AUTOMATED PRIMARY HELICOPTER INSTRUCTION: THE INTELLIGENT FLIGHT TRAINER

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ABSTRACT

The Army Research Institute Rotary Wing Aviation Research Unit (ARI RWARU) has developed and evaluated a family of low-cost training devices designed specifically to support initial entry training in rotary wing flight. This effort has led to the development of the Intelligent Flight Trainer (IFT) which is an automated, Expert System based device designed to train the basic helicopter flight skills such as hovering flight and traffic pattern flight.

The UH-1 Training Research Simulator (UH-1TRS), developed in FY86, demonstrated that a low-cost trainer could: 1) Provide positive Transfer of Training (TOT) to the UH-1 aircraft using Army Initial Entry Rotary Wing (IERW) flight students as research subjects. 2) Substitute for actual UH-1 flight time in Primary Phase IERW training. 3) Serve as a vehicle for the development of the Automated Hover Trainer; an Expert System (ES) based training device that demonstrated positive TOT to hovering skills in the UH-1 aircraft.

The UH-1TRS/Automated Hover Trainer (AHT) was shown to support significant TOT to the aircraft at substantially reduced training cost given that the hourly operating cost of the simulator is approximately 10% that of the aircraft. The AHT used ES logic to provide initial training in hovering flight in lieu of a dedicated Instructor Pilot (IP).

As the Army adopted the TH-67 Creek aircraft for Primary Phase IERW training, it was necessary to upgrade the low-cost trainer to the TH-67 airframe. The IFT was developed to simulate the TH-67 and to further develop the idea of automated initial entry training to include additional maneuvers from the Primary Phase IERW curriculum. Work in FY96 has developed a TH-67 simulator from a crashed OH-58 airframe and further developed the automated training concept to train traffic pattern maneuvers using Intelligent Tutoring System (ITS) technology.

The IFT is designed for implementation as a primary pre-trainer for IERW students who learn basic flight skills in the simulator and then transfer those skills to the helicopter on the flight line saving training costs and enhancing flight training safety.

BIOGRAPHY

Jack Dohme earned a Ph.D. in experimental psychology from the University of Arizona. He has been performing aviation human factors research with ARI RWARU for 19 years. He is currently serving as Chairman of the SAE Simulation Technology Committee. Jack was appointed as an Adjunct Professor of Aerospace Engineering at The University of Alabama. He holds Private Pilot ratings in fixed wing and rotary wing aircraft..

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BACKGROUND

The majority of US Army aviators arrive at Fort Rucker, Alabama for the Initial Entry Rotary Wing (IERW) training course with no prior flight training. These *ab initio* Student Pilots (SPs) are currently trained in a "lock step" program in which approximately 40 individuals comprise a flight class, progressing through flight and academic training together following a fixed training curriculum. All SPs follow the same curriculum regardless of their individual rates of progress or their specific strengths or deficits in acquiring flight skills. Various research and development efforts are underway at ARI RWARU to develop training methods to optimize training efficiency through the use of simulation and individualized training strategies. Cutbacks and downsizing in the DoD have affected training budgets thereby increasing the salience of research efforts to improve training efficacy.

Prior research efforts to enhance the effectiveness of the IERW curriculum through improved training technologies included the development of a low-cost primary training simulator called the UH-1 Training Research Simulator (UH-1TRS). The UH-1TRS, developed in FY87-88, demonstrated that a low-cost simulator could provide positive Transfer of Training (TOT) to the UH-1 aircraft on the flight line using a random sample of Army SPs as research subjects. The success of the UH-1TRS as a training concept led to the development of the Automated Hover Trainer (AHT) using the UH-1TRS as the host vehicle.

The author first observed IERW primary training in FY77. In training hovering flight, the IP demonstrated hover and then guided the SP through the function of the flight controls one control at a time. First, the anti-torque pedals were trained followed by the cyclic pitch control, the collective pitch control (including manual throttle operation in the TH-55 piston-powered training helicopter) and finally, the integration of all the flight controls. This "monkey-see, monkey-do" training method is still used in Army flight training today. However, it has a serious drawback from the perspective of human factors engineering. When a complex coordinated task such as hovering flight is fragmented into its separate components for training, there is a penalty to pay in increased training time and student frustration when the separately-learned components are integrated in real time. A review of the manual control literature by Wightman and Lintern (1985) suggests that the training time needed to integrate the separately learned tasks may be longer than the time required to learn the tasks simultaneously.

