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AIRCREW-AIRCRAFT INTEGRATION: A SUMMARY OF U.S. ARMY RESEARCH PROGRAMS AND PLANS

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Abstract

A review of selected programs which illustrate the research efforts of the U.S. Army Aeromechanics Laboratory in the area of aircrew-aircraft integration is presented. Plans for research programs to support the development of future military rotorcraft are also described. The crew of a combat helicopter must, in general, perform two major functions during the conduct of a particular mission: flightpath control and mission management. Accordingly, the research programs described are being conducted in the same two major categories: 1) flightpath control, which encompasses the areas of handling qualities, stability and control, and displays for the pilot's control of the rotorcraft's flightpath and 2) mission management, which includes human factors and cockpit integration research topics related to performance of navigation, communication, and aircraft systems management tasks. Both of these areas of research are being performed in collaboration with the National Aeronautics and Space Administration's Ames Research Center.

1. Introduction

In a mission scenario developed for the Army's future Scout/Attack (SCAT) rotorcraft, the aircrew will be required to reconnoiter and contact enemy elements, hand off targets to attack helicopters, and help select firing positions. In order to perform these basic mission elements, the crew must supervise or control the data management and transfer system; the flight control, navigation and guidance, and communications systems; target acquisition and designation systems; fire control and weapon delivery systems; threat identification systems; and electronic countermeasures systems. All of these tasks must be performed while at nap-of-the-Earth (NOE) altitudes in either daytime or night/adverse weather conditions with the constant threat of engagement by both ground and airborne enemy units.

The primary task of the pilot of a two-crew rotorcraft is to stabilize the aircraft and to control the magnitude and direction of its velocity vector, that is, to perform the flightpath management function. The copilot's responsibilities include most of the other systems supervisory and control tasks; these responsibilities will be defined as the mission management function. The desire of the Army for a one-crew rotorcraft that can perform the SCAT role implies that both the flightpath and mission management functions must be performed by a single crewmember.

This single-crew requirement provides a significant challenge to the research and development community. Historically, flightpath management or handling qualities have been studied in the context of two-crew aircraft by stability and control engineers. Mission management development has been left to engineering psychologists or to human factors specialists who have studied cockpit controls and displays independently. If the Army's desire for a single-crew version of the Light Helicopter Family (LHX) aircraft is to be realized, then these two research communities must join forces and pursue the goal of a single-crew cockpit with a unified approach (Fig. 1).

Working under the auspices of the Army/NASA Joint Agreement, the Army Aeromechanics Laboratory and NASA Ames Research Center have been addressing both of these research topics: handling qualities and human factors. This paper reviews some of the studies and results from the individual program elements: first, the handling qualities or flightpath management topics and second, the human factors or mission management work. The final section of this paper describes the need for a more unified approach to support the LHX development and a plan for a new initiative to develop fundamental principles which are needed for efficient man-machine interface design.

2. Flightpath Management

The ability of a rotorcraft pilot to perform the flightpath management function is determined by the handling qualities of the vehicle: "those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role" [1]. Handling qualities are determined not only by the stability and control characteristics of the vehicle, but also by the displays and controls which define the pilot-vehicle interface, the environmental characteristics, and the performance requirements for the task (Fig. 2).

The analysis of the effects of rotorcraft handling qualities on mission effectiveness is broken down into two components: 1) a determination of the influence of handling qualities parameters on the performance of the pilot-vehicle combination and on the physical and mental workload of the pilot, and 2) an analysis of the effects of the achieved precision of flightpath control and workload capacity of the pilot on selected measures of mission effectiveness. Handling qualities investigations by both NASA Ames and Army Aeromechanics Laboratory researchers have concentrated on the former component; these experiments have focused on nap-of-the-Earth (NOE) mission tasks conducted during daytime or night/adverse weather conditions by a two-crew aircraft in which the pilot is only required to perform the flightpath management function. These programs have investigated either generic handling qualities effects or the handling qualities characteristics of specific rotorcraft configurations; the results of both types of programs are being used as sources of data upon which a revision to the U.S. military helicopter handling qualities specification, MIL-H-8501A, can be based [2].

This section summarizes the results of NOE handling qualities investigations, for both day and night/adverse weather conditions, and describes an initial effort to relate achieved system performance and pilot workload to mission effectiveness.

NOE Flight Under Visual Meteorological Conditions

An initial series of helicopter handling qualities studies—including analysis, piloted simulation, and flight research (Table 1)—was conducted to assess the effects of rotor design parameters, inter-axis coupling, and various levels of stability and control augmentation [3]. As a result, recommendations were made for: 1) minimum levels of pitch and roll damping and sensitivity; 2) maximum values of pitch-roll, collective-to-pitch, and collective-to-yaw coupling; and 3) generic stability and control augmentation system (SCAS) requirements.

The effects of thrust-response characteristics on helicopter handling qualities have, until recently, remained largely undefined. Helicopter thrust is influenced by several factors, including 1) engine governor dynamics, 2) vertical damping resulting from rotor inflow, and 3) the energy stored in the rotor, which is a function of rotor inertia. A multiphase program is being conducted to study these effects on helicopter handling qualities in hover and in representative low-speed NOE operations. To date, three moving-base piloted simulations [4,5] have been conducted on the Vertical Motion Simulator (VMS) at Ames (Fig. 3). It was found that variations in the engine governor response time can have a significant effect on helicopter handling qualities. For the tasks evaluated, satisfactory handling qualities and rpm control were achieved only with a highly responsive governor, but increases in rotor inertia (thus in the stored kinetic energy) have only a minor, though desirable, effect on handling qualities (Fig. 4). The excess power requirement (T/W) was found to be a strong function of Z_w and is minimized at a Z_w-value around -0.8 rad/sec. The effect on handling qualities of requirements for pilot monitoring and control of rotor rpm can be significant. For a slow engine governor, the degradation in pilot rating in the bob-up tasks was as much as two ratings (Fig. 5). Techniques to relieve the pilot of the task and concern for monitoring proper rpm therefore need to be considered.

In support of the U.S. Army's Advanced Digital/Optical Control System (ADOCS) program, a series of piloted simulations was conducted both at the Boeing Vertol facility and on the VMS to assess the interactive effects of side-stick controller (SSC) characteristics and stability and control augmentation on handling qualities. An initial experiment [6] revealed that angular rate stabilization in pitch and roll was sufficient to provide satisfactory handling qualities when a two-axis SSC was employed for control of those axes; however, when a rigid three- or four-axis device (which added directional and directional-plus-collective control, respectively, to the SSC) was employed, attitude stabilization was required to maintain adequate handling qualities. These results were substantiated and expanded upon by the Ref. 7 experiment which demonstrated that a four-axis, small-deflection SSC yielded satisfactory handling qualities for NOE tasks when integrated with a SCAS that incorporated higher levels of augmentation; however, separated controllers (Fig. 6) were required to maintain satisfactory handling qualities for the more demanding control tasks or when reduced levels of stability and control augmentation were provided.

Current research programs being conducted to support the development of the handling qualities specification include investigations of roll-control requirements, hover and low-speed directional control characteristics, and helicopter air combat maneuverability and agility requirements.

