two aircraft to be independently piloted on a single CGI database. Engagements were begun with the blue aircraft already in a tail-chase position behind red and also with the two aircraft originating from positions unknown to each other. Maneuvering was very aggressive and safety requirements for minimum altitude, separation, and maximum bank angles typical of flight test were not used. Results indicate that the presence of terrain features adds an order of complexity to the task performance over clear air ACM, that a mix of attitude and rate command type Stability and Control Augmentation System (SCAS) design may be desirable, and that the weapon system capabilities have a significant impact on air-to-air engagement success. The simulation system design, the flightpaths flown, and the tactics used were compared favorably to actual flight test experiments by the evaluation pilots.

Introduction

The Army has recently recognized the need to provide its helicopters with the capability to engage both helicopter and fixed wing threats. In January of 1982, the U.S. Army Aviation Mission Area Analysis Report identified helicopter air-to-air and air defense suppression capabilities as the first priority deficiency of Army aviation. Flight tests and crew training have been in progress for some time. The U.S. Marine Corps Marine Aviation Weapons and Tactics Squadron One (MAWTS 1) has been training senior Marine and U.S. Navy pilots since 1978 in the most effective use of their current aircraft and weapons. As part of this training, MAWTS instructs pilots in helicopter-versus-helicopter evasive maneuvering.

Due to a lack of flight test data on the subject of helicopter air combat maneuvering, the U.S. Army Applied Technology Laboratory has undertaken a series of instrumented flight tests at the Naval Air Test Center, Patuxent River, Maryland. In April 1983, Phase I of the Air-to-Air Combat Test (AACT I) was conducted utilizing OH-58 and

AH-1S aircraft. In July 1983, Phase II flights were completed utilizing Sikorsky S-76 and UH-60 aircraft.¹ From May 1978 through February 1979, the Army and U.S. Air Force also conducted a series of flight tests involving current Army aircraft against Air Force fixed wing threats (J-CATCH). In addition, members of the Third Squadron, Fifth Cavalry, located at Ft. Lewis, Washington, have been working since August 1982 to develop a Rotary Wing Air Combat Maneuvering Guide to standardize Army air combat training and tactics.² In all of these flight tests, safety restrictions for minimum altitude, roll attitude, and relative range are required.

Digital simulation studies to date have included work by Flight Systems, Incorporated, and Grumman Aerospace Corporation, among others.^{3,4} These non-real-time studies have investigated topics concerning the air-to-air combat effectiveness of helicopters, the impact of flying qualities on mission effectiveness, and the impact of speed, maneuverability, and armament for LHX design concepts. None of these simulations included a pilot in the loop or any sort of sophisticated visual terrain model. Fixed-wing manned simulators in government and industry have not lent themselves easily to helicopter engagements because of aircraft modeling complexities and the lack of high fidelity, low level, visual scene generating systems.

Since Army aircraft frequently operate at nap-of-the-earth (NOE) altitudes, encounters with threat aircraft are likely to occur at this low level. It was desired, therefore, to design a simulation system which would allow the effects of terrain to be included in an investigation of helicopter air combat maneuvering without the safety restrictions necessary in flight tests. The helicopter modeling capability, wide field-of-view CGI display, and the large motion travel of the NASA Ames Research Center Vertical Motion Simulator were well suited for this task, although new system capabilities were required.

These new capabilities included a dual-eyepoint CGI real-time software program which allowed for two independently maneuverable views of a common visual database. The database itself was specially designed for this project as was a system of head-up and panel-mounted information displays. The red aircraft pilot station and equations of motion were new, as were a weapons

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model and scoring algorithms. These systems are described fully in the Facilities section below.

Facilities

Vertical Motion Simulator

The simulation was conducted using the NASA Ames six-degree-of-freedom Vertical Motion Simulator (VMS) for the blue (or friendly) aircraft (Fig. 1). The VMS was designed to provide extensive cockpit motion to aid in the study of handling qualities of existing or proposed aircraft.⁵

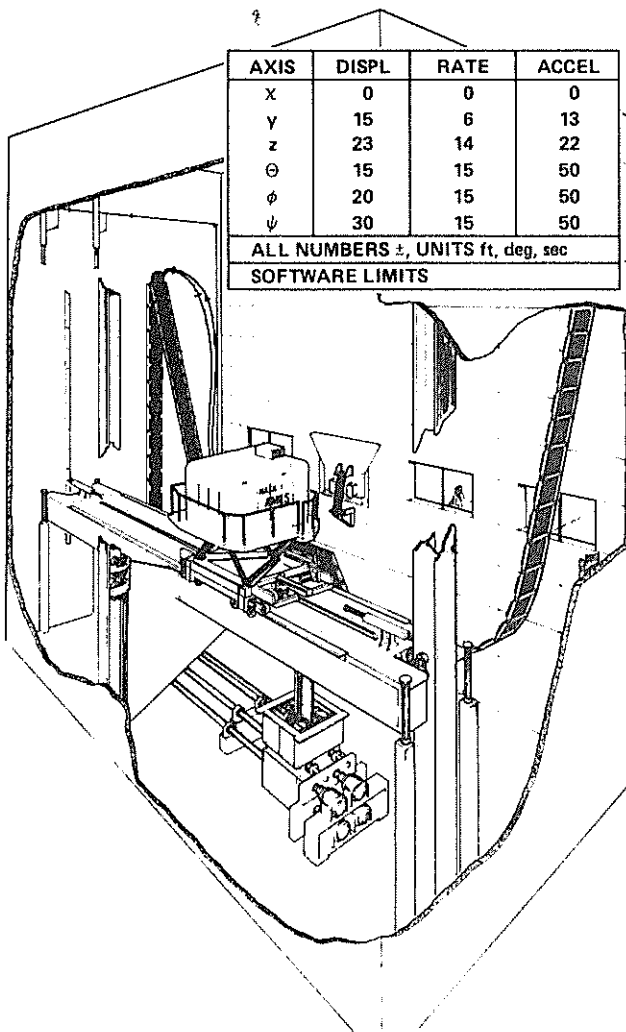


Fig. 1 Vertical Motion Simulator.

The VMS cockpit instrument panel design is shown in Fig. 2. Instruments included a radar altimeter, vertical speed indicator, attitude director indicator, airspeed meter, horizontal situation indicator, "g" meter, and a clock. A set of panel lights gave targeting and weapon information and a panel-mounted CRT displayed the tactical situation. The function of both of these systems is discussed later in this report.

In the stowed position, and therefore not visible in Fig. 2, is a head-up display (HUD) which provided information shown in Fig. 3 in a format similar to that developed in Ref. 6. This display was by far the primary source of flight information, as the pilot's vision was almost constantly directed outside the cockpit. The HUD weapon sighting was aligned daily to be certain that it corresponded to the firing logic, lights, and tones. Pilot utilization of the HUD information, particularly the velocity vector display, increased with experience.

