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Fighter Pilot Trainee Retention of Knowledge and Skills: an Exploratory Study

Dee H. Andrews

Christopher B. Sinclair

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Dee H. Andrews
Patricia C. Fitzgerald
Air Force Research Laboratory
Mesa, AZ

Christopher B. Sinclair
Ian B. Farquharson
Advanced Training Systems International
Mesa, AZ

An exploratory study was conducted to investigate knowledge and skill retention of foreign military fighter pilot trainees with intermediate levels of flying experience. Twenty participants completed a standardized advanced skills fighter-training program that lasted about 10 months for the first class (n=12) and eight months for the second (n=8). Following flight training, the students engaged in non-flying duties (i.e., leave, English training classes). Members of the first class did not resume flying for a minimum of eight months; the second class returned to the simulator or the flight line within three months of completing initial training. Thus, two retention intervals were available for analysis. Analyses of instructor estimates of the students' skill and knowledge retention revealed significantly greater perceived decay among the students in the first class. Furthermore, the students in the second class were perceived to have been better prepared for their sorties than those in the first.

Introduction

Research psychologists have been examining the acquisition and retention of human learning for well over one hundred years. Learning acquisition has been extensively examined in many thousands of research papers. However, the retention of knowledge and skills acquired in the learning process has been less extensively studied and therefore less is known about the topic.

Pilots must learn a tremendous number of skills and considerable knowledge to be safe and effective. This learning takes place over many months or perhaps even years. While most pilot certification testing takes place soon after the initial learning occurs, the pilot may not be called upon to use many skills or pieces of knowledge until a considerable time after the initial learning takes place. The retention of skill and knowledge of pilots is the theme of the study reported in this paper.

Of the relatively few aviation learning retention studies that have been performed, most examined the retention of lower order skills such as procedures. As we explain in the literature review section of this paper, we have found few aviation learning retention studies that have examined higher order cognitive skills such as decision-making. This study examined retention of a variety of skills, both simple and complex, but we believe the most interesting findings relate to the complex cognitive skills necessary for basic fighter maneuvering and air combat.

One reason for this relative dearth of research into learning retention has to do with the difficulty of conducting such retention research, especially compared to what is required to investigate learning acquisition. Most human retention studies require the subjects to return to be retested days, weeks or months later. It is often difficult to entice all of the subjects to return for this retesting. Some reasons might be: subject leaves the local area, subject is too busy, the subject did not like the experiment in which they participated, or the subject simply forgets to come at the appointed time. Regardless of the reason, it can be difficult to get a complete sample of subjects to participate in the retention part of a learning study.

For this study the experimenters were able to avoid many of the problems usually associated with enticing retention subjects to return for the retention portion because the pilot subjects were enrolled in a military training program and they had to return as part of their military duties. In addition, the study had a unique advantage over other studies that have examined pilot learning retention because the pilots did not fly between their first training course and a seasoning course that was offered many weeks later. Typically, pilot trainees start flying operational missions shortly after their initial training is complete. Even if researchers wish to measure learning retention, the operational flying performed by recently graduated pilots serves to bias the retention measurements. That is, if the operational flying requires the pilot to use any of the skill or knowledge being measured in the retention study, the retention measures eventually taken are not true reflections of how much skill or knowledge decay that has occurred after the learning acquisition portion of the study.

A majority of the research concerning knowledge and skill retention has been conducted in the laboratory rather than in applied settings (Arthur et al., 1998; Hagman & Rose, 1983; Nembhard, 2000). Because the literature on natural tasks supports the contention that retention is stronger in this condition than for artificial tasks (Arthur, et. al., 1998), more research needs to be conducted in real world settings. This is important for the military because Reserve and National Guard units are often called to service with long periods of non-use of the skills required when deployed (Arthur et al., 1998). Furthermore, although retention research was conducted in aviation several decades ago, few recent research undertakings have addressed the issue. Finally, given the complexity of modern aviation systems, and the conflicting findings in the literature concerning the retention of complex tasks, it is necessary to readdress these issues.

Literature Review

The learning research literature records decades of studies examining the acquisition of knowledge and skills. However, by comparison to the acquisition literature, the literature on retention of skills and knowledge is relatively sparse (Hagman & Rose, 1983; Lance, Parisi, Bennett, Teachout, Harville, & Wells, 1998). Although the phenomenon has been studied for more than a century, the lack of regularities in the findings cause the construct to often be excluded from theories and models (Rubin & Wenzel, 1996). Despite the fact that retention has not been the subject of much research in aviation, empirical studies from a variety of domains have suggested a number of factors that have been associated with the decay of learned information and skills.