In the real world of primary flight training, it may not be possible for *ab initio* SPs to successfully manipulate all the flight controls simultaneously in hovering flight. At the least, concerns are raised regarding the safety of allowing the neophyte helicopter pilot to attempt to hover without help and without having first learned the dynamics and the interactions of the flight controls. One solution to this apparent quandary occurred to the author when he was learning to hover; develop an augmented control system to reduce pilot workload during hovering flight training but phase out the control augmentation as the SP develops appropriate control strategies, i.e., a viable "control touch". Such a control augmentation system could be used in the actual training helicopter providing that the aircraft used fly-by-wire rather than direct control linkages. However, it was considerably less expensive to develop this training concept using the low-cost simulator as the training vehicle. This concept led to the development of the Automated Hover Trainer (AHT).

THE AUTOMATED HOVER TRAINER

A team of aerospace, electrical and human factors engineers designed the AHT to provide individually-tailored and response-guided training by synthesizing a variable stability mathematical model of the training helicopter. The Optimal Control Model (OCM) developed by Kleinman, Baron and Levison (1970) was chosen to represent the man-machine interface between the pilot-in-the-loop and the simulator. The OCM application to flight training is presented in diagrammatic form in Figure 1.

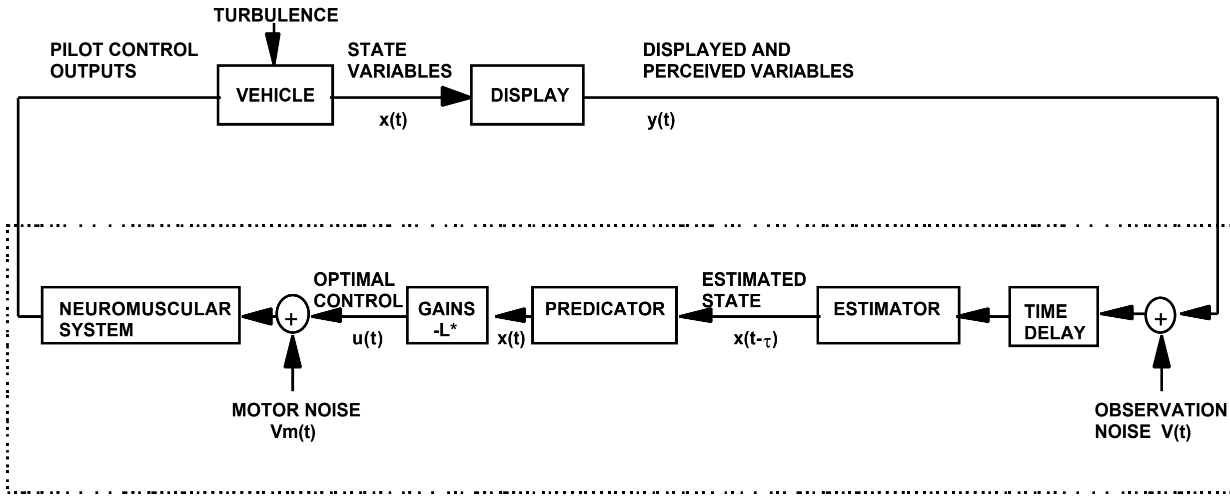

Figure 1

The OCM assumes that a skilled helicopter pilot behaves in an optimal manner to minimize control inputs, i.e., to avoid unnecessary and spurious motions. Thus, an economy of control inputs defines piloting skill. By contrast, the neophyte learns the functions and interactions of the flight controls by making many (and often large!) control inputs and observing the resultant reactions of the vehicle. Using the OCM, a quadratic Performance Index (PI) of piloting skill can be calculated for each axis of control input:

$$PI = E\left\{x^T Qx + u^T Ru + \dot{u}^T G\dot{u}\right\}$$

where: E = Average value over time
x = Vehicle state parameter
u = Pilot control input
$\dot{u}$ = Rate of pilot control input
Q, R, G = Values in weighting matrices corresponding to "autohelp" levels

The "Q", "R", and "G" weighting matrices are empirically derived from simulator flights performed by expert pilots and by neophytes. Thus, the weighting values correspond to different levels of pilot expertise. Large "Q", "R", and "G" values describe an expert pilot striving to minimize deviations in the vehicle state ("x") by use of small control inputs ("u", and "$\dot{u}$"). Similarly, the neophyte whose relatively large control inputs correspond to large deviations in vehicle states is represented by small values of "Q", "R", and "G".