The collective, cyclic, and directional controls were of a typical helicopter design. The force-feel characteristics of the cyclic stick and pedals were provided by an electro-hydraulic unit with adjustable breakout, static gradient, and viscous damping. These settings and the control travels are shown in Table 1.

A drawing of the cyclic stick grip is shown in Fig. 4. The index finger trigger switch allowed the pilot to stop the simulation run at any time and return the motion and visual systems to initial conditions. The lower thumb switch was the weapon firing control; the upper thumb switch would remove the stick force gradient if depressed.

CGI Visual System

The CGI database (Fig. 5) consisted of a detailed modeled area of approximately 9 km². The terrain included pyramid-type hills measuring up to 1000 ft in height, individual trees and buildings. Solid "tree blocks" 30-50 ft in height were arranged with four clearings inside. The clearings were four-sided, measuring approximately 600 to 800 ft on a side. To increase visual cues, "postage stamp" type dark squares were drawn on the hillsides, allowing the pilots better judgment of their height above the terrain than they would have had with monochromatic hillsides. The ground plane was a dusty brown color while the hills were various shades of green with sun vector shadowing.

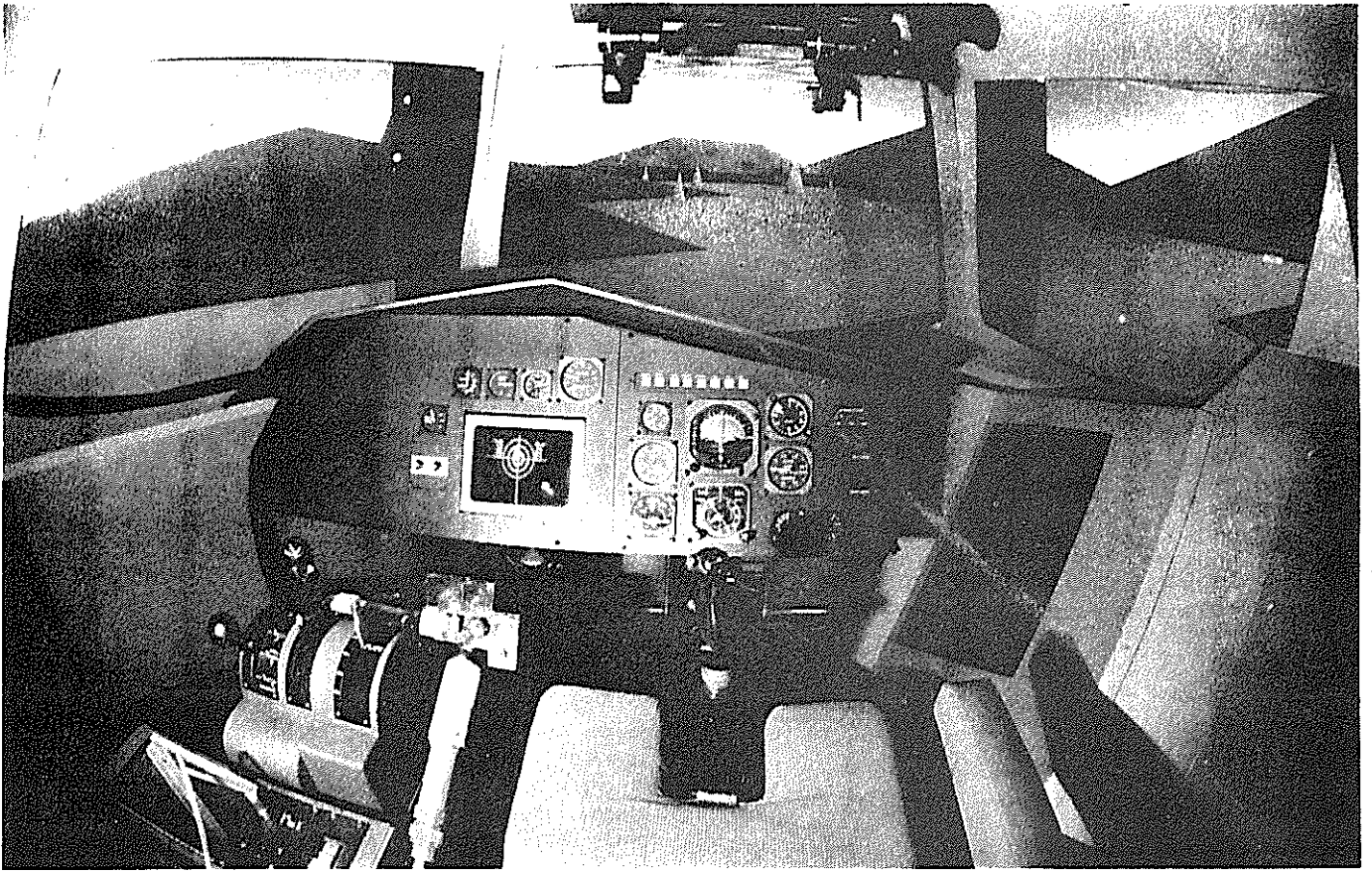


Fig. 2 Blue aircraft cockpit and computer generated imagery.

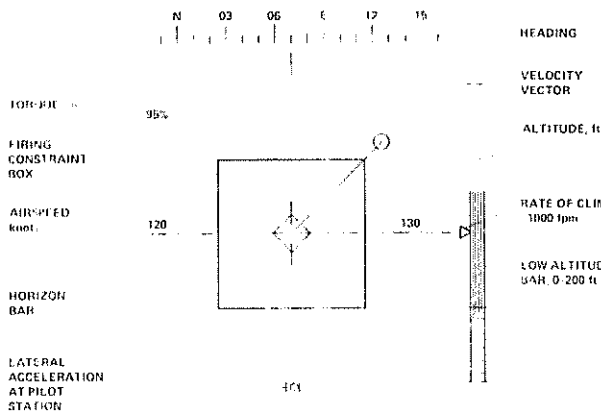


Table 1 Control travels and force gradients

Control	Travel, in.	Breakout, lb approximate	Gradient, lb/in.
Collective	10.0	0.50	0
Pedals	± 3.25	2.00	2.00
Longitudinal cyclic	± 6.00	1.00	0.67
Lateral cyclic	± 6.00	1.00	1.00

Fig. 3 Blue aircraft head-up display.

