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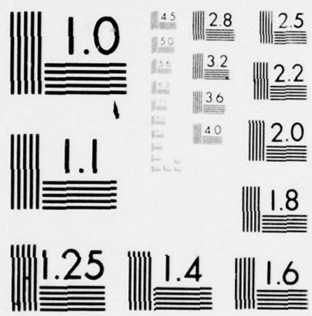

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HIGH ACCELERATION COCKPIT SIMULATOR EVALUATION
Summary Report

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JUNE 1977

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TECHNICAL REVIEW AND APPROVAL

AMRL-TR-75-123

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Chief
Human Engineering Division
Aerospace Medical Research Laboratory

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Since 1970, the Aerospace Medical Research Laboratory (AMRL) and the Air Force Flight Dynamics Laboratory (AFFDL) have jointly sponsored a unique and innovative approach to fighter cockpit design termed the High Acceleration Cockpit (HAC). As a result of indicated improvements in pilot-vehicle compatibility during and following exposure to moderate-to-high G force fields, HAC is entering a stage of advanced development and planned flight demonstration by AFFDL. Improved pilot capability with HAC results from repositioning the pilot to place him in a more favorable position with respect to the applied loads, thereby

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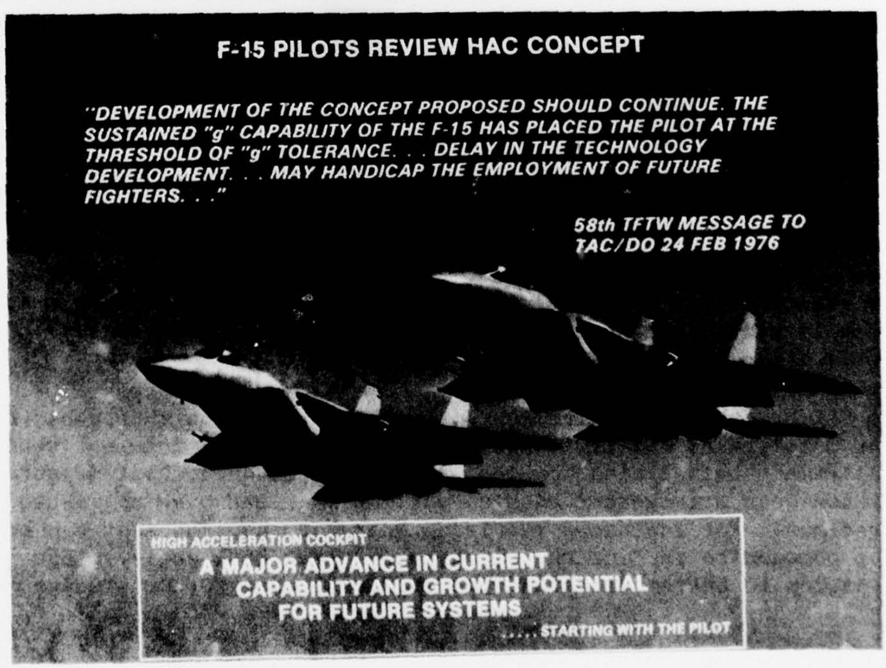
reducing the chance of grayout and blackout as well as improving tracking ability and resistance to body fatigue. The material presented herein is from a comprehensive manned simulator assessment of the tactical utility and combat capability projected for the HAC concept. Four Air Force and Navy tactical fighter pilots with recent air-to-air experience explored the advanced aircraft configurations from a set of close-in starting conditions. These engagements sought weapon delivery opportunities in one-vs-one interactive air combat. The Manned Air Combat Simulator (MACS) at the McDonnell Aircraft Company (MCAIR) was used for this evaluation. Systems were completely modeled, including aircraft and weapon dynamics, cockpit with flight control and fire control systems. A full complement of offensive and defensive situation displays and cues were provided to cover all aspects of the simulated combat. Selected results are presented to illustrate that, relative to conventional cockpit design, the configuration employing HAC was able to decisively control the engagements. HAC achieved more kills sooner and established larger kill margins relative to a common threat opponent. These promising results are deemed to be conservative due to the fixed-base nature of the simulation and the sterile nature of one-vs-one combat wherein the airspeeds rapidly decay, leading to excessive maneuvering in lift-limited regions. Validation of these results is one of the major flight test program and evaluation goals.

PREFACE

This report summarizes the results of High Acceleration Cockpit Manned Air Combat Simulator Evaluations conducted by McDonnell Aircraft Company under USAF Contract F33615-75-C-5087 and McDonnell-Douglas Corporation Independent Research and Development, Project 7016. The USAF Contract was administered by the Aerospace Medical Research Laboratory, under the technical monitorship of Mr. Philip V. Kulwicki, Visual Display Systems Branch, Human Engineering Division.

This information was also presented to the second Air Force Avionics Laboratory/ United States Air Force Academy Air-to-Air Fire Control Review as part of the Weapon Delivery System Hardware Improvements session to identify High Acceleration Cockpit (HAC) as a technology that can significantly improve the air combat capability of today's fighters.

Contract F33615-75-C-5087 addressed the tactical payoffs derived by incorporation of HAC with a 65° reclined seat into a 10 +g advanced fighter (structurally strengthened to pull the increased load factor throughout its flight envelope). This fighter's combat capability was compared to a fighter of conventional 7.5g design that incorporated an upright seat. Project 7016 addressed the tactical payoffs of incorporating the HAC with the 65° reclined seat into the 7.5g fighter. The comparisons presented herein summarize the combat capability measurements for the 7.5g fighters, with the seat both upright and reclined to 65°.



INTRODUCTION

High Acceleration Cockpit (HAC), as a hardware improvement, matches the pilot's g tolerance to that of his aircraft's sustained maneuvering capability. Through Manned Air Combat Simulator (MACS) evaluations HAC has been found to produce a quantum step improvement in the ability of fighters to achieve missile and gun opportunities and to deliver the ordnance to the opponent. This results from the fundamental physiological improvements (reduced work and fatigue) that increase the pilot's ability to effectively use his weapon system in a hight stress, high load environment. Integration of HAC is accomplished through cockpit design modification to accommodate the articulating seat while maintaining a usable cockpit arrangement for all operational mission phases. Additional advanced hardware, software and weaponry improvements may be advantageously combined with HAC to produce synergistic improvements in air combat capability before introduction of a major new air superority weapon system.

DISCUSSION

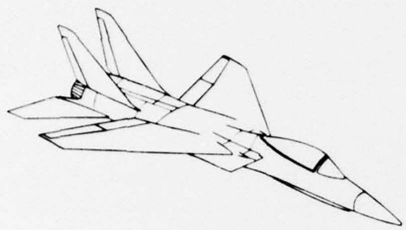
Today's fighter aircraft possess more maneuverability than has been observed in past aircraft. Current design trends continue to emphasize the need for high maneuverability coupled with advances in avionics and armament. High maneuvering load factors can be sustained (i.e. no loss of airspeed or altitude) in a significant portion of the total flight envelope. This new capability is a consequence of the emergence of more powerful engines, lightweight materials and new fabrication techniques, and efficient high lift systems and wing design. From the pilot's perspective, especially with regard to combat maneuvering, the availability of added maneuver agility can lead to increased tactical advantage and enhanced survivability.

Figure 1 compares the sustained load factor envelopes of the Advanced Conventional Fighter (ACF) used in this study with the F-4E envelopes. The ACF retains a level of maneuverability typical of the F-15 class of fighter. The curves present the sustained load factor envelopes achievable by the individual designs, solid and broken lines for the ACF and F-4E, respectively. The shaded regions illustrate the increased flight regime relative to the F-4E for which the ACF can sustain the indicated load factors. Of particular interest is the 3 to 7g envelopes emphasizing added aircraft capability at moderate-to-high G which can lead to degraded pilot performance in the stressful sustained air-to-air environment unless a concerted effort is undertaken to improve the crew member's G tolerance. The high acceleration cockpit fills this need.

Flight experience with current air superiority fighters has demonstrated that pilot G-tolerance can limit the full exploitation of inherent vehicle maneuverability. To alleviate this limitation the high acceleration cockpit (Figure 2) features a multi-position seat arrangement with an upright 15° seat back angle used for routine flight operations. For instances requiring "hard" turns, the seat can be repositioned at pilot command to recline the pilot to 65° seat back angle. This places the pilot in a position to better withstand the applied loads. Other studies have developed and

FIGHTER TRENDS EMPHASIZE SUSTAINED AGILITY

NEW FIGHTERS ⇨ *EXPANDED ENVELOPE*



ADVANCED CONVENTIONAL FIGHTER (ACF)

- 1983 DESIGN IOC
- CONVENTIONAL DESIGN
- AIR SUPERIORITY MISSION
- SRM + GUN ARMAMENT
- 7.5g STRUCTURE
- 25,000 LB CLASS TOGW