A major shortcoming in the current handling qualities data base is known to be roll-control effectiveness. This critical and fundamental criterion can have a major effect on the basic design of a helicopter. Analyses and piloted simulations are being conducted to assess required levels of damping and the control power required to trim, to recover from external upsets, and to maneuver for various rotorcraft configurations operating in an NOE environment. Similarly, to compensate for a lack of mission-oriented handling qualities data, a piloted simulation is being conducted to evaluate the effects of: 1) mission task requirements; 2) basic yaw sensitivity and damping; 3) directional gust sensitivity; and 4) yaw SCAS implementation on the handling qualities of generic-LHX candidates, including tilt-rotor, coaxial rotor, and no-tail-rotor configurations (Fig. 7).

To support the requirement for an air-to-air combat capability for future military helicopters, a facility is being developed which can be used to investigate handling qualities requirements in terrain flight air combat. One-on-one air combat (Fig. 8) is simulated using the VMS as the cockpit of the friendly aircraft which is engaged in a computer-generated visual data base by an enemy aircraft which may be flown manually from a fixed-base station or automatically through an interactive maneuvering algorithm. Variations in the performance, stability and control, controllers, and displays of the friendly aircraft are being investigated.

Effects of Night/Adverse Weather Conditions

The requirement that military rotorcraft operations be conducted at night and under other conditions of limited visibility has given impetus to research programs designed to investigate the interactive effects of vision aids and displays on NOE handling qualities.

In a program conducted to support the development of the Advanced Attack Helicopter (AAH), various levels of stability and control augmentation together with variations in the format and dynamics of the symbols provided on the Pilot Night Vision System (PNVS) (Fig. 9) were investigated in a piloted simulation [8]. It was found that the handling qualities of the baseline control/display system were unsatisfactory without improvement; recommendations for alterations to the PNVS symbol dynamics and the implementation of a velocity-command system for a hover/bob-up/weapon delivery task were made to the Army Program Manager.

An investigation involving the simulation of a less complex night vision aid was carried out to support the Army Helicopter Improvement Program (AHIP) [9]. In this simulation, the effects of presenting the PNVS flight symbology on a panel-mounted display (PMD) versus a head-up display (HUD) were compared for a nighttime scout helicopter mission in which the pilot was provided with simulated night vision goggles. Although no clear preference for the HUD or PMD was established, the use of the display improved handling qualities for the lower levels of augmentation. However, higher levels of augmentation, which included a velocity-command system and augmentation of the directional and vertical axes, were required for satisfactory handling qualities.

The state-of-the-art night vision system for combat helicopters includes a visually coupled helmet-mounted display of infrared imagery and superimposed symbology: the Integrated Helmet and Display Sight System (IHADSS) (Fig. 10). This system was employed in two simulator investigations [10,11] designed to assess the effects of reduced visibility conditions on the ADOCS visual flight simulation results cited previously. Significant degradations in handling qualities occurred for most tasks flown with the IHADSS relative to the identical tasks flown under visual flight conditions (Fig. 11). In general, higher levels of stability augmentation were required to achieve handling qualities comparable to those achieved for the visual flight tasks.

Handling Qualities Effects on Mission Effectiveness

A preliminary computer simulation was conducted to relate certain handling qualities effects, such as precision of flightpath control and pilot workload, to the ability of a single scout helicopter, or helicopter team, to accomplish a specified anti-armor mission successfully [12]. A key feature of the program is a simulation of microterrain features and their effects on detection, exposure, and masking for NOE flight.

For the purpose of this study, degraded scout helicopter handling qualities were assumed to manifest themselves in four ways: 1) increases in the basic NOE altitude at which the helicopter can fly at a given speed, 2) increases in the amount and frequency content of altitude excursions above the basic NOE altitude, 3) increases in the amount and frequency content of altitude excursions in hover above that required for observation, and 4) decreases in the amount of visual free time available to the crew for surveillance and fire control functions. The effects of each of these parameters on selected measures of effectiveness (MOE) were investigated separately for three different combat scenarios. These MOE included primary measures such as: 1) the probability of the scout(s) being killed: $P_K(B)$, 2) the number of enemy vehicles killed: $N_K(R)$, and 3) the exchange ratio: the number of enemy vehicles killed divided by the number of scouts killed (E/R). Certain intermediate MOE, involving detection probabilities and average times required to detect and kill, were also analyzed to gain further insight into the engagement outcomes.

In order to assess the overall effect of handling qualities on the MOE, three "grades" of handling qualities—"perfect," "fair," and "bad"—were defined by specifying the associated values of basic NOE altitude, NOE altitude error, hover altitude error, and visual free time. The resultant values of the primary MOE for each grade of handling qualities are presented in Fig. 12.

This study demonstrated that handling qualities do have a significant effect on the ability to perform a specific mission, as indicated by variations in the selected MOE. This effect resulted primarily from variations in the probability of the scout helicopter being detected, particularly during a precision hover.

3. Mission Management

The objectives of the mission management or human factors part of the program are: 1) to explore and develop the fundamental principles and methodologies necessary to exploit pilot perceptual, motor, and information processing capacity for application to advanced helicopter cockpit design, and 2) to develop objective and predictive techniques for assessing pilot workload.

Display-Control Compatibility

This experimental effort was undertaken to investigate one aspect of the pilot-vehicle interface problem: stimulus-response compatibility between instrument location and vehicle control position in current and near-future helicopter cockpits. For example, the altitude and rate-of-climb indicators, which are conventionally located to the right of the pilot centerline, display parameters which are controlled at NOE airspeeds by the collective stick in the left hand. These instrument positions are holdovers from fixed-wing aircraft design practice. The flexibility of new electronic display formats such as those associated with the PNVS provide the opportunity to minimize any performance penalties associated with this opposite, or contralateral, control-display relationship by adopting a same-side, or ipsilateral, arrangement. Accordingly, an experiment was conducted to measure and compare the time to effect airspeed and altitude control with a contralateral and an ipsilateral control-display relationship [13].

Figure 13 shows the contralateral display format; the ipsilateral format was obtained by interchanging the airspeed and altitude scales. The subjects were asked to bring a pointer to a specific position on each scale using the appropriate helicopter control; the task was analogous to a pilot reaching a new command altitude or airspeed by manipulating the flight controls. Performance was assessed by measuring both reaction time and the control movement time required to achieve a criterion; the sum of these two times yields the total time required to achieve control. An index of difficulty for performing the task was hypothesized based upon Fitts' Law [14] which indicates that the time to effect a reduction in error amplitude, A, to a given target with width, W, varies in a linear fashion with the index of difficulty defined as $ID = A + B \log_2(2A/W)$.