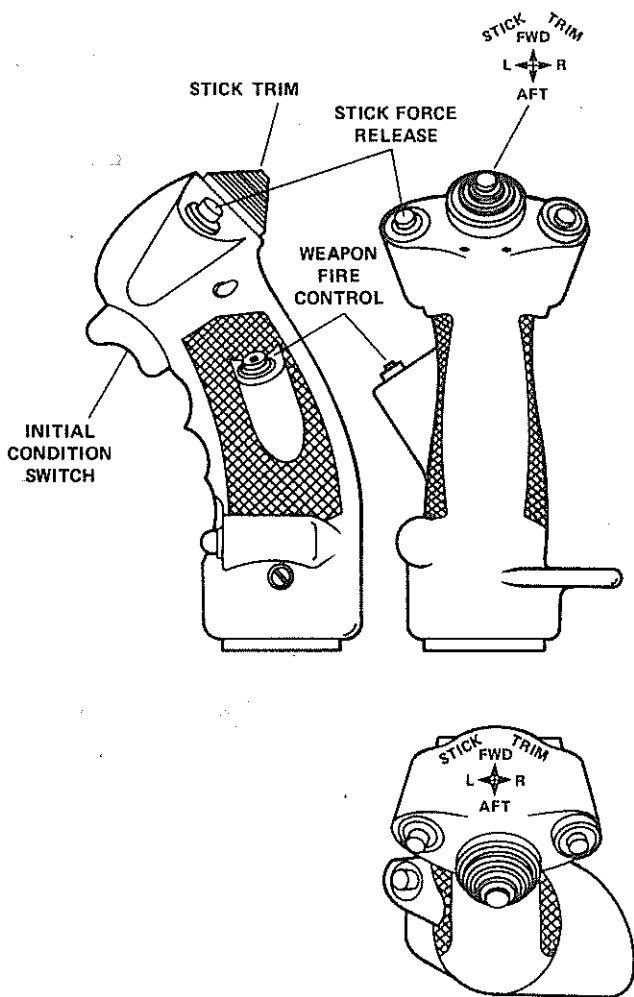


Fig. 4 Blue aircraft cyclic stick grip.

There was no ground texturing. A two-dimensional mountain range surrounded the detailed modeled area in a square pattern, 10 km on a side. In between the high detail area and this range was a flat ground plane. Both aircraft were free to fly anywhere in the database.

The need for two independently piloted aircraft presented unique CGI requirements. The Singer-Link Digital Image Generator (DIG) normally provides the VMS pilot with four out-of-the-cockpit "windows" of CGI scenery. Since the DIG system has a capacity of four windows only, a two pilot system must split the four available windows between the two cockpits. For this simulation, a new DIG software program was developed to allow multiple eyepoints to be maneuvered about the database. Three CGI windows were assigned to one eyepoint, the blue aircraft in the VMS cab, and one window was assigned to the other eyepoint at the red (or enemy) aircraft station.

The pictorial presentation of the blue helicopter was that of a UH-60 Blackhawk while the red aircraft was represented as an MI-24 Hind. Both aircraft were depicted with rotating main rotor blades. Note that these were visual representations only; the math models producing the flight characteristics of the two aircraft are discussed later in this report. Occulting of the two aircraft images as they were obstructed by buildings, trees, or terrain occurred as it would normally in actual flight.

Special features of the new CGI database include a flash in the CGI screen of each aircraft when a successful shot from the blue aircraft is fired. Visibility, though variable, was always set at clear daylight conditions for this experiment. Flightpaths of the red or blue helicopter may be recorded and then played back as a separate target during a simulation run. Thus, three aircraft, one preprogrammed and the other two piloted, can maneuver about the database.

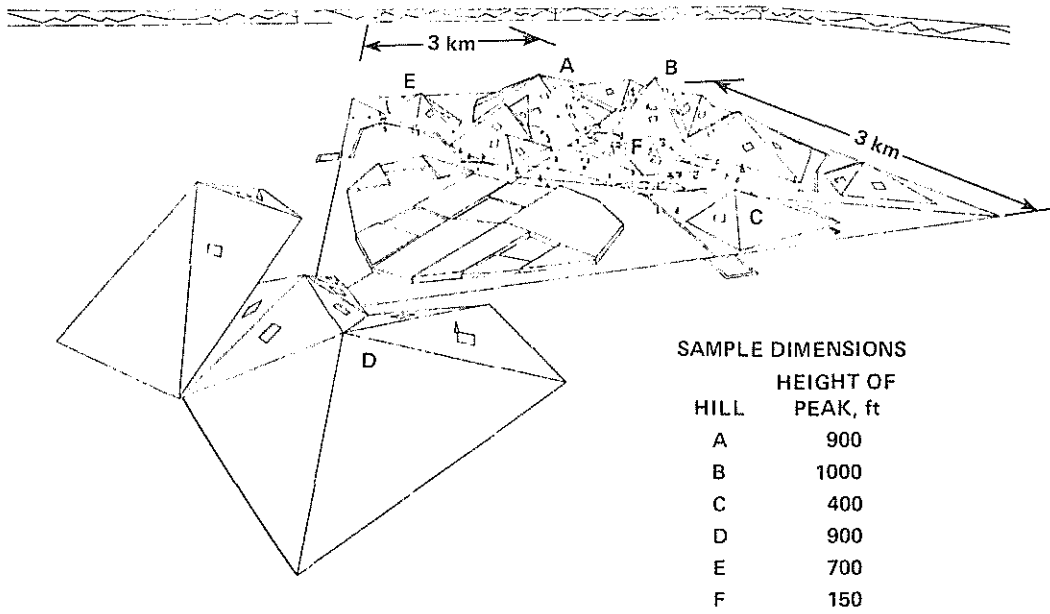


Fig. 5 CGI gaming area.