Retention Intervals

The retention interval is the period of time between the initial learning and the subsequent use of a skill or learned material. Research in which varying retention intervals were studied reported that retention decreased as the length of the interval increased (e. g., Adams and Hufford, 1962; Arthur, Bennett, Stanush, and McNelly, 1998). Fleischman and Parker (as cited in Prophet, 1976) found that participants trained on a flight simulator retained virtually all of their perceptual-motor skills after retention intervals of up to 24 months, after which decay was marked. Studies conducted by Bahrick (1984) and Bahrick and Phelps (1987) indicated that learned information started to decay shortly after it was acquired, but reached a plateau after five or six years.

Retention of Procedural Skills

The retention of procedural skills has received a great deal of research attention. In their meta-analysis of the literature on retention, Arthur, et al., (1998) found that procedural skills (e. g., pre-flight checks) were more prone to decay than continuous skills (e. g., tracking, flight control). Adams and Hufford (1962) reported nearly complete loss of procedural skills (i.e., a bomb toss exercise) following a 10-month retention interval.

In addition to being prone to decay, highly proceduralized tasks may have negative implications when an anomalous situation occurs. In their study on memory and cockpit operations, Nowinski, Holbrook, & Dismukes (2003), stated that when a habitual procedural task is delayed the typical cue is no longer present and the task may be forgotten, especially if the person is busy or tired.

Retention of Intellectual Skills

Although there is much research on the acquisition of complex intellectual skills, there is little literature on the retention of those skills. In their analysis on the retention of complex skills required to perform military tasks, Lance, et al. (1998) found that more complex skills were more likely to be forgotten than less complex skills, especially over long retention intervals.

In a study on the learning and retention of a complex industrial skill, Nembhard (2000) found that experienced workers learned and forgot faster than their inexperienced counterparts. As task complexity increased, however, the rate of decay evidenced for the more experienced workers decreased. Nembhard attributed the more robust retention rate to the better developed schemas of the experienced workers. Similarly, Sauer, Hockey, and Wastell (2000) conducted an experiment in which participants were trained to perform complex spacecraft life support control functions. They found that participants retained the skills acquired following an 8-month layoff, regardless of whether they received procedure-based training or system-based training in which a higher-order understanding of the system was fostered.

Practice

Investigators have found that retention is facilitated by spacing the initial learning over time, rather than by massing practice in a shorter time frame (Baddeley, 1999; Hagman and Rose, 1983). In a review of retention studies, Hagman and Rose found that spacing learning trials was most effective before the participant became proficient at the task. In addition, providing a greater interval between learning sessions was not as effective as spacing trials. During the early phases of learning complex skills such as flying, regular well-spaced lessons promote the acquisition of the requisite skills. Although the number of trials of any given procedure or maneuver are limited during each session, further practice occurs in subsequent lessons as the required skills are integrated.

Practice may also take place apart from the actual training conditions. Mental practice is "the symbolic, covert, mental rehearsal of a task in the absence of actual, overt, physical rehearsal" (Driskell, Copper, and Moran, 1994, p. 481). In their meta-analysis, Driskell et al. found that, although practice in the actual training condition was found to be more effective, mental practice enhanced retention for physical and cognitive skills, with a greater positive effect for cognitive tasks. The meta-analysis also supported the idea that mental practice was less effective when employed by novices. Finally, brief periods of mental practice were optimal; the benefits of the practice decreased as the practice period increased.

Methods

Participants

Twenty participant pilot candidates completed a standardized advanced skills fighter-training program in the A-4 aircraft that lasted about 10 months for one class (n=12) and eight months for a second class (n=8). Upon completion of the initial training program, the students in the first class engaged in duties that were not related to aviation (i.e., leave, English training classes) for a period of eight months. They then returned to the training facility for seasoning training. Students in the second class also had a break between initial and seasoning training, however, the retention interval was limited to three months.

The seasoning training included a combination of activities that were designed to enhance the retention of the previously learned skills and knowledge. Once the seasoning portion of the curriculum was completed, the students were introduced to new skills and knowledge.

Sixteen instructor pilots (IP's) were employed by a private commercial flight training company to instruct the students. All had previous fighter instructor pilot experience. For any given sortie, students were paired with an instructor based upon scheduling constraints. Thus, the students trained with a variety of instructors during the course of the program.