Results of the experiment indicate a 74 msec more rapid average reaction time with the ipsilateral control-display arrangement compared to the contralateral relationship when both controls are considered together. For a helicopter flying at a speed of 20.6 m/sec (40 knots), this difference in reaction time corresponds to a savings of 1.5 m (5 ft) in distance traveled. While this distance is of little consequence for up-and-away flight, in night NOE flight the advantage of the ipsilateral arrangement may be critical for obstacle avoidance. Using a regression analysis of the control movement time data, the validity of Fitts' Law was demonstrated for this experiment by high correlation coefficients (Fig. 14). The difference in slopes for the cyclic control data for the two cases implies that an increase in task difficulty causes a propagation of the adverse contralateral effect into the control movement phase of the airspeed control task. For the highest value of ID there is a 1700 msec difference in control movement time between the ipsilateral and contralateral conditions for cyclic control; given the conditions of NOE flight stated above, the helicopter would have traveled 35 m (115 ft), or over three OH-58D rotor diameters, farther with the contralateral condition before reaching the commanded control state than with the ipsilateral display.

The results of this experiment suggest the need to reconsider the stimulus-response compatibility of the information displayed in the PNVS in particular and in future rotorcraft cockpits in general.

Integrated Controller

Another study on cockpit flight controls was performed under contract by Sikorsky Aircraft Division [15]. The experiment investigated the use of multi-axis sidestick controls for flightpath control in configurations such as were developed for the ADOCS program and the simultaneous performance of a keyboard entry task with the free hand. As would be expected, the results show that keyboard entry tasks interfere with the performance of flightpath tracking, and, conversely, the flightpath tracking interfered with keyboard entry. If a degradation in performance occurs, the use of a multi-axis controller to free a hand for mission management tasks may not be appropriate. The ADOCS data (Section 2) generally show that for most tasks, with a high level of SCAS, similar pilot ratings can be obtained independent of the level of controller integration. However, as the SCAS degrades, separated controls generally become superior. This result has implications on reliability which must be designed into the flight control system SCAS; the four-axis controller may imply a mission-critical SCAS, or even a flight-critical SCAS at more complex levels. This requirement may force the costs associated with a fully integrated controller to a prohibitively high level. An alternative approach, which provides the ability to change control and display functions without removing the hand from the flight controls or directing visual attention to switch or function locations, would be attractive in an NOE environment and is a logical situation in which to incorporate voice command and display technology.

Voice Command and Display

Customary cockpit design relies heavily on visual and auditory signals, but there are technically feasible alternatives. One of the most promising is voice-interactive systems in which both input and output are spoken words; that is, the pilot can control on-board systems by voice command as well as receive computer-generated spoken flight information. The advantages of voice-interactive systems appear to be significant, principally because the pilot can command system output or prescribe system input without interrupting his physical control activities.

The application of speech output principles to a voice interactive electronic warning system (VIEWS) was performed to examine the use of an integrated visual and speech display for a threat warning system [16]. The current radar warning receiver uses a combination of visual strobe lines and proportional rate frequency (PRF) audio tones to give pilots information concerning the location of enemy radar emitters; it was desired to replace the strobe lines with visual symbols and the PRF tones with a set of voice messages.

To evaluate the effectiveness of an integrated visual and speech radar detection warning system in a high workload flight environment, subject pilots were required to fly through a computer-generated maze of trees as quickly as possible while staying low enough to avoid radar detection by threats hidden in the maze. A threat within the helicopter's radar detector range resulted in a voice message and the appropriate symbol on a warning indicator screen; changes in threat status were also indicated by a voice message and symbol indicator. When threats were encountered, the pilots were required to maneuver to avoid being shot down.

Two problems associated with integrated speech and visual displays were addressed in this experiment. Visual displays can provide more than one item of information at the same time, allowing the pilot to prioritize the displayed information; however, speech displays must also include some "intelligence" to prioritize information output if they are to be effective. To solve this display priority problem, a message output priority logic was developed which provided a continual update of threat information and ensured that the next message to be initiated would have the most recent information; however, an ongoing message was always completed before the next one was initiated. The second problem concerns the inherent lag in a speech display compared with a visual display; because of the time required to articulate a message, a speech display may provide information which conflicts with the associated visual display. For this experiment, this problem of temporal veridicality was solved by providing a visual indicator under the threat symbol that was the subject of the current voice message to eliminate any confusion.

The VIEWS project demonstrated the feasibility of using an integrated speech and visual display to assist in avoiding radar-guided threats. The subject pilots rated the system as being well integrated with a minimum of interference between the two subsystems; the visual display frequently provided the necessary information if parts of the voice message were missed. The pilots were less satisfied with the total system when either one of the subsystems had "failed."

Pilot Workload Assessment

Several approaches toward assessing pilot workload have been proposed. According to a study by Phatak [17] these methods fall into the following general categories:

1) Methods based upon secondary task performance.

2) Physiological measurement methods.

3) Methods based upon primary task performance.

4) Method using subjective opinion rating/scale.

5) Time line and task analysis methods.

6) Pilot model methods.

The secondary task performance method has the possibility of the secondary task affecting or modifying the pilot's performance and/or strategy in accomplishing the primary task. A popular secondary task method that has been applied to handling qualities work [18] is the Sternberg task where the pilot is given several letters to remember, then asked to decide if a letter presented at a certain frequency during the test is in or out of his group. The study [19] by Hemingway applied this technique during a related helicopter handling qualities study. For several reasons, including the methodology, no clear correlations were obtained.

The use of physiological measures on the operator for assessing workload is restricted because physiological metrics only measure states of arousal and do not represent measures of pilot workload except under special situations.

Closed-loop system performance on the primary task is generally not a satisfactory measure of workload because of its relative insensitivity to large variations in workload except at the extremely low or high levels.

A pilot's evaluation or opinion about a task provides the most direct window into the mental perception, or notion, of experienced workload. However, even this approach is fraught with methodological problems related to standardization of terminology and the large degree of intra- and inter-subject variability in the subjective interpretation of the factors perceived to be contributing to workload. In spite of these drawbacks, the bottom line in the acceptance of any new system is the pilot's subjective opinion or assessment of the system performance and required workload.

Time line analysis methods are based upon the intuitive notion that workload must be related to the time pressure imposed upon the human operator performing a given task. These methods use systematic task analysis procedures to estimate the time needed to complete each elemental or primitive task and hence the total time required for accomplishing the overall task. One problem, of course, is that some tasks are very much more difficult to perform than other tasks even though they perhaps take the same amount of time.

None of the above methods provides the system designer significant insight into identifying the individual factors or components of human effort which are responsible for the increased pilot workload. Furthermore, the measures may only be used to assess the pilot workload for existing systems and are not suitable for workload prediction in the design phase of building a new system.

A much better understanding of the fundamental issues embodied in the concept of workload may be possible with models that describe the perceptual, cognitive, and motor processes actually used by the human pilot in accomplishing a given task. The use of mathematical modeling as a tool for analyzing man-systems performance has been of substantial interest to researchers for over 30 years. During that period the human has been characterized as a servo-compensator, a sample data controller, a finite-state machine, an optimal controller, and most recently as an intelligent system. Although there is currently no clear consensus about the utility of available model-based methods for assessing pilot workload and performance in realistic military helicopter missions, the potential benefits are such that we have a continuing effort to develop such models.