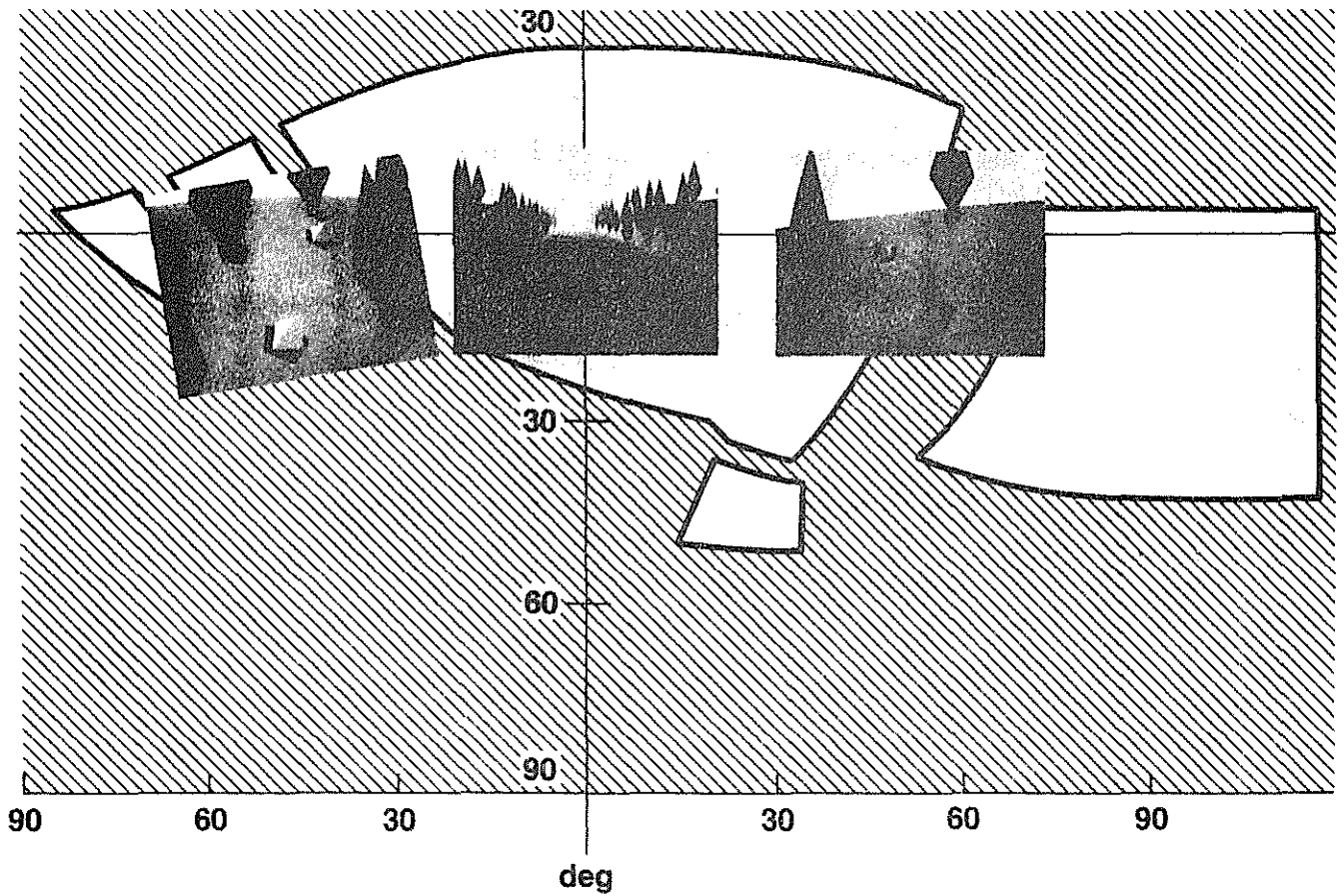


Fig. 6 Blue aircraft field-of-view.

To compensate for the restricted field-of-view of the CGI visual system for air combat, a CRT panel-mounted display (PMD) for the blue aircraft cab and a similar HUD for the red aircraft were designed. The displays gave information as to the relative range, altitude, bearing, and heading of the opponent aircraft to each respective pilot in the pilot's own reference system. A continuous scoring readout was also presented on each display.

Figure 7 shows a sample diagram of the information on the blue aircraft PMD and the red aircraft HUD. Interpreting the display as the red aircraft HUD, the sample shows the blue aircraft in the seven o'clock position and heading directly at the redship. Range is 1567 ft, and the large arrow and digits above it indicate that blue altitude is 222 ft greater than red. A short or medium length arrow would appear if blue were below red or at approximately the same altitude, respectively. The scales at the upper left and right indicate the probability of survival (PSR, PSB) of each aircraft, starting at 100% and decreasing as shots were scored and the run progressed. The lower two scales appeared on the red aircraft HUD only and indicate red altitude and airspeed in analog and digital form.

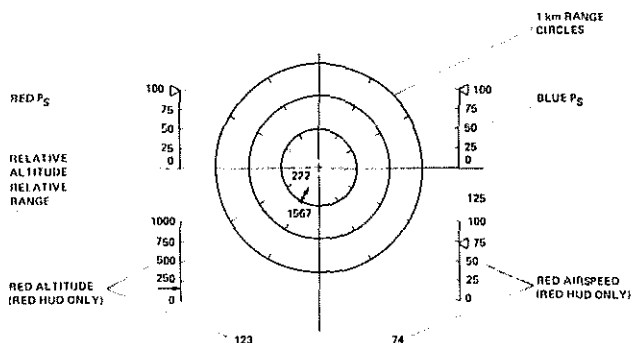


Fig. 7 Blue panel-mounted display/red head-up display.

The opponent aircraft indicator arrow and accompanying information were displayed only if a clear line-of-sight existed between the two aircraft. The coordinates of every hill and tree block vertex were stored in the mainframe computer memory. Planar surfaces were defined by grouping appropriate vertex sets. An algorithm was developed to determine if the line segment connecting the two aircraft intersected any of the planes. If an intersection was found, the line-of-sight was not clear, and the target information would not be displayed. Thus, the pilots were not given tactical information which they would not have during air combat engagements in actual aircraft.

The blue aircraft PMD provided the evaluation pilots aid in initial acquisition during free engagements and they learned to use the display with quick glances whenever contact with the red aircraft was lost. One pilot commented that the PMD functioned similarly to an APR-39 missile warning radar system. The green light indicating a clear line-of-sight would alert the pilot to a threat presence and then a look at the PMD would give the location of the threat.

Red Aircraft Station

The red aircraft pilot operated the aircraft from a console set up in the VMS control room (Fig. 8). Aircraft controls were a three axis joystick for roll, pitch, and yaw and a potentiometer knob for collective control. A single window CGI picture was displayed on a 25-in. monitor incorporating a field-of-view as shown in Fig. 9. The HUD discussed previously was projected on a beam splitter system in front of the CGI monitor. A set of green, blue, and red panel lights duplicated the light display information in the VMS cab.

The math model for the red aircraft was developed especially for this experiment. It consisted of a set of kinematic equations of motion fully described in Ref. 7. The model responded to joystick inputs from the red aircraft pilot so as to exhibit helicopter-like dynamics to the red pilot looking out of the cockpit and also to the blue pilot, who saw the aircraft as an outside observer.

