AN OVERVIEW OF LITERATURE ON HUMAN FACTORS AND PART-TASK TRAINING WITH IMPLICATIONS FOR VISUAL SIMULATION IN PRIMARY FLIGHT TRAINING

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June 5, 1984
ABSTRACT

Research issues are identified through the application of a conceptual model of human factors interactions in pilot performance. The application of part-task training concepts and methodology shows that simulation has a great potential to address pilot training research design issues. This and new technologies indicate that the best medium for the cost effective application of part-task training methodology would be a computer generated video graphics display. The U.S. college and university aviation programs have all the ingredients on hand to develop this training device and the best minds with which to do it. Appendices hold collections of references for those interested in these subjects.
1. **Introduction:**

Great progress in reducing general aviation accidents has been made. These accomplishments are hampered by the fact that the percentage of continuing accidents attributed to pilot error remains at nearly 80%.\(^1\) During the past decade the FAA has undertaken a broad systems approach to study the factors affecting pilot performance. This has led to an embracing of the body of human factors knowledge and the use of a human factors approach to research.\(^2\)

There is a large body of human factors knowledge and research concerning the concept of part-task training. Part-task training involves the practice of some subsets of components of a whole task prior to practice or performance of that whole task.\(^3\) Flight simulation and particularly visual flight simulation shows new promise for enhanced effectiveness using part-task principles.\(^4\)

Major technological advances have greatly reduced the cost of hi-fidelity color video motion recording and playing equipment. Computer generated video systems capable of simulating out-of-cockpit views in flight are presently available even at the personal computer market level.\(^5\) The FAA has waived some of the minimum flight time requirements for specifically approved college level general aviation training programs. This and the high cost of flight training in aircraft has opened the door to innovation in cost effective alternatives that reduce flight time needed to achieve performance standards. Visual simulation appears ripe for innovation.

This work initially presents an overview of recent work that has identified a systematic framework for research into human factors affecting pilot performance. A compilation of pertinent references from literature reviews and papers on this subject for general aviation is presented in appendix A. The appendix is for the convenience of those interested in human factors knowledge as it is applied to general aviation. Next an overview of part-task training theory and methodology is presented. Then there is a review of current aviation research on part-task
training of pilots with flight simulators that have visual systems. A compilation of pertinent references on part-task training applicable to aviation is presented in appendix B.

Finally the potential for visual simulation to improve pilot performance in primary flight training is discussed. The present use of visual simulation systems in primary flight training is reviewed in the light of a human factors approach. Part-task training methodology applications are hypothesized and recommendations for further research are made.

2. Human Factors Problems In Pilot Performance

The all encompassing "pilot error" cause for accidents may satisfy legal demands but it does little to advance understanding of cause. This simplistic description of pilot performance problems is a poor guide to the prevention of similar accidents. Better schemes employed to classify factors thought to affect pilot behavior are of three general types. "Operational Tasks Executed Incorrectly" includes failure to see and avoid aircraft, failure to maintain or the misjudgement of distance, altitude or speed; mismanagement of fuel, and failure to extend landing gear. "Psychological Failures Associated With Procedural, Perceptual-Motor, and Decisional Errors" include workload problems, fatigue, stress, attention and decision-making. The third scheme is based on "Factors Associated With The Conditions Surrounding The Occurrence" such as phase of flight, type of mission, time of day, geographic location, weather conditions, total pilot flight time, and pilot certificates held.

These schemes help identify existing pilot performance problems but provide no direct guidance toward actions to be taken to prevent the problems. Descriptions of what happened must be followed by an understanding of why an error occurred to identify preventative or corrective actions. A research structure based on these concepts of the human factors discipline provides an effective means of developing corrective actions. One model attributes pilot performance problems to incongr-
ruities between the level of demands imposed by pilot tasks and the pilot's ability or motivation to perform them. Solutions to these problems require modification of task demands and/or pilot capabilities to eliminate physical, psychological, and physiological incongruities. Incongruities must be identified and one or more elements of an incongruity must be susceptible to change.