Retention Measurement Instrument

A paper questionnaire instrument was developed to obtain the instructor pilots' subjective assessment of the level of knowledge and skill retention exhibited by each trainee (see Appendix A). In addition, the instructors were asked to estimate the extent to which the student was prepared for the seasoning sorties. That question was asked so that the experimenters could make an estimate of whether student preparation contributed to the IPs estimates of retention. Both assessments were measured on a scale from 0 to 100, representing the percentage of retention and preparation. IPs also indicated whether or not they had instructed the student on the skill set in initial training. The assumption was that IP familiarity with the trainee from previous flights would likely lead to a higher estimate of retention. Finally, IP's indicated the sortie identifier, the date of the flight, and the student's class number (i. e., 1 or 2).

Procedures

Upon the completion of each flight during seasoning training, the IPs completed the instrument to provide an assessment of the student's retention and preparation for that flight. Five functions were included in the seasoning training and were evaluated for the present study. For each function, a series of re-familiarization sorties was flown. Transition training consisted of a series of flights that addressed aircraft handling and basic and aerobatic flight maneuvers. A series of simulator flights were conducted to practice emergency procedures. Instrument flight procedures, including basic instrument, radio, and navigation procedures, were also practiced in a series of flights. Basic and tactical formation skills were addressed in two- and four-ship formation flights. Finally, a minimum of ten training flights dealt with basic fighter maneuvers, including offensive and defensive maneuvers.

Results

Knowledge and Skill Retention

For the retention measure, a total of 102 usable IP ratings (64 for class 1 and 38 for class 2) were obtained for the sorties identified as the first flights using the skills associated with the function since initial training. Incomplete or illegible rating sheets were excluded from the analyses. T-tests were conducted to assess the IP's perceptions of the level of learning retention in the interval between the basic and the seasoning courses. Analyses of IP estimates of the students' retention for all sorties for each class revealed a significant difference between the classes ($t_{(100)} = -2.523$, $p < .05$), with greater decay perceived among the students in the first class.

Also of interest was the retention evidenced based on the type of function (e. g., emergency procedures, basic fighter maneuvers, formation). Due to the small number of IP evaluations for some of the function types for each class, statistical analyses were not conducted. To determine if there were evident trends between the classes, however, the data were plotted on a bar chart. As Figure 1 illustrates, retention was perceived by the IPs to be poorer for the first class in all phases of training with the exception of Formation.

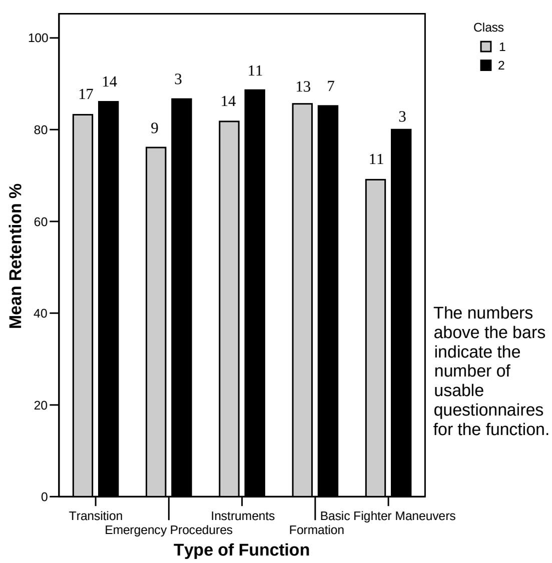

Figure 1. *Bar chart illustrating IP ratings of skill and knowledge retention by function.*

Student Preparation

Similarly, a difference was detected between the classes regarding the IP's assessment of student preparation for seasoning training ($t_{(82)} = -2.258$, $p < .05$). Students in the second class appeared to arrive better prepared than those in the first class.

The small number of assessments of student preparation for many of the sortie types also precluded statistical analyses at this level. The bar chart in Figure 2, however, illustrates a similar trend as was detected for knowledge and skill retention. Students in the second class were generally better prepared than those in the first for all function types except Formation.