Firing Logic and Scoring

A fixed forward-firing weapon was modeled as armament for each aircraft. It was assumed that if one aircraft could successfully track the other within certain range, pitch-off, and angle-off constraints for a representative time, then a probability of kill (PK) could be associated with that track. Pitch-off and angle-off are defined as the angles between an aircraft's body axis coordinates and an opponent aircraft in pitch and azimuth, respectively. These constraints describe a truncated cone as depicted in Fig. 10. Although the parameters were varied, the cone size was nominally set to $\pm 2^\circ$ in pitch and azimuth and the optimum range to be between 500 and 750 ft. These conditions had to be held for two continuous seconds to score a shot with $PK = 0.10$. A series of panel lights and headset tones alerted the pilot to the tactical situation and as to when he was able to fire. When a successful shot was scored, the CGI displays flashed white for approximately 60 msec. A flow chart depicting the timer, light, and tone sequence for blue weapon firing is shown in Fig. 11.



Fig. 8 VMS control room and red pilot station.

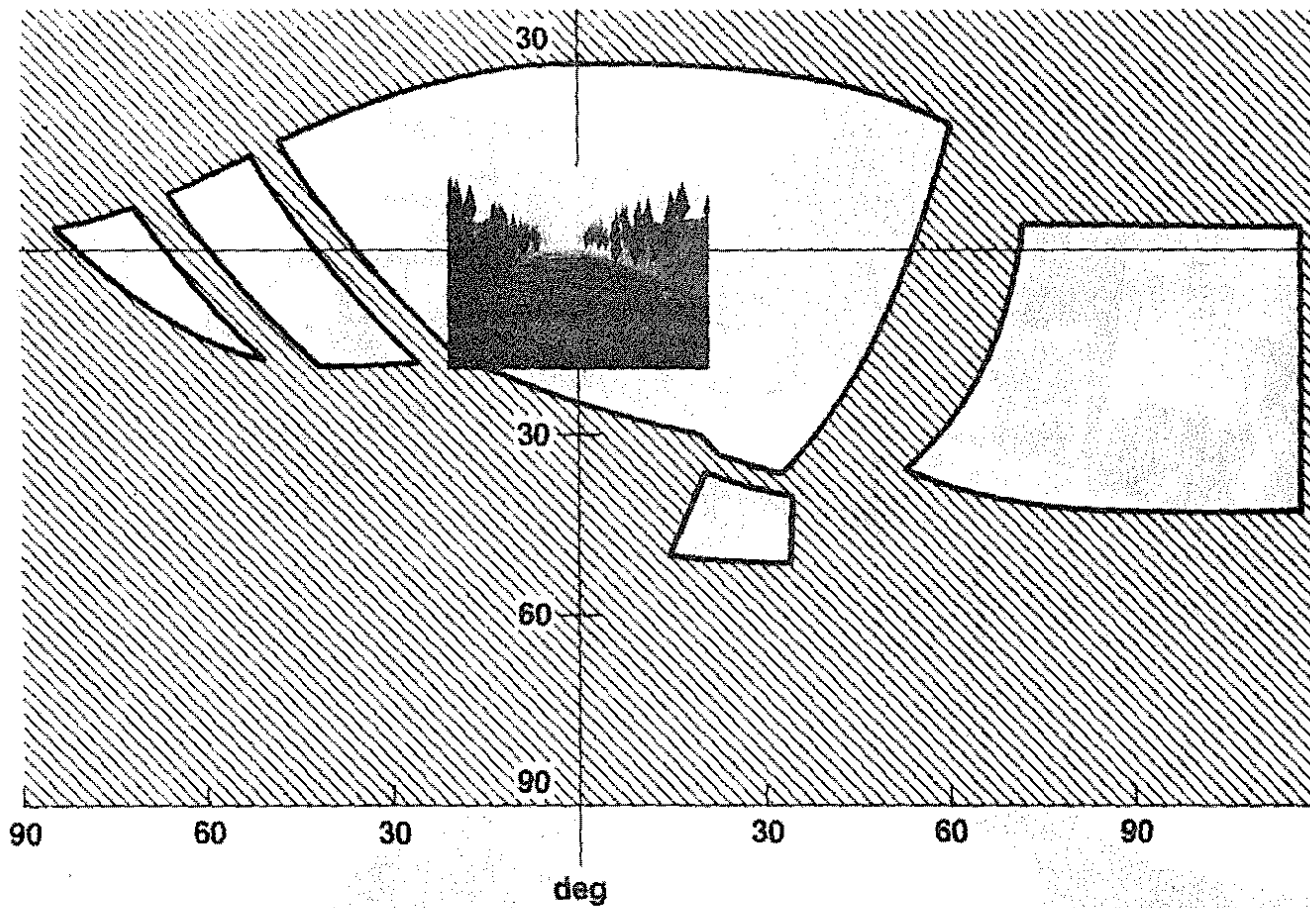


Fig. 9 Red aircraft field-of-view.

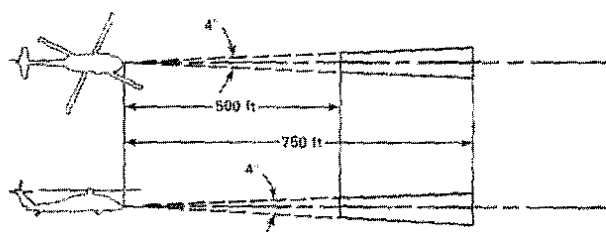


Fig. 10 Simulated weapon envelope.

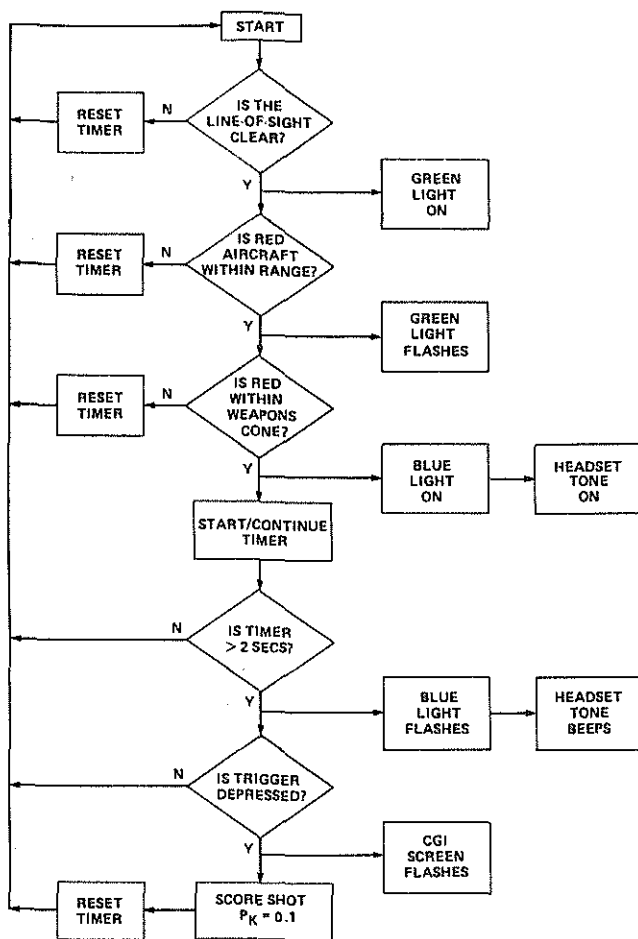


Fig. 11 Blue aircraft firing logic.