A design oriented approach using the body of knowledge of human factors affecting pilot performance has yielded a complex system model. In this model, developed for the FAA by Shelnutt, Childs, Prophet and Spears, three major components interact to produce pilot task demands. Three other major components interact to produce pilot capabilities. The task demands and pilot capabilities interact to produce either effective pilot performance or pilot performance problems. Figure 1 illustrates the model and shows design elements resulting from major design decisions that are associated with each model component.

Shelnutt et al analyzed a broad spectrum of information concerning pilot performance problems and associated human factors design issues using their model. Human factors design issues were formulated from inadequate information about system interrelationships and the effects of design alternatives on pilot performance. Thirty-five design issues were identified as requiring research to generate needed data required to support system design decisions. Figure 2 lists the design issues and shows their relationship to the design elements affecting the model components. Research into the use of part-task training and its enhancement of visual simulation effectiveness provides data for design issues number 23 through 27 and 32 in Figure 2. This data probably contributes to all issues and elements of the training and proficiency assessment component of the system model in Figure 1. Some or all of the issues formulated for components affecting pilot capability will also be enlightened by part-task training research. Appendix A is a compilation of references pertinent to a systematic, human factors, approach to evaluating pilot performance problems.
1. Identify Req. for Human Factors Engineering Standards and Guidance for Aircraft Controls and Displays
2. Develop Objective Assessment Methods for Aircraft Handling Qualities
3. Identify Req. for Extracockpit Visibility Criteria and Guidelines
4. Identify Requirements for Human Factors Guidelines and Standards Concerning Intracockpit Noise and Vibration
5. Identify Requirements of Integrated Flight Management Systems
6. Generate Runway Surface, Marking, and Lighting Requirements
7. Identify Requirements for Airport Approach Aids
8. Identify Requirements for Normal and Emergency Aircraft Operating Procedures
9. Determine Information Dissemination Methods for Aircraft and Subsystem Operating Procedures
10. Determine Requirements for Aircraft and Subsystem Performance Data
11. Specify Formats to Present Aircraft & Subsystem Performance Data
12. Assess Impact of Different Airspace Assignments on Pilot Performance
13. Identify Requirements for Modification of Minimum Visibility and Cloud Clearance Standards for VFR Flight
15. Identify Requirements for Communications Between General Aviation Pilots and Air Traffic Control Personnel
16. Identify Requirements for Communications Between General Aviation Pilots and Flight Service Personnel
17. Determine Flight Experience Requirements for Certificates and Ratings
18. Determine Medical/Psychophysiological Req. for Certificates and Ratings
19. Identify Task Subsets for Current Certificates and Ratings
20. Identify Needs of New Certificates
21. Identify Needs for New Ratings
22. Identify Training Requirements for Certificates and Ratings
23. Determine Training Techniques for Use in the Aircraft
24. Determine Training Methods for Use in Pilot Training Devices
25. Determine Training Device Fidelity Requirements
26. Design of Instructional Support Features for Pilot Training Devices
27. Determine Instructor Training Requirements
28. Develop Guidance for Recurrent Instructor Training
29. Develop Guidance for the Modification of Written Proficiency Tests
30. Develop Objective Flight Checks
31. Identify Techniques for Using Alternative Test Media
32. Determine Requirements for Continuation Training
33. Identify Methods for Encouraging Continuation Training
34. Determine Req. for the Recurrent Assessment of Pilot Proficiency
35. Determine Guidance for Structuring the BFR

Figure 1. -- Structure for Addressing Human Factors Design Issues.

Figure 2 Human Factors Design Issues
3. Part-Task Training Theory

Part-task training is practice on some set of components of a whole task before practice or performance of the whole task. Three general types of part-task manipulation schemes are identified in psychological literature. Simplification makes tasks easier by adjusting one or more characteristic of the task such as the turbulence level adjustments on flight simulators. Fractionation provides independent practice of subtasks that are executed simultaneously for the whole task such as pitch and roll control. Segmentation partitions a whole task either spatially or temporally such as takeoff, climb, cruise, descent, landing.