Expert Systems and Artificial Intelligence

With the need to simplify the total pilot workload, there is impetus to help with decisionmaking and to automate certain tasks. A grant with the Ohio State University is addressing the question of the cost and benefit of one crew and high automation versus two crew and nominal automation [20,21]. The approach is an iterative program of experimental studies using a video game-like task followed by an analytical effort employing discrete control modeling. The goal of this effort is to produce a predictive methodology to aid in the understanding of human supervisory control of highly interactive systems. In addition, a contract has been initiated with Perceptronics, Inc., to use the modified Petri-net as an analytical tool for developing guidelines and concept designs for incorporating artificial intelligence and smart systems techniques into LHX cockpit automation features [22].

4. Aircrew-Aircraft Integration Plans

Except for single pilot IFR in the civil/FAA context, single-crew concepts have not been considered in helicopter flight control research. If the tasks performed by the copilot are to be taken over by the pilot, increased levels of automation are required. The LHX will need control laws for automatic and manual control of flightpath including integration with propulsion, fire control, and navigation functions. Configuration effects such as thrust vectoring and X-force control will also have to be taken into account if the LHX configurations is a compound helicopter, ABC configuration, or a tilt rotor. In addition, concepts for safety-of-flight automation will have to be developed for such functions as obstacle avoidance, threat avoidance, flight-envelope limiting, and automatic failure recovery.

These developments will have to rely heavily on ground-based simulation and will require high-fidelity dynamic simulation such as will be available in the Rotorcraft Systems Integration Simulator (RSIS) [23] at Ames Research Center. In addition, to adequately represent the pilot's mission-management functions such as battle captain tasks, navigation, and aircraft systems management, it will be necessary to develop surrogate tasks which can be incorporated in the simulation on a realistic real-time basis; the cognitive workload associated with battle management may have a significant impact on total mission performance, and realistic simulation of these functions is considered particularly important.

Numerous LHX Man-Machine issues remain as unknowns. The extremely difficult task of flying NOE at night and in weather will leave the pilot little capacity to perform his battle management functions unless extensive innovation is applied to all the man-machine interface tasks. The allocation of control and display media between manual, visual and voice, the extent of automation, and the application of artificial intelligence/ expert systems will have to be extensive, yet little is known to guide the appropriate choice of these applications.

For the night and poor weather situations, candidate external scene visual displays which will permit single-crew operation for the LHX mission tasks must be assessed. Wide field-of-view display devices are in the embryonic stage even for ground-based simulators; other display devices, such as night vision goggles, HUD, and IHADSS, have not been applied to such a demanding role. Sensor fusion and real-time image processing for both flight and target tasks have not been developed for an operational system. Not only are hardware advances needed, but a better knowledge of the required functional capabilities, such as field-of-view, resolution, detail, and image update rates, must also be developed to guide the hardware design objectives.

In addition to the outside world visual scene, it will be necessary to display to the pilot an easily understood image of the tactical situation and navigation functions. The achievement of this capability will require the development of real-time tactical situation scenarios which can be used to investigate the man-machine interface required for battle captain functions such as target engagement and threat defense.

Artificial intelligence and expert systems will be required to aid the pilots' decisionmaking tasks and to automate routine prescribed functions. Replacement or supplementation of specific manual controls and visual displays with speech recognition and speech generation techniques is intuitively appealing for pilot workload reduction. However, a significant amount of work will be required to determine which functions are best controlled by voice, how these voice modes should be implemented, and how they are to be interfaced with other modes. Finally, a better understanding is required on how a human interacts with a highly automated system so that the dynamics of switching from one automated mode to another, or back to a manual function as the mission needs change can be defined, and so that guidelines can be developed for the synthesis of the total cockpit.

Some of the problems described above will be addressed in the Advanced Rotorcraft Technology Integration program [24] and these results will form the basis for the LHX cockpit design. In addition, the work described in Sections 2 and 3 will be expanded to improve understanding of the fundamental questions.

In recognition of a lack of a fundamental approach to the pilot-cockpit design, a new initiative has been developed and will be initiated towards the end of FY 1984 (Fig. 15). The objective of this 5-year joint Army/NASA program is a focused effort to develop a validated predictive methodology: a set of analytic structures with which cost-effective and efficient guidelines and principles for man-machine integration designs can be derived before a commitment to hardware is made. The analytic (modeling) approach is motivated by the high cost of redesign and retrofit of nonoptimal systems and the ever-increasing cost of the training simulators and systems required to support the operational units in the field. The focus of the program will be the mission of a single-crew scout/attack helicopter operating at night, in adverse weather, in the NOE environment. Although the aircraft will employ the most advanced technology, this mission will produce extreme workload, demand superior performance, and require extensive training of the aircrew. The essential issues are the triad of pilot workload, performance, and training which are inexorably intertwined and affect all integrated design considerations in future helicopter cockpits. Current design practice relies on a cut-and-try approach, and on questionable procedures for evaluating effectiveness. Consequently, it is not possible to quantify what is essential to the design of a system for an effective man-machine interface and, therefore, there exist no future benefits from lessons learned.

To achieve the objective, a fundamental understanding must be established of how the human operator processes the information by which he perceives his environment, how he acts upon that perception, how training modified this perception, and how the foregoing relate to pilot performance and workload. Considerable research has already been accomplished in an attempt to understand human perception and cognition and to establish measures of pilot performance and workload. These efforts have generally been ad hoc and fragmented; the results have seldom been focused on the design of a man-machine system and have never been conveyed in terms useful to the engineering user community.

The planned program will be an interdisciplinary effort involving pilots, display engineers, control engineers, mathematicians, and engineering psychologists. Essential tools for this program will be flexible, versatile, ground-based, and in-flight simulator research capabilities that permit the study of the interactions of variations in display laws and control laws on the human's ability to interface with automatic aids in order to perform specified missions. The ground-based simulation capability at Ames is already exceptional and will be augmented when the RSIS and NASA's Manned Vehicle Research Simulation Facility are put into operation. The in-flight research capability could, for example, be provided by an integration in the UH-60A Black Hawk of the ADOCS flight controls and NASA/Army digital avionics packages. Inhouse efforts utilizing these unique facilities will be designed to complement contracted work.

5. Concluding Remarks

Numerous single-crew helicopter man-machine issues remain as unknowns. Handling qualities research conducted by the U.S. Army Aeromechanics Laboratory and NASA Ames Research Center to date has emphasized the interactive effects of basic stability and control characteristics, type of SCAS, controller characteristics, and vision aids and displays on the ability of a two-crew rotorcraft to conduct specific NOE mission tasks. Extrapolation to the single-crew situation from these data must be based on sound engineering and piloting judgment. The extremely difficult task of flying NOE at night and in weather will leave the pilot little capacity to perform his battle management functions unless extensive innovation is applied to all the man-machine interface tasks. The allocation of control and display media between manual, visual and voice, the extent of automation, and the application of artificial intelligence/expert systems will have to be extensive, yet little is known to guide the appropriate choice of these applications. To address these concerns a new Army/NASA program is planned which will be an interdisciplinary effort involving pilots, display engineers, control engineers, mathematicians, and engineering psychologists.