Assuming that the behavior of all man-in-the-loop pilots is oriented toward minimizing the PI value (for each control axis), then the performance of the neophyte trainee can be equated to the performance of the skilled expert by inserting appropriate values for "Q", "R", and "G" in the weighting matrices. The derivation of the values in these matrices is described by Krishnakumar, Sawal, Bailey and Dohme, (1991).

The OCM approach provides a means of aiding the neophyte SP to simultaneously manipulate all of the flight controls by providing an "autohelp" function to augment the neophyte's control inputs to match the performance of an experienced IP. The "autohelp" function provides inner-loop stability augmentation in direct proportion to the SP's requirement for assistance in maintaining aircraft control. In all, twenty levels of "autohelp" are provided with appropriate values derived for the "Q", "R", and "G" matrices with level zero corresponding to no augmentation to level 20 corresponding to an automatic hover function where even large control inputs barely perturb the simulated helicopter. The PI value is calculated continuously for each control axis and a decision is made (typically every 30 seconds) whether the current PI values suggest that the SP needs more, less, or the same amount of augmentation that he/she is currently receiving. When the SP maintains autohelp level zero for two consecutive minutes for a given maneuver, he/she is considered to have learned the maneuver.

EVALUATION OF THE AHT

The AHT was empirically evaluated in a series of experiments that used Army SPs as research subjects (Dohme, 1995, pp. 115-123). The five basic hovering maneuvers (stationary hover, hover taxi, hovering turn, takeoff to hover, and land from hover) were trained to the criterion of two minutes at level zero. All five maneuvers demonstrated significant positive TOT to the UH-1 aircraft. The average training time to meet the criterion on all five maneuvers was 2.9 hours per SP. In a comparison with a control group that did not have simulator pretraining, the experimental SPs met the criterion for hovering flight performance in the aircraft with 19.9% fewer maneuver iterations.

DEVELOPMENT OF THE INTELLIGENT FLIGHT TRAINER

These positive results provided strong support for the concept of an automated, simulator-based pretrainer to prepare SPs for effective and efficient training in the aircraft. Before further research could be conducted with the AHT, the Army made a decision to replace the UH-1 with a new training aircraft to reduce operational training costs. Thus, it was necessary to change the AHT training vehicle to simulate the new trainer: the TH-67 Creek primary training helicopter. Accompanying the requirement to simulate the new aircraft was a desire to expand the functionality of the automated trainer beyond hovering flight to include additional primary training maneuvers.

A functional diagram of the TH-67/IFT is presented at Figure 2. The current configuration employs four PCs and two BBN 120TX/T Image Generators (IGs). One PC is used solely to support the sound generator board and software for synthesized speech. This function could be incorporated into the IFT PC in a future generation of IFT design. An effort is underway to redesign the IFT architecture to use fewer computers by taking advantage of the power available in modern Pentium PCs. Ultimately, it would be preferable to use two high-powered PCs to perform the functions currently implemented in the suite of four PCs and to replace the BBN 120TX/T IGs with PC-based graphics engines.