The schedule used to reintegrate the parts is a crucial variable. Of the three schedules identified for fractionation and segmentation, pure-part training employs isolated practice of parts before whole task practice. In repetitive-part training one part is practiced, a second part is added and both are practiced together before another part is added. Progressive-part training uses isolated practice of new parts before they are added in repetitive fashion to parts that have been practiced. With simplification the number and size of step increases in difficulty could be varied.

Learning has been described as problem solving wherein knowledge of results is information about error that communicates the level of success at the problem solving task. Such information is actively processed generating hypothesis about how to improve performance. Any simplification condition that provides trainees with unambiguous error information should evoke early correct performance.

Current analysis of the process by which people approach learning tracking tasks indicates that it has three stages. First the trainee learns the proper direction of control movements to correct error conditions. Second, the trainee
develops facility with timing of error correction response by learning to
detect conditions which demand corrective input. Finally the trainee learns
the proper magnitude of control movement for any given error condition. Im­
proved early performance should result from simplification matching of the
nature of error information to the trainee needs at each stage of learning.

Segmentation practice on critical elements of a perceptual-motor task
requiring performance over time or space can lead to early proficiency. This
provides a larger amount of practice on the part of the task producing the
strongest error information when the trainee needs it most.

4. Part-Task Training Research

Flying tasks can be described as continuous, perceptual-motor tasks
characterized by complex multidimensional tracking. The search for new
training techniques should follow suggestions from learning principles developed
from research on perceptual-motor and tracking learning. However the organiza­
tion, directions, and nature of motor behaviors studied in psychology labora­
tories have shortcomings in the application to complex training tasks.13 The
principles need to be tested in a more systematic fashion on more complex and
realistic tasks.

Performance differences during training do not imply similar differential
learning in relation to the criterion or whole task. Applications research
must be designed to evaluate the transfer-of-training (TOT) to substantiate
the effectiveness of any specific technique. Appropriate TOT design must have
multiple groups with at least one control group that is trained and tested en­
tirely on the whole task. Each group should be trained for equivalent pre­
determined periods in only one condition prior to criterion testing. A balanced
schedule of training periods employed in incremental transfer design15 is accept­
able and can provide supplemental information.

Proper TOT design allows comparison of the transfer effects of prior exper­
ience of a specific type on performance of the criterion task. Differential transfer estimates of the relative effects of equal amounts of experience with experimental and control conditions is also possible. Transfer theory and formulae\textsuperscript{16} show that transfer can be positive or negative but not greater than 100%. Differential transfer can be greater than 100%. This would indicate that training with the experimental condition is more efficient than the control condition for future performance in the criterion task. A positive differential transfer value below 100% indicates that the experimental condition is less efficient but does teach skills useful in the criterion task. Cost effective application of this experimental training technique could result if it was sufficiently less expensive than training in the control condition.

Besides early proficiency, an effective training strategy must facilitate maximum transfer by meeting three general conditions.\textsuperscript{17} First, any changes in response requirements resulting from the training technique must have perceptible changes in stimuli. Second, supplemental feedback should be provided when a task is low in intrinsic feedback. Third, to insure unambiguous error information, trainees should have a clear understanding of any differences between training and transfer tasks.

Wightman and Lintern\textsuperscript{18} have recently reviewed the literature and research in valid part-task training applicable to flight simulation. Most of the recent flight simulator work has been done by the Air Force, Navy, and the FAA. Most military work was done on advanced flight tasks such as carrier landings, dive bombing, and night flight in multi engine jet simulators. Most of the research involved the use of visual simulation systems added to an instrument cockpit simulator.

Recent fractionation research, some using visual flight simulation, has uncovered a strong interaction between task complexity and task organization. For tasks with high component complexity and high component interdependence,
Fractional progressive part-task training has been less effective than whole task training.\textsuperscript{19} Apparently the early proficiency in separate part practice does not transfer well to whole task performance. Since flight control tasks fit the character of these experiments, fractionation may not produce effective primary flight training.

However, fractional progressive part training for high component complexity and low component interaction has showed positive differential transfer greater than 100%. This means the technique was found to be totally superior to whole task training. Other research in similar complex tracking task training has shown high positive differential transfer below 100%.