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TABLE 1. SUMMARY OF INITIAL TERRAIN FLIGHT EXPERIMENTS

Experiments	Objective	Tasks	Simulator	Rotor type	Control system type
I	To determine effect of large variations in rotor design parameters	Longitudinal vertical task; Lateral slalom task; Combined task	Fixed base (Ames S-19)	Teetering; Articulated; Hingeless	Basic helicopter (rate-type in pitch, roll, and yaw)
II	To assess effect of various levels of SCAS	Combined task	Moving base (Ames FSAA)	Teetering; Articulated; Hingeless	SCAS Input Decoupling: Rate command; Attitude command in pitch and roll
III	To evaluate a sophisticated SCAS for hingeless rotor helicopter	Combined task	Moving base (Ames FSAA)	Hingeless	SCAS: Attitude and rate; Stability augmentation; Control augmentation
IV	To investigate roll damping, roll sensitivity, and pitch-roll cross-coupling and correlate results with Experiments I and II	Prescribed lateral slalom course over a runway	In-flight (UH-1H/ VSTOLAND)	Teetering	Rate-type in pitch, roll, and yaw

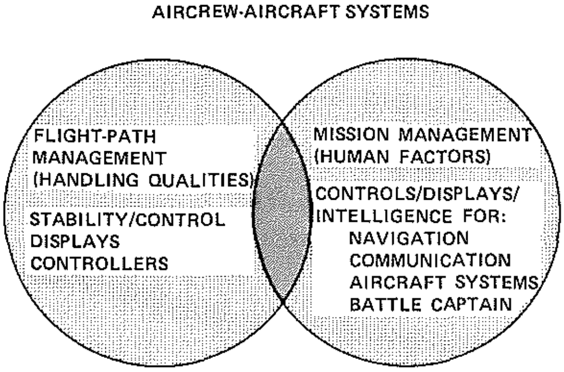


Figure 1. Flightpath/mission management interaction.

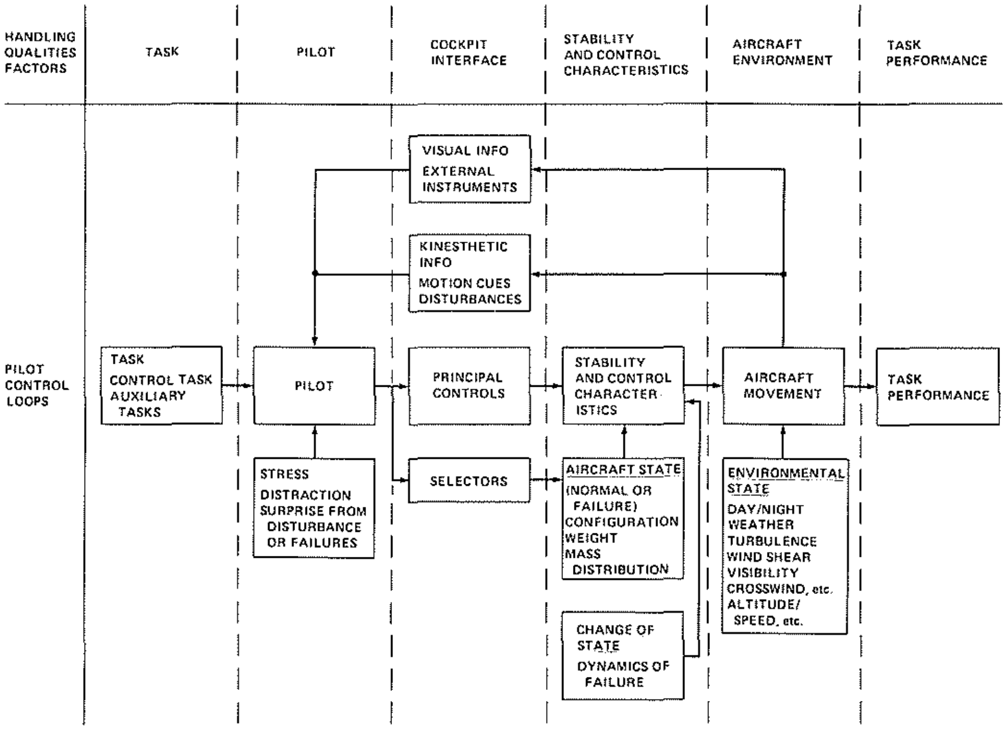
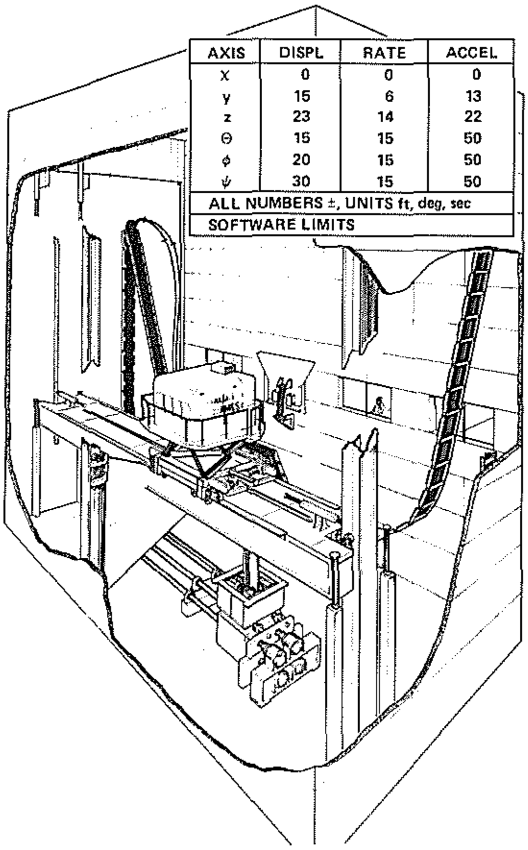


Figure 2. Elements of control loop that influence handling qualities (Ref. 1).



AXIS	DISPL	RATE	ACCEL
x	0	0	0
y	15	6	13
z	23	14	22
Θ	15	15	50
φ	20	15	50
ψ	30	15	50

ALL NUMBERS ±, UNITS ft, deg, sec

SOFTWARE LIMITS

Figure 3. NASA Ames Vertical Motion Simulator (VMS).

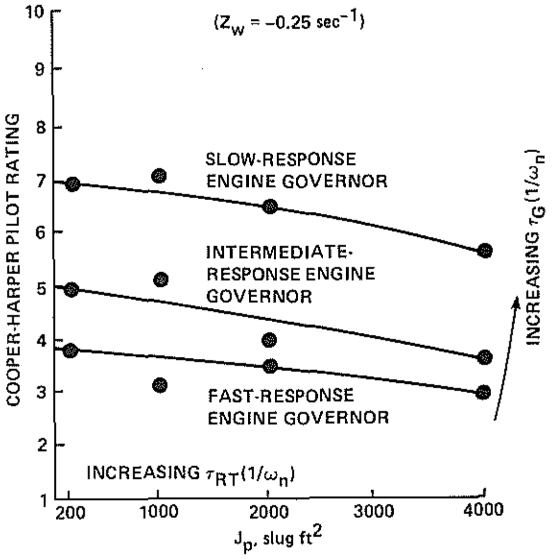


Figure 4. Effect of rotor inertia and engine governor.