Since the primary task of this experiment was tracking, measurements were set up to record and display to the blue pilot the relative success of his maneuvering. An "optimum" tail chase position was defined as a 30° body-axis cone projecting from the red aircraft as shown in Fig. 12. The cone is biased down somewhat to reflect the advantage of being in the opponent's "blind spot." A maximum range of 1200 ft was also defined outside which the opponent was assumed to have a turning advantage. If the blue aircraft strayed outside these constraints for longer than 5 sec, a probability of kill of 0.05 was charged to that event. During low level engagements, an altitude limit of 300 ft maximum was set in order to avoid ground-based defenses. If the blue aircraft exceeded this limit for longer than 13 sec, a probability of kill of 0.10 was charged.

For offensive maneuvers, the red aircraft was given a weapons cone identical to that of the blue aircraft. Red, however, did not need to depress a switch to fire a shot. If blue was held within

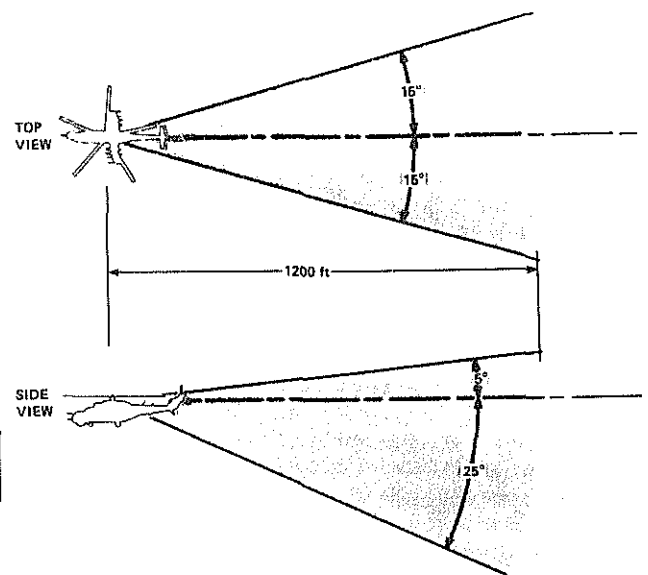


Fig. 12 Optimal tail chase cone.

the firing parameters for the required time, a shot was automatically scored with $PK = 0.10$. Whenever the blue aircraft was within the red weapons parameters during offensive engagements, or whenever blue strayed outside the defined tail chase position during tail chase scenarios, a red light would be displayed on both the red and blue instrument panels. One second before a shot was to be fired, the light would begin to flash.

Experimental Design

To investigate the handling qualities requirements necessary for NOE air combat maneuvering, a simulation experiment measuring combat performance and eliciting pilot comments and ratings was conducted using the facilities just described. Experimental variables included rotor hub type, basic SCAS design, initial altitude, initial position, target aggressiveness, and weapon parameters.

The rotor hub model and SCAS parameters of the blue aircraft were varied to represent a sample of the teetering, articulated, and hingeless design configurations of a previous NOE handling qualities experiment using the NASA-developed ARMCOP helicopter math model. Details of the configuration types and ARMCOP model are found in Refs. 8, 9, and 10. In general, the ARMCOP model consists of equations for the separate aerodynamic force and moment contributions of the main rotor, tail rotor, fuselage, fin, and horizontal stabilizer. For this simulation, the aerodynamics of the fuselage and empennage and the

Inertias were based on the characteristics of the AH-1G Cobra helicopter.

The design characteristics and a listing of the stability and control derivatives for each configuration are provided in Ref. 7. Hub type was set by the value of hinge offset (0% for a teetering hub, 5% for articulated, 14% for hingeless). The SCAS type was also varied from a rate command system (A204,B11) to an attitude command system (T05). Configurations T05 and B11 had augmentation to minimize pitch and yaw coupling to collective inputs.

In order to evaluate the effects of terrain on air combat maneuvering, the initial altitude of the two aircraft was varied from clear-air (1000 ft) to low-level (200 ft). Initial position was also varied. Early in the experiment, the blue aircraft started each run at the same altitude and 1000 ft behind red. Later, however, free engagements were conducted with the two aircraft starting from random positions in the visual database unknown to each other.

A fundamental factor in air combat maneuvering is the unpredictability of the opponent aircraft. This factor, however, makes an ACM experiment design and data analysis somewhat more difficult than an exactly repeatable and more controlled task. A general effort was made, though, to keep the target level of aggressiveness fairly consistent during the configuration evaluation engagements prior to free maneuvering. Three levels of target maneuvering were chosen. "Gentle" maneuvering consisted of small roll and pitch attitude changes ($\pm 20^\circ$ and $\pm 10^\circ$, respectively) in clear air. "Hard" maneuvering involved larger variations ($\pm 80^\circ$ roll and $\pm 20^\circ$ pitch). "NOE" maneuvering was most aggressive, largely because of the proximity of terrain obstacles which both aircraft needed to avoid.

Finally, weapon parameters were varied. Gun range and firing cone for each aircraft (Fig. 10) were nominally set to a maximum of 750 ft and $\pm 2^\circ$ in pitch and azimuth, respectively. The effects of increasing range up to 2000 ft or decreasing the firing cone to $\pm 1^\circ$ were briefly examined.

Task

The majority of simulation runs were started with the blue aircraft already in a tail-chase position approximately 1000 ft behind the red aircraft. The blue pilot's task was to close to weapons range and maintain a proper tail-chase position as defined in the Firing Logic and Scoring section. The red aircraft was flown at various levels of aggressiveness from gentle pitches and rolls to much harder pitches, rolls,

accelerations, and decelerations. Initial altitude was also varied from low-level to 2000 ft.

Some engagements were staged in which the two aircraft were placed in positions in the data base unknown to each other. Each pilot was assigned a mission to fly to another designated point. During that transit, the aircraft would encounter each other, and air combat maneuvering would ensue. These free engagements resulted in the most aggressive maneuvering of the entire simulation. Structuring the task in this way also added to the pilot workload by forcing him to think tactically and organize his maneuver strategy accordingly. The free engagement was a more realistic (although less measurable) scenario than the tail chase since both aircraft were maneuvering offensively, though the results were somewhat less measurable. A timer limited the length of each run from 90 to 120 sec for tail-chase scenarios and to 4 to 5 min for free engagements.