Fractionation by visual pretraining for teaching landings in an aircraft simulator with a visual display was tested. Passive-preprogrammed landings were viewed by the experimental group before simulator practice with no resultant improvement in their performance.\textsuperscript{20} However, the long history of attempts to pretrain perceptual skill (perceptual pre-differentiation) indicate that positive transfer is very possible. Subjects need to actively seek distinguishing perceptual cues or make some decision about the visual stimuli during pretraining. This was not done in the reported study.

Simplification is most effective for tracking tasks that are so difficult that learning is slowed since very little meaningful practice is achieved. Practice at easier tasks extends skills so the criterion task is no longer beyond trainee capability. Practice on easy tasks may establish a high performance standard as a goal that motivates the trainee after transfer to a more difficult task. Manipulations of rotation speed and control-display lag have shown differential transfer values from medium to high difficulty tasks of greater than 100%. Manipulations of system order, gain, lag, forcing function, stability and damping ratio were found to generally not enhance training efficiency in
flight tasks. Some general research that indicates the unlikely possibility of
greater transfer from difficult-to-easier tasks\textsuperscript{18} have found possible correlation
in present research.

The concept of augmented feedback is not strictly a simplification or
even a part-task training technique. However, simulator studies have shown\textsuperscript{21} that
it can speed acquisition if trainees are not permitted to develop dependencies
on the supplementary cuing. An adaptive withdrawal technique to avoid such
dependencies is suggested. Recent visual simulation experiments\textsuperscript{22} in a dif-
ficult ground reference maneuver task showed a strong effect of adaptive visual
cuing. Differential transfer for augmented feedback training was positive and
greater than 100%.

With segmentation, difficult parts of a spatial or temporal task can be
practiced intensively without spending time on easier or proficient parts.
In three out of four recent experiments in segmented part task training of
landing type maneuvers\textsuperscript{18} positive differential transfer was greater than 100%.
Visual simulations of dive bombing and carrier landings used a segmentation
reintegration technique called backward chaining where the terminal segment
was practiced first. Both pure-part and progressive-part reintegration (back-
wards) were successful. Only an experiment testing ground position freeze for
enhancing carrier visual approach glidescope control produced less than 100%
positive differential transfer. This is unexpected as mere isolation of a
critical element for extended practice does not appear to be a strong technique.
Even when the control group had more total training time, backward chaining
produced superior results.

Wightman and Lintern\textsuperscript{18} discuss several concepts from perceptual-motor
learning literature as hypotheses for the unusual success of backward chaining.
In terminal tasks, such as landing an airplane, earlier segments may not be
learned quickly because they are separated from the strong feedback of the final result. Activity between an action and the participant's knowledge of results (KR) of that action interferes with the progress of learning. Perhaps the association between the action and errors is obscured. In a backward progression, later task segments, once learned well, become the source of information feedback for earlier segments. Also, the post KR period apparently permits trainees to relate error information to earlier actions. Other activity such as prompt repetition of earlier task segments may interfere with this process. Prompt repetition of the same segment could enhance action-error correlation.

Also, in backward chaining, trainees do not have to cope with the ambiguities resulting from errors accumulated in prior segments. This follows the consistency in stimulus-response relationships concept. Trainees may learn more quickly simply because they experience a correct (errorless) performance more frequently than the whole task control group. Perhaps this results in learning to recognize the correct behavior more quickly.

The effects of individual subject differences has been a source of concern when creating and testing instructional treatments based on task manipulation. Measures of subject aptitude or abilities on the skills in question should contribute to the validity and knowledge gained in experiments. This question was addressed in one carrier-landing experiment previously discussed. A previously established valuable measure of motor skill for research on human perceptual-motor tasks was used to calibrate the subject differences. This allowed tracking of high vs low motor skill subjects throughout the experiment. The results showed that high motor skill subjects performed best in all cases. However lag manipulations hurt low ability subjects and not hi ability subjects while segmentation variations helped the low much more than the hi. This aptitude
by treatment interaction shows how transfer performance is influenced by both training technique employed and subject's ability. Appendix B is a compilation of references pertinent to human factors part-task training applications to flight training.