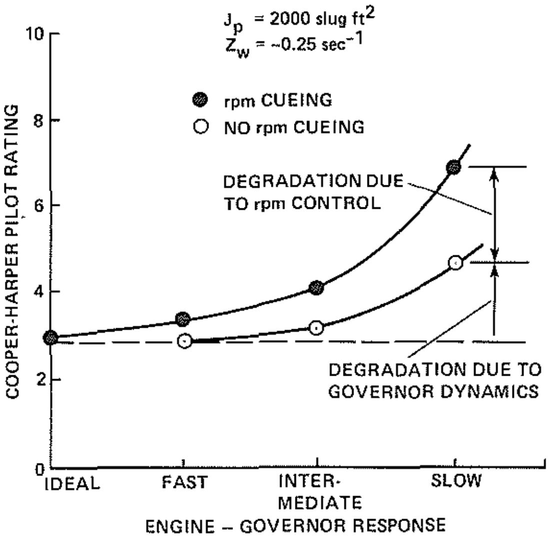


Figure 5. Effect of requiring rpm control.

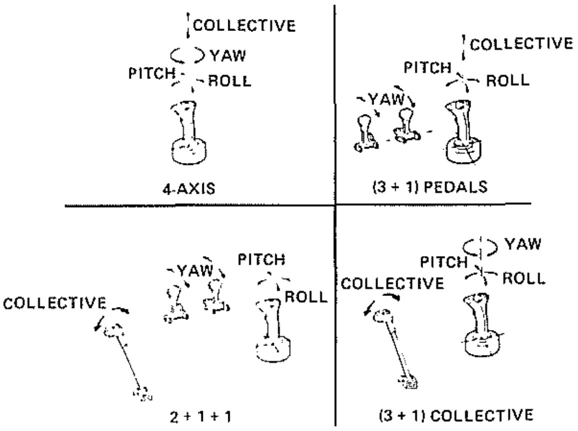


Figure 6. Controller configurations.

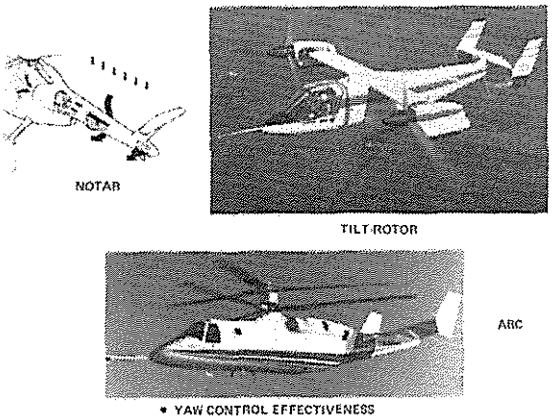


Figure 7. Generic LHX configurations.

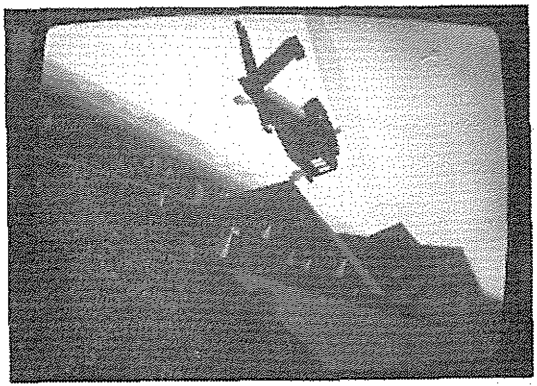
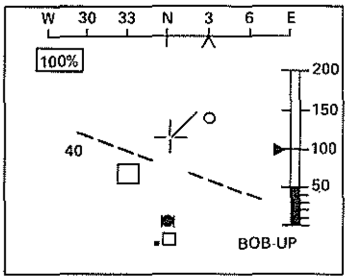


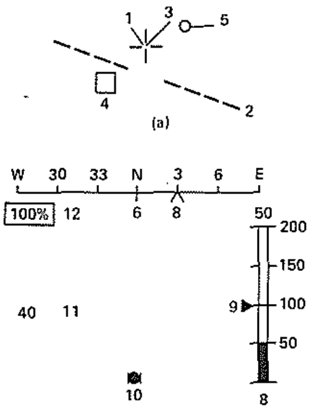
Figure 8. Simulation of air-to-air combat.



(a) BASELINE DISPLAY FORMAT

SYMBOL	INFORMATION
1. AIRCRAFT REFERENCE	FIXED REFERENCE FOR HORIZON LINE, VELOCITY VECTOR, HOVER POSITION, CYCLIC DIRECTOR, AND FIRE CONTROL SYMBOLS
2. HORIZON LINE (CRUISE MODE ONLY)	PITCH AND ROLL ATTITUDE WITH RESPECT TO AIRCRAFT REFERENCE (INDICATING NOSE-UP PITCH AND LEFT ROLL)
3. VELOCITY VECTOR	HORIZONTAL DOPPLER VELOCITY COMPONENTS (INDICATING FORWARD AND RIGHT DRIFT VELOCITIES)
4. HOVER POSITION	DESIGNATED HOVER POSITION WITH RESPECT TO AIRCRAFT REFERENCE SYMBOL (INDICATING AIRCRAFT FORWARD AND TO RIGHT OF DESIRED HOVER POSITION)
5. CYCLIC DIRECTOR	CYCLIC STICK COMMAND WITH RESPECT TO HOVER POSITION SYMBOL (INDICATING LEFT AND AFT CYCLIC STICK REQUIRED TO RETURN TO DESIGNATED HOVER POSITION)