Data Acquisition

Data taken for each simulated engagement were of four forms. Strip chart recorders kept track of 42 variables including control movements, airspeed, altitude, rate-of-climb, torque, and pitch, roll, and yaw angles and rates for each aircraft. Tracking information such as relative range, angle-off, pitch-off, timer histories for each scoring case, and cumulative survival probabilities were also recorded on strip charts. An initial condition printout recorded the trim state of the blue aircraft and all design constraints, SCAS and control system settings. A final condition printout calculated the final survival probability of each aircraft and the total number of blue and red shots fired. (Each time a red scoring timer was exceeded a "shot" was fired.) Brief pilot comments were recorded on tape following each run and a Cooper-Harper handling qualities rating¹¹ was assigned for each configuration. Videotapes of the blue aircraft CGI and HUD displays were also taken for most of the engagements.

Results

The most significant results of the entire experiment were pilot comments regarding the high degree of realism of individual simulated encounters and of the overall simulation design. Both pilots are instructors at the U.S. Navy Test Pilot School, Patuxent River, Maryland, and have significant helicopter, simulator, and evasive maneuvering experience (Table 2). Following one encounter, pilot B commented:

You have completely ruined me now. I am flying this mission the way I would a real

EVM [evasive maneuvering] engagement. I was flying off the cues that I perceived and off the relative motion of the target aircraft. Even when I was above him in a hover, in a pedal turn, I've adapted enough now that I had him in the center of the right console window, maybe 20° down and was doing pedal turns keeping him there. I really flew that one the way I flew the ones at Patuxent River in relationship to the other aircraft, disregarding the ground. I never looked at my altimeter one time and I am now assimilating enough cues so I'm flying [the simulator] the way it is flown in the aircraft.

Following another engagement, the comments were similar:

The scenario we just went through, as far as what I have seen, other than the bank angles--the bank angles were larger here--but the maneuvering was as realistic as anything that we have done in here and very representative of what I would expect to see in an encounter like that.

Table 2. Pilot experience

Parameters evaluated	Pilot	
	A	B
Total hours	3350	5700
Total rotary wing, hr	3100	4700
Primary A/C	CH-46, AH-1, UH-1	AH-1, UH-1, UH-60
Other A/C	OH-58, BO-105, Bell 412, CH-53, others	OH-58, CH-47, OV-1, CH-46, ABC, others
Evasive maneuvering time, hr	30	30
Simulator time, hr	50	300

Angles and Rates

The chart in Fig. 13 is presented as a summary of the degree of maneuvering involved in the air combat task. The blue aircraft data are taken from 57 aggressive target maneuvering runs at low level and clear air altitudes. (Minimal differences were found between low level and clear air maximum rates and angles, and the data are presented in combined form. However, the overall aggressiveness of the low level engagements

seemed greater, although this is a subjective judgment.) Maximum roll rates between 25 and 55°/sec were most common. Maximum achieved values were an 84°/sec roll rate and 100° roll angle. These data lie somewhere between the 40°/sec maximum rate set for an OH-58 and the 60-100°/sec rates reported in Ref. 12 for the UH-60 and S-76 during ACM flight tests. The target aircraft was somewhat less agile and had a maximum achievable roll rate of just over 40°/sec. Red's maneuvering capability, therefore, was in the class of a teetering rotor-system-type aircraft in the roll axis.

Because the math models for each aircraft were not power limited, the aircraft could be accelerated to speeds in excess of 200 knots. This capability, however, was not used even during the free engagements, when both aircraft maneuvering in an aggressive offensive manner. The highest speed ever attained was approximately 160 knots, and this occurrence was rare. Figure 13 shows the maximum speeds used to be centered around 108 knots. These speeds seemed to result because the math models handled best there rather than because of any specific speed requirement. That is, if the math models were most maneuverable at 80 knots, it is believed that the engagement airspeeds would have been lower. This observation is in accord with fixed-wing air combat practice. Supersonic jet fighters slow to speeds under Mach 1 during air-to-air engagements since it is at these speeds that those aircraft are most maneuverable.

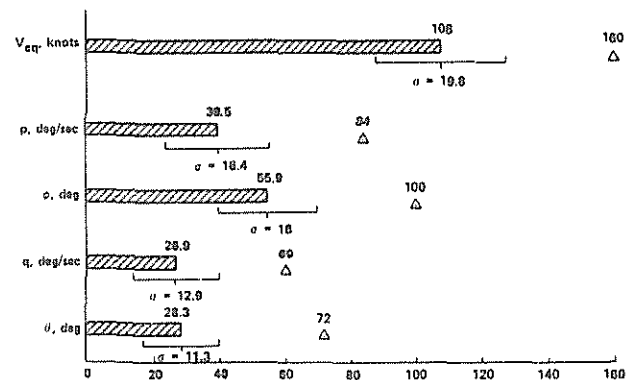


Fig. 13 Blue aircraft mean maximum rates with aggressive target.

SCAS and Hub Configuration

As seen in Fig. 14, the effect of SCAS type was very noticeable while a change in modeled hub type seemed to have little effect. Data presented in the figure are averaged from all aggressive target maneuvering engagements (clear-air and

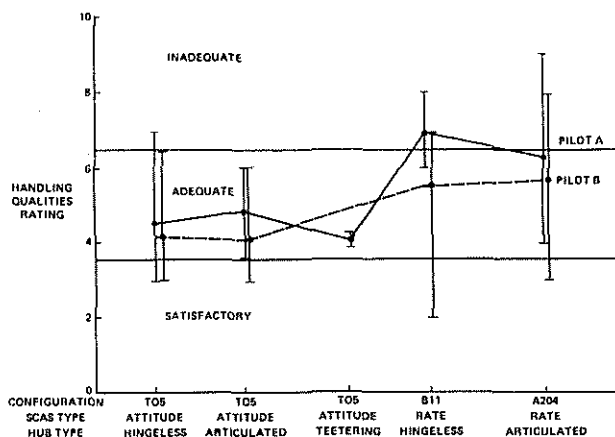


Fig. 14 Handling qualities rating versus configuration for combined aggressive target maneuvering runs.

low-level, tail chase, and free engagements). A minimum of eight to a maximum of 19 engagements were totaled for each listed combination of configuration and pilot. The attitude command system was rated from 1 to 2-1/2 rating points better on average than the rate command system. For the very high gain tracking task, tight control is required to keep the pipper sight on the target. The attitude command system allows the pilot to roll and pitch the aircraft to a desired angle with a single control movement. A rate command system requires two control movements to establish the same angle. During large amplitude maneuvering, however, some of the qualities of the rate system were desired. Larger angles could be commanded with smaller control inputs than with the attitude SCAS. In general then, for the tight tracking task, an attitude command SCAS had advantages and whenever that track was lost or in maneuvering to attain a track, a rate command SCAS may be desirable.