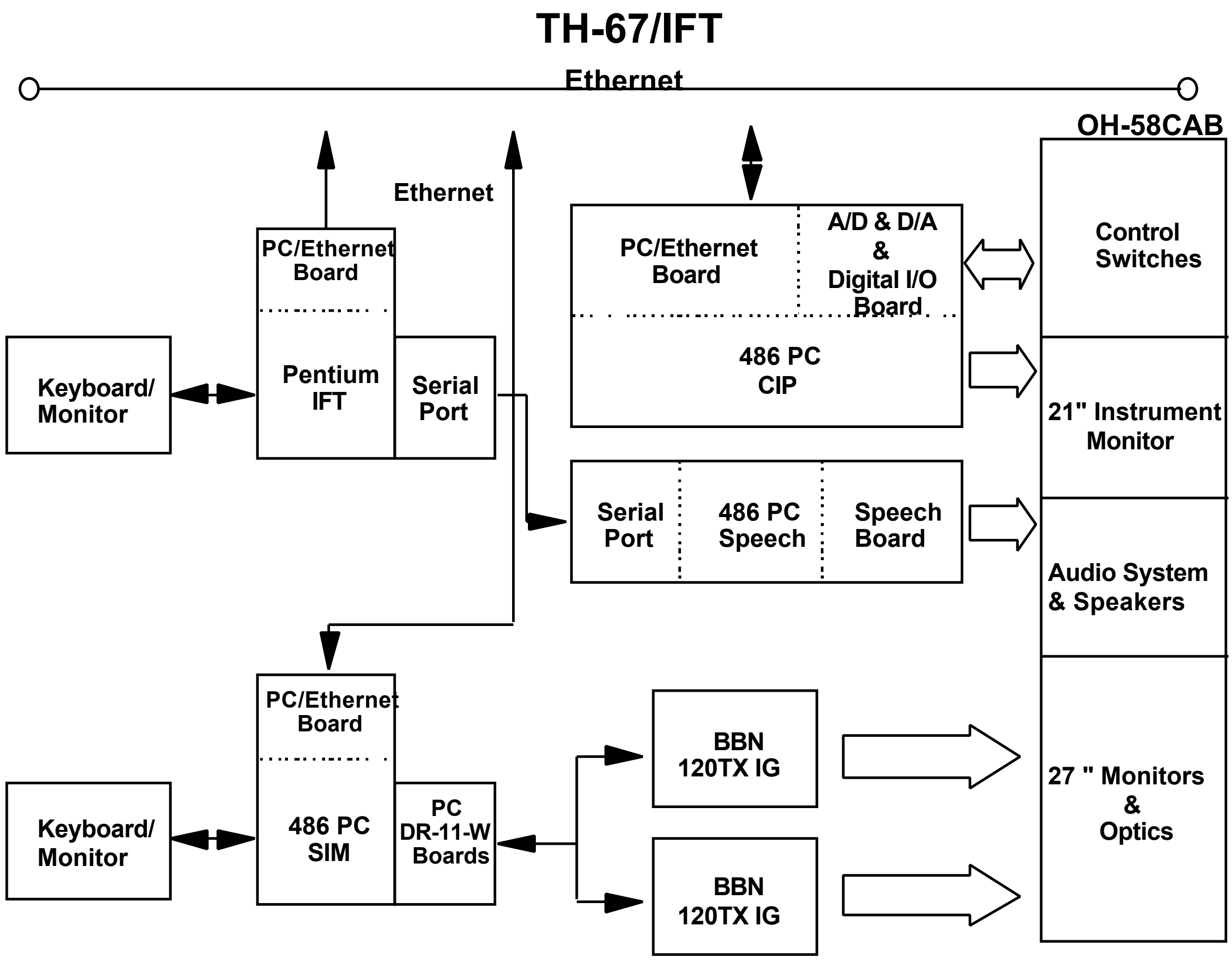
TH-67/IFT
Ethernet
OH-58CAB
Ethernet
PC/Ethernet Board
A/D & D/A & Digital I/O Board
Control Switches
Keyboard/ Monitor
Pentium IFT
Serial Port
486 PC CIP
21" Instrument Monitor
Serial Port
486 PC Speech
Speech Board
Audio System & Speakers
PC/Ethernet Board
BBN 120TX IG
27 " Monitors & Optics
Keyboard/ Monitor
486 PC SIM
PC DR-11-W Boards
BBN 120TX IG

Figure 2.