5. Visual Simulation And Primary Flight Training.

To control an aircraft while visually scanning the airspace to navigate and avoid other traffic, a pilot must use an outside visual reference system. This reference system, mostly in the mind of the pilot, relates the aircraft attitude to the natural horizon. Learning and gaining confidence in using this outside visual reference system is difficult for the beginning pilot. There are many sources of distractions, such as noise, new surroundings, and new physical and visual perceptions associated with beginning flying experiences. These distractions are compounded by fluctuations in aircraft attitude induced by atmospheric turbulence and untrained pilot control inputs. Because of these distractions, initial progress in learning to safely control an aircraft in flight is often slow. This discourages students and instructors and can incur significant costs in dollars, time, aircraft operating life, and air traffic control service.

Not only must pilots see and avoid other aircraft in busy airport terminal areas, they must maneuver their aircraft with respect to airports and runways. This has to be done while at low altitudes and slow speeds where margins for error are reduced. Considerable attention is needed to hear and understand radio communications, and make radio transmissions, while maneuvering the aircraft and looking for traffic. Pilots must control the attitude and speed of the aircraft by outside visual references with only occasional reference to the instruments inside the cockpit.

Today most aircraft have a complete set of attitude control instruments
in the cockpit and there is widespread use of cockpit instrument flight simulators. For most pilots there is strong emphasis on learning to control the aircraft solely by reference to cockpit instruments early in their training program. The cockpit instruments provide many exact points, marks, numbers and items of information about the aircraft's attitude and performance. Outside visual references of aircraft attitude and performance are usually less discrete, more subtle, often combined, and appear to vary from aircraft to aircraft. Visual references also depend on the pilot's head and body position in the aircraft at any instant of time.

Beginning pilots often find it easier to deal with the discrete cockpit instrument indications than the seemingly more combined outside visual references. There is an early and continued strong emphasis on learning to control the aircraft by reference to cockpit instruments. Many pilots develop the habit pattern of controlling their aircraft primarily by reference to cockpit instruments for all phases of flight. This incorrect aircraft control habit pattern often leads to poor or inadequate visual clearing to see and avoid other air traffic. Erratic airspeed and directional control, loss of navigation orientation awareness, unacceptable maneuvering with respect to the ground, and increased pilot fatigue also result. A thorough understanding of and confidence in the ability to control the aircraft by outside visual references is a necessary step toward becoming a safe and competent pilot.

Visual simulation pilot training devices designed according to the principles described earlier should be more cost effective than purely in flight training. A systems analysis of military, FAA, and collegiate flight training by McDermott developed a list of 756 elements of flight training. Further refinement of elements for visual flight could determine visual flight training tasks that should be addressed with simulation. Effective training devices need
not always reproduce the aircraft cockpit inflight conditions with hi-fidelity. Success occurs when performance in required tasks is learned in a manner that transfers to the aircraft at an overall cost savings. Oftentimes, as has been shown, part-task training techniques can produce both cost effective and totally superior training schemes. Until the recent research reviewed here, all aviation simulation strived for maximum fidelity to inflight conditions. Since present simulators emphasize instrument flight conditions, add on visual motion systems have not resulted in effective primary visual flight training.

Recent FAA research\textsuperscript{24} has found that a $50,000. price range generic multi-engine flight simulator was ineffective for basic multi-engine flight training. The device tested was a commercially available multi-engine instrument flight simulator with a rudimentary extra-cockpit visual display. Ten (10) hours of simulator instruction preceded eighteen (18) hours of flight training for two experimental groups. The simulator training produced no significant increase in performance either during flight training or on the FAA multi-engine class rating flight test. Simulator training did not even significantly enhance the instrument skills tested over the control group that just received the 18 hours of flight training.

This suggests the possible ineffectiveness of current general aviation simulation trends. Perhaps if the same effort were put into a multi-engine visual flight simulator with rudimentary instrument capabilities, more effective training would occur. It was noted in this study that multi-engine training is primarily visual-flight training. The simulator tested was little more effective than a static cockpit procedure training device that could probably be produced for one tenth the cost. High performance business aircraft training, the airlines, and the military make judicious use of these simple, but cost effective "mock up" training devices.
The military has also used simple motion video recordings of the cockpit view of basic in-flight maneuvers for over a decade. Primary flight students view these real time motion recordings of maneuvers as part of their ground training. The military total systems approach also includes hi-fidelity instrument flight simulators but as yet no primary flight visual simulation. The USAF produces multi-engine ATP level pilots with less than 100 total hours of flight time.