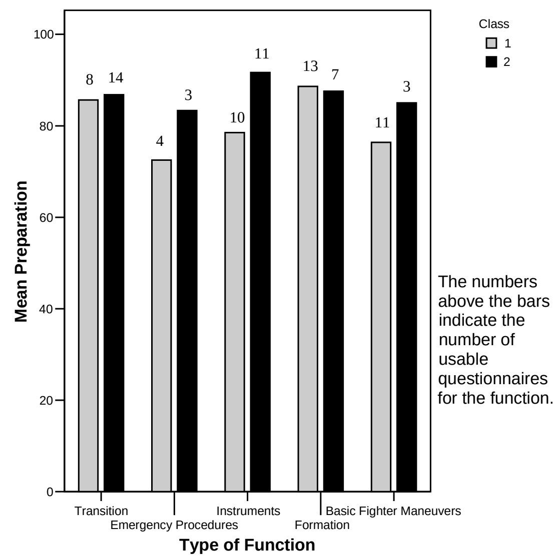

Figure 2. *Bar chart illustrating IP ratings of student preparation by function.*

IP/Student Training Continuity

T-tests were also conducted to assess differences in IP ratings based upon whether or not the pair flew together in initial training. Mean ratings of retention were not significantly different. Ratings of student preparation, however, were significantly different ($t_{(38)} = -2.653$, $p < .05$). IPs indicating that they flew with the student during initial training were more likely to rate preparation lower than those who had not flown with the student.

Discussion

It is difficult to design aviation learning retention studies that prevent the learning subjects from practicing their aviation skills between the initial learning events and the retention measurement. Pilots want to fly and look for every opportunity to do so. There is very little that will prevent them from flying, even if it is to advance the cause of science. This study took advantage of a mandatory aviation "grounding" of the learning subjects because they were not allowed to fly in the retention interval. For that reason the study is unique.

Due to the necessities of the aviation training program, the first group did not fly for eight months after their initial training course, and the second group did not fly for three months. Not surprisingly the IPs perception of the group with the shorter retention interval was that they retained significantly more skills and knowledge compared to the group with the longer retention interval. Clearly, the five extra months that the first group had to wait between their last flight in the initial training and the first flight in the seasoning training had a very deleterious effect on their overall performance.

An important question for future research is to examine whether the drop off in learning retention came fairly suddenly during the five additional months that the first group didn't fly, or whether the skill decay was consistently gradual across those five months. Co-authors of this paper, who are IPs instructing in the course described here and who have considerable Instructor Pilot experience, believe that the new learning decays at a fairly constant rate, and then suddenly drops fairly precipitously sometime between the three and eight month retention interval. Their experience, which is supported both by this study and by literature reviewed, is that procedural skills (e.g., emergency procedures) decay very rapidly, motor skills (e.g., landing skills) less rapidly, and higher order skills, such as decision making, decay with the greatest variability based on individual differences.

The students in the training program described here were not from the U.S., and English was a second language for them. The IPs in the program were convinced that language difficulty contributed to the skill and knowledge decay observed. It stands to reason that trainees who struggle with understanding concepts because their English language skills are deficient will suffer in both their acquisition of the skills and knowledge and perhaps in their retention of the skill and knowledge. The authors are not yet ready to ascribe retention difficulties solely to language problems. Since the IPs were only asked to rate the retention of the trainees in the two classes, and not to make judgments about the quality of their acquisition, it is difficult to know how much retention suffered compared to acquisition. The authors assumed that the trainees had reached at least the minimum criteria level in the acquisition phase of training since the trainees were all graduated to the seasoning phase. However, since actual acquisition levels were not measured as part of this study, it may be that language difficulties effected acquisition but not retention. The literature review did not reveal any studies that examined the impact of language skills on retention, but we suggest that this would be an interesting topic of research given the international nature of aviation training.

IPs in this study were asked to rate the flight preparation of trainees that the IPs flew with in seasoning flights. Not all IPs flew with all students in the acquisition stage either because of scheduling or because there were new IPs hired for the seasoning phase. The surveys revealed that IPs rated students with whom they had flown with in the acquisition phase of training as being less prepared for the seasoning flights than trainees they had not flown with in the acquisition phase. This finding seems counterintuitive because one might assume IPs would be somewhat biased toward students they had already instructed and would be more likely to give them higher preparation ratings. We believe that the counterintuitive finding might stem from a bias in the opposite direction from what we expected. That is, IPs had certain "pride of ownership" in the capabilities of the students they had previously trained and therefore had higher expectations for them in the seasoning phase of training. If that is true, we believe that the IPs were somewhat harsher in their judgment of the preparation of their former trainees than they were for students with whom they had not previously flown. Such a phenomenon would account for the low ratings for former students regarding their preparation.

Piloting skills and knowledge are prone to decay over time. We believe this study contributes to a fairly small body of literature that casts some light on this decay and retention phenomenon. The aviation research community can do the aviation industry a great service by continuing to conduct aviation skill and knowledge retention studies. Data gathered from these studies can be used to eventually build models of learning retention which would be of great value to those responsible for training and retraining pilots.