Hovering flight is primarily a psychomotor skill evidencing little in the way of cognitive (knowledge-based) learning. The decision was made to evaluate automated training of a primary helicopter flight skill that required substantial cognitive learning: traffic pattern flight. In learning to fly the traffic pattern, the SP needs to memorize the correct performance indices, e.g., airspeed, altitude, heading, and rate of climb as well as learning correct procedures, e.g., when to make radio calls, where (geographically) to make turns onto each flight leg, and learning perceptual cues, e.g., the correct "sight picture" of a normal vs. a steep approach. The addition of these cognitive components to the automated training system required a new approach to the automated training procedure.

The inclusion of cognitive training components drives the design of the IFT beyond the OCM psychomotor training model to the inclusion of a knowledge-engineering or Intelligent Tutoring System (ITS) approach. The OCM "autohelp" function was retained to aid the SP to overcome the tendency to overcontrol the aircraft and/or to initiate Pilot-Induced-Oscillation (PIO). An ITS function was added to provide guidance, information, and feedback to the SP during traffic pattern training. Following Steinberg (1991), the IFT architecture was designed to include three knowledge databases: an instructional (teacher) model, a domain expert model, and a student model. The instructional model includes submodels for three functions: the student helper, the student advisor, and the performance evaluator. The domain expert model includes knowledge of the published maneuver standards, how to fly the maneuvers, and specific knowledge of the TH-67 aircraft. The student model represents the increasing knowledge and proficiency of the SP as training progresses.

The instructional model uses an Expert System (ES) shell to provide feedback to the SP in the form of synthesized voice messages. Four functions were performed by the ES, corresponding to the four feedback functions that would be performed by an IP instructing an SP:

1) Performance monitoring, e.g., "Check hover height"

2) Control activity monitoring, e.g., "You're overcontrolling the pedals"

3) Diagnostic statements, e.g., "You're too high"

4) Advisory statements, e.g., "Descend a bit using down collective"

These four functions are considered to be hierarchical and listed in order of increasing guidance to the SP. In practice, the ES shell followed this hierarchical order providing performance monitoring at the first indication of a parameter out of tolerance, and advancing to diagnostic and advisory statements if the SP did not correct the error. If the SP did not correct the error after an advisory statement was provided and/or if the magnitude of the error continued to increase, the simulator was automatically reset to the beginning of training for that maneuver (but the autohelp level remained at the same value last used in training).

KNOWLEDGE ENGINEERING FOR TRAFFIC PATTERN TRAINING

A method was developed to compare the SP's performance (the Student Model) with the desired performance (the Domain Expert Model) to generate appropriate feedback to the SP. A series of IF:THEN statements was generated by a highly experienced IP to evaluate simulator performance indices *vis a vis* the maneuver standards published in the IERW Flight Training Guide. Following the successful ES model utilized by the AHT, three levels of feedback were provided to the SP:

1) Performance/control activity monitoring: IF parameter out of limits:THEN identify the parameter(s), e.g., "Check airspeed" or "Check trim".

2) Diagnostics: IF parameter out of limits:THEN identify the nature of the error(s), e.g., "Reduce airspeed to 60 knots" or "Climb to 1,300 feet MSL".

3) Advisement: IF parameter out of limits:THEN specify the control movement(s) needed to correct the error, e.g., "Reacquire trim using left pedal" or "Reduce airspeed and climb rate by applying aft cyclic and reducing collective pitch".

Feedback was hierarchical; the first SP error cued a performance/control activity monitoring verbalization, the second, a diagnostic verbalization and, if the error was still not corrected, an advisement verbalization. If the third level of message did not result in a correction of the error within the preset time-window (typically 20 seconds), the SP was automatically reset to the beginning of that training segment and provided a message that a reset had occurred (with the stated reason for that reset). The assumption was made that, if the SP could not complete the maneuver within training standards, it was better to start over than to continue an out-of-tolerance maneuver.

The traffic pattern was divided into six phases: Takeoff, Crosswind, Downwind, Base, Final and Approach. For each phase, a separate IF:THEN matrix was developed to catalog all SP errors that could be made during that training phase (Dohme and Couch, 1995). The last column of the IF:THEN matrix was programmed to drive a Pentium computer, programmed in the CLIPS language, to activate the appropriate feedback message contingent upon the SP's error(s) at that time. An example of the IF:THEN matrix, e.g., the first ten statements for the crosswind phase, is presented in Table 1.