A television video tape program using through-the-cockpit real time scenes enhanced with graphics and voice is in college use. This augmented feedback, pretraining fractionation, pure part reintegration, flight training instrument is now part of a pre-solo simulator course using instrument simulators. The program describes and shows how to control and coordinate the aircraft using only outside visual references. Qualitative response from students and flight instructors indicates favorable learning effectiveness when students transferred to aircraft. Computer interactive video driving of the tape was demonstrated but found ineffective due to the long video tape search times. Computer interactive video disk technology as is being developed by the Jeppeson Sanderson Company holds great promise for increasing the training cost effectiveness of video recordings.

Computer generated video motion scenes appear to hold the greatest promise for flexibility and cost effectiveness in visual flight simulation training. The ATARI Air Combat Maneuvering (ACM) game has been proven to be a reliable, and effective gage of perceptual-motor skill applicable to flight. Several visual flight simulation programs are on the market for a variety of home computers.

The Flight Simulator II computer program marketed by Sub LOGIC Corporation can be purchased for under $50. to run on several home computers. The video
display is split between the windshield view and the instrument panel in forward view mode. Eight different directions of view can be selected independently for monitoring during flight. The video scene with a color monitor is realistic enough for useful flight simulation, having a scene projection rate of six (6) frames a second.\textsuperscript{26} An initial qualitative hands on assessment of the programs features and capabilities shows the Flight Simulator II has great potential. Sub LOGIC is working to replace the standard computer gaming joystick with aircraft like flight controls to seek FAA certification of the program as a flight simulator. With flight control inputs the program should be able to address all flight maneuvers required for the private pilot flight test.

Innovations in college level pilot training curriculums as have occurred at Daniel Webster College\textsuperscript{27} benefit the most from effective training techniques. The program organization and control allows proper analysis of both where and when to use new techniques and their effectiveness. The large number student base also provides the test subjects needed to verify the effectiveness of new training techniques. Large, well organized, flight training programs are the best setting for the research needed to apply the human factors approach to solving pilot performance problems.

College faculty are professionals who can understand the human factors approach and create experiments to exploit it in developing educational techniques. Molenaar\textsuperscript{28} has elegantly conceived the need and the potential of part-task visual simulation to enhance aviation education with his "single concept simulation" idea. Maximum effectiveness in this multi-faceted, interdisciplinary type of research requires experts from several areas of expertise. Hutchings\textsuperscript{29} shows an excellent example of the enhanced results of professional collaboration between aviation faculty and faculty from other disciplines. All faculty, their students, the university and society benefit from this type
of activity.

6. Conclusions

A systems analysis of human factors in pilot performance problems has generated a conceptual model for examining human factors interactions. Human factors design issues identified as needing research include many flight training issues. Human factors part-task training theory and methodology indicates that simulation can be very effective in addressing flight training issues.

Visual flight simulation shows new promise from new technology and recent theoretical and empirical investigations using a human factors approach to training. High fidelity simulation is not a mandatory requirement of an effective training device when theories of learning are applied. Part-task training capabilities have the potential to increase the effectiveness of a visual simulation training device beyond that of hi-fidelity whole task simulation. Part-task training schemes can best be implemented with computer video graphics displays.

College level education institutions have the best setting for the development of visual flight pilot training devices. They have the existing program organization, test facilities, test subjects, and most of all, the college faculty research expertise. The depth and variety of academic and research disciplines available at the college level will be necessary to fully exploit the human factors approach to solving pilot performance problems.

The successful transfer of learning from simulation training techniques to pilot flight performance validates both the training device and the training technique. New training techniques should also be applied to actual inflight training when possible to enhance the overall training program effectiveness. The Cessna 152, Piper Tomahawk, and Beech Skipper are excellent flight simulators.
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