References

Adams, J. A. & Hufford, L. E. (1962). Contributions of a part-task trainer to the learning and retention of a time-shared flight maneuver. *Human Factors, 4,* 159-170.

Arthur, W., Bennett, W., Stanush, P., & McNelly, T. (1998). Factors that influence skill decay and retention: A quantitative review and analysis. *Human Performance, 11(1)*, 57-101.

Baddeley, A. D. (1999). *Essentials of Human Memory*. East Sussex, UK: Psychology Press Ltd.

Bahrick, H. P. (1984). Semantic memory content in permastore: Fifty years of memory for Spanish learned in school. *Journal of Experimental Psychology: General, 113,* 1-29.

Bahrick, H. P. & Phelps, E. (1987). Retention of Spanish vocabulary over 8 years. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*(2), 344-349.

Driskell, J. E., Copper, C., & Moran, A. (1994). Does mental practice enhance performance? *Journal of Applied Psychology, 79(4),* 481-492.

Hagman, J. D. & Rose, A. M. (1983). Retention of military tasks: A review. *Human Factors, 25(2),* 199-213.

Lance, C. E., Parisi, A. G., Bennett, W. R., Teachout, M. S., Harville, D. L., Wells, M. L. (1998). Moderators of skill retention interval / performance decrement relationships in eight U. S. Air Force enlisted specialties. *Human Performance, 11*(1), 103-123.

Nembhard, D. A. (2000). The effects of task complexity and experience on learning and forgetting: A field study. *Human Factors, 42*(2), 272-286.

Peck, A. C. & Detweiler, M. C, (2000). Training multistep procedural tasks. *Human Factors, 42*(3), 379-389.

Prophet, W. W. (1976). Long-term retention of flying skills: An annotated bibliography. HumRRO Final Technical Report FR-ED(P) 76-36 (ADA036114).Alexandria, VA: Human Resources Research Organization.

Rubin, D. C. & Wenzel, A. E. (1996). One-hundred years of forgetting: A quantitative description of retention. *Psychological Review, 103*(4), 734-760.

Sauer, J., Hockey, G. R. J., & Wastell, D. G. (2000).Effects of training on short- and long-term skill retention in a complex multiple-task environment. *Ergonomics, 43*(12), 2043-2064.

Appendix A. Retention Measurement Instrument

This scale below presents a simple scale from 0 % to 100 %. For each flight we ask that you provide an overall assessment of how much of the skill set you believe the student has retained since the last time they used that skill set. That is, please give us an overall assessment of the amount of skill retention the student has maintained in the period between the last time they used the skill set and the flight you just finished with them.

Mission Number _________
Date __________________
Class 1 2

0 % = No retention at all of the skill set
100 % = Complete retention of the skill set

0% 10 20 30 40 50 60 70 80 90 100%

Did you instruct this student on this skill set in the initial training? Y N
How well prepared do you feel the student was for this sortie?

0 % = Not at all prepared for the sortie
100 % = Extremely well prepared for the sortie

0% 10 20 30 40 50 60 70 80 90 100%

Comments:

CAPTURING THE RESEARCH AND DEVELOPMENT PROCESS OF AVIATION SYSTEMS: CREATING A MULTI-MEDIA LIVING LEGACY

Anthony D. Andre
San Jose State University / NASA Ames Research Center
Moffett Field, CA 94035

Becky L. Hooey
San Jose State University / NASA Ames Research Center
Moffett Field, CA 94035

David C. Foyle
NASA Ames Research Center
Moffett Field, CA 94035

Too often, successful system development projects fail to leave a legacy of design transfer information, beyond providing access to the mere physical descriptions of the system, or the software code itself. Yet, information about high-level design decisions, assumptions, constraints, philosophies and methodologies is often sought after by system designers, engineers, and researchers alike. Such information is critical for facilitating an understanding of the design and evaluation decisions that underlie the final design. In contrast, published articles about a given complex system are usually limited to discussions of experimental results and in applicability beyond the academic and research community. This paper presents an argument for the development of an interactive multi-media design transfer library that provides a detailed legacy of the philosophy, design rationale and supporting data behind new aviation systems and conveys important guidelines, methodologies and "lessons learned" from the course of their research and development.

Introduction

To increase the efficiency and safety of surface operations, the Taxiway Navigation and Situation Awareness (T-NASA) cockpit display suite (see Figure 1), comprised of an electronic moving map (EMM) and a scene-linked head-up display (HUD was proposed, and then subjected to an extensive human-centered design and evaluation process over a 6-year period (Andre et al. 1998; Foyle et al. 1996; McCann et al. 1998; Hooey, Foyle and Andre, 2002).