One pilot's comments highlighted this observation:

As far as the configuration is concerned, it is certainly a degradation over the attitude command system in terms of being able to nail an attitude and use it, but in terms of maneuverability, it is not nearly as restricted as the attitude command system seems to be. I notice I only use about plus or minus two inches of stick to get virtually any attitude I want out of the vehicle, whereas with the attitude command system, it seems that at some point, you want at least another twenty degrees of roll. Again, it is a tradeoff. I would be more inclined to take the attitude command system where I can at

least get some shots off than I would to chase around all day with a system that is very maneuverable, but rather undependable in terms of being able to track with it.

As previously stated, a change in modeled hub type had little effect on pilot rating. The SCAS design was always the dominant variable and seemed to mask the effect of any change in hub type. No restrictions due to rotor system type were imposed upon the pilots. As reported in the experimental design section, the hub configuration changes were modeled in a general way. Any future simulation investigating these parameters would need to be more detailed.

Figure 15 presents a summary of the blue aircraft scoring and timer results. The total

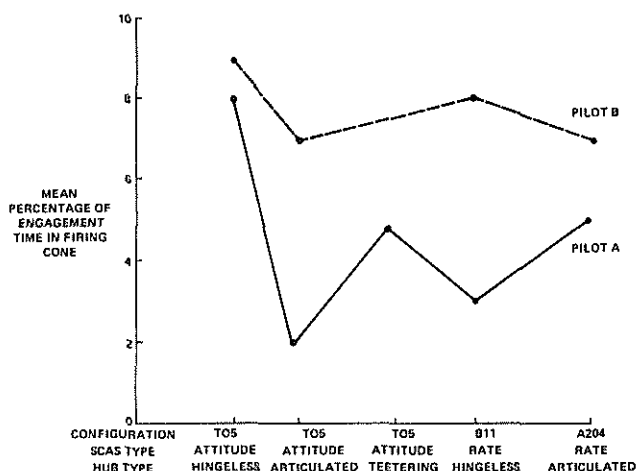


Fig. 15 Blue aircraft timer scoring versus configuration for aggressive NOE tail chase scenarios with nominal weapon characteristics.

time the blue aircraft established a successful track on red (excluding momentary swings through the firing cone) was tabulated as a percentage of the total time of each run. This method was used over final probability of survival and shot-fired data due to the variability in run length. Only the NOE tail chase runs with nominal firing constraints were considered. Mean values for different configurations and pilot combinations are shown. The data seem to support pilot rating evaluations of the attitude command over the rate command SCAS and some evidence of performance differences due to hub type. The standard deviation for each of the points is on the order of their value, however, and the results cannot be considered conclusive. The sample size for the required combination of pilot/SCAS type/hub type/weapon parameters/initial relative position and initial altitude was unavoidably small. The

sample sizes for the values presented range from a minimum of five to a maximum of 20 runs. The extremely variable nature of the task also led to somewhat variable results. A configuration with good handling qualities may have a very low timer score on a particular engagement due to poor pilot technique, tactics, or more aggressive opponent maneuvering. A large number of runs with limited variability is required to establish conclusive results.

Effect of Weapon Parameters

A brief examination was made of the effect of extending the weapon range and constricting the firing constraint cone. The effect of opening the range from a maximum of 750 ft to 2000 ft while keeping a $\pm 2^\circ$ firing constraint cone was fairly dramatic (Fig. 16). The tracking task was easier than during any other engagements even though the target maneuvering was still aggressive. Although simple geometry would indicate this is the case, it is still worthwhile to note the degree to which the task was affected. Decreasing the size of the firing cone at the increased range made the task somewhat more difficult to perform, although Fig. 16 shows that performance was still substantially better than when operating with a larger firing cone but shorter range. Although this extended range is probably too long for a gun to be fired accurately, the launch constraints are applicable to missile systems. Thus, the relative ease of missile tracking compared to close-in gun tracking is highlighted.

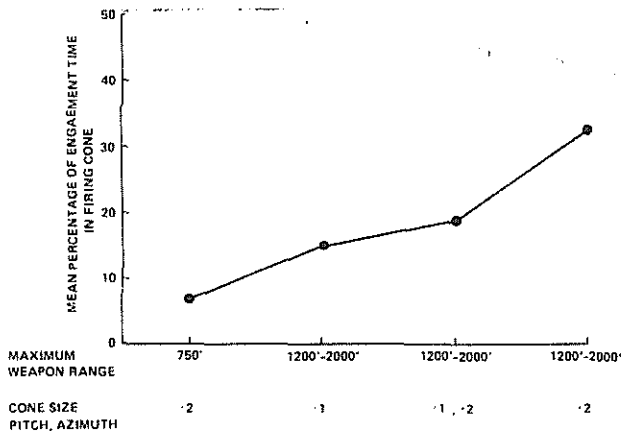


Fig. 16 Effect of simulated weapon range and acquisition window size.

Conclusions and Recommendations

The large number of experimental variables and the exploratory nature of the simulation prohibit specific definitive conclusions from

being set forth. However, some general conclusions can be stated with confidence. The simulator system design, facilities, and pilot tasks were all judged to be extremely useful tools for evaluating a wide variety of aspects of the helicopter air combat maneuvering problem. Engagement tactics and flightpaths of both the red and blue aircraft were found to be very representative of both flight test encounters and scenarios that military pilots would expect to see in actual combat. In short, a legitimate capability to perform realistic and meaningful simulations of low altitude helicopter air combat encounters has been developed and proven.

Other general conclusions can be drawn. Pilot comments, handling qualities ratings, and scoring performance showed the characteristics of the attitude command SCAS to be superior during the tracking phase of the task, while the rate command system had characteristics desired for larger amplitude maneuvers. While this was only a limited examination, a control system which can combine the qualities of both systems is worthy of future investigation; for example, a transition from attitude to rate command system as a function of controller displacement may provide the desired blend of control response.

Low level maneuvering in the presence of terrain features brought a high degree of realism to the simulation. The effect of the terrain seems to be an important one although exact performance agility differences from clear air maneuvering cannot be determined from the limited data taken. Certainly, maneuver strategies were affected and ground and obstacle avoidance were continuous pilot concerns. It seems imperative to include these terrain features in any high fidelity simulation of helicopter air combat. Quantification of their effect on handling qualities requirements will be an important focus of future studies.

Although only a simple examination of a change in weapon parameters was performed, the substantial effect any change had on the tracking task has been highlighted. The weapon system model will have a first-order effect on any encounter result, either actual or simulated. A more precise model or an examination of various weapon types should be included in future tests.

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