IF: THEN Matrix for TH-67 Trainer
Crosswind Phase

Condition Label	**IF Aircraft:**	**1st Then:**	**2nd Then:**	**3rd Then:**
C -1	Crashes	Reset "You have crashed" **RC 1.1**	Reset "You have crashed..." **RC 1.2**	Reset **RC 1.3**
C -2	Has encroached into the avoid area on the airfield side	"You have entered the traffic pattern's inner avoid area.." **RC 2.1**	"You are too far right of the Downwind track. Turn left to intercept the Downwind track.." **RC 2.2**	Reset after 10 seconds **RC 2.3**
C -3	Is within 100 meters of entering avoid area on the airfield side	"Check position.." **RC 3.1**	"You are right of the Downwind track. .." **RC 3.2**	"Turn left and fly heading ___ to intercept the down- wind track.." **RC 3.3**
C -4	Angle of bank exceeds 60 degrees at any time	Reset **RC 4.1**	Reset **RC 4.2**	Reset **RC 4.3**
C -5	Descends lower than 100 feet AGL	"Check altitude..." **RC 5.1**	"You are too low.." **RC 5.2**	Reset at 50 feet AGL **RC 5.3**
C -6	Descends for > 3 seconds while 150 feet or more below Downwind pattern altitude	"Check climb rate..." **RC 6.1**	"Stop descent, continue climb to Downwind altitude..." **RC 6.2**	"Increase collective; check the VSI..." **RC 6.3**
C -7	Descends lower than 150 feet AGL	"Check altitude..." **RC 7.1**	"Check altitude, stop descent, start a climb to Downwind altitude."**RC 7.2**	"Increase collective and start a climb.." **RC 7.3**
C -8	Rate of descent > 1,200 fpm anytime	"Check rate of descent..." **RC 8.1**	"Check rate of descent..." **RC 8.2**	Reset after 10 seconds or at 50 feet AGL **RC 8.3**
C -9	Angle of bank > 45 degrees for more than 5 seconds	"Check bank angle..." **RC 9.1**	"Your bank angle to the right (left) is too steep, decrease angle of bank to 30 degrees or less.." **RC 9.2**	"Your bank angle was too steep..." Reset after 5 seconds **RC 9.3**
C -10	Airspeed >100 KIAS > 3 seconds	"Check air- speed" **RC 10.1**	"You are too fast. Reduce airspeed .." **RC 10.2**	Reset after 10 seconds above 100 KIAS **RC 10.3**
C -11	Airspeed is > 90 KIAS for > 3 sec- onds while $\geq$ 200 feet lower than Downwind altitude	"Check airspeed..." **RC 11.1**	"You are too fast. Reduce airspeed to 60 knots..." **RC 11.2**	"Reduce airspeed by applying aft cyclic and lowering the collective..." **RC 11.3**
C -12	Stops climb for > 3 seconds while 200 feet or more below Downwind pattern altitude	"Check climb rate..." **RC 12.1**	"Continue climb to Downwind altitude..." **RC 12.2**	"Increase collective; check the VSI..." **RC 12.3**

Table 1: An example of the If-Then matrix

SPs commonly commit more than one error at a time during flight training. The knowledge engineering approach established rule priorities to determine which training error would take precedence and evoke the first feedback message to the SP. The priority of the rules was determined by a panel of IERW primary phase training experts who used flight safety and the consequences of continuing a given error to prioritize the list in that same way that they would prioritize errors during flight training. Thus, the expert judgment of the training community is incorporated into the automated feedback provided to the SP.

RESEARCH EVALUATION OF THE IFT

Automated hover training has been evaluated and found to provide significant positive transfer of training to the UH-1 aircraft using Army SPs as research subjects (Dohme, 1993). The capability of the IFT to provide traffic pattern flight training has not been experimentally evaluated. Army IPs, current in primary phase IERW instruction, have "flown" and evaluated the IFT. Changes and improvements have been made to the IFT in accordance with their suggestions. The IFT has been pre-experimentally evaluated using neophytes who are not Army SPs as research subjects. Minor "tuneup" changes have been made to the software as a result of these pre-experimental trials. An experimental evaluation of the IFT is planned for late in FY 96.

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