During this period, nearly every type of research activity was performed, including:

- Jump seat field observations of pilots and air traffic controllers.
- Focus group studies with pilots and air traffic controllers.
- Studies using head and eye-tracking equipment.
- Low fidelity part-task desktop design concept studies.
- Medium-fidelity part-task simulation studies.
- Full-mission high-fidelity simulation studies.
- Flight tests in NASA's B757.

The focus of the studies varied as well, to include:

- Research to determine pilot information requirements during taxi.
- Research on user interface design options.
- Research to identify factors that contribute to current-day problems (safety/efficiency).
- Research comparing future operational concepts against current conditions.
- Research focused on crew roles and procedures.
- Research focused on systems integration issues.
- Research focused on near- vs. far-term technology assumptions.
- Research focused on benchmarking and quantifying safety and efficiency benefits of T-NASA.
- Research on usage characteristics.

Figure 1. *The T-NASA System.*

The Need for Design Knowledge Capture

Looking back on the T-NASA project, the research and development team realized that there was a vast quantity of information that could be passed on to manufacturers interested in the T-NASA system, regulatory agencies such as the FAA, aviation researchers and system developers, airlines and airline purchasing agents, and others outside of aviation who might generalize the philosophy, research approach and principle-based design techniques to their non-aviation product or system projects. Moreover, this information is not traditionally made available to those outside of the research and development team. For example, design concepts that were dismissed are rarely, if ever, discussed in publications or design specifications. Yet, that information, and specifically why a given design element was not deemed applicable or optimal for a given context, could be vital information to another researcher or developer, or to a regulatory agency.

Another common problem occurs when transferring software code. Often, those on the receiving end (manufacturers, system developers, etc.) forget that there is more to a system specification than just the software code behind the interface. Important design details, recommended procedures and other usage constraints are not contained within the code, and therefore can be easily ignored or misrepresented as the code travels through the development process.

Clearly, then, there is gap between what is typically published about the design or evaluation of a proposed system design and the information deemed necessary for facilitating an understanding of the critical design and evaluation decisions that underlie it. In an effort to both capture the activities and results of the T-NASA program and others like it, and to provide a useable form of traceability of the system philosophy, design guidelines, and research decisions, we argue the need for knowledge capture tools that can be used during the development process.

There are few tools in existence that purport to aid in the capture of design-relevant knowledge, and what tools do exist either focus purely on communications (e.g., the electronic cocktail napkin; Gross, 1996) or are used for the purpose of enabling people outside the project group to understand, supervise, and regulate what is done by the team (e.g., Gorry et al. 1991), or to secure intellectual property generated by the design team (Shipman & McCall, 1997). Further, they do not support real-time knowledge capture. Perhaps most telling is that few design teams make use of such tools.

While not the main focus of this paper, we advocate the future development of an easy-to-use, web-based, real-time knowledge capture or "design knowledge archive" tool; one that will capture, without undue effort on the part of the design team, high-level design decisions and rational associated with the design of complex aviation systems, as they are crafted. Such a tool would provide the underlying knowledge data base to support the automatic creation of an electronic, interactive multi-media design technology transfer library. The value and potential makeup of such a resource is described in the following section.

A Design Technology Transfer Library

The true amount of "data" and documentation that describes the research and development of a complex avionics system designed for human interaction can be daunting. In our initial concept for a prototype design technology transfer library, we have employed a familiar "ladder" metaphor. As shown in Figure 2 below, the user "climbs" the ladder, ending at the top shelf of the library with a description of the final design of the T-NASA system. The left side of the ladder presents the user with information specific to the development of the system, while the right side of the ladder presents the user with various categories of more generalized knowledge transfer information.

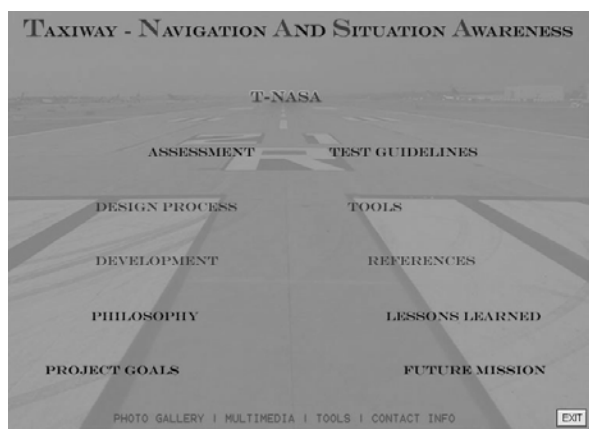

Figure 2. *Illustration of main menu category items from a prototype of the T-NASA design technology transfer library.*

The following is a brief description of the proposed purpose and content of each of these categories. The examples cited are specific to the T-NASA system and are intended only to illustrate the type of content that should be represented for any aviation system.

System Development Information

The categories of information related to system development are represented on the left side of the ladder in Figure 2.

Project Goals. To appreciate any system design one has to understand the project goals and objectives that the designers attempted to achieve. These goals and objectives may be defined by indices of safety, performance, capacity or usability, or specific use contexts, and may have derived from a government or industry program. For example, the main objective of the T-NASA system was to improve terminal area productivity in low-visibility conditions (Foyle et al., 1996). Design decisions were made based on this objective, which might have been different if, for example the goal was to improve safety in 'zero-zero' (no visibility) conditions. Specifically, for the former context we deemed augmented reality displays to be most appropriate, in which information is overlaid onto actual elements in the visual environment. In contrast, the latter context (no visibility) would require computer-generated virtual reality displays.

Clearly, then, without knowledge of the target goals and use contexts one could not understand, evaluate or appreciate the design of T-NASA. Worse still, the system could be adopted and used under circumstances for which it was never intended, creating safety hazards, or a failure to realize potential benefits.

Philosophy. Whether explicitly known to the designers or not, behind every design effort is an inherent design philosophy. This philosophy guides the design process and is the root of many design decisions. For example, a core philosophy of the T-NASA design was to support local control of the aircraft only with conformal, "head-up" information, while supporting global situation awareness with a head-down display (Foyle et al., 1996). Documenting, and communicating the design philosophy helps avoid "feature creep", and prevents future designers and developers from adding elements or modifying the design in a way that violates the original design philosophy.

Development History. Many end-users of this design transfer library may be interested in the development history of the system in question. Often, to better understand the ultimate design of a system, it is necessary to study the various incarnations it took during its development. This is a golden opportunity for the design team to explain and justify features and design elements that are NOT included in the final design. In fact, one could argue that it is often more informative to know why something was not included than to know why something was included.

For example, in the design of the T-NASA moving map, there was an active decision to NOT display taxiway centerlines in order to maximize eyes-out time and discourage the use of the map for local control purposes. Without documentation of this decision, and the rationale for it, future designers/developers could add a centerline without realizing the potential negative consequences.

In addition, systems engineers are often looking for information about a given system's hardware/software platform; information rarely specified in a human factors publication. Details regarding the assumptions that were made about data resolution, sensor reliability, and false alarm rates (as examples) are important to document. With rapid advancements in technology, it is very likely that what is considered a design constraint at the beginning of a design process is no longer a limitation by the time the system is fielded. This information would enable system engineers to differentiate between characteristics that were intended by design, or simply legacy due to (outdated) technology limitations.

Design Process. Capturing the design process and demonstrating a human-centered approach is recognized as an important element to document among the human factors community (e.g., Hooey, Foyle and Andre, 2001). Often, manufacturers or regulatory agencies are interested in the activities and process carried out to evaluate and/or validate the design. How were design requirements determined? How was the system tested? Were subject matter experts used to validate the proposed design? Was there a process to identify relevant procedural issues that might need to be addressed in order to accommodate the system? The processes that were engaged in to answer these questions can, and should be, articulated.

Evaluation/Assessment. Here, information on the assessment methods and data is found. Both quantitative and qualitative studies can be summarized, with samples of actual data, statistical analyses, etc. Documenting this information allows manufacturers, regulatory agencies, potential users, and purchasing agents to understand the extent to which the system has undergone a comprehensive evaluation process. For example, it is possible that a system demonstrates increased productivity, yet was never tested for safety impacts, or workload effects. Further, it is possible that a system was tested under nominal, or ideal operating conditions, yet was never tested under off-nominal or failure scenarios.

Without this form of documentation, it is difficult for various stake-holders to make informed decisions about adopting a system.

The System Design

In Figure 2 the final system design is represented by the T-NASA "shelf" at the top of the ladder. Here, the end-user would see the actual system design, be able to watch video of the system in action, and have access to an interactive design specification. The latter component could be presented in the form of an illustration with embedded hyperlinks that allows the user to hover over any design element and read a description and justification of that element.

In addition to design details, this category would also include information on usage assumptions, roles and responsibilities and assumed procedures. For example, information about usage assumptions can be helpful for future users of the system, those involved in developing training programs and standard operating procedures, and those responsible for integrating systems into future cockpits.

Knowledge Transfer

The categories of information related to knowledge transfer are represented on the right side of the ladder in Figure 2.

Test Guidelines. Beyond the data obtained from any given test or evaluation, it is often the case that useful methodological guidelines for testing similar systems or in similar contexts can be gleaned from the various research activities (Andre et al. 1998). As such, this section is devoted to conveying test guidelines, methods and best practices.

Tools and Techniques. Just as there are useful test guidelines to transfer, there are various tools and techniques employed by the design team over the course of the system's research and development that are useful to document. For example, a particular design technique (shadowing, perspective, transparency, etc.) or software program may have been used to render the specific look or behavior of a given interface element.

References. Most research and development efforts produce some amount of published material. Here, all references (and actual publication content) directly and indirectly related to the project are contained, ideally in an electronic form. Also this category could contain industry standards and guidelines that were used in the process.

Lessons Learned. All large-scale systems design projects are inherently educational in nature. Too often, the valuable lessons learned are not captured and transferred to future designers or engineers. This section provides an opportunity for the design team to communicate valuable information in perhaps a more personable form. Information on how system designers can best communicate design information to developers, or how to avoid feature creep are examples of useful lessons learned.

Future Mission. This section provides an opportunity for the design team to "close the loop" by indicating where the end-user might expect to see a commercial production of the system and/or future activities planned by the design team. In addition, insights into how the product may be adapted or useful for other contexts can be communicated.

Making it Interactive

Having the right information is one thing, making it easy, engaging and worthwhile to interact with is another. We advocate that the information contained in the library be presented in an interactive, multi-media format, making use of the latest software and audio-visual technologies, including images, sounds, animation and video.

Summary

Too often, successful system development projects fail to leave a legacy of design transfer information, beyond providing access to the mere physical descriptions of the system, or the software code itself. Thus, a gap exists between what is published or can be gleaned from looking at the final system design and the comprehensive library of knowledge, activities, guidelines and data often left to the memories of the design team. We argue the need for easy-to-use, real-time distributed software tools for capturing the knowledge and process behind the research and development of complex avionics systems. We advocate that the output of this tool be used as the input to an interactive, multi-media design technology transfer library, with the end-purpose of creating a detailed legacy of the philosophy, design rationale, development history and supporting data behind new aviation systems and conveying important guidelines, methodologies and "lessons learned" from the course of their research and development.

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References

Andre, A.D., Hooey, B. L., Foyle, D. C., and McCann, R. S., (1998). Field evaluation of T-NASA: Taxiway Navigation and Situation Awareness System. IEEE/AIAA Digital Avionics Systems Conference. Seattle, WA.

Foyle, D. C., Andre, A. D., McCann, R. S., Wenzel, E., Begault, D., & Battiste, V. (1996). Taxiway Navigation and Situation Awareness (T-NASA) system: Problem, design philosophy, and description of an integrated display suite for low-visibility airport surface operations. SAE Transactions: Journal of Aerospace, 105, 1411-1418.

Gorry, G. A., Long, K. B., Burger, A. M., Jung, C. P., & Meyer, B. D. (1991). The virtual notebook system: An architecture for collaborative work. Journal of Organizational Computing, 1(3), 233 – 250.

Gross, M. D. (1996). The electronic cocktail napkin – Computer support for working with diagrams. Design Studies, 17 (1).

Hooey, B. L., Foyle, D. C., & Andre, A. D. (2001). The design of aircraft cockpit displays for low-visibility taxi operations. In A. G. Gale (Ed.) Vision in Vehicles IX. Holland: Elsevier Science Publishers.

Hooey, B. L., Foyle, D. C., & Andre, A. D. (2002). A human-centered methodology for the design, evaluation, and integration of cockpit displays. In proceedings of the NATO RTO SCI and SET Symposium on Enhanced and Synthetic Vision Systems. September, 10-12, 2002. Ottawa, Canada.

McCann, R.S., Hooey, B.L., Parke, B., Foyle, D.C., Andre, A.D. & Kanki, B. (1998). An evaluation of the Taxiway Navigation and Situation Awareness (T-NASA) system in high-fidelity simulation. SAE Transactions: Journal of Aerospace, 107, 1612-1625.

Shipman, F. M., & McCall, R. J. (1997). Integrating different perspectives on design rationale: Supporting the emergence of design rationale from design communication. Artificial Intelligence in Engineering Design, Analysis, and Manufacturing (AIEDAM), 11 (2), 141-154.