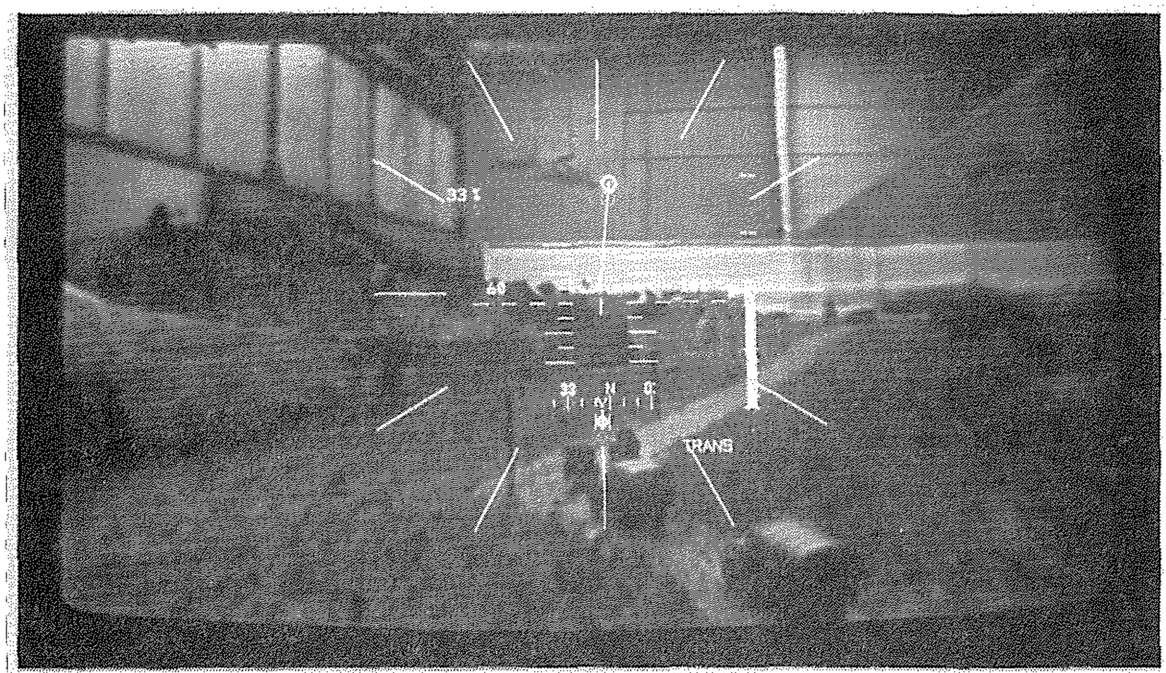
(b) CENTRAL SYMBOLOGY



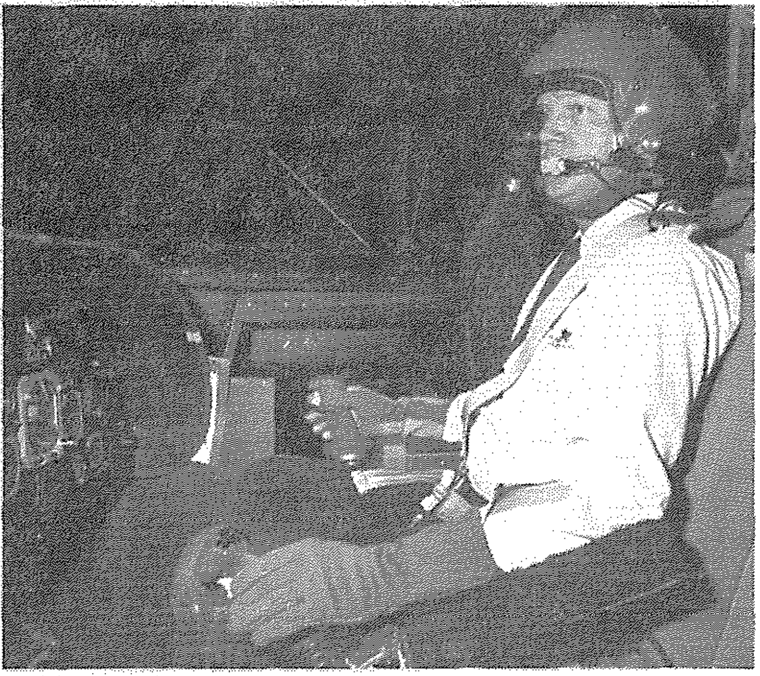
SYMBOL	INFORMATION
6. AIRCRAFT HEADING	MOVING TAPE INDICATION OF HEADING (INDICATING NORTH)
7. HEADING ERROR	HEADING AT TIME BOB-UP MODE SELECTED (INDICATING 030)
8. RADAR ALTITUDE	HEIGHT ABOVE GROUND LEVEL IN BOTH ANALOG AND DIGITAL FORM (INDICATING 50 ft)
9. RATE OF CLIMB	MOVING POINTER WITH FULL-SCALE DEFLECTION OF 1,000 ft/min (INDICATING 0 ft/min)
10. LATERAL ACCELERATION	INCLINOMETER INDICATION OF SIDE FORCE
11. AIRSPEED	DIGITAL READOUT IN knots
12. TORQUE	ENGINE TORQUE IN percent

(c) PERIPHERAL SYMBOLOGY

Figure 9. PNVS display mode symbology.



(a) SUPERIMPOSED SYMBOLS



(b) INTEGRATED HELMET AND DISPLAY SIGHT SYSTEM INSTALLATION

Figure 10. Helmet-mounted display.

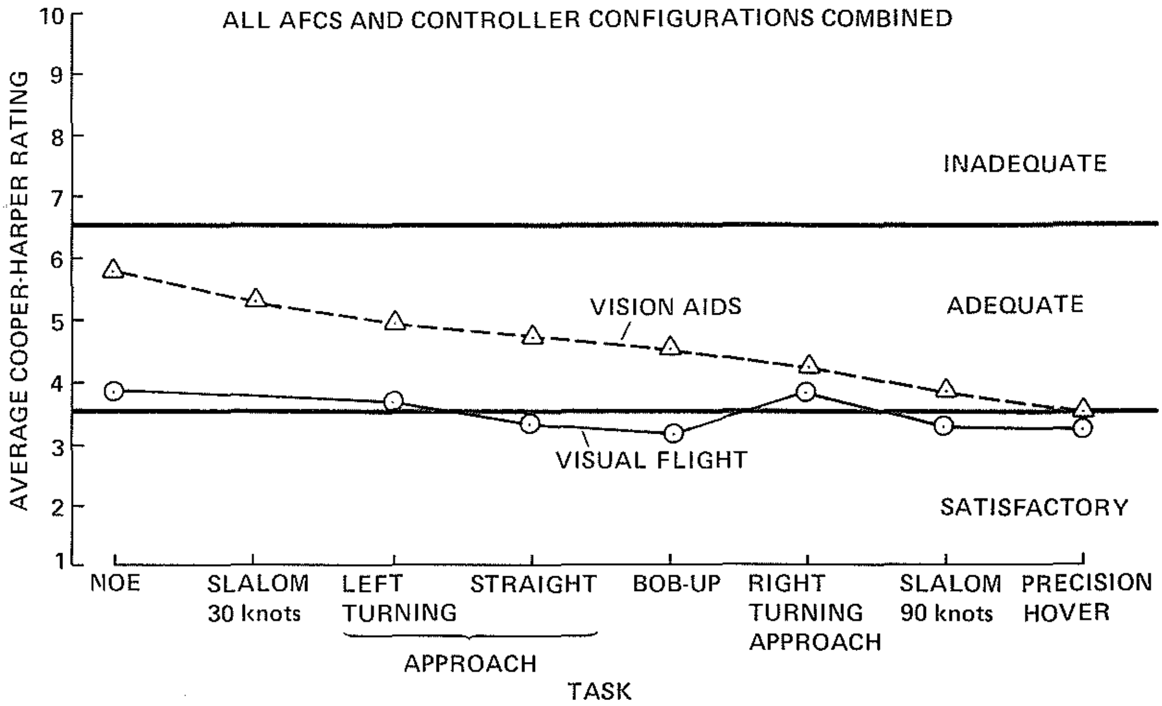


Figure 11. Effect of reduced visibility conditions on pilot ratings.