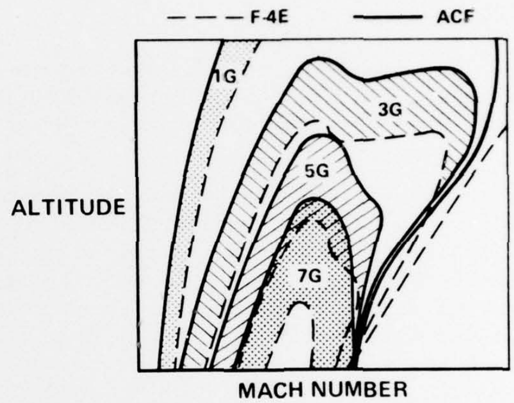


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FIGURE 1

COCKPIT APPROACH: REMOVE THE LIMITING CONSTRAINT

- HIGH SUSTAINED G
- HIGH STRESS ACM ENVIRONMENT
- CAPABLE PLATFORM/ WEAPON

- HIGH ACCELERATION COCKPIT
  - REDUCE STRAINING/FATIGUE
  - DELAY BLACKOUT

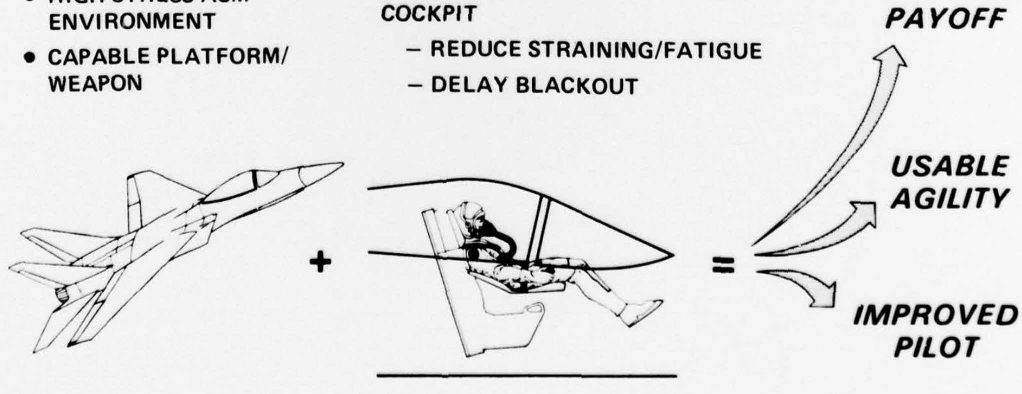

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FIGURE 2

refined the design concepts (such as retaining full external vision) which render HAC operationally feasible with today's technology. Likewise, manned centrifuge tests have confirmed the medical, physiological and physical benefits attributable to HAC. In parallel with these related efforts, a series of simulator experiments using operational military fighter pilots has investigated the improved combat capability projected for HAC and estimated its tactical utility in an air combat scenario. Sample results from a recent manned simulator evaluation illustrate the combat payoffs which can be realized by incorporating HAC into existing high performance tactical fighters.

The remainder of this summary consists of a short description of the cockpit features, the simulation concept and environment, the experiment itself, figures of merit used to determine tactical payoff and representative results and conclusions.

The key features of HAC are depicted in Figure 3. These features have evolved since 1970 by means of iterative development through stages of analysis, design, test and evaluation characterized by continual involvement of the user...the operational fighter pilot. More than 175 Air Force Systems Command and Tactical Air Command pilots (from First Lieutenant to Major General) have participated in static simulation, dynamic simulation, or on-site evaluation focusing on derivation of a credible cockpit that would be usable in the combat arena. This development has produced a functioning cockpit which was installed in the Manned Air Combat Simulator at the MCAIR flight simulation facility and exercised in simulated one-vs-one aerial combat maneuvering totaling more than 1000 individual duels.

CENTRAL FEATURES OF HAC

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FIGURE 3

Use of a multiposition, reclining seat is a principal feature of HAC. The seat is mechanized as an ejection seat insert to preserve a conventional escape capability. When articulated by the pilot (e.g. upon entry into a combat zone) the insert raises the seat pan and reclines the seat back rest sufficiently to provide both added G-protection and excellent external visibility. Parallel testing using manned centrifuge facilities has confirmed a 2-3G improvement in pilot G-tolerance (defined by blackout onset), reduced straining and fatigue, and marked improvement in physiological workload (substantial heart rate reduction implies improved cardiac workload) when the back rest is inclined 65 degrees from the G-vector. The structured cockpit evaluations performed during the iterative development have determined that excellent external visibility can be achieved in a usable cockpit layout to increase combat performance without degrading noncombat performance. This is made possible through the use of integrated avionic components, side-arm primary controllers, fingertip weapons management and a head-up display with simplified formats to provide steering and attack information.

The tactical utility of this improved cockpit configuration was confirmed by this HAC simulator evaluation. The fact that participating pilots identified potential tactical gains for HAC is noteworthy since the entirely fixed based simulation presented identical aircraft (design and aerodynamic performance) to the pilots with the only differences being the seat position (15° upright and 65° reclined)and associated light loss scheduling. Even with this simplistic representation of pilot "g" tolerance differences, the evaluators found tactical benefits for HAC.

This simulator evaluation is a successor to an earlier guns only manned simulation which also examined potential gains in combat effectiveness. The tactical environment simulated here was freeplay, one-vs-one, within visual range, interactive air combat representative of a dogfight scenario emphasizing the use of short range missiles in addition to conventional cannon armament. Figure 4 illustrates the Manned Air Combat Simulator (MACS) Facility in which the HAC was installed. This simulation provided a high fidelity representation of HAC in the air combat environment.

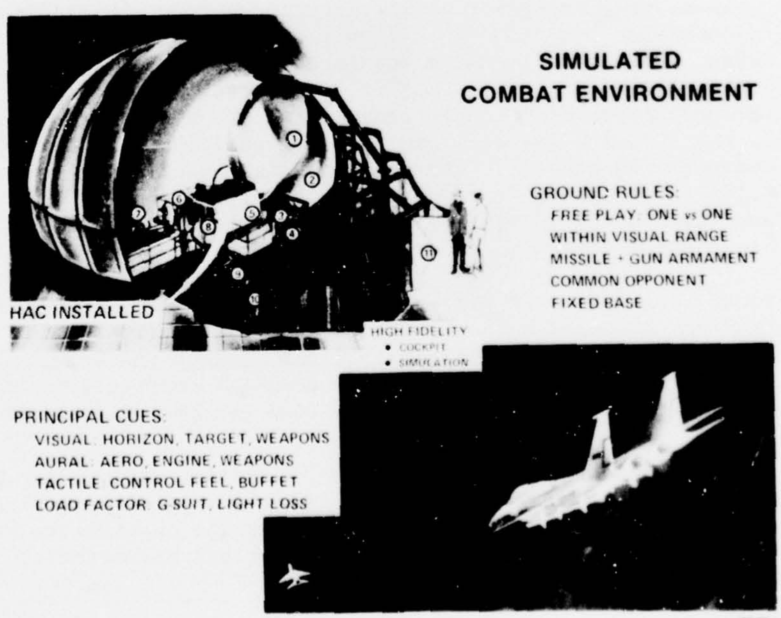

FIGURE 4

Cockpit integration refinements were made based on the earlier simulation. Specific areas updated included seat design, controller placement, rudder pedals, and a small displacement primary controller. The combat environment fidelity was upgraded through use of F-15 head-up display to provide improved optical quality for attack displays. New simulator hardware provided a color presentation of the out of the window situation. The addition of AIM-9L missiles expanded the available tactical options beyond the "guns only" study.

The simulated aircraft were a conventional design high quality fighter used as a common opponent and the Advanced Conventional Fighter (ACF) noted earlier. Both aircraft were designed and mechanized for the earlier guns only simulation. The ACF was "flown" against the common threat both with and without HAC from a variety of initial conditions. All aircraft retained identical armament, avionics, displays, structural limit and modeling of lethality/vulnerability.

A full complement of combat situation cues were provided, including (1) external view of the opponent, horizon, ground terrain, and weapon firing, (2) sound cues depicting aerodynamic noise, engine setting, stall warning, threat warning, and weapons, (3) load factor cues of G-suit and seat pressure and light dimming to simulate the onset of grayout and blackout, and (4) both offensive and defensive in-cockpit displays. The cues of primary interest herein were the load factor cues. The ACF with HAC (denoted HAC-65°) was equipped with relaxed G-cue schedules to simulate the grayout, straining and fatigue benefits for HAC previously noted in centrifuge experiments. The ACF without HAC retained the same load factor cues as the common threat opponent.

The objective of this evaluation was threefold: (1) achieve pilot acceptance of HAC for air combat, (2) determine tactical opportunities where HAC exhibits tactical payoff, and (3) quantify potential combat advantages (predicted kill advantage, rounds on target, etc.). To address this objective, an experiment was designed using the MACS facility as the basis for test. The test basis, illustrated in Figure 5, was 144 valid duels developed from appropriate combination of the four military fighter pilots, three cockpit/aircraft configurations and six starting geometries. The pilots each possessed more than ten years of tactical fighter experience including combat as well as recent experience in air combat tactics with a conventional cockpit. Each pilot was a USAF or USN Fighter Weapon School graduate or instructor. The cockpit/aircraft configurations were the ACF with the upright 15° seat position, the ACF with the reclined 65° seat position and the common threat opponent with a conventional cockpit. The start conditions were six geometries initiated co-altitude at 20,000 ft at transonic speeds and with visual contact by both pilots. A balance of offensive, neutral and defensive relative geometries were represented by this set at the beginning of combat.

Every individual engagement was limited to a maximum of 120 seconds duration. A total of 144 engagements comprise the formal data to follow (i.e. each "friendly" cockpit/aircraft configuration was exercised 72 times against the common opponent). The test plan called for each pilot to fly each "friendly" configuration in opposing each other pilot from all initial conditions in a counterbalanced experimental design.

This simulation encompassed large amplitude differential maneuvering in addition to terminal tracking and weapon delivery tasks. The pilot's objective in each encounter was to aggressively seek the offensive advantage and deliver the appropriate weapon (maximizing kills and/or minimizing losses depending on the tactical situation).

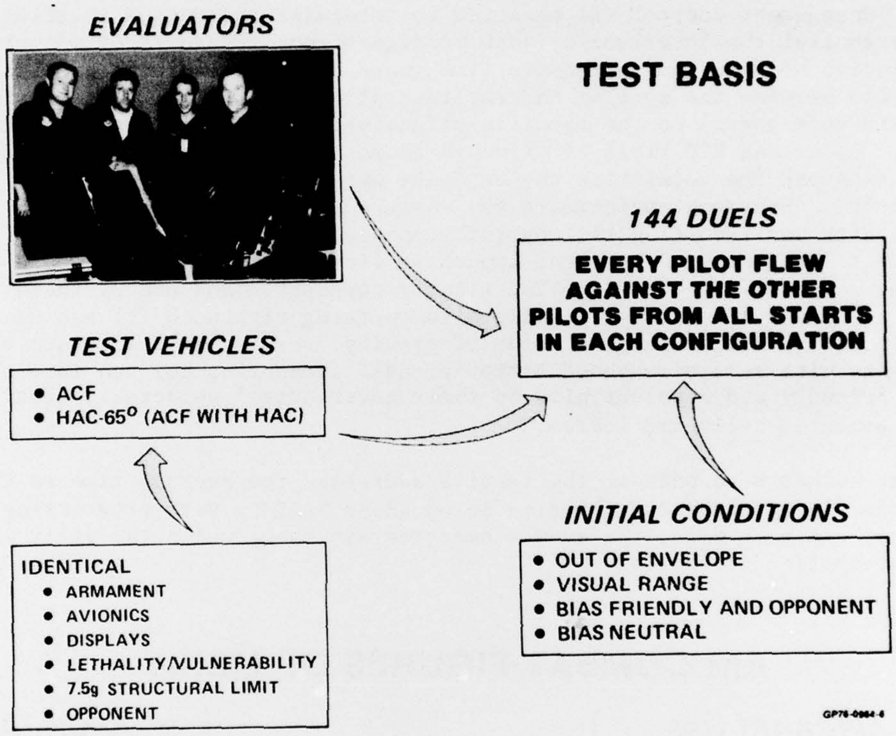

FIGURE 5

All systems were modeled. The simulation represented a six degree of freedom model of aircraft dynamics and a five degree of freedom model of missile dynamics with performance verified by other simulation or in-flight studies. The flight control systems of all aircraft were identical and of conventional augmented design. Each configuration was equipped with two missiles and 1000 rounds of cannon armament. Each configuration had an offensive radar (ten nm acquisition range) for fire control and a tail warning receiver (two nm range) to assist defensive maneuvering. Identical fire control algorithms provided attack information to the pilots via the head-up display for missile and gun modes. A conventional lead computing optical gunsight was used when the pilot selected a gun attack mode. It is noteworthy that the air-to-air attack display formats developed herein were highly regarded by the evaluation pilots.

All aspects of the air combat (Figure 6) were monitored and recorded to provide measurements of each configuration's ability to perform the tasks necessary for achieving combat kills. Engagement control was measured to determine the unique relative geometry and positional control characterized by each configuration. Measures of positional advantage (relative heading) and offensive time (nose to tail quadrant) provide clear distinction between the upright and reclined piloted aircraft. The remaining figures of merit were geared to the specific offensive and defensive tasks performed by the pilots. Radar and HUD field of view are characterized by both the first target acquisition and the total time the opponent was held within the appropriate angular parameters. End game performance was measured in terms of missile and gun opportunities, hits and resulting kill by both combatants. Opportunities were measured as the time spent within actual launch or fire parameters which would result in a hit if the weapon were employed. The pilot's perception and use of these opportunities is measured as actual missile hits (passing within 15 ft) and gun hits (passing within 20 ft) of the target center of gravity. Kills and losses are computed from the ordnance hits as a time based Markov process accounting for the interaction and timing of friendly and opponent hits on their adversaries' vulnerable area. Results are quoted as expected kills and losses.

The format selected to present the results addresses the average time to the first event, time in envelope and the time in envelope buildup with progressing engagement time. In each case, the events selected are those which the pilot was specifically attempting to control.

AIR COMBAT FIGURES OF MERIT

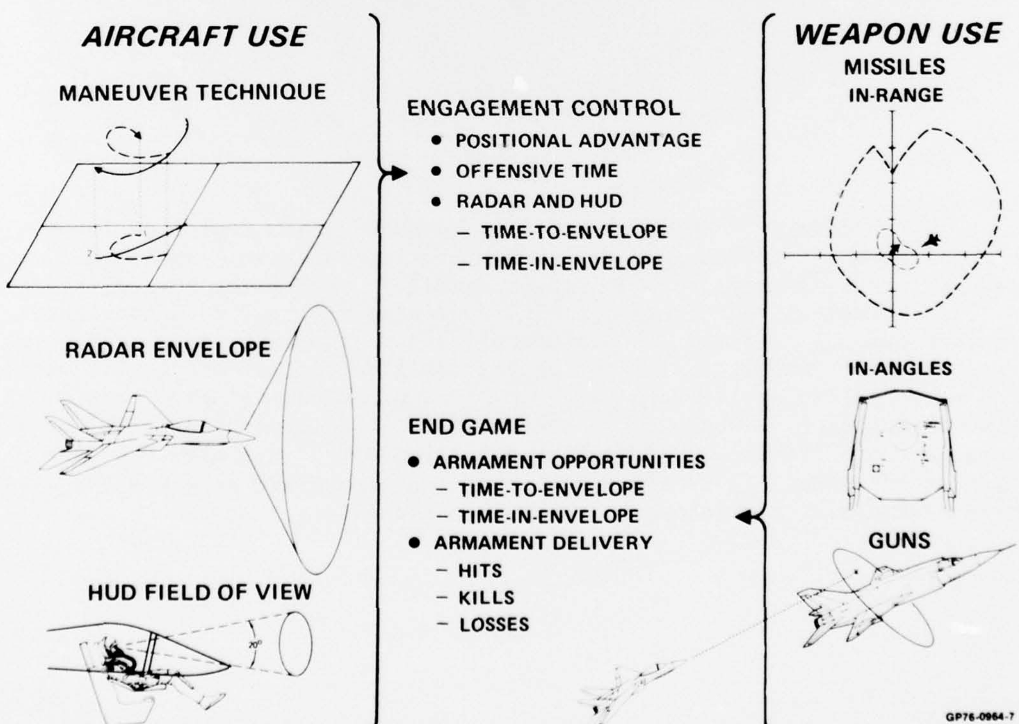

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FIGURE 6

The remainder of this paper will discuss the endgame combat benefits attributed to HAC-65°. To achieve these benefits it is clear that the engagement characteristics leading up to the endgame assessments also present an image quite favorable to HAC. Subsequent discussion will address missile and gun opportunities, hits and kill measures.

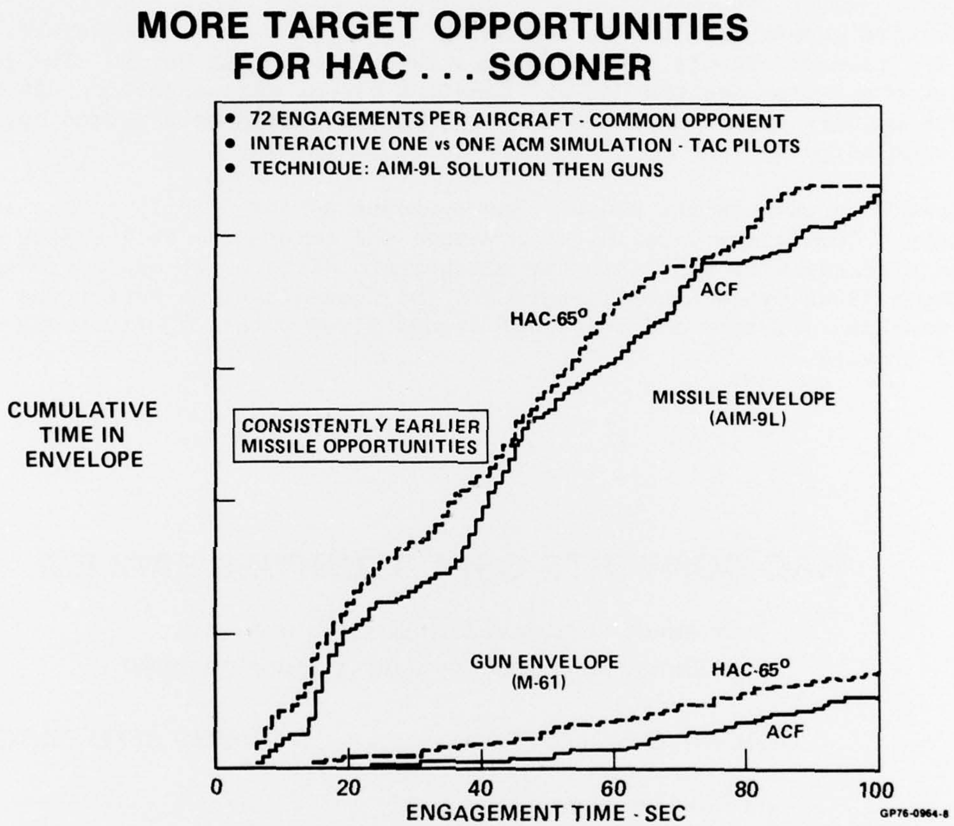

FIGURE 7

The weapon opportunities achieved by HAC-65° and ACF are presented in Figure 7 as a function of time into the engagement. The opportunities are depicted as the cumulative time within missile launch and gunfire parameters totaled for the 72 engagements flown by each configuration. The region between the curves indicate the margin of HAC-65° improvement over ACF against the same opponent.

Spacing of the missile and gun envelope curves as a function of time points to the technique which was employed by the TAC pilots. At engagement initiation, the pilots employed the large off-boresight, all-aspect capability of the AIM-9L missile during the first pass in an attempt for initial kill at longer ranges. As the situation closed and the opportunity presented itself the gun armament was employed.

Repetitive application of this technique provided first missile and then gun envelope time buildup with progressively more emphasis on guns as the dueling progressed to lower speeds. The result is a buildup in missile time followed by gun time. As much as an order of magnitude difference is noted between the amount of the missile and gun time. The consistently earlier time in envelope provided by HAC-65^{o} indicates the superior capability the 65^{o} seat provides the pilot in initiating the attack and controlling the situation development to obtain effective missile and gun position.

Effective gunnery has a very demanding set of geometric constraints. Target aspect and rate of closure become as important as pointing angle. The demands on the pilot are high and the HAC-65° benefits become more dramatic. An effective first gunnery opportunity means the pilot does not need a second opportunity for the same target.

Figure 8 focuses on the HAC-65° improvements achieved early in the engagement for gunnery. Cumulative time in gun envelope and cumulative bullet hits are presented as a function of time into the engagement. Totals are again presented for the 72 duels flown by each configuration. The shaded regions depict the increased time in tracking solution and number of rounds fired within 20 ft of the target's center of gravity.

HAC CONVERTS OPPORTUNITIES EARLIER

- INTERACTIVE COMBAT SIMULATION - TAC PILOTS
- 72 ENGAGEMENTS PER AIRCRAFT - COMMON OPPONENT

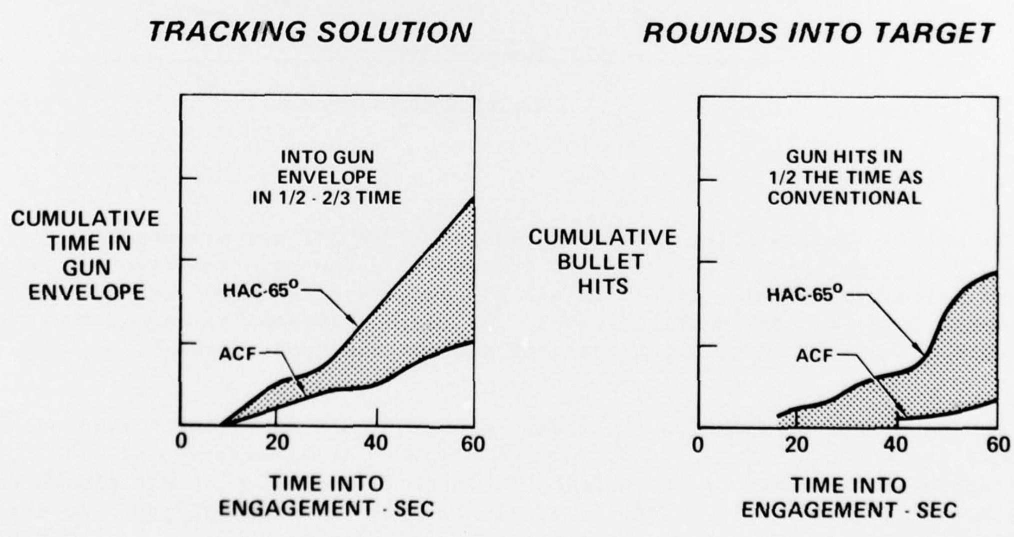

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FIGURE 8

The tracking solution comparison is highlighted by HAC-65° achieving equivalent time-in-envelope to ACF in 1/2 to 2/3 of the time required by ACF. The quality and utility of this time is indicated by increased margins of time and hit advantage for HAC-65°. HAC-65° achieves enough gun time-in-envelope to be useful as evidenced by its hit buildup, whereas ACF achieves only a marginal number of hits. HAC-65° achieves its first hits in less than half the time of ACF and by the end of the first minute has gained an 8 to 1 advantage in the number of hits relative to ACF.

Combining the opportunities and hits by both combatants provides a single combat figure of merit. This is accomplished by providing a probabilistic interpretation to the individual firing/hit events and then combining them as a time based Markov process. The result is an estimate of engagement kills and losses. The kills and losses were computed based on identical USAF lethality and vulnerability modeling for both combatants, friendly and opponent. The kills and losses are then combined as kills minus losses (kill advantage) to provide a single number for engagement interpretation.

COMBAT KILL ADVANTAGE

- INTERACTIVE MANNED SIMULATION - TAC PILOTS
- 72 ENGAGEMENTS PER AIRCRAFT - COMMON OPPONENT

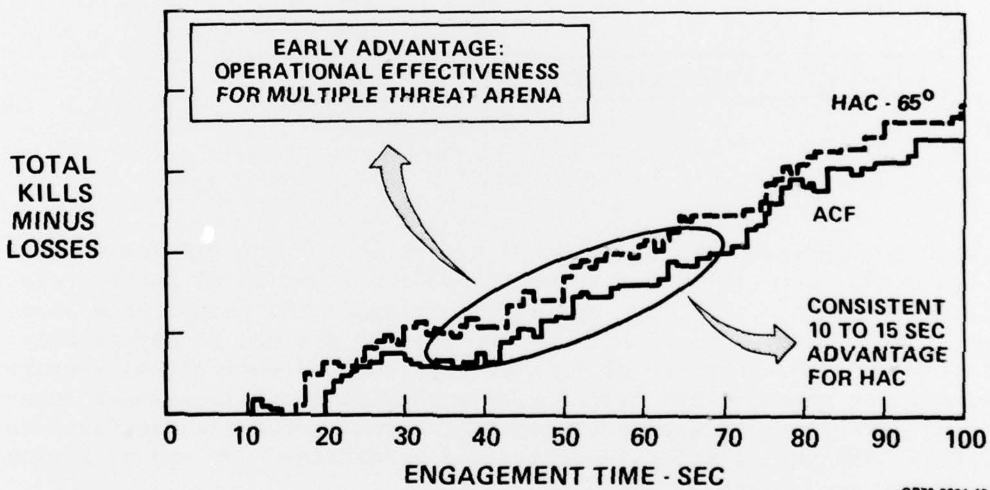

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FIGURE 9

Figure 9 presents the cumulative kill advantage for HAC-65° and ACF. The dashed line and solid line represent HAC-65° and ACF, respectively. The trend of this probabilistic interpretation follows that previously discussed for the actual opportunities and firing hit situations. HAC-65° provides a consistent advantage throughout most of the engagement. This is especially highlighted as a 10-15 second time advantage relative to ACF for equal levels of kills minus losses. This early advantage was identified by the participating pilots to imply significant improvements in a multiple aircraft environment where the pilot simply cannot afford to remain preoccupied with a single opponent for extended periods of time.

HAC-65° enhances the pilot's ability to utilize his weapon system thereby achieving earlier opportunities and kills. This has significant implications for real combat where extended one versus one combat is the exception and not the norm. Rather, multiple opponents have to be assumed by the fighter pilot for purposes of survival. In this context the nature of the duels becomes high energy maneuvering with increased emphasis on first pass kills and rapid subsequent disengagement if the target survives. Or, another target may be engaged depending on the immediacy of the opportunity.

HAC OPERATIONAL PROJECTION

- MULTIPLE DUEL SCENARIO - 1000 AIRCRAFT
- TWO 40 SECOND DUELS PER SURVIVING AIRCRAFT

		ACF	HAC-65°
1st SERIES	INITIAL FORCE	1000	1000
	KILLS	103	145
	LOSSES	61	71
2nd SERIES	SURVIVING FORCE	939	929
	KILLS	97	135
	LOSSES	57	66
TOTAL KILLS MINUS LOSSES		82	143

75% GREATER KILL ADVANTAGE FOR HAC IN 40 SEC COMBAT

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FIGURE 10

Figure 10 presents an operational projection of the simulation results to illustrate the potential benefits of HAC-65° in a series of short duels. To avoid fractional numbers of aircraft an initial friendly and enemy force size of 1000 fighters is assumed. The combatants are further assumed to engage only one-on-one due to the one-on-one nature of this simulation. An operational requirement of 40 seconds per opponent was selected to emphasize short engagement duration. This 40 second duration corresponds to two full turns by the high performance fighters simulated. However, similar results would be obtained for any selection of duration between 30 and 70 seconds.

The first series of duels are executed with each of the 1000 fighters engaging in only one duel. This is not to indicate that 2000 fighters (1000 friendly and 1000 opponent) are in the air at the same time, but that 1000 duels will take place independently. For this situation the kills, losses and surviving friendly forces are summarized. Then, each surviving fighter will engage in a second duel. For this duel it is assumed (as a mathematical convenience) that friendly forces are not replenished and that threat forces are adequately replenished to match friendly forces. Each fighter finishes the second duel. The combat summary of total kills minus losses indicates a 75 percent improvement for HAC-65° relative to ACF.

This analysis does not account for multiple aircraft combat such as 2 vs 1, nor is it appropriate to imply that this could be accomplished due to the one-on-one tactics employed by the pilots. However, for short duration repeated single opponent encounters it is clear from this extrapolation that HAC-65° can provide the needed margin of advantage.

The nature of this simulator evaluation was such that the anticipated results were estimated to be conservative. It was not even known if the fixed base simulation could distinguish measurable tactical differences utilizing only light loss scheduling to depict the differences between upright and reclined pilot positioning. The differences which were measured indicate a consistent advantage for HAC-65°. The conservatism of the measured differences is indicative of the absence of the actual G forces which would tend to further separate the combat capability figures of merit.

Based on their experience with HAC during this simulation, the tactical pilot evaluators provided by the USAF and Navy unanimously recommend development of the HAC concept for earliest practical operational introduction.

TEST RESULTS

QUANTITATIVE

HAC CONSISTENTLY DEMONSTRATED

- IMPROVED ENGAGEMENT CONTROL
- EARLIER FIRING OPPORTUNITIES
- MORE "HITS"
- GREATER KILL ADVANTAGE

QUALITATIVE

HAC

"......VIABLE CONCEPT......"

"......SHOULD BE...FLIGHT DEMONSTRATED......"

"......FUTURE TACTICAL AIRCRAFT SHOULD INCORPORATE THIS......"

The High Acceleration Cockpit should be subjected to flight technology demonstration.

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