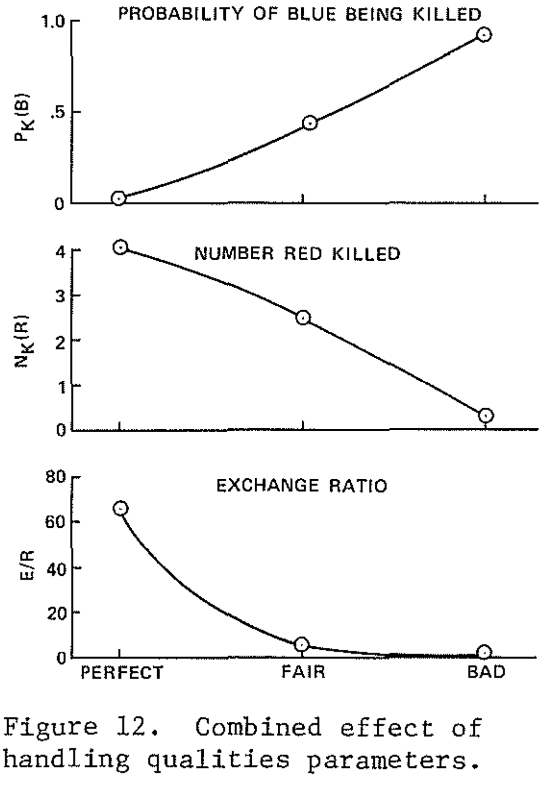


Figure 12. Combined effect of handling qualities parameters.

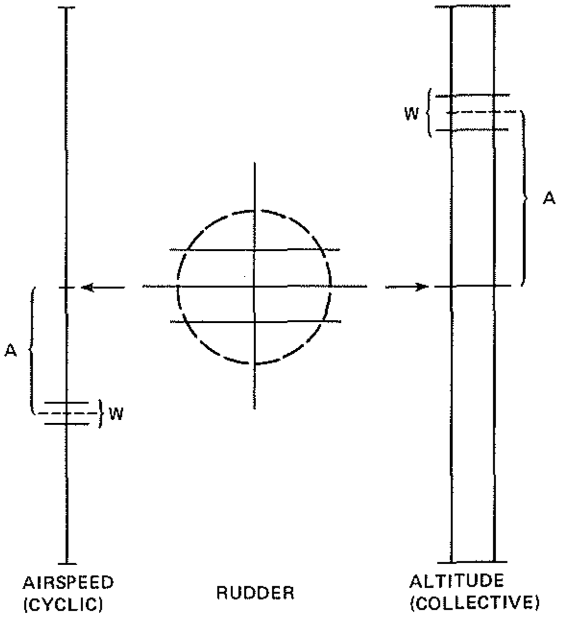


Figure 13. Modified pilot night vision system (PNVS) display, contralateral configuration, showing amplitude (A) and width (W) of sample targets.

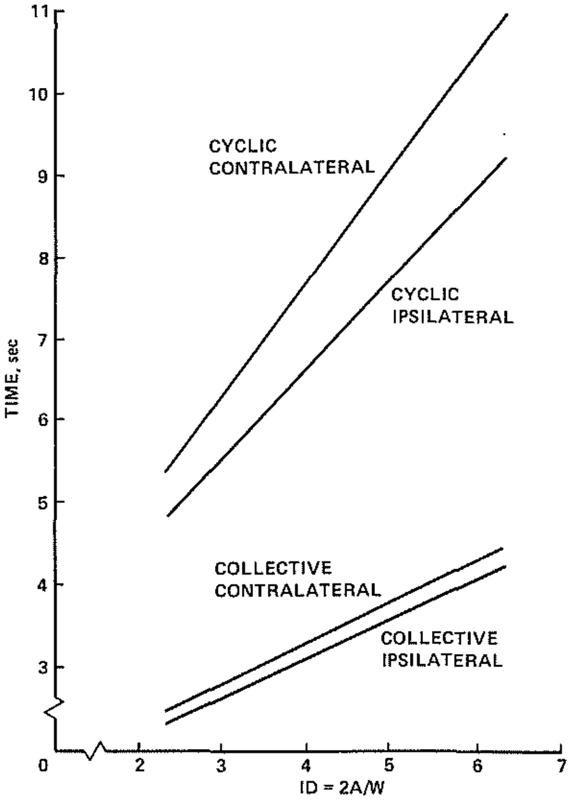


Figure 14. Variation of control movement time with index of difficulty.

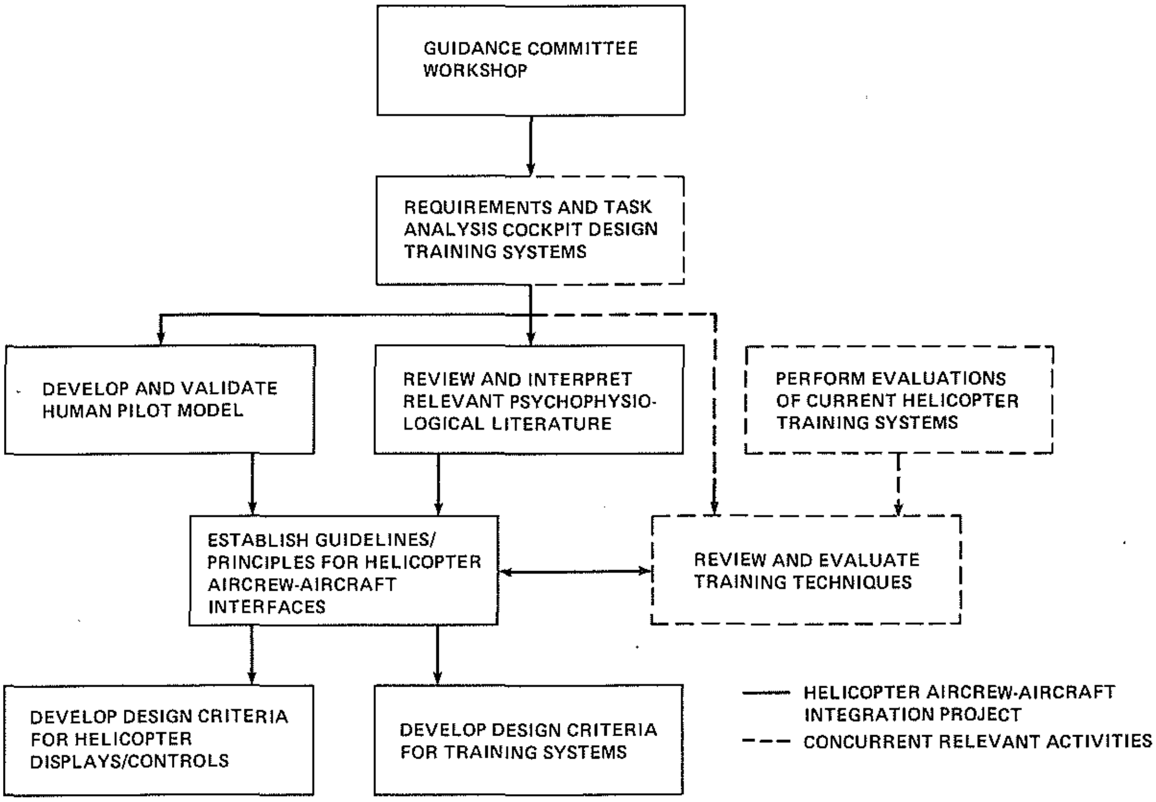


Figure 15. Approach to aircrew-aircraft